Journal of Civil Engineering (IEB), 41(1) (2013) 1-12

Journal of
Civil Engineering
IEB

# Investigation on erosion of Kuakata sea beach and its protection design by artificial beach nourishment

Md. Ataur Rahman[1], Manik Chandra Mitra[2] and Aysha Akter[3]

[1]*Department of Water Resources Engineering*
*Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh*
[2,3]*Graduate Students, Department of Water Resources Engineering*
*Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh*

Received 12 December 2011

**Abstract**

The Kuakata, a panoramic sea beach on the southernmost tip of Bangladesh, located in the northern part of Bay of Bengal. From the satellite image analysis it has been found that the main part of Kuakata beach, which is famous as tourist attractive place, is exposed to continuous erosion due to wave action and storm surges. Study prevails that in 23.56 km long shoreline, erosion occurs in 13.59 km reach and deposition occurs in 9.97 km during the period of 1973 to 2010. Maximum width of beach area, which has been eroded, is about 450 m and accreted is about 1075 m during last 37 years. To protect the central 5 km reach of eroded beach this study also investigates the design aspects of protection work using artificial beach nourishment with Dean's equilibrium beach profile method considering intersecting and non-intersecting profiles. The design volume of nourished sand required for per unit length of Kuakata beach has been estimated as 1433 $m^3$/m, 934 $m^3$/m and 761 $m^3$/m for fill grain size of as 0.15 mm, 0.20 mm and 0.25 mm respectively. The study also calculates the half life of the designed nourished sand, which is estimated as 4.62 years.



*Keywords:* Beach erosion, nourishment, Dean's equilibrium beach profile method, intersecting profile, non-intersecting profile, half life

## 1. Introduction

Kuakata sea beach, the second most famous beach and a rare scenic beauty spot on the southernmost tip of Bangladesh, is located at Patuakhali district some 320 kilometers from the capital city of Dhaka. Locally known as Shagor Kannya (Daughter of the Sea), the beach consists of long strip of dark, marbled sand stretches for about 24 km (Figure 1). This wide sandy beach has gentle slopes into the Bay of Bengal and patches of mangrove trees behind it withstanding the perpetual forces of the tides. The inland area of Kuakata is protected from tidal wave by earthen flood embankment (Polder No. 48), which was constructed few hundred meters away from the shoreline. Kuakata is one of the attractive tourist destinations and perfect place for holidaymakers and sun-seekers, because one can see both the sunrise and sunset in the sea from this place. Other attractions at Kuakata include blue sky, huge expanse of water, the evergreen forest in surrounding areas, rows of coconut trees, boats of many different kinds and their colorful sails and surfing waves. Kuakata is also a sanctuary for migratory winter birds. Because of vast natural beauty it draws hundreds of tourists from home and abroad every year.

Coastal erosion at main beach of Kuakata over the decades caused by the waves and tidal surges results the shoreline shifting towards inland. It has endangered Kuakata sea beach and now the beauty of the beach is under great threat. At present, coconut garden, jhaw-bithi, jhinuk market, LGED rest house, cluster village and rehabilitation project and other establishments are under threat of erosion. Because of erosion the soil from the root zone is being washed out which results the mangrove and coconut trees uprooted as seen in Figure 2(a). Due to attack by the tidal waves the flood embankment behind it has already been shifted and reconstructed for two times during last 10 years (Figure 2(b)). So, the local people and investors have sought immediate steps by the government and other agencies to save Kuakata sea beach.

Few studies have been conducted on some aspects of Kuakata beach. Rahman (1999) studied the beach materials of the Kuakata coast. The study reveals that the Kuakata beach sand is more or less uniform in the context of particle mean diameter ($d_{50}$), which lies between 0.177 mm to 0.207 mm. The beach is relatively flatter at both western and eastern ends and the middle part has got steep slope. The beach slope of Kuakata coast lies between 1:19 to 1:66. The widths of the beach (foreshore zone) vary from 100 m to 340 m. The waves in the beach approaches from the sea and the wave breaking phenomena is of spilling type. Khan (2004) studied the impact of erosion and shoreline change on tourism at Kuakata beach. He studied the characteristics of the beach materials, the effect of beach tourism on local people’s livelihood and attractiveness of the beach area to the tourists. Masuma et al (2011) investigated the physical characteristics of dynamic topography change due to cyclone SIDR around Kuakata beach. They investigated long-term influence of the cyclone SIDR on the coastal processes around Kuakata beach. Numerical analysis was also performed to explore the influence of the newly emerged shoals on wave and current field as well as on the sediment transport rate. This study aims to estimate the shoreline shifting due to coastal processes at Kuakata by analyzing the satellite images of the year 1973, 1984, 1990, 1996, 2005 and 2010. The study also designs the artificial beach nourishment to protect the erosion of central 5 km reach in west part of Kuakata main beach.

## 2. Study area and data collection

The study area lies between latitude N21°48'05" to N21°51'36" and longitude E90°05'06" to E90°15'07". While inland of the coast is mostly covered by dense plantation, coastal area at Kuakata is directly exposed to the Bay of Bengal. The coast is wider and the beach has a very flat slope. Daily waves are very small, i.e., averaged wave heights are around 1 m. Tides in the beach area are semi-diurnal and daily tidal level varies within the range of 1 to 1.5 m Masuma et al (2011). From March to October the wind blows over Kuakata area from south with an average velocity of 3.5 m/s. From November to January the wind blows from the north with an average velocity of 2.6 m/s Masuma et al (2011). According to the local neighbors, the coastal area is experiencing rapid erosion especially at the west part and the natural sandy beach is under threat due to regular wave action. To conduct this study various types of data were collected from different organizations. Moreover, the authors visited the site twice to observe the field condition. Satellite images of the whole region of Kuakata beach of six different years covering 37 years from 1973 to 2010 were collected from CEGIS. The image resolution varies from 24 m to 80 m as given in Table 1.

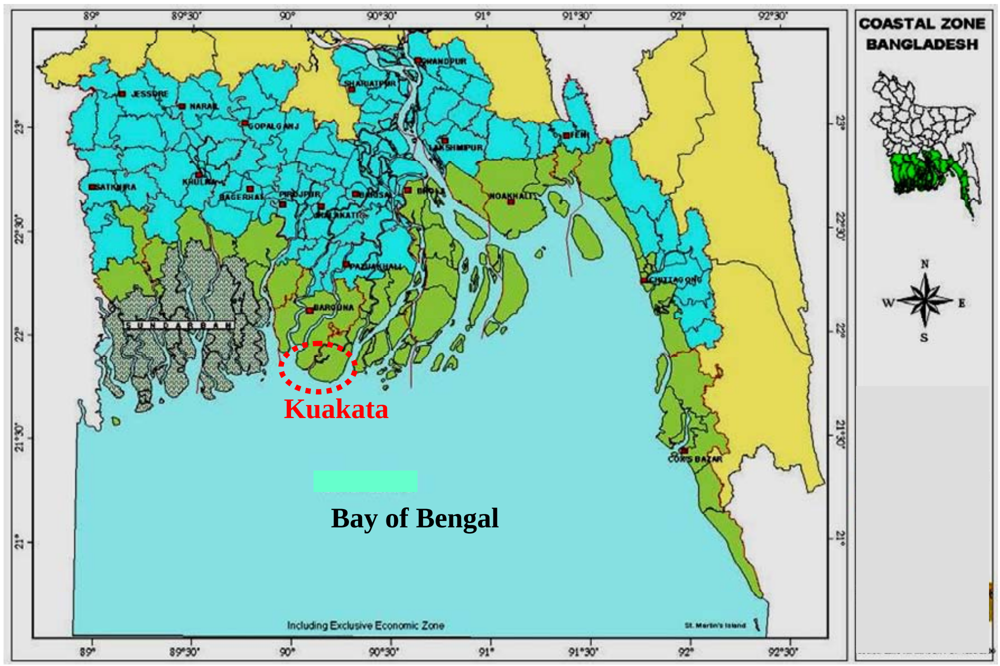



Fig. 1. Location of Kuakata at coastal zone map of Bangladesh

Fig. 2(a). Trees are uprooted due to beach erosion at Kuakata

Fig. 2(b). Flood embankment behind the beach has failed under wave action

All the images are taken during dry period i.e. between the months of November to February. Bangladesh Water Development Board (BWDB) is responsible for maintenance of the flood embankment of Polder 48 behind the Kuakata beach. Some cross-sectional data measured on 2010 at eroded west part of Kuakata beach were collected from BWDB. Bangladesh Inland Water Transport Authority (BIWTA) has a tide gauge station near Kuakata and tidal data were collected from this organization. Some data, specially the beach sediment particle size and characteristics, are collected from previous studies.

Table 1
List of collected satellite images of Kuakata

| Year | Sensor | Resolution |
|---|---|---|
| 1973 | Landsat MSS (Canada) | 80m |
| 1984 | Landsat MSS (Canada) | 80m |
| 1990 | Landsat TM (Canada) | 30m |
| 1996 | Landsat TM (Canada) | 30m |
| 2005 | IRS LISS III (India) | 24m |
| 2010 | Landsat TM (Canada) | 30m |

## 3. Estimation of shoreline change

Very little field survey has been done so far in the coastal areas of Bangladesh including Kuakata due to the lack of financial and technical facilities. As a result, availability of data for coastal research is poor. Under such situation, remote sensing data can be used to effectively monitor the changes along the coastal zone with reasonable accuracy. This study hence applied satellite images to capture the changes of shoreline causing erosion or accretion along Kuakata beach. The satellite images of the Kuakata shore for the years of 1973, 1984, 1990, 1996, 2005 and 2010 have been digitized using ArcView GIS 3.3 Software. For quantitative comparisons of the shoreline locations, it is needed to georeference all the images with respect to some selected control points of known geographic coordinate. After georeferencing all the images the shoreline in each image was extracted by line digitizing. In this manner, regardless of the image resolutions, obtained shoreline positions are all based on the same coordinate system and thus should be readily comparable to each other in a quantitative manner. Fluctuation of tidal level is usually considered during identification of shoreline position in satellite image (Chen et al 2009). But due to non availability of measured long time tidal level data, this study considers the edge of the dry sand as the shoreline position. The extracted shorelines of six different years are shown in Figure 3. In 23.56 km long shoreline, erosion occurs along 13.59 km reach of west part, whereas siltation occurs along 9.97 km reach of east part of the Kuakata beach.

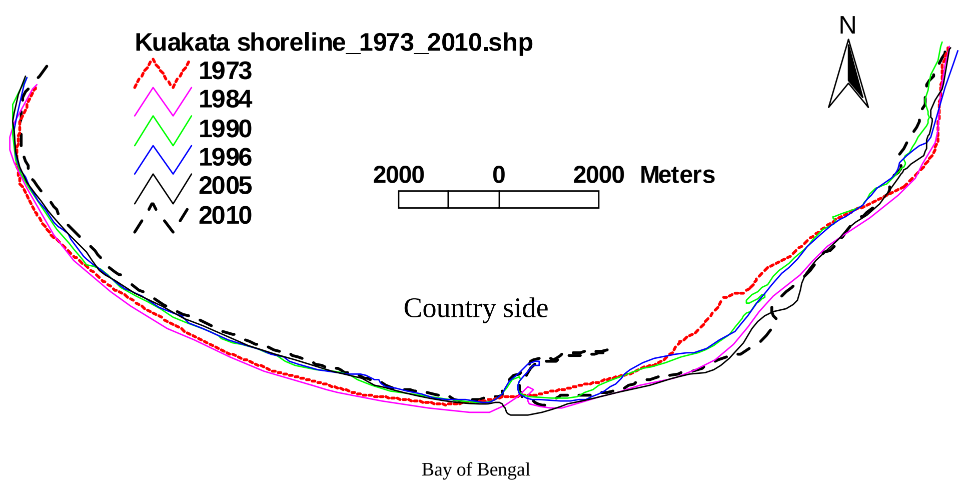
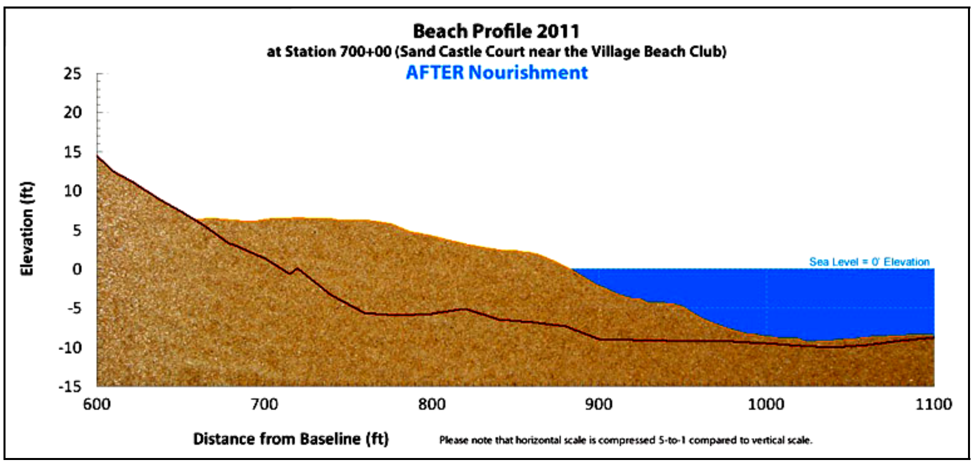



Fig. 3. Extracted shorelines from satellite images of Kuakata beach of different years

Figure 3 reveals that most of the western part of Kuakata beach happened to accretion during the period of 1973 to 1984, resulting a shifting of shoreline of 60 m to 80 m toward sea. After 1984 this reach started to suffer erosion which continued till the year of 2010. During this period most part of this reach had suffered erosion causing a shoreline shifting of around 350 m on an average toward inland, which had maximum value of 450 m. Analysis of eastern part, shown in Figure3, shows that most portion of this reach had been accreted during the period of 1973 to 2010. It is seen that after 1973 there started siltation in this reach which continued at faster rate till 1984. After 1984 this accreted zone suffered erosion till 1996. During the period of 1996 to 2010, again it caused a huge siltation there. Comparing the shorelines of 1973 and 2010, it is prevailed that most part of this reach had been accreted resulting the shoreline shifting of around 600 m on an average toward the sea, which had maximum value of 1075 m. It prevails that during the period of 1973 to 1984, the whole reach of Kuakata shore was silted up, which suffered erosion during the period of 1984 to 1996. After 1996 erosion continued along the western part till the year 2010, while it caused huge siltation in eastern part during this period. It indicates that long shore sediment transport causes erosion along western part and those eroded sediments deposit in the downstream resulting siltation along eastern part during the period of 1996 to 2010.



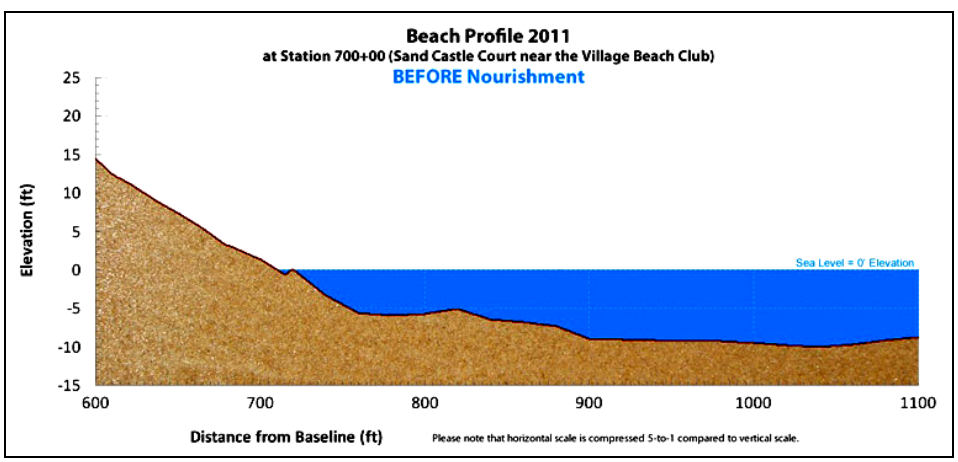




Fig. 4. The profile of Nags Head beach at North Carolina, USA
(before and after nourishment)

## 4. Design of Kuakata beach nourishment

### *4.1 Beach nourishment*

It is mentioned before that the continuous erosion along the western part of Kuakata beach has resulted the failure of earthen coastal embankment of polder no. 48. BWDB has designed the revetment type protection using cc block along the sea side slope of the embankment and has started to construct the protection works, which is temporary type protection to save the embankment from failure. Traditional coastal protection with hard structures like breakwater, groins, seawalls etc may protect the coastal embankment, but the beach will be completely washed out as because the hard structure attracts erosion in front of it. So this study suggests the soft structure coastal protection like artificial beach nourishment along eroded western part of Kuakata beach.

Beach nourishment is the replenishment of beaches with imported sand and is one of the best available means of restoring beaches where erosion has become a problem (Figure 4). Sand nourishment increases the width of land available to accommodate erosion, while at the same time allowing the beach to continue to behave naturally. Nourishment has gained popularity because it preserves beach resources and avoids the negative effects of hard structures. Instead, nourishment creates a soft structure by creating a larger sand reservoir, pushing the shoreline seaward. Risio et al (2010) investigated the cross-shore short term changes of protected and unprotected beach nourishments through laboratory experiments. Dean et al (2011) studied the performance of beach nourishment project in Florida.

Table 2
Summary of beach nourishment in European and USA (Hamm et. al., 2002)

| Country | Date of 1st recorded nourishment project | Number of nourished sites | Total fill volume ($Mm^3$) | Mean annual rate of projects | Long term strategy | Origin of funding |
|---|---|---|---|---|---|---|
| France | 1962 | 26 | 12 | <1 | No | Local |
| Italy | 1969 | 36 | 15 | 1 | No | National / Regional |
| Germany | 1951 | 60 | 50 | 3 | Yes | Federal / National |
| Netherlands | 1970 | 30 | 110 | 6 | Yes | National |
| Spain | 1985 | 400 | 110 | 10 | No | National |
| Denmark | 1974 | 13 | 31 | 3 | Yes | National / Local |
| U.K. | 1950s | 32 | 20 | 4 | No | National / Local |
| Total Europe | - | - | - | 27.5 | - | National / Local |
| USA | 1922 | - | - | 30 | No | Federal / Local |

Beach nourishment has become one of the most popular methods of coastal protection to solve the problem of beach erosion in both the United States and Europe. The first nourishment project in the U.S. was at Coney Island, New York in 1922-23 and is now a common shore protection measure utilized by public and private entities (Dornhelm, 2004). Federal and state governments in Mexico have invested about $71 million dollars ($957 million pesos) throughout the state of Quintana Roo in restoring the beaches along Cancun, Playa del Carmen and Cozumel. Gold Coast beaches in Queensland Australia have experienced periods of severe erosion. The 1971 Delft Report outlined a series of works for Gold Coast Beaches, including beach nourishment and an artificial reef. By 2005 most of the recommendations had been implemented. More than one-quarter of the Netherlands is below sea level and about 80% of the coast consists of sand dune or beach. The shoreline is closely monitored by yearly recording of the cross section at points 250 meters apart, to ensure adequate protection. Where long-term erosion is identified, beach nourishment using high-capacity suction dredgers is deployed (Pilarczyk et al. 1996). Spain has the highest number of nourished sites out of all of Europe. Germany started their beach nourishment program in 1951 and they have performed projects on 60 sites since then with more than 130 fills over those sites. U.K. uses beach nourishment in combination with traditional forms of coastal defense, most likely hard structures. Table 2 is a summary of beach nourishment in European countries that have coastal management programs as well as some information on the USA.

### *4.2 Design of Kuakata beach nourishment by Dean's method*

The main beach of Kuakata, which is developed as tourist spot over years having the facilities of communication, commercial hotels etc, is situated at the west part. From the analysis it is seen that the west part of Kuakata beach has been suffering erosion since 1984 and it is still continuing. The photos of uprooted trees and failed flood embankment behind the west part of beach, shown in Figure 2, are taken by the authors at the end of year 2010 during the field visit. The authors observed that the natural beauty behind the beach such as coconut-mangrove garden, flood embankment behind it, tourist shopping market, LGED rest house and most of the hotels close to sea are under great threat of coastal erosion in near future. It motivated the authors to carry out a study on design of protection for beach erosion at Kuakata. Considering the advantages of restoring and widening the recreational beach, it is decided to design the artificial beach nourishment protection among various types of coastal protection options. As for example, seawalls may protect structures behind the beach, but they almost always cause the beach in front of the wall to become narrower. This study investigates the design of artificial beach nourishment at central 5 km eroded reach of main beach along west part of Kuakata and is described in this section.

Dean (1991) presents a method for determining the volume of sand required in a beach fill to produce a desired width of the subaerial beach. Dean's method is based on the equilibrium profile of beaches. Bruun (1954) and Dean (1977, 1991) proposed that beach profiles develop a characteristic parabolic equilibrium profile given by Eq. (1).

$$h = Ax^{\frac{2}{3}} \tag{1}$$

in which $h$ is the water depth at a distance $x$ from the shoreline and $A$ is the sediment-dependent scale parameter, $A=0.21D^{0.48}$ , where $D$ is the beach grain diameter size in mm.

Dean (1991) defines three basic types of nourished profiles - an intersecting profile where the profile after nourishment intersects the equilibrium profile before closure depth, a non-intersecting profile where the nourished profile does not intersect the equilibrium profile before closure depth and a submerged profile where there is no dry beach after equilibrium (Figure 5). Dean shows that whether a profile is intersecting or non-intersecting is determined by the following equations:

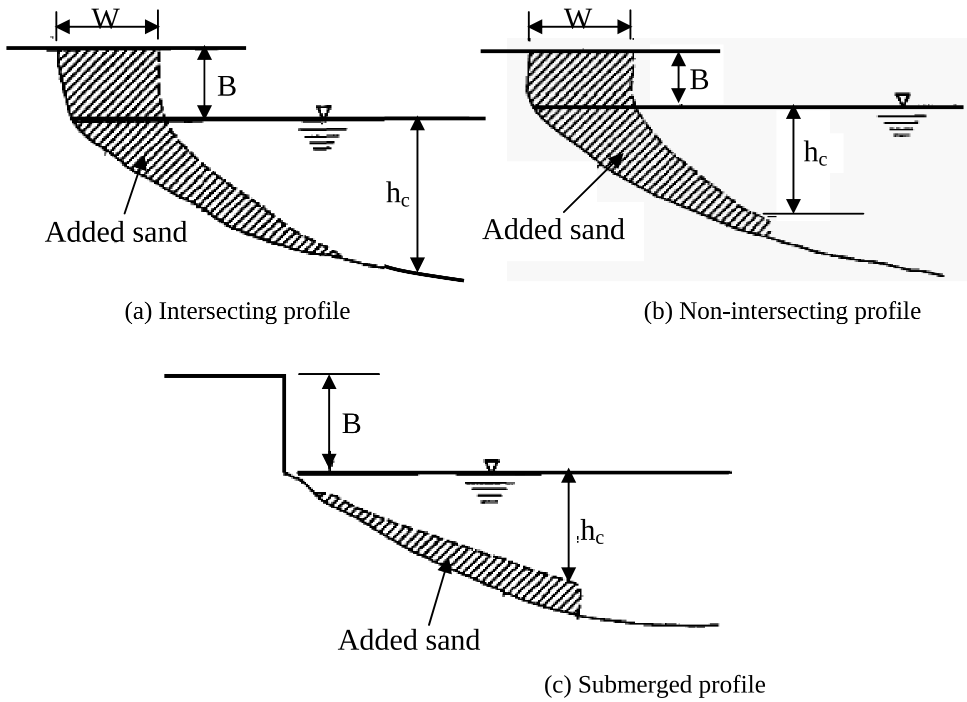



Fig. 5. Three basic types of nourished profiles (adapted from Dean 1991)

$$W\left(\frac{A_N}{h_c}\right)^{\frac{3}{2}}+\left(\frac{A_N}{A_F}\right)^{\frac{3}{2}}<1 \quad \text{(for intersecting profile)} \tag{2}$$

$$W\left(\frac{A_N}{h_c}\right)^{\frac{3}{2}}+\left(\frac{A_N}{A_F}\right)^{\frac{3}{2}}>1 \quad \text{(for non-intersecting profile)} \tag{3}$$

where $A_N$ is the *A*-value (sediment-dependent scale parameter) for native sediment, $A_F$ is the *A*-value for fill sediment, *W* is the dry beach width defined as the width of the dry beach after the beach profile reaches equilibrium beach and $h_c$ is the closure depth defined as the water depth beyond which no significant longshore or cross-shore sediment transports take place due to littoral transport processes. Houston (1996) defined the closure depth as 6.75 times the nearshore average significant wave height. Considering a berm height *B* of nourished sand (as shown in Figure 8), Dean (1991) estimates the volume of nourished sand must be placed after the equilibrium profile per unit beach length as follows:

$$V = W.B+\frac{\frac{3}{5}A_N A_F W^{\frac{5}{3}}}{\left(A_F^{\frac{3}{2}}-A_N^{\frac{3}{2}}\right)^{\frac{2}{3}}} \quad \text{(for intersecting profile)} \tag{4}$$

$$V = W.B+\frac{3}{5}\left(\frac{h_c}{A_F}\right)^{\frac{5}{2}}\left(A_N\left[1+W\left(\frac{A_F}{h_c}\right)^{\frac{3}{2}}\right]^{\frac{5}{3}}-A_F\right) \quad \text{(for non-intersecting profile)} \tag{5}$$

When the fill grain size is same as of native grain size, the nourished profile becomes non-intersecting type and in this case the volume of nourished sediment must be placed after equilibrium profile per unit beach length is as below:

$$V = W(B + h_c) \quad \text{(for fill grain size is same as of native grain size)} \tag{6}$$

To design the beach nourishment, a 5 km reach of eroded part at the main beach of Kuakata has been considered in this study. The beach cross section data measured on 2010 at 5 sections with 1 km interval have been plotted as existing profile and the equilibrium profile defined by Eq. (1) is plotted as equilibrium profile, which are shown in Figure 6. At first the existing profiles should be prepared so that it coincides with equilibrium profile. After calculating the volume differences between existing and equilibrium profiles at section 1 to 5, it is averaged along the design beach reach which calculates the sediment volume as 584 $m^3$/m. After beach profile in the design reach is prepared as equilibrium profile, the volume of nourished sediment per unit beach length is calculated by Dean's method mentioned above. From the collected data it is found that the size of the native material at Kuakata beach is 0.20 mm (which makes $A_N$=0.097) and the nearshore average significant wave height of 1 m (Bhuiyan et al 2005) makes the closure depth as $h_c$=6.75 m. In the design it is considered the dry beach width of 40 m and berm height of 2 m. Three different sizes of fill material are considered as 0.15 mm (fill sediment size less than native sediment size), 0.20 mm (fill sediment size equals native sediment size) and 0.25 mm (fill sediment size greater than native sediment size), which makes $A_F$ values of 0.084, 0.097 and 0.108 respectively. Eq. (2) and (3) determines that the nourished beach profile will be non-intersecting for fill sediment size 0.15 mm and 0.20 mm, whereas it will be intersecting for fill sediment size 0.25 mm. Using the Eq. (4), (5) and (6), the volumes of nourished sand to be placed after the equilibrium profile per unit beach length are 849 $m^3$/m, 350 $m^3$/m and 177 $m^3$/m for fill grain size of as 0.15 mm, 0.20 mm and 0.25 mm respectively. By adding the net sediment volume required to prepare the existing beach profile to equilibrium profile and the nourished sediment volume calculated by Dean's equations, the design nourished sediment volumes at 5-km reach of eroded part at the main beach of Kuakata have been estimated as 1433 $m^3$/m, 934 $m^3$/m and 761 $m^3$/m for fill grain size of as 0.15 mm, 0.20 mm and 0.25 mm respectively.

### *4.3 Estimation of Half Life*

Half life is defined as the time at which half (50%) of the nourished beach fill material remains within the placement area after another half portion lost by the coastal erosion. It is of interest to illustrate the dependency of project performance. The half life for above mentioned designed beach nourishment for the 5 km reach of eroded part at the main beach of Kuakata has been calculated in this study using the following equations as described in CEM (2010).

The percent of beach fill material remains after time t in seconds,

$$P(t) = 1 - \frac{\sqrt{\varepsilon . t}}{a\sqrt{\pi}} \tag{7}$$

where, *a* is the one-half of the length of the rectangular profile in meters, which becomes 2500 m for this study. $\varepsilon$ is the shoreline diffusivity parameter which is defined as,

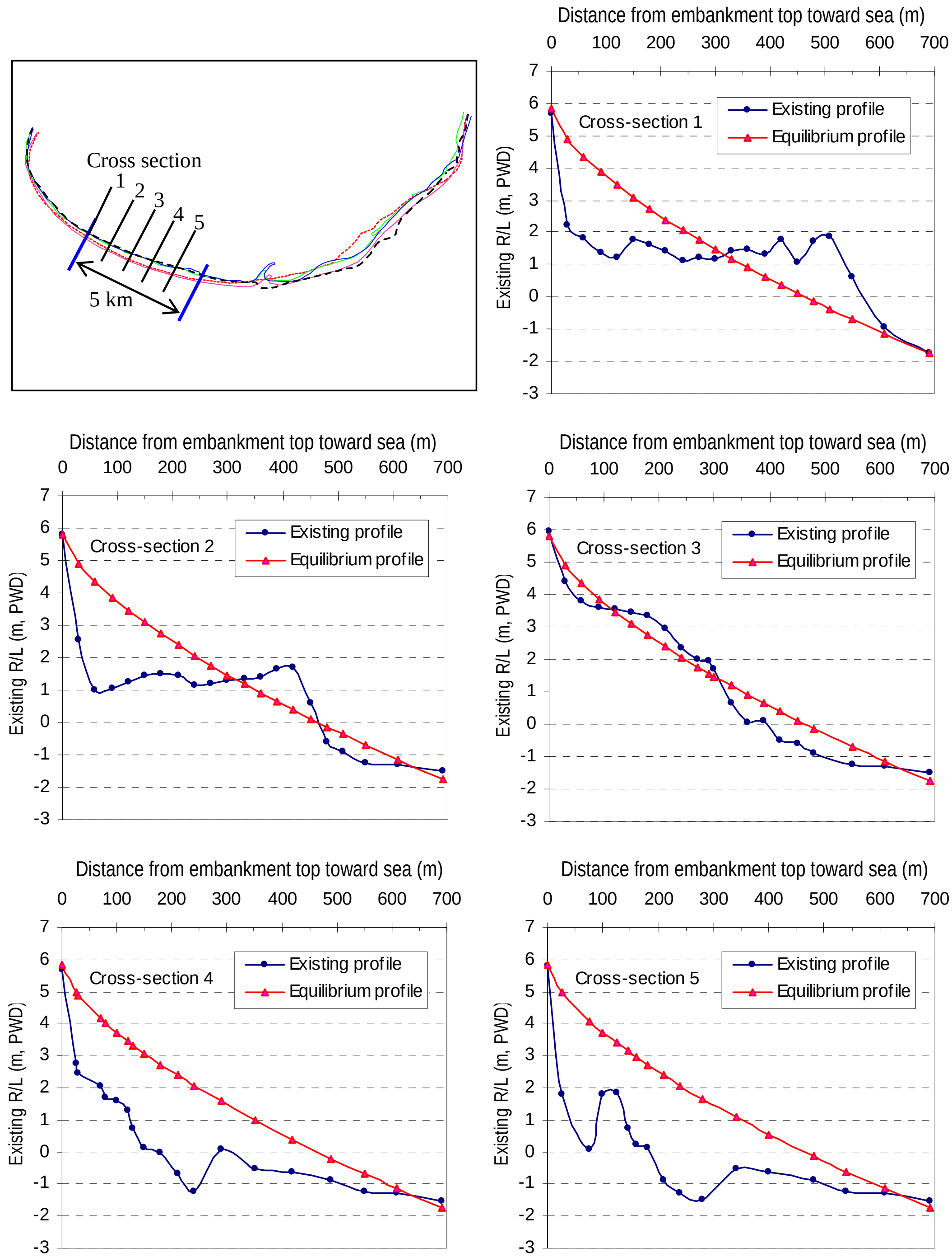



Fig. 6. Existing and equilibrium profile measured from embankment top toward sea at five cross-sections along the five km long eroded reach at main beach of Kuakata

$$\varepsilon = \frac{K.H_b.C_{gb}}{8}\left(\frac{\rho}{\rho_s - \rho}\right)\left(\frac{1}{1-n}\right)\left(\frac{1}{B+h_c}\right) \tag{8}$$

where, $\rho$ and $\rho_s$ is the density of water and fill sediment considered as 1.03 gm/cc and 2.65 gm/cc respectively, $n$ is the in-place sediment porosity considered as 0.4, $H_b$ is the breaking wave height, $C_{gb}$ is the wave group speed at breaker line $= \sqrt{g/\kappa}$, g is the gravitational acceleration, $\kappa$ is breaker index which is 0.78 for flat beaches and $K$ is a proportionality coefficient which depends on maximum oscillatory wave velocity, sediment fall velocity and wave breaking angle relative to shoreline. The design value of K was introduced as 0.77 by Komar and Inman (1970), which is commonly used in many longshore sediment transport computations and used in this study also. Using Eq. (8), the shoreline diffusivity parameter $\varepsilon$ is estimated as 0.0337 $m^2$/s. Considering *P(t)* equal to 0.5 in Eq. (7), the half life (t) for designed beach nourishment for the 5 km reach of eroded part at the main beach of Kuakata is calculated as 4.62 years.

## 5. Conclusions

Kuakata is one of the attractive tourist destinations and perfect place for holidaymakers and sun-seekers in Bangladesh. The western part of the beach, which is attractive for the tourists for its unexplainable scenic beauty, has been experiencing rapid erosion for last few decades caused by the waves and tidal surges. This study investigates the shore line shifting at Kuakata during the period of 1973 to 2010 by satellite image analysis. It is found that during the period of 1973 to 2010 the western part of Kuakata beach had suffered erosion causing a shoreline shifting of around 350 m on an average toward inland, which had maximum value of 450 m. The study investigates the design of the protection for eroded western part by artificial beach nourishment by Dean's method. The design volume of nourished sand required per unit length of Kuakata beach has been estimated as 1433 $m^3$/m, 934 $m^3$/m and 761 $m^3$/m for fill grain size of as 0.15 mm, 0.20 mm and 0.25 mm respectively. The half life of the designed nourishment, which indicates that within this time 50% of the beach fill material remains within the placement area, has been estimated as 4.62 years. This study is expected to be helpful for the concerned coastal managers to protect the Kuakata beach erosion using artificial beach nourishment technique.

### References

Bhuiyan, M.A. and Matin, M.A. (2005). "Coastal zone management", Postgraduate Lecture Note, Dept. of Water Resources Engineering, BUET.

Bruun, P. (1954). "Coastal erosion and development of beach profiles." U.S. Army Beach Erosion Board Tech. Memo. No. 44, Beach Erosion Board, U.S. Army Corps of Engrs., Washington, D.C.

Chen, W. and Xhang, H. (2009). "Estimation of shoreline position and change from satellite images considering tidal variation", Journal of Estuarine, Coastal and Shelf Science, Elsevier, Vol. 84, Issue 1, pp. 54-60.

Dean, R. G. (1977). "Equilibrium beach profiles: U.S. Atlantic and Gulf Coasts." Oc. Engrg. Rep. No. 12, Dept. of Civil Engg., Univ. of Delaware, Newark, Delware.

Dean, R. G. (1991). "Equilibrium beach profiles: Characteristics and applications." Journal of Coastal Research, 7(1), 53-84.

Dean, R.G. and Absalonsen, L. (2011). "Predictability of beach nourishment project performance in Florida", Proceedings of the 2011 Conference on Coastal Engg. Practice, ASCE.

Dornhelm, R. (2004). "Beach Master". Invention & Technology Magazine (American Heritage Publishing) 20 (1).

Hamm L, Capobianco M, Dette HH, Lechuga A, Spanhoff R, and Stive MJF (2002). "A Summary of European Experience with shore nourishment", Coastal Engineering 47: pp. 237-264.

Houstan (1996). “Simplified Dean’s method for beach fill design.” Journal of Water way, Port, Coastal and Ocean Engg., ASCE, Vol. 122, No. 3, pp. 143-146

Khan, M. M.H. (2004). “Study on impact of erosion and shoreline change on tourism at Kuakata beach”, M. Sc (WRD) Thesis, Institute of Water and Flood Management, BUET.

Komar, P.D. and Inman, D.L. (1970). “Longshore sand transport on beaches”, Journal of Geophysical Research, Vol. 75, No. 30, pp. 5914-5927.

Masuma, T.K. and Tajima, Y. (2011). “Investigation of the physical characteristics of dynamic topography change around Kuakata beach of Bangladesh”, Proceedings of the 3rd International Conference on Water and Flood Management (ICWFM-2011).

Pilarczyk, K. W.; Zeidler, Ryszard (1996). "Dutch case studies". Offshore breakwaters and shore evolution control. London: Taylor and Francis. p. 505. ISBN 9054106271.

Rahman, M. M. (1999). “Study of beach materials at the kuakata coast”, M. Engg. Thesis, Dept. of Water Resources Engineering, BUET.

Risio, M.D., Lisi, I., Beltrami, G.M. and Girolamo, P.D. (2010). “Phisical modeling of the cross-shore short-term evolution of protected and unprotected beach nourishments”, Journal of Ocean Engineering, Vol. 37, Issue 8-9, pp. 777-789.

U.S. Army Corps of Engineers (2010). “Coastal Engineering Manual”, U.S. Army Engineer Research and Development Center.