

# Seismic Retrofitting of Existing Structures

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## I. INTRODUCTION

The construction industry is a major contributor to global carbon emissions, with cement production being one of the largest sources of CO<sub>2</sub> emissions worldwide. Portland cement, the primary binding agent in concrete, is essential in various construction applications, including pavement blocks. However, the environmental impact of cement production is raising concerns, driving the search for more sustainable alternatives. This report focuses on the development of cement-free interlocking pavement blocks using Ground Granulated Blast Furnace Slag (GGBS), silica fume, and geopolymer technology, which present a promising solution to reduce the carbon footprint of construction materials. Ground Granulated Blast Furnace Slag (GGBS) is a by-product of steel production, rich in alumina and silica. When used in concrete applications, it exhibits excellent pozzolanic properties, which contribute to the long-term strength and durability of concrete. Similarly, silica fume, another by-product of industrial processes, is composed of ultra-fine particles that can significantly improve the performance of concrete by reducing its permeability and enhancing its strength. The combination of GGBS and silica fume in the production of interlocking pavement blocks can potentially lead to a more sustainable and high-performing material. In addition to GGBS and silica fume, geopolymer technology plays a crucial role in this development. Geopolymers are inorganic materials formed by the reaction of alumino-silicate materials, like GGBS and silica fume, with alkaline activators. Unlike traditional cement-based materials, geopolymers are characterized by their low carbon footprint and enhanced durability. They offer superior chemical resistance and are less energy-intensive to produce, making them an attractive alternative for creating sustainable pavement blocks. This report aims

to investigate the process of developing these cement-free interlocking pavement blocks, including the mix design, material selection, and manufacturing techniques. The key focus is on optimizing the combination of GGBS, silica fume, and geopolymer binders to achieve the desired mechanical properties such as strength, durability, and resistance to environmental factors. Additionally, the report will examine the curing process, which is vital for the development of geopolymer concrete, and assess the performance of the blocks under real-world conditions. The potential environmental benefits of using these alternative materials are significant. By replacing traditional cement with industrial by-products and utilizing low-carbon geopolymer technology, the production of these pavement blocks can help reduce the carbon emissions associated with construction. Moreover, this approach contributes to the circular economy by repurposing waste materials that would otherwise be discarded. Ultimately, the goal of this report is to highlight the advantages of cement-free pavement blocks in terms of sustainability, cost effectiveness, and long-term performance, paving the way for a greener, more resilient construction.

## II. APPLICATIONS

The development of sustainable cement-free interlocking pavement blocks using Ground Granulated Blast Furnace Slag (GGBS), silica fume, and a geopolymer binder presents numerous applications that contribute to environmental sustainability and construction innovation. First, the use of GGBS and silica fume in place of traditional cement reduces the carbon footprint of pavement block production. Cement manufacturing is a significant contributor to CO<sub>2</sub> emissions, and by substituting it with industrial byproducts like GGBS

and silica fume, the environmental impact is minimized, promoting the concept of recycling and circular economy in the construction sector. Another key application is the potential for these sustainable interlocking blocks to be used in urban infrastructure development. As cities grow, the demand for durable and low-maintenance paving solutions increases. The geopolymer binder, combined with GGBS and silica 2 fume, can create stronger and more durable pavement blocks. These blocks are ideal for high-traffic areas such as roadways, sidewalks, and parking lots, where longevity and resistance to wear and tear are crucial. This makes them a promising alternative to traditional cement-based pavement blocks in urban and suburban areas. Additionally, the interlocking nature of these blocks offers ease of installation and maintenance. Unlike traditional paving systems that require extensive mortar or cement, the interlocking design allows for faster assembly and disassembly, which is beneficial for repair work or replacement of damaged blocks. This characteristic is particularly advantageous in regions where rapid construction and frequent maintenance are needed, such as in commercial and industrial zones. Moreover, the reuse of these blocks makes them highly adaptable for temporary or long-term projects. The development of cement-free interlocking pavement blocks also aligns with sustainable construction practices by conserving natural resources. The use of GGBS and silica fume reduces the demand for virgin materials like limestone and clay, which are typically used in cement production. This approach supports sustainable resource management by recycling industrial byproducts that would otherwise contribute to landfill waste. Furthermore, the geopolymer binder, being based on waste materials, provides a cost-effective and environmentally friendly alternative to traditional concrete formulations. And the integration of these sustainable pavement blocks into green building initiatives and eco-friendly infrastructure projects can significantly support global efforts toward carbon neutrality. As governments and organizations push for more sustainable construction methods, the use of cement-free, geopolymer-based interlocking blocks represents a forward-thinking solution. These blocks not only offer environmental benefits but also align with the growing demand for green materials in construction, offering a pathway toward more resilient and sustainable urban environments.

### III. BENEFITS

The benefits of developing sustainable cement-free interlocking pavement blocks using GGBS, silica fume, and geopolymer binders are multifaceted, particularly from an environmental perspective. The most significant advantage is the substantial reduction in CO<sub>2</sub> emissions. Cement production is one of the largest industrial contributors to global greenhouse gas emissions, and by replacing cement with GGBS and silica fume both industrial byproducts the environmental impact of pavement block production is greatly minimized. This not only lowers the carbon footprint of the construction process but also supports the principles of recycling and circular economy by utilizing waste materials. From a performance standpoint, these sustainable interlocking blocks offer enhanced durability and strength compared to conventional concrete blocks. The combination of GGBS, silica fume, and geopolymer binders results in a highly durable material that resists wear, weathering, and chemical attacks. This makes them ideal for use in high-traffic areas, such as streets, sidewalks, and parking lots, where longevity and low maintenance are key. Their ability to withstand heavy loads and harsh environmental conditions also reduces the frequency of repairs and replacements, making them a cost-effective solution over the long term. In addition to environmental and performance benefits, these interlocking blocks also provide practical advantages in terms of installation and maintenance. The interlocking design simplifies the installation process, reducing the need for mortar and minimizing labor costs. Furthermore, the blocks can be easily replaced or reconfigured when necessary, which is particularly useful for repairs or temporary installations. This modular approach makes them an ideal choice for a variety of applications, from permanent infrastructure to temporary construction projects, ensuring flexibility and efficiency in urban planning and development.

### IV. LIMITATIONS

One of the main limitations of cement-free interlocking pavement blocks using GGBS, silica fume, and geopolymer binders is the potential for limited availability and higher costs of raw materials. While GGBS and silica fume are industrial byproducts, they may not be as readily available in all

regions, and transportation costs could make them less economically viable in certain locations. Additionally, the production of geopolymer binders requires specialized knowledge and equipment, which may not be widely accessible, especially in smaller or less developed regions. This could limit the widespread adoption of this technology in areas with less infrastructure for such materials. Another limitation is the need for thorough testing and standardization. While geopolymer-based materials offer numerous benefits, their performance in different environmental conditions, particularly in extreme climates, may not be fully understood yet. More extensive research and testing are required to ensure that the interlocking blocks meet the necessary strength, durability, and safety standards across various applications. Without comprehensive quality control and standardized guidelines, there could be inconsistencies in the final product, potentially affecting its long-term reliability in infrastructure projects.

#### OBJECTIVES

This study aims to establish the design mix for geopolymer concrete equivalent to the M40 grade. It further evaluates the optimum percentage of Ground Granulated Blast Furnace Slag (GGBS) and Silica Fume (SF) in geopolymer concrete, considering different mix ratios (80:20, 60:40, 50:50, and 100% GGBS) based on strength parameters. Additionally, the research seeks to determine the material cost involved in the optimum mix geopolymer pavement block (GPC-PB) and M40 grade Ordinary Portland Cement pavement blocks (OPC-PB) while ensuring similar strength properties. To establish the design mix for geopolymer concrete equivalent to M40 grade.

#### SCOPE OF WORK

The scope of this work focuses on the development and analysis of cement-free interlocking pavement blocks using Ground Granulated Blast Furnace Slag (GGBS), silica fume, and geopolymer technology. The study will begin with an in-depth exploration of the material properties of GGBS, silica fume, and geopolymers, including their pozzolanic reactions and contributions to the strength, durability, and chemical resistance of the pavement blocks. It will also cover the optimization of the mix design, identifying the most effective proportions of GGBS, silica fume, and alkaline activators for achieving the desired

performance characteristics. The work will include a detailed analysis of the manufacturing and curing processes, including determining the appropriate curing conditions for geopolymerization.

#### METHODOLOGY

##### Literature review

The literature review is to be carried out to review of previous studies related to the project work. It helps to understand the significance of the study and is suitable for methods to carry out the success of the project work.

##### Collection of materials

The raw materials are collected and the materials like GGBS, silica fume, fine aggregate, coarse aggregate and sodium silicate, sodium hydroxide

##### Testing of raw materials

The tests are to be conducted to check the properties of raw materials. The various tests conducted for cement are fineness test, specific gravity, standard consistency, initial setting time. Fine aggregates and coarse aggregates are tested for its specific gravity and grain size analysis.

##### Mix design Geopolymer mix design of M40 grade

according to IS 5. Casting and testing of specimen the interlock is casted for finding the compressive strength of pavement block at 7 day and 14 days. The interlock is casted to determine the flexural strength of pavement block at 7 day and 14 day. And the size of mould is 22.5cm\*12cm\*6cm. 12 6. Analysis of test result and evaluation to study the influence of fully replacement of cement with GGBS and silica fume and determine the compressive strength and flexural strength of interlocking block. To compare the results of normal concrete pavement block with geopolymer pavement block.

#### V. EXPERIMENTAL INVESTIGATION

##### 1. GENERAL

The primary objective of this project is to develop and evaluate geopolymer interlocking paver blocks by utilizing industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS) and Silica Fume, completely eliminating the use of Ordinary Portland Cement (OPC). This aligns with the global

goal of sustainable and environmentally friendly construction practices. According to IS 15658: 2006 generally, the acceptance criterion of paving blocks is based on three main tests; compression strength test, water absorption. Flexural strength test is an optional test, which is also done here.

## 2. COLLECTIONS OF MOULDS

The mould is a mandatory material in the making of interlocks. The mould is available in different sizes like 60 and 80 mm and different shapes like zigzag, rectangle, round duple, square etc. are available in market. The most suitable one for pavements is zigzag 80mm which has good strength and capacity among other shapes and sizes.

## 3. PREPARATION OF CONCRETE MIX

The preparation of geopolymers concrete mix begins with the careful weighing of raw materials, including 1.54 kg of GGBS, 0.51 kg of fine aggregate, and 0.51 kg of coarse aggregate. These dry materials are thoroughly mixed in a clean mixing tray or concrete mixer for about 2–3 minutes to ensure uniform distribution. Meanwhile, the alkaline solution is prepared by dissolving 0.44 kg of sodium hydroxide in 1.01 kg of sodium silicate, ensuring proper stirring until a homogeneous mixture is achieved. This solution is allowed to rest for at least 24 hours before use to complete the necessary chemical reaction. Once both the dry mix and alkaline solution are ready, 24 the solution is gradually added to the dry materials while continuously stirring to form a consistent paste. A low-speed mechanical mixer is used for approximately 5–7 minutes to ensure proper binding and uniformity. The well-mixed geopolymer concrete is then poured into zig-zag paver block molds, which have been pre-treated with a release agent to prevent sticking. To ensure proper compaction, a table vibrator is used for about 30–60 seconds to eliminate air voids. Unlike conventional cement concrete, geopolymer concrete does not require water curing. Instead, the molded blocks are left at room temperature for 24 hours before being demolded carefully. After demolding, they are stored in a shaded area for ambient curing, allowing them to gain full strength over a period of 7 to 28 days. Once cured, the geopolymer paver blocks undergo various quality tests, including compressive strength, water absorption, density measurement, and flexural

strength tests, ensuring durability and high performance. The demoulding process of interlock is done 24 hours. And the curing period of the interlock is 7 and 14 days. Actually, it has an ambient curing. This is was its major advantage. Fig: 5.4 Interlock by varying percentage the compressive strength was assessed by crushing to the destruction of the test specimens by means of compression testing machine according to IS 516:1959 (Reaffirmed 2013). Cubes of 150 mm size were used for the testing the strength of control mix. All other compressive strength tests were done on pavement block specimens. . A material under compression tends to reduce the size, while in tension, size elongates. Size of the specimen is 225mm x 120mm x 60mm. The compression testing was conducted in a Universal Testing Machine (UTM) as shown in. Clean the bearing surface of the testing machine. Place the specimen in the machine in such a manner that the load shall be applied to the opposite side. Align the specimen centrally on the base plate of the machine. Rotate the movableportion gently by hand, so that it touches the top surface of the specimen. Apply the load gradually without shock and continuously at the rate of 140 kg/cm<sup>2</sup>/minute till the specimen fails. Record the maximum load and note any unusual features in the type of failure. Fig 5.1 Compression Testing Machine 27 The supporting and loading rollers shall have diameter in the range of 25 to 40 mm. They shall extend on both sides beyond -the dimensions of the specimens by at least 10mm. The distance from centre-to-centre of the two supporting rollers shall be adjustable to the overall length of the specimen minus 50 mm; and the loading roller shall be arranged for application of load from the top of the specimen along the vertical centerline between the supporting rollers. The load shall be applied from the top of the specimen in the form of a simple beam loading through a roller placed midway between the supporting rollersThe load shall be applied without shock and increased continuously at a uniform rate of 6 kN/min. The load shall be increased until the specimen fails, and the maximum load applied shall be recorded. Note down the appearance of the fractured faces of the paver block.

## VI. CONCLUSION

An experimental study was carried out to examine the effect of geopolymer paver block incorporating GGBS

and silica fume. The replacement of GGBS with silica fume was considered in proportions of 100%, 80:20%, 60:40%, and 50:50%. From these mixtures, the optimum combination of silica fume and GGBS was determined based on strength parameters. The results and discussions of the conducted tests are presented below. Based on this experimental investigation, the following conclusions were derived.

1. Geopolymer paver block with the combination of GGBS and silica fume shows excellent compressive strength.
2. Efflorescence was observed in mixtures containing 100%, 80%, and 50% GGBS. However, when the Silica Fume ratio was adjusted to 60:40, the efflorescence was completely eliminated.
3. The color of the pavement block changed with varying ratios. A 100% mix resulted in black, an 80:20 ratio produced light brown, a 50:50 mix yielded green, and a 60:40 combination resulted in greyish colour.
4. The partial replacement of silica fume by GGBS in geopolymer paver block increases the compressive strength.
5. Maximum compressive strength and flexural strength of 53.2 N/mm<sup>2</sup> and 21.85 N/mm<sup>2</sup> was obtained for 60% silica fume replacement by GGBS in geopolymer paver block specimen.
6. The workability of geopolymer concrete improved with the incorporation of silica fume due to its fine particle size and high pozzolanic activity, which enhanced the overall mix cohesion.
7. The curing process played a crucial role in strength development, with ambient curing proving to be an effective alternative to oven curing, making the mix more suitable for the test.
8. The reduction in efflorescence at higher silica fume content suggests better chemical stability and reduced alkali leaching, improving the long-term durability of the pavement blocks.
9. The incorporation of silica fume in geopolymer concrete enhanced resistance to environmental factors such as moisture and temperature variations, making it a viable alternative for sustainable pavement applications.
10. The study confirms that geopolymer concrete incorporating GGBS and silica fume offers a

sustainable and eco-friendly solution by utilizing industrial by-products while achieving superior mechanical properties compared to conventional concrete.

## VII. RECOMMENDATION

The study suggests that the geopolymer cement free interlock can be used in the production of pavement blocks with better strength parameters. The optimum mix with 40% of GGBS replaced by Silica Fume pavement block can be used as a suitable material for pavement blocks. Hence the modified geopolymer concrete can be successfully employed to pavement blocks in medium traffic areas.

## FUTURE SCOPE

Further investigations that can be carried out on this topic are: • Extending the study for testing durability properties such as acid resistance, sulphate resistance etc. • Studies can be conducted by incorporating other geopolymer materials and other alkali activators.