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Simulation of the Evolution of Cross-Shore Beach Profiles using SBEACH Modelling

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Abstract:- Coastal erosion significantly threatens sandy beaches worldwide, impacting coastal communities and ecosystems. This research investigates the application of SBEACH (Storm-induced BEAch Change), a numerical beach modelling computer programme, as a tool for coastal engineers to predict beach profile evolution in response to wave and tidal actions. The study used SBEACH simulations to explore the equilibrium beach profiles under varying conditions, including wave height, wave period, sediment grain size, and beach slope.

This study also examined the effects of storm tides on equilibrium profiles and proposed protective sand dunes' dimensions to safeguard against storm surges.

This research highlights SBEACH's potential as a valuable tool for assessing and planning coastal erosion mitigation strategies. While SBEACH provides insights into cross-shore beach profile dynamics, combining it with GENESIS offers a more comprehensive approach to coastal management. However, it is crucial to consider real-world engineering experience and safety factors when deciding on beach stabilisation and protection measures. Coastal countries can benefit from such modelling approaches to better manage and protect their sandy beaches, which play a crucial role in coastal defence and maintaining ecosystem integrity.

Keywords:- *Cross-Shore Transport, Depth of Closure, Deterministic, Irregular Waves, Littoral Drift, Long-Shore Transport, Monochromatic Wave, Reach, Stochastic, Swash Zone.*

I. INTRODUCTION

One of the major problems faced by the world's sandy beaches is erosion by the action of waves and tides. Since beaches act as a natural buffer between the sea and coastal lands by dissipating or reflecting wave and tidal energy, erosion of sandy beaches is of great concern to people living along the coast (Komar, p. 4; Shore Protection Manual, Vol. 1). The researcher has observed the effects of erosion on coastal lands in Guyana where the buffering beach has been either reduced or removed. (Plates 1 – 3). In many places, beaches also serve as buffers between the sea and sea defence structures such as concrete seawalls and rock armour that protect coastal areas from flooding. Coastal and maritime countries must implement the best beach management practices. The use of SBEACH could serve as one of these best practices.

Plate 1: Fine Sand Beach, High Water Berm, and Coconut Plantation at Wellington Park, Guyana. (Photo: Hackett, 2008)

Plate 2: Berm Covered by Seashells Indicates the Reach of High-Water Spring.
(Photo: Hackett, 2008)

Plate 3: Erosion of Topsoil at Berm. Agricultural Lands in the Background.
(Photo: Hackett, 2008)

- *What is SBEACH?*

"SBEACH" is an acronym for Storm-induced BEAch Change, a numerical beach modeling computer programme. The U.S. Army Corps of Engineers initially developed it, and it was further developed by Veri-Tech Inc (now Veritech Enterprises, LLC). It is used to simulate the two-dimensional cross-shore evolution of beach profiles caused by the action of waves and tides. It is programmed to assume that changes in the beach profile are due to cross-shore transport and not to long-shore transport and that non-cohesive sediment can move up and down along the profile but not beyond the depth of closure. Hence, there should be no net loss of sediment from the profile. Since it only simulates a two-dimensional cross-section of the beach profile, it also assumes that the beach being modelled has the same profile along its long-shore length so that any changes the model simulates are applicable along that beach. (SBEACH, 2006, 2020, 2023).

It is used by coastal engineers working on beach management schemes to investigate how beach profiles may be eroded, built up, or otherwise changed by wave and tidal action. It enables them to predict possible responses of the profile to environmental conditions so that protective measures may be taken where necessary. It is also used as a guide in beach nourishment to determine the volume of sand needed and its placement on a beach threatened by erosion.

An initial profile, linear or non-linear, and protective sand dunes are set up in SBEACH, and the evolution of the profile is simulated under varying combinations of sediment type, wave and tidal action, and other parameters to see how the profile responds. Parameters to be input into SBEACH include beach profile characteristics, sediment data, wave and tidal conditions, storm data, wind conditions, and the presence or absence of a seawall. These parameters are taken from empirical data obtained in the field. Alternatively, simulated data, but based on reality, can be input. The model is then set to run, taking from several seconds to several minutes to reach the final output profile, depending on the duration set by the researcher.

Because SBEACH does not simulate all possible real-world parameters and processes that can influence beach evolution and because many real-world processes are stochastic rather than deterministic, its predictive value is subject to limitations. Its results should only be used as a guide, along with other engineering tools and experience, to decide on optimum beach management practices.

II. METHODOLOGY

Initially, trial and error experiments were done with SBEACH to understand how it works, how beach profiles respond to parameter changes, and how they evolve toward equilibrium. After these initial runs and reading the relevant literature, the researcher defined the equilibrium beach profile as a constant net profile reached after a specific time duration for a given beach under given conditions. Although the profile is constant in shape, this does not mean that sediments are stationary and are not being transported cross shore. The profile is in a state of dynamic equilibrium where the upward and downward cross-shore movements of sediment are balanced, being of equal quantities per unit time so that there is no net change of the profile in the zone between the depth of closure and the swash zone, called the active zone. In other words, there is no net long-term littoral drift and no loss or gain of sediments from the beach (Komar, p. 249; Silvester, II, p. 24).

➢ *In Summary, the Main Operational Assumptions of SBEACH are:*

- There is no movement of sediment seaward beyond the depth of closure.
- Cross-shore sediment transport occurs in the active zone.
- Long-shore sediment transport is uniformly parallel to the beach profile.
- The model is valid only for non-cohesive or sand particles with grain sizes 0.10 mm to 1.0 mm.
- A long-term equilibrium profile exists for a given sandy beach under given wave conditions.

➢ *Setting up Simulations and Model Runs*

Using the provided parameters of starting slopes (1:20 and 1:10), grain sizes (0.15 mm, 0.35 mm, and 0.90 mm), constant wave heights (3.0 m and 6.0 m), constant wave periods (10.0 s and 15.0 s), and constant water levels, simulations for twenty-four different combinations of these parameters were done using (a) monochromatic waves and (b) irregular waves.

The initial profiles, for example, in Figure 1, were set up in MS Excel Spreadsheet and then imported into the reach, i.e., profile input, in SBEACH. Each combination was then set to run until an equilibrium profile was reached using the maximum time duration available on SBEACH and with a time step of 10 minutes, as recommended in the Help file. In many cases for monochromatic waves, equilibrium was reached very quickly, so the run was stopped, and some fine-tuning was done to the number of time steps to determine the time required to achieve equilibrium. No discernible changes were seen in the initial profile in four cases with mono-waves.

The first combination (slope 1:20; grain size 0.15 mm; wave height 3 m; wave period 10 s) reached a definite equilibrium profile (Figure 2) for monochromatic waves in 200 hours with a run-time of about 2 seconds. When the same combination was subjected to irregular waves, it ran for the maximum number of 999,999 times steps (= 166,666 hr). At the same time, the profile changed continuously, albeit very slowly, nearing the end of the run. The profile attained was very much different from that obtained with mono-waves. The run-time was about 6 minutes. To find a possible equilibrium profile, a run was made with a time step of 60 minutes for 166,666 time steps (= 166,666 hr). The run-time was a little over 1 minute. The final profile reached was almost identical to the previous profile in general shape and extent and, like the previous one, changed very slowly, nearing the end of the run. A correlation comparison of the two profiles using MS Excel graphs yielded a coefficient of determination $R^2 = 0.935$, indicating a very strong similarity between the two profiles (Figure 3). Given that both profiles changed very slowly near the end, they can be approximate equilibrium profiles for the first combination under irregular waves. Because of the difficulty of estimating equilibrium from the model in this case, the figure of 166,666 hr is not precise; it merely indicates that the model has reached maximum duration for a time step of 10 minutes.

Model runs for the other twenty-three combinations of monochromatic and irregular waves, searching for equilibrium profiles and adjusting and fine-tuning the time steps, continued in the same manner until all the runs were completed.

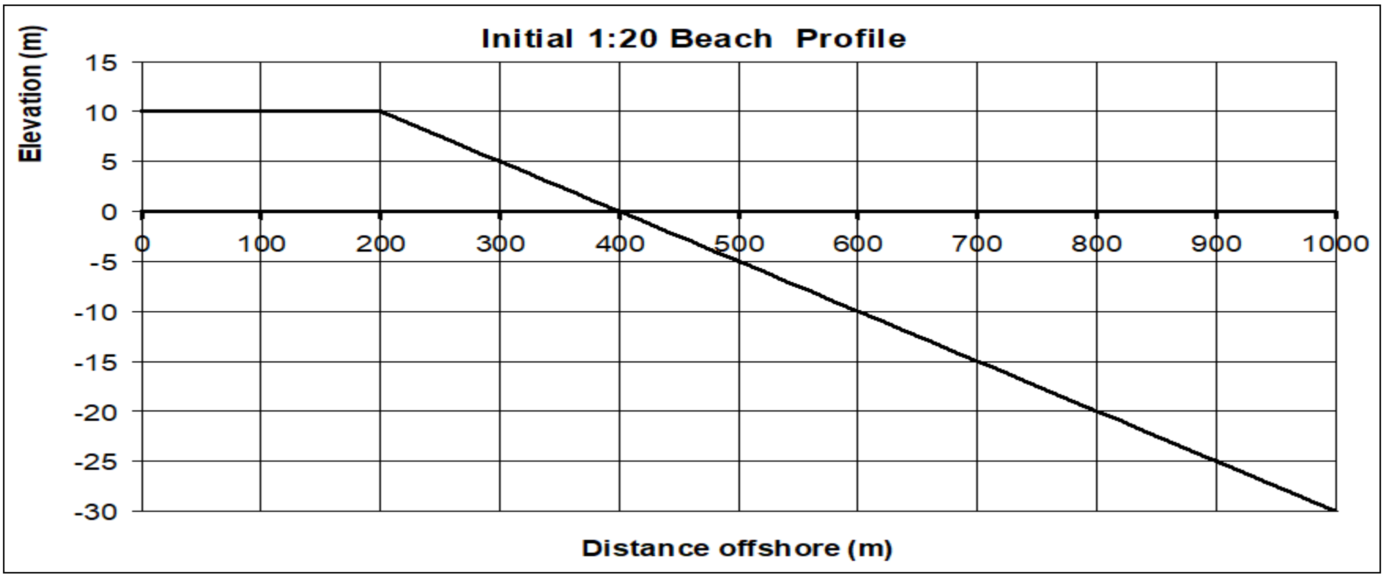

Fig 1: Initial 1:20 Beach Profile

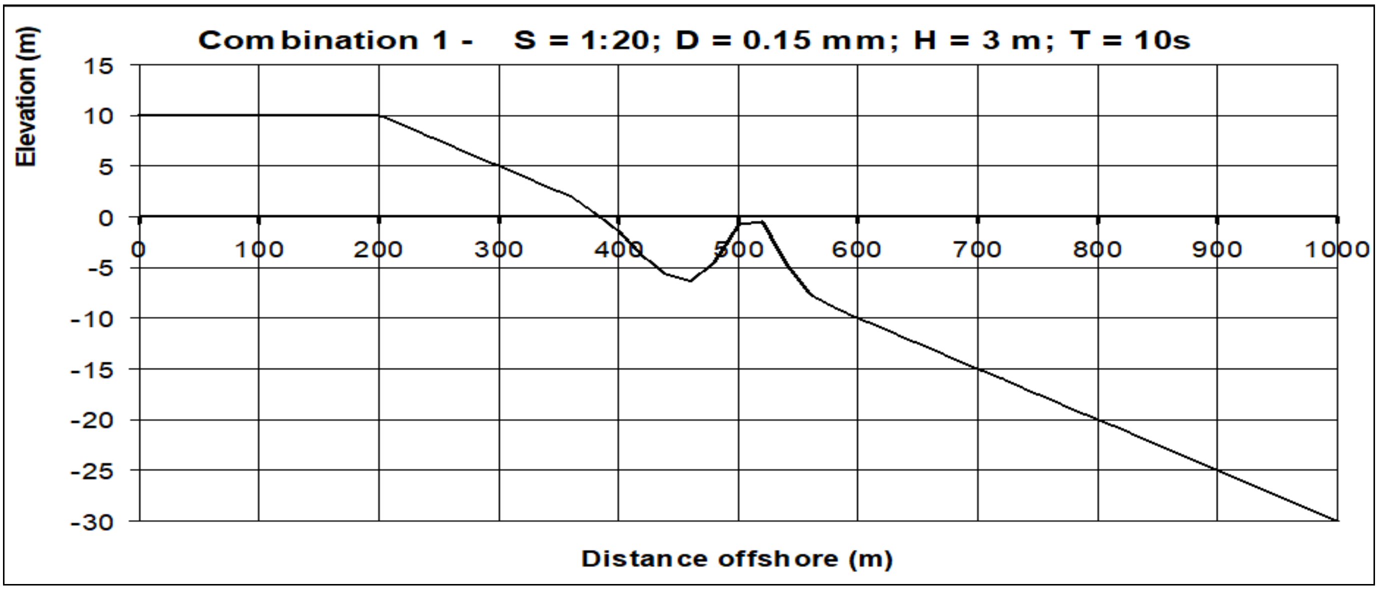

Fig 2: Equilibrium Profile for Combination 1

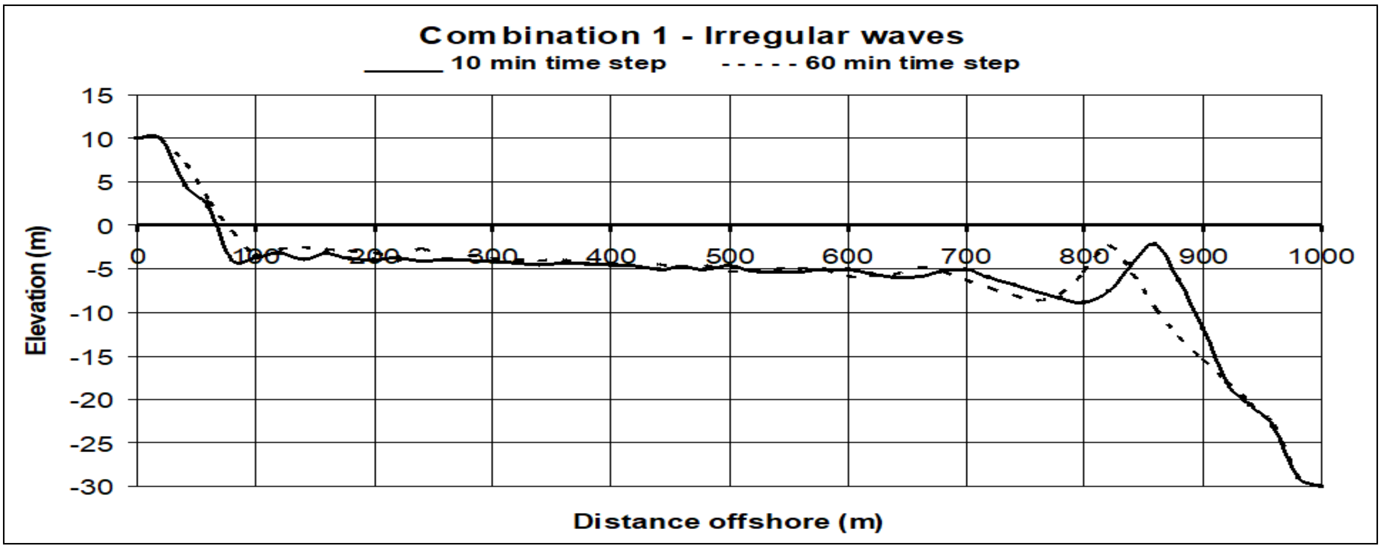

Fig 3: Combination 1 – Irregular Waves for 10-Min Time Step and 60-Min Time Step

III. RESULTS

Table 1: Combinations and Time Taken to Reach Equilibrium
Entire Profile Inundated (EPI) in … hr

Combination	**Slope**	**Grain Size/mm**	**Wave Height/m**	**Wave Period/s**	**Time to reach equilibrium profile/hr**	
					Monochromatic	**Irregular**
1	1:20	0.15	3	10	200	166 666
2	1:20	0.35	3	10	275	100 000
3	1:20	0.90	3	10	300	140 000
4	1:20	0.15	6	10	9 000	EPI 18,000
5	1:20	0.35	6	10	8 000	EPI 130 000
6	1:20	0.90	6	10	12 000	50 0000
7	1:20	0.15	3	15	200	EPI 65 000
8	1:20	0.35	3	15	6 000	75 0000
9	1:20	0.90	3	15	800	No change
10	1:20	0.15	6	15	17 000	EPI 12 000
11	1:20	0.35	6	15	25 000	EPI 30 000
12	1:20	0.90	6	15	28 000	166 666
13	1:10	0.15	3	10	300	EPI 45 000
14	1:10	0.35	3	10	No change	50 000
15	1:10	0.90	3	10	No change	100 000
16	1:10	0.15	6	10	80	EPI 5 600
17	1:10	0.35	6	10	80	EPI 9 300
18	1:10	0.90	6	10	80	166 666
19	1:10	0.15	3	15	500	EPI 20 000
20	1:10	0.35	3	15	No change	EPI 97 000
21	1:10	0.90	3	15	No change	100 000
22	1:10	0.15	6	15	2 800	EPI 4 100
23	1:10	0.35	6	15	2 000	EPI 5 300
24	1:10	0.90	6	15	26 000	EPI 166 666

IV. DESCRIPTION OF BEACH PROFILES

The combinations and time taken to reach equilibrium are summarised in Table 1 above. No profile change happened for monochromatic waves in Combinations 14, 15, 20 and 21. This suggests that these beach slopes reflected the wave energy due to the relatively large grain size of 0.35 mm and 0.90 mm and the steeper slope of 1:10, as well as the fact that the incident waves consisted of a very narrow energy spectrum of the low-energy 3.0 m waves.

The other slopes that responded with profile changes to mono-waves to attain equilibrium (or an approximation) are dissipative slopes. These were able to dissipate the wave energy by two mechanisms: (i) causing them to break when they enter the surf zone where a lot of energy is dissipated, (ii) absorbing the energy from the orbiting water particles at the bed and using the energy for the cross-shore transport of sediments. All the milder 1:20 slopes responded this way, indicating that milder slopes are better at dissipating wave energy than steeper slopes (Silvester, 1, pp 240 – 249).

Also, for monochromatic waves, slopes with the smallest grain size and/or lower wave height (wave energy $\propto$ wave height^2) reached equilibrium in the shortest time. This is because the low-energy waves easily move the smaller grains. Those with the largest grain size and/or greater wave height took longer to reach equilibrium. This is because waves do not so easily move larger grains, and it takes longer for high-energy waves to dissipate their energy.

For the irregular waves, it is seen that the situation is more highly energetic because these waves have a broader energy spectrum since the irregular wave height used in SBEACH is the significant wave height, the average height of the highest one-third of all incoming waves (Waves, Tides and Shallow-water Processes, p. 13). Hence, there will be waves of greater and lower heights than the average, and these will have a greater impact on the beach than mono-waves. This is why thirteen of the initial profiles experienced total erosion and inundation when subjected to irregular waves. Of these, nine were struck by the high-energy 6-m waves and four by the low-energy 3-m waves. Twelve of these inundated slopes consisted of 0.15 mm and 0.35 mm grains, which are less able to dissipate wave energy than the much larger 0.9 mm grains. The lone 0.9 mm grain slope that eroded completely was hit by 6-m waves, and this happened at the very end of the simulated duration of 166,666 hr. The four inundated slopes incident by 3-m waves comprised the lighter 0.15 mm grains.

These simulated results are generally expected of SBEACH since the programme was designed from empirical observations of flume experiments. Limited though it might be, the results still bear some resemblance to real-world observations on real-world sandy beaches. For example, the steeper slopes with the largest grain size were better able to withstand wave action and dissipate/reflect energy (Dean, p. 4).

V. EFFECT OF STORM TIDE ON AN EQUILIBRIUM PROFILE

The final equilibrium profile for Combination 3 was selected as the new equilibrium profile (Figure 4) to be subjected to the idealised storm tides of (a) 3 m and 12 hours and (b) 3 m and 24 hours (Figures 5a & b), modelled on the positive half wave of a sine function over 180º (= π radians).

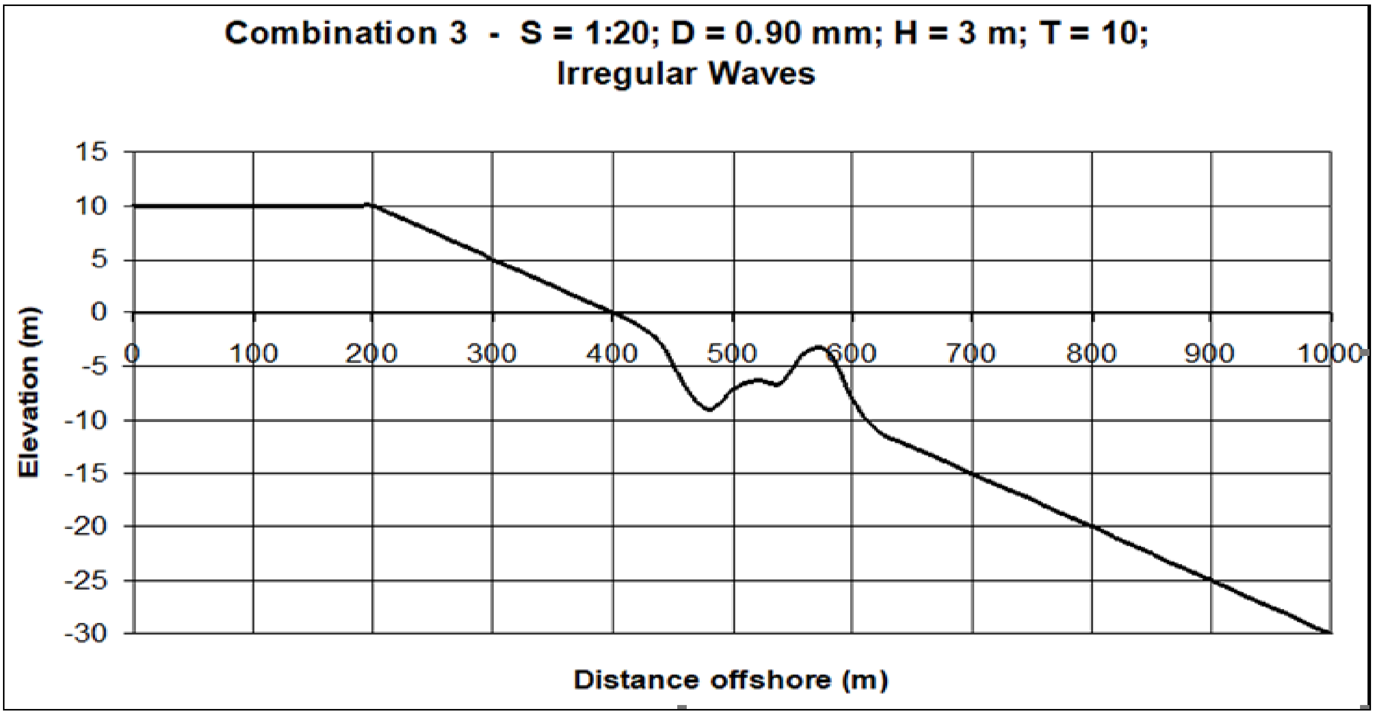

Fig 4: Combination 3 - New Equilibrium Profile to be Subjected to Irregular Waves

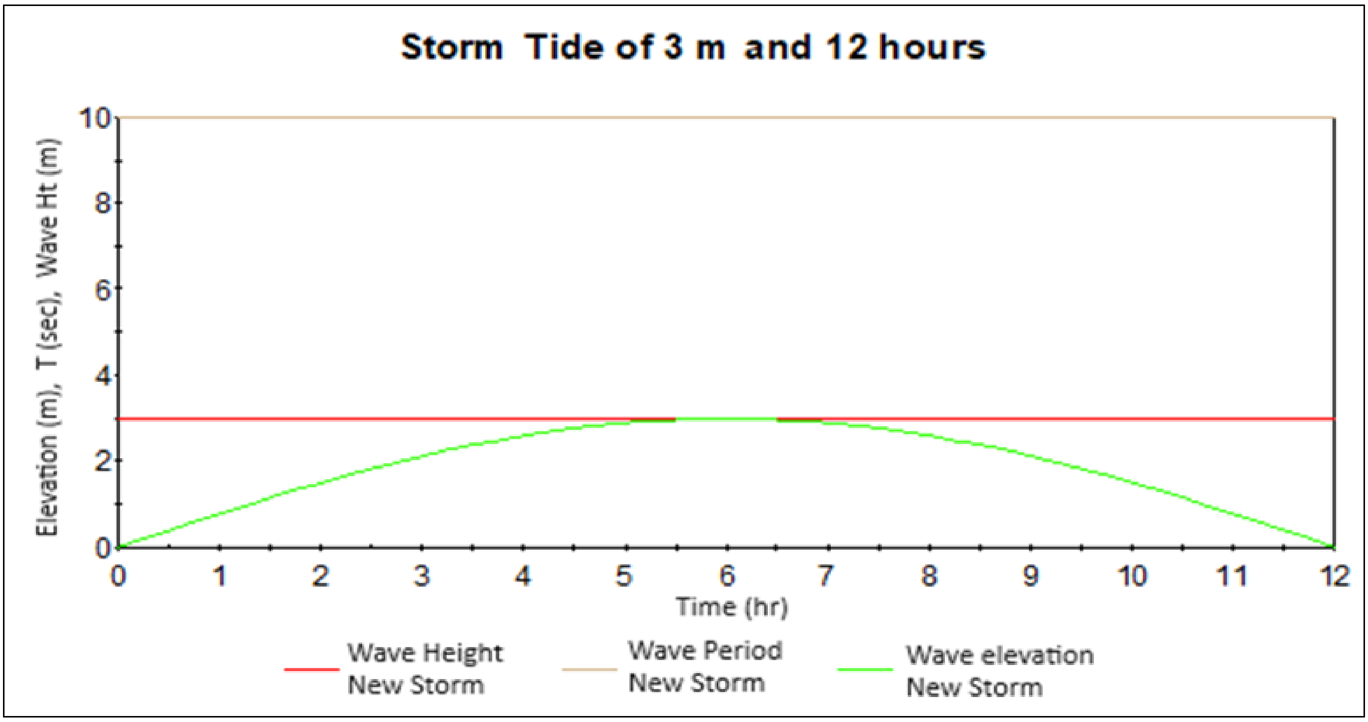

Fig 5(a): Idealised Storm Tide of 3 m and 12 Hours

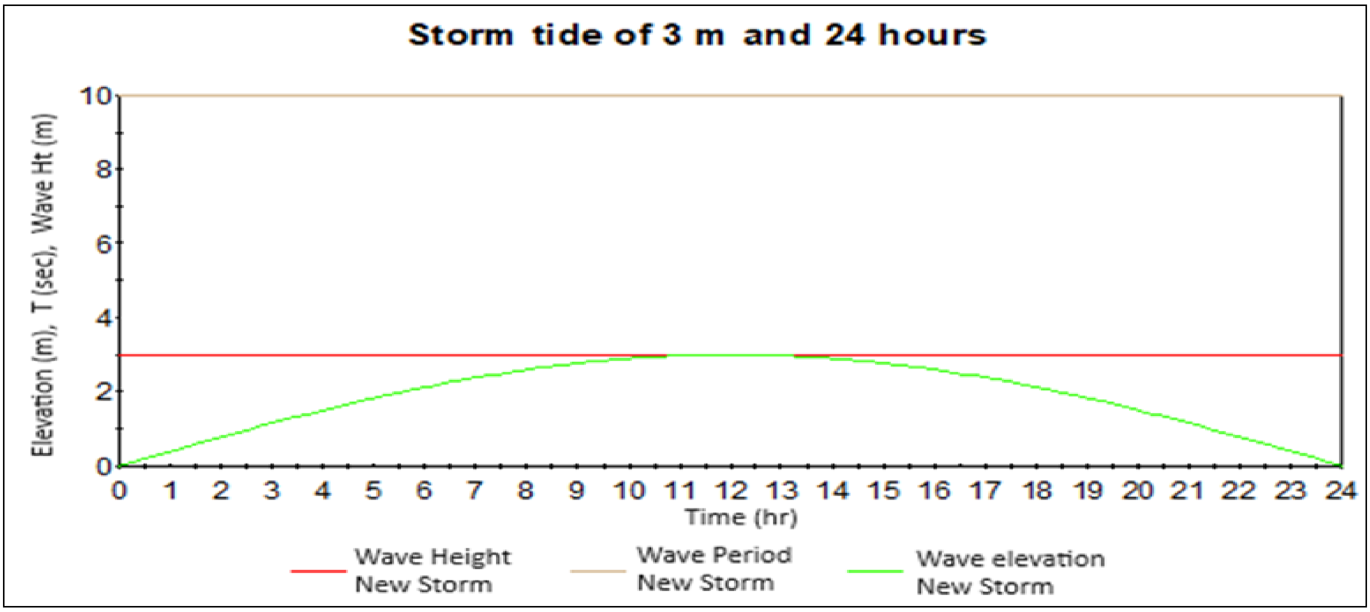

Fig 5(b): Idealised Storm Tide of 3 m and 24 Hours

- *Combination 3 was Selected as the Equilibrium Profile Based on the Known Features of Equilibrium Beach Profiles:*

- “They tend to be concave upwards,
- “Larger sand diameters are associated with steeper slopes,
- “The beach face is approximately planar,
- “Steep waves result in milder slopes and a tendency for bar formation” (Dean, p. 2)

Figures 6 a & b below show the resultant profiles (in broken lines) after the initial profiles were subjected to the storm tides. The final profiles differ a little. This is because the mild slope, large grains, and the offshore bar effectively dissipate the combined energy of the storm tide and the prevailing wave conditions.

A. *Protective Sand Dunes*

A sand dune of minimum height to protect against the two storms will have to protect against the 24-hour storm since it is of longer duration. Several SBEACH trials were done using dunes of trapezoid cross-section in the initial profile, which was subjected to the 3-m 24-hour storm tide. The dimensions of the dune were gradually reduced until storm waves just began to overtop the dune and wash over on the leeward side. Using the reach and output parameters in SBEACH, this minimum dune size was found to be of height 4 m, base width 100 m, and crest width 20 m. To determine a safety factor for the dune, its height and width gradually increased until there was no danger of the storm tide overtopping it. These dimensions were found to be of height 7 m, base width 120 m, and crest width 40m (Figure 7).

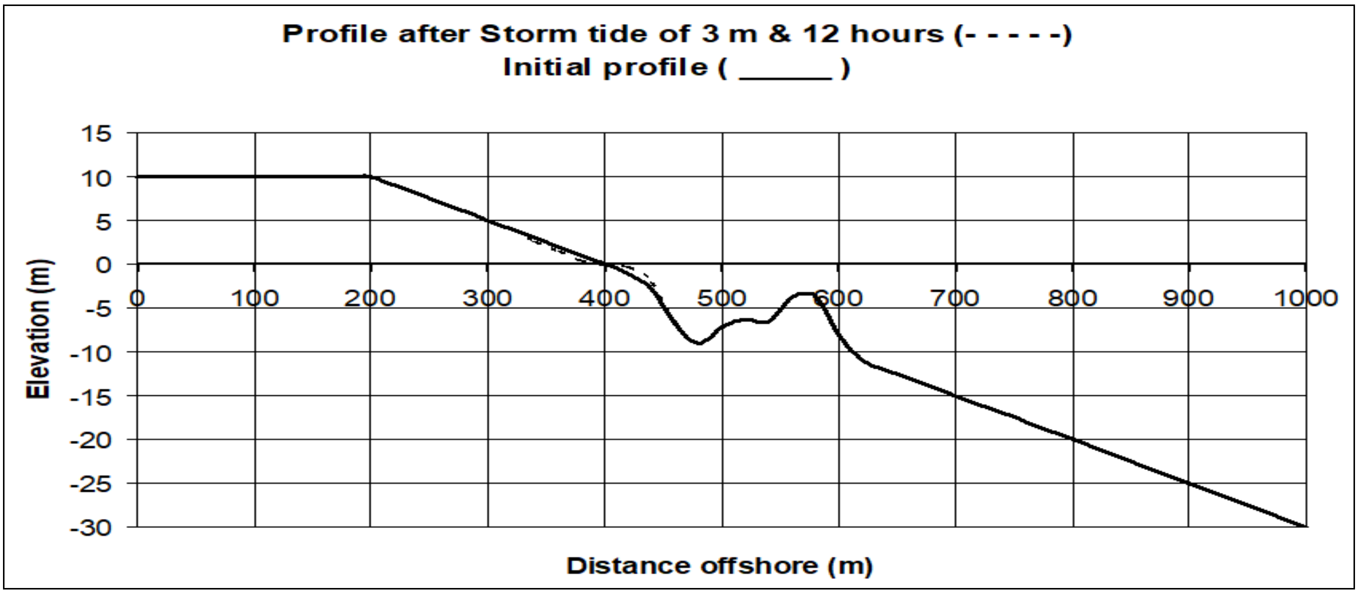

Fig 6(a): Resultant Profile after Storm Tide of 3 m and 12 Hours

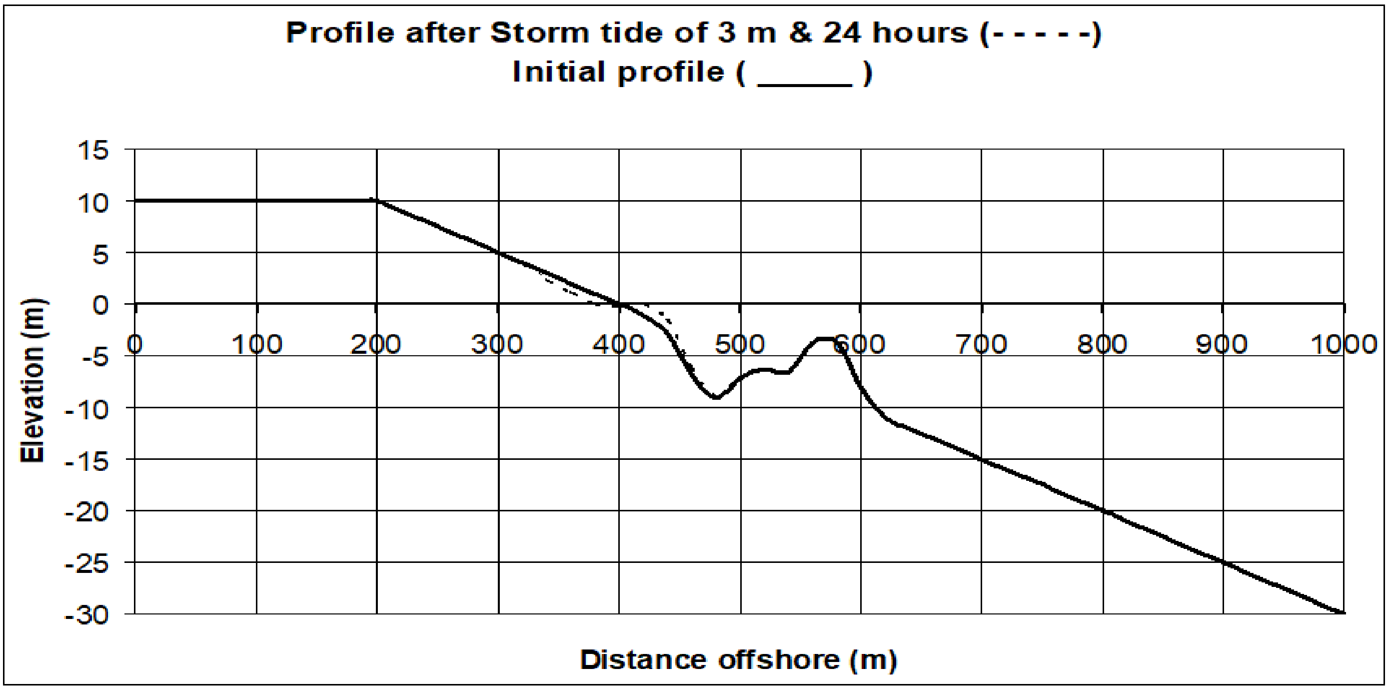

Fig 6(b): Resultant Profile after Storm Tide of 3 m and 24 hours

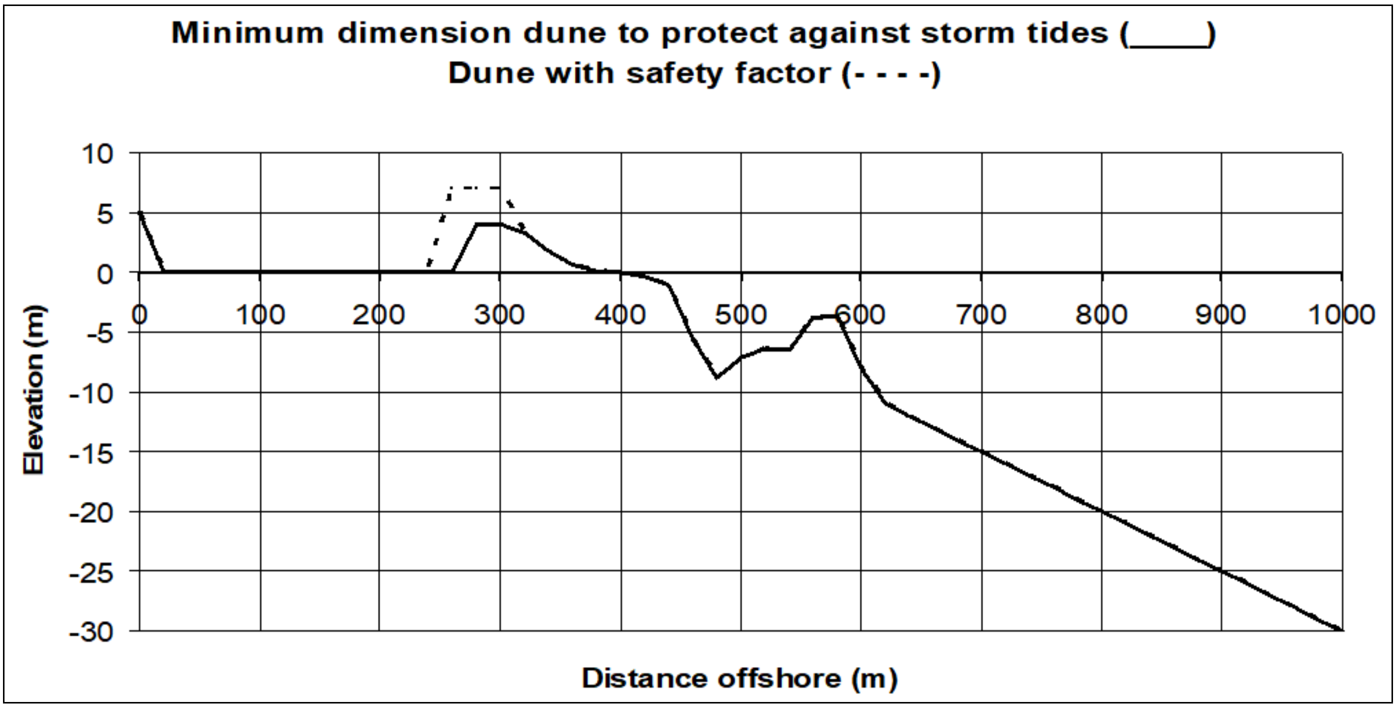

Fig 7: Minimum Dimension Dunes to Protect Against Storm Tide & With Safety Factor

B. *Using GENESIS with SBEACH*

One limitation of SBEACH is that it is only a two-dimensional cross-shore model. It does not model long-shore sediment transport and changes in longshore contours; it simply assumes that long-shore transport is constant along the beach contours, whereas on natural beaches, long-shore transport and contours vary continuously over time. So SBEACH would be unable to predict long-shore changes, and prediction or information on these to decide on the volume of material would be necessary to plan and design good beach management practices.

This is where GENESIS (GENeralised model for Simulating Shoreline change) comes in useful. Like SBEACH, GENESIS is a numerical modelling programme that simulates beach changes. Still, it is designed to calculate only shoreline changes caused by long-shore transport, not cross-shore changes, as SBEACH does (GENESIS Overview, 2023). It assumes that the cross-shore beach profile does not change so that it can predict longshore changes (SBEACH, 2023). It can be said to be the opposite of SBEACH, and the two models can complement each other.

VI. CONCLUSION

SBEACH gives the beach profile from which the cross-sectional area can be calculated. For example, the cross-sectional area of the trapezoid dunes, or any shape cross-sectional area, can be readily calculated. GENESIS would give the shape and length of the longshore contours. Using the basic concept that volume = cross-sectional area × length, the volume of beach material can be easily determined. So, SBEACH and GENESIS are used to predict cross-shore and long-shore changes, respectively, and in doing so, they can effectively complement each other in designing long-term beach management projects. With the caveat that they are only numerical simulations with limitations, safety factors and real-world engineering experience should always be adhered to when making final and accurate beach stabilisation decisions.

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REFERENCES

[1]. Dean, R. G. (1990). Equilibrium Beach Profiles: Characteristics and Applications, Coastal and Oceanographic Engineering Dept., University of Florida.
[2]. Komar, P. D. (1976) Beach Processes and Sedimentation, New Jersey: Prentice Hall, Inc.
[3]. Silvester, R. (1974) Coastal Engineering, I & II, Amsterdam: Elsevier Scientific Publishing Co.
[4]. Shore Protection Manual, Vol. 1, 4th Ed. (1984). CERC, Department of the Army, US Army Corps of Engineers.
[5]. Waves, Tides and Shallow-Water Processes. (1989). Oxford: Open University, Oceanography Course Team.
[6]. SBEACH Help Files, CEDAS-SBEACH Version 4.03. (2006). Vicksburg: Veri-Tech Inc.
[7]. SBEACH, CEDAS TECHNICAL REPORTS. (2023)https://www.veritechinc.com/support/downloads/cedas-reference-material. Arlington: Veritech. Enterprises, LLC
[8]. GENESIS Overview, CEDAS DETAILS. (2023). https://www.veritechinc.com/products/cedas/cedas-details. Arlington: Veritech Enterprises, LLC.
[9]. SBEACH Model, Community Surface Dynamics Modeling System. Explore Earth's surface with community software. (2020). https://csdms.colorado.edu/wiki/Model:SBEACH. Boulder: University of Colorado.