MANUAL ON CANAL LINING
(Revised)

INCID - इनसिड

भारतीय राष्ट्रीय सिंचाई एवं जल निकास समिति
(जल संसाधन मंत्रालय, भारत सरकार द्वारा गठित)

INDIAN NATIONAL COMMITTEE ON IRRIGATION & DRAINAGE
(Constituted by the Ministry of Water Resources, Govt. of India)

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FOREWORD

The existing Manual on Canal Lining was prepared in 1973 and published by the Central Board of irrigation and Power (CBI&P) in the year 1975. Since then, much work has been done and studies carried out in different States in the country in connection with lining of canals. We accumulated a large volume of experience about canal lining, adopted new techniques of construction, and also gained experience about new materials, like plastics, in regard to canal lining.

The need for revising the 1973 manual was left for long. The Uttar Pradesh Irrigation Research Institute (UPIRI) had submitted a project proposal in August, 1987 to the Central Board of irrigation & Power (CBI&P). This proposal underwent revisions through a process of examination. Later, the scheme was submitted to INCID in August, 1992 and was approved by Ministry of Water Resources for Rs.1.3 lakhs for a period of two years in March, 1993. The Ministry of Water Resources later approved the revised cost of the scheme as Rs.1.65 lakhs vide CWC letter dated 25th March, 1996.

The UPIRI has attempted to part their experience with that of other States. For this purpose, two questionnaires were prepared by them and circulated by INCID to other States. The responses to these have improved the contents of the publication.

The revised updated manual contains information about the research and field work done on canal lining both in India and abroad including data on performance of various types of lining in different types of soils in the country. Detailed information has been incorporated in the manual about suitable linings for canals of different discharges. The manual also contains all the research and observation data, which was collected from various research stations/laboratories and also from the construction sites in the country. The Bibliography on lined canals, glossary of terms and data of the design, construction and field performance of various types of lining adopted for major canals all over the country has also been given in the appendices at the end of the manual.

Periodic updating of such manuals is necessary. Perhaps, to mention a few topics, the economics of lining of canals in alluvials, where seepage supports conjunctive use, may need a more detailed treatment. More information may be needed about lining of running of canals, designing the lining and drainage systems for a common embankment between two parallel canals is another area requiring information. Readers may like to give their suggestions, both about widening the scope of the manual and about available information, which needs to be included. All such suggestions are welcome and may be sent to the member-Secretary, INCID.

INCID expresses its gratitude to all those individual organisations and institutions who have contributed to this manual by providing valuable information and constructive suggestions. We are especially thankful to Mr. Laxminaraian, Chief Engineer & Director, UPIRI, Dr. B.N. Asthana, Former Chief Engineer, UPIRI and Dr. A.S. Chawla, Professor in WRDTC in Roorkee and other officers and staff of UPIRI. Our thanks to Ministry of Water Resources not only for providing the grant to UPIRI for revising the manual, but also for the grant given to INCID for publishing this Manual. INCID also expresses its gratitude to the Central Water commission officers who reviewed the draft and the Chairman and Members of the INCID Sub-Committee-IV who processed the manual.

I hope that this revised version of the manual will be very useful not only to the Practicing Engineers but also to others who are working in this field in Research Institutes and Academical institutions as on important reference book; and that the publication would be considered as an important milestone in the Planning, design and construction of canal linings.

New Delhi
29.03.2000

(A.D. MOHILE)
Chairman (INCID & CWC)

CONTENTS

1. NEED FOR LINING

1.0 INTRODUCTION

The efficiency of the conveyance and distribution system means the transportation of water at minimum cost and with minimum water loss, therefore essentially affects the total economy of an irrigation project. Earthen irrigation canal in permeable soils can lose a lot of water through seepage. Large losses through the bed and sides of canals lead to low conveyance efficiency. Earthen canals also get clogged-up with weeds which reduce the water carrying capacity. In unlined canals, the conveyance efficiency is commonly influenced by erosion resistance, weed resistance and seepage resistance due to sub-grade soils etc. and therefore unlined canals are blamed for inefficient and inadequate in performance of irrigation water system. The most important decisions to be taken in this regard are whether or not to line a canal and how much portion of an irrigation canal system is to be lined.

The decision to line the canal should be based on an analysis of benefits such as water conservation, reduced waterlogging or lower drainage requirement, reduced excavation and right-of-way cost, lower operation and maintenance cost and structural safety. Similarly, the selection of the right type of lining should be based on a careful analysis of the local conditions such as, availability and cost of labour, the requirement of mechanical equipments and lining materials, transportation facilities etc. However, out of all these, the availability of lining material and skilled and unskilled labour for the construction purposes are the most important factors for the successful completion of the Project.

1.1 ADVANTAGES OF LINING

Lining of an irrigation channel is resorted to achieve all or some of the following objects.

(a) Water conservation :

Water conservation due to reduced seepage loss and weed control are the chief advantages of lining. In fact, this aspect has become important all over the world as the demand of water has been increasing rapidly and the new sources of supply are becoming scarcer. In such a case, canal lining is best method to take maximum use of available water. Water losses in unlined canal system are usually high. Emergent aquatic weeds also transpire large quantity of water from canals which can be saved by lining.

Lining a canal will not completely eliminate losses, therefore it is necessary to measure systematically present losses or estimate the losses which might reasonably be saved by lining before a proper decision can be made. Some authors say that roughly 60 to 80 percent of the water lost in unlined canals can be saved by hard surface lining. As a rule of thumb, a properly lined canal should not lose more than about 0.03 $m^3/m^2/24$ hour. This is roughly a loss of 0.6 percent per kilometre of the conveyed water in a canal carrying 0.2 cumec. Conservation of water has little significance unless the water saved can be put to beneficial use. When water saved can be controlled and delivered to productive lands, it would mean additional yield and increased net income over to the individual farmers.

(b) Prevention of Waterlogging :

Seepage water often disappears into a pervious underground stratum to reappear in low lying area usually at some distance from the canal. This creates waterlogging conditions adjacent to the canal specially if the drainage conditions in the area are also poor. Consequently, the fertility of the land in the area is decreased. Lining of canals reduces this seepage and is thus helpful in preventing waterlogging. However, lining of main canals may only partially alleviate the problem unless the distributaries and minors are also lined and farmers apply only that much of water as needed by the plants and drain away the balance water without causing any rise in the existing water table. So when assessing the benefits of lining in this respect, factors like natural drainage of the area, expected irrigation efficiencies, probable salt problems, loss of land and the economic implications of high water table (due to excessive canal losses) should all be considered carefully. It should also be borne in mind that lowering the water table increases seepage from unlined canals and as such gives no solution to the waterlogging and drainage problems.

(c) Reduced dimensions and right of way costs :

Canals lined with exposed hard surface materials such as cement concrete, asphalt concrete, stone and brick masonry and certain other types of lining, greater velocities are permissible than normally possible in earthen canals. The maximum non-erosive velocities for different soils are shown in table-1, given below:

Table – 1 : Maximum Non-erosive Velocities

Type of Soil	Maximum velocity in m/sec.
Fine sand under quick sand condition	0.2 to 0.3
Sandy soil	0.3 to 0.75
Sandy loam	0.75 to 0.90
Loam to clay loam	0.85 to 1.10
Stiff clay	1.10 to 1.50
Coarse Shingle or gravel with clay	1.25 to 1.80

As can be seen, these non-erosive velocities for different soil conditions range from 0.2 to 1.8 m/sec while the permissible velocities for concrete and brick linings range from 1.50 to 2.5 m/sec. Although clay stands velocities upto 1.5 m/sec (Table-1) in a newly excavated canal, in time the flow resistance may drop considerably owing to alternate wetting and drying effects and other structural changes.

Table-2, shows the relative quantities of water which can be transported through a concrete lined canal and an unlined canal of the same size showing the effect of reduced rugosity.

Table – 2 : Relative Capacities of Concrete, lined and unlined canals

Bottom Width	Flow Depth	Quantity (m^3/sec)	
		Concrete Lined	Unlined
0.30	0.45	0.40	0.23
0.90	0.60	1.27	0.71
1.20	0.75	2.40	1.33
1.50	0.90	4.0	2.24

When erosion resistant linings (such as concrete) are used, the slope of the bed or depth of flow may be increased and side slope made steeper. The narrower bed width needed for the canal reduces the land area required for the canal and the right-of-way cost savings may be substantial.

Considering that a lined canal system for a given supply area need not carry the water which is lost in an unlined system, the dimensions of any lined canal system, including cross-drainage structures will be further smaller than those of an unlined system.

Greater velocities in canals reduce maintenance costs when silting is a problem. The silt, by remaining in suspension, does not deposit in the canal bed but rather settles down on the land being irrigated and thus making it more fertile. Also greater conveyance velocities resulting in increased discharges offer the advantage of shorter irrigation time.

(d) Reduced maintenance and operation costs :

The type of lining must be considered when evaluating the benefits of canal with reference to maintenance costs. A large part of the maintenance revenue goes in removal of weeds and water-loving plants from the canal section. High quality hard surface lining being relatively impenetrable by weeds and water loving plants greatly reduce the cost of weed control and removal from the canal. Any hard surface lining will allow water velocities high enough to reduce substantially the deposit of silt, thus lowering maintenance cost.

Maintenance costs are greatly dependent upon local conditions such as climate, period of operation, availability of labour and machinery, type of lining etc. Therefore, comparison of maintenance expenses between projects is not generally practicable. Estimation of maintenance cost can be obtained from data for existing lined and unlined canals operating under similar climatic, geographic and agricultural conditions. The following data on maintenance cost may serve as a guide for estimating lining benefits as illustrated in Table-3 given below,

Table – 3

Country	**Reduction in maintenance cost after lining**
U.S.A.	About 75%
INDIA	About 50%
USSR	About 67%

(e) Protection against erosion, structural safety and other benefits.

The stability of the slope and bottom of unlined canals is a major problem in areas of sandy and silty soils, particularly where irrigation practices require an intermittent running and closing of the canal. The lining when designed and constructed properly also gives better structural stability for the canal side slopes in all types of sub grade soils, including expansive soils. Lining also reduces the danger of canal breaches resulting from erosion and burrowing animals. This is particularly important when the canal is in filling. Lining also prevents water from absorbing salts from the soil which may be harmful to crops.

(f) Due to reduced exposed area, evaporation losses are reduced.

(g) Lining increases available head for power generation as a flatter gradient can be provided in power channel due to reduced value of rugosity coefficient.

1.2 TYPE OF SUB-GRADE MATERIAL AND REQUIREMENT FOR LINING

Generally, the types of soil that are likely to have the heaviest losses are relatively clean sands and gravels. Uniform gravels have the highest permeability followed by well-graded gravel, uniform and well-graded sand follow. Another type of material that is usually questionable is a very plastic clay (Casagrande CH type) because of its tendency to develop large shrinkage cracks upon drying. This type of soil should have small seepage losses when continually wet. Other soils that will have moderately heavy seepage losses are very fine sands.

A list of soil types in tabular form with their soil classification symbols and a relative rating as to permeability and probable need for lining is given below.

Sl.No. and relative rating	Soil class-ifica-tion	Soil Description	Remarks
1	2	3	4
1	GP	Poorly graded gravels or gravel sand mixtures; little or no fines.	Extremely permeable, needs lining.
2	GW	Well graded gravels,gravel sand mixtures;little or no fines.	Extremely permeable, Needs lining.
3	SP	Poorly graded sands or gravelly sands; little or no fines.	Moderate to highly permeable, usually requires lining.
4	SW	Well graded sands, gravelly sands, little or no fines.	Moderately permeable, usually requires lining.
5	CH	Inorganic clays of high plasticity, fat clays.	Very impermeable when wet or extremely permeable after drying, needs special consideration.

1	2	3	4
6	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with none to low plasticity.	Fairly impervious, but bank section is difficult to hold in place. Needs special consideration.
7	MH	Inorganic silts of high compressibility micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Fairly impervious, but bank sections difficult to hold. Needs special consideration.
8	GC	Clayey gravels, poorly graded gravel-sand - clay mixtures.	May range from moderate to very low permeability.
9	SC	Clayey sands, poorly graded sand-clay mixtures.	Usually impermeable, good stability.
10	GM	Silty gravels, poorly graded gravel sand-silt mixtures.	Usually fairly impermeable but hard to hold on bank. Lining requirement is minimal.
11	CL	Inorganic clays, gravelly/ sandy/silty clays, lean clays of low plasticity.	Usually very impermeable. Lining requirement is minimal.
12	OL	Organic silts & silty clay of low plasticity.	Permeability fairly low but stability is questionable. Provision of lining needs judicious considerations.
13	OH	Organic clays of medium to high plasticity.	Low permeability if soil is kept wet but stability is questionable and shrinkage cracks are probable. Provision of lining needs judicious considerations.

Source : IS Code No.1498-1970(First Revision) and C.B.I.& P. Publication No. 82

1.3 ECONOMICS OF LINING

1.3.1 Techno-economical Studies

Lining of canals at the time of original construction itself is more advantageous than at a later stage because the size of associated structures such as cross-drainage works, bridges, pumping plants and distributaries necessary to provide the given amount of water will also be reduced. Major economics in construction is possible when concrete lining is planned and placed at the time of the original canal construction. Unlined or Earth lined canals require much larger cross-sectional areas than concrete or tile lined canals of equal capacity. To prevent damagingly high velocities, unlined canals usually are built wider, shallower and with flatter side slopes than lined canals. When it subsequently becomes necessary or desirable to line such a canal, the engineer is forced to choose between constructing an unnecessary large lining in the existing canal or backfilling and reshaping the canal to accommodate the more efficient concrete lining. Both these alternatives are costlier than a properly designed lined canal.

It is extremely important that the lining of a main canal be carefully considered at the time of its planning and construction, it is almost impossible to stop the water for the length of time required to line the canal. Therefore, in addition to the cost of reshaping the canal to a smaller cross-section, there may be large expenditure for constructing temporary by-passes to carry irrigation water during reconstruction. These added costs may exceed the cost of lining itself. All these factors emphasize the importance of weighing the need for lining carefully in advance, and if, they are needed, of including them in the original construction. The calculations needed for the economic study of the canal lining are given in tabular form as Annexure 1 to 4.

1.3.2 System approach to economics of canal lining

Lining of canals is generally considered as one of the measures for water conservation. However all water which is lost by seepage in an unlined canal system is not total loss and a significant part of it joins groundwater by way of deep percolations, which can be recovered under favourable conditions. Lining of canal thus affects groundwater availability and therefore, the advantage of lining needs proper evaluation in context of total surface and groundwater system performance. Further more extent of conveyance losses and their contribution to groundwater from different component of canal distribution system (main canal, distributaries & field channels) are different. Therefore, the cost effectiveness of lining of various components individually and in combination needs careful assessment for deciding the extent of lining.

Main advantage with groundwater is that it can be tapped almost at any place as and when needed, depending upon the pumping capacity. Only disadvantage with this is that, it requires energy for pumping. Advantage of lining therefore be viewed alongwith the associated loss in groundwater recharge due to reduced canal seepage, and their overall impact on ground and surface water resource availability of the area. An attempt may be made to study the economics of canal lining by using a suitable programming model associated with conjunctive use of surface and groundwater.

References

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3. Kraatz, D.B.,"Irrigation Canal Lining", FAO-1977, FAO Land and Water Development Series No.1.

4. "Lining Irrigation Canals" Portland Cement Association, 33 West Grand Avenue, Chicago 10, Illinois, U.S.A.

Annexure -1

Table-A

Estimation of additional annual cost of a lined canal over an unlined canal (original construction) and net annual saving

Sl. No.	Details of works	Cost in Rs.	
		(a)Lined *	(b)Unlined *
1.	Excavation, filling, compaction and trimming	-	-
2.	Lining	-	-
3.	Earth work, Cross drainage works, bridges and other necessary works	-	-
4.	Incidental structures	-	-
5.	Total construction cost= (1)+(2)+(3)+(4)=5(a) or 5(b)	-	-
6.	Difference in construction cost 5(a)-5(b)	-	-
7.	Life expectancy, years	NIL	NIL
8.	Salvage value at life expectancy	-	-
9.	Total depreciation during life = (6) - (8) = (9)	-	-
10.	Annual depreciation charges = (9) ÷ (7) = (10)	-	-
11.	Annual interest charges $= \frac{(6)+(8)}{2}$ x interest rate]=(11)	-	-
12.	Total annual cost= (10)+(11)=(12)	-	-
<u>Net annual savings</u>			
13.	Total annual benefits [refer annexure-4]	-	-
14.	Net annual savings = (13)-(12)	-	-

* Benefit cost ratio = (13) ÷ (12)

Table-B

For comparing annual costs of two different types of linings

Sl. No.	Details of works	Cost in Rs.	
		Type I Lining *	Type II Lining *
1.	Excavation, filling, compaction and trimming	-	-
2.	Lining	-	-
3.	Earthwork, Cross drainage works, bridges and misc. structures	-	-
4.	Incidental structures	-	-
5.	Total construction cost= (1)+(2)+(3)+(4)=(5)		
6.	Life expectancy Type I ... years Type II ... years	NIL	NIL
7.	Salvage value at life expectancy	-	-
8.	Total depreciation during life = (5) - (7) = (8)	-	-
9.	Annual depreciation charges = (8) ÷ (6)	-	-
10.	Annual interest charges $= \frac{(5)+(7)}{2} \times$ interest rate	-	-
11.	Annual maintenance charges	-	-
12.	Total annual cost = (9)+(10)+(11)=(12)	-	-

* The actual costs as calculated shall be filled in the table.

requirements and availability of equipment. When required in small quantities, slabs may be cast individually in steel or timber moulds. With well graded aggregates, 1:3:6 concrete with enough slump convenient for hand moulding is used. The slabs are cured as usual for 24 hours in air and thereafter under water. In smaller projects where slabs are cast individually in steel or timber moulds and compacted on vibrating table, the quantity of water is sometimes required to be increased for achieving better workability.

When required in large quantities, the slabs are manufactured by machines which are generally located at 12 to 16 km distance along the canal to reduce transportation costs. The machine made units are generally prepared with a water cement ratio of 0.6. Some manufacturers have, however, recommended reducing this ratio upto 0.4, but due to difficulty of handling very dry concrete, its strength is adversely affected (Ref. 21).

3.3.2 Laying and Jointing of Precast Slabs

For manual handling the slabs should be cast in 50 cm x 25 cm x 5.0 cm sizes, weighing about 16 kg each. They have a 10 mm wide and 16 mm thick rebate on all the four sides so that, when laid side by side, 20 mm wide and 32 mm deep open joints are formed. The open joints formed by the rebates are sealed with 1:3 cement mortar of dry consistency, properly packed to eliminate shrinkage. The details of slabs, their placement and joints are shown in Fig. 1. The precast slabs are directly laid on compacted subgrade both in the bed and side slopes. When the canal passes through broken ground or the subgrade is weak, precast slabs may be reinforced with 16 mm mild steel bars for strength. It is however, always better to compact the subgrade properly and do without reinforcement, as these bars create difficulty in repair work. A spacing of 3.5 to 5.0 m is recommended for siting expansion joints on sleepers. These are grouted with a suitable bituminous mastic. a mixture of 5 percent crude oil (B.O.C. furnace oil) with 1:3 cement mortar would render it impervious and also reduce shrinkage. Precast slabs 1:3:6 cement concrete in sizes varying from 60 cm x 37.5 cm to 60 x 60 cm were laid in Tungbhadra Project. Karad Canal in Gujarat has also been lined with 42.7 cm x 30.5 cm x 3.8 cm precast blocks in 1:6 cement mortar. Precast concrete slab lining has also been provided in left bank canal, Kuttiady Irrigation Project in Kerala.

3.4 BRICK LINING AND CLAY TILE LINING

Brick lining or burnt clay tile lining are economical and have been used extensively. Such linings are constructed where suitable soil for bricks is available and suitable aggregates for cement concrete lining are not available within reasonable distance. They can be constructed without expensive equipment. The advantages of this type of lining in comparison to those of concrete lining are not only equal impermeability but also lower maintenance cost and natural safe-guards against cracking. The individual tiles or bricks have an infinite number of joints in which hair cracks can appear without causing any significant damage to the work as a whole. To increase the impermeability and strength of the lining, two layers of bricks or tiles with a sandwiched layer of plaster are also provided, although their use is generally confined to sides from stability considerations.

Brick or tile lining is laid manually. The subgrade should be properly dressed and moistened before laying the lower layer of bricks or tiles over 13 mm thick mortar. The lower layer of bricks or tiles should be thoroughly wetted with water before laying the plaster on it. The fine cracks which appear on the surface of plaster should be widened and repaired. After treating the cracks the plaster should be cured for a week. Tiles should be laid over another layer of 6 mm plaster. The composite lining is then cured for three to four weeks.

This type of lining is most popular in India and has been provided on several canals, especially in North India. The details of the lining for Gandak Canal Project, Lower Ganga Canal, Rajasthan Feeder Channel, Banaskantha L.B. Main Canal, R.B. Mahi Canal have been included in the Appendix given at the end of the book.

3.5 STONE MASONRY LINING

Stone masonry lining may prove to be cheaper than cement concrete where stone obtained during excavation is readily available. Stone masonry lining has little flexural resistance or flexibility and slightest settlement of the subgrade may cause distress. Such lining is not satisfactory for canals in filling. The most common type of lining reported in Karnataka is the rough stone revetment but this does not help much in the reduction of seepage losses except that it provides additional stability to the sides of the channel. In Maharashtra two types of lining have been adopted, one is 38 cm thick uncoarsed rubble masonry for the sides and bed, and the other is 38 cm thick uncoarsed rubble masonry for the sides

Annexure - 3

Table-C

Estimation of annual cost of lining
on existing canals and net annual saving

Sl. No.	Details of work	Cost in Rs.
1.	Excavation, filling,compaction and trimming	-
2.	Lining	-
3.	Bridges, Cross drainage works etc.	-
4.	Incidental structures	-
5.	Total construction cost = (1)+(2)+(3)+(4)=(5)	-
6.	Life expectancy ... years	NIL
7.	Salvage value at the life expectancy	-
8.	Total depreciation during life = (5)-(7) = (8)	-
9.	Annual depreciation charges = (8) ÷ (6)=(9)	-
10.	Annual interest charges= $\frac{(5)+(7)}{2}$ x interest rate = (10)	-
11.	Total annual cost = (9)+(10)=(11)	-
Net annual savings		
12.	Total annual benefit s= (20) of (Table D) = (12)	-
13.	Total annual cost = (11) = (13)	-
14.	Net annual savings = (12) - (13)	-

Annexure - 4

Table- D

Estimation of annual benefits from lined canals

Sl. No.	Details of works	Cost in Rs.
Land saved		
1.	Right of way, unlined canals in acres	-
2.	Right of way, lined canals in acres	-
3.	Right of way, saved (1)-(2) in acres = (3)	-
4.	Reclaimed waterlogged land in acres	-
5.	Total land saved in acres (3)+(4)=(5)	-
6.	Annual value of total land saved in acres at net crop value per acre	-
Water saved		
7.	Flow when in use, in cusecs	-
8.	Hours in use (in whole year=365x24)	-
9.	Total flow per year=(7)x(8)x(0.0826)=(9) in acres ft.	-
10.	Estimated loss from unlined canal [% of (9)] in acre ft. = (10)	-
11.	Annual value of water saved in acre ft = [(10) x rate per acre ft] = (11)	-
Savings in maintenance (include maintenance of necessary drainage facilities)		
12.	Annual maintenance cost of unlined canal	-
13.	Annual maintenance cost of lined canal	-
14.	Annual savings in maintenance (12) - (13) = (14)	-
Labour saved		
15.	Labour. Irrigation from unlined canal in man days per year (if any)	-
16.	Labour. Irrigation from lined canal in man days per year (if any)	-
17.	Annual savings in labour in man days per year= (15) - (16) = (17)	-

Sl. No.	Details of works	Cost in Rs.
18.	Total annual tangible benefits = (6)+(11)+(14)+ (17) =(18)	-
19.	Estimated annual intangible benefits (Socio-economic uplifts etc. including pride of the nation)	-
20.	Total annual benefits = (18) + (19) = (20)	-

2. SELECTION OF TYPE OF LINING AND GENERAL DESIGN CONSIDERATIONS

2.0 GENERAL

Once the purpose and necessity of lining a canal is decided, sincere efforts should be made to select a type of lining that fits best into the given conditions from technical and economic considerations. The various factors governing the selection of the type of lining are discussed below:

a) Availability of Construction Material

Generally, the most economical lining is the one which makes the best use of locally available materials. Though it is seldom possible. The extent of utilising off-site materials depends largely on transport facilities. If both cement and aggregates have to be transported from long distances to the job site, lining other than cement concrete may be considered. In sandy soils, soil-cement lining requiring only the procurement of cement may be a cheaper and suitable.

b) Availability of Labour and Machinery

Some lining are more suitable for manual labour and others, like cement-concrete, for machine installation. The choice, therefore, is often governed by the relative availability of labour and machinery. Tile linings are examples of labour intensive types. Even compacted earth linings may be economically carried out by manual labour. The requirement of prompt and quick completion of the lining to obtain early benefits may require mechanisation.

c) Durability and Repairability of Lining

The canal lining should be able to withstand the effect of flowing water, rain, sunshine, thermal and moisture changes, chemical action etc. It should also be able to withstand the damaging effect caused by cattle movement, rodents and weed growth.

The durability of lining depends on the type of lining, the quality of construction and canal operation and maintenance. Properly constructed and maintained cement concrete linings may have a service life of at least 50 to 60 years. The life expectancy of thin exposed membrane may be shorter than 2 years, but still may be economically feasible as a temporary lining.

Some times the canal transports considerable amount of sediment which can damage the lining by abrasion. The lining should, therefore, be able to withstand such abrasion. Also with the passage of time, the lining may get damaged, so it shall be such that it can be repaired easily and economically.

Brick tile, boulder and precast slab linings are more easily replaceable than cast-in-place concrete lining.

The benefit - cost calculations while making economic study of the lining, require the durability period of the linings, the latter should be determined carefully. Performance of lined canals of other projects may provide valuable data in this regard.

d) Structural Stability

The lining though supported by sub-grade, should be able to withstand the differential sub-soil pressure from behind the lining due to sub - grade material getting saturated through seepage or rain or due to sudden drawdown of the canal. The lining should be sufficiently heavy and strong to withstand the effect due to local cavity formation, if any, behind the lining, due to defective compaction of sub-grade or otherwise.

To provide relief from differential pressures, adequate sub-soil drainage arrangements and pressure relief valves should be provided, wherever necessary.

e) Hydraulic Efficiency

The discharge carrying capacity of canal varies inversely with the value of rugosity coefficient. Each type of lining has a specific value of rugosity coefficient which may undergo change with the passage of time. It increases, with the lining undergoing deterioration, thereby increasing the roughness.

f) Watertightness

The seepage losses from the canal depend on the nature of soil, depth of water in the canal and the relative position of sub-soil water table.

If the water table is high, the aim should be to mitigate the seepage losses to the minimum possible value. In such areas a relatively watertight type of lining should be adopted. The most impermeable lining is a thin plastic, asphalt or rubber sheeting, placed under concrete lining.

g) Type of Subgrade

Concrete and some other rigid type lining when constructed on sub-grades containing swelling clays or gypsum are likely to get damaged, hence in such cases lining should be designed carefully after extensive investigations. For a hard surface lining it is often advantageous to remove the unsuitable soils, present in short reaches to be crossed, to a certain depth by over excavation and replace it with sand, CNS layer or some other locally available suitable material like muram etc. Also, a minor change in alignment in case of small canals may be made, so as to bypass the areas with unsuitable soils and may provide a more economical solution to the problem.

If sufficient amounts of sand and gravel are available in the areas nearby, cement concrete or soil cement lining may be adopted. Similarly, if soils are fit for compaction, a compacted earth lining should be favoured. In case the available soils can neither be used as aggregate nor they are found suitable for compaction but may provide a good cover material, a membrane lining may be considered keeping in view their resistance to erosion, as detailed in IS:1498-1970.

h) Operation and Maintenance

If the operation of the canal requires frequent running and closing or large water level fluctuations, a hard surface lining will be prefered. In case of earth linings or earth covered membrane linings such conditions would speed up the deterioration process. As regards weed control, small repairs and silt removal etc., hard surface linings have greater advantages over the latter type of the linings.

i) Water Table

If the water table is above the bed level of the canal, closing the canal will cause external hydrostatic pressure on the lining. So suitable drainage and pressure release facilities shall be provided as no lining can resist such pressures.

j) Land Value

In urban and some other areas where the land value is quite high lining with minimum value of rugosity coefficient should be preferred.

2.1 PRECONSTRUCTION INVESTIGATIONS

The parameters which are needed to be investigated for planning of a canal lining project in a certain area include type and permeability of the sub-grade in different reaches, water table conditions, quantitative assessment of seepage losses and area likely to be waterlogged.

The soil investigations should include determination of type of soil by taking bore logs 30-50 metres deep (or upto impervious layer if encountered earlier) spaced at about a kilometre for larger canals. Where soil strata are variable, intermediate bore holes may be located to define the soil profile as best as possible. If the soil stratum continues to be pervious for large depth as indicated by a few deep borings, the stratum may be assumed as extending to infinity for seepage computations. Soil tests to be carried out on bore hole samples should in addition to usual classifications tests, also include tests for expansive nature of sub-grade material and chemical tests to guard against presence of any possible deleterious substances which may adversely affect the lining materials. Sulphates of sodium and magnesium are known to be the worst enemies of concrete and brick work. Suitable remedial measure should therefore be adopted in the reaches where total dissolved solids are more than 0.25 percent by weight.

In order to determine the overall permeability of the strata below canal bed, pumpout tests should be conducted in representative strata.

The likely seepage losses from an unlined canal depend upon the bed width, water depth, side slope of the canal, permeability of the sub-grade, distances of the governing drainages and depth of water-table below the canal water surface. The seepage losses from lined canal also depend upon the thickness and effective permeability of the lining material.

In order to assess the likely seepage losses from the channel, cross-sections upto governing drainages on either side of channel should be taken at every kilometre. Starta charts of bore holes, water table position and water level in the drainage should be marked on the cross-section. The method of assessment of the likely seepage losses through unlined and lined canals are dealt with in chapter 12.

The availability of material for canal lining such as aggregates and sand for cement concrete lining, soil suitable for brick tiles, bentonite, soil suitable for earth linings, etc., should also be investigated.

2.2 TYPES OF LINING

The various types of lining can be grouped into two categories: (i) Exposed and hard surface lining. (ii) Buried Membrane linings. The advantages and disadvantages of various types of linings which need be kept in view while deciding the type of lining to be adopted are indicated below.

2.2.1 Exposed and Hard Surface Lining

These linings are of the type placed directly upon the sub grade of the canal and are exposed to wear erosion and deterioration effect of the flowing water, operation and maintenance equipment and other hazards. Such linings are constructed of cement concrete, mortar, precast concrete slabs, bricks or tiles, stones, asphaltic concrete, soil-cement and earth etc.

(a) Cement Concrete Lining

The in-situ cement concrete lining is one of the most conventional type of lining which has successfully been used in India and other parts of the world. Cement concrete lining is more preferable than any other lining where channel is to carry high velocity water because of its greater resistance to erosion. Velocities upto 2.5 m/sec are generally considered permissible with adequate water depth although higher velocities upto 5.0 m/sec in case of Kosi Feeder Channel in U.P. have been provided. Cement concrete lining eliminates weed growth and thereby improves flow characteristics. Burrowing animals can not penetrate concrete. Provision of concrete lining reduces maintenance charges to a minimum.

A distinct disadvantage of concrete lining is its susceptibility to development of frequent cracks due to temperature effects as well as drying, shrinkage and settlement of sub-grade material, Panelling reduces these effects. It is also likely to be damaged from alkaline water.

The reinforced cement concrete lining can withstand external water pressure but at a very high cost. Where unexpected water pressures are encountered, unreinforced lining will crack more easily than the reinforced lining and will relieve the pressure thereby reducing the area of damage.

(b) Shotcrete Lining

In this type of lining cement mortar is applied by pneumatic pressure. Shotcrete lining can be easily placed over rough sub-grade and is, therefore, better suited for use in existing cuts where finishing to exact shape and slope would be expensive. The lining may be constructed with or without reinforcement (in the form of mesh or expanded metal), reinforcement increases its useful life specially, when laid over earth sub-grade.

Since the thickness of lining is limited to 5.0 cm mostly such linings are applied on smaller channels or where operational requirements are not severe. The lining is also likely to be damaged by external water pressure easily due to small thickness. It is very difficult to control the thickness of lining, which may leave areas where thickness is less than the minimum required, such patches constitute the areas of weakness where lining may give way.

(c) Precast Concrete Lining

Precast concrete slab/tile has been used extensively for canal lining. The main advantage of precast concrete lining is that it is possible to exercise a close and continuous quality control over the selection, proportioning of concrete materials, mixing, compaction and curing operations. The precast slabs are more compact and impervious. The precast lining has smaller thickness and smoother surface than other type of linings. The facilities of construction and storage close to the site of works are additional advantages of precast concrete lining. The slabs are laid on compacted sub grade and joints have to be sealed to prevent leakage. Proper back filling and careful tamping under and around each section is of utmost importance to prevent breakage from minor movements and uneven settlement of the subgrade. The joints are sealed with mortar or bituminous mastic. This type of lining provides slightly flexibility and it may adjust itself to minor movements of the subgrade.

Lining of canals with precast slabs is labour intensive and is competitive with other types of lining only when cheap labour is available.

(d) Brick (or Tile) Lining

This type of lining has been used extensively on major canals in India such as Sarda Canal, Bhakra Canal, Rajashthan Canal and Parallel Upper Ganga Canal which is under construction at present. This type of lining is preferred where suitable soil is available in the vicinity of the canal.

The brick linings are not only equally impermeable as cement concrete linings, but have the additional advantage of low initial and maintenance cost, quicker construction and natural safe guard against cracking due to closely spaced joints. This type of lining is economical where aggregates for concrete lining are not available. It does not require skilled labour as needed for concrete lining.

(e) Stone Lining

Stone lining has been employed in areas where suitable materials, such as sand stone or basalt, are available in abundance. This type of lining is cheaper than concrete lining. The construction of stone lining is however, relatively slow but labour intensive.

Since seepage losses are very high, stone lining may prove advantageous only where erosion control is the main purpose for lining. Stone lining is not suitable for canals in filling. The slightest settlement of the sub-grade causes distress and lining fails.

(f) Asphaltic Concrete Lining

Asphalt mixed with sand and gravel, is used as a lining material. Asphaltic concrete lining is cheaper than cement concrete lining. It has an edge over the cement concrete lining because of its better adjustment to sub-grade changes and the possibility to use slightly poorer quality aggregate.

The life of asphaltic concrete lining may range between 10 to 20 years. Other disadvantages of asphaltic concrete lining are the permissible velocity limitation of 1.5 m/sec, danger of weed growth, poor resistance to external hydrostatic pressure and danger of sliding during hot weather.

(g) Soil-Cement Lining

Soil cement lining as the name implies, is constructed with a mixture of port-land cement, natural soil and water all of which hardens to concrete like material. Soil-cement offers possibilities for use as a canal lining material in localities where the climate is mild and where the sub - grade soils or those adjacent to the canal are of a sandy nature and other suitable materials are not readily available. Laboratory tests indicate that for best results soils for this purpose should be well graded with a maximum size of 20 mm and containing between 10 & 35 percent fines, passing through Indian Standard Sieve No. 8.

The soil cement lining is not weather - resistant and its life is comparatively short and maintenance charges are relatively high. It does not permit velocities higher than those in an unlined canal but reduces seepage losses and prevents waterlogging.

(h) Earth Lining

The lining of an irrigation channel using natural or processed soils as lining material is termed as earth lining. Soils selected for lining purposes should be impermeable and non-erodible and should not crack or disintegrate under the weathering action. In this regard, gravel - sand - clay mixture is considered a suitable material for lining even large canal sections because such a material has low permeability, high stability and good resistance to erosion. The stability and impermeability of the available soils may be improved by mixing soils with bentonite, asphalt emulsions, resins, chemicals, cement, lime and petrochemicals etc. However, use of chemically stabilised soils for canal linings is still in an experimental stage. Secondly, the stabilization of soils may make the lining more expensive.

2.2.2 Buried Membrane Linings

A buried membrane lining consists of a thin and impervious water barrier covered by a protective layer. Hot-applied or sprayed-in-place asphalts, prefabricated asphaltic materials, shotcrete, plastic films, synthetic rubber, etc. have been found effective when covered. The turbulent water, maintenance equipment and animals. Generally, earth and gravel are used as a covering material. However, in case of such linings, the permissible water velocity is low and the life of lining is uncertain.

The commonly used buried membrane linings are;

1. Sprayed-in-place asphaltic membrane lining.
2. Ready made asphaltic membrane lining.
3. Plastic film and synthetic rubber membrane lining.
4. Bentonite and clay membrane lining.

2.3 SELECTION OF TYPE AND EXTENT OF LINING UNDER BUDGETORY AND OTHER CONSTRAINTS

As we have already discussed type of lining to be done in any canal project depends on many factors viz. availability of material, type of sub-grade, depth of water table in the area, availability of machinery and labour etc. Hence in case of budgetory and other constraints we may have to decide on the type and extent of lining, for which the following point should be considered.

1. Concrete lining has high initial cost, longer life and lesser operation and maintenance cost as compared to other types of lining.
2. Whether entire canal system be lined or a part can serve the purpose.

Lining of the distribution system can save more water as percentage seepage losses are more in smaller channels, because, the perimeter of a smaller channel is more in proportion to the area of the channel and secondly, the smaller channel may be running intermittently.

On the other hand, lining of the main canal only will be costly and saving in water may not be commensurate with it. It may, however, reduce the cost of the main canal.

Hence, for deciding the type and extent of lining it is recommended that -

i. Techno - economic studies should be carried out for each case in detail.

ii. System approach using aquifer modelling and optimisation techniques may be adopted to study the complete water balance of the area, considering water availability demands, water table conditions, seepage losses from different parts of the canal system, pumping requirements etc.

2.4 GENERAL GUIDELINES FOR SELECTION OF TYPE OF LINING

The suitable types of linings adequate for different sizes of canals are given below for general guidance.

a. Channels with bed width upto 3.0 m.

   1. Single burnt clay tile or brick lining where seepage considerations are important;

   2. P.C.C. slab lining; and

   3. Flexible membrane lining with adequate earth/tile cover;

b. Channels with bed width 3.0 to 8.0 m.

   1. Lining of single burnt clay tile;

   2. P.C.C. slab lining; and

   3. Combination lining (flexible membrane lining in the bed and rigid lining on the sides) This may be adopted where the channels have become stable and no danger of scour is expected; and

c. Channels with bed width greater than 8.0 m.

   1. Insitu cement concrete lining in bed and sides in accordance with IS : 3873-1978 ;

   2. Insitu cement concrete lining in bed and P.C.C. slab lining on sides; and

3. Burnt clay tile lining in accordance with IS : 3872-1966 (double on sides and single on bed) where aggregates for manufacture of concrete are not available economically.

Note : For lining of canals in expansive soils refer IS : 9451-1980.

2.5 PART LINING

Part lining of the canal has also been suggested for reducing the cost of lining. Theoretical solutions for steady state seepage from unlined canals of various cross-sections and different types of boundaries are presented by various investigators, notably by Vedernikov [See Harr (1), Muskat (2) and Hammad (3)]. However, such detailed information for partially lined canals is not available. Analog studies of partially lined canals using resistance net work, analog have been reported by Bouwer (4). The study conducted at Indian Institute of Technology, Kanpur by Subramanya, K. et al (5) aims at obtaining solutions to problems of partially lined trapezoidal canals with only sides lined (Fig.1a) and only bed lined (Fig. 1b). The results of this study with deep water table for both the cases are given in Fig 2 & 3.

These results indicate that when the sides of the canal are lined, the slope of the sides has negligible influence on seepage loss. As b/h ratio increases, the seepage loss increases. In the case when canal bottom is lined and seepage occurs through sides only, Fig. 3 shows that the slope of the canal banks has considerable influence on the quantity of seepage. In this figure, q is the seepage loss from one side per unit length of the canal. Fig. 4 shows the variation of the percentage reduction of seepage due to lining of bed and side slopes with b/h for various side slopes m, ($m = \cot \beta\pi$). This indicates that for canal having side slope 2.5:1 and b/h = 9.0, if the bed is lined, a 50% reduction in the quantity of seepage is expected and if the sides are only lined, a 25% reduction in the seepage quantity would be achieved.

Experiments conducted at U.P. Irrigation Research Institute, Roorkee on electrical analogy model for shallow water-table condition indicate that even a very small open area results in seepage losses nearly equal to those taking place from unlined canal. Part lining of a canal with shallow water-table condition is, therefore, not considered economical from seepage considerations.

2.6 GENERAL DESIGN CONSIDERATIONS

2.6.1 Design of canal section

The discharge that can pass through a canal section is calculated by;

$Q = A \times V$ Where ,

A = Area of cross-section in m^2, and

V = Mean velocity in m/sec.

Mean velocity for lined canal case is given by Manning's

equation i.e., $V = 1/n\ R^{2/3}\ S^{1/2}$

where

R = Hydraulic mean depth,

S = Slope of canal, and

n = Rugosity coefficient.

From the Manning's equation, it is clear that the conveyance of canal increases as the hydraulic radius increases or as the wetted perimeter decreases. Thus from the view point of hydraulics, among all possible channel section, the best section is a semi circle since, for a given area, it has the the minimum wetted perimeter. Except for small channels, a trapezoidal section is preferable. Typical cross sections of the lined canals in cutting and filling are given in Fig. 5. Some typical cross-sections of lined canal in rock cutting are shown in Fig.6.

2.6.2 Coefficient of Roughness

In a given channel, the rate of flow is inversely proportional to the roughness of the surface. The rugosity coefficient, n, usually recommended for use in Manning's formula for the design of several types of linings is given in Table-1.

Table-1

Values of Rugosity Coefficient (n) for lined channels with straight alignment

Sl. No.	Surface characteristics	Value of n
1.	Concrete with surface as indicated below:	
	a. Formed, no finish/PCC tiles or slabs	0.018 - 0.020
	b. Trowel float finish	0.015 - 0.018
	c. Gunited finish	0.018 - 0.022
2.	Concrete bed trowel/float finish and slopes as indicated below:	
	a. Hammer dressed stone masonary	0.019 - 0.021
	b. Coursed rubble masonary	0.018 - 0.020
	c. Random rubble masonary	0.020 - 0.025
	d. Masonary plastered	0.015 - 0.017
	e. Dry boulder lining	0.02 - 0.03
3.	Brick tile lining	0.018 - 0.020
4.	Asphalt	
	a. Smooth	0.013 - 0.015
	b. Rough	0.016 - 0.018

Notes : 1. For channels with an alignment other than straight, loss of head by resistance forces, shall be increased. A small increase in the value of `n' may be made to allow for additional loss of energy. In case the channels with relatively higher discharges in straight reaches, lower values of `n' than indicated above may be taken.

2. The `n' value shall be decided in view of the age of lining, surface roughness, weed growth, channel irregularities, canal alignment, silting, suspended material and bed load etc.

The values of rugosity coefficients, shown above, be adopted only where the channel has flushing velocity and no sediment deposition will take place. The value of `n' may increase due to deposition of silt in course of time and should in such cases be taken as that of for Earthen Channel.

The actual value of 'n' based on observations taken on Yamuna Power Channel, Dak Pather, Dehradun, in November, 1971 ranged between 0.0175 and 0.0229 at Km. 0.60 and between 0.0164 and 0.0175 at Km. 2.05. The higher value of `n' at Km. 0.60 could be attributed to the deposition of silt in head reaches of the channel.

2.6.2.1 Equivalent Roughness

In some channels, different parts of the channel perimeter may have different roughnesses. Canals in which only the sides or bed are lined, are typical examples. For such channels it is necessary to determine an equivalent roughness coefficient that can be applied to the entire cross-sectional perimeter in using the Manning's formula. In such cases calculation of equivalent roughness may be calculated by the following formula [8].

$$n = \frac{\sum_{i=1}^{N}\left[n_i^{3/2} P_i\right]^{2/3}}{P^{2/3}}$$

Where,

P_i = are the lengths of different portion of perimeter with corresponding roughnesses.

n_i = is the roughness of portion P_i

$$P = \sum_{i=1}^{N} P_i$$

The calculation of equivalent roughness may be best illustrated by an example and is given in Appendix – A.

2.6.3 Side slopes of canal section

Lining is usually made to rest on stable slopes of the natural soils, so slopes shall be such that no earth pressure is exerted on over the back of the lining. However, where chance of sudden drawdown in the canal is considerable, proper slip circle analysis should be made for the stable slopes. For a general guidance, the following side slopes are recommended as given in Table-2.

Table - 2

Recommended side slopes

Sl. No.	Type of soil	Side slopes (Hor:Vert.)
1.	Very light loose sand to average sandy soil	2:1 to 3:1
2.	Sandy soil/loam	1:1 to 2:1 (in cutting) 1.5:1 to 2:1 (in embankment)
3.	Sandy soil or gravel	1:1 to 2:1
4.	Muram gravel mixed soil	1:1 to 1.5:1 (in cutting) 1.5:1 to 2:1 (in embankment)
5.	Black cotton	2:1 to 3.5:1 1.5:1 to 2:1 (in cutting)
6.	Clayey soils	2:1 to 2.5:1 (in embankment)
7.	Rock	0.25:1 to 0.5:1

Source : IS:10430-1982 (Criteria for design of lined canals and guidelines for selection of type of lining).

Note : The above slopes are recommended for depth of cutting/height of embankment upto 6 metre. For depths/height in excess of the above special studies for the stability of slopes are recommended.

2.6.4 Free Board

The free board (measured from full supply level to the top of lining) depends upon the size of canal, velocity of water, curvature of alignment, wind and wave action and method of operation. The U.S.B.R. practice (8) for the minimum permissible free board for various sizes of canal is given in Figure 7.

IS : 10430-1982 recommends a free board of 0.75 m for main and branch canals carrying a discharge of more than 10 cumecs and 0.60 m for branch canals and distributaries carrying a discharge of less than 10 cumecs but greater than 5 cumecs. For discharges between 5.0 - 1.0 cumecs, free board shall be 0.5 m for discharges less than 1.0 cumec (that is minors) free board should be 0.3 m. For discharges less than 0.06 cumec (that is water course) free board should be limited to 0.1 to 0.15 metre.

On the other hand, Central Water Commission, New Delhi has proposed the following values of free board related with corresponding discharges:

Discharge (in cumecs)	-	Upto 0.7	0.7 to 1.4	1.4 to 8.5	over 8.5
Free board(m)	-	0.46	0.61	0.76	0.92

However, for the case of power channels and in lengths in the vicinity of intake and forebay area, consideration should also be given to the surge heights due to sudden closure or start of the power house.

Freeboard alongwith other hydraulic parameters in some of the major canals in India (9) are given in Table-3.

2.6.5 Miscellaneous details

Miscellaneous details like bank width, Dowla, Roadway & Drainag etc., may be provided as per IS:10430-1982 "Criteria for Design of Lined Canals & Guidelines for selection of type of lining".

Example for calculating equivalent roughness

Example:

An earthen trapezoidal canal (n = 0.025) has bed width, B = 5.0 m, and water depth y = 1.1 m. The channel has a side slope of 1.5:1. In an economic study to remedy excessive seepage from the canal two proposals, viz (a) to line the sides only and (b) to line the bed only, are considered. If the lining is of smooth concrete (n = 0.012), determine the equivalent roughness in the above two cases.

Case (a): Lining on the sides only.

$P_1 = 5.0$ m, $n_1 = 0.025$

$$P_2 = 2\left[\sqrt{1^2 + (1.5)^2}\right] x1.10$$

= 3.966 m, $n_2 = 0.012$

Now, $P = p_1 + p_2 = 8.966$,

$$Equivalent \quad roughness = \frac{\left[5x(0.025)^{1.5} + 3.966x(0.012)^{1.5}\right]^{2/3}}{(8.966)^{2/3}}$$

$$= \frac{0.085447}{4.31585} = 0.02$$

Case (b): Lining on Bottom only.

$P_1 = 5.0$ m, $n_1 = 0.012$

$P_2 = 3.966$ m, $n_1 = 0.025$

$$Equivalent \quad roughness = \frac{\left[5x(0.012)^{1.5} + 3.966x(0.025)^{1.5}\right]^{2/3}}{(8.966)^{2/3}}$$

$$= \frac{0.079107}{4.31585} = 0.018$$

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Table-3

Details of some Major Canals in India

Sl. No.	Name of Canal/ Project	State/Year of completion	Canal Design discharge in cumecs	Water depth in m	Bed width in m	Water surface width in m at design discharge	Side slopes	Free board in m	Remarks
1	2	3	4	5	6	7	8	9	10
1.	Godavari control main canal/ Godavari delta system	Andhra Pradesh 1990	90	2.90	29.28	35.08	1:1	1.0	Unlined
2.	Godavari Western main canal Godavari delta system	-do-	198.1	3.26	51.80	58.32	1:1	1.0	Unlined
3.	Jawahar canal (Nagarjunasagar right canal	Andhra Pradesh	481.1	-	76.20	87.63	1.5:1 to 2:1	0.91	Lined
4.	Nizam Sagar	Andhra	96.22	-	30.48	39.62	1.5:1	1.067	Unlined

1	2	3	4	5	6	7	8	9	10
5.	Bardi Karai main canal	Assam	30.01	1.38	15.7	19.05	1:1	0.75	Lined
6.	Western Kosi canal/Western Kosi project	Bihar	236.7	-	35.06	46.037	1.5:1	0.762	Lined & partially Lined
7.	Main canal/ Solauli Irrigation Project	Goa Daman Diu 1983	14.0	1.65 depth with 13 cumecs discharge	7.1	-	1.33:1	0.60	Lined
8.	Bhadar left bank main canal	Gujarat 1969	14.32	1.98	8.54	10.52	1:1 & 2:1	0.60	Unlined
9.	Kodana left bank canal/Kodana project	Gujarat 1980	11.04	-	7.0	10.66 m cutting & 14.32m filling	1.1 m cutting & 2.1 m filling	0.61	Unlined
10.	Karad right bank canal	Gujarat 1964	5.66	1.55	4.26	8.59	1.5:1 in	0.61	Present

1	2	3	4	5	6	7	8	9	10
11.	Karjan Reservoir left bank main canal	Gujarat	28.30	-	3.89	11.99	1.5:1	0.90	Some part of canal
12.	Mahi right bank canal	Gujarat 1980	198.1	-	16.46	35.14	1.5:1	0.91	Lined
13.	Narmada main canal/Sardar Sarovar Project	Gujarat	1132.83	7.6	75.6	98.4	1.5:1	1.50	Lined
14.	Bhakra canal	Haryana 1956	192.0	-	12.3	28.5	1.5:1	0.75	Lined
15.	Gurgaon canals	Haryana	640.0	-	11.59	22.3	1.5:1	0.75	Lined
16.	Satluj-Yamuna link canal/ SYL Project	Haryana 1980	212 at Haryana Border	-	14.02	32.0	1.5:1	0.75	Lined
17.	Western Yamuna canal	Haryana	454.0	-	50.0	58.0	1.5:1	0.75	Lined
18.	Sunder Nagar	Himachal	240.69	6.26	9.45	28.23	1.5:1	0.91	Lined

1	2	3	4	5	6	7	8	9	10
19.	Loktak Lift Irrigation main canal	Manipur	17.0	-	10.0	13.4	1:1	0.76	Some part of lined
20.	Yamuna Power Channel Yamuna Project	Uttar Pradesh 1965	198.1	5.709	10.98	-	1.5:1	0.76	Lined
21.	Lower Ganga canal (link canal)	Uttar Pradesh 1967	213	3.355	51.45	-	1.5:1	0.3	Lined
22.	Pattanankal main canal	Tamilnadu	8.4	1.68	2.44	-	1:1	0.152	Lined
23.	Manniaru canal	Tamilnadu	43.2	1.524	30.48	-	1.5:1	0.3048	Lined

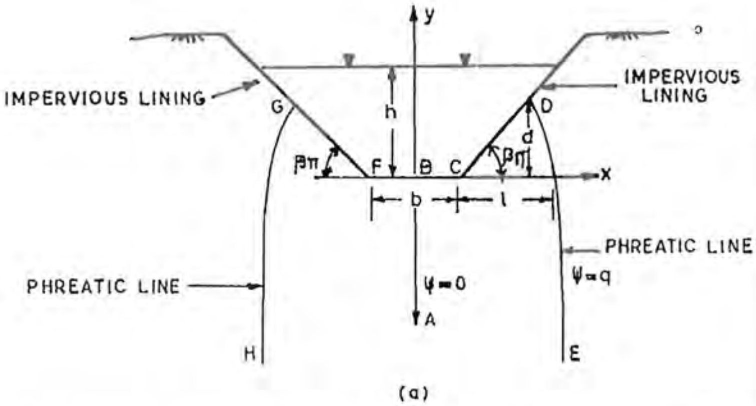


FIG.1 (a)-CANAL WITH SIDES LINED AND BOTTOM UNLINED

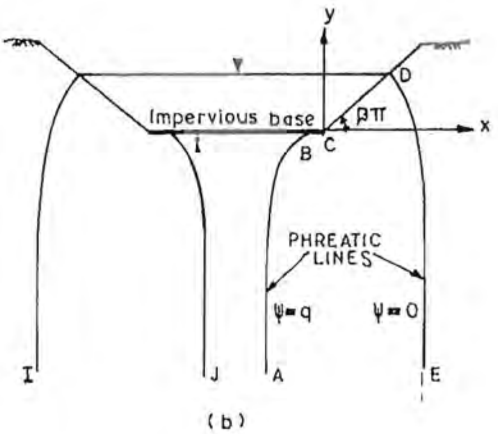


FIG.1 (b)-CANAL WITH BOTTOM LINED AND SIDES UNLINED

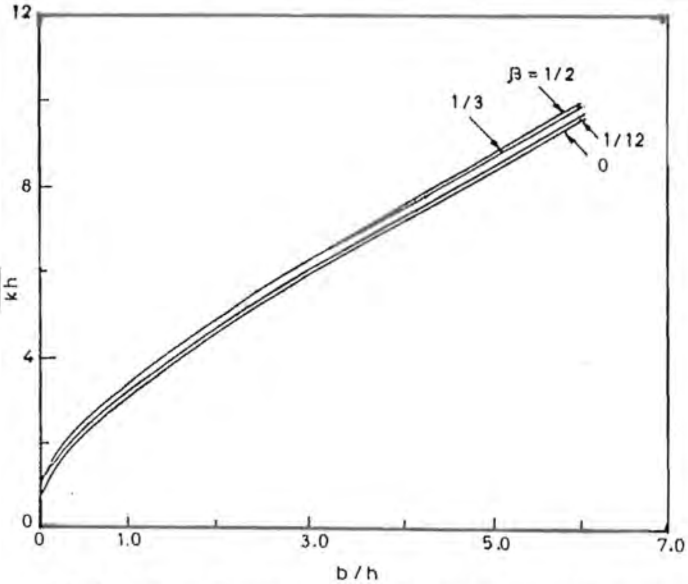


FIG. 2 - VARIATION OF Q / (kh) WITH b / h AND β

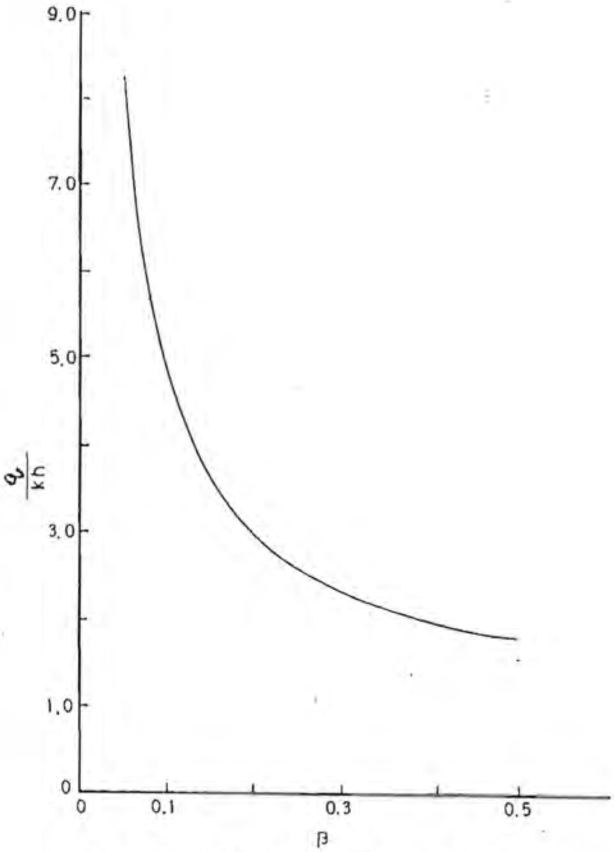


FIG.3 – VARIATION OF q / kh WITH β

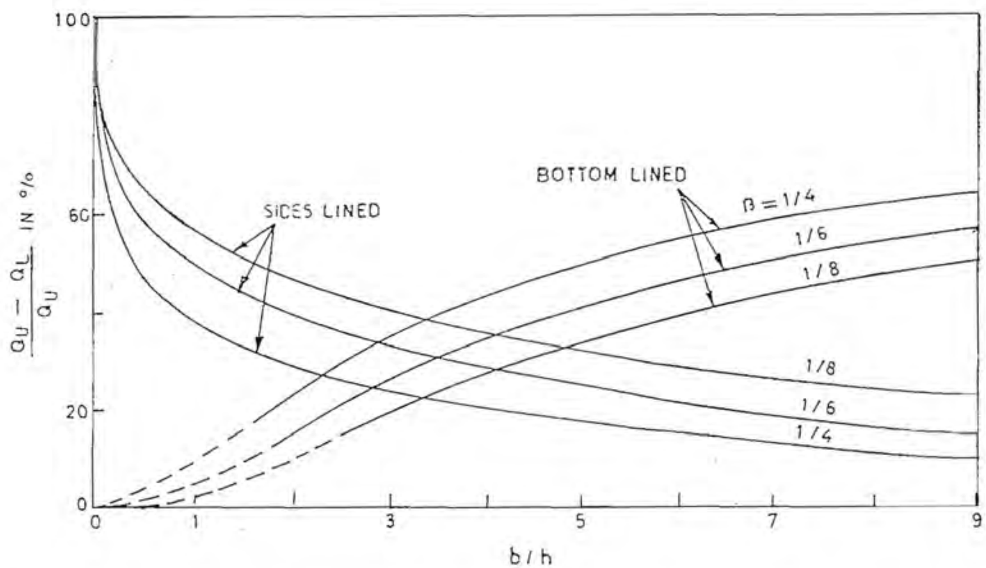


FIG. 4 - VARIATION OF PERCENTAGE REDUCTION IN SEEPAGE DUE TO LINING WITH b/h FOR VARIOUS VALUES OF β

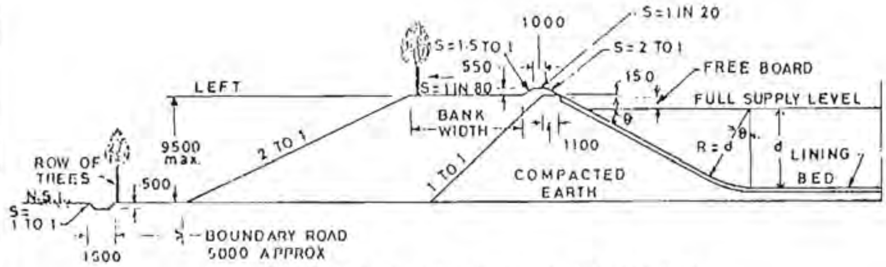


FIG. (a) – NATURAL GROUND BELOW BED

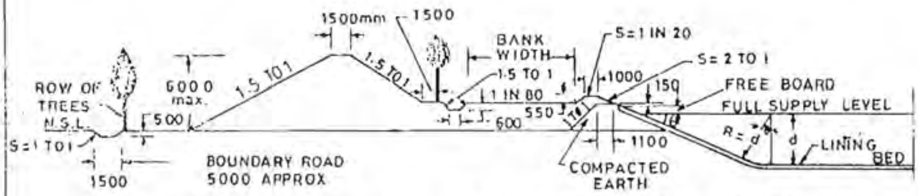


FIG. (b) – NATURAL GROUND BETWEEN BED AND FULL SUPPLY LEVEL

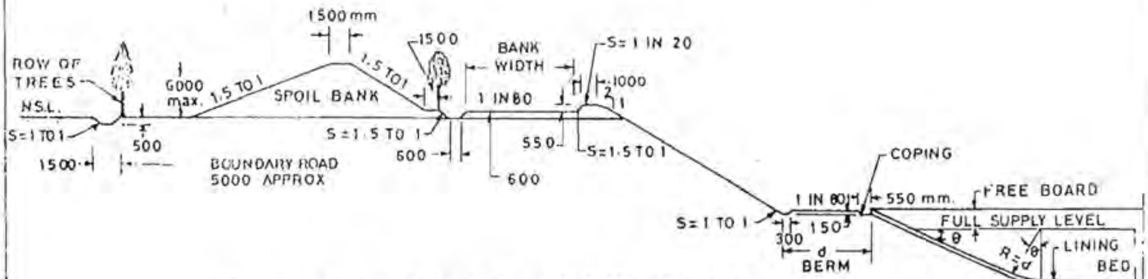
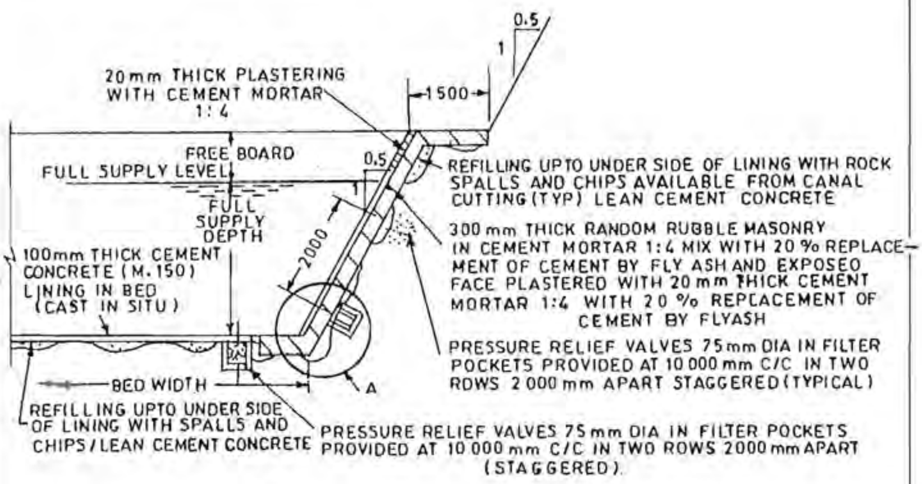


FIG. (c) – NATURAL GROUND IS ABOVE TOP OF LINING

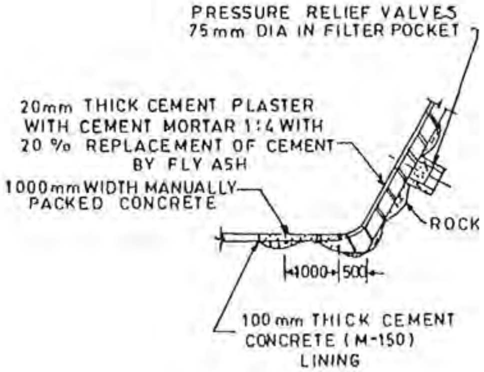
NOTE 1 – The width of coping should be adequate to cover the layers of filter behind lining, if any. However, the minimum width of coping shall be 550 mm.

NOTE 2 – Whenever the permeability of back fill material is high, the catch water drain should be properly pitched.

FIG. 5 – TYPICAL CROSS SECTIONS OF LINED CANALS



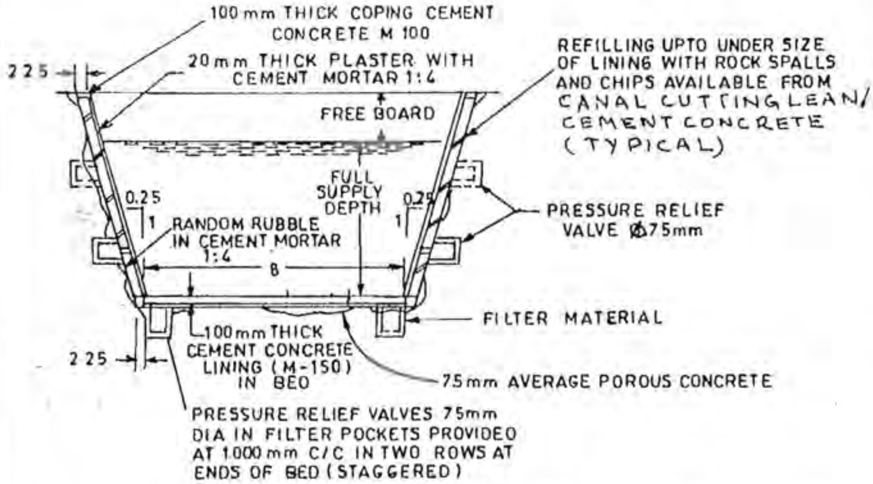
CAST IN SITU CEMENT CONCRETE LINING IN BED AND RANDOM RUBBLE MASONRY LINING ON SIDES



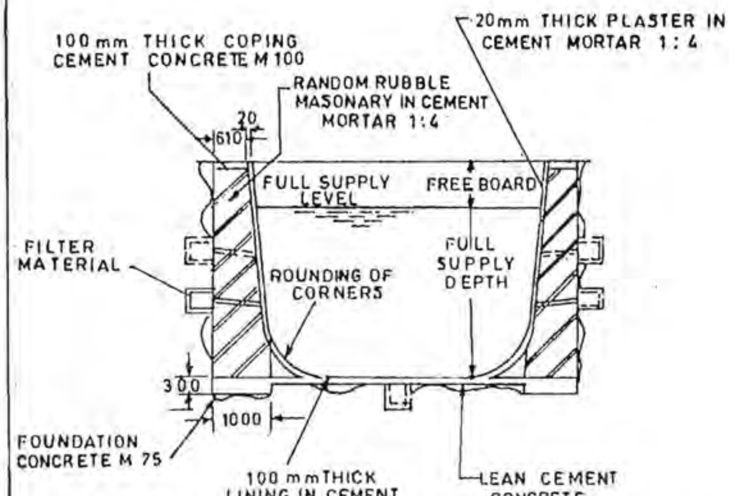
DETAIL AT A

FIG.6(a)-TYPICAL CROSS SECTIONS OF LINED CANAL IN ROCK CUTTING

SOURCE :- IS: 10430-1982 - (CRITERIA FOR DESIGN OF LINED CANALS AND GUIDE LINES FOR SELECTION OF TYPE OF LINING.)



CAST-IN-SITU CEMENT CONCRET (M-150) LINING IN BED AND RANDOM RUBBLE MASONRY LINING ON SIDES



CAST IN SITU CEMENT CONCRETE (M-150) LINING IN BED AND RANDOM RUBBLE MASONRY LINING ON SIDES

NOTE.1– IN CASE OF SOUND ROCK CEMENT CONCRETE LINING MAY BE PROVIDED IN BED AND SIDES ON SIDES THE LINING MAY BE ANCHORED SUITABLY TO THE ROCK BEHIND.

NOTE.2– ALL THE DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SPECIFIED.

FIG. 6(b)-TYPICAL CROSS SECTIONS OF LINED CANALS IN ROCK CUTTING

SOURCE :– IS : 10430-1982

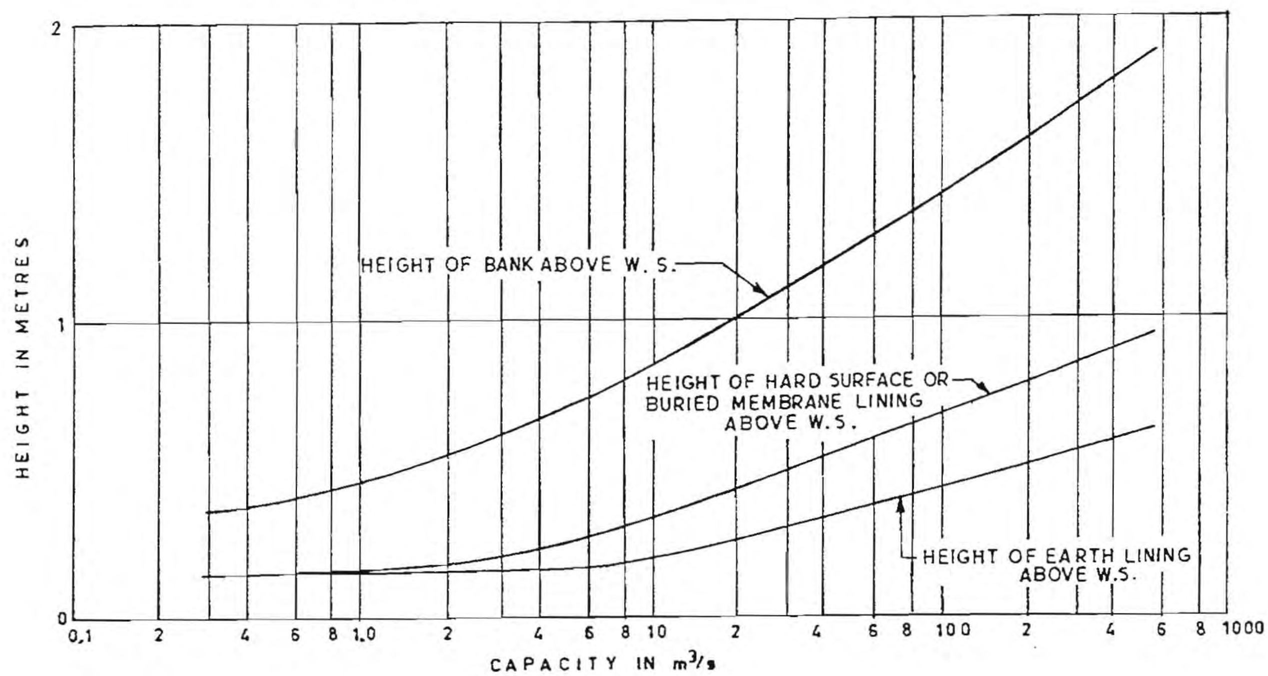


FIG. 7– BANK HEIGHT FOR CANALS AND FREE BOARD FOR HARD SURFACE BURIED MEMBRANE AND EARTH LININGS (U.S.B.R.-LININGS FOR IRRIGATION CANALS)

3. EXPOSED AND HARD SURFACE LINING

3.0 INTRODUCTION

The exposed and hard surface linings generally comprise cement concrete, reinforced cement concrete, precast concrete blocks, bricks or tiles, and stone masonry linings. The first three types of linings are mostly used in the country.

Brick tile lining can be successfully used in relatively small jobs or where suitable soil and other infrastructure for bricks is readily available. The effectiveness of brick lining in reduction of seepage and its long term durability are questionable.

In-situ cement concrete lining has been successfully adopted for large canals in India and abroad. It can withstand high velocities upto 2.5 m/sec. It eliminates weed growth and thereby improves flow characteristics. It can be constructed using sophisticated machinery like slip form or other types of pavers. Due to mechanisation, required quality can be assured and desired progress can be achieved. Reinforced concrete lining is generally avoided and its provision is limited to locations of heavy filling where danger of subsidence is feared or where the canal intercepts drainages. Boulder or stone masonry lining is generally used where these are available in plenty so as to make the lining work economical.

3.1 CEMENT CONCRETE LINING

An ideal canal lining would be water tight, moderate in cost, prevent growth of weeds, resist attack of burrowing animals, be strong and durable, provide maximum hydraulic efficiency and have a reasonable amount of flexibility. Concrete lining largely meets these requirements. Concrete lining made of selected aggregates with proper control of placing, finishing and curing on a suitable subgrade requires minimum maintenance and has long life.

Small canals are generally lined by hand screeding and finishing. For large canal system, it is done by use of subgraded guide slip-forms or by paver machine.

3.1.1 Lining Equipment

There are two methods for mechanical construction of concrete lining. One is known as slip-forming and the other screeding or paver machine. The slip-form machine operates longitudinally along the canal while in case of paver machine, concrete is screeded in transverse direction and from bottom to top on the sloping face of the canal.

In slip-forming the concrete is spread by machine and is vibrated over the entire length of paving by means of needle or screed vibrator. The slip-form machines are necessarily heavier and costlier in comparison to paver machines. However, they are speedier in construction and provide better finish of the lining. In India slip-form machine was used on Poocham Pad canal in Andhra Pradesh.

In paver machine the concrete spread over the subgrade is finished with cylinder which rotates or moves at a fixed speed equivalent to the resonant frequency of green concrete and is vibrated with a needle vibrator. Paver machine was used in the state of Uttar Pradesh for lining of some unlined reaches of Sharda Sahayak feeder channel during closure periods (Ref. 14). The concrete paver machine is currently being used on Narmada main canal, which is under construction in the state of Gujarat. The rated capacity of the paver is 20 m^3/hr. However, as reported in literature, in actual practice the output of the order of 12 m^3/hr only could be achieved. The equipment used is shown in Photographs 1&2.(Ref. 15).

3.1.2 Construction details

The concrete lining work involves the following main operations :

(i) Trimming and preparation of subgrade.

(ii) Laying of cement concrete.

(iii) Cutting joints.

(iv) Curing.

Trimming can be done either manually or mechanically. Mechanically, it can be done by using self aligned trimmer also called automated trimming machine. Subgrade preparation should be performed enough in advance to delay the lining operations. The subgrade is prepared by watering and tamping or rolling just before laying cement concrete lining to ensure firm base. It should be ensured that the subgrade is thoroughly moist to a depth of about 15 cms to prevent subgrade from absorbing water from the freshly laid concrete. Where subgrade is rocky, it is over-excavated by 7.5 to 10 cms and backfilled with semipervious type of material properly compacted before trimming.

For proper workability control on consistency of concrete is important as even small variation in slump will leave honey combs on the under surface if concrete is too dry or too wet. Moreover, concrete will not stay on the slopes. A slump of 4 cm is considered suitable for concrete to be placed manually on slopes of the canal and 5.0 to 6.5 cm for concrete in the bed. (Ref. 1) For heavier longitudinally operating machines, slump of about 5 cm is recommended. Concrete for canal lining should include enough well-graded sand to ensure a reasonably good finish.

The laying of concrete lining should be in conformity with relevant I.S. Codes or as per U.S.B.R. practice (Ref. 3). The workability and quality of concrete with the same quantity of cement can be improved with the use of air-entraining agents or super-plasticizers. Air-entrainment of 3.5 to 5.5 % also helps materially in securing a satisfactory finish for concrete containing 40 mm maximum size aggregate. Another factor that will considerably improve the finishability of concrete is the reduction of the pea-gravel. The maximum size of aggregate should ordinarily not be greater than one-half the thickness of the lining. Use of richer wearing coat laid simultaneously with a leaner base might also be considered to affect economy if extra thickness is provided.

Due to low flexural strength plain concrete lining is easily damaged in filling reaches. In such cases additional thickness and/or reinforcement shall be provided. It is difficult to lay and properly compact concrete on side slopes and curing poses serious problems. As a result, lining is generally weaker on the side slopes than that in the bed. The thickness of lining on the side slopes should, therefore, be kept slightly more than on the bed, (Ref. 2).

The lining should normally be placed first in bed and then in the sides. Where site conditions require laying of lining on the side slope first, it should be supported on toe walls so as to ensure its stability. Curing of concrete for the lining can be done either in conventional manner, i.e. by application of water or by spraying the curing compound. Though water curing by ponding can be quite effective on canal bed, curing of lining on slopes using water may not be an effective arrangement. Generally a white-pigmented wax based compound is used for curing concrete lining.

White-pigmented curing compound conforming to A.S.T.M. specifications C-309-38 is being used for Narmada Main Canal lining, which is under construction in the state of Gujarat.

3.1.3 Low Cost Lining

With a view to evolve economical canal lining materials, Maharashatra Engineering Research Institute, Nasik conducted experimental field studies (23) on following types of materials used for lining of distributaries and minors of three projects viz., Jayakwadi, Dhom and Kukadi.

1. Cast-in-situ cement fly ash concrete.
2. Cast-in-situ cement surkhi concrete.
3. Cement fly ash concrete tiles.
4. Cement surkhi concrete tiles.
5. Mortar-faced stabilised soil tiles with fly ash.
6. Thixotropic concrete

The performance of these experimental linings was observed for 4-5 years and it was found that the performance of cast-in-situ cement fly ash concrete, cement surkhi concrete is good and may be economically adopted.

3.1.4 Reinforcement concrete linings

Reinforcement in canal linings is normally not needed except in specific areas where structural considerations are involved in the design. Reinforcement is not required, if transverse joints are provided at proper interval (less than 6 m) to avoid cracking. It can be justified under unusual conditions, such as high back pressure, high flow velocities, swelling soils, unstable subgrade and in reaches where the canal crosses large cross drainage works.

The amount of reinforcement required depends on slab length for longitudinal steel and width of slab for transverse steel. The necessary area of reinforcement can be found by the following formula (Ref. 13)

$$A = \frac{Lfw}{2s}$$

where

A = Area of steel in square cms per metre of width in the direction in which L is measured.

L = Distance in metres between free transverse joints in compacting longitudinal steel or between free longitudinal joints or edges in figuring transverse joints.

f = Coefficient of friction between slab and subgrade (which varies from 0.5 to 3.0 depending on subgrade material, a value of 1.5 to 2.0 usually being assumed for average conditions).

w = Weight of concrete slab in kg/m^2.

s = Allowable working stress in steel in kg/cm^2.

The amount of reinforcement steel generally vary from about 0.1 to 0.4 % of the area in longitudinal direction and from 0.1 to 0.2 % of the area in the transverse direction.

In case of Narmada Main Canal, where it runs in heavy banking near cross drainage works, it is proposed to increase the thickness of lining in bed as well as on slope from 10 cm to 20 cm and 12.5 cm to 25.0 cm respectively. The canal lining near structures is proposed to be reinforced with 12 mm bars at 30 cm c/c both ways and at both faces. The reinforced lining is extended upto 15.0 metres length on either side of cross drainage works without break at contraction joints. Similar is the practice in the canals of U.P. The joints are provided with water stops.

3.1.5 Joints

Four kinds of joints are used in concrete canal linings.(Ref.13). They are :

1. Construction joints
2. Transverse joints
3. Longitudinal joints
4. Expansion joints.

A construction joint is placed at any location where it is expedient during construction.

Transverse contraction joints are installed to control transverse cracking that results from shrinkage change caused by drop in temperature or moisture loss. Spacing of transverse contraction joints to control cracking should be 2.5 m to 5.0 m with the shorter intervals being used in thinner section.

Longitudinal joints spaced 2.5 m to 5.0 m apart are used to control irregular longitudinal cracking in unreinforced slabs where the perimeter of the lining is greater than 5.0 metres.

Expansion joints in concrete canal lining are ordinarily not required, except where the structures intersect the canal.

3.1.6 Transverse and longitudinal joint details adopted in the W.J.C. link channel constructed with in-situ cement concrete by using paver machine is given in fig.7. The technical specifications for longitudinal and transverse P.V.C. water stops for the 150 mm thick M_{10} cement concrete lining used on the W.J.C. link channel are given as under.

a) Technical Specifications :

S.No.	Characteristics	Unit	Values
1.	Tensile Strength	Kg/Cm^2	116 Minimum
2.	Ultimate Elongation	%	300 Minimum
3.	Tear Resistance	Kg/Cm^2	49 Minimum
4.	Stiffness in flexure	Kg/Cm^2	24.6 Minimum
5.	Accelerated Extraction		
a)	Tensile Strength	Kg/Cm^2	105 Minimum
b)	Ultimate Elongation	%	250 Minimum
6.	Effect of alkali at 7 days		
a)	Weight Increase	%	0.10 Maximum
b)	Weight Decrease	%	0.10 Maximum
c)	Hardness Change	Point	± 5

7.	Effective of alkali at 28 days		
a)	Weight Increase	%	0.4 maximum
b)	Weight Decrease	%	0.3 maximum
c)	Dimension Change	%	± 1

Weight of PVC strip shall be a minimum of 460 g/m for the longitudinal strip are a minimum of 420 g/m for the transverse strip.

b) The surface finish of PVC strips shall be mat finish and off white in colour.

c) The above technical specifications are the dimensions of PVC water stops as shown in the drawing are based on such PVC stops being used for concrete lining on Narmada Main Canal of Sardar Sarovar Project.

3.2 SHOTCRETE LINING

Shotcrete is a term adopted to designate pneumatically applied cement mortar. Pneumatic application is accomplished with the help of special equipment. Because of small and mobile equipment, this process is well suited for construction or repair work on small or widely scattered canal lining jobs. Another advantage is that it can be placed on an irregular surface obviating the need of trimming which is costly in case of rocks.

The equipment for placing shotcrete usually has a system of air locks with the mechanism for feeding the premixed relatively dry sand and cement into a large flexible loss through which it is transported to the discharge nozzle under pressure. At the discharge end, water introduced through a second hose is added to the sand cement mixture and the mortar is discharged under pressure. A minimum air pressure of 3.0 kg/cm^2 is required for a hose length less than 30 m. Shotcrete is usually applied to the canal section by holding the nozzle about 1 metre from and normal to the surface being covered. The lining is suited for rough surfaces as in case of channel through rocky reaches where it will serve to smoothen surface and eliminate leakage through joints and fissures.

As the rate of placement of shotcrete is very slow in comparison to conventional concreting and since no coarse aggregates are used, it requires more cement than is used in conventional concrete. So it is always more costly than conventional concrete lining.

Shotcrete expands and contracts with changes in temperature and moisture, so joints are also required to be provided as in case of conventional concrete lining. Curing of shotcrete is as important as curing of concrete and similar methods can be used.

A further disadvantage of shotcrete is the difficulty sometimes encountered in controlling the thickness within specified limits. Such control is particularly difficult if the subgrade is not trimmed to a reasonable degree of smoothness. Placement of shotcrete in two or more layers of 12 mm to 20 mm each rather than one thick layer, will help produce linings which meet thickness requirements.

3.3 PRECAST CONCRETE LINING

The main advantage of precast concrete lining is that it is possible to exercise close and continuous quality control over the selection and proportioning of concrete materials, mixing, compaction and curing operations, as the work is carried out in centralized locations. The precast slabs are more compact and impervious due to vibration in their moulds. As the thickness of blocks is less than in-situ concrete lining, the surface is rendered more smooth than other lining. It also provides facility of construction as the blocks can be manufactured and dumped in each heading at suitable sites. The blocks are laid on compacted subgrade and the joints are sealed with cement to prevent leakage. This type of lining is especially suitable for use on side slopes and over weaker soils. It is possible even at later date to rectify easily the settlement in slabs.

The common defects in this lining are that the joints are the weakest points and lining is susceptible to damage due to external hydrostatic pressure because of limited thickness of slabs. The joints can also be grouted with bituminous mastic or similar material instead of cement mortar. The former would have the advantage of flexibility and would need no curing (Ref. 2). With flexible joints precast slabs would be able to withstand relatively large settlements and movement without suffering failure.

3.3.1 Manufacture of Precast Lining

Precast slabs and tiles are generally manufactured under controlled conditions in central depots located at suitable distances along the canal and transported to the site after curing. The precast slabs are generally manufactured both by hand casting and machine depending on and lime concrete (1:2:4) for the bed. In Andhra 15 cm to 23 cm thick random rubble masonry in cement mortar (1:6 to 1:8) with 2 cm to 2.5 cm thick cement plaster (1:4 to 1:6) has been used with fair success in Kurnool-Cuddapah, Rajulbanda Diversion Scheme and Tungbhadra Project Canals. Details of stone masonry lining adopted at high level Tungbhdra Canal are given in the Appendix at the end of the book.

3.6 DESIGN STANDARDS

From economic considerations the section of lined canal should be such that the cost of excavation and lining is a minimum. This may yield a relatively deeper section with small bed width and water depth ratio. But in practice the depth of the canal may have to be limited in view of the difficulties in excavating a deeper channel and the likely external pressure to which the lining below the water-table would be subjected to. Small canals provided with hard surface lining are usually designed to have a base width and water depth ratio of 1 to 2. However, channels with larger discharge may have higher base width and water depth ratio upto 20 or even more depending on permissible depth and available slope.

Hard surface linings permit higher water velocities than in unlined earthen sections. The recommended thickness of hard surface linings which are based on the discharge of the canal are given in Fig. 2. The Shotcrete linings are usually 4.0 cm or more thick. The single brick or burnt tile lining is usually 5.0 or 7.5 cm thick, whereas double brick or burnt tile lining is 10.0 to 15.0 cm thick. For resurfacing with asphaltic concrete a minimum thickness of 5.0 cm is usually provided.

In case of concrete lining provision of permanent joints becomes a necessity to allow for dimensional changes of the lining blocks due to temperature and moisture variations. The joints should be of suitable shape and size and should be properly filled and sealed with adequate material. 20 cm wide and 10 cm deep sleepers are provided under the joints. The size of sleepers could be reduced to 15 cm x 7.5 cm in case of canals with capacity less than 15 m^3/sec. The sleeper should be placed centrally below the joints (Fig. 3).

The various considerations for selecting a suitable joint filler are given below;

(i) It should permit free movement of lining slabs in expansion and contraction.

(ii) It should be elastic enough to take up the reduction in the thickness of the joint due to expansion of the lining blocks, and should regain its shape and remain sticking to the sides of the joints on subsequent contraction of the blocks.

(iii) It should provide a water-proof seal at all times under the prototype head.

(iv) It should be resistant to variation in temperature and should have low susceptibility to flow during hot weather.

(v) It should have a long life and should be moss and fungus resistant.

Various sealing compounds available in the market were at U.P. Irrigation Research Institute, for judging their suitability as joint filler for lining Yamuna Power Channel with 30 cm x 30 cm x 5 cm precast concrete blocks laid over 7.5 cm bricks with 12 mm thick sandwiched plaster in the sides. The results of tests of Nomoloid compound and nomotex Board, for their resistance to variation in temperature and the leakage through joints under the prototype head, indicated that these materials were unsuitable for use as a joint filler for Yamuna Power Channel. The basic studies carried out at the Institute led to the evolving of a sand mastic with blown grade of bitumen, named as U.P. Irrigation Research Institute joint filler compound. This compound was also found cheaper as compared to other materials. As such it was used for Yamuna Power Channel. The ingradients of the joint filler are given below : (Ref. 20)

Maxphalt R 85/25	43 %
Fine sand having F.M., 1 to 1.5	55 %
Asbestos Powder	2 %

The mastic should be prepared by heating the bitumen sand separately to 190 C. The sand should be mixed with 2/3[rd] quantity of bitumen first and then asbestos powder will be added to it. The remaining 1/3[rd] quantity of bitumen is then adopted to this mix and stirred thoroughly. The mastic is poured after cleaning and painting the sides of joint with Shalitex primer. This compound has also been used in Link Canal at Narora, District Bulandshahr, in the year 1966-67. It is learnt that the compound has been giving a satisfactory performance.

Concrete for canal lining should be plastic enough for thorough consolidation and stiff enough to stay in place on the side slopes. Usually a mix with excess of sand is needed for machine-placed lining to give adequate workability.

Hard surface linings require a firmer base to reduce the amount of cracking and danger of failure due to settlement. The use of hard surface linings on expansive soils should be avoided.

Sulphates of sodium and magnesium have adverse effect on cement concrete lining. Following methods (Ref. 18) may be adopted for the protection of lining in the reaches where total dissolved solids are more than 0.25 percent by weight.

(i) A protective coating of maxphalt 30/40 grade is applied over the subgrade before laying the lining. The thickness of coating obtained by using 2.5 to 3.0 kg/m^2 is sufficient.

(ii) To coat the bottom tile with maxphalt. This method is cheaper.

3.7 SEEPAGE CHARACTERISTICS OF LINING MATERIALS

Cement concrete lining is the most impermeable lining. The results of seepage measurements made by U.S.B.R. and U.P.I.R.I., Roorkee on various projects are given in Table 1. A perusal of the table indicates that seepage losses in case of reinforced and unreinforced concrete linings range from 0.03 to 0.32, and 0.25 to 2.93 $m^3/sec/10^6m^2$ respectively. In case of shotcrete the observed seepage losses are 0.11 $m^3/sec/10^6m^2$. Brick lining with sandwitched layer of cement plaster is equally impermeable. The seepage losses in a 7.2 km reach of Lower Bhavani concrete lined channel were evaluated by Inflow and Outflow method as 0.72 $m^3/sec/10^6m^2$. (Ref. 6)

Overall values of field permeability of brick tile lining derived on the basis of field observations of head loss through the linings of Sarda Power Channel and Lower Ganga canal work out to 0.217×10^{-4} and 0.19×10^{-4} cm/sec respectively against laboratory value of 8×10^{-6} cm/sec, the increase in permeability value being due to the effect of leakage through joints and cracks.

Laboratory experiments were conducted at U.P. Irrigation Research Institute, Roorkee (Ref. 19) to determine permeablity, seepage losses and flexural strength of single tile lining laid over a layer of bentonite and double tile lining with sandwiched cement sand plaster replaced by a layer of bentonite. The test results indicated that the seepage losses through the tile lining laid over neat bentonite or bentonite soil mix with betonite percentage less than 20 are significantly higher than seepage losses through tile lining laid over plaster. The flexural strength of the tile lining laid over bentonite layer is much less as compared to that with cement plaster.

The laboratory and semi-field experiments conducted by Punjab Research Institute indicated that initial seepage losses through asphaltic lining are very high. But with the lapse of time due to some sort of self-healing property exhibited by it, water tightness of the lining undergoes a significant improvement. The steady value of seepage losses has been found to be less than 0.6 $m^3/sec/10^6 m^2$ during five years of observation.

3.8 FIELD PERFORMANCE

Study of several concrete and shotcrete linings which have been in operation indicates that such linings, if properly designed, constructed and maintained, will have an average life of about 50 years. The service history of concrete linings has proved to be good in general and such linings have been constructed on almost all types of subgrade.

Linings comprising of cement concrete/clay brick tiles are able to withstand the vagaries of the weather and have sufficient resistance against erosion due to high velocities of silt laden water flowing in the channel. The life of these linings is very well comparable to conventional conrete linings. Considerable hand work is required for all precast type of linings, as proper backfilling and careful tamping under and around each section is of utmost importance to prevent leakage from uneven settlement. Moreover, this type of lining behaves as semi-rigid lining and no large scale failure occurs due to minor defects left in subgrade preparation. It is also experienced that if 25 to 30 % of the portland cement is replaced by surkhi or lime kankar the watertightness of the lining is increased as temperature cracking is reduced.

Seepage losses may be very high if the joints of stones/boulders lining are not mortared. Non-mortared boulder linings have proved advantageous where erosion control is the main reason for lining.

The performance of three major lined canals of the country, viz, Nangal Hydel Channel (Punjab), Yamuna Power Channel (U.P.) and Rishikesh -Chilla Hydel Channel (U.P.) has indicated that the lining has behaved satisfactorily. The details of performance of these canals are given below.

3.8.1 Nangal Hydel Channel

The channel has been provided with cement concrete lining except in some reaches of tail portion where tile lining has been adopted due to non-availability of aggregate for concrete. The canal was commissioned in July, 1954. The lining has proved to be relatively more stable in filling reaches than in reaches involving heavy cutting. The behaviour of canal in various reaches is as below.

Lining in Continuous Running Reaches : Ever since the canal was commissioned, it has not been possible to close it up to km 33 due to requirements of water at Kotla and Ganguwal Power Houses. The continuous running in this reach has given rise to the following problems:

(a) Failure and collapse of slabs have been caused due to unequal settlement in the backfill or due to creation of cavities underneath arising from movement of lines through joints.

(b) The bulging of slabs has been caused due to excess hydrostatic pressure as a result of inadequate drainage against high water-table outside the canal.

(c) Due to continuous running of the canals the joints could not be attended to during the last several years in which the hot pour compound has been washed out.

(d) Some leakage has been observed through the canal embankment and at the cross-drainages during the past few years. Although the source of the leakage can only be located on closure of canal, it appears to be a result of gradual saturation of the banks and the subsoil due to continuous seepage through joints and cracks.

Lining in Heavy Cutting Reaches : Some major damages have occured due to sub-soil water in the reaches of heavy cutting especially downstream of km 33. The reaches, where proper drainage arrangements were initially provided, gave less trouble. General rise in water-table has taken place in the vicinity of the canal. Serious damage has resulted due to closure for annual repairs downstream of Lohand Regulator. Experience on this canal has indicated that concrete lining has given better overall performance in high water-table reaches than tile lining.

Lining in Filling Reaches : There have been practically little damages in filling or partly filling reaches. In such cases major cause of damage was the entry of rain water into the subgrade behind the lining on the slopes.

3.8.2 Yamuna Power Channel

The lining consists of cement concrete tile lining in sides and 100 mm thick 1:2:4 mix of concrete as shown in Fig. 4. Expansion joints of 20 mm width were provided in the lining at every 10 metre interval. The arrangements of expansion joint and joint between colcrete and tile lining is shown in Fig. 5.

In the interest of power generation, the power channel runs throughout the year. The power channel was specially closed in the years 1972,1978 and 1984 for detailed inspection of the damages and to carryout repairs. It has been noticed that in the following reaches some panels of side lining of the channel were found damaged in almost every closure.

(i) In 00-1 km on the hill side bank and just d/s of the curve.

(ii) In 8.00 to 9.5 km on both banks.

The concrete lining in the bed was damaged in small patch in a length of almost 30 metre at km 13.40 km, as was noticed in the year 1984. It has also been noticed that the damages to channel lining are frequent during rainy season.

The damage to side lining in deep cutting reaches might have occured due to :

(i) Bulging of tiles due to back pressure generated by high spring level or otherwise and absence of arrangement for release of back pressures. This damage is further extended by the forces of continuous flow in channel specially in the downstream of curve.

(ii) Loosening of the joints in the lining due to continuous water seepage from the earthen embankment into channel due to high spring level. This loosened mortar is further sucked by the flow in the channel thus damaging the lining.

The damage in the concrete lining in bed was observed only in the year 1984 and that too at only one place. The seepage of water from toe of the embankments and pits of 0.3 m to 1.0 m in the damaged area were seen. It is probable that some cracks in the bed lining had developed giving way to seepage of canal water. Such damaged panels were repaired with modified lining, in which 300 mm boulder pitching was done over 250 mm thick filter. Panels were formed along the length and slope of the channel to lay boulder pitching. Seventy percent area of the boulder pitching was grouted and 30% area in patches at the bottom was left ungrouted to release back pressures developed due to high spring level. This lining was first experimented in 1978. In the closure of 1984 these panels of modified lining were found satisfactory except dislodging of some boulders. On casual closure of the channel it was seen that these panels had again been damaged due to unloading of boulders. The channel is running since 1965. The channel lining has behaved well generally except in the deep cutting reaches. Special care should be taken while providing lining in the channels in deep cutting reaches. Suitable changes are proposed as wire crating of the ungrouted boulder pitching. Suitable pressure release valves and drainage arrangement alongwith proper filter is also recommended for adoption in high spring areas along channel alignment.

Proper drainage arrangement is required at the outer toe of the embankment to avoid damages in the channel bed lining. A boulder pitching alongwith suitable filter is recommended for that purpose.

3.8.3 Rishikesh-Chilla Power Channel

The following types of lining have been provided in the power channel :

(i) Boulder Pitching Lining

(ii) In-situ Concrete Lining

(iii) Cement Concrete Tile Lining

The power channel was first time run in July,1980. After running continuously for more than 4 years it was closed for 4 weeks for inspection and necessary repairs in Feb.1985. In all 39 panels of c.c. tile lining were found partially damaged. These were mostly in deep cutting reaches where the ground water level on the back was quite high. The rest of the lining was found in good condition. The damage to panels was apparently on account of high back water pressure which could not be released through pressure release valves when the water level in power channel got suddenly reduced during monsoon due to choking of head regulator trash rack. It was observed that in most of the pressure release valves, the rubber flapper had damaged and silt laden water from the channels had entered into the pipe and had virtually choked it. Silt was coming out of some of the valves when the channel was closed indicating release of back water pressure through them. A number of valves had to be cleaned manually by inserting mild steel bars and when silt was thus removed, back water pressure could release. Some of the valves were found damaged and had almost dislodged from their respective place.

It was apparent that in the damaged panels the pressure release valves had not discharged their function properly. The damaged panels were repaired in the same manner as original tile lining was done and instead of installation of new valves, pockets of 1 metre x 1 metre at 3 to 4 metres centre to centre staggered in elevation, were left in the lining as shown in Fig. 6. These pockets were filled up with filter material and boulder pitching flushing with the lining surface was done. This has been found to work very well. The panels in which such arrangement was tried have not damaged again.

Canal closure of 3 days was taken in Feb. 1986 and 10 other panels found damaged were repaired in the manner detailed above including arrangement for the release of back water pressure. Seven days closure of the channel was taken during March, 1987 and 14 other panels were found damaged. The same procedure for repair and pressure release arrangement was provided.

The lining of power channel using compressed cement concrete tiles has been quite successful. These have performed well except in reaches where back water pressure had developed and could not be effectively released in case of suddan draw-down in the channel. The functioning of pressure release valves has not been very effective.

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Exposed and Hard Surface Lining

Table 1

Results of Seepage Tests on Different Lining Materials

Sl. No.	Project/Canal	Type of Lining	Design discharge rate m^3/sec	Design depth (m)	Measured seepage $m^3/sec/10^6\ m^2$
1	2	3	4	5	6
(a)	**Field Conditions (U.S.A.)**				
1.	BOISE Project, IDAHO				
	Lateral 0.1-1.0	ASPHALT	-	0.61	0.14
2.	Central Valley Project, California				
	Contra Costa Canal				
	Station 1805+56 to 1857+55	Reinforced Concrete	3.96	1.49	0.03
	Station 1857+67 to 1873+85	Reinforced Concrete	3.96	1.49	0.32
3.	Central Valley Project, California				
	Fraint-Kern Canal				
	Station 3644+07 to 3673+56	Unreinforced Concrete	127.40	5.24	0.25
4.	Rio Grande Project, New Maxico				
	Texas-West Canal				
	Station 50+84 to 273+32	Unreinforced Concrete	-	-	2.93
	Station 273+32 to 314+76	Unreinforced Concrete	-	-	1.77
	Station 314+76 to 342+87	Unreinforced Concrete	-	-	0.92

contd....

1	2	3	4	5	6
5.	GILA Project, ARIZONA				
	Lateral A-8.9-N	Shotcrete	0.40	-	0.11
	Lateral B-3.7-1.8	Shotcrete	0.40	-	0.11
6.	Delta-Mendota canal	Compacted earth lining	93.71	4.69	0.03
7.	Courtland Canal	Earth lining	19.39	2.59	0.53
8.	Helena Valley Canal	Compacted earth lining	4.81	1.35	0.28
9.	Meeker Driftwood canal	Earth lining	7.08	1.59	0.18
(b)	**Field Conditions (U.P.) India**				
10.	Right Lalitpur Canal (Chainage 29.27 km)	Stone lining	7.13	-	1.42
11.	Ken Canal (chainage 53.20 km)	C.C. blocks	71.40	-	0.66
12.	Right Sharda Sahayak Feeder Channel (chainage 85.95 km)	Brick lining	-	-	2.25
13.	Right Sharda Sahayak Feeder Channel (chainage 81.00 km)	Bed with brick tile & sides with double brick tile lining	-	-	2.06
14.	Left Sharda Sahayak Feeder Channel (chainage 61.50 km)	Bed lined with C.C.while sides with brick PMCD lining	-	-	2.027

contd....

1	2	3	4	5	6
15.	Sharda Sahayak Feeder Channel (chainage 48.95 km)	Bed with brick tile & sides with double brick tile lining	-	-	1.913
16.	Sharda Sahayak Feeder Channel (chainage 36 km)	C.C. lining	-	-	1.381
17.	Gursarai Canal (Jhansi Canal) (Chainage 14.60 km)	Stone clay	-	-	2.94
18.	Gursarai Canal (Chainage 23.20 km)	Stone lining	-	-	2.04
19.	Gursarai Canal (Chainage 36.90 km)	Stone lining	-	-	2.34
20.	Right Lower Khajuri Canal (Chainage 0.60 km)	Stone lining	-	-	0.90
21.	Cheeti Minor of Bulandshahr Dy. covered with brick using 1:4 mortar	100 micron LDPE film lining	-	-	0.15
22.	Machkauli Minor of Bulandshahr Dy.	-do-	-	-	0.05
(c)	**Field Conditions (Haryana) India**				
23.	Bhainswal Dy. brick lining	Single layer	2.84	-	0.653
24.	Banyani Mr.	-do-	0.38	-	0.70

contd....

1	2	3	4	5	6
(d)	**Semi Field Conditions, U.P.I.R.I., Bahadrabad**				
25.	-	Ist class brick lining in 1:4 CM	-	-	0.47
26.	-	C.C. tiles	-	-	0.384
27.	-	2nd class brick lining in 1:6 CM	-	-	0.662
28.	-	Clay tile lining	-	-	0.225
29.	-	Ist class brick lining in 1:1 white lime and surkhi mortar	-	-	1.565
30.	-	Ist class brick lining in 1:2 white lime and surkhi mortar	-	-	2.126
31.	-	Ist class brick lining in 1:3 white lime and surkhi mortar	-	-	1.975
32.	-	Ist class brick lining in 1:1:1 white lime,surkhi and sand mortar	-	-	1.741
33.	-	Ist class brick lining in 1:1:2 white lime,surkhi and sand mortar	-	-	2.265
34.	-	Alkathene film lining overlaid with 3" flat bricks in 1:4 cement sand mortar	-	-	1.199

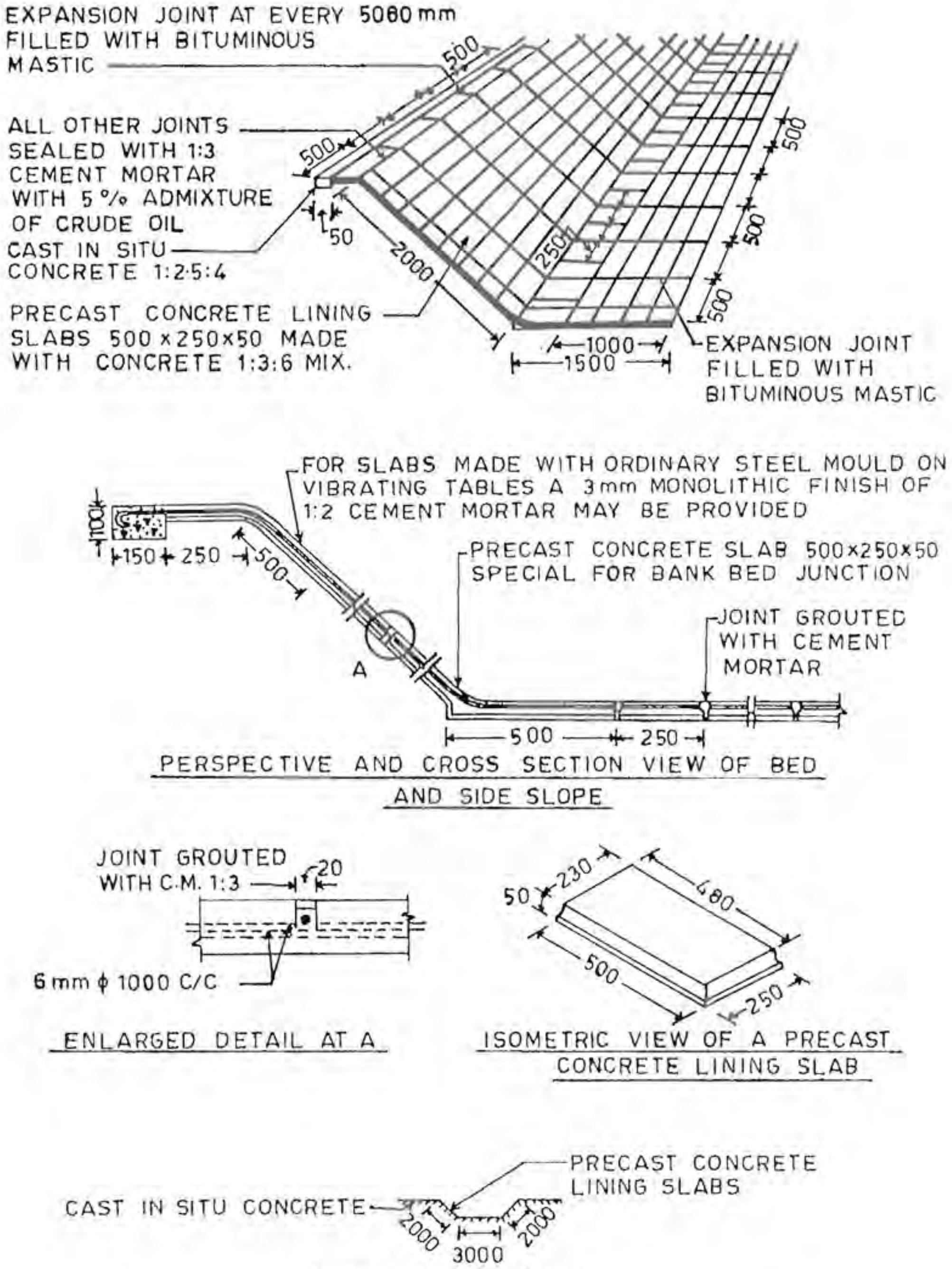
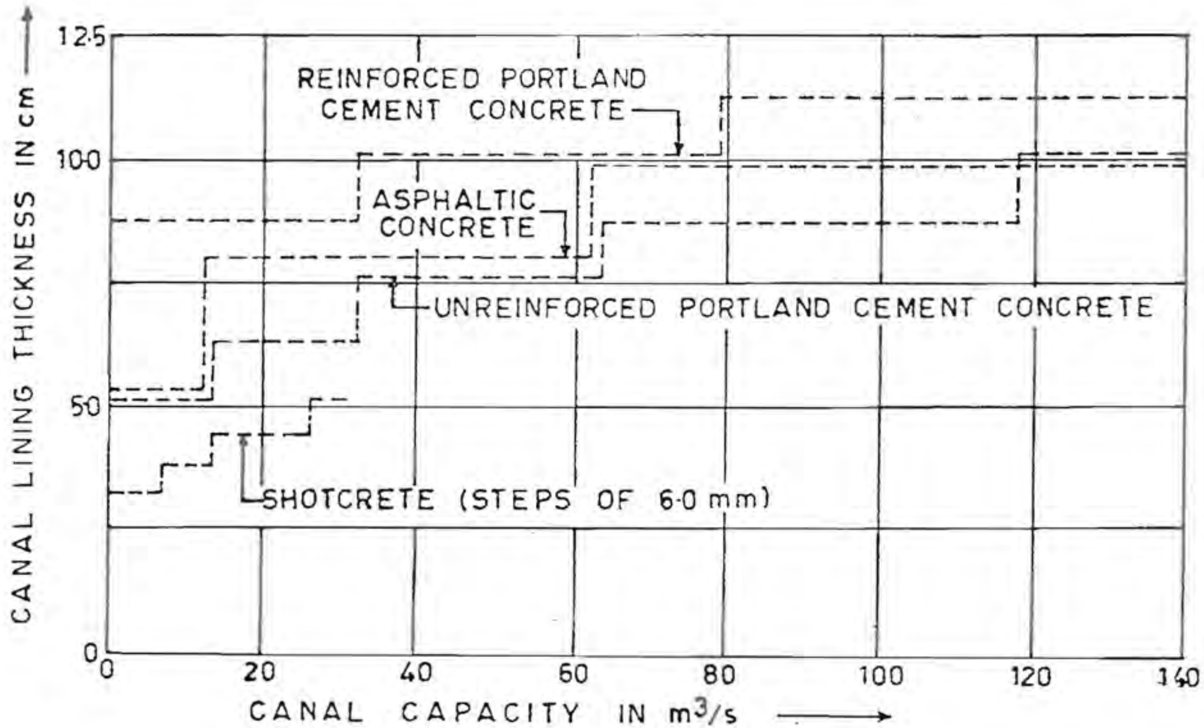
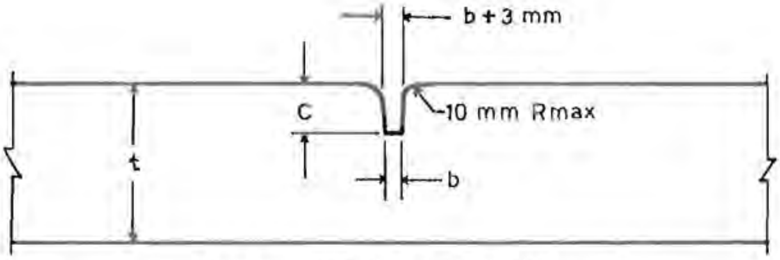


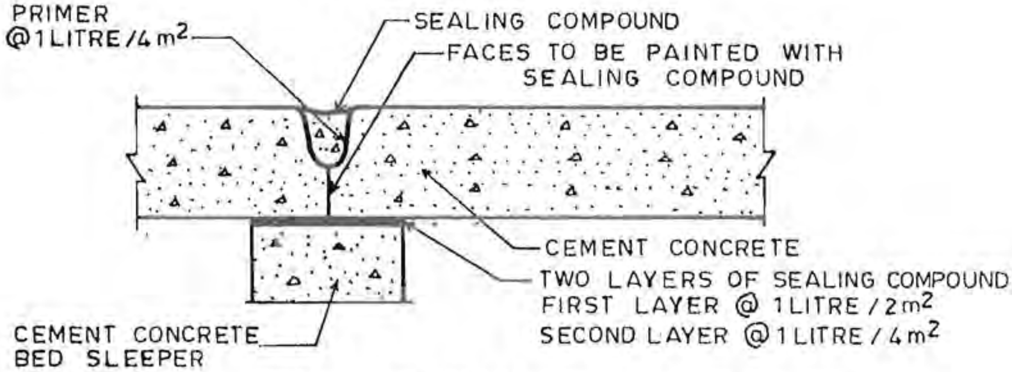
FIG.1 :- PRECAST LINING FOR CANALS



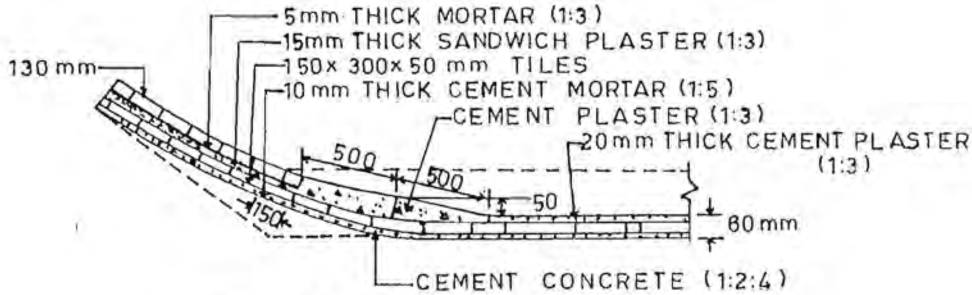
125
100
50
0
REINFORCED PORTLAND
CEMENT CONCRETE
ASPHALTIC
CONCRETE
UNREINFORCED PORTLAND CEMENT CONCRETE
SHOTCRETE (STEPS OF 6·0 mm)
0
20
40
60
80
100
120
140
CANAL LINING THICKNESS IN cm
CANAL CAPACITY IN m3/s



(a) SHAPE OF GROOVE



(b) DETAILS OF CONSTRUCTION JOINTS WHEN LINING CAST IN PANELS



DOUBLE TILE LINING ON SLOPES MEETING SINGLE TILE LINING ON BED

(c) TYPICAL SKETCH OF CANAL LINING WITH BURNT CLAY TILES

NOTE:- ALL DIMENSIONS ARE IN mm.

FIG.3 :- DETAILS OF JOINTS

Photo - I. C. C. Lining on Side Slope with Paver Machine (NMC)

Photo - 2. C. C. Lining on Side Slope of Narmada Main Canal (NMC)

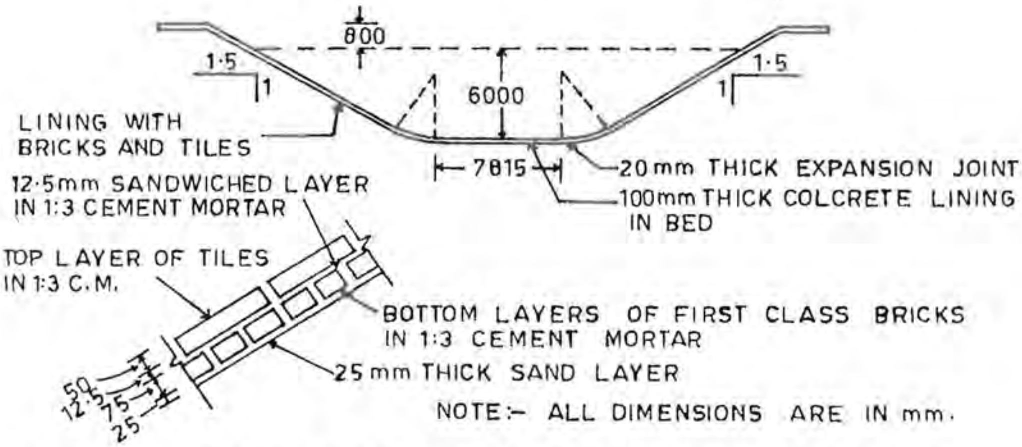
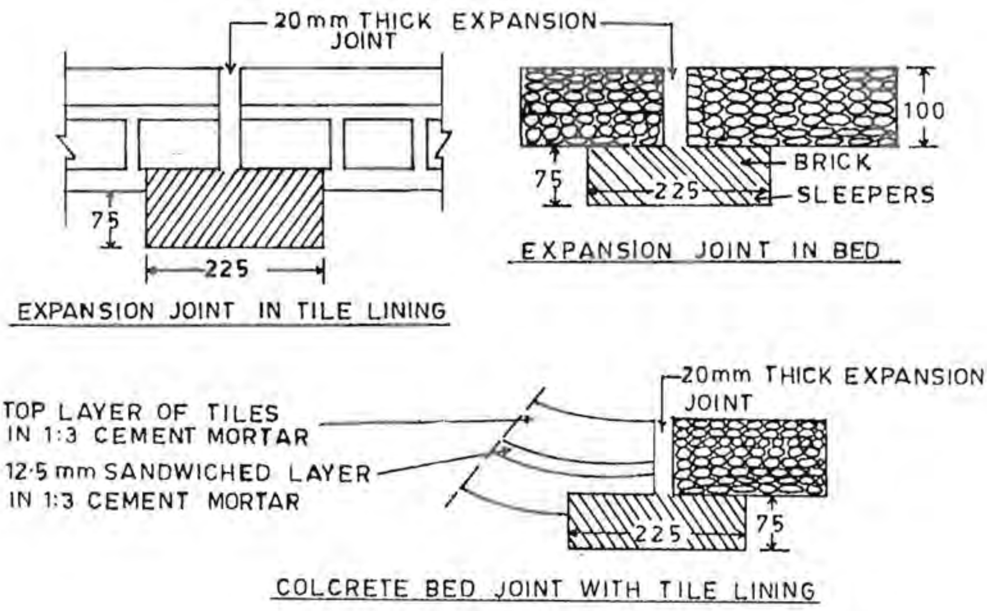


FIG. 4:- DETAILS OF LINING IN YAMUNA POWER CHANNEL



NOTE:- ALL DIMENSIONS ARE IN mm.

FIG. 5:- LINING IN YAMUNA POWER CHANNEL

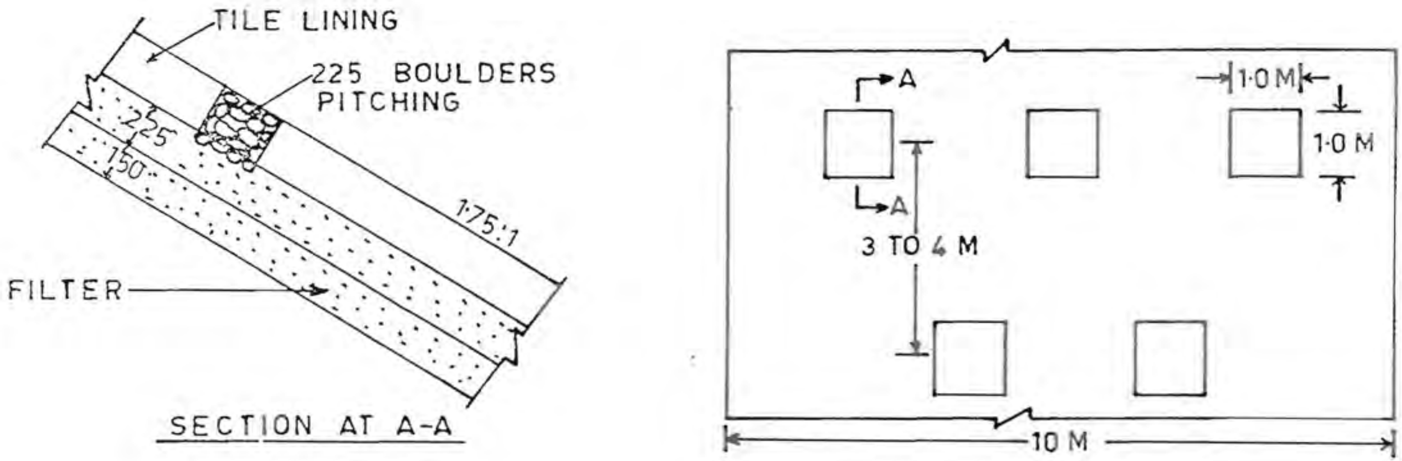


FIG 6:— FILTER POCKETS IN RISHIKESH-CHILLA POWER CHANNEL

4. BURIED MEMBRANE LININGS

4.0 INTRODUCTION

A buried membrane lining consists of a relatively thin and impervious water barrier covered by a protective layer. The protective layer saves the membrane from exposure, damage by turbulent water, weeds, maintenance equipments and animals. Generally stable earth and gravel are used as the covering material. Other materials like shotcrete and asphalt macadam have also been used for protecting the membranes.

4.1 TYPES OF MEMBRANES

The commonly used buried membranes are:

i. Sprayed-in-place asphalt membrane linings,

ii. Prefabricated asphaltic membrane linings,

iii. Plastic film and synthetic rubber membrane linings, and

iv. Bentonite and clay membrane linings.

4.1.1 Sprayed-in-place Asphalt Membrane Linings

It is composed of a special high-softening-point asphalt sprayed-in situ at a high temperature and is laid on a prepared subgrade to form approximately 6 mm thick water-proof barrier. It is protected from damage and weathering usually by a protective layer of earth and gravel. It provides an effective and cheap means of seepage control and can be satisfactorily laid in cold and wet weather.

4.1.2 Prefabricated Asphaltic Membrane Linings

These ready made membranes are used in smaller channels or in relatively short reaches of large canals where the use of sprayed-in-place linings is costlier on account of the requirement of special equipment and skilled personnel. Such linings are fabricated from low cost material of adequate watertightness and durability. They are relatively thin and light and can be transported to long distances, stored in hot weather and placed at low temperature. Originally this type of lining was developed by

U.S.B.R. This consisted of a layer of catalytically blown asphalt on a heavy sheet of untreated paper so that it could decay rapidly after placement, leaving the asphalt membrane in place. After installing, it worked satisfactorily but its transport to site and handling were difficult. At high temperature, the asphalt softened and the rolls stuck together, while at low temperatures, the asphalt became so brittle that the lining cracked on rapid unrolling. An improved design consists in using reinforcement of thin glass fibre mat which is saturated and coated with blown and filled asphalt. Such a lining has proved durable and can be handled and transported easily.

4.1.3 Plastic Film and Synthetic Rubber Membrane Linings

Initially canal linings using Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE) and Butyl-coated fabrics were tried in many canal projects on experimental basis. Trials with the use of butyl rubber sheathing used as an exposed canal lining material by U.S.D.A. Agriculture Research Service and Utah State University, Utah appear to have been recorded an excellent success as early as 1960. But due to high initial cost and vulnerability of the same for mechanical damage limited their wide spread use as a low cost lining material.

Plastics in place of synthetic rubber, though performed equally well, soon proved ineffective as an exposed membrane liner because of their deterioration due to sun, weather and mechanical erosion.

Later on, the most promising plastic formulation developed and tested, appeared to be the polyvinyl and polyethylene varieties and have been used with success as lining materials in many of the installations, but as a buried membrane only, after providing a cover protection. PVC lining has several limitations when compared to LDPE as PVC use for the manufacture of flexible film.

Low density Polyethylene (LDPE) with a commercial name of `AGRIFILM' is a tough, wide width, black film and is used widely in the country these days.

For more details reference may be made to Chapter Five which exclusively deals with Plastic Film and synthetic rubber membrane linings.

4.1.4 Bentonite and Clay Membrane Linings

Bentonite has got the peculiar characteristic of becoming impervious on wetting due to swelling and imbibing of water. As such, it is a very useful material for controlling seepage from canals if available locally at low cost. It has been used by spreading as a membrane 25-50 mm or more in thickness over the canal subgrade and covering with a 15-30 cm protective blanket of stable earth or gravel.

Based primarily on their swelling characteristics, bentonites have been classified into the following two groups :

i. High swelling sodium type montmorillonite clay having a high water absorption capacity, and

ii. Low swelling clays, such as calcium montmorillonite, beidellite, and nontronite, having low water absorption capacity.

Both the groups are closely related to each other, but their absorption capacities differ because of their slight structural and compositional differences.

Low swelling clays too, when used in canal linings, may give equally satisfactory results, but the quantity of material required will be greater than high swelling clays for securing the same reduction in seepage. For laying the membrane lining, finely ground bentonite are best suited. If a good distribution of particle size is obtained, coarse ground pit-run bentonite may by equally satisfactory although for comparable results, a greater quantity of material is required.

4.2 DESIGN CONSIDERATIONS

(a) If properly placed, the buried membranes are almost completely watertight. Their durability depends primarily on the adequacy of the cover material used to protect them from damage. The earth is mostly used as cover material, because usually it is the cheapest.

In order that the membrane may not get damaged by erosion or sliding, the channel section must be completely stable and resist the scouring effect of flowing water. A bed width to water depth ratio of about 4 to 1 in most of the materials is usually sufficient to overcome such erosion. As regards the sliding of banks, it is understood that no particular side slope will satisfy all subgrade and cover types. However, a side slope of 2:1 has been found satisfactory in most of the cases. Even a flatter slope will probably be required for asphalt or plastic membranes if the cover is composed of relatively unstable material such as uniformly graded sands, fine gravels or silty sands.

(b) Cover Material : The excavation and placement of cover material involves heavy expenditure. It would be economical if this material is available locally and placed to optimum thickness. When the cover material is a clayey gravel, a gravel surfaced soil or some equally erosion resistant material, a minimum depth of cover equal to 1/12 of water depth plus 25 cm is recommended. In case of fine grained and non-cohesive material, a greater total thickness is required and gravel protection should be provided.

Rapid drawdown of water surface will tend to cause the cover to slide down the slope. Therefore, repid water fluctuations should be avoided otherwise the slope will have to be flattened or the cover material should be selected so as to be free draining without loss of fines. In such cases the thickness of the cover may be increased. The stability of the cover may be improved by compaction also. In case of less desirable soils, the suitability of the cover can be improved by rolling.

(c) Permissible Water Velocity : It is customary to permit somewhat less velocities than those in an unlined canal constructed in a soil having the same characteristics as the cover material for the buried membrane. In the case of earth covers generally placed without benefit of maximum consolidation, scour is a hazard to the membrane.

4.3 CONSTRUCTION DETAILS

These include the preparation of the subgrade, the types and quantity of asphalt and bentonite and the method of application, type of cover material and its thickness.

i. Subgrade Preparation : Before laying a membrane, the canal section must be excavated sufficiently to accommodate the required water prism plus the cover material. In existing canals, the excavation, can be accomplished by dragline. After excavation, the surface is made smooth so that it may facilitate the laying of a membrane of uniform thickness and serve as a satisfactory membrane support. For asphalt application, the surface can be smoothened by light dragging and rolling. It will help in obtaining a reasonably uniform membrane of minimum specified thickness without wastage of excessive amount of asphalt. The subgrade surface is made smooth with fine sand or soil padding where the subgrade is composed of rough, irregular, angular or fractured rock and gravel or open gravel and cobbles.

ii. Asphalt Membrane : While spraying an optimum quantity of asphalt required to obtain a minimum thickness of 6 mm, some patches of inadequate thickness may be left due to non-uniform spray. The lining may get damaged at such spots during covering operations. To avoid this, a 20 percent extra quantity of asphalt may be used. It has been shown by laboratory tests that asphalts made with phosphate pentoxide or other phosphorous compounds are superior to those produced with other catalysts. Asphalts blown with catalysts of ferric chloride or other salts or iron are not suitable.

For satisfactory performance of the membrane, it is important that it is laid uniformly and that there are no pockets of inadequate thickness of asphalt. After raising the temperature of the asphalt to approximately 400° F, It is sprayed through short type nozzles at a pressure of 3.5 kg/cm^2.

iii. Bentonite Membrane : As determined by laboratory tests, specifications for bentonite membrane provide for minimum swelling requirements. Relatively finer bentonite may be used without regard to gradation. A maximum moisture content, such as a 20 percent, is specified with the thickness of the membrane depending on the amount of moisture already present in bentonite. Higher the moisture content, thicker the membrane should be to insure adequate solid material.

iv. Placement of Protective Cover : As the asphalt layer cools quickly, the cover material can be laid soon. In addition to other materials, earth or a combination of earth and gravel may generally be used to protect the membrane in view of economy. Great care should be taken in placing earth cover materials containing large rocks which can tear and crack the membrane. According to U.S.B.R. specifications, first the bottom is covered carefully with fine-grained soils and than the slopes are similarly covered from bottom towards top. Finally according to necessity, additional cover of coarse material can be given. The same procedure should also be followed in covering other types of membrane linings.

4.4 OTHER PROTECTIVE COVERS

Several installations using shotcrete and macadam have been used experimentally, although they are costlier than earth and gravel. They eliminate very thick covers of earth and gravel and the need for over-excavation.

(a) Shotcrete : It consists of a 2 cm thick cover of shotcrete over an asphalt membrane placed directly on the canal subgrade. It should be of the same quality as that required for regular shotcrete canal lining. The approach and requirement for curing are also the same. The thickness is less than ordinary laid shotcrete.

(b) Asphalt Macadam : In order to lay satisfactory macadam surface, asphalt should penetrate to full depth for which aggregate must be graded to obtain a relatively open layer. Asphalt must be applied in flooding action in one operation.

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5. PLASTIC FILM AND SYNTHETIC RUBBER MEMBRANE LINING

5.0 INTRODUCTION

Extensive use is being made of a variety of plastic and rubber membranes for different engineering purposes. The most commonly used materials are plasticized Poly Vinyl Chloride (PVC), Polyethylene and Butyl rubber. In recent years with the development of manufacturing and process control technology, the puncture resistance of polyethylene which was its weak point earlier has been improved considerably. Low Density Polyethylene (LDPE) film lining has been preferred over PVC and butyl rubber lining due to its longer life, availability in any desired size and length, lesser needed thickness hence lesser weight and cost. Moreover LDPE is highly impermeable and as such it cuts off completely the seepage. Also, it is easy to transport as it is available in rolls and convenient in placement at site.

Where there is a possibility of cattle crossing the canal, a suitable additional earth cover shall have to be provided to protect the non-rigid lining getting damaged. This is more important for small channels, where maintenance and quality control during construction may be a practical problem. Care has to be taken for its use where weed growth may be a problem. Considering its performance and cost, polyethylene may be the most economical material for flexible membrane canal lining.

Certain properties of LDPE as aging, resistance to sunlight, microbiological action, stability of side slopes and its bond with concrete etc. require further research in its application in the field.

5.1 EMERGENCE OF SYNTHETIC PRODUCTS AS EFFICIENT LINING MATERIAL

5.1.1 Evidence of success with the conventional lining materials like cement concrete, bricks, tiles, stone etc. in controlling seepage in canals eventually led to a search for alternatives and synthetic materials offered a bright proposal. Trials with Butyl rubber sheathing used as an exposed canal lining material by U.S.D.A. Agricultural Research Service and Utah State University, Utah appear to have been recorded an excellent success with the use of Butyl rubber sheathing as exposed canal liner as early as 1960. But due to high initial cost and vulnerability of the same for mechanical damage limited their wide spread use as a low cost lining material.

5.1.2 Plastics in place of synthetic rubber, though performed equally well, soon proved ineffective as an exposed membrane liner because of their deterioration due to sun, weather and mechanical erosion. Later on, the most promising plastic formulation developed and tested appear to be the polyvinyl and polyethylene varieties and have been used with success as lining materials in many of the installations, but as a buried membrane only, after proving a cover material for protection. Early production cost of plastic films of Polyvinyl Chloride (PVC) and polyethylene varieties restrained their use as canal lining materials, but their progressively lower cost of production made them costwise competitive and thus their choice as canal lining material picked up.

5.1.3 PVC lining has several limitations when compared to LDPE film. PVC used for the manufacture of flexible film contains plasticizers which have a tendency to migrate, resulting in the film becoming brittle and cracking. Secondly, PVC film can not be produced in wide widths and so its use results in higher jointing costs. The density of flexible PVC is between 1.2 and 1.4 gm/cm, whilest that of LDPE is 0.931 gm/cm. This results in the coverage of a larger area by LDPE than by PVC for the same weight and thickness of film, which in turn leads to appreciable economy in the use of LDPE film over PVC lining.

5.1.4 LDPE film lining which had been tried on experimental basis for the past several years is being used now extensively for canal lining works in the states of Gujarat, Haryana, Karnataka, Rajasthan, Uttar Pradesh, Punjab and West Bengal etc. Annexure-1 gives some details about the places where LDPE film for canal lining has been used successfully.

5.2 LOW DENSITY POLYETHYLENE FILM

5.2.1 Low Density Polyethylene (LDPE) with a commercial name of AGRIFILM is a tough, wide width, black in colour and tailor made for canal lining applications and marketed through Indian Petrochemical Corporation Limited (IPCL) producer of raw material of such film in the country. It has excellent water barrier properties, very good blend of physical properties like tensile-impact strength coupled with good weatherability and chemical resistance properties.

5.2.2 LDPE film is usually available in rolls having a continuous unspliced length in various widths without joints as per requirements. The length of rolls may be of about 40 metres for convenience in handling. Film rolls can be obtained in specified lengths and widths as per requirements of the designed cross-section of a canal to avoid wastages and minimise the joints. LDPE film for use in canal lining work must conform to the relevant Indian Standard specifications. However, the film samples may be got tested before use at the nearest Plastic Development Centre or Laboratory having facilities for testing LDPE film.

5.2.3 Thickness of LDPE

Wherever plastic film has been used as a primary barrier with rigid cover, the film having heavy thickness and of the order of 200-250 microns has been generally used as a canal liner. In case of secondary seepage barrier but with better sub-grade and rigid lining, film having thickness of 100-150 microns has been used. For use of film with soil cover still higher thickness have been adopted. From the data available regarding thickness of the film used at various irrigation canals, it appears that no hard and fast rule may be adopted for deciding the thickness of film and mainly depends on the engineering judgement, experience of the Engineer-in-charge and importance of the project. Details of the thickness of film used along with other parameters of various canals in different states are given in Annexure-2.

Following criteria may be adopted for deciding the thickness of the film.

TABLE-1

Minimum thickness of LDPE film with rigid cover/earth cover corresponding to water depth

Sl. No.	Water depth (m)	Film thickness in microns		
		With Rigid Cover		
		Film as Primary Barrier	Film as Secondary Barrier	With Earth Cover
1.	Upto 1 m	150	100	200
2.	Upto 2 m	200	100	250
3.	More than 3 m	250	100	300

5.3 GENERAL CONSIDERATIONS

5.3.1 Investigations

The following information based on necessary investigations shall be collected for the entire length of the canal before commencing the work.

1. Nature of soil (physical properties upto 1.0 metre depth below canal bed).
2. Sub-soil water conditions : In case water remains at the canal bed level, even during closures due to depressions, this water should be pumped out ; and
3. Longitudinal and cross-section of the canal.

5.3.2 Materials

i. Cement

Portland cement conforming to IS : 269-1976 or IS : 455-1976 or IS : 1489-1976 as specified by the Engineer-in-charge must be taken in use.

ii. Sand

Sand required for cushion layer below the film shall be of fine quality, passing through 53-micron IS sieve.

iii. Top cover

As the main purpose of using LDPE film for canal lining works is to arrest seepage water, which can be achieved by using a very thin film say 100 microns or more, hence, LDPE is always used as burried membrane lining LDPE is placed on a prepared canal sub grade and can be covered with soil; or any suitable rigid top cover. The top cover may consist of any of the following -

1. Insitu cement concrete M-10 conforming to IS : 456
2. Precast cement concrete tiles conforming to IS : 3860
3. Burnt clay tiles conforming to IS : 3367
4. Bricks

5. Stone slabs and

6. Compacted soil.

Proper placement of the cover material is important to avoid possible puncturing, tearing or stressing the film. While placing the cover material, care should be taken that the film is not displaced or injured. The protective cover plays important role in the longevity of LDPE film lining. The cover material should be such that it is free draining, erosion resistant and stable on side slope. In case of soil cover, the inclusion of rocks, boulders, vegetative matter should not be permitted in the covering material and for affecting economy as for as possible, the soil of the canal excavation unless found unsuitable will be used as covering material.

iv. Film

Polyethylene film quality shall conform to IS : 2508-1984 and shall have :

1. Nominal thickness of not less than 100 microns (0.1mm).

2. Seamless width of atleast 5 metres.

Moreover, natural or any other colour film shall be of ultra-violet stabilized quality only. Ultra-violet absorbers incorporated in the film shall conform to IS : 7277.

Following points should be kept in mind while covering LDPE film with soil.

1. For canals with velocities less than or equal to 0.6 m/sec, minimum thickness of cover over the film shall be not less than 30 cm in bed and 60 cm on the sides as shown in Fig. 1(a).

2. For canals with velocities more than 0.6 m/sec, the polyethylene film in bed shall have a rigid cover against possible bed erosion. For sides the cover shall be of any rigid type.

3. Recommended techniques of jointing polyethylene film is shown in Fig. 1(b).

4. Side slope shall be designed in accordance with stability requirements with lining in position.

5. If the cover material contains kankar or sharp angular material, a cushion layer 7.5 cm thick of sieved earth may be provided over the film.

6. To prevent 'beaching' effect at water line, kankar or material of size of 4 to 5 cm may be spread over the cover prior to compacting, using light roller or manual ramming.

7. It is also recommended that side slopes should be covered first.

5.3.3 In practice, it has been seen that, in most of the major canal projects of India, Cast-insitu concrete, precast concrete blocks, brick tiles or concrete tiles have been used as a covering material over LDPE film. In World Bank aided Parallel Upper Ganga Project and Indira Gandhi Nahar Project brick/concrete tiles have been used over LDPE film. The only irrigation project which has successfully used plastic film overlaid with soil cover is in the modernisation of unlined canal system of Kangsabati irrigation project, West Bengal. The general profile of the canal section with polyethylene film in bed and sides would be similar as shown in Fig. 1 & 2.

5.4 HIGH MOLECULAR MASS HIGH DENSITY POLYETHYLENE FILMS (H.M.H.D.P.E.)

5.4.1 Films made from high molecular mass high density polyethylene (HMHDPE) are also being used for canal lining purposes. IS : 10889-1984 deals with the specifications for HMHDPE. It has been reported that this film has distinctly superior qualities compared to low density polyethylene film.

5.4.2 With increased density of HMHDE film, several properties like tensile strength, toughness, permeability, moisture barrier properties, surface hardness, puncture and pinhole resistance are reported to be higher than that of LDPE film. The HMHDPE film is resistant to attack by acids and alkalies and stabler under high temperatures.

5.5 PREPARATION OF SUB-GRADE

Laying techniques, preparation of sub-grade etc. for both HMHDPE and LDPE films are similar and described as below.

5.5.1 Kankar of any sharp angular material shall be removed to provide reasonable smooth subgrade. Any weeds, roots and Vegetation that may damage the film shall be removed.

5.5.2 If the reaches are weed infected, antiweed treatment to subgrade may be provided to discourage the weed growth under the film.

5.5.3 A layer of fine sand, preferably passing through 53 micron IS sieve of suitable thickness 12 mm to 25 mm shall be provided over the subgrade (on bed only) to facilitate working condition over the film.

5.5.4 The sub-grade shall be prepared, dressed and rolled true to level and according to the required cross-section of the canal to form a firm base of lining.

5.5.5 In other than predominantly sandy reaches where the dry bulk density of the natural soil is not less than 1800 kg/m^3, initial excavation shall be done upto about 30 cm above the final section and the lip cutting shall be done immediately before lining.

5.5.6 If at any point, material of prepared sub-grade has been excavated beyond the neat-lines required to receive for lining, the excess excavation shall be filled with material compatible with sub-grade material and thoroughly compacted.

5.5.7 When partial filling of an existing unlined canal is necessary to reduce the cross-sectional area to that required for lined canals, the fill shall be placed and suitably compacted to avoid settlement and rupture of the lining.

5.5.8 To cover up any lapses in the compaction of the inner core of the banks near the edges and to allow sufficient width for a labourer to work conveniently a lip cutting width of not less than 50.0 cm horizontally shall be provided. Depending upon the nature of soil and the side slopes of the canal, the lip cutting width may be in the range of 50 to 100 cm.

5.6 COMPACTION OF SUBGRADE

5.6.1 Compaction in predominantly sandy reaches

5.6.1.1 Bed – The compaction shall be done by over-saturating the bed by flooding it with water before lining is laid.

5.6.1.2 Sides – The consolidation of sides shall be done by vibro-compactors.

5.6.2 **Compaction in other than predominantly sandy reaches**

5.6.2.1 All compaction shall be done at optimum moisture content in layers not more than 15.0 cm thick to obtain a dry bulk density of not less than 95-98% for bed sides of the density at optimum moisture content in accordance with IS : 2720 (part VII) - 1974.

5.6.2.2 Where the dry bulk density of the natural soil is equal to or more than 1800 kg/m^3, the procedure described in 5.7.2 shall be followed.

5.6.2.3 Bed - Where the dry bulk density of the natural soil is less than 1800 kg/m^3, and subsoil water is near the subgrade, the consolidation shall be done by under cutting the bed by 7.5 cm and then ploughing upto 15.0 cm below the subgrade level. The loosened soil shall then be recompacted with sheep foot rollers or other suitable devices. Where the subsoil water is low, requiring no dewatering and the dry bulk density of the natural soil is less than 1800 kg/m^3, the consolidation shall be done by digging the canal upto subgrade level and after that loosening the earth below the subgrade upto 15.0 cm by disc barrows or ploughing and compacting the same to a layer of 11.0 cm. Again the second layer of 15.0 cm of earth shall be laid over the compacted layer by taking earth from lip cutting and compacting this to a depth of 11.0 cm. The compacted layer of 7.0 cm above the subgrade level shall be removed and the subgrade brought to design profile before laying the lining.

5.6.2.4 Sides - Compacting of sides shall be done by manual labour or suitable compactors to a depth of 30.0 cm to obtain a minimum dry bulk density of not less than 95% of the density at optimum moisture content obtained in accordance with IS : 2720 (part VII) - 1974.

5.7 LAYING TECHNIQUE OF LDPE FILM

5.7.1 The film shall be laid over the subgrade prepared below the designed bed level to the extent of cover thickness in strips perpendicular to water flow.

5.7.2 The loose ends of the film strip shall be anchored with an allowance of 50 cm for anchoring in the toe walls. Toe walls shall be constructed at such a level that film when laid on the bed is retained at design depth. Necessary space shall be kept vacant at toe wall for anchoring the film.

5.7.3 The film shall be spread loosely over the subgrade so that it shall attain the contours of subgrade and compensate for thermal variation during the day. It is recommended that an extra length of 3.5 percent over the length of the film required for spreading over bed side slope including anchorages shall be provided to take care of thermal variations during the day. When film laying is undertaken at midday, it is recommended that the film be spread only on the area that can be covered with tiles by the end of day. As polyethylene film is likely to be affected by very high temperatures of about 45°C obtaining in summer days it would be advisable to avoid laying the film under such high temperature. In case it is necessary to continue the work on hot days as well it should be restricted to morning hours only.

5.7.4 The adjacent layers of film shall be laid in such a manner that the width of an overlap shall not be less than 15.0 cm and overlap shall point towards downstream of canals. The overlap joints shall be heat sealed with hot iron as shown in Fig. 1(b).

5.7.5 The film shall be spread on well prepared subgrade and shall be held in position at two extremities of bed by placing excavated earth on it, while the two ends of film are being loosely held over the embankment.

5.7.6 Excavated earth shall be placed over the film to build up the canal section. The earth layer shall be compacted by using light rollers and manual templates. It may be so arranged that earth from over excavation of adjacent section be used for covering the film in earlier section. Thus, by the time, earth cover is provided in one section, the adjacent section is ready to receive film lining.

5.7.7 Extra length of the film shall be placed in trench at embankment top and covered with earth. The embankments may be then raised to designed level.

5.8 ANCHORING OF FILM

5.8.1 For smaller canals where the width of the film available is sufficient to cover the canal section from one end to the other, no toe wall is necessary and the polyethylene film lining can be laid continuously from one end to the other.

5.8.2 For larger canals, a masonary toe wall of 60 x 20 cm deep shall be constructed at two extremities of the bed with a view to provide anchorage for film laid both on bed and sides (Fig. 2). The top layer of the tile is to be laid only after anchoring the film.

5.8.3 A trench 15 x 15 cm at a distance of 40 cm away from the lip and 30 cm above the FSL shall be dug all along the canal length, to hold the loose end of the film laid on side slopes (Fig. 1).

5.9 WATER COURSE LINING

5.9.1 Water courses are generally small earthen channels running along the borders of the fields. The loss due to seepage and evaporation which can occur in the water courses/field channels can be staggering high. Width of water courses and velocity of flow is generally quite low.

The enormous loss of water in field channels has attracted attention of the irrigation authorities and considerable efforts are being made to construct lined water courses which would reduce seepage losses. Method of water course lining will be similar to as described earlier for any irrigation canal.

5.10 EXPERIENCES OF LDPE FILM IN SEMI- FIELD AND FIELD CONDITIONS

5.10.1 In order to improve operational efficiency of the channels, U.P. I.R.I., Roorkee has carried out long range experiments to develop low cost and less permeable lining materials. The study was divided into following two phases.

Phase I : Semi-Field Conditions

Irrigation channels often pass through areas of different type of soils. As such it was decided to construct channel sections at Hydraulic Field Research Station, Bahadrabad, in different type of soils available in the vicinity or Bahadrabad. Besides this, the channels were lined using LDPE film with various covering materials and then tested for seepage losses measurements. The seepage losses in various types of conventional lined channels constructed on experimental basis vary from 18 to 44% relative to unlined channel while on the other hand LDPE film lined and covered with brick and clay tiles vary 2 to 5 % relative to unlined channel. When LDPE film was used in bed only the seepage losses further increases to the order of 27 % relative to unlined channel. More details are given in Annexure 3 & 4.

Phase II : Field Conditions

Upper Ganga Canal system is about 150 years old, initially its discharging capacity was 189 m^3/sec (6750 cusecs) which was subsequently increased to 294 m^3/sec (10500 cusecs). Due to increased demand of water for irrigation it would have been better if its capacity could be increased. But due to limitations of existing masonry structures this is not possible. In view of this, modernization of Upper Ganga Canal (U.G.C.) system has been taken up. Under. this project a Parallel Upper Ganga Canal (PUGC) is proposed to be constructed from km 6.0 to the tail and will be lined in its entire reach to further increase its capacity and save water loss due to seepage. The reach from km 6.0 to 8.5 and km 9.0 to 9.5 of PUGC are lined using LDPE film. Salient features of the canal at these reaches are given as below.

1.	Channel section	Trapezoidal
2.	Bed width	30.0 m
3.	Water depth	4.5 m
4.	Free board	0.75 m
5.	Side slopes	1.75:1
6.	Design discharge	370 m^3/s
7.	Velocity	2.05 m/s
8.	Rugosity coefficient	0.018
9.	Channel bed slope	0.25 m/km
10.	Thickness of LDPE film	200 micron bed & sides
11.	Type of Lining	Bed : 100 mm thick cast-in-situ A-20, M-15 CC Side : Double layer of Precast CC. A-20, M-15 slabs of size 300x300x40mm.
12.	Jointing of LDPE film	Coat of hot bitumen

Note : LDPE film on bed and sides are provided to serve as an assured barrier against seepage.

5.10.2 In addition, some of the distributaries and minors of PUGC system have also been proposed for lining. Lining of Harduaganj distributary is one such where LDPE film has been used, depending on the canal section, discharge and groundwater conditions. The salient features of the lined section are furnished below.

1.	Channel Section	Trapezoidal
2.	Bed Width	1.3 m
3.	Water Depth	0.86 m
4.	Free Board	0.5 m
5.	Side Slopes	1.5:1
6.	Design Discharge	6.75 m^3/sec
7.	Thickness of LDPE film	200 micron Used.
8.	Overlain Lining	Single layer of burnt clay tiles in 1:4 cement mortar.
9.	Overlapping of Film	Overlap of 20 cm and folded in the direction of film as per IPCL manual.
10.	Anchoring of film on sides	Folded and embedded in the soil as per IPCL manual.

The seepage losses observed in various distributaries and minors are presented in Annexure 5 & 6.

5.10.3 Experiences

From the studies conducted in semi-field and field conditions following conclusions may be drawn.

1. The use of LDPE film should be encouraged as it is quite effective in reducing seepage losses by 70 to 95%, depending upon the maintenance of the lining, soil type and groundwater table conditions.

2. Although the cost of LDPE film combined with clay tile is slightly more than the conventional C.C. tile lining, the saving in seepage is, however, substantial.

3. In case the channel is to be lined with LDPE film, it should cover entire perimeter since the partial covering of the perimeter may defeat the purpose.

4. The type of soil practically has no effect when the channel is lined with LDPE film. Normally the soil free from pebbles should be used as a subgrade below LDPE film.

5. It is preferable to cover the LDPE film lining with rigid lining instead of earth cover which is prone to erosion on bed and sliding on sides. Also for earth cover on sides, flatter slope is required which will need more land acquisition and excavation, thus enhancing the cost indirectly.

6. The LDPE film supplied by IPCL was used for 2 years. The same was sent to IPCL for testing its properties after use as a liner. The result indicates that no significant degradation has been shown on the film used after two years. Some variation in thickness was reported which was within the permissible range.

5.11 DURABILITY OF LDPE FILM

Field observations by different departments and Research organisations have revealed the following facts.

1. An increase in film thickness prolongs its life as the process of oxidisation and hence its degradation is considerable slowed down.

2. Protection of the LDPE film with the layer of soil or rigid lining is essential to prevent degradation due to Ultra Violet Radiation and also to provide more favourable temperature conditions for the film. The result of accelerated laboratory tests have shown that the service life of stabilised (black) film of 0.2 mm (200 micron) thick film is between 40 to 50 years when used as seepage barrier.

3. The polyethylene film has been found durable for lining the irrigation channels. At places where soil cover is used and there may be animal traffic, the film has not been effected by hooves of the animals when laid under 30.0 cm thick soil cover. In case of soil cover the thickness of soil cover may be increased after considering the chances of scour & stability of the banks.

4. According to CBI&P, New Delhi publication "Guide lines for use of Plastics (LDPE film) for lining of canals" 1989, the thickness used may be calculated by the formula.

$$C = 25.4 + D/12$$

Where C = Soil cover in cm

D = Depth of water in cm

Subject to a minimum of 30 cm in bed and 60 cm on sides. The above formula may be used for large and medium canals and for water courses etc., it may be reduced on the discretion of the Engineer-in-charge.

The main problem of using LDPE in water courses is the damage of the film by the movement of stray cattle.

5. LDPE has been successfully used in bed and sides with soil cover or with brick tiles for medium and small canals. If insitu concrete is to be laid on sides, difficulties are expected due to development of bond between LDPE and concrete. For this purpose if serratted LDPE is used, it may serve the purpose. In Punjab necessary technique has been developed to make the smooth polyethylene film surface rough by suitable coating with Bitumen- Kerosine emulsion and as a long range studies, the Bitumen coated polyethylene film has been incorporated in selected reaches of some distributaries and minors of the state.

6. Field engineers from Punjab on the basis of their experiences have recommended that limiting depth of a typical section should be 5.48 m, with maximum velocity of 1.8 m/sec. Also they have recommended that normally for discharge below 85 cumecs, the cup shaped section has been considered adequate and for higher discharges, trapezoidal section was considered useful.

7. The kinetic coefficient of friction between the film and the materials in contact with it should not be less than 0.40, because higher the value, steeper the bank slope which may be provided.

Annexure 1 gives the details of the performance of lined canals using LDPE film as burried membrane.

5.12 COMPUTATION OF LDPE FILM REQUIREMENTS

"A manual on canal and reservoir lining with Agrifilm" a publication of Indian Pertrochemicals Corporation Limited contains very simple and exhaustive calculations in their Annexure-3 for the requirement of LDPE film. For preliminary calculations, the following points should be remembered –

1. Density of LDPE film - 0.931 gm/cm^3
2. For bed as well as for side linings, 5% allowance may be given both along the width and length of the lining.
3. A width of around 1.55 metre may be kept for the purpose of anchoring the film in the trench on the embankments of the canal.
4. For joints along the length of the canals, overlap of not less than 15 cm may be provided.
5. For toe wall anchoring an allowance of 50 cm may be provided.

5.13 SAVING IN CEMENT CONSUMPTION WHEN USING LDPE FILM

As reported by CWC engineers in their paper "Lining of Canals with special reference for the burried plastic lining" (Ref. 11) that Haryana state Engineers have conducted a technoeconomic study with conventional single tile lining vis-a-vis polyethylene film with tile covering. The analysis of rates as worked out for above studies for all types of lining actually laid on Israna and Jundla distributaries of Haryana are given in table.

Table - 2

Saving in Cement Consumption

Sl. No.	Specification Adopted	Cement % Consumption in bags in per sq.m. of lining	of % saving in cement	reduction in seepage due to LDPE film
1	2	3	4	5
1.	Conventional single tile lining with two plasters on Israna distributary	0.275		

1	2	3	4	5
2.	150 micron LDPE film lining in bed covered with tile lining in 1:3 mortar 10mm thick and sides with single tile linings with two plaster layers.	0.220	20%	33%
3.	150 micron LDPE film linings in bed and sides covered with tile lining laid in 1:3 mortar 10 mm thick.	0.145	47%	56%
4.	100 micron LDPE film lining in bed covered with tile lining in 1:3 mortar 10 mm thick and sides with single tile lining with two plaster layers on Jundla.	0.20	27%	-

On the basis of analysis of rates, Cement consumption and use of LDPE film as seepage barrier it was experienced that:

1. Lining with LDPE as compared to conventional lining was approximately of equal cost per square metre of lining.
2. Cement consumption was reduced by about 20 to 47% against conventional type lining and it may prove beneficial and economical when availability of cement may be a problem.
3. With the use of LDPE, extra seepage loss to tune of 33% to 56% could be reduced as compared to conventional linings, detailed in the above table.

5.14 ANTI-WEED AND ANTI-TERMITE TREATMENT OF SUBGRADE SOIL

In the normal circumstances use of chemicals against weeds and termites is discouraged. However in places where obstinate weed and termites are in abundance and the use of anti-weed and anti-termite chemical is unavoidable we shall recommend the following treatment.

5.14.1 Treatment for weed-infested areas

For safeguarding LDPE film against the growth of weeds, weedicides (such as Biodex-C, Gammoxone, Fernoxone or equivalent products) should be mixed with water in accordance with the manufacturer's instruction (3 litres of weedicides mixed with 200 litres of water is a standard practice), and this solution should be spread over the earth with a chemical-spraying pump. The anti-weed treatment should be given only after the moisture content of the soil is brought below 29%. After completion of the spraying of anti-weed chemicals and before taking up the next activity, a period of 24 hours should be allowed for penetration of the chemical into the soil.

5.14.2 Treatment against termite damage

In tropical areas where termites are present, they have been known to attack all type of synthetic membranes. Insecticides such as BHC can be suitably applied for preventing damage caused by termites.

5.15 DO'S AND DON'TS FOR USE OF L.D.P.E. FILM FOR CANAL LINING

Central Board of Irrigation and Power, New Delhi in their publication in the year 1989 "Guidelines for the use of plastics (LDPE film) for Lining of Canals" have recommended the following Do's and Don'ts for use of LDPE film on canal.

i. See at the time of purchase that the film rolls are pasted properly. Keep the film rolls in original packing prior to actual use or laying the film.

ii. Don't leave unpacked film rolls exposed to sun over prolonged periods. Store them preferably indoors.

iii. See that uniform pressure is applied while heat sealing the film.

iv. Don't rough handle or drag the film rolls as the film may got damaged in the process.

v. Don't let workers walk on the film while the lining operation is in progress to avoid any damage to the film. If unavoidable they should walk barefoot.

vi. Don't slide the cover material like bricks, tiles etc. on the film to avoid any damage and displacement.

vii. Don't use hooks for lifting the rolls.

viii. Don't use reprocessed LDPE film, as the quality of reprocessed LDPE film can not be guaranteed and may lead to premature failure of the film.

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Annexure - 1

DETAILS OF CANALS LINED WITH BLACK LDPE FILM IN INDIA

Name of canal and year of lining	Discharge rate (cumecs)	Type of soil	Type of lining Bed/Side	Length lined km	Remarks
1	2	3	4	5	6
Doburji Distributary Punjab 1960-61	2.236	Sandy loam	PS/PS	.088	Lining intact. The 400 gauge film at the bed has remained free from preceptible damage. 250 gauge film got damaged.
Jethuwada Distributary Punjab 1961	0.538	-do-	PS/SB	1.067	Film has been found intact and free from damage caused by weed growth and water insects.
Hatmati canal Gujarat-1962	11.320	Sandy	PB/PB	0.25	Lining intact. Film inspected in 1971 and again in 1973, was found in good condition.
3 R Distributary Ex-Dantiwada L.B. Canal, Gujarat-1966	3.650	Sandy	PB/PB	1.08	Lining intact. Seepage trails conducted in 1968 & 1970 indicated seepage of 0.057 cumecs/m.sq.m. compared to unlined 0.736 cumecs/m.sq.m.
Nadiad Distributary Ex-Mahi R.B. Canal Gujarat-1972	99.050	Loessic to sandy loam	PB/DT (SW)	6.0	Total lining approved was 20 kms. Lining intact.

contd....

1	2	3	4	5	6
Sunder sub branch Ex-Hansi Branch, Haryana-1974	55.185	Sandy	PB/DT (SW) PB/PB PS/DT (SW) PB/PB	3.8 1.0 - -	Lining completed in 1974. -do- 24 km. lining was proposed during 1975 Lining completed in 1974
Cambay Branch Gujarat	66.500 58.580	Alluvial	PB/PBS	30.2 12.0	Lining intact.
Limbasi Branch Gujarat.	84.900	Alluvial	PB/PBS	22.0	Lining intact.
Nadiad Branch Gujarat.	84.900	Alluvial	PB/PBS	23.5	Lining intact.
JLN Feeder Canal, Haryana	93.390	-	PB/PCC	7.0	800 gauge LDPE film used in the bed lining intact.
TSMC (N) Kangsabati Project, W.B. 1981.	0.857	Lateritic	PS	1.179	Lining intact.
TSMC (S) W.B. 1981.	21.220	-do-	PS	1.219	Lining intact.
Kangsabati canal Project, W.B. (1982 & 1984)	42.450 84.900	-do-	PS/PS	2.0 5.0	Bedwidth 12.2 m side 2:1 1000 gauge LDPE film.
Subarnarekha Multipurpose Project.	56.600	Sandy	PCC/PCC	15.0	Bedwidth 7.6 m 400 gauge LDPE film.
Dhaka Canal Bihar-1984	16.980	Clay	PS/PS	2.0	7.6 m Bedwidth 1000 gauge LDPE film.

contd....

1	2	3	4	5	6
Parallel Upper Ganga canal km 6-8.5 & km 9-9.5	367.900	Clay	M-15 insitu in bed/ Double C.C.Tiles on sides	3.0	200 micron LDPE below M-15 C.C. Tiles.
Indira Gandhi Nahar Project 1983-84	523.550	Sandy Soil Tiles in bed/Double P.C.C.Tiles on sides & brick lining	Single P.C.C.	-	250 micron LDPE below P.C.C. Tiles
Kangsabati Project. West Bengal	9.622-31.130	-	i) 250micron LDPE + 60cm soil cover		-
			ii) LDPE + 15 cm C.C.lining on side & soil cover of 60cm in bed.		250 micron LDPE below M-15 CC/soil cover.

<u>Note</u> : Main Source "A manual on canal and reservoir Lining with Agrifilm" Published by I.P.C.L., Vadodara.

Key :

PLB - LDPE film with single tile without mortar.

PS - LDPE film with soil cover.

PB - LDPE film with single tile with cement mortar.

PB (P) - LDPE film with single tile in mortar with pointing.

PCT - LDPE film with concrete slabs in cement mortar.

PCC - LDPE film with cement concrete in-situ.

SB - Conventional single tile lining in cement mortar.

DT(SW) - Conventional double tile sandwich type lining.

PSC - Polyethylene film with soil cement 100.6.

PSS - Polyethylene film with size stone.

PBM - Polyethylene film with brick in CM and top plastered.

PBS - LDPE film with double brick tiles.

Annexure-2

Details of thickness of L.D.P.E. Film used in various canals

Name of Project/ details	Type of section	Discharge	Depth of flow	Bed slope	Free Board	Thickness of film in micron (μ)		Covering Material	
						At bed	At sides	At bed	At sides
1	2	3	4	5	6	7	8	9	10
GUJARAT									
Mahi RB Canal Project									
a. Anklav Dy. -	Trapezoidal	$3.4m^3$ /sec	1.2m	1 in 2000	0.6m	100	100	Soil cover	Soil cover
b. Wansal - sub-minor	Trapezoida	$10.16m^3$/sec	0.45m	1 in 2000	0.3m	100	100	Single tile brick lining	Single tile brick lining
PUNJAB									

1	2	3	4	5	6	7	8	9	10
d. Phulewala Minor	Cup shaped	-	-	-	0.45m	250	250	-do-	-do-
HARYANA									
a. Israna Dy.	Trapezoidal	-	1.5m	-		150	100	Brick masonary 1:3 CM	Brick masonary 1:3CM
b. Loharu Feeder Channel	-do-	-	-	-	-	175	175	cement line concrete 1:3:6	Cement line concrete 1:3:6
c. JNL Feeder	-do-	-	-	-	-	200	175	-do-	-do-
MADHYA PRADESH									
Tawa Project									
a. Bortolai Dy.	Trapezoida	10.55m^3/sec	0.55m	-	0.45m	150	150	30 cm soil cover	30 cm soil cover
b. Biora Minor	-do-	0.06m^3/sec	0.3m	-	0.45m	150	150	30 cm soil cover	30 cm soil cover
WEST BENGAL									

1	2	3	4	5	6	7	8	9	10
UTTAR PRADESH									
a. PUGC km 6 to 8.5 and 9 to 9.5	Trapezoidal	370m^3/sec	4.5m	-	0.75m	200	200	Burnt clay tile lining	Burnt clay tile lining
b. Harduaganj Dy.	-do-	6.75m^3/sec	0.86m	-	0.5m	200	200	-do-	-do-
c. Komari Dy.	-do-	3.35m^3/sec	-	-	-	200	200	-do-	-do-
d. Bulandshahr Dy.	-do-	3.00m^3/sec	-	-	0.5m	200	200	-do-	-do-

Dy. = Distributary

Annexure-3

COMPARATIVE SEEPAGE LOSSES OF VARIOUS TYPES OF LINING

Sl. No.	Type of lining	Seepage losses $m^3/sec/10^6m^2$	Seepage losses in % relative to unlined channel
1.	Unlined channel	1.52	100
2.	a. Hard surface (without LDPE film) Lining		
	i. First class brick lining in 1:4 mortar	0.470	30.9
	ii. Clay tile lining 1:6 mortar	0.275	18.1
	iii. C.C. tile lining 1:6 mortar	0.384	25.3
	iv. 2nd class brick lining 1:6 mortar	0.662	43.6
	b. Hard surface (with LDPE film) Lining		
	i. 100 micron LDPE film covered with clay tile with 1:6 mortar	0.065	4.3
	ii. 100 micron LDPE film on bed and sides overlaid with 1st class brick.	0.030	2.0
	iii.100 micron LDPE film on bed only overlaid with brick masonary using 1:4 mortar.	0.410	27.0
	iv. 100 micron LDPE film lining with 15 cm earth cover on bed and brick lining on sides in 1:6 mortar.	0.064	4.2

LDPE FILM ON DIFFERENT TYPES OF SOIL

	Details of channel	Seepage losses $m^3/sec/10^6m^2$	Remarks
1.	100 micron LDPE film over-laid with brick masonary using 1:4 mortar on clayey soil.	0.044	1. The identical lining were done on channels constructed on sandy, clayey and sand mixed clayey soil.
2.	100 micron LDPE film over-laid with brick masonary using 1:4 mortar on sand mixed clayey soils.	0.051	2. It indicates that type of soil is immaterial when the channel is lined with LDPE film.
3.	100 micron LDPE film over-laid with brick masonary using 1:4 mortar on sandy soil.	0.058	

Annexure-5

SEEPAGE LOSS IN LINED AND UNLINED MINORS UNDER FIELD CONDITIONS OF UGC SYSTEM, U.P.

Sl. No.	Name of channel	Design discharge m^3/sec	Type of channel	Type of lining	Average seepage losses $m^3/sec/10^6m^2$	% saving in seepage losses due to lining compared with unlined channel.
1	2	3	4	5	6	7
1.	Harduaganj Dy.					
	At km					
	i. 27.90	6.75	Unlined	-	1.950	-
	ii. 27.00	-do-	Lined	200 micron LDPE film lining overlaid by single layer of burnt	0.169	91.3

1	2	3	4	5	6	7
2.	Komar Dy.					
	At km					
	i. 1.800	3.35	Unlined	-	1.995	–
	ii. 0.225	-do-	Lined	200 micron LDPE film lining overlaid by burnt clay tiles 1:4 cement mortar.	0.140	93.0
3.	Panethi Minor					
	At km					
	i. Tail	0.32	Unlined	-	1.480	-
	ii. 0.25	-do-	Lined	100 micron LDPE film lining overlaid by bricks in 1:4 cement mortar.	0.188	87.3

1	2	3	4	5	6	7
	ii. 7.00	-do-	Lined	100 micron LDPE film lining covered with brick using 1:4 mortar.	0.295	74.1
5.	i. Cheeti Minor of Bulandshahr Dy.	0.311	Unlined	-	1.304	-
	ii. -do-	-do-	Lined	100 micron LDPE film lining covered with bricks using 1:4 mortar.	0.150	88.5
6.	i. Machkauli Minor of Bulandshahr Dy.	0.396	Unlined	-	1.259	-
	ii. -do-	-do-	Lined	100 micron LDPE film lining covered with	0.045	96.4

Annexure-6

FIELD SEEPAGE LOSSES IN OTHER STATES

	State	Average Seepage loss $m^3/sec/10^6m^2$	% Saving in water due to lining compared with unlined canal.
HARYANA			
A.	Unlined Canal	2.25	-
B.	Conventional lined canal without LDPE film	0.43	81
C.	Lined canal with LDPE film 250 micron.	0.16	93
GUJARAT			
A.	Unlined Canal	2.50	-
B.	Conventional lined canal without LDPE film	1.00	60
C.	Lined canal with LDPE film 250 micron.	0.80	68
WEST BENGAL			
A.	Unlined Canal	2.94	-
B.	Conventional lined canal Without LDPE film	0.30	90
C.	Only LDPE film with soil Cover.	0.12	96

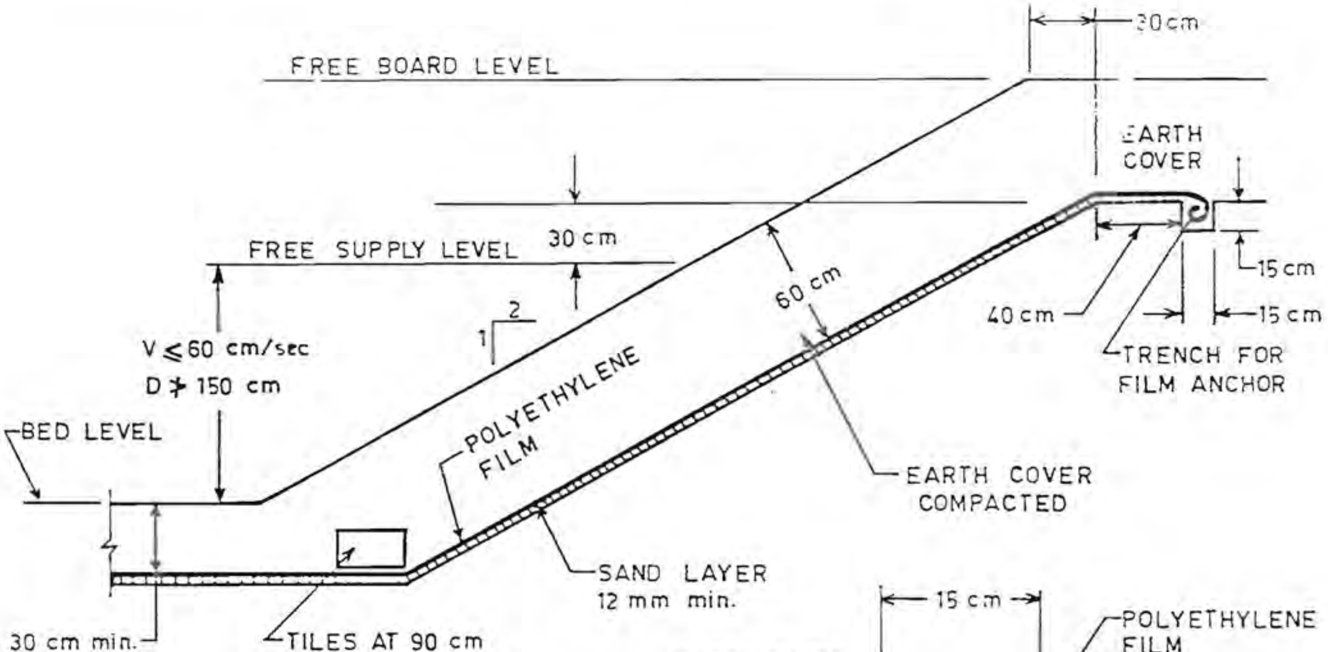


FIG-1A - EARTH COVER OVER POLYETHYLENE FILM LINING ON BED AND SIDES.

FIG-1B - RECOMMENDED TECHNIQUES OF JOINTING POLYETHYLENE FILM

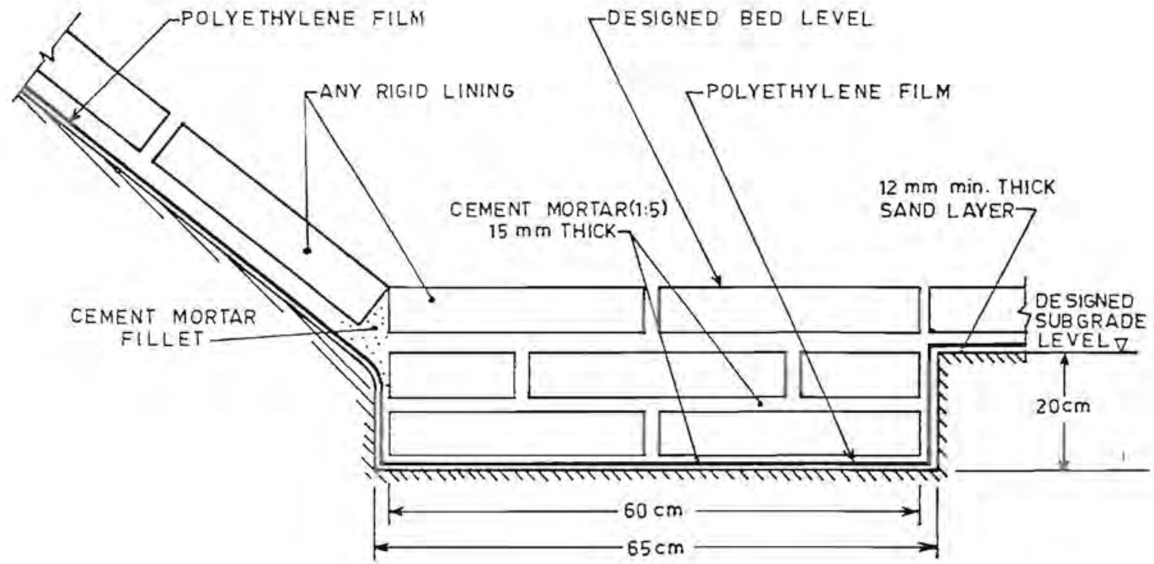


FIG.8: TOE WALL CONSTRUCTION DETAILS

6. EARTH LINING

6.0 INTRODUCTION

The lining of an irrigation channel with natural or processed soils is termed as earth lining. Such linings may prove economical if suitable earth materials are available locally with in reasonable distance. Earth linings give best results in canals traversing very pervious reaches such as in sandy or gravelly materials.

In order to reduce the permeability of the available soils and to provide stability, bentonite, resinous polymers, petroleum based emulsions, cationic asphalt emulsions, sodium chloride, sodium carbonate or soda ash and other such materials may be mixed. The proportions indicated apply to all types of earth lining, except that the lining thickness may vary considerably. A typical section of a compacted-earth lined canal is shown in Fig. 1.

Freezing and thawing action as well as alternate wet and dry cycles are serious hazards to most types of compacted earth linings as they reduce the soil density and thus reduce the effectiveness of the lining as a water barrier.

The earth linings are susceptible to damage also by erosion and weed growth. It is, therefore, desirable that these are provided in canals which have stable section, are continuously running and free from weed growth and erosion.

The earth lining can also be used in combination with hard surface lining, i. e., earth lining in the bed and brick or concrete lining on the sides as has been done in the high filling reach of Upper Ganga Canal (discharge 286 m^3/sec) from km 25.6 to 29.8 where the clay puddle has been laid in the 69 m width of the canal bed and masonry walls have been provided in the sides.

6.1 TYPES OF EARTH LININGS

The various types of earth linings are:

i. Thin compacted Earth Linings

ii. Thick Compacted Earth Linings

iii. Loosely Placed Earth Linings

iv. Stabilised Soil Linings

v. Bentonite Soil Linings

These are discussed below in detail.

6.1.1 Thin Compacted Earth Linings

At locations where highly suitable earth material is available but has to be hauld considerable distances, thus necessitating its most economical use, thin compacted linings consisting of 15-30 cms layer of cohesive soils thoroughly compacted may be used. Generally this is further protected by 15-30 cms cover of coarse soil or gravel to protect the lining from erosion.

In general, the following soils are suitable for compacted earth linings.

i. Gravel with sand-Clay Binder

ii. Clayey gravel

iii. Sand with clay binder

iv. Clayey sands

v. Clays

On account of the risk of relatively severe damage that may result from the erosion or cleaning operation, thin compacted earth linings have found limited use, which has been mostly confined to straight reaches of continuous running stable channel where weed growth is not a problem. The additional cost of its maintenance may be greater than the difference in the initial cost of thin and thick compacted earth linings.

6.1.2 Thick Compacted Earth Linings

Thick compacted earth linings may prove to be the most economical type of lining with regard to both first and ultimate costs if the channel is large enough to warrant the use of heavy earth moving equipment and a suitable soil is available in sufficient quantity without excessive hauling. The cheapest linings will be those for which material obtained from the required excavation of the canal can be used for the purpose of lining.

The equipment operation problems and weather conditions also govern the cost of lining as the lining is placed at a proper moisture content. Water will have to be added if the soil is too dry and if it is too wet, it must be spread for drying up.

Thick compacted earth lining is usually constructed by compacting suitable impervious soil both at the bed and side slopes in horizontal layers. The thickness of lining varies from 0.6 to 0.9 m on sides and from 0.3 to 0.6 m in the bed. The performance of such linings has generally been found to be relatively more satisfactory than that of the other types of earth linings. It can also withstand considerable external, hydrostatic uplift pressure without loss of effectiveness, and it can be used in many instances, without drains under the lining in areas the canal prism intersects the ground water table and for similar reasons, it can be used to advantage over expansive clays. This type of lining utilizes the earth moving and compaction equipment employed in the construction of earth dams.

For canals which are subjected to wetting and drying, fat clays can be used only when the lining is protected by gravel-sand cover. Gravels and sands with clay binder and poorly graded gravel-sand-clay mixtures are best suited for use in thick compacted earth linings, because of their low permeability, high stability and good resistance to erosion. Usually, it is economical to mix coarse subgrade soils with fine soils from outside to make an impervious, stable and blended lining. In order to compensate for the less thorough mixing obtainable in the field, the silt or clay that is added to the coarse excavated soils, should be slightly in excess of the percentage determined by laboratory tests.

After lining, the canal losses should be less than 30 litre/M^2/day. If the local or imported soils do not have the desired sealing quality at standard thickness it may be necessary to increase the lining thickness.

6.1.3 Loosely placed Earth Linings

Loosely placed earth lining is constructed by spreading uncompacted earth blanket of suitable clayey soils over the bed and sides of the canal in layers upto a thickness of 30 cm. This type of lining is not as effective and durable as compacted earth lining, although it may reduce seepage losses. It is subjected to erosion and scour.

Soils for loosely placed earth linings should be selected on the basis of their impermeability in loose condition. Also they should be able to resist piping of soil fines in the subgrade. Loosely placed earth linings have found limited use to check seepage as a temporary measure.

6.1.4 Stabilized Soil Lining

Over the years, Investigators and Field Engineers have investigated and tried a number of admixtures and chemical agents for controlling seepage in canals. These materials ranged from common products such as portland cement, lime, bentonite and sodium carbonate to specially designed asphalt emulsions, resinous polymers and petrochemicals etc.

The action of these materials may be physical plugging of pores, formation of distinct impermeable membrane or chemical reactions with soil constituents. Application of these agents may be made by surface spraying, subsurface injection, addition or spraying on the canal water for subsequent deposition in the subgrade and mixing with soil. For use in irrigation canals, a admixture (soil sealant) must be, nontoxic to human beings, animals and crops, reduce seepage less than 0.1 m^3 per square metre per day, resistant to damage by animals, erosion or hydraulic pressures, durable and low in cost. It is experienced that soil sealants will produce specific results with certain soils, but produce highly variable results with different soils. Also soils treated with chemicals are likely to suffer damage if exposed to wetting & drying or freezing and thawing cycles.

Soil linings stabilized with the help of cement shall be discussed in the next chapter while two cases each of laboratory research works regarding soil stabilization are briefly described below.

6.1.4.1 Laboratory Research Work

The following two research works are briefly described below.

A. Reducing Seepage with Sodium Carbonate

Studies conducted at Colorado University U.S.A. (Ref. No.1) by Mr. J.A.Robertson Jr. show that chemical materials may be used to reduce seepage losses from ponds and canals. For example, Sodium carbonate (Soda Ash) has been found to be an effective sealant for clay soils and also is relatively low in cost.

A laboratory evaluation was conducted to determine the effect of varying amounts of Sodium Carbonate on several soils and their properties. Soils from three ponds previously treated with this method were used in this study. Properties viz. compaction, swelling, permeability and shear strength were investigated.

The results so obtained indicate that -

1. Maximum dry densities are found to be increased at lower optimum moisture contents for application rates less than 0.2% of sodium carbonate by dry weight of soil.

2. Soil stability as determined by swelling & strength characteristics, is not changed by the dispersant unless rates exceed 0.2%.

3. Permeability is decreased considerably by the addition of as little as 0.1% sodium carbonate.

B. Lining of Irrigation Canals by Chemically Treated Soils.

Because of its location in an arid and semi-arid zone, Iran has always suffered shortage of water and therefore, prevention of water loss in agriculture had always been an important problem. One of the way to reduce water loss is to increase the efficiency of the canal system.

One of the easiest way to reduce permeability of the earth lining is to use sodium salts. Sodium ions, upon saturation, ause the clay particles to disperse, clogging the pores and reduce the permeability. Sodium salts are relatively cheap and easily available and besides, prevent growing of weeds on the bottom or side slopes of canals.

Based on the overall results of the experiments conducted by M/S Hassan Rahimiand Mahmood Bazar of college of Agriculture, University of Tehran, Iran (Ref. No.2) Using the sodium carbonate, asphalt emulsion and portland cement, the following conclusions are made.

1. Treatment of the earth canal lining by Sodium Carbonate can reduce seepage loss considerably by dispersing the soil particles.

2. To stabilize the dispersed soil particles, either asphalt emulsion or Portland cement can be used.

3. A mixture of sodium carbonate treated clayey or silty-clay soil and portland cement or asphalt emulsion can be used as a cheap canal lining which is able to reduce the seepage by 95%.

4. Quality of irrigation water is not much affected by chemical treatment of canal earth lining.

5. Chemically treated earth lining could be easily placed on the sides and bottom of irrigation canals or reservoirs.

Following two field examples are described herein brief.

<u>Example-1</u>

Treatment of expansive clay canal lining. (Ref No.3)

The Friant-Kern canal, part of the central valley project in california, U.S.A., extends from the Friant dam on the San Joaquin River east of Fresno, south to the Kern River near Bekers field. The canal was constructed during the period 1945 to 1951. It is 245 km long with discharging capacity of 113 m sec. (4000 cusecs). Approximately one third of the length of the canal from km. 55 to km. 142, passes through an area of expansive clay. About one-half of this canal reach is earth lined; the remaining part of the canal is concrete lined.

The canal lining experienced cracking, sliding and sloughing of the sides slopes in both the concrete and Earth lined sections of the area of expansive clays after 3 years of operation. In the early 1970's, it was decided to remove portions of canal lining, flatten the canal slopes and reline the canal using compacted soil-lime mixture in an attempt to stabilize the slopes.

Laboratory tests were conducted to determine the amount of lime to be added and to evaluate soil-lime lining performance. The test results indicated that the clay has a liquid limit ranging from 57 to 70, plasticity index from 37 to 46 and shrinkage limit of approximately 8. For stabilization of the expansive clay soils, 4 percent granular quicklime was added to the soil. The addition of lime reduced the plasticity index of the soil to about 10, with significant increase in compacted soil-lime strength.

The evaluation of the soil-lime lining in the expansive clay formation consisted of unconfined compression tests, chemical analysis, erosion measurements and extensive visual examinations. The inspection and testing indicated that the soil-lime canal lining performed excellently with no sliding, sloughing or erosion problems.

Conclusions of Example-1

i. Since the rehabilitation of the canal lining has not experienced and failures in the area where compacted soil-lime was used.

ii. The addition of lime to the expansive clay modified the volume change characteristic of the clay. The plasticity index was reduced and the shrinkage limit increased. Consideration should be given to additional use of lime to condition wet, expansive class. The lime acts as a drying agent and also changes the workability and increase the strength of the material and shear resistance of the canal lining.

iii. The soil-lime lining is extremely erosion resistant. The erosion was, in general, restricted to less than 0.03 m after upto 6 years of operation. Even there were some locations where the original compaction tracks were clearly visible at the time of visual inspection which was made after 6 years of canal in operation.

Example-2

Lining of Green Valley Reservoir, California, U.S.A.(Ref No.4)

Since 1967, the U.S.B.R. has been conducting studies on a synthetic polymer soil sealant. This material, a polyacrylamide, is supplied in dry powder form which contains two active components. When the powder is added to water one component is soluble and it penetrates into the soil and adherdes on the clay particles to form a seal. The other component forms a gel which is intended to plug cracks and larger soil capillaries.

The material can be applied by several different methods. In operating canals, the material can be applied to the surface of the water as a dry powder using a blower mounted on the bank or on a boat. Also the material can be mixed with polyethylene glycol to form a slurry and then to be introduced into the water at the head works, allowing the water to carry it downstream.

D. Engineering Properties

Type of Bentonite	Liquid Limit	Plastic Limit	P.I. %	Coefficient of Permeability cm/sec
Kashmir	283	33	250	$8x10^{-10}$
Rajasthan	353	43	310	$5x10^{-10}$
Bihar	120	25	95	$6x10^{-10}$
Thoroseal	475	55	420	$2x10^{-10}$

A perusal of the above tables indicates that Rajasthan bentonite is better than Kashmir or Bihar bentonite, thoroseal being the best among all.

6.1.6 Activation of Bentonite

It has been found that on activation, Indian bentonite displays very good properties, even better than best American Wyoming bentonites (Ref No.5). The Hungarian process of activating the bentonite consists of testing bentonite with 1 to 6 percent sodium carbonate. The most important feature of this process is the mixing and kneading of raw material in pulverized state with alkali at temperature 80-100°C, a moisture content of 30-40 percent and preferably in a closed apparatus provided with steam heating device. It is claimed that the technique enable the alkali to react with macro, micro, and sub-microscopic surfaces of montmorillonite contained in the bentonite and to that are attributable the markedly increased thixotropic properties of the activated bentonite than obtained by ordinary sodiumization of bentonite. It is also claimed that sodium bentonite obtained by activation process is less able to revert back to its original state subsequently. Activation of bentonite can also be done by 1 percent soap solution. The mixture of soap solution and bentonite is thoroughly mixed in churning machine. The mixture is dried in sunlight. After grinding the powder is the activated bentonite (Ref No.6).

6.1.7 Methods of Lining

Following three mathods can be employed for lining the channels with bentonite :

A. Percentage of Clay Minerals

Type of Bentonite	Monbnori-llonite	Illite	Chlorite	Halloy-site	Kaolinite
Kashmir	40	25	20	5	10
Rajasthan	50	20	20	5	5
Bihar	30	30	10	5	25
Thoroseal	50	25	15	5	5

B. Exchangeable Cations m.e./100 gm.

Type of Bentonite	K	Na	Ca	Mg	H	Base exchangeite capacity
Kashmir	-	75	20	05	-	100
Rajasthan	10	100	20	10	10	150
Bihar	-	10	50	10	15	85
Thoroseal	10	100	40	15	10	175

C. Physical Properties

Type of Bentonite	Swelling Moisture	Absorption capacity %	Ethylene Glycol retained %	P^F
Kashmir	225	100	75	1.75
Rajasthan	325	125	85	2.85
Bihar	125	85	55	0.95
Thoroseal	400	150	100	3.15

Note:

1. P^F indicates water retention capacity of bentonite.
2. Ethylene Glycol retention indicates capacity of bentonite to react with organic compounds.

At later stage, the manufacturer recommended blending of this sealant with bentonite soil and then compacting the mixture on the subgrade soil to form a lining. For this type of mixed in place application, the manufacturer recommends using from 5 to 10 kg/m^2 of the sealant-bentonite mixture.

In 1973, this method of application was used in constructing a lining for the Green Valley Reservoir, California, U.S.A. field reports indicate that the sealant is performing satisfactory, although there has been some wave action damage to areas of the reservoir slopes. Riprap has been placed in those areas for erosion protection.

6.1.5 Bentonite Soil Linings

Out of all types of earth linings, Bentonite lining has been found the maximum use due to its high impermeability and provides maximum potential for development in future. This will, therefore, be described in more detail.

Bentonite is natural earth material in the form of hydrosilicates of aluminium with a high percentage of montmorillonite and some beidellite as a result of decomposition of material of igneous origin. The basic structural unit of montmorillonite clay has a residual negative charge which attracts cations such as sodium and calcium satisfying about 80% of the net negative charge. The bonds between the various units are very weak and depend on the nature of exchangeable cations. Bentonite is characterised by high water absorption accompanied by swelling. The bentonite clays are known as sodium bentonite or calcium bentonite depending on the nature of exchangeable cations.

Sodium bentonites are charaterised by much higher swelling characteristics than calcium bentonite due to larger ionic radius of sodium. The fact that bentonite does swell and become impervious on swelling makes it a very useful material in the control of seepage from canals, if it can be obtained from local deposits at low cost.

In India bentonite is available in Kashmir, Rajasthan and Bihar. In addition another variety of bentonite under the trade name of Thoroseal is being marketted. Thoroseal is sodium mixed bentonite and also known as activated bentonite. The percentage of clay minerals in these bentonites and their physical, engineering properties and base exchange capacities as determined at U.P. Irrigation Research Institute, Roorkee are given below:

(a) Bentonite Water Mixture - The channels can be treated with bentonite by dispersion or Multiple Dam Methods (Ref No.7). These methods are used where soils have large permeability so that the seepage velocity of water is relatively higher to carry the bentonite into the pores.

(i) Dispersion Method :- When dissolved in water, bentonite particles consist of agglomerations. The dispersion of bentonite consist in the breaking of afflomerations into individual particles which can be done either mechanically by churning the bentonite suspension or by addition of certain chemicals known as dispersants which by increasing the electric repulsion between adjacent particles, reduce the cohesion between them. The chemicals which can be used as dispersants (peptizers) are potassium nitrate, potassium carbonate, Sodium aluminate, Sodium silicate, Lithium carbonate and Sodium hydroxide.

In the dispersion method water is ponded in the channel with the help of temporary bunds. At the upstream end of the mix point a check structure with a controlled bypass and a screen to catch the lumps are provided. Bentonite fed from air slide hopper, is mixed with pumped water to produce bentonite slurry. Intake pressure is kept about 2.5 kg/cm^2. The mix efficiency increases with increase in pressure. With the help of 10 cm pump and 5 cm jet, 90 kg of bentonite can be mixed in a minute. The feed rate of bentonite is adjusted till it gives-lump free and smooth slurry. Undispersed lumps are collected & broken with the help of jet of bubbling air. About 1 percent or slightly higher concentration of bentonite is maintained in the pool. Clear water is admitted through the bypass to produce 1.2 percent concentration at the test point (Figure.2) This will keep the concentration of the entire pond at 1 percent or higher. The banks and bottom of the channel are harrowed to ensure proper mixing. Pending should last for two days. After this the canal is kept full of water to prevent cracks due to drying. This method is used in sandy soils.

Sodium bentonite produces best results in soft water. When sodium bentonite is dispersed in hard water, particle flocculation and setting out occurs. Calcium bentonite reacts in similar manner but at faster rate. This problem can be countered by using a chemical dispersing agent. Main action of the dispersing is to soften the water. The quantity of dispersant required for calcium bentonite would be more than that required for sodium bentonite.

The roots of weeds should be removed properly before bentonite treatment. The feed rate of bentonite should be slow to obtain thin and lump-free slurry which is easy to disperse in the diluting water. Whenever erosion or shifting of bed is noticed, immediate steps should be taken to stabilise the banks and to retreat the section with bentonite.

(ii) Multiple Dam Method:-A number of temporary bunds, made of sealing mixture, consisting of 30 percent or more of activated bentonite and locally available blending material such as wet saw dust, natural silt or coarse clays are constructed (Fig. 3).

Where the bund is overtopped by the flowing water, it breaks up into a lump slurry which flows into the leaky holes and plugs them. At least 5 kg of bentonite is required for every 1 sq.m. of wetted area. This method is found effective in rocky to gravelly materials.

(b) Bentonite Soil Mixture:- This method is recommended for sandy soil.Local sandy soil is mixed in place with bentonite to form 5-10 cm thick finished lining. The optimum percentage of bentonite ranges between 5-25, which should be predetermined in laboratory. This type of lining can be used without protective cover where velocities are low. With higher velocities a protective cover is recommended.

(c) Bentonite Membrane Lining:- In this method a 3-5 cm thick bentonite membrane is laid over the bed. The membrane is protected by 15-30 cm thick soil cover or by a layer of tiles or brick. This type of lining is suitable for continuous running channels.

Bentonite lining is subject to damage by weed growth and cracking due to drying. It is not strong and durable. The lining has been used in U.S.A. for channels carrying discharge upto 4 m^3/sec. Experiments have been conducted at U.P. Irrigation Research Institute, Roorkee to determine the stability of bentonite as a lining material.A 5 cm thick layer of 20,30 and 40 percent unactivated bentonite sand mixture was laid over the bed and protected by 12.5 cm thick soil cover. The experiments indicated that mixture of 20-30 percent of bentonite with soil was effective in reducing seepage losses and further increase in bentonite percentage did not result in proportional decrease in seepage losses. The lining was damaged by weed growth and was not strong and durable. Experiments on bentonite lining, consisting of 5 to 8 cm thick layer of unactivated bentonite protected by tiles laid in cement mortar was found inferior to tile lining with plaster layer.

6.2 DESIGN STANDARDS

Usually velocities ranging from 0.3 to 1.3 m/sec are permitted through the earth linings. The velocities may vary depending on the type of lining material used. If higher velocities have to be permitted, a gravel can be provided to prevent erosion. Large curvatures in the canal are generally avoided as otherwise the outer bank may get damaged due to scour.

The value of Manning's `n' is taken as 0.025 for canals having discharge less than $3m^3$/sec. For large canals, this value is taken as 0.0225 or 0.020. The bed width and water depth ratio is usually about 3 for small canals and 8 or even higher for large canals. The side slopes in earth lined canals are generally kept 1.5:1 or flatter depending on the size of the canal, the type of subgrade and lining provided. The minimum free board to be given may be determined from Fig. 7 of the chapter 2.

The subgrade treatment depends upon the subgrade material. In some cases subgrade material may be used as a part of the lining. Where subgrade consists of fine grained soil, it is ploughed and compacted. In case of sands and sandy gravels, no subgrade treatment is required. However, if the subgrade contains open voids, such as in the case of gravel and fractured rocks, it may be necessary to over excavate and place a sand-gravel filter layer before placing the lining to avoid piping.

6.3 SEEPAGE CHARACTERISTICS OF LINING

Seepage losses through various types of earth linings have been measured by U.S.B.R. under the programme of low cost canal linings. These are given in annexure-I. It may be seen from the annex. that the seepage losses through thick compacted earth linings and loose earth linings range from 0.03 to 0.28 $m^3/sec/10^6m^2$ and from 0.18 to 0.53 $m^3/sec/10^6m^2$ respectively. The observed seepage losses through loosely placed earth linings range between 1.32 and 1.66 percent of the canal discharge per kilometer.

6.4 CONSTRUCTION DETAILS

Before using the available soils for lining, their maximum density, optimum moisture and permeability should be determined in the laboratory. Construction specifications should require a minimum inplace density sufficiently high to provide some excess over apparent permeability requirements. This requirement, usually 95 percent of the proctors density, is established from a knowledge of soil characteristics and the construction practices and equipment. Preliminary field tests may be carried out with the equipment to be used in the construction of the lining to determine the minimum inplace density. If compacted to higher densities, soils that are less suitable from permeability considerations may often prove satisfactory. Laboratory tests have clearly indicated that with the stable side slopes normally used, linings can be placed at moisture content somewhat higher than the optimum because the permeability of a soil generally decreases with the increase in placement moisture. Fairly satisfactory compaction is accomplished with the help of sheep foot roller.

In the case of thin earth linings, best compaction is accomplished by a final rolling by smoothroller after compacting by sheep foot roller. However, other equipments have also been satisfactorily used. The method consists in operation of the equipment along the berm. Side slopes are compacted by the longitudinal operation of the compaction equipment with roller tied to heavy mobile equipment on the berm.

In case of thick compacted linings, both the bottom and side slopes are compacted in successive horizontal layers not more than 15 cm thick after compaction. To line the canal, 1-3 metre wide successive layers on the side slopes can be overbuilt as required to accommodate the conventional large earth moving and compaction equipment and then trimmed to required lines. The actual thickness of the lining on the sides is kept usually about 0.6 to 0.9 metre as measured normal to the slope. Lining in the bed is kept 0.3-0.6 metre thick but may also vary with the requirement of the job.

1		2	3	4	5	6
Provo River Project, Utah Provo Canal						
Station	665+48 to 752+00	Silt	12.74	1.62	1.66%/km	1946
Station	665+48 to 752+00	Silt	12.74	1.62	1.32%/km	1947

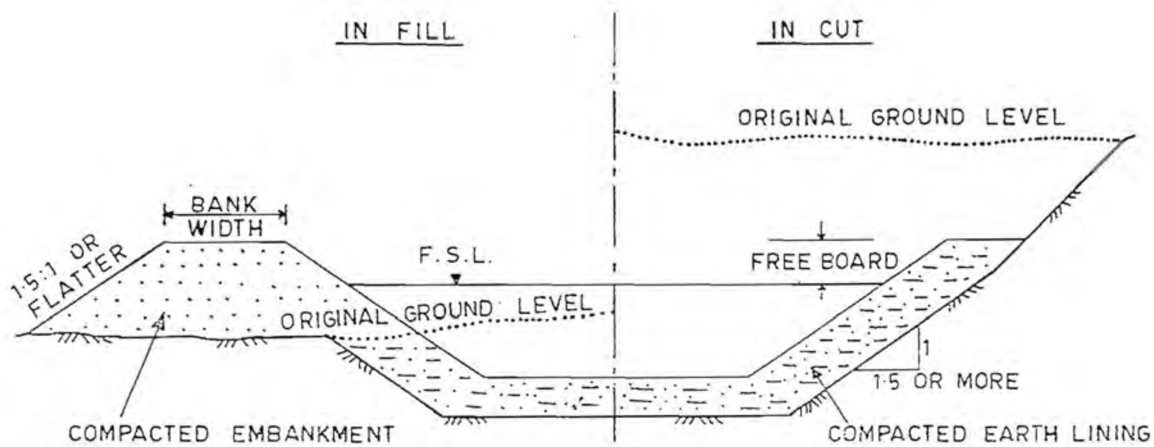


FIG. 1:– TYPICAL SECTION OF A COMPACTED-EARTH-LINED CANAL.

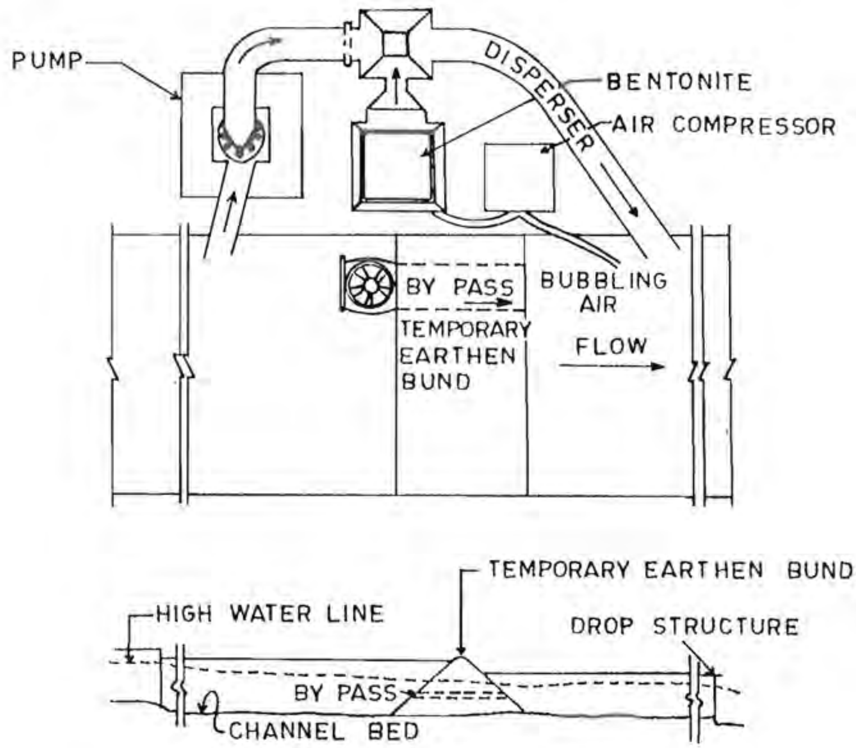
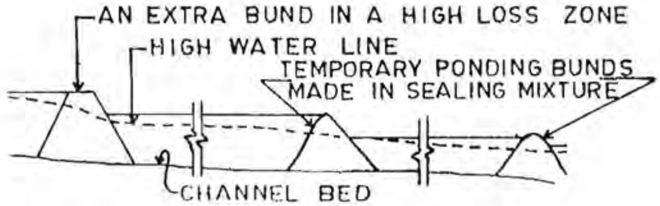


FIG. 2:- DISPERSION METHOD



(FIGURE NOT TO SCALE)

FIG. 3:- MULTIPLE DAM METHOD

7. SOIL - CEMENT LININGS

7.0 INTRODUCTION

Cement has since long been used with success in the construction of cast-in-place concrete and mortar linings, and precast concrete blocks and slabs. More, recently, it has been combined with soil to produce soil-cement linings for use under mild exposures and with possible saving in cost. Thus, as the name implies, soil-cement linings are made up of a mixture of portland cement and the natural soil.

Soil-cement offers possibilities for use as a canal lining material in localities where the climate is mild and where the subgrade soils or those adjacent to the canal are of a sandy in nature and other suitable materials are not readily available. Although different types of soils, as available at site, can be considered fit for use as a lining material, laboratory tests indicate that for best results soils for this purpose should be well graded with a maximum size of 20 mm and contain between 10 and 35 percent fines passing the Indian Standard sieve No.8. However, this type of lining is not weather-resistant. Its life is comparatively short and maintenance charges relatively high.

Soil-cement lining is a type of exposed lining as it exposes the water barrier to the wear, erosion and deterioration due to flowing water and also to other hazards. It may also be included in the category of hard surface linings like cement concrete, brick, stone and cement mortar linings. However, like other hard surface linings, it does not permit velocities higher than those in an unlined canal and its merit lies only in the reduction of seepage losses and prevention of waterlogging in the adjoining areas. Whereas other hard surface linings may be provided in new canals where high flow velocities are to be maintained to reduce the excavation cost or even in the existing canals to increase their water-carrying capacity; soil-cement lining may be used in the existing canals where the primary purpose of lining is the reduction in seepage losses. In fact, soil-cement lining is a low cost lining which sometimes affects considerable saving as compared with portland cement concrete lining. It is considered fit for minor canals with low velocities.

There are two types of soil-cement linings : compacted and plastic. The former type also known as standard soil-cement lining is compacted to its maximum density keeping the moisture content of the mix at about optimum. Tests to determine and control the optimum cement content are carried out in the laboratory. However, about 2 percent increase in cement content is allowed to ensure adequate resistance to the flow of water. Such linings have been used in some cases, but not with a measure of success.

Plastic soil-cement lining is laid with soil-cement mixture in plastic form. This type of lining has higher water and cement contents and a consistency (and hence workability also) comparable to that of concrete. These properties permit placement of plastic soil-cement linings by means of a slip form similar to that used in the placement of portland cement concrete linings. Properly manufactured and applied, plastic soil-cement has been found to approach in serviceability portland cement concrete, if conditions of exposure are not severe.

7.1 GENERAL DESIGN CONSIDERATIONS

While proposing to provide a soil-cement lining in a canal the following points should be taken into consideration :

(i) The side slopes for most canals should not be kept steeper than 1½ : 1.

(ii) A firm foundation ia a prerequisite to the success of soil-cement lining. It will reduce, as far as possible, the amount of cracking and the danger of failure due to settlement of the subgrade. Undisturbed soils are often satisfactory for a foundation of lining without further treatment. However, natural in-place soils of low density should be thoroughly compacted or removed and replace with suitable material.

(iii) Reaches with expansive soils

Lining should be avoided, as far as practicable, on expansive clays. But, if the canal has to traverse a reach of expansive clay and no alternate route or construction type is economically feasible, any of the practices detailed below shall be adopted to reduce the damage to the lining depending upon the swelling properties of the soil encountered.

If the expansive clay is in thin layer or in small pockets in an otherwise suitable subgrade it shall be over-excavated and

Sand (0.02 t0 2.0 mm) content not less than 35 percent by weight, pH value 8.0 to 12.0, and organic matter < 1 percent.

The Central Board of Irrigation and Power specifications stipulate that the quantity of portland cement used for soil-cement blocks shall be 5 percent by weight of the dry soil.

(x) Cracks in soil-cement lining may develop due to moisture and temperature variation or due to differential settlement of subgrade. The cracks in soil-cement lining can be minimised by laying the lining in panels of suitable size and by properly sealing the joints between adjacent panels. If the grooves are properly formed and spaced, cracking will usually occur at these predetermined planes of weakness.

Experiments on soil-cement lining reported by the Karnataka Engineering Research Station, Krishnarajasagar show that there is practically no cracking when the standard type of soil-cement lining is laid in slabs having a width of 1.55 m. A joint filler of sand mastic with blown grade of bitumen has been involved at U.P. Irrigation Research Institute, Roorkee for the expansion joints of Yamuna Power Channel. This joint filler is economical and laboratory tests have indicated that its performance is better than that of other joint filling compounds.

7.2 CONSTRUCTION DETAILS

7.2.1 Field Control

The following factors shall be checked for controlling field operations during the progress of the work :

(i) Subgrade Condition : Prior to placing of the soil-cement mix the condition of the subgarde shall be checked to ensure that it is well compacted (to a density not less than 95 percent of the standard maximum for the soil) and clean and the surface is moist.

(ii) Cement Content : An adequate cement content is a primary control factor deserving maximum attention in the field. Samples of the mixed materials from a batch shall be frequently examined to ensure that they are uniform in colour and texture.

(iii) Moisture Content : The moisture content of the soil and the soil-cement mixture shall be checked at regular intervals prior to batching, whenever the source of soil is changed from one stock-pile to another, and also after mixing.

(iv) Compaction of Soil-Cement Mix : The dry density of the compacted soil-cement mix shall be measured at a spacing of 100 m along the length of canal at points widely distributed across the bed and slopes. In no case shall the measured dry density fall below the specified maximum dry density by more than 80 kg/m^3. For plastic type soil-cement lining the dry density 5 to 10 percent less than specified for standard type soil-cement shall be acceptable.

(v) Thickness of Processed Layer : This shall be checked continuously during the construction to ensure that the correct thickness is being laid. The thickness of the compacted layer shall be measured in conjunction with the dry density.

(vi) Regularity of Surface : There shall not be any depression in the level of the final surface, either transversely or longitudinally of more than 5 mm under 3 m template of straightedge.

(vii) Curing : It shall be ensured that the surface of the soil-cement is maintained moist continuously throughout the curing period by checking frequent intervals.

7.2.2 Control of Cracking

If the soil-cement mix is compacted at the optimum moisture content and to the maximum dry density there should not be significant cracking when sandy soil is used. Anyhow, the cracks can be minimised by minimising the rate of evaporation from the finished surface.

In plastic type soil-cement lining there are likely to be more cracks than in standard type. Therefore, relatively greater effort will have to be made to minimise evaporation by keeping it covered with used wet gunny bags or moist straw, etc. This provision is only ofcourse possible during construction period and therefore the use of plastic type linings to be discouraged.

7.3 LABORATORY STUDIES

In India, some experimental studies on soil-cement lining have been carried out at two Research Stations, viz :

(i) Karnataka Engineering Research Station, Krishnarajasagar, and

(ii) Land Reclamation, Irrigation and Power Research Institute, Punjab, Amritsar.

The details of the studies and their results are reproduced as below :

K.E.R.S., Krishnarajasagar : Five percent soil-cement lining gave a seepage of 1.34 $m^3/sec/10^6m^2$ of wetted area. The high rate of seepage was due to formation of hair cracks. Hence prevention of cracks assumed importance. Soil-cement slabs 6.1 m long, 0.9 m wide and 7.6 cm thick were, therefore, provided with 20 gauge steel wires near the surface at 0.6 cm depth. The wires were arranged at a different spacings, viz, 12.7 cm, 15.2 cm, 17.8 cm and 22.9 cm centre to centre. Distribution wires were spaced at 38.1 cm centre to centre. After three months, surface cracks were noticed in the slab with reinforcement wires at 22.9 cm centre to centre and others did not develop any cracks.

An additional coat of 1:4 cement mortar over 5 percent soil-cement was also applied, as it was felt that 5 percent soil-cement by itself might gradually disintegrate under continuous flow. The seepage through this lining was found to be 0.00483 $m^3/sec/10^6m^2$ of wetted area.

Based on these test results it was proposed to use 20 gauge steel wires just at the surface of lining as a measure to prevent the possible formation of hair cracks over the surface. Use of 7.5 percent soil-cement lining was also recommended in cases where occurrence of salt was anticipated in the neighbourhood.

L.R.I.P.R.I., Amritsar : Experiments conducted on soil-cement blocks showed that these require skilled labour and have a very limited useful life. The reduction of seepage losses is also not very great. Five percent soil-cement blocks when subjected to moistening were found to indicate an increase of 0.167 percent in length.

7.4 FIELD PERFORMANCE

Experience has shown that the soil-cement lining is not weather resistant, its life is comparatively short and maintenance charges are relatively high.

1	2	3	4
	As above	Plastic Soil : as above Portland cement:16% Thickness: as above Installed in 1945	After 12 years of ser-ice,in fair,condition.
	As above	Plastic Soil: poorly graded silty fine sands Portland cement : 4 different sections containing 11.1 to 22.2 % Thickness : all sec-tions 8 cm (3 in) Installed in 1947	After 10 years of service the lining with 11.1 % cement content was badly deteriorated. The sec-tions with 14.5 to 22.2 % cement content were in fair to good condition and still effective in reducing seepage losses.
	Canal on the Boise Project, Idaho, U.S.A. Experimental reach	Plastic Portland cement : 14.3 % Thickness:not quoted Installed in 1948	After 14 years of service, still in very good condition.
	Storage reservoir, Port Isabel, Texas	Dry-mix Portland cement:12% Soil Moisture content : 18 % Thickness : 10 cm (4 in) constructed in 1945	After 23 years of service, the soil-cement was still per-forming satisfactorily and the maintenance had been negligible.
	Drainage canals, Calverton, Long Island, New York	Dry-mix (mixed in place) Soil : sand of open texture with no binder	In good condition after 4 years, except for some deterioration on steep slopes. (cause: non-uniform

1	2	3	4
		Portland cement:14.5% Cured with asphalt emulsion Thickness:not quoted	mixing of cement and soil and inadequate compaction).
	Drainage canals, U.S. Naval Auxiliary Air Station, Whiting Field, Florida	Plastic Soil:sandy with 10-20 % silt, scarcely any clay Portland cement:13% Thickness:13 cm(5 in) Cured with wet earth or curing compound	Very effective after 8 years of service. Very little, if any, notice able deterioration has occurred.
	Small irrigation canals of the Eden Project, Wyoming, U.S.A. Field tests for the evaluation of dry-mix soil-cement linings	Dry-Mix (Machine mixed) Soil : sandy with high sulphate content Portland cement:9 % (design); 5.2-5.8 % (actual) 12% design; 6.5 % (actual) Thickness:not quoted	"Seepage losses associated with intermittent use seldom justify lining field ditches on the basis of the value of the water saved in this or other areas. Ditch stability may be all that should be sought. If this is assumed, soil-cement even that of poor quality has been reasonably effective for a period of 10 years."

8. LINING OF CANALS IN EXPANSIVE SOILS

8.0 INTRODUCTION

8.0.1 Origin of Expansive Soils

The parent material that can be associated with expansive soils may be classified into two groups.

The first group comprises the igneous rocks such as basalt of the Deccan Plateau in India, the dolerite in the central region of South Africa and the gabbros in the west of Pretoria North, Transvaal. In these soils, the feldspar and pyroxene minerals of the parent rocks have decomposed to form montmorillonite and other secondary minerals. The second group comprises the sedimentary rocks that contain montmorillonite as a constituent which breaks down physically to form expansive soils. Montmorillonite is therefore the main source of expansive soil.

The montmorillonite was probably formed from two separate origins. The products of weathering and erosion of the rocks in the high lands were carried by streams to the Coastal plains. The fine grained soils eventually became shale accumulating in the ocean basin. Meanwhile, volcanic erruptions, sending up clouds of ash, fell on the plains and these ashes were changed to montmorillonite.

8.0.2 Distribution of Expansive Soils

G.W. Donaldson summarized the distribution of reported instances of expansive soils around the world. Expansive soils are found in abundance where the annual evapotranspiration exceeds the precipitation. This follows then the theory that in semi-arid zones, the lack of leaching has aided the formation of montmorillonite. Potentially expansive soils can be found almost anywhere in the world.

Expansive soils found in India, contain montmorillonite or combination of montmorillonite and illite clay minerals. They cover about one third of the total surfacial deposits of India, predominantly in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamilnadu, Rajasthan, Orissa, Bihar and Uttar Pradesh. The majority area of expansive soil is found in the above first five states. Expansive soils are locally known as 'Black Cotton Soils'. Deep deposits of such soils, cover some 73 million hectares or about 22.2% of the total Geographical Area of the Country.

8.0.3 Damage caused by Expansive Soils

The problem of expansive soils was not recognized by soil engineers till 1930. Considerable damage has taken place in India over years to canals, roads buildings and other engineering structures on or with the use of this soil. As such there is great reservation among engineers for using them on important construction works. Sustained research extending over the last 40 years in this country and abroad reveals considerable progress that has taken place to develop a rational approach to the design of canals on expansive soils, nick named as `Hidden disaster' by Jones and Holts.

To bring greater efficiency in irrigation water management, irrigation canals were lined in India and lining process is also continuing on most of the new irrigation projects. However, lined canals passing through expansive soils suffered large scale damages, some even before their operation. Most of such canals where failure have taken place were lined by conventional methods without properly accounting for swelling, swelling pressures and the corresponding reduction in shear strength.

8.0.4 Research and Field work done in India

Research work in India and abroad over the past 40 years, led to the invention of cohesive non-swelling soil (CNS) that counteract effectively the swelling pressures of even as high as 3 to 5 kg/cm^2 with the interposition of 1.0 to 1.25 m of CNS layer between the lining and the swelling soil base. The CNS layer effectively prevents the swelling of the underlying soils and retains their high intrinsic shear values even under variable moisture conditions ranging from insitu to saturation level. In other words, the composite swelling soil i.e. CNS system for all practical purposes behaves as a normal soil system, provided the thickness of the CNS layer is adequate.

Field observations have revealed that, even in case of swelling soils, the swelling phenomena are confined within a small depth of 1.0 to 1.5 m below the swelling surface. At and below this depth the expansive soils, on its own can develop enough cohesion, starting from zero at the surface, to swelling pressure.

8.1 IDENTIFICATION OF SWELLING SOIL

(a) Expansive soils are those which during their moisture content increase, exhibit heave and if arrested, exert swelling pressures on the structure retaining the heave. Walking over such soils is rendered difficult after heavy rains.

(b) Thorny bushes, thorny trees (Babul) and cactus constitute the normal vegetation in such soils in India. During summer, wide, deep and map type cracking is normally observed in the area.

(c) Buildings and other light structures like warehouses constructed using conventional methods exhibit heaving of floors, cracking of walls and jamming of doors during rainy season.

8.1.1 Field Identification of Expansive Soils

Landslope	-	Normally 0 to 2°
Colour	-	Black, grey, yellow and
Drainage	-	Generally poor

8.1.2 Physical and Chemical properties of Expansive Soils

The grain size, index and other physical and Chemical properties of such deposits expressed in percentage are in the following ranges.

(a) Gradation

Clay (less than 0.002 mm)	-	50 to 70%
Silt (0.002 mm to 0.060 mm)	-	20 to 35%
Sand (0.060 mm to 2.00 mm)	-	30 to 50%
Gravel (greater than 2.00 mm)	-	upto 10%

(b) Dry density

1300 to 1600 kg/m^3 at 1.5 m below the ground level and moisture content 22 to 30%.

(c) Index properties

Liquid limit	60 to 100%
Plastic limit	30 to 50%
Plasticity index	30 to 40%
Shrinkage limit	8 to 12%

(d) Chemical composition of expansive soils

SiO_2	content	-	45 to 58%
Al_2O_3	content	-	13 to 18%
CaO	content	-	1 to 8%
MgO	content	-	2 to 5%
pH	value	-	8 to 8.5

8.1.3 Mechanics of Swelling

If the environment of the expansive soil is not changed, swelling will not take place. Environmental change can consist of pressure release due to excavation, changes caused by temperature increase and volume increase because of the introduction of moisture. By far the most important element and concern to the practicing engineer is the effect of water on expansive soils.

The most common method of moisture transfer is by gravity. The seepage of surface water, precipitation and snow melting into the soil are common examples. The moisture migration can occur in all directions. Under artesian condition, the flow can be upward.

The moisture content variation with depth in a homogeneous soil may vary considerably. The depth of seasonal moisture content fluctuations depends on the variation of surface moisture, permeability of the soils and climatic conditions. In areas where precipitation and evapotranspiration are fairly constant, this depth may be only a metre or so. When a long drought is followed by an intense rainfall, the depth of moisture variation can reach 3 m or even more. It should be noticed that watering of lawns, planting of trees and shrubs, discharge of roof drains etc.may cause the depth of moisture variation as high as 7 to 8 m.

8.1.4 Swelling Pressures

From research and field observations, the following conclusions have been drawn regarding the swelling pressure developed as a result of wetting of expansive soils.

(a) The swelling pressure of clay is independent of the initial moisture content, degree of saturation and the thickness of the stratum.

(b) The swelling pressure increases with the increase of initial dry density.

(c) For undisturbed soil, the swelling pressure can be defined as the pressure required to keep the volume of soil at its dry density constant.

(d) For remolded soil, the swelling pressure can be defined as the pressure required to keep the volume of a soil at its maximum proctor density constant.

(e) Swelling pressure can be used as a yard-stick for measuring swelling soil. Swelling pressure reflects only the swelling characteristic of the soil and will not be changed by placement conditions or environmental conditions.

8.2 FIELD INVESTIGATIONS OF COHESIVE NON-SWELLING SOILS

Cohesive Non-swelling Soils (CNS) are those that possess cohesion to varying degree but do not exhibit heaving during saturation. The clay minerals normally present in such soils are of non-expanding type including Illite and Kaolinite. Most murums exhibit CNS characteristics. Yet some murums may be of swelling type.Unlike swelling soils, they do not exhibit cracking during summer, nor heaving and stickness during and after heavy rains. Structures constructed on such soils do not exhibit heave though they may sometimes settle.

8.2.1 Field Identification of CNS

Colour - Red, reddish yellow, brown, yellow, white, whitish grey, whitish yellow green and greenish grey.

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Colour - Red, reddish yellow, brown, yellow, white, whitish grey, whitish yellow green and greenish grey.

Land slope	-	Normal land slopes are between 2° and 10°, though on flatter slopes, they are often encountered within 3 m below the overlying expansive soils.
Drainage	-	Generally good.

It is to be kept in mind that although, several soils containing non-expanding type clay mineral may exhibit CNS properties, the CNS suitable for canal side lining should preferably be selected from among those that lie within the following range of properties.

8.2.2 Physical properties of CNS soils

(a) Gradation

Clay (less than 0.002 mm)		15 to 20%
Silt (0.06 mm - 0.002 mm)	-	30 to 40%
Sand (2 mm - 0.06 mm)	-	30 to 40%
Gravel (greater than 2 mm)	-	0 to 10%

(b) Index properties

Liquid limit	-	30 to 55%
Plasticity index	-	15 to 30%

Moreover the CNS material selected should be such that a minimum 10 KN/m^2 cohesion should be assured. Also swelling pressure of 15 KN/m^2 at optimum moisture content may be permitted.

8.3 GUIDE LINES FOR LINING OF CANALS

8.3.1 General

In theory, the swelling potential of an expansive clay can be minimized or completely eliminated by one of the following methods.

(a) Isolate the soil so that there will be no moisture change.

(b) Decrease the density of the soil by compaction control.

(c) Prewetting or flood the in-place soil to achieve swelling prior to construction.

(d) Change the properties of expansive soils by chemical injection.

(e) Replace the swelling soils with non-swelling soils.

Out of the above five methods,the last method as developed by Dr. R.K. Katti Ex. Professor of I.I.T. Bombay has been widely accepted by field engineers all over the country. However, the basic concept of the first four methods and the details of last method are discussed herein.

8.3.2 Provision of Moisture Barrier

Provide moisture barriers or isolate the soil so there will be no moisture change. Theoretically the above said isolation can be achieved by providing L.D.P.E. film behind the canal lining and provide rigid or flexible pavement all around the canal structure so that there is no change of moisture in the soil. This is very expensive and impractical method for a major canal structure.

8.3.3 Decrease the Density of the Soil by Compaction Control

This method may be tried for isolated and light building structures and is not practical for canals etc. as the canals are not always in filling.

8.3.4 Prewetting or Flood the in place soil to achieve Swelling prior to Construction

An old established concept among engineers and contractors as well as laymen in dealing with swelling soils is prewetting. The prewetting theory is based on the assumption that if soil is allowed to swell by wetting prior to the construction and if the high soil moisture content is maintained, the soil volume will remain essentially constant, achieving a no-heave state and therefore structural damage will not occur.

This method again becomes impracticable as the time needed for prewetting will be in the range of 30 to 40 days for each part of the area prewetted and hence may result in an inordinate delay of the project and making it uneconomical and even unfeasible.

8.3.5 Change the Properties of soil by Chemical Injection

To stabilize the subgrade having expansive soils, mainly, the following methods have been used:

(i) Stabilization with the help of chemicals, both organic and inorganic.

(ii) Stabilization with lime.

These are discussed in brief as follows:

(i) Stabilization with Chemicals –

Chemicals, both organic and inorganic can be used to stabilize expansive soils. Cements and flyash have both been used in the laboratory with successful results. It is seen that 2 to 6% of portland cement when added to expansive soils, may result in considerable reduction of volume change characteristics of such soils. Other organic chemicals such as sodium silicate, calcium hydroxide, sodium chloride, calcium chloride and phosphoric acid have been used to stabilize expansive soils. Most of these chemicals are effective under laboratory conditions or where we have to construct isolated small structures like residential buildings or stores or factory sheds of small or medium class, but not in case of canal lining works where the extent of work is large and generally under different conditions of subgrade like canal in cutting or in filling or in combination of both. Chemical stabilization method may not be used in subgrade soil where lining work is envolved because these chemicals may deteriorate the lining materials within the short span of time depending on the reactivity of the chemical with respect to the subgrade or lining material.

(ii) Stabilization with lime -

The use of lime to stabilize subgrade soil has been known to engineers all over the world for a long time. For centuries, the Chinese have used lime as a stabilizing agent in foundation soils. Modern engineering rejected the use of lime in preference to cement because the cementation reaction of lime requires many months and the gain in strength is much smaller than that of cement. Since strength is not the main requirement in our case of canal lining works, lime is favourable agent to reduce the swelling potential of foundation soils as the addition of lime reduces the plasticity of expansive soil.

The chemical reaction occurring between lime and soil is quite complex. The amount of lime required to stabilize the expansive soils ranges from 2 to 8 % by weight. By over excavating the site both in depth (about 1 metre) and area and replacing the soil in compacted layers having adequate treatment, a stable slab can be expected.

In India, the stabilization of expansive soil with lime has been done mainly for road construction and no large scale use of lime for the stabilization of expansive soils has been done on canals and related structures.

Laboratory experiments have been done in Central Road Research Institute, New Delhi for the stabilization of the expansive soil and with these experiments the following conclusions have been drawn :

(i) Pulverization of Black Cotton soil is necessary in achieving full benefit of lime stabilization. With bigger clods, the admixed lime reacts only partly, thus vitiating the economic viability of the technique.

(ii) Period of curing plays a significant role in the development of strength of lime soil mix. Test results have shown that the process of development of strength is quick in the initial stages but slow down thereafter. However, the process of development of strength continues for quite some time. A curing period of 28 days, if permissible from practical consideration, is most conclusive from the view-point of gain in strength.

(iii) Besides these, other parameters like compacted density, type of soil, time gap between mixing and compaction also influence the success of this technique in some measure.

Finally, with the present day limited knowledge of soil stabilization for use in large canal projects, it is recommended that lime stabilization shall be limited to small projects.

8.3.6 Replace the Swelling Soil with Non-swelling Soils

A simple and easy solution for structures founded on expansive soils is to replace the foundation soil with cohesive non-swelling soils (CNS).

The physical properties, field identification etc. has already been detailed earlier in para 8.2 of this chapter.

8.4 OTHER ALTERNATIVES

8.4.1 Replacement of the Expansive Soil with locally available material

In some of the areas, where expansive soils are available predominantly but cohesive non-swelling-soils are not available upto the required amount, murum having very less swelling properties has been utilised in place of CNS soils in some parts of the country e.g. Maharashtra, Madhya Pradesh and Bundelkhand area of U.P. As per available literature (8) attempts have been made in Maharashtra during the period 1981-85 where locally available murum soil has been used in place of CNS soils for the construction of canals in expansive soils. Performance of such canal sections has been reported to be satisfactory. The field engineers have also reported that the period required for saturation and subsequent swelling of the insitu expansive soil is expected to be more than that for which the performance of the above sections is observed. Therefore, it is recommended that observations for a longer duration only will reveal the true performance of canal sections and the efficacy of the method adopted.

The above method of using locally available material has been adopted in the following canal projects of Maharashtra.

1. Kukadi left bank canal
2. Purna main canal
3. Pench left bank canal
4. Jayakwadi L.B. canal

The details of above canal sections are shown in Fig. 1.

8.4.2 Provision of LDPE film with sand cushion and boulder pitching

The expansive soil is, by nature, not very porous. But it cracks when dry and is also susceptible to slip in saturated condition or even by contact with water. Hence maintenance of desired slope is very difficult. Under certain conditions, this soil may also acquire quick sand property. In saturated condition, it yields to application of any kind load from above and the resultant uneven surface produces cracks at random on a hard cover lining.

Hence, the ideal lining material for canals in this type of soil where replacement of expansive soil with CNS is not, any how, possible should be flexible. Problems in expansive soils start, when it comes in contact with water. So lining should also provide a perfect water tight barrier between the embankment and the water prism of the canal.

For several years, LDPE film is being tried as a lining material all over India. As per available literature, the thickness of the LDPE film should be kept at or around 300 microns in the canal passing through the expansive soil. This type of lining has also been tried in similar soils in West Bengal Projects (9) and it is reported that it is functioning efficiently. The possible arrangement for this type of lining is shown in Fig. 2.

8.5 GENERAL GUIDELINES FOR DESIGN OF CNS LINING

8.5.1 To counteract the swelling pressure and prevent deformation of the rigid lining material, a CNS layer of required thickness depending on the swelling pressure of expansive soil is sand-witched between the soil and the rigid lining material. The thickness of CNS shall be measured perpendicular to the surface of expansive soil.

8.5.2 Recommended Thickness of CNS Layer

The amount of heave permitted behind lining depends upon the structural characteristic of the lining in relation to deformations, which would vary from one type of lining to another. Normally, in the case of precast concrete slabs or masonry, not more than 2 cm of heave should be permitted. The recommended thickness of CNS layer conforming to the specifications mentioned in para 8.2 for negligible deformation should be as given in para 5.2 of IS : 9451-1994 and is reproduced below in Table-1(A) & 1(B).

Table-1(A) Thickness of CNS layer, carrying capacity less than 2 cumecs

Discharge in cumecs	Thickness of CNS layer in cm (Min)	
	Swell pressure 50-150 kN/m	Swell pressure more than 150 kN/m
1.4 - 2	60	75
0.7 - 1.4	50	60
0.3 - 0.7	40	50
0.03- 0.3	30	40

Table-1(B) Thickness of CNS layer, carrying capacity of 2 cumecs and more

Swelling pressure of Soil kN/m	Thickness of CNS Materials cm (Min)
50 to 150	75
150 to 300	85
300 to 500	100

Note :

1. However optimum thickness of CNS material has to be worked out for different swelling pressure values determined by actual experiments both in field and laboratory.

2. For swelling pressures below 50 KN/m^2, CNS layer may be omitted.

3. For finding the swelling pressures etc., refer the following IS Codes :

   (a) IS : 2720 (Part XL) 1977, "Determination of free swell Index of Soils".

   (b) IS:2720 (Part XLI) 1977, " Measurement of Swelling Pressures of Soils".

8.5.3 Design of Canal Slopes

(a) Canal slope in filling reach -

Canal side slopes should be designed in accordance with IS:10430-1982. The shear parameters to be adopted in the stability analysis of the expansive soil slopes underlying CNS layer and those of CNS material should be based on tests on -

(i) The representative samples of expansive soil, saturated under no volume condition.

(ii) Saturated samples of CNS material both compacted to densities at which they are going to remain in position after lining.

(b) Canal slope in cutting reach -

Canal slopes in cutting should be over excavated to accommodate the recommended thickness of the C.N.S. layer, with additional thickness of 30 cm to account for dressing. The thickness of CNS should be measured normal to the slope surface, and should conform to the standards as specified in Table-1. The dressing of the canal slopes should just precede the placement of CNS and of the CNS just preceding lining. Until then, the canal earth slopes should be kept around one metre and the CNS at least by 30 cms as shown in Fig.3.

8.5.4 Laying of CNS Soil

(i) The CNS layer should be firmly bonded at the interface of CNS and expansive soil through provisions of serrations in expansive soil base and thorough compaction of interface layers.

(ii) Before placement of CNS material, the surface of excavation or embankment to receive CNS shall be thoroughly wetted to a depth of 6".

(iii) CNS soil should be compacted in suitable layers to the required density at its moisture content or slightly on the drier side of optimum, but not lower than 1 percent.

(iv) CNS layer at the sides should be carried above the full supply level to at least one metre or the recommended free board (whichever is higher) and terminated with a berm formed of CNS soil of not less than 1 metre width and 1 metre thickness above the expansive soil as shown in Fig.4. The outer canal slope length not covered by CNS should be turfed to prevent erosion and sloughing.

8.5.5 Choice of Lining

Any suitable type of lining may be adopted but since both the expansive soil and the CNS layer are relatively impervious, the joints of the precast slab linings should preferably be filled with porous but strong cement mortar to relieve pore pressure that may be built up behind the lining during drawdown. The joints of cast insitu concrete lining may, however, be kept open.

8.5.6 Lining of Small Channels

With reference to the channels designed to carry less than 0.2 cumec flow, if adoption of CNS technology becomes costly, precast semicircular or trapezoidal concrete troughs may be used for lining in which case CNS layer may be omitted.

8.5.7 Under-Drainage Arrangement and Joints

(i) Canals below 0.2 cumec -

In such canals hydrostatic pressure would be low and concrete troughs/other type of linings are capable to withstand some amount of hydrostatic pressure. Moreover drainage arrangement is costly affair and if possible, it may be omitted in such cases.

(ii) Canals between 0.2 cumec and 3.0 cumec -

Where a lined canal crosses area subject to seasonal high groundwater levels, under-drainage arrangement as per clause 6.1 of IS: 4558-1983 may be provided. Where groundwater level is well below canal bed, under drainage arrangement need not be provided. Strong but porous cement mortar joints in block lining and open joints in cast insitu lining will serve the purpose of releasing hydrostatic pressure which may be developed due to seepage of water through lining.

(iii) Canal above 3.0 cumec -

Under-drainage arrangement as per clause 6.1 of IS:4558-1983 shall be provided where lined canal crosses area subject to seasonal high ground water. Where ground water is well below canal bed, and soil has permeability less than 10^{-4} cm/sec under drainage arrangement as per clause 6.1 of IS:4558-1983 may be judiciously provided depending upon permeability and discharge of canal. Typical sections of lined canals in expansive soils are shown in Fig.3.

(iv) The joints shall conform to IS:3873-1978.

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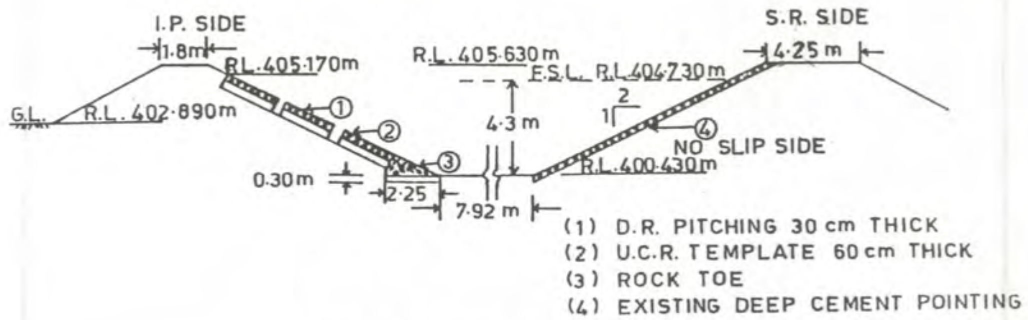
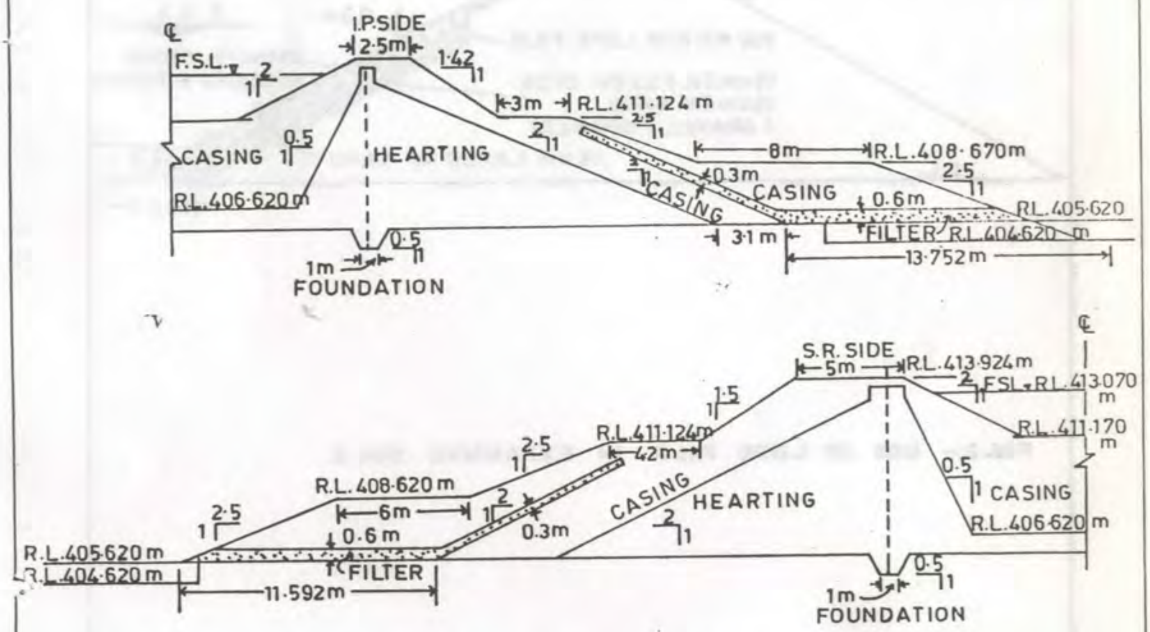


PURNA MAIN CANAL, Km 21



JAYAKWADI L. B. CANAL, CHAINAGE 192–196 Km

FIG.1 :– REPLACEMENT OF THE EXPANSIVE SOIL WITH LOCALLY AVAILABLE MATERIAL IN MAHARASHTRA.

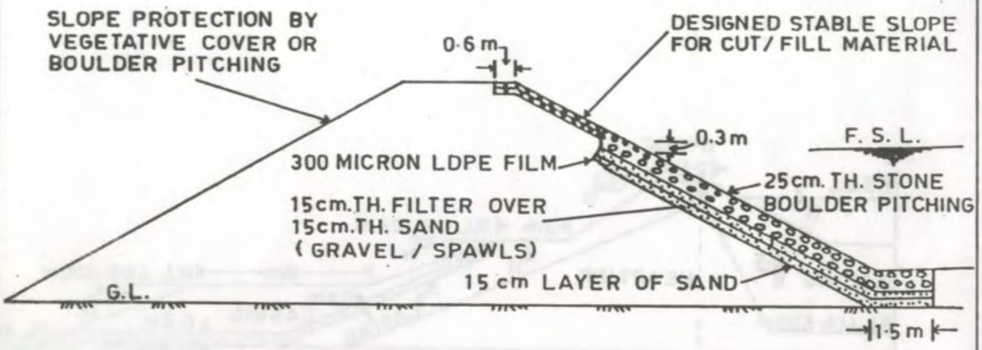
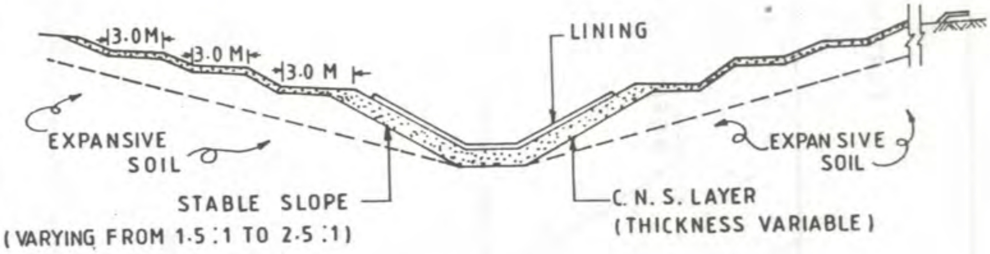
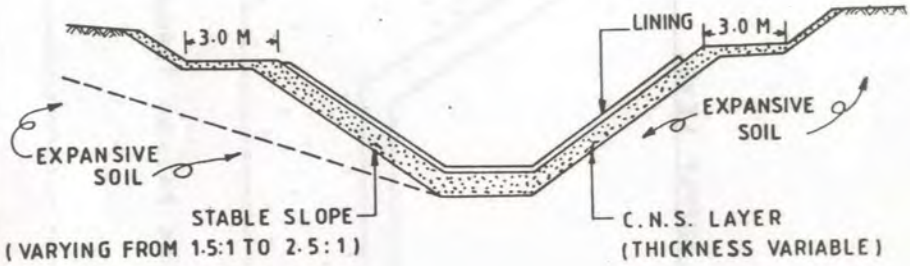


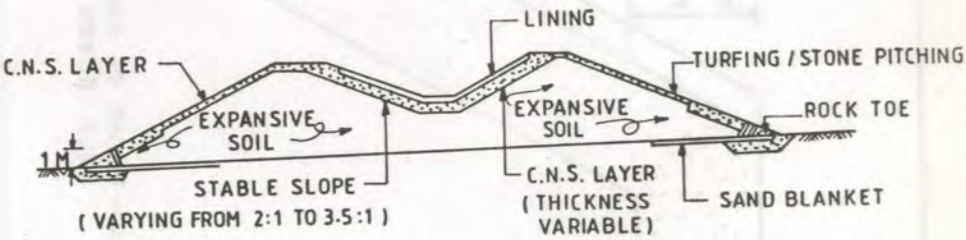
FIG. 2:- USE OF LDPE FILM IN EXPANSIVE SOILS.



TYPICAL SECTION OF CANAL IN DEEP CUTTING



TYPICAL SECTION OF CANAL IN CUTTING



TYPICAL SECTION OF CANAL IN EMBANKMENT

FIG.3:– Typical sections of lined canals in Expansive Soils.

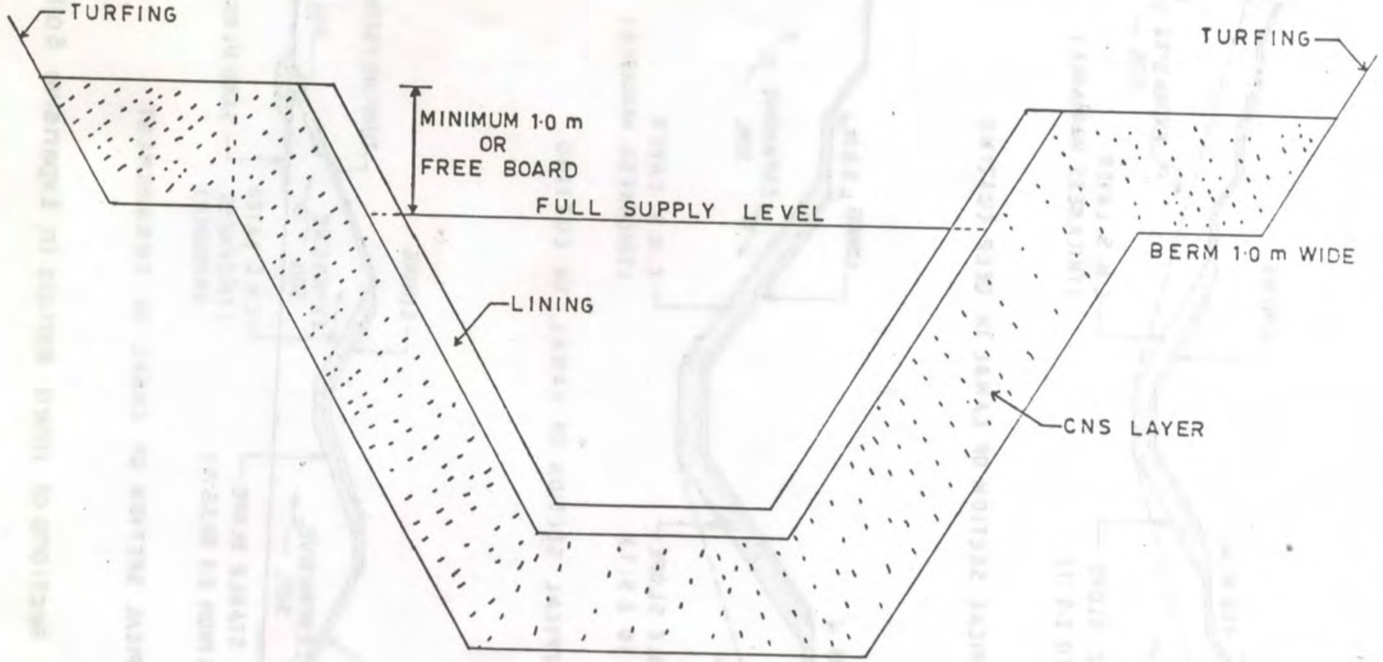


FIG. 4:— LINING OF CANALS IN CUTTING PASSING THROUGH EXPANSIVE SOILS (BLACK SOILS)

9. DRAINAGE AND PRESSURE RELEASE ARRANGEMENT

9.0 INTRODUCTION

Failures of canal lining in most cases occur due to excess hydrostatic pressure behind the lining resulting from either high water-table condition or excess uplift pressure build up due to time lag in drainage of the subgrade following drawdown of the canal. In order, therefore, to improve stability of lining under such conditions, it is essential to eliminate the excess pressure by provision of adequate drainage arrangement.

9.1 VARIOUS CONDITIONS OF WATER-TABLE AND SUBGRADE

The drainage arrangement to be provided would depend upon the site conditions, viz., position of water table and permeability of subgrade. The hydrostatic pressure at the soil and lining interface is the determining factor for the stability of the lining. Even when the pressure build-up behind the lining is controlled through provision of adequate drainage, pressure lag in a poorly draining subgrade may be important from the point of view of the stability of the bank itself. Any inadequacy of drainage at the time of initial design or due to subsequent mal-functioning of drainage will lead to gradual accumulation of water within the contact space of soil and lining and cause failure of the lining. Drainage arrangements have, therefore, to be designed such that excess hydrostatic pressures are eliminated. The necessity for provision of filter behind the lining also stems from the consideration of inhibiting the movement of fine material from the subgrade following drawdown which, if not guarded against, may lead to progressive formation of cavities resulting in subsidence of the lining. The various conditions governing the design of drainage arrangements and pressure release valves for different water table conditions are given in Fig. 1.

Similarly, a broad categorisation based on Cassagrande's classification indicating the range of permeability, the subgrade may be of the following three types as referred in IS code 4558-1983.

a. Free draining : Soil comprising gravel with sand or sandy soil having permeability greater than 10^{-4} cm/sec.

b. Poorly draining : Soil comprising very fine sand, admixtures of sand, silt and clay, clays or soil having permeability between 10^{-4} cm/sec. and 10^{-6} cm/sec.

c. Practically Impervious : Soil comprising of homogeneous clays with permeability less than 10^{-6} cm/sec.

9.2 SELECTION OF DRAINAGE ARRANGEMENT

Drainage arrangement usually provided to reduce longitudinal pressure on lining consists of longitudinal and transverse drains as well as pressure release valves. Recommended provisions of drainage arrangement for various conditions of water-table and type of subgrade are given below.

9.2.1 Water-table below canal bed :

(a) Sub-grade free draining: In this condition there will be no time lag in the dissipation of drawdown pore pressure in the backfill and as such no drainage arrangement will be necessary. Pressure release valves (PRV) may be provided as a precautionary measure.

(b) Sub-grade poorly draining: In this condition because of poor draining subgrade the backfill will get saturated in course of time due to seepage of water through joints and cracks, and if quick drawdown occurs, pressures will buildup behind the lining. This will necessitate a well designed drainage arrangement including a 150 to 200 mm thick layer of well graded filter. Also longitudinal and transverse drains with P.R.V's in bed and pressure relief valves on sides may be provided.

(c) Subgrade practically impervious: A layer of 300 to 500 mm thick of pervious material may be provided as a precaution measure. No drainage arrangement is usually required. However, in case of quick drawdown condition arrangement as in condition (b) above may be required.

9.2.2 Water-table between Canal Bed and Full supply level (F.S.L.) and Sub-grade Either Free Draining, Poor Draining or Practically impervious.

In this case the soil behind the lining will remain submerged upto the level of water-table and in saturation condition above the watertable as in 9.2.1 (a) or 9.2.1 (b). The lining will therefore, be subjected to hydrostatic pressure. Wall-designed drainage arrangements will therefore be necessary including a 200 mm to 300 mm thick layer of well graded filter. However, if subgrade in practically impervious it should be removed to a depth of 600 mm and replaced by sand, murram on suitable pervious material.

9.2.3 Water table above canal F.S.L. and subgrade either Free draining, Poor draining or Practically Impervious.

In this case pressure on canal lining will be larger, therefore, elaborate drainage arrangements consisting of drains and PRV's will be required including a 300 to 450 mm thick layer of well designed filter. However, in case of practically impervious subgrade, the same should be removed to a depth of 600 mm and replaced by sand, murram or suitable pervious material.

9.3 LONGITUDINAL AND TRANSVERSE DRAINS

9.3.1 Longitudinal Drains

- The section of drain should be trapezoidal with bottom width 500 mm, depth 525 mm and sides as nearly vertical as practicable. The drain should be carefully filled up to the bottom of the lining with graded filter as shown in Fig-2 and properly compacted so as to form an even bedding for lining. Care should be taken that the filter does not get clogged during lining. The drainage pipe may be of asbestos cement or PVC. It should be perforated. Usually 150 mm diameter pipes are used. The perforations/holes should be 12 mm in diameter and should be done by drilling. On an average there should be a minimum of 100 perforations/holes per metre length of pipe and perforations/holes in adjacent rows should be staggered.

The number of longitudinal drains should depend on the bed width of canal. In the bed of canal, in general, one drain for every 10 metre width should be provided. Minimum one drain and for bed width of 10 m or more minimum two drains should be provided. The drains should be placed symmetrically with reference to the centre line of canal.

The longitudinal drains consisting of open jointed pipes encased in graded filter, should have outlets in a trench as shown in fig.2(b).

9.3.2 **Transverse Drains**

Transverse drains, where necessary should be provided in the bed and on the side slopes upto free board level. Section of transverse drains and other details should be same as that of longitudinal drains shown in Fig.-2.

Spacing of transverse drains should depend on the size, location and efficiency of pressure relief valves. Generally transverse drains should be provided at 10 metre interval.

9.3.3 **Pressure Relief Valves (PRV)**

Pressure release valve which open into the canal are provided to relieve excessive hydrostatic pressure behind lining. The valves should be provided in pockets of suitable sizes & shape and filled with graded filter underneath the lining. The PRV's can be classified according to their material of construction e.g. metallic and non-metallic. These can further be termed according to their mode of placement such as vertical, horizontal etc. Still further they are classified according to their closing member such as flap type and ball type. At present usually non-metallic valves are used as they have clear advantages over the metallic PRV's used earlier.

Field Engineers and experts both have different opinion about the performance of ball type and flap type valves. Hence it is suggested that final selection of the PRV's to be used should be done after reviewing the performance of different types of PRV's which are already installed on different canal projects of the country. These may be got tested before their actual use from some Research/testing laboratory. Such a testing facility is available at U.P. Irrigation Research Institute, Roorkee. For further details reference may be made in the concerned papers of the publication Proceedings of Seminar on canal lining, held at Roorkee on Nov. 1-2, 1988 at Irrigation Design Organization, Roorkee. (Ref. 6)

Generally, horizontal and vertical pressure release valves are installed and 75 mm diameter valves are normally used on the side slopes and 150 mm diameter valves are used in the bed. The details of the valves generally used are shown in fig. 3 to 5.

9.3.4 Pressure relief valves should be provided on the longitudinal/transverse drains if these are provided as shown in Fig.-6. If there are no transverse drains, the PRV may be provided in pockets filled with graded filter underneath the lining. Pockets may be 600 mm squares or cylindrical with diameter 600 mm.

Pockets on slopes should be excavated with their sides at right angles to the slope. The PVC perforated housing pipe for the PRV should be 750 mm long for sides and 430 mm long for bed and should conform to class - 2 of IS 4985-1988. It should be placed in the centre of the pocket. Graded filter as shown in Fig.-7 should then be carefully placed in the pocket and compacted to form an even bedding for canal lining. Perforations in the housing pipe should be as shown in Fig.-8.

On the sides, in general, one row at every 4 metre spacing should be provided. The first row should be provided about 50 cm above bottom and top row at 50 cm to 100 cm below full supply level. If the water depth is less than 1.5 m, one row should be adequate. Valves in adjacent rows should be staggered.

The spacing of PRV should be decided as per the site conditions. However, one pressure relief valve for every 100 square metres area may be provided in the canal bed and for every 40 square metres of area on the sides.

9.4 MODEL STUDIES

Experiments were conducted on three-dimensional electrical analogy model to determine the residual pressures on the lining for various spacings of drains and pressure release valves for the following boundary conditions. For model studies the section of the canal with bed width as 90 m and water depth 4.5 m was investigated as shown in Fig.-9.

9.4.1 Water-table above Canal F.S.L.

The water level outside the canal banks was assumed 1 m above the canal F.S.L. The uplift pressure were determined with and without longitudinal drains in the bed and pressure release valves or drains behind the lining on the sides. The spacing of drains behind the lining on the sides was kept 5, 10 and 15 m c/c. Two staggered rows of pressure release valves at a spacing of 5, 10 and 15 m were also tried instead of drains behind the lining on the sides. The rows of pressure release valves were kept 1m above the bed and 1m below the canal full supply level. The safe differential pressures were evaluated on the basis of observed pressures for (i) 14 cm thick double tile lining both in the bed and sides and 14cm thick double tile being on the sides and 7cm thick single tile lining in the bed. The safe pressures have been plotted in Fig.-10. A perusal of the figure indicates that safe differential heads between the canal water level and the water-table are 87 cm and 66 cm respectively for double tile and single tile lining in the bed for three longitudinal drains in the bed and drains at a spacing of 5 m on the sides. Similarly safe differential pressures with no longitudinal drains in the bed, and drains behind the lining on the sides at a spacing of 15 m c/c are 40 cm and 17 cm respectively for double and single tile lining in the bed respectively.

9.4.2 Water-table above Canal bed

The water-table was assumed to be 1 m above the canal bed and the canal was assumed drained at the bed level. The water-table was represented in the model at a distance of 8m from the toe of embankment assuming a gradient of 1:8. The uplift pressures behind the lining in the bed were determined for canal bed widths of 50 m and 90 m with various spacings of drains. The safe differential pressures were then evaluated for single and double tile lining in the bed and plotted in Fig.-11. A perusal of the figure indicates that safe differential pressures for 14 cm thick lining are 125 cm and 35 .cm with longitudinal drains spaced at 5 and 20 m respectively.

9.4.3 Sudden Drawdown

The saturation line inside the banks for steady seepage from the canal was first determined. The pressures behind the lining were then determined for sudden lowering of the canal F.S.L. by 1 m and seepage taking place from the banks into the canal through drainage system. The pressures were determined for the following combinations of drainage arrangements in the bed and sides:

i. No longitudinal drains in bed; drains or pressure release valves @ 5, 10 and 15 m c/c in sides.

ii. Two longitudinal drains in bed; drains or pressure release valves @ 5, 10 and 15 m c/c in sides.

iii. Three longitudinal drains in bed; and drains or pressure release valves @ 5, 10 and 15 m c/c in sides.

The safe differential head or the extent of sudden drawdown inside the canal was evaluated for single and double tile lining in the bed and thick double tile being on the sides and 7cm thick single tile lining in the bed. The safe pressures have been plotted in Fig.-10. A perusal of the figure indicates that safe differential heads between the canal water level and the water-table are 87 cm and 66 cm respectively for double tile and single tile lining in the bed for three longitudinal drains in the bed and drains at a spacing of 5 m on the sides. Similarly safe differential pressures with no longitudinal drains in the bed, and drains behind the lining on the sides at a spacing of 15 m c/c are 40 cm and 17 cm respectively for double and single tile lining in the bed respectively.

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i. No longitudinal drains in bed; drains or pressure release valves @ 5, 10 and 15 m c/c in sides.

ii. Two longitudinal drains in bed; drains or pressure release valves @ 5, 10 and 15 m c/c in sides.

iii. Three longitudinal drains in bed; and drains or pressure release valves @ 5, 10 and 15 m c/c in sides.

The safe differential head or the extent of sudden drawdown inside the canal was evaluated for single and double tile lining in the bed and plotted in Fig.-12. A perusal of the figure indicates that safe drawdown for two or three longitudinal drains in the bed, and drain spacing on the sides varying between 5 and 15 m as detailed, ranges between 22 and 18 cm. When longitudinal drains are provided in the bed in combination with cross drains or pressure release valves on the sides, the observed pressures behind the lining on the sides are much higher than those below the lining on the bed. Greater thickness would, therefore, be required on the sides.

9.4.4 A perusal of Fig.-12 indicates that pressure release valves behind the lining on the sides hardly effect any release of pressures. With two longitudinal drains provided in the bed, the observed maximum pressures behind the lining on the sides for sudden drawdown condition are 83.3 percent, 78.0 percent and 74.0 percent of differential head with pressure release valves provided at 15, 10, 5 m c/c respectively against 85.9 percent without pressure release valves. The evaluated safe differential head for double tile lining on the sides works out to 17, 18 and 19 cm with pressure release valves @ 15, 10 and 5 m c/c respectively against a safe differential head of 16 cm without pressure release valves. It is therefore, obvious that pressure release valves do not provide appreciable relief to the lining against pressures due to sudden drawdown or high spring level.

9.5 EXPERIMENTS IN SEMI-FIELD CONDITIONS

Experiments to determine hydrostatic pressures for single and double tile lining with different drawdown rates in semi-field conditions were conducted by Dr. G.S. Dhillon et al, Director, Irrigation and Power Research Institute, Amritsar, Punjab regarding the structural stability of the canal linings. The detail of study of the experiments are furnished below. (Ref.-1)

9.5.1 Experimental Channel

An experimental channel 30 metre long, 3.40 metre wide having depth of 90 cm was constructed at Irrigation and Power Research Institute, Amritsar, Punjab, to study the development of pressure behind canal linings. The tests have been carried out on single tile and double tile linings and the maximum hydrostatic pressure which these linings can with stand have been found out. In this channel single tile lining was laid in 20 metres long reach where as the length of double tile lining was 10 metres only. The specifications of the linings laid are given below.

Single tile lining : The lining consists of a single layer brick tile. The joints filled with mortar of 1:5 (Cement:Sand). A 20 mm thick, 1:3 cement sand plaster laid on brick masonry and given a smooth finish.

Double tile lining : The lining consists of a double layer of bricks with 15 mm thick sandwich layer of cement mortar of 1:3. The first layer of tiles was laid on the subgrade and joints filled with 1:5 cement mortar. The first layer of tiles was covered with 1:3 cement plaster not less than 15 mm thick. The top layer of brick was laid with 1:3 cement mortar.

In order to develop hydrostatic pressure, a sandy backfill was provided behind the lining. For this purpose, an impervious barrier was created by spreading polythene film, 100 micro metre thick on the subgrade. A 60 cm thick coarse sand having permeability 3.3×10^{-2} cm/sec was laid on the polythene film. Longitudinal drains 20 cm x 20 cm with graded filter were provided at the junction of the bed and side. Transverse drains 20 cm x 20 cm were also provided 5 metres apart. Provision was made to provide pressure release valves both at bed and sides, in pockets 45 cm x 45 cm x 45 cm filled with graded filter 5 metres apart. Piezometers pipes were installed at the side slope and along the central line of the bed of the channel one metre apart as shown in Fig.-13. Manometers were connected to the piezometric pipes in order to observe the pressure behind lining.

9.5.2 Experimental Work

9.5.2.1 Single tile lining

Water was filled in the channel upto F.S.L. The backfill was saturated by feeding clean water to the sandy layer below the canal lining. The various piezometers fixed at the bed and sides of the channels were connected with the manometers in order to know the hydraulic pressure acting at different points of the lining. Two double flap type pressure release valves of 5 cm diameter were installed at the bed 10 metres apart where as only one elliptical shaped valve was installed at the sides of the channel. Two conditions of hydrostatic pressure development were studied as described below.

In the first case water level was not maintained in the backfill and allowed to fall alongwith the drawdown in the channel. Three different rates of drawdown of 15 cm/hr, 22.5 cm/hr and 30 cm/hr were applied. As the drawdown was started the pressure release valves started working and the water level in the backfill was lowered alongwith level in the channel.

But due to insufficient capacity of the valves installed differential pressures were created both at the bed and the sides which increased gradually with the drawdown. In the second case the water level was maintained in the backfill during the drawdown condition which represented the field condition of the channel passing through highly water logged areas. Studies were made at the three different rates of drawdown of 15.0 cm/hr, 22.5 cm/hr and 30.0 cm/hr as in the first case.

Differential pressures at the bed and sides of Single Tile Lining :-

High hydrostatic pressures were created on the lining when the water level was maintained in the backfill specially at 30 cm drawdown rate. Water started oozing out of the lining as the differential head reached 15 cm and cracks also started developing in the lining.

9.5.2.2 Double tile lining

In order to study the effect of hydrostatic pressure on double tile lining, the reach having single tile lining was also convented into double tile lining. The same procedure as mentioned in case of single tile lining, was adopted for testing the double tile lining. Observations were taken for drawdown rates of 30.0 cm/hr and 45.0 cm/hr and differential pressures created at the bed and sides of double tile lining were observed.

The displacement of the double tile lining was observed as in case of single tile lining. High uplift pressure was created on the lining at both the drawdown rate. Water started oozing out and numerous cracks developed in the lining at a hydrostatic pressure of 24 cm.

9.5.3 Conclusions of Semi-Field Studies

Authors of the semi field studies have reported that the series of tests carried out show that damages occur in the lining when the pressure release measures are inadequate. The single tile lining can withstand differential hydraulic pressure upto 15.0 cm whereas double tile lining can withstand differential pressures upto 24.0 cm. These damaging pressures can be avoided by controlling the drawdown rate in the channel. In the case of single tile lining, drawdown rates below 30 cm/hr are safe whereas in the case of doubles tile linings the drawdown rate should be kept preferably below 45 cm/hr.

9.5.4 Discussions of results of Model studies and Semi-Field Studies

Theoretically model studies as well as studies conducted in semi-field conditions indicate only the extent of relief provided by drainage assuming it to be functioning continuously without deterioration. Both of these studies were conducted assuming steady state conditions to be prevailing throughout during the experimental work. But in actual practice such ideal conditions don exist. The development and variation of hydrostatic pressure in real life situation will be governed by dissipation of hydrostatic pressure with respect to time and other conditions of subgrade material and prevailing flow conditions in the canal operation.

The stability of lining, therefore, generally depends upon the long-term performance of the drainage system. The more is the stability of lining dependent on drainage, the more it is likely to suffer damage depending on the extent of deterioration of drainage arrangement with time. The provision of drainage, therefore, should be restricted to situations where it is essential, and where provided, rigorous control should be exercised on laying of the filter.

If the lining is likely to be subjected to differential pressure due to very high spring level or large operational variations as may be the case in power channels, the most effective measures to eliminate excess pressures on the lining is to provide continuous filter with adequate outlets to release seepage water as provided in Sundernagar Hydel Channel. Pressure release valves may, however, be useful in case of slow operational variations, as also serve to release excessive pressure built up through seams of pervious material present in the subgrade bank material.

Further more, the moving part of pressure release valves may get damaged or get rusted in course of time so each one of them must be inspected and repaired at least once a year. If canals cannot be emptied for frequent inspection, the lining should be made safe without drainage or otherwise the drainage system may be found inoperative when it is most needed.

9.6 PROVISIONS OF DWARF REGULATORS

9.6.1 Dwarf regulators are regulators of part height constructed across lined canals at suitable intervals for ponding up water to counteract exess uplift pressure below the lining. These are provided in situations where the water table remains continuously high and the conventional pressure release arrangements are not likely to prove adequate. The height and spacing of the dwarf regulators will depend on the minimum depth of water required to be maintained inside the canal for counter-balancing residual pressures on the slope of the canal. The regulators also help in maintaining minimum water depth inside the canal even when canal is operated at part capacity with lower normal depths. Their disadvantage is that the canal made stable with dwarf regulators can not be emptied for repairs till the water-table goes down the bed level. These may also cause additional head loss and silt deposition in the canal.

9.6.2 Main Western Gandak Canal is designed for head discharge of 442 m^3/sec. The canal is lined with double brick tile lining on the sides and single brick tile lining in the bed. The spring level upto km 88 of the canal is upto 4 m above the bed of the canal. Dwarf regulators have been provided at a spacing of about 3 km in reaches where spring level is above canal bed to keep the canal bed loaded with water at least upto subsoil water level. In addition drainage arrangement has been provided to release uplift pressure behind the lining for operational variations.

9.7 DRAINAGE MEASURES ADOPTED IN SOME MAJOR CANALS

9.7.1 Drainage Measures provided in Sarda Sahayak Feeder Channel

Sarda Sahayak Feeder Channel, 250 km in length with a head discharge of 650 m^3/sec was constructed to provide irrigation to about 18 lakh hectares annually in the area commanded by lower reaches of Sarda Canal System in Ganga-Ghagra Doab. The feeder channel is a twin Channel between km 26.3 and km. 104.15 and a single channel in the remaining reaches. The area traversed by the channel mostly comprised medium sand in the head reaches upto 10 km and medium to fine sand in the lower reaches. Due to high estimated seepage losses the channel was proposed to be lined from km 7.06 to km. 98.73 (Ref. 7).

The initial seven kilometers of the channel are not proposed to be lined in view of high spring level condition which persists throughout the year. During rainy season the spring level is even higher than the canal F.S.L. (Fig. 14). The provision of lining in this reach would have necessitated extensive drainage provisions to lower the uplift pressures to values which could be withstood by proposed single or double tile lining. The overall proposal was likely to be prohibitive in cost besides the uncertainty associated with proper long-term functioning of the drainage system and maintenance of pressure release valves.

In the reaches proposed to be lined and where May spring level remains about 0.5 metre above bed, the uplift behind the lining during closure is proposed to be counter-balanced by ponding up water in the channel with the help of 0.5 metre high humps in the canal bed at every kilometer (Fig. 15). The drainage system consisting of longitudinal drain in the bed and pressure release valves on the sides have been proposed to release pressures due to minor operational variations.

9.7.2 Drainage arragements provided in Khara Power Channel, U.P.

Khara Power Channel is 13 km. long. The power house at Khara utilises a drop of 44 metres to generate 72 MW of power. In the head reach upto km 5.5, H.F.L. of river Yamuna is above channel bed. In the head reach, the water table is upto 3 metres above the canal bed. Beyond km. 5.5, H.F.L. of river Yamuna is below channel bed. The maximum filling in the power channel is of the order of 28 metre at km. 12.35 and the maximum cutting is also of the order of 28 metres at km 10.8.

The index map showing the power channel is shown in Fig. 16.

On sides, lining with double layer compressed c.c. tile 300 x 300 x 40 mm with 15 mm sandwiched plaster has been provided in Khara Power Channel.

In bed 120 mm thick M_{15} concrete lining has been provided. In bed no filter has been provided. However, 75 mm thick porous concrete has been provided below concrete lining in bed where the subgrade is non free draining.

Where the subgrade material is free draining, two nos. of pressure relief valves in filter pockets have been provided on side slope at 5 m c/c in longitudinal direction. Details of filter pockets is shown in Fig. 17.

Where the subgrade material is non free draining 1 m x i m filter pockets with open jointed boulder set encased in G.I. wire have been provided at 5 m c/c in longitudinal drains and on side slopes to replace the Conventional Pressure relief valves. The details are shown in Fig. 18.

Annexure-1 shows the different type of lining provided in Khara power channel for various conditions.

Typical sections of the lining with free draining and non free draining subgrade are shown in Fig no. 19 and 20 respectively.

9.7.3 Drainage Measures adopted in Garhwal-Rishikesh-Chilla Power Channel, U.P.

Garhwal-Rishikesh-Chilla Power Channel with a discharge capacity of 565 cumecs and water depth of 8.6 metres was constructed to generate 144 MW of power. The power Channel is aligned along the foot of the hills in its entire length. On the right it is quite close to river Ganga and on its left it is along hill region. Thus the left bank is mostly in cutting and the right bank mostly in heavy filling. The right bank of the channel is an earthen embankment of the height of a medium dam with a maximum filling of 33 metres. Depending on the subgrade and the available construction material, following types of lining have been provided in the power channel :

i. Boulder Pitching

ii. In-situ Concrete Lining

iii. Cement Concrete Tile Lining

The drainage and pressure release arrangements shown in Fig 21 and 22 and are described briefly as below :

1. In the reaches where the water table was above the bed of the channel and in cutting reaches, the provisions were as below :

    (a) In the bed 3 Nos. longitudinal drains, one in centre and one each at sides, with 300 mm diameter stoneware or concrete perforated pipe with open joints were provided. The 75 mm dia pressure release valves were provided over these longitudinal drains and cross drains @ 10 m c/c, duly staggered.

    (b) On side slopes continuous filter comprising of bottom layer 150 mm thick of material size 1 to 50 mm and top layer 225 - 300 mm thick of material size 37 to 100 mm was provided. Two rows of 75 mm diameter PRV's duly staggered @ 5 m c/c were provided.

2. In filling reaches where water table is below the bed of canal the provision was as below :

(a) In the bed 2 longitudinal drains one on each side with 300 mm diameter stoneware or perforated concrete pipe with open joints, were provided. The 75 mm diameter pressure release valves were provided @ 10 m c/c duly staggered over these longitudinal drains and cross drains.

(b) On side slopes continuous filter in 3 layers connecting the bottom most line of pressure release valves and longitudinal drains in bed was provided. The filter compressed of 150 mm thick bottom layer of coarse sand, intermediate layer 150 mm thick coarse material of size 1 to 50 mm and top layer of gravel fill 37 to 100 mm. Three rows of 50 mm dia pressure release valves were provided duly staggered.

9.7.4 Drainage Arrangements Provided in Parallel Upper Ganga Canal, U.P.

The Parallel Upper Ganga Canal with a discharging capacity of 370 m^3/sec and varying water depth and ground water table with respect to canal bed level would replace the existing Upper Ganga Canal.

Keeping in view the above parameters, on the basis of earlier field experience and three dimensional electrical analogy model studies, the following types of lining and drainage arrangements have been provided in different reaches of this lined canal.

Lining :

1. In bed 100mm to 150mm thick M-15 concrete lining or single tile lining has been provided. On experimental basis LDPE film has also been used in some reaches.

2. On slopes double tile lining with a tile size of 300x150x50 mm.

Drainage arrangements :

While on slopes it consisted of continuous filter, porous concrete, pressure relief valves and pressure outlet in the form of open windows filled with stone. In the bed the drainage arrangements consists of continuous filter, longitudinal and transverse drains, pressure relief valves and 1.0m high humps at locations where the minimum ground water table lies above the bed through out the year.

Under drainage arrangements provided from km 12.5 to 15.5 have been detailed below while annexure 2 gives the details of these arrangements at some of the other chainages.

On slopes :

1. 100mm thick course sand filter of D_{15} 40.3 mm with F.M. 1.5 or above.
2. 100 mm thick graded shingle filter of size 4.75 mm to 20 mm.
3. Two rows of 75 mm pressure relief valves @ 10 metres c/c staggered.

In bed :

1. 100 mm thick course sand filter of D_{15} 40.3 mm with F.M. 1.5 or above.
2. 100 mm thick graded shingle filter of size 4.75 mm to 20 mm.
3. 150 mm dia stoneware or A.C. perforated pipe longitudinal drains at the junction of side slopes and bed and one along the centre line of the canal.
4. 150 mm dia stoneware or A.C. perforated pipe transverse drains @ 10m c/c.
5. 75 mm dia plastic pressure relief valves @ 10m c/c on junction of transverse and longitudinal drains at both end drains and also at centre of the canal.

The details shown in Fig. 23 (a, b, c, d).

9.7.5 Drainage measures adopted in Narmada Main Canal, Gujarat

Narmada Main Canal of length 460 km and with discharging capacity of 1133 cumecs is under construction. On completion it will irrigate 17.92 lakh hectares. It is a fully lined canal with base width of 75.6 m and water depth of 7.6 m at head where it takes from right bank of prestigious Sardar Sarovar Dam in the state of Gujarat.

In its length, it passes through different types of subgrades. At many places it is entirely in filling or cutting or in partial cutting or filling and as such the drainage arrangements provided differ from section to section.

The type of lining and drainage arrangements as provided between km 16.842 to 21.315 are briefly described below and shown in Fig. 24 (a, b).

In bed :

1. 100 mm thick M-15 CC lining has been provided.

2. Two numbers 150mm dia pressure relief valve one on each end and staggered @ 16 metres C/C in plan have been provided.

On slopes :

1. 125mm thick M-15 in-situ CC lining has been provided.

2. Two numbers of 50mm diameter staggered in plan pressure relief valves @ 16 m c/c have been provided. The lower row of PRV has been provided 1.70 metre above the canal bed while the upper row is 5.275 metres above the canal bed.

9.7.6 Drainage measures adopted in Eastern Ganga Canal, U.P.

Eastern Ganga Canal with a design discharge of 137.3 m^3/sec and having bed width 12.0 m offtakes from left bank of river Ganga at Hardwar. The normal water depth in this canal is 4.50 m. This canal runs in monsoon season only. It is lined upto km 35.5 and passes in cutting and filling reaches where the subgrade also changes.

Depending on the subgrade the following type of lining and drainage arrangement has been provided. These are further detailed in Annexure-III.

Typical Section type - I

In bed :

1. 100 mm thick CC of M-15 grade.
2. Longitudinal drains two numbers at ends and one at centra with 75 mm ϕ PRV.

On slopes :

1. 100 mm thick Double CC tile lining of size (300x300x40) M-15 grade.

2. One row of 75 mm ϕ PRV at 2500 mm below FSL

Typical Section type - II

In bed :

1. 100 mm thick CC of M-15 grade.

2. Two longitudinal drains numbers at ends.

On slopes :

1. 130 mm thick Double clay tile lining of size (300x150x50).

2. Porous concrete (1:0:4) windows @ 2.5 metres C/C.

9.8 PROVISION FOR STRUCTURAL STABILITY OF EMBANKMENTS OF PARALLEL CANALS

With a view to modernise the existing canal or to increase the availability of water for irrigation or other purposes, it is now-a-days practice to construct a new canal generally parallel to the existing canal either as a risk aversion work or increasing the capacity of water transport system. Also, the existing cross drainage or regulating structures on the canal may have become so old, that their continuous use may be unsafe. The construction of parallel canal to the existing one under modernisation program has following likely reasons.

1. No closure of canal is required when modernisation of canal is done by constructing a new parallel canal. In this way, agricultural production of the command area of the canal would not suffer due to lack of irrigation water.

2. Even if the existing canal is remodelled for increasing its discharge capacity or improving its conveyance efficiency by closing it intermittently or otherwise for different construction activities needed, then this proposal becomes time consuming and uneconomical comparative to the construction of a new parallel canal.

While on one side we economise our construction project, on the otherside, we have to face the problem of increased pore pressure development in the common bank of the twin canals. This increase is for all conditions of the running of the canals/canal and creates stability problem of the common bank and hence the unstability of both the canals. In such cases, in the old canal which, in general, is found to be unlined or even if lined, proper provision for releasing hydrostatic pressures behind lining might not have been made, which may suffer more because of ignorance of unwanted forces at the time of its initial design. In old days, engineers depended on constructing the bank of clay for checking seepage but now-a-days this practice is generally discouraged because provision of clay layers behind lining pose serious problems of differential pressures as the same could not be released without provision of continuous filters.

In such cases the operational conditions and engineering properties of the subgrade material of the two canals may be studied in detail, model studies by electrical analogy method done. Suitable treatment for the common bank and drainage arrangements behind the lining of the new canal may be designed accordingly. Also for such cases for reducing the extra pore pressures due to operation of either or both the canals following methods may be tried.

(i) Canal in filling

When the canal is in filling, the following methods may be tried.

Method-1 : A suitable filter layer may be tried below the new canal. This filter shall not allow to develop unnecessary high pore pressures in the common bank. It shall also reduce the normal pore pressures which would have developed in the far end bank of the new canal, as this filter will work as a source of pressure release path for both the effected banks in all cases of operation of the twin canals. This method shall work when the new canal is in embankment only. This method of stabilizing the common bank of parrallel canals has been adopted in Parallel Upper Ganga Canal project, under construction in Uttar Pradesh and is shown in Fig.-25(a).

Method-2 : Instead of providing a filter as in method-1, a provision of a trench filled-up with filter material having an open jointed A.C. or P.V.C. pipe may be made in the centre. This open jointed pipe shall work as pore pressure reducer and seepage collector. The size and location of the trench, which depends on the permeability of the subgrade, may best be decided by electrical analogy model studies. This seepage may be discharged into the side drains at suitable locations of the new canal with the help of cross drains or the outlet may be provided in some local drain, crossing the canal system. The arrangement is shown in Fig.-25(b).

Method-3 : If the new canal is in embankment then provide number of filters as shown in Fig.-25(c) for the release of pore pressures. Depending on the height of fill, these filters may be provided at different locations on the common bank and at the far end bank of the new canal.

(ii) Canal in Cutting

When the new canal is in excavation & even if the spring levels are high, the methods suggested above may not be practically possible to construct. In such cases extra provisions of filter behind the lining, pressure release valves or provision of dwarf regulators are suggested. This type of regulator has been provided in PUGC under construction.

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DETAILS OF LINING IN KHARA POWER CHANNEL, U.P.

Sl. No.	Type of Sub-grade	Filling/ Cutting	HFL of Yamuna	Spring level	Filter thickness		Porous Concrete thickness		Lining thickness		Pressure Release arrangement	
					Bed mm	Sides mm	Bed mm	Sides mm	Bed mm	Sides mm	Bed	Sides
1.	Free draining	Cutting	Above FSL	Above bed	-	150 75	-	75	120 M-15	Double tile	3 rows of PRV	2 rows of PRV
2.	-do-	Filling	No effect on spring	Below bed	-	-	-	75	-do-	-do-	-do-	-do-
3.	-do-	Cutting	Above bed	-do-	-	150 75	-	75	-do-	-do-	-do-	-do-
4.	Non-free draining	-do-	Below bed	-do-	-	150 75	75	75	-do-	-do-	3 rows of boulder set pockets	2 rows of boulder set pockets
5.	-do-	Filling	-do-	-do-	-	150	75	75	-do-	-do-	3 rows of PRV	2 rows of PRV
IMPERVIOUS APRON ON DRAINAGE CROSSINGS												
1.	Free draining	Filling	-	-	-	-	100 M-8	100 M-8	300 M-15	300 M-15	2 rows of PRV at the end of apron	-
2.	Non-free draining	-do-	-	-	-	-	100 M-8	100 M-8	300 M-15 RCC	300 M-15 RCC	-do-	-
CONCRETE LINING U/S & D/S MASONRY WORKS												
1.	Free draining Filling	-	-	-	-	75 75 150	75 porous	75 porous	120 M-15	225 M-15	3 rows of PRV	2 rows of PRV
2.	Non-free draining	-	-	-	-	-do-	75 porous on 75 M-8	75	-do-	-do-	-do-	-do-

Annexure-2

DRAINAGE ARRANGEMENT IN PARALLEL UPPER GANGA CANAL, U.P.

Name of Channel	Position of W.T.	Type of soil	Permeability (K)	Filter below lining		Details of drain				Spacing of drains		PRV details			Type of lining
				Slope	Bed	Course Sand	Graded gravel	Graded gravel	Perforated Pipe	L-drained	T-drains	Dia mm	Spacing at slope	Spacing at bed	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. PUGC (Km 6.0-10.0)	Below bed	SP & SM	Poorly draining soil 10^{-4} to 10^{-6}	(i)75mm coarse sand of FM 1.5 (ii)75mm local sand of FM 0.8	75mm local sand of FM 0.8	75mm FM≥1.5	100mm 5-20mm	20-40 mm	150mm	On ends and in centre	@10mm	75mm	10m c/c Ist row 1.5m below FSL IInd row 3.0m below FSL	@10m c/c staggered	Bed: 100mm thick cast-in situ A-20, M-15 concrete Sides: Double layer of precast c/c A-20, M-15 200micron LDPE film is provided in bed and sides.
2. PUGC (Km 16.0-19.2)	Above bed 3.0m from FSL	Stratified formation of SP/SM (sand or silty) and silty clay CL/CI		(i)75mm graded shingle 4.75 to 20.0mm (ii)75mm thick coarse sand D_{15} 0,3mm (FM ≥1.5mm)	100mm thick sand of FM≥1.5 D_{15}< 0.3 mm	75mm FM≥1.5	75mm 4.75-20mm	20-40 mm	150mm	On ends and in centre	@10mm	75mm on sides & 100 mm in bed	10m c/c 2 nos. along the slope Ist row 1.34m below FSL & IInd row 2.68m below FSL	10m c/c in 3 rows	Bed: 100mm thick M-15 concrete Sides: Double clay tile (300x150x50) lining.
3. PUGC (Km 3.65-24.55)	Above bed 2.29m from FSL			(i)75mm coarse sand of FM≥1.5 (ii)75mm fine local sand of FM≥0.8	(i)75mm coarse sand of FM≥1.5 (ii)75mm fine local sand of FM≥0.8	75mm FM≥1.5	150mm 5-20mm	20-40 mm	150mm	On ends and in centre	@10mm	75mm	10m c/c Ist row 1.5m below FSL IInd row 3.0m below FSL	10m c/c staggered on ends drain & in centre drain	Bed: Single tile (300x150x50) lining over 10mm thick 1:3 C/M & 20mm thick 1:5 C/M. Sides: Double clay tile (300x150x50) lining over 10mm thick 1:5 C/M.

contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
4. PUGC (Km 25.36-25.54)	Above 3.0 m From FSL	Clay Soil		-	(i)75mm coarse sand of FM≥1.5 (ii)75mm fine sand of FM≥0.8 (iii)15mm graded shingle upto 20mm size	75mm FM≥1.5	150mm 5-20mm	20-40 mm	150mm	In centre drain only	@10mm	75mm	-	10m c/c in centre drain	Bed : 150mm thick M-15 concrete. Side : Ladder with tread 40cm and rise 20cm
5. PUGC (Km 25.64-27.27)	At bed level			(i)75mm coarse sand of FM≥1.5	(i)75mm coarse sand of FM≥1.5	75mm FM≥1.5	150mm 5-20mm	20-40 mm 40-80 mm	75mm PRV with casing of 150mm perforated pipe with blind cap.	On ends and in centre	@10mm	75mm	10m c/c Ist row 1.8m below IInd row 3.3m below FSL Sugges-ted	10m c/c on ends drain &10m in centre chain	Bed : 100mm thick concrete M-15 lining in bed. Sides: Double clay tile lining (300x150x50) over 15mm thick 1:3 C/M.
6. PUGC (Km 27.2-28.2)				(i)75mm coarse sand of FM>1.5 (ii)75mm sand of FM >0.8	(i)75mm coarse sand of FM>1.5 (ii)75mm Sand of FM>0.8	75mm FM>1.5	150mm 5-20mm	20-40 mm	75mm perforated PVC PRV casing of 150mm perforated pipe	On ends and in centre @ 8.69m c/c	@10mm	75mm	10m c/c on penel one at 1.2m height & other at 2.7m height above bed	10m c/c on ends drain and in centre drain 10m c/c	Bed :Double clay tile lining (300x150x50) over 15mm thick 1:3 C/M. Sides: Double clay tile lining (300x150x50) over 15mm thick 1:3 C/M LDPE film is provided in bed only.

contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
7. PUGC (Km 28.2-28.6)	Below bed	Clay Soil		(i)75mm coarse sand of FM>1.5	(i)75mm coarse sand of FM>1.5	75mm FM>1.5	150mm 5-20mm	20-40 mm 40-80 mm	75mm PRV casing of 150mm PVC perforated pipe	On ends and in centre @ 8.69m c/c	@10mm	75mm	10m c/c Ist row 1.8m below FSL IInd row 3.3m below FSL	10m c/c on ends. 10m c/c in centre stagg-ered	Bed: 100mm thick cocrete M-15 lining in bed. Sides: Double clay tile lining (300x150x50) over 15mm thick 1:3 C/M.

Annexure-3

DRAINAGE ARRANGEMENT IN EASTERN GANGA CANAL, U.P.

Location & type of soil	Permeability (K)	Filter below lining		Details of drain				Spacing of drains		PRV details			Type of lining
		Slope	Bed	Course Sand	Graded gravel I	Graded gravel II	Perforated Pipe	L-drained	T-drains	Dia mm	Spacing at slope	Spacing at bed	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Typical X-Section Type-I	From km 4.5 to km 18 $K>10^{-4}$ cm/s	(i) 75mm C.S. of 1.5 or above (ii) 75mm local sand of FM 0.8 or above	- Sleeper spacing of 9280	FM 1.5 or above	5 to 20 mm	20 to 40 mm	150∅ mm	On ends and in centre	-	75∅ mm	At 2500 below FSL on slope	One each on ends, drains @ 10m C/C one on incentre drain @ 10m C/C	Bed: 100mm thick CC of M-15 Side: Double CC tile lining of size (300x300x40) M-15 (100mm thick lining)
Typical X-Section Type-II	-do-	(i)100mm thick graded sand filter (coarse sand FM <2.0, D_{15} <0.3 mm) (ii)Bottom 200x300mm	- Sleeper spacing of 9280	-	100mm thick 4.75 to 20 mm	20 to 40 mm	150∅ mm	On ends	-	75 ∅ mm	@10m C/C replaced by porous concrete (1:0:4)	(i)On the edge of bed & slope @ 10m C/C in centre of slope PRV's (ii)Porous concrete (1:0:4) window @ 2.5 m C/C on both edge	Bed: 100mm CC of M-15 Side: Double clay tile lining (300x150x50) lining. (130mm thick lining)

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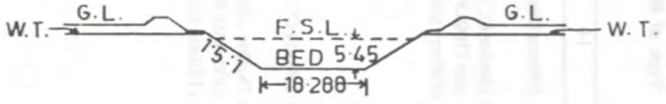
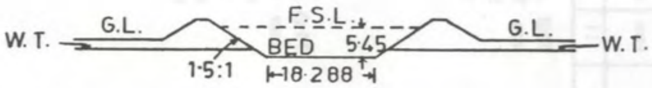
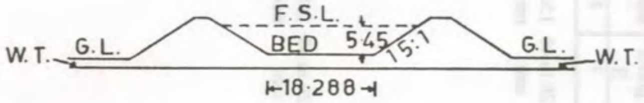


(a) WATER TABLE ABOVE F.S.L.



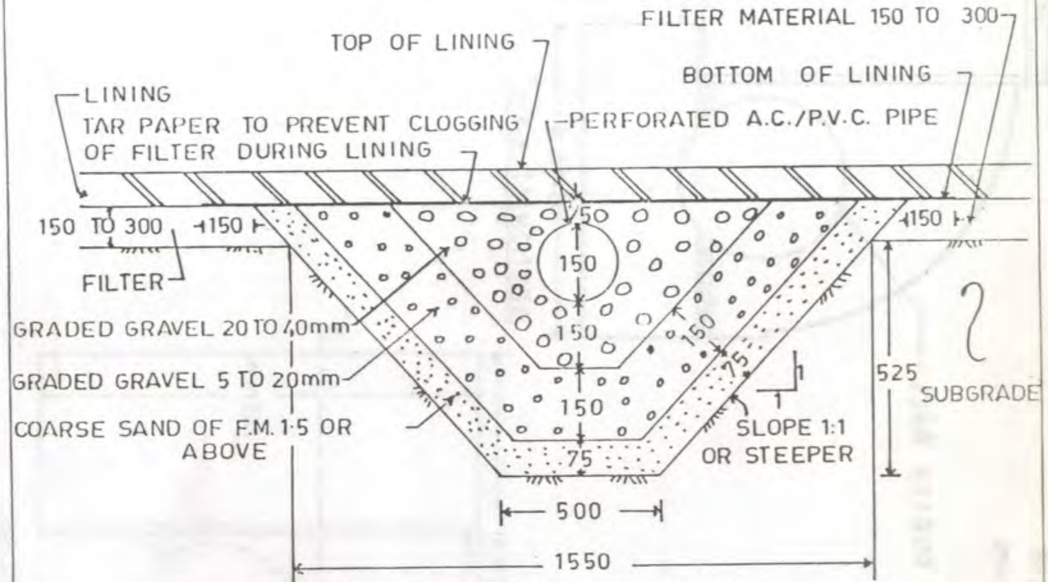
(b) WATER TABLE ABOVE BED



(c) WATER TABLE BELOW BED

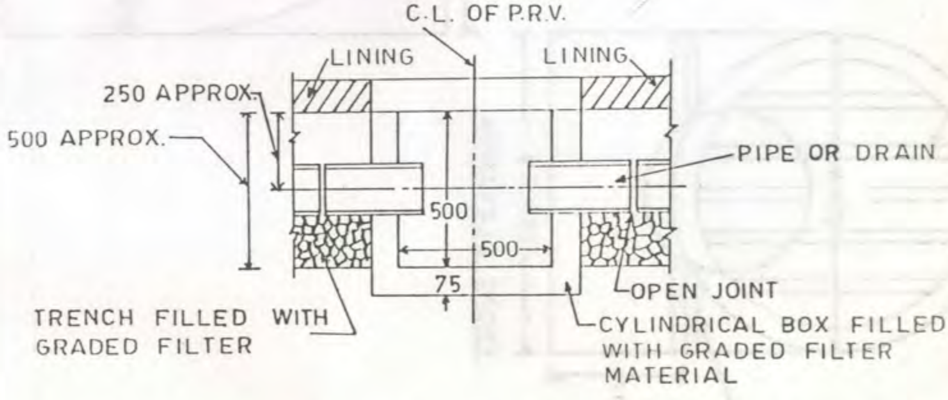
NOTE:- ALL DIMENSIONS ARE IN METRE.

FIG.1 :- DIFFERENT WATER-TABLE CONDITIONS.



NOTE:- 1. ALL DIMENSIONS ARE IN MM.
2. PRESSURE RELIEF VALVE NOT SHOWN.

FIG. 2(a) :- SECTION OF LONGITUDINAL / TRANSVERSE DRAINS.



NOTE:- ALL DIMENSIONS ARE IN MM.

FIG.2 (b) :- OUTLET FOR DRAIN WITH OPEN JOINTS.

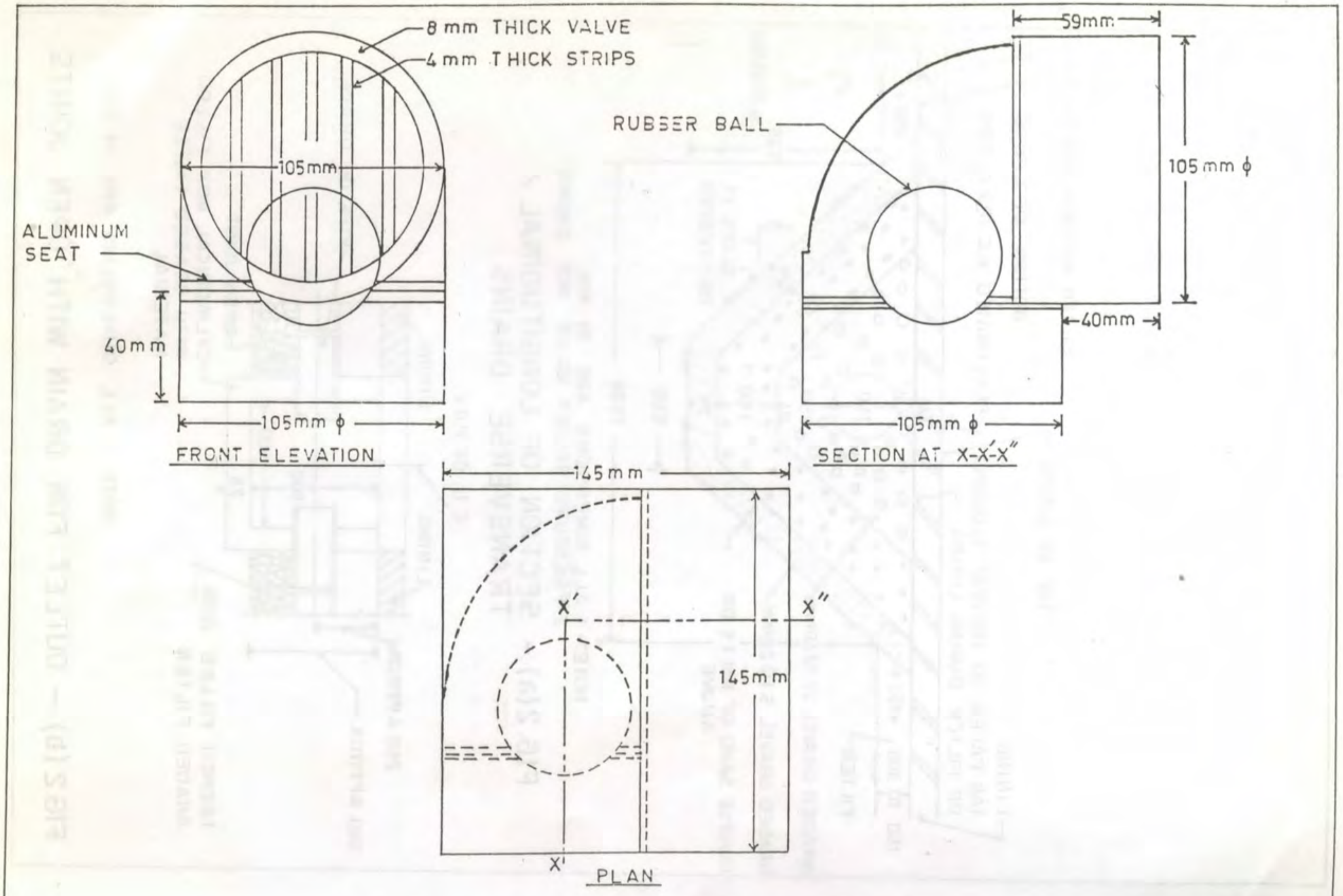


FIG. 3:- BALL TYPE VALVE FOR BED.

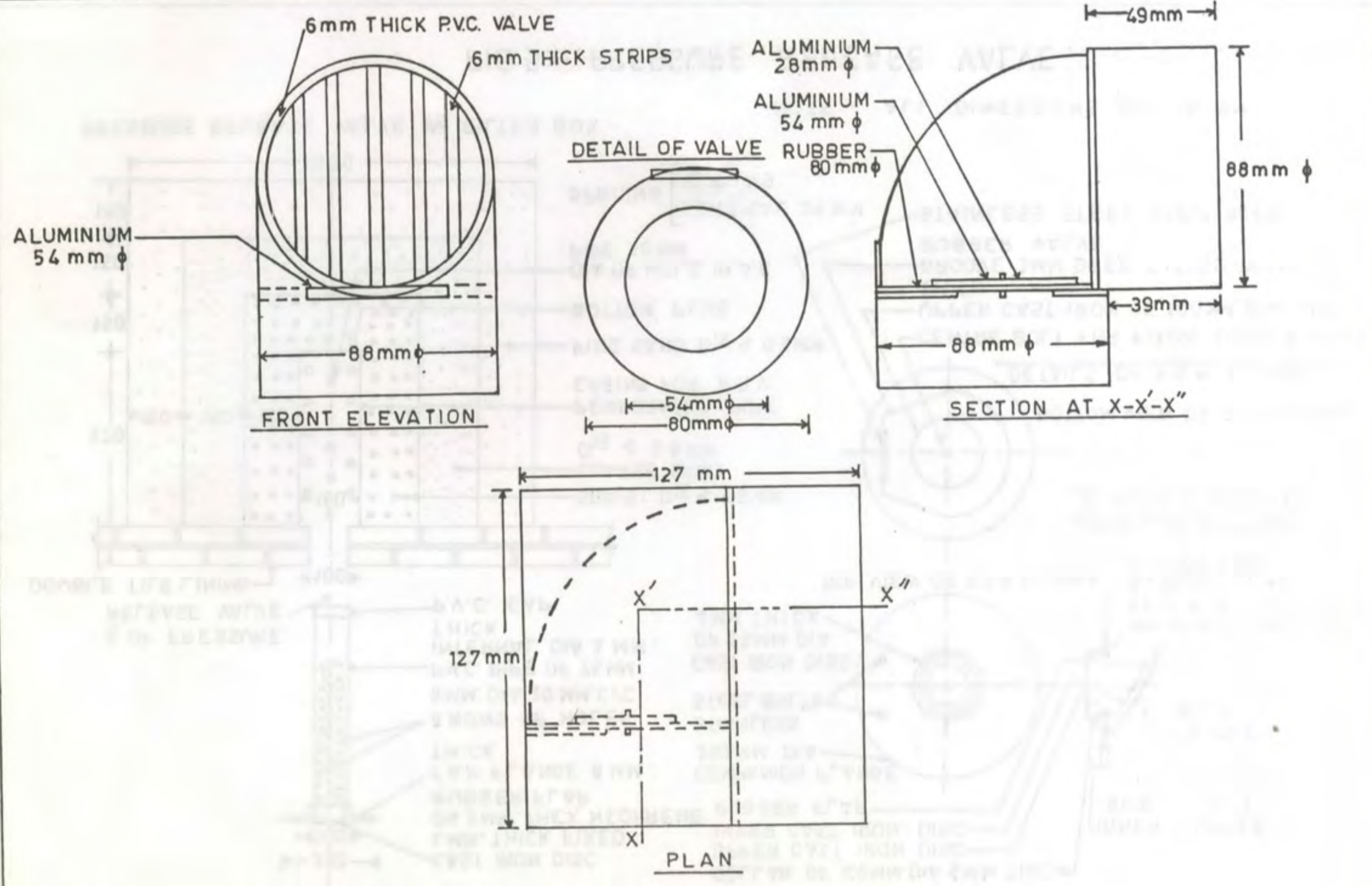


FIG. 4 :- FLAP TYPE VALVE FOR SIDE SLOPE.

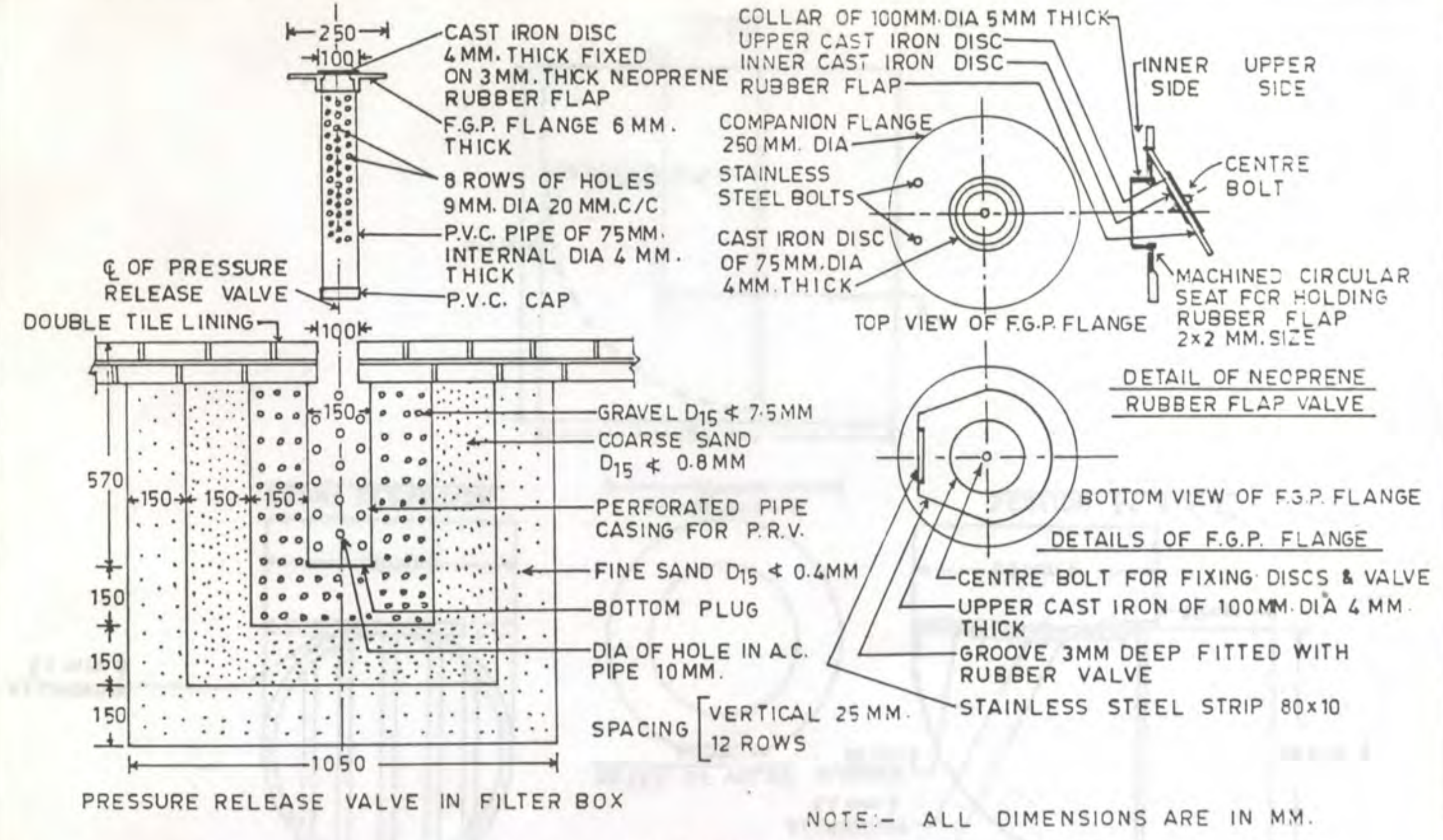


FIG. 5:- PRESSURE RELEASE VALVE.

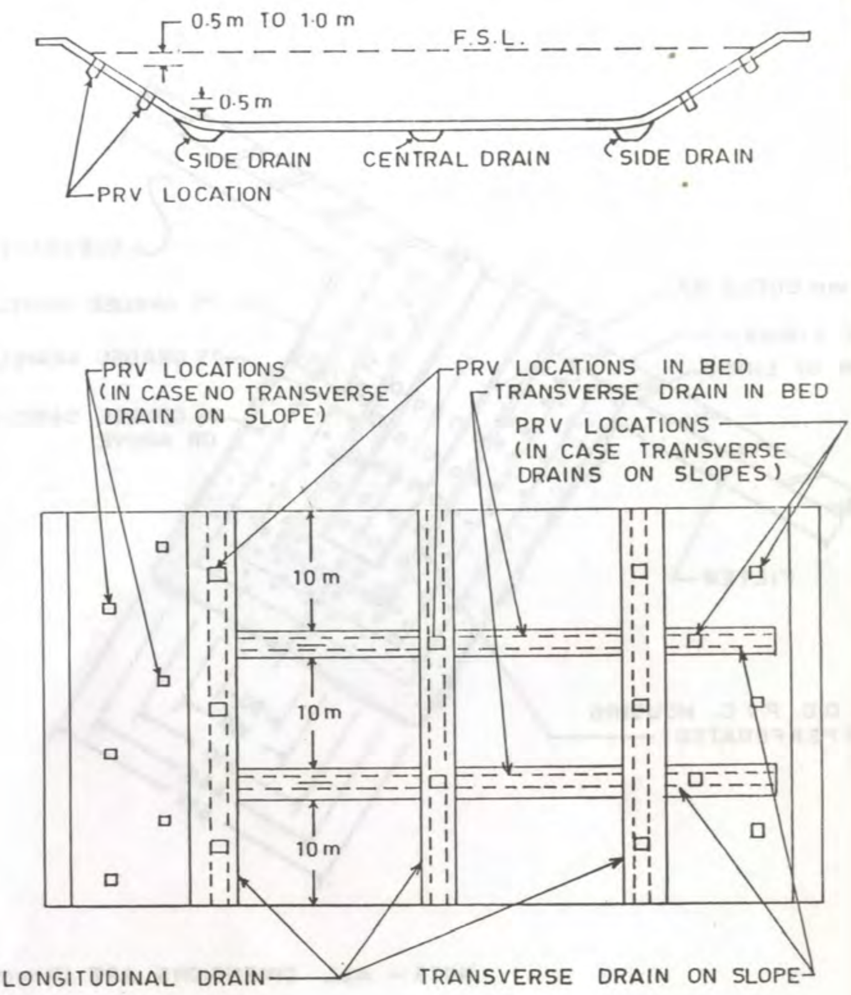
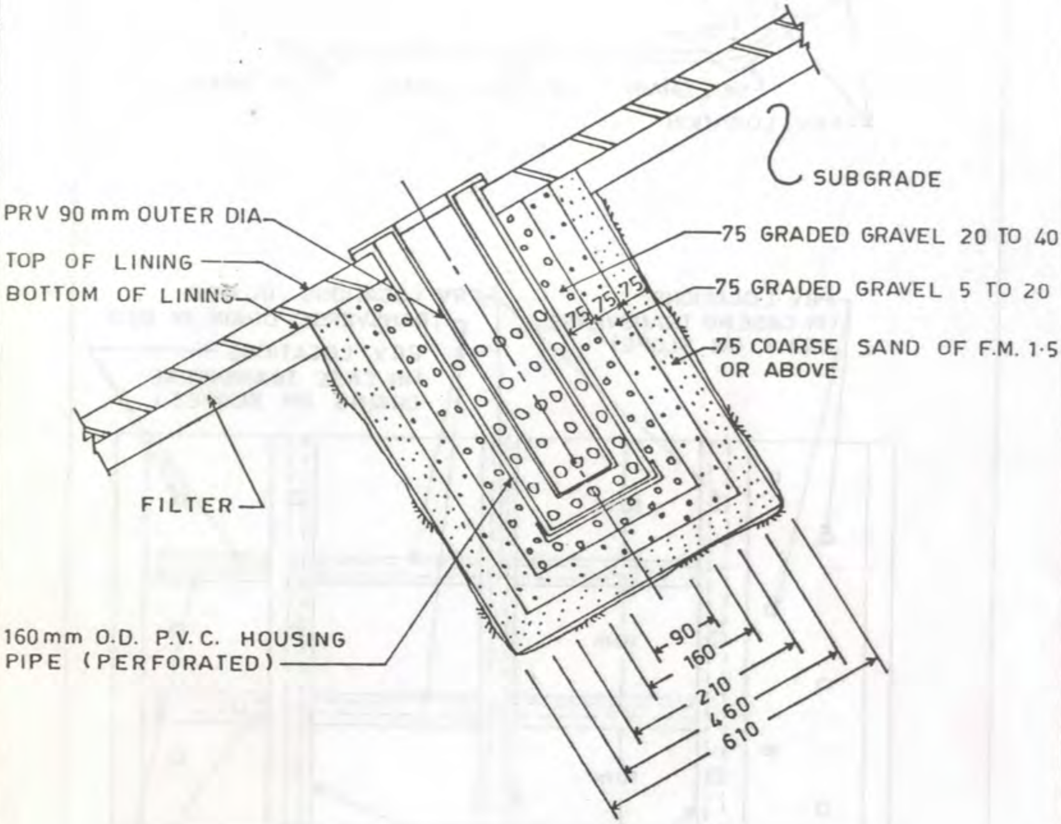
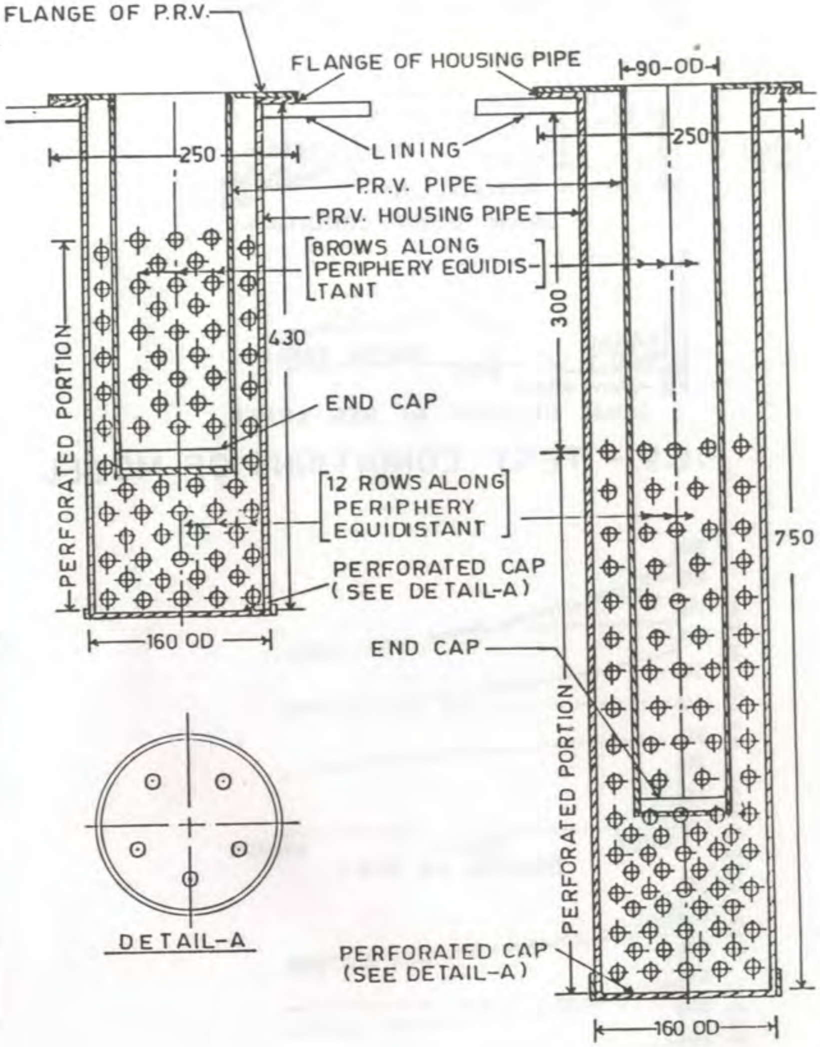


FIG. 6 :- ARRANGEMENT SHOWING DRAINS AND P.R.V. LOCATIONS.



NOTE:- ALL DIMENSIONS ARE IN mm.

FIG. 7 :- P.R.V. POCKET ON SLOPE.



NOTE:-1. ALL DIMENSIONS ARE IN MM.
2. DETAIL OF P.R.V. NOT SHOWN.

FIG.8:- DETAIL OF PERFORATIONS IN P.R.V. HOUSING PIPE.

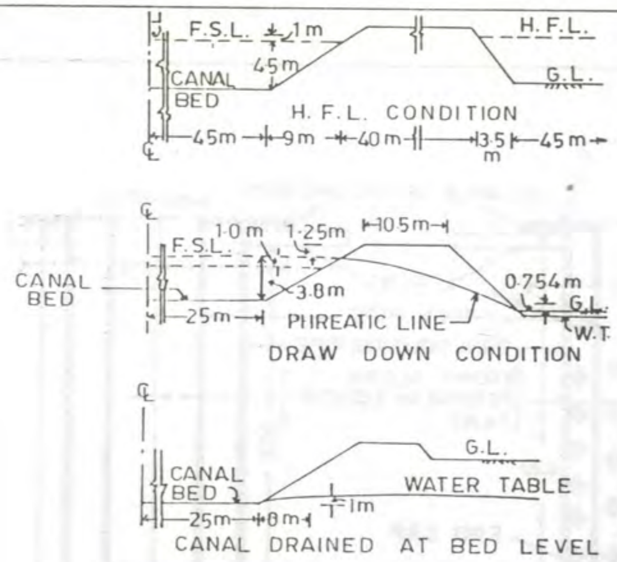
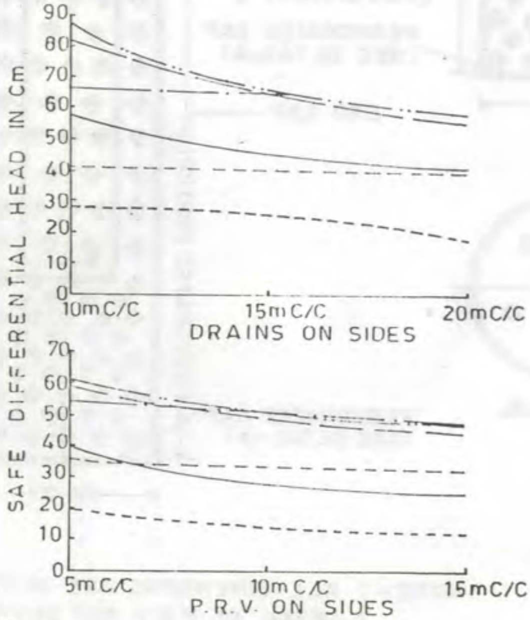


FIG. 9:- TEST CONDITIONS OF MODEL



LEGEND:—

- ——— NO DRAIN IN BED, 14 Cm THICK LINING
- ------- NO DRAIN IN BED, 7 Cm THICK LINING
- —— — 2 DRAIN IN BED, 14 Cm THICK LINING
- -- ---- 2 DRAIN IN BED, 7 Cm THICK LINING
- —·—··— 3 DRAIN IN BED, 14 Cm THICK LINING
- —·—·— 3 DRAIN IN BED, 7 Cm THICK LINING

FIG. 10:- SAFE PRESSURES BEHIND LINING-WATER TABLE ABOVE F.S.L.

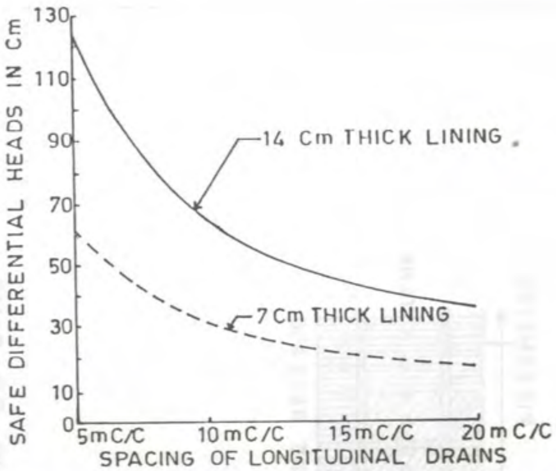


FIG.11:- SAFE PRESSURES BEHIND LINING-WATER-TABLE ABOVE CANAL BED.

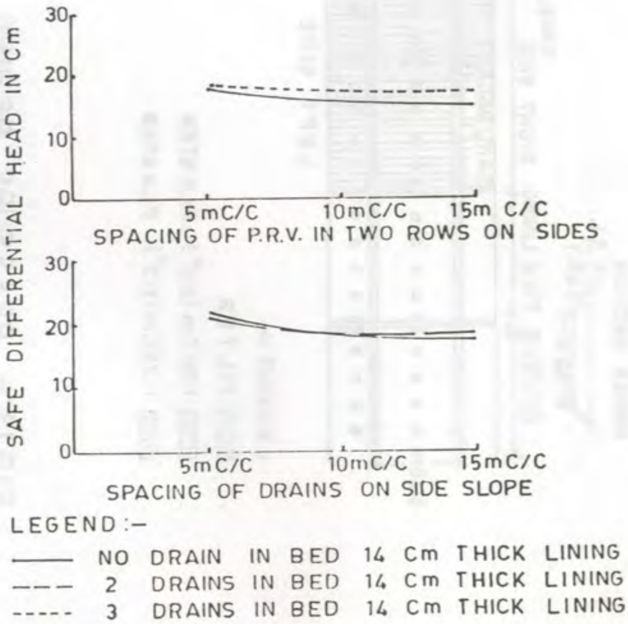


FIG.12:- SAFE PRESSURES BEHIND LINING (SUDDEN DRAWDOWN CONDITION).

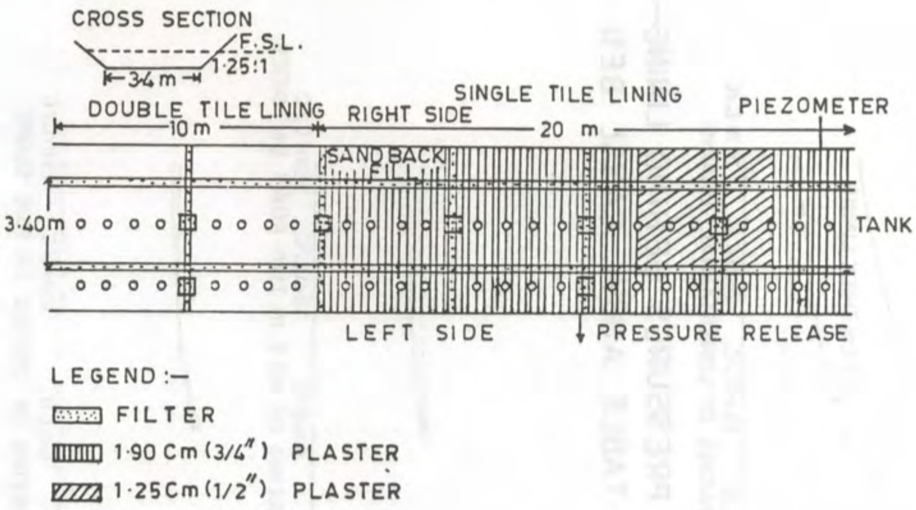


FIG.13 :– PRESSURE BEHIND LINING AND SPACING OF PRESSURE RELEASE VALVE.

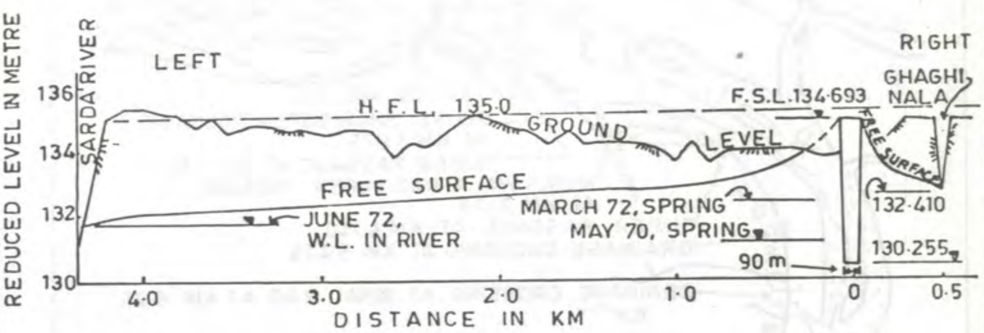


FIG.14:- CROSS-SECTION AT KM 5·0 OF SARDA SAHAYAK FEEDER CHANNEL.

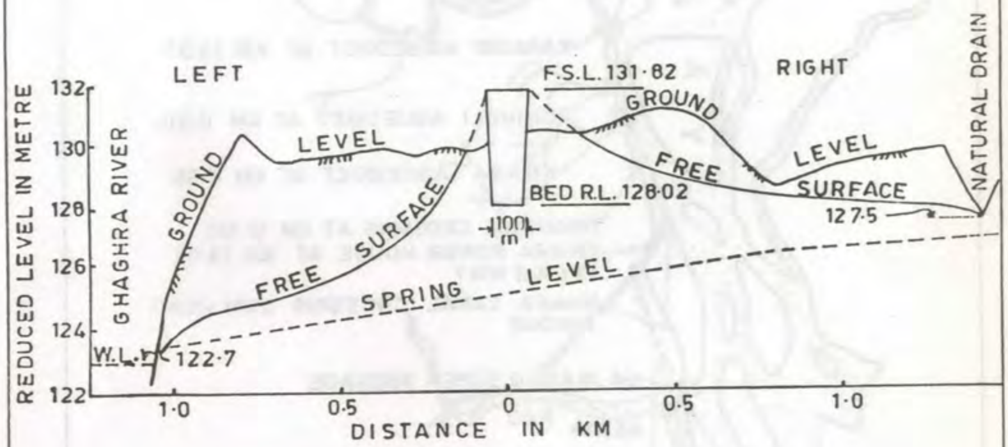


FIG.15:- CROSS-SECTION AT KM 30·0 OF SARDA SAHAYAK FEEDER CHANNEL.

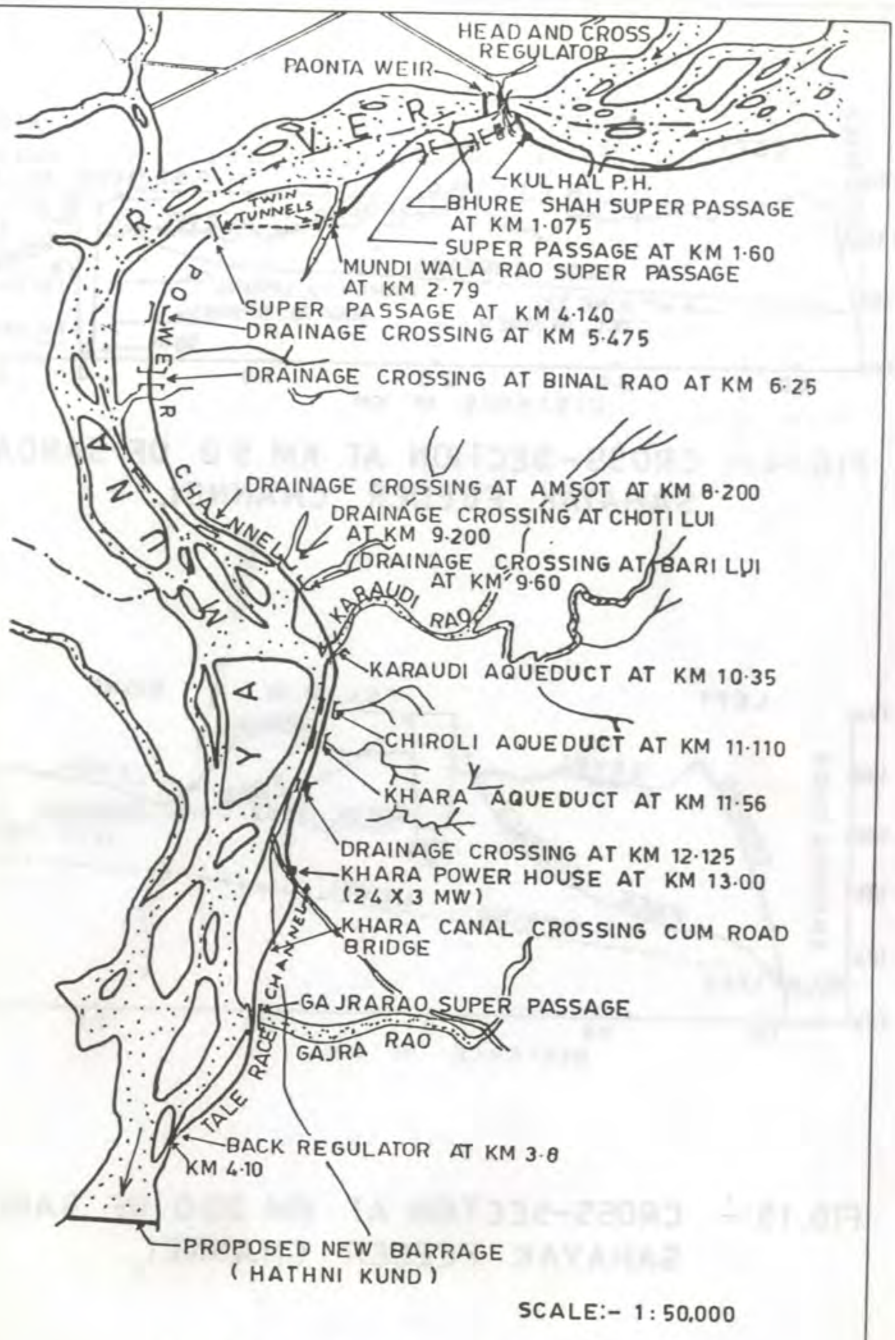
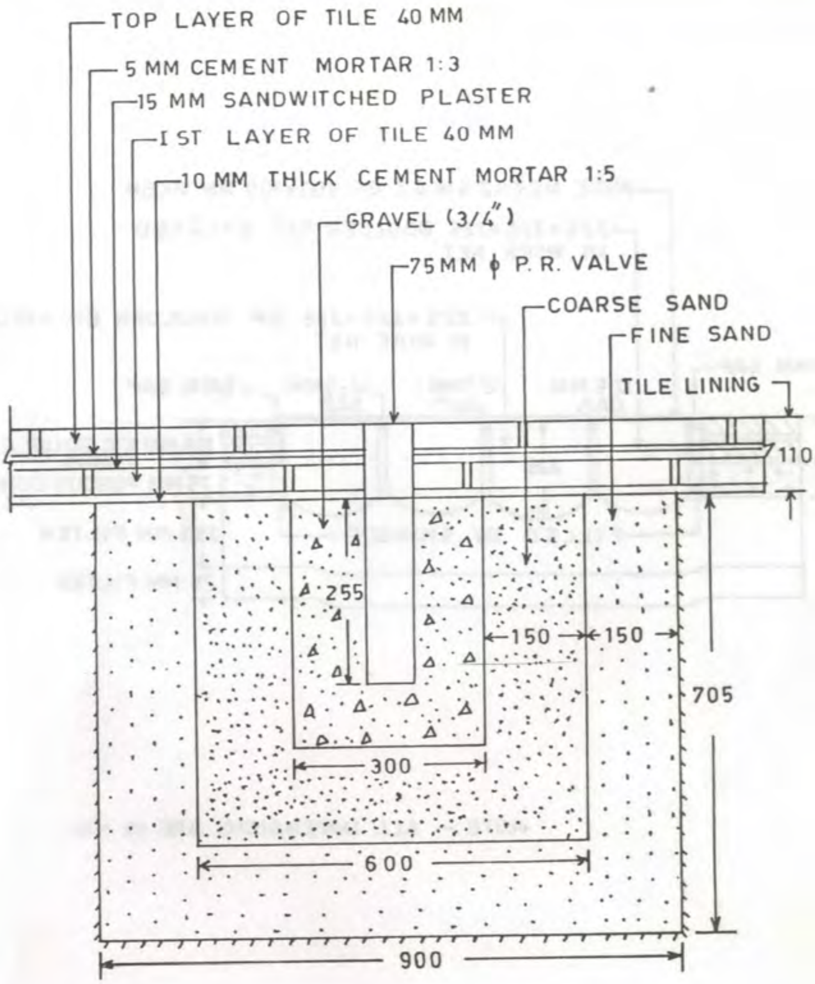


FIG.16:– KHARA POWER CHANNEL



NOTE:- ALL DIMENSIONS ARE IN MM.

FIG. 17:- DETAILS OF FILTER POCKETS IN FREE DRAINING SUBGRADE.

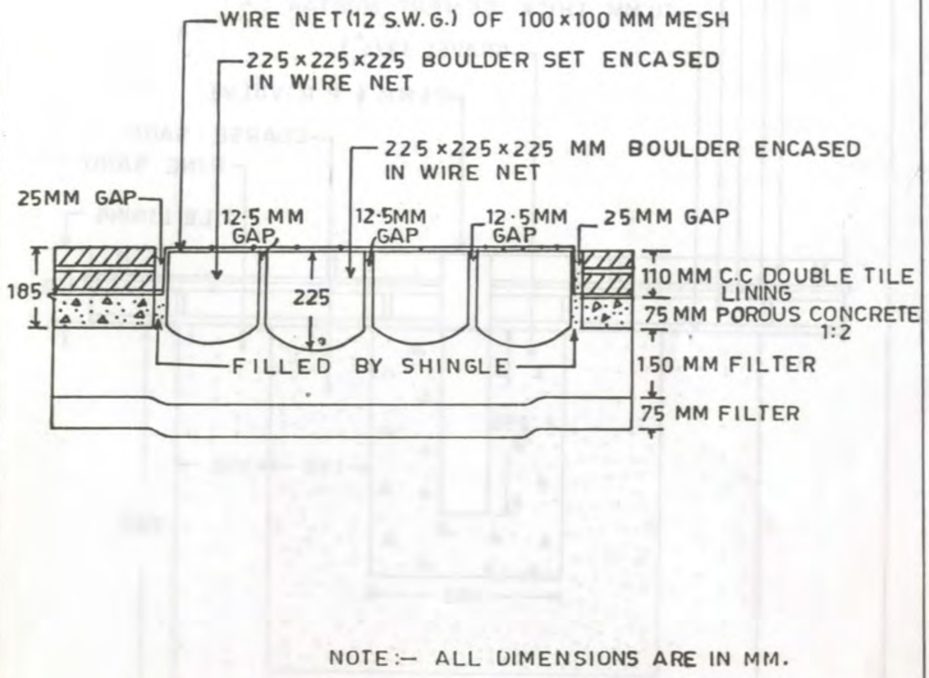
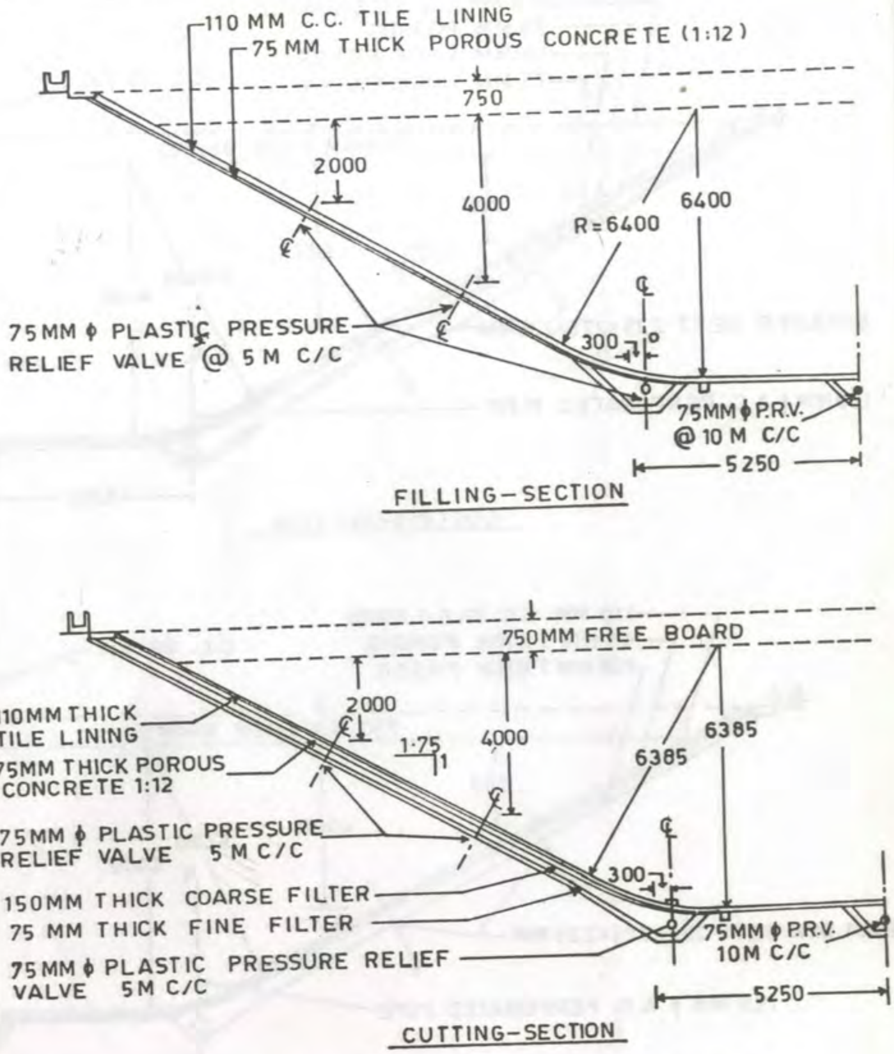
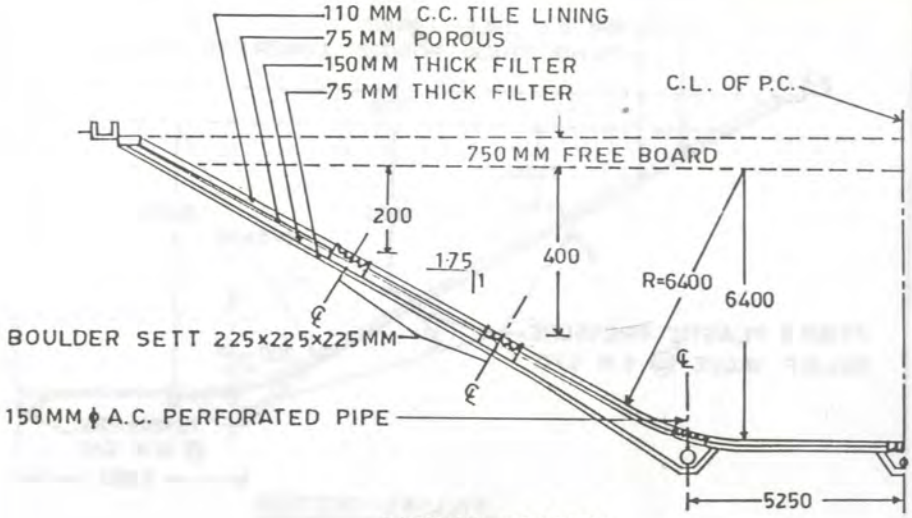


FIG. 18:- DETAILS OF BOULDER SET POCKETS IN NON-FREE DRAINING SUBGRADE.

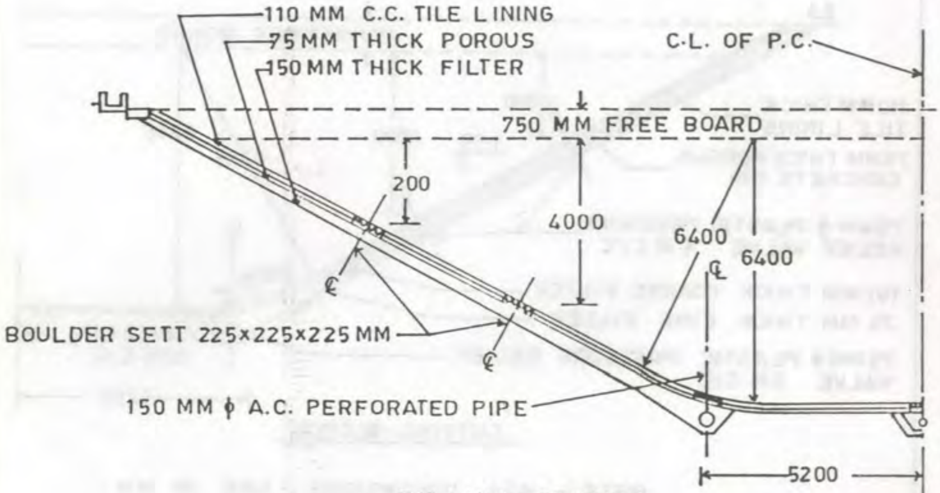


NOTE:- ALL DIMENSIONS ARE IN MM.

FIG. 19:- DETAIL OF LINING IN FREE DRAINING SUBGRADE.



CUTTING-SECTION



FILLING-SECTION

NOTE:- ALL DIMENSIONS ARE IN MM.

FIG. 20 :- DETAILS OF LINING IN NON FREE DRAINING SUBGRADE.

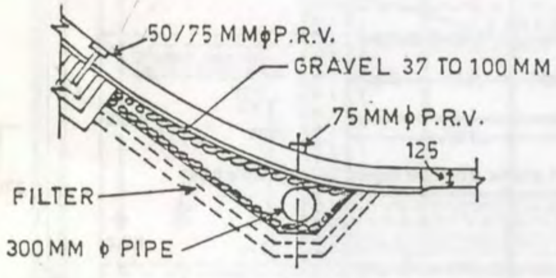


FIG. 21

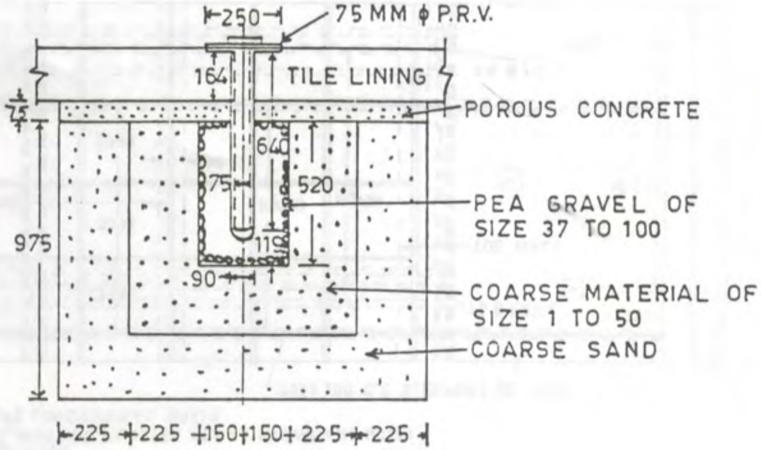
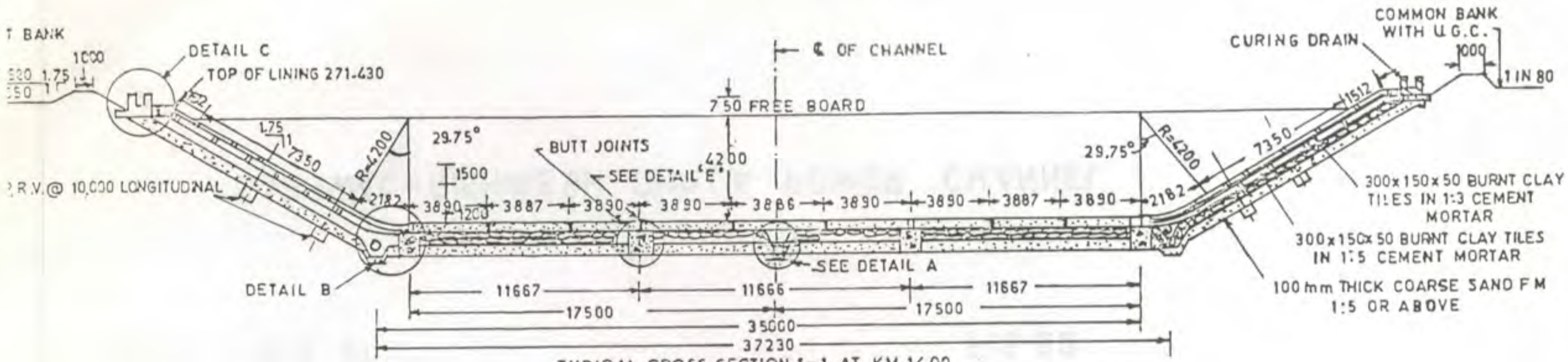
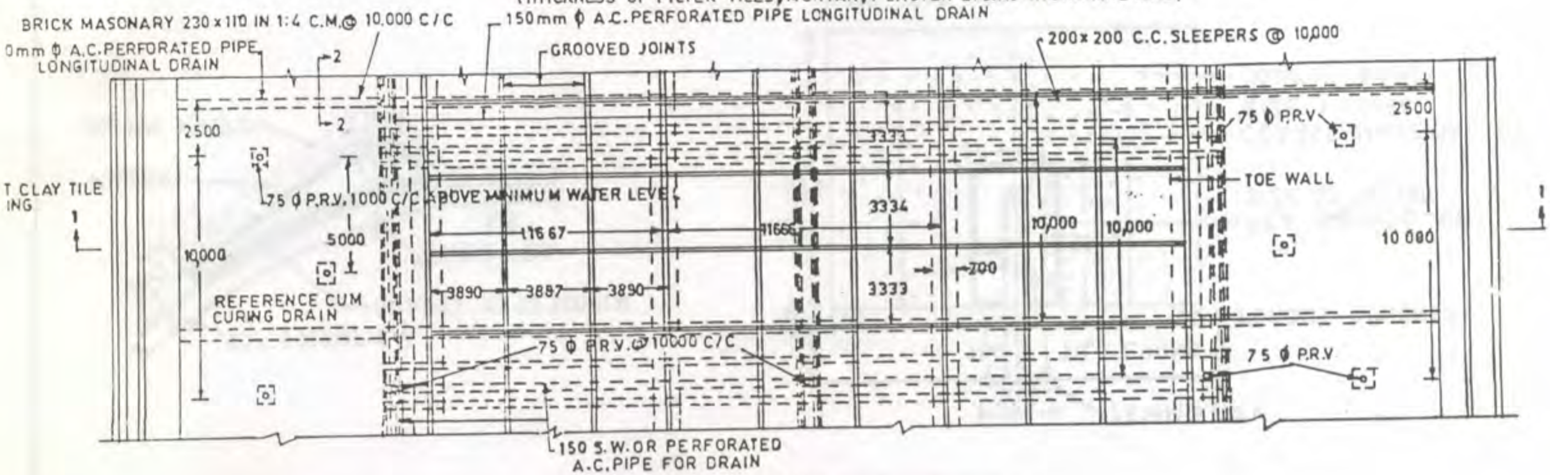


FIG. 22

GARHWAL-RISHIKESH CHILLA POWER CHANNEL



TYPICAL CROSS SECTION 1–1 AT KM 14.00
SCALE: 1:100
(THICKNESS OF FILTER TILES, MORTAR, PLASTER ETC. AS SHOWN ARE N.T.S)



PLAN
(JOINTS AND SLEEPERS ARE NOT TO SCALE)

FIG.23(a)–CROSS SECTION OF PLAN OF PUGC

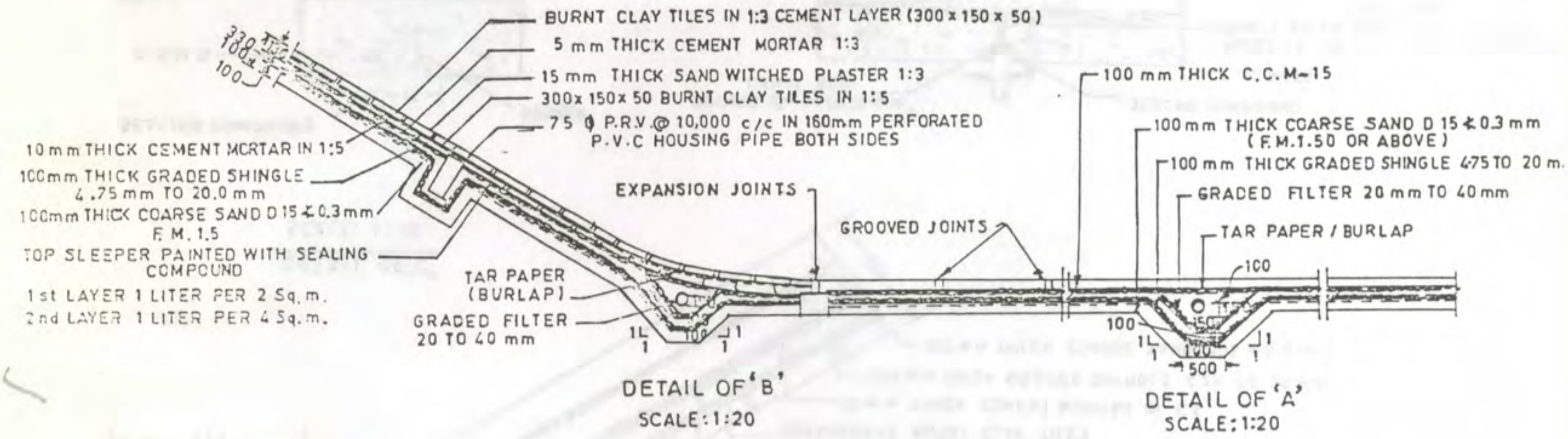


FIG.23 (b) – DETAILS OF 'A' AND 'B' OF PUGC

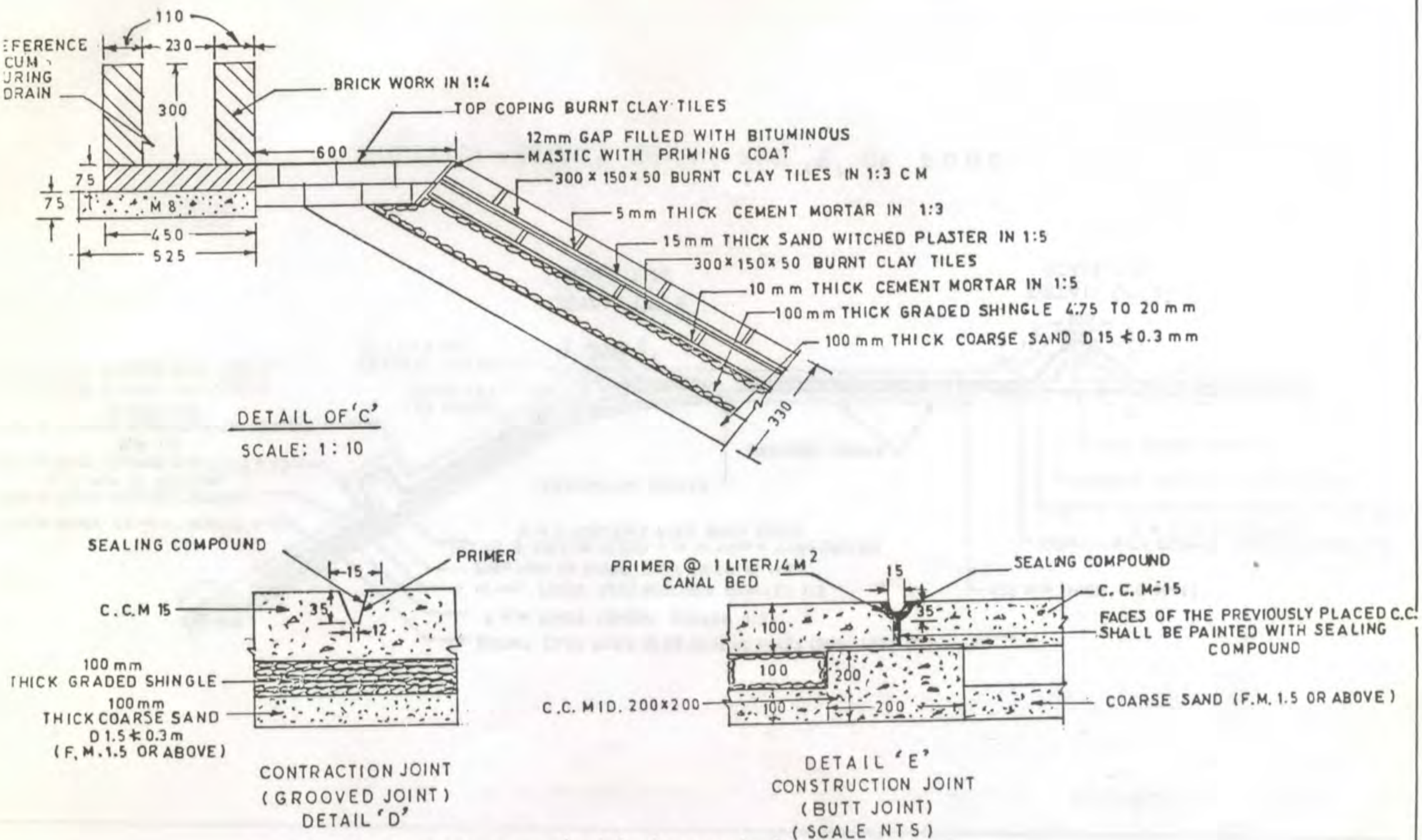


FIG.23 (c)– DETAILS OF 'C', 'D' AND 'E' OF PUG C

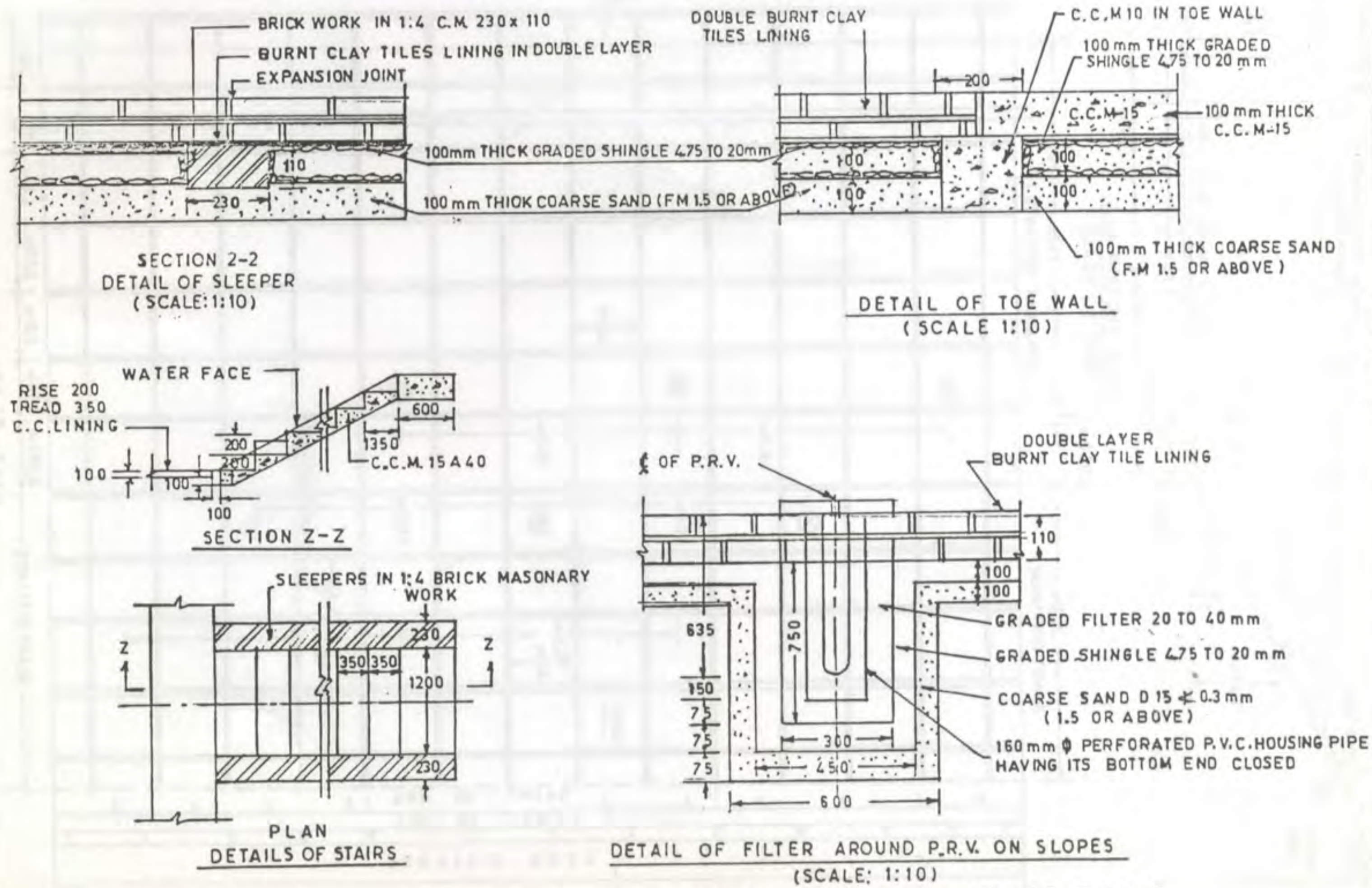


FIG.23 (d) – DETAILS OF SLEEPER TOE WALL STAIRS PRV ON SLOPE OF PUGC

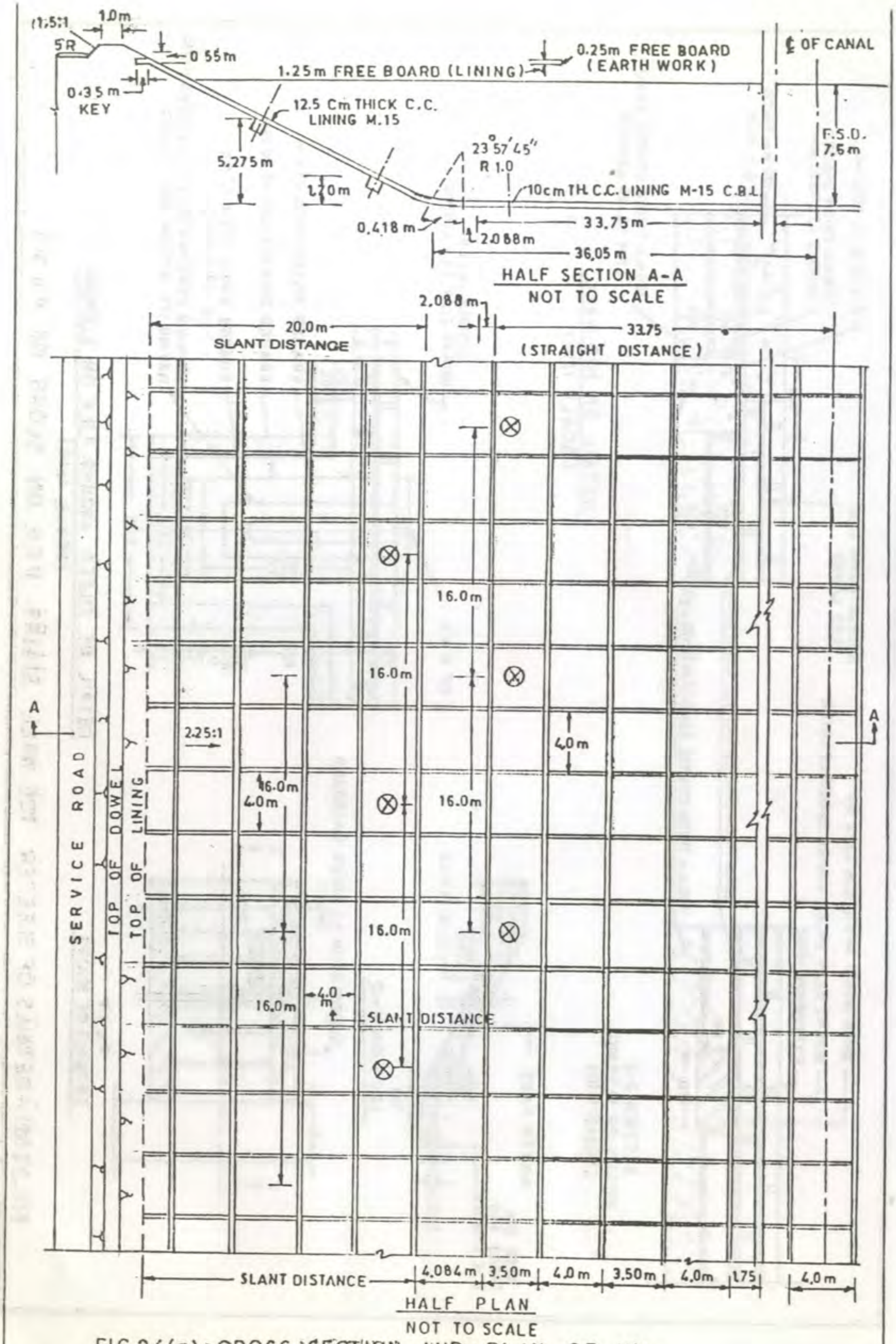


FIG.24(a)–CROSS SECTION AND PLAN OF NMC

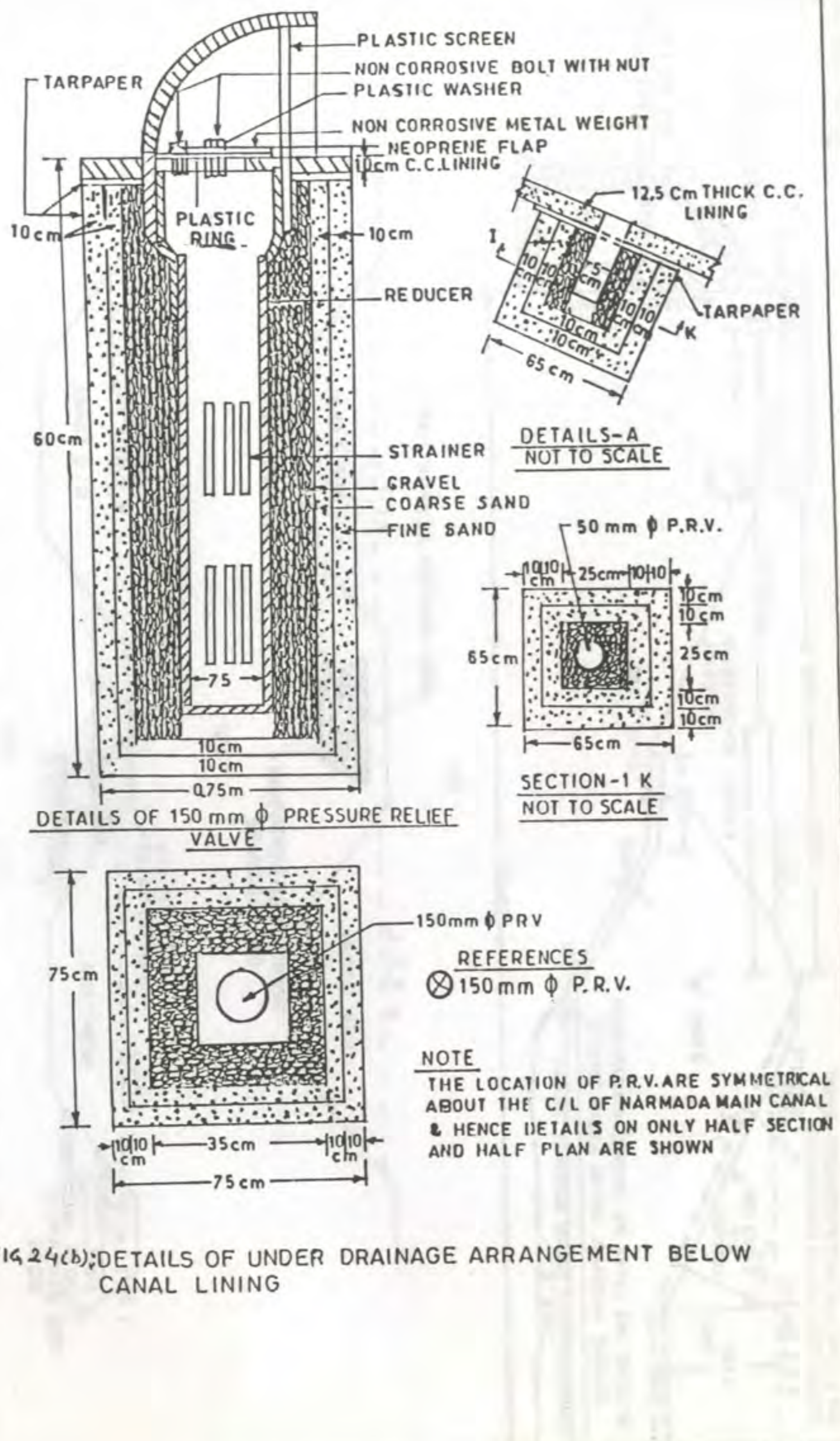


FIG.24(b); DETAILS OF UNDER DRAINAGE ARRANGEMENT BELOW CANAL LINING

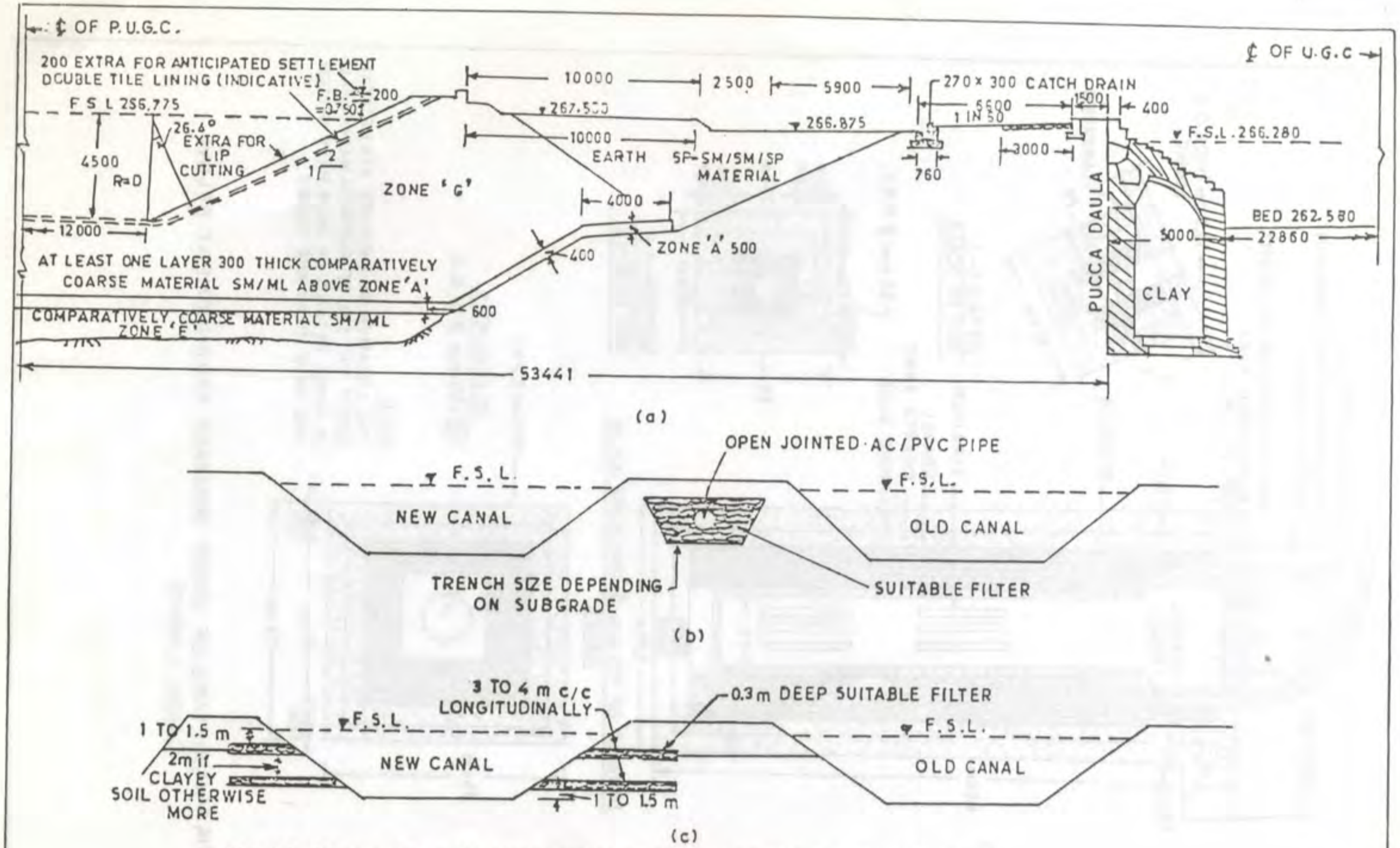


FIG.25-DRAINAGE ARRANGEMENT BELOW COMMON IN P U G C

10. LINING OF FIELD CHANNEL & WATER COURSES

10.0 INTRODUCTION

A water courses is the name given to the smallest channel conveying water to the farmer's fields. it has been observed that as much as 45 % of water may be lost in unlined channels before reaching the fields. The seepage losses in water-courses are particularly high since ratio of wetted area to volume of water carried is higher and they are mostly in filling with poor maintenance. So a major portion of the total losses from a canal system can thus be controlled economically if the water courses are provided with relatively impervious linings.

Basically linings for water courses may be divided into two main categories; Soft or flexible linings and Hard surface lining. Both types of linings have their advantages and disadvantages.

10.1 TYPES OF LININGS

Although major part of loss of water from seepage occurs from unlined water courses has not been given its due importance in the past with the result that even at present most of the water courses of the country are unlined.

10.1.1 Soft or flexible linings

These linings are Soil sealants, Bentonite, Soil cement, P.V.C., Synthetic rubber membrane and Asphaltic linings. Although in the period 1955-62 large scale research work was taken up at important research station of the country where it was found that as far as seepage reductions are concerned, these types of lining are cheaper and cost effective but these could not become popular as their life was very short say one to few years only (1, 2) and as such their use has not been made in the country.

10.1.2 Hard surface linings

Hard surface linings are adopted to reduce the seepage losses more effectively and to overcome the problems of soft linings as weed growth, regular maintenance, frequent repairs and relining due to their very short life. Hard surface linings, are more durable but costlier than soft linings. Still these are generally proved to be economical than soft linings and so are popular and widely used. Hard surface linings have also the advantage of reducing the cross-section area of canal section due to the low coefficient of rugosity. Although this saving does not appear appreciable in a water course channel due to its small cross-section, however, it has the advantage of adopting a flatter bed slope as compared to the earthen section and so in mildly sloping terrain it may have more command area. The specifications for excavation and compaction of water courses shall be same as for medium/large canal sections.

Generally following are the types of lining used for water courses and field channels.

(a) Brick/tile lining.

(b) Composite cement concrete and Brick mason any lining.

(c) Cement concrete in-site/pre-cast lining and

(d) L.D.P.E film with rigid cover.

Method of construction and other details of above linings are similar to the methods of constricting of large/medium canal sections and have already been described in their the respecting chapters of this manual.

10.2 PREPARATION OF SUBGRADE

The earth work and preparation of subgrade for water causers shall be done in accordance with IS:12379-1988 (Ref 3).

10.3 SHAPE OF WATER COURSES AND FIELD CHANNELS

The shape of the lined-water-courses may be trapezoidal, semi-circular or rectangular. The semi-circle has the least perimeter among all sections with the same ares, hence it is the most hydraulically efficient of all sections. Other sections are listed in table-1 in the order of their hydraulic efficiency.

All the sections listed above may not always be practical owing to difficulties in construction and use of material. In general a channel section is designed for the best possible hydraulic efficiency with due modifications for practicability. The details of lined sections are given below.

(A) **Semi-circular sections** - These sections are difficult in construction, and can only be constructed with cement-concrete which may be precast or cast-insitu. Precast concrete sections are more common and easy in construction. Cost-in-situ lining is costly, difficult in construction and require special form work as subgrade soil can not be shaped easily in semicircular shape and moreover because of the steepness of side slopes near the top, it becomes unstable.

Freeboard in these sections can be provided by either adopting vertical additional concrete or with brick masonry, as for the depth of flow less than the radius, hydraulic efficiency reduces. In some cases taken the discharge is less, free board may be provided in the semicircular section itself (fig 1).

Reinforcement may be provided to reduce temperature cracks and cracking due to any settlement of subgrade. The inside surface is smooth finished with cement plaster to reduce rugosity coefficient and generally a value of N equal to 0.014 to 0.016 is adopted.

(B) **Trapezoidal sections** - Generally only trapezoidal sections can be constructed for all types of materials as then hard surface linings and therefore trapezoidal sections are the most common sections used for canal linings. These have the advantages of stability of earthen slopes, ease of constriction and are suitable for all Kinds of lining and various combination of materials.

Best hydraulic trapezoidal section is for a side slope of 0.66:1 and bed width-depth ratio of 0.82 . The bed width depth ratio in small channels may be maintained to some extent but generally a side slope of 0.66:1 is not practicable from the view point of stability of Earth slopes. For various side slopes, best trapezoidal sections are given in table 2.

Due to the small cross-section of the water courses a side slope off 1:1 is most commonly adopted for most of the soils and all types of lining materials. This slope is also very near to that for the best trapezoidal section.

Trapezoidal sections are generally constructed with tiles, bricks, cement concrete of cut stone according to the availability of national. The details are given below.

(i) Tile Lining - Tiles for water courses lining work are generally manufactured in a size of 30x15x5 cms. Due to less thickness than bricks, tile lining is generally cheeper than brick lining and is more commonly adopted. Single tile lining is generally adopted for water courses. Details of tile linings adopted on two projects is given below.

Bikaner Loonkaransar Lift Canal- The typical sections adopted are shown in figure 2. In these sections, the bank width is 0.6m (2\9') to 0.9m (3ft) and the water course has trapezoidal section in single tile lining with 1:1 side slopes. A freeboard of 0.15 metre (6") is provided.

Rajasthan Canal Project stage 1, Command Area Development Phase I-Typical sections are shown in fig 3. The bank width is 0.45m (1.5\9') for any depth of cutting of filling. The water courses is trapezoidal section in single tile lining with 1:1 side slope. A free board of 0.30 metre (1\9') is provided.

(ii) Brick Lining - Brick lining has been extensively used in the Parallel upper Gangs Modernization Project of Uttar Pradesh. Typical section of a with L D P E minor of Harduagang Distributory is given in Fig4 below. The minor is lined with a single layer of Brick over 100 micron LDPE film. The side slopes of the miner has been Kept on 1:1.

(C) Rectangular sections - Rectangular sections are now being preferred more, because of greater stability and ease in construction as compared to other sections. These are not easily susceptible to damage by cattle and over topping. Also, as compared to trapezoidal section, rectangular section involves an approximate saving of 5 to 15% of cultureable land coming under the water course and 20 to 30% in the cast of earth work. The lining is generally a little costlier as thin linings can not be adopted from structural considerations, and thick walls section involves the use of more materials. The other advantage of rectangular section is that maintenance of earthen banks are not that important as in trapezoidal sections and the earthen banks behind the walls may be allowed to go down by 0.15 metre or even more for masonry sections.

Suitable rectangular sections are constructed with bricks, cement concrete with and with out LDPE film stone masonry and precast concrete, etc. IS:12379-1988 (3), gives specifications and other details of lining of water courses with rectangular sections. These are described below in brief.

(1) **Brick lining** - Bricks required for brick work shall be according to specifications laid down in IS: 1077-1986 and shall be soaked in clear water immediately before use for one hour or till the complete cessation of air bubbles, whichever is later. They shell be kept free from sand and silt. The bricks shall be laid in English bond with frogs upward. Hard or cutbricks should be used only where required near the end of the walls.

Typical sections showing the details of masonry section and section of side walls are given in fig 5.

(2) **Composite cement concrete and brick masonry lining** - Following are the two methods for carrying out the lining work :

(i) A bed of 50 mm thick 1:3:6 cement concrete is laid over100 micron L D P E film conforming to 15 : 9698-1980 (Ref. 4). Side walls are constructed in brick masonry in 1:4 cement sand mortar (with out plaster) of 1:5 cement sand mortar (with plaster). The inside and top of these vertical walls should be finished with 10 mm thick 1:3 cement sand plaster (Fig.6).

(ii) Brick masonry in 1:5 cement sand mortar (with waster) or 1:4 cement sand mortar (with out plaster) on the sides and 5 cm thick 1:3:6 cement concrete in the bed should be laid over 1.5 to 2.0 cm thick subgrade of slate pieces or 100 micron LDPE film.

(3) **Cement concrete lining** - 50 mm thick 1:3:6 cement concrete should be laid in the bed over a 100 micron LDPE. The vertical side walls should be constructed with 75 mm thick 1:3:6 cement concrete. In case LDPE film is not used, 75 mm thick 1:3:6 cement concrete shall be laid (Fig 7).

(4) **Stone slab/stone masonry lining** - Stone slab used for the bed shall have thickness of 25 mm. Stone slab should be laid in 1:2:8 mortar (Cement:2 line: 8 stone dust) or 1:5 Cement sand mortar:

All the joints should be raked and pointed. Masonry on the sides shall be laid in 1:2:8 cement lime/1:4 Cement sand mortar. The remaining course of side walls may be laid in 1:4 cement sand mortar.

For stone masonry work, stone shall be free from laminations, soft spots etc. Stone masonry should be laid in 1:2:8 mortar of 1:5 cement mortar. The joints should be raked and pointed with 1:3 cement (see Fig.8).

(5) **Pre-cast cement concrete lining** - Precast cement concrete rectangular sections may also be used. Typical precast concrete rectangular channel section alongwith its form work is shown in Fig.9 The specifications to be adopted for lining work shall be in accordance with IS:;10646-1983 (Ref. 5).

Lining of Tubewell Guls in Uttar Pradesh - In the state of Uttar Pradesh, while unlined guls are constructed trapezoidal in section with side slopes of 1:1 and outer slopes of 1:5:1 with 600 mm wide banks on both sides. The lined guls are constructed in Brick masonry. The lining of guls have been divided in two types, one for plane areas and the other for Bundel Khand Areas of the state. Typical sections for a discharge of 1.5 cusec (0.042 cumec) are shown in Fig no 10. The minimum bed slope of the guls in plane area in kept as 300 mm per kilometer while for Bundel Khand Area it is kept at 450 mm per Kilometer.

Field Experiences in Problematic Soils Area - The water courses lining in Agra Region of Uttar Pradesh is such an example. In Agra region black cotton soil is met with at some places in Chambal Colour and highly expansive. Due to high shrinkage and swelling properties, the performance of lining is poor.

In Bah Tehsil of Agra region there is great variation in soil characteristics ranging from light Dumat to sandy loam to black cotton soil. The spring level in the area is around 30 meters below the grand level.The area where black cotton soil is predominant, is in Pinahat block in Chambal ravines.

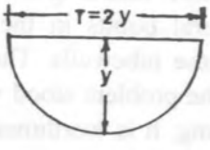
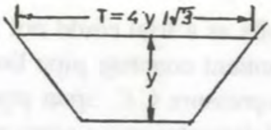
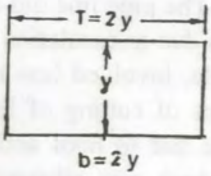
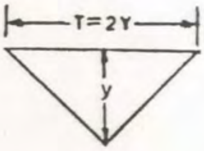
In Bah Tehsil of Agra, urigetion is being provided through about 150 Tubewells. The distribution system has been provided through about 2 km lined water courses (Known as Guls) and about 2 to 3 km long unlined Guls her Tubewell. The alternate wetting and drying of the lining on account of operation of the canal/Gul system and physical weathering may affect the earth lining, because there may possibly be a decrease in density and increase in permeability of the soil resulting in impairment of the officiency of the lining.

Brick lining in Guls with trapezoidal section tor carrying 0.04 to 0.05 m^3/sec of water was provided in this area. Due to erratic behaviour of black cotton soil present in the area, Guls in bricks lined with 1.4 cement mortar (Fig 5) gave way in about 5 years. Later on vertical section brick lined Guls in 1:4 cement mortar were provided. But these also could not with stand due to wide spread cracking of earth resulting in dislodging of bricks and thus leakage of water at several points in the Guls. This naturally affected the irrigation through these tubewells. The Guls were relaid and subsequently reconstructed bat the problem stood where it was the vertical Guls too could not stand for long. It is worthmentioning that on state tubewells No 78, 81, 82, 84 & 85 in Bah area not even a single brick could remain in position. Due to expansive soil characteristics of the area, proposal the construct of repair lined guls was abondoned.

The concrete lining tried on a few tubewells as a trial could not stand in the area. As an alternative underground cement concrete pipe lines were tried in a big way in 1972-1973. The non-pressure C.C. spun pipes were manufactured departmentally. The internal diameter of c.c pipes was kept 30 cms and thickness 3 cms, which was capable of with standing a test pressure of 0.7 Kg/cm^2 (7meters) water head. The pipe line was laid one metre below Ground level. As the cracks due to shrinkage and swelling of the soil remain confined to top layers, the one metre cover on the pipe line was considered adequate for its safety. The pipe line did not prove to be uneconomical, vis-a-vis, brick lined guls due to escalation in prices of bricks. Besides, pipe line was more durable, involved less maintenance and provided efficient distribution. Chances of cutting of lined guls by cultivators to field their fields and damage due to hoof action of cattle was also practically avoided. The land which was otherwise used for laying guls was also reclaimed and put under cultivation.

TABLE-1

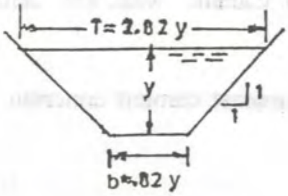
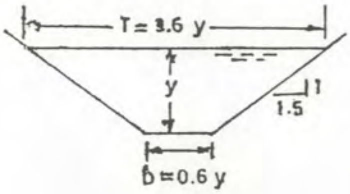
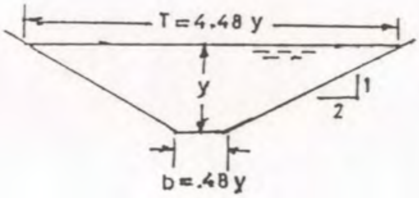
Best Hydraulic Section

Section with geometrical proportions	Area A	Wetted perimeter P	Hydraulic radius R	Top width T	$AR^{2/3}$
1. CIRCULAR (Semi circle)					
	$\frac{\pi}{2} y^2$	πy	$\frac{y}{2}$	$2y$	$0.987 y^{8/3}$
2. TRAPEZOIDAL (Half of a Hexagon)					
	$\sqrt{3} y^2$	$2\sqrt{3} y$	$\frac{y}{2}$	$\frac{4y}{\sqrt{3}}$	$1.088\ y^{8/3}$
RECTANGLE (Half of a Square)					
	$2y^2$	$4y$	$\frac{y}{2}$	$2y$	$1.257\ y^{8/3}$
4. TRIANGLE (Half of a Square)					
	y^2	$2\sqrt{2} y$	$\frac{y}{2\sqrt{2}}$	$2y$	$0.5\ y^{8/3}$

° R = A/P

TABLE - 2

Best Hydraulic Trapezoidal Sections for given Side slope

Side slope (H:V) and Shape	Bed width	Area (A)	Wetted Peri-meter	Hydraulic Radius(R)	Top width	$AR^{2/3}$
1. Trapezoidal with 1:1 side slopes						
	0.82 y	$1.82\ y^2$	3.64y	$\frac{y}{2}$	2.82y	$1.146y^{8/3}$
2. Trapezoidal with 1.5:1 side slopes						
	0.60 y	$2.1\ y^2$	4.2y	$\frac{y}{2}$	3.6y	$1.32y^{8/3}$
3. Trapezoidal with 2:1 side slopes						
	0.48 y	$2.48\ y^2$	4.96y	$\frac{y}{2}$	4.48y	$1.56y^{8/3}$

Note: $Q = 1/N\ AR^{2/3}\ S^{1/2}$; $Q = 1.486\ AR^{2/3}\ S^{1/2}/N$ F.P.S. System; y = depth of flow

References

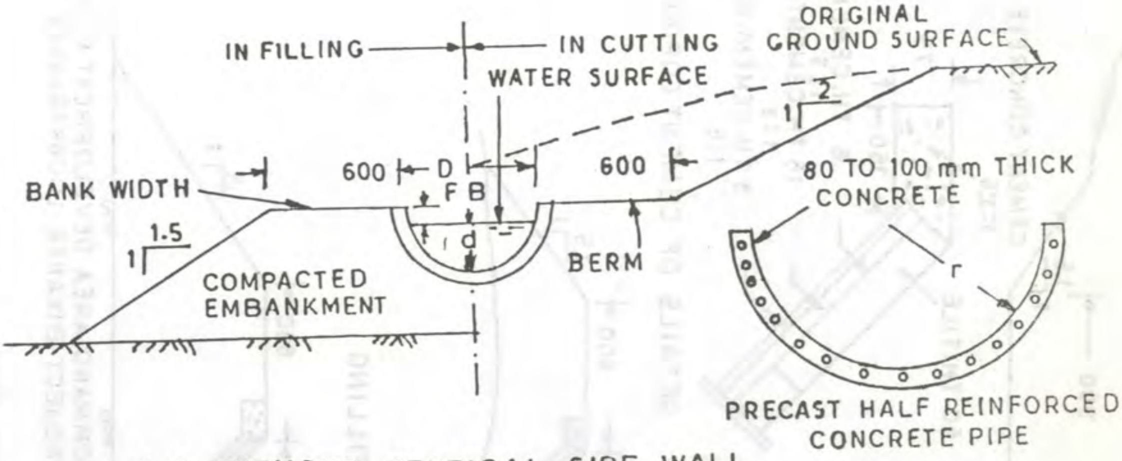
1. "Lining of water courser in Laboratory and under field Conditions." T.M.No. 31-R.R. (G-44). U.P.I. Research Institute, Roorkee.

2. "Lining of water courser under Laboratory and field conditions".

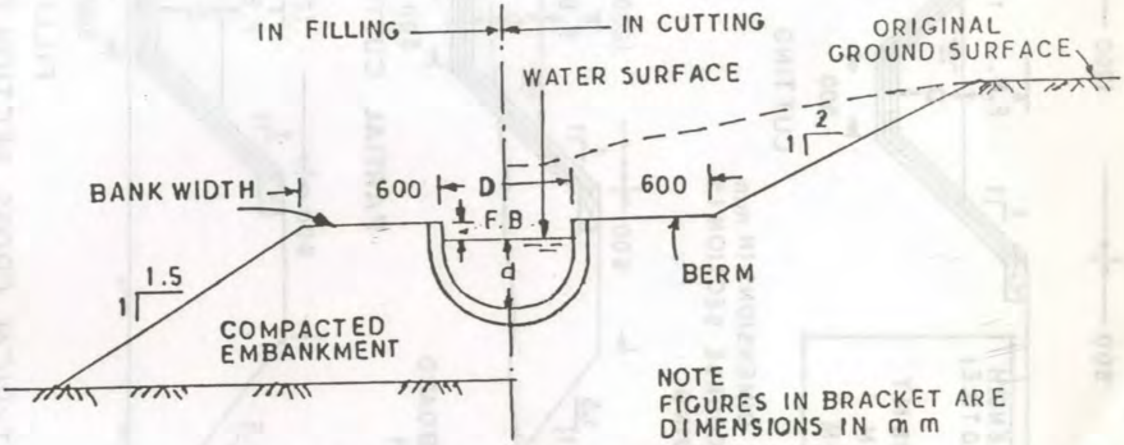
3. IS : 12379-1988 Code of Practice for Lining of Water Courses & Field Channels.

4. IS : 9698-1980 " Code of Practice for lining of Canals with low density polyethylene film".

5. IS : 10646-1983 "Specifications for compressed precast cement concrete tile canal lining".



(a) WITHOUT VERTICAL SIDE WALL



(b) WITH VERTICAL SIDE WALLS

FIG.1—SEMI CIRCULAR SECTIONS

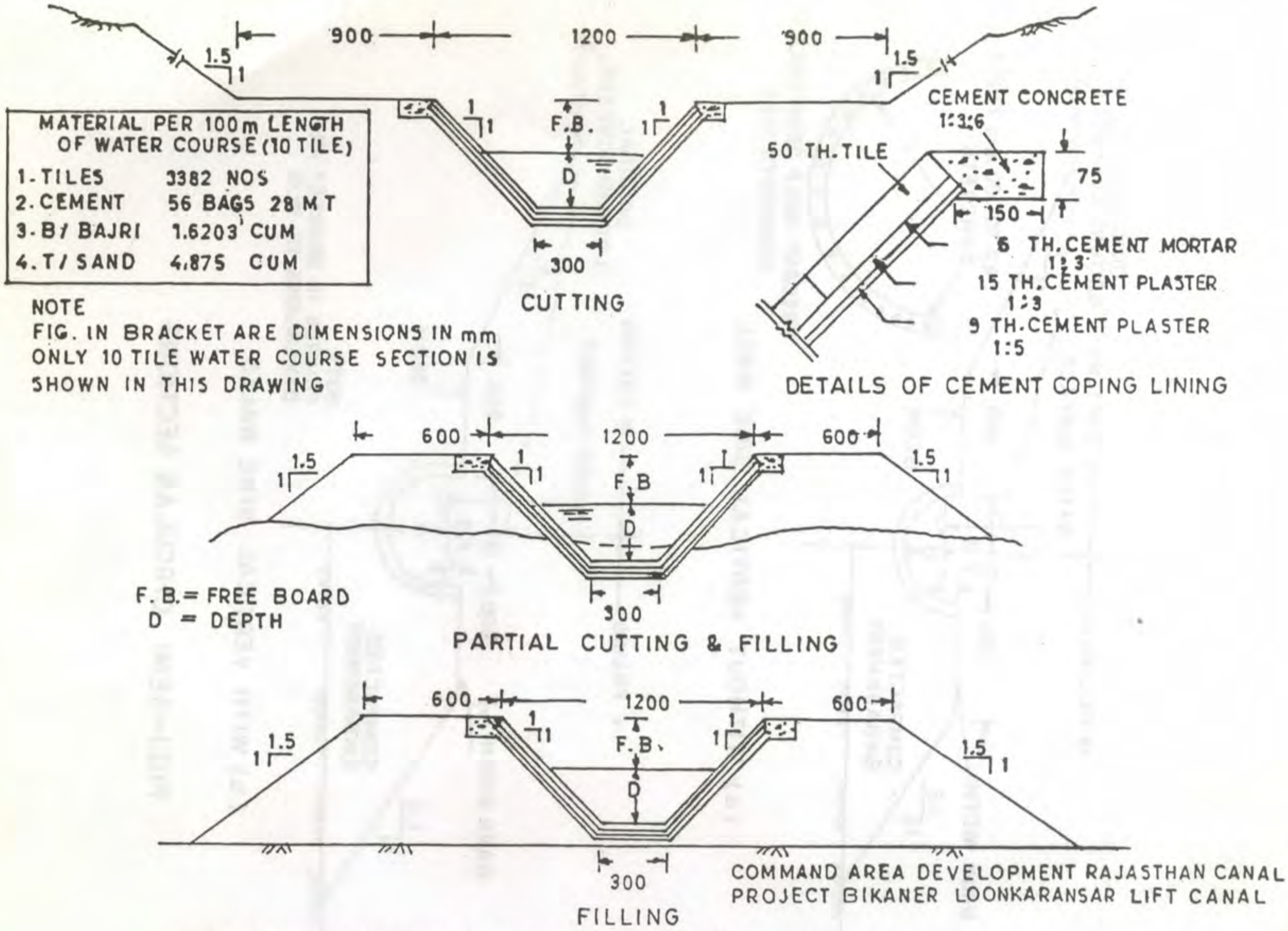


FIG. 2– TYPICAL CROSS SECTION OF LINED WATER-COURSES

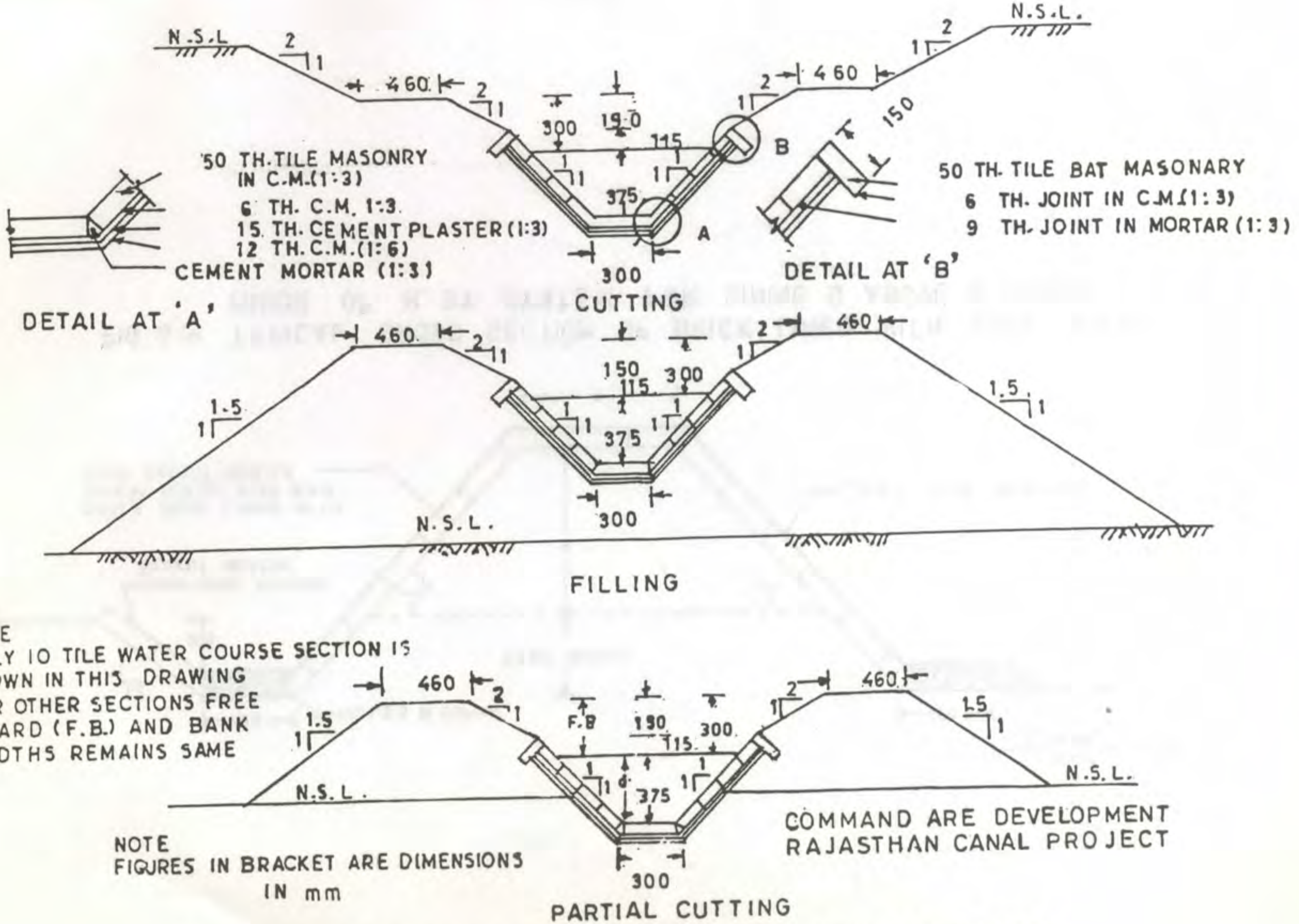


FIG.3-TYPICAL CROSS SECTION OF LINED WATER-COURSE

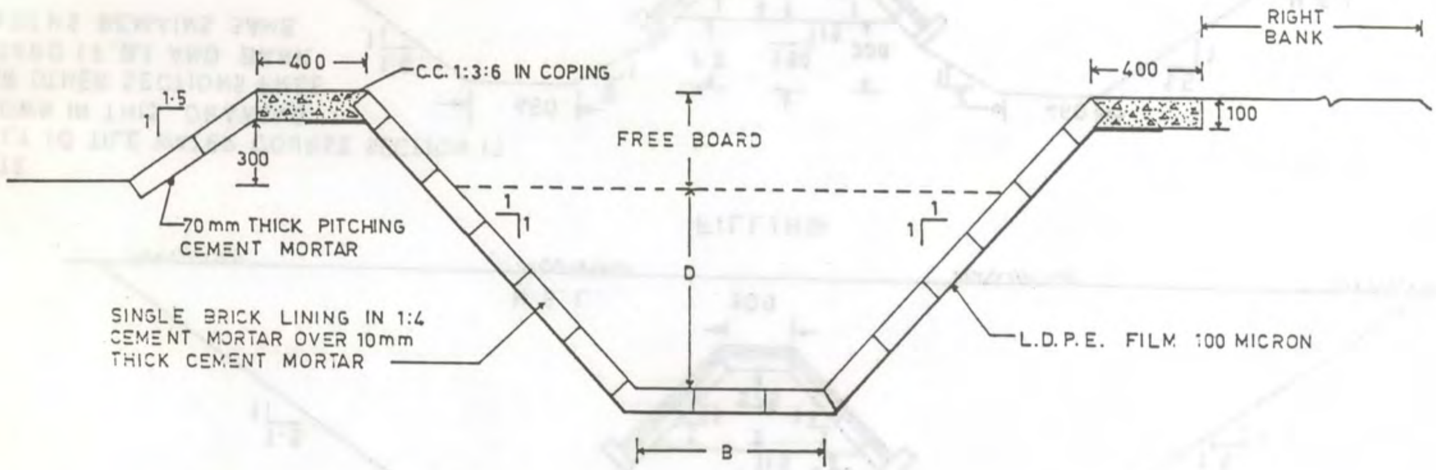
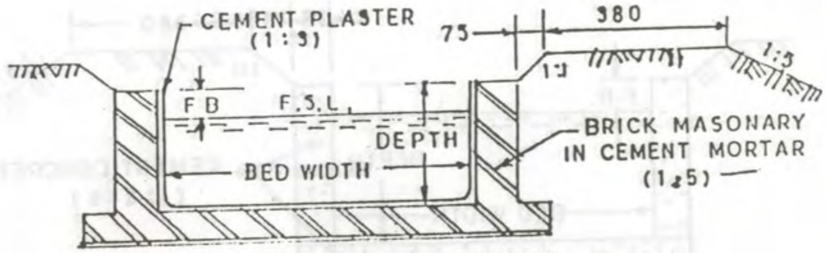
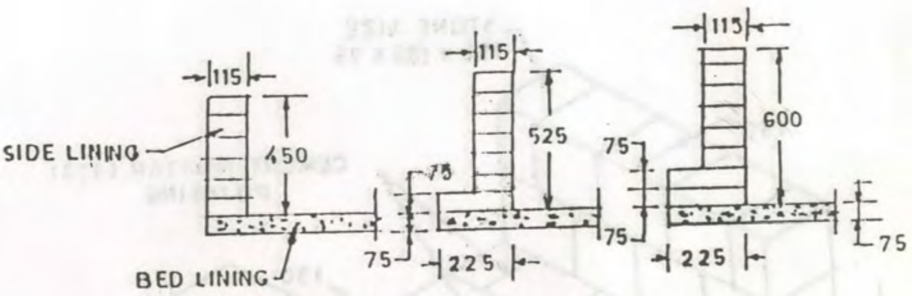


FIG. 4 :- TYPICAL CROSS SECTION OF BRICK LINED WITH LDPE FILM MINOR OF H. DY. SYSTEM FOR LINING Q ABOVE 10 CUSEC.



ALL DIMENSIONS IN MILLIMETRES

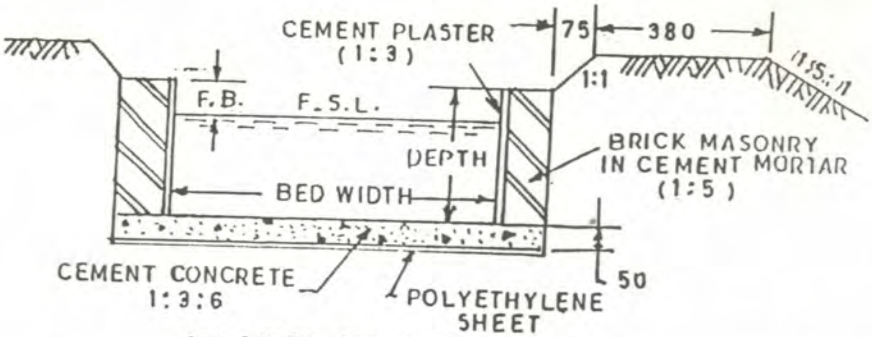
(a) TYPICAL BRICK MASONRY SECTION



ALL DIMENSIONS IN MILIMETRES

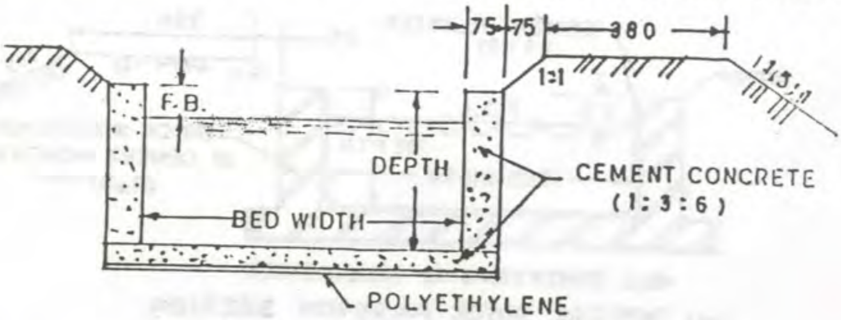
(b) TYPICAL SECTION OF SIDE WALLS

FIG.5 - TYPICAL SECTION OF BRICK MASONRY AND SIDE WALLS



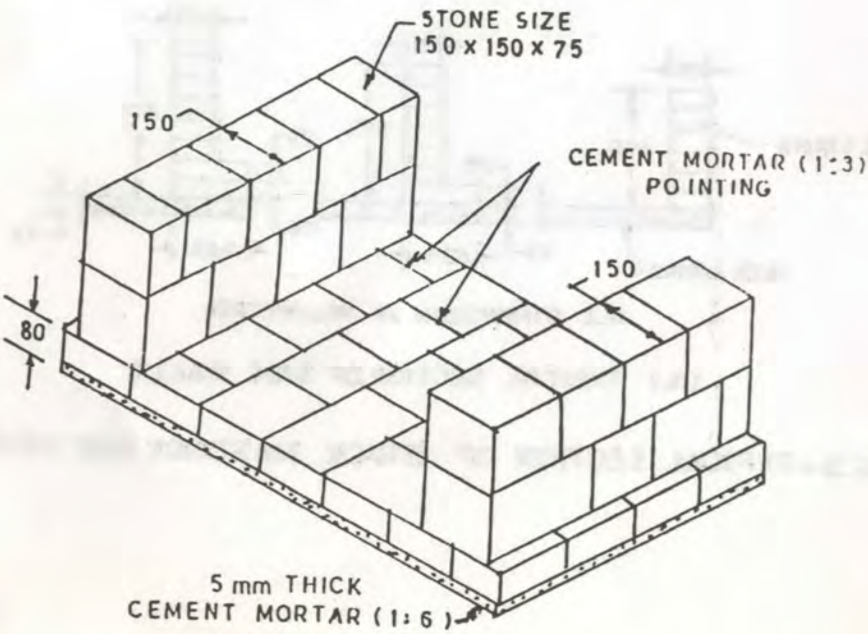
ALL DIMENSIONS IN MILLIMETRES

FIG.6–TYPICAL CEMENT CONCRETE AND BRICK MASONRY SECTION



ALL DIMENSIONS IN MILLIMETRES

FIG.7 –TYPICAL CEMENT CONCRETE SECTION



ALL DIMENSIONS IN MILLIMETRES

FIG.8 – STONE MASONARY LINING

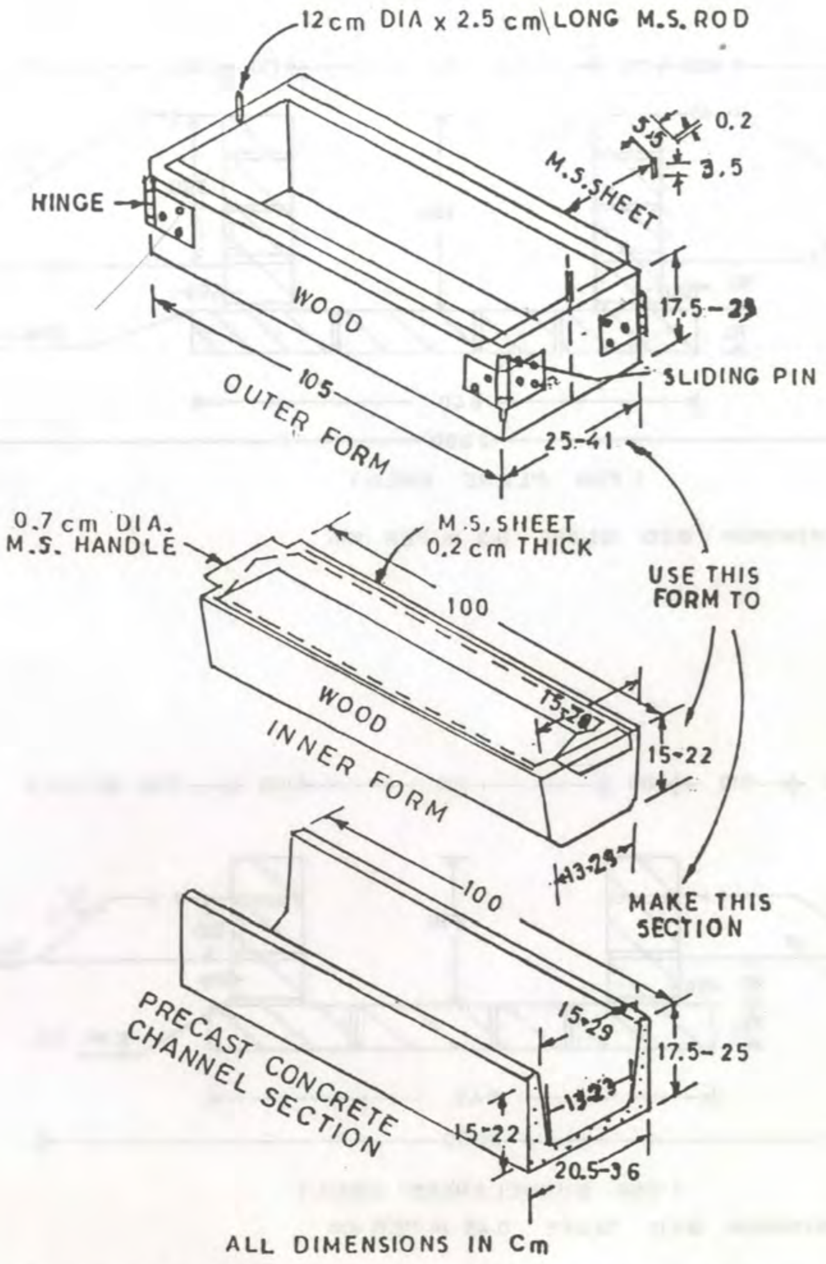


FIG.9 –RECTANGULAR SECTIONS FOR WATER-COURSES

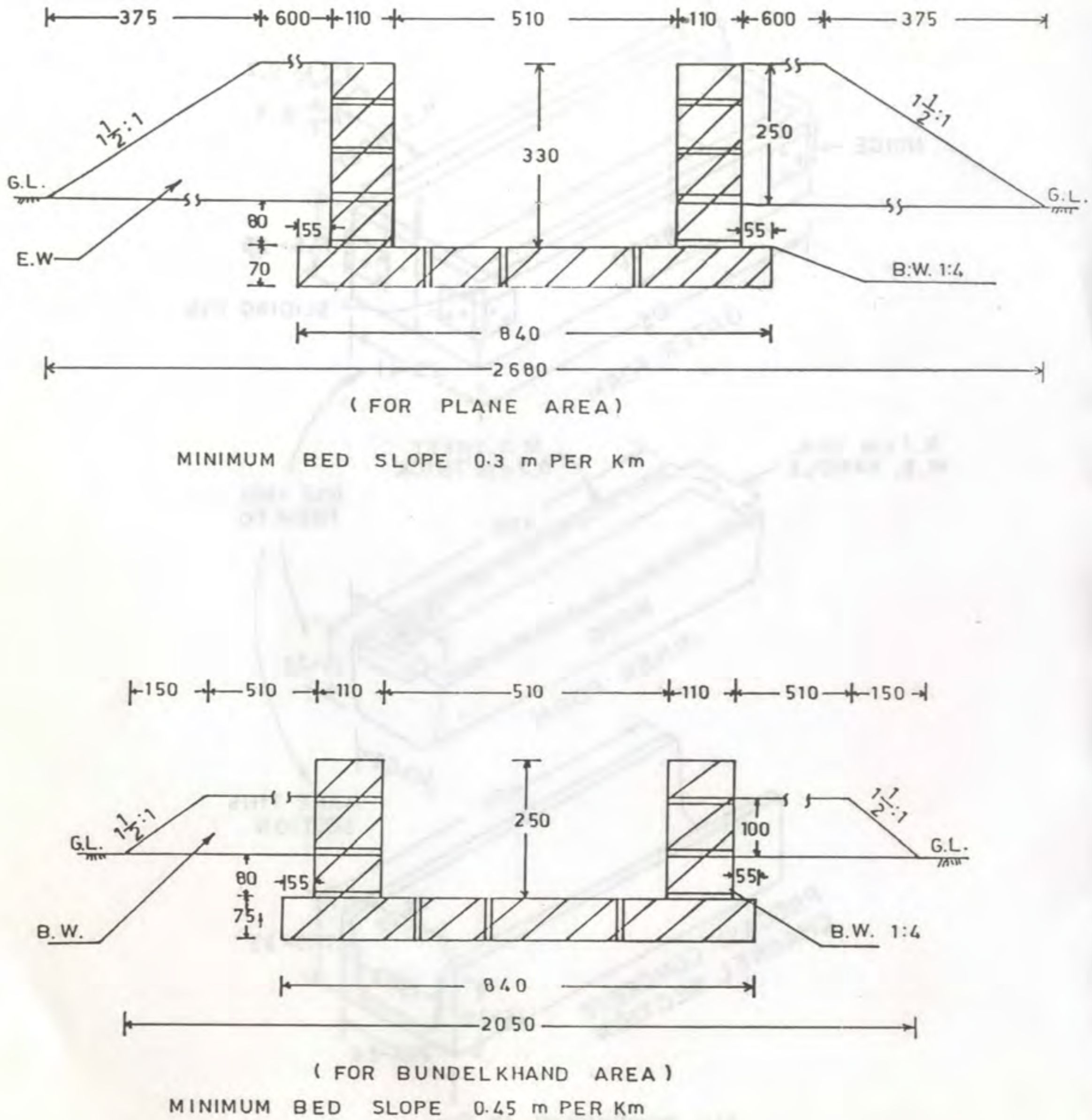
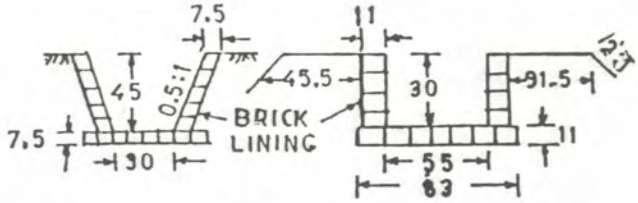
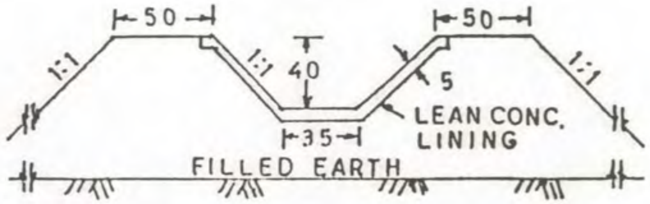


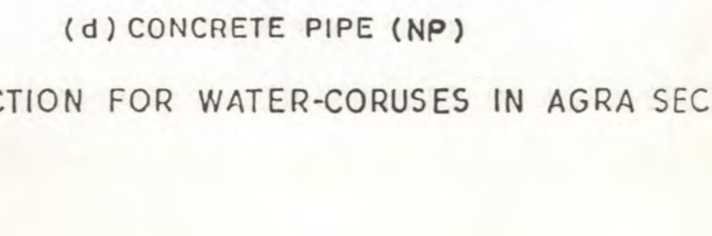
FIG.10:- SECTION OF LINED GUL FOR TUBEWELL



(a) TRAPEZOIDAL SECTION (b) RECTANGULAR SECTION



(c) SECTION WITH LEAN CONCRETE LINING



(d) CONCRETE PIPE (NP)

FIG 11–LINING SECTION FOR WATER-CORUSES IN AGRA SECTION

11. SPECIFICATIONS OF LININGS

11.0 INTRODUCTION

Laying of lining in a channel involves a number of operations, viz., preparation of subgrade, laying of under drainage, placing of lining and curing and filling of joints. The details of construction procedure and specifications which should be adopted with reference to more important types of linings are dealt with in this chapter.

11.1 PREPARATION AND COMPACTION OF SUBGRADE

Preparation of subgrade is one of the most important factors on which the successful performance of the lining depends. Failure or cracking of lining in many cases can be attributed in some measure to poor preparation of subgrade. Due stress is, therefore, to be laid on control and proper preparation of subgrade for lining.

11.1.1 Subgrade consisting of Soil

The subgrade should be prepared, dressed and rolled true to level and according to the required cross-section of the canal to form a firm compacted subgrade for the lining. Further more, the following points should be kept in mind. (Ref. 1)

1. In other than predominantly sandy reaches, where the dry bulk density of the natural soil is not less than 1.8 g/cm^3, initial excavation should be done upto about 30 cm above the final section and the cutting to final shape should be done immediately before lining.

2. For checking the uniformity of side slopes, sample profiles at an interval of 20 m in straight reaches and 10 m in curved reaches should be made. For this the use of concrete templates of suitable size may be made to laydown the correct profiles.

3. If some over excavation is seen, it should be filled up with graded filter material compatible with the subgrade material and thereafter compacted properly.

4. For canals in embankment it should be ensured that one monsoon is passed for proper consolidation before lining is done. To

coverup any lapses in the compaction of inner core of banks lip cutting width of 500 mm - 1000 mm shall be provided which will depend on nature of soil and side slopes of canal and type of mechanical compactors/manual compaction used. This pride should be removed only just prior to the placement of lining.

For compaction of subgrade consisting of predominantly sandy reaches the following procedure may be employed.

Bed - The compaction of bed should be done by over saturating the bed by flooding it with water before lining is laid.

Side - The compaction of sides may be done in any of the following two ways :

i. Over-cutting the subgrade by about 15 cm and refilling it with lean mortar containing adequate quantities of lime or cement and compacting it properly.

ii. Under - cutting the subgrade by about 10 cm and compacting the subgrade by using surface vibrators along with sprinkling of water and then lip cutting upto the desired profile.

6. For compaction of subgrade in other than predominantly sandy reaches, all compaction should be done at optimum moisture content in layers not more than 15 cm thick to obtain a dry bulk density of not less than 95 % of the density at optimum moisture content obtained in accordance with IS : 2720(part 7)-1980.

Where the dry bulk density of the natural soil is equal to or more than 1.8 g/cm^3, the procedure described in point 1 should be followed.

Where the dry bulk density of the natural soil is less than 1.8 g/cm^3 and the subsoil water is near the subgrade, the consolidation should be done by under-cutting the bed by 7.5 cm and then ploughing upto 15 cm below the subgrade level. The loosened soil should then be recompacted with sheep foot rollers or other suitable devices.

Where the subsoil water is low, requiring no dewatering and the dry bulk density of the natural soil is less than 1.8 g/cm^3, the consolidation should be done by digging the canal upto subgrade level and after loosing the earth below subgrade upto 15 cm by disc burrows or ploughing and compacting the same to a depth of 11 cm. After that, the second layer of

15 cm of earth should be laid over the compacted layer by taking earth from lip cutting and compacting this to a depth of 11 cm. The compacted layer of 7 cm above the subgrade level should be removed and the subgrade brought to design profile before laying the lining.

Consolidation on sides should be done by manual labour or suitable compactors to a depth of 30 cm to obtain a minimum dry bulk density of not less than 90 % of the density at optimum moisture content.

11.1.2 Subgrade consisting of Rock

The subgrade in rock should be excavated to the required cross-section. Over-excavation in rock is generally unavoidable and should be minimized by using wedging and barring methods, for final dressing.

Over-excavation in hard strata having side slopes more than 1:1 beyond the profile line may be backfilled with gravel and aggregate, large aggregate forming the bulk of backfill with smaller aggregate filling the voids and a layer of pea gravel as binding material. The bed may then be compacted with Road Rollers and sides with rammers to form a firm backing for the lining.

For over-excavation in hard strata having side slopes less than 1:1 , beyond the profile, the backfilling may be suitably done with chip masonry or lean concrete. However, for bed the backfilling may be done with properly compacted murum. Over-excavation upto 5 cm may be backfilled. If over-excavation is upto 10 cm, lean concrete may be used beyond 10 cm backfilling with chip masonry is preferable.

For slip-form paving, over excavation upto 10 to 15 cm may be required. Such over-excavation may be backfilled with selected material and compacted at optimum moisture. The material selected should be machine trimmable and be gravel/stone-free earth.

Excavated profile provides the final base for the lining and the tolerances should be comparable to those required for paving.

Departure from established alignment may be permitted upto:

± 20 mm on straight section

± 50 mm on tangents, and

± 100 mm on curves.

Departure from established grade is permitted upto ± 20 mm.

11.1.3 Subgrade consisting of Expansive Soil

Lining on expansive clays should be avoided as far as possible. However, if it is not possible and the canal proposed to be lined has to traverse a reach of expansive clays, suitable measures should be taken to prevent damage. These may comprise replacement of soil by over-excavating the section and placing a layer of 15-30 cm thickness of suitable non-expansive soil duly compacted preferably good clean sand.

If the swelling of the clay encountered can be controlled by loading the surface with non-expansive compacted soil or gravel, the expansive clay bed should be over-excavated to a depth of suitable thickness and filled to the grade of the underside of lining with good draining material leading away the seepage water to specially constructed points either to the outside of the canal or releasing it into the canal by provision of suitable pressure release valves etc. However, the excavated surface of expansive clay should be given a coat of asphalt (Ref. 2) before loading it to prevent the entry of water into the clay.

11.2 PLACING OF CONCRETE LINING

Concrete should normally be mixed in a mechanical mixer. Placing of concrete should not be started until all form work, installation of parts to be embedded and preparation of surface upon which concrete is to be laid have been completed. All absorptive surfaces against which concrete is to be laid should be moistened thoroughly so that moisture will not be withdrawn from freshly placed concrete. The surfaces, however, should be free from standing water and mud and 1:3 cement slurry shall be spread over the moist subgrade before placing the concrete to prevent absorption of water from concrete making it spongy. A plastic membrane of low density polythene film of suitable thickness may be used below the concrete lining in sides and in beds where the subgrade of the lining is of pervious materials like murum etc., so as to prevent absorption of water in subgrade from green concrete, during placement on the subgrade. The approved film is to be laid on the neatly well dressed subgrade, and fixed in the subgrade so as to prevent displacement during the placement of the concrete. The use of polythene sheets is for achieving better ultimate imperviousness of the lining as whole.

In case filter material is to be provided over subgrade to take care of differential hydrostatic pressure and draw-down in canal, designs of coarse filter material blanket immediately in contact with lining would be necessary. To make such filter blanket effective and to prevent ingress of concrete into it, before placement of concrete, polythene sheet should be placed over filter blanket. All concrete should be placed directly in its final position within 20 minutes of mixing. Concrete should not be dropped from excessive height and free fall should be kept to a minimum to avoid segregation. Construction should be continued until satisfactory construction joint is made. Concrete should not be placed faster than the placing crew can compact it properly.

11.2.1 Hand Placing

Hand placing of concrete should normally be adopted where cheap labour is available particularly in case of branch canals or water courses where the quantity of concrete to be placed is small. The lining should normally be placed first on the bed and then on sides. Where site conditions require laying of lining on sides first, it should be supported on toe walls.

The concreting of the sides and bed should be done in alternate panels. The panel width should vary from 2 to 3 m. The construction joints should be either parallel or perpendicular to the direction of flow. In case the full supply depth is high, construction joints along the direction of flow to divide the length of the panel should be provided. For this purpose wooden rafters should be used.

The succeeding panels should be laid at an interval of one day. If the sloping length is less than 2.5 to 3.0 metres, concrete should be placed in one operation over the entire length. The bays/panels should be formed by proper form-work of M.S. channels laid all around the bay. The channels should be firmly spiked to the subgrade so that no movement takes place at the time of concreting and vibration. The depth of M.S. channels should correspond to the required thickness of concrete lining. The concrete should be dumped in the bay from bottom to top and then spread all over the bay uniformly and to the required thickness guided by the channels. The spread concrete should then be compacted properly and thoroughly by means of mechanical or sacred vibrators. In order to test the effectiveness of vibration, permeability and strength of concrete cores at suitable places from the sides as well as from the bed concrete should be taken.

11.2.2 Mechanical Placing of Concrete

Concrete for slip form should be air entrained to provide a more workable and slipable mix. Percentage of air may be as follows :

Maximum aggregate size (mm)	Air percent by volume mm
10	8.0
12.5	7.0
20	6.0
25	5.0
40	4.5

Air entraining agents will always be used in concrete by means of slipform paving machine for entraining air.

Subgrade guided slipform -

This should be used for lining small to moderate size canals. The slipform should be supported directly on the subgrade and operated longitudinally along it. Concrete should be screeded on the bed along the canal and on the sides from bottom to top.

Rail guided slipform -

This should be adopted for larger canals of considerable length. Slipforms supported on rails placed along both berms of the canals should be operated longitudinally. Concrete should be spread uniformly on the bed longitudinally and on the sides from bottom to top.

11.2.3 Thickness of lining

The thickness of lining should be fixed depending upon the nature of the canal requirement, namely, hydel channel or irrigation channel, full supply depth, channel capacity quality of subgrade and expected hydrostatic pressures. Hydel channels should have a greater thickness than irrigation channels because of draw-down effects and where closure for repairs may not be usual. Deeper channels should have greater thickness than shallow depth channels. Minimum thickness of canal lining based on canal capacities are given below. (Ref. 1)

Capacity of canal (Cumecs)	Depth of water (metres)	Minimum thickness (mm)
0 - 5	0 - 1	50 - 60
5 - 50	1 - 2.5	60 - 75
50 - 200	2.5 - 4.5	75 - 100
200 - 300	4.5 - 6.5	90 - 100
300 - 700	6.5 - 9.0	120 - 150

<u>Note</u> : If surface deterioration in freezing climate is expected, hickness may be increased. Similarly, care should be taken if the lining is subjected to external hydrostatic earth pressures or uplift caused by expansive clays or frost heave.

In Garhwal Rishikesh Chilla Power channel of 565 cumecs capacity about 100 m length u/s & d/s of all 11 Nos. cross drainage works insitu concrete consisting of 300 mm thick M_{150} concrete laid over 100 mm thick M_{80} base concrete has been provided.

In Narmada main canal in head reaches 125 mm M_{15} cc lining has been provided. From safety considerations near cross drainage works, thickness of M_{15} concrete lining in bed & sides has been kept as 200 mm & 250 mm respectively. On either side of drainage crossing in a lengh of 15 m, lining has been reinforced with 12 mm ∅ bars 300 mm c/c spacing.

Accepted Tolerance in Concrete Lining - The following tolerances may be accepted :

(i)	Departure from established alignment	± 20 mm on straight reaches ± 50 mm on curves or tangent
(ii)	Departure from established grade	± 20 mm on small canals
(iii)	Variation in thickness	± 10 mm provided average thickness is not less than specified thickness.

11.2.4 Finishing

The surface of concrete finished against forms should be smooth and should be free from projections, honey combing and other objectionable defects. Immediately on the removal of forms, all unsightly ridges or lips should be removed and undesirable local bulging on exposed surface should be remedied by tooling and rubbing. Repair of concrete surface and additions where-ever reuired should be made by cutting regular opening not less than 7 cm in depth into the concrete and placing fresh concrete to the required lines. The fresh concrete should be reinforced and chipped and troweled to the surface of the opening. The mortar should be placed in layers not more than 2 cm in thickness after being compacted and each layer should be compacted thoroughly. All exposed concrete surfaces should be cleaned of impurities, lumps of mortar or grout and unsightly stains.

11.2.5 Curing

Subsequent to laying of concrete lining and after a period of about 24 hours, the lining should be cured for at least 28 days. On bed this may be done by constructing 15 cm deep earthen bunds across the bed so that a small depth of water will stand on the bed. The curing of side slopes may be done by constructing masonry drains with weep holes or perforated pipes on the coping at the top of the lining or by sprinklers.

Curing may also be done with white pigmented curing compound as described in chapter 3 para 3.1.2, construction details.

11.2.6 Safety Ladders

Safety Ladders consisting of ladder rungs should be constructed in canal lining about 30 m upstream of the point where canal enters some underground structure. In other reaches safety ladders may be provided at a spacing of about 300 m; the ladders being provided alternatively on either side.

As an alternative to safety ladder of steps of rise 150 mm, tread 300 mm and 1500 mm wide may be provided in plain cement concrete of grade M-10 or masonry at a spacing of 300 m centre to centre on either side of canal. Details of safety ladders and steps are shown in Fig. 1.

11.3 PRECAST CEMENT CONCRETE SLABS FOR LINING

Dimension : The nominal dimensions of the slabs should be as specified below :

Length (mm)	Breadth (mm)	Thickness (mm)
500	250	60
500	250	50
250	250	50

The permissible tolerance on length and breadth should be ± 3 mm. The difference in the length of diagonals of a slab should not be more than 4.5 mm. The thickness should be not less than the specified value. The permissible tolerance on thickness should be ± 2 mm.

Shape : The slabs should be either with all its sides at right angles to the faces or with two of its sides bevelled at a particular angle to the faces.

11.4 BURNT CLAY TILE LINING

11.4.1 Design Considerations

The lining on bed may consist of single tile lining or double tile lining. The lining on sides should be double tile lining.

Single Tile Lining : This consists of a single layer of burnt clay tiles laid on about 10 mm thick 1:5 cement mortar on well dressed subgrade. Joints should be well filled with mortar of the same consistency. Joints should then be raked to 12 mm depth, and after that not less than 20 mm thick cement plaster 1:3 should be laid on it, which should be given smooth finish. The mortar should be laid on 6 m lengths being laid alternately. The total thickness of lining should not be less than 80 mm. The thickness of joints should not exceed 10 mm.

Double Tile Lining : The sides should consist of double layer of tiles with not less than 15 mm thick sandwiched layer of cement mortar 1:3 mix. The first layer of tile should be laid on about 10 mm thick 1:5 cement mortar spread on compacted subgrade dressed to specified slope. The joints should be filled with mortar of the same consistency. The first layer of tiles should be covered with 1:3 cement plaster not less than 15 mm thick on the top of which second layer of tiles should be laid in about 5 mm thick 1:3 mortar except for the bottom 1 m length before its junction with single tile lining in the bed. The last metre in such case should be joined to the single tile lining in the bed by laying 1 : 2 : 4 cement concrete in half metre width and by laying 1 : 3 mortar in the rest half. Total thickness of lining masonry should not be less than 130 mm.

Mix for Cement Mortar : The following proportions for cement mortar should be used for lining works. However, the mortar should conform to IS : 2250-1960 (Refer IS : 3872-1966) :

(a)	For 10 mm thick cement mortar subgrade	1 : 5 by volume
(b)	Mortar for masonry of first layer of tiles	1 : 5 by volume
(c)	For 15 mm thick sandwiched cement and sand plaster	1 : 3 by volume
(d)	For 5 mm thick cement and sand mortar and for tile masonry for top layer	1 : 3 by volume
(e)	For 20 mm thick cement and sand plaster over the layer of tiles single tile lining in bed	1 : 3 by volume

The use of pozzolanas and other admixtures including water proofing compounds may be permitted.

11.4.2 Top Coping

To check the leakage of rain water behind the lining on sides, not less than 150 mm thick cement concrete coping should be provided horizontally on the top of the lining. The width of the coping at the top should not be less than 350 mm.

11.4.3 Preliminary Work

Humps of concrete or masonry about 150 mm high should be provided where-ever necessary in the bed of the canal at every 300m intervals, to ensure that during short closures the bed of the canal does not dry and thus does not expose the plaster to direct rays of sun which may otherwise result in formation of cracks. Arrangements should be made to soak the tiles in water for at least two hours.

11.4.4 Laying of Tiles - Phased steps

Lining of First Layer of Tiles - First and Second Day Programme : The lining should be started only when at least 30 m length of canal with subgrade is properly dressed to receive the lining. The lining should normally be placed first on the bed and then on the sides. Where site conditions require laying of lining on sides first it should be supported on the toe walls. Necessary arrangement for proper soaking of tiles and mortar mixing should be made and sufficient number of tiles should be made available before starting the work. Where spring level is high, the water-table should be lowered to at least 30 cm below the subgrade by dewatering. The subgrade should then be uniformly soaked with water without making it slushy to ensure that water penetrates to a depth to about 300 mm in sandy soil and about 150 mm in other soils. Wetting of subgrade should continue in advance of laying of tiles so that the soil does not absorb moisture from 10 mm thick mortar laid on the subgrade for laying the layer of tiles.

Single tile profiles of lining parallel to centre line of the canal should be prepared at suitable intervals. Mortar should be uniformly spread over the subgrade and the tiles should be properly laid in position soon after. Care should be taken to see that the vertical joints are completely filled with mortar. The tiles should be laid in bed at right angles to the centre line of the canal while on the side slopes they should be laid parallel to the centre line. Enough number of profiles both in the bed and slopes should be laid each day so that when the work is started next day the marks should already be in position. Construction points of panels at suitable width each in bed and sides should be perfectly rolled, levelled and laid with profiles every day to receive lining of the first layer of tiles on the next day.

Curing and Correction - Third and Fourth Day Programme : On the third day the layer of tiles should be kept wet by sprinkling water over it, to keep the mortar well wetted. On the fourth day, the surface should be kept wet and joints of the tile masonry should be carefully tested. Hollow joints should be raked to a depth of 12 mm, loose mortar removed from sides and top of tiles and the joints properly refilled. Any loose tile should be removed and relaid.

Laying Cement Mortar Layer - Fifth Day Programme : For single tile lining not less than 20 mm thick cement plaster of 1:3 mix should be laid on the completed portion of the bed. To ensure proper thickness of mortar being laid and to achieve perfect level in spreading of cement mortar, L-shaped wooden frames of 1.0m x 1.5 m made of 20 mm thick wooden plankings. should be used. The plaster should be well pressed while laying so that any excess of water or air locked within the pores is driven out, thereby providing uniform plaster over the layer of tiles. The surface of the plaster should be finished even and smoothened after lightly sprinkling it with pure cement. This ensures smooth hard surface thus checking the erosion of the surface of the plaster by water action.

When double tile lining is to be laid either on bed or on side slopes, not less than 15 mm thick sandwiched layer of 1:3 cement sand mortar should be laid by using L-shaped wooden frames of 1.0 m x 1.5 m made of 15 mm thick wooden plankings. This should be done to ensure that correct thickness of 15 mm is obtained over the whole surface. The plaster should be well pressed while laying so that any excess of water or air locked within the pores is driven out, thereby providing uniform plaster over the first layer of tiles. The upper side of the plaster should be made rough for proper bond with the layer of tiles by means of fibre brushes of brooms. Wire brushes and nails should not be used for the purpose.

Keeping Plaster Wet - Sixth Day Programme : The cement sand plaster should be kept well wetted on the sixth day.

Laying Top Layer of Tiles - Seventh Day Programme : The top layer of tiles in case of double tile lining should be laid in 1:3 cement mortar about 5 mm thick. This layer of tiles should be laid firmly and properly to proper levels in beds and correct slopes on the sides with joints not more than 10 mm thick.

Tiles used on the top layer should be the best and laid with great precision. Vertical joints should be laid flush with cement mortar and no cement pointing lining should be checked for level with wooden templates and spirit levels.

11.4.5 Curing

Work done on each day should be kept thoroughly wet for curing. In case of single tile lining, subsequent to laying of cement plaster layer and after 24 to 36 hours, and in case of double tile lining after laying the second layer of tiles, the lining should be cured for at least 28 days as per 11.2.5.

11.5 BOULDER LINING

11.5.1 Stones used for lining should be round or subangular river cobbles or blasted rock pieces with sufficient base area to be stable. Individual stones should be sound, hard and durable and should be such that they will be able to sustain weathering and water action. They should be free from laminations, soft spots, cracks, seams and other defects. All the stones should have a reasonably uniform size with dimensions as given below depending upon the canal capacity:

Sl. No.	Canal Capacity m^3/sec	Thickness of lining mm	Average dimension along the longest axis mm	Minimum dimension at any section mm
1.	Less than 50	150	150	75
2.	50 to less than 100	225	225	110
3.	100 and above	300	300	150

Note : 1. A maximum tolerance of 10 percent is permissible in the thickness of lining and dimensions of stones.

2. Limiting safe velocity may be adopted as 1.5 m/sec.

For judging the suitability of stones for canal lining, the following tests may be got conducted. (Ref. 3)

Sl. No.	Test	Requirements
1.	Specific (apparent) gravity when tested according to the method given in IS : 1126-1974	Greater than 2.5
2.	Soudness (sodium sulphate method) when tested according to IS : 1126-1974	Less than 10 % loss of weight after 5 cycles.

11.5.2 Laying of Boulder Lining

Subgrade (both bed and slope) of the canal should be divided into compartments by stone masonry or concrete ribs. The compartments should have dimensions of more than 15 metres along the centre line of the canal. The spacing of ribs across the centre line should be so chosen as to divide the canal bed and slope symmetrically about the centre line and in such a manner that ribs are provided at the junction of the slope and bed and at upper extremity of the slope. The ribs along the slope of the bank should be continuous. (Fig.2)

If stone masonry ribs are used, the stones should meet the requirement as specified in clause 5.3 of IS : 4515-1993. In case concrete ribs are used they should be made of grade M 10 concrete in accordance with IS : 456-1978.

Space between stones should be minimized. Such spaces should be wedged with spells of suitable size to avoid filter material being washed away . Such filling should immediately follow the placing of stones. A 15 cm thick layer of filter material where-ever required, should be laid in compartments formed by ribs.

11.5.3 Requirements of filter material

Filter material where required, should be free from flakes, soft particles, shale, organic matter or other deleterious substances and should satisfy the following criteria :

i. $\frac{D_{15} \text{ of filter}}{D_{15} \text{ of base material}} > 4 \text{ and } < 20$

$$\text{ii. } \frac{D_{15} \text{ of filter}}{D_{85} \text{ of base material}} < 5$$

Where a large difference exists between the grading of the free draining material and of the soil to be retained, it may be necessary to use more than one layer of filter material, each progressively larger in grain size but satisfying the above filter criteria.

11.5.4 Construction of Filter

The subgrade, before placing the filter, should be firm and compacted suitably, wherever necessary, according to IS : 3873-1993.

Clean filter material should have sufficient water content (3 to 10 percent) during placement and placement should be such that segregation is prevented.

11.6 PRECAST CONCRETE TILES/STONE SLAB LINING

The tile should conform to IS : 10646-1991 and stone slab to IS : 1128-1974 or IS : 3622-1977 of length 0.45 to 0.90 m, with 0.45 m and thickness 35 to 50 mm (Ref. 1). The lining should be started only when at least 35 m length of canal subgrade is properly dressed to receive lining. The arrangement of mortar and availability of sufficient number of tiles/stone slabs should be ensured before starting the work. The subgrade should then be uniformly soaked with water without making it slushy to ensure that water penetrates to a depth of 300 mm in sandy soil and about 150 mm in other soils. Wetting of subgrade should continue in advance of laying of tiles so that soil does not absorb moisture from the mortar laid on the subgrade on laying the layer of tiles.

Single tiles/stone slab profile of lining parallel to central line of the canal should be prepared at suitable intervals. Mortar (1:3) should uniformly be spread over subgrade for a minimum thickness of 12 mm and the tiles should be properly laid in position quickly. It should be ensured that vertical joints are completely filled with mortar. The tiles/slabs should be firmly embedded in mortar. Hollows if any should be rectified by relaying the defective portions with fresh mortar.

On completion of laying lining should be kept wet by sprinkling water over it to keep the mortar wetted. On the next day, the surface should be kept wet and joint should be carefully wetted. Hollow joints should be raked to a depth of 12 mm, loose mortar removed from sides and top of tiles/stone slabs and the joints properly refilled. Loose tiles/stone slab should be removed and relaid.

11.7 SOIL-CEMENT LINING

11.7.1 Pulverising the soil

The soil should be pulverised preferably mechanically to make sure that there are no clods.

11.7.2 Mixing Soil and Cement

The required quantity of cement should be thoroughly mixed with the dry soil either mechanically or by hand mixing through manual labour. The mixing should be continued till the soil-cement mix acquires uniform colour through out which can be examined under a magnifying glass. The required quantity of water will be added and mixing continued to ensure uniform distribution of the moisture through out the soil-cement mass.

Batching of the materials should be by weight or by volume conforming to the weight. The appropriate quantities of soil and cement required for one batch should be measured out after making due allowance for the moisture present in the soil. The correct amount of water to bring the moisture content of the mix to the optimum should then be added.

11.7.3 Placing

The mixed material should be discharged uniformly on to the prepared subgrade and distributed to a uniform loose layer by means of shovels and rakes. Care should be taken to obtain uniformity in depth. Sufficient depth of loose material to give the required thickness after compaction should be spread in one operation. Generally, it is necessary to process 13 to 15 cm of loose soil to obtain a compacted thickness of 10 cm.

In the case of plastic type soil-cement lining the mixed material at the specified moisture content should be placed over the moist subgrade to a uniform thickness which may be 15 to 20 percent more than the required thickness. The minimum thickness of finished plastic type soil-cement lining should not be less than 5 cm.

11.7.4 Compaction of Soil-Cement Mix

Compaction should be carried out continuously as the mixed material is spread but the equipment should be kept sufficiently far back from the free edges of the layer to prevent lateral movement of the mixed material. The compaction should be affected by means of a smooth wheeled roller, vibratory roller, tempers or any other type of equipment capable of achieving the desired degree of compaction.

The time between the discharge of the mixed material and the commencement of the compaction should be as short as possible and in no case should exceed 30 minutes. Compaction of any portion of the layer to the required density should be compacted within 1½ hours after the material has been spread.

For the plastic type soil-cement lining compaction may be done by wooden templates and rendered smooth with a wooden float. In plastic type soil-cement lining relatively less compactive effort is required to obtain the desired density.

Finishing Standard Soil-Cement : After compacting the mix, the soil-cement layer should be rolled with smooth wheeled rollers to the exact profile.

11.7.5 Finishing Plastic Soil-Cement

After compacting with templates and wooden floats the final finish for plastic soil-cement lining should be obtained by wooden floats.

11.7.6 Immediately after final compaction and finishing the surface of the soil-cement should be kept continuously damp for at least seven days. This should be achieved by covering the surface with damp hessian, straw, or sand maintained moist throughout the period of curing.

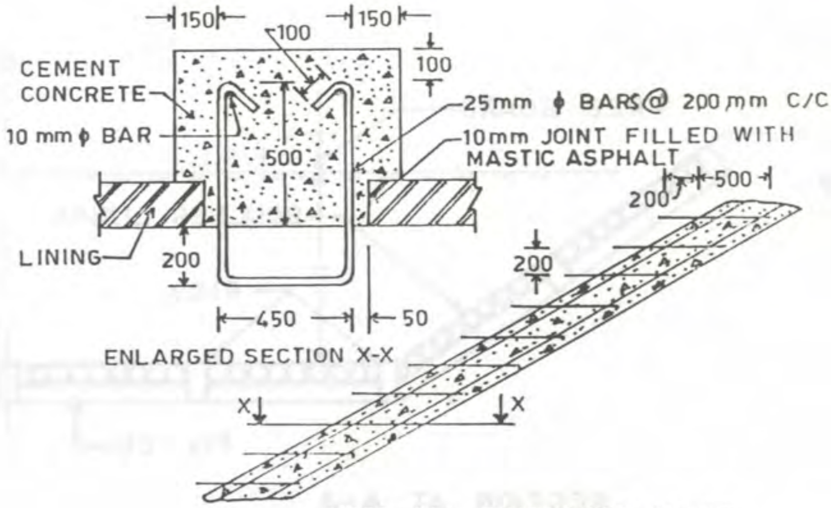
References

1. Indian Standard : "Code of Practice for Laying Cement Concrete/Stone Slab lining on canals" IS : 3873-1993 (Second Revision).

2. Indian Standard : "Specification for Plastic Asfalt" IS : 424-1965 (Revised).

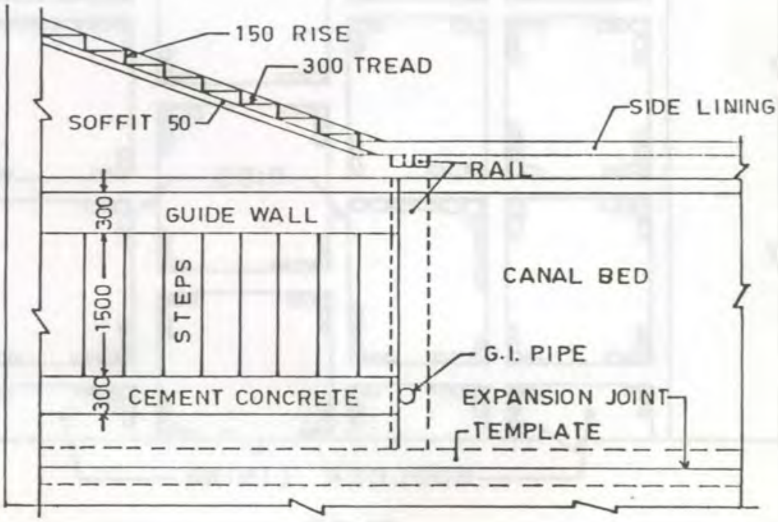
3. Indian Standard : "Code of Practice for Stone Pitched lining for canals" IS : 4515-1993 (First Revision).

4. Indian Standard : "Code of Practice for Lining of Canals with Burnt clay Tiles" IS : 3872-1966.



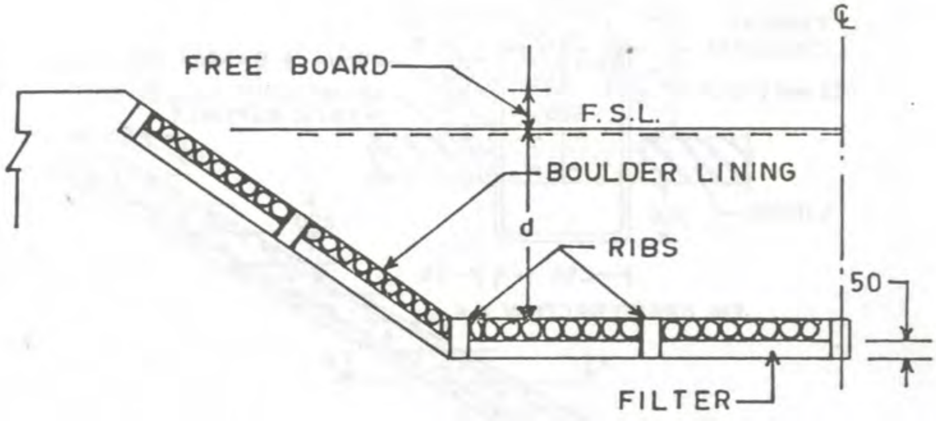
NOTE:-ALL DIMENSIONS IN mm.

DETAILS OF SAFETY LADDERS

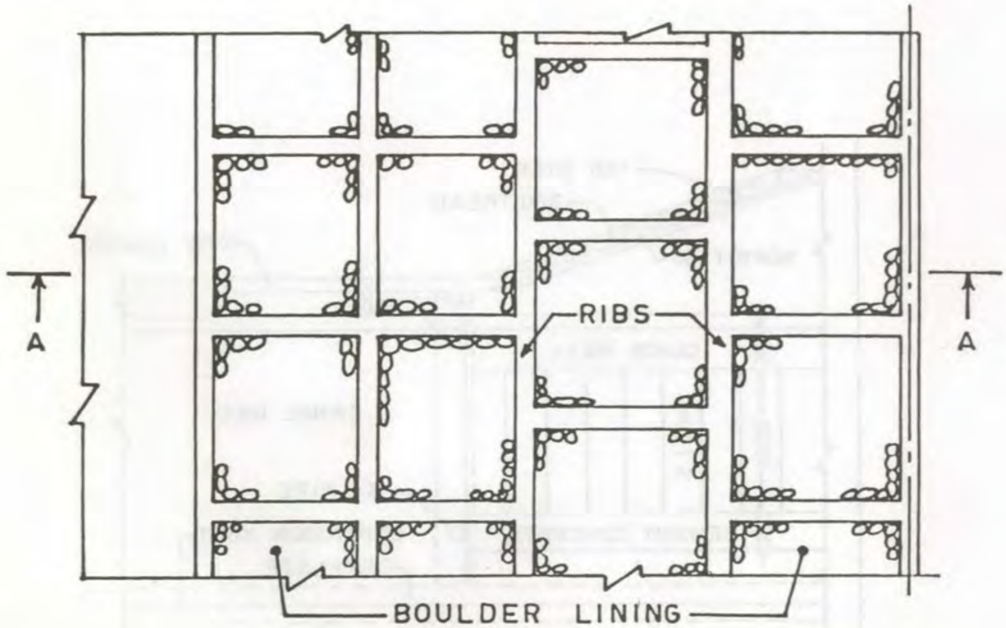


NOTE :- ALL DIMENSIONS IN mm.

FIG.1 :- DETAILS OF STEPS



SECTION AT A-A



PLAN

FIG. 2:- ILLUSTRATORY LAYOUT OF STONE PITCHED LINING FOR CANALS.

12. ASSESSMENT OF SEEPAGE LOSSES FROM CANALS

12.0 INTRODUCTION

The seepage losses from unlined canals in India have been found to vary from 0.3 to 7.0 $m^3/sec/10^6m^2$ for different soils and drainage conditions. The results of actual field measurements of seepage losses in different reaches of Upper Ganga main canal, its branches, distributories and minors are given in Table 1. These tests were conducted in 1980-81 by field division of WAPCOS and Irrigation Research Institute, Roorkee.

The seepage losses from unlined channels can be determined by direct measurement on the channels or calculated by theoretical methods. The theoretical calculations of seepage losses based on coefficient of hydraulic conductivity of soil and the boundary conditions of the flow system, are of particular value for the canals, which are in the planning stage. The methodology for direct measurement of seepage from channels has progressed sufficiently to enable acquisition of quantitative data for wide variety of conditions.

12.1 DIRECT MEASUREMENT OF SEEPAGE LOSSES

The methods available for direct measurement of seepage losses from open channels are the inflow-outflow, ponding, seepage meter, and tracer techniques. The inflow-outflow and ponding methods are applicable regardless of canal or soil conditions. The seepage meter cannot be used where the channel has rocky bottom or heavy weed growth.

12.1.1 Inflow-Outflow Method

The inflow-outflow method utilizes measurement of discharges at the upstream and downstream ends of the reach being studied. The quantities of water flowing into and out of the reach of canal are carefully measured, and the difference is taken as seepage loss in the reach. The inflow-outflow method gives the seepage losses from a canal section under normal operating conditions.

Existing calibrated weirs and flumes in the canals can be used for measuring flows. Where permanent installation such as these are not available, or not located at convenient points, temporary weirs or gauging stations can be installed. Temporary weirs introduce considerable loss in head, which may make their use impracticable. The ideal gauging sites would be where canal has rectangular cross-section. Current meters are used at gauging stations to measure the velocity from which the rate of flow is derived. When seepage tests are of long duration and when the tests are to be repeated in the future, the gauging stations should be rated. Water stage recorder and the rating curve can then be used to determine flows without frequent recourse to current meter gaugings.

Limitations : The method is not very accurate as the order of error involved in measurement of canal discharge may be of the same order or even higher than the quantum of seepage loss involved. In case seepage losses are determined for a long section of the canal, it is not possible to know the distribution of seepage losses in various reaches. The knowledge of reach-wise seepage losses would help in taking decision in favour of lining and in fixing priorities for lining. Also when applied to a large reach of the canal, the steady state condition may be established, after a long time and the leakage and outflow of the off-taking channels would have to be evaluated to determine the seepage losses.

12.1.2 Ponding Method

The ponding method can be applied to smaller reaches of a canal. This method is particularly useful in measuring small seepage losses.

This method consists of measuring the rate of drop in a pool formed in the section of the canal to be tested. Since the observations can be made with reasonable accuracy, the results may be taken as a good indication of the average loss from the section. The still water in the pool may seep out at a different rate from that of the flowing water in the canal. However, the difference is probably reconsequential in view of the errors associated with other methods of making seepage measurements. To eliminate the effect of wind, the rate of drop should be measured at each end of the pool. Staff or hook gauges attached to already existing structures or to stakes driven into the canal bed should be used. All leaks must be carefully measured, and evaporation and rainfall should be recorded so that the drop in water surface can be corrected for these items.

A modification of the ponding method consists of adding water to the pond to maintain a constant water surface elevation. The volume of water so added is taken as the seepage loss and the elapsed time establishes the rate of loss.

Limitations : Ponding tests can be made only when the canal is not in use. Constructing bunds to form the pools is expensive. Providing water to fill the pools sometimes involves difficulties, particularly because the pools must be filled several times before the seepage rate becomes stabilized which may take considerable time. Filling the pools also is a problem. For these reasons, the ponding method is not used unless the importance of the tests warrants fairly large expenditure. Furthermore, although the ponding method gives the average seepage from a pool, it does not show what the variation in the seepage rates from different parts of the pool may be. The sedimentation of suspended material that would normally be carried downstream may result in severe under-estimation of the normal seepage rate.

12.1.3 Seepage Meter Method

Seepage meters are in principle suitable devices for measuring local seepage rates in canals or ponds. They are, therefore, more suited for investigational work, for example evaluation of seepage losses in different reaches of the canal or its distribution system. Information of this type may be of help in locating reaches of heavy seepage to decide the necessity of lining. Advantages of seepage meter are :

(i) It can be used under water and normal working of channel is not disturbed.

(ii) It can be used for measurement of seepage losses from the bed as well as from sides.

(iii) The use of seepage meter gives quick results and is economical.

Types of Seepage Meters : The design principle of the seepage meter is based on the assumption that the rate of water loss for an isolated surface area of the canal can be measured. The water head acting on that area must be identical to that acting simultaneously on the adjacent surface. Several types have been used, as for instance the submerged flexible bag of the meter developed by the Salinity Laboratory of Department of Agriculture, the well hook gauge of the Soil Conservation Service, and the variable head technique seepage meter developed by Bouwer. A constant head seepage meter developed by U.P. Irrigation Research Institute, Roorkee working on the principle of Mariotte tube is an improvement in this respect over the other types of seepage meters and is described below :

U.P.I.R.I. Type Seepage Meter : The seepage meter designed at U.P. Irrigation Research Institute is shown in Fig. 1. In order to maintain constant head of water on the confined area of the canal perimeter within the seepage meter cup, the principle of the Mariotte syphon is used. Water is supplied to the cup from the burette acting as Mariotte vessel which also acts as a reservoir. As the water flows out from the vessel (burette) into the cup the water level inside it falls resulting in inflow of air into the vessel; the quantity of air thus drawn in would adjust itself in a manner such that the combined pressure of the water and air within the vessel at the level of point E is equal to the atmospheric pressure. The position of Mariotte vessel is so adjusted that the point E is in line with the canal water surface while carrying out measurements of seepage loss so that the pressure inside the seepage meter is identical with the pressure outside.

Working of Seepage Meter : The seepage cup is lowered into the canal with its air release valve open to allow the entrapped air to escape. The valve is then closed and the seepage cup gently pressed on to the canal bed till the baffle plate is in contact with the canal bed. The tube of the constant head vessel is then taken out and the vessel is filled with water up to the top, it should be ensured that all the air entrapped inside the plastic tube is expelled before any observations are taken.

The tube is then replaced and the vessel is clamped to the stand in such a way that the lower end of tube is in level with water inside the canal. The fall in water-level of the gauge tube during a known period of time is noted. From the observed fall in water-level the seepage losses can be calculated.

Limitations : Seepage meters provide a clean and quick method of measurement of seepage from canals. It does not disturb the normal working of the canal. If the condition of equal pressure outside and inside, and the minimum soil disturbance requirement are met the seepage meter should give an accurate measure of seepage rate for part of the channel bottom enclosed by the seepage cup. Because this area is small and conditions vary from point to point, number of measurements will usually be required to adequately evaluate the average seepage for a certain canal section. Jenson reports that with the technique described, 18 seepage measurements were sufficient to yield a 15 percent standard error in the mean and 40 measurements would give a 10 percent standard error in the mean.

The seepage meter is difficult to be used in deep canals, particularly if the water is turbid or flowing at high velocity. There are at least three possible sources of error in measuring seepage with seepage meters. One may be due to disturbance of bottom materials when the meter is installed. This error may be reduced by minimising the depth of penetration of seepage meter into the canal bottom. Secondly, error may also be introduced if, when the outflow from the seepage meter is measured, the pressure head inside the meter is not exactly equal to that due to the free water surface. A third source of error may be due to the pressure distortion around the meter from inflowing water. The error caused by such a difference is only significant in case of low seepage gradients.

12.1.4 Tracer Technique

The method is best suited to homogeneous and isotropic foundations. The tracer technique is more economical from the point of view of time, cost and repeatability of the studies than other methods. This approach is direct and independent for the determination of filtration velocity and direction of flow. The tracer technique is relatively simple to use and can be applied in deep canals with turbid and/or fast flowing water, for canals with heavy weed growth and adverse bottom conditions.

Earlier, salts, dichromates and dyes were used as tracers. These are being replaced by the use of radio-tracers because of their high sensitivity to detection. A radio-active tracer is a mixer of isotopes of an element which may be incorporated into a sample to make possible observations of course of that element, alone or in combination through a chemical, biological or physical process. The observations may be made by measurement of radio-activity. A few of the advantages of using radio-tracer for seepage flow measurement are as below :

(i) Radio-tracers are detected even in the minutest concentration of the order of 10^{-10} to 10^{-11} miligram of radio-active substance per litre volume of water. The low concentration does not disturb the ground flow pattern.

(ii) These are readily detected by the help of detecting equipment.

(iii) Disintegration of radio-tracer does not involve any temperature, chemical, or biochemical reactions.

(iv) The radio-isotopes used as tracer do not get precipitated or absorbed in sub-soil.

Selection of Radio-Tracer : The success and accuracy in the determination of ground water flows depend to a large extent on the proper selection of the radio-active tracer. Tritium in the form of tritiated water is suitable for hydrological problems. But its long half life, weak beta energy and its readiness to get exchanged with hydrogen of water molecules are some of the drawbacks of this rådio-tracer. There are large number of artificial radio-isotopes, any one of which can be conveniently selected depending upon the type of problem. The following factors usually govern the choice of a radio-tracer for seepage flow measurements :

(i) The radio-isotope should be gamma emitting to enable efficient detection in water.

(ii) It should be available in highly water soluble form and should be stable in water medium, i.e., it should neither get precipitated nor absorbed in the soil.

(iii) It should be easily detectable at site.

(iv) It should have a high tolerance level or in other words higher concentration of radio-tracer injection should be allowed.

(v) Its half life should be reasonably high so that observations may be continued for a reasonable time.

The radio-isotopes generally used in tracer technique, which have been found to give satisfactory results, are given in Table 2.

Quantity of Radio-Tracer : The quantity of radio-tracer needed for a particular experiment is governed by many factors including :

(i) The quantity of water involved in diluting the tracer

(ii) The fraction of the tracer lost

(iii) The sensitivity of the detecting unit

(iv) The maximum permissible concentration in drinking water to be used by the public.

A rough estimate taking into account the above factors gave a value of 1.2/μc/litre as the required specific activity for these types of experiments. However, a larger quantity than this can be proposed to be injected to allow for unforced factors.

Methods & their limitations : Following methods are generally used in the measurement of sub-surface flow :

(i) Double Well Method

(ii) Single Well Pumping Method

(iii) Single Well Dilution Method

Double Well Method : In this method the tracer injected in one well and the observations for the tracer are made in another well located down gradient at known distance. From the travel time of the tracer concentration and the distance between the injection well and the observation well, the velocity of flow can be calculated. The time of the travel of tracer in the bore-holes is determined by a lower watertight G.M. or scintillation probe. The method is quite suitable for soil having high permeability when velocity of flow is large. In case of silty clayey soil wherein the flow is bound to be too slow, this method will take considerably longer time.

Single Well Pumping Method : This method is termed as pulse technique. In this procedure a small quantity of tracer is added into the aquifer through a well and the tracer is left to move with natural flow for prefixed time interval. Then the tracer is recovered by pumped water from the same injection well. The pumped water is continuously monitored for radio-activity. Knowing the time elapsed between injection and pumping, pumping rate and the pattern of activity flowing out during pumping, the sub-surface flow rate can be calculated. The technique is adopted when the volume of water in the well is large, high permeability is encountered, and when more than one well can not be economically drilled (Ref. 1).

Single Well Dilution Method : Single well dilution method has been tried by many workers for determining the localised velocity and direction of ground water flow. In this method, the radio-tracer is injected in a single well and its dilution is noted with passage of time after injection. The general principle of single well dilution method is that when a tracer is injected into the entire volume of water in a well uniformly, its concentration decreases with time. Since the well intercepts the sub-soil water flow, fresh water enters the well and water concentrated with isotope leaves the well uniformly in the direction of sub-soil flow. Thus the water in the well gets diluted. However, since total volume of water in the well remains the same and as the fresh water flows into the well at a constant rate, the decrease in concentration follows a simple exponential law.

The filtration velocity (V_f) of the horizontal water flow in the absence of all other flows through the bore-hole is given by the formula

$$V_f = \frac{\pi d \ln(Co/c)}{4\phi t} \quad .....(1)$$

Where, d is the diameter of bore-hole, Co is the initial concentration of the tracer at time t = 0, and ∅ is the correction factor which accounts for the distortion of the flow lines owing to the presence of the bore-hole. The value of ∅ = Qb/Qf, where, Qb is the horizontal flow rate and Qf is the flow rate in the same cross-section of the formation. The disturbances around the bore hole during drilling will modify the permeability of the surrounding soil and consequently the factor ∅. The maximum value of ∅ may be taken as 2 for a bore without strainer and gravel as mentioned by Mc-Whorter. (Ref. 10). Factor ∅ has also been determined in the field and ranges from 0.8 to 1.2 for silty clay loam. Thus, the value of ∅ may be taken as 1 while calculating seepage velocity for estimating seepage loss from canals having silty clay soil.

In cases of flows through finite depth of porous medium, the seepage losses can be calculated by determining the average horizontal filtration velocity. However, in case of large depth of pervious medium, the permeability can be evaluated from filtration velocity from Darcy's Law, knowing the value of local hydraulic gradient. Using the permeability value, thus obtained, the seepage rate can be calculated from analytical formulae taking into consideration the boundary conditions (Ref. 2).

12.2 ASSESSMENT OF SEEPAGE LOSSES FROM CANALS IN THE PLANNING STAGE

The seepage losses from unlined canals depend on their dimensions, permeability of the sub-soil, distance of the drainages and the head difference. Initially the seepage losses are high due to steep gradients, but as the sub-soil becomes saturated, the gradients flatten and ultimately stabilise, if the channel is continuously running. Also, with the passage of time the permeability of the subgrade reduces to some extent either by deposition of fine particles coming with the canal water in the pores of the subgrade material or densification of the subgrade itself, which in turn causes the reduction of seepage.

Mainly the following theoretical methods may be used for finding the seepage losses from canals in the planning stage itself.

1. Empirical formulae based on experience.

2. Use of flownets

3. Theoretical methods.

1. Empirical Formulae Based on Experience

(i) Davis and Wilson (Ref. 12) have suggested the following relationship for the estimation of seepage losses in lined canals :

$$S_L = 0.45 x C x \frac{P_w x L}{4x10^6 + 3650\sqrt{V}} x H_w^{1/3}$$

where

S_L = Seepage losses (m^3 per length of canal per day);

L = Length of canal (m);

P_w = Wetted perimeter (m);

H_w = Water depth in the canal (m);

V = Velocity of flow in the canal (m/sec);

C = Constant value depending on lining.

Type of lining and thickness	Value of C
Concrete (10 cm)	1
Mass clay (15 cm)	4
Light asphalt	5
Clay (7.6 cm)	8
Asphalt or cement mortar	10

(ii) After obtaining the results of surveys on eight different canal systems, the U.S. Bureau of reclamation proposed the following relationship, known as the Moritz formula:

$$S = 0.2C\sqrt{Q/V}$$

where

S = Seepage losses (Cusecs per mile length of canal);

Q = discharge (cusecs);

V = velocity (ft/sec);

C = constant value depending on soil type.

Soil type	Value of C
Cemented gravel and hard pan with sandy loam	0.34
Clay and clayey loam	0.41
Sandy loam	0.66
Volcanic ash	0.68
Sand or volcanic ash or clay	1.20
Sandy soil with rock	1.68
Sandy and gravelly soil	2.20

(iii) In India, the following formula has been used:

$$S = c.a.d$$

where

S = total loss (ft^3/sec);

a = area of wetted perimeter (million ft^2);

d = water depth in the canal (ft);

c = a constant

Observations made on some of the important canals in the Punjab showed that c ranged from 1.1 to 1.8.

However, in the State Uttar Pradresh, the seepage losses in unlined channels are usually computed using the following formula :

$$\text{Losses in cumecs/km} = \frac{c}{200}(B+D)^{2/3}$$

where B and D are the bed width and depth of the channel in metres and c is a constant, being 1.0 for intermittent running channel and 0.75 for constant running channel.

(iv) For estimating conveyance losses of canals, Egypt's Irrigation Department used the Empirical formula of Molesworth and Yennidumia:

$$S + c.L.P.\sqrt{R}$$

where

S = Conveyance losses [m^3/sec per length (L) of canal]

L = length of canal (km);

P = Wetted perimeter (m);

R = hydraulic mean depth (m);

c = a coefficient depending on nature and temperature of soil (For clay c = 0.0015 and for sand c = 0.003).

(v) In the U.S.S.R. the following formula is used to calculate a general seepage loss rate :

$$S = \frac{1.16}{Q} xKxq_r$$

where

S = loss as percentage of canal discharge per km of canal length;

Q = canal discharge (m^3/sec);

K = saturated permeability (m/day);

q_r = reduced specific seepage loss, i.e.; ratio of seepage velocity to saturated permeability of bed material.

(vi) Offengenden proposed the following equation for estimating seepage losses from earth canals or ditches :

$$S = s.\frac{Qx1}{100} m^3 / sec$$

where

s = Water losses per km of canal length (in percent);

Q = water flow (m^3/sec);

l = length of canal (km);

S is calculated by the formula :

$$S = \frac{A}{Q^m}$$

A and m are empirical constants depending on soil permeability :

	Permeability		
	Low	Medium	High
A	0.70	1.90	3.40
m	0.30	0.40	0.50

CWC Criteria

As per Central Water Commission criteria New Delhi, for planning purposes, the range of seepage losses from unlined canals having different subgrade material may be taken as given in Table-3.

2. Use of Flownets

For finding the seepage with the help of flownets, the first step is to draw the flownet depicting the seepage flow from the channel, keeping in view the various parameters such as position of water table and position of impervious layer, position of drain etc. Flownets for two typical cases are given; one is for shallow water table [Fig 2(a)] and the other for deep water table [Fig 2(b)].

For drawing flownets the shape and position of top flow line can be finalised by adopting the trial & error procedure keeping the following points in view.

(1) Flow lines and equipotential lines must intersect at right angles to form areas which are basically squares.

(2) Certain entrance and exit requirements must be met

(3) A basic deflection rule must be followed in passing from a soil of one permeability to a soil of different permeability.

(4) Adjacent equipotentials have equal head losses.

(5) The same quantity of seepage flows between adjacent pairs of flow lines.

The construction of flownets is considerably simplified, if the position and shape of the top flow line is determined independently by laboratory tests on Electrical Analogy models or from hydraulic models using pretreated sand (Ref.4)

Having drawn the flownets, the seepage flow can be calculated using the following formula :

$$S = K.P_w \times \frac{\Delta h}{\Delta l} \qquad \ldots (8)$$

Where,

K = Permeability of the soil

Pw = Wetted perimeter of the channel

$\frac{\Delta h}{\Delta l}$ = Average hydraulic gradient in the close vicinity of the channel.

12.3 THEORETICAL METHODS

The discharge given by the theoretical formulae corresponds to steady state conditions which rarely exist in real life situation. The seepage loss computed from theoretical method can serve to indicate the order of seepage losses for deciding the necessity or otherwise of the lining.

Analytical solutions are available for evaluating seepage losses from canals under steady state conditions for the following cases :

i. Canals located in homogeneous and isotropic medium extending up to infinite depth with shallow water-table.

ii. Canals located in homogeneous and isotropic medium extending to finite depths with shallow water-table.

iii. Canals located in homogeneous and isotropic medium extending to infinite depth with very deep water-table.

The working details of these methods are given below :

12.3.1 Infinite Depth of Permeable Medium

The seepage from canal flows to the drain in a direction approximately transverse to the direction of flow in canal and meet the drains at various slopes, depending upon the cross-section of the canal. The problem can be simplified by consideration of the following two extreme conditions (Fig.3).

Horizontal Drainage : If the drain is shallow and wide the streamlines from the canal may join the bottom of the drain at various points along its width.

Vertical Drainage : If the drain is narrow, the seepage may enter into it from both sides. In this case the streamlines from the canal on both the flanks of the drain would reach the drain in the horizontal direction.

In practice the flow may not fall distinctly into either a horizontal or a vertical drainage but may be a combination of the two. In such case a fair idea of the flow can be obtained by a study of the two extreme cases.

Different curves are plotted which make it easy to obtain the seepage discharge and the phreatic surface for any canal size. The procedure, both for horizontal and vertical drainage combination is given below :

Horizontal Drainage : Knowing the dimensions of the system in the physical plane, the two parameters β and γ are determined as follows (Ref. 2) :

i. The bed width B, the slope angle $\pi\alpha$, the distance upto drainage L, and the water depth inside the canal H are recorded for the subject case.

ii. Figure 4(a) can be used to obtain initial values of β and γ from these quantities. In these curves in addition to L/H, the quantities b/H and 'α' which correspond to B/H and α respectively are to be used. The values of B/H and α are not far different from b/H and α' respectively, and former can be used as a first approximation.

iii. After reading of the values of β and γ corresponding to these ratios, the values of α ' and b/H are read from the curves in Fig. 5 and 6.

iv. With these values better approximations to β and γ are determined from Fig. 4(a), and the process is repeated until variation in the values of β and γ from one trail to another is negligible. This condition is normally achieved within two or three trials.

Seepage Discharge : Knowing β and γ, the seepage discharge in terms of kh is obtained from Fig. 7.

Free Surface : Figs. 4(a) and 8 can be used parametrically to obtain x and y coordinates of the free surface. For any assumed value of the variable t between O and γ, a ratio t/γ is determined and Fig. 8 yields the value of y/h. For the same value of t and the known value of β the value for x/H can be obtained from Fig. 4(a).

Vertical Drainage : The procedure with vertical drainage is similar. The difference is that Fig. 4(b) is used instead of Fig.4(a) for determining β and γ, and x/H.

Figs. 9 and 10 show the observed free surface on either side of Ganga canal at km 37.6, of Hardoi Branch at km 31.8 side by side with computed free surface at these sections for comparison. A perusal of the Figs. indicates that the observed free surface is generally higher than computed free surface, the difference can be mainly attributed to infiltration from rainfall and irrigation, which take time to drain off. The observed free surface will tend to approach the theoretical line with more and more drainage. Other factors that may affect the free surface are the depth of impervious layer and non-homogeneity of sub-soil.

12.3.2 Finite Permeable Medium with Shallow Water-table

Dachler combined both model experiments and approximate analysis to give a simple procedure for computing the seepage discharge and finding free surface of the system. The flow system is divided into two separate regions, the region I of curved flow extending upto a distance of $(B+H_2)/2$ from the axis of the canal and the region II extending beyond it in which this is taken as approximately linear, where B = surface width of canal, H_2 = depth of impermeable layer below canal FSL Fig.11(a).

Equating the discharge in two regions, the following equation is obtained (Ref. 5) :

$$q = 2ke\left(H_2 + eL_1 - \sqrt{(H_2 + eL_1)^2 - \left(H_2^2 + H_0^2\right)}\right) \quad .....(9)$$

where, k is coefficient of permeability, H_0 = depth of impermeable layer below drain water-level, L = distance of drainage from the central line of canal, $L_1 = L - (B+H_2)/2$ and e is form factor. The value of e which depends upon the geometry of the canal and the region in its vicinity is obtained from Fig. 11(b). Knowing the discharge q, the elevation of free surface at the dividing line can be obtained by evaluating H_1, being the height of free surface above impermeable boundary, from the following equation :

$$q/2 = ke(H_2 - H_1) \quad ... (10)$$

Knowing H_1, the approximate position of phreatic line can be obtained by joining the point M at the inter-section of the phreatic surface and the dividing line with the canal and drainage water lines respectively.

12.3.3 Infinite Depth of Permeable Medium with very Deep Water-table

The solution for this boundary condition was obtained by Vedernikov with the help of conformal mapping. The seepage discharge, q per unit length of channel is given by (Ref.6):

$$q = k\,(B + AH) \qquad \text{...(11)}$$

where, B = surface width of channel ; H = water depth inside channel ; and A is function of geometry of canal. The value of A is obtained from Fig. 11(c) for the known values of B/H and m, where $m = \cot \alpha$ and α = side slope angle.

12.3.4 Example 1

Following are the physical dimensions of a canal for which seepage discharge and free surface on either side are to be determined (Fig. 12).

i.	Bed width	B	=	90 m
ii.	Water depth	H	=	4.438 m
iii.	Side slope angle	α	=	$0.463\ \pi$

Right side of channel

i.	Drainage distance	L	=	500 m
ii.	Difference in channel and drainage water-level	h	=	2.175 m

Left side of channel

i.	Drainage distance	L	=	4362 m
ii.	Difference in channel and drainage water-level	h	=	2.947 m

Assuming drainage to be vertical the values of β and γ are obtained from Figs. 4(b), 5, & 6 as 3.5 and 104 respectively for right side. The corresponding values for left side are 3.416 and 7,500. The seepage losses work out to 0.088 m^3/sec/km and 0.108 m^3/sec/km on the left and right sides respectively. The coordinates of free surface have been determined from Figs. 4(b) and 8 and plotted in Fig.12.

If in the problem, impermeable boundary is located at a depth of 50 m, the seepage discharge by Dachler method is obtained as below :

B	=	94.44 m (surface width)	
H_2	=	50 m	
L on right	=	500 m	
L on left	=	4362 m	
H_o on right	=	50.00 - 2.175	= 47.825 m
H_o on left	=	50.00 - 2.947	= 47.053 m

The values of L_1 work out to 427.78 and 4289.7 for the right and left sides of the channel respectively. The seepage losses from Fig. 11(b) and above equation work out to 0.0035 m^3/sec/km and 0.0225 m^3/sec/km on the left and right sides respectively. It is, therefore, seen that seepage discharges determined by this method are less as compared to the values obtained for infinite depth of pervious stratum.

12.4 SEEPAGE FROM LINED CANALS

An assessment of likely seepage losses from lined canals can be made by theoretical method for steady state condition. The direct measurement of seepage after construction of canal can also be made by the inflow-outflow, ponding and tracer techniques although there may be large errors due to quantity of seepage being very small.

The seepage from a lined canal depends upon the thickness and permeability of lined material in addition to the factor on which the seepage from unlined canal depends. Referring to Fig. 13, the seepage discharge through the lining of a channel, which is homogeneous and free from leaky joints, is given by :

$$q = P.k_l \frac{h_l}{t} \qquad .....(12)$$

where,

P = perimeter of the channel

k_l = permeability of the lining

t = thickness of the lining

h_l = head loss through the lining.

This quantity of seepage discharge would flow to the natural drainage through the sub-soil under the residual head ($h-h_l$), and is given by :

$$\frac{q}{k(h-h_l)} = f(\beta/\gamma) = c$$

.....(13)

where, k is the permeability of sub-soil material and value of c is obtained from Fig. 7.

Eliminating h_l from above equations

$$q = \frac{c.P.kh}{crt + P}$$

.....(14)

where, $r = k/k_l$. Knowing values of P, r, t and c, the seepage discharge q is obtained from above equation.

The free surface due to seepage from lined canal would have a drop of h_l through the lining, and thereafter would correspond to the free surface as obtained for seepage from unlined canal under a residual head of ($h-h_l$), Fig. 13 coordinates being obtained from Figs 4 and 8 as explained in para 12.3.1.

Due to very small quantity of water seeping from a lined canal, it would take considerable time to attain steady condition. In case of lined channels running intermittently, the steady state condition may not be attained at all. Thus the main advantage of canal lining is that besides reduction in discharge, the development of free surface is considerably delayed, thus restricting the rise in water-table to inappreciable level.

Table - 1

Seepage loss in Unlined Canal

Sl. No.	Name of Canal	Reach Chainage (km)	Season	Method of Observa-tion	Seepage Loss (Cumecs/ M.Sqm.)	Average (Cumecs/ M.Sqm.)
1	2	3	4	5	6	7
	Main Canal	(0 to 21.4)	Kharif	IO	3.8	3.8
1.	Upper Ganga Canal	(40 to 48)	Kharif	IO	2.694	
				SM	2.519	
		(128-154.2)	Rabi	IO	3.28	
		(154.2-164.6)	Rabi	IO	2.30	
		(128-164.6)	Rabi	IO	2.71	2.5
		(154.2-164.6)	Kharif	IO	2.43	
				SM	2.412	
		(249-267.6)	Kharif	IO	2.33	
				SM	2.603	
	Branches					
2.	Anupshahr Branch	(0-32)	Kharif	IO	2.43	
				SM	1.957	
3.	Mat Branch	(43.8-74.8)	Rabi	IO	1.70	
		(83.2-95.2)	Kharif	IO	1.242	
				SM	1.536	1.795
4.	Hathras Branch	(0-32)	Kharif	IO	1.34	
				SM	2.054	
		(16-29.6)	Rabi	IO	2.10	

contd....

1	2	3	4	5	6	7
	Distributories					
5.	Thansipur Dy.	(5.6-9.6)	Kharif	IO	2.42	
6.	Etherpura Dy.	(4.8-6.4)	Kharif	IO	1.98	
7.	Shakrauli Dy.	(0.2-6.6)	Kharif	IO	5.19	3.85
8.	Toshigarh Dy.	(0-7.6)	Kharif	IO	5.81	
	Minors					
9.	Godd Judd Mr.		Kharif	p	0.99	
10.	Magai Mr.		Kharif	p	1.60	
11.	Solani Mr.		Kharif	p	1.02	1.39
12.	Kulsath Mr.		Kharif	p	1.65	
13.	Rankhandi Mr.		Kharif	p	1.96	
14.	Said Pur Mr.		Kharif	p	1.12	

Abbrevations :

IO = Inflow Outflow,
S_M = Seepage meter,
p = Ponding

Table 2

Some Characteristics of Commonly used Artificial Radio-active Tracers in Hydrology

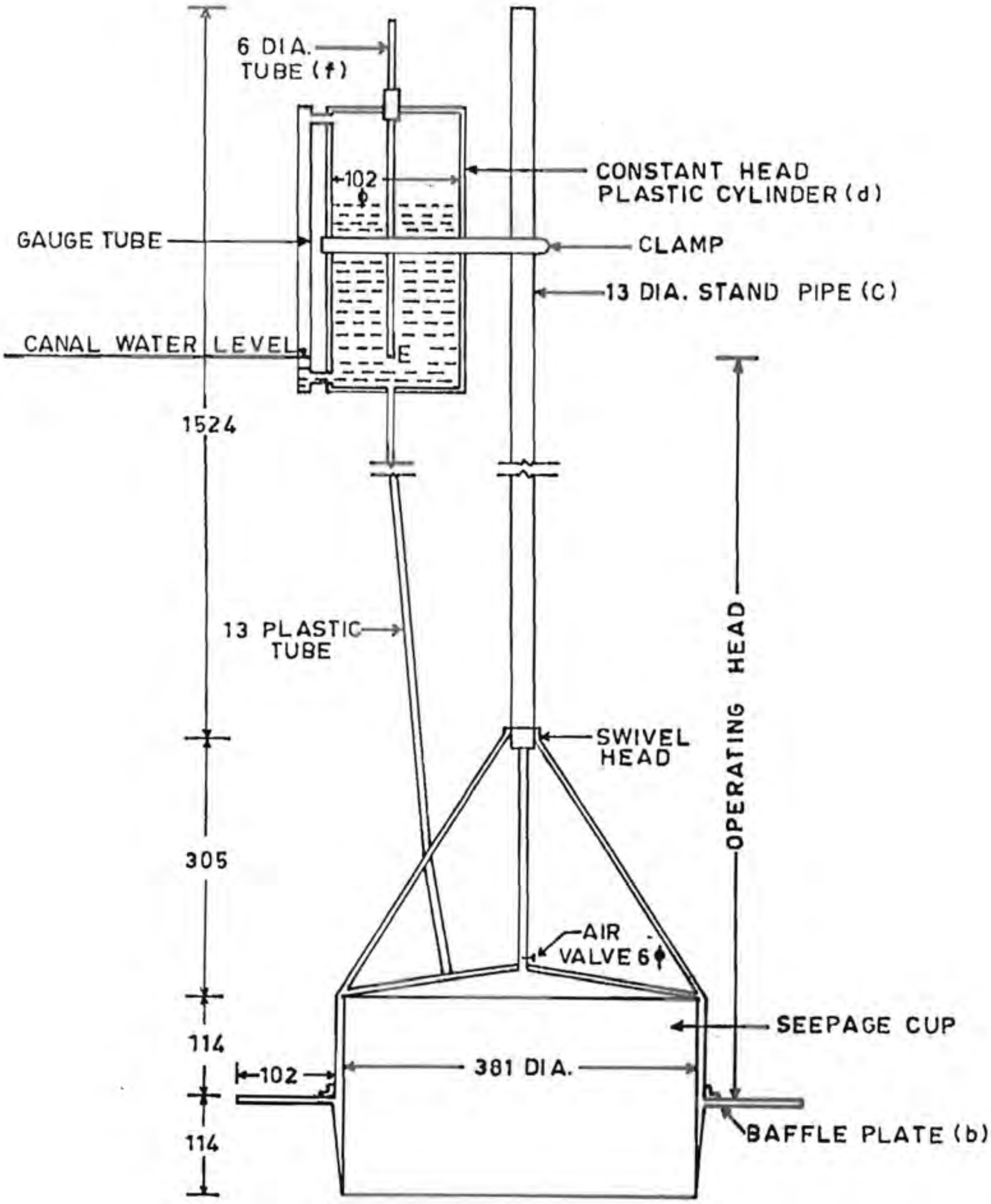
Isotope	Half Life	Max. permissible Concentration in drinking water μ Ci/ml	Min. amount detectable in water μ Ci/ml
3_H (Tritium)	12.26 yrs	$3x10^{-3}$	$1x10^{-6}$
24_{Na} (Sodium)	15.0 Hrs	$2x10^{-4}$	$1x10^{-8}$
51_{Cr} (Chromium)	27.8 days	$2x10^{-3}$	$8x10^{-7}$
58_{Co} (Cobalt)	71.0 days	$1x10^{-4}$	$6x10^{-8}$
82_{Br} (Bromine)	35.7 Hrs	$3x10^{-4}$	$2x10^{-8}$
$116m_{Ag}$ (Silver)	249 days	$3x10^{-5}$	$3x10^{-8}$
131_I (Iodine)	8.05 days	$2x10^{-6}$	$8x10^{-8}$
198_{Au} (Gold)	64.8 Hrs	$5x10^{-5}$	$1x10^{-7}$

Table 3

Seepage Loss Characteristics of Diffirent Soils

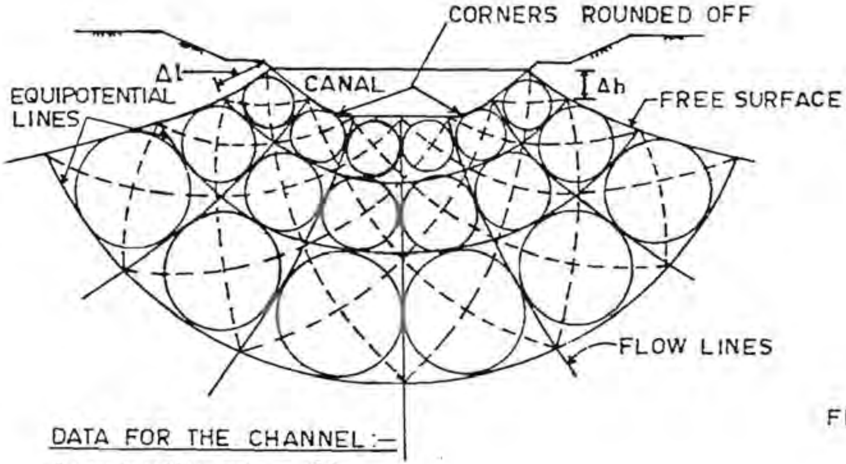
Character of Material	Seepage loss Cumecs/million m^2 of wetted permeter
Impervious clay loam	0.90 to 1.20
Medium clay loam underlaid with hard pan at depth of not over 0.60 to 0.90 m below level	1.20 to 1.80
Ordinary clay loam silt soil or lavash loam	1.80 to 2.70
Gravelly or sandy clay loam, cemented gravel, sand and clay	2.70 to 3.60
Sandy loam	3.60 to 5.20
Loose sandy soil	5.20 to 6.10
Gravelly sandy soil	7.00 to 8.80
Porous gravelly soil	8.80 to 10.70
Very gravelly soil	10.70 to 21.30

Source : Central Water Commission



NOTE:- ALL DIMENSIONS ARE IN mm.

FIG. 1 :- U. P. I. R. I. TYPE SEEPAGE METER



DATA FOR THE CHANNEL :—

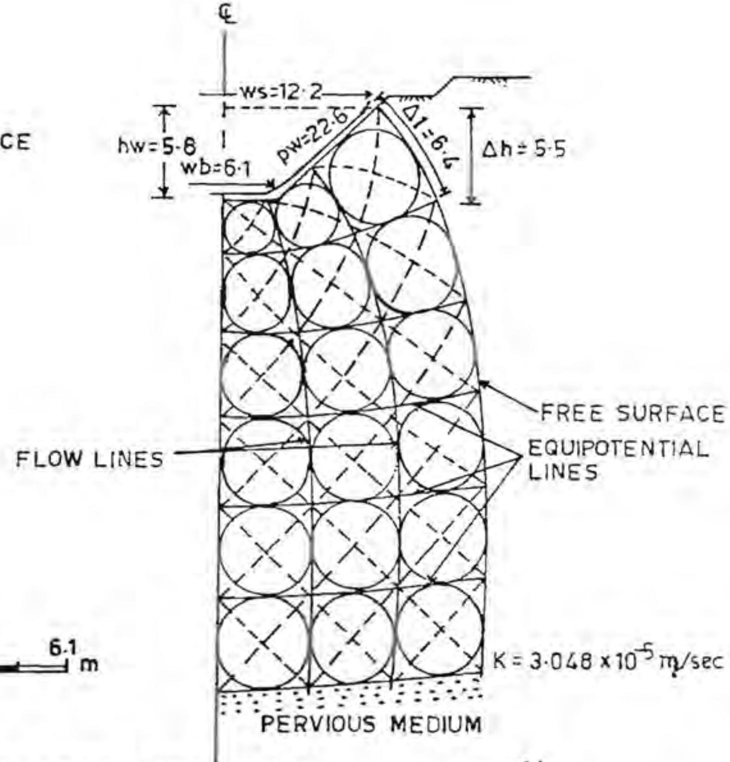
BED WIDTH $wb = 6.1$
F.S. DEPTH $hw = 2.7$
WETTED PERIMETER $pw = 17.9$
SURFACE WIDTH $ws = 15.5$
$\Delta l = 3.3$
$\Delta h = 1.8$
$k = 3.048 \times 10^{-5}$ m/sec

SCALE :- 0 —— 6.1 m

CALCULATIONS FOR SEEPAGE LOSSES :—

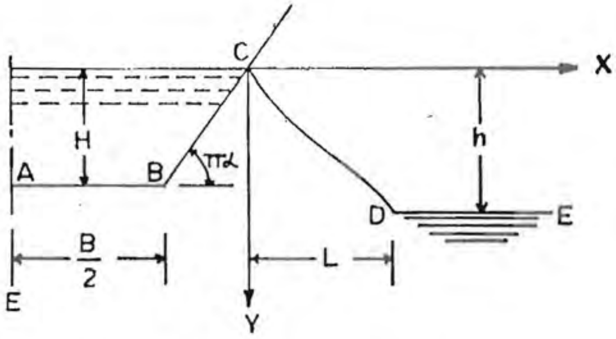
SEEPAGE LOSSES PER m. $= k \times pw \times \frac{\Delta h}{\Delta l}$

$= 3.048 \times 10^{-5} \times 17.9 \times \frac{1.8}{3.3}$

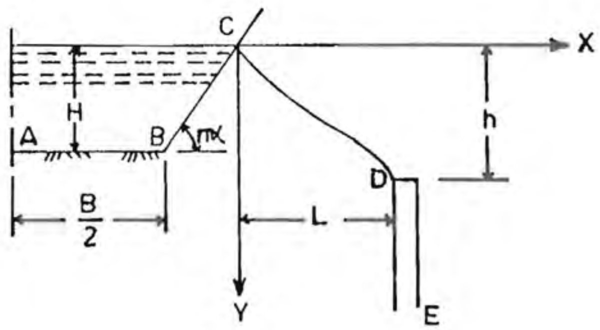


SEEPAGE LOSSES PER m $= k \times pw \times \frac{\Delta h}{\Delta l}$

$= 3.048 \times 10^{-5} \times 22.6 \times \frac{5.5}{\ldots}$



A — HORIZONTAL DRAINAGE



B — VERTICAL DRAINAGE

FIG. 3 :- PHYSICAL PLANE

13. ANALYSIS OF DATA OF EXISTING LINED CANALS

13.0 INTRODUCTION

13.0.1 This chapter provides a detailed information and data on irrigation canal lining so as to make manual more useful for planners, designers and construction engineers.

13.0.2 Type of soil, cost-benefit ratio, discharge of the canal and efficiency, life etc. are several parameters which help planners & designers to decide about lining of a project. Collection and analysis of above data, firstly gives an idea about the practices prevailing in various states regarding type of lining, which in turn depends mainly on the availability of the raw materials. Secondly, the type of lining for a particular project is selected on the basis of the characteristics of soil on which lining has to be laid. Thirdly, the type of lining may also be selected on the basis of its efficiency keeping in view the velocity and rugosity coefficient, i.e. the extent of its ability to check the seepage rate.

13.1 PRACTICES ADOPTED IN VARIOUS STATES

13.1.1 In general the choice of a particular type of lining depends on many factors such as the availability of material, labour, cost of lining, hydraulic efficiency, degree of impermeability and coefficient of rugosity etc. The data of lining, type of soil, discharge etc. as collected for channels of various states has been shown in Table -1.

The practices adopted for canal lining for some of the channels in various states are also explained in detail as below:

13.1.2 Gujarat

During the last 20 years Gujarat has executed a number of irrigation projects involving significant work on lining of different canal systems. Canal lining works executed in the state, cover almost all types of lining methods and materials.

The main soil types and the most common types of lining are as under:

(a) Soil type

  (i) Silty, Sandy subgrade

  (ii) Silty , Clayey.

(b) Types of lining executed

  (i) Sandwiched brick lining and brick over LDPE membrane

  (ii) Insitu cement concrete lining over LDPE membrane.

  (iii) Precast cement concrete block lining over LDPE membrane.

13.1.2.1 The sandwiched brick lining and brick over LDPE membrane linings have so far worked well. Distress to this lining has been observed at some places, especially where ground water table is high and subgrade soil is silty sandy. The pressure release valves where provided are not functioning well. It has led to formation of cracks and cavities underneath the lining.

The insitu cement concrete lining is more commonly used in comparison to other types of linings. However, it has also shown signs of distress at the junction of two soil strata or at the level of natural ground surface and the new earth work for the canal in filling reaches.

At some locations, where the laying and curing of insitu cement concrete lining is not suitable, the precast cement concrete blocks have been provided. But due to lack of poor workmanship in laying and filling joints, slippage of the precast cement concrete blocks have been reported at several places. These blocks are also reported to have been removed on account of pilferage etc.

13.1.2.2 The present practices of lining in the state can mainly be classified as under :

(i) Lining on sandy-silty soil with high ground water table conditions.

(ii) Lining on expansive clayey soil.

(ii) **Eastern Ganga Canal :** A 48.5 km long Eastern Ganga Canal with a discharge capacity of 137 cumec passes through silty and sandy strata. Most of the canal length has been lined in bed with 100 mm thick cement concrete M-15 and double layer of cement concrete tiles or burnt clay tiles in sides slopes.

(iii) **Sarda Sahayak Feeder Channel :** A 258.80 km long feeder channel of designed capacity of 650 cumec was constructed under Sarda Sahayak Project to provide irrigation facilities to about 18 lakh hectares. The channel passes through the soil having high permeability. Due to this reason, high seepage in filling reaches would have occurred if lining was not provided. As such the Sarda Sahayak Feeder Channel has been lined in certain reaches. In the first stage construction of the project prior to 1976, single burnt clay tile lining with plaster in the bed and double burnt clay tile lining with sandwiched plaster on side slopes has been provided. In other reaches concrete lining in the bed and double layer of precast concrete tile with sandwiched plaster on side slopes has been provided.

Lining work has been done in the closure periods of the canal. This lining work has been done mainly by mechanised paver for speedy completion of the work. In view of the high spring level conditions, the longitudinal filter drains inter-connected by cross drains alongwith pressure release valves are provided for release of excess hydrostatic pressure behind lining.

(iv) **Madhya Ganga Canal :** Madhya Ganga Canal with a discharge capacity of 233.6 cumecs passes through sandy strata. The canal was lined only in the filling reaches. Single brick tile (300x150x50 mm) lining in bed and double brick tile lining in 1:5 cement mortar has been provided on side slopes.

(v) **Mat Branch Feeder :** This feeder mostly traverses through a strata comprising of medium to fine sand and silt clay and in some reaches the soil is salty and comes down in colloidal state when mixed with water. No lining is provided in bed, only 75 mm thick brick lining in 1:4 cement mortar over 100 micron LDPE film is proposed to be laid on side slopes. This lining is provided only for slope protection. This channel is under construction.

(vi) **Kosi Feeder Channel :** The channel was designed for a discharge of 42.5 cumec and traverses through soil strata containing coarse sand and gravel. Lining in the bed and sides consists of precast cement concrete tiles (400x300x75 mm) laid over 100 mm thick concrete.

The examples illustrated above are for irrigation canals. In U.P. there are many perennial rivers like Ganga and Yamuna and as such some power channels for power projects have been constructed.

Adoption of hard surface lining is preferred in the power channels so as to avoid any major damages and consequent canal closures resulting in generation losses. Power channels are generally constructed near hilly areas. It is economical to provide concrete lining in power channels. Moreover, these have more resistance against erosion due to higher velocity of water. Besides preventing weed growth, concrete lining provides better protection against burrowing animals and its maintenance is easier. The concrete lining is, however, not flexible and cracks develop due to settlement of subgrade, contraction , drying and shrinkage etc. This can also be damaged due to high back water pressure. Concrete lining can be either in-situ or precast.

Some of the examples of power channels are given below:

(i) **Rishikesh - Chilla Power Channel (Garhwal Rishikesh-Chilla Hydel Channel) :** A 14.2 km long power channel of 680 cumec discharge capacity , takes off on the left bank and feeds water to Chilla Power House. The following types of lining have been provided in the power channel both in the bed and sides at different locations.

(a) Boulder Pitching lining

(b) In- situ Concrete lining

(c) Cement Concrete Tile lining.

These types of linings have been adopted in the power channel because of availability of sand and coarse aggregate in the river.

(ii) **Khara Power Channel (Khara Hydel Scheme) :** A 13 km long power channel with a discharge capacity of 198.3 cumec was constructed under Khara Hydel Scheme. This channel mostly passes through sandy rock and clay shale overlain boulder conglomerates.

The lining of this channel consists of cement concrete (M-15) lining in bed and double layer compressed cement concrete tiles with sandwitched plaster in sides slopes.

(iii) **Yamuna Power Channel (Yamuna Hydel Scheme) :** Yamuna Power Channel with a design discharge capacity of 198 cumec passes through sand with gravel and boulder strata. Composite lining of brick and cement concrete tile was provided in the sides of Yamuna Power Channel.100 mm thick concrete lining was provided in the bed of channel in normal reaches and 150 mm thick concrete lining in the reaches where ground water table is high. The channel lining has behaved generally well except in deep cutting reaches due to excessive differential head.

From the analysis of the data of lining of canals of U.P. it is concluded that in most of the canal lining projects hard surface lining consisting of concrete in-situ and brick or c.c. tiles has been provided.

The detailed specifications of lining of some important projects are given separately in Table -2.

13.1.4 Karnataka

In Karnataka various types of linings have been used depending on the sub-grade and availability of construction material. Earlier, soil cement and lime surkhi concrete lining has been used in gravel sub-grade of Krishnaraj Sagar Canal. The latest trend in the state for small channels is to use LDPE film overlaid with other hard surface linings.

13.1.5 Tamilnadu

Available mager data shows the use of LDPE film protected by concrete for small discharge canal and also the use of PCC or in-situ concrete.

13.1.6 Kerala

In Kerala state the data available reveals that either rubble masonary or precast cement concrete slabs/ blocks have generally been used.

However, on experimental basis in Kuthanpur Branch, bitumen with cement mortar was used but its performance has not been satisfactory.

13.1.7 West Bengal

In Kangsabati Irrigation Project in West Bengal, plastic film lining with soil cover was provided . It has proved to be successful . In most of the other canals cast in-situ concrete or precast block over LDPE film lining has been adopted. In some projects of the state, brick lining over LDPE film has also been used in canal lining works.

13.1.8 Haryana

In Haryana, the general practice is to line the big canal with double tile lining and small channels with single tile lining with LDPE film. However, in some canals upto a discharge of 93.45 cumec passing through areas having sandy soil LDPE film lining was also tried. The practice for lining canals having higher discharge was to use 200 μ LDPE film with single tile lining in mortar on bed and cement concrete lining on side slopes. In case of low discharge channels LDPE film of 150 μ with single tile lining in mortar on bed and single tile lining without mortar on side slopes was used. The lining has been found to be intact and functioning satisfactorily. Some of the experiences of this type of lining in Haryana are given in Table 3.

13.1.9 Rajasthan

In Rajasthan, adoption of canal lining was taken up quite late. The sub-soil being sandy, is susceptible to huge amount of seepage losses. Therefore , the only solution to seepage problems in canals of Rajasthan is the use of LDPE film generally of thickness 200 μ LDPE film lining ensures stability of canal section and reduce seepage losses to a greater extent.

Details of lining in some channels are given below :

(a) **Rajasthan Canal (Newly named as Indira Gandhi Canal) :** Rajasthan canal with a discharge capacity of 510 cumec mostly passes through sandy soil. The bed was lined with single tile lining and top was highly smooth finished with 19mm thick 1:3 cement plaster. Double tile lining (300x150x50) mm with a cement mortar layer sandwiched was provided in side slopes. In some reaches, LDPE film of thickness varying from 175 μ to 200 μ was used.

(b) **Ranjeetpura Distributary :** Ranjeetpura distributary with a discharge capacity of 13.65 cumec traverses through sandy strata. LDPE film lining with cement concrete in bed and precast concrete tiles in cement mortar in side slopes was provided. Similar type of linings have also been provided in Samewala distributary and Ahmad walia minor (Rajasthan) on experimental basis. In Water Supply Channel, LDPE film with concrete tiles was provided in bed and side slopes. Detailed specifications of lining on above channels have been shown in Table 4.

13.1.10 Punjab

13.1.10.1 Initial attempts to line the channels were made round about early sixties. Different practices have been adopted for small channels upto a discharge of 6.145 cumec and for big channels. The details are as below:

13.1.10.2 ***Small Channels*** : The small channels of discharge upto about 6.145 cumec on sandy strata were lined using LDPE film with soil cover. The practice adopted was to line the bed as well as sides slopes with 100 μ LDPE film with a soil cover over it. The lining has been reported intact and free from damage by weed growth and water insects. LDPE film about 60 μ was also tried but that got damaged due to lesser thickness (Table 5).

13.1.10.3 ***Big Channels*** : Double tile lining with sandwiched layer of cement plaster and cement concrete lining became very popular and was adopted in various canal lining projects including Nangal Hydel Channel, Sirhind Feeder Channel, Ferozpur Feeder Channel and Bhakra Main Canal. The suitable drainage arrangement were also provided in high sub-soil water reaches and in the reaches having semi pervious subgrade. All of these linings are working quite satisfactorily. Experience of Nangal Hydel Channel has indicated that concrete lining has given better performance in high water-table reaches than tile lining.

13.1.10.4 ***Bhakra Main Canal*** : Bhakra Main Canal with a discharge capacity of 192 cumecs was lined with double layer burnt tiles with cement sand mortar layer sandwiched between the tiles.

13.1.11 General Practice of Using LDPE Film

13.1.11.1 The use of plastic film in canal lining was introduced in India way back in 1959. Subsequently, a number of irrigation projects have tried plastic films, specially LDPE film on an experimental basis. In most of the major canal projects in India, insitu concrete, precast concrete blocks, brick tiles or concrete tiles have been used as a covering material over LDPE film. In World Bank aided Parallel Upper Ganga Canal Project and Indira Gandhi Nahar Project, brick/concrete tiles have been used over LDPE film. The only project using plastic film overlaid with soil cover successfully is Kangsabati Irrigation Project, West Bengal.

13.1.11.2 The National Seminar on the "Use of Plastic for lining of water conveyance system in irrigated agriculture", was organised in 1982 by National Committee on the use of Plastics in Agriculture (NCPA) which provided an impetus to Gujarat, Madhya Pradesh, West Bengal, Punjab, Haryana, Bihar and some other states to adopt LDPE film for lining canal systems. More than 4500 km length of canal of 45 irrigation projects was lined with plastic mainly LDPE film in above states. This film has been used in minors and some main canals of lower discharges. Nevertheless, irrigation engineers have raised certain points regarding suitability of LDPE film such as stability of cover material in side slopes, damage to the film by weeds etc. Keeping such apprehensions in mind NCPA conducted a census-cum-evaluation study of plastic film in canal lining. The major findings of the study are as below :

1. The performance of lining has been found satisfactory where the plastic film overlaid with soil covers as well as hard cover lining was adopted in the bed as well as in side slopes.

2. It has been found from the seepage loss report of different irrigation projects that the plastic film combination lining will be able to save 10 to 15% additional water by preventing seepage losses, compared to conventional hard cover lining using brick/concrete.

3. The cost of plastic film lining overlaid with rigid cover is comparable with conventional rigid cover lining. There is scope for reduction of the cost of plastic film combination lining by reducing the thickness of the concrete over film and plaster at the outer surface of the brick.

4. No damage to the film due to weeds and rodents was reported.

5. The film collected from the canal bed was subjected to a laboratory test and it was found that there was no change in the film properties.

6. In Rasulpur distributary (Punjab) where 100 m thick film was laid in the year 1964, a few samples were taken out in August 1980. Although a few pinholes were observed at random, the sand below the polyethylene film was dry indicating the imperviousness of the film. This shows that the polyethylene film of 100 μ thickness remained in good condition even after 16 years of lining in the bed of the channel.

7. Seepage losses from combination type of lining laid in Doburji and Rasulpur distributary after making due corrections for evaporation losses have been found to be 0.21 $m^3/sec/10^6m^2$ of wetted surface. Seepage losses observed from Bhatinda distributary have been found to be 0.08 $m^3/sec/10^6m^2$ of wetted surface.

8. At places where there is animal traffic, the film has not been affected by the hooves of the animals when laid under 300 mm thick soil cover. The film is not exposed to the damaging effect of the ultraviolet rays of the sun when covered with soil.

9. The polyethylene film laid at the bed of Jullundur distributary has not been affected by the submerged aquatic weeds.

13.2 GENERALISATION OF TYPES OF LINING BASED ON TYPES OF SOILS AND DISCHARGE CARRYING CAPACITY OF CANAL

13.2.1 Although type of lining to be adopted depends on many factors, a rough idea of international and Indian experiences achieved are given in succeeding paragraphs.

13.2.2 International Experiences

13.2.2.1 ***Buried Membrane Lining on Expansive Soils*** : Failures have occurred where concrete and some other rigid-type linings have been laid on subgrades containing swelling clays . In such cases a more flexible type of lining, such as thick compacted earth lining or a buried membrane lining (LDPE) would serve better. In Bow canal, Canada the soil was lean clay and sand. The seepage rate was of the order of 7.06 $m^3/sec/10^6m^2$ On lining it with LDPE film overlaid with, soil and gravel cover, the seepage rate reduced to 0.52 $m^3/sec/10^6m^2$. After 10 years the seepage decreased marginally to 0.45 $m^3/sec/10^6m^2$. Thus, it is clear that the lining was very successful.

13.2.2.2 ***Concrete Lining on Sand Gravel Reaches*** : If sufficient amount of sand and gravel are contained in the soil, they may favour the choice of a concrete lining. In reaches containing sandy and gravelly soils, the seepage rate is of the order of 7.76 $m^3/sec/10^6m^2$. Fraint Kern Canal, California (depth 5.24 m) was lined by 100 mm thick cement concrete lining. The seepage rate reduced to 0.25 $m^3/sec/10^6m^2$ Unreinforced cement concrete lining of thickness 50 mm to 100 mm (according to requirement) will be suitable for all sizes of canals on firm subsoils.

13.2.2.3 ***Soil-Cement Lining on Sandy Soils*** : Soil-cement lining may be preferred in the localities having mild climate, sandy subgrade and lacking in other suitable materials. While selecting this type of lining for a particular reach, the designer has to be very careful, as this type of lining is not weather resistant, short lived and requires high maintenance charges. In W C Austin Project. Oklahoma some canal reaches were lined with 80 mm thick 15.5% soil cement. The seepage rate decreased from 3.35 $m^3/sec/10^6m^2$ to 0.11 $m^3/sec/10^6m^2$. The seepage rate increased marginally upto 0.21 $m^3/sec/10^6m^2$ after one year. Best results are obtained if soil has a size of 20 mm and contains 10 to 25% fines passing through IS: sieve No. 8.

13.2.3 Indian Experience

13.2.3.1 ***Precast Concrete Tile /In-situ Cement Concrete Lining on Gravelly and Sandy Soil*** : A primary prerequisite to the success of cement concrete lining and other hard surface linings is that, it should be laid over a firm foundation in order to reduce cracking and settlement. This requirement is fulfilled by sandy and gravelly subgrade. Therefore, in India cement concrete lining and other such type of linings have generally been laid in the canals passing through the reaches containing gravelly & sandy soil. In Nangal Hydel Channel, Yamuna Power Channel, Kosi Feeder Channel, Krishnaraja Sagar Canal, Pattanankal Main Canal, Pamba Irrigation Project, Kuttiady Irrigation Project and many other canal lining projects, subsoil was gravelly/gravelly cum sandy. Therefore cement concrete lining was preferred.

13.2.3.2 ***LDPE Film with Single/Double Tile Lining on Alluvial Sandy Soil*** : LDPE film lining provides only impermeability not structural strength. Its laying needs smooth subgrade. The data reveals that most of the canals passing through alluvial/sandy reaches have been lined with LDPE with suitable protective cover. Single or double tile lining as per requirement have been used as protective cover. This combination of soil type and type of lining has been used in Gujarat in Mahi Right Bank Canal, Petlad

Canal, Borsad Branch, Cambay Branch, Limbasi Branch, Nadiad Branch & Kingwa distributary. (Refer Table-1)

13.2.3.3 ***LDPE Film with Soil Cover or Insitu Cement Concrete Concrete Slab Lining on Black Cotton Soil*** : Data for canal lining in reaches having black cotton soil as subgrade was available for few canals. From the data, it is concluded that in small channels soil cover of sufficient thickness may be used as protective cover over LDPE, e.g. Lambhvel Distributary (Gujarat) Simardas minor, distributaries & minors of Mahi Canal system, Bortalai distributary and Biora minor. On the other hand big channels passing through black cotton soil reaches are preferably lined with LDPE film with cement concrete insitu on bed and concrete slabs on side slopes e.g. Heren's Minor, Amravati Main Canal, Contour Canal and Parambikulam Main Canal.

13.2.3.4 ***Double Tile Lining on Sandy Rock*** : In Khara Project the subgrade has sandy rock and clay shale over -lain boulder conglomerates. In Khara Power Channel, lining was done with double layer compressed C.C. tiles with sandwiched plaster.

13.2.4 The analysis done with respect to the soil type gave no conclusive results and different states have adopted different types of lining irrespective of type of soil.

13.2.5 Type of Lining Related to Discharge

From the data of some major and minor canals, an analysis regarding the type of lining adopted and discharge capacity revealed no conclusive results. However, a rough idea can be extracted from the data which shows that for canals of moderate discharge size (around 200 cumec), brick tile /concrete tile lining has been used in many canal lining projects. Cement concrete lining is preferred in big canals to ascertain the speed of work and to overcome the problems created due to joints. Other types of lining are mostly dependent on the subgrade and availability of raw materials in the vicinity and not on the discharge/size of the canal. However, the thickness of concrete lining depends to certain extent on the discharge of the canal, depth of water and ground water table of the area.

13.3 EFFICACY OF VARIOUS TYPES OF LINING

(i) **Insitu Concrete Lining and Precast slabs :** Hard Surface linings generally comprise two types of lining i.e. Cement concrete lining and precast concrete slabs/tiles. Insitu cement concrete lining is used in the cutting reaches and where ground water table is high. Performance of insitu concrete lining has been good in general and such types of lining have been constructed on almost all types of sub-grade. However, in both the linings, most of the failures have occurred in the bank portions due to low flexural strength and high ground water table. Failure of canal lining in most cases occur due to excess hydrostatic pressure resulting from either high ground water table condition or pressure build up due to timelag in drainage of the subgrade following drawdown of the canal. This calls for provision of adequate drainage arrangements for dissipation of excess hydrostatic pressures. As the functioning of the drainage arrangement depends on the efficacy of the drainage filter and pressure release valves, the performance of which can not be taken for granted unless laid under vigorous control and maintained regularly. It is considered advisable for important continuously running channels to make the lining safe without considering the effect of dissipation of pressures through such drainage arrangements. The drainage filters often get choked and likewise the pressure release valves also become non-functional without regular maintenance. It has also been found that pressure release valves do not provide appreciable relief to the lining against pressure due to sudden drawdown. In such cases it is considered better to provide continuous filter with adequate outlets to release seepage pressure. Drainage windows of suitable size and made up of porous concrete may prove effective when located over drainage filters on slopes below sub-soil water level. For proper working of the drainage arrangements e.g. pressure release valves, longitudinal, cross drains and filters, proper investigation and research work must be performed in a well equipped electrical analogy and mathematical modeling laboratory.

(ii) **LDPE Film Lining :** LDPE film overlaid with different types of hard surface lining have been used in various states in small and big channels. This lining is easy to install and require a minimum of equipment and skilled labour. This film is placed on a well prepared canal sub-grade and can be covered with soil or cement concrete tiles, cement concrete of suitable thickness. From the experience of LDPE film lining in different states, it was observed that this film was able to save seepage losses to a greater extent.

(ii) Loosening of the joints in the lining due to continuous water seepage from the earthen embankment into channel due to high spring level.

B -Bed lining

The concrete lining in the bed was damaged in a small patch in a length of almost 30 metres at km 13.40 as was noticed in the year 1984. It has also been noticed that the damages to the channel lining are frequent during rainy season.

The damage in the concrete lining in the bed was observed only in the year 1984 and that too at only one place. The seepage of water from toe of the embankments and pits of 0.3 m to 1.0 m in the damaged area were seen. It is probable that some cracks in the bed lining had developed giving way to seepage of canal water. Such damaged panels were repaired with modified lining, in which 300 mm boulder pitching was done over 250 mm thick filter.

The channel is running and tile lining has behaved well generally except in the deep cutting reaches. Special care should be taken while providing lining in the channels in deep cutting reaches. Suitable P.R.V. and drainage arrangement alongwith proper filter should be provided for adoption in high spring level areas.

13.3.1.3 ***Haveli Canal (Punjab)*** : The Haveli canal lining consists of two layers of tiles with sandwitched mortar in between. This lining failed in servel reaches within a year of its completion. The failure of lining perhaps may be due to inadequate compaction of the backfill and lack of proper drainage provision for the canal banks.

13.3.1.4 ***Indira Gandhi Main Canal*** : LDPE film has been extensively used in Indira Gandhi Nahar Project -Stage II in combination with clay or cement concrete tiles. But since the plain LDPE film has very low punching shear strength, and very poor bond strength, horizontal and vertical slippage cracks in the side slope lining of Indira Gandhi Main Canal have been observed at many places.

13.3.1.5 ***Ranjeetpura Dy. (Rajasthan)*** : The damages due to poor bond strength of the LDPE film were observed in this distributary where the precast cement concrete tile layer installed over the LDPE film expanded in the hot weather & buckled at few places. The tile edges lost bond and contact with the film and lifted up at some places where the top tile buckled.

13.4 CONCLUSIONS

The review of experiences of present practice of canal lining in India and the findings of recent experimental works lead to the following conclusions.

1. Subgrade and water table conditions, climatic conditions, availability of materials, size of the canal, service requirments, economy and experience are the factors affecting selection of the type of lining. Adoption of a particular type of lining will require consideration of all these factors and hence it is not possible to recommend any one type of lining suitable for all conditions.

2. In major canals hard surface lining has been provided. Depending on ease of construction, availability of equipment and material, it has consisted of concrete in-situ, c.c. or brick tiles.

3. In small canals LDPE film protected with hard surface lining has widely been used. Use of LDPE film below any hard surface lining has been found effective for canals in silty sandy soils with high ground water table condition. It has proved as one of the low cost method of lining, particularly plastic film overlaid with hard cover for lining old channels.

4. Pressure release valves and under drainage system are very necessary for canals with high ground water table conditions or in the areas where rise in ground water table or waterlogging is expected due to canal operation. The performance of drainage arrangements must be monitored from time to time.

5. Cohesive-Non Swelling (CNS) treatment should be adopted for lining of canals in expansive soils. However, ferrocement lining is also one of the effective methods worth to be tried in such type of soil.

1	2	3	4	5	6	7
8.	Delhi	Power Channel	-	Cast in situ, Concrete precast tile lining with LDPE film	Hard Gravelly soil, soft rock, sand,boulder	-
9.	Gujarat	Damanganga canals	11.45 "	C.C.Lining 1:3:6	-	-
10.	-do-	Karjan Reservoir left bank main canal	28.30 "	Concrete M-100	-	-
11.	-do-	Mahi Right Bank canal	198.1 "	(i) Sandwich type (ii) 1:3:6 concrete lining LDPE Film with soil cover.	Alluvial	Experimental lining
12.	-do-	Sheterunji Right bank main canal	19.681	Masonry and concrete lining	-	-
13.	-do-	Ukai Left bank canal	35.00 "	Plain cement concrete in proportion 1:3:6	-	-
14.	-do-	Sabarmati Project main Canal	20.25 "	1:3:6 cast in-situ concrete	-	-
15.	-do-	Waterak reservoir	10.20 "	C.C. Lining 1:3:6	-	-

1	2	3	4	5	6	7
16.	-do-	Banaskantha Left bank main canal of Dantiwada project	31.10 "	C.C. Lining	Sandy loam Soil	-
17.	-do-	Karad Project canal	200.00 "	Precast block	-	-
18.	-do-	Banas Left bank main canal	31.13 "	Sandwiched brick lining	-	-
19.	-do-	Rangala Canals	4.25 "	C.C. lining 7.5 cm thick in bed 30 cm thick masonry inside	-	-
20.	-do-	Sipu Right main canal	7.668cumec	C.C. lining (1:3:6) 7.5 cm thick	-	-
21.	-do-	Sukhi project canal				
		(Left bank canal)	3.66 "	Precast concrete block	-	-
		(Right bank canal)	12.82 "	-do-	-	-
22.	-do-	Hatmati canal	11.33 "	LDPE film with single tile with cement mortar	Sandy	Lining intact.Film inspected in 1971 & again in 1973.

1	2	3	4	5	6	7
23.	-do-	Colony minor Ex-dantiwada canal	0.14 "	-do-	-do-	Lining intact. An experimental lining to prevent sliding/sinking of lining in slushy soil Experimental lining impervious earth of banks carted from 80 km.
24.	-do-	Lambhvel Distributary	0.425 "	LDPE film with soil cover	Black	Lining intact. Seepage rate with lining 0.18 cumec compared to unlined 0.14 cumec m.sq.ft.
25.	-do-	Herens minor	4.25 "	LDPE film with concrete slabs in cement mortar	-do-	Experimental lining still intact.
26.	-do-	Simarda S minor	0.27 "	LDPE film with soil cover	-do-	Lining still intact seepage losses considerably reduced and breaches in the embankment minimised
27.	-do-	Distributary and minor Mahi canals	3.39 "	-do-	-do-	Lining provided in embankment reaches (banking 0 to 2.1 m) to minimise seepage rate and prevent breaches

1	2	3	4	5	6	7
28.	-do-	Wansal sub-minor, Ex-nadiad Branch	5.38 "	-do-	Clayey	Experimental lining still intact.
29.	-do-	Rania distributary Ex-nadiad Branch	1.86 "	LDPE film with soil cover/LDPE film with single tile with cement mortar	Loessic noncohesive	-do-
30.	-do-	Nadiad distributary Ex-Mahi R B Canal	99.15 "	LDPE film with single tile with cement mortar/Conventional to double tile sandwich type lining	Loessic to sandy loam	Total lining approved was 20 kms lining intact
31.	-do-	Petlad distributary Ex-Mahi R B canal	67.90 "	LDPE film with soil cover	-	Experimental lining
32.	-do-	Petlad branch	31.20 "	LDPE film with single tile with cement mortar/LDPE film with double brick tiles	Alluvial	Lining intact
33.	-do-	Anklav distributary Ex-Petlad branch	-	LDPE film with soil cover	-	Experimental lining
34.	-do-	Adas distributary Ex-Borsad branch	-	-do-	-	-do-

1	2	3	4	5	6	7
35.	-do-	Cambey branch	66.50 "	LDPE film with single tile with cement mortar/Conventional double tile sandwich type lining	Sandy	-do-
36.	-do-	Borsad branch	38.10 cumec	LDPE film with single tile with cement mortar/LDPE film with double brick tiles	Alluvial	Lining intact
37.	-do-	Limbasi Branch	58.6 "	-do-/do	-do-	-do-
38.	-do-	Nadiad branch	84.9 "	-do-/do	-do-	-do-
39.	-do-	Kingwa Distributary	3.93 "	LDPE film with single tile with cement mortor/conventional single tile lining in cement mortar	Alluvial	250 μ LDPE film used incup section lining intact
40.	-do-	Phule wala Minor	0.38 "	-do-	Sandy	-do-
41.	-do-	Sailbura Minor	0.15 "	-do-	-do-	150 μ LDPE film used lining intact
42.	-do-	Saurashtra Branch Canal	425.00 "	10 cm thick C.C. lining in bed and sides	Sand, clay, sandy stone expansive	-

1	2	3	4	5	6	7
43.	-do-	Narmada Main Canal (Sardar Sarover Project)	1132.83	M150 concrete 10 cm thick in bed & 12.5 cm thick on sides	Hard gravelly soil, soft rock, sand gravel boulders	-
44.	-do-	RB Main Canal	-	Precast CC 1:3:6 block lining in-situ, tiles & brick lining	Sandy loam, Alluvium sandy and medium black	-
45.	-do-	Sardarpur Dy	-	- do -	-do-	-
46.	-do-	Abasana Dy	-	- do -	-do-	-
47.	-do-	Jantral Dy	-	- do -	-do-	-
48.	-do-	Kamalpur Dy	-	- do -	-do-	-
49.	-do-	Vad Dy	-	- do -	-do-	-
50.	-do-	Vadodara Branch Canal	53.09	10 cm & 7.5 cm thick M15 C.C. Lining	-	-
51.	-do-	Panam Reservoir Main Canal	27.95	Concrete and masonary lining	-	-

1	2	3	4	5	6	7
52.	Bihar	Western Kosi Canal	236.70 "	Boulders lining in head reach & brick tile lining (Single tile in canal bed and double layer in canal sides)	-	-
53.	-do-	Gandak Main Canal	113.30 "	LDPE film with soil cover/-do-	Clay	7.6 m Bed width 250 μ LDPE film
54.	-do-	Dhaka canal	16.99 "	LDPE film with soil cover/-do-	-do-	-do-
55.	Goa,Daman Diu	Salauli Irrigation Project	14.00 "	C.C. 1:3:6 lining 75 mm thick	-	-
56.	Haryana	Augumentation Canal	87.60 "	-do-	-	-
57.	-do-	Jawahar Lal Nehru left canal	90.80 "	Double tile lining(main canal) single tile lining concrete & kattle lining (distributary)	-	-
58.	-do-	Gurgaon Canal	640.00 "	Double tile lining(main canal) & single tile lining in distributary	-	-
59.	-do-	Jui Left canal	21.14 "	Single & double tile lining	-	-
60.	-do-	Satluj-Yamuna link Canal	212.00 "	-do-	-	

1	2	3	4	5	6	7
61.	-do-	Western Jamuna canal	454.00 "	Double tile lining	-	-
62.	-do-	Sewani Left Canal	24.16 cumec	Single & double tile lining & block lining	-	-
63.	-do-	Sunder sub-branch Ex-Hansi Branch	55.24 "	LDPE film with soil cover/conventional double tile sandwich type lining	Sandy	Lining completed in 1974
				LDPE film with single tile with cement mortar/LDPE film with single tile with cement mortar	-	-do-
				LDPE film with soil cover/ conventional double tile sandwich type lining		24 km lining was proposed during 1975
				LDPE film with single tile cement mortar		Lining completed in 1974
64.	-do-	Jeti feeder canal	- "	LDPE film with single tile with cement mortar/LDPE film with cement concrete insitu		Experimental lining
65.	-do-	JLN feeder canal	93.48 "	-do-	-	200 μ LDPE film used in the bed. Lining intact
66.	-do-	Dhamtan feeder canal	-	-do-	-	150 μ LDPE film used Lining intact

1	2	3	4	5	6	7
67.	-do-	Israna Distributary	5.32 "	Conventional single tile lining in cement mortar	sandy clay	-do-
				LDPE film with single tile without mortar	-do-	-do-
68.	-do-	Jundla Distributary	4.64	-do-	-do-	-do-
69.	-do-	Loharu Feeder canal	39.65	LDPE film with single tile with cement mortar / LDPE film with cement concrete in-situ	-do-	Experimental lining 175 µ LDPE film used for lining the bed portion.
70.	Manipur	Loktak left irrigation main canal	17.00 "	Cement concrete	-	-
71.	Punjab	Nangal Hydel Channel	254.00 "	Concrete and tile lining	Gravel and Land	-
72.	-do-	Sunder nagar Hydel channel	254.84 "	Cement Concrete lining	-	-
73.	-do-	Doburji Distributary	2.23 "	LDPE film with soil cover	-	Lining intact. The 100 µ film at the bed has remained free from perceptible damage 62.5 µ film got damaged.

1	2	3	4	5	6	7
74.	-do-	Jethuwada Distributary	0.538 "	LDPE film with soil / Conventional single tile lining in cement mortar	-	Film has been found intact & free from damage caused by weed growth & water insects.
75.	-do-	Rasulpur Distributary Ex-Kasur branch	3.85 "	LDPE film with soil cover	Sandy	Experimental lining carried out by IPRI, Amritsar. The buried film has remained free from perceptible damage due to insect and animal traffic etc. When examined after removing the cover.
76.	-do-	Kasur branch lower	22.18 "	-do-	-	-
77.	-do-	Jalandhar Distributary	6.14 cumec	-do-	-	Lining is intact and free from any damage by animal traffic, water insects etc
78.	-do-	Havely Canal	146.28 "	Lining in double layers of brick tile of sandwiching a layer of 12 mm thick cement mortar of 1:3 mix Reinforced with 1/4 steel,12.5"x12.5" mash in sides and 24.5"x24.5" in bed.	- -	

1	2	3	4	5	6	7
79.	-do-	Bhakra Main Canal	352.70 "	Two layer of well burnet tiles with 15 mm thick layer of 1:31 cement, surkhi and sand mortar sandwiched between the tiles	-	-
80.	-do-	Narwana Branch	126.28 "	-	-do-	-
81.	-do-	-	-	-	-	-
82.	-do-	-	-	-	-	-
83.	-do-	Bhawarigarh Dy	-	Single layer Brick Lining	Very loose sand	-
84.	-do-	Kotra Dy	-	- do -	-do-	-
85.	-do-	Niwada Dy	-	- do -	-do-	-
86.	-do-	Nidanpur Dy	-	- do -	-do-	-
87.	-do-	Bhiki Dy	-	7.5 thick brick lining	Clay with sand	-
88.	-do-	Bhani Dy	-	- do -	-do-	-
89.	-do-	Lad Bangali Dy	-	7.5 cm thick Brick Lining with LDPE film linings	Sandy loam, Alluvium sandy and medium black	-

1	2	3	4	5	6	7
90	-do-	Sutlej Yamuna Canal	-	C.C. Lining	-	-
91.	-do-	Left Bank Canal	-	Single layer of brick lining	Alluvial soil	-
92.	-do-	Musoo Branch	-	7.5 thick brick lining	Clay with sand	-
93.	-do-	Bhatinda Dy	-	250 μ thick LDPE film lining with brick masonary in 1:3 cement mortar	-	-
94.	-do-	Sailbura Mr.	-	150 μ LDPE covered with brick lining in 1:3 cement mortar	-	-
95.	-do-	Kingwah Dy	0.384	**i**. 250 μ LDPE with single brick lining in 1:3 cement **ii**.Top single layer of brick of 75 mm thick laid in 1:31 cement sand mortar in the layer of 12.5 mm thick cement plaster, 1.5 cm sub-grade and second layer of 10 mm thick cement plaster 1:3 properly rendered.	Alluvial soil	-

1	2	3	4	5	6	7
96.	-do-	Phulewala Dy	-	250 μ LDPE with single brick lining in 1:2 cement mortar	-	
97.	Rajasthan	Chambal Canal System	-	LDPE film with soil cover/-do-	Sandy,Sandy clay with high content of lime	Lining intact
98.	-do-	Ranjeetapura Distributary Rajasthan Canal	13.64 cumec	LDPE film with cement concrete in-situ/LDPE film with concrete slabs in cement mortar	Sandy	Experimental lining
99.	-do-	Ahmadwalia Minor Rajasthan Canal	0.32 to 0.16 "	-do-	-do-	-do-
100.	-do-	Samewala Distributary	1.60 "	-do-	-do-	-do-
101.	-do-	Water Supply Channel	2.74 "	LDPE film with soil cover/LDPE film with concrete slabs in cement mortar	-do-	-do-
102.	-do-	Indra Gandhi Main Canal	510.00 "	LDPE film with single tile with cement mortar/Conventional double tile sandwich type lining	Sandy soil/ Clay soil	Lining work undertaken with Agrifilm of 10-12 m width and 250 μ thickness

1	2	3	4	5	6	7
103.	-do-	Bikaner Canal	60.75 "	150 mm thick Kankar lime concrete.	-	-
104.	-do-	IGMC	-	Single Tile lining/Double tile lining	-	
105.	Uttar Pradesh	Gandak Canal	241.44 "	Bricktile lining	-	-
106.	-do-	Lower Ganga Canal-Link Canal	213.00 "	Sandwiched Brick lining	Sand	-
107.	-do-	Kosi Feeder Channel	42.50 "	Cement concrete tile lining	Coarse sand with gravel	-
108.	-do-	Sarda Sahayak Feeder Channel	650.00 "	Double tile and CC lining	-	-
109.	-do-	Azamgarh Canal	11.32 "	LDPE film with soil cor / LDPE film with single tile with cement mortar	Sandy	Experimental lining
110.	-do-	Mat Branch	59.30 "	No lining in bed 7.5 cm thick brick lining over 100 μ LDPE on sides	Medium to fine sand, silt & clay	-

1	2	3	4	5	6	7
111.	-do-	Madhya Ganga Canal	233.6	Brick tile lining in 1:5 cement mortar in bed/Double brick tile lining 1:5 cement mortar on sides	Sandy	Performance is satisfactory
112.	-do-	Eastern Ganga Canal	137.30 "	C.C. lining/Double tile lining	Sandy and Silty	Lining in some reaches damaged
113.	-do-	Khara Power Channel	-	C.C. lining/Double layer compressed CC tile	Sand rock clay shall	-
114.	-do-	Rishikesh Chilla Power Channel	680.00 "	Boulder pitching/Insitu C.C. C.C. tile lining	-	C.C. tile lining partially damaged after 4 years in deep cutting high GWT reaches
115.	-do-	Parallel Upper Ganga Canal	370.00 "	Double tile lining with LDPE film	SP & SM	-
116.	Karnataka	Krishnaraja Sagar Right Bank Low level canal	7.08 cumec	Soil Cement lining	Good gravel	-
117.	-do-	-do-	2.89 "	Lime Surkhi concrete lining	Gravel	

1	2	3	4	5	6	7
118.	-do-	Tungbhadra Left Bank Canal	0.34 "	LDPE film with cement concrete in-situ/LDPE film with concrete slabs in cement mortar	Clayey	Lining intact. An experimental lining to prevent sliding / sinking of lining in slushy soil
119.	-do-	24th Mile Distributary of Visvesuaraian Canal	1.13 "	LDPE film with cement concrete in-situ/LDPE film with single tile with cement mortar	Gravelly soil	Experimental lining
120.	-do-	Vaddarnodabay Distributary	0.28 "	LDPE film with cement concrete insitu/polyethylene film with soil cement 100:6/LDPE film with concrete slabs in cement mortar/Polytheylene film with size stone	-	-do-
121.	-do-	Right Bank Canal	-	Pre cast concrete slabes	Very loose sand	-
122.	-do-	Harangi Left Bank Canal	-	15 cm thick C.C. 1:3:6 over LDPE film of 1000 gauge	Hard gravelly soil, soft rock, sand gravel boulder	-
123.	-do-	Tungbhadra Low Level Canal	-	PCC slab lining and CC lining and masonary lining	Black cotton soil	-

1	2	3	4	5	6	7
124.	-do-	Left Bank Canal	-	PCC slab	Hard soil	-
125.	Tamilnadu	Manniaru Canal	43.20 "	In-situ cement concrete lining	Sandy	-
126.	-do-	Pattanamkal main Canal	8.40 "	Cement concrete.	Hard gravelly soil	-
127.	-do-	Rathapuram Channel	4.20 "	-do-	-do-	-
128.	-do-	Amrawati Main Canal	13.58 "	LDPE film with cement concrete in-situ/LDPE film with concrete slabs in cement mortar	Black cotton	Experimental lining
129.	-do-	Manimather Main Canal	.5-6.7 "	Polyethylene film with brick in CM and top plastered.	Sandy	-do-
130.	-do-	Contour Canal	32.50 "	LDPE film with concrete slabs in cement mortar	Black cotton	Experimental lining
131.	-do-	Parambikulam Main Canal	29.09 "	-do-	-do-	-do-
132.	-do-	RMC of thiauparappal Anicut & modernisation of existing canal	-	CC 1:3:5, 5 cm thick on bed and precast PCC 1:2:4 slab 5 cm thick on sides	Hard gravelly soil, red gravelly hard rocky strata and soft rock, sand gravel & boulder	-

1	2	3	4	5	6	7
133.	-do-	Anant hanar Modernisation scheme	-	P.C. slab	Clayey soil	-
134.	-do-	Right Main Canal	-	P.C. slab	-	-
135.	Kerala	Left bank Main Canal Pamba Irrigation Project	20.376cumec	R.R. Masonry and cement concrete lining	Gravelly & Laterite soil	-
136.	-do-	Left bank Canal Kuttiady Irrigation	18.123 "	Precast cement concrete slabes	Hard Gravelly soil to hard rock	-
137.	-do-	Right Bank Main Canal Peechi Irrigation Schemes	7.08 "	Double masonry in cement mortar	-	-
138.	-do-	Left Bank Canal	21.225 "	Precast slabes and blocks	-	-
139.	-do-	Kuthanur Branch	1.698 "	Bitumen and cement	-	-
140.	Madhya Pradesh	Distributary 1, Ex-Chambal Right Main Canal	3.40 "	LDPE film with soil cover LDPE film with single tile with cement concrete mortar	Sandy loam	Experimental lining
141.	-do-	Bortalai Distributary Tawa Canal	0.55 "	LDPE film with soil cover	Black Cotton soil	150 μ LDPE film used lining intact

1	2	3	4	5	6	7
142.	-do-	Biora Minor Tawa Canal	0.06 "	-do-	-do-	-do-
143.	-do-	-	-	-	-	-
144.	-do-	RABS Project	127.40 "	10 cm thick 1:3:6 C.C. Lining	Hard soil & Moorum + rock	-
145.	West Bengal	TSMC(N),Kangsabati project	0.86 "	LDPE film with soil cover	Lateritic	Lining intact
146.	-do-	Distributary 14R of TNMC (N)	3.96 "	-do-	-do-	-do-
147.	-do-	TSMC (S)	21.23 "	-do-	-do-	-do-
148.	-do-	Distributary 18R of TSMC (S)	13.00 " 9.60	-do- -do-	-do- -do-	-do- -do-
149.	-do-	Kangsabati Canal Project	42.45 " to 84.90	LDPE film with soil cover/-do-	-do-	Bed width : 11.8m, Side slopes 2:1 250 μ Agrifilm
150.	-do-	Teesta Canal Project	-	-	-	-

Table -2

DETAILS OF LINING IN SOME IMPORTANT CANALS OF UTTAR PRADESH

Sl No.	Name of Project/ Canal	Type of Lining: Bed	Type of Lining: Side	Remarks
1	2	3	4	5
1.	Parallel Upper Ganga Canal (km.16.0 to 19.2)	(i) 100 mm thick sand (ii) 100 mm thick C.C. M15	(i) 75 mm thick coarse sand (ii) 75 mm thick Graded shingle (4.75 to 20 mm) (iii) 10 mm thick C.M. (iv) 300x150x50 mm burnt clay tile in 1:5 C.M. (v) 15 mm thick sandwitched plaster 1:3 C.M. (vi) 5 mm thick C.M. in 1:3 (vii) 300x150x50 mm burnt clay tile in 1:3 C.M.	Refer Fig. A-16 of Appendix
2.	Parallel Upper Ganga Canal (km.29.1 to 29.6)	(i) 75 mm coarse sand (ii) 100 mm thick C.C. M15	(i) Coarse sand of F.M. 1.5 or more (75 mm thick) (ii) 10 mm thick C.M. (iii) 300x150x50 mm burnt clay tiles in 1:5 C.M. (iv) 15 mm thick sandwitched cement plaster 1:3 C.M. (v) 5 mm thick C.M. in 1:3 (vi) 300x150x50 mm burnt clay tile in 1:3 C.M.	-
3.	Parallel Upper Ganga Canal (km.177.5 to 189.5)	(i) 75 mm thick Ganga sand (ii) 75 mm 4.75 to 20 mm graded gravel (iii) 100mm thick C.C. M15	(i) 75 mm thick coarse sand (ii) 75 mm thick shingle 5 to 20 mm. (iii) 100 mm thick C.C. M15 (iv) 20 mm thick 1:25 cement plaster	
4.	Eastern Ganga Canal (km.11.1 to 19.5)	(i) 100 mm thick C.C. M15	(i) 75 mm thick coarse sand (ii) 150 mm thick graded filter 5 to 20 mm. (iii) 10 mm thick 1:5 C.M. (iv) 300x150x50 mm burnt clay tiles (v) 15 mm thick sandwitched cement plaster 1:3	Refer Fig. A-15 of Appendix

1	2	3	4	5
			(vi) 5 mm thick C.M. 1:3. (vii) 300x150x50 mm mechanised burnt clay tiles	
5.	Eastern Ganga Canal (Upstream km.29.0)	(i) 100 mm thick C.C. M15	(i) 75 mm thick local sand F.M. 0.8 or above. (ii) 75 mm thick coarse sand F.M. 1.5 or above. (iii) 10 mm thick 1:5 C.M. (iv) 15 mm thick sandwitched cement plaster 1:3 (v) 5 mm thick C.M. in 1:3. (vi) Tiles 300x150x50 mm laid in 1:3.	-
6.	Madhya Ganga Canal	(i) 10 mm C.M.1:5 (ii) Bricks tiles 300x150x50 mm in 1:5 C.M. (iii) 20 mm thick cement plaster in 1:3 C.M.	(i) 10 mm thick C.M. in 1:5 (ii) Bricks tiles 300x150x 50 mm laid in 1:5 C.M. (iii) 15 mm thick sandwitched plaster in 1:3 C.M. (iv) 50 mm thick C.M. 1:3. (v) Tiles 300x300x40 mm of C.M. C.C. M15.	Refer Fig. A-22 of Appendix
7.	Sharda Sahayak Feeder Channel	(i) 100 mm thick C.C. M10	(i) 10 mm thick C.M. in 1:4 (ii) 70mm brick lining in 1:4 C.M. (iii) 15 mm sandwitched plaster in 1:3 C.M. (iv) 5 mm mortar in 1:4 C.M. (v) 50 mm tiles 300x300x50 or brick tile 300x150x50 mm in 1:4 C.M.	Refer Fig. A-17 of Appendix
8.	Main Western Gandak Canal	(i) 10mm cement plaster in 1:4 C.M. (ii) 50 mm tile layer in 1:4 C.M. brick tile (300x150 x50) mm (iii) 20 mm cement plaster in 1:3 C.M.	(i) 10 mm cement plaster in 1:5 C.M. (ii) 50mm bottom tile layer in 1:5 C.M.brick 300x150x50mm (iii) 15 mm cement plaster in 1:3 C.M. (iv) 5 mm cement sand mortar 1:3 (v) 50 mm thick tile (300x150x 50) mm in layer in 1:3 C.M.	-
9.	Khara Power Channel	(i) 100 mm thick C.C. M15	(i) 10 mm thick C.M. 1:5 (ii) 300x300x40 mm tiles of M15 C.C.	Refer Fig. A-19 0f Appendix

1	2	3	4	5
			(iii) 15 mm thick sandwitched plaster 1:3 (iv) 5 mm thick mortar 1:3 (v) 300x300x40 mm tile of M15 C.C.	
10.	Rishikesh Chilla Power Channel	(i) 125 mm thick C.C. M15	(i) 10 mm thick C.M. 1:5 (ii) 300x300x40 mm tiles of M15 C.C. (iii) 15 mm thick sandwitched plaster 1:3 (iv) 5 mm thick mortar 1:3 (v) 300x300x40 mm tile of C.C. M15.	Refer Fig. A-20 of Appendix

Table -3

EXPERIENCE OF CANAL LINING WITH LDPE FILM IN STATE OF HARYANA

Notations :

PS	-	LDPE film with soil cover.
DT (SW)	-	Double tile sandwich type lining
SB	-	Single tile lining in cement mortar
PLB	-	LDPE film with single tile without mortar.
PB	-	LDPE film with single tile with cement mortar
PCC	-	LDPE film with cement concrete in-situ.

Name of Canal Year of lining	Discharge Cumec	Type of Soil	Type of lining bed/side	Length lined metres	Remarks
Sunder Branch 1974	55.2	Sandy	PS/DT(SW)	3800	Lining completed in 1974.
JLN Feeder Canal	93.45	Alluvial	PB/PCC	7000	200 μ LDPE film used in the bed, lining intact
Israna distributary 1980	5.32	Sandy clay	SB/PLB	600	150 μ LDPE film used, lining intact
Jundla distributary 1980	4.65	-do-	-do-	-	-do-

Table -4

EXPERIENCE OF CANAL LINING WITH LDPE FILM IN STATE OF RAJASTHAN

Notations :

PCC	-	LDPE film with cement concrete in-situ.
PCT	-	LDPE film with concrete tiles in cement mortar.
PS	-	LDPE film with soil cover.
DT(SW)	-	Double tile sandwich type lining

Name of Canal Year of lining	Discharge Cumec	Type of Soil	Type of lining bed/side	Length lined metres	Remarks
Ranjeetpura distributary	13.65	Sandy	PCC/PCT	140	Experimental lining
Ahmad walia Minor	0.31	Sandy	PCC/PCT	130	-do -
Samewala distributary	1.61	Sandy	PCC/PCT	140	-do-
Water Supply Channel	12.74	Sandy	PB/PCT	110	-do-
Rajasthan Canal	510.00	Sandy	PB/DT(SW)	-	Lining work under taken with Agrifilm of 10-12 m width & 175 to 200 μ thickness.

Table -5

EXPERIENCE OF CANAL LINING WITH LDPE FILM IN STATE OF PUNJAB

Notations : PS - LDPE film with Soil cover
SB - Single tile lining in cement mortar

Name of Canal Year of lining	Discharge Cumec	Type of Soil	Type of lining bed/side	Length lined metres	Remarks
Doburji distributary 1960-61	2.24	-	PS/PS	81	Lining intact. The 100 μ film at the bed remained free from perceptible damage 62.5 μ film got damaged.
Jethu wada distributary 1961	0.538	-	PS/SB	1067	Film has been found intact and free from damage caused by weed growth and water insects.
Rasulpur distributary Ex-Kasur branch Punjab-1963-64	3.85	Sandy	PS/PS	150	Experimental lining carried out by IPRI Amritsar.The buried film has remained free from perceptible damage due to insect and animal trafic etc , when examined after removing the cover.
Jullunder distributary 1972-73.	6.147	-	PS/PS	610	Lining is intact and free from any damage by animal trafic, water insects etc.

Table -6

COMPARATIVE COST AND SEEPAGE LOSSES OF VARIOUS TYPES OF LINING BASED ON M/S CARRIED OUT BY UPIRI AT BAHADRABAD

Sl. No.		Type of lining	Seepage losses $m^3/sec/10^6m^2$	Comparative seepage losses in %
I.		Unlined Channel	1.52	100
II.	(a)	Hard cover (without LDPE film)		
	(i)	1:4 brick lining	0.470	30.9
	(ii)	1:6 Clay tile lining	0.275	18.1
	(iii)	1:6 C.C. tile lining	0.384	25.3
	(iv)	1:6 2nd class brick lining	0.662	43.6
II.	(b)	Hard cover over LDPE film		
	(i)	1:6 clay tile lining over 100 micron film	0.065	4.3
	(ii)	Brick lining over 100 micron film	0.030	2.0
	(iii)	1:4 brick lining over 100 micron film on bed only	0.410	27.0
	(iv)	1:6 brick lining over 100 micron film on sides with 15 cm earth cover on bed.	0.064	4.2

Table -7

CLAY TILE LINING ON CLAYEY SOIL

Sl. No.	Details of Channels	Seepage losses $m^3/sec/10^6m^2$	Savings in seepage losses in %
1.	Unlined Channel	0.560	-
2.	1:6 clay tile lining	0.235	58
3.	1:6 clay tile lining over 100 micron film	0.065	88

Table -8

LINING ON BED COVERED WITH LDPE FILM AND BED AND SIDE COVERED WITH LDPE FILM ON CLAYEY SOIL

Sl. No.	Details of Channels	Seepage losses $m^3/sec/10^6m^2$	Savings in seepage losses in %
1.	1:4 brick lining over 100 micron film laid on bed only	0.410	27
2.	1:4 brick lining over 100 micron film	0.030	95

Table -9

LDPE LINING ON DIFFERENT TYPE OF SOIL

Sl. No.	Details of Channels	Seepage losses $m^3/sec/10^6m^2$
1.	1:4 brick lining over 100 micron film (clayey soil)	0.044
2.	1:4 brick lining over 100 micron film (sandy soil)	0.058

Table -10

SEEPAGE LOSSES IN LINED AND UNLINED CHANNELS UNDER FIELD CONDITIONS

Sl. No.	Name of Channel	Design discharge cumec	Type of channel	Type of Lining	Average seepage losses $m^3/sec/10^6m^2$	Percentage saving in seepage losses due to lining compared with unlined channel
1.	Harduganj Dy. at km. (i) 27.90	6.75	Unlined	–	1.950	–
	(ii) 27.00	-do-	Lined	200 micron LDPE film lining over laid single layer of burnt clay tiles in 1:4 cement mortar.	0.169	91.33
2.	Komari Dy. at km. (i) 1.800	3.35	Unlined	–	1.995	–
	(ii) 0.225	-do-	Lined	200 micron LDPE film lining over laid by burnt clay tiles in 1:4 cement mortar.	0.140	92.98
3.	(i) Cheeti Minor of Bulandshar Dy. (Bulandshar)	0.31	Unlined	–	1.304	–
	(ii) -do-	-do-	Lined	100 micron LDPE film lining covered with brick using 1:4 cement mortar.	0.150	88.4
4.	(i) Machkauli Minor of Bulandshar Dy. (Bulandshar)	0.396	Unlined	–	1.259	–
	(ii) -do-	-do-	Lined	100 micron LDPE film lining covered with brick using 1:4 cement mortar.	0.045	96.40

Details of Major Canal Linings

The details regarding the design, specifications and performance of various types of linings as provided in the case of the following projects are appended herewith.

1. Nangal Hydel Channel (Punjab) - Concrete and Tile Lining
2. Sundernagar Hydel Channel, Beas Project (Punjab) - Cement Concrete
3. Yamuna Power Channel (U.P.) - Concrete, Brick and Concrete Tile
4. Gandak Canal (U.P.) - Brick Tile Lining
5. Lower Ganga Canal Link Canal (U.P.) - Sandwiched Brick Lining
6. Kosi Feeder Channel (U.P.) - Cement Concrete Tile Lining
7. Rajasthan Feeder Channel (Rajasthan) - Tile Lining
8. Banaskantha Left Bank Main Canal of Dantiwada Project (Gujarat) - Cement Concrete Lining
9. Banaskantha Left Bank Main Canal of Dantiwada Project (Gujarat) - Brick Lining
10. Mahi Right Bank Canal (Gujarat) - Sandwiched Brick Tile Lining
11. Shetrunji Canal Project (Gujarat) - Masonry Lining
12. Shetrunji Canal Project (Gujarat) - Lime Concrete Lining
13. Karad Project Canal (Gujarat) - Precast Blocks
14. Tungabhadra Project (A.P.) - Cement Concrete and Rubble Masonry
15. Krishnarajasagar Canal (Karnataka) - Cement Concrete Lining
16. Krishnarajasagar Right Bank Low Level Canal (Karnataka) - Soil Cement Lining

17. Krishnarajasagar Right Bank Low Level Canal (Karnataka) - Lime Surkhi Concrete Lining

18. Manniaru Canal (Tamil Nadu)- Insitu Cement Concrete Lining

19. Pattanamkal Main Canal (Tamil Nadu)- Cement Concrete and Metal

20. Rathapuram Channel (Tamil Nadu)- Cement Concrete and Metal

21. Left Bank Main Canal, Pamba Irrigation Project (Kerala) - R.R.Masonry and Cement Concrete Lining

22. Left Bank Canal, Kuttiady Irrigation (Kerala)- Precast Cement Concrete Slabs

23. Right Bank Main Canal, Pecchi Irrigation Scheme (Kerala)- Rubble Masonry in Cement Mortar

24. Left Bank Canal (Kerala) - Precast Slabs and Blocks

25. Kuthanur Branch (Kerala) - Bitumen and Cement

26. Rani Avanti Bai Sagar Project, Jabalpur

27. Eastern Ganga Canal

28. Parallel Upper Ganga Canal

29. Sarda Sahayak Feeder Channel

30. Indira Gandhi Main Canal

31. Khara Power Channel

32. Rishikesh Chilla Power Channel

33. Saurashtra Branch Canal

34. Madhya Ganga Canal

35. Narmada Main Canal (Sardar Sarovar Project)

36. Krishna Water Supply Project Canal - Tamil Nadu

1. NANGAL HYDEL CHANNEL

1.	Name of project/ canal	: Nangal Hydel Channel (Punjab) (Figure A-1)		
2.	Year of construction	: Not specified		
3.	Channel dimensions	: (i)	Bed width	...24 m & 24.9 m
		(ii)	Water depth	...6.18m & 5.88 m
		(iii)	Side slopes	...1.25:1
		(iv)	Free board	...not specified
		(v)	Channel bed slope	...15/1000
4.	Design standards	: (i)	Discharge	...354 m^3/sec
		(ii)	Velocity	...2.19 m/sec
		(iii)	Value of Manning's n :	0.018
5.	Length of lining	: (i)	49.9 km of concrete lining	
		(ii)	14.4 km of tile lining	
6.	Sub-grade details	: Strata comprises gravel and sand.		
7.	Type of lining	: Concrete lining and tile lining.		
8.	Pressure release arrangements			
	(a) Bed	: (i)	75 mm thick filter was used in bed where the strata was porous and water-table was high along with longitudinal drains.	
		(ii)	Flap valves operating automatically at 101.6 mm differential head at 152.4 m interval in the centre and on either side.	
	(b) Sides	: (i)	114 mm thick filter was used on sides along with transverse drains in reaches of porous strata and high watertable.	
		(ii)	Same as item (ii)of bed.	
9.	Purpose of lining	: To economize the section and to reduce the lining losses of seepage.		
10.	Joints	: 9.5 m x 38 mm expansion joints were provided		

11. Construction details

(a) Bed : (i) 1:3:6 cement concrete, 127 mm thick in 7.6 x 6.1 m slab. The bed slabs rest on cement concrete bed sleepers of 1:4:8 mix of 229 mm x 114 mm laid in situ.

(ii) 203 mm thick cement concrete in reaches below Kotla Power House where sub-soil water-level was high.

(iii) Two layers or well-burnt tiles 50 mm thick with a 15.9 mm layer of 1:3 cement plaster sandwiched in between. The first layer of tiles is laid on 9.5 mm thick layer of 1:5 cement mortar and the other on 6.3 mm thick layer of 1:3 cement mortar.

(b) Sides : (i) 1:3:6 cement concrete 150 mm thick. The side slabs rest on precast cement concrete bed blocks 22 mm x 114 mm and of about 0.60 m length.

(ii) 229 mm thick 1:3:6 cement concrete in the reach below Kotla Power House where sub-soil water-level was high.

(iii) Two layers of well-burnt tiles 50 mm thick with a 15.9 mm layer of 1:3 cement plaster sandwiched in between. The first layer of tiles is laid on 9.5 mm thick layer of 1:5 cement mortar and other on 6.3 mm thick layer of 1:3 cement mortar.

12. Field performance : The lining has proved to be relatively more stable in filling reaches than in reaches involving deep cutting. Some major damages have occurred due to sub-soil water in the reaches of heavy cutting. The reaches with proper drainage arrangements were less troublesome. Experience on this canal has indicated that concrete lining has given better overall performance in high water-table reaches than tile lining.

2. SUNDERNAGAR HYDEL CHANNEL BEAS PROJECT

1.	Name of project/ canal	: Sundernagar Hydel Channel, Beas Project (Punjab) (Figure A-2)		
2.	Year of construction	: Not specified		
3.	Channel dimensions	: (i)	Bed width	...9.45 m dimension
		(ii)	Water depth	...6.13 m
		(iii)	Side slopes	...1.5:1
		(iv)	Free board	.0.91 m
		(v)	Channel bed slope	..1 in 6666
4.	Design standards	: (i)	Discharge	...254.85 m^3/sec
		(ii)	Velocity	... 1.89 m/sec
		(iii)	Value of Manning's n :	0.016
5.	Length of lining	: Not specified		
6.	Sub-grade details	: Not specified		
7.	Type of lining	: Cement concrete lining		

8. Pressure release arrangements

(a) Bed : Two longitudinal drains connected with filter blanket through 61 cm wide filter @ 4.57m c/c.

(b) Sides : Continuous filter up to 3.05 m from top laid in two layers each 7.5 cm thick.

9. Purpose of lining : To economize the section and to reduce the seepage losses.

10. Joints
- (i) Transverse joints at 4.57 m apart.
- (ii) Three longitudinal joints in bed.
- (iii) Two longitudinal joints in each slope.

11. Construction details

(a) Bed : 10 cm thick cement concrete lining laid in panels. 23 cm x 11 cm concrete sleepers provided below joints. The top of sleepers painted with bitumen.

(b) Sides : 12.7 cm thick cement concrete lining without sleepers below joints.

12. Field performance : No data on field performance available.

3. YAMUNA POWER CHANNEL

1. Name of project/ canal : Yamuna Power Channel (U.P.) (Figure A-3)

2. Year of construction : 1963-65

3. Channel dimension :

(1)	Bed width	...10.98 m
(ii)	Water depth	...5.70 m
(iii)	Side slopes	...1.5:1
(iv)	Free board	...0.76 m
(v)	Channel bed slope	...not specified

4. Design standards :

(i)	Discharge	...198.1 m^3/sec
(ii)	Velocity	...1.775 m/sec
(iii)	Value of Manning's n :	not specified

5. Length of lining : 13.6 km

6. Sub-grade details : Fine and coarse consolidated sand with gravel and boulders. K=600 to 7,500 m/yr.

7. Type of lining : Concrete lining in bed, brick and concrete tile lining on sides.

8. Pressure release arrangements

   (a) Bed : Normal reaches-no pressure release arrangement has been provided. Reaches where ground water-table is high, 30 cm diameter perforated cement concrete pipes at either junction of the side and bed, one at the centre of the bed fitted with pressure release valves at 5.18 m c/c.

   (b) Sides : Reaches where ground water-table is high (i) The first layer of the filter consists of 150 mm thick layer of the material ranging from 2 mm to 50 mm. (ii) The next 150 mm thick layer consists of the material ranging from 37.5 mm to 50 mm in size. Special drain was constructed at the berm level for curing arrangement and dewatering.

9. Purpose of lining : To economize section and to reduce seepage losses.

10. Joints : 12.5 mm wide expansion joints have been provided at 10.06 m interval. The joints are on brick sleepers and filled by a joint filler developed at U.P.I.R.I. Roorkee, using maxphalt.

11. Construction details

(a) Bed : Normal Reaches-100 mm thick concrete laid in situ in 1:3 colgrout. Reaches where Ground water-table is high 150 mm thick concrete lining.

(b) Sides : In normal Reaches-69 mm thick Ist class flat bricks; with joints in 1:3 cement mortar, 12.5 mm thick 1:3 cement mortar layer sandwiched between brick and tiles, 50 mm thick concrete tiles of 300 mm x 300 mm size with joints in 1:3 cement mortar laid simultaneously with sandwiched mortar layer. Reaches where ground water-table is high 100 mm thick porous concrete placed over filter. 12.5 mm thick sandwiched layer of 1:3 cement mortar with 50 mm thick cement concrete tiles.

12. Field performance : The lining in general has behaved well. During closure in March 1972, about 263 panels were found damaged due to excessive differential head due to high water table in deep cutting reaches. The pressure release valves have not proved effective as these got choked.

4. GANDAK CANAL

1.	Name of project/ canal	: Gandak Canal (U.P.) (Figures A-4 & A-5)		
2.	Year of construction	: Not specified		
3.	Channel dimension	: (i)	Bed width	...41.4 m
		(ii)	Water depth	...3.8 m
		(iii)	Side slopes	...1.5:1
		(iv)	Free board	...not specified
		(v)	Channel bed slope	...not known
4.	Design standards	: (i)	Discharge	...241.44 m^3/sec
		(ii)	Velocity	...1.50 m/sec
		(iii)	Value of Manning's n :	not specified
5.	Length of lining	: From 18.91 km to 130.7 km		
6.	Sub-grade details	: ML-CL to SP,K = 30 to 600 m/yr		
7.	Type of lining	: Brick tile lining		

8. Pressure release arrangements

(a) Bed : (i) Where the permeability is less than 30 m/yr, a continuous blanket or 75 mm thick sand has been provided at bed and two nos. longitudinal drains with 150 mm diameter pressure release valves at 91.5 m c/c at the junction of bed and side slopes have been provided.

(ii) Where the permeability is more than 30 m/yr and less than 150 m/yr, 150 mm diameter longitudinal drains with 150 mm pressure release valves at 91.5 m c/c have been provided.

(iii) Where the permeability is more than 150 m/yr, 50 mm diameter pressure release valves at 30.5 m c/c at the junction of the bed and side slopes have been provided.

(b) Sides : (i) Where the permeability is less than 30 m/yr, same as item (i) of bed.

(ii) Where the permeability is > 30 and < 150 m/yr, 50 mm diameter pressure release valves at 15.25 m c/c have been provided.

(iii) Where the permeability is more than 150 m/yr, same as item (ii)of sides.

9. Purpose of lining : The channel passes through pervious reaches, the adjacent areas are susceptible to waterlogging. Hence lining was proposed to reduce seepage and waterlogging. The lining also resulted in economy of section.

10. Joints : No expansion and construction joints are provided either in longitudinal direction or in transverse direction. Dwarf regulators have been provided to maintain water depth in reaches with high water table.

11. Construction details

(a) Bed : (i) 9.0 mm thick cement mortar 1:4 on compacted sub-grade.

(ii) Ist class brick tiles 50 mm thick in cement mortar 1:4.

(iii) 19 mm thick cement plaster 1:3.

(b) Sides : (i) 9.0 mm thick cement mortar 1:4 on compacted sub-grade.

(ii) 2nd class well-burnt brick tiles 50 mm thick in cement mortar 1:5.

(iii) A sandwiched 16 mm thick cement mortar 1:3.

(iv) Ist class well-burnt brick tiles 50 mm thick in cement mortar 1:3.

(v) 12.5 mm thick plaster on top.

12. Field performance : No data on field performance is available.

5. LOWER GANGA CANAL

1.	Name of project/ canal	: Lower Ganga Canal-Link Canal (U.P.) (Figure A-6)		
2.	Year of construction	: 1965-1967		
3.	Channel dimension	: (i)	Bed width	...51.450 m
		(ii)	Water depth	...3.355 m
		(iii)	Side slopes	...1.5:1
		(iv)	Free board	...30 cm
		(v)	Channel bed slope	...1/9250
4.	Design standards	: (i)	Discharge	...213.0 m^3/sec
		(ii)	Velocity	...1.13 m/sec
		(iii)	Value of Manning's n :	0.018
5.	Length of lining	: 1.81 km		
6.	Sub-grade details	: Sub-grade consisting fine to medium sand (d_{50} = 0.18 to 0.30 mm), K = 1500 to 3000 m/yr.		
7.	Type of lining	: Sandwiched 1st class brick lining		
8.	Pressure release arrangements			
	(a) Bed	: Three 225 mm diameter longitudinal drains with 225 mm diameter pressure release pipes spaced 18.3 m c/c.		
	(b) Sides	: 150 mm diameter pressure release pipes spaced 18.3 m c/c in one row at 0.915 m above bed.		
9.	Purpose of lining	: To reduce seepage losses		
10.	Joints	: Expansion joints provided at 18.3 m c/c. They are 25 mm wide and 150 mm deep filled with bitumen sand and saw-dust. Damaged portions were replaced and inverted filter in 0.61 m width across the slope at 18.3 m c/c was provided.		
11.	Construction details			
	(a) Bed	: One layer of 1st class brick lining in 1:4 cement mortar with 18.75 mm thick 1:3 cement sand plaster at top and 9.3 mm thick 1:5 cement sand plaster at the bottom.		

(b) Sides	:	Two layers of 1st class bricks laid in 1:4 cement mortar with a 12.5 mm thick sandwiched layer of cement sand plaster. At top 12.5 mm thick 1:3 cement sand plaster.
12. Field performance	:	Due to sudden drawdown in August, 1967 lining on both canal banks was damaged. The bed was covered with 0.6 m silt which made pressure release arrangement in bed ineffective. Side pressure release pipes, projecting 22 cm into the canal, entangled grass and floating materials and therefore, their proper functioning was obstructed.

6. KOSI FEEDER CHANNEL

1. Name of project/ canal : Kosi Feeder Channel (U.P.) (Figure A-7)

2. Year of construction : 1971-1972

3. Channel dimension :
   - (i) Bed width ...5.0 m to 2.15 m
   - (ii) Water depth ...2.07 to 2.0 m
   - (iii) Side slopes ...1:1
   - (iv) Free board ...not specified
   - (v) Channel bed slope ...1/675 to 1/161

4. Design standards :
   - (i) Discharge ...42.5 m^3/sec
   - (ii) Velocity ...5.12 m/sec
   - (iii) Value of manning's, n : Not specified

5. Length of lining : 10 km

6. Sub-grade details : Coarse sand with gravel.

7. Type of lining : Cement concrete tile lining.

8. Pressure release arrangements : No drainage arrangement provided as the water-table is below bed and sub-grade is free draining.

9. Purpose of lining : To economize the section and to reduce lining seepage losses.

10. Joints : Lining provided in 6 m long panels on the bed and sides. 225 x 110 mm sleepers provided below joints.

11. Construction details : Lining in the bed and sides consists of precast cement concrete blocks 450 x 300 x 75 mm tile laid over 100 mm thick concrete.

12. Field performance : No data on field performance is available.

7. RAJASTHAN FEEDER CHANNEL

1.	Name of project/ canal	: Rajasthan Feeder Channel (Figures A-8 & A-9)		
2.	Year of construction	: 1958-59		
3.	Channel dimension	: (i)	Bed width	...78.3 m
		(ii)	Water depth	...4.5 m in upper reaches and 6.4m in lower reaches
		(iii)	Side slopes	...1.5:1
		(iv)	Free board	...not specified
		(v)	Channel bed slope	...not specified
4.	Design standards	: (i)	Discharge	...523 m^3/sec
		(ii)	Velocity	...1.425 m/sec
		(iii)	Value of manning's n :	not specified
5.	Length of lining	: 64.3 km		
6.	Sub-grade details	: Sandy soils free draining material and clay soil in some reaches.		
7.	Type of lining	: Single tile lining in bed and double tile lining in sides.		
8.	Pressure release arrangements			
	(a) Bed	: Pressure release valves at 72.5 m c/c in reaches where sub-soil water is high.		
	(b) Sides	: Pressure release valves at 15.2 m c/c in reaches where sub-soil water is high.		
9.	Purpose of lining	: To reduce seepage losses and economize the section.		
10.	Joints	: No. expansion joints were provided.		
11.	Construction details			
	(a) Bed	: (i)	9.0 mm thick 1:5 cement mortar.	
		(ii)	305x152x50 mm size tiles laid in 1:5 cement mortar.	
		(iii)	19 mm thick 1:3 cement plaster finished smooth and hard with steel trowel.	

(b) Sides	:	(i)	9.0 mm thick 1:5 cement mortar.
		(ii)	305x152x50 mm size tiles laid in 1:5 cement mortar and cured for 24 hours.
		(iii)	16 mm thick 1:3 cement plaster cured for three days.
		(iv)	305x152x50 mm size tiles laid in 1:3 cement mortar and over 6.0 mm thick 1:3 cement mortar layer.

12. Field performance : No data is available for the assessment of its performance.

8. DANTIWADA PROJECT

1.	Name of project/ canal	: Bańaskantha Left Bank Main Canal Dandiwada Project (Gujarat) (Cement Conrete Lining) (Fig. A-10)
2.	Year of construction	: 1964
3.	Channel dimension	: (i) Bed width ...4.95 m (ii) Water depth ...2.44 m (iii) Side slope ...1.5:1 (iv) Free board ...0.91 m (v) Channel bed slope ...not specified
4.	Design standards	: (i) Discharge ...31 m^3/sec (ii) Velocity ...not specified (iii) Value of manning's, n : 0.017
5.	Length of lining	: 0.48 km
6.	Sub-grade details	: Sandy loam
7.	Type of lining	: 1:3 cement concrete lining.
8.	Pressure release arrangements	: No drainage arrangement provided
9.	Purpose of lining	: To reduce seepage losses.
10.	Joints	: Expansion joints provided at every 15 m. The joints are filled with bitumen.
11.	Construction details	: Before laying the concrete 1:3 cement and slurry was spread over the moist sub-grade. 12.5 cm 1:3:6 thick cement concrete of specified strength and slump was laid. The concrete was vibrated for proper compaction.
12.	Field performance	: During the last eight years the performance of lining has been excellent. Maintenance cost is negligible.

9. DANTIWADA PROJECT

1.	Name of project/ canal	: Banaskantha Left Bank Main Canal, Dandiwada Project (Gujarat) (Brick Lining) (Figure A-11)		
2.	Year of construction	: 1964-65		
3.	Channel dimension	: (i)	Bed width	...4.95 m
		(ii)	Water depth	...2.44 m
		(iii)	Side slope	...1.5:1
		(iv)	Free board	...0.91
		(v)	Channel bed slope	...Not specified
4.	Design standards	: (i)	Discharge	...31.1 m^3/sec
		(ii)	Velocity	...1.49 m/sec
		(iii)	Value of Manning's, n :	0.018
5.	Length of lining	: 80 km		
6.	Sub-grade details	: Sandy loam soil		
7.	Type of lining	: 13.34 cm thick sandwiched brick lining on bed and sides.		
8.	Pressure release arrangements	: No pressure release arrangement has been provided at bed as well as on sides, since the water-table was below the bed of the canal.		
9.	Purpose of lining	: To economize the section and to reduce the seepage losses.		
10.	Joints	: 1.25 cm wide transverse joints have been provided at 15.6 m c/c. Along the joints the extra layer of brick tile is provided at 15.6 m c/c. Along the joints the extra layer of brick tile is provided at the bottom. The joints so left are filled with bitumen.		
11.	Construction details	: (i)	10 mm thick layer of red cement (20 % replaced by surkhi) mortar laid on compacted sub-grade.	
		(ii)	50 mm thick bricks in cement mortar	
		(iii)	16 mm thick sandwiched plaster in red cement mortar 1:3.	
		(iv)	50 mm thick second layer of brick.	

12. Field performance : The behaviour of lining on this canal and its branches is found to be very satisfactory. Only minor repairs like replacement of few bricks, which were eroded during the period of six years since its laying, were carried out.

N.B. :- Similar lining has been provided on the canals of Hathmati Canal Project, Saraswati Project and Kharicut Canal Project under similar conditions. Their performance has also been found satisfactory.

10 MAHI RIGHT BANK CANAL

1.	Name of project/ canal	: Mahi Right Bank Canal (Gujarat)		
2.	Year of construction	: 1958-59		
3.	Channel dimension	: (i)	Bed width	...16.46 m
		(ii)	Water depth	...4.93 m
		(iii)	Side slopes	...1.25 :1
		(iv)	Free board	...0.76 m
		(v)	Channel bed slope	...not specified
4.	Design standards	: (i)	Discharge	...198m^3/sec
		(ii)	Velocity	...1.52m/sec
		(iii)	Value of manning's n :	not specified
5.	Length of lining	: 45.82 km		
6.	Sub-grade details	: Soft to hard rock and goradu soil and black cotton soil from Ch. 80,000 to 1,80,000.		
7.	Type of lining	: 13.3 cm thick sandwiched brick tile lining on bed and sides.		
8.	Pressure release arrangements	: Since the water-table is below the bed of the canal, no pressure release arrangements have been provided on bed and sides.		
9.	Purpose of lining	: To economize the section and to reduce the seepage losses.		
10.	Joints	: 1.25 cm wide transverse joints have been provided at 15.6 m c/c. Along the joints, the extra layer of brick tile is provided at the bottom. The joints are filled with bitumen.		
11.	Construction details	: (i)	10 mm thick layer of red cement (20% replaced by surkhi) mortar laid on compacted sub-grade.	
		(ii)	50 mm thick bricks in cement mortar	
		(iii)	16 mm thick sandwiched plaster red 1:3 cement mortar.	
		(iv)	50 mm thick second layer of brick.	
12.	Field performance	: The behaviour of this lining is found to be very satisfactory. Only minor repairs were carried out like replacement of few bricks which were eroded.		

11. SHETRUNJI CANAL PROJECT

1.	Name of project/ canal	: Shetrunji Canal Project (Gujarat) (Masonry Lining)		
2.	Year of construction	: 1965-66		
3.	Channel dimension	: (i)	Bed width	...9.14 m
		(ii)	Water depth	...2.36 m
		(iii)	Side slopes	...2:1
		(iv)	Free board	...Not specified
		(v)	Channel bed slope	...1 in 6000
4.	Design standards	: (i)	Discharge	...18.56 m^3/sec
		(ii)	Velocity	...Not specified
		(iii)	Value of Manning's, n :	0.0225
5.	Length of lining	: 0.12 km		
6.	Sub-grade details	: Murrumish and sandy soil		
7.	Type of lining	: 22.86 cm thick masonry		
8.	Pressure release arrangements	: Not specified		
9.	Purpose of lining	: To economize the section and to reduce seepage losses.		
10.	Joints	: Not specified		
11.	Construction details	: This type of lining was used, where stone was available locally. The canal was over-excavated to slighty more than the desired section of lining and 22.5 cm thick rubble masonry in 1:6 cement mortar was laid in the canal on bed and sides. The rubble masonry was then cement painted.		
12.	Field performance	: The lining has stood well and seepage losses are considerably reduced. There has been no weed growth. The coefficient of rugosity is high.		

12. SHETRUNJI CANAL PROJECT

1.	Name of project/ canal	:	Shetrunji Canal Project (Gujarat) (Line Concrete Lining)
2.	Year of construction	:	1963-64
3.	Channel dimension	:	(i) Bed width ...8.53 m (ii) Water depth ...1.00 m (iii) Side slopes ...1:1 (iv) Free board ...not specified (v) Channel bed slope ...1 in 5500
4.	Design standards	:	(i) Discharge ...12.02 m^3/sec (ii) Velocity ...Not specified (iii) Value of Manning's, n : 0.0025
5.	Length of lining	:	0.43 km
6.	Sub-grade details	:	Fissured rock
7.	Type of lining	:	Concrete lining on bed and sides.
8.	Pressure release arrangements	:	Not specified
9.	Purpose of lining	:	To economize the section and to reduce seepage losses.
10.	Joints	:	Not specified
11.	Construction details	:	The mortar of hydraulic lime with usually equal quantity of sand was prepared in a lime mortar mill. The prepared mortar was thoroughly mixed with the specified quantity of loose aggregate. The concrete was laid on properly dressed sub-grade and compacted. It was cured for 30 days.
12.	Field performance	:	The lining was badly damaged due to washing away of lime mortar from the concrete exposing the coarse aggregate.

13. KARAD PROJECT CANAL

1.	Name of project/ canal	: Karad Project (Gujarat)
2.	Year of construction	: 1971
3.	Channel dimension	: (i) Bed width ...4.27 m (ii) Water depth ...1.52 m (iii) Side slopes ...not specified (iv) Free board ...not specified (v) Channel bed slope ...not specified
4.	Design standards	: (i) Discharge ...200 m^3/sec (ii) Velocity ...not specified (iii) Value of Manning's, n : not specified
5.	Length of lining	: 0.06 km
6.	Sub-grade details	: Not specified
7.	Type of lining	: Precast blocks 42.7 x 30.5 x 3.8 cm of 1:6 cement mortar.
8.	Pressure release arrangements	: Not specified
9.	Purpose of lining	: To economize the section and to reduce seepage losses.
10.	Joints	: Not specified
11.	Construction details	: Precast tiles of 1:6 cement mortar were precast. The tiles were laid over the bed with their length at right angles to the centre line of the canal while those on side were laid parallel to the centre line. The joints between tiles were filled with 1:3 cement mortar and then cement painting.
12.	Field performance	: The performance of the lining is satisfactory.

14. TUNGABHADRA PROJECT

1.	Name of project/ canal	: Tungabhadra Project (A.P.) (Figure A-12)		
2.	Year of construction	: Not specified		
3.	Channel dimension	: (i)	Bed width	...12.20 m
		(ii)	Water depth	...4.88 m
		(iii)	Side slopes	...1.5:1
		(iv)	Free board	... 0.3 m
		(v)	Channel bed slope	...not specified
4.	Design standards	: (i)	Discharge	...not specified
		(ii)	Velocity	...not specified
		(iii)	Value of Manning's, n :	not specified
5.	Length of lining	: Not specified		
6.	Sub-grade details	: Not specified		
7.	Type of lining	: Cement concrete lining in bed and sides. In reaches of deep cuttings rubble masonry 1:4 has been provided on sides.		
8.	Pressure release arrangements			
	(a) Bed	: Not specified		
	(b) Sides	: 0.3 m thick rubble packing		
9.	Purpose of lining	: To economize the section and to reduce seepage losses.		
10.	Joints	: Bituminous felt 10 mm thick used for filling joints.		
11.	Construction details			
	(a) Bed	: 10 cm thick 3.05 x 6.1 m panels resting on toe walls and strips.		
	(b) Sides	: 10 cm thick 3 x 2.74 m panels. All four sides resting on rubble masonry.		
12.	Field performance	: No data on field performance is available.		

15. KRISHNARAJASAGAR CANAL

1.	Name of project/canal	: Krishnarajasagar Canal (Karnataka)		
2.	Year of construction	: 1968		
3.	Channel dimension	: (i)	Bed width	...4.8 m
		(ii)	Water Depth	...Not specified
		(iii)	Side slopes	...1.25 :1
		(iv)	Free board	...not specified
		(v)	Channel bed slope	...not specified
4.	Design standards	: (i)	Discharge	...not specified
		(ii)	Velocity	...not specified
		(iii)	Value of manning's, n :	not specified
5.	Length of lining	: Not specified		
6.	Sub-grade details	: The sub-grade consists of gravel.		
7.	Type of lining	: 1:5:10 Cement concrete lining. Top has been plastered with 12 mm thick 1:6 cement mortar.		
8.	Pressure release arrangements	: No pressure relief pipes are provided on the sides, since the canal runs in cutting on right hand side and in embankment on left hand side and water seeping either through the sides or the bed was not observed.		
9.	Purpose of lining	: To arrest the seepage losses.		
10.	Joints	: Joints of 12.5 mm thick are left at 1.524 m spacing. However, at a later stage the joints were eliminated since the cracks were supposed to develop between the old and new concretes. The joint filler used is saw dust, maxphalt 3/40 laid on maxphalt surface.		
11.	Construction details	: The sides and bed were trimmed to uniform section by providing gravelly soil backing of 150 mm thickness. The lining was constructed with the help of a special device named as portable form work. The teak wood planks were introduced to leave a gap of 100 mm. After placing the lowest plank, cement concrete was placed behind the plank, and was consolidated by pin vibrator. After leaving for2 hours for initial setting of concrete, the form work was moved to the next place and this way the lining was done up to end.		
12.	Field performance	: The performance of the lining in the field is quite satisfactory.		

16. KRISHNARAJASAGAR RIGHT BANK LOW LEVEL CANAL

1.	Name of project/ canal	: Krishnarajasagar Right Bank Low Level Canal (Karnataka) (Soil-Cement Lining)		
2.	Year of construction	: 1962		
3.	Channel dimension	: (i)	Bed width	...4.1194 m
		(ii)	Water Depth	...1.6459 m
		(iii)	Side slopes	...1.5 :1
		(iv)	Free board	...not specified
		(v)	Channel bed slope	...not specified
4.	Design standards	: (i)	Discharge	...7.08 m^3/sec
		(ii)	Velocity	...0.652 m/sec
		(iii)	Value of manning's, n :	not specified
5.	Length of lining	: 180 m		
6.	Sub-grade details	: The strata met beneath the revetment in sides and bed is a good gravel sub-grade.		
7.	Type of lining	: 100 mm thick soil-cement lining.		
8.	Pressure release arrangements	: No pressure relief arrangement has been provided below the lining.		
9.	Purpose of lining	: To reduce the seepage losses of the canal.		
10.	Joints	: Joints have been filled with joint filler made out of RC 3 and sand (1.2 kg:0.028 m^3).		
11.	Construction details	: The uneven sides were trimmed to 1.5:1 slope with templates. The slopes were sprinkled with water (optimum moisture content). Cement was added @ 5 percent by weight of soil and the mixed material was laid in the form of single slab over the sides of trimmed channel and finished to required thickness after compaction. The intermediate space was then filled with the same material. For evolving suitable spacings slabs of different spans from 0.76 m to 6.1 m were laid and the sides were plastered with 12.5 mm thick 1:4 cement mortar.		

12. Field performance	:	This is a low cost lining material and its field performance is quite satisfactory. The durability observations were made over a period of about 4 years. In the fourth year some transverse cracks developed in the lining. No further cracks were observed. The developed cracks were given treatment of cement slurry by cutting "V" shaped groove along the cracks and no further deterioration has been observed and the lining is in good condition.

17. KRISHNARAJASAGAR RIGHT BANK LOW LEVEL CANAL

1.	Name of project/ canal	: Krishnarajasagar Right Bank Low Level canal (Karnataka) (Lime Surkhi Concrete Lining)		
2.	Year of construction	: 1966		
3.	Channel dimension	: (i)	Bed width	...4.10 m
		(ii)	Water Depth	...1.53 m
		(iii)	Side slopes	...1.25:1
		(iv)	Channel bed slope	...not specified
4.	Design standards	: (i)	Discharge	...2.89 m^3/sec
		(ii)	Velocity	...0.314 m/sec
		(iii)	Value of manning's, n :	Not specified
5.	Length of lining	: 0.64 km		
6.	Sub-grade details	: 15 cm thick gravel backing well compacted details was provided in bed and sides.		
7.	Type of lining	: Lime surkhi concrete lining.		
8.	Pressure release arrangements	: Pressure relief pipes of 63.5 mm diameter provided at 15.24 m intervals on both the slopes. The pipes are fixed in two rows at 0.45 m and 1.22 m from bed level.		
9.	Purpose of lining	: To arrest seepage losses.		
10.	Joints	: Joints have been packed with a mixture of saw dust and maxphalt in 1:1 proportion and finished smooth without any projection.		
11.	Construction details	: The 1:4:8 surkhi concrete consisting of one part of lime, four parts of brick bats ground together in a mortar mill for about 30 minutes to form a paste like substance and mixed with eight parts of granite metal jelly. This was cast to 89 mm thickness slabs of widths 0.762 m, 1.524 m, 2.286 m, 3.048 m, 3.8 m, 4.8 m and 6.096 m.		
12.	Field performance	: Performance of lining is satisfactory.		

18. MANNIARU CANAL

1.	Name of project/ canal	: Manniaru Canal (Tamil Nadu) (Figure A-13)		
2.	Year of construction	: Not specified		
3.	Channel dimension	: (i)	Bed width	...30.48 m
		(ii)	Water Depth	...1.524 m
		(iii)	Side slopes	...1.5:1
		(iv)	Free board	...0.3048 m
		(v)	Channel bed slope	...1 in 1610
4.	Design standards	: (i)	Discharge	...43.2 m^3/sec
		(ii)	Velocity	...0.862 m/sec
		(iii)	Value of Manning's, n :	0.016
5.	Length of lining	: Not specified		
6.	Sub-grade details	: Sandy		
7.	Type of lining	: In situ cement concrete lining.		

8. Pressure release arrangements

(a) Bed : Pressure relief holes of 45 cm x 30 cm having reverse filter at a distance of 7.62 m from the centre line of the canal on either side have been provided.

(b) Sides : 15 cm x 15 cm transverse filter at 20 m c/c connected to longitudinal drains at the junction of side slope and bed have been provided on either side. Weep holes of 10 cm x 10 cm at the spacing 90 cm have been provided at F.S.L. on either side.

9. Purpose of lining : To economize the section and to reduce the seepage losses.

10. Joints : Not specified

11. Construction details

(a) Bed : 7.6 cm thick cement concrete cast in-situ with the top plastered with 12 mm thick 1:4 cement mortar laid in the bed.

(b) Sides : 10 cm thick precast cement blocks were used on sides.

12. Field performance : No data available.

19. PATTANAMKAL MAIN CANAL

1.	Name of project/ canal	: Pattanamkal Main Canal (Tamil Nadu)		
2.	Year of construction	: Not specified		
3.	Channel dimension	: (i)	Bed width	...2.44 m
		(ii)	Water Depth	...1.68 m
		(iii)	Side slopes	...1:1
		(iv)	Free board	...15.2 cm
		(v)	Channel bed slope	...1 in 5280
4.	Design standards	: (i)	Discharge	...8.4 m^3/sec
		(ii)	Velocity	...2.82 m/sec
		(iii)	Value of Manning's, n :	0.016
5.	Length of lining	: Not specified		
6.	Sub-grade details	: Lining has been laid in all types of soils such as hard gravelly soil, hard stiff clay, disintegrated rock, sort rock, medium rock and dense medium rock which are encountered in the whole length of the canal.		
7.	Type of lining	: The side slope of the canal is lined with cement concrete 1:4:7 using 60 percent of 38 mm metal and 40 percent of 19 mm metal. The top finished with 1:4 cement mortar plaster. The bed of the canal is lined with 1:6:10 cement concrete using 60 percent of 38 mm metal and 40 percent of 19 mm metal. The top of the bed is finished with 1:4 cement mortar plaster. The thickness of lining is 7.6 cm. R.R. masonry lining has been provided in places, where the canal is taken through row cutting.		
8.	Pressure release arrangement	: Sufficient number of weep holes have been provided on the lining for pressure relief.		

9.	Purpose of lining	: To arrest the seepage losses.
10.	Joints	: Data on joints is not available
11.	Construction details	: Concrete lining has been cast in-situ. The sides and the bed of the channel were trimmed for about 7.6 cm to make the earthen surface suitable to receive the lining concrete. The bed and sides were then moistened by sprinkling water in order to minimize the absorption losses of concrete. Templates having thickness 7.6 cm were fixed at a spacing of 9.15 m. The concrete was mixed and placed from bottom to top. It was rammed by hard rammers. The surface finished in 1:4 cement mortar.
12.	Field performance	: No major problem is encountered in the maintenance of channel.

20. RATHAPURAM CHANNEL

1.	Name of project/ canal	: Rathapuram Channel (Tamil Nadu)		
2.	Year of construction	: Not specified		
3.	Channel dimension	: (i)	Bed width	...3.50 m
		(ii)	Water Depth	... 1.22 m
		(iii)	Side slopes	...1:1
		(iv)	Free board	...0.533 m
		(v)	Channel bed slope	...1 in 5280
4.	Design standards	: (i)	Discharge	...4.2 m^3/sec
		(ii)	Velocity	...0.76 m/sec
		(iii)	Value of Manning's, n :	0.016
5.	Length of lining	: Not specified		
6.	Sub-grade details	: Lining has been laid in all types of soils such as hard gravelly soil, hard stiff clay, disintegrated rock, softrock, medium rock and dense medium rock, which are encountered in the whole length of the canal.		
7.	Type of lining	: The side slope of the canal is lined with cement concrete 1:4:7 using 60 percent of 38 mm metal and 40 percent of 19 mm metal. The top finished with 1:4 cement mortar plaster. The bed of the canal is lined with 1:6:10 cement concrete using 60 percent of 38 mm metal and 40 percent of 19 mm metal. The top of the bed is finished with 1:4 cement mortar plaster. The thickness of lining is 7.6 cm. R.R. masonry lining has been provided in places, where the canal is taken through rock cutting.		
8.	Pressure release arrangement	: Sufficient number of weep holes have been provided on the lining for pressure relief.		
9.	Purpose of lining	: To arrest the seepage losses.		
10.	Joints	: Details not available		
11.	Construction	: The lining for the canal done is cast in-situ. The canal was cut open to required section. The sides and the bed of the canal trimmed for about 7.6 cm to make the earthen surface suitable to receive the lining concrete. The bed and sides were then moistened by sprinkling water in order to minimize the		

absorption losses of concrete. Templates having thickness 7.6 cm were fixed at a spacing of 9.15 m. Strings had been tied in between the tamplates both at top and bottom so as to limit the thickness of the concreted. The concrete was mixed and placed from bottom to top. It was rammed by hand rammers. The surface finished in 1:4 cement mortar.The sides were lined first and the bed later on.

12.	Field performance	: No major problem is encountered in the maintenance of channel.

21. PAMBA IRRIGATION PROJECT

1.	Name of project/ canal	:	Left Band Main Canal, Pamba Irrigation Project		
2.	Year of construction	:	Lining done alongwith construction of canal		
3.	Channel dimension	:	(i)	Bed width	...3.66 m
			(ii)	Water Depth	...2.90 m
			(iii)	Side slopes	...1:1
			(iv)	Free board	...0.90 m
			(v)	Channel bed slope	...1 in 5000
4.	Design standards	:	(i)	Discharge	...20.376 m^3/sec
			(ii)	Velocity	...1.08 m/sec
			(iii)	Value of Manning's, n :	0.018
5.	Length of lining	:	10 km		
6.	Sub-grade details	:	Mainly gravelly earth and laterite soils.		
7.	Type of lining	:	R.R.Masonry and C.C.lining.		
8.	Pressure release arrangement				
	(a) Bed	:	Only a layer of filter medium provided at the rear side of lining and weep holes for discharge of seepage water.		
	(b) Sides		-do-		
9.	Purpose of lining	:	-		
10.	Joints	:	Transverse joints at 10 m interval with width 12 mm and depth 30 cm were provided. Joint filler maxphalt 80/100, sand cement and saw dust in proportion of 30.60 percent, 61.20 percent, 6.15 percent and 2.05 percent respectively by weight.		
11.	Construction details				
	(a) Bed	:	1:3:6 C.C.lining.		
	(b) Sides	:	R.R.Masonry lining.		
12.	Field performance	:	Not commissioned till date.		

22. KUTTIADY IRRIGATION PROJECT

1. Name of project/ canal	:	Left Bank Canal Kuttiady Irrigation Project
2. Year of construction	:	Partially completed by 2/73
3. Channel dimension	:	(i) Bed width ...7.62 m (ii) Water Depth ...2.44 m (iii) Side slopes ...1:1 (iv) Free board ...1 m (v) Channel bed slope ...0.24/1000
4. Design standards	:	(i) Discharge ...18.123 m^3/sec (ii) Velocity ...2.818 m/sec (iii) Value of Manning's, n : 0.025
5. Length of lining	:	37 km
6. Sub-grade details	:	Hardly gravelly soil to hard rock
7. Type of lining	:	Precast C.C. Slabs
8. Pressure release arrangement		
(a) Bed	:	(i) 45 cm x 15 cm longitudinal reverse filter provided at middle of bed and filled with 20 mm to 40 mm metal and sand. (ii) Pressure release valves of size 50 cm at 10 c/c.
(b) Sides	:	-do-
9. Purpose of lining	:	-
10. Joints	:	Half grooved slabs jointed with 1:2 cement mortar and painted. Rail of size 25 cm x 15 cm fixed in full length without reinforcement longitudinally and 1:2:4 cement concrete sleepers of size 15 cm x 15 cm fixed at 10 cm centre to centre transversely.
11. Construction details		
(a) Bed	:	Precast cement concrete slabs of size 5x75 cm with 7.8 cm thick cement mortar.
(b) Sides	:	-do-
12. Field performance	:	Observations just started. Certain portion cracked.

23. PEECHI IRRIGATION SCHEME

1.	Name of project/ canal	: Right Bank Main Canal, Peechi Irrigation Scheme		
2.	Year of construction	: 1953		
3.	Channel dimension	: (i)	Bed width	...3.65 m
		(ii)	Water Depth	...1.52 m
		(iii)	Side slopes	...1 vertical to 1.5 Horizontal average
		(iv)	Free board	...0.5 m average
		(v)	Channel bed slope	...1/2000 app. average
4.	Design standards	: (i)	Discharge	...7.08 m^3/sec
		(ii)	Velocity	...1.468 m/sec
		(iii)	Value of Manning's, n :	0.0225
5.	Length of lining	: 36.85 m (Main canal)		
6.	Sub-grade details	: Not available		
7.	Type of lining	: Rubble masonry in cement mortar.		
8.	Pressure release arrangement			
	(a) Bed	: NIL		
	(b) Sides	: NIL		
9.	Purpose of lining	: NIL		
10.	Joints	: NIL		
11.	Construction details			
	(a) Bed	: Rubble masonry in cement mortar.		
	(b) Sides	: -do-		
12.	Field performance	: The observations were taken in the initial reach, where there is rubble lining for a distance of 5000 m. It is seen that the seepage is negligible. The value of Manning's "n" assumed for the design is 0.0225 which is an average value for the unlined portion. The value obtained in the lined portion is 0.03321 which is a higher value. This is due to the protrusion of rubble surface into the flowing water. Some more studies are required for ascertaining the performance of the lining in		

24 LEFT BANK CANAL

1.	Name of project/ canal	: Left Bank Canal at 34 km		
2.	Year of construction	: March 1972		
3.	Channel dimension	: (i)	Bed width	...12.30 m
		(ii)	Water Depth	...1.3716 m
		(iii)	Side slopes	...1:1
		(iv)	Free board	...0.3048 m
		(v)	Channel bed slope	...1/5510
4.	Design standards	: (i)	Discharge	...21.225 m^3/sec
		(ii)	Velocity	...0.665 m/sec
		(iii)	Value of Manning's, n :	0.025
5.	Length of lining	: 31.5 km		
6.	Sub-grade details	: Precast slabs and blocks		
7.	Type of lining	: Rubble masonry in cement mortar.		
8.	Pressure release arrangement			
	(a) Bed	: NIL		
	(b) Sides	: NIL		
9.	Purpose of lining	: NIL		
10.	Joints	: Longitudinally 4.8 m and transversely 0.30 m with 1:3 cement mortar with admixture of 5 percent crude oil and combination join trussing tar felts of cement, sand and jute.		
11.	Construction details			
	(a) Bed	: P.C.Slabs for 30x50x7.5 cm with suitable grooves in 1:3:6 cement concrete comprising 6,12 and 18 mm in equal quantities.		
	(b) Sides	: P.C.slabs for 30x50x7.5cm with 3 mm monolith finish of cement concrete 1:2 on side slopes with toe of precast blocks of 45x45x30 cm in 1:5:10 cement concrete using 45, 18, 12 and 9 mm metal on equal quantities.		
12.	Field performance	: No damage was seen.		

25. KUTHANUR BRANCH

1.	Name of project/ canal	: Kuthanur Branch		
2.	Year of construction	: March 1960		
3.	Channel dimension	: (i)	Bed width	...1.8 m
		(ii)	Water Depth	...0.6 m
		(iii)	Side slopes	...1 : 1
		(iv)	Free board	...0.3
		(v)	Channel bed slope	...1 in 5280
4.	Design standards	: (i)	Discharge	...1.698 m^3/sec
		(ii)	Velocity	...0.365 m/sec
		(iii)	Value of Manning's, n :	0.025
5.	Length of lining	: 13.47 m		
6.	Sub-grade details	: Not known		
7.	Type of lining	: Bitumen and cement		
8.	Pressure release arrangement			
	(a) Bed	: NIL		
	(b) Sides	: NIL		
9.	Purpose of lining	: NIL		
10.	Joints	: Vertical joints are provided with tar felts of cement, sand and jute.		
11.	Construction details	: The canal was lined using mixture of bitumen and cement.		
12.	Field performance	: Performance not satisfactory. Initial and maintenance costs are very high.		

26. RANI AVANTI BAI SAGAR PROJECT, JABALPUR LEFT BANK CANAL

1.	Name of project/ canal	: Rani Avanti Bai Sagar Project (Left bank Canal) (Figure A-14)	
2.	Year of construction	: 1978	
3.	Channel dimension	: (At R.D. 16 km)	
		(i) Bed width	...11.70 m
		(ii) Depth	...4.57 m
		(iii) Side slopes	...1.5 :1
		(iv) Free board	...1.20 m
		(v) Channel bed slope	...1 in 6,000 or 0.167 m/km
4.	Design standards	: (i) Discharge	...127.40 m^3/sec
		(ii) Velocity	...1.489 m/sec
		(iii) Value of Manning's, n :	0.018
5.	Length of lining	: 66.50 km	
6.	Sub-grade details	: Sub-grade Consists of Hard soil, Hard moorum, Disinteqrated rock, softrock, Hard rock and expansive soil.	
7.	Type of lining	: 10 cm, thick 1:3:6 Cement Concrete lining.	
8.	Pressure release arrangements	: 100 mm ϕ flop valve provided at each junction point of longitudinal and cross drains.	
9.	Purpose of details	: To reduce the seepage losses and economize the section.	
10.	Joints	: Construction joints are provided at every junction filling with primer @ 1 Ltr./4m ^{2}.	
11.	Field performance	: The performance of lining is satisfactory.	

27. EASTERN GANGA CANAL (Km 11.1 To 19.5)

1.	Name of project/ canal	: Eastern Ganga Canal (Figure A-15)		
2.	Year of construction	: 1987		
3.	Channel dimension	: (i)	Bed width	...12.0 m
		(ii)	Water Depth	...4.5 m
		(iii)	Side slopes	...2.5 :1
		(iv)	Free board	...0.75
		(v)	Channel bed slope	...1/5000 or 0.20 m/km
4.	Design standards	: (i)	Discharge	...137.30 m^3/sec
		(ii)	Velocity	...Not specified
		(iii)	Rugosity "n"	...Not specified
5.	Length of lining	: Not specified		
6.	Sub-grade details	: RBM, Sandy & silty sand.		
7.	Type of lining (a) Side	: Double Tile Lining.		
	(b) Bed	: C.C.Lining		

8. Pressure release arrangement
   (i) 75 mm ϕ P.R.V @ 10 m c/c at side slope.

   (ii) 75 mm ϕ P.R.V. at the junction of bed and side solpe.

9.	Purpose of lining	: To reduce seepage losses increase capacity of Feeder Channel.
10.	Joints	: Not specified
11.	Construction details (a) Side	: 300x150x50 clay tile lining in 1:3 cement mortar.
	(b) Bed	: M_{15} C.C.Lining.

28. PARALLEL UPPER GANGA CANAL
(Km. 6.0 to 8.5 and 9.0 to 9.5)

1.	Name of project/	: P.U.G.C (Figure A-16)		
2.	Year of construction	: 1988-89		
3.	Channel dimension	: (i)	Bed width	...30.0 m
		(ii)	Water Depth	...4.5 m
		(iii)	Side slopes	...1.75:1
		(iv)	Free board	...0.75 m
		(v)	Channel bed slope	...0.25 m/km
4.	Design standards	: (i)	Discharge	...370 m^3/sec
		(ii)	Velocity	...2.05 m/sec
		(iii)	Value of Manning n :	0.018
5.	Length of lining	: Fully lined		
6.	Sub-grade details	: Clay, Generally SP & SM		
7.	Type of lining	: Double tile lining with LDPE film A_{20} M_{15}		
8.	Pressure release arrangement	: Longitudinal & cross drains with PRV		
9.	Purpose of lining	: To reduce seepage losses.		
10.	Joints	: Construction joints		
11.	Construction details (a) Bed	: 100 mm thick cast insitu M-15 cement concrete with 200 \7m LDPE film.		
	(b) Sides	: Double layer of precast C.C. slabs M-15 with 200 μ LDPE film.		
12.	Field performance	: Under construction.		

29. SARDA SAHAYAK FEEDER CHANNEL

1.	Name of project/ canal	: Sarda Sahayak Twin feeder Channel (Figure A-17)
2.	Year of construction	: 1986
3.	Channel dimension	: (i) Bed width ...50 m Single (ii) Water Depth ...5.05 m (iii) Side slopes ...2 : 1 (iv) Free board ...0.65 m (v) Channel bed slope ...not specified
4.	Design standards	: (i) Discharge ...650 m^3/sec (ii) Velocity ...not specified (iii) Rugosity 'n' ...0.018
5.	Length of lining	: 258.8 km
6.	Sub-grade details	: -
7.	Type of lining (a) Bed	: : C.C. Lining M_{10}
	(b) Sides	: Double tile lining
8.	Pressure release arrangement	: (i) Longitudinal drains at the junction of bed & side slope and cross drains @ 30 m c/c. (ii) Staggered PRV of 50 ϕ at the side slope and 90 ϕ at logitudinal drains and cross drains.
9.	Purpose of lining	: To reduce the seepage losses and increase capacity of feeder channel.
10.	Joints	: Not available
11.	Construction details (a) Bed	: : M_{10} C.C. lining.
	(b) Side	: 300x300x150 mm or 300x150x50 mm lining in 1:4 cement mortar (double tile)

30. INDIRA GANDHI MAIN CANAL (RAJASTHAN)

1.	Name of project/ canal	:	I.G.M.C (Figure A-18)		
2.	Year of construction	:	-		
3.	Channel dimension	:	(i)	Bed width	...not specified
			(ii)	Water Depth	...6.3 m
			(iii)	Side slopes	...2 : 1
			(iv)	Free board	...0.75 m
			(v)	Channel Bed slope	...not specified
4.	Design standards	:	(i)	Discharge	...510 cumec
			(ii)	Velocity	... -
			(iii)	Rugosity	... -
5.	Length of lining	:	649 km		
6.	Sub-grade details	:	Sandy soil		

7. Type of lining

(a) Sides :

- Double tile lining over 1.5 cement mortar.
- Bottom Layer of tiles (300x150x50) mm with 1:5 cement mortar.
- 15.6 mm thick 1:5 cement mortar over bottom layer of tiles.
- Top layer of tiles (300x150x50) mm with 1:3 cement mortar.
- 6.3 mm thick 1:5 cement plaster over top layer of tile

(b) Bed :

- Single tile lining over 9.4 mm thick 1:5 cement mortar
- 18.8 mm thick 1:3 cement plaster over tiles.

31. KHARA POWER CHANNEL

1.	Name of project/ canal	: Khara Power House (Figure A-19)		
2.	Year of construction	: 1949		
3.	Channel dimension	: (i)	Bed width	...10.5 m
		(ii)	Water Depth	... 6.4 m
		(iii)	Side slopes	...1.75:1
		(iv)	Free board	...0.75 m
		(v)	Bed slope	... -
4.	Design standards	: (i)	Discharge	...198.3 m^3/sec
		(ii)	Velocity	... -
		(iii)	Value of mannings	... -
5.	Length of lining	: 13 km		
6.	Sub-grade details	: Sand rock/stones, clay shale/clay stone		
7.	Type of lining	:		
	(a) Bed	: 120 mm thick M_{15} C.C. lining. No filter in bed. 75 mm thick porous concrete below concrete lining.		
	(b) Sides	: (i)	Double layer compressed c.c. tile 300x300x40 mm with 15 mm sandwitched plaster has been provided.	
		(ii)	Two layers filter 75 mm and 150 mm thick.	
		(iii)	75 mm thick porous concrete 1:12 provided between tile lining.	

32. RISHIKESH CHILLA POWER CHANNEL

1. Name of project/canal : Rishikesh Chilla Power House (Figure A-20)

2. Year of construction : 1973

3. Channel dimension : After silt ejector Upto silt ejector

(i)	Bed width	...12.5 m :42.0 m
(ii)	Water Depth	...8.6 m : 6.2 m
(iii)	Side slopes	...1.75:1 :1.75:1
(iv)	Free board	...1 m : 1.0 m
(v)	Bed slope	...1 in 6000 :1 in 2000 or 0.167 m/km or 0.50 m/km

4. Design standards :

(i)	Discharge	...680 cumec
(ii)	Velocity	... -
(iii)	Value of manning	...-

5. Length of lining : 14.2 km

6. Sub-grade details : -

7. Type of lining :
   - Boulder pitching lining.
   - In-situ C.C. lining.
   - Cement concrete tile lining.

8. Pressure release arrangements :

   (a) In the bed 3 nos. longitudinal drains, one in centre and one each at sides with 300 mm diameter stoneware or concrete perforated pipe with open joints were provided. The 75 mm dia pressure release valves were provided over these longitudinal drains and cross drains @ 1.0 m C/C duly staggered.

   (b) On side slopes continuous filter comprising of bottom layer 150 mm thick of material size 37 mm to 100 mm was provided. Two rows of 75 mm diameter PRV's duly staggered @ 5 m C/C were provided.

9. Purpose of lining : To economize the section and to reduce the seepage losses.

10. Field performance : Cement concrete tile lining in the power channel of Rishikesh Chilla power project was found to be partially damaged after 4 years of construction, mostly in those reaches which were lying in deep cutting with very high water table. The pressure release arrangements were found choked.

33. SAURASHTRA BRANCH CANAL (GUJARAT)

1.	Name of project/ canal	:	Saurashtra Branch canal (Gujarat) (Figure A-21)		
2.	Year of construction	:	-		
3.	Channel dimension	:	(i)	Bed width	...38.0 m
			(ii)	Water Depth	...5.75 m
			(iii)	Side slopes	...2:1
			(iv)	Free board	...1.50 m
			(v)	Channel Bed slope	...1/10000 or 0.10 m/km
4.	Design standards	:	(i)	Discharge	...425 Cumecs
			(ii)	Velocity	... -
			(iii)	Value of 'n'	... -
5.	Length of lining	:	-		
6.	Sub-grade details	:	Expansive soil		
7.	Type of lining	:	100 mm thick C.C. lining		
8.	Pressure release arrangements	:	Longitudinal drains in bed and PRV's on sides		
9.	Purpose of lining	:	To economize section and to reduce seepage losses.		
10.	Joints	:	-		
11.	Constructin details	:			
	(a) Bed	:	100 mm thick C.C. lining		
	(b) Sides	:	100 mm thick C.C. lining		
12.	Field performance	:	-		
13.	Name of Joint filler used	:	-		

34. MADHYA GANGA CANAL

1.	Name of project/ canal	:	Madhya Ganga Canal (Figure A-22)		
2.	Year of construction	:	-		
3.	Channel dimension	:	(i)	Bed width	...60.0 m
			(ii)	Depth	...3.5 m
			(iii)	Side slopes	...1.5:1
			(iv)	Free board	...0.3 m
			(v)	Channel bed slope	...0.11 m/km
4.	Design standards	:	(i)	Discharge	...233.6 cumecs
			(ii)	Velocity	... -
			(iii)	Value of 'n'	... -
5.	Length of lining	:	-		
6.	Sub-grade details	:	Sandy Soil		
7.	Type of lining	:			
	(a) Bed	:	Single Brick tile (300x150 x50) lining in 1:5 CM		
	(b) Sides	:	Double Brick Tile lining 1:5 CM 10 mm CM Ist Layer, 15 mm second layer of plaster.		
8.	Pressure release arrangements	:	No arangement proposed		
9.	Purpose of lining	:	To reduce seepage losses		
10.	Joints	:	No		
11.	Construction details	:			
	(a) Bed	:	Single Brick tile (300x150 of lining x50) lining in 1:5 CM		
	(b) Sides	:	Double Brick Tile lining.		
12.	Field performance	:	Canal lining performance is satisfactory as told by Field Engineers		
13.	Name joint filler used	:	No		

35. NARMADA MAIN CANAL

1.	Name of project/ canal	: Narmada Main Canal (Sardar Sarover Project) (Figure A-23)		
2.	Year of construction	: In Progress		
3.	Channel dimension	: (i)	Bed width	...73.1 m
		(ii)	Water Depth	...7.6 m
		(iii)	Side slopes	...2:1
		(iv)	Free board	...1.25 m
		(v)	Channel bed slope	...1 in 12,500
4.	Design standards	: (i)	Discharge	
			At head	...1133.0 cumecs
			At tail	...71.0 Cumecs
		(ii)	Velocity	
			At head	...1.692 m/sec
			At tail	...0.90 m/sec
		(iii)	Value of 'n'	...0.018
5.	Length of lining	: 460 km		
6.	Sub-grade details	: -		
7.	Type of lining	: C.C. lining		
8.	Pressure release arrangements	: PRV in bed and sides		
9.	Purpose of lining	: To reduce seepage losses		
10.	Joints	: Contraction joints 4 m c/c both ways with PVC strips.		
11.	Construction details	:		
	(a) Bed	: 10.0 cm thick CC lining (M_{15})		
	(b) Sides	: 12.5 cm thick CC lining (M_{15})		
12.	Field performance	: Under construction		
13.	Name joint filler used	: PVC strips		

36. KRISHNA WATER SUPPLY PROJECT CANAL (Tamil Nadu)

Krishna water supply project to Chennai City envisages raising the present FRL of the 3 reservoirs at the outskirts of the city by '2' in each and linking them with lined canals, besides lining the Poondi reservoir to the Kandaleru - Poondi canal coming from Andhra Pradesh at the Tamil Nadu - Andhra Pradesh border.

This project involves excavation of 3 canals lined with m15 concrete cast-in-situ bed lining for 15 cm thickness and P.C.C. slabs of 7.5 cm, thickness of M15 concrete in the side slopes.

HYDRAULIC PARTICULARS OF THE CANAL

i.	**Kandaleru-Poondi Canal**	:	**(Fully Lined)**
	Bed width	:	6.5 m
	F.S.D.	:	3.5 m
	Side slopes	:	1:1
	Free Board	:	0.75 m
	Discharge	:	1000 cusecs
	Bed Fall	:	1:12000
	Length (Lined)	:	25.275 Km
ii.	**Link Canal**	:	**Linking Poondi Reservoir with Chembarampakkam Tank (Fully Lined)**
	Bed width	:	3.00 m
	F.S.D.	:	3.50 m & 3.00 m
	Side slopes	:	2:1
	Free Board	:	0.75 m
	Discharge	:	1000 cusecs
	Bed Fall	:	1:10000 & 1 : 5000
	Length (Lined)	:	25.75 Km
iii.	**Feeder Canal**	:	**(From 10th KM of link canal to Chembarampakkam Tank - Total Length 21.5 km)**
	Bed width	:	2 to 16 m
	F.S.D.	:	2 m to 2.80 m

Side slopes	:	2:1
Free Board	:	0.75 m
Discharge	:	500 cusecs
Bed Fall	:	1:12000
Length (Lined)	:	14 Km
Balance (6.94 Km)	:	Bed unlined and sides provided with rough stone dry packing

Maximum depth of cutting in Kandalery-Poondi canal is 9 m and maximum height of embankment is 2.50 m.

The type of soil met with in K.P. Canal is mostly clay with 10% to 14% only gravelly soil. The clay is also highly swelling type. It becomes very hard when dry and swells and flows when comes in contact with water. Due to this slipping, problems have been faced between 5 to 22 Km of K.P. Canal. In this, the 5 to 10 Km reach faced slipping of sides due to heavy seepage from nearby tanks and paddy fields into the canal. From 12 Km to 22 Km, typical slip-circle failures have repeatedly occurred and finally the entire overburden was removed and sides filled with mother earth mixed with 50% gravel and 0.3% lime (by volume) as suggested by Anna university. Moreover, the P.C.C. slab side lining in slipped areas were replaced by R.R. Masonry 45 cm thick, upto 1.8 m and then 23 cm thick upto the top of free board. Still the side slope is maintained as 1:1. The canal performs well without any problem of excessive seepage etc.

TYPE OF LINING :

Bed	:	M15 concrete (i.e. C.C. 1:2:4) with 20 mm metal was laid in-situ for entire length.
Sides	:	P.C.C. slabs of 7.5 cm thick in M15 concrete with necessary lugs, hunches, bern concrete etc.

CROSS SECTION PLAN : Details of canal lining (K.W.S.P. DR. No.5A) and details of cross section (K.W.S.P.DR.No.5B) plans are attached.

DISCHARGE AND AYACUT : The canals have been designed as lined canals and hence there is no change in discharge envisaged due to lining. This is a drinking water supply canal.

SPECIAL METHODS ADOPTED : The Kandaleru-Poondi canal with side slope 1:1 has been slipping due to excessive seepage from nearby tanks and paddy fields between 5 Km and 10 Km of the canal. This has been overcome by proper collection of drain water and disposal into and away from the canal, provision of reverse filters and replacing P.C.C. lining by R.R. masonry lining. The side slope was slipping largely from 12 Km to 22 Km due to swelling clay. This was overcome by removing the entire earth within and just beyond the slipped circle and replacing it by 50% mother earth and 50% gravelly soil mixed with 0.3% lime by volume and re-forming the side slopes only upto top of free board. R.R. retaining walls (with weep-holes) were provided for some lengths where the slip was recurring after treatment and now it is functioning effectively.

BOTTLENCKS DURING EXECUTION : The link canal between 16 and 19 Km : The earth at bed level and around was very hard. Hence mild blasting of hardened earth was done to cut the canal upto bed in these reaches.

PERFORMANCE OF CANAL IN SWELLING SOILS : After replacing the swelling soil with mixed earth and lime and replacing the P.C.C. lining by R.R. masonry lining 45 cm thick upto 1.8 m depth and 23 cm thick above 1.8 m depth, the slope of 1:1 in K.P. canal is performing well.

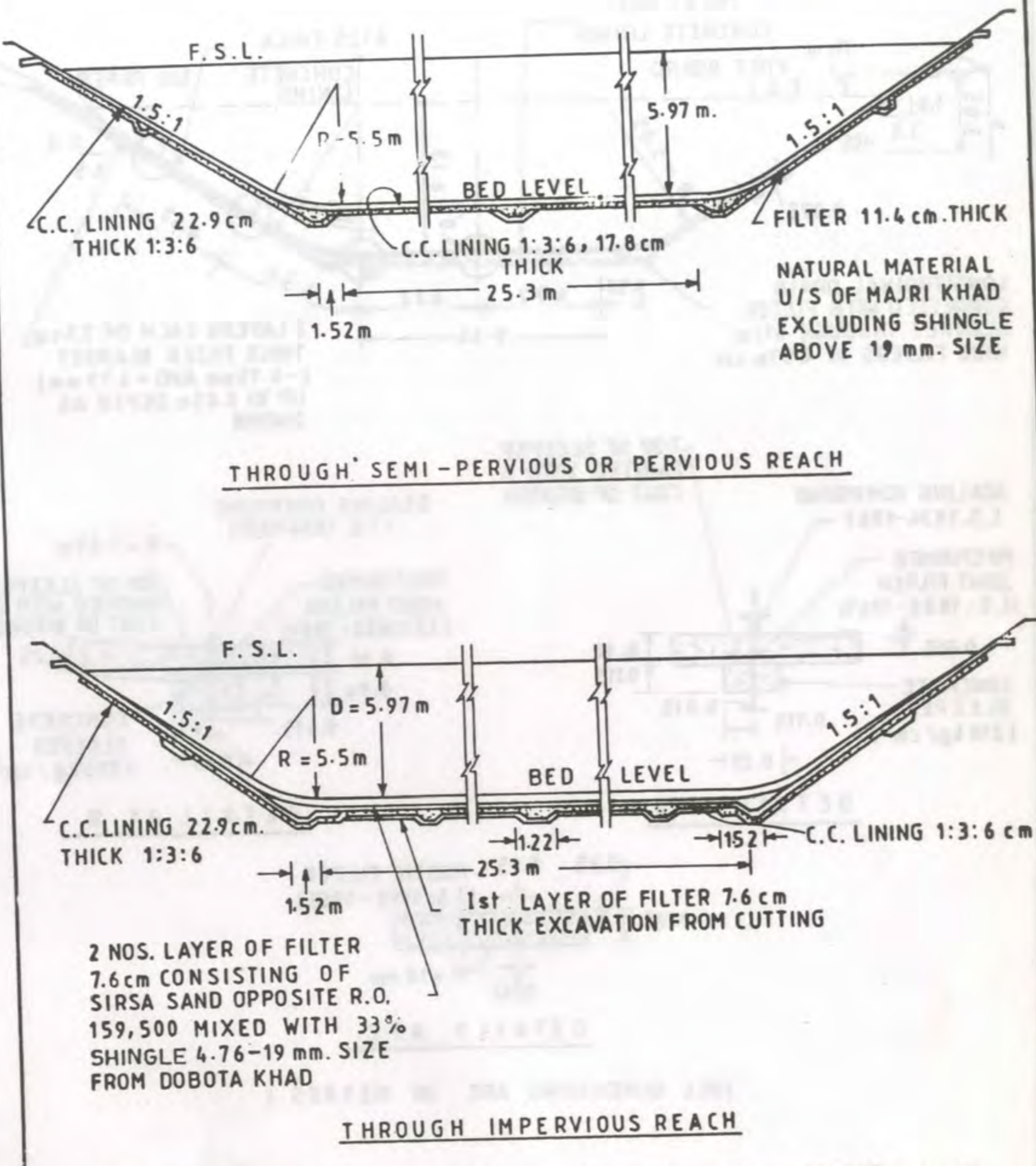
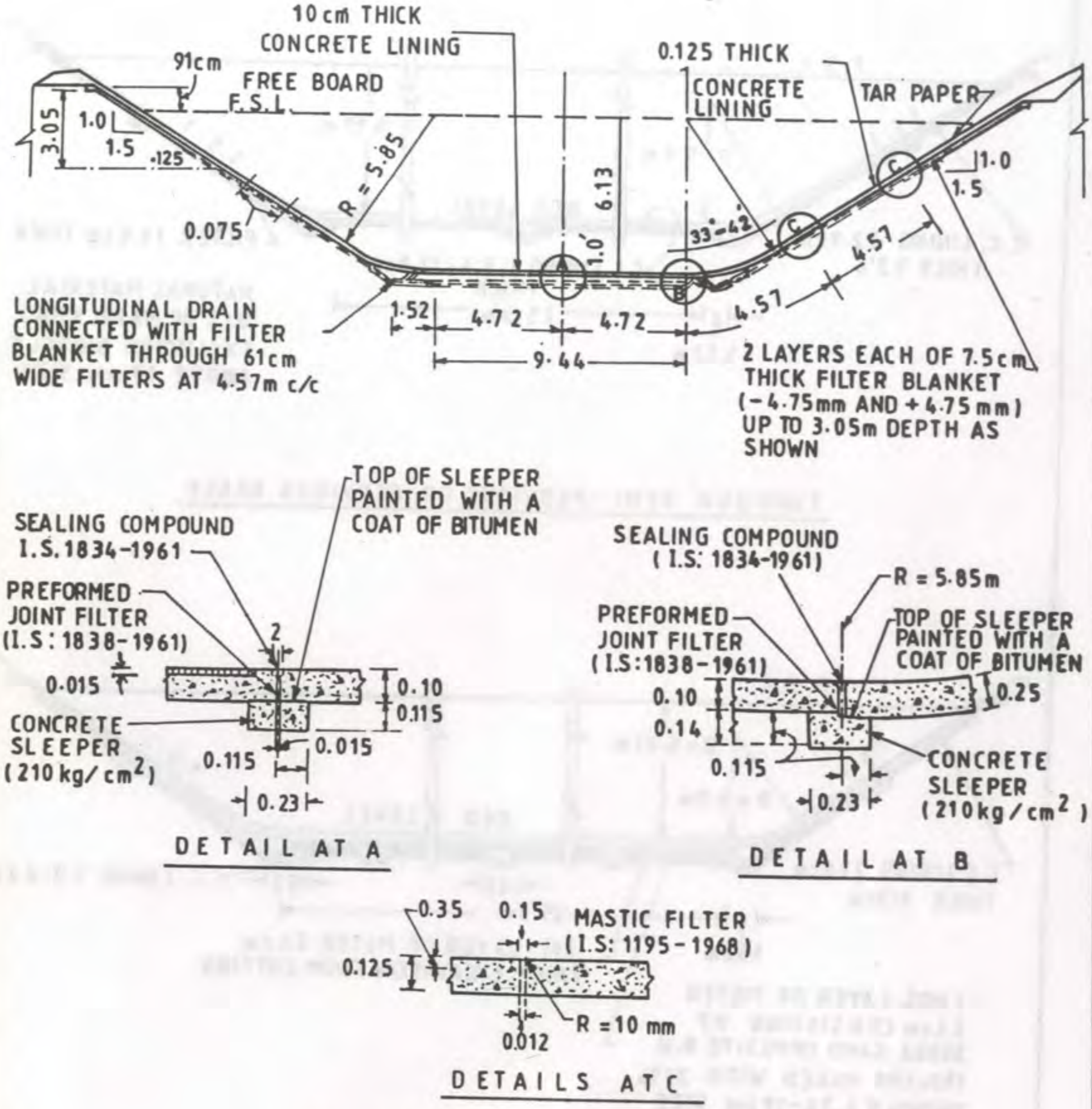


FIG. A-1 :- Nangal Hydel Channel drainage arrangement.



(ALL DIMENSIONS ARE IN METRES)

FIG.A-2:-Typical Section of Sundernagar Hydel Channel

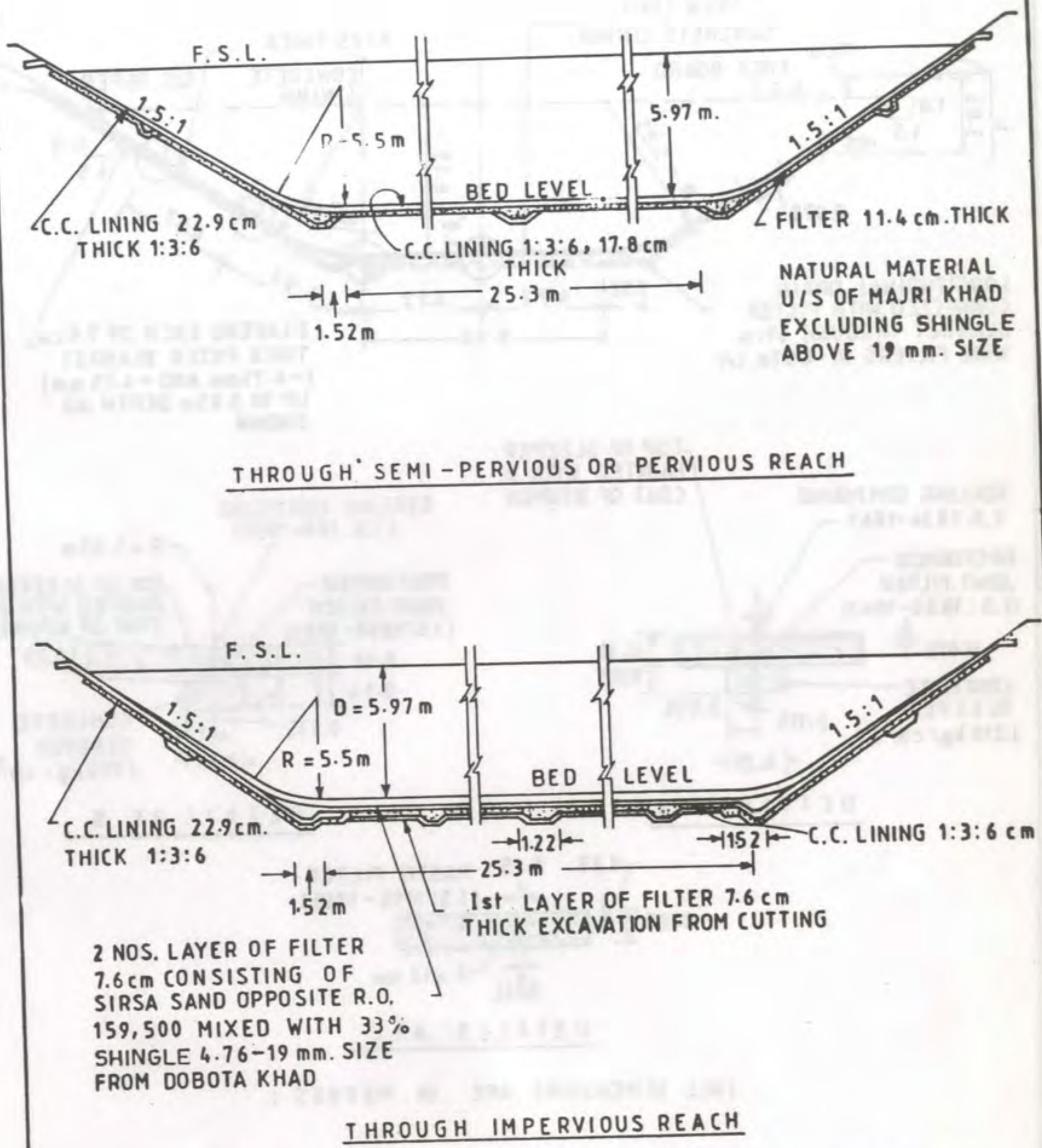
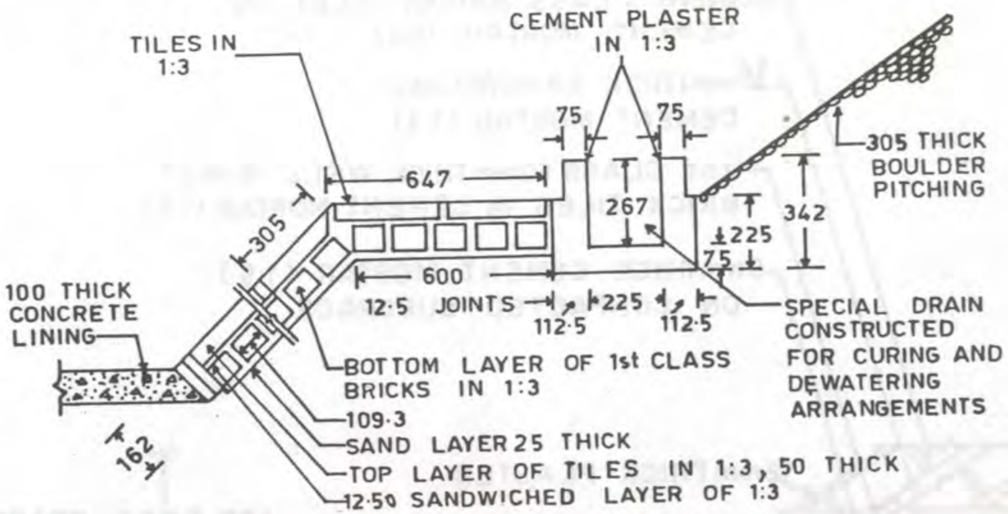
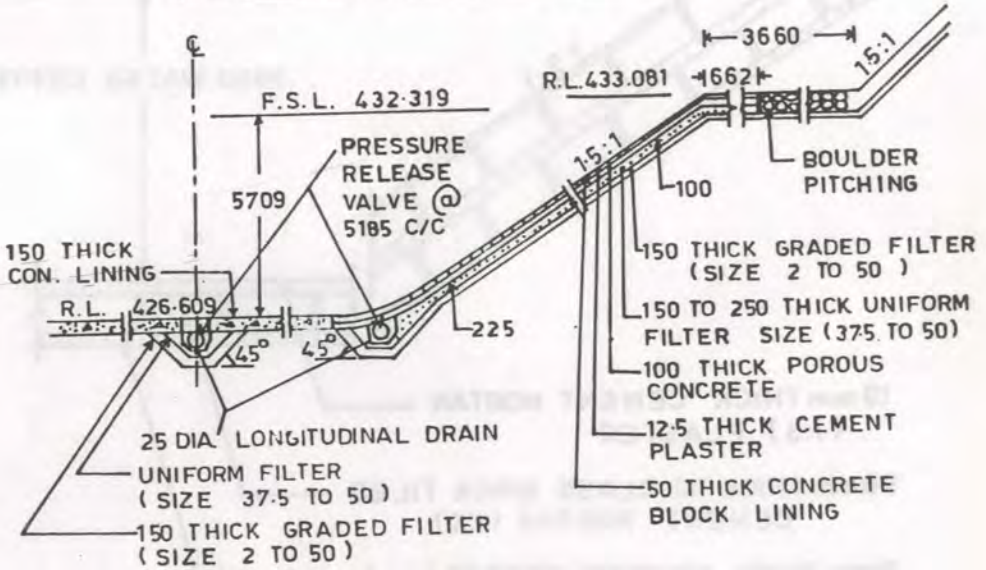


FIG. A-1 :- Nangal Hydel Channel drainage arrangement.



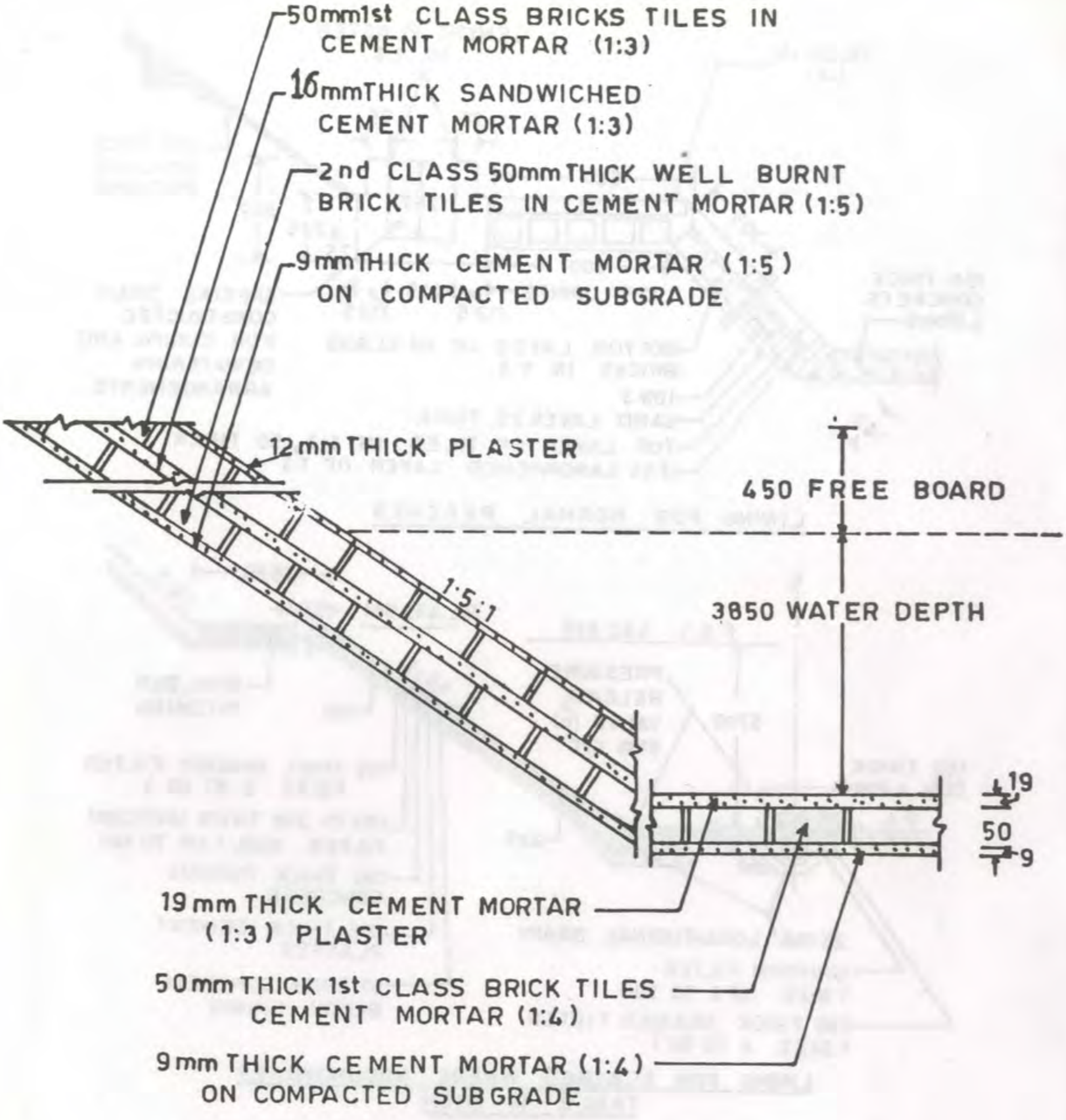
LINING FOR NORMAL REACHES



LINING FOR REACHES WHERE GROUNDWATER TABLE IS HIGH

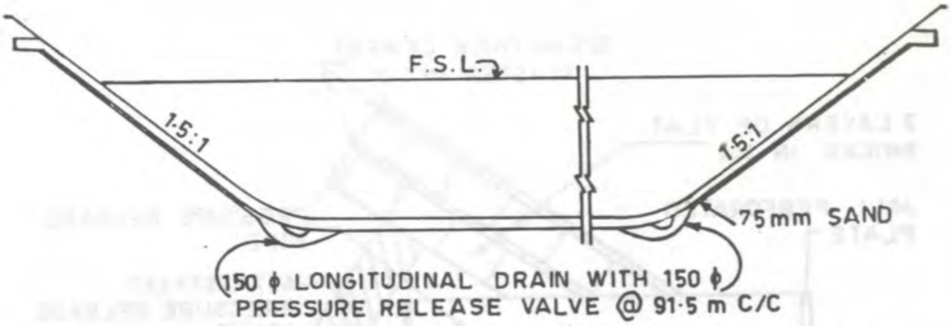
NOTE :– 1. SUBGRADE CONSISTS OF FINE AND COARSE CONSOLIDATED SAND WITH GRAVEL AND BOULDERS.
2. ALL DIMENSIONS ARE IN mm.

FIG. A-3 :– DETAILS OF LINING AND PRESSURE RELEASE ARRANGEMENT OF YAMUNA POWER CHANNEL.

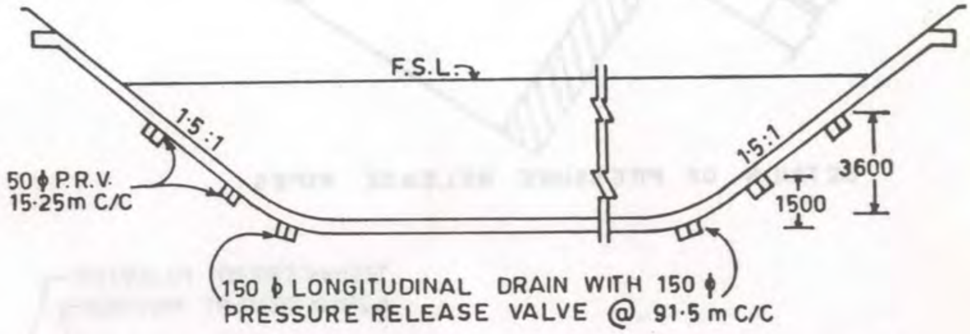


NOTE :- 1. SUBGRADE CONSISTS OF ML-CL TO SP.
2. ALL DIMENSIONS ARE IN mm.

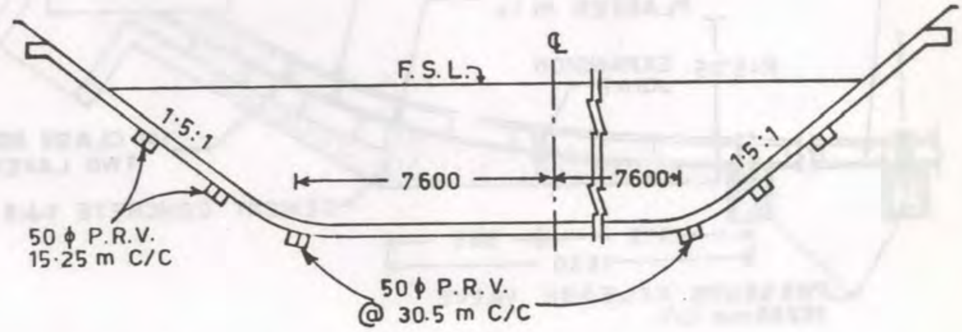
FIG. A-4 :- DETAILS OF BRICK TILE LINING ON GANDAK CANAL.



(a) FOR REACHES WHERE PERMEABILITY IS LESS THAN 30 m/YEAR



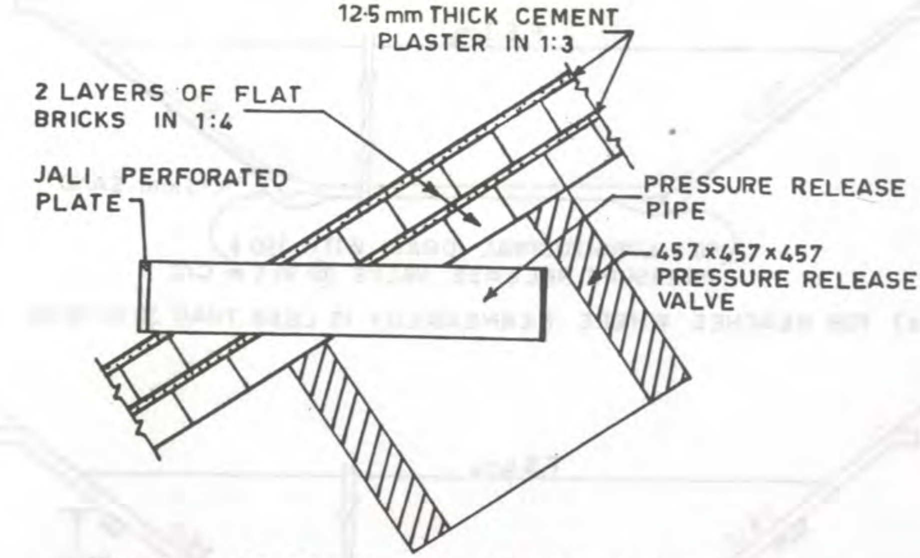
(b) FOR REACHES WHERE PERMEABILITY IS BETWEEN 30 m TO 150 m PER YEAR



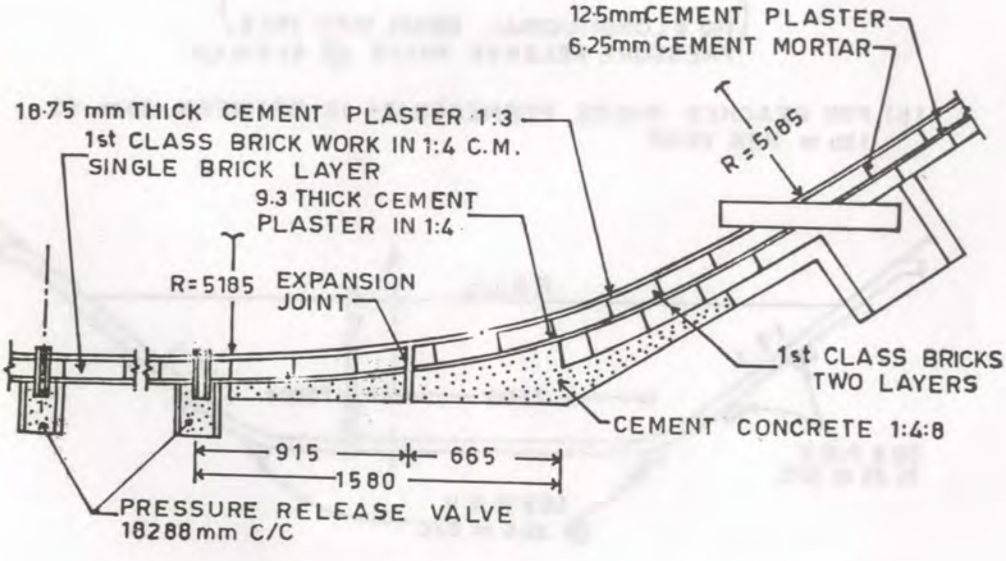
(c) FOR REACHES WHERE PERMEABILITY IS MORE THAN 150 m PER YEAR

(NOTE :- ALL DIMENSIONS ARE IN mm)

FIG. A-5 :- UNDER-DRAINAGE ARRANGEMENTS IN GANDAK CANAL LINING.



DETAILS OF PRESSURE RELEASE PIPES



(NOTE :- ALL DIMENSIONS ARE IN mm)

FIG.A-6:- DETAILS OF LINING AND PRESSURE RELEASE ARRANGEMENT FOR LINK CHANNEL AT NARORA.

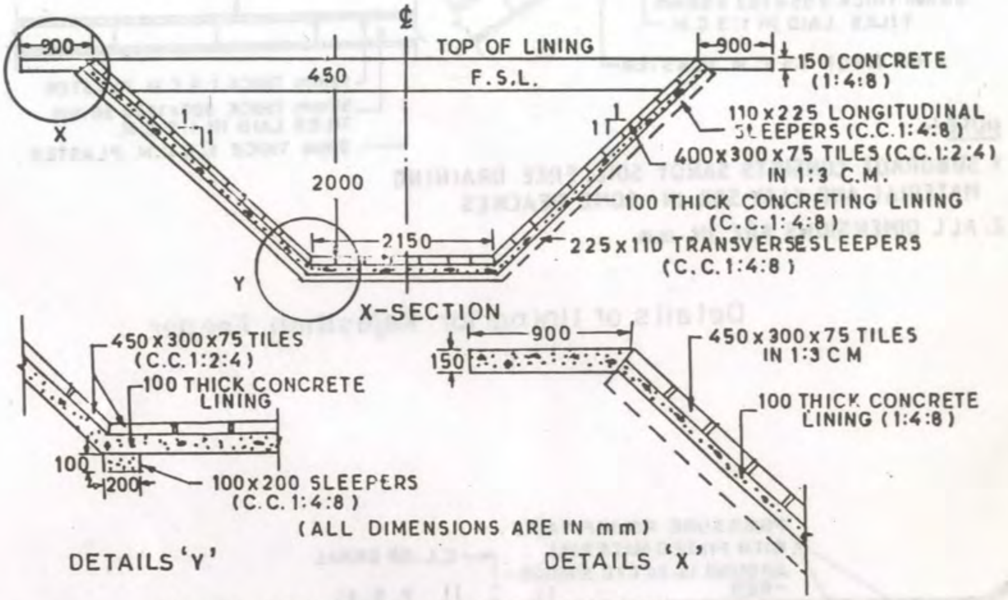
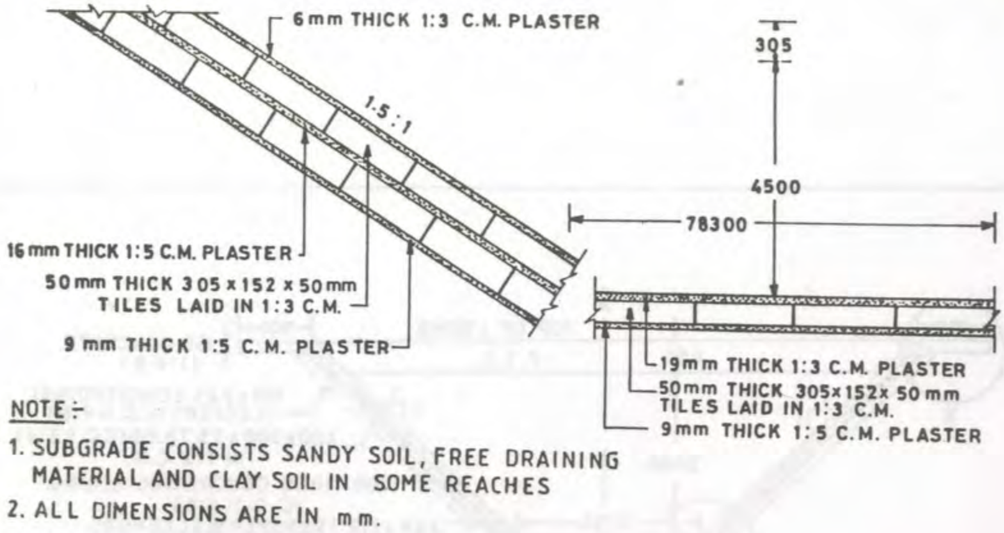


FIG.A7:- DETAILS OF LINING OF KOSI FEEDER CHANNEL



Details of lining for Rajasthan Feeder.

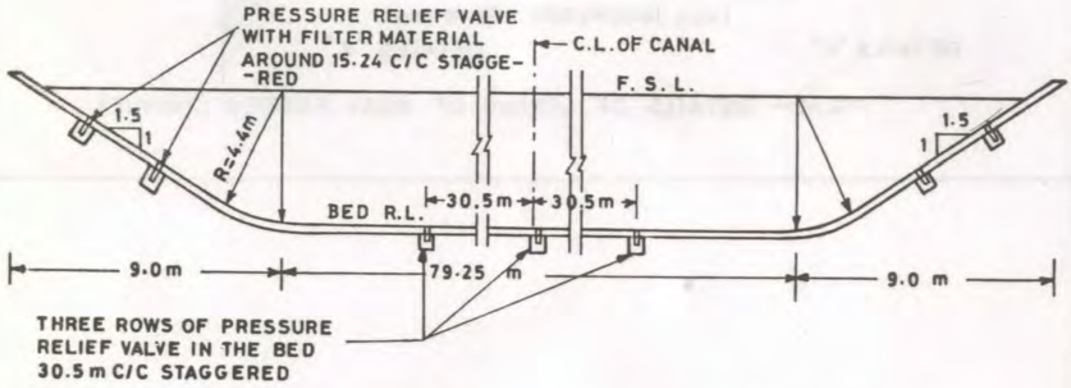
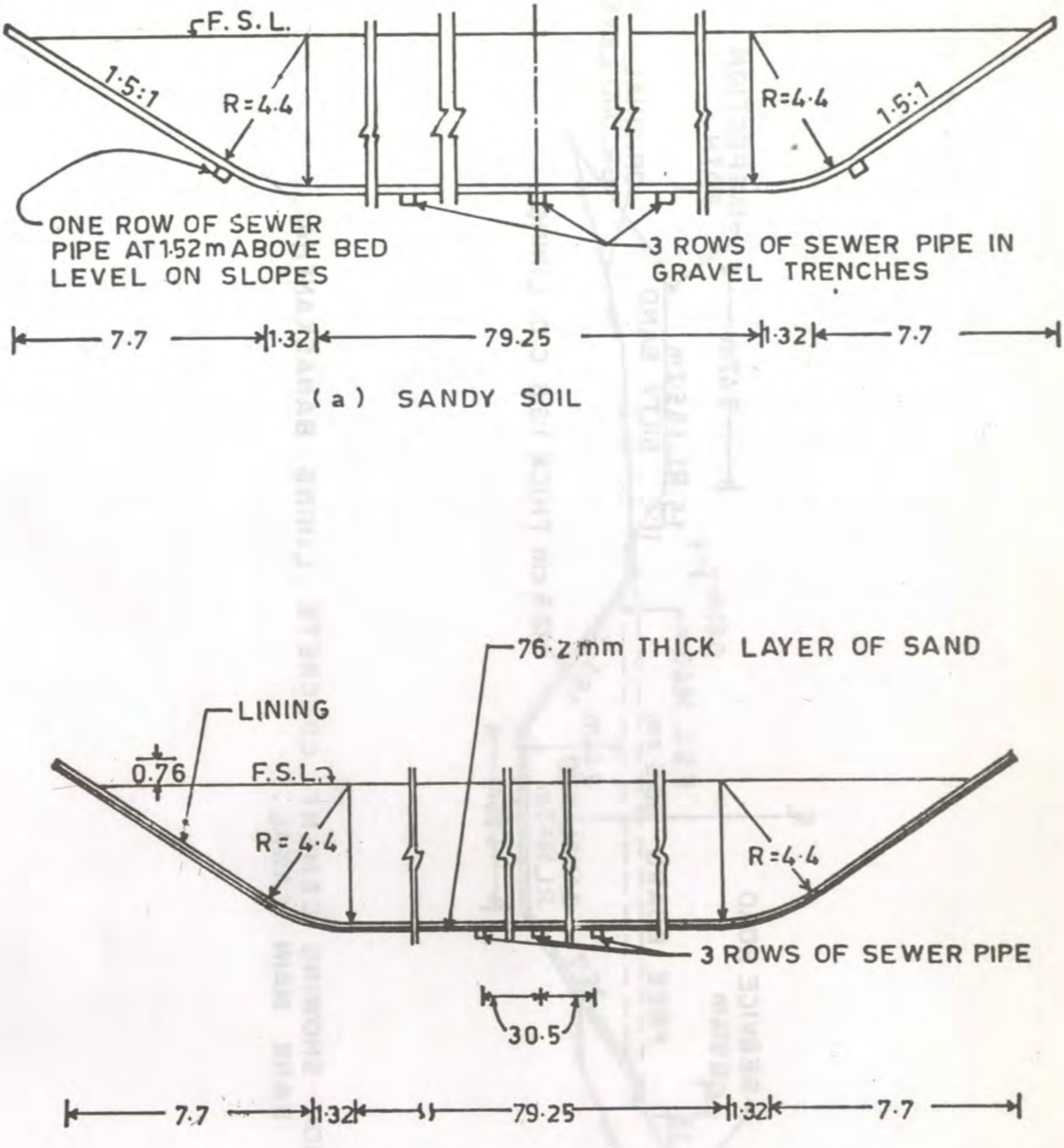


FIG. A-8 :- Details of lining for Rajasthan Feeder.



(b) CLAYEY SOIL

(NOTE:- ALL DIMENSIONS ARE IN m.)

FIG.A-9 :- DRAINAGE BEHIND LINING OF RAJASTHAN FEEDER.

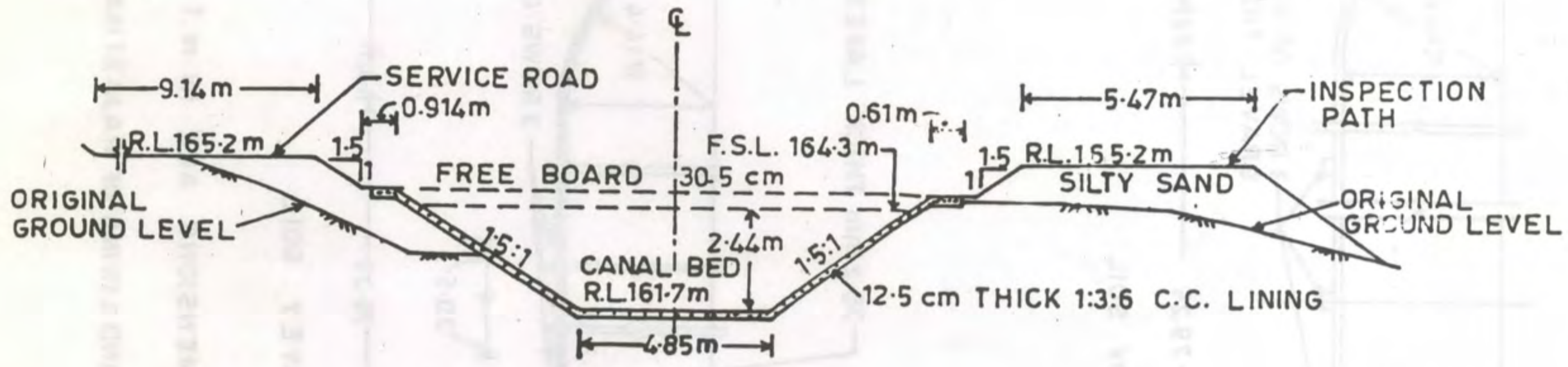


FIG.A-10 :- SECTION SHOWING CEMENT CONCRETE LINING BANASKANTHA, LEFT BANK MAIN CANAL.

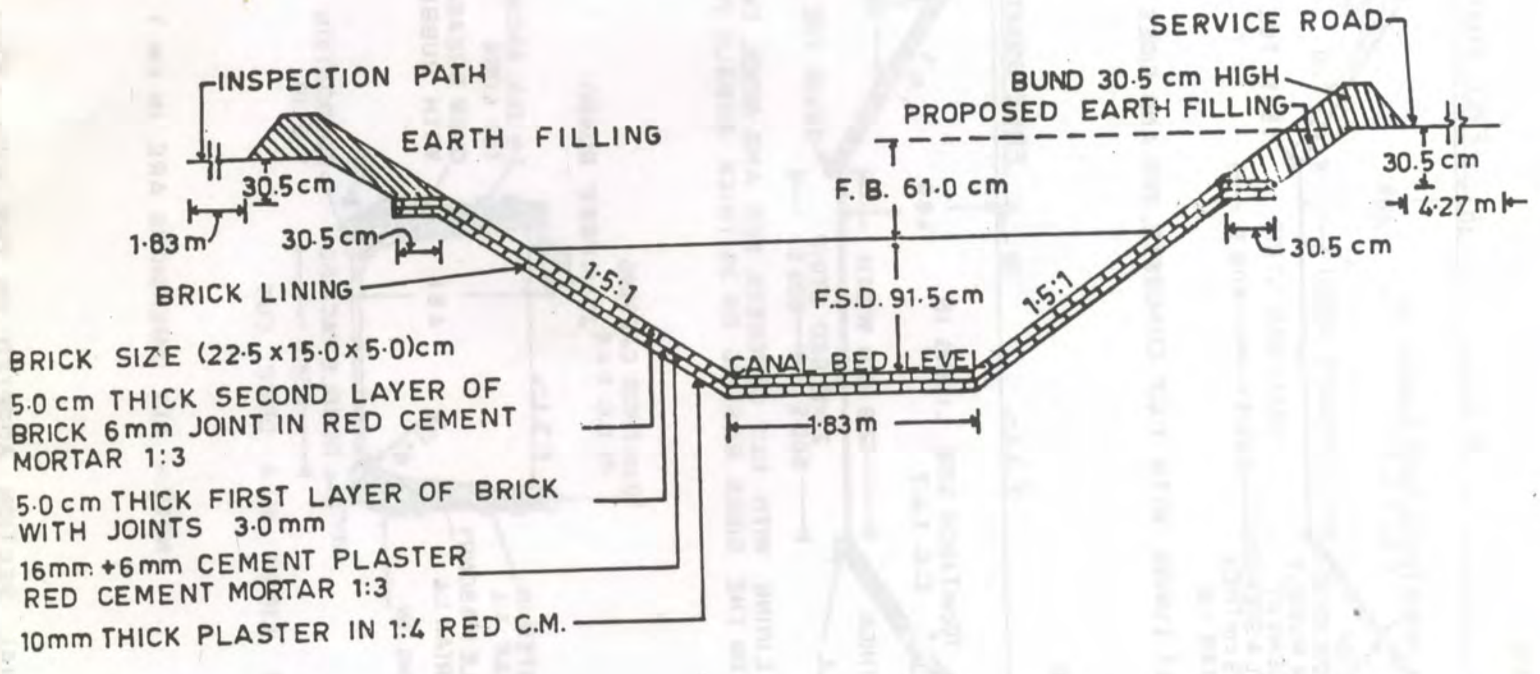
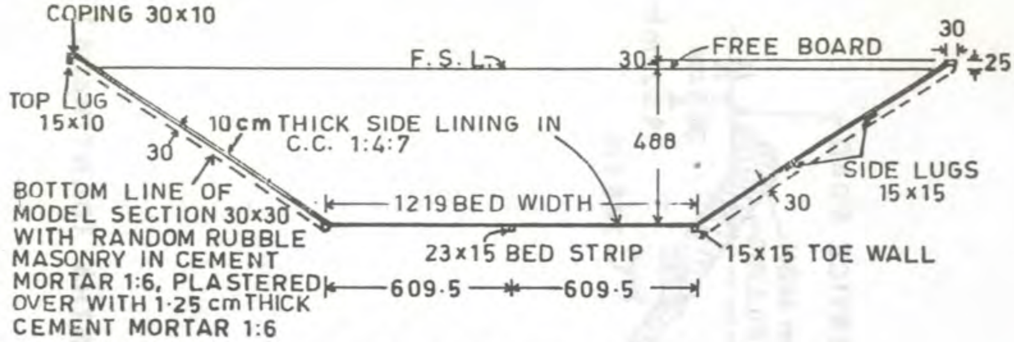
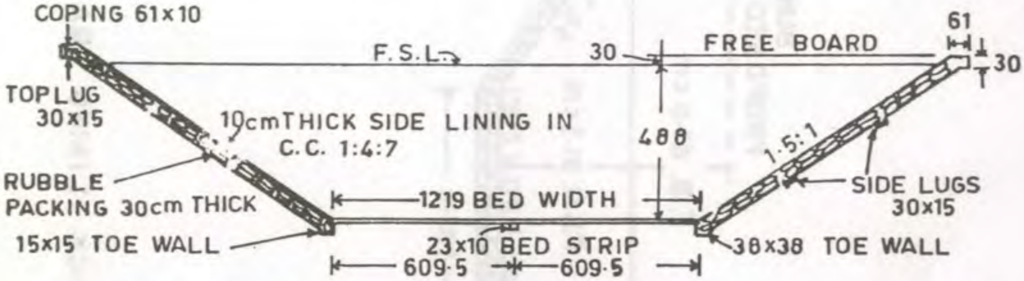


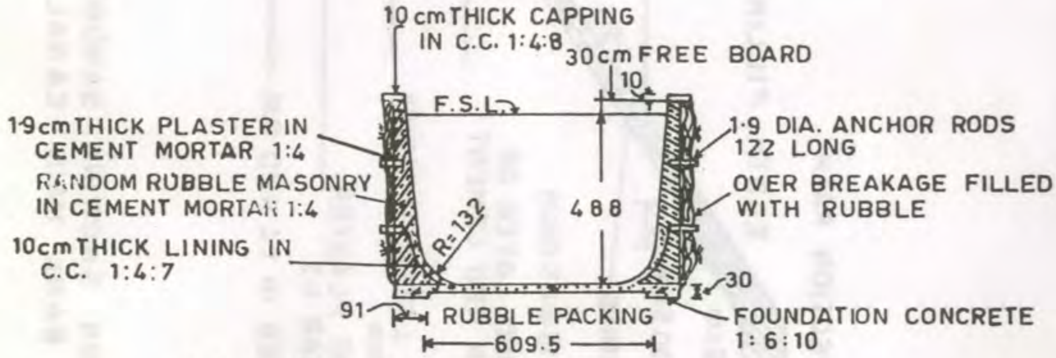
FIG. A-11 :- SECTION SHOWING SANDWICH BRICK LINING BANASKANTHA (DANTIWADA) LEFT BANK MAIN CANAL.



(a) LINING WITH 1:4:7 CONCRETE, BED AND SIDES



(b) LINING WITH 1:4:7 CONCRETE, BED AND SIDES, THE LINING ON THE SIDES RESTING ON 30 THICK RUBBLE PACKING



(c) LINING IN A DEEP CUT

(NOTE:– ALL DIMENSIONS ARE IN cm.)

FIG. A-12 :— CANAL SECTION ADOPTED ON THE HIGH LEVEL CANAL OF THE TUNGAB PROJECT.

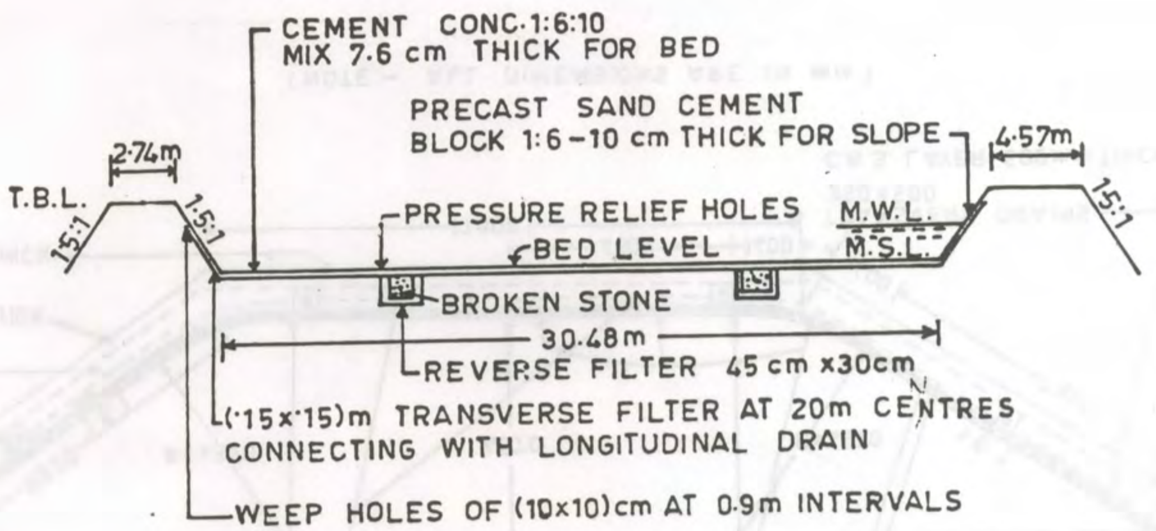
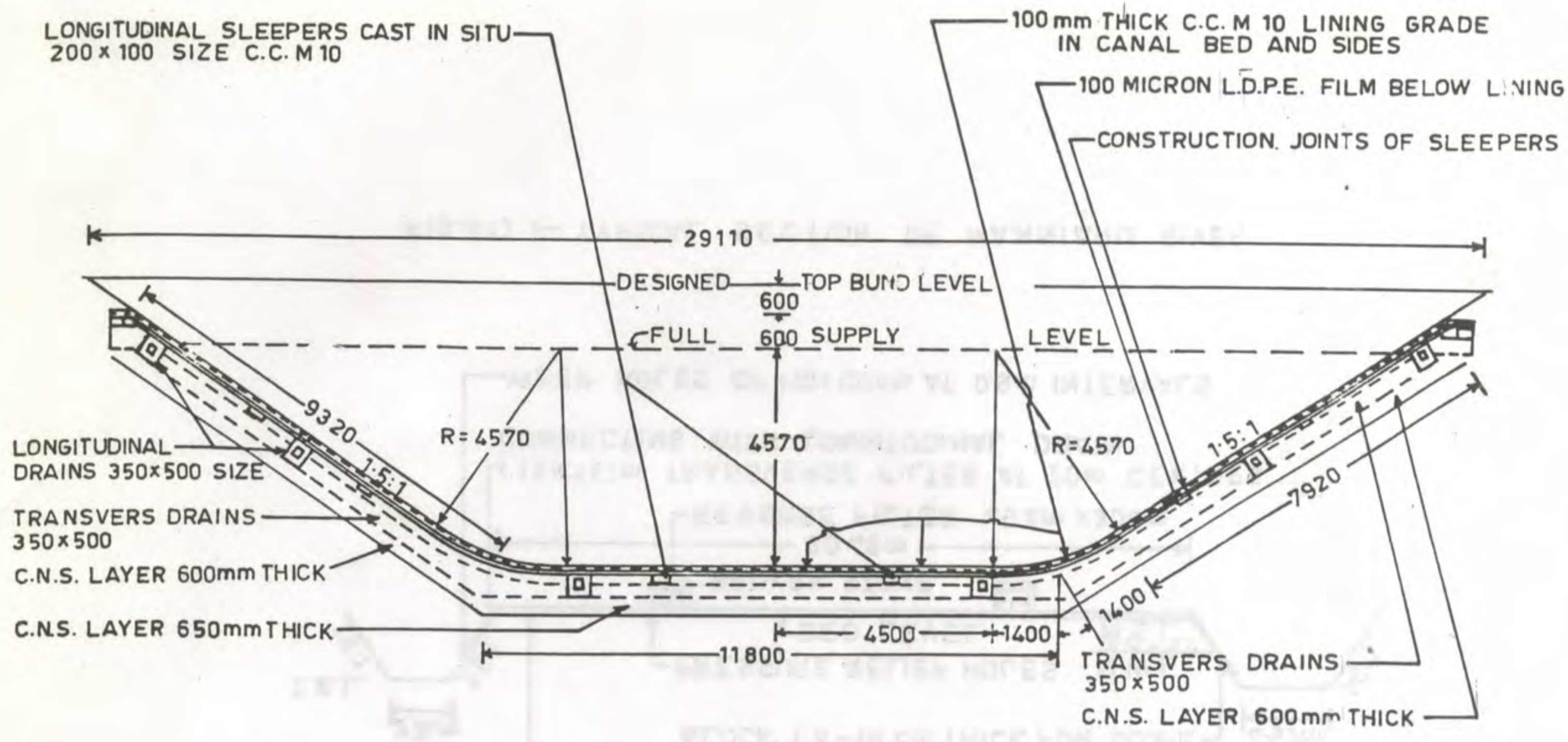
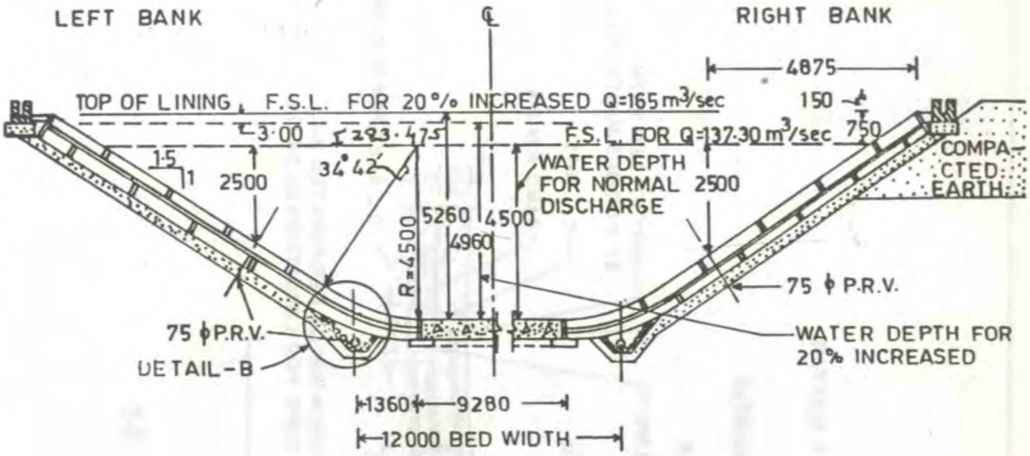


FIG.A-13 :— TYPICAL SECTION OF MANNIARU RIVER

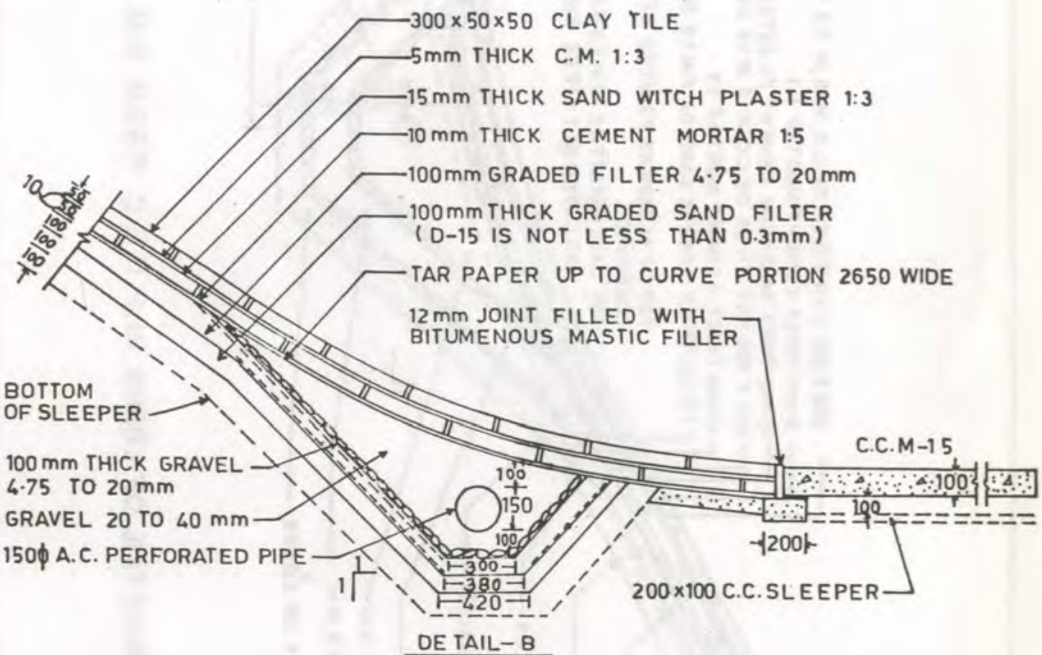


(NOTE:– ALL DIMENSIONS ARE IN mm)

FIG. A-14 – CROSS SECTION OF LINED CANAL (R.A.B.S. PROJECT, M.P.)



TYPICAL CROSS-SECTION



DETAIL-B

NOTE:- ALL DIMENSIONS ARE IN mm.

FIG. A-15:-SEMI MECHANISED CLAY TILE LINING EASTERN GANGA CANAL. (Km 11·10 to 19·5)

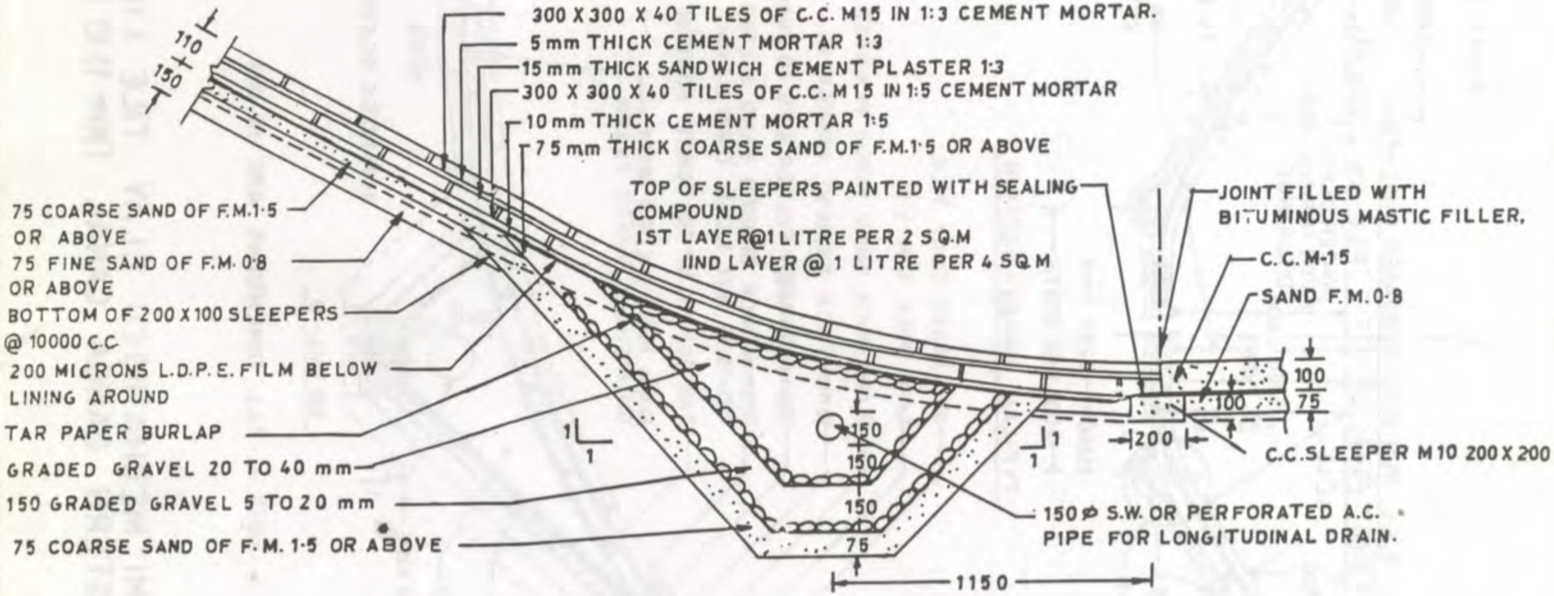
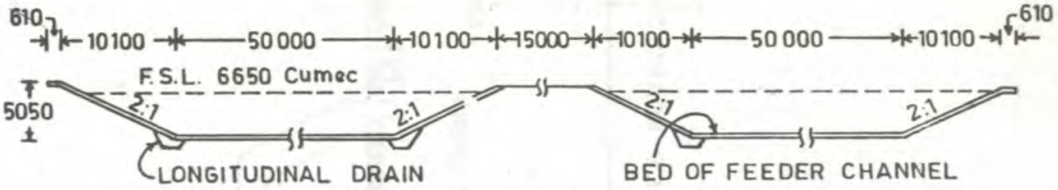
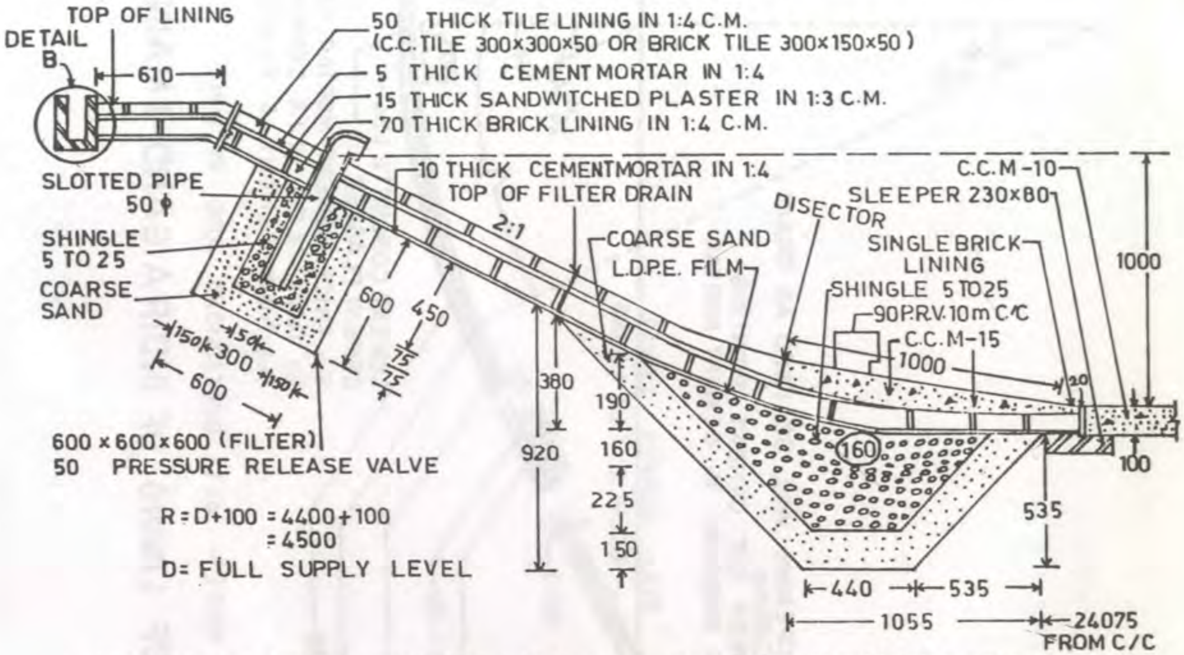


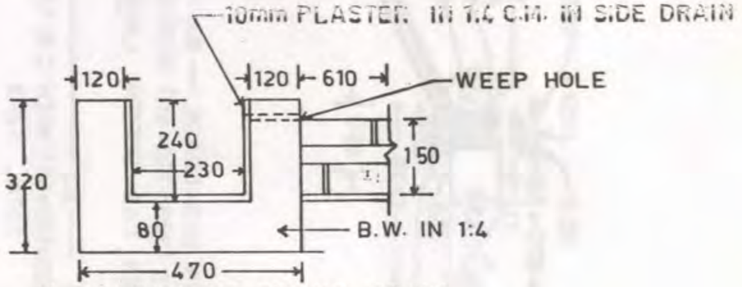
FIG.A-16:-DETAIL OF LINING IN P.U.G.C. FROM K.M. 6 TO 9·5



X-SECTION OF FEEDER CHANNEL



DETAILS OF LINING, PRESSURE RELEASE VALVE & LONGITUDINAL DRAIN

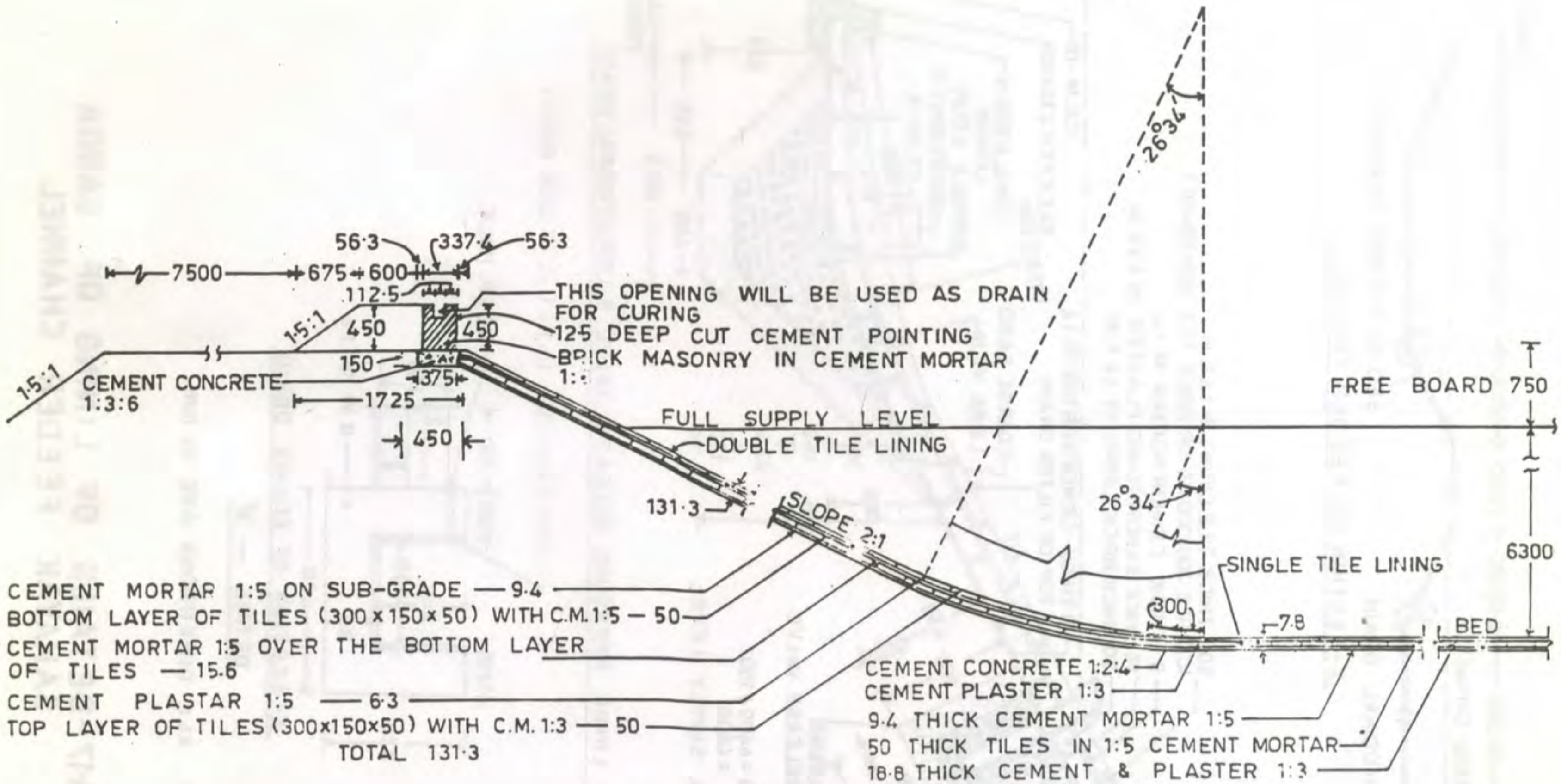


X-SECTION OF EDGING DRAIN

DETAIL — 'B'

NOTE :- ALL DIMENSIONS ARE IN mm.

FIG. A-17 :- DETAILS OF LINING OF SARDA SAHAYAK FEEDER CHANNEL



NOTE:- ALL DIMENSIONS ARE IN mm.

FIG. A-18-TYPICAL CROSS SECTION OF LINING OF INDIRA GANDHI MAIN CANAL

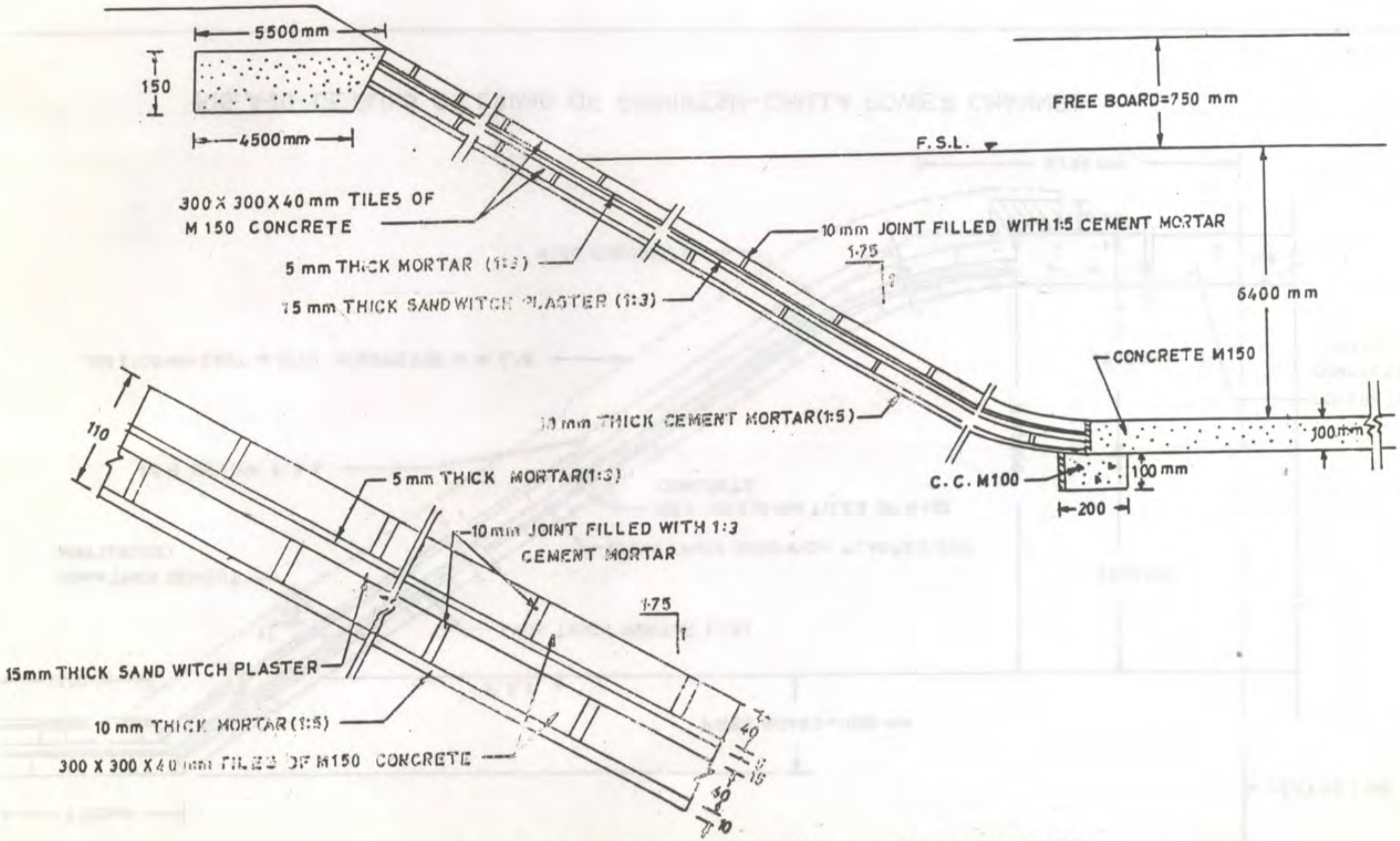


FIG. A-19:-DETAILS OF LINING OF KHARA POWER CHANNEL

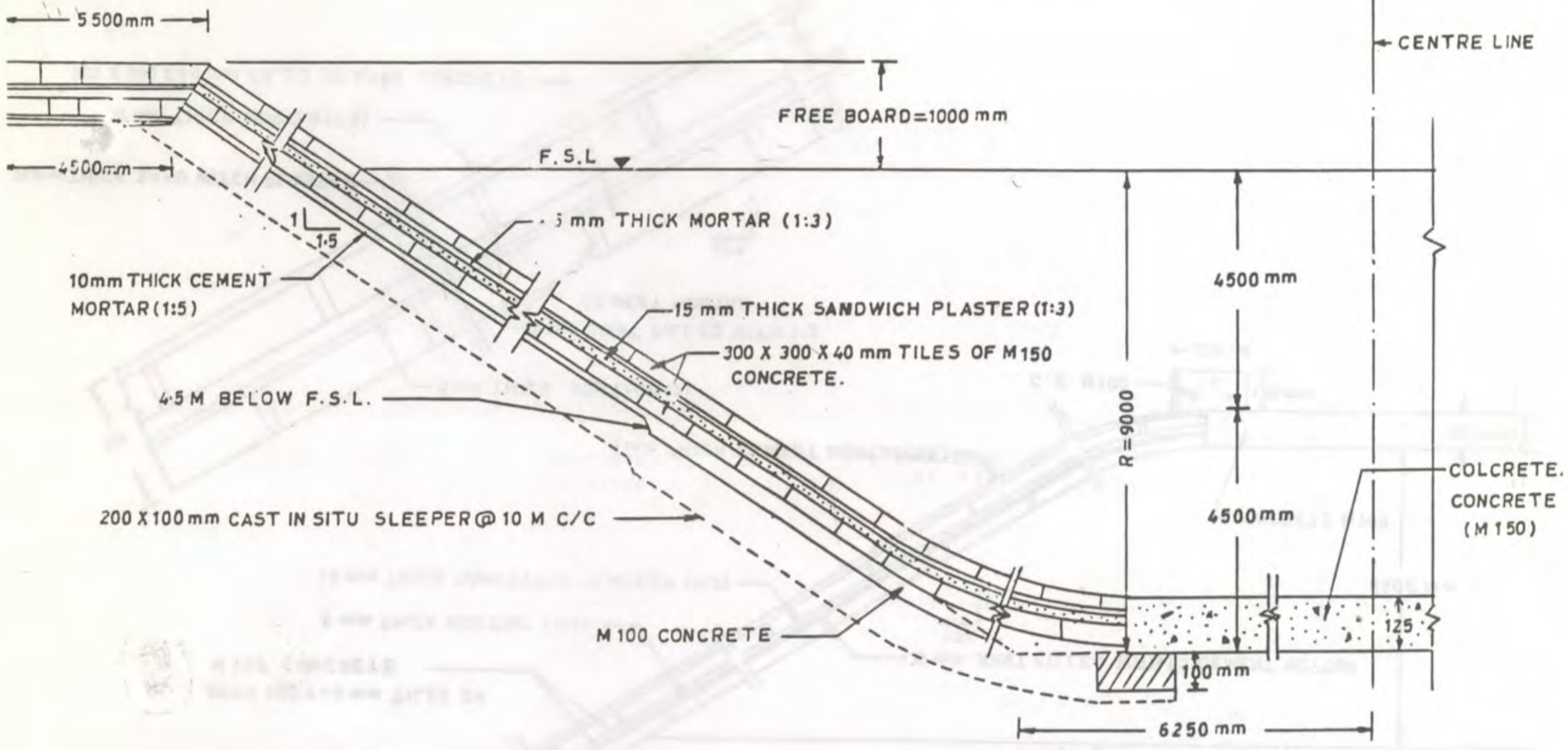


FIG. A-20 - DETAILS OF LINING OF RISHIKESH-CHILLA POWER CHANNEL

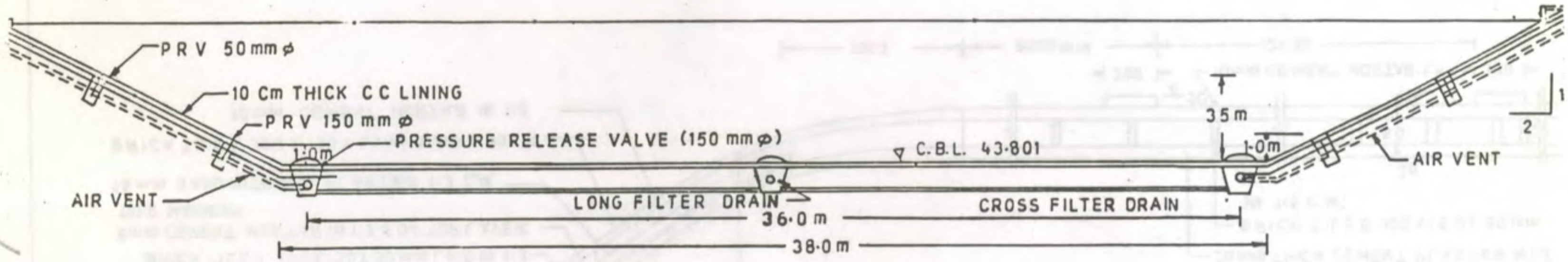


FIG.A21:-DETAIL OF LINING OF SAURASHTRA BRANCH CANAL

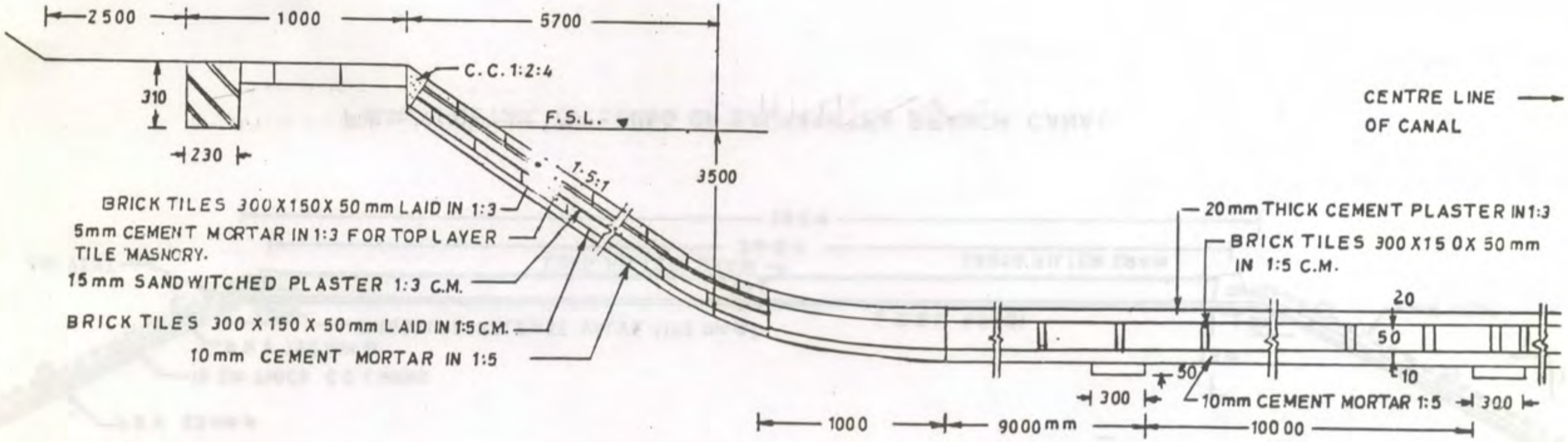


FIG. A-22:-DETAILS OF LINING OF MADHYA GANGA CANAL

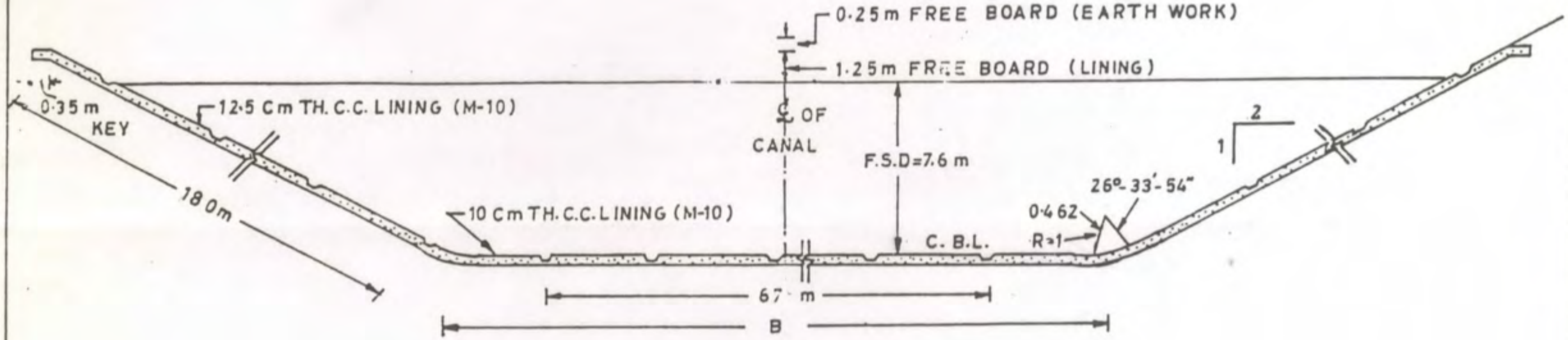
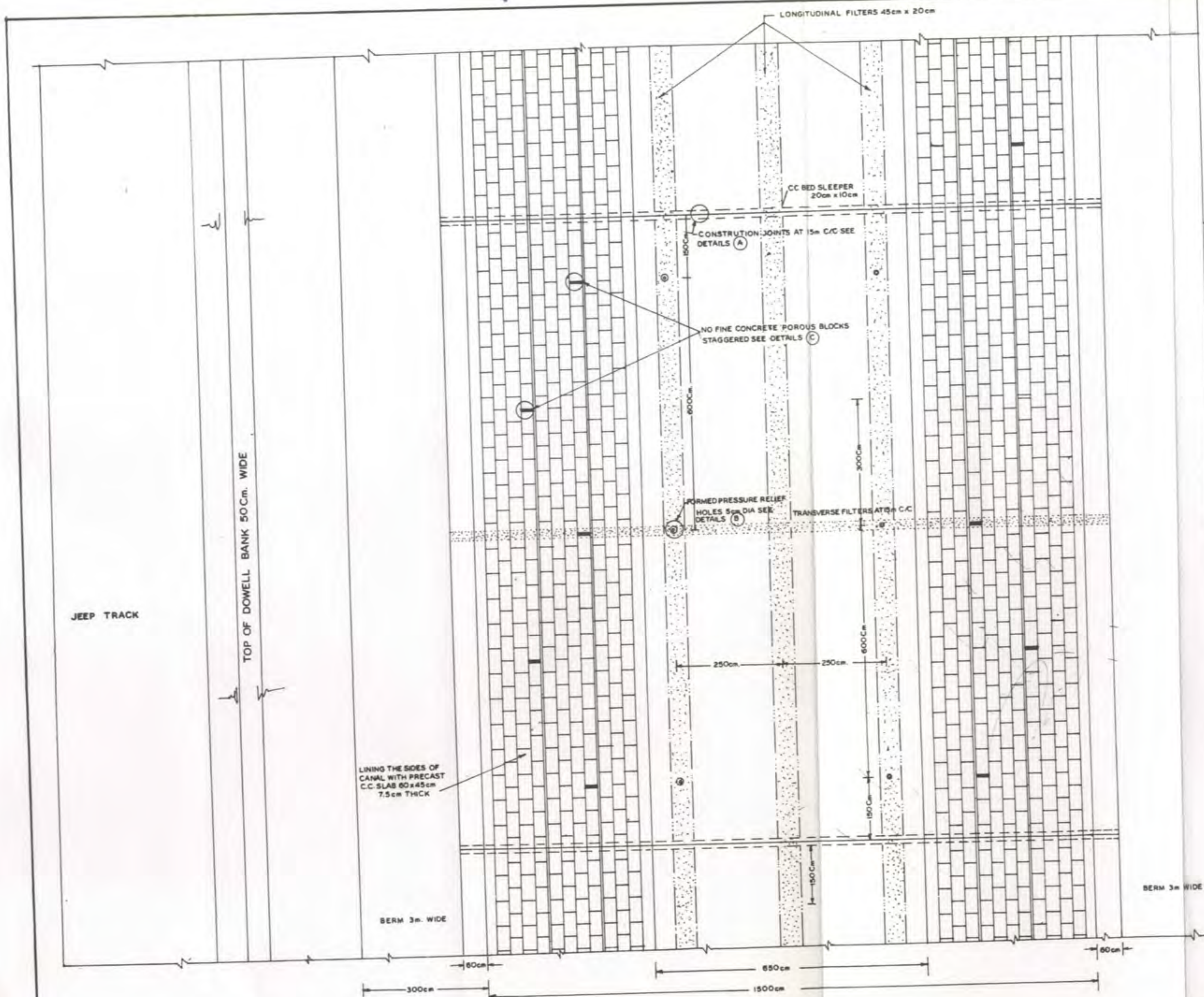
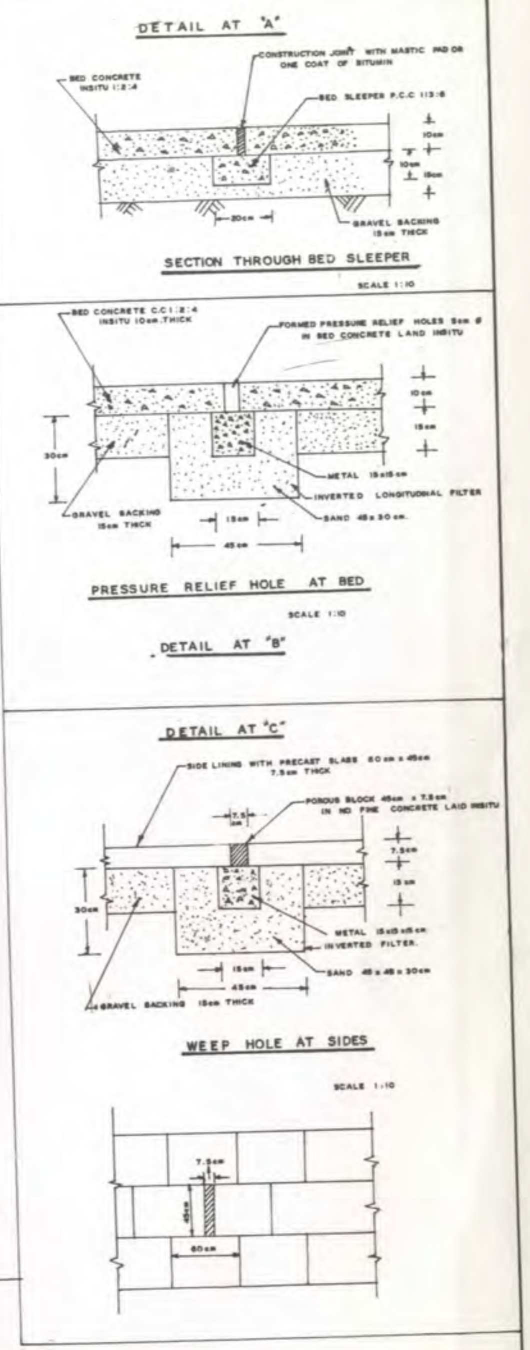


FIG. A-23-DETAILS OF LINING OF NARMADA MAIN CANAL



PLAN FOR LINED CANAL SECTION

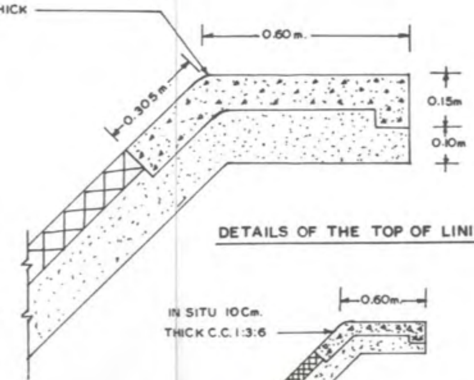


GOVERNMENT OF TAMILNADU
PUBLIC WORKS DEPARTMENT

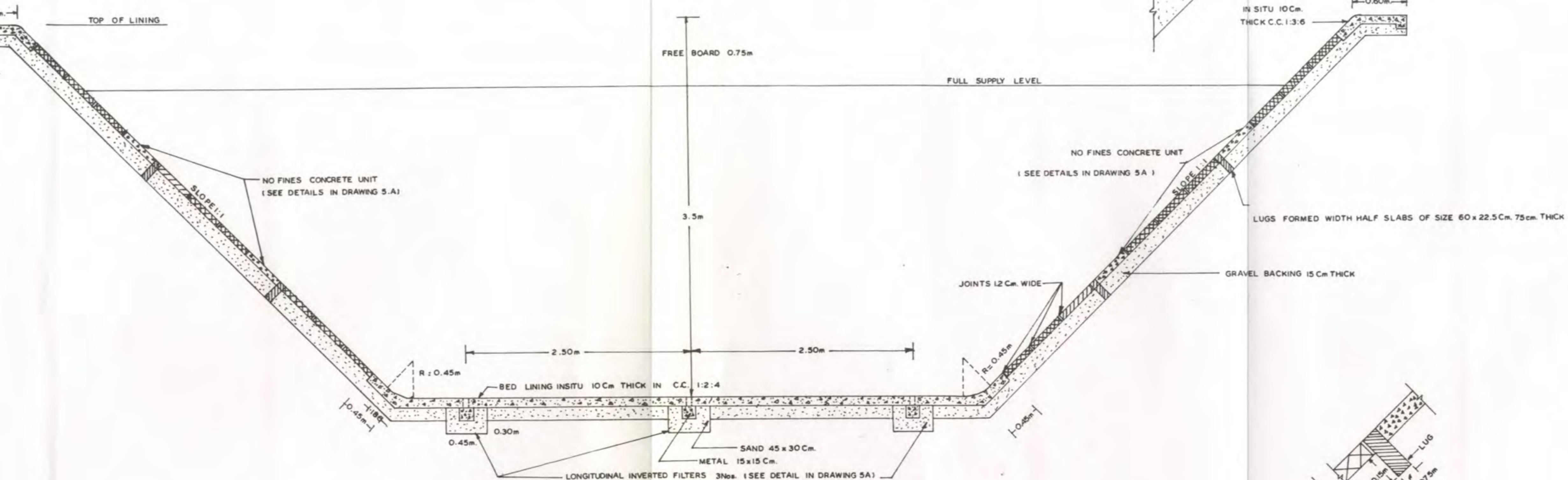
KRISHNA WATER SUPPLY PROJECT

CANAL FROM TAMILNADU BORDER TO POONDI RESEVOIR

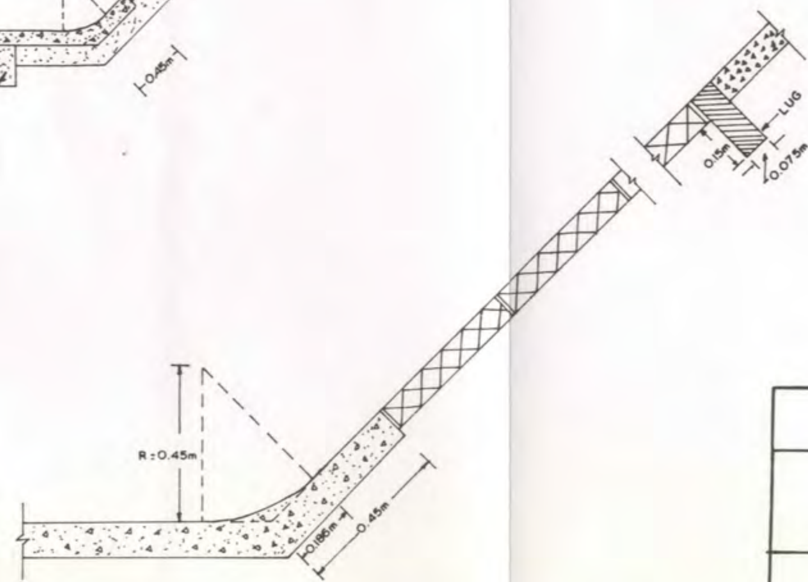
SCALE: 1:50	DETAILS OF CANAL LINING (READ WITH DRAWING 5B).	KWSP. DR NO 5A (REVISED)



DETAILS OF THE TOP OF LINING (SCALE 1:10)



TYPICAL CANAL CROSS SECTION (SCALE 1:25)



DETAILS OF FLANGE AND LUG (SCALE- 1:10)

GOVERNMENT OF TAMILNADU
PUBLIC WORKS DEPARTMENT

KRISHNA WATER SUPPLY PROJECT

DETAILS OF CROSS SECTIONS (READ WITH DRAWING 5A)	KWSP. DR.NO 5B (REVISED)

GLOSSARY OF TERMS

ACRE-FOOT : It is unit of volume used in irrigation practice. It means the volume of water required to cover an area of one acre to a depth of one foot .

AFFLUX : The rise above the natural surface of water in a channel caused by placing an obstruction in the water-way.

AGGLOMERATE : A single mass or cluster of soil consisting of many soil particles held together such as a clod, prism, crumb, or granule.

AGEING : Changing of the physical and chemical properties of a material with time.

AIR-ENTRAINED CONCRETE : Concrete produced with the addition of purposeful air-entraining agents to improve durability and other properties

ALIGNMENT : The course along which the centre line of a canal or drain is located.

ALKALINE SOIL : A soil that has an alkaline reaction i.e. a soil for which the pH reading of the saturated extract is higher than 7.0.

ANISOTROPIC : Properties of soil in which the flow varies with the direction.

APRON : A floor of concrete, masonry or stone, etc., to protect a

		surface across a river drain, canal etc. to carry water above the natural surface level.
ARTIFICIAL DRAINS	:	Man made or constructed drains
AREA, NON-PERENNIAL	:	The area served by a non-perennial canal.
AREA, PERENNIAL	:	The area served by a perennial canal.
AUTHORIZED OR DESIGNED FULL SUPPLY DISCHARGE	:	The maximum discharge for which a channel is designed. In irrigation practice, the authorized full supply discharge should never be exceeded.
AVERAGE SUPPLY	:	The average supply in a channel is the sum of the daily discharges at the head of the channel divided by the number of days when channel is in flow.
ANGLE OF FRICTION	:	It is defined as the angle between the horizontal and the maximum slope at which a soil may remain stable.
ASPHALTIC CONCRETE	:	It consists of a mixture of asphalt, cement and selected aggregates mixed hot and mix is placed by hand or equipment.
AYACUT	:	The irrigable command of an irrigation work. It is a Tamil word for culturable area.
AGGREGATE	:	The inert mineral/materials, such as sand, stone dust gravel, shells, slag, broken stone, or combinations thereof, with which cement, lime or bituminous material is mixed to bind into a mortar or concrete.
ASPHALT	:	A mix of bitumen ...

BACK -FILL	:	Earth or other material used to replace material removed during construction, such as in culvert and pipe line trenches and behind bridge abutments: also refers to material placed between an old structure and a new lining.
BAFFLE	:	A cross wall or a set of vanes or some other device built in a channel downstream of hydraulic structure, to dissipate energy.
BED DUNES	:	A succession of mounds of incoherent sediment formed by flow on the bed of a channel.
BEACHING	:	A protective covering of material placed on the canals and drains to prevent or minimise erosion.
BED	:	The area between two adjacent furrows.
BED DEPTH	:	The distance between the bottom of the furrow and the highest point of the bed area.
BED WIDTH	:	The horizontal distances between two adjacent furrows.
BERM	:	A horizontal strip of shelf built into an embankment to break the continuity of an otherwise long slope.
BLANKETING	:	(1) The covering of the bed of a channel by fine sediment deposited from suspension. (2) The layer of impervious material extending from the core in an earth dam towards the water side covering the natural bed.

but it has the advantages of low maintenance cost, quicker construction and natural safeguard against cracking due to closely spaced joints.

BASIN	:	The area drained by river.
BULLDOZER	:	A tractor used with a front pusher blade.
BULK DENSITY	:	The ratio of the mass of water-free soil to its bulk volume Bulk density is expressed in gram per cubic centimeter.
BURIED MEMBRANE LINING	:	A buried membrane lining consists of an impervious and relatively thin membrane material covered by a protective cover.
BENTONITE & CLAY MEMBRANE	:	Bentonite becomes impervious on wetting due to swelling and imbibing of water. Therefore, it is very useful material for controlling seepage from canals.
CANAL	:	An artificially constructed channel for the conveyance of appreciable quantities of water for the purpose of irrigation, navigation or other uses.
CANAL INUNDATION	:	This term is ordinarily applied to a canal with or without some form of head regulator, dependent upon the surface level of the water in the river for its supplies. It follows that inundation canals will only run when the supply in the river rises to a level which permits the feeding of the canal.
CANAL INTERMITTENT	:	A canal designed to irrigate only when demand arises and usually takes its supply from a storage or reservoir.

CAVING : The collapse of a bank caused by undermining due to the wearing away of the bank by the action of flowing water.

CHANNEL CAPACITY : Flow rate of a ditch, canal, or natural channel when water is flowing at design depth.

CHANNEL IRRIGATION: A small channel taking its supply from a government channel, but owned and maintained by the cultivators commonly known as water-course.

CHANNEL NON-PERENNIAL : A channel which is designed to irrigate during only part of the year, usually the "kharif" or summer season.

CHANNEL PERENNIAL : A channel which is designed to irrigate all the year round.

CHEMICAL WEED CONTROL : Control of weeds by chemicals (herbicides)

CLAY : A very fine material which is more or less plastic when wet manifests colloidal properties classified according to soil texture and soil separates classifications. According to the International Society of Soil Science, the particle size of clay is mainly less than 0.002 mm in diameter.

COMPACTION : Increasing the density of soil by means of mechanical equipment.

CLOGGING : The impeding of the flow of water through drain joint openings or drain pipe perforations, or along drain pipes, or the blocking of subsurface drains by silt, sand, roots etc.

of water.

CORRUGATED PLASTIC PIPE : A plastic pipe of tube, formed with alternating circumferential ridges and valleys to provide circumferential stiffness and longitudinal flexibility.

CONVEYANCE LOSS : Loss of water from a channel due to absorption and evaporation. This is also known as transmission losses.

CRITICAL DEPTH : The depth of water in a channel corresponding to the critical velocity.

CRITICAL VELOCITY : Velocity in open channels for which the specific energy (sum of the depth and velocity head) is minimum for a given discharge.

CROSS SECTION : A vertical section of the drain at right angle to the central line.

COHESIVE MATERIAL : Material possessing sufficient shear strength to resist the shearing stress of the flow of water.

CULTURABLE COMMAND AREA : The area of culturable land in a command area or the area in which crops are actually grown satisfactorily.

CUSEC : The unit of discharge used in irrigation practice and means a rate of flow of one cubic feet per second.

CARRIER CANAL : A canal which besides doing irrigation carries discharge for another channel is called a carrier canal.

CONTOUR CHANNEL : A channel aligned nearly parallel to the contours of the considered permissible. This type of lining has been used successfully in India. A marked disadvantage of the concrete lining is its lack of extensibility which results in frequent cracks due to contraction. It is also likely to get damaged by the high alkaline content of the water.

DESIGN FLOW : The flow for which the cross sectional area of a drain is determined.

DESIGN FLOW DEPTH : The depth of water in a channel or pipe when design flow moves through the cross-sectional area present.

DISTRIBUTARY SYSTEM : Water from rivers has to be carried through canals, branches, distributaries, minors and water-courses on the fields. These as a whole are known as Distributory System.

DITCH : Artificial open water channel for distribution of irrigation water at farm and field level. Normally the Velocity of water in ditches is less than 0.5m/s.

DRAIN : A channel either artificial or natural, for carrying surplus ground or surface water.

DRAIN SPACING : Horizontal distances between centres of adjacent drains.

DRAIN TRENCH : Excavated trench in which drain pipes are installed.

DRAWDOWN : Lowering of the water table or piezometric surface, midway between drains or at a well resulting from withdrawal of water by a drainage system or by pumping.

DURABILITY	:	Resistance of lining to weathering, chemical attack and wearing.
ESCAPE	:	A channel through which surplus or excess water may be removed from a canal or reservoir.
EFFICIENCY	:	The ratio of water delivered at one point to water released from another point.
EFFICIENCY OF IRRIGATION SYSTEM	:	It is measured by the ratio of supply available to cultivators in the fields to the supply at the head.
ECONOMICAL SECTION	:	Maximum cross-sectional area for the minimum wetted perimeter.
EXPOSED LINING	:	Linings which are influenced by flowing water and maintenance equipment. Such linings are constructed of cement concrete and mortar, asphaltic materials, bricks, stone and synthetic membranes.
EARTH LINING	:	A thick, compacted earth lining may prove economical where suitable material for construction is available at site. Bentonite is conisidered to be a good lining material.
ENVELOPE	:	Composed of permeable materials, which is placed around the drain pipe to prevent fine particles entering into the drain, e.g. synthetic, granular or organic materials.
EQUIPOTENTIAL LINE	:	A line in an equipotential surface (an imaginary surface) within a field of flow in isotropic media, such that the total head is the same for all points on the surface.

		these lining materials have a low resistance to puncturing and it disintegrates rapidly. Thicker sheets exhibit greater resistance but are expensive.
FEEDER	:	A Channel constructed to convey water from one source of supply to another or within the same system.
FIELD CHANNEL	:	Channel carrying water from a watercourse to individual fields. (Field channels are often absent with field-to-field irrigation).
FLOAT GAUGING	:	Measurement of the discharge of water by floats to determine velocities.
FREE BOARD	:	The vertical distance between the full supply level in a channel and top of the bank. Free boards are primarily meant to prevent spilling over of water by wave action and safeguard against danger from extra supplies passing down the canal by operational errors.
FREE SURFACE	:	A water surface where the pressure of water equals atmospheric pressure.
FREE WATER	:	Water which drains through the soil under the influence of gravity.
FROUDE NUMBER	:	A dimensionless number expressing the ratio between the influences of inertia and gravity in a fluid and expressed as V/g D, where V= velocity, g = gravitational acceleration & D = depth.
F.S.L.	:	The water level in a channel when it is carrying the

GRAVEL ENVELOPE :	A layer of coarse sand or fine gravel about 50 to 100 mm thick,placed completely around a subsurface drain pipe to provide a support for the pipe, to increase the permeability near the pipe, and to control the inflow of sediment to the pipe (gravel pack, gravel jacket or gravel filter).
GROUNDWATER :	Water occurring in the zone of saturation in an aquifer or soil profile.
HYDRAULIC MEAN RADIUS OR HYDRAULIC MEAN DEPTH :	The right cross-sectional area of a stream of water divided by the length of that part of its periphery which is in contact with its containing body. OR It is the ratio of the area of flow of a canal and its wetted perimeter.
HARD SURFACE LINING:	This category includes all exposed linings constructed of cement concrete, mortar, soil cement, asphaltic materials, brick & stone.
HYDRAULIC CONDUCTIVITY :	The proportionality factor in the Darcy Flow Law which states that the effective flow velocity is proportional to the hydraulic gradient. Hydraulic conductivity, therefore, is the effective flow velocity at unit hydraulic gradient and has the dimensions of velocity.
IMPROVING PERFORMANCE :	Enhancing well being by increasing benefits from canal irrigation, including those from productivity, equity and stability, in relation to costs including financial costs and adverse social, health, environmental and other effects.

intercept groundwater flow and to control movement of water into the drainage problem area.

IRRIGATION : The artificial application of water to lands for agricultural purposes.

LAMINAR FLOW : The flow of water in which particles of water move in parallel layers, each of which has a constant or only a very slightly differing velocity.

LINING : A protective cover over a channel periphery to prevent seepage losses, to reduce friction or improve conditions of flow.

LDPE FILM LINING : LDPE means low density polyethylene film. LDPE film lining is found best among all membrane linings. Thus LDPE film for canal lining is successfully used in various state irrigation departments of India.

MEAN DEPTH : Cross-sectional area of a stream divided by its surface width.

MILLION CUBICFEET : A unit of volume of a reservoir capacity.
1 M.C.Ft. = 22.96 Acre Feet.

MINOR : Small channel usually taking its supply from a distributary. Its function is to supply water to outlets.

NON-UNIFORM FLOW : Flow having non-uniform velocity is called non-uniform flow. If the discharge is constant it is referred to as "steady non-uniform flow".

PARTICLE SIZE DISTRIBUTION : Composition of soil particles, usually

PERVIOUS : The capability of porous rock of sediment to permit the flow of fluids through its pore spaces.

PHREATIC SURFACE : The level to which water will rise in an unconfined aquifer under atmospheric conditions.

POROSITY : Total volume of voids expressed as the ratio of volume of voids to the total soil volume.

PIPING : The flow of water under or around a structure built on permeable foundations which if not prevented or stopped will remove material from beneath the structure and cause it to fail.

PONDING : The condition produced by surface water collecting in shallow pocket in an area.

PUDDLE : Clayey material placed to form a compact mass to reduce percolation.

PUDDLING : The process by which a soil loses granular structure and becomes deflocculated. It is caused by excessive water, excessive handling tilling or deflocculating agents.

RED CEMENT : Mixture of four parts portland cement to one part surkhi.

REGIME : A channel flowing in incoherent silt is said to be in regime for the particular type of silt carried when its slope and shape have reached stability under constant flow. In general a channel is in regime when it is stable i.e. it does not silt or scour.

REGULATOR : A structure through which the discharge can be varied at will.

SAFE VELOCITY : The greatest velocity at which it is possible to let water flow in a drainage channel without causing erosion or washing of the banks.

SAND : The fine material resulting from the natural disintegration of rock or crushing of friable rock. Classified according to soil texture and soil separates with a diameter greater than 0.02 mm according to the International Classification System.

SAND TRAP : Device, often a simple enlargement in a ditch, open channel, or pipe to detain sand or other heavy particles carried by water. May also include means for removing such material.

SCOUR : The removal of material from the bed of a channel by flowing water.

SEEPAGE : The movement of water through small cracks , pores, interstices out of a body of surface or subsurface water.

SEEPAGE FLOW : The movement or flow of water through a porous soil that causes drainage problems.

SERVICE LIFE : Time during which a material or structure can be used economically or maintains its designed characteristics or strength.

SHOVEL : An excavator that digs and loads material using a digging bucket on the end of a boom and provides an action similar to a man digging with a shovel.

SPECIFIC DISCHARGE : Flow rate per unit of cross-sectional area.

SYNTHETIC ENVELOPE MATERIAL :	A manufactured fabric material, such as nylon polypropylene or polyester, which is put around drain pipes to prevent soil particles from entering the drainage in the pipes.
SEEPAGE LOSS :	Volume or rate of loss of fluid by seepage . Seepage loss from canals and reservoirs is usually expressed in terms of cusec per million square feet.
SIDE SLOPE :	The slope of the sides of a canal, dam or embankment. The slope of the sides of a canal is given by the horizontal distance first and then vertical distance, for example 1.5:1 means 1.5 horizontal and 1 vertical.
SHINGLE :	Round pebbles of stones.
SHOTCRETE LINING :	In this type of lining cement mortar is applied by pneumatic pressure. Since the thickness of the lining is limited to 5.0 cm such linings are mostly applied on smaller channels.
SOIL CEMENT LINING :	This type of lining is made from a mixture of cement and natural sandy soil. The use of soil cement lining is sometimes hampered by the non-availability of suitable soil.
TAIL :	Work constructed at the end of a channel for the distribution of water.
TANK :	A small reservoir is named as tank in some parts of the country.
TANK FED CANAL :	It is a canal which derives unreliable supply f...

UNIFORM FLOW : Flow in which depth, cross sectional area, velocity and hydraulic slope remain constant from section to section. Surface line in this case remains parallel to bottom line.

UNSTEADY FLOW : Flow in which features such as velocity, cross-sectional area and hydraulic slope vary in the course of time.

VELOCITY : The speed in a specified direction.

WATER-COURSE : Channel taking its supply from distributary and fields are irrigated directly from these channels.

WEARING-ACTION The wearing action of water on the brick or concrete lining is negligible for all velocities under ordinary conditions which are of the order of 6 ft. per second. If the joints are properly filled the wearing action is almost negligible.

WATER-LOGGING : State of land in which the subsoil water table is located at or near the surface with the result that the yield of crops commonly grown on it is reduced well below the normal for the land. An area is considered to be waterlogged if depth to watertable is 1.5m or less.

WEEP HOLES : Opening left in retaining walls, lining foundations, etc. to permit drainage to reduce pressures.

WATER TABLE : The upper surface of an unconfined aquifer at which the pressure in the ground water is equal to atmospheric pressure.

ZONE OF SATURATION: It is a zone below the water table in which the intersticed spaces are filled with ground water.

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