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Evaluation of the Performance of Floating Fiber Embankment Models for Tidal Flood Mitigation in Coastal Areas: Contributing to SDG 11

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ABSTRACT

Objective: *To evaluate the development of floating fiber embankment technology as an innovative solution for mitigating tidal flooding in coastal areas of Indonesia, particularly along the northern coast of the Java Sea. The proposed system is designed to automatically adapt to tidal level fluctuations, addressing challenges related to land subsidence and sea level rise.* ***Method:*** *The study employed a combined simulation and laboratory experimental approach to analyze the performance of the floating fiber embankment. Numerical simulations were conducted to evaluate the structural behavior under hydrostatic pressure, while laboratory testing was performed using a scaled physical model to validate the simulation results.* ***Results:*** *The findings indicate that the floating fiber embankment demonstrates stable structural performance under tidal loading conditions. The maximum recorded deformation was 0.0043 meters, with a maximum stress of 8.231×10^6 Pa and a strain of 0.00045. These results confirm that the structure can maintain elasticity and structural integrity under hydrostatic pressure.* ***Novelty:*** *The application of adaptive floating fiber embankment technology that can automatically adjust to tidal fluctuations as a sustainable alternative to conventional static embankments. This system provides an effective and efficient solution to reduce the impact of tidal flooding in coastal regions while advancing SDG 11 (Sustainable Cities and Communities) by strengthening coastal resilience and supporting sustainable flood mitigation efforts.*

INTRODUCTION

Tidal flooding, also known as high-tide flooding, is a natural phenomenon that often occurs in Indonesia's coastal areas. This coastal area, especially along the north coast of the Java Sea, has relatively flat topography, making it more vulnerable to rising sea levels. According to Marfai (2004), tidal flooding occurs when seawater rises onto land, triggered by the gravitational pull among the Earth, Moon, and Sun and exacerbated by atmospheric conditions. This phenomenon causes seawater that should remain in the sea to flow onto land, resulting in waterlogging that damages settlements, agricultural land, and infrastructure, and disrupts people's economic activities.

Tidal flooding is not a rare event in Indonesia. This phenomenon is even a routine problem for coastal communities every year. This is exacerbated by the increasing frequency and magnitude of tidal flooding, driven by a combination of factors, including land subsidence, coastal development, global climate change, and sea-level rise (Aerts et al., 2014; Kong, 2024; Sunarto, 2003; Wang et al., 2022). The cumulative effect of these factors worsens tidal flooding conditions, which are increasingly widespread each year and result in significant economic losses. Losses from tidal flooding in coastal areas are not limited to physical damage but also affect the social and economic life of the community. According to Abidin et al. (2013), losses caused by tidal flooding in various regions in Indonesia can take the form of infrastructure damage, disruption of transportation and the distribution of goods, and decreased agricultural and fishery yields. Tidal flooding also contributes to declining public health, as tidal water often carries contaminants that increase the risk of infectious diseases.

The increasing frequency of tidal flooding also highlights the importance of strengthening efforts to achieve Sustainable Development Goal (SDG) 11: Sustainable Cities and Communities. Coastal flooding threatens the safety, livelihoods, infrastructure, and well-being of coastal populations, particularly in densely populated and economically productive regions. Therefore, developing adaptive and resilient coastal protection systems is essential to reducing disaster risks and enhancing the capacity of coastal communities to withstand and recover from environmental disturbances. In this context, innovative flood mitigation technologies can play a strategic role in supporting sustainable and resilient coastal development in line with SDG 11 targets.

One effort to mitigate tidal flooding is the construction of embankments along coastlines, rivers, and estuaries, aimed at preventing the tide from entering land. However, this effort has not been fully effective. Many existing embankments are unable to adapt to the dynamics of sea level fluctuations. Conventional embankments, such as concrete or fill embankments, are static, so their height is set to the maximum predicted tide level, which is often insufficient to anticipate extreme tidal flooding. In addition, this type of embankment is often damaged because it cannot withstand the increasing hydrostatic pressure associated with rising sea levels (Triatmodjo, 1999; Sunarto, 2003). In this context, innovation in embankment technology is essential. One proposed solution is a floating fiber embankment that can automatically adjust to water levels. This embankment is designed to float with sea-level fluctuations, providing more adaptive protection against tidal flooding. This technology has the potential to be a long-term solution for mitigating tidal flooding because it can hold water under various tidal conditions without requiring manual intervention (Temmerman et al., 2013).

Research on floating embankments as a solution to tidal flooding has been widely conducted in several countries, including China and the Netherlands, which have long histories of dealing with flooding. For example, the patent CN107700422A introduces the concept of a floating embankment capable of automatically adjusting the water level. However, these studies have not been widely applied in Indonesia, even though the conditions are very relevant. Therefore, this study aims to evaluate the performance of floating fiber embankments along the Indonesian coast, particularly on the northern coast of the Java Sea, which is among the areas most prone to tidal flooding (Sunarto, 2024). The use of fiber materials in the manufacture of floating embankments is also an innovative aspect of this technology. Fiber material is chosen for its light, flexible, and corrosion-resistant properties, making it well-suited to the maritime environment. Fiber also has advantages in tensile strength and resistance to deformation, which are important for withstanding hydrostatic pressure from seawater. Based on Callister (2007), fiber has a low density and a small coefficient of thermal expansion, so it can maintain its shape and function even when exposed to extreme temperature changes in the marine environment.

Furthermore, the floating fiber embankment is designed on a simple yet effective principle. The upper part of the embankment, made of fiber material, will float following the water level, while a strong concrete base supports the lower part. When the sea level starts to rise, the embankment will be raised to prevent seawater from entering the land. When the seawater recedes, the embankment will return to its original position. This design is not only operationally efficient but also more environmentally friendly, as it requires no additional energy. This innovation is expected to overcome various weaknesses of conventional embankments, such as high maintenance costs and structural damage from excessive water pressure (Triatmodjo, 1999; Sunarto, 2003).

In addition, floating fiber embankments offer aesthetic advantages. Unlike conventional embankments that often obstruct views and disrupt the spatial layout of coastal areas, floating fiber embankments feature a minimalist design and can be adjusted to local environmental conditions. This is very important in the context of developing coastal tourism areas, where aesthetics is often a main consideration in infrastructure development. This study uses a simulation approach and laboratory testing to evaluate the performance of the floating fiber embankment. The simulation was carried out using ANSYS software, which has been proven effective in modeling the structural behavior of buildings under hydraulic pressure. ANSYS is used to calculate the stress, strain, and deformation in the floating embankment under hydrostatic pressure from high tide. Meanwhile, laboratory testing was conducted to assess the behavior of the floating fiber embankment under conditions that resemble real-world field conditions, namely full- and half-tide (Liu et al., 2020; Morris et al., 2008; Zhao et al., 2019).

The results of this simulation and testing are expected to provide a clearer picture of the effectiveness of floating fiber embankments in overcoming tidal flooding. Specifically, this study aims to answer several key questions: (1) To what extent can floating fiber embankments withstand hydrostatic pressure? (2) How does the deformation behavior of floating embankments change when exposed to sea level fluctuations? (3) Can this technology be widely applied in coastal areas of Indonesia that are prone to tidal flooding? The answers to these questions are critical in determining the feasibility of floating fiber embankment technology as a long-term solution to tidal flood mitigation. This research is expected to provide significant contributions to the development of flood mitigation technology in Indonesia. In the long term, floating fiber embankment technology has the potential to be widely adopted in various coastal areas, especially those that often experience tidal flooding. Thus, the results of this study can be a reference for the government, infrastructure developers, and coastal communities in planning and implementing more effective and sustainable mitigation strategies.

LITERATURE REVIEW

Tidal flooding is a natural phenomenon that often occurs in coastal areas and gentle beaches. This condition is triggered by a combination of rising sea levels and local geophysical factors that cause seawater to overflow onto land, resulting in inundation or flooding. Along with the increasing frequency of tidal flooding in coastal areas worldwide, including Indonesia, mitigation efforts and technical solutions have become a focus of research and technology development (IPCC, 2021). One solution being developed is the use of floating embankment technology, which can adapt to sea-level changes. In this section, several important aspects of the research carried out on tidal flooding, conventional embankments, and innovations in floating embankments will be discussed.

Tidal floods and problems in coastal areas

Tidal flooding is a natural phenomenon influenced by many factors, including tides, atmospheric pressure, wind speed, and coastal topography. In areas with low and gentle topography, such as the north coast of the Java Sea in Indonesia, tidal flooding is becoming an increasingly serious problem. This is caused by land subsidence from human activities, such as excessive groundwater pumping, which accelerates the process (World Bank, 2021). When land subsidence occurs, areas that were previously safe from seawater inundation become more vulnerable during high tides.

In a study by the IPCC (2021), it is explained that coastal flooding in coastal cities, such as Semarang, is caused by recurring tidal phenomena combined with global climate change, which drives sea-level rise. In the context of climate change, sea levels are projected to continue rising due to thermal expansion and melting ice sheets (IPCC, 2021). In some areas, tidal flooding has even become an annual event that significantly affects the lives of local communities, especially in the agriculture, fisheries, and tourism sectors (World Bank, 2021).

The government and the community have made various efforts to mitigate the impact of tidal flooding, including the construction of embankments, land elevation, and drainage arrangements. However, these conventional solutions are often ineffective, especially in the long term. One of the weaknesses of conventional static embankments is their inability to adjust their height in response to dynamic sea-level fluctuations (UNDRR, 2022).

Conventional embankments and the problems faced

A dike is a structure designed to protect land areas from seawater or river overflow. Conventional dikes are typically constructed from materials such as stone, concrete, and fill soil (PUPR Indonesia, 2020). Their function is to prevent water from entering lower-lying areas. Dikes are often the primary choice in flood mitigation efforts because these structures are relatively simple and can be built quickly along coastlines or rivers (UNDRR, 2022).

According to Setiawan (2022), conventional embankments are usually built to a fixed height based on the estimated maximum water level reached during the highest tide. However, sea level can fluctuate unpredictably, especially during storms or atmospheric disturbances. As a result, many conventional embankments cannot retain water when the water level exceeds the design limit. In addition, embankment materials such as concrete and stone can experience degradation under repeated hydraulic loading (PUPR Indonesia, 2020). Another problem is the high maintenance cost of conventional embankments. Embankments damaged by flooding or coastal erosion require periodic repair, which is often not economically efficient for local governments (World Bank, 2021). In addition, conventional embankments often block coastal views, reducing aesthetic and tourism value (UNDRR, 2022).

Floating dike technology: Adaptive solution to tidal flooding

To overcome the weaknesses of conventional embankments, researchers and engineers have begun developing floating embankment technology designed to adapt to sea-level fluctuations. Floating embankments are an innovation that uses floating structures to automatically adjust to changes in water level (Deltares, 2020).

Patent CN107700422A describes a floating embankment system comprising lightweight floating units that adjust to sea-level changes. This system allows vertical movement without manual intervention, reducing operational costs (Deltares, 2020). The material used for floating embankments also plays an important role. Fiber materials are widely used because they are lightweight, flexible, and corrosion-resistant. According to Callister (2020), fiber-based composites have high tensile strength and excellent resistance to environmental degradation, making them suitable for marine environments.

Study on the use of floating embankments

Studies on floating dikes have been conducted in countries such as the Netherlands, where adaptive coastal infrastructure is part of the national flood management strategy (Deltares, 2020). This system is effective in reducing flood damage while maintaining coastal usability.

In China, floating embankment systems have also been developed, using hydraulic sensors to automatically adjust water levels. Although still in development, early results show high potential for adaptive flood protection (UNDRR, 2022).

In Indonesia, research on floating embankments is still emerging. Recent studies show that floating structures have strong potential for application in coastal areas experiencing tidal flooding (Fell et al., 2015; Setiawan, 2022; Ogie et al., 2019). However, further research is still needed under more complex field conditions.

RESEARCH METHODS

Research methods are a crucial part of the scientific process to achieve valid and reliable results. In this study, the method used was designed to evaluate the performance of floating fiber embankments in mitigating tidal flooding in coastal areas. The approaches used are experimental methods and numerical simulations to understand the behavior of floating fiber embankments under varying hydrostatic pressure. In this section, the research steps will be explained in detail, including the experimental design, materials and tools used, data collection procedures, and data analysis methods.

Research design

This study combines two main approaches, namely numerical simulation and laboratory experiments. The design of this study was conducted to test the hypothesis that floating fiber embankments are able to adapt to sea level fluctuations automatically and provide more effective protection against tidal flooding than conventional embankments. An experimental approach was conducted to verify the simulation results using a physical model of floating embankments on a laboratory scale.

The research design is divided into three main stages:

1. Numerical simulation stage: Simulations were conducted using ANSYS software to evaluate the mechanical behavior of floating fiber embankments under hydrostatic and wave pressure. This simulation aims to obtain data related to stress, strain, and deformation that occurs in floating embankments when facing high and low tides.
2. Laboratory experiment stage: Physical experiments were conducted to test the behavior of the floating embankment under real conditions in the laboratory. The floating embankment model was made to a certain scale and tested in a water test tank to measure the response to variations in water level and hydrostatic pressure.
3. Validation stage: The results of simulation and experiment are compared to validate the proposed floating embankment model. The results of numerical simulation will be compared with the results of laboratory experiments to determine whether there is a significant difference between the two.

Materials and tools

The materials and tools used in this study consist of several important components to support the simulation and experiment process. Here is a list of the materials and tools used:

Material:

1. Floating Fiber: The main material used to make floating embankments is fiber, which is known for its light, flexible, and corrosion-resistant properties. This material was chosen because it can adapt to fluctuating seawater conditions and has high tensile strength (Callister, 2007).

2. Concrete for Seats: The floating embankment seat is made of K250 grade concrete, which is a strong structural material that is resistant to mechanical stress. Concrete is used to ensure the stability of the embankment during changes in sea level.
3. Water: The test medium in laboratory experiments is water filled in a test tank to simulate tidal conditions.

Tool

1. Acrylic Test Tank: Acrylic test tank with dimensions of 2 meters x 1.2 meters x 1.5 meters is used to hold water and floating embankment models. The walls of the tank are made transparent to facilitate observation of deformations that occur in the embankment during testing.
2. LVDT (Linear Variable Differential Transformer): LVDT is used to measure the shift or displacement of the floating embankment. This tool is able to detect the vertical movement of the embankment when the water rises and falls.
3. Strain Gauge: This tool is used to measure the stress and strain that occurs in fiber materials when the embankment receives hydrostatic pressure. Strain gauges are installed at strategic points on the floating embankment to ensure good distribution of measured stress.
4. Load Cell: Load cell is used to measure the hydrostatic pressure received by the floating embankment. The pressure data collected will be analyzed to determine the magnitude of the force acting on the embankment.
5. Data Logger: All measuring instruments (LVDT, Strain Gauge, Load Cell) are connected to the data logger to record measurement results in real-time during the testing process.

Table 1 summarizes the specifications of the studies included in this review, covering the study design, participants, measures and data analysis, and the principal findings reported in each study.

Table 1. Specifications of tools and materials used

Source: Callister, 2007

Tools/Materials	Specification	Function
Floating Fiber	Density: 2.54 g/cm³	Main material for embankment
Concrete Stand	Concrete quality: K250	Embankment support
Test Tank	Dimensions: 2m x 1.2m x 1.5m	Holding water for laboratory testing
LVDT	Sensitivity: 0.01 mm	Measuring vertical displacement
Strain Gauge	Capacity: 350 ohms	Measuring stress and strain
Load Cell	Capacity: 5 kN	Measuring hydrostatic pressure

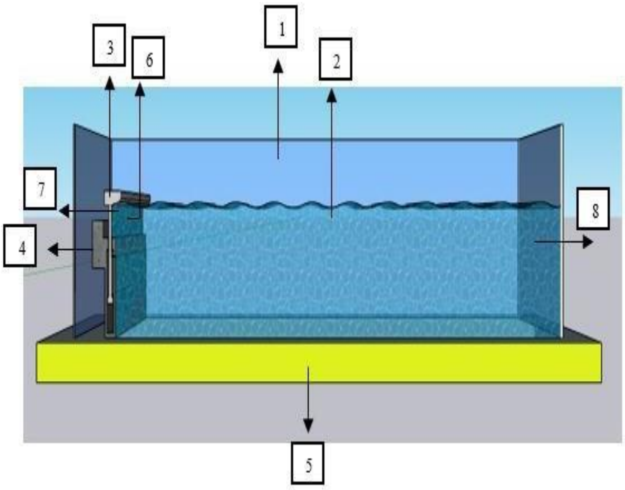

Figure 1. Research prototype layout

Information :
1 : Test Tank
2, 8 :Water
3 : Fiber
4 : Concrete stand
5 : Test stand
6 : Load Cell and Starin gauge
7 : LVDT

Figure 1 illustrates the layout of the research prototype used in this study, including the arrangement of the test tank, floating fiber embankment model, supporting structures, and measurement instruments employed during the laboratory testing process.

Research procedures

The research procedure is divided into two main parts: numerical simulation using ANSYS and physical experiments in the laboratory.

1. Numerical Simulation Using ANSYS
   Numerical simulations were performed to model the mechanical behavior of floating fiber embankments under hydrostatic pressure. ANSYS Workbench version 20 was used in this study. ANSYS is a finite element (Finite Element Method)-based software that allows mechanical, hydraulic, and hydrodynamic analysis of complex structures. The simulation stages performed are as follows:
2. Geometry Modeling:
   The first step in the simulation is to create a geometric model of the floating fiber embankment. The dimensions of the floating embankment are designed with a length of 1 meter, a width of 0.5 meters, and a height of 0.5 meters. The concrete supports are also modeled with the appropriate dimensions to support the floating embankment.
3. Meshing:
   After the geometry model is created, the meshing process is carried out to break down the embankment structure into small elements. The mesh size is determined with a resolution of 0.15 meters to ensure accurate simulation results.

4. Definition of Loading Condition:
   The hydrostatic pressure caused by the tide is modeled in this simulation. The hydrostatic pressure value is determined based on the water depth and the density of the seawater, which is applied to the sides of the embankment exposed to the water. The fluid pressure is calculated using the hydrostatic pressure equation:

$$P = \rho \; x \; g \; x \; h \tag{1}$$

   - P is the hydrostatic pressure,
   - ρ is the density of sea water,
   - g is the acceleration due to gravity, and
   - h is the water depth.
5. Flow Fluent Simulation:
   The simulation was performed using the ANSYS Flow Fluent module to model the fluid flow and pressure distribution on the floating embankment. The water velocity was entered with a value of 0.5 m/s to simulate tidal conditions. The results of this simulation were used to measure the pressure distribution on the floating fiber embankment.
6. Static Structure Analysis:
   This simulation is used to model the deformation and stress distribution on the floating embankment under the influence of hydrostatic pressure. The analysis is carried out to determine the maximum stress, strain, and total deformation that occurs on the embankment.

Laboratory experiments
Laboratory experiments were conducted to verify the results of the numerical simulation. The experimental process was conducted in the laboratory using a physical model of the floating fiber embankment. The experimental stages are as follows:
1. Making Floating Dike Model
   The floating dike model is made of fiber material with appropriate technical specifications. Fiber is chosen because this material has light and flexible properties, and is resistant to sea water. The dimensions of the floating dike in the laboratory are made at a scale of 1:20 of the original design, see in Figure 2.

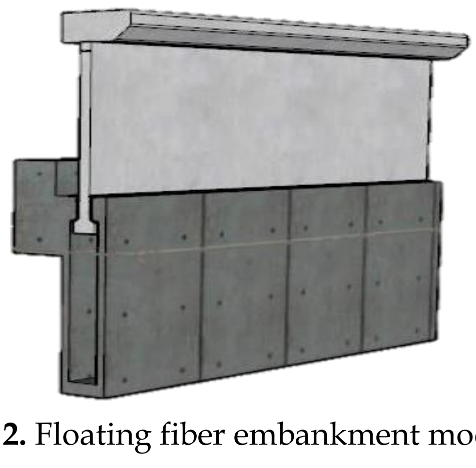

Figure 2. Floating fiber embankment model

2. Test tank preparation
   Acrylic test tanks are installed in the laboratory by filling water to a certain height adjusted to tidal conditions. The water used is static to simulate hydrostatic conditions on the embankment.
3. Measuring instrument settings
   LVDT is installed to detect vertical shift of floating embankment, while strain gauge is installed at critical points to measure stress and strain that occurs. Load cell is also installed to measure hydrostatic pressure received by floating embankment.
4. Testing process
   The test was conducted under two conditions, namely full tide and half tide. In each condition, displacement, stress, strain, and hydrostatic pressure data were recorded using a data logger. Each experiment was repeated three times to ensure consistency of the results.
5. Data collection
   The measurement data were collected and analyzed to obtain the average values of displacement, stress, and strain that occurred on the floating embankment. These values were then compared with the simulation results to validate the model used.

Data analysis methods

Data obtained from simulations and laboratory experiments were analyzed quantitatively to evaluate the performance of the floating fiber embankment. The following are the analysis steps taken:

1. Deformation analysis
   The deformation that occurs on the floating embankment is measured in the form of vertical displacement. The measurement results from the LVDT are compared with the results of numerical simulations to determine the differences between the experimental and simulation results.
2. Stress and strain analysis
   The measured stress and strain from the strain gauge are analyzed to determine the stress distribution in the fiber material. These results are compared with the simulation results to determine whether the floating embankment is able to withstand the given hydrostatic pressure.
3. Comparison of simulation and experimental results
   Simulation and experimental results are directly compared to validate the model used. If there is a significant difference, further analysis is performed to determine the cause of the difference.
4. Validation of results
   After all data is analyzed, the final step is validation of the research results. Validation is done by comparing the results of numerical simulations and laboratory experiments. If the results of both approaches show agreement, then the proposed floating embankment model can be considered valid and ready to be applied on a larger scale. However, if there are significant differences, improvements to the model need to be made before being implemented in the field.

RESULTS AND DISCUSSION

Results

In this study, the performance evaluation of the floating fiber embankment was conducted using two main methods: numerical simulation with ANSYS and laboratory physical experiments. The results of both methods were analyzed to understand how the floating fiber embankment responds to hydrostatic pressure from rising sea levels and how it performs in tidal flood mitigation.

Numerical simulation results using ANSYS

Numerical simulations were performed using ANSYS software with a finite element model to analyze stress, strain, and deformation on the floating fiber embankment. This simulation is important because it provides an initial prediction of how the embankment will behave when subjected to hydrostatic pressure under various tidal conditions in Figure 3.

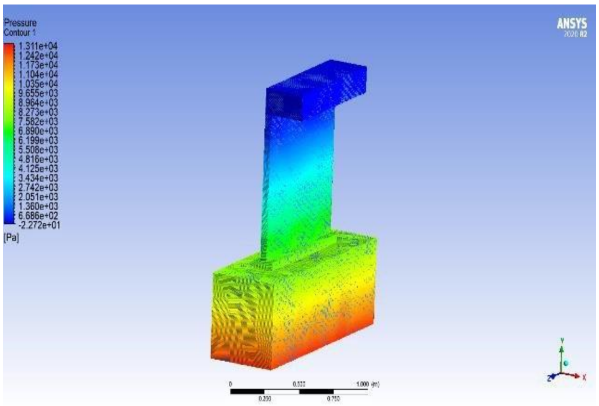

Figure 3. Results of hydrostatic pressure simulation on floating fiber embankment

Stress and strain

Based on the simulation results, the floating fiber embankment experiences a maximum stress of 8.231 × 10^6 Pa under hydrostatic pressure from full-tide conditions. This stress value occurs in the area of the embankment that experiences the greatest pressure from seawater, namely at the bottom of the embankment, which is in direct contact with the concrete support. Meanwhile, the maximum strain is 0.00045 meters per meter and is also distributed in the same area.

These results indicate that the fiber material used in the embankment can withstand water pressure without significant damage. The strain remains within the material's elastic limits, meaning the embankment can return to its original shape once the water pressure is reduced. This indicates that the floating fiber embankment has good elasticity and can adapt to tidal fluctuations.

Deformation

The simulation results also show that the maximum deformation that occurs in the floating fiber embankment is 0.0043 meters. This deformation occurs at the top of the embankment, which is directly subjected to water pressure from above. Although deformation occurs, its magnitude remains within safe limits, indicating that the embankment does not experience significant damage or structural failure.

Deformation of the floating fiber embankment is primarily caused by water pressure, which pushes the embankment upward as the water level rises. The advantage of the floating embankment is its ability to automatically adjust its height in response to sea-level changes, so that the resulting deformation does not cause functional failure. This deformation is one indicator that the floating fiber embankment is effective in reducing the risk of tidal flooding by following fluctuations in water levels.

Laboratory experiment results

Laboratory experiments were conducted to validate the results of the numerical simulation and to test the performance of the floating fiber embankment in real conditions. In this test, the floating fiber embankment model was tested in a water test tank with two main scenarios, namely full tide conditions and half tide conditions.

Stress and strain

In the laboratory test, the maximum stress measured was 8.210 x 10^6 Pa, which is very close to the simulation results. This shows that the stress prediction from the numerical simulation has been well validated. Similar to the simulation results, the maximum stress occurs in the area in direct contact with the concrete seat, where the greatest water pressure is received.

The maximum strain measured in the experiment was 0.00044 meters per meter, which is also close to the simulation results. These results strengthen the conclusion that the floating fiber embankment has the capacity to withstand the hydrostatic pressure generated by the tide, with a strain that is within the elastic limit of the fiber material.

Deformation

The deformation measured in the experiment was 0.0041 meters, slightly smaller than the simulation results. This difference is likely due to the laboratory environment being more controlled than the assumptions used in the simulation. However, this difference is still within an acceptable margin, and does not indicate any significant discrepancy between the simulation and experimental results.

The deformation that occurred in the experiment showed that the floating fiber embankment can move vertically following the rise and fall of sea level. This shows that the floating fiber embankment system works according to the design, namely floating following changes in sea level and returning to its original position when the water recedes.

Discussion

The results of numerical simulation and laboratory experiments show high agreement, indicating that the proposed floating fiber embankment model can perform well in real conditions. Some important points that can be discussed from the results of this study are as follows:

Elasticity and flexibility of floating fiber embankments

One of the main advantages of floating fiber embankments is the elasticity of the fiber material which allows the embankment to withstand significant hydrostatic pressure without experiencing permanent damage. Based on the simulation and experimental results, the stress and strain that occur in the embankment are within the elastic limits of the material, which means that the embankment can return to its original shape after the pressure is reduced. This is important to ensure that the embankment can be used in the long term without experiencing functional degradation, see in Figure 2.

Table 2. Comparison of simulation and experiment results

Test Conditions	Voltage (Pa)	Strain (m/m)	Deformation (m)
Simulation (ANSYS)	8.231×10^6	0.00045	0.0043
Laboratory Experiments	8.210×10^6	0.00044	0.0041

Source: Analysis Results, 2024

In addition, the flexibility of the floating fiber embankment allows the system to follow fluctuations in sea level. This capability is very important in dealing with tidal flood conditions, where sea levels can change suddenly due to the ebb and flow. The floating fiber embankment that can adapt to these fluctuations provides better protection than conventional embankments that are static and cannot adjust the water level.

From an SDG perspective, the proposed floating fiber embankment technology contributes to the achievement of SDG 11 (Sustainable Cities and Communities) by strengthening the resilience of coastal areas against recurrent tidal flooding. The adaptive characteristics of the system enable more effective flood mitigation while reducing the vulnerability of coastal infrastructure and communities to tidal hazards. Furthermore, its sustainable and low-maintenance design supports the development of disaster-resilient infrastructure and promotes long-term coastal sustainability. Therefore, the implementation of this technology has the potential to assist policymakers and coastal planners in developing more adaptive, inclusive, and resilient coastal protection strategies in line with the objectives of SDG 11.

Hydraulic and structural stability

The hydraulic stability of the floating fiber embankment is greatly influenced by the design of the concrete pedestal that supports the embankment at the bottom. The experimental results show that the concrete pedestal is able to withstand the embankment load and the hydrostatic pressure received by the embankment without experiencing shifting or instability. This shows that the combination of floating fiber and concrete pedestal is a stable and effective design in dealing with varying water pressures.

The structural stability of the floating fiber embankment is also indicated by the minimal deformation results. Although there is deformation during high tide, the deformation is still within safe limits and does not cause damage to the embankment. This deformation also serves as an indicator that the embankment functions well in adjusting the water level, it can see in Figure 4.

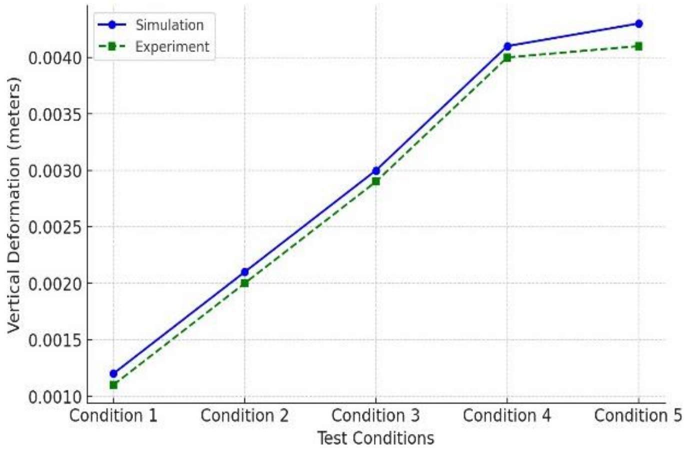

Figure 4. Vertical deformation graph of floating fiber embankment

Advantages compared to conventional embankments

Floating fiber embankments have several advantages compared to conventional embankments. Conventional embankments, such as those made of concrete or stone, are usually designed with a fixed height that is only effective at certain high tide conditions. When the water level exceeds the design limit, these embankments cannot hold back the water, causing flooding. In contrast, floating fiber embankments are able to adjust their height automatically, making them more effective in dealing with tidal flooding.

In addition, floating fiber embankments do not require manual intervention or intensive maintenance because the system works automatically based on the principle of flotation. This is different from conventional embankments that often require periodic repairs and maintenance, especially after experiencing extreme water pressure.

CONCLUSION

Fundamental Finding: The results of this study show that floating fiber embankments are an effective solution for mitigating tidal flooding in coastal areas. Both numerical simulations and laboratory experiments indicate that the structure is able to withstand high hydrostatic pressure, with a maximum stress of 8.231×10^6 Pa and a maximum deformation of 0.0043 meters. The fiber material demonstrates elastic behavior, allowing the embankment to return to its original shape after the applied load is removed. In addition, the system is capable of automatically adjusting its height according to water level changes, making it more adaptive than conventional static embankments. The structural system is also stable, supported by a concrete base that prevents shifting or instability during testing. **Implication**: These findings indicate that floating fiber embankments have strong potential as an alternative coastal protection system. The technology is more flexible, environmentally friendly, and does not require manual operation. Compared to conventional embankments, this system provides more efficient protection against tidal fluctuations and offers improved adaptability for coastal infrastructure planning and flood mitigation strategies, thereby contributing to the achievement of SDG 11 (Sustainable Cities and Communities) through the development of more resilient and sustainable coastal infrastructure. **Limitation**: This study is limited to controlled laboratory experiments and numerical simulations. Therefore, real-field conditions such as wave dynamics, long-term material degradation, and complex coastal environmental interactions were not fully represented in the analysis. **Future Research**:

Future studies are recommended to conduct field-scale testing under real coastal conditions to validate laboratory findings. Further development is also needed in scaling up the embankment design and exploring alternative fiber materials with higher resistance to marine corrosion. In addition, economic feasibility analysis should be conducted to evaluate cost efficiency and long-term sustainability. Collaboration between government, research institutions, and industry stakeholders is essential to support large-scale implementation of this technology in coastal regions affected by tidal flooding.

AUTHOR CONTRIBUTIONS

Sunaryo contributed to the conceptualization of the study, research design, project supervision, validation of research findings, and critical review of the manuscript. **Imam Wahyudi** contributed to the development of research methodology, supervision of experimental procedures, validation of simulation and laboratory results, and revision of the manuscript. **Moh. Faiqun Ni'am** contributed to data analysis, numerical simulation modeling, interpretation of results, visualization, and drafting of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no financial, personal, or professional conflicts of interest that could have affected the research process, results, or conclusions of this study.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors confirm that no artificial intelligence tools, automated content generation systems, or digital writing aids were used in any stage of the research, including data analysis, interpretation of results, or manuscript preparation. All processes were carried out independently by the authors, who take full responsibility for the originality, accuracy, and integrity of the work presented in this study.

REFERENCES

Abidin, H. Z., Andreas, H., Gumilar, I., Sidiq, T. P., & Fukuda, Y. (2013). Land subsidence in coastal city of Semarang (Indonesia): Characteristics, impacts and causes. *Geomatics, Natural Hazards and Risk,* 4(3), 226–240. https://doi.org/10.1080/19475705.2012.692336

Adhi, R. N., Santoso, B., & Pradana, G. L. (2017). Study of the effect of sea walls on floods in the Tenggang River drainage system. *Jurnal Teknik Sipil*, *1*(1), 1–10. http://dx.doi.org/10.32832/astonjadro.v14i3.17976

Aerts, J. C. J. H., Botzen, W. J. W., Emanuel, K., Lin, N., de Moel, H., & Michel-Kerjan, E. O. (2014). Evaluating flood resilience strategies for coastal megacities. *Science, 344*(6183), 473–475. https://doi.org/10.1126/science.1248222

Djunarsjah, E., & Poerbandono. (2005). *Hydrographic survey*. Refika Aditama.

Fell, R., MacGregor, P., Stapledon, D., Bell, G., & Foster, M. (2015). *Geotechnical engineering of dams (2nd ed.)*. CRC Press. https://doi.org/10.1201/b17800

Hastowo, P. (2003). *General criteria guidelines for dam design*. Directorate General of Water Resources.

Hidayati, D. (2017). The fading value of local community wisdom in water resources management. *Indonesian Population Journal*, *11*(1), 39–52. https://doi.org/10.14203/jki.v11i1.36

Kamkar, S., & Safabakhsh, R. (2016). Vehicle detection, counting, and classification in various conditions. *IET Intelligent Transport Systems*, *10*(6), 406–413. https://doi.org/10.1049/iet-its.2015.0157

Kong, F. (2024). Rising to the climate challenge: Better understanding rural rainstorm flooding disaster risk management using practical insights from China. *Natural Hazards Review, 25*(2), 04024002. https://doi.org/10.1061/NHREFO.NHENG-1877

Kurniawan, T. A., & Babel, S. (2003). A research study on Cr(VI) removal from contaminated wastewater using low-cost adsorbents and commercial activated carbon. In *Proceedings of the 2nd Regional Conference on Energy Technology Towards a Clean Environment (RCETE)*. (pp. 1110–1117). https://doi.org/10.2175/193864703784343758

Leroux, S., Li, B., & Simoens, P. (2022). Automated training of location-specific edge models for traffic counting. *Computers & Electrical Engineering*, *99*, 107763. https://doi.org/10.1016/j.compeleceng.2022.107763

Liu, J.-E., & An, F.-P. (2020). Intelligent traffic monitoring system based on computer vision and deep learning. *Scientific Programming*, *2020*(1), 7607612. https://doi.org/10.1155/2020/7607612

Liu, L., Ouyang, W., Wang, X., Fieguth, P., Chen, J., Liu, X., & Pietikäinen, M. (2020). Deep learning for generic object detection: A survey. *International Journal of Computer Vision, 128*(2), 261–318. https://doi.org/10.1007/s11263-019-01247-4

Marfai, M. A. (2004). Spatial modeling of sea water flood in Semarang. *Geography Forum, 18*(1), 60–69. https://doi.org/10.23917/forgeo.v18i1.599

Morris, M. W., Hassan, M. A. A. M., & Veldman, S. J. (2008). The science of embankment dam engineering. *Proceedings of the Institution of Civil Engineers – Water Management, 161*(2), 63–73. https://doi.org/10.1680/wama.2008.161.2.63

Ningsih, D. H. U., & Wismarini, T. D. (2010). GIS-based drainage system analysis in Semarang City. *DINAMIK*, 15(1), 41–51. https://doi.org/10.35315/dinamik.v15i1.110

Nugroho, H., Kurniani, D., Asiska, M., & Nuraini, N. (2016). Polder system performance study in Semarang City. *Civil Engineering Media*, 22(1), 43–52. https://doi.org/10.14710/mkts.v22i1.12508

Nugroho, S. H. (2013). Prediction of tidal inundation area in Semarang City. *Journal of Environmental Geology*, 4(1), 71–87. https://doi.org/10.34126/jlbg.v4i1.51

Ogie, R. I., Perez, P., & Dignum, M. (2019). A review of structural approach to flood management in coastal megacities of developing nations: Current research and future directions. *Journal of Environmental Planning and Management, 63*(2), 127–147. https://doi.org/10.1080/09640568.2019.1579952

Patel, D., Hosseini, P., & Jalayer, M. (2023). A framework for proactive safety evaluation of intersections. *Accident Analysis & Prevention*, *192*, 107264. https://doi.org/10.1016/j.aap.2023.107264

Permatasari, A. (2015). *Embankment planning for flood control in Cileungsi River* (Research report). Universitas Brawijaya, Malang, Indonesia.

Redmon, J. (2018). YOLOv3: An incremental improvement. arXiv. https://doi.org/10.48550/arXiv.1804.02767

Salim, M. A., Siswanto, A. B., & Mindiastiwi, T. (2022). Study of flood impact handling in Pekalongan District. *IOP Conference Series: Earth and Environmental Science*, 955(1), 012014. https://doi.org/10.1088/1755-1315/955/1/012014

Sunarto. (2003). *Coastal geomorphology: Coastal dynamics* (Monograph). Laboratorium Geomorfologi Terapan, Fakultas Geografi, Universitas Gadjah Mada, Yogyakarta, Indonesia

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M. J., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature, 504*(7478), 79–83. https://doi.org/10.1038/nature12859

Triatmodjo, B. (1999). *Coastal engineering*. Beta Offset.

Wang, L., Kaspersen, P. S., Jensen, N. H., Müller, M., & Jiang, Y. (2022). A review of the flood management: From flood control to flood resilience. *Heliyon, 8*(11), e11763. https://doi.org/10.1016/j.heliyon.2022.e11763

Wibisono, A. B. (2017). *Analysis of embankment height against flood elevation of Way Sekampung River*, *East Lampung*, *Lampung Province* [Undergraduate thesis, IPB University]. IPB University Repository. Retrieved from https://repository.ipb.ac.id/handle/123456789/92007

Yuwono, N. (1998). *Technical guidelines for embankment and sea wall planning*. Gadjah Mada University.

Zhao, Z. Q., Zheng, P., Xu, S. T., & Wu, X. (2019). Object detection with deep learning: A review. *IEEE Transactions on Neural Networks and Learning Systems*, 30(11), 3212–3232. https://doi.org/10.1109/TNNLS.2018.2876865

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