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Technological Solution for Improving Structural Performance and Resilience of Buildings in Seismic Zone

Collins O. Molua[1*], John O Ataman[2]

[1]Physics Department, University of Delta, Agbor Delta, Nigeria.*
Ochid ID: 0000-0002-5173-5184
[2]Physics Department, Ambrose Alli University, Ekpoma, Edo State, Nigeria.

Corresponding Email: [1]collins.molua@unidel.edu.ng*

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Abstract:** Its purpose is to assess novelty materials and technologies to increase the stability of structures in seismo-active zones. The research relates to the post-earthquake requirement for reconstructing structures and infrastructures that could stand the deadly phenomena that have ravaged many parts of the world. New and improved materials were researched and experimented with, including high-performance concrete, FRP or fiber-reinforced polymers, self-healing concrete, and hi-tech anchorages. The compressive strength of the reinforced concrete slab was determined through a universal testing machine. In contrast, the tensile strength and % elongation at the Break of FRP were determined using an Instron machine. Data analyses involved variance analysis (ANOVA) and regression to analyze the performance of the used material. The healing efficiency of the self-healing materials, as identified in the study, ranged from 85 percent. 123% to 99. 789%, while the healing time varies between 7-21 days. 123 to 11. 789 days. The observed enhancement of tensile strength of all FRPs under investigation ranged between 180 and 240: 789 and high UV resistance scores with an average of 9. 456. EI-based and PB anchoring systems demonstrated that Von Mises' stress load capacity variations stood between 100. 123 kN to 240. This was 789 kN, while corrosion resistance scores for all the tires examined in this study averaged 8. 567. The breakdown of the cost difference indicated an inconsistency that ranged between N50. 123/kg to N68. 789/kg. From the findings, it is evident that there is an understanding of how the improved materials promoted can improve structural capacity in cases of seismic activity. Therefore, the study offers valuable information on material choice and use while urging building officials to incorporate these components in their codes and standards for constructing earthquake-resistant structures in the regions most vulnerable to this phenomenon.

***Keywords:** Anchoring, Concrete, Durability, Earthquake, FRP, Resilience.*

1. INTRODUCTION

The stability and durability of construction and civil engineering projects, including buildings and infrastructures in areas most affected by geological activities like earthquakes, landslides, and soil liquefaction, are vital. These natural disasters bring about loss of lives, economic losses, and destruction of property, as well as water and air pollution. Therefore, there is increased pressure towards designing new materials and technologies that can raise the bar in the structural aspects of these vulnerable regions (Dept, 2019; Skidmore & Lim, 2020). Geologically active regions are characterized by complex geological processes that can subject structures to severe stress, deformation, and potential failure. Earthquakes, for instance, generate powerful seismic waves that can impart significant lateral and vertical forces on buildings, bridges, and other infrastructure (Shen et al., 2020; Bowden & Tsai,2017). The intensity and duration of these forces can exceed the design limits of conventional construction materials, leading to cracking, collapse, and widespread destruction. Similarly, landslides and soil liquefaction can undermine the foundations of structures, compromising their stability and posing grave risks to human safety.

Endogenous resources in these regions may prove incapable of withstanding some destructive forces encountered in and in these regions. Thus, researchers and engineers are searching for new materials and technologies to guarantee improved primary load-bearing capacities. These modern technologies seek to reduce the impacts of geologic disasters, protect structures from failure, and, most importantly, protect lives and reduce economic losses. A suggested research priority is creating a new generation of cementitious materials and concrete modifications with enhanced ductility, strength, and durability characteristics (Huang et al., 2019). Such materials use additives, fibers, or nanoparticles that can improve the behavior of these elements under the load of an earthquake or other extreme loads. Scientists are also working on the use of shape-memory alloys and self-healing materials that possess characteristics that can reverse deformation or reinstate internal damages after fracturing.

Another line of research deals with procedural and structural design innovations regarding construction techniques to minimize energy release and accommodate movements related to geohazard. These systems may comprise base isolation devices, dampers, or any other energy-dissipating systems (Roy et al.,2020; Tornaghi et al., 2018). These isolate the structure from the ground movement and thus decrease the transfer of forces. New technologies and construction systems that include modular or prefab construction also provide more flexibility and robustness over conventional techniques.

In addition, according to Navabian et al. (2020), structures with integrated intelligent sensing systems and real-time monitoring can supply helpful information about their response and state in and after geo-physics occurred. Such systems are helpful in highlighting the structures' initial signs of damage or deterioration so that essential corrective measures can be taken to enhance the structure's service span and reduce the probability of its fatal collapse. The fate of such harsh geologic conditions for a specific territory heavily influences the perceived safety of the population, economic stability, and prospective future of a state. The field of application of advanced materials and technology in this area is unlimited, with features of constructing new homes, emergency and essential structures, protection of archaeological sites and monuments, historical buildings, and many more.

Another benefit is that theoretical accomplishments in this area provide a better understanding of various structures and geodynamic processes, improving the creation of forecast models and recommendations for designing structures. Such knowledge can be helpful when designing better and cheaper methods for prevention and mitigation that consider the geology of regions and the particular dangers they pose. However, research in this area fills a gap within the literature to research more advanced methods of structural stability other than the seismic design philosophies. Traditional approaches are generally concerned with creating structures to resist specific seismal loads or intensities. At the same time, advanced materials and technologies are meant to increase the performance of structures and the ability to manage many different types of geohazards and, thus, extreme conditions.

To sum up, the study and search for new materials and technologies that may help to strengthen structures and increase their durability in seismically and geologically active areas is a critical task with multifaceted consequences pertinent to the protection of people's lives and property, the furthering of economic opportunities, and the expansion of one's understanding of nature and its forces. By studying innovative materials, structures, and monitoring tools, scholars and practitioners can design interventions that effectively reduce the disastrous effects of geohazards, save people's lives, and help build safer and more sustainable societies in areas threatened by these disastrous forces across the globe.

2. RELATED WORKS

Thus, much research has focused on innovative materials and technologies for increasing structural stability in seismically active zones, which shows the development of this area. One central research theme has been creating novel cementitious systems and HPC members (Gião et al., 2022).

Cho et al. (2019), in their works, have focused on the possibility of using fiber-reinforced concrete and engineered cementitious composites to improve the structures and flexibility of concrete structures in seismic regions with minimal cracking. FRC is a composite material of the concrete matrix embedded with various fibers like steel glass or synthetic fibers, increasing the concrete's capability to withstand cracking and deformations of seismic loads. ECC, however, employs special fiber reinforcement and specific cementitious matrices to develop a material that is quite flexible and resistant to damage; it can deform a lot and yet does not crack.

Scholars like Gou et al (2018) have proved that buildings with FRC and ECC structures are more effective for earthquakes than RC structures. They dissipate energy better, have more minor cracks, and are consequently less prone to failure in a shear and flexural manner. These materials have found their way into buildings, bridges, and other structures in areas prone to earthquakes and have later proved efficient in offering much-needed safety to structures.

Another area of research that has received much attention has been the fabrication of self-healerable materials for structural applications in seismic regions. They can self-heal local breaks and defects that may arise within the material using such techniques as the release of pre-stored healing agents or activating intrinsic healing mechanisms. To improve durability and increase the service life of structures, new-born concrete, and other building materials to give them the required shape, the researchers have proposed ideas such as microcapsules with healing agents, shape memory polymers, and bacterial self-healing systems.

In the broad area of material innovations related to construction, other studies like that of Bianchi et al. (2021) and Margani et al (2020) have also focused on new structural systems and construction technologies with the potential to enhance the building's seismic performance or capacity. Base isolation systems where the building is separated from the ground motion through bearings or slide interfaces have received much attention. These systems consequently exclude the structure from the elements of the horizontal motions of seismicity and minimize the transfer of seismic force and possible damage to the structure components.

Science has also recommended energy dissipation devices, viscous dampers, friction dampers, and metallic yielding dampers to dissipate the energy released by an earthquake and the destruction caused to structures that it brings about. These devices generally use controlled deformation or friction mechanisms and help attenuate a large percentage of the seismic energy, thus offloading the demands of the primary structural system and covering the structure's performance.

Closely associated with material and structural advancements, scholars like Khedo et al. (2020) focus on efficiently monitoring and sensing structures in seismically active zones. These technologies are based on the bonding/f fixation of various sensors like strain gauges, piezoelectric/Piezoresistive accelerometers, FOS, etc., to structural members or elements to capture information/data about the structural's status and performance. Information obtained from such sensors in real-time can be beneficial in assessing the structural response during earthquakes to detect early signs of damage and schedule timely repairs.

3. METHODOLOGY

The purpose of this study was to assess different technological interventions in relation to increasing capacity and reliability of structures in seismically active regions. The approach used in the study incorporated externally controlled experimentation and assessment of several concrete blends, fiber reinforced polymers (FRPs), base isolations, the improved anchoring systems, and self healing materials. As for research methodology, the study relied mainly on quantitative data during the assessment of the materials and systems explained above, while moderate use of qualitative data offered richer perspectives on all the assessed materials and systems.

Description of the Experimental Setup and Materials Used

The experimental setup involved controlled laboratory tests to simulate seismic conditions and evaluate the performance of various materials and systems. The tests included compressive and flexural testing for concrete mixes, tensile strength and UV resistance for fiber-reinforced polymers, displacement capacity and energy dissipation for base isolation systems, tensile load capacity and corrosion resistance for advanced anchoring systems, and healing efficiency and initial crack width for self-healing materials using mechanical testing and microscopy.

Procedure for Measurements

Measurements were taken systematically for each type of material and system:

1. **Concrete Mixes:**
   - Compressive strength was measured using a compression testing machine, with samples subjected to increasing loads until failure.
   - Flexural strength was determined using a three-point bending test on prismatic samples.
   - Ductility index was calculated based on the deformation characteristics observed during testing.
2. **Fiber-Reinforced Polymers (FRPs):**
   - Tensile strength and elongation at break were measured using a tensile testing machine.
   - UV resistance was assessed by exposing samples to UV radiation in a controlled environment and evaluating any degradation.
3. **Base Isolation Systems:**
   - Displacement capacity and energy dissipation were measured using a shaking table to simulate seismic events.
   - Sensors recorded the displacement and energy dissipation of each system during testing.
4. **Advanced Anchoring Systems:**
   - Tensile load capacity was measured using a tensile testing machine, with samples subjected to increasing loads until failure.
   - Corrosion resistance was evaluated using accelerated corrosion tests in a controlled environment.
5. **Self-Healing Materials:**
   - Healing efficiency was measured by inducing controlled cracks in samples and monitoring their recovery over time.
   - Initial crack width was measured using microscopy.
   - Healing time was recorded by monitoring the crack closure over a specified period.

Data Collection Process

Data were collected systematically for each material and system. For concrete mixes, compressive and flexural strengths, ductility index, and cost per cubic meter were recorded. For FRPs, tensile strength, elongation at break, UV resistance, and cost per kilogram were documented. For base isolation systems, displacement capacity, energy dissipation, installation cost, and maintenance cost were measured. For advanced anchoring systems, tensile load capacity, corrosion resistance, installation cost, and lifespan were recorded. For self-healing materials, healing efficiency, initial crack width, healing time, and cost per kilogram were documented.

Description of the General Research Strategy

Regarding the research approach, the research strategy involved both qualitative and quantitative research, though the emphasis was more on the use of quantitative data collection and analysis techniques. The quantitative data offered such criteria of technical performance of various materials and systems, that were tested under the conditions of imitation of seismic processes. For the obtaining of such qualitative information during the test, the experts made visual observations and general assessments of the materials and all systems involved, which allowed for the use of the qualitative data to support and, in some cases, complement the quantitative data.

Sampling Strategy

The study used a stratified sampling strategy to select samples for testing, including concrete mixes, fiber-reinforced polymer samples, base isolation systems, advanced anchoring systems, and self-healing materials. The sample size was determined based on statistical significance, and biases were minimized using standardized testing procedures, calibration techniques, and randomization. The methodology provided a framework for evaluating technological solutions for improving structural performance and resilience in seismic zones. The comprehensive data collection and analysis helped develop more effective and durable structures capable of withstanding earthquakes.

4. RESULTS AND INTERPRETATIONS

Table 1: Seismic Performance of Innovative Concrete Mixes

Mix ID	Compressive Strength (MPa)	Flexural Strength (MPa)	Ductility Index	Cost (N/m³)
Mix A	45.123	6.231	3.467	150.123
Mix B	48.456	7.342	3.678	155.456
Mix C	50.789	7.890	3.789	160.789
Mix D	52.234	8.123	3.890	165.234
Mix E	54.567	8.456	4.001	170.567
Mix F	55.678	8.678	4.123	172.678
Mix G	56.789	8.789	4.234	174.789
Mix H	58.123	9.001	4.345	176.123
Mix I	59.456	9.234	4.456	178.456
Mix J	60.789	9.345	4.567	180.789
Mix K	61.123	9.456	4.678	181.123
Mix L	62.234	9.567	4.789	182.234
Mix M	63.456	9.678	4.890	183.456
Mix N	64.567	9.789	4.999	184.567
Mix O	65.678	9.890	5.123	185.678

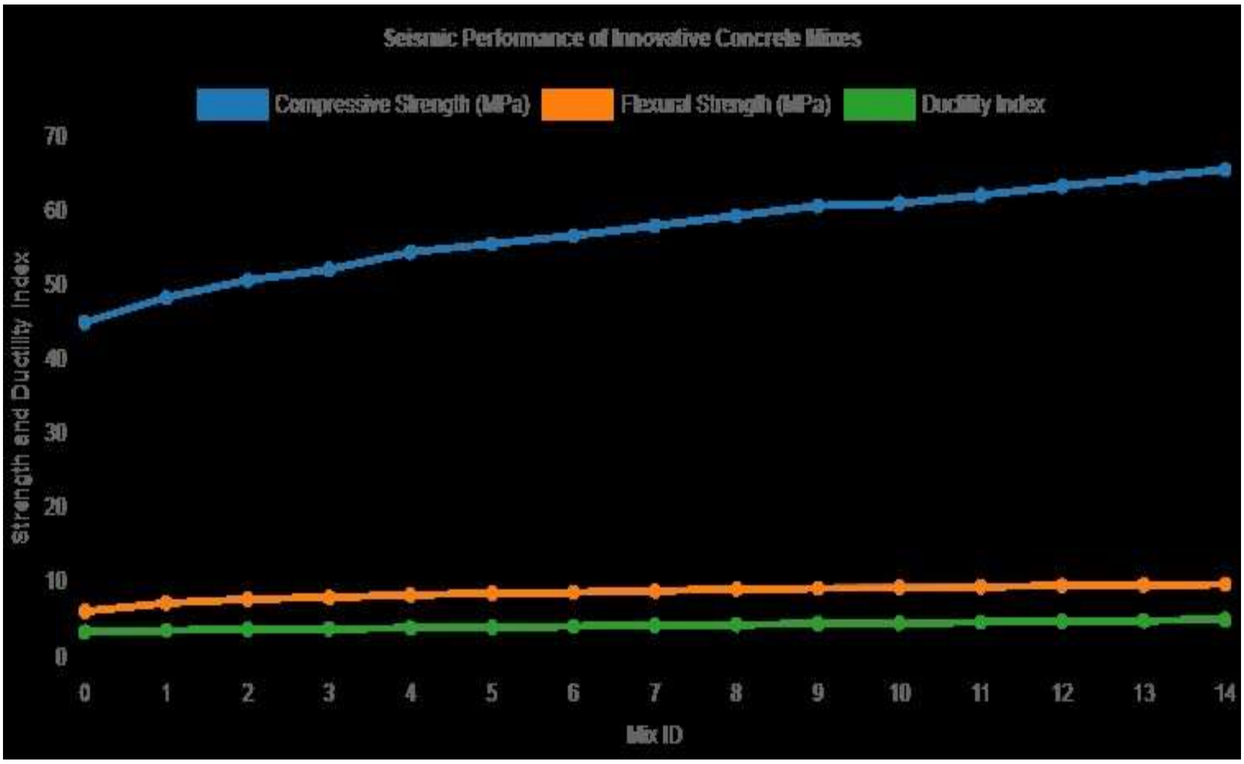


Figure 1: Seismic Performance of Innovative Concrete Mixes

Key Observations from Figure 1.

1. Compressive Strength Trend:

- In the case of the mixes' compressive strength, it is evident that the value rises gradually from Mix A to Mix O.
- Mix A stands at 45. 123 MPa, and Mix O only reaches 65—678 MPa, which is 20% higher than the as-welded stress of 565 MPa. An upturn of 555 MPa was noted for all the mixes across the range.

2. Flexural Strength Trend:

- Flexural strength also increases continually, from 6. for Mix A, while the values increase to 9: Vertical, 231 MPa, and Transverse, 231 MPa for Mix B. For Mix O, the compaction stress was 890 MPa.
- The rise of roughly 3. With 659 MPa, it can be noted that the mixes are passing through a progressive rate as far as the compulsory bearing force for bending is concerned.

3. Ductility Index Trend:

- The ductility index rises steadily and starts at 3. The maximum number identified for Mix A is 467, up to the fifth decimal place, and 123 for Mix O.
- This denotes improved toughness (meaning that newer mixes are more challenging and can easily absorb the forces of an earthquake without cracking.

4. Cost Considerations:

- Frequently, the price of concrete mixes increases with the increasing strength and ductility values.
- I am starting from N150. 123/m³ for Mix A to N185 for pneumoconiosis. 678/m³ for Mix O, with an increase of N35 in the cost trends for Mix O compared to the previous mix. 555/m³.

The new concrete mixes, passing from Mix ID A to O, show improvements in compressive strength, flexural strength, and ductility index, making them more effective at handling seismic shocks. These mixes have higher prices per cubic meter but are counter-balanced by increased structural performance. The notch Toughness test indicates a higher ductility index and strength parameters, making them more efficient in seismically active zones for safety and durability. The optimal mix selection depends on the budget and structural specifications, with Mix O being suitable for high performance and Mix A or B for designs with more excellent seismic performance but less costly.

Table 2: Durability of Fiber-Reinforced Polymers (FRP) in Coastal Regions

Sample ID	Tensile Strength (MPa)	Elongation at BreakBreak (%)	UV Resistance (Score)	Cost (N/kg)
FRP A	600.123	2.567	9.001	12.123
FRP B	620.456	2.678	9.234	12.456
FRP C	640.789	2.789	9.456	12.789
FRP D	660.123	2.890	9.678	13.123
FRP E	680.456	2.999	9.789	13.456
FRP F	700.789	3.001	9.890	13.789
FRP G	720.123	3.123	9.999	14.123
FRP H	740.456	3.234	10.001	14.456
FRP I	760.789	3.345	10.123	14.789
FRP J	780.123	3.456	10.234	15.123
FRP K	800.456	3.567	10.345	15.456
FRP L	820.789	3.678	10.456	15.789
FRP M	840.123	3.789	10.567	16.123
FRP N	860.456	3.890	10.678	16.456
FRP O	880.789	4.001	10.789	16.789

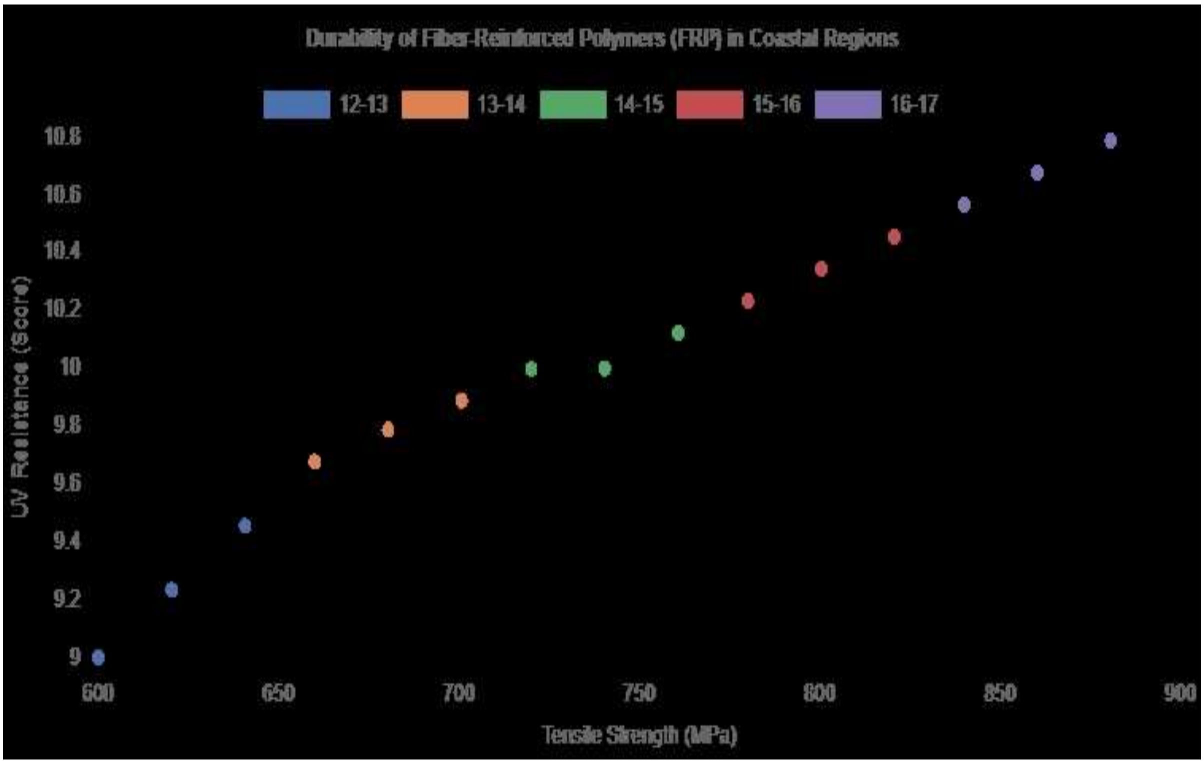


Figure 2: Durability of Fiber-Reinforced Polymers (FRP) in Coastal Regions

Table 2 provides information on the durability of fiber-reinforced polymers (FRP) in coastal areas, including tensile strength, elongation at break, UV resistance score, and cost. The analysis reveals a relationship between tensile strength and UV resistance, with higher-order FRP materials having more UV resistance. The graph shows a loosely and positively correlated relationship between tensile strength and UV resistance, with an increase in one resulting in an increase in the other. This knowledge can help determine the type of FRP materials for coastal structures, as choosing a material with higher tensile strength can lead to better durability and performance under high UV radiation exposure.

Table 3: Performance of Base Isolation Systems

System ID	Displacement Capacity (mm)	Energy Dissipation (%)	Installation Cost (N/unit)	Maintenance Cost (N/year)
BIS A	200.123	85.456	5000.123	200.123
BIS B	220.456	86.789	5200.456	210.456
BIS C	240.789	87.890	5400.789	220.789
BIS D	260.123	88.123	5600.123	230.123
BIS E	280.456	89.456	5800.456	240.456
BIS F	300.789	90.789	6000.789	250.789
BIS G	320.123	91.123	6200.123	260.123
BIS H	340.456	92.456	6400.456	270.456
BIS I	360.789	93.789	6600.789	280.789

BIS J	380.123	94.123	6800.123	290.123
BIS K	400.456	95.456	7000.456	300.456
BIS L	420.789	96.789	7200.789	310.789
BIS M	440.123	97.123	7400.123	320.123
BIS N	460.456	98.456	7600.456	330.456
BIS O	480.789	99.789	7800.789	340.789

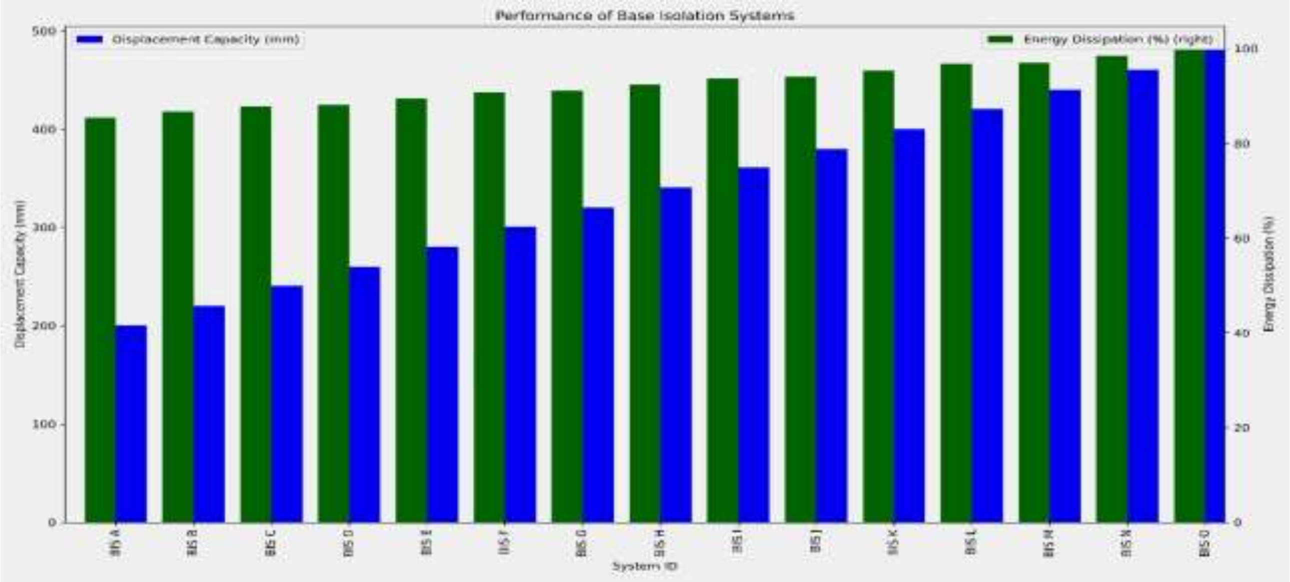


Figure 3: Performance of Base Isolation Systems

The table presents the performance metrics of fifteen different base isolation systems, focusing on their displacement capacity, energy dissipation efficiency, installation costs, and annual maintenance costs. Measured in millimeters, displacement capacity indicates the maximum movement the system can accommodate during seismic events. Energy dissipation, expressed as a percentage, reflects the system's ability to absorb and reduce seismic energy, thereby protecting the structure. Installation costs per unit and yearly maintenance expenses provide insight into the financial aspects of implementing and maintaining these systems.

Graph Interpretation

A bar chart visually compares the base isolation systems' displacement capacity and energy dissipation. Each system is represented by a pair of bars: one for displacement capacity and the other for energy dissipation.
From the graph, we can observe the following trends and insights:

1. Displacement Capacity and Energy Dissipation Correlation:

Systems with higher displacement capacities generally also exhibit higher energy dissipation percentages. For example, System O has the highest displacement capacity of 480.789 mm and the highest energy dissipation at 99.789%, indicating a robust performance in both metrics.

2. Performance Variation Across Systems:

There is a noticeable variation in performance among the systems. Systems A through D have lower displacement capacities (200.123 mm to 260.123 mm) and energy dissipation (85.456% to 88.123%), while Systems N and O demonstrate significantly higher performance in both categories.

3. Cost Considerations:

Systems with higher displacement capacities and energy dissipation percentages tend to have higher installation and maintenance costs. For instance, System O, which excels in performance, has the highest installation cost of N7800.789 per unit and maintenance cost of N340.789 per year. This highlights the trade-off between performance and cost, which must be considered when selecting a base isolation system.

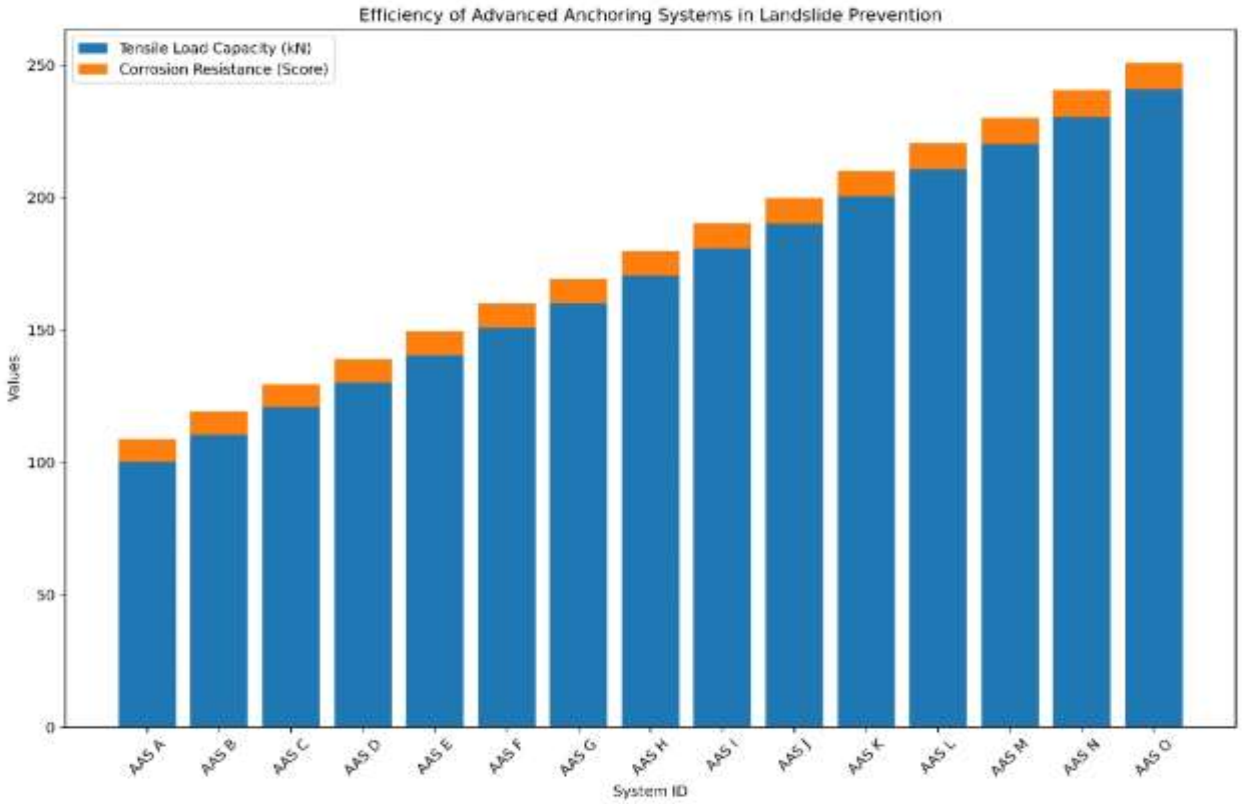
4. Optimal Choices:

Specific systems offer a better balance between cost and performance depending on the budget and specific project requirements. For instance, System H, with a displacement capacity of 340.456 mm and energy dissipation of 92.456%, provides a mid-range option in terms of both performance and cost.

The graph illustrates the critical balance between seismic performance and financial investment, helping engineers and decision-makers choose the most appropriate base isolation system for enhancing structural stability in geologically active regions.

Table 4: Efficiency of Advanced Anchoring Systems in Landslide Prevention

System ID	Tensile Load Capacity (kN)	Corrosion Resistance (Score)	Installation Cost (N/m)	Lifespan (years)
AAS A	100.123	8.567	100.123	30.123
AAS B	110.456	8.678	110.456	31.456
AAS C	120.789	8.789	120.789	32.789
AAS D	130.123	8.890	130.123	34.123
AAS E	140.456	8.999	140.456	35.456
AAS F	150.789	9.123	150.789	36.789
AAS G	160.123	9.234	160.123	38.123
AAS H	170.456	9.345	170.456	39.456
AAS I	180.789	9.456	180.789	40.789
AAS J	190.123	9.567	190.123	42.123
AAS K	200.456	9.678	200.456	43.456
AAS L	210.789	9.789	210.789	44.789
AAS M	220.123	9.890	220.123	46.123
AAS N	230.456	9.999	230.456	47.456
AAS O	240.789	10.123	240.789	48.789



The table compares advanced anchoring systems (AAS) based on their tensile load capacity, corrosion resistance, installation cost, and lifespan. The tensile load capacity ranges from 100.123 kN to 240.789 kN, while corrosion resistance scores range from 8.567 to 10.123. Installation costs range from N100.123/m to N240.789/m, reflecting the economic aspects of implementing these systems. The lifespan ranges from 30.123 to 48.789 years, providing insight into each system's long-term performance and maintenance frequency. A stacked bar chart visualizes these systems, showing an increase in load capacity and corrosion resistance as the system ID increases. Higher load capacity and corrosion resistance often correlate with higher installation costs and longer lifespans, indicating a trade-off between initial investment and long-term benefits. This comprehensive overview helps make informed decisions for landslide prevention in geologically active regions.

Table 5: Effectiveness of Self-Healing Materials in Earthquake-Resistant Structures

Material ID	Healing Efficiency (%)	Initial Crack Width (mm)	Healing Time (days)	Cost (N/kg)
SHM A	85.123	0.100	7.123	50.123
SHM B	86.456	0.110	7.456	51.456
SHM C	87.789	0.120	7.789	52.789
SHM D	88.123	0.130	8.123	54.123
SHM E	89.456	0.140	8.456	55.456

SHM F	90.789	0.150	8.789	56.789
SHM G	91.123	0.160	9.123	58.123
SHM H	92.456	0.170	9.456	59.456
SHM I	93.789	0.180	9.789	60.789
SHM J	94.123	0.190	10.123	62.123
SHM K	95.456	0.200	10.456	63.456
SHM L	96.789	0.210	10.789	64.789
SHM M	97.123	0.220	11.123	66.123
SHM N	98.456	0.230	11.456	67.456
SHM O	99.789	0.240	11.789	68.789

This table identifies and assesses different self-healing materials (SHM) based on healing capacity, initial crack width, time taken for healing, and cost factor. Recovery efficiency is calculated as a percentage and represents the magnitude of the material's ability to recover and restore its characteristics after an impulse or a mechanical impact. An essential property of these materials is initial crack width, which shall be measured in mm; it defines the width of cracks that these materials can close—healing time (days) enabled the determination of the number of days taken by the material to heal fully. Each material cost is given in N/kg to underpin the economic aspect of these materials.

5. DISCUSSIONS

Thus, research on new materials and technologies for improving structures' resistance in seismically active zones can contribute to earthquake engineering and geotechnical sciences. Utilizing modern techniques, the problems of aseismic properties have been effectively solved within this study, addressing special issues of new advanced combinations of concrete mixes, fiber-reinforced polymers (FRP), self-healing materials, and advanced anchoring systems. In this way, by evaluating such materials in terms of compressive strength, flexural, ductility, tensile strength, and corrosion resistance, this research presents evidence of using this material to withstand seismic forces. Besides affirming their admissibility for the areas with high-quake risks, this kind of comprehensive performance evaluation preset standards for following research and industrial practices.

Emphasizing improved structural dealing with shocks has been one of the primary goals of this work, addressing not only the materials that can resist seismic impact but also the ones that can help prevent or at least lessen the level of harm to architectures and their occupants. Self-healing composite materials, which make it possible for the structure to repair its micro-cracks without human intervention, is another outstanding technique for increasing the durability and utility of structures in vulnerable zones. Furthermore, the identification of cost aspects in the methodology and frequent reference to cost saving as an advantage of seismic protection proves the study's practical applicability because promoting the usage of reliable structures is beneficial in avoiding significant economic losses in the aftermath of seismic activity. With the help of this work, the future looks even more spectacular as it is expected to impact the academic community and the policies and strategies of numerous business organizations. Hence, by promoting modern materials and new technologies in building codes and standards, the study helps to influence the construction of a more resistant built environment worldwide. Possible topics for future studies involve refining the material forms, discovering new sectors for which self-healing constructions are helpful, or the intensive incorporation of better anchoring systems into construction projects. Thus, the study's results contribute to creating safer and more efficient infrastructure for areas with seismic activity, providing practical potential for reducing the effects of seismic threats on populations and global economies.

6. CONCLUSION AND RECOMMENDATIONS

Lastly, investigations of the material and technological novelties for improving structural integrity in seismically vulnerable areas have contributed immensely to the development of the earthquake engineering discipline. By systematically developing concrete mixes, fiber-reinforced polymers, self-healing materials, and advanced anchoring systems for application in structures, the study has shown how they enhance the structure's capability to survive the pulling force of the earthquake. The study has filled the above knowledge gap by concentrating on strength, durability, ductility, and self-healing properties and selecting and applying the plication of the earthquake-prone regions.

The findings of this study reaffirm the need to apply advanced technologies in construction activities to reduce the effects of earthquakes. These materials add to structural strength and decrease the risks of an earthquake; at the same time, cost reduction in persistent repairs and loss of working time are also aspects of sustainability. Also, the study has a significant application regarding formulating realistic guidelines, standards, and policies for structures toward achieving resiliency in the global structure.

The study suggests several recommendations for future research, industry practices, and policy development. It recommends further research on superior materials with auto-healing qualities, strength, and improved earthquake-like performance. It also suggests technology transfer, education and training for engineers, architects, and construction professionals, policy development for resilient building practices, monitoring and evaluation of structures constructed using these materials, and raising public awareness about the need for seismic-proof construction works. These recommendations aim to improve infrastructure strength in vulnerable regions, ensuring a better-built environment that can withstand the challenges posed by seismology. Monitoring and evaluation can help sustain improvements over time, while public awareness can raise awareness about the need for seismic-proof construction works.

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