Evaluation of Aggregate Properties for Enhancing Infrastructure Resilience in Disaster-Prone Environments

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Abstract*: The functionality and performance of building infrastructure are profoundly affected by natural hazards, particularly floods and earthquakes. Among the various factors contributing to infrastructure resilience, the selection and quality of construction materials—especially coarse aggregates—are of critical importance. Coarse aggregates serve as fundamental components in concrete and pavement construction, directly influencing structural durability and long-term performance. These materials are typically sourced from natural deposits such as riverbeds and quarries and processed through extraction, crushing, and grading to achieve the desired engineering characteristics. This study presents a comprehensive evaluation of the engineering properties of coarse aggregates collected from 50 distinct locations across Assam, India. The objective is to assess their suitability for structural applications and to inform material selection practices aimed at enhancing infrastructure resilience. Laboratory testing was conducted to determine key properties, including water absorption, specific gravity, abrasion resistance, aggregate crushing value, aggregate impact value, flakiness index, elongation index, and soundness. Based on these results, a Coarse Aggregate Reliability Map of Assam was developed, categorizing the aggregate sources into three reliability classes: highly reliable, moderately reliable, and low reliable.

To validate the practical implications of this classification, representative samples from each reliability category (six in total) were used to produce concrete specimens, which were subsequently subjected to compressive strength testing. The experimental findings demonstrate a clear correlation between aggregate quality and concrete performance: aggregates classified as highly reliable produced concrete with significantly superior compressive strength compared to aggregates from lower reliability categories. The study highlights the pivotal role of informed material selection in improving the resilience, structural integrity, and service life of infrastructure. The use of high-quality coarse aggregates not only enhances performance under normal service conditions but also contributes to reduced maintenance costs and mitigates potential losses during disaster events. The findings advocate for a scientifically rigorous and data-driven approach to aggregate sourcing and selection within construction practices. Adoption of such strategies will advance engineering standards, promote community safety, and foster sustainable, disaster-resilient infrastructure development. The outcomes of this research offer valuable insights for policymakers, engineers, and practitioners working toward building more resilient and adaptive built environments.

***Keywords*: Infrastructure resilience, disaster management, pavement materials, structural integrity, sustainability.**

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I. INTRODUCTION

A disaster is defined as the significant disruption of the normal functioning of a society or community. Disasters occur in various forms, with some being natural and others human-made. However, the scope of this study is confined to natural disasters. According to the EM-DAT database, India ranks second in the national total disaster death toll [9]. Infrastructure is widely regarded as a critical lifeline for any community, playing a vital role in economic sustainability, urban resilience, and maintainability. It also forms the functional backbone of any community. All communities possess various types of physical infrastructure systems, such as transportation, housing, water supply, electrical grids, and telecommunication networks [30]. Among these, housing infrastructure holds particular importance, as it meets a fundamental human necessity. According to the annual report by the Assam State Disaster Management Authority (ASDMA), over 600 houses were fully destroyed, and 25,000 houses were partially damaged by flood hazards in the Cachar district (Assam) of India between 2015 and 2019 [29]. The Indian government frequently allocates significant financial resources to reconstruct these damaged houses, thereby supporting the economies of the affected local communities. While flood hazards are natural and unavoidable, enhancing infrastructure resilience would reduce the damages caused by such hazards.

In the construction sector, coarse aggregates play a crucial role in producing concrete, road bases, and other building materials. These aggregates are typically sourced from natural deposits, such as riverbeds, or, more commonly, from quarries, where rocks are extracted, crushed, and graded according to specific requirements. Granular materials with particle sizes exceeding 4.75 mm are commonly classified as coarse aggregates [19]. The quality and properties of coarse aggregates significantly influence the durability and structural integrity of the built environment. Since geological formations dictate aggregate materials' physical and chemical properties, extracting coarse aggregates from quarries necessitates a deep understanding of these formations. Xu et al. (2022) [32] highlight that quarries are often situated in areas with diverse and abundant rock types, including sedimentary, metamorphic, and igneous rocks. These geological formations, shaped by natural processes such as weathering, erosion, and sedimentation, comprise a range of rock types and characteristics [2]. For instance, igneous rocks such as granite and basalt, known for their durability and hardness, are highly sought after for construction. Although sedimentary rocks like sandstone and limestone are also widely used, they must be carefully inspected due to their varying strengths and porosities. Metamorphic rocks like schist and quartzite, known for their higher strength and resistance to weathering, are similarly utilized in construction [22].

Coarse aggregates are indispensable in the construction industry as they constitute most of the material used, providing compressive strength and mitigating cement-related shrinkage and cracking [25]. The aggregates' size, shape, texture, and grading significantly impact concrete's mechanical and workability properties. Similarly, the durability of concrete, especially its resistance to chemical attacks from substances like sulfates and chlorides, is influenced by the composition of the aggregates [6]. Understanding these characteristics is crucial to ensuring that the aggregates used in construction meet the required standards and performance expectations. The chemical properties of coarse aggregates are largely determined by the mineral composition of the source rocks [27]. For example, aggregates derived from siliceous rocks, such as quartzite, exhibit excellent durability and high resistance to chemical weathering.

Conversely, calcareous aggregates, such as those composed of limestone, may be more susceptible to chemical reactions with acidic substances. In addition, the suitability of aggregates for various construction applications is influenced by physical properties such as density, porosity, and absorption [31]. Aggregates with high density and low porosity are preferable for heavy-duty projects, such as foundations and load-bearing structures, while more porous aggregates may be suitable for applications requiring enhanced drainage.

Rapid urbanization and infrastructure development in Northeast India, particularly in Assam, highlight the importance of evaluating the geotechnical properties of coarse aggregates [23]. Assam, often called the gateway to Northeast India, is witnessing substantial growth in urban and rural infrastructure [29]. The region's unique geographical and geological diversity presents opportunities and challenges for sourcing high-quality aggregates. The demand for durable and sustainable construction materials is increasing as the state invests in roads, bridges, residential complexes, and commercial buildings to accommodate its growing population and expanding economic activities. The geological formations of Assam and the broader Northeast region comprise various rock types, ranging from ancient Precambrian rocks to more recent sedimentary deposits [8]. Given the variability in the geology, a careful evaluation of the available aggregates is necessary to ensure their suitability for construction. The region's tropical climate, characterized by high humidity and heavy rainfall, adds another layer of complexity to the selection of aggregates, which must be resistant to such conditions. Assessing the geotechnical properties of coarse aggregates obtained from quarries is critical to ensuring the reliability and durability of construction projects. A comprehensive understanding of the characteristics of locally sourced aggregates is essential for sustainable development in the region, particularly in light of Assam's rapid urbanization and its strategic importance as a link to other northeastern states [10]. Rajan and Singh (2022) [28] thoroughly analyzed aggregate characterization methods, including conventional and digital image-based techniques, specifically focusing on pavement applications. The authors highlighted the significance of aggregate properties, such as abrasion resistance, impact resistance, and angularity, and compared traditional methods with modern image-based approaches.

While several studies on coarse aggregates exist, it is well-known that they are used for housing and pavement construction. In Assam, numerous locations offer sources of coarse aggregates, and there is a possibility that some aggregates may be more suitable for pavement construction while others may be better suited for housing. However, a study identifying which aggregates are appropriate for which infrastructure in Assam has not yet been conducted. Therefore, this research aims to identify the coarse aggregates suitable for pavement and housing construction by conducting various experimental investigations. The primary objective of this article is to determine the reliability of coarse aggregates for pavement and housing applications. This objective will be achieved by thoroughly examining aggregates from different locations through various tests of coarse aggregates sourced from specific quarries. The study will evaluate their appropriateness for diverse construction uses within the unique context of Assam, Northeast India, as illustrated in Figure 1.

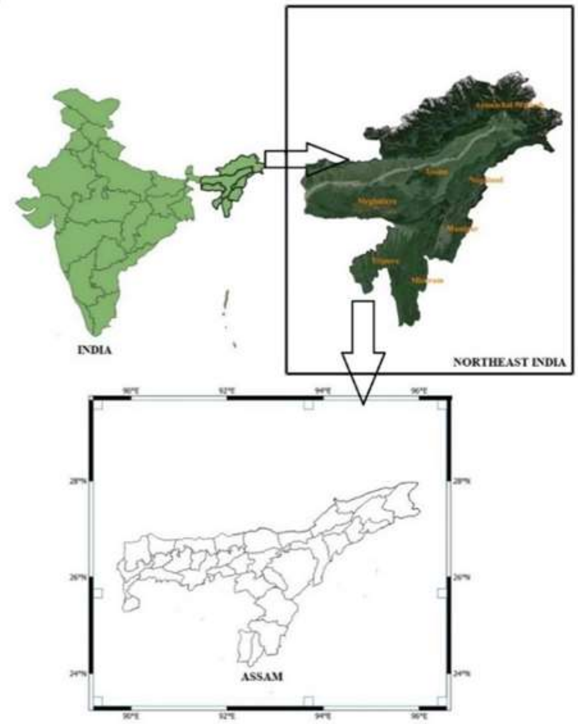


Fig. 1. Study area (Assam, Northeast, India)

II. Methodology

The framework of the study is shown in Figure 2. The work has been divided into two stages. In Stage I, a review of various literature related to coarse aggregate was initially conducted. The literature reviewed includes information from various experiments on coarse aggregate and recommendations for its use in different infrastructures. Following the review, a total of 8 experiments on coarse aggregate were selected. Some of these experiments are related to transportation infrastructure (pavement), while others are related to housing infrastructure (house construction concrete). Subsequently, coarse aggregate samples from 50 locations across Assam, India, were collected in Stage II. Eight experiments were conducted for each sample, and all results were recorded in an Excel sheet. It was not feasible to conduct all the experiments in a single laboratory, so various laboratories from different universities were utilized. Given that coarse aggregate is used for pavement and housing, recommendations have been made regarding the suitability of aggregates from specific locations for use in particular infrastructures based on the results obtained from the experiments.

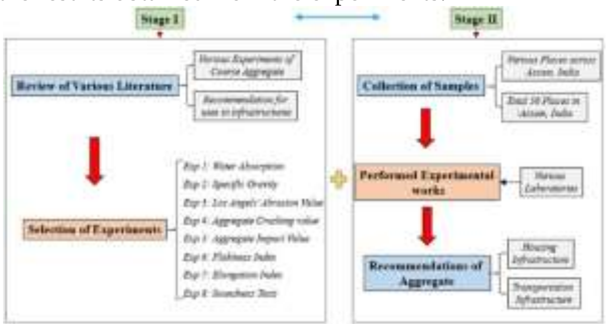


Fig. 2. A framework of the study

A. Stage I (Experiment Selection Based on Literature)

In this study, 8 experiments were conducted on coarse aggregates, considering their application in housing and transportation infrastructures. The experiments are detailed in Table 1. The selected experiments (Exp) include Exp 1: Water Absorption, Exp 2: Specific Gravity, Exp 3: Los Angeles Abrasion, Exp 4: Aggregate Crushing Value, Exp 5: Aggregate Impact Value, Exp 6: Flakiness Index, Exp 7: Elongation Index, and Exp 8: Soundness Test. Exp 1, Water Absorption, measures the moisture absorption capacity of the aggregates. High water absorption values indicate high porosity, which can decrease the durability of the aggregates and increase their susceptibility to freeze-thaw cycles [12].

Conversely, low water absorption values suggest better quality and enhanced durability. Exp 2, Specific Gravity, determines the density and strength of the aggregate material. Lower specific gravity indicates weaker and more porous aggregates, which can reduce concrete's overall strength and durability [20]. On the other hand, higher specific gravity values reflect denser and stronger aggregates, which contribute to better structural performance. Exp 3, Los Angeles Abrasion, assesses the resistance of aggregates to wear and abrasion. Higher abrasion values signify aggregates that will wear down more quickly under traffic or environmental conditions, leading to surface degradation and a shorter lifespan [11]. Aggregates with lower abrasion values are considered more durable and resistant to wear. Exp 4, Aggregate Crushing Value, evaluates the aggregate's ability to resist crushing under gradual compressive loads. Higher values suggest weaker aggregates, which may compromise the load-bearing capacity of concrete. Lower crushing values indicate stronger and more durable aggregates. Exp 5, Aggregate Impact Value, is similar to Exp 4 but measures the resistance of aggregates to sudden impact loads. High values indicate that the aggregate may fracture under impact, compromising structural integrity. Lower values suggest tougher and more resilient aggregates, which are ideal for construction.

Exp 6, Flakiness Index, and Exp 7, Elongation Index, assess the shape and texture of the aggregates. Higher values in both tests indicate the presence of irregular or elongated particles, which can negatively affect the workability of the concrete and reduce bond strength [17]. Such aggregates can lead to structural deficiencies. Lower values, representing more evenly shaped particles, are preferred for better workability and strength. Exp 8, Soundness Test, evaluates the durability of aggregates when subjected to weathering conditions such as freeze-thaw or wetting-drying cycles [1]. Low soundness values indicate potential strength degradation, reducing aggregate lifespan and structural integrity over time. Higher values are desirable for maintaining durability under such conditions.

TABLE I. Name of the Selected Experiments

Experiment	Name of Experiment	Reference
1	Water Absorption	[14]
2	Specific Gravity	[14]
3	Los Angels' Abrasion Value	[15]
4	Aggregate Crushing value	[15]

5	Aggregate Impact Value	[15]
6	Flakiness Index (20mm)	[13]
7	Elongation Index (20mm)	[13]
8	Soundness Tests	[16]

B. Stage II (Experiments Performed)

After selecting coarse aggregate experiments, various samples were collected from different locations. In total, samples were gathered from 50 sites across Assam, as indicated in Figure 3. In the figure, only two rivers, the Brahmaputra and Barak, are displayed. This simplification was necessary because both rivers have numerous tributaries, and illustrating each would make it difficult to identify the specific locations from which samples were collected. The details of each location, along with their coordinates, are provided in the Annexure I. As samples were collected from 50 locations, presenting them all became challenging. Therefore, only a portion of the collected samples is shown in Figure 4.

Fig. 3. Sample collected places


Garuchuka

Bogamati

Bhutia Chang

Goreswar

Nagrijuli

Khanapara

Byrnihat

Umduba

Fig. 4. Some of the collected samples.

After collecting samples, each experiment was conducted three times, and the average value was taken. In the same manner, all the experimental results were gathered. The procedure for each experiment was followed according to the Indian Standard, as referenced in Table 1. The apparatus used for the experiments is shown in Figure 5.


Aggregate Impact Value

Aggregate Crushing Strength

Elongation Index

Flakiness Index

Water Absorption Test

Specific Gravity Test

Los Angels' Abrasion Value

Soundness Test

Fig 5. Various experiment setup of coarse aggregate

III. Results and Discussion

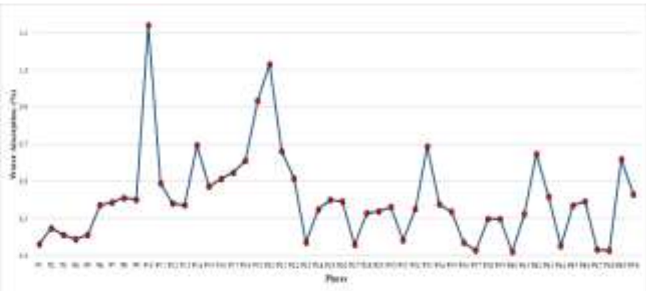
A. Experimental Work Results

The evaluated value of experiments 1 to 8 for 50 places is shown in Figure 6 (a-h). Experiment 1 (Exp 1) ranged from 0.121% to 1.34%, with P37 and P40 showing the lowest values, indicating minimal porosity and making these samples preferable for concrete applications due to their strength and durability. Conversely, samples like P10 and P19, with higher absorption values of 1.34% and 0.933%, respectively, exhibit higher porosity and are more suited for pavement where higher absorption is less critical. Exp 2 values ranging from 2.50 to 2.99. Aggregates with higher specific gravity, such as P1 and P3, which have values of 2.96 and 2.89, respectively, are denser and stronger, making them ideal for concrete where strength is a primary concern. In contrast, samples like P10 and P19, with lower specific gravity values of 2.55 and 2.50, are less dense and more suitable for pavement where strength requirements are relatively lower. Exp 3 results ranged from 7.73% to 44.92%. Lower values suggest better resistance, with P1 and

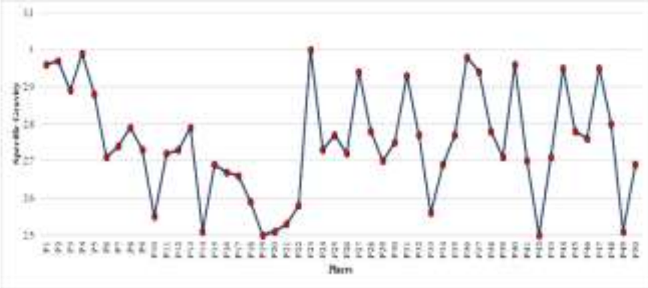
P3 having values of 7.73% and 8.91%, making them highly suitable for concrete. In contrast, aggregates with higher abrasion values, such as P10 and P19, with values of 21.94% and 43.77%, respectively, are more appropriate for pavement due to their ability to withstand higher levels of wear. Exp 4 ranged from 6.77% to 44.92%. Lower values are preferred for concrete, and samples such as P1 and P3, with values of 7.82% and 7.91%, respectively, exhibit good resistance to crushing. Aggregates like P10 and P19, with higher values of 26.17% and 42.38%, are more suitable for pavement where such resistance is less critical.

Exp 5 results ranging from 5.4% to 28.76%. Lower impact values are better for concrete due to higher toughness, with samples like P1 and P3 showing values of 8.12% and 7.89%. Samples with higher impact values, such as P10 and P19, with values of 28.55% and 44.16%, are more suitable for pavement applications with higher impact resistance. Exp 6 ranged from 5.2% to 28.76%. Lower values are preferred for concrete, as they indicate better shape and stability. Aggregates like P1 and P3, with values of 6.8% and 7.12%, are thus suitable for concrete. Conversely, higher values, such as those from P10 and P19 at 23.56% and 26.28%, are more appropriate for pavement. Exp 7 results ranged from 5.5% to 21.6%. Lower values indicate better stability and are preferred for concrete, with P1 and P3 showing values of 5.5% and 6.1%. Higher values, such as those in P10 and P19 at 21.6% and 22.6%, are more suitable for pavement where shape irregularities are less of a concern. Exp 8 showed values ranging from 5.4 to 11.9. Higher values indicate better durability under environmental conditions. Aggregates like P1 and P3, with values of 11.2 and 10.5, respectively, are ideal for concrete due to their high resistance to weathering. In contrast, samples such as P10 and P19, with lower values of 5.8 and 5.4, are more appropriate for pavement where the aggregate's resistance to weathering is less critical.

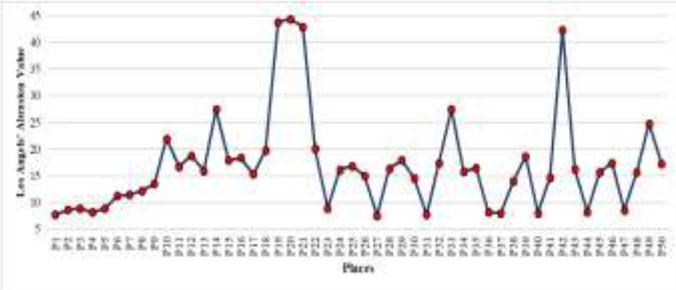
Based on the comprehensive analysis, aggregates from P1, P3, and P37 are highly recommended for concrete applications due to their low water absorption, high specific gravity, low abrasion, crushing, and impact values, low flakiness and elongation indices, and high soundness. They exhibit the desired strength, durability, and resistance to wear and weathering, making them suitable for constructing robust, long-lasting house concrete. Conversely, aggregates from P10, P19, and P33 are better suited for pavement due to their higher water absorption, abrasion, crushing, and impact values, as well as higher flakiness and elongation indices. These properties make them capable of withstanding the wear and impact experienced in pavement applications while addressing the less stringent water absorption and density requirements.



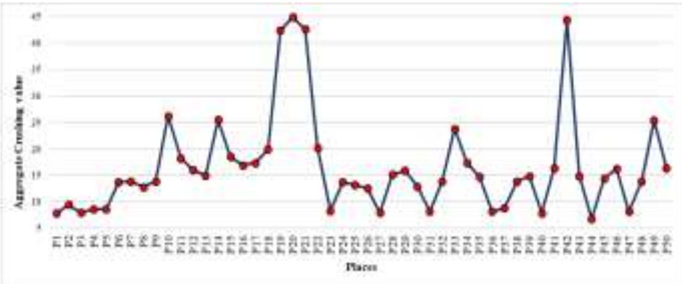
(a) Exp 1



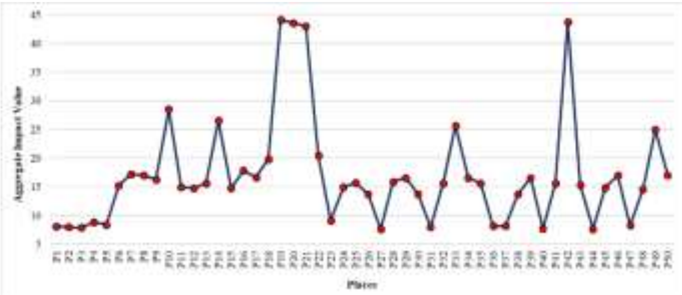
(b) Exp 2



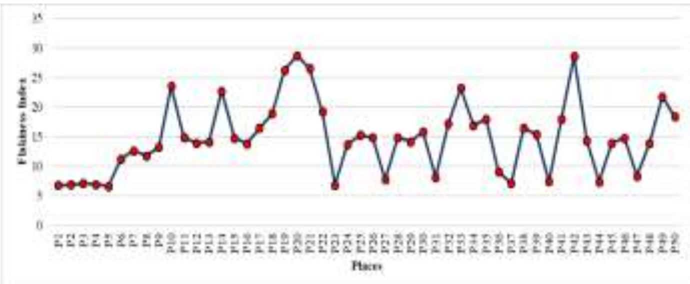
(c) Exp 3



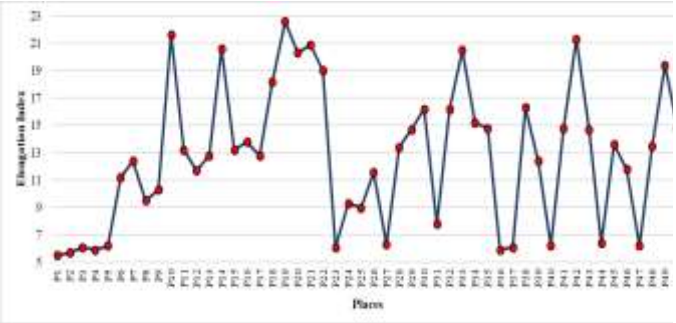
(d) Exp 4



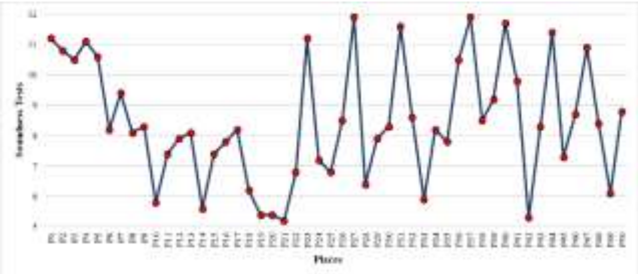
(e) Exp 5



(f) Exp 6



(g) Exp 7



(h) Exp 8

Fig. 6(a-h). Experiments results of various places

B. *Impact on Infrastructure in Disaster-Prone Areas*

Based on the results of the various tests on coarse aggregates, the variations in properties such as water absorption, specific gravity, abrasion resistance, crushing value, and impact resistance can significantly influence the structural performance in disaster-prone areas.

Aggregates with high water absorption (such as P10, P19, etc.) rates are more porous and tend to absorb moisture, which can weaken the structure, especially in flood-prone areas. In disaster scenarios, such as heavy rainfall or floods, these aggregates can cause concrete to deteriorate faster due to water infiltration, freeze-thaw cycles, and chemical reactions. In contrast, aggregates with low water absorption rates (such as P1, P2, etc.) are more resistant to moisture and help maintain the durability of structures. In earthquake-prone areas, using high-specific-gravity aggregates (such as P1, P2, etc.) can improve the overall weight and stability of structures, making them more resistant to seismic forces. Aggregates with lower specific gravity (such as P19, P21, etc.) may result in lighter, less durable concrete, which can increase the risk of structural failure during earthquakes. In disaster-prone areas, especially those susceptible to landslides, earthquakes, or heavy traffic during evacuations, materials with high abrasion resistance ensure that roads, bridges, and pavements maintain their integrity for longer periods. Aggregates with a high abrasion value (such P20, P21, etc.) can wear down more quickly, leading to faster degradation of infrastructure. A lower aggregate crushing value indicates higher resistance to crushing under compressive loads. In areas prone to earthquakes or landslides, aggregates with a low crushing value contribute to stronger concrete that can better withstand sudden impact or compression forces. High crushing values, on the other hand, may lead to brittle structures that are more vulnerable to collapse during such disasters.

Aggregates with a lower impact value (such as P1, P40, etc.) are more resistant to sudden shocks or impacts, which is crucial in earthquake-prone zones. Structures made with high-impact-resistance aggregates are less likely to suffer from cracking or spalling under seismic stress. Conversely, aggregates with a high impact value (such as P42, P19, etc.) can result in more brittle structures, increasing the chances of catastrophic failure during earthquakes or other impact-related disasters. Flaky and elongated aggregates can lead to weaker concrete mixes because they do not compact as well as cubical aggregates. In disaster-prone areas, such as earthquake zones, these weak points in the concrete can result in poor structural integrity, making buildings more susceptible to cracking and failure under dynamic loading. Using well-shaped aggregates with low flakiness and elongation indices improves the structural stability of buildings and roads. Aggregates that perform well in soundness tests are more resistant to weathering and environmental stress. In disaster-prone areas where structures are exposed to extreme conditions (floods, storms, earthquakes), sound aggregates will last longer without disintegration, ensuring the longevity of infrastructure. Poor soundness can lead to premature weathering and the weakening of structures, especially in regions experiencing repeated natural disasters.

C. *Recommendations for All Places*

The aggregates of places P1, P2, P3, P4, P5 and P27 have low water absorption, high specific gravity, low abrasion, low crushing value, low impact value, low flakiness, low elongation and high soundness. These aggregates are suitable for house concrete construction. The aggregates of places P10, P14, P19, P20 and P33 have high water absorption, low specific gravity, high abrasion, high crushing value, high impact value, high flakiness, high elongation and low soundness. These aggregates are suitable for pavement construction.

According to the results of the experiment (Figure 6), the aggregates of P6 are suitable for specific pavement conditions or mixed-use scenarios. P7 and P13 aggregates can be used in lower-demand applications. P8 aggregates are suitable for non-critical pavement areas. P11, P25 and P46 aggregates are potentially usable for lower-demand concrete or pavement. P12 aggregates are suitable for less critical applications. P15 and P22 aggregates are suitable for various applications with moderate demands. P16 and P49 aggregates are suitable for specific pavement applications. P17 aggregates are suitable for critical concrete or pavement. P26 aggregates are suitable for specific pavement or concrete scenarios. P28 aggregates are suitable for specific applications. P29, P32, P39 and P43 aggregates are suitable for moderate-demand conditions. P30 aggregates are suitable for less critical pavement or concrete applications. P31, P36, P44, P47 and P48 aggregates suit specific concrete scenarios. P34 aggregates are suitable for pavement with moderate demands. P35, P38, P45 and P50 aggregates can be used for various conditions. P37 aggregates are highly suitable for concrete. P41 aggregates are suitable for specific applications.

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For high-demand concrete applications, samples with low water absorption, high specific gravity, low abrasion, crushing, and impact values, and low flakiness and elongation indices are ideal, such as P1, P2, P3, P4, P5, and P37. Aggregates with higher water absorption, abrasion, crushing, and impact values, and those with higher flakiness and elongation indices, such as P10, P14, P19, and P20, are suitable for pavement construction. Depending on the demand and environmental conditions, aggregates with mixed properties may be used for specific applications. This analysis underscores the importance of selecting aggregates based on specific criteria to ensure their suitability for various construction purposes. By matching the aggregate properties with the intended application, optimal performance and longevity of the construction materials can be achieved.

Based on the analysis of aggregate properties from various places, it can be concluded that aggregates from places such as P1, P2, P3, P4, P5, P37, P27, P31, P36, P44, P47 and P48 are suitable for house concrete construction and aggregates from P6, P7, P8, P11, P12, P13, P15, P16, P17, P22, P25, P26, P28, P29, P30, P32, P34, P35, P38, P39, P41, P43, P45, P46 and P50 are suitable for pavement construction. Similarly, aggregates from P10, P14, P19, P20, P33 and P49 are suitable for pavement construction, especially for low-cost road construction.

By matching the properties of these aggregates with the appropriate construction work, the optimal use of materials can be ensured for durability and strength. By identifying the most suitable aggregates for different types of construction (e.g., houses, pavements, low-cost structures), this study ensures that buildings and roads will be constructed with materials that enhance durability, safety, and longevity. Properly matching aggregates to the type of construction reduces waste and lowers the chances of using inadequate materials, leading to cost savings in both initial and long-term maintenance. Using the right type of aggregate in construction can prevent structural failures, ensuring safer buildings, homes, and roadways for the community. The study helps efficiently use local resources by determining which areas provide aggregates most suitable for specific types of construction, minimizing the need for transporting materials from distant places. By identifying suitable aggregates for low-cost housing and pavements, the study contributes to developing affordable and sustainable housing solutions, benefiting economically weaker sections of society. The data and conclusions from the study can be used by civil engineers, builders, and local authorities to make informed decisions, leading to better planning and execution of construction projects.

D. Coarse Aggregate Reliability Map of Assam

After obtaining the results for each experiment at each location, the lowest and highest values of the experimental outcomes were noted. It is understood that in some experiments, a high value indicates poor quality of the aggregate, while in others, a high value signifies the aggregate is suitable for use. Based on the evaluated results, the data were categorized into low, medium, and high reliability. For example, in Experiment 2 (specific gravity), where higher values indicate better quality aggregate, the highest value observed was 3, and the lowest was 2.5. The difference between these values is 0.5 (3-2.5). Dividing this difference by three gives 0.17. Therefore, aggregates with a specific gravity between 2.5 and 2.67 (2.5+0.17) are considered to have low reliability, those between more than 2.67 and less than equal to 2.84 are considered to have medium reliability, and those between more than 2.84 and less than equal to 3 are classified as highly reliable. Using this criterion, the results of each experiment have been categorized and represented in the coarse aggregate reliability map, as shown in Figure 7. Figure 7 is divided into three zones: zone I (right circle), zone II (left circle) and zone III (bottom circle). Now it can be observed that in zone I, 60% and 40% of aggregates are highly and moderately reliable for construction.

In zone II, 4%, 64% and 32% of aggregates are highly, moderately and low reliable; in zone III, 30%, 30% and 40% of aggregates are highly, moderately and low reliable for construction. These may be because of elevation differences between zones. The elevation of Zone I is much higher than that of zone II and III5. In high-elevation regions, rocks are often subjected to greater tectonic forces, leading to more robust and more compact formations. These areas may also experience slower weathering processes, preserving the integrity of the rock over time. The result is denser, harder, and more durable aggregates, making them ideal for construction purposes. Low-elevation areas are typically more exposed to intense weathering and erosion due to water flow, temperature fluctuations, and other environmental conditions. Over time, rocks in these areas may weaken, resulting in softer, more fragmented aggregates. These processes can reduce the aggregate's strength, making them less suitable for heavy construction. Materials tend to accumulate in lower elevations due to erosion from higher elevations. These sediments often include finer particles, organic matter, and weaker rock fragments, reducing the overall quality of the aggregate. Aggregates in low-lying areas may also be exposed to higher moisture levels, leading to potential degradation or contamination, further decreasing their suitability for construction.

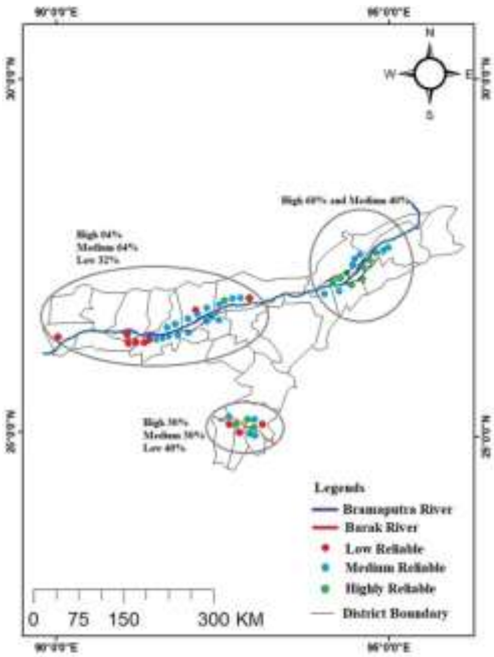

Fig. 7. Coarse aggregate reliability map

In 2024, approximately 23 lakh people were affected across 28 districts, with Dhubri, Cachar, Sivasagar, Barpeta, and Golaghat being the most impacted [4]. This study recommends that infrastructure in these districts should be built using Zone I coarse aggregate. Conversely, in districts that are not disaster-prone, construction can be carried out using Zone II and III coarse aggregates. There could be several other reasons why coarse aggregates from different locations show varying results. The geological source of the aggregate can significantly affect its properties [21]. Aggregates from different rock formations will naturally have other characteristics like strength, hardness, and density. Aggregates exposed to environmental conditions like weathering, chemical reactions, and erosion might lose some quality [24]. Aggregates from places with more moisture, heat, or pollution exposure could be more prone to degradation. The extraction method and equipment used in the quarrying process can also influence the aggregate quality [26]. Poor handling or crushing techniques might introduce fractures or inconsistencies in the aggregate, leading to lower-quality results. Organic materials, dust, or other impurities may have contaminated some aggregate samples. This contamination can adversely affect the results of experiments, such as specific gravity or impact value.

E. Comparison of Compressive Strength

It is known that coarse aggregate is a component of concrete, and houses are constructed using concrete. This implies that the compressive strength test is essential to verify. Since coarse aggregate plays a crucial role in compressive strength, good quality aggregate will result in high compressive strength of the concrete. To validate this study, the compressive strength of concrete was tested using collected samples. A total of six places' aggregates were selected, with two samples taken from highly reliable places (P1 and P44), two from moderately reliable places (P9 and P18), and two from low-reliability places (P19 and P42). M25 (1:1:2) grade of concrete with a water-cement ratio of 0.45 was used, and the test was conducted using a universal testing machine. Initially, the cement, fine aggregate, and coarse aggregate were mixed following the standard mix ratio, then water was added, and the mixture was thoroughly blended. The concrete was placed in a standard mould (150 x 150 x 150 mm) and left to dry for 24 hours. Afterward, the cubes were placed in curing pots for 28 days. After 28 days, the compressive strength of each cube was evaluated. For each place, three cubes were prepared, and the average strength of these three cubes was considered. Thus, a total of 18 cubes were prepared in this study. Here three six models are prepared as M1, M2, M3, M4, M5 and M6. M1 consists of concrete with P1 coarse aggregate, M2 consists of concrete with P44 coarse aggregate, M3 consists of concrete with P9 coarse aggregate, M4 consists of concrete with P18 coarse aggregate, M5 consists of concrete with P19 coarse aggregate and M6 consists of concrete with P42 coarse aggregate. The evaluated compressive strength is shown in Figure 8. The results of the compressive strength tests indicate a clear correlation between the quality of coarse aggregates and the performance of concrete, reinforcing the significance of aggregate selection in construction.

The highest compressive strengths were observed in M1 and M2, with values of 26.02 MPa and 26.24 MPa, respectively. Both aggregates are sourced from highly reliable locations, indicating that they possess favorable properties. Both models aggregate have low water absorption values, indicating lower porosity. This means less water is absorbed, leading to denser concrete, which enhances compressive strength. Additionally, both aggregates have high specific gravity, contributing to a stronger mix. High specific gravity often indicates better quality aggregate, which positively affects the concrete's overall strength. High-quality aggregates contribute to better interlocking and bonding within the concrete matrix, leading to increased strength. Conversely, the lower compressive strengths in M5 and M6, which registered 21.07 MPa and 22.64 MPa, suggest that these aggregates are less reliable. The water absorption of the coarse aggregate of M5 is very high indicating very high porosity which severely affects strength. The specific gravity of the coarse aggregate of M5 and M6 is the lowest among all, leading to a weaker concrete mix. This correlates with the high Los Angeles Abrasion and Impact values, which indicate poor durability and toughness. Similarly, the water absorption of the coarse aggregate of M6 contributes to higher porosity compared to the coarse aggregate of M1 and M2, which explains the lower strength. When the experiment results of each coarse aggregate test are observed, a significant difference in water absorption values between the coarse aggregate of M5 and M6 is evident. Upon comparing M5 and M6, it can be noted that, out of the 8 experiments, the coarse aggregate of M6 performs better in 4 experiments, while M5 performs better in 3. The specific gravity of both models' coarse aggregates is the same. However, the critical factor is the water absorption value. Apart from the water absorption test, the differences between the evaluated test values of the coarse aggregates of M5 and M6 are minimal. Yet, the water absorption value of M5 is nearly 44% higher than M6, which is a significant disparity. This explains the 7.5%

decrease in the compressive strength of M5 compared to M6. It indicates that water absorption of coarse aggregate plays a crucial role in the compressive strength of concrete, as noted by many researchers [7,33].

The classification of aggregates into high, medium, and low reliability is crucial for understanding their performance. M3 and M4 yielded moderate strengths, reflecting the characteristics of moderately reliable aggregates. The water absorption of coarse aggregate of M3 is high, which suggests increased porosity. Higher porosity can lead to weaker concrete as there are more voids within the mix, which compromises the load-bearing capacity. The specific gravity of the coarse aggregate of M3 is low, indicating less dense aggregate, which can also contribute to the lower compressive strength. The water Absorption and specific gravity of the coarse aggregate of M4 is more and less than the coarse aggregate of M3, again indicating higher porosity and a trend of decreasing compressive strength. Due to this, it can be observed that there is an increase of 4.3% in compressive strength of M3 compared to M4.

The results highlight the importance of using quality aggregates in areas prone to disasters, where structural integrity is paramount. Low compressive strength can lead to increased vulnerability to cracking and failure, especially under load or during seismic events. Using high-quality aggregates can enhance the resilience of structures, ensuring they can withstand extreme conditions. While high-quality aggregates may come at a higher cost, the long-term benefits, including reduced maintenance and longer service life of concrete structures, justify the investment. In disaster-prone regions, this approach not only safeguards infrastructure but also minimizes future repair costs and enhances community safety.

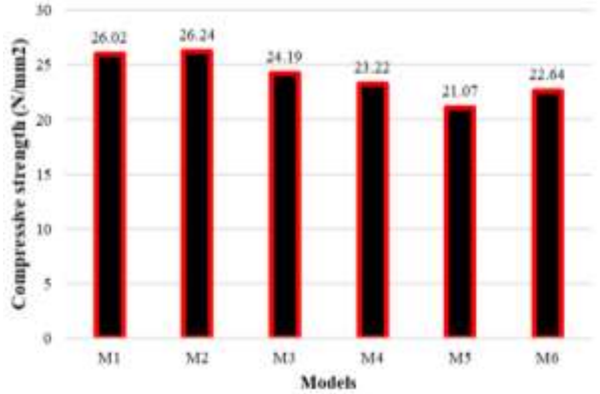

Fig. 8. Compressive strength of each model.

IV. Conclusion and Recommendations

This study thoroughly evaluates coarse aggregates sourced from 50 distinct locations across Assam, India, utilizing eight standardized experiments to assess their physical and mechanical properties. The results demonstrate significant variability in coarse aggregate quality, critically impacting their suitability in various infrastructure (such as pavement and house) applications. For example, P1, P3, and P37 aggregates exhibited superior strength, low porosity, and durability, making them ideal for concrete construction, particularly in housing projects. Conversely, aggregates from sites like P10, P19, and P33, which showed higher abrasion and impact values, are more appropriate for pavement construction, where resistance to wear and tear is essential.

As the coarse aggregates from some locations are classified as low reliable, some as moderately reliable, and others as highly reliable, a total of 6 samples were selected, with 2 from each reliability category. Concrete was then made using these aggregates, and the compressive strength of each sample was tested. From the test results, it was observed that the aggregates from highly reliable locations provided higher compressive strength compared to those from low and moderately reliable locations. The implications of this study for the construction industry in Assam are far-reaching. By providing clear, data-driven guidelines for selecting suitable aggregates based on their properties, this research facilitates using region-specific materials, optimizing resource utilization, and enhancing the quality of construction projects. This, in turn, contributes to the longevity and durability of infrastructure, reducing the frequency of repairs and maintenance, thus lowering long-term costs.

The significance of this study lies in its contribution to the sustainable development of Assam's infrastructure. By identifying aggregates that meet specific requirements for housing and transportation, the research promotes efficient material use, minimizes waste, and encourages the sustainable extraction of natural resources. The findings also emphasize the importance of localized material testing, as aggregate properties can vary widely even within a single region. Future work could focus on assessing the long-term performance of these aggregates in real-world conditions, such as their behavior under extreme weather conditions or heavy traffic loads. Additionally, examining the environmental impact of aggregate extraction from various sites could provide valuable insights into more sustainable sourcing practices, helping to balance infrastructure development with environmental conservation. The societal benefits are substantial. By improving the selection of aggregates, the lifespan and safety of roads and buildings can be enhanced, directly benefiting public safety and reducing maintenance costs. This research also supports sustainable development goals by promoting the use of local materials, thereby fostering resource conservation and minimizing environmental degradation.

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Data availability statement

All the data used in this work is available with the corresponding author and can be obtained on request.

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Declaration of competing Interests

There is no conflict of interest against this manuscript.

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Annexure I: Details of sample collected places

Sl. No	Place Name	Location
P1	Garuchuka	26.639N, 90.6253E
P2	Bogamati	26.6653N, 91.3401E
P3	Bhutia Chang	26.548065N, 91.796413E
P4	Goreswar	26.5329N, 91.7296E
P5	Nagrijuli	26.734472N, 91.669751E
P6	Khanapara	26.4486N, 91.815857E
P7	Byrnihat	26.3767N, 91.854563E
P8	9th Mile	26.37002N, 91.821956E
P9	Umduba	26.296N, 91.4949E
P10	Killing	26.4958N, 91.857578E
P11	10th Mile	26.74010N, 91.824208E
P12	Amerigog	26.835N, 91.835862E
P13	Gorchuk	26.2963N, 91.710859E
P14	Rani	26.37443N, 91.628528E
P15	Sonamukhi	26.412339N, 90.298195E
P16	Chirakuti	26.35972N, 90.149376E
P17	Bethbari	27.02236N, 94.6823E
P18	Ahutali	26.975N, 93.223611E
P19	Shilipata	25.091667N, 93.240278E
P20	Baithalangso	24.966243N, 92.693793E

P21	Chaprakata	26.485189N, 91.600922E
P22	Motonga	26.685111N, 91.347716E
P23	Dakshin	26.311574N, 94.774844E
P24	Natuancha	26.269729N, 94.729537E
P25	Gopeswar	26.931589N, 94.742977E
P26	Lankar	27.466667N, 94.816111E
P27	Nakula Pahar	27.108914N, 92.189410E
P28	Hatipota	26.2262N, 94.273201E
P29	Mylliem	25.4988N, 92.818975E
P30	Kumarikata	25.1298N, 93.147563E
P31	Mawaiangdiang	24.8985N, 92.948226E
P32	Kafitoli Hills Area	25.025978N, 92.803156E
P33	Bhairab Kunda	25.11835N, 93.112722E
P34	Tirimari Champabati	25.01486N, 93.100531E
P35	Dolamara	26.9780N, 94.570023E
P36	Tokrabandha Hill	27.05948N, 94.2872E
P37	Chitalmari	26.8062N, 93.809478E
P38	Chandrapur No.2	26.236750N, 91.911108E
P39	Boghora	26.2519704N, 92.3427723E
P40	Kathalguri mikirgaon	26.306501N, 92.397530E
P41	Bhairab Hill	27.018932N, 93.916763E
P42	Sonapur	26.122054N, 91.881146E
P43	Barpathar	26.05N, 94.0075E
P44	Ranga-De-Reserve	27.236317N, 94.095840E
P45	Nangalbhanga	26.966667N, 91.016389E
P46	Kumnagarh	26.145103N, 91.793239E
P47	Daisam	26.627033N, 92.123543E
P48	Champa	26.7444N, 92.097397E
P49	Tapatjuri	26.35037N, 92.6922529E
P50	Chandrapur	26.22956N, 91.91906E

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