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Mid-1997 tidal surge of bay of Bengal at Digha on the East Coast of India: Its damage evaluation and mitigation

A. Acharyya, B. Sengupta, and R. N. Ghosh
Geological Survey of India, Calcutta, India

ABSTRACT

The sea resort of Digha (21° 37' N: 87° 31' E) on the east coast of India runs the risk of natural disasters due to frequent development of atmospheric depressions in the bay of Bengal. A 3.7 km sea-wall (brick/concrete/boulder embankment) was built long back to protect the ENE-WSW coastline of this sea resort from erosion vis-à-vis wave action.

An unusual tidal surge struck the Digha coast on 20 August 1997 causing extensive damage to the seawall, various structures within CRZ-II and natural landscape. The Geological Survey of India (GSI) studied the cause and effect of this natural calamity. A deep depression was formed in the northern Bay of Bengal and the eye of anticlockwise circulation of wind from east to west became incremental with the attainment of minimum atmospheric pressure at the coast. The maximum wind speed was at 8:30 in the morning of 20 August 1997, which was second lunar day next to the full moon, and the highest spring tide was anticipated at 10:00. Besides, this was a period of autumn equinoctial tides when maximum tide raising forces were expected. This highest spring tide coupled with the easterly high velocity wind and prevailing longshore current of the sea towards ENE resulted in abnormal tidal surges for nearly one hour on 20 August 1997 (around 10:00). The sea at Digha otherwise attains an average of highest wave-crest height ranging between 3.5 m and 4.0 m above msl. The plunging breakers were reported to have risen that day to a wave crest height of about 6.4 m above msl and they overtopped the seawall upper level having 5.4 m of average Reference Level. About 378 million litres of seawater spilled over the wall and returned to the sea in just one hour's time by breaking the wall in the weak zones and adjoining structures. Geological parameters, measured in the natural setting of beach-coastline dunes, revealed marked changes in the magnitude of beach dimensions; lowering of beach front dune top by 2.46 m and erosion of the beach surface by 0.65 m constitute the direct fall out of this tidal surge.

The GSI recommended both short- and long-term mitigation measures to minimise effects of such natural disasters. These included, interalia, a design of an ideal seawall with three consecutive foundation piles and one seaside sheet pile; lined drains to ease the surface runoff especially in case of overtopping by surges; provision for landslide filter drain and seaside geotextile apron, and systematic network of sewerage.

As of now, the largely damaged part of the sea-wall has been newly laid by a 28.0 m wide concrete ramp with 2.44 m deep sheet pile in the seaward side. Lined surface drain and impermeable filter drain of clay have been constructed behind the seawall. Raising of vertical height of the sea-wall and laying of sewerage network have also commenced. In addition, the proposal of laying geotextile mat in the unrestored part of the wall is on the anvil.

INTRODUCTION

The western flank of the Bengal delta in Eastern India unveils an interesting coastal stretch on the bay of Bengal characterised by a dynamic interface of beach-tidal flat-shallow marine milieu. This entire coastline of nearly 75 km is punctuated by several tidal creeks intercepting the coast, right from the debouchment mouth of the river Hugli (Ganges) in the east to the estuary of the river Subarnarekha in the west. The coast experiences multifarious interplay of physical processes due to marine-coastal, estuarine, fluvio-tidal, tidal, and aeolian actions.

In the southwestern fringe of the coast, the 7.0 km long the Digha shoreline in particular may be delineated as the coastal stretch between the West Bengal-Orissa state border in the west to the Shankarpur creek (Digha Mohana) in the east. Between this creek and another 7.5 km further east at Jaldah, the stretch of Shankarpur-Chandpur coast exists. The coastal stretch has domains (often narrow) of alternating accretional, erosional, or relatively stable beaches (Fig. 1, 2). Apart from being a picturesque, popular, and affordable resort the coast and the creeks are livelihood for numerous fishermen engaged in the fisheries, which is the primary economic resource of the area.

The Digha beach resort (21° 37' N, 87° 31' E) on this mesotidal coast (tidal range 2.0 m to 4.0 m) is precariously poised within the erosional coastal domain. The already substantially developed area of this resort known as 'Old Digha' falls under Coastal Regulation Zone II (CRZ II, Fig. 2), where ideally construction should not have taken place within 200 m from High Water Line. However, the beach sector 2.0 km west of Old Digha, popularly known as New Digha, is showing accretional/stable phase of coastal growth.

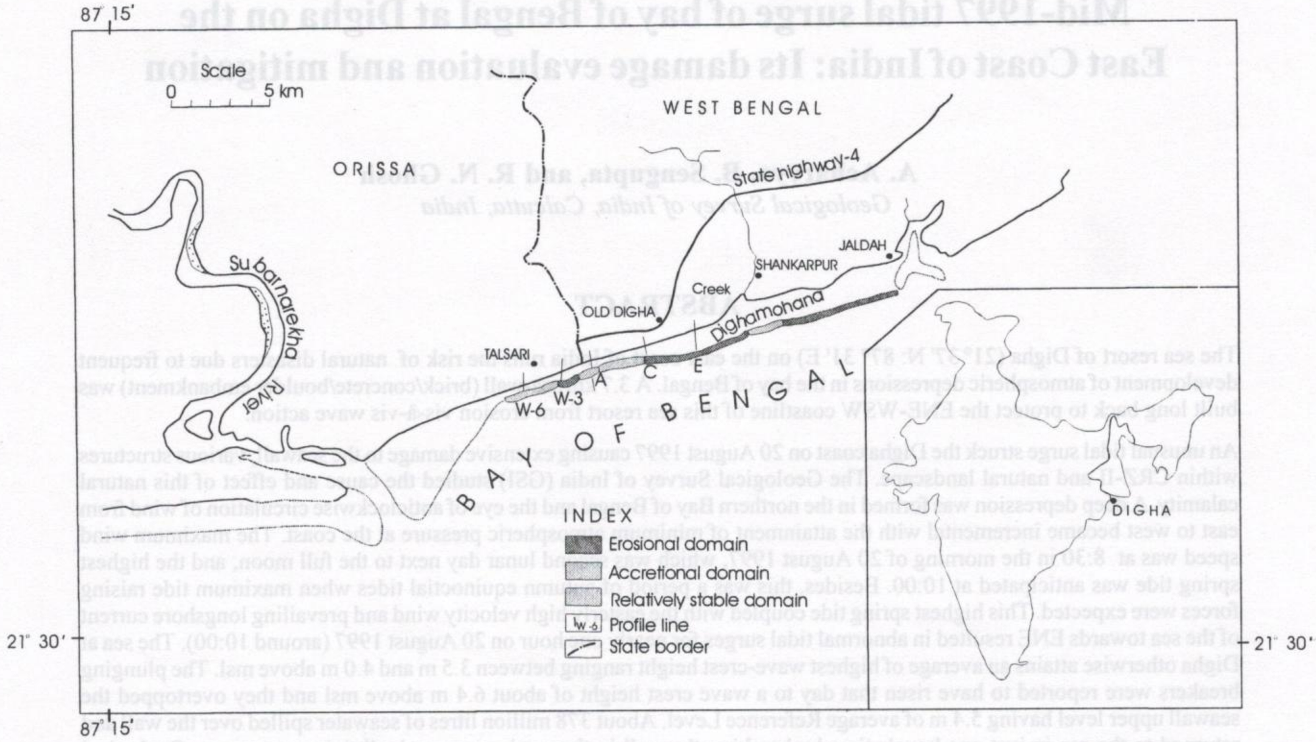


Fig. 1: Location of the Digha coast and position of profiles

Digha has a smooth, flat, essentially sandy beach with a gentle seaward slope (1:47 to 1:79), which is slowly but constantly modified by tidal fluctuations. Incidentally, this part of the country experiences gales and cyclonic storms of various intensities and these storm surges result in drastic changes in dimensions and configurations of the coast. During such calamities, the beach lowering process gets accentuated with a large-scale removal of beach sand. The unusual high waves due to storms can reach right up to the coast. And despite the presence of protective embankment, mitigation of damage of infrastructure from natural disaster becomes an uphill task for authorities.

GEOLOGICAL SETTING

Common to many other sea coasts, Digha too has record of oscillations in sea level resulting in advance and retreat of shoreline during the Quaternary period. These are evident from successive palaeo-strandlines represented by rows of beach/dune ridges (3-12 m in height trending WSW-ENE) from north to south parallel to the present-day shoreline (Fig. 3). The oldest ridge located 12 km north of the present coast, marks the limit of Flandrian transgression. This dune ridge has been assigned 5760 ± 160 years B.P. (^{14}C dating from a peat in adjacent ancient intertidal flat) whereas the middle ridge is as old as 2920 ± 160 years B.P. consequent upon Holocene regression (Chakraborty 1987; Goswami 1997). This entire coast has since been prograded by the accretion of ridges and barriers with intervening intertidal flats/lagoon deposits and the progression continued at least upto 6.0 km south of present coast line where the original Digha village existed (1775 AD). However, last couple of decades record landward advancement of High Water Line (HWL) coupled with beach lowering and subsequent decrease in beach face width. Through this span of time, beach ridges activated by aeolian action got transformed into dune ridges which attainedconsiderable height (9-12 m) at places and these are clearly discernible in aerial photos and imageries.

The geological unit of the recent beach deposits is designated as Recent Digha-Junput coastal deposit (Fig. 3), which encompasses beach, beach front dunes, and adjoining intertidal flats. When geomorphologically classed, this however, comes under active marine-coastal plain.

Beach face, the stretch of beach between the mean high water level (HWL) and mean low water level (LWL), is composed of light grey to yellowish grey sand. The constituent sand falls chiefly under fine to very fine (2.5 f to 3.5 f) grain size and mineralogically composed chiefly of quartz and feldspar with subordinate biotite, ilmenite, pyroxene, amphibole, and zircon. The sand thickness is variable with intervening clay partings, the upper sand layer is nearly 8.0 m at Digha beach whereas it is reduced to 0-3 m at Shankarpur beach. The upper interface between the fresh water and saline water is reported to be at a depth of about 12.0 m at Digha.

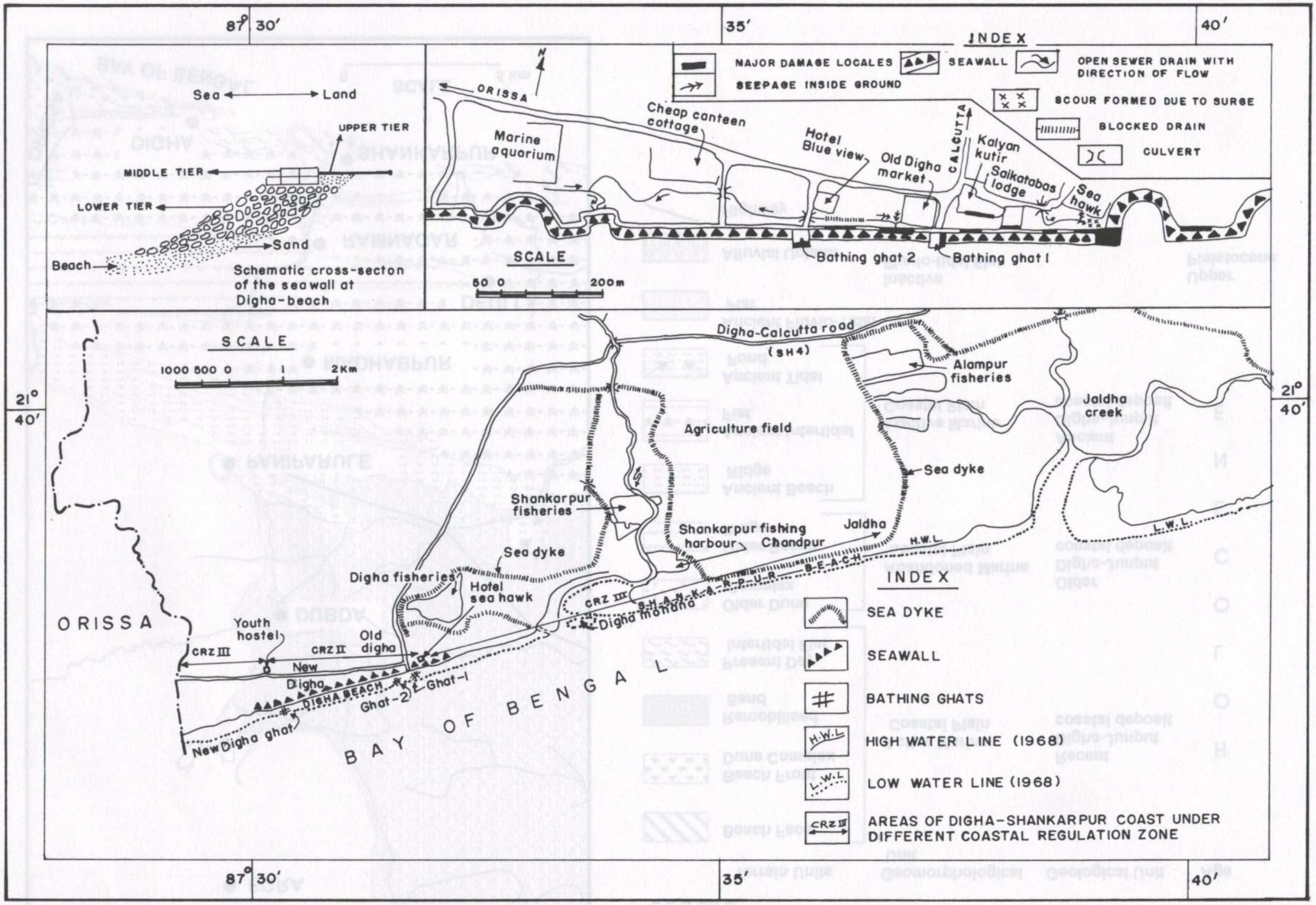


Fig. 2: The Digha-Shankarpur coastal plain prior to the mid-1997 surge

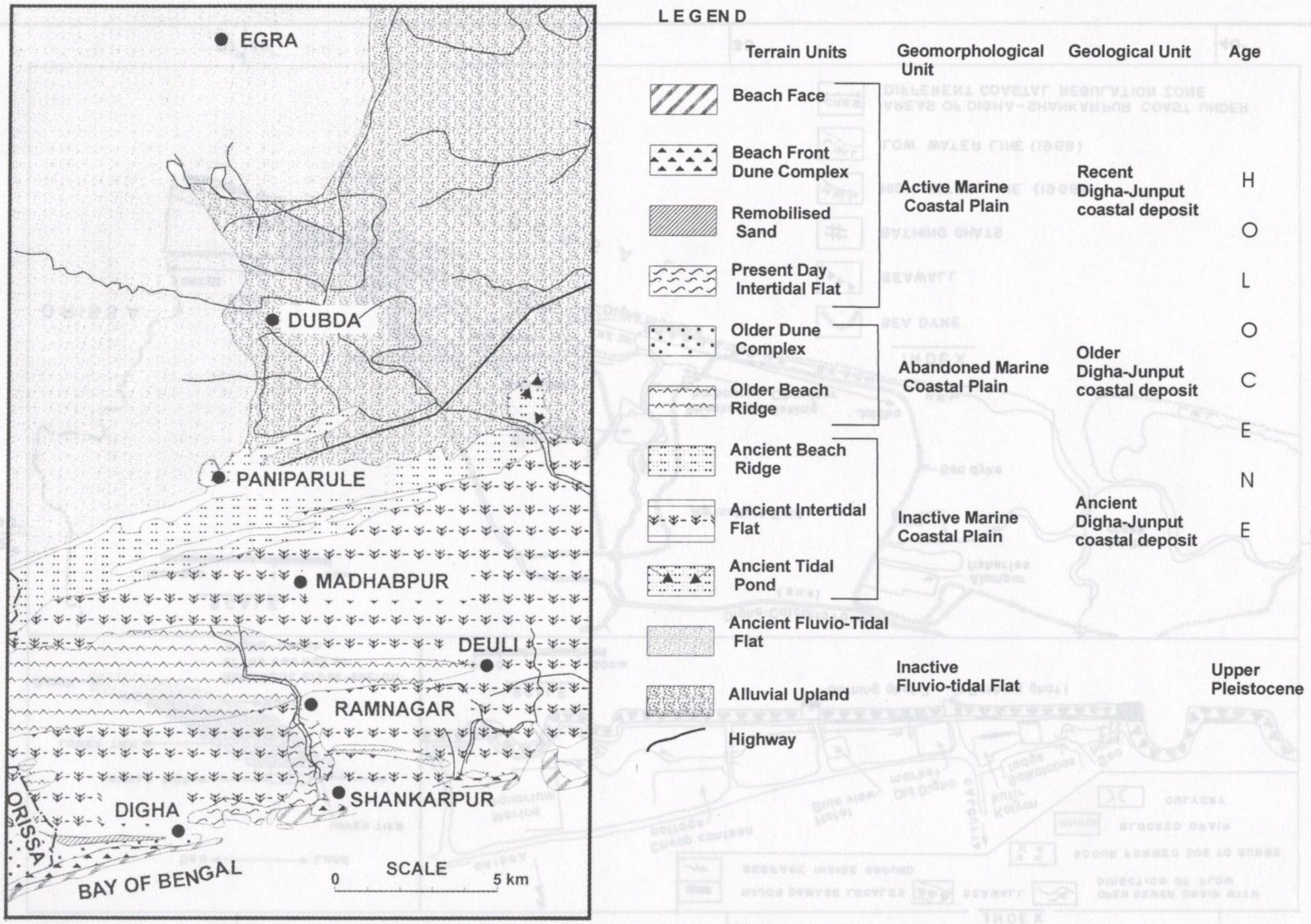


Fig. 3: Quarternary geological map of the Digha coast (after Chakraborty 1987)

COASTAL DOMAIN

The Bay of Bengal at the Digha coast is generally calm with regular plunging to spilling breakers during the hightide. The breakers rarely attain a wave crest height of 4.5 m (from msl). The sea appears turbid in most part of the year. The direction of longshore current is towards ENE, hence, nourishment of sand to the beach is mainly dependent from the Subarnarekha estuary. A reversal in the direction of this current in monsoon season was also argued (Niyogi 1970). An offshore ridge (known as "western brace") SE of the Digha coast, however, thwarts the sediment supply from the Hugli estuary in the east. The wave refraction diagram revealed that the erosion-prone Digha coast is the locale of convergence of wave orthogonals whereas, from accretional domains those are diverging out (Chatterjee and Ghosh 1995).

The beach face at Digha is extremely flat having an angle between 51' and 1°22'. The beach face width at present varies between 130 m and 270 m (1999). The widest beach face gets exposed during the spring tide time in the winter seasons and continuous shortening has been noted over the years (Table 1).

Table 1: Width of beach face in various years

Beach face width	Year
230 - 532 m	1986
210 - 375 m	1994
75 - 325 m	1997
119 - 265 m	1998

This indicates a decrease in maximum exposed beach face by (532-265) m = 267 m between 1986 and 1998 in the Digha sector.

The backshore of the beach (portion between the HWL and beach front dunes) could only be developed in the western part of the Digha beach (in the vicinity of profile-A, Fig. 1) where accretion was recorded with 1.0 m of beach raising between 1986 and 1998 in the upper beach face (landward side of beach face). The HWL has been shifted 60.0 m seawards between 1986 and 1998. Further, the growth of the beach in the form of bar-barrier couplet has been noted farther west, near Talsari (Profile W3/W6, Fig. 1), Orissa.

On the contrary, the HWL is continuously progressing towards the land at the eastern Digha beach without having a seawall (Fig. 2). The landward advancement of the HWL at this area was 56 m between 1986 and 1998. This resulted in a maximum of 1.325 m of beach lowering during that period. During phenomenal storms and even in spring tides, wavefronts with all its energy touch beach front dune faces leading to collapse of the dunes and formation of seaward steep cliff faces. After storm-surge event, the beach face becomes covered by numerous scars as a result of large-scale removal of sand by strong rip channels.

BEACH PROTECTIVE MEASURES AT DIGHA PRIOR TO MID-1997 SURGE

The attempt to protect the near-coast agricultural field from tidal inundation was initiated during 1930's with an earthen embankment (known as "Sea dyke", Fig. 2). This was reconstructed and replaced in the 1960's by a brick wall at some places. This embankment is running in a sinuous fashion in this coastal plain extending from east of old Digha to the mouth of the river Hugli farther east.

The seawall right on the beach was 3.7 km long and 5.4 m high (from msl) embankment, built in the 1970's, along the shoreline extending from 700 m west of the New Digha beach approach road to 400 m east of Hotel Sea Hawk (Fig. 2). This 'seawall' was essentially built to protect the erosion-prone coast from the landward progression of the HWL and to withstand the thrust of wave action.

The lowermost tier of the wall towards sea was the armour of hand packed boulders comprising chiefly of blocks of laterite dumped on the beach face to act as rip-rap. These loose boulders or chunks of rock were not netted with wire-mesh. The boulder-array was overlain by 1.3 m wide two-step horizontal stairs of laterite blocks which acted as the middle tier. A 4.0 m wide *tourist path*way (pavement) landward to that stair constituted the uppermost tier of the seawall (see top-left inset in Fig. 2). The laterite boulders were the original rip-rap material which had suffered severe erosion over the years and became spherical/ellipsoidal in shape. In few places, masonry blocks of granitic rocks were arranged over the old laterite boulders without any apparent engineering design.

There had neither been any systematic underground sewerage network for this resort nor had it planned outlets for surface runoff adjacent to the seawall. The untreated, polluted sewer water was directly disposed to the sea through the wall causing seepage (see top-right inset in Fig. 2; seepage locations are shown by arrow heads). In the reverse, seawater also used to enter below the wall leading to the development of backwater pressure with considerable weakening of the toe portion of the seawall.

In the absence of appropriate measures in the lower tier, scouring of sand from below the wall by waves imperiled the seawall. Removal of sands from beach during or after storm surges was ubiquitous. The setting was fragile and experts predicted imminent danger.

STORM PATTERN AT WEST BENGAL COAST

The coastal zone of the state and the adjoining country (Bangladesh) is susceptible to disasters as a result of the frequent development of Northwesters, squally winds, storms, cyclones and floods. Indirect and rare effects of distant earthquakes, volcanic eruptions, or passage of cyclones over lower latitudes also inflict distress on the coastal belt (Bandyopadhyay 1989). India Meteorological Department has classified the winds and the low pressure systems into the following classes (Table 2).

Table 2: Classification of winds and low pressure systems by India Meteorological Department

S. N.	System	Associated winds
1.	low-pressure	<17 knots [< 30 km/h]
2.	Depression	17 - 27 knots [30 - 48 km/h]
3.	Deep depression	28 - 33 knots [49-59 km/h]
4.	Cyclonic storm	34 - 47 knots [60 - 83 km/h]
5.	Severe cyclonic storm	48 - 63 knots [84 - 111 km/h]
6.	Severe cyclonic storm with a core of Hurricane	> 64 knots [> 112 km/h]

Cyclones formed over Bay of Bengal are more in number than those over Arabian sea and the ratio is about 4:1 (Guha and Bhattacharyya 1989). The pre-requisites for the development of tropical cyclones are warm water surface (at least 26° C, commonly in the belt between Equator and 23° N) of sufficient area to supply the overlying air with large amounts of vapour and consequent strong convection with tangential velocity in the order of 100 ms^{-1}, pronounced instability in the air column or relatively low pressure at the surface or little or no vertical wind shear. Frequency analysis of the occurrences of cyclones during a period of sixty years (between 1891 and 1950) is given in Table 3.

Table 3: Freqency analysis of the cyclones during 1891 and 1950 (Bandopadhyay 1989)

Month	% of occurrence	Month	% of occurrence
January	1.3	July	14.6
February	0	August	10.7
March	1.6	September	12.0
April	4.3	October	16.7
May	6.9	November	14.9
June	10.9	December	6.1

The above table shows that the percentage of maximum occurrence of cyclonic storms was confined between July and November (Bandyopadhyay 1989).

The historical records of cyclonic storms show that one of the most catastrophic cyclones hit near Calcutta was on 7 October 1737, causing a 12.0 m storm surge and killing about 300,000 people. A 12 m storm surge killed some 50,000 people and 100,000 livestock near Contai (30 km northeast of Digha) in 1864. The cyclone of 1942 took 40,000 human lives and several thousands in 1960 as well as in November 1970. Another severe cyclone in the last decade was on 29 November 1988, that struck the West Bengal coast and the Sunderbans on the delta, with a very high wind velocity accompanied by tidal waves, rising 7-8 m in height (Bandyopadhyay 1989).

Though medium intensity storms are not rare in the Digha coast in particular, yet phenomenal storms are cyclic at an interval of one to four years. The storms are sometimes local in the sense that these are developed in the upper Bay of Bengal within 500 km off shoreline. During storm surges, seawater level is temporarily raised and much larger and stronger waves than normal travel on this nearly flat nearshore and foreshore region of Digha with dissipation of huge energy on the coastline. Thus, severe erosion is a consequence of the surges and the phenomenal storm in September 1965 resulted in the lowering of 30-50 cm of Digha beach (Niyogi 1970). However, water overtopping the seawall happened to be a common incidence at Digha during or prior to autumn equinoctial tides. The general direction of Bay of Bengal storms and cyclones in the months of August-September is shown in Fig. 4 (after Bandyopadhyay 1989).

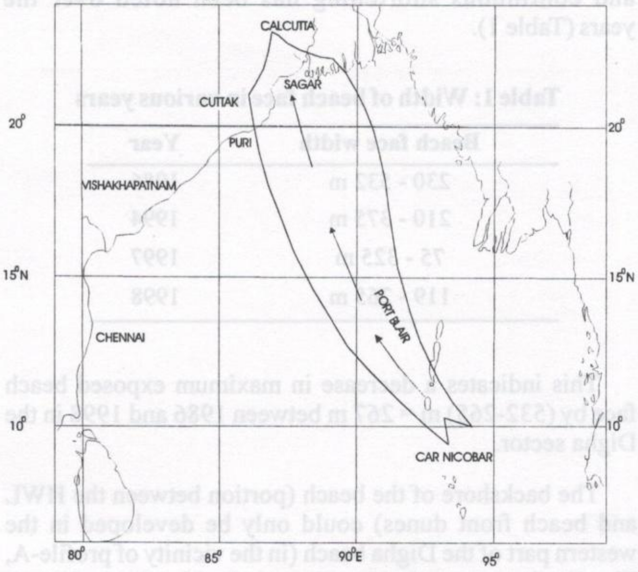


Fig. 4: General direction of Bay of Bengal storms and cyclones in August-September (after Bandyopadhyay 1989)

MID-1997 TIDAL SURGE

After an interval of a few years, the unusual tidal surge again struck Digha on 20 August 1997. There was warning for depression but the resultant of several physical factors produced devastations beyond apprehension.

The track record of this August 1997 depression on Bay of Bengal revealed that it was first observed as a cyclonic circulation over northwest bay and neighbourhood on 16 August 1997. Under the influence, a marked low pressure area was formed over adjoining parts of north Orissa - West Bengal coast on 17 August and became prominent on 18 August, over the same region. The system concentrated into a depression, probably deep depression, near 20.5° N/ 87.5° E, about 80 km ESE of Chandbali (122 km SW of Digha) on 20 August (Fig. 5). The estimated maximum wind speed was 65 km/hr. The atmospheric pressure at Digha proper during that period attained a minimum of 993.9 millibar at msl at 17:30 of 19 August (against the normal of 1013.6 millibar at 25°C = 76 mm of Hg = 1 atmospheric pressure) with a wind speed of 10 km/hr easterly. With the attainment of minimum atmospheric pressure at the coast, the wind speed became incremental and on 20 August at 8:30 wind speed became maximum from the east to the tune of 50 kmph or more (the instrument installed by the Meteorological Department at Digha is not capable of registering more than 24 km/hr). The high wind speed of about 50 km/hr is evidenced by the uprooting of casuarina trees, street light posts, concrete sits, etc. The easterly wind was a consequence of the depression due to anticlockwise circulation of wind (the 'eye') from east to west and this always happened to incur danger to the Digha coast.

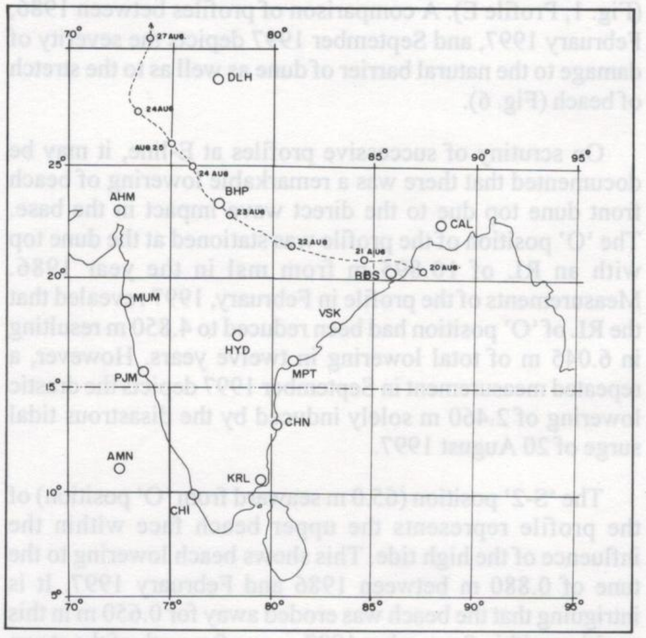


Fig. 5: Track of the depression of August 1997

Incidentally, 20 August was the second lunar day next to full moon and highest spring tide in that morning was expected around 10:00 (calibrated after CPT 1997). Besides, this was a period of autumn near-equinoctial tides when the highest tides were anticipated. This highest spring tide coupled with the easterly high speed storm wind and prevailing ENE flowing longshore current of the sea resulted in abnormal tidal surges which lashed the Digha coast for nearly one hour.

The sea at Digha otherwise attains an average of highest wave crest height ranging between 3.5 m and 4.0 m above msl. The wave breakers reported to have risen that day to a wave crest height of about 6.4 m above msl and overtopped the seawall having average reference level (RL) of 5.4 m at the upper level.

The wind speed at Digha reduced to 12 km/h easterly by the evening of 20 August at 20:30 and the depression moving in WNW direction, crossed the north Orissa coast between Paradwip (170 km SSW of Digha) and Chandbali in the same afternoon. It lay over Orissa (21.0°N / 84.5° E; about 180 km northwest of Bhubaneswar in the inland) on 21and over east Madhya Pradesh on 22 August. The rainfall recorded at Digha was 26.8 mm between 19 and 20 and was 108.6 mm between 21 and 22 August.

Seawater in enormous volume spilled over the seawall and returned to the sea by breaking the wall at weak zones. An estimate of spillover water that impounded for a stretch of 1 km of extremely damaged portion of the seawall may be attempted as below:

(i)	The line length of most damaged part of seawall	= 1000 m;
(ii)	The height of water column (over the seawall) that impounded	= (6.4 - 5.4) m = 1.0 m;
(iii)	Approximate average surf width for plunging surges	= 1.0 m;
(iv)	If the volume of water be considered a parallelepiped with 1000 x 1 x 1 cubic m then the volume of water that overtopped in a single pulse of the surge (assuming an unbroken plunge axis of 1000 m).	= 1000 cubic m;
(v)	Duration of the tidal surge	= 1 hour = 3600 seconds;
(vi)	Average wave period in normal time	= 19 seconds;
(vii)	Hence, average number of pulses that struck the coast in one hour	= 3600 ÷ 19 = 189;
(viii)	Hence, the approximate total volume of water that impounded during that one hour	= 189 x 1000 cu m = 189 x 10^3 x 10^3 1 = 189 million 1; and
(ix)	Assuming a realistic wave period of 9.5 sec during storms, total volume of impounded seawater would be 2 x (viii).	= 378 million l.

The destruction of the seawall and adjoining structures were primarily due to the backthrust of this enormous volume of water.

DAMAGE TO INFRASTRUCTURE

The major damage was observed in the seawall from its easternmost extremity to bathing *ghat* (ramp) no. 2 in the west (see top-right inset in Fig. 2). There was no major damage of the seawall west of bathing *ghat* 2 except local tilting/displacement of middle tier and dismemberment of the setting of laterite boulders in the lowermost tier.

There was an extensive damage in all the tiers in the stretch between bathing *ghat* no. 1 and 2, south of the old Digha market. Large portions of middle tier were found to be tilted towards the seaside with omnipresent rupture and dislodgment. There was an open narrow drainage channel south of "Cheap Canteen Cottage". Trailing westward, that joined the main drain SE of Marine Aquarium. However, the drain was completely blocked (shown as barbed line, Fig. 2, inset, top right) south of Hotel Blue View and major damage occurred in the nearest vicinity.

Towards the immediate east of bathing *ghat* no.1, the sloping concrete ramp was partially destroyed. On examination, huge chunks of lower part were found accumulated in the upper level. Such was the might of the sea waves that the broken angular fragments of ramp and laterite boulders were tossed upward by the surging waves. Bathing *ghat* no. 1 itself was also ruptured, faulted, and displaced.

The seawall rip-rap design became absolutely haphazard and downfall of middle tier for a vertical height of 0.9 m to 2.0 m was noted. The children's park and wall of Kalyankutir, a lodge, were also badly damaged. The tourists' pavement was caved-in along most part of the wall.

The maximum damage occurred at the southeast corner of Hotel Sea Hawk. The boundary wall of the hotel collapsed due to incoming slash of surging waves. All the tiers of the seawall were totally breached away at this corner and after the storm episode there was no existence of any pre-existing wall. Portions of nearby shops were washed away. A 50 m long, 10 m wide, and 0.7 m deep scour was formed following an open drain through which spillover water with huge thrust could find an outlet causing that severe damage.

The spillover seawater entered the basement and ground floor of hotels right on the coast. The kiosks adjacent to the upper tier of the seawall were uprooted. The streetlight posts along the beach were fallen down and tilted. The casuarina plantation by the social forestry was damaged and the laterite boulders completely lost the array all along the seawall.

It was conspicuous that the severity of damage in the seawall was in fact due to the back-slash of seawater which spilled over the upper tier. Furthermore, continuous seepage from the drain at SW corner of Old Digha market and near hotel Sea Hawk had already sufficiently weakened and subsided the wall. During seaward return, in the absence of any surface drain/channel, a tremendous thrust was developed which resulted in the total devastation. This was again evidenced by tilting of tiers/concrete seats towards the south.

The "Seadyke" right at the Shankarpur beach (Fig. 2) was buried under beach front dunes for last couple of years. That became exposed for a length of 312 m due to this tidal surge. Dune cover over the brick wall was removed and the wall collapsed and displaced. The supporting underground column of the brick wall had markedly risen above the beach surface.

The temporary settlements / hutments of Digha Fisheries near *Digha Mohana* (Fig. 2) were damaged, but there was no reported loss of life in view of precautionary measures taken by the local administration.

DAMAGE TO THE NATURAL LANDSCAPE

The impact of the tidal surge on the beach and beach front dunes (where there was no seawall) aligned in the coastal strip between eastern extremity of seawall and *Digha Mohana* resulted in maximum havoc of the natural setting. The damage had presumably accelerated in the nearest locus of engineering structure.

The impact could be actually measured in one of the Geological Survey of India's ground monitoring stations (Fig. 1, Profile E). A comparison of profiles between 1986, February 1997, and September 1997 depicts the severity of damage to the natural barrier of dune as well as to the stretch of beach (Fig. 6).

On scrutiny of successive profiles at E-line, it may be documented that there was a remarkable lowering of beach front dune top due to the direct wave impact in the base. The 'O' position of the profile was stationed at the dune top with an RL of 10.895 m from msl in the year 1986. Measurements of the profile in February, 1997 revealed that the RL of 'O' position had been reduced to 4.850 m resulting in 6.045 m of total lowering in twelve years. However, a repeated measurement in September 1997 depicts the drastic lowering of 2.460 m solely induced by the disastrous tidal surge of 20 August 1997.

The 'S-2' position (65.0 m seaward from 'O' position) of the profile represents the upper beach face within the influence of the high tide. This shows beach lowering to the tune of 0.880 m between 1986 and February 1997. It is intriguing that the beach was eroded away for 0.650 m in this position within September 1997 as an aftermath of the storm event.

Now for quantifying lateral of dune face, maximum strip of dune cover in the lower slope of sea-facing side may be considered. This amounts to nearly 10.0 m of dune face removal as a result of the tidal surge. However, the dune face retreat was more or less gradual in the preceding years when nearly 12.0 m of thickness of sand from widest part of the dune face had been washed away.

Both high water and low water lines have been advancing towards land over the years. The HWL shifted 49.0 m landward between 1986 and September 1997. As a result, the beach face width of 275.0 m in 1986 has been reduced to 165.0 m in September 1997.

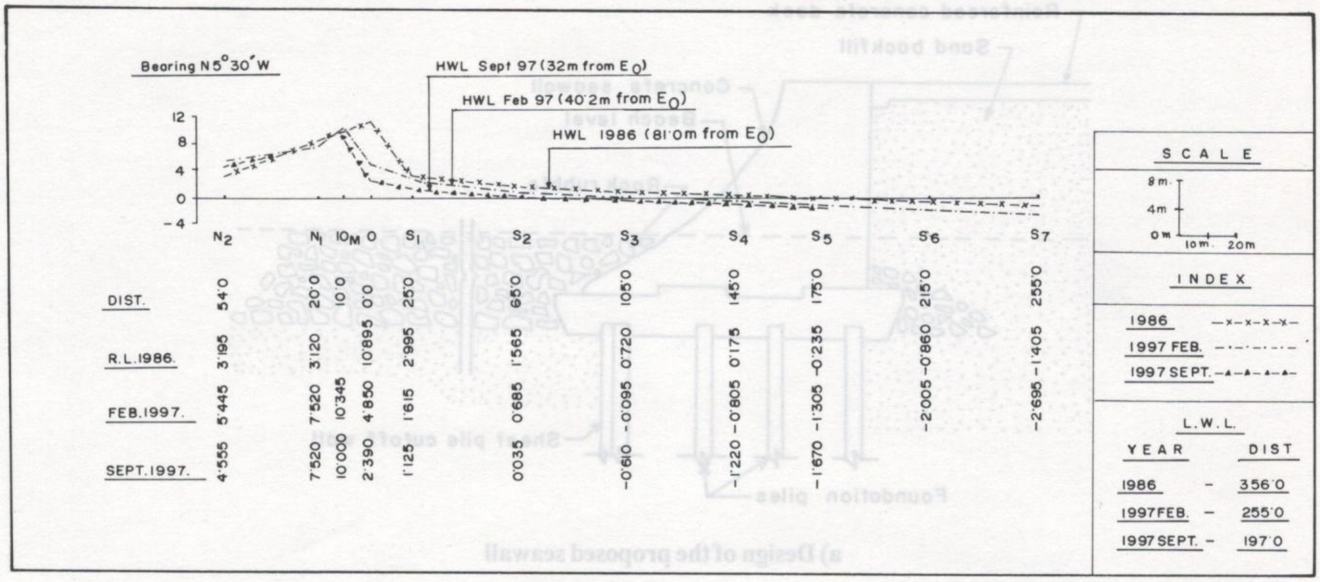


Fig. 6: Comparision of beach profiles at station E, Digha

In another ground monitoring station of GSI at Old Digha (Profile 'C', Fig. 1) where there was a protective seawall, erosion was not rampant. Coinciding profiles were usually stable with only 0.095 m lowering of upper beach face between 1986 and February 1997. However, the August 1997 tidal surge itself resulted in 0.355 m of beach lowering in the same place.

The indications of huge retreat of beach front dunes at the Shankarpur beach was also noteworthy from the aerial exposure of previously buried 'seadyke'. Moreover, clay windows got exposed on the Shankarpur-Chandpur beach face as a consequence of sand erosion. These lines of evidence indicate that the storm events induce sudden large-scale changes in the beach dimensions.

MITIGATION MEASURES SUGGESTED BY GSI

On investigating the cause and effect of the natural disaster, GSI recommended both short-term and long-term mitigation measures (Bhattacharjee et al. 1997). The recommendation contained, interalia, some positive imperious measures within the existing framework and a few suggestions for feasibility studies in the future.

(i) A design of an actualistic protective seawall instead of the preexisting retaining wall was suggested (Fig. 7A). The wall was shown to be a concrete ramp with three consecutive foundation piles and one seaside sheet pile. The sheet pile acts as a toe and should be a continuous one which prevents seawater to percolate beneath the wall. A layer of rock rubble at the lower end was suggested to withstand the energy of wave attack.

(ii) The GSI report underlined the urgency of systematic network of drainage to ease the surface runoff. This was felt essential for quick passage of encroaching seawater in the event of overtopping the seawall during tidal surges.

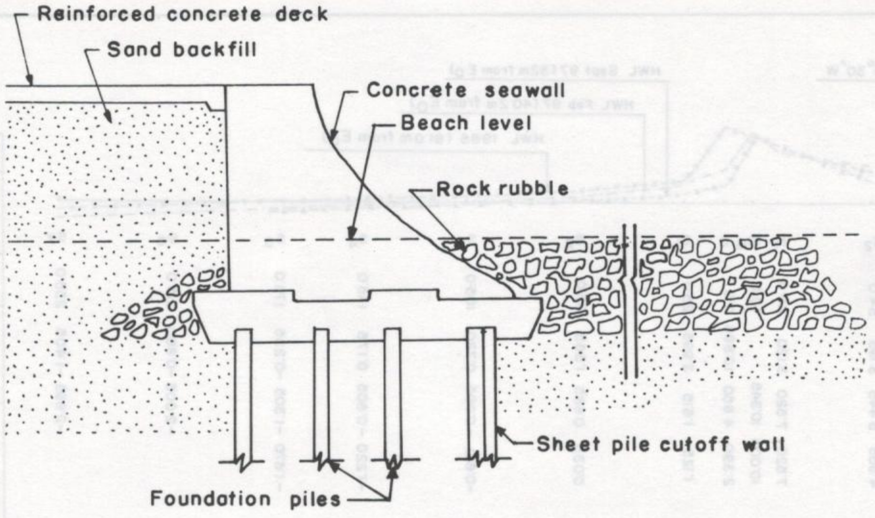
(iii) A provision for land-side filter drain to prevent seepage of water from behind the wall and seaside geotextile mat to entrap beach sands was also suggested. Geotextile would facilitate auto-replenishment by allowing only seawater to percolate, whereas the sediments, whatsoever, get sieved.

(iv) An underground sewerage system was urgently needed. This was to be planned in a manner keeping in view regional relief and contour, distribution in the dune-interdunal flats. The practice of discharging sewer water right through the seawall was to be prevented forthwith.

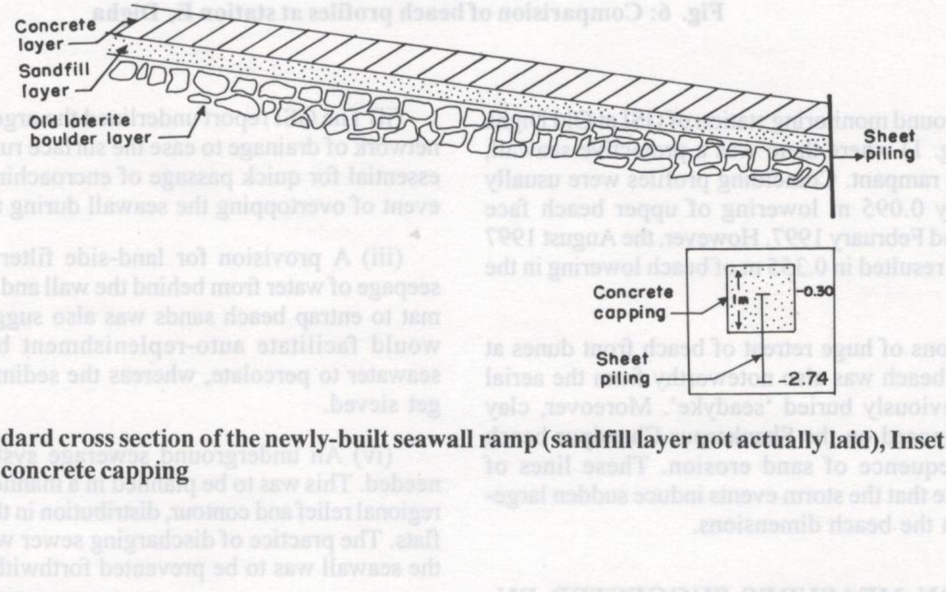
(v) In the already substantially developed area of old Digha a 50.0 m of buffer zone from the seawall/HWL towards the land to be created and should be treated as Primary Protective Zone. This zone can only be used for afforestation and effort for precipitating dunes can be attempted.

(vi) All existing beach front dunes, being the natural barrier should be protected. Erosion should be controlled by planting sand-loving creepers like *Ipomea biloba.* Erection of palisade fencing, especially near back shore, can also initiate accumulation of sand, which may contribute to dune formation. Removal of dune sands for construction purposes must be prevented.

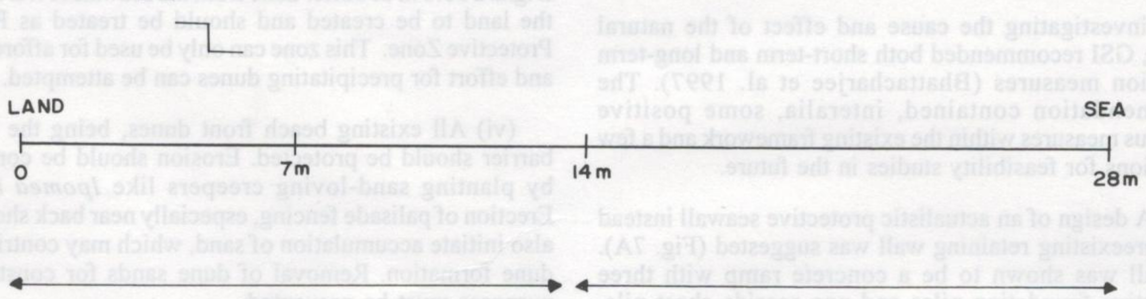
(vii) Feasibility of extending the seawall up to *Digha Mohana* was to be studied. This was needed to protect the dune ridge and for providing immediate relief to the landward



a) Design of the proposed seawall



b) Schematic standard cross section of the newly-built seawall ramp (sandfill layer not actually laid), Inset: blow-up of the sheet pilling with concrete capping



c) Schematic sectional width of the newly-built seawall ramp

Fig. 7: Mitigation measures suggested and executed at the Digha coast

establishments (Digha fisheries/village/agricultural field) from impingement of high sea wave.

(viii) Construction of groyne systems perpendicular to the shoreline to trap sediments for beach nourishment could also be effective. The en-échelon pattern of the groynes would help obstruct littoral drift which might alter erosional regime into a stable one.

(ix) Reduction of wave energy by dumping concrete hexapod/tetrapod at a distance towards offshore was also suggested. Even breakwaters or detached spurs of laterite at a distance from coastline may be so aligned to absorb wave impact as well as to deflect the rip channel/littoral drift sediments towards the shore.

(x) Raising of vertical height of seawall was recommended to impede water spillover at unusual tides.

(xi) The anthropogenic and fishing activity right on the beach, a continuous practice at Digha, was suggested to be monitored regularly. Otherwise, It may severely disturb natural sediment stability and may accelerate erosion.

CORRECTIVE MITIGATION MEASURES AFTER TWO YEARS

1. As of now, the damaged seawall has been redone by the Government of West Bengal. A 28.0 m wide concrete ramp for 1 km has come up in the beach front over the pre-existing laterite boulders (Fig. 7B). It has a continuous sheet pile for a depth of 2.44 m (bottom RL 2.74 m) at the seaward margin of the ramp. This sheet pile has a concrete capping of 0.6 m width and 1.0 m depth. In the 28.0 m sectional width of ramp, first 14.0 m is having a slope of 1:4 and rest with a slope of 1:10.76. In the first 7.0 m from the pavement (previous upper tier), a few wave breakers have been built (Fig. 7C). The concrete ramp has been built as separate square blocks of 2.0 x 2.0 m^2 size. However, there is no foundation pile below the ramp.

2. The work for lined surface drain has also been completed. It has two components. First, along a lined trench adjacent to *tourists' pathway* a 2.0 m deep clay parting as filter has been artificially laid. This is expected to minimise the seepage from landward side. Secondly, the actual linear surface drain of about 5 m landward from that clay parting has been built parallel to the shore line with one opening near Hotel Sea Hawk at SE corner and another near Marine Aquarium. This has been found to be very effective for easy passage of surface runoff, even during the influx of seawater.

3. Underground sewerage network is being laid in the Digha town.

4. Raising of vertical height of seawall up to 6.40 m from msl has nearly been completed.

5. There is also a proposal for laying geotextile mat overlain by boulder pitching in the unrestored stretch of seawall from bathing *ghat* no. 2 to Marine Aquarium in the west.

CONCLUSIONS

The Coastal Zone Management Plan for Digha has been prepared by GSI and coastal regulation zones (CRZ) have been delineated. Strict imposition of CRZ measures are to be adhered to protect Digha from any future devastation, loss of property and life in the event of yet stronger tidal surges, or neotectonic activity in the offshore.

Future planning for the development of the resort ought to be judiciously carried out. The nature, the sea, the tide, and the wind need to be given a chance to play within an adequate natural space. The planners and commoners must have a consensus on the sustainable development of the coast without jeopardising the inevitable natural system.

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