GOVERNMENT OF INDIA

MINISTRY OF WATER RESOURCES

TECHNICAL MEMORANDUM

ON

GUIDELINES FOR DESIGN & CONSTRUCTION OF SEAWALLS

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CENTRAL WATER & POWER RESEARCH STATION, PUNE

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CENTRAL WATER & POWER RESEARCH STATION

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GUIDELINES FOR DESIGN & CONSTRUCTION OF SEAWALLS

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PREFACE

The fragility of land-water interface has always been a matter of concern to the coastal population. The threat is often intensified both by natural and manmade factors. With a long coastline of about 7500 km, the subject of coastal erosion and protection assumes a great importance for India. The erosion problem calls for protection of houses, cultivated lands, valuable properties, monuments etc. in the coastal belt.

The best natural protection against erosion is an adequate beach on which waves expend their energy. Creation of beach is rarely possible due to economic reasons. As such, the engineering structures like seawalls, revetments, groynes, offshore breakwaters, etc. are adopted for coastal protection. Rubblemound seawall is more commonly used measure in India for combating coastal erosion.

The practical difficulties / deviations encountered during the design and construction of seawalls are described in the memorandum. The basic design and construction methods are generally available in Coastal Engineering books / manuals. However, this memorandum provides the essential guidelines and the precautions to be taken during design and construction of seawalls. These guidelines are prepared based on the vast experience of CWPRS in the design of coastal protection works and the field observations for more than 100 erosion sites. I am sure that this memorandum would be useful for the field engineers who are dealing with the design and construction of seawalls.

Dr. I.D. Gupta
Director

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GUIDELINES FOR DESIGN AND CONSTRUCTION OF SEAWALLS

1.0 INTRODUCTION

Coastal erosion is a problem faced by all the coastal population in different parts of the world. With a long coast of about 7500 km, the subject of coastal erosion and control in India assumes great importance. This problem calls for the protection of houses, cultivable lands, valuable properties, monuments etc. in the coastal belt. The solution to this problem involves scientific analysis of the same with a view to devise methods for preventing and/or minimizing the damage due to erosion caused by the destructive forces of the waves.

It is well known that the erosion of a coast is mainly due to action of waves in addition to the currents setup by the oblique attack of waves. Erosion of the coast depends on many factors like storm waves, nature of the beach, beach material and the shape of the coast, tidal level changes, movement and quantity of the littoral drift material. Human interference is also an important factor causing coastal erosion. The best natural defence against erosion is an adequate beach on which waves expend their energy. However, provision of an adequate beach is rarely possible due to economical reasons. Resort has therefore, to be taken to provide appropriate engineering structures such as seawalls, revetments, anti-sea erosion bunds, groynes, offshore breakwaters, etc. to prevent beach erosion. Seawalls, revetments and groynes are structures located on the beach, while offshore breakwaters are located away from the beach. Since waves are the prime cause of beach erosion, it is natural that the protective methods are evolved so as to dissipate the energy of waves either by absorbing this energy on the beach or dissipating / diverting the same before the waves approach the beach. Rubblemound seawalls are the most commonly used measure for preventing coastal erosion in India.

For the design of these coastal structures, it is necessary to collect the data regarding wave climate (wave height, wave period, direction), the nature of bed and the material on which these structures are to be constructed, availability of stones of different sizes, availability of appropriate equipment and the purpose for which the structure is to be constructed. Once the construction of the structure is completed, little or no attention is given to its performance or efficiency. Although maintenance of a structure is essential, hardly any care is taken to maintain the structure. The practical difficulties / deviations encountered during the design and construction of the seawalls are discussed herewith and the importance of post-construction maintenance of coastal structures is emphasized. The guidelines are based on the vast experience of Central Water & Power Research Station (CWPRS) in the design of coastal protection works and field observations for more than 100 erosion sites (Annexure –I).

2.0 VARIOUS METHODS OF SHORE PROTECTION

Various methods to prevent beach erosion are briefly indicated below :

1) Coastal Structures :
   (a) Seawalls, revetments, anti-sea erosion bunds
   (b) System of groynes or jetties – shore connected
   (c) System of offshore breakwaters - away from the shore
2) Nourishment of the beach by artificial method
3) Planting vegetation along the beach
4) Institutional i.e. local or state bodies regulate or prevent the construction in certain coastal zones
5) Combination of the above methods in case of protection in zones of high littoral drift.

Of the above methods although the method of nourishment of the beach is the preferred method, construction of seawalls, revetments, anti-sea erosion bunds are generally adopted for preventing the coastal erosion, mainly because of ease of construction and economics.

3.0 DESIGN CONSIDERATIONS

For coastal protection works rigid structures (Photo-1) should normally be avoided and the flexible structures, which dissipate energy should be adopted. In case of rigid structures, if unavoidable, may be provided with slope and vertical face should in any case be avoided. The vertical face leads to the reflection and scouring and subsequently failure of the wall (Photo-2). The vertical rigid retaining wall is normally mistaken with the seawalls. However, it should be kept in mind that the function of the seawall is to dissipate the wave energy and allow formation of beach in front of it. As such, the sloping rubblemound seawall is the most suitable type of seawall.

Photo 1 : Action of Waves Against Vertical Seawall

Photo 2 : Failure of Vertical Wall

The rubblemound seawall is generally designed to consist of three layers. Viz. core, secondary layer and an armour layer (Fig.1). A minimum of two layers of stones (units) in the armour and secondary layer is always necessary. While the thicknesses of these layers are determined by the size of stones used, the levels including that of the core are determined based on maximum water level, design wave height, wave run-up, permissible overtopping and method of construction.

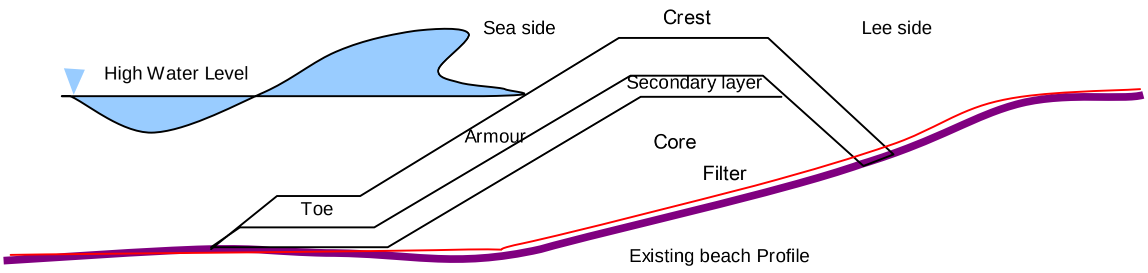

Fig 1: Typical Section of a Seawall

The usual steps needed to design an adequate and efficient rubblemound seawall / revetments are:

1) Determine the water level range for the site
2) Determine the wave heights
3) Determine the beach profile after the storm condition / monsoon
4) Select the suitable location and configuration of the seawall
5) Select suitable armour to resist the design wave
6) Select size of the armour unit
7) Determine potential run-up to set the crest elevation
8) Determine amount of overtopping expected for low structures
9) Design under-drainage features if they are required
10) Provide for local surface runoff and overtopping runoff and make any required provisions for other drainage facilities such as culverts and ditches
11) Consider end condition to avoid failure due to flanking
12) Design toe protection
13) Design filter and under layers
14) Provide for firm compaction of all fill and back-fill materials. This requirement should be included on the plans and in the specifications. Also, due allowance for compaction must be made in the cost estimate
15) Develop cost estimate for each alternative.
16) Provision for regular maintenance and repairs of the structure

4.0 DEVIATIONS IN DESIGN AND CONSTRUCTION

4.1 Position of the seawall

For locating the seawall, determination of the beach profile and the water levels are important. The highest and the lowest water levels at the site must be known before evolving a design. The highest water level helps in deciding the exact crest level while the lowest water level guides the location of the toe. The bed slope in front of a coastal structure also has an important bearing on the extent of damage to the structure and wave run up over the structure. With steeper slopes, damage to armour stones is more as compared to flat bed slope. The wave run-up is also higher on steep bed slopes.

The seawall should be located in such a position that the maximum wave attack is taken by the armour slope and the toe (Photo-3). The seawall, if located above the high water level contour, the waves will break in front of the structure causing scouring and subsequent failure of the seawall. The increase in the depths would cause higher waves to break on the coastline aggravating the erosion problem. It should be kept in mind that seawall is for dissipating the wave energy and not merely for avoiding inundation of the land.

Photo 3: Location of Seawall Between High Water & Low Water

4.2 Under design of Armours

Various factors contribute to render the armours provided in a seawall ultimately inadequate to withstand the wave action at a given spot. Under-estimation of maximum water level, incorrect information of beach slope considered at the design stage, steeping of foreshore after the construction of seawall, presence of a large number of smaller stones than design size (armour size could vary from 0.75 W to 1.25 W such that 50% of the stones weigh more than W, where W is design-size) are a few of them. In case of seawalls provided with a large percentage of undersized armour, there has been considerable displacement and dislocation of armours. Stones having excessively rounded corners attribute to repetitive displacements and consequent attrition and abrasion which have been possibly compounded by poor quality stones. The stones in the lower reaches have been excessively subjected to such forces. The displacement of the armours has resulted in the exposure of secondary layer, which is mostly removed from the section that has created small pockets of breaches completely exposed to the fury of waves (Photo-4).

Photo 4 : Under Design of Armour layer Leads to Failure of Seawall

4.3 Toe protection

Toe protection is supplemental armouring of the beach or bottom surface in front of a structure, which prevents waves from scouring and undercutting it (Photo-5). Factors that affect the severity of toe scour include wave breaking (near the toe), wave run-up and backwash, wave reflection and grain size distribution of the beach or bottom material. Toe stability is essential because failure of the toe will generally lead to failure throughout the entire structure.

Toe is generally governed by hydraulic criteria. Scour can be caused by waves, wave induced currents or tidal currents. Design of toe protection for seawalls must consider geo-technical as well as hydraulic factors. Using hydraulic considerations, the toe apron should be at least twice the incident wave height for sheet-pile walls and equal to the incident wave height for gravity walls.

Photo 5 : Seawall With Toe Protection

4.4 Inadequate or no-provision of filters

Many rubblemound structures have failed due to no or inadequate provision of filter underneath (Photo-6). As a consequence, the insitu soil is leached resulting in the collapse of the structure. In a typical case of a seawall the crest of which subsided due to removal of fill material by overtopped water, there is no proper filter between the sloping fill and the seawall. In some cases, the toe of the seawall sank over the years due to inadequate filter and removal of insitu bed material. With the failure of the toe, armours in the slope, which were otherwise intact, were dislodged by gravity and wave forces. These stones occupied the toe portion and sank further due to the absence of filter. Thus the failure is progressive and renders the seawall ineffective within a short period, if not attended promptly. In situations such as these, the reformation of the profile to design slope alone would not be adequate. It is necessary to provide a proper filter before reforming the section, which could be done by dumping additional stones or retrieving some of the displaced stones.

Photo 6: Inadequate Filter Layer Exposed After Damage to Seawall

4.5 Overtopping

Underestimation of design wave or the maximum water level leads to excessive overtopping of seawalls and eventual failure particularly when the free board is inadequate. Such failures also lead to the failure of leeside slope and damage to reclamation, if any. This calls for not only proper estimation of wave run-up and the crest level of the seawall, but for also providing proper filter between the backfill and the seawall. It is also necessary to provide facilities for drainage of overtopped water, which otherwise will find its way through seawall itself causing further damage. There are instances where the reclamation fill in the lee has shown local depressions. Subsurface fill/soil has been removed in the process of draining of overtopped water. In situations where it is not possible to raise the level of seawall crest to avoid overtopping, it is advisable to provide a deflector to throw a part of the overtopping water back to the seaward slope of the seawall. As mentioned earlier, the leeside fill and the seawall core (or secondary layer) should be sandwiched by an appropriate filter and adequate drain be provided for safe discharge of overtopped water. However, some of the seawalls are designed as semi-submerged bunds, which allows overtopping at the higher Water Levels (Photo-7). A proper care needs to be taken to prevent damage to the crest and the leeside slope during the design of such seawalls.

Photo 7: Overtopping of Waves Over Seawall

4.6 Rounded Stones

The in-place stability of an armour unit which is distinct from the overall stability of a rubblemound structure, but which is an essential prerequisite for the same, is dependant, interalia, on the interlocking achieved at placement of armours. In order to achieve efficient interlocking, the rock should be sound and the individual units should have sharp edges. Blunt or round edges result in poor interlocking and hence poor stability (lower stability factor K_D), other conditions remaining the same. Rounded stones result in lower porosity and are less efficient in dissipation of wave energy. Lower stability factor necessitates a higher weight in a given situation, which renders the structure costlier. The in-place stability of such units is highly precarious and sensitive to small disturbances. Hence such stones should not be used in rubblemound structures (Photo-8).

Photo 8 : Rounded Stones in Armour Layer of a Seawall

4.7 Weak Pockets

Several weak spots are often present in rubblemound structures, which may be attributable to reasons such as lack of supervision, quarry yielding smaller stones or deliberate attempts to dispose of undersized stones etc. (Photo-9). The failure thus initiated could lead to the failure of the structure as a whole. Concentration of stones much smaller than the required armour should therefore be avoided at any cost, lest the entire structure, however carefully executed, can become functionally ineffective.

Photo 9: Pockets in Armour Layer of a Seawall

4.8 Discontinuities in seawalls

The discontinuities in the seawalls are often forced to meet the needs of certain activities of the coastal population such as beaching of small crafts, providing pedestrian access to beach etc. (Photo-10). It is observed that these discontinuities, when improperly terminated, trigger failures of rubblemound structures, which then progressively render the same functionally ineffective. If the seawall on both sides is abruptly terminated without proper placement of armours resulting in corners, in the event of severe wave attack this is one of the most vulnerable locations along the seawall and could be the first to fail. The area in the lee of the structure would experience considerable inundation. These waters, while flowing back to the beach, would erode considerable in-situ soil which could undermine the stability of seawall on both sides of the opening. Inundation and erosion surrounding the 'fishing gaps' in seawall of Kerala is a serious problem. Where such gaps are unavoidable, proper care should be taken to terminate the seawall, which should be keyed with sufficient returns, if necessary and by providing armours on the leeside to some length along the seawall depending on the expected level and extent of inundation.

Photo 10: Discontinuity of a Seawall

4.9 Armour in Single Layer and / or Pitched

Pell-mell dumping of rubble is ideal in a wave climate from consideration of dissipation of incident energy and wave run-up. However, several constructions in the country have been taken up with revetment type pitching of rubble along the beach instead of normal type of rubblemound structures (Photo-11). In some cases this might have been forced by constraints of resources. Whatever the circumstances under which single layer pitching has been adopted, such structures result in poor dissipation of wave energy due to very low porosity of the top layer and higher wave run-up. This calls for increasing the crest level, which would upset the cost, thereby defeating the economy considerations. Moreover, when single layer of armour is to be used there is no alternative but to lay it in a pitched fashion to avoid secondary layer stones being exposed to the fury of waves. In the event of these armours being dislodged, there is no reserve or cover left to protect the secondary layer. It is therefore, essential to provide the armours in at least two layers. Considerations such as a structure have not been damaged so far are not true indicators of their safety. They might have been saved from damages due to other reasons such as there has been no appreciable wave activity on the seawall and the seawall is located landward. However, a revetment type of construction with a single layer of armour is not recommended in a marine environment. There are instances of revetments failures in large reservoirs attributable to wave action.

Photo 11: Revetment with Single Layer Armour

Moreover, wherever such constructions have been undertaken, a very flat slope (1:6 or flatter) has been provided. Such flat slopes call for large quantities of armour and secondary stones. A pell-mell dumping would result in a void ratio around 45%. Thus, in terms of the quantity of stones required to construct a seawall with two layers of pell-mell dumping (to a steeper slope-1:3 or so) is more or less the same as that required to construct a flat slope (1:6) revetment with a single layer or armours. Thus the economy achieved in such structures is just apparent or marginal if at all achieved. A larger stone is required on a steeper slope than that on a flatter slope (depending on the values of cot α in the formula defining the armour size). As the weight of the armour increases, the unit cost also increases to some extent. Typical cost comparisons in the actual works being carried out in the range of stones being handled in the seawall has, however revealed, that this increase is only marginal. It is therefore recommended to adopt 'two-layer pell-mell' type of rubblemound structures in marine environment.

4.10 Unsound Temporary Measures

When erosion is active, authorities at site are compelled to do 'something' which normally assumes the form of dumping available rubble (Photo-12). Often, such exercises end up in a fiasco. The benefits derived are only apparent and not even temporary. On many occasions, by the time the work commences, the fury of waves subsides and the situation is abated before any work is carried out.

Photo 12: Rubble stones Dumped as Temporary Measure

It is therefore necessary to give due technical consideration before affecting any protective measure, whether permanent or temporary.

There are other reasons why a rubblemound structure could fail. One such fact is the use of a large number of flat stones, which often break into two or more pieces either during initial period or while achieving stable positions under wave action or over a period of time. Finally, the authorities should recognise the need to select the right type of structure for a given situation. A wrong selection is a permanent failure.

5.0 PLANNING OF CONSTRUCTION PROGRAMME

From the bathymetry in the vicinity of the coastal structure and the data regarding littoral drift, the pattern of erosion/accretion can be anticipated. The construction of beach protection structures in such regions should be undertaken at the appropriate time. For example, construction of a seawall along the coast where considerable erosion has been taking place should be started immediately after the monsoon wave action, when the eroded levels are the lowest and wave action is comparatively reduced. In an eroding coastline, if a long length of the coast, say about 500 m, is to be protected with a seawall and it is not possible to construct this seawall in one season [of about 4 months], which is generally the case due to various procedural constraints; then it is best to start construction of the seawall from both ends and proceed towards the centre rather than constructing the seawall from one end only. With such planning, the extent of erosion along the beach and penetration into the beach in the coastline is reduced as compared to the extent and penetration of erosion when the construction of seawall is started from one end only.

6.0 MAINTENANCE OF COASTAL STRUCTURES

The most important aspect is the post construction maintenance of coastal structures. It is a general experience that once these structures are constructed, hardly any maintenance of the structure is undertaken. This is particularly evident in case of structures constructed in remote areas or near small fishing areas etc. It must be remembered that no coastal structure is permanent, since it has to bear the brunt of coastal wave attack, which is random in nature and acts at different locations along the structure due to tidal fluctuations (of water levels). The toe normally suffers initial damage, which leads to subsequent damage to armour, secondary and core stones (Photo-13). Whenever the toe is damaged, the entire structure is endangered. It is, therefore, essential to replenish the damaged toe periodically. Many times, the leeside slope and berms or the crest are gradually damaged due to constant overtopping and same should be repaired. If proper maintenance at regular interval is undertaken, it is possible to prevent these damages and improve the performance of the structure (Photo-14).

Photo 13: Damage to Seawall due to Non-maintenance

7.0 CONCLUDING REMARKS

1) The coastal protection work should be based on the principle of dissipation of the wave energy and not merely protecting the land by constructing rigid vertical walls.

2) A diligent construction is as important as a sound design for the success and stability of rubblemound structures. Conclusions on the success or the stability of rubblemound structures should be based on the performance of the structure when it has really been exposed to design force.

3) Where deviations from design have occurred, the completed structure should be re-examined for its stability and necessary measures be implemented to strengthen and reform the structure to design profiles.

4) Maintenance of the flexible rubblemound seawalls is a must and should be carried out regularly.

Photo 14: Well Maintained Seawall Serves the Purpose

ANNEXURE-1

COASTAL PROTECTION WORKS RECOMMENDED BY CWPRS

MAHARASHTRA

1 Dahanu
2 Satkale-Wattar, Thane
3 Dandi – Thane
4 Pachubandar – Thane
5 Band Strand – Mumbai
6 Chimbai – Mumbai
7 Worli-Koliwada-Mumbai
8 Worli-Seaface-Mumbai
9 Haji Ali – Mumbai
10 Amerson Garden – Mumbai
11 Silver Sand – Mumbai
12 Rajbhavan – Mumbai
13 INS Hamla – Mumbai
14 Marine Drive - Mumbai
15 Free-Press– Mumbai
16 Cuff Parade – Mumbai
17 Children's Park - Mumbai
18 Mandava – Raigad
19 Ranjankhar – Raigad
20 Awas – Raigad
21 ONGC Uran – Raigad
22 Versoli – Raigad
23 Alibag-Koliwada – Raigad
24 Kawalekhar, Pen – Raigad
25 Theronda – Raigad
26 Korlai – Raigad
27 Navedar, Navagaon – Raigad
28 Murud Koliwada – Raigad
29 Harne – Ram Mandir-Ratnagiri
30 Harne –Ratnagiri
31 Harne – Navanagar – Ratnagiri
32 Khed – Sirsi Bhoi – Ratnagiri
33 Khed – Khurd – Ratnagiri
34 Khed – Shiv Khurd – Ratnagiri
35 Borya – Ratnagiri
36 Palshet – Aghadevi – Ratnagiri
37 Guhagar – Khalchapat – Ratnagiri
38 Guhagar – Varchapat – Ratnagiri
39 Guhagar Bag – Ratnagiri
40 Kachare – Ratnagiri
41 Someshwar – Ratnagiri
42 Bhati Mirya – Ratnagiri
43 Bhatkarwada – Ratnagiri
44 Rajiwada Creek – Ratnagiri
45 Jhaki Mirya – Ratnagiri
46 Are-Ware Bridge – Ratnagiri
47 Kajirbhati Bridge – Ratnagiri
48 Maldoli – Chiplun – Ratnagiri
49 Purnagad – Ratnagiri
50 Talashi Tondivali – Sindhudurg
51 Mith Mumbri – Sindhudurg
52 Tambaldeg – Sindhudurg
53 Muthwadi – Sindhudurg
54 Kawlewadi-Jamsande – Sindhudurg
55 Navabag-Ubhadanda – Sindhudurg
56 Tarkarli – Sindhudurg
57 Kelus – Sindhudurg
58 Bhogvey – Sindhudurg
59 Wayangani – Sindhudurg
60 Devbag – Malvan – Sindhudurg

GUJARAT

1 Umargaon
2 Umarsadi – Machiwad
3 Udwada
4 Kolak
5 Kosamba
6 Tithal
7 Moti Danti
8 Borsi-Machiwad
9 Onjal-Machiwad
10 Navsari – Dandi
11 Bhat – Navsari
12 Mendhar – Navsari (Jhuj)
13 Surat – Dandi
14 Mor-Bhagwa – Creek site
15 Dumas – Sultanabad (Surat)
16 Madhi (Bharuch)
17 Anakaleshwar – ONGC
18 INS Dwarka
19 Dwarka
20 Bhavnagar

GOA

1 Kerim
2 Betal Batim
3 Kolva
4 Polem
5 Talpona
6 Baina Bay
7 Kahnanuini
8 Candolim

KARNATAKA

1 Devbag – Karwar
2 Bhavikeri – Ganeshbag
3 Karwar
4 Keni – Gavitwada
5 Gorate
6 Sashishthilu
7 Gangoli
8 Belke
9 Jali Kodi
10 Pavinkurve
11 Maravanthe
12 Paduvari
13 Belambur Khariwada
14 Bada Yeramal

KERALA

1 INS Dronacharya, Kochi
2 Puthuvypeen, Cochin
3 Ezhimala
4 Thiruvananthapuram

TAMILNADU & PONDICHERRY

1 North of Madras
2 Kalpakkam
3 Pondicherry
4 Ennore

ANDHRA PRADESH

1 Ramakrishna Beach, Vizag
2 Uppada
3 Catamaran Beach, Vizag
4 China golapalem

ORISSA

1 Paradip
2 Outer Wheeler Island
3 Chandipur
4 Puri
5 Konark
6 Chilika Lake

WEST BENGAL

1 Shankarpur – New Jalda
2 Boat Khali – Sagar Island
3 Begua Khali - Sagar Island
4 Digha

ANDAMAN & NICOBAR ISLANDS

1 Campbell Bay
2 Mus, Car Nicobar
3 Malacca, Car Nicobar
4 INS Kardip, Kamorta

LAKSHADWEEP ISLANDS

1 Kavaratti
2 Kalpeni
3 Agatti
4 Kadmath
5 Androth
6 Minicoy
7 Amini,
8 Chetlat