

Evaluation of the Geomorphic Character and Hydraulic Stability of the Shrivardhan Inlet, Konkan Coast, Maharashtra

Subhamita Chaudhuri

Abstract

The stability of coastal inlets is a complex parameter to be determined. It depends on several factors like the wave climate, the direction and amount of littoral drift, the relative power of flood and ebb currents, the flow condition and hydraulic geometry of the inlet, the fresh water inflow into the inlet and the bay geometry. None of these factors are constant. Apart from these factors, a single event of severe storm can disturb the balance among the above-mentioned factors and lead to the closure of the inlet mouth. The Shrivardhan inlet is one of poor stability and though the inlet has so far maintained its cross sectional area there is high probability of its closure. The stability criteria have been determined following the methods proposed by Mehta (1975), Keulegan (1967) and Escoffier (1940).

Introduction

The general straightness of the sandy coasts is interrupted by the presence of inlet mouths. These inlets may be the mouths of streams, which are falling to the sea through an estuary, or they may be of purely tidal origin, with no direct connection with the terrestrial sources of water. However, in both cases, the effect of tide is considerable. The distance up to which the tidal effect penetrates varies from inlet to inlet, depending upon the tidal range and the slope of the inlet. It has been rightly stated that the inlets are in a condition of dynamic equilibrium with the changing flow, drift and wave conditions. However, the equilibrium gets disturbed when any one of the variables change in such a way that the other variables fail to cope up with the change after a particular threshold value (Brunn and Gerritson, 1960). It has been observed in various parts of the world that the inlet mouths tend to shift; mostly in direction of the long shore drift (Bruun and Gerritsen, 1960).

Not only do the inlets shift in their relative location, they are also susceptible to become choked. The littoral drift brings material, which may be pushed inside the inlet during flood tide

and again flushed out with the ebb current. The material flushed out by the ebb current may be pushed, so far into the sea that they may be eventually lost, but sometimes the flushing mechanism is not so effective and the material remains partly inside the inlet and partly moved towards the inlet mouth, only to get re-distributed with the next incoming tide or lead to the formation of an ebb tidal delta at its mouth. Material settling inside the inlet itself may form a shoal.

Such shoaling may ultimately lead to shallowing of the inlet bed and probable bifurcation of the flow. Repetition of the process can eventually choke the inlet.

Inlets can also experience closure by natural 'bar by-passing' i.e. prolongation of a bar in the down drift direction to by pass the inlet mouth leading to its closure.

Objective

Many of these coastal inlets are favorable sites for construction of jetties and sometimes these inlets act as natural conduit through which the adjoining bay maintains its connection to the sea. In an inlet bay system where the supply of fresh water to the bay is negligible, the flow through

the inlet is the only flushing mechanism by which the bay maintains itself. If on any circumstance the inlet gets choked then it will render the bay isolated from the sea and will eventually lead to reclamation of the bay; if the same trend of events continue. Hence, it is important to study the geomorphology and hydraulics of the inlet in order to assess its stability i.e. to know if the inlet is susceptible to get closed or not.

Previous Study

A number of investigators like Bruun and Gerritsen(1960), O'Brien (1969), Escoffier (1940), Keulegan (1967) and Mehta (1975) have dealt with the stability criteria of coastal inlets. Some of the investigators studied the relationship among various geometric parameters of the inlet, such as cross sectional area, channel length, maximum depth, ebb delta area etc. Many have established statistical correlation among these parameters. Some of these stability studies tried to establish a relation between throat cross-section and tidal prism. While Mehta developed his stability criteria on the basis of the relation between long shore wave power and the flushing and scouring capacity of the inlet, based on the inlet cross sectional area, the current velocity and tidal prism, Escoffier was of the opinion that a plot of velocity versus cross section area can give good idea about the stability of the inlet.

Study area

The Shrivardhan Bay, together with the bay catchment area lies between 18°0'N to 18°5'N and 73°0'E to 73°7'E. Excluding the catchment, the bay itself covers only about 7.53 Sq. Kms. North of this area there are a few more areas like Nandgaon, Murud, Diveagar, Valvati etc. which appear as reclaimed bays. Most of these areas now appear as straight stretches of sandy beach, existing between rocky headlands. The straightness is broken at the entrance of coastal inlets. The shape of the 20m contour gives the impression of bay like depressions, which may have once existed, in these locations.

The Shrivardhan Bay, though partially silted up has not yet been fully reclaimed. But from frequent field visits it appears that the process of siltation is ongoing. The bay has very few small seasonal streams which drain into it, and the contribution from these streams plays a negligible role in maintaining the capacity of the bay. The main source of water and sediment coming in to the bay is the sea. The flood and ebb tide has managed to maintain the bay via one tidal inlet, which connects the bay to the sea. As such, the bay acts as a classic example of an inlet-bay system.

Before going into the discussion about the geomorphic and hydraulic character of the inlet, it is necessary to have some idea about its physical setting. The bay, as seen in the figure (Fig. 1) is of roughly circular shape with a very prominent bay mouth bar developed at the entrance.

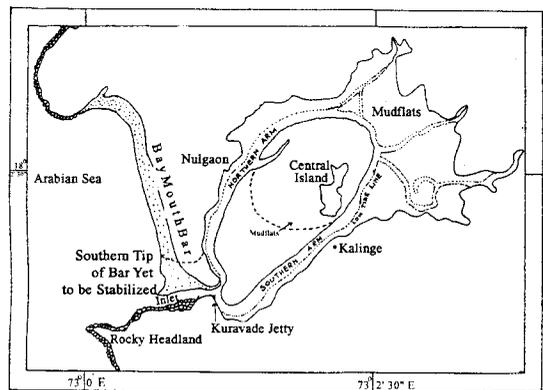


Fig. 1: Physical Setting of the Shrivardhan Inlet-Bay System

The bar extends in a north-south direction for about 4 Kms. The Southern margin of the bay is backed by rocky headland and the main inlet is seen in between the Southern tip of the bar and the rocky headland. This so called bar can well be termed as a 'spit' since it has not blocked the mouth of the inlet totally. The southern tip of the bar is yet to get stabilized. This portion of the bar gets fully exposed only during the time of low tide. The central portion of the bay is occupied by extensive development of mudflats, which has now attained the dimension of an island. The presence of the island

restricts the water inside the bay into two narrow arms – the northern arm and the southern arm.

The length of the Shrivardhan inlet from the mouth to its junction with the bay is almost 888m. The average width of the inlet channel is 200m below mean low water level. The Kuravde jetty is located on the Southern bank of the inlet adjoining the rocky platform. The jetty almost marks the point after which the inlet opens out into the bay. However, the jetty is not under operation since the last decade. According to local fishermen, Kuravde jetty has become inactive because the depth of water near the throat of the inlet has become so shallow that except during high tide the boats cannot go out or enter the bay. These problems faced by the local people makes one think about the stability condition of the inlet.

The Geomorphic and Hydraulic conditions of the inlet

Prior to the discussion about the geomorphic and hydraulic character of the inlet it would be justifiable to give some idea about the nature of flow of water during flood and ebb tide. Tidal monitoring was carried out at the Kuravde jetty on 3rd November 2001. The tide is semi diurnal in nature. It was observed that on the same day the tidal range in the open sea was 3.2m while at the jetty the range was only up to 2.0m. Moreover, as the flood tide started coming in, it was observed that the water remained confined within the inlet boundary up to a level of 2.05m above the chart datum; after which the water spills over to the adjoining bar and the incoming water loses its nature as a channelised flow. The water then moves into the bay as a continuous sheet of water. Nearing the time of high tide the effect of waves can be felt at the Kuravde jetty. However, while withdrawing, the major ebb current is diverted through the Shrivardhan inlet and the movement of water once again attains the character of channelised flow. Once the water goes below 0.2m above chart datum the

water does not withdraw any further and the volume of water below this may be considered as 'dead storage'.

The long and cross profiles of the Shrivardhan inlet has been drawn from the sounding chart prepared by the Maharashtra State Hydrographers' Office, Mumbai. Though the depth conditions shown in the map are that of 1965, but still it has been used for the present study because of two basic reasons. Firstly, due to lack of proper instrumentation it was difficult to estimate the exact depths. Attempts were made to estimate the depth with plumb, dropped from small country boat. But it was difficult to locate the exact points of which the depth was measured. Moreover, the boat drifted with current hence exact vertical measurement could not be taken and water level was constantly changing with the passage of time.

Secondly from the frequent visits to the area, the trend of the long profile as seen from the sounding chart matched with the previous experience of depth measurement. Again from the Geomorphological perspective it may be assumed that, within a span of 30-35 years the depth conditions and the details of the bottom topography may have altered but the basic slope of the long profile is not likely to get drastically changed. Hence, observations regarding the flow condition in the inlet from this sounding chart may be of considerable value (Fig. 2).

Six cross sections have been drawn along the inlet (Table-1), starting from Kuravde jetty and extending to 888m towards the sea. From the sections it can be seen that the thalweg line shows a tendency to shift towards the rocky platform to the south. In the first three sections the thalweg is almost midway between the platform to the south and the bar to the north. From the 4th section onward i.e. beyond 440m from the jetty the thalweg line had visibly shifted towards the platform. The maximum depth attained in these sections is hardly 4m, as compared to a maximum 6.7m in the 2nd section. This continuous shift of the thalweg towards the platform

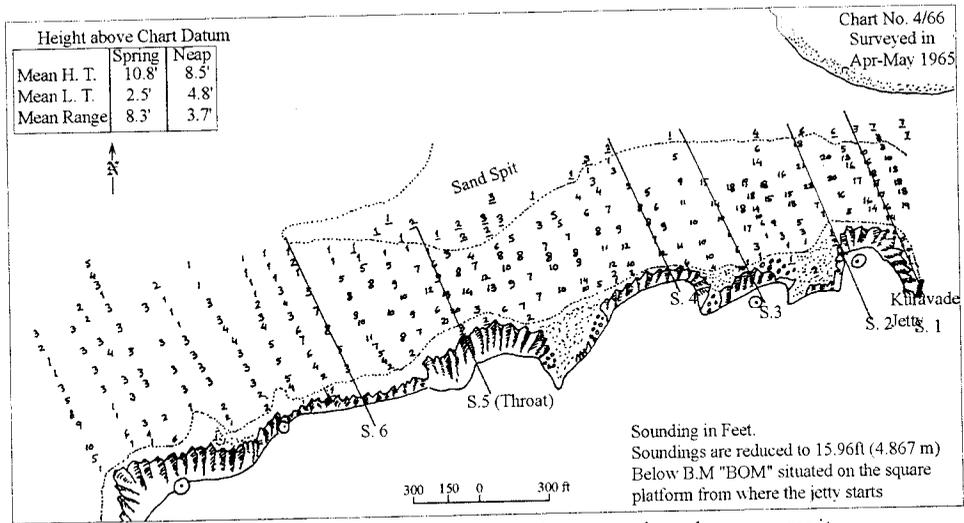
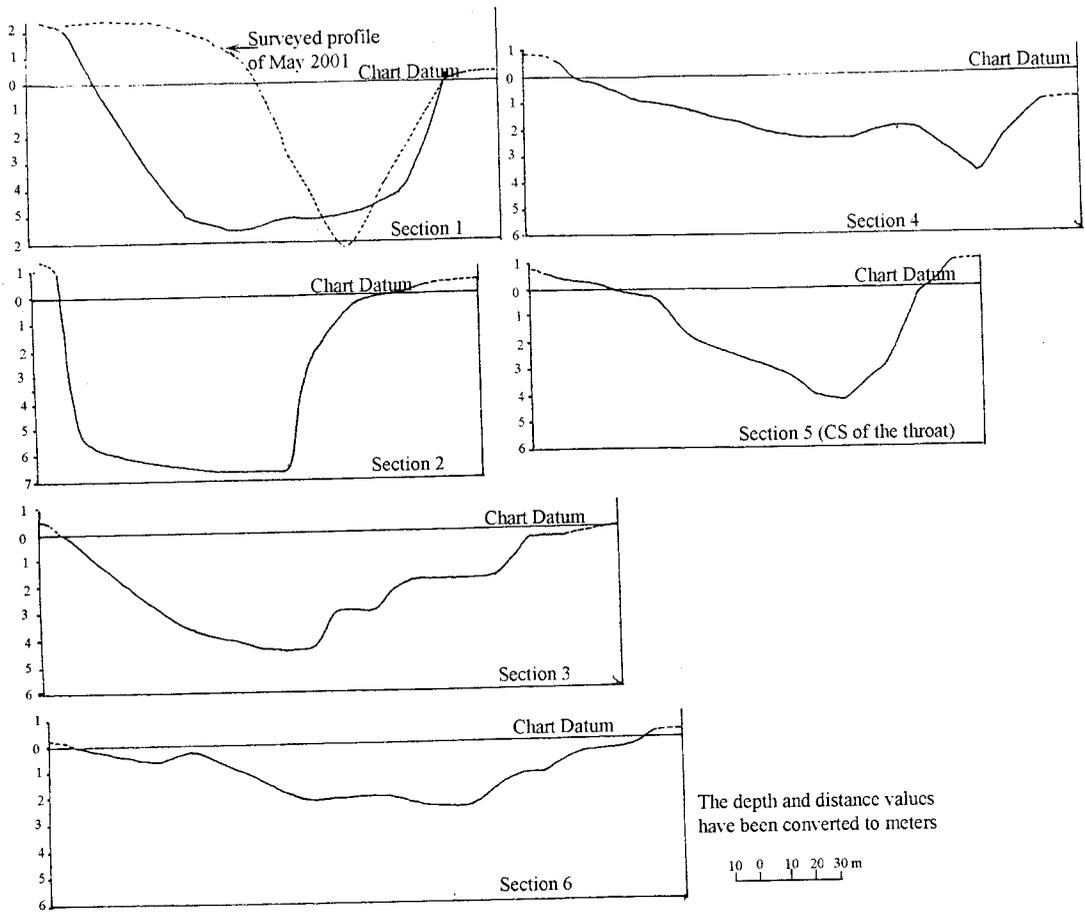


Fig. 2: Sounding chart of Shrivardhan inlet and cross sections drawn across it

Table 1:

Location	P in ft ³	Ac in ft ²	Wp in ft.	Rc in ft.	Ls in ft.	Pa in ft lb/ft/hr	Tide	M
Shrivardhan inlet	4.27*10 ⁸	4815.78 (447.4m ²)	556.17 (169.52m)	8.66 (2.64m)	2913.38 (888m)	1.86*10 ⁶	12.4 hrs	3.06

and the shallowing at the throat of the inlet may be due to subsurface extension of the bar. The south-western tip of the bar, which protrudes towards the sea, must have extended further, resulting in drastic shallowing of the inlet throat. It is true that in the absence of recent data one cannot be absolutely sure of such conclusions. However, one cross section which could be measured in May 2001 indicates the shift of the thalweg towards the jetty and the bar has clearly extended southwards; drastically reducing the cross sectional area of the inlet (Fig. 2). However, it is interesting to note that the maximum depth has not changed much since 1965. If such an alarming change can take place near the jetty, where the depth is substantial, it is not unlikely that in other shallower parts the same trend would follow (Table 1).

The long profile has been drawn along the thalweg line, starting from the Kuravde jetty and continuing up to 880m towards the sea. The peculiarity of the section is that, for larger part of it, the profile shows a bay ward gradient instead of a seaward one. In fact the minimum depth is recorded across the throat of the inlet and the maximum depth of water is seen near the Kuravde jetty i.e. just before the inlet opens out into the bay. However, from this point if we move a little towards the east, i.e. towards the bay the depth again decreases substantially and one can find shoals developed in this location. Crossing the shoal if we still move eastwards, the bay water gets restricted in two distinct arms – northern arm southern arm, separated by an island in the middle. Sounding charts in the vicinity of Mulgaon jetty (located on the northern arm) shows that maximum depth attained is less than

1m below the chart datum, as compared to a depth of almost 6m below chart datum near the southern jetty at the entrance of the bay.

Keeping these depth conditions in mind one can have a rough idea about the bathymetry of the bay. Towards the sea, while entering the main inlet, depth decreases rapidly up to 1m below chart datum. After this point depth goes on increasing in the main inlet as we move towards the bay, attaining a maximum of 6.5m near the southern jetty. Hence we have a distinct slope of the tidal inlet towards the bay. Once we have crossed the jetty, depth again starts decreasing in the northern and southern arms of the bay, where maximum depth attained is around 0.3m below datum (as per sounding charts of 1982 and 1990). This indicates that, as we move towards the east along the two arms of the bay, the bottom configuration shows a slope from bay to sea. However, this slope is much gentle than the slope of the inlet channel from sea to bay.

At this juncture some explanation can be given of the probable flow conditions that can be expected in the main inlet channel and the bay. During the time of incoming tide the water starts moving inside the tidal inlet. Aided by wind, tidal force and being confined within the rocky platform on one side and the spit on the other, the incoming water moves with considerable velocity through the inlet channel. But as the water comes out of the inlet at its eastward end, it suddenly spreads out as it enters the bay. This sudden spread in the width of the cross section results in sudden decrease in velocity and subsequent deposition in the form of a shoal. It is likely that the shoal has an underwater connection with the southeastern edge of the bay

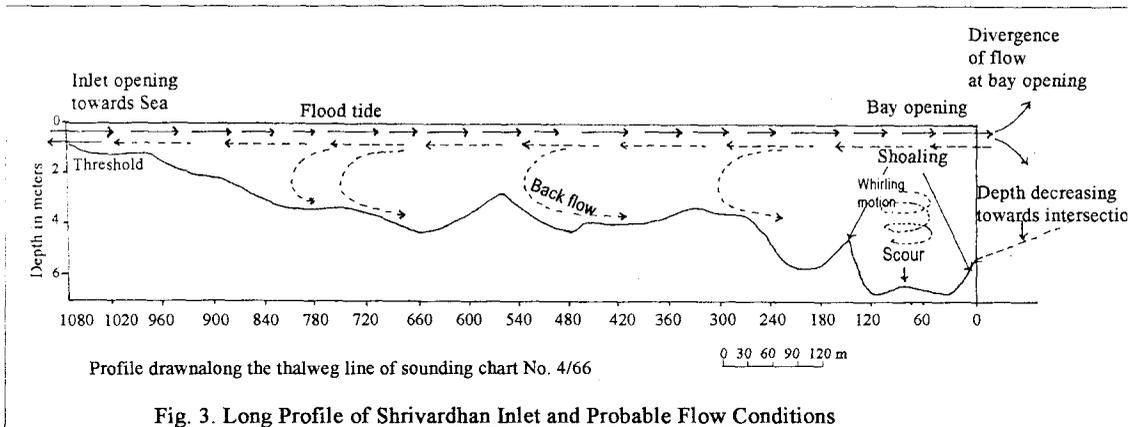


Fig. 3. Long Profile of Shrivardhan Inlet and Probable Flow Conditions

mouth spit and the central island. Crossing the shoal, the water has to move against the slope inside the bay. Hence, it has a much lower velocity. As a consequence the rate of sedimentation is likely to increase as one moves in to the interior of the bay. This interpretation may explain the formation of the shoal at the entrance of the bay, but it cannot explain the depth of the inlet channel near the jetty. This may be explained by the nature of movement of the ebb tide. While draining out of the bay, the outgoing water is principally aided by gravity; hence it is the natural tendency of the water to follow the general slope of the ground. When this outgoing water reaches the southern jetty it becomes increasingly difficult for the water to move against the slope (as the slope of the inlet is not towards sea but towards bay). The deposition at the mouth of the inlet acts as a threshold above which the water has to pass. Water in the upper part of the water column, i.e. up to a depth of 1m below chart datum can easily pass over the threshold towards the sea. But water below the depth of 1m will find it difficult to move up-slope. Hence a large volume of water starts flowing in the opposite direction following the slope as a "back flow" or "return flow". The general out flowing water of the ebb tide confronts this water and they may produce a whirling motion that results in scouring of the inlet bottom at that particular location (Fig. 3).

Such a reverse gradient from sea to bay is not an uncommon phenomenon in case of tidal inlets. 'At the seafloor in the immediate vicinity of the coastal inlet the interrupted littoral sediment tends to accumulate and raise the floor, leading to the formation of an ebb delta' (Dombrowski and Mehta, 1996). The threshold at the entrance of Shrivardhan inlet may represent the formation of an ebb delta. However, the trend of the bathymetric contours does not give the impression of an ebb delta, which usually has a lobe facing the sea and these are usually well defined by the bottom contours. Hence the deposition at the inlet throat as a subsurface extension of the bay mouth spit seems more probable.

The stability criteria of the Shrivardhan inlet

Keeping these parameters in mind one is bound to speculate over the stability of the Shrivardhan Inlet. The stability of an inlet depends on the cumulative effect of two opposing factors: the near shore wave climate and the flow regime of the inlet (Mehta, 1975).

Depending on the relative dominance of these two factors there will be either erosion or accumulation of sand in a particular inlet. Sudden influx of sand due to storm may choke an inlet, but on a long term basis the inlet should have enough capacity to counter the obstruction and maintain a state of non-silting, non-

scouring equilibrium (Mehta, 1975). If the inlet fails to do so, then the unstable inlet will try to shift and orient itself according to the direction of long shore current or lengthen its course – rendering it more unstable. The Shrivardhan inlet being backed by the rocky platform on one side has little chance of re-orientation.

Many of the proposed methods for determining the stability of coastal inlets relied heavily on deep-sea wave statistics, which are difficult to obtain for majority of locations. Hence, in this paper the method formulated by Mehta (1975) has been followed.

Mehta (1975), has proposed a dimensionless co-efficient – M to explain the stability of an inlet:

$$M = PaT/2W\tilde{a}Ac \quad \dots(1)$$

Where, Pa is the long shore wave power, T is the tidal period, Ac is the inlet throat cross sectional area below mean water level and \tilde{a} is the unit weight of water.

$$W = 4.19 \times P^3/C^2RcT^2Ac^3 \quad \dots(2)$$

Where, P is the tidal prism, C is the Chezy coefficient and Rc is the hydraulic radius.

In the equation the numerator depicts long shore wave energy over a tidal period and the denominator indicates the flushing capacity of the stream. However, where the tidal prism is not known, Mehta proposed an alternative equation for M:

$$M = PaT^3_c (1.82 \times 10^{-3}Lc/Rc)/2 \times 10^{12} \times \tilde{a}bc \quad \dots(3)$$

Where, Ls is the distance measured along the deepest part of the inlet channel between outer bar and the junction of the inlet with the open bay and

$$bc = Ac/Rc \quad \dots(4)$$

In assessing the stability criteria of Shrivardhan inlet the second method has been followed. In this context it should be mentioned that while applying the method proposed by Mehta the cal-

culations have been done in English unit (FPS) since the graph provided to assess the stability criteria is in English units. The above equation was solved in the following steps:

- I) The computation of the Pa (long shore wave power) was done following the equation formulated by Mehta (1975).

$$Pa = 0.48 Q \quad \dots(5)$$

Here, Q is the rate of littoral drift in cubic yards/year. The Q has been computed following the procedure mentioned in the Shore Protection Manual (1984). As mentioned in the procedure:

$$Q = 2 \times 10^5 \times Hb^2 \text{ (for English units)} \quad \dots(6)$$

$$Q = 1.646 \times 10^6 \times Hb^2 \text{ (for metric units)}$$

Here, Hb represents the average breaker height. The average breaker height has been taken from pre and post Monsoonal observations carried out in a nearby area (Karlekar, 1993). However, to compute Hb, the ‘significant breaker height’ had to be calculated and according to Munk ‘significant wave height is the average height of the one third of the highest waves’ (Shore Protection Manual, 1984). In this case, since the data set is not too large, the average of all the breaker heights above 1m (3.28 ft.) have been considered and the values of Hb has been calculated to be 4.4 ft (1.34m).

Putting the value of Hb in equation 6:

$$Q = 3872000 \text{ cubic yards/year.}$$

Substituting the value of Q in equation 5:

$$Pa = 1.86 \times 10^6 \text{ foot-pound/foot/hr.}$$

Hence, per second Pa will be $1.86 \times 10^6/3600 = 516.67 \text{ foot-pound/foot/sec.}$

- II) Determination of the hydraulic geometry of the inlet:

Section No. 5 of Fig. No. 2 has been considered since it truly represents the throat of the inlet, as has been described by Mehta (1975). From the cross section the following parameters were derived:

Table 2:

Section	Ax (m ²)	Wetted perimeter (m)	Rx (m)
1	729.5	128.89	5.66
2	761.7	161.01	4.73
3	732.4	237.22	3.09
4	572.8	209.39	2.74
5	447.4	169.52	2.64
6	558.2	250.16	2.23

Source: bathymetric chart, 1965

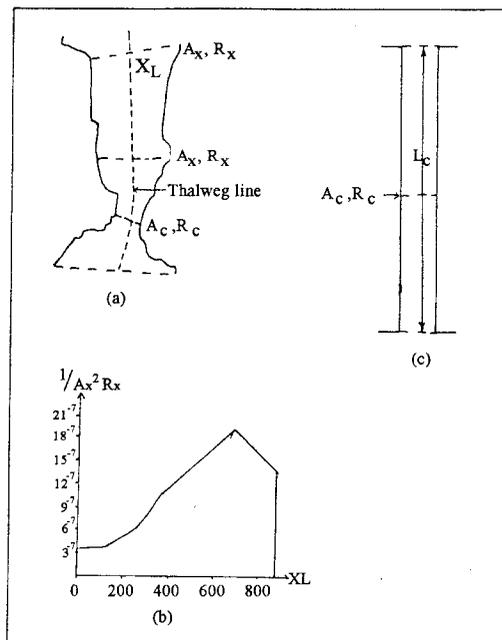


Fig. 4 Definition (a), Calculation (b) and Equivalent Length (c) of the inlet (After Mehta)

$\bar{\alpha}$ (the unit weight of water) has been taken as 64.00 lb/ft³ for salt water. βc has been calculated as per Equation No.4

P is the hydraulically computed tidal prism as proposed by Keulegan (1967):

$$P = UmTAc / \delta Ck \quad \dots(7)$$

Where, U_m as been calculated in equation 10 and C_k is taken as 0.86.

The problem of working with the hydraulic geometry of inlets is that they do not have a constant cross section. Therefore velocity – U changes along the channel. To overcome this difficulty O’Brien and Clark (1973) tried to formulate an idealized channel with cross section area equal to the throat area and the length of the equivalent channel (L_c) is adjusted, so that the slope is not altered in the two channels. To find out the L_c one simple graphical method has been used. From the cross sectional areas mentioned in Table-1, the hydraulic radius and the corresponding $1/R_x A_x^2$ was calculated. The results have been plotted in the Y axis of a graph, against corresponding distance – XL in the X axis. Straight lines joined the points and the area under the curve has been calculated. The calculated value was then multiplied by the throat area and hydraulic radius of the inlet ($R_c A_c^2$). The length of the equivalent channel was found to be 533.14m (1749.15 ft) (Fig. 4, Table 2).

Substituting all the values in Equation 3 the M coefficient was calculated to be 0.93 (Table-1). The stability coefficient M has been plotted in a graph by Mehta (1975) as a function of tidal prism (Fig. 5). Based on the correlation between these two parameters the graph shows areas of good, intermediate and poor stability. The computed value of $M = 0.93$ has been plotted against a tidal prism of 4.27×10^8 (ft³) or 1.21×10^7 (m³). From the graph it can be seen that this particular inlet falls into the zone of poor stability (Fig. 5).

In this connection it should be mentioned that an inlet of poor stability as described by Mehta corresponds to Bruun’s “bar bypassing inlet”. Shrivardhan inlet does fall into the category of “poor stability but its proximity to the zone of intermediate stability suggests that the inlet is still within the range of equilibrium conditions. Even, from the oldest SoI

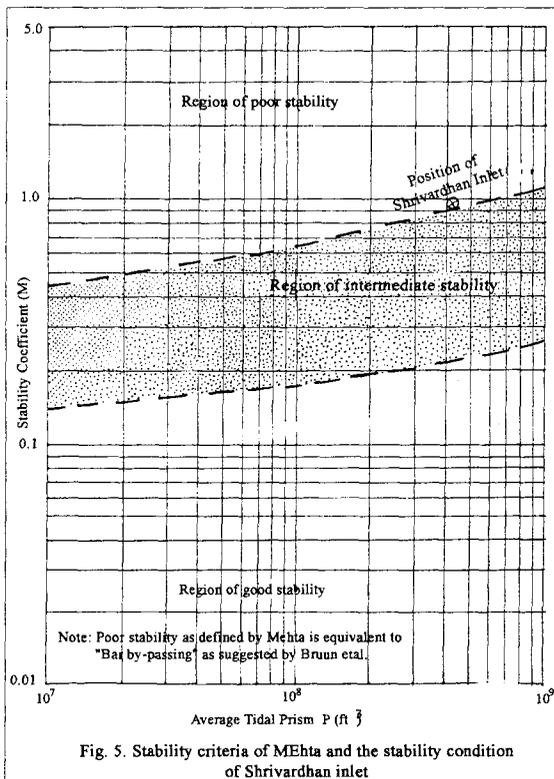


Fig. 5. Stability criteria of MEhta and the stability condition of Shrivardhan inlet

topographical sheet available and the current satellite images, it can be seen that the inlet has managed to keep its throat open. This characteristic of the inlet gives an interesting dimension to its stability conditions.

In an attempt to understand the stability condition of the inlet it is necessary to estimate its critical cross sectional area. Keulegan has given a new concept of inlet stability. He explains stability by a “repletion co-efficient” – K, the larger the K, faster the tide water will pass through the inlet. He relates the ocean (a_o) and bay tide (a_s) amplitude, the inlet cross section (A_c), the bay surface area (A_B), and an “impedance” factor (F) to the flushing capacity of the inlet. According to him the F is related to frictional loss of the flood and ebb current while entering (k_{en}) and out going out of the bay (k_{ex}).

$$F = k_{en} + k_{ex} + fLc / 4.0 \quad \dots(8)$$

The Repletion Coefficient is defined as:

$$K = T / 2\delta a_o A_c / A_b \sqrt{2ga_o} / F \quad \dots(9)$$

a_o is semi tidal range of the ocean and F has been already defined). The friction factor (f) is calculated by:

$$f = (8g/C^2) \quad \dots(10)$$

Where C is the Chezy discharge coefficient.

Following equation No. 8,9 and 10 the repletion coefficient (K) was calculated to be 0.91 for the throat cross-section. Here, a_o has been taken as 1.83m (average of spring and neap tidal range), and bay area A_B is 7.53 Sq. Kms.

Keulegan’s repletion coefficient has been plotted as a function of the dimensionless maximum velocity – $U'm$ in Fig 6. As per the graph a K value of 0.91 gives a $U'm$ equal to 0.71. With this computed value of $U'm$ the maximum velocity Um in m/s for a given cross sectional area may be calculated by the following equation:

$$Um = U'm \times 2\delta a_o / T \times A_B / A_c \quad \dots(11)$$

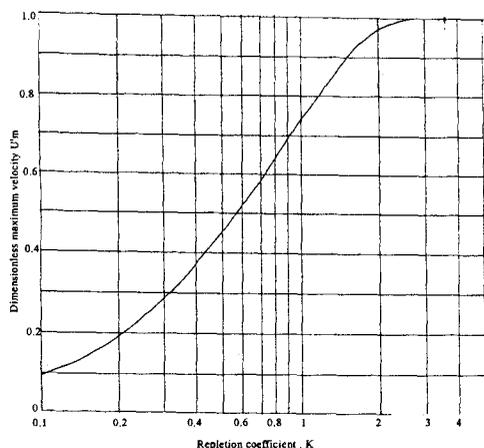


Fig. 6 Dimensionless maximum velocity as a function of repletion coefficient

In the same procedure the variation in Um can be calculated with selected values of A_c , keeping other values constant and then results may be plotted in a curve. This curve, as proposed by Escoffier (1940) and O’Brien (1972) can be

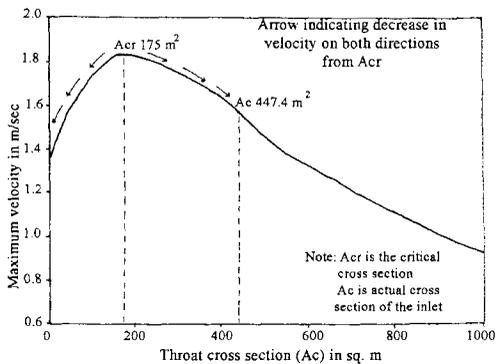


Fig. 7. Hydraulic curve of Shrivardhan inlet after Escoffier and O'Brien

referred to as the “hydraulic curve”. The hydraulic curve for Shrivardhan inlet has been shown in Fig. 7.

The reason behind preparing the hydraulic curve is that, every inlet must have a minimum cross sectional area and velocity in order to maintain the hydraulic stability of the inlet and the bay. Reduction in cross sectional area may lead to initial increase in velocity, but once the critical value is crossed, further reduction in cross section do not lead to increase in velocity.

The hydraulic curve of Shrivardhan inlet shows two distinct arms. The left falling arm of Um shows that beyond the critical point A_{cr} , the reduction in cross section leads to decrease in velocity. If the throat cross section – A_c is less than the critical value of A_{cr} , any reduction in cross section will bring about more sand deposition and this will enhance the possibility of inlet closure. In the right falling arm the reduction in cross sectional area leads to increase in velocity, resulting in scouring of bed. In the Shrivardhan inlet, the throat cross section falls within the falling right arm of the curve, hence any reduction in cross section, may be due to sand deposition will increase its velocity, but only up to the critical point of 175 Sq. m. A lesser cross section will lead to inlet closure. The increase in velocity will lead to scouring and enlargement of the cross section, thereby reduc-

ing its velocity and encouraging shoaling until equilibrium is reached.

Conclusion

The study of the Shrivardhan inlet reveals certain facts, which are unique and needs special mention. The inlet shows a distinct slope towards the bay, which itself is a limiting factor for the stability of any inlet. The deposition near the inlet throat acts as a threshold between the bay and the sea and in every probability it is the sub-surface extension of the bay mouth spit. The inlet falls within the sector of “poor stability” following the principle of Mehta. The reverse gradient of the inlet can be easily correlated with its condition of poor stability, however, it is surprising that the inlet has managed to maintain itself in spite of its poor stability conditions. One possible explanation can be provided with the help of the hydraulic curve. It can be stated that though the inlet faces the danger of possible closure by extension of the bay mouth spit, its cross sectional area is still well within the critical value. Hence, it is not likely that the inlet will be choked in the near future, if the present set of conditions remain unaltered. However, the fates of coastal inlets are highly unpredictable, and the whole state of equilibrium may get disturbed by a single severe storm. Lastly it should be mentioned that availability of recent bathymetric data would have helped in a better understanding of the inlet behaviour.

Acknowledgement

The author would like to express deep sense of gratitude to Prof. S.R. Jog, who provided constant inspiration and eminently sound guidance all through. Prof A.J. Mehta, Professor, College of Engineering, University of Florida, went out of his way to help the author in the present study by inputs from his valuable papers and lecture notes and the author acknowledges the gesture with particular gratefulness. The author is indebted to Dr. L.K. Ghosh, Civil Engineering Division, CW&PRS, who guided the author to

think about the stability of the Shrivardhan inlet. The author would like to thank the Maharashtra Maritime Board, Mumbai for providing the sounding charts of the concerned area. Last but not the least, the author would like to thank all her friends without whose help and unstinted support the associated field works would not have been possible.

References

- Bruun, P. and Gerritsen, F. (1960): "*Stability of Coastal Inlets*". North Holland, Amsterdam, pp 6-107.
- "*Considerations Governing the Stability of Upputeru River Entrance*" Technical Paper, Central Water and Power Research Station, Khadakwasla, Pune.
- Escofier, F.F. (1940): "The Stability of Tidal Inlets", Shore and Beach, Journal of the *American Shore and Beach Preservation Association*, Vol.8, No.4, pp 114-115.
- Karlekar, S. (1993): ed. "*Coastal Geomorphology of Konkan*", pub. Aparna Publications, Pune,
- Keulegan, G.H. (1967): "Tidal Flow in Entrances: Water Level Fluctuations of Basins in Communication with the Seas". Committee on *Tidal Hydraulics Technical Bulletin*, No. 14, U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi.
- Mehta, A.J. (1975): "*A long term stability criterion for inlets on sandy coasts*", Coastal and Oceanographic Engineering Laboratory, University of Florida; Florida. pp. 1-28.
- Mehta, A.J., Dombrowski, M.R. (1996): "Ebb tidal delta evolution of coastal inlets" Coastal Engineering, proc of the 25th international conference, pub. *American Society of Civil Engineers*, pp 3271-3283
- Mehta, A.J., Devine, Paul T. (1999): "*Modulation of micro-tidal inlet ebb deltas by severe sea*", *Coastal Sediments*, Vol.2; pub. American Society of Civil Engineers, Virginia. pp 1387-1401.
- "*Shore Protection Manual*", U.S. Army Corps. Of Engineers Coastal Engineering Research Center, Vol. – I (1984).

Ms. Subhamita Chaudhuri
Lecturer in Geography,
Jogamaya Devi College,
Calcutta