

A Systematic Approach of Invention of Wave Resilient Wrap Face Embankment with Electricity Production Capacity

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ABSTRACT: Climate-resilient infrastructure is the burning question in today's world. Resilient infrastructure will affect future scenarios for future generations, particularly low-carbon infrastructure that is resilient to future climate impacts (UK Climate Change Risk Assessment 2022). The accelerated pace of meeting ambitious carbon emissions targets includes mitigation and adaptation processes that impact all social and economic aspects. Reducing our dependence on fossil fuels requires the development of reliable technologies to better harness natural energy sources (e.g., solar, wind, geothermal). In particular, hydropower has the potential to significantly reduce carbon emissions and become an environmentally friendly energy source. In this paper, a systematic approach has been taken to build a wave resilient wrap face embankment that can produce electricity, and can be a sustainable, environmentally friendly solution. In most countries, there is a shortage of electricity, and they do not use waves to produce electricity. According to the Center for Policy Dialogue, in the financial year 2022-23, 2.5 million US dollars was allocated for the electricity sector, whereas in the budget for FY2023-24, the allocation for the energy and power sector is 3.2 US dollars in Bangladesh. This indicates the increasing demand for electricity, which can be met by using wave energy. Studies and research from various countries over the past years have been reviewed in this research. The sustainable electricity generation and building secure embankments both are needed and a wave resilient wrap face embankment with the ability to produce electricity is a great solution to this problem.

KEYWORDS: Climate Resilient, Wrap Faced Embankment, Electricity, Accelerator Converter, and Low Carbon.

1. INTRODUCTION

In today's world, sustainable low-carbon infrastructures are needed that are resilient to future climate impacts, and that will be sustainable for future generations. A reduction in reliance on fossil fuels requires the development of credible technologies to further utilize natural energy sources (e.g., solar, wind, geothermal), and the accelerated pace of reaching ambitious carbon emission objectives entails both mitigation and adaptation measures affecting all social components. One energy source with the potential to substantially reduce carbon emissions and protect the environment is wave power (Jin & Greaves, 2021).

There is a target of £90/MWh by 2035, as well as installing 22-gigawatt capacity by 2050, as per EPSRC, addressing the Net Zero target in 2020. However, energy from the tides and waves can provide up to 20% of the UK's current electricity needs and has a total capacity of 30-50 gigawatts (GW). Utilizing the energy from the various rivers should be encouraged in order to reach the desired electricity milestone (the UK Centre for Ecology and Hydrology estimates that there are about 1500 separate river systems with more than 200,000 km (Jin & Greaves, 2021) of watercourses throughout the UK).

Among ocean-based power-generation technologies are tide-generated electricity, wave-generated electricity, ocean thermal power, seawater currents, ocean winds, and salinity variations. Ocean thermal power transformation, tide-generated electricity, and wave-generated electricity are the 3 most modern techniques. The momentum in the ocean and tides can be converted into electricity

using traditional turbine devices. Many ideas have been developed to address the additional technical hurdles required to capture the energy generated by wave motion (Etemadi et al., 2011).

The world experienced the anticipated energy crisis in 2015. The lack of oil and rising energy demand are also factors. Something unique is required for harvesting power besides fossil fuel-based energy. Dependence on non-renewable energy made it challenging to capture this energy due to future population growth and energy needs. Although it has been discussed in publications from the last decades of the 18th century, the global oil crisis triggered modern research into utilizing waves to generate electricity. The focus on producing power from sustainable sources is once more a crucial field of research as the world increasingly pays heed to climate change and the escalating amount of CO₂. Since many nations, including Indonesia, currently employ wave power, it is available. The ocean has three types of energy: marine thermal power, tidal energy, and wave energy. The energy generated from waves in the water is one of the resources that can be used. The primary cause of waves on the ocean's surface with periods of 3 to 25 seconds is wind, which is a typical occurrence along beaches worldwide. In the sea, there are additional tidal motions, such as internal waves, tides, and edge waves. Only surface gravity waves between 3 and 25 seconds in length will be subject to waves. The wave is an invaluable source of power in Indonesia. The sea's waves are rolling or up-and-down motion of the water. The effects of air-pressure changes caused by wave motion are used to generate wave energy in alternative energy systems (Suryaningsih, 2014). Considering wave energy solutions to meet current electricity demand is necessary in the present world.

Shallow river wave energy with low frequency and modest amplitude has now become a key part of wave energy exploration due to its broad accessibility and low operation costs. (Wang et al., 2019)

One of the biggest problems in the flood zone during the annual flooding season is the slope stability of the river embankment. In light of the challenges, many studies on reinforced soil wrap-around embankments have been conducted (Yasuhara & Recio-Molina, 2007; Murali Krishna & Madhavi Latha, 2007; Murali Krishna & Bhattacharjee, 2017). Despite the fact that a large amount of research has focused on reinforced embankments that wrap around a structure to provide excellent wave resistance (Yasuhara & Recio-Molina, 2007; Murali Krishna & Bhattacharjee, 2019) the number of studies on wrap faced embankments on soft clay soil, particularly for deltaic reasons, is rather few. Research by Hore has been done on Wrap Face embankment on soft clay in Bangladesh (Hore et al., 2021). Etemadi et al. (2011) presented a demonstration of a tidal barrage, which was actually a dam constructed across a bay or estuary. It was also evaluated in detail how the tidal barrage produced electricity. According to research, Indonesia's wave power plant captures more kinetic energy than other renewable energy sources. For this study, one large pipe was equivalent to the wave power plant's use of seventeen small pipes in terms of air-pressure efficiency. The southern coast of the Special Region of Yogyakarta is where the electricity was generated. (Suryaningsih, 2014) The impact of power production in the small wave action area was not the main focus of this study. On the contrary, Shah (Salimullah et al., 2014) evaluated an alternative concept involving wave power using a wave energy converter (WEC) to generate electricity in Bangladeshi coastal regions. The MATLAB simulation displayed electricity vs. wave height and electricity vs. wave duration graphically at various locations in Bangladesh.

The earth occasionally moves. Due to sunlight, the earth's surface warms up somewhat, and water and land absorb differing amounts of heat. These temperature differences lead to density changes, which, in turn, are impacted by gravity and the rotation of the earth to produce winds. On motionless water, this wind causes ripples to form. If the fetching period is sufficiently long, the waves gradually develop into substantial marine surges as the wind continues to blow. Ocean waves are capable of traveling over a great deal with minimal loss of energy until they smash into a distant shore. Thus, wave power is always being renewed. It is available each day of every year, at all times, and fluctuates in intensity. (Salimullah et al., 2014)

It was found that the scale-model embankment's seismic response was significantly affected by changes in frequency, base-shaking acceleration, and surcharge loads. Both sand- and clay-rich soil layers experienced increased acceleration at higher frequencies and with an elevated base acceleration. Low surcharge pressures also exacerbated accelerations. It was discovered that the acceleration-amplifying response to frequency variations was nonlinearly proportionate. (Chakraborty et al., 2021)

In the deltaic plains of Bangladesh, floods frequently occur. The interruption of company operations caused by the flooding will inevitably have a detrimental impact on GDP. A country like Bangladesh cannot continue to bear the cost of such continuing, unthinkable human misery and tremendous devastation. Even though Bangladeshis have modified their way of life to accommodate floods, each monsoon season still causes damage to numerous locations due to flooding, riverbank erosion, breaches of river structures, etc. (Jahan et al., 2014).

There are several studies on both the stability of embankments and wave energy. Rarely does an embankment's stability and wave energy combine. In the current study, a wave-resistant wrap-faced embankment will be developed. A wave converter of this kind will also be developed, using small-scale wave energy from a river or lake to generate power. To produce power from wave energy, an embankment form especially resistant to wave action, such as flooding, was designed. The wrap-faced embankment is essentially a sand embankment with layers of geotextile wrapped around it to create a steep or sloping embankment. This embankment fills with sand that has various properties. The river will be approached from

the embankment using wave energy converters (Acceleration-Based Converter and Deformation-Based Converter).

The objective of this study is

- To review the different studies on embankments.
- To analyze the stability of an embankment that resists the residual wave and dynamic behavior of the embankment using experimental testing.
- To propose a system of an embankment with the ability to generate electricity.

2. EFFECTS OF CLIMATIC CHANGES ON EMBANKMENTS

A study was conducted to observe the impacts of climate change on embankments. There were six unique panels on the embankment (excluding the end slopes) as shown in Figure 1. The four middle panels, which were 18 meters in length and represented two distinct construction techniques—"well compacted" and "poorly compacted"—were built. For biological research, panels—each measuring 4 meters—were used. The 'poorly compacted' panels (panels (A) and (D) in Figure 1) were created with very little compactive effort to resemble railroad embankments constructed more than 100 years ago.

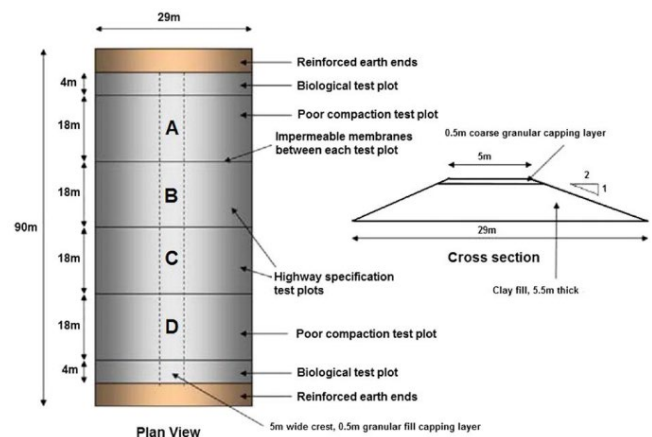


Figure 1 Plan view and cross section of the embankment. (Toll et al., 2012)

These panels were simply compacted with a tracked hydraulic excavator after being set in 1 m lifts, with as little plant function on the panels as feasible in order to minimize compaction. The 'well compacted' panels (panels (B) and (C) of Figure 1) were built utilizing the most recent compaction standards for highways to mimic contemporary highway embankments. To provide engineering and hydraulic separation, perpendicular impermeable membranes were positioned between panels and end slopes. A thick layer of coarse fill (crushed basalt) measuring 0.5 m thick was constructed at the top of the embankment. The side slopes of the embankment were covered with a 200 mm layer of topsoil to encourage plant growth and mimic real infrastructural embankments. The glacial soil (Durham Lower Boulder Clay), a typical fill material in NE England and thus characteristic of earthwork construction, was used to fill the embankment. An intermediate plasticity sandy clay can be used to describe the fill material. The analysis and determination of soil behavior utilized both conventional and recently developed methods. The monitoring data between September 2007 and March 2009 displays the pore water pressure variations that might be anticipated in an embankment. During the winter months (usually January), pore water pressures were higher and then declined to lower values in March. Lower values might typically be anticipated during the summer, but the environment in the summers of 2007 and 2008 was "untypical," with heavy summertime rainfall and artificial flooding. To better understand the situations that can arise during a dry summer, further monitoring is necessary. The embankment has seen surface

heaves and shrink/swell cycles in response to changes in pore water pressure. (Toll et al., 2012)

3. PAST ATTEMPTS TO GENERATE ELECTRICITY USING EMBANKMENT

3.1 Electricity Generation by Oscillating Water Column

The two fundamental components of a power generator are a wave energy collector and a generator that converts the collected energy into electricity. There are three methods for gathering wave energy. The first is buoys technology. The vertical and circular movement of the float will power this device. This device may be anchored to an ocean floor instrument or to a floating raft. Oscillating water column (OWC) is the second. This device uses the rise and fall of the water caused by water waves in a cylindrical conduit with holes to produce power. The air will enter and exit the pipe hole at the top due to the upward and downward motion of the water column, driving the turbine that is seen in Figure 2.

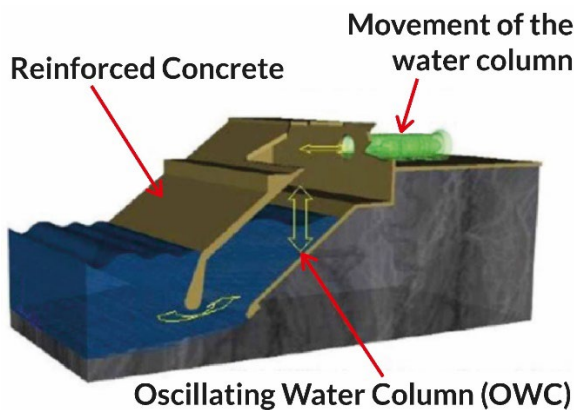


Figure 2 Electricity generation via OWC (Suryaningsih, 2014)

The last possibility is Wave Surge or Focusing Devices. This device, also known as a tapered (tapered channel) or canal embed system, is installed on a building constructed in a marine canal to concentrate waves and direct them into an elevated reservoir. Using conventional hydropower techniques, water draining from the storage ponds is used to generate energy. The oscillating water column is used to generate electricity using wave capture technology, which is appropriate for the Yogyakarta model wave power plant. Through the use of a wave in a cylindrical pipe with perforations, this device produces electricity. Air entered and exited via the upper part of the pipe hole as a result of the column of water rising and falling, which drove the turbine.

To convert this to electricity, the generator is the second essential component. The energy collector is made out of a reinforced shell that is sloped and set into the shoreline's rock face. The center chamber's inlet is large enough to allow seawater to enter and exit freely. The air at the top of the chamber is compressed as the water level increases as surges enter the shell chamber. The "Wells Turbine" is then "filled" with this air after being forced through a "blowhole". Regardless of the direction of the air flow, the turbine is built to keep whirling in the exact same orientation. The air is drawn back into the chamber under pressure as the water is drawn in by the waves outside, keeping the turbine spinning. The pulsating water column generates a steady flow of air in both directions, which moves the turbine enough to power a generator that turns the mechanical energy into electrical energy. (Suryaningsih, 2014)

3.2 Wave Energy Prototype Testing

In a study, a prototype was tested. With wood, a box 7.5 feet long was constructed. The polymer material covering made the DC motors waterproof. The four motors were now neatly positioned in the wood stand. There was a series connection between each motor. The wood

box was sealed with polyethylene before being filled with water. A single-phase induction motor powered by a 220-volt AC source created the wave. This study focuses on wave energy that is mostly caused by wind. This prototype used a single-phase induction motor to create artificial wind. Every time this wave moved, the little fan or blade of the DC motor was affected. In this case, the DC motor generates voltage in a manner similar to a generator. We used four motors (6v rating) in series with an output voltage of 1.5 volts, which is sufficient to light one LED.

Table 1 Experimental data (Salimullah et al., 2014)

Sl. No.	1-phase induction motor speed (rpm)	6v motor speed (rpm)	Wave height (m)	Wave period (s)	Voltage output (v)
01	2609	150	0.01	1	0.95
02	3200	225	0.015	1	1.2
03	3608	350	0.02	1	1.5

The study revealed that using additional motors in sequence will result in higher voltage generation. The wave power plant may operate in deep water, including the ocean. It wasn't fair how high the waves were. They only have 1.5 volts of output due to this. But it's clear from this study that output power is inversely related to wave height. The output voltage was 1.5 volts, and the wave height was only 0.02 meters, when the wave height at Cox's Bazar is 2.8 meters. Therefore, there is no question that Cox's Bazar and Saint Martin's will see a positive outcome. (Salimullah et al., 2014)

3.3 Electricity Generation via Acceleration-Based Converter

In a study, a prototype was built to assess the feasibility of electricity generation using an acceleration-based converter. The converter enclosure is a clear box, and at the center of the enclosure is a large mass. On the enclosure's outside, piezoelectric generators are mounted. There are spring connections between the converters and the substantial mass. It is a small-scale device that is capable of capturing energy from low-frequency, low-height waves. This is due to the fact that the small-scale device, when subjected to waves, will have sufficient displacement and acceleration to generate a large amount of electrical power. The displacement and acceleration of a large inertial mass inside the enclosure serve as the foundation for the converter's basic operating concept. The general principle of the converter's operation is depicted in Figure 3 and Figure 4.

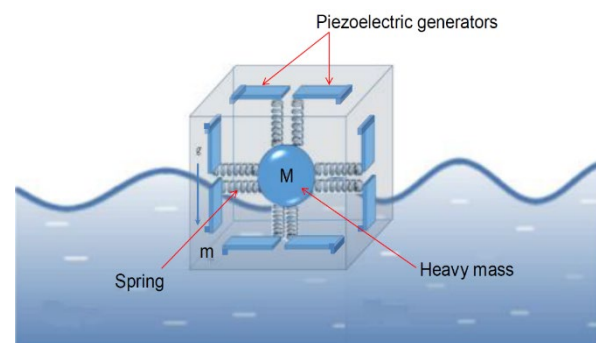


Figure 3 3-D diagram of the Acceleration-based converter system (Cai, 2017)

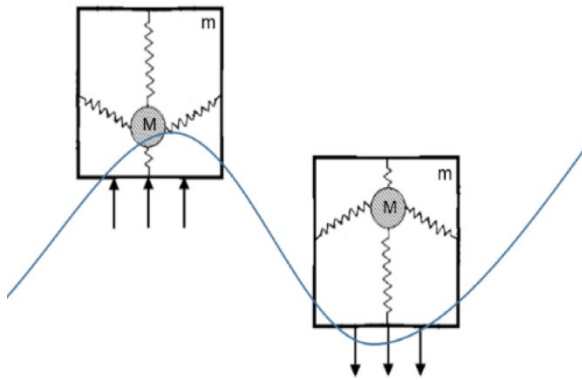


Figure 4 2-D diagram of the Acceleration-based convertor system (Cai, 2017)

After getting the findings of the theoretical modelling, a prototype was constructed and tested along a river under various wave scenarios. The enclosure is constructed of a transparent acrylic plate, and the hefty mass that drives the piezoelectric beams is made of corrosion-resistant stainless steel. The ideal converter measurement is $L = 10$ cm with a mass ratio of 0.65 ($m = 0.05$ kg, $M = 0.132$ kg). The piezoelectric generators were attached to a DAQ terminal to record the power output of the converter, and the prototype was then sealed. The wave frequency and amplitude measured in the field testing ranged from 0.2 to 0.8 Hz and 2 to 6 cm, respectively. Wave amplitude and frequency improve the power output. At an amplitude of 6 cm and frequency of 0.8 Hz, the converter produced its maximum output of $\sim 5.0 \pm 0.6$ mW. (Cai, 2017)

3.4 Scottish WES program

The Scottish government established WES in 2014 to continue supporting Scottish wave energy developers. The knowledge and extensive experience accumulated throughout their development and implementation were recorded by WES. WES established a structured innovation approach under Project SEAWEED, aiming at the development of more effective subsystems that could be adopted across many WECs. Each of the five financing areas—power take-off systems, new WECs, structures and materials, control systems, and rapid connection systems—targets a particular component. A stage-gate development method was combined with pre-commercial procurement (PCP), creating a novel finance strategy. Only the most successful ideas are chosen to advance to the following funding round, with technology converging towards the end stage. The 'ArchimedesWaveswing' from AWS is a submerged heaving oscillating body that produces power via a direct-drive generator. The 'Blue Horizon' from Mocean Energy is a floating articulated type WEC with a special geometry that is said to greatly improve performance in comparison to the conventional articulated WECs and boost survival by diving through the largest waves (Figure 5). Through investments in the parallel WES program or other programs, both WEC firms have created partnerships with additional subsystem technologies that have been independently developed and validated. In general, the WES program significantly contributes to the advancement of wave energy, particularly by creating a supply chain specifically designed for wave energy. (Jin and Greaves 2021)



Figure 5 Concept diagram of 'Blue Horizon' (image courtesy of Mocean Energy Ltd.) (Jin & Greaves, 2021)

Wave is a great source of energy. It is natural, green and free to use. An oscillating water column can be a good way to generate electricity. It uses a turbine to generate electricity. The Scottish WES program also uses direct-drive generators. Electricity generation via an acceleration-based converter is the most efficient way to convert wave energy into electricity. Sustainable embankment can be incorporated with these types of converters to produce electricity, which can fulfill the need for electricity of the people living adjacent to the embankment area or even can be added to the national power grid.

4. PAST STUDIES FOCUSING ON BUILDING AN EMBANKMENT WITH BETTER STABILITY

4.1 Shake Table Test of Wrap-Faced Embankment

In a research study, the horizontal shaking action associated with seismic and other vibration situations was simulated using an automated servo-hydraulic single-degree-of-freedom shake table. To minimize boundary impacts, a model embankment using soft clayey soil was built. Rectangular frames make up each layer. The lowest layer is permanently fastened to a steel plate with dimensions equal to those of the laminar layers. Through four valves, the base offers some room for watering and dewatering. For the safety of the ball bearings and the hydraulic cut-off system, a 2-mm-thick rubber membrane was installed within the laminar box. The sand was reinforced using non-woven polypropylene multifilament geotextile (DF50). As illustrated in Figure 6, the current investigation was carried out on a foundation of 610 mm (24 inches) of clayey soil, followed by a 50 mm (2 inches) thick sand cover.

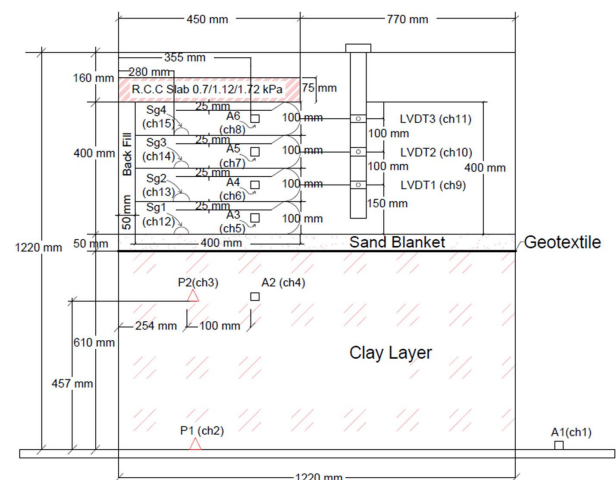


Figure 6 Diagram with configuration and instrumentation of the embankment (Chakraborty et al., 2021)

At various points inside the clayey soil layer, geotextile-wrapped face wall, and backfill soil, the accelerations and lateral displacements were monitored using accelerometers and displacement transducers, respectively. In this model test, nine

sensors were used: six accelerometers (A1, A2, A3, A4, A5, and A6), two pore water pressure sensors (P1 and P2), four strain gauges (Sg1, Sg2, Sg3, and Sg4), and three linear variable differential transformers (LVDT1, LVDT2, and LVDT3). Results from various shaking table tests using the embankment model were obtained. To understand their behavior under harmonic sinusoidal input motions, several shaking table investigations were conducted on a wrap-faced reinforced soil wall in a 1/10 size model. It was found that the scale-model embankment's seismic response was significantly affected by changes in frequency, base-shaking acceleration, and surcharge loads. At higher elevations and with a high base acceleration, accelerations were magnified for both sand- and clay-rich soil layers. Low surcharge pressures also exacerbated accelerations. The acceleration amplification response to frequency variation was found to be nonlinearly proportional. The top of the reinforcing layer experienced large face deformations due to the high base acceleration, but the impact at the lower layers was comparatively minor. In general, substantial face deformations at modest surcharge pressures were observed. Additionally, frequency was found to have a negative effect on face deformations. With higher base acceleration, pore water pressure increases. At higher elevations, the disparity between pore water pressure and surcharge pressure shaking is greater. The dynamic behavior of the wrap-faced soil retaining wall sitting on the soft clay layer can be observed using these data, which is useful for the design of this type of retaining wall taking into account the seismically active conditions in Bangladesh. (Chakraborty et al., 2021)

4.2 Embankment under Various Wave Conditions

At the USDA-ARS National Sedimentation Laboratory in Oxford, MS, experiments were conducted in a wave tank measuring 20.6 m long, 0.7 m wide, and 1.2 m deep (Figure 7). Transparent polycarbonate sheets made up one side of the tank, and the other wall was coated with aluminum. A plywood fake floor boosted the wave tank's bottom by 0.3 meters. In order to create a steady ascent to the fake floor, a ramp with a 1/7 slope was constructed in front of the wave generator. A polyethylene screen eliminated the splashing that was caused by the wave paddling. A computer-controlled electromechanical wave paddle that could produce both regular and irregular waves was installed in the wave tank. The wave generator was 1.2 meters away from the flume's up wave end. With a distance of 16.2 m from the wave paddle to the bottom of the model embankment, it was built on the down wave end of the wave tank. To lessen reflected waves from the model embankment and the paddle, a polyethylene screen was positioned 9 m down wave of the wave paddle.

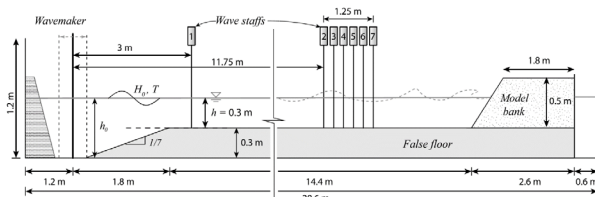


Figure 7 Diagram of the wave tank (Ozeren & Wren, 2017)

There were six alternative conditions in the research, each with regularly spaced waves of differing heights (Table 2). The study was conducted with a constant wave period ($T = 1.2$ s), water depth ($h = 0.3$ m), and embankment conditions. For at least a day prior to the experiment, the water level in the wave tank was gradually raised at a rate of 10 cm/day until the embankment was fully submerged. Just before the experiment started, the water level was gradually lowered to 30 cm. 10-min active periods with 3-min resting times in between were used to generate the waves. The rate of embankment retreat determined the overall number of active periods.

Table 2 List of Experiments (Ozeren & Wren, 2017)

Experiment	H_0 (cm)	# of runs
060815	6.5	87
062915	4	103
072915	5.4	77
081715	8.2	62
121415	5.5	36
070716	4.2	156

Seven capacitance water level sensors (wave staff from Ocean Sensor Systems) were used to monitor the elevation of the water surface at 30 Hz. Six of the wave staffs were put close to the embankment, and the other one was placed close to the wave paddle to measure the partial standing waves. The waves were initially observed travelling along the wave tank until they reached the embankment face. The erosion or mass failure caused by the waves immediately altered the geometry of the embankment face. During this time, there was significant wave reflection, leading to standing waves along the wave tank. Additionally, a turbidity current moving offshore was observed. During the initial phases of the studies, block failures mobilized the majority of the embankment material. During the first few minutes of the run, the upper embankment face slope grew steeper and a scarp developed above the water-embankment junction. Due to the steep embankment face slope, the reflected wave was relatively high during the first few hours of the experiment. In reaction to the numerous mass collapses during this time, both direct and reflected wave heights changed. Once a slight slope was built to the seaward of the embankment, the height of the reflected waves stabilized. Breaking waves dispersed the majority of the wave energy, and for the remainder of the experiment, the reflected wave height was less than 10 cm. The process used to identify the incident and reflected waves in the recorded envelope may have introduced an artifact that caused the initial variation in the incident wave height. (Ozeren & Wren, 2017)

4.3 Effectiveness of Geotextile in Embankment Construction

In a study, a layer of geotextile as a filter medium was proven to be a more trustworthy material for protecting riverbanks, if not the riverbed itself, as a means of preventing erosion. To prevent the movement of tiny soil particles caused by water flow velocity and wave action, which leads to soil erosion, a geotextile has been placed between the riprap and the embankment slope soil. To determine the efficiency of the geotextile under conditions comparable to those encountered in the field, a model test was conducted. Using disturbed local soil, a physical model that closely matched the site's features and its 2:1 side slope was built. The tested geotextile sheet was applied to the slopes as intended, covering them from the bottom to a point above the anticipated water level. After being anchored, the geotextile sheet was covered with a 60-mm-thick stone riprap. The performance was evaluated using flood depth and velocity (up to 1.2 m/sec) of varying magnitudes. Additionally, a comparable test was performed without a geotextile covering. It has been determined that the geotextile test was safe and that there was no evidence of pitching material movement or foundation material dislocation beneath. Without a geotextile layer, the base material and foundation deteriorated at flow rates greater than 0.3 m/sec.

According to research, the foundation material can be restored using woven polypropylene geotextile with enough pores to alleviate pore pressure. Woven geotextile, sometimes known as "silt fence," is used as barrier during the construction of embankments to prevent tiny soil particles from migrating due to river flow velocity and wave action. At the study section, riprap pitching of 15 cm thick gravel with sizes ranging from 30 mm to 125 mm and more than 20 cm thick water front stone boulders with sizes ranging from 200 mm to 400 mm may be suitable for protecting the embankment. The geotextile-reinforced revetment could provide protection against the damaging cutting and erosion in the Kamla Balan River. According to the

applicable rules and other provisions, the protection must be extended to the scour depth as well. At kilometer 37 and km 62, the normal scour depth was predicted to be 5.4 m and 6.4 m, respectively. (Verdhen & Kumar, 2020)

4.4 Application of sand and geotextiles on embankment

An experimental model for a study was made (Figure 8). The pipe used to make the model conduit had a diameter of 50 mm, a length of 250 cm, and a crack measuring 10 cm in width and 8–10 mm in diameter.

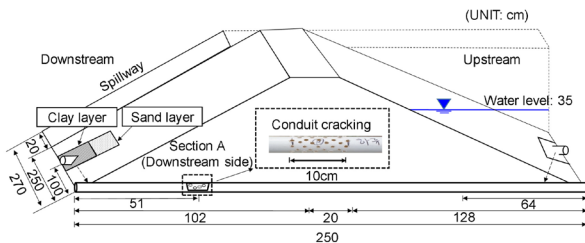


Figure 8 Prototype model (Lee et al., 2022)

An overview of the current and improved models is shown in Figure 9. To reduce water pressure on the conduit, the existing design applied a clay coating to its exterior. The structural environment of these conduits, however, has become more uncertain regarding the stability of the embankment due to recent facility deterioration. For instance, the conduit will always experience higher water pressure due to the inevitable loss of clay particles over time. Additionally, in small, aging reservoirs with increased water pressure, issues such as erosion and piping on downstream slopes are possible. The plumbing in a fill-type embankment has a high failure rate (30.5%), thus it was also required to figure out how to lower the water pressure on the slope downriver.

In this situation, the enhanced model described in this work is a technique for covering the clay layer in the existing model with a layer of sand and geotextiles. This additional layer serves the dual purposes of applying geotextile to prevent soil particle loss and installing a sand layer on the downstream slope to prevent water from ascending to the downstream embankment zone.

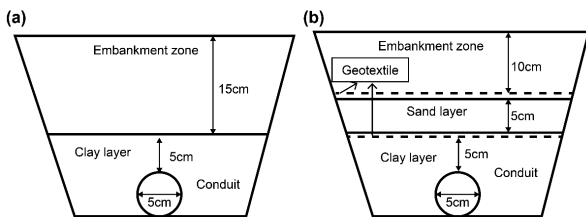


Figure 9 Comparison of conduits: (a) current model, (b) proposed model. (Lee et al., 2022)

In order to comprehend the impact of internal erosion owing to conduit cracking on the stability of the embankment dam in the existing design model, a large-scale model test and three-dimensional deformation-seepage analysis were conducted in this research. Additionally, the proposed improvement model's reinforcing impact, which aimed to lessen internal erosion, was assessed, and its validity was examined. The existing design approach for conduits was found to pose a high risk of embankment failure under cracking conditions in a conduit, because cavitation and erosion often occur near the damaged location. Despite erosion taking place along the conduit in the improved model, which uses a layer of sand and geotextile, cavitation did not. (Lee et al., 2022)

5. SYSTEMATIC APPROACH OF THIS RESEARCH

This paper takes a systematic approach to building a wrap face embankment with the capabilities of wave resilience and electricity production as shown in Figure 10. A non-woven geotextile is to be

used as reinforcement. Sand should be filled in the geotextile and wrapped around.

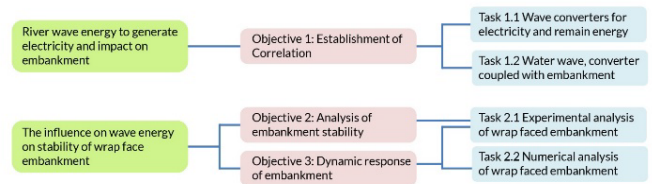


Figure 10 Systematic Approach of this study

The use of two types of small-scale wave converters, namely, acceleration-driven converters and displacement-based converters, and their power output efficiency will be checked. Once the converters are subjected to water, they will follow the motion of the wave, and the energy of the wave will be transferred as the mechanical energy of the converter. The acceleration and displacement of the converters bring together the potential and kinetic energy of water, and convert it into electricity. The acceleration-driven converter will be designed to naturally float on the water surface, and will not require anchoring (Cai, 2017).

The fundamental working principle of the converter is based on the displacement and acceleration of a heavy inertial mass inside the enclosure. Figure 11 illustrates the general operation of the converter. Triggered by the motion of the wave, the floating enclosure with mass (m) starts to accelerate. The motion of the wave provides a lift (buoyancy) force on the enclosure with an upward motion. Consequently, the heavy inertial mass (M) inside follows the motion with delay and much smaller acceleration. The difference in the acceleration between the two masses m and M creates the necessary displacement to trigger oscillations of the two masses connected with springs as shown in Figure 12. On the other hand, in the displacement-based converter in shallow water, there is a change in the orientation of the flow along the depth of water, developing the energy distribution and the generation of longshore currents. Each part of the wave travels in different directions and velocities depending on the depth, since the motion of the wave is affected by the bed. Both converters utilize piezoelectric generators to convert the periodic and oscillatory wave motion into electrical power.

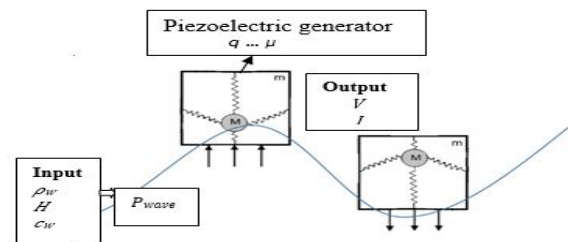


Figure 11 Diagram of the converter system (Cai, 2017)

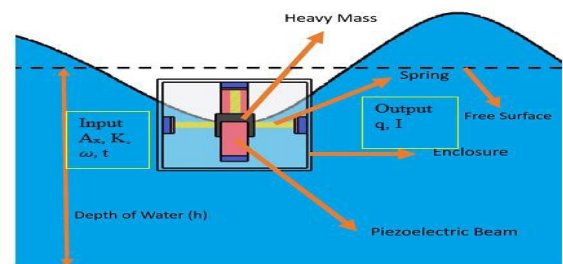


Figure 12 The converter floats on water (Cai, 2017)

Secondly, establishing a correlation among different parameters relating to wave energy, soil properties and the configuration of converters considering the dynamic stability of the embankment to be affected by the residual wave. A link between the wave energy

converter system and the properties of a wrap-faced embankment will be established to develop a resilient embankment that is less affected by residual waves. A theoretical model has been developed to describe the dynamics of the acceleration-based generator and its potential to convert wave energy into mechanical energy (Cai, 2017). It is assumed that the traveling wave propagates along the y and z-axes, and it is normal to the walls of the converter. The displacements caused by the wave can be described mathematically by harmonic functions in Equations 2 and 3.

$$\Delta x = A_x \cos(k \vec{x} - \omega t) \quad (2)$$

$$\text{and } \Delta z = A_z \sin(k \vec{z} - \omega t) \quad (3)$$

In the equations, A_x and A_z are the amplitudes of the wave, k is the wave vector, ω is the angular frequency and t is the time. As a result of the wave motion, the undisturbed free surface will be displaced, and the floating converter will start to heave, as shown in Figure 12. On the other hand, Figure 13 shows a diagram of the placement of the wave energy converters near the embankment.

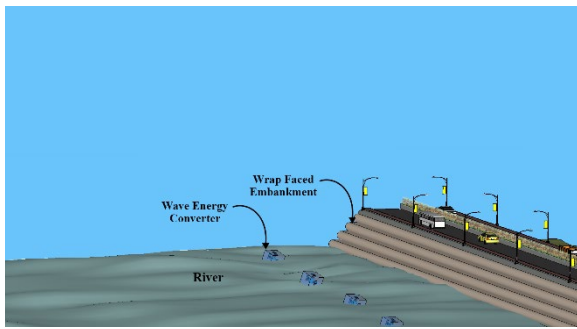


Figure 13 Placement of wave energy converters near wrap faced embankment

This motion will result in reaction forces applied between the heavy mass and the enclosure. In the vertical x-direction, the enclosure is subjected to both gravity and buoyancy forces acting in opposite directions. On the horizontal surfaces along the y and z axes, the enclosure will be subjected to a drag force F_d (Murali Krishna & Madhavi Latha, 2007; Murali Krishna & Bhattacharjee, 2017). The resultant forces (F_r) are applied to the spring connections, which act on both the inertia mass and the enclosure driving vibrations of the tip of the piezoelectric beam. The power take-off force (FPTO) accounts for the damping of the portion of the mechanical energy into electricity by the piezoelectric generators. On the other hand, in the deformation-based converter, there is a change in the flow orientation with water depth, thereby influencing the energy distribution and the generation of longshore currents in shallow water. In this process, the wave energy converter can produce electricity from low-frequency waves. Considering the input parameters of the wave (amplitudes of the wave, wave vector and angular frequency), the output of the remaining wave after harvesting can be analyzed in this task and a correlation will be developed among the remaining wave after harvesting (parameters: wave frequency, amplitude and wave velocity) with the soil parameters (displacement, pore water pressure, strain, etc.).

In recent years, new threats to riverside areas have emerged as a result of climate change and sea-level rise induced by global warming. Therefore, alternative solutions to protect the riverbank are required to replace the traditional embankment materials and systems, such as those constructed of rock or concrete blocks. One of these alternative solutions is the geotextile wrap-faced embankment which can resist wave action and is cost-effective. In this study, the dynamic behavior of the embankment such as acceleration (a), displacement (d), pore water pressure (u) and strain (ϵ) with respect to residual wave action (P_{wave}) after conversion of wave power (P_{wave}) from the river will be analysed based on the mathematical correlation between the dynamic properties of soil with wave power which established in

WPI. The saturated slope in a $c-\phi$ soil will have seepage parallel to the surface of the slope and the same limit equilibrium concepts may be applied to determine the Factor of Safety (FS). This FS will depend on the effective normal force (N'). In the analysis, effective shear strength parameters, c' and ϕ' will be used (Hadžić et al., 2005). The slope stability analysis after accounting for wave action will be performed as shown in Figure 14.

The stability and dynamic analysis, including effects of frequency, amplitude, surcharge, pore water pressure and displacement along the different elevations of the model, will be measured. Other parameters of soil such as acceleration, displacement, pore water pressure, and strain for dynamic effect embankment due to residual wave after converting the main source wave will be investigated.

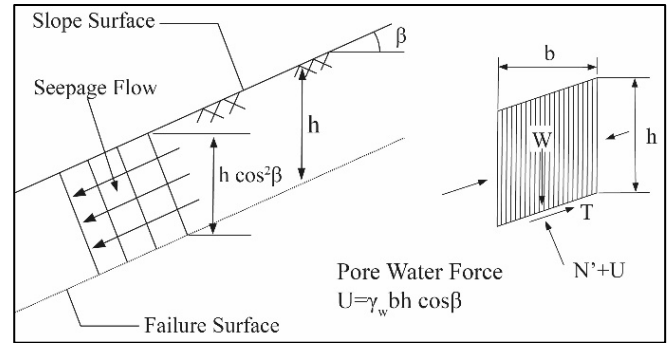


Figure 14 Slope failure in a $c-\phi$ soil

Numerical modelling will also be performed to compare and verify the results from the experiments. The experimental studies (scale 1/10) will be carried out on scale model wrap-faced reinforced soil walls to obtain apparent insight into their behavior under static and dynamic input motions in task 1. A series of tests will be executed with variations in the surcharge loading, frequency and acceleration. Based on the experiments, numerical modelling will be performed by PLAXIS 3D (Brinkgreve & Broere, 2004). In the numerical modelling, the boundary condition, as well as the soil properties of different layers and dynamic load parameters, will be input into the software interface to create a model that reflects the features of the experimental model. The PLAXIS 3D numerical model will also analyze the factor of safety and deformation of the embankment. The comparison between the experimental observations and numerical results will be used to analyze and develop a sustainable and resilient embankment.

6. ADVANTAGES OF THE SYSTEMATIC APPROACH

The main advantage of the approach is creation of electricity while protecting the riverside areas. It solves two of the major issues for a riverine country, the issues being damage of floods every year and low electricity production capacity. There are multiple advantages to the approach if we assess it closely. Some are discussed below:

- The waves will hit the energy converter first before hitting the embankment. So, waves with less power will hit the embankment, increasing the durability of the structure.
- Wrap face embankment has been seen to have better strength than traditional embankment.
- Electricity generated from the embankment can be added to the national grid of electricity.
- Wrap face embankment is also more earthquake resilient than traditional embankments.
- The cost for electricity generation can be minimized as wave power is a free natural source of energy.
- Use of fossil fuel to generate electricity will be minimized if wave power is used for power generation.

Overall, it can be said that the proposed systematic approach is a sustainable and environmentally friendly alternative to traditional embankments as well as a green electricity generation process.

7. POSSIBLE CHALLENGES DEVELOPING WAVE RESILIENT EMBANKMENT WITH ELECTRICITY GENERATION CAPABILITY

A few challenges may arise while implementing of a wrap faced wave resilient embankment with electricity generation capacity. Such as:

- i. As the convertors will be floating near the embankment, the boats can hit and harm the convertors. The same goes for the nets of fishermen.
- ii. Large boats or even cattle can harm the geotextile of the wrap faced embankment.
- iii. Maintenance of the convertors might be an issue as there could be fewer available professionals for the job.

Even though there are a few possibilities for challenges arising while implementing the idea, they can all be easily resolved. Figure 15 shows a diagram depicting possible challenges and solutions to implementing the idea. Raising awareness among boatmen, fishermen and people residing along the embankment area can be a great way to deal with the safety of the embankment and convertors from man-made harm. On the other hand, proper training can address the issue of the unavailability of expert maintenance professionals.

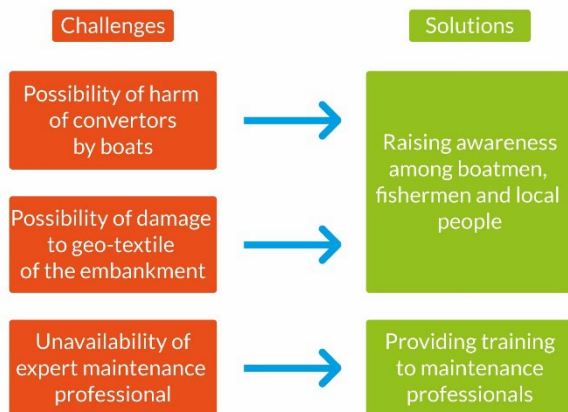


Figure 15 Diagram showing possible challenges and solutions implementing the idea

8. CONCLUSIONS

Building a wrap face embankment which is wave resilient and can produce electricity is very practical and a great solution to many problems. Several wave power studies have been conducted on ocean waves. Even so, there are a number of drawbacks to ocean waves, including location, high maintenance costs, disruption to marine life, and a lack of shoreline in the nation. River energy and other non-ocean energy alternatives should be considered to meet current electricity demand. Due to its widespread availability and low maintenance costs, shallow river wave energy with low frequency and modest amplitude has since taken on a prominent role in wave energy research. The flooding season, which has never been seen as a viable energy source, intensifies this energy even more.

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