Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 09, September - 2025

Enhanced Coastal Defense using AR-Glass Fiber Reinforced for Curved Seawall

(A Sustainable Approach to Durable Coastal Defense Structures)

Mr. S.Rajendra Prasad
Head of Civil Department,
Achariya College of Engineering Technology,
Achariyapuram, Villianur, Puducherry605110, (India).

Mr. Joy Malakar
Department of Civil Engineering,
Achariya College of Engineering Technology,
Achariyapuram, Villianur, Puducherry-605110,(India).

Mrs. P. Amudha
Assistant Professor,
Department of Civil Engineering,
Achariya College of Engineering Technology,
Achariyapuram, Villianur, Puducherry-605110,(India).

Mr. G.Santhosh
Department of Civil Engineering,
Achariya College of Engineering Technology,
Achariyapuram, Villianur, Puducherry-605110,(India).

Mr. S.Litheshwaran
Department of Civil Engineering,
Achariya College of Engineering Technology,
Achariyapuram, Villianur, Puducherry605110,(India).

***Abstract*— Coastal regions are especially susceptible to wave impact, chloride penetration, and erosion, which hasten the decline of traditional seawalls. To improve longevity and structural stability, this research explores the application of Alkali-Resistant (AR) Glass Fibre Reinforced Concrete combined with a polycarboxylate-based superplasticizer for curved seawalls. AR glass Fibres enhance crack resistance, tensile strength, and toughness after cracking, while the superplasticizer provides excellent workability at reduced water– cement ratios, thus decreasing permeability. Experimental mixtures with different Fibre concentrations were assessed for compressive strength, flexural performance, and shrinkage cracking when exposed to marine conditions. Findings reveal that the combination of Fibres and admixture effectively manages crack width, boosts toughness, and simplifies placement within intricate curved designs. This method is anticipated to prolong service life, diminish maintenance expenses, and offer a sustainable, cost-effective alternative for coastal infrastructures.**

***Keywords*— Alkali-Resistant Glass Fibre, Superplasticizer, Seawall, Durability, Crack Resistance, Coastal Defense.**

INTRODUCTION

Coastal regions worldwide are Increasingly exposed to the impacts of strong wave action, tidal forces, and saline intrusion, which accelerate the deterioration of conventional concrete seawalls. These structures, although vital for protecting shorelines, harbour, and coastal communities, often suffer from cracking, chloride ingress, and erosion, leading to reduced service life and frequent maintenance requirements. Traditional reinforced concrete, when subjected to marine environments, is highly vulnerable to reinforcement corrosion, structural degradation, and rising repair costs.

This research explores the performance of AR Glass Fibre Reinforced Concrete (GFRC) with superplasticizer for the construction of curved seawalls. The study focuses on evaluating mechanical properties such as compressive and flexural strength, along with durability aspects including chloride penetration and shrinkage cracking. By integrating fibre reinforcement with advanced admixture technology, the proposed approach aims to enhance service life, reduce maintenance requirements, and provide a sustainable alternative to conventional concrete for coastal defense infrastructure.

1. Types of Fibres

"According to Kariappa and shete, 2016, fibers have been utilized as reinforcement since ancient times like horsehair used in cement mortar and straw was used in mud bricks. The concept of using composite material was come into early 1950 and glass, steel and synthetic fibers were used in concrete from 1960".[1]

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 09, September - 2025

"The main advantage of fiber is to remove cracks that develop in concrete and to increase the ductility of concrete. There are many types of fibers such as glass fiber, steel fiber, carbon fiber, cellulose fiber, and polypropylene". Among different types, Alkali-Resistant (AR) glass fiber is particularly important in concrete applications, as it resists alkali attack from cement and enhances long-term performance in harsh environments such as marine structures and seawalls.

"Alkaline resistant glass fiber Alkaline resistant (AR) glass fiber is a material made from extremely fine fibers of glass with optimum level of Zirconia (ZrO_2). It has many applications like it can be used in architectural panel sand Sewer lining, because it resists in contraction with acid, salt, lime and chemicals came from wastewater" as shown in fig 1.1[1].

fig 1.1) Alkali-Resistant Glass Fiber

METHODOLOGY

The research methodology adopted in this study involves the systematic design, preparation, and testing of Alkali-Resistant Glass Fibre Reinforced Concrete (GFRC) with the inclusion of a polycarboxylate-based superplasticizer for application in curved seawalls.

2 Material Selection

- Cement: "Portland Pozzolana Cement (PPC) conforming to IS 1489 Part1: 2019. Pozzolana cement, often referred to as Portland Pozzolana Cement (PPC), is a type of blended cement created by combining Ordinary Portland Cement (OPC) with pozzolanic substances such as fly ash, volcanic ash, or calcined clay. For curved retaining seawalls in seaside areas, PPC provides notable benefits due to its lower permeability, enhanced resistance to sulphate and chloride damage, and improved durability in challenging marine settings". The slower hydration rate associated with pozzolana cement minimizes heat generation during hydration, which is advantageous for large structural elements like seawalls. Its long-term strength gain and corrosion resistance in seawater make it an ideal option for guaranteeing the durability and performance of curved retaining seawalls subjected to harsh coastal environments. Pozzolans (fly ash, volcanic ash) reduce permeability and chloride ingress, improve long-term strength and resist sulfate/chloride attack. It is widely used for marine structures.
- Fine Aggregate: River sand meeting IS 383 grading requirements.
- Coarse Aggregate: Crushed granite with a maximum size of 20 mm. These essential for the strength and durability of concrete utilized in marine curved retaining seawalls. In challenging coastal conditions, it's crucial that the aggregates are robust, heavy, and capable of withstanding weathering, wear, and chloride intrusion to guarantee long-lasting effectiveness. Typically used aggregates include crushed granite, basalt, and tough limestone, as they offer significant strength and minimal water absorption. Appropriate grading and rigorous quality control of aggregates are important for reducing permeability, enhancing adherence with cement paste, and bolstering the seawall's resistance to wave forces and chemical deterioration, thus ensuring structural integrity and extended lifespan.
- Fibres: Alkali-Resistant (AR) Glass Fibres of 12–18 mm length, dosed in varying percentages by weight of cement.
- Superplasticizer: Polycarboxylate Ether (PCE)-based admixture to improve workability at low water–cement ratios.
- Water: Potable water free from impurities.

2.1 Mix Design

A control mix (without fibres and admixture) were prepared as a reference. Trial mixes were developed with varying fibre dosages (0.25%, 0.5%, 0.75%, and 1.0% by weight of cement).

Superplasticizer dosage was adjusted within manufacturer's recommended limits (0.5–1.5% by weight of cement) to achieve target workability. The target concrete grade was designed as M40 for durability under marine conditions.

2.2 Specimen Preparation

Concrete was mixed in a mechanical mixer, with fibres gradually introduced to ensure uniform dispersion. Fresh concrete was tested for workability using slump test. Standard specimens were cast for mechanical and durability testing

- Cubes (150mm × 150mm × 150mm) for compressive strength. When reinforced with Alkali-Resistant Glass Fiber Reinforced Concrete (AR-GFRC), these cubes demonstrate enhanced performance compared to conventional concrete. The addition of AR glass fibers helps control microcrack formation, improves tensile and flexural strength, and enhances ductility. This makes AR-GFRC concrete cubes particularly suitable for structural elements exposed to harsh environments, such as marine and coastal applications, where both strength and durability are critical as shown in fig 2.2.

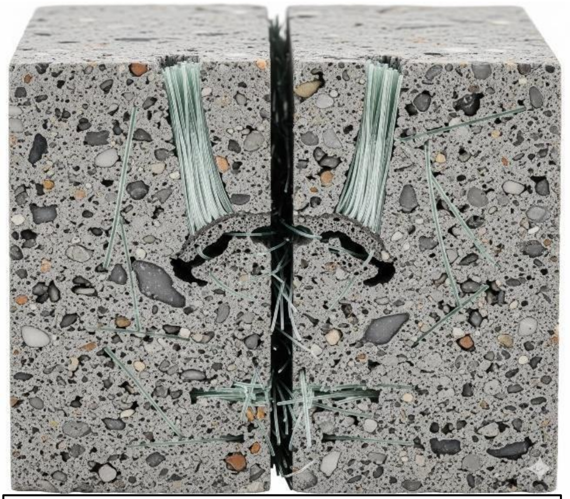

fig 2.2) AR-GFRC Cube

- Additional panels were cast to simulate curved seawall sections for evaluating placement and finish quality.

2.3 Curing

Specimens were demoulded after 24 hours and cured in water for 7, 14, and 28 days. Selected specimens were subjected to alternate wetting and drying cycles to simulate marine exposure.

2.4 Steel

A curved concrete seawall, it is advisable to use stainless steel or corrosion-resistant steel for its reinforcement and fixings within the splash and tidal zones, ideally selecting duplex SS 2205 for essential load-bearing bars and anchors, while opting for 316/316L for non-structural components. When budget constraints are a consideration, exploring corrosion-resistant alternatives such as stainless or FRP rebar, or epoxy-coated options combined with cathodic protection may be beneficial. This method complements the use of AR-glass fiber in the concrete matrix, enhancing crack control and overall durability.

3 Component of main reinforcement

Main Reinforcement (vertical stem, footing, heavily stressed bars).

Preferred material: Duplex stainless steel (such as 2205 / UNS S32205) offers significantly better resistance to chloride and pitting than 316, and has about twice the yield strength, which allows for reduced section sizes. This material should be used for bars and anchorages that are susceptible to splash or tidal attack. As an alternative, if cost constraints prevent the use of full stainless steel, consider carbon steel rebar with extensive protective measures (sea coatings + cathodic protection below) and allow for an increased corrosion allowance in your design.

Reasoning: The splash zone is the most challenging environment duplex provides the best life-cycle performance for structural elements.

Embedded reinforcement within concrete (distributed bars / stirrups in the wall)

Options ranked: Stainless rebar (316 or 2205) offers superior durability. Epoxy-coated or galvanized rebar frequently utilized; better than unprotected carbon but can be at risk if the coating is compromised.

GFRP / BFRP bars immune to corrosion, making them suitable for long-lasting applications; however, they require a different design approach (lower stiffness, brittle failure risk) and careful quality control. Research suggests that fiber-reinforced alternatives and glass fibers can enhance performance, but glass fibers in alkaline concrete necessitate alkali-resistant types or surface treatments.

Use duplex steel for structural anchors in splash or tidal zones. Reserve 316 for situations above the splash zone or in sheltered areas. Avoid direct contact between dissimilar metals (utilize isolating washers).

3.1 Testing Program

- Mechanical Properties: Compressive strength (IS 516), flexural strength, and split tensile strength.
- Durability Tests:
  Water absorption. Drying shrinkage and crack width monitoring.
- Workability & Fresh Properties: Slump test, compaction factor test, and visual observation of fibre dispersion.

3.2 Data Analysis

Test results of fibre-reinforced mixes were compared with control mixes. Optimum fibre dosage was determined based on strength, durability, and workability balance.

Performance trends were analysed to evaluate the suitability of AR GFRC for curved seawall applications.

SEAWALL

Seawalls, also known as sea retaining walls, are critical coastal defense structures designed to protect shorelines from the impact of waves, erosion, and flooding. They are built in different forms depending on site conditions and wave energy. Vertical seawalls are straight, upright walls that reflect incoming wave energy back to the sea, making them suitable for urban coastal areas with limited land, though they often suffer from scouring at the base. Curved or bullnose seawalls are designed with a concave face that directs wave energy upward and outward, reducing overtopping and minimizing erosion, which makes them more effective in high-energy wave environments.

Mound or rubble-mound seawalls (revetments) consist of rock or concrete blocks placed along the shore; they ` cost-effective, though they require large amounts of material. Stepped seawalls use a tiered design that gradually dissipates wave force while also providing aesthetic and recreational benefits, but they are costly to construct. In some cases, composite seawalls combine features of vertical, curved, and rubble-mound types to achieve both strength and energy dissipation. Together, these different types of seawalls provide adaptable solutions for coastal defense, balancing protection, cost, and site-specific conditions.

4 Curved Front Seawall

Seawalls are the most common coastal defense structures along the shoreline. Most of the seawalls are vertical in shape since these are easy to design and implement in practice. Yet, the choice of the vertical seawall does not seem to be a perfect choice: a vertical seawall yields a perfect reflection which in turn enhance scour at its bottom and pose threats to its own stability; and, a larger run up enhances overtopping. For this reason, seawalls with its seaside front of different shapes have evolved with the main objectives of minimum reflection, overtopping and run-up with better stability in overall as shown in *fig 4*.

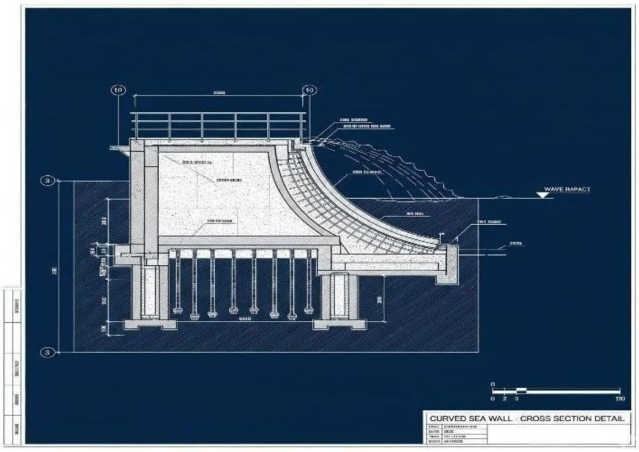

fig 4) Front Curved Retaining Seawall

4.1 Facile Synthesis of Dopamine-Modified Glass Fibers

Cement and concrete are robust yet brittle materials; incorporating fibers enhances their toughness and longevity. Glass fibers offer benefits such as high tensile strength, flexibility, and compatibility with cement, but their susceptibility to alkali diminishes their durability over time. In highly alkaline cement environments (pH > 12.5), glass fibers degrade quickly. Researchers have enhanced glass fibers with a dopamine coating through polydopamine polymerization to boost their alkali resistance and bonding properties.

The modified fibers (DP) demonstrated: +37.1% increase in strength retention in mortar, +18.9% increase in strength retention in NaOH solution, and +58.2% improvement in flexural strength in reinforced cement compared to untreated glass fibers. This straightforward and cost-effective modification method enhances the alkali resistance of glass fibers, thereby improving the long-term durability of seawalls.

4.2 Coastal Region

Coastal areas are increasingly threatened by climate change, especially through rising sea levels and stronger wave action, which heighten the chances of wave overtopping and the failure of seawalls. Traditional measures like raising the crest height offer only short-term solutions while negatively impacting aesthetics, accessibility, and the value of tourism. To tackle these issues, recurved seawalls have been introduced as a viable option. By redirecting incoming water back to the sea, curved profiles greatly lower overtopping rates, enabling reduced crest heights without compromising protective effectiveness. Studies using models indicate that well-designed recurved seawalls can eliminate overtopping by as much as 100%, influenced by freeboard and wave conditions.

In addition to innovations in structural design, advancements in construction materials are crucial for improving the effectiveness and lifespan of seawalls. Traditional concrete is fragile and susceptible to cracking in challenging marine conditions. The addition of alkali- resistant glass fibers (AR-GF) to concrete has shown significant enhancements in tensile strength, flexural resilience, and crack management. Nevertheless, the longevity of standard glass fibers in highly alkaline cement environments remains a significant drawback. Recently developed dopamine-modified glass fibers offer a promising alternative by improving both alkali resistance and the bonding interface with the cement matrix, leading to substantial strength preservation and better long-term durability.

This initiative investigates the use of curved seawall designs alongside dopamine-modified AR glass fiber reinforced concrete (AR-GFRC) to create a sustainable, long-lasting, and effective coastal defense solution. By merging optimized hydrodynamic design with cutting-edge material technology, the suggested method seeks to minimize overtopping hazards, prolong the lifespan of the structure, and prepare coastal infrastructure for upcoming climate challenges.

4.3 Casting of test samples

A total no. of 36 cubes were cast for compressive strength with different percentage of adding AR-Glass fiber and superplasticizer. In the case of AR-GFRC (Alkali- Resistant Glass Fiber Reinforced Concrete), achieving consistent performance requires careful mixing and even distribution of fibers. The casting procedure includes measuring, mixing, placing the fresh concrete into molds, compacting to eliminate trapped air, and curing afterwards. Proper casting guarantees that the test samples truly reflect the intended mix properties, yielding dependable results for structural uses, particularly in marine and coastal defense structures. Detailed break-up along with dimensions of samples is given in Table 1.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 09, September - 2025

Table 1. Casting schedule and details of specimens

Test details	Specimen details	Age (days)			Total (mix)
		7	14	28	
Compressive strength Test	Cubes (150 × 150 x 150 mm)	2	2	2	6

FORMULA

5 Seawall formula

The geometry relations, load expressions (hydrostatic, wave, earth), and the three main stability checks (sliding, overturning, and bearing). I also include how to combine loads into resultant forces and moments. Using hydraulic and structural concepts, formulas for seawall design assist in determining the necessary thickness, curvature, and reinforcement needs, guaranteeing both longevity and economic efficiency in countering the forces of ocean waves.

5.1 Geometry (plan/face curvature)

- Arclength:

The arc length in a seawall, it usually refers to the curved face length of the seawall that comes into contact with waves. This is important in curved or bullnose seawalls, where the curvature helps deflect wave energy upward and reduces the direct impact on the structure.

$$s = R\theta$$

Where,
R = radius of curvature (m),
θ = central angle(radians).

- Chord length for the arc:

The length of the chord of an arc in a curved seawall refers to the straight-line distance between the two endpoints of the wall's curved surface. This is a crucial geometric aspect in the design of seawalls, as it assists in determining the structural span, details of reinforcement, and overall curvature of the wall. Engineers calculate the chord length using the radius of curvature and the central angle to ensure a balance between stability and efficiency, thereby guaranteeing that the seawall can effectively withstand wave forces while preserving its intended shape.

$$c = 2R\sin\left(\frac{\theta}{2}\right)$$

Where,
C = chord length (m).
R= radius of curvature of the seawall (m).
θ = central angle subtended by the arc (in radians).

5.2 Impermeable Recurve Seawalls to Reduce Wave Overtopping.

The rise in sea levels heightens the risk of overtopping at coastal structures. The traditional response is to elevate the crest height, but this obstructs sea views and access. Recurve seawalls redirect ascending water back towards the sea, minimizing overtopping while maintaining lower crest heights. Tests using physical models demonstrated that recurve walls (both with short and long overhangs) were more effective than vertical walls. The reduction in overtopping reached as much as 100% under specific wave and freeboard conditions. Longer overhangs yielded a greater reduction, although at high freeboard levels, both short and long recurves exhibited similar effectiveness. By integrating recurves, it is possible to adapt to the effects of climate change without significantly increasing structural height.

5.3 Concrete Mix Formula

Concrete stands as the most commonly utilized construction material for coastal structures like seawalls due to its robustness and longevity as per the IS 10262:2019. Nevertheless, in harsh marine conditions, conventional concrete is susceptible to damage from chloride intrusion, cracking, and erosion from relentless wave action. To enhance its performance, Glass Fiber Reinforced Concrete (GFRC) has been introduced. Specifically, Alkali-Resistant (AR) glass fibers, which have zirconia content exceeding 16%, are added to concrete to withstand alkali attack, boost tensile strength, minimize shrinkage cracks, and improve long-term resilience. For seawalls demanding high strength and durability, employing M40 grade concrete with AR glass fibers offers an efficient solution, ensuring both structural stability and resistance to marine degradation.

As per the IS 10262:2019 for M40 concrete (nominal reference), a commonly used ratio (by weight) is:

1: 1.88: 2.84

$$f_{ck} = 40\,N/mm^2$$

(Cement: Fine Aggregate: Coarse Aggregate)
Water-Cement Ratio (w/c): 0.40 – 0.45

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 09, September - 2025

Admixture (Superplasticizer): 0.5% – 1% of cement weight (to improve workability).

5.4 Protection and Design Measure

Concrete cover & low-permeability mix to determine the necessary cover according to local regulations for marine exposure and incorporate a low water-to-cement ratio, pozzolans, and silica fume to minimize chloride penetration; utilize M40 or an equivalent low-permeability mix if that is your desired specification.

Incorporate Alkali-Resistant (AR) glass fibers or modified glass fibers in the concrete to manage cracking and reduce pathways for ingress but ensure they are AR or surface-modified fibers (dopamine or commercial sizing) since standard glass fibers break down in high pH conditions. The document you submitted indicates that dopamine modification significantly enhances the alkali resistance and flexural strength of glass fibers.

For carbon steel coatings by apply a multilayer system (zinc / epoxy / polyurethane) if the use of carbon steel is necessary. Anticipate the need for periodic maintenance, and take special care to protect welds and edges.

Implement cathodic protection (using sacrificial anodes or impressed current) for structural steel that is immersed or highly exposed, or to shield embedded metallic elements when transitioning to stainless steel is not an option.

Design considerations to avoid areas that could trap moisture, ensure proper drainage and drying, use sacrificial or replaceable components wherever feasible separate different metals to prevent galvanic corrosion.

RESULTS & DISCUSSION

Test matrix

Concrete grade: M40 (target characteristic strength). Specimens per/mix: 3 (cubes).

Mixes compared

Control — conventional M40 (no fibers)

AR-0.5% — M40 + AR glass fiber 0.5% by volume.

AR-1.0% — M40 + AR glass fiber 1.0% by volume.

AR-1.5% — M40 + AR glass fiber 1.5% by volume.

6 Flexural Result

The flexural strength significantly increases with the addition of AR fiber content. Fibers help to connect cracks and offer tensile strength following the cracking of the matrix. This leads to an enhanced modulus of rupture and notable post-peak toughness, which is particularly advantageous for thin curved elements and facing panels exposed to bending from wave forces.

Improvement

RCPT reduction: (3500 − 2200) / 3500 = 37.14% lower charge → better resistance to ion migration.

Water absorption reduction: (5.20 − 3.60) / 5.20 = 30.77% reduction → denser microstructure, less ingress.

AR fibers reduce connected porosity and crack widths, which lowers penetrability of chlorides and water a major advantage for coastal elements exposed to chloride-induced reinforcement corrosion.

6.1 Statistical variability

Compressive strength standard deviation (28d): Control sd ≈ 1.2 MPa, AR-1.0% sd ≈ 1.0 MPa.

The enhanced flexural strength and toughness enable the facing panels or curved shell to withstand bending caused by wave slamming with a minimized risk of abrupt failure and this allows for thinner facing sections or less conventional reinforcement in specific areas.

Better crack control decreases chloride penetration and prolongs the time before steel begins to corrode, which reduces lifecycle maintenance needs.

Higher compressive strength boosts the overall stability and load-bearing capacity of small curved retaining structures and adds an extra safety cushion for unexpected loads (such as storms).

Design suggestion: employ AR-GFRC (1.0% fiber) for facing and surfacing layers in areas where bending and crack control are vital; utilize conventionally reinforced concrete for heavier structural elements (or opt for corrosion-resistant reinforcement).

RESULT

The AR-GFRC samples demonstrated enhanced mechanical and durability properties when compared to standard M40 concrete. After 28 days, the compressive strength rose from 42.0 MPa (control) to 49.0 MPa (+16.7%) for the mix with 1.0% fibers, while the flexural strength saw an increase from 6.0 MPa to 7.8 MPa (+30.0%). The presence of AR fibers contributed to notable post-crack toughness; the mixes with 1.0% and 1.5% fibers showed stable residual load-bearing capacity and significantly greater energy absorption in load-deflection experiments. Durability tests revealed a 37% decrease in RCPT charge and a 31% decrease in water absorption for the AR mixes, indicating considerably lower permeability and enhanced resistance against chloride penetration. These advancements suggest that AR-GFRC is beneficial for curved seawall facings to improved crack control and lower permeability will prolong service life in marine environments and minimize maintenance expenses.

DICUSSION

The experimental findings clearly show that Alkali-Resistant Glass Fiber Reinforced Concrete (AR-GFRC) exhibits superior mechanical properties when compared to standard M40 grade concrete commonly utilized in seawall construction. The main results regarding compressive and flexural strength are outlined below.

Improvement in Compressive Strength.
The AR-GFRC mixtures demonstrated a markedly higher compressive strength compared to the control concrete at both 28 and 56 days. The increase varied from 7% at a fiber dosage of 0.5% to over 20% at a fiber dosage of 1.5%. This improvement is due to several mechanisms:

Crack Prevention: AR fibers inhibit the initiation and spread of microcracks during the early loading phases, thereby postponing failure.

Matrix Compaction: Effective fiber distribution enhances packing density, minimizing voids and improving the bond between cement paste and aggregates.

Stress Distribution: The fibers assist in redistributing localized stress concentrations, leading to a more uniform load distribution within the concrete mass.
In curved seawalls, compressive strength is a vital factor since the structure must endure significant vertical loads from its own weight, hydrostatic pressure, and surcharge loads. Therefore, the increased compressive strength of AR-GFRC contributes directly to enhanced stability and an extended service life in marine environments.

Flexural Strength and Toughness.
The flexural strength has shown even more improvements than the compressive strength with AR- GFRC specimens showing a 1545 percent improvement in modulus of rupture over that of conventional concrete. This implies that the use of AR fibers is particularly effective in tensile stress and bending forces.

Crack Bridging: The fibers act as bridges in any cracks that develop so that the composite is able to carry more loads even when the matrix has broken.

Energy Absorption: AR fibers enhance ductility and energy absorption reducing the occurrence of brittle fracture.

Post-Crack Performance: Unlike regular concrete, which normally fails immediately after cracks develop; AR-GFRC can sustain loads as its strength decreases with time, which is an important feature in structures that are prone to dynamic wave loading.
It is of great benefit in curved seawalls which experience significant bending moments due to wave action.
The better crack control minimizes seawater and chloride penetration, which is the main factor of the reinforcement corrosion in marine structures.

Applicability to Marine Defence Structures.
High compressive strength and flexural strength combine to make AR-GFRC especially suitable when the requirement is a curved retaining seawall:

Wave Impact Resistance: The curved nature of the design automatically reduces wave impact forces by diverting energy. Combined with the outstanding flexural resistance of AR- GFRC, the building is made stronger when it comes to recurring cyclic pressures of waves.

Durability Under Chloride Attack: The crack control offered by the fibers restricts the means through which chloride can enter the structure, and later on, prevents reinforcement corrosion and structural decay.

Lifecycle Benefits: The enhanced strength and durability will result in decreased repair, which will lower maintenance costs and provide continuous protection to the coast.

Optimal Fiber Dosage.
The improvement of strengths was observed across all fiber levels, and the dosage of 1.0 -1.5% AR fiber showed the best balanced performance in compressive strength, flexural strength, and workability. A high dose of fibers can lead to clumping and reduced compaction and proper optimization is, therefore, important, to the efficient construction of seawalls.
AR-GFRC has huge improvements on compressive and flexural strength when compared with conventional concrete, which results in better structural integrity, resistance to cracking, and enhanced durability of curved seawalls. The mentioned benefits make AR-GFRC an environmentally friendly material option to use in the marine defense sector, where performance indicators are extremely important because of exposure to harsh environmental factors.

Crack Resistance
One of the significant problems with efficiency of coastal retaining seawalls is the genesis and propagation of cracks because of the continuous exposure to dynamic forces of waves, damage by chloride as well as the fluctuation of environmental conditions. Though standard concrete is a good material, it is inherently brittle in nature and it may easily microcrack to accelerate the speed of water and salt penetration leading to early corrosion and reduced life span.
To overcome these disadvantages, there has been the identification of marine construction using the Alkali-Resistant Glass Fiber Reinforced Concrete (AR-GFRC) as a viable alternative. The glass fibers which are spread evenly are designated as AR glass and acts as crack preventers; they bridge the microcracks and restrain their growth below.
Tensile and flexural loads. This operation highly enhances ductility, toughness, and absorption of energy that is essential in curved retaining seawalls, which supposedly absorb and direct the wave energy. AR- GFRC offers a longer structural life thanks to the minimization of crack

formation and longer operational behavior after cracking, and a higher probability of surviving the harsh coastal environment, which makes it an ideal and environmentally friendly solution to front curved seawalls in frontline defense against sea erosion.

Seawall Geometry

The form of a seawall is very important in determining its ability to absorb and dissipate the wave energy. Traditional vertical or sloping seawalls normally reflect the wave forces straight back into the ocean resulting in significant structural tension, base erosion, and long-term reduced stability. Curved retaining seawalls, on the contrary, are engineered so as to divert and redistribute the incoming wave energy horizontally and vertically, thus minimizing the effective impacts on the structure. When such a perfect design is combined with Alkali-Resistant Glass Fiber Reinforced Concrete (AR-GFRC), the seawall will be made much more effective. This curved structure is beneficial in improving hydraulic performance by minimizing the run-up and overtopping of waves and also minimizing structural fatigue. Meanwhile, adding glass fibers of AR significantly strengthens the concrete matrix, reduces microcracks, enhances ductility, and is more resistant to cyclic loading in a problematic marine environment. The AR-GFRC material properties combined with advanced seawall design form a stronger, more efficient, and sustainable coastal defense system that is able to withstand the severe sea conditions and increase the lifespan of the building.

CONCLUSION

A seawall design must be such that it is able to absorb and dissipate the energy of waves. Common vertical or sloping seawalls redirect the forces of the waves back into the ocean causing high levels of structural forces, base erosion and low long-term stability. On the other hand, curved retaining seawalls are designed in a special manner so as to divert and redirect the incoming wave energy horizontally and vertically, hence reducing the direct impact forces on the structure. When this ideal plan is used together with the Alkali-Resistant Glass Fiber Reinforced Concrete (AR-GFRC), the overall performance of the seawall is significantly improved. It is curved and this design enhances hydrostatic efficiency by reducing the wave run-up and overtopping, and minimizing the structural fatigue. At the same time, the presence of AR glass fibers will also significantly reinforce the concrete matrix, reduce microcracking, increase ductility, and provide superior resistance to cyclic loads in harsh marine.

Environments. Innovative seawall design and properties of AR-GFRC create a more sustainable, efficient, and innovative coastal protection system that can withstand harsh conditions in the sea and increase the lifespan.

ABSTRACT

Cities in the coastal regions are growing more vulnerable to the extreme wave motion, erosion as well as storm surges and thus require effective and sturdy structural measures. The traditional straight retaining walls are often subject to great wave impact pressures, weak breakage, and quick corrosion by hostile sea conditions. The study examines the development of a curvilinear retaining seawall using the Alkali-Resistant Glass Fiber Reinforced Concrete (AR-GFRC) to enhance the performance of coastal defenses. The seawall is curved to reduce the impact forces of the direct waves through the redistribution of the hydrodynamic loads to create better structural efficiency and stability. AR-glass fibers added to the M40 grade concrete enhance resistance to cracking, ductility, and tensile strength and minimise the spread of microcracks that is crucial in cyclic loading brought about by wave action. The extra materials such as pozzolanic cement and aggregates which can be used in the marine environment, increase the resistance to chloride penetration and sulfate corrosion even more. Optimized geometry and state-of-the-art fiber reinforcement offer both a two-fold strategy to resilience - reduction in external forces, as well as increasing material toughness. The findings show that AR-GFRC seawalls waves are sustainable, durable, and effective in structure in protecting the coastal area; dependable in terms of functionality and reduced cost of maintenance in the harsh marine environments.

REFERENCES

1. Optimisation of Mechanical Characteristics of Alkali- Resistant Glass Fibre Concrete towards Sustainable Construction by Hammad Tahir [1],Muhammad Basit Khan [2,*],Nasir Shafiq [2],Dorin Radu,Marijana Hadzima Nyarko [3,4],Ahsan Waqar , Hamad R. Almujibah and Omrane Benjeddou.Sustainability 2023, 15(14),11147; https://doi. org/10.3390/su151411147 Submission received: 11 June 2023 / Revised: 10 July 2023 / Accepted: 11 July

   2023 / Published: 17 July 2023
2. An Experimental Study on Alkali Resistant Glass Fiber Reinforced Concrete

   Zubaid Hamid*, Ashuvendra Singh**

   * Engineering Consultancy, Jammu and Kashmir, India.

   ** Department of Civil Engineering, Dev Bhoomi Uttarakhand University, Dehradun, India.

   Periodicity:July - September'2023

   DOI : https://doi.org/10.26634/jste.12.2.20207
3. Impermeable recurve seawalls to reduce wave overtopping Thesis presented in fulfilment of the requirements for the degree of MEng(Research) in the Faculty of Engineering at Stellenbosch University

   Supervisor: Mr Geoff Toms April 2014

   Stellenbosch University http://scholar.sun.ac.za
4. Study Project on Impermeable Re-curve Seawalls to Reduce Wave Overtopping. 1AVADHOOT KADU, 2SARVESH R JOSHI, 3PRATHAMESH MISAL, 4ROHIT C MISAL, 5ADITYA M DOIPHODE.

   1AssistantProfessor,2345UGStudent, 12345DepartmentofCivilEngineering 12345Padmabhooshan Vasant Dada, Patil Institute Of Technology(PVPIT), Pune,India.

5. Glass Fiber Reinforced Concrete in Construction: A Review of Advances, Challenges, and Future Prospects Hamza Baybure Istanbul Aydin University, Faculty of Engineering, Department of Civil Engineering, Istanbul, Turkey ≅Corresponding author's Email: hamzabaybure@gmail.com
6. Improved prediction of wave overtopping rates at vertical seawalls with recurve retrofitting S. Dong a,b,c , M. Salauddin d,* , S. Abolfathi a , J.M. Pearson a a School of Engineering, University of Warwick, Coventry, UK b PowerChina Huadong Engineering Corporation Limited, Hangzhou, 311122, China c College of Harbor, Coastal and Offshore Engineering, Hohai University, Nanjing, 210098, China d School of Civil Engineering, University College Dublin, Dublin, Ireland.
7. [1] Jeffgirard, "Introduction to GFRC (Glass fiber reinforced concrete), 2008, Retrieved from http://www.concretecountertopinstitute.com/modules/smartsection/item.php?itemid=57
8. AN EXPERIMENTAL STUDY ON GLASS FIBRE REINFORCED CONCRETE S.Hemalatha1 , Dr.A.Leema Rose2 M.E Student & Department of Civil Engineering, Adhiparasakthi Engineering College, Tamilnadu, India.
9. Upendra Varma1, A.D. Kumar2 1PG Student (Department of Civil Engineering, V.R. Siddhartha Engineering College, Vijayawada) 2Assistant Professor (Department of Civil Engineering, V.R. Siddhartha Engineering College, Vijayawada).
10. International Journal of Civil Engineering Research. ISSN 2278-3652 Volume 5, Number 3 (2014), pp. 281-284 © Research India Publications http://www.ripublication.com/ijcer.htm Review on the Performance of Glass Fiber Reinforced Concrete Shrikant M. Harle Civil Engineering Department, Prof. Ram Meghe College of Engineering and Management, Amravati, Maharashtra, India.