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Wave Statistics of Digha Coast and Beach Profile, West Bengal, India

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***Abstract*--** **The aforesaid research paper deals with wave properties and its impact on beach shaping. Through this research work wave profile of the Digha coast has been sketched. Wave is undulation of sea water which shaped the coastal beach profile. To analyse, the study of wave spectrum is important. Wave spectrum is depends on its' properties viz. wave length (L), wave height (H), wave amplitude (A), relative depth (d), wave period (T), wave frequency (f), radiant frequency (σ), wave celerity (C), wave height during breaking (Hb), crest velocity of breaking wave (Cb) and velocity of breaking wave. Wave energy flux rate on beach is important determining factor for beach shaping and beach morphodynamics.**

***Keywords*--** **Wave Properties, Beach, Wave Spectrum, Radiant Frequency.**

I. INTRODUCTION

Wave is an undulation on the surface of water which is occurred due to wind. The wave form appears as a periodic undulation of the water surface above and below the still-water level (swl) - the level the water surface would assume in the absence of waves (Robin Davidson-Arnott 2010, p.78). Water waves propagate on the ocean surface as a result of a generating force (Dean and Dalrymple 1991). The most common generating force for water waves is the moving air or wind (Faizal et al. 2011). The generation of waves by the wind results in a complex mixture of waves of various shapes all moving in different directions (Pethick, 1984 p.10). Energy is transferred from the wind to the water by the frictional drag of the air on the ocean surface, thus creating waves (Janssen 2004). Analysis of such wave mixtures back into their constituent wave forms can be performed by spectral analysis (Komar 1976). Beach, the landform of coastal geomorphology, is an interaction or transitional zone between land and sea.

Beach has been shaped and grouped by wave properties. A beach is an accumulation on the shore of generally loose, unconsolidated sediment, ranging in size from very fine sand up to pebbles, cobbles and occasionally boulders, often with shelly material (Eric Bird, 2008 p.133). The driving force behind almost every coastal process is due to waves (Pethick 1984, p.9). Statistical descriptions of wave parameters (Wave length, height, amplitude, depth, period, frequency etc) influence to Digha coastal beach profile which has been evacuated through this aforesaid research work.

II. STUDY AREA

Digha is an important tourist destination of West Bengal (Dey and Shukla February 2019) which is part of Kanthi Coast. The 7 km long beach stretches from the mouth of the tidal river Champa in the east to West Bengal - Odisha Border. The sedimentary geology of the great Bengal basin has been totally controlled by regional tectonic activities, quaternary as well as Holocene sea-level fluctuation and sedimentation history (Banerji 1984; Hutchison 1989; Achharyya et al. 2000; Goodbred and Kuehl 2000; Morley 2002; Alam et al. 2003; Sikder et al. 2003; Mukharjee, et al. 2009; Jana, et al. 2018). Digha coastal beach is also divided into 15 beaches, viz. from west, beaches are Udaypur (80.32m), Jatranala (1632.9m), Police Holiday Home (304.73m), Larika (656.42m), Hospital (368.90m), Jagannath Temple (170.00m), Aparajita Cottage (342.00m), Blue View (161.60m), 1st Gate (260.30m), Saikatabas (154.51m), Hotel (362.57), Breack (260.00m), Digha Mohana (1662.60m) (Dey and Shukla 2017; Mondal and Dey 2018; Dey and Shukla February 2019).

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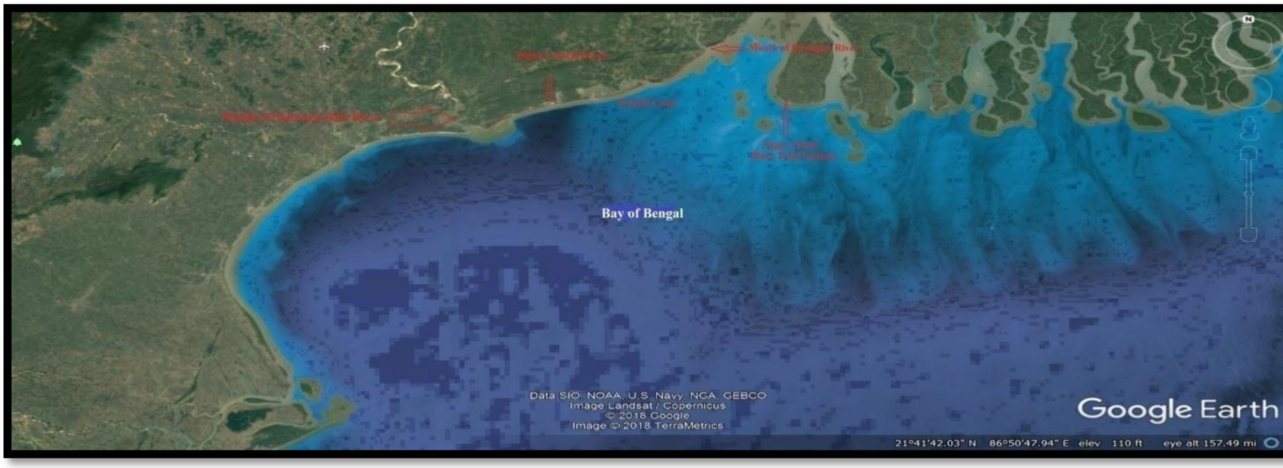

Figure 1: Kanthi Coastal Beach (Source: Google Map) (Dey and Shukla, February 2019)

III. Methodology

The research work has two aspects, viz. (a) quantifying the wave properties or spectrum (b) impact of wave statistical parameters to beach profiling. Primary data has been used to evacuate the wave conditions. Simple wave properties such as wave length (L), wave height (H), wave amplitude (A), relative depth (d), wave period (T), wave frequency (f), radiant frequency (σ), wave celerity (C), wave height during breaking (Hb), crest velocity of breaking wave (Cb) and velocity of breaking wave are quantified according to Airy's Wave theory (1845). Formula of Airy Wave theory applies in shallow water zone. Thus, it is more applicable than Stokes' Wave theory (1847). The said research work has done on basis of primary data. Through the various conventional instruments primary data has been collected in field work e.g. Garmin GPS, Dumpy level etc.

IV. Result And Discussion

Wave Properties

A study of the ocean waves and their characteristics is essential for the design of ocean structures and of energy extraction devices (Faizal et al. 2011). The motion of the waves sets the water particles in orbital motion (Constantin 2001; Sverdrup et al. 2006). The particles do not move with the wave, but oscillate up and down about their individual stable positions (Russell 2001). As the waves are formed, the surface water particles rise and move towards coast with the crest and trough.

When the crest passes, the particles slow down and fall during the forward motion and when the trough advances, particles slow their falling rate and move backward (Faizal et al. 2011). When the trough passes, the particles slow their backward speed and start to rise and move forward with the crest (Constantin 2001). On all natural beaches, processes and morphology are predominantly influenced by waves (Masselink and Short 1993). Whereas the importance of waves is self evident and well documented (Wright et al. 1984, 1985). Thus, the said research paper addresses the wave properties to focus on beach shaping.

1. Wave Length (L)

Length between two successive approximation wave crests and troughs is known as wave length (L). Wave length (L) depends on wave period (T), relative water depth (D), wind direction, wind velocity. Consequential relationship between wave length (L) and wave period (T) is positive. If the wave period is large then the wave length will be large and vice versa. But wave length is gradually increases with the decrease of water depth (D). In addition the wind direction and wind speed positively influence to wave length. in case of short wave length beach will be more erosional due to energy concentration by wave and also in case of larger wave length beach will be accretion of sediments due to less energy flux by wave. Coastal Sea is considers as a shallow water zone. Thus, quantification of wave length of Digha coast is more permissible according to formula of Airy's theory (1845) which is follows. Wave length (L) of Digha coast is 13.91m. Thus, Digha is an Erosional beach and more energy flux on beach due to its' small wave length.

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Wave Length $(L) = T\sqrt{gd}$ ----- (1)

Where, L = Wave length
T= Wave period
g= Gravitational Acceleration (9.81m/s^2)
d= Depth of water

2. Wave Height (H)

Wave height (H) is defined as the vertical distance between crest and trough of a wave. Wave height is controlled by the depth of the water. It increases with decreasing the water depth. In addition wave length is influenced by the orbital motion of water particles. For sinusoidal waves in deep water this orbit is exactly circular and the diameter of the circle at the surface is equal to the wave height and the orbital diameter decreases with depth below the surface and is negligible at a depth equal to Lo/2. (Robin Davidson-Arnott 2010, p.78). Wind velocity and fetch positively influence to wave height. Wave height is measured through following those formulas (2, 3, and 4). The easiest method to measure the wave height is by holding staff.

Mean of the Wave Crest Height $(\bar{C}) = \frac{\sum C}{N}$ --------- (2)

Mean of the Wave Trough Height $(\bar{T}) = \frac{\sum T}{N}$ --------- (3)

Wave Height $(H) = \bar{C} - \bar{T}$ --------- (4)

Mean wave crest height $(\bar{C})$ of Digha coast has been measured 1.035 m and mean wave trough height $(\bar{T})$ is 0.28 m. Average wave height of Digha coast is 0.755 m. According to Short (1991) Digha beach is considered as a higher wave planar beach.

3. Wave Amplitude (A)

Wave amplitude is half of the wave height. The amount of energy carried by a wave which is relate to the wave amplitude (A). Wave amplitude is the positive indicator to wave energy. High wave amplitude refers to high wave potential wave energy and low wave amplitude denotes to low wave energy. Wave amplitude also depends on orbital radius. It refers to the maximum amount of particle displacement on the medium from its rest position. The relationship between wave energy-amplitude is proportional and as well as the amount of particles displacement also. Wave amplitude is related to Energy transport. According to Airy's Wave theory (1845) Wave amplitude has been quantified following the formula (5). Wave amplitude of Digha coast has been measured 0.3775 m.

Wave Amplitude $(A) = \frac{H}{2}$ --------- (5)

where, H = Wave height.

4. Wave Height during Breaking (Hb)

Ocean wave propagates on a sloping beach begin to slow down and during this time wave height increases to maintain a constant energy flux until breaking occurs. This breaking occurs when the wave amplitude has reached a critical point (H/L = 1/7 = 0.147) at which wave becomes unstable. According to Stokes' Wave theory predicts that when the angle at the wave crest reaches 120 the wave form becomes unstable and it breaks (Pethick 1984 p.26). The top of the wave then overturns and falls onto the front face of the wave and during this process a large portion of the wave energy is converted into currents and turbulent kinetic energy (Mukaro et al. June 2013). The breaking process generates eddies while a large amount of air bubbles is entrained into water downstream of the breaking point (Hoque 2008). The wave height during breaking (Hb) has been quantifying by following formula (6). Average wave height during breaking (Hb) is quantified as 0.755 m.

Wave Height during Breaking $(Hb) = \bar{C}b - \bar{T}b$ --------- (6)

where,
$\bar{C}b$ = Wave crests height during breaking.
$\bar{T}b$ = Wave troughs height during breaking.

5. Relative Height

Relative height is the ratio between wave height (H) and depth of the water (D). The following formula has been used to measure the relative height. Relative height of Digha coast is 1.8 m.

Relative Wave Height $= \frac{H}{d}$ --------- (7)

6. Depth of Water (d)

According to Airy's wave theory (1845) depth of water (d) is measured by following formula (8). It could be measured by holding staff. About 0.66 m water depth has observed.

Depth of water $(d) = \frac{\bar{C} - \bar{T}}{2}$ --------- (8)

7. Relative Depth

Ratio between length of wave (L) and depth of water (d) is known as relative depth. Relative depth is 0.22 m.

Relative Water Depth $= \frac{d}{L}$ --------- (9)

International Journal of Recent Development in Engineering and Technology
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8. Wave Period (T)

The wave period (T) is defined as a time between two successive wave crests to pass a fixed point. The wave period is controlled by depth of water. In addition direction of wind, wind velocity, and fetch also influence the wave period. Wave period is associated with wave velocity. The relation between wave period, wave velocity and wave length is proportional but the relation between wave period and wave height is inversely proportional. Following the formula (10) is being used to measure for wave period. Period between two successive waves in Digha coast is 8.11 secs.

Wave Period $(T) = 2\Pi$ --------- (10)

9. Wave Frequency (f)

Wave frequency defined as the no. of occurrence of wave per second in a fixed point. Hz is the measuring unit of wave frequency. Relation between wave frequency and wave period is inversely proportional and also has a negative relation with water depth, wave length. Wind direction and velocity both is main controller of it. It has been quantified by the following formula (11). Wave frequency of Digha coast is 0.12 Hz.

Wave Frequency $(f) = \frac{1}{T}$ --------- (11)

10. Wave Number (λ)

Wave number or repentance of wave is indices to spatial frequency of a wave. It measures per unit distance in radians or in cycle. Here temporal frequency can be considered as the number of passing waves per unit time and wave number is the number of waves per unit distance. According to Airy's wave theory (1845), it could be calculate by following formula (12). Wave number is inversely proportional to wave length. Wave number (λ) of Digha coast is 0.45.

Wave Number $(\lambda) = \frac{2\Pi}{L}$ --------- (12)

11. Radiant Frequency (σ)

Radiant frequency is the overall wave where the wave is form to marginal, where the wave gives the strike. The total wave is called radiant frequency. Radiant frequency of Digha coast is about 0.77.

Radient Frequency $(\sigma) = 2\Pi f$ --------- (13)

12. Wave Celerity (C)

A wind wave is a progressive wave in which the wave form advances across the water surface and the speed at which it travels is the wave celerity (C) (Robin Davidson-Arnott 2010, p.54). Wave celerity at which the wave travels is given by the ratio of wave length and wave period. Airy theory gives a fundamental relationship between wave lengt6h and wave period (Pethick 1984 p.11) via wave celerity. Average velocity of Digha coastal wave is 1.72 m/s.

Wave Celerity (C) $= \frac{L}{T}$ --------- (14)

Or Wave Celerity (C) $= \sqrt{gd}$ --------- (14)

13. Crest Velocity of Breaking Wave (Cb)

Crest velocity of breaking wave is very important to evacuate the energy flux account on beach. It is a positive indicator of wave energy. Crest velocity of breaking wave is 3.85 m/s which is very high than the wave celerity. It indicates to high energy flux on beach.

Crest Velocity of Breaking Wave $(Cb) = \sqrt{2g.Hb}$ --------- (15)

14. Velocity of Breaking Wave

The ratio between wave length of breaking wave (Lb) and Period of breaking wave (T) is known as velocity of breaking wave. It is a positive influencer of wave energy flux on beach. After collapsing, wave velocity of Digha coast is about 1.72 m/s.

Velocity of Breaking Wave $= \frac{Lb}{T}$ --------- (15)

Relation between Wave Length, Period, Celerity

According to Tricker (1964) Airy wave theory gave the fundamental relationship between wave lengths, wave period and wave celerity. The aforesaid relation seems on two sub relationship e.g. wave length vs. wave period and wave velocity vs. wave period. The relationship between wave length and wave period can be formulated by the following formulas (16, 17, and 18).

$L = \frac{g.T^2}{2\Pi} r$ --------- (16)

$r = \tanh \frac{2\Pi d}{L}$ --------- (17)

where, tanh = The hyperbolic tangent.

$L = 1.56\,T^2$ --------- (18)

The measurement of wave period is relatively easy than wave length. Thus, wave length can be measured from the following formula (19).

$C_0 = \frac{L}{T}$ --------- (19)

then, $C_0 = 1.56\,T$

Wave length depends on the square of wave period. It has been concluded that small augmentation of wave period (T) is associated with increase of length.

Long wave occurs during storm and move faster. In variety of different periods and in a confused sea, long faster wave gradually emerge ahead of the shorter wave due to high velocity. Long wave travels fast than a short wave and long wave losses less proportion of energy than short wave. Therefore, long wave much employed on coastal morphodynamics than short wave. Generally open sea beach gets long swell wave and also closed or semi closed sea beach gets short wave. Digha coast is characterized by short to medium wave length and medium wave celerity.

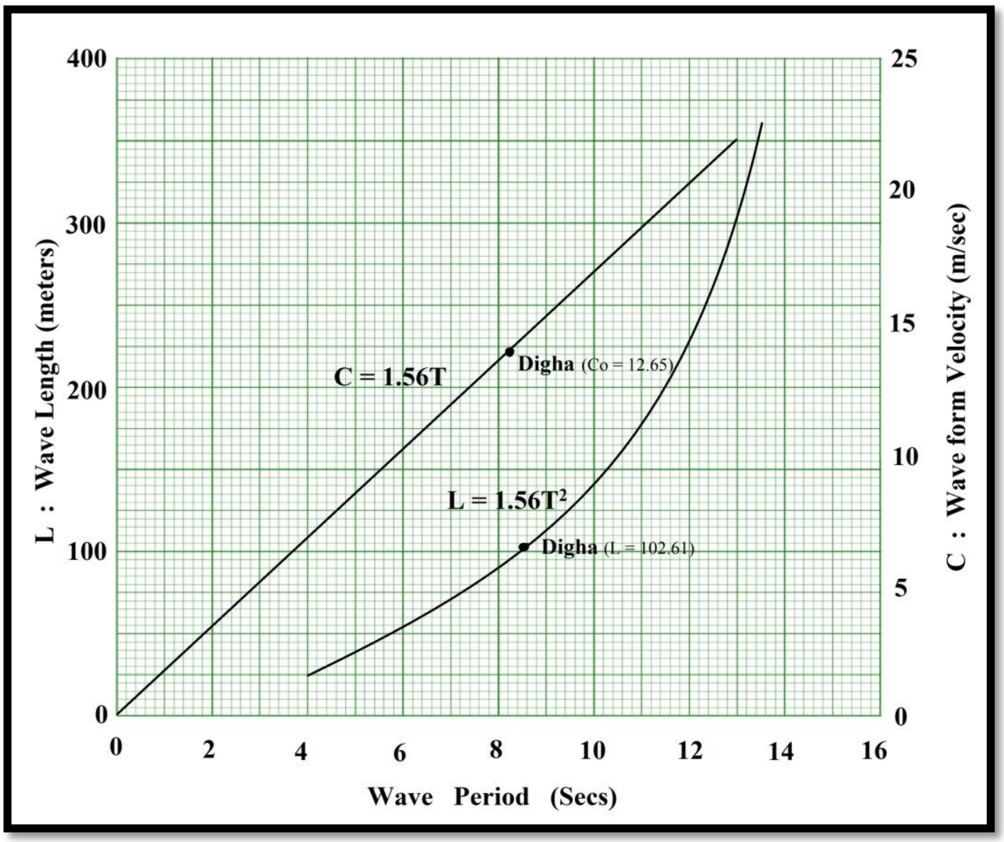

Figure 2 The Relation between Wave Celerity (C), Length (L) and Wave Period (T) (According to Airy Wave Theory 1845)

Wave Steepness

Wave steepness is a ratio between wave height (H) and wave length (L). In addition, water depth wind velocity etc directly influence to wave steepness. If the wave height is more than the wave length then the wave steepness is high but the wave height is less than the wave length then the wave steepness will be less.

$\text{Wave Steepness} = \frac{\text{Wave Height during breaking } (H)}{\text{Wave Length } (L)}$ -------(20)

Wave steepness is a controlling parameter to beach erosion. Relation between wave steepness and beach erosion is proportional.

IJRDET

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According to Airy wave theory (1845), Waves whose steepness exceeds 0.14 (1/7) become unstable and collapse; in practice waves with steepness greater than 0.1 are rarely encountered while at the other extreme few waves are less steep than 0.056 (1/18) (King 1972; Pethick 1986, p.15). Wave steepness of Digha coast is 0.05.

Wave Energy (E)

A wave is an energy transport phenomenon which transports energy towards coast along a medium without transporting water particles. The wave energy could exist in two forms viz. Potential and Kinetic energy. Potential energy occurs due to the deformation of wave on still-water surface and also kinetic energy forms due to the orbital movement of water as wave. Airy wave theory predicts that these two forms of energy are equal and the total of these is directly related to the square of wave height (Pethick 1986, p.15). The following expression (21) is to quantify the energy of per unit wave crest. Wave energy of Digha coastal wave is 0.87 J.

Wave Energy (E) $= \frac{1}{8}\rho g H^2$ --------- (21)

where, ρ = Water Density (1024 Kg/m^3)

Wave Energy Flux (P)

A single wave does not move at the same rate in a group. In fact individual waves move twice as quickly as the group in deep water so that a single wave can be seen progressing through the group and disappearing at the front to be replaced by a new wave at the rear (Pethick 1986, p.16).

The flowing formula (22) is been express to measure this group velocity for the rate of energy flux on beach. Amount of wave energy flux on Digha coastal beach is 1.4877 J/m/s.

Wave Energy Flux or Wave Power (P) $= ECn$------- 22)

Beach Profile

Energy moves towards coastal beach via wave without displacement of water particles. After collapsing of wave, energy flux on beach. Some energy also reflect back to sea on the basis of beach slope after dissipate. Small gentle waves and swell tend to build up beaches, whereas storm waves tear them down (Paul 2002, p.85). Digha, the open coast receives high proportion of long swell wave. The long Swell waves of Bay of Bengal have travelled considerable distance. Length of the long swell wave is gradually decreased in the shallow water. During storm time, cyclone time and high speed wind, long wave occurs and hits to coast. Wave approaching the shore in the southerly and easterly wind have longer fetch (500-900 km) than the approaching waves in the southwesterly wind, which have comparatively a shorter fetch (250-400 km) in the coast of West Bengal (Paul 2002, p.86). According to M. O. Hayes, 1979; Davis and Hayes, 1984; Paul, 2002 it has been revealed that Beach geomorphic stability is controlled by wave energy. High wave energy occurs unstable beach condition and vice versa. In addition wave energy shapes the beach profile. Digha coast is characterised by moderate to high wave energy condition. Consequently Digha coast is being shaped as concave pattern due to winnowing of sediment by wave.

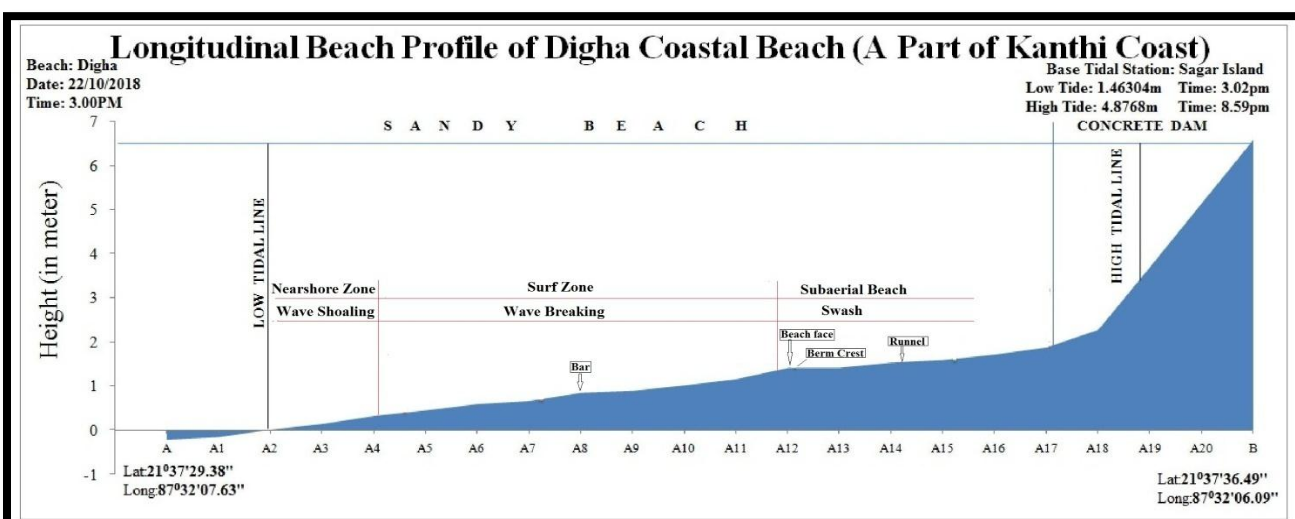

Figure 3 Longitudinal Beach Profile of Digha Coast (A Part of Kanthi Coast) (Dey and Shukla, February 2019)

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V. CONCLUSION

Waves at sea are usually smooth, sinusoidal shapes (Dey 2018, p.148). The waves of the real sea are generated by wind and nearly every wave differs from its immediate predecessors in height, period, and shape (Harris August 1976, p.10). The aim of this study is to determine the statistics of wave properties of Digha coast and its impact on longitudinal beach shaping. The calibrating parameter is wave power flux rate on beach. Results of wave power estimation in the entire domain represent that the Digha coast is characterized by medium to high wave energy flux condition. The investigation of the textural characteristics revealed that the size distributions of the mean values are indicates the dominance of fine grained nature (Parthasarathy et al. 2016) and also well sorted platform (Dey and Shukla 2019). Therefore, the percolation rate of Digha coast is very low. Consequently the concave shape beach faces the high erosion for dissipate of medium to high wave energy. At the end it is concluded that Digha coastal beach is considered as a Dissipative Beach according to beach model of Wright and Short (1984).

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