Coastal Erosion Mitigation Measures at Arattupuzha

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ABSTRACT

Coastal erosion is a major environmental issue affecting many coastal regions, including Arattupuzha in Kerala, where the shoreline is rapidly receding due to strong wave action and sediment transport. This project proposes a sustainable erosion mitigation strategy using a combination of T groynes and a seawall. The structural performance of these protective measures was evaluated through numerical simulations using ANSYS software. Key parameters such as velocity vectors, turbulence kinetic energy, and streamline flow were analysed to understand the hydrodynamic behaviour around the structures. The study compared the performance of T groynes and conventional straight groynes. Results indicated that T groynes are more effective in stabilizing the shoreline and retaining sediment, offering better performance in wave energy dissipation. The addition of a seawall behind the groynes provides an extra layer of defensive measure, reducing direct wave attack and preventing further coastal retreat. This integrated approach not only enhances the protection of the shoreline but also ensures the long-term safety of nearby communities. The findings underline the value of advanced modelling tools in coastal engineering and provide a strong foundation for future design improvements based on site-specific environmental data.

Keywords: T-groyne, seawall, shoreline protection

I. INTRODUCTION

Arattupuzha is a coastal village in the Alappuzha district of Kerala, located along the Arabian Sea. Since the land is mostly low-lying, the village is highly vulnerable to natural problems like flooding, coastal erosion, and rising sea levels caused by climate change. Every year, especially during the monsoon season, strong waves hit the coast, washing away parts of the land. Over time, this erosion has become worse due to human activities like unplanned construction and sand mining. These actions disturb the natural movement of sand along the coast, making the shoreline weaker and more likely to get damaged. As a result, the local environment is harmed, and people living in the area face serious risks to their homes, farms, and incomes. Many families have already lost land and property as the sea continues to move closer inland. Important infrastructure such as roads and public buildings are also at risk. To protect Arattupuzha from further damage, strong and smart coastal protection measures are needed. Two useful solutions are building seawalls and groynes. A seawall is a strong barrier placed along the shore to block the force of waves and prevent land behind it from being washed away. This helps protect houses and other buildings from storms and tides.(Miller et al., 2019) .Groynes are structures that go out into the sea at right angles to the shore. They slow down the flow of water and help sand collect on one side, which helps rebuild the beach. These structures support natural processes and create a stronger defense against erosion. Using both

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seawalls and groynes as part of a larger coastal management plan can help keep Arattupuzha safe for the future. It is important to combine these efforts with sustainable practices to protect the land, the people, and their way of life.(Dutta et al., 2020). Coastal erosion poses significant threats to infrastructure, ecosystems, and local economies. It causes loss of land that supports critical facilities like roads, homes, and utilities. Studying mitigation strategies is necessary to protect these assets, preserve biodiversity, and ensure sustainable development.

Climate change accelerates sea-level rise and storm intensity, heightening the urgency for effective erosion control. Human-induced erosion must be distinguished from natural processes to formulate targeted solutions. A well-researched approach reduces long-term repair costs, aids informed policymaking, and guides zoning and development. A comprehensive study also enhances community awareness and drives innovation in coastal defense, such as hybrid systems that blend engineering with ecological preservation.The specific Objectives of this study are:

1. To compare the performance of T-head groynes with straight groynes.
2. To design and draft a seawall and groyne system for coastal accretion at Arattupuzha.
3. To conduct flow and deformation analysis using ANSYS software

1.1 COASTAL PROTECTION STRUCTURE

Coastal erosion is the removal of shoreline materials due to wave action, tidal currents, and river drainage. While natural, human interventions like construction and sand mining accelerate this process. The consequences include loss of land, infrastructure damage, and ecosystem disruption. To combat erosion, coastal protection structures are essential. Among them, seawalls and groynes are the most commonly used. Seawalls protect by deflecting or absorbing wave energy, while groynes help accumulate sediment and prevent longshore drift, helping retain beach width. A seawall is a barrier constructed parallel to the shoreline to protect against waves, tides, and storm surges.(Kalaitzi et al., 2023) It is typically used in urban areas where property and infrastructure require direct protection. Seawalls are built in different forms Vertical – Reflect wave energy but can cause scouring at the base, Curved – Deflect waves downward, reducing their energy. Sloped/Revetments – Use rocks or concrete to absorb wave energy. Each design is chosen based on local wave conditions, environment, and budget.

Key Components of a Seawall:

1 Armour Layer (Tetrapods): Concrete units designed to interlock and dissipate wave energy. Ideal for high-energy zones like Arattupuzha.

2. Filter Layer (Quarry Stone): Prevents finer materials from being washed out and distributes load from the armour layer.

3. Core Layer (Quarry Run Stone): Forms the internal mass, providing structural stability.

4. Toe Protection: Prevents undermining by placing heavy materials at the base.

5. Drainage Layer (Gravels): Allows trapped water to escape, preventing pressure build-up and structural damage.

Groynes are typically constructed using materials like wood, stone, or concrete and extends from the shore into the sea. The primary purpose of a Groyne is to interrupt the movement of sand and sediment along the coast, which is mainly driven by wave action and longshore drift. A T-groyne is a coastal structure with a T-shape, where the main part extends perpendicular to the shoreline, and a horizontal extension projects into the sea. This design helps trap sediment more effectively, reducing erosion on the downdrift side. A straight groyne extends directly perpendicular to the shore without any horizontal extension. While it also traps sediment, it is generally less effective at preventing erosion on the downdrift side compared to T-groynes. T-groyne designs are often preferred in areas with significant longshore drift.

2. LITERATURE REVIEW

Noujas et al. (2023) In his study investigates coastal erosion along India's southwestern coast, an area facing severe erosion. Previous efforts using traditional seawalls and groynes were insufficient, prompting the exploration of more innovative solutions. The proposed hybrid strategy of combining seawalls with T-groynes offers a more effective approach by not only providing direct defense against wave action but also enhancing sediment retention, thereby reducing erosion and promoting coastal stability. The study suggests that integrating both structures could lead to better long-term coastal management in regions facing similar challenges. Charuka et al. (2023) examines the reliance on hard-engineered structures along the coast of Ghana, particularly in response to the impacts of sea-level rise (SLR). Groynes, seawalls, and revetments are widely used for erosion and flood protection, but their ecological impacts and sustainability are concerning. The study advocates for a more balanced approach by integrating hard-engineered solutions with natural measures, such as restoring mangroves and wetlands. It also emphasizes the importance of Integrated Coastal Zone Management (ICZM) practices, involving public engagement, continuous monitoring, and alignment with both environmental and socio-economic needs for sustainable coastal resilience. Through his study Toda et al. (2023) focuses on riverbank protection strategies for the Jamuna River in Bangladesh, known for its dynamic and braided morphology. The research highlights the successful implementation of T-shaped groynes, which divert the flow of water, reduce erosion, and aid in sediment deposition. These groynes not only stabilize vulnerable riverbanks but also contribute to long-term morphological adjustments in the river. The study emphasizes the importance of adaptive management, continuous monitoring, and community-driven approaches to mitigate any negative downstream effects and ensure the sustainability of riverbank protection measures. Hriday Mani et al. (2020) explores river training structures, particularly groynes, which are used to prevent bank erosion and facilitate navigation. It compares straight-head and T-head groynes, noting that T-head groynes are more effective in river bends, leading to greater sediment deposition and shifting the thalweg (main flow of water). This comparative analysis highlights the superiority of T-head groynes in certain river conditions, providing valuable insights for improving river management and erosion control. Uijttewaal et al. (2020) investigates how the design of groynes affects flow patterns, turbulence, and shear properties around the groyne head. The study shows that groynes significantly alter the riverbed structure, flow resistance, and sediment transport dynamics. By modifying the design of groynes, such as adjusting their permeability and shape, the flow patterns can be optimized for better sediment management and flood prevention. This work contributes to the broader understanding of groyne performance, particularly in terms of river navigation and flood risk mitigation.

3.METHODOLOGY

After conducting literature review, it was decided to use groynes and seawall for the coastal protection. T shaped groynes will be used. Combination of seawall and groyne structures will be used. Seawall will be parallel to the coastal area and the Groynes will be perpendicular to the seawall forming a T shape. Using this hybrid combining structures, it will help in reducing the coastal erosion. For developing the 2dimensional plan for the structure, use of both architectural software and structural software are needed. Mainly AutoCAD and ANSYS are used for this

4.SITE VISIT

The 2004 tsunami significantly impacted the Arattupuzha-Alappad coast in Kerala, leading to coastal erosion, water quality issues, and economic losses for the fishing community, with some areas experiencing extensive inundation and damage. The tsunami caused widespread coastal erosion and inundation, with seawater entering the estuarine and canal systems, and widening estuarine mouths. Seawater inundation and subsequent evaporation led to environmental degradation, particularly impacting groundwater quality. The tsunami resulted in loss of life and extensive damage to property, including houses and agricultural land.

5.SOFTWARE DESCRIPTION

Structural analysis software helps engineers design and analyze structures like buildings and bridges by creating digital models, applying various loads, and performing analysis to determine forces and deflections. It also ensures designs meet safety standards and provides visualization tools for better understanding. AutoCAD and ANSYS are key examples, with AutoCAD excelling in 2D and 3D modeling and ANSYS offering advanced simulation for fluid dynamics and structural stability. These tools improve the accuracy and efficiency of engineering projects.

AutoCAD, developed by Autodesk, is a leading computer-aided design (CAD) software used for creating precise 2D and 3D models, drawings, and blueprints. It is widely utilized in various industries, including architecture, engineering, and construction, for its accuracy and efficiency in drafting and modeling. AutoCAD offers powerful tools for creating detailed designs, customizing workflows, and collaborating with team members. Its 3D modeling capabilities provide enhanced visualization and simulation, helping engineers and designers make informed decisions and improve project outcomes.

ANSYS is a comprehensive simulation software suite used for analyzing complex engineering problems across multiple domains, such as structural analysis, fluid dynamics, and thermal management. It is particularly useful for tasks like wave impact analysis, sediment transport modeling, and structural stability testing. ANSYS Fluent, part of the suite, specializes in Computational Fluid Dynamics (CFD), allowing for detailed analysis of fluid flow in various systems. By simulating real-world conditions, ANSYS helps engineers optimize designs, improve performance, and ensure

6.PROPOSED COASTAL STRUCTURE

The coastal region of Arattupuzha faces severe erosion, prompting the implementation of a hybrid coastal defense system combining seawalls and groynes. Seawalls act as solid barriers against wave energy, preventing shoreline retreat, while groynes extend into the sea to trap sand and minimize longshore sediment drift. This dual structure improves overall coastal resilience, ensuring long-term shoreline stability and protecting infrastructure.

In the hybrid setup, seawalls are typically constructed using materials like tetrapods, quarry stones, and gravels to withstand high wave forces. Groynes, often T-shaped, are positioned perpendicularly to the coast to stabilize beach width by encouraging sediment deposition. Together, they counterbalance each other's weaknesses: groynes reduce the wave reflection caused by seawalls, and seawalls provide backup during extreme events when groynes alone are insufficient.

Key design elements involve optimal spacing and length of groynes, seawall height and slope, and use of durable materials. This integration also supports tourism by preserving beach areas and helps maintain ecological balance when combined with proper planning. While the system offers superior coastal defense, reduced beach erosion, and improved flood protection, challenges include higher construction costs, potential downdrift erosion, disruption of marine ecosystems, and periodic maintenance to handle sediment movement and structural wear. Figure 7.1 shows the 2 D View of Straight Groynes and 2D View of Seawall.

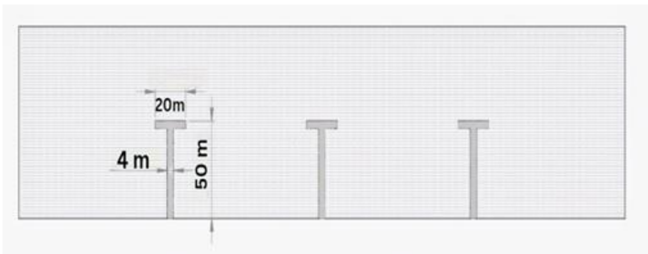

Fig 7.1 2 D View of Straight Groynes

7. DESIGN OF SEAWALL

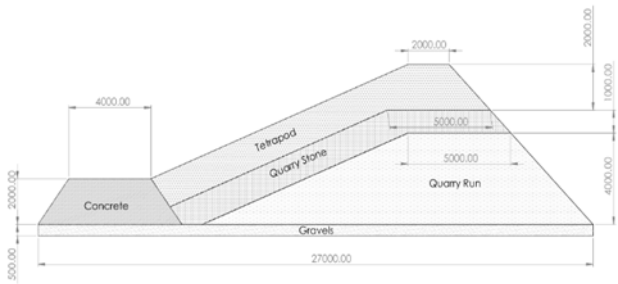

Fig 8.1 2 D View of Seawall

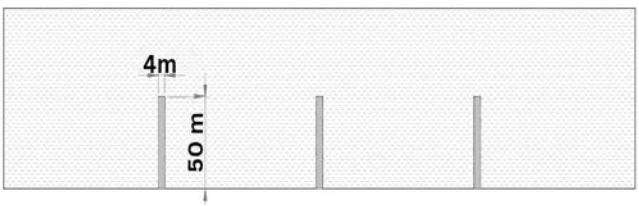

Fig 8.2 2D View of Straight Groynes

DESIGN CONDITIONS

Significant Wave Height (Hs)	Depth of Water (d)	Time Period of Approaching Wave	Seawall Length	Slope of the Structure	Tetrapod
6m	6m	8sec	27,000mm	1:2 (As inferred from the cross section)	6-12 (Depends on Interlocking)

TETRAPOD DESIGN

Weight of tetrapod (Wa)	Wa = $\gamma s.Hs3$/Kd.Δ^3Δ.tan θ
Significant Wave Height (Hs)	• Hs = 6 m
Density of Sea	ρw =1.025 kg/m3
Delta	3.18
Kd	8 (For tetrapod stability)
Wa	2.3T
Crest width of tetrapod layer	B = 1.90
Thickness of Tetrapod Layer	T= 1.90
Thickness	2m

QUARRY STONE LAYER

The quarry stone layer provides additional protection and supports the tetrapods

Weight of quarry stone layer	Wa = Wa /10 to Wa /15 = 2.3/10 to 2.3/15 = 0.23 to 0.153 T
Crest width of quarry stone layer	B = 4.76 mm
Thickness of Quarry Stone Layer	0.95 m

QUARRY RUNLAYER DESIGN

Weight of Underlayer	Wu = Wa /100 to Wa /400 Wu = 2.3/100 to 2.3/400 = 0.023T to 0.0057T
Thickness of quarry stone layer	3.81m
Thickness Provided	4m

GRAVEL LAYER

Weight of Gravel Layer	Wg = Wa /100 to Wa/400 Wg= 2.3/100 to 2.3/400 Wg = 0.023T to 0.0057T
Concrete Thickness	2m
Grade of Concrete	M30 Concrete
Structure Height	Thickness of Tetrapod layer + Thickness of Quarry stone layer + Thickness of Quarry run layer = 2+1+4 = 7m

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8.DESIGN ANALYSIS

Engineering design analysis ensures the structural integrity and performance of systems under real conditions. With complex challenges, simulation tools like ANSYS are vital for predicting structural behaviour. In coastal engineering, ANSYS models interactions between water flow and protective structures. For this project at Arattupuzha, ANSYS was used to assess the stability of seawalls and groynes under wave, tide, and sediment forces. Parameters such as total deformation, Von-Mises stress, shear stress, mesh quality, TKE, streamline, and velocity vectors were analysed, alongside a comparison of T-groynes and straight groynes. Seawalls, being key coastal defences, were further evaluated for stress distribution, deformation, and potential failure zones to ensure long-term durability.

9.SEAWALL ANALYSIS

Seawalls protect coastlines from wave action and erosion. Their effectiveness depends on design, materials, and wave interaction. Using ANSYS, stress distribution, deformation, and potential failure zones are analysed, ensuring the design can endure harsh conditions and remain durable. Table I shows the Material Properties.

Table 1 Material Properties

MATERIALS	**Density**	**Youngs Modulus**	**Poisson Ratio**
TETRAPOD	1440 kg/m^3	15000 MPa	0.25
QUARRY STONE	1740 kg/m^3	70000 MPa	0.25
QUARRY RUN	1680 kg/m^3	50000 MPa	0.3
GRAVELS	1775 kg/m^3	300 MPa	0.3
TOE BERM	2400 kg/m^3	35000 MPa	0.2

9.1 Total Deformation

The total deformation analysis helps us understand how different components of the seawall react under applied loads. It highlights regions experiencing maximum displacement, enabling us to identify weak zones that may require reinforcement or design modifications. Maximum Deformation: 0.01337 mm (Red region) – This indicates the highest displacement in the structure under applied loads. Minimum Deformation: Near zero (-Blue region) – Shows stable areas with negligible movement.

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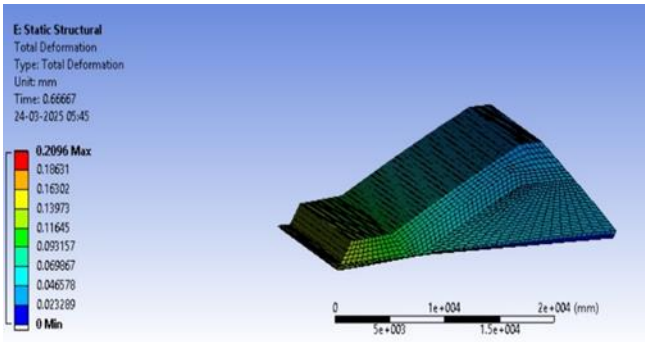

Figure 9.1 Analysis of Total Deformation

9.2 Equivalent (von-mises) stress

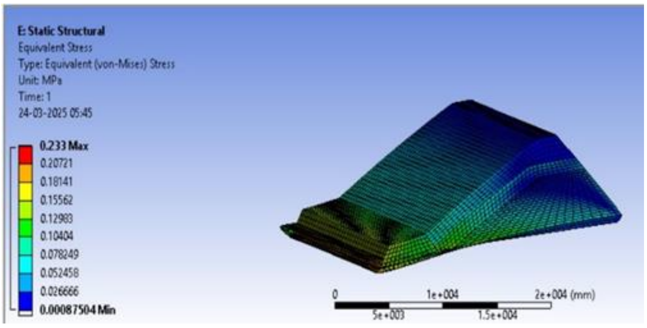

Figure 9.2: Analysis of Equivalent Stress

The Von-Mises stress distribution is crucial in determining the material's ability to withstand external forces without yielding. By evaluating this stress, we ensure that the structural materials such as tetrapod, quarry stones, and gravel layers are capable of resisting the applied wave forces without failure. Maximum Von Mises Stress 0.24950 MPa (Red region) this is the highest stress concentration and is a critical point for material failure. Minimum Von Mises Stress 0.027 MPa (Blue region) indicates the least stressed area. The green-yellow regions represent moderate stress levels. Figure 9.2 shows the analysis of equivalent stress.

9.3 Maximum Principal Stress

The analysis focuses on the Maximum Principal Stress, which helps in identifying potential failure points due to tensile stresses. Principal stress analysis is useful for brittle materials where failure typically occurs due to tensile stress. The colour legend on the left represents stress values ranging from -0.068 MPa (Minimum, dark blue) to 0.14814 MPa (Maximum, red). Red zones indicate the highest tensile stresses, which might be critical for material failure. Blue zones indicate compressive or low-stress regions. The negative stress values suggest compressive stresses in some regions.

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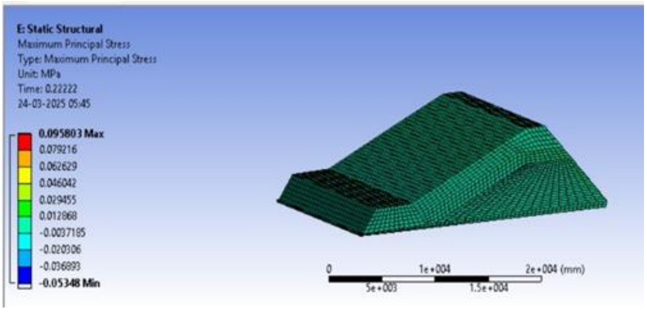

Figure 9.3 shows the analysis of maximum principal stress

9.4 Shear Stress

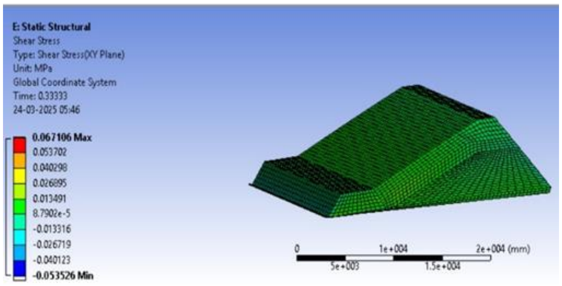

Figure 9.4 Shear Stress

Shear stress analysis helps in identifying points where internal forces act parallel to the structure which can lead to potential sliding or cracking or displacement of materials. This is particularly important in coastal structures where water flow exerts lateral forces on the foundation. Figure 9.4 shows the analysis of shear stress. Table II shows the Result of seawall analysis B.

10. GROYNE ANALYSIS

Groynes are coastal structures designed to reduce shoreline erosion by interrupting water flow and promoting sediment deposition. Analysing groynes in ANSYS allows for a detailed understanding of their interaction with hydrodynamic forces. This study focuses on evaluating key parameters such as Turbulence Kinetic Energy (TKE), Velocity Vectors, and Streamlines to assess the effectiveness of groynes in controlling coastal erosion. By simulating flow patterns and turbulence, the analysis provides insights into the stability and efficiency of groynes under varying wave conditions.

10.1‘T’ groynes: Turbulence kinetic energy

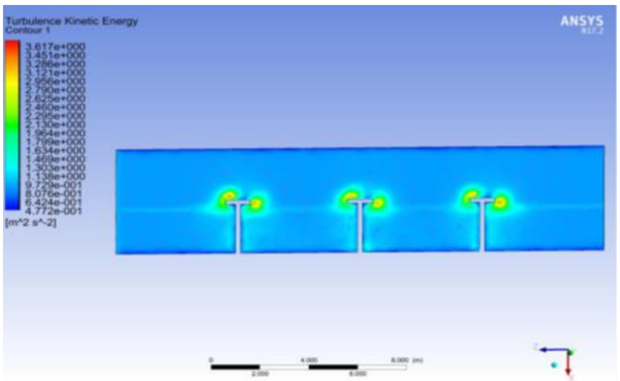

Figure: 10.1 Turbulence Kinetic Energy

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The TKE distribution for T-shaped groynes, exhibit a different turbulence pattern, with reduced energy dissipation along the structure. The presence of cross-arms in T-groynes helps in dispersing energy more evenly, potentially reducing localized scouring effects. These calmer zones may favour sediment deposition, leading to the formation of sandbars or accumulation zones. Indicates the effectiveness of groynes in slowing down currents and protecting shorelines from direct wave action. Figure 10.1 shows the turbulence kinetic energy.

10.2 Streamline

The velocity streamlines for T-groynes create a broader area of reduced velocity, which can enhance sediment deposition and improve shoreline stability. The presence of cross-arms alters the flow pattern, reducing the direct impact of high-velocity currents. Figure 10.2 shows the Streamline

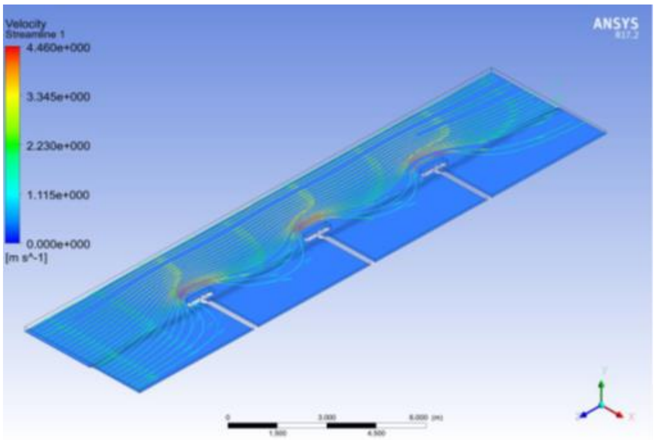

Figure 10.2 Streamline

Table 2 Seawall Analysis

Parameters	Observations	Allowable Limit (IS Code)	Remarks	Safety status
Equivalent (von-mises) stresses	0.2496	20MPa	Observed Stress is far below the limit	Safe
Maximum Principal Stress	0.1481	2000Mpa	Observed Stress is below the tensile limit	Safe

10.3 Velocity Vector

The vectors show a clear recirculating flow behind each groyne, forming vortex zones that trap sediments. The alternating high and low-velocity regions suggest that the groynes effectively redirect and dissipate energy, minimizing direct wave impact on the coastline. The flow separation at the groyne tips indicates the influence of turbulence, which can impact the long-term structural stability of the groyne.

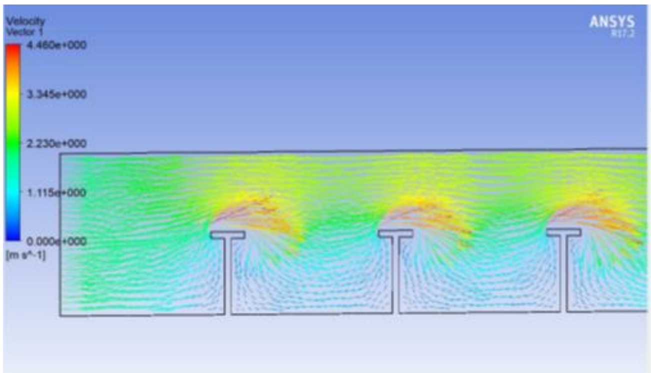

Figure 10.3 Velocity Vector

10.4 Straight groynes:Turbulence kinetic energy

The distribution of turbulence kinetic energy (TKE) around straight groynes have higher TKE values (indicated in red and yellow) are observed near the tips of the groynes, suggesting increased mixing and turbulence. While some turbulence is beneficial for sediment deposition, excessive turbulence can lead to scouring and structural instability. Fig 10.4 shows the Turbulence kinetic energy. This is a replica of the kinetic energy momentum principle. There needs to be an evaluation of sediment deposition and movement and the ways of creating this movement can be explained in Detail. Groyne performance in controlling flood flow, sediment transport and river morphologywas investigated in the middle stream stretch. From the viewpoints not only controlling floods but also of preserving the natural environment , the present study provides scientific findings useful for a proper river management by installing structures such as groyne.

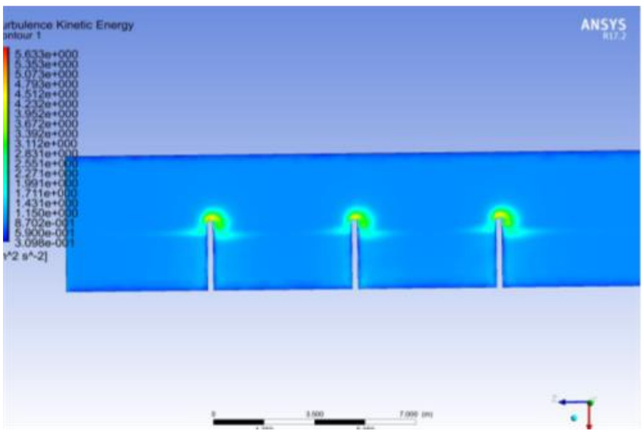

Figure 10.4 Turbulence Kinetic Energy

10.5 Streamline

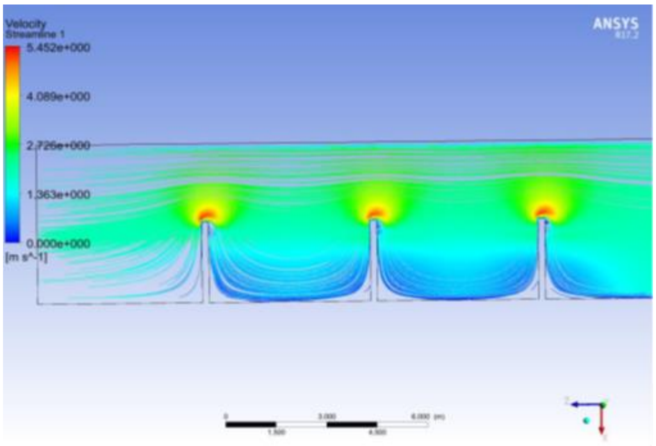

Figure 10.5 Streamline

The velocity streamlines for a series of straight groynes. The colours indicate velocity magnitudes, where red represents higher velocities and blue represents lower velocities. The streamlines show how water interacts with the groynes, creating eddies and recirculation zones behind each structure. This information is essential to understanding how effectively the groynes reduce flow energy and protect the shoreline from erosion. Figure 10.5 shows the Streamline.

11 RESULTS AND DISCUSSIONS

ANSYS analysis confirmed that the proposed T-groyne and seawall combination provides better stability against wave forces. The study compared T-groynes and straight groynes, with T-groynes proving to be more effective in reducing coastal erosion. T-groynes showed superior performance in dissipating wave energy, reducing wave impact on the shoreline. The T-groyne structure was more effective in trapping sediment and maintaining beach stability. Flow velocity and turbulence kinetic energy results indicated controlled water movement with T-groynes, minimizing erosive currents. The seawall provided additional protection by absorbing wave energy and preventing landward erosion. The combined approach of T-groyne and seawall offers a sustainable long-term solution for coastal protection at Arattupuzha.

12. CONCLUSIONS

Coastal erosion is a significant challenge at Arattupuzha, necessitating effective mitigation strategies to protect the shoreline and infrastructure. This project explored the combination of T-groynes and seawalls as a coastal protection measure. Through structural analysis using ANSYS software, the proposed design was evaluated for its stability, effectiveness in reducing wave impact, and ability to retain sediment. The results demonstrated that the integration of these structures offers a robust defence against coastal erosion. The comparative study between T-groynes and straight groynes revealed that T-groynes perform better in dissipating wave energy and promoting sediment deposition. Velocity vector analysis and turbulence kinetic energy evaluations indicated that T-groynes effectively control water flow and minimize erosive currents. Additionally, the seawall acts as a secondary defense, preventing direct wave attack on the landward side. The synergy between these structures ensures long-term coastal stability. The proposed solution of T-groynes combined with a seawall provides an efficient and sustainable coastal protection strategy for Arattupuzha. The findings of this study highlight

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the importance of integrating multiple engineering solutions to address coastal erosion comprehensively. Future work can focus on further optimizing the design by incorporating real-time wave and sediment data to enhance the effectiveness of the mitigation measures. The estimated beach deformation findings reveal that when a submerged groyne is built on the beach, sediment accumulation is slightly lower than when a non-submerged groyne is built; this is because the transfer coefficient for the submerged groyne is greater than that of the non-submerged groyne. This will result in more sediment travelling along the submerged groyne. Finally, the findings of this study suggest that employing submerged groynes is an effective technique to reduce silt and beach erosion without inflicting significant environmental damage to the shore. When the groyne is positioned at the right bank, an increased accumulation of sediment typically occurs on the sandbar that has already developed in front of the confluence. Sediment Trapping -The main way that groynes work is by interfering with the longshore current, which is in charge of the sediment flow down the shore. By serving as a barrier, they lessen the waves' force and speed, which results in the deposition of sediments behind the building. A broader beach area is progressively created and maintained when the sediment-laden current slows down and deposits the sediments on the groyne's updrift side. The buildup of sand and gravel is referred to as accretion. Less silt is available for beach maintenance on the downdrift side as a result of the groyne's ability to trap sediment. As the beach erodes and the waves rise, erosion may result.

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