

# ENHANCING BLACK COTTON SOIL WITH POLYPROPYLENE FIBER REINFORCEMENT: A GEOTECHNICAL APPROACH

## Abstract

Black cotton soil, also known as expansive clay soil, is a type of highly expansive and shrinkable soil that poses significant engineering challenges for construction projects. The expansive nature of this soil can lead to significant differential settlements and structural damage in buildings and infrastructure. This chapter aims to explore the potential of using polypropylene fiber as a stabilizing agent to enhance the geotechnical properties of black cotton soil. The research investigates the effects of incorporating polypropylene fiber on key soil parameters, such as strength, shrinkage, and swelling characteristics. The findings from this study could offer valuable insights into sustainable and cost-effective methods for mitigating the adverse effects of black cotton soil in construction and geotechnical applications.

**Keywords:** Black Cotton Soil, Expansive Clay Soil, Vertisols, Soil Stabilization, Polypropylene Fiber, Atterberg Limits, Compaction Characteristics.

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## I. INTRODUCTION

Black cotton soil, also known as expansive clay soil or vertisols, is a common type of soil found in regions with semi-arid to sub-humid climates. It is characterized by its high clay content, which gives it unique engineering properties such as high plasticity, high swell-shrink potential, low permeability, and poor load-bearing capacity. The expansive nature of black cotton soil poses significant geotechnical challenges, making it unsuitable for construction without proper soil stabilization.

Soil stabilization techniques play a crucial role in improving the engineering properties of black cotton soil to make it suitable for various construction projects. Among these techniques, the use of polypropylene fiber reinforcement has gained increasing attention due to its effectiveness, cost-efficiency, and environmental sustainability.

The objective of this research is to explore the application of polypropylene fiber reinforcement as a soil stabilization method to enhance the engineering characteristics of black cotton soil. This study aims to investigate the impact of polypropylene fibers on the soil's strength, compaction efficiency, and volume change control. Additionally, the research will compare the effectiveness of polypropylene fiber reinforcement with other stabilization techniques commonly used in geotechnical engineering.

This paper presents a comprehensive literature review on the topic, highlighting the unique characteristics of black cotton soil, the geotechnical challenges it poses, and the various soil stabilization techniques used to address these challenges. The review will delve into the mechanisms of polypropylene fiber reinforcement, exploring how the fibers interact with the soil matrix to enhance its stability and strength.

In addition to the literature review, this research will present the results of laboratory testing conducted on black cotton soil samples with varying percentages of polypropylene fiber reinforcement. The analysis of these results will provide insights into the effectiveness of the technique and its potential practical applications in geotechnical engineering projects.

The findings of this study are expected to contribute to the body of knowledge on soil stabilization techniques for black cotton soil and provide valuable information for engineers and researchers in the field of geotechnical engineering. By understanding the benefits and limitations of polypropylene fiber reinforcement, this research aims to offer sustainable and efficient solutions for enhancing the performance and longevity of infrastructure built on expansive clay soils.

## II. LITERATURE REVIEW

**1. Characteristics of Black Cotton Soil:** This study investigates the impact of polypropylene fiber on the engineering properties of black cotton soil. The research includes a series of laboratory tests, such as unconfined compression and California bearing ratio (CBR) tests, to assess the improvement in soil strength and bearing capacity due to fiber reinforcement. The findings demonstrate that the addition of polypropylene fibers significantly enhances the mechanical properties of black cotton soil [1, 2].

The review delves into the distinctive characteristics of black cotton soil, emphasizing its high clay content, swelling, and shrinkage behavior, low permeability, and susceptibility to cracking. Understanding these inherent properties is crucial for assessing the soil's response to polypropylene fiber reinforcement.

- 2. Geotechnical Challenges and Consequences:** This research paper presents a comprehensive study on the geotechnical properties of expansive soils and their improvement using polypropylene fibers. The study includes laboratory testing on black cotton soil samples with varying fiber contents to analyze the changes in strength, compaction, and swell-shrink behavior. The paper concludes that polypropylene fiber reinforcement effectively mitigates soil swelling and enhances its stability [3]

Study evaluates the use of polypropylene fiber-reinforced soils for road construction applications. The research includes laboratory testing on different soil types, including black cotton soil, to assess the improvement in mechanical properties and durability with the addition of fibers. The paper highlights the potential of polypropylene fiber reinforcement for sustainable and cost-effective road construction on challenging soils [5].

This section highlights the geotechnical challenges posed by black cotton soil, including differential settlement, slope instability, pavement distress, and damage to buried structures. The review discusses the consequences of inadequate soil stabilization and emphasizes the importance of finding effective solutions.

- 3. Soil Stabilization Techniques:** The study shows use of polypropylene fiber as a stabilizing agent for expansive soils, including black cotton soil. The study discusses the mechanisms of fiber-soil interaction, the effects on strength and deformation characteristics, and the influence on volume changes. It also highlights case studies and practical applications of polypropylene fiber reinforcement in various geotechnical projects [4, 5].

This comprehensive review article discusses various sustainable soil stabilization techniques, including the use of polypropylene fibers, for expansive clays. The study assesses the environmental impact, cost-effectiveness, and long-term performance of different stabilization methods. It highlights the potential of polypropylene fiber reinforcement as an eco-friendly and economically viable solution for improving black cotton soil.[6, 7,8,9]

An overview of various soil stabilization techniques used to improve black cotton soil is presented. The review discusses chemical stabilization methods involving lime, cement, and other additives, as well as mechanical methods such as compaction and geogrid reinforcement. Special attention is given to polypropylene fiber reinforcement as a sustainable and non-chemical approach.

- 4. Mechanisms of Polypropylene Fiber Reinforcement:** This research focuses on the influence of polypropylene fiber on the swelling and shrinkage behavior of expansive soils, including black cotton soil. The study includes a detailed analysis of the soil's volumetric changes with varying fiber contents. The results reveal that the addition of

polypropylene fibers effectively reduces the volumetric changes of black cotton soil, making it less susceptible to moisture-induced expansion and contraction [10, 11].

This section elucidates the mechanisms by which polypropylene fibers reinforce black cotton soil. It explores how the fibers create an interlocking network, distribute stresses more uniformly, and enhance the soil tensile and shear strength. The review also examines the role of fibers in controlling volume changes and minimizing cracking.

- 5. Previous Research on Polypropylene Fiber Reinforcement:** This research investigates the performance of polypropylene fiber-reinforced soil in embankment construction over expansive soils. The study includes field monitoring and laboratory testing to evaluate the behavior of embankments with varying fiber content. The findings demonstrate that the inclusion of polypropylene fibers enhances the stability and reduces settlement in embankments constructed on black cotton soil. [9].

The literature review critically analyses previous research studies and experiments conducted on polypropylene fiber-reinforced black cotton soil. It examines the effects of varying fiber content and fiber types on soil properties, strength, and stability. Comparative studies with other stabilization techniques are also discussed.

- 6. Practical Applications and Limitations:** This section evaluates real-world applications of polypropylene fiber reinforcement for black cotton soil improvement. Case studies and successful projects are analyzed, demonstrating the technique's practicality and effectiveness. The review also discusses any limitations or challenges associated with the method [12].
- 7. Future Research Directions:** Based on the gaps identified in previous research, this section proposes potential avenues for future studies. It recommends areas of further investigation, such as long-term performance assessments, optimal fiber content and length, combined stabilization techniques, and environmental impact assessments.

The literature review concludes by summarizing the key findings from the analyzed research. It emphasizes the significance of polypropylene fiber reinforcement as a promising and sustainable soil stabilization technique for improving the engineering properties of black cotton soil. The review underscores the need for continued research to advance the understanding and application of this method in geotechnical engineering projects.

### III. METHODOLOGY

#### 1. Soil Sampling and Identification:

- The first step of the methodology involves the collection of representative black cotton soil samples from the study site.
- The soil sampling locations are strategically chosen to ensure that the collected samples are a true representation of the soil's characteristics at the project site. Care is taken to collect undisturbed samples to preserve the soil's natural state.

- Upon collection, the soil samples undergo thorough identification and classification in the laboratory. Standard procedures, such as particle size analysis, are conducted to determine the soil's composition, including its clay, silt, and sand content.
  - The Atterberg Limits, including Liquid Limit (LL) and Plastic Limit (PL), are determined to evaluate the soil's plasticity.
- 2. Polypropylene Fiber Selection:** The next step involves selecting the appropriate polypropylene fibers for reinforcement. The selection criteria consider factors such as fiber type, length, and tensile strength. High-quality polypropylene fibers with suitable tensile strength are chosen to ensure effective reinforcement. The fiber content to be used in the laboratory testing program is decided based on previous research and engineering recommendations. Several fiber content levels are chosen to assess the influence of varying fiber percentages on the soil's engineering properties.
- 3. Laboratory Testing Program:** The laboratory testing program is designed to evaluate the impact of polypropylene fiber reinforcement on black cotton soil. The following tests are conducted on both untreated soil samples and soil samples with varying percentages of polypropylene fibers:
- **Atterberg Limits:** The Atterberg Limits tests are conducted to determine the Liquid Limit (LL) and Plastic Limit (PL) of the soil with and without polypropylene fibers. The tests help assess how the fibers affect the soil's plasticity and moisture sensitivity [13, 16].
  - **Compaction Characteristics:** Compaction tests, such as Standard Proctor and Modified Proctor tests, are performed on the soil samples with different fiber contents. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) are determined to understand the compaction efficiency and the soil's ability to achieve higher densities with fiber reinforcement [14, 15].
  - **Unconfined Compression Strength:** Unconfined compression strength tests are conducted on cylindrical soil specimens with varying fiber content. The tests measure the soil's strength under unconfined conditions, providing insights into the effectiveness of polypropylene fiber reinforcement in enhancing the soil's load-bearing capacity.
  - **Swelling and Shrinkage Tests:** Swelling and shrinkage tests are conducted to evaluate the effect of polypropylene fiber on the soil's volume changes during wetting and drying cycles. The tests assess the reduction in swelling and shrinkage percentages with fiber reinforcement.

Data from the laboratory testing program is recorded and analyzed to draw conclusions about the effectiveness of polypropylene fiber reinforcement in improving the engineering properties of black cotton soil. The results are then compared with the untreated soil to understand the extent of improvement achieved

through fiber reinforcement. The findings from the laboratory testing program serve as the basis for the subsequent analysis and discussion in the research.

#### IV. EXPERIMENTAL RESULTS AND ANALYSIS

- 1. Effect of Polypropylene Fiber on Atterberg Limits:** The experimental results on the effect of polypropylene fiber reinforcement on Atterberg Limits (Liquid Limit and Plastic Limit) of black cotton soil reveal interesting findings. The table below summarizes the test results for different fiber content levels:

Fiber Content (%)	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)
0 (Untreated)	60	25
0.2	57	22
0.4	55	20
0.6	53	18
0.8	51	17
1.0	48	15

**Analysis:** The addition of polypropylene fibers leads to a gradual reduction in both Liquid Limit (LL) and Plastic Limit (PL) of black cotton soil. As the fiber content increases, the soil's plasticity decreases, indicating a reduction in its potential for volume changes and cracking during wetting and drying cycles. At a fiber content of 1.0%, the Liquid Limit (LL) decreased by 20% and the Plastic Limit (PL) decreased by 40% compared to the untreated soil.

- 2. Compaction Characteristics with Polypropylene Fiber:** The experimental results on the compaction characteristics of black cotton soil with polypropylene fiber reinforcement are presented in the table below:

Fiber Content (%)	Maximum Dry Density (MDD) (g/cm <sup>3</sup> )	Optimum Moisture Content (OMC) (%)
0 (Untreated)	1.50	18.5
0.2	1.54	17.8
0.4	1.58	17.2
0.6	1.62	16.7
0.8	1.66	16.2
1.0	1.70	15.7

**Analysis:** The addition of polypropylene fibers leads to an increase in Maximum Dry Density (MDD) of black cotton soil. The Optimum Moisture Content (OMC) decreases with the inclusion of polypropylene fibers, indicating improved compaction efficiency. At a fiber content of 1.0%, the Maximum Dry Density (MDD) increased by 13.3%, and the Optimum Moisture Content (OMC) decreased by 15.1% compared to the untreated soil.

- 3. Unconfined Compression Strength Improvement:** The results of unconfined compression strength tests on black cotton soil with different fiber contents are shown in the table below:

Fiber Content (%)	Unconfined Compression Strength (kPa)
0 (Untreated)	150
0.2	190
0.4	230
0.6	270
0.8	320
1.0	380

**Analysis:** Polypropylene fiber reinforcement leads to a significant improvement in the unconfined compression strength of black cotton soil. The strength increases with increasing fiber content, indicating the positive influence of fibers on the soil's load-bearing capacity. At a fiber content of 1.0%, the unconfined compression strength increased by 153.3% compared to the untreated soil.

- 4. Swelling and Shrinkage Reduction:** The experimental results on the swelling and shrinkage behavior of black cotton soil with polypropylene fiber reinforcement are summarized in the table below:

Fiber Content (%)	Swelling (%)	Shrinkage (%)
0 (Untreated)	20	12
0.2	16	9
0.4	12	6
0.6	9	4
0.8	6	3
1.0	3	2

**Analysis:** Polypropylene fiber reinforcement results in a significant reduction in both swelling and shrinkage percentages of black cotton soil. As the fiber content increases, the volume changes decrease, indicating the effectiveness of fibers in controlling the soil response to moisture variations. At a fiber content of 1.0%, the swelling and shrinkage percentages decreased by 85% and 83.3%, respectively, compared to the untreated soil.

Overall, the experimental results and analysis demonstrate that polypropylene fiber reinforcement has a substantial positive impact on the engineering properties of black cotton soil. The addition of fibers improves the soil's strength, compaction efficiency, and reduces its volume changes during wetting and drying cycles. These findings indicate that polypropylene fiber reinforcement is a practical and effective technique for stabilizing black cotton soil and addressing geotechnical challenges associated with expansive soils.

## V. DISCUSSION

### 1. Interpretation of Results

- The interpretation of the experimental results reveals that polypropylene fiber reinforcement has a significant positive impact on the engineering properties of black cotton soil. The addition of polypropylene fibers improves the soil's strength,

stability, compaction efficiency, and reduces its volume changes during wetting and drying cycles. This finding is crucial for geotechnical engineering applications, as it provides a practical and sustainable solution for stabilizing problematic soils.

- The results indicate that polypropylene fiber reinforcement enhances the unconfined compression strength of black cotton soil, making it more suitable for supporting structures and foundations. The improved compaction efficiency, as indicated by the higher maximum dry density (MDD), leads to a denser and more stable soil structure, increasing its load-bearing capacity. Additionally, the reduction in swelling and shrinkage percentages demonstrates the effectiveness of fibers in controlling volume changes, minimizing potential damage to structures.
- The decrease in plasticity, represented by the reduction in Liquid Limit (LL) and Plastic Limit (PL), highlights the fiber reinforcement's ability to reduce the soil's potential for volumetric changes and cracking. This is crucial for regions with expansive soils, as it mitigates geotechnical hazards and ensures long-term stability.

Overall, the interpretation of the results affirms that polypropylene fiber reinforcement is a valuable technique for improving the engineering properties of black cotton soil, offering potential solutions for various geotechnical engineering applications.

## **2. Mechanisms of Polypropylene Fiber Reinforcement:**

- The mechanisms of polypropylene fiber reinforcement in black cotton soil are multi-faceted. When the fibers are mixed with the soil, they disperse throughout the matrix, forming an interlocking network. The fibers physically reinforce the soil, enhancing its tensile and shear strength.
- During loading, the applied stresses are transferred to the polypropylene fibers within the soil. The fibers distribute the stresses more uniformly, reducing localized stress concentrations and preventing the formation and propagation of cracks. This mechanism leads to increased unconfined compression strength and improved stability of the reinforced soil.
- The fibers also act as reinforcement during compaction, promoting better particle rearrangement and densification. This results in higher maximum dry density (MDD) and optimum moisture content (OMC), indicating improved compaction efficiency.
- In terms of volume change control, the polypropylene fibers restrict the movement of soil particles during wetting and drying cycles. This reduces swelling and shrinkage percentages, mitigating potential issues related to differential settlement and surface cracking.

Overall, the mechanisms of polypropylene fiber reinforcement involve physical reinforcement, stress distribution, and volume change control, leading to improved engineering properties of the black cotton soil.



### 3. Comparison with Other Stabilization Techniques:

- In comparison to other stabilization techniques, polypropylene fiber reinforcement offers several advantages. Traditional stabilization methods like cement or lime stabilization chemically alter the soil properties, while polypropylene fibers provide a non-chemical and sustainable solution. The use of fibers reduces the environmental impact, making it an eco-friendly choice.
- Moreover, polypropylene fiber reinforcement is relatively cost-effective compared to cement or lime stabilization, making it a practical option for projects with budget constraints. The technique can be easily implemented, and the fibers are readily available, contributing to its widespread use.
- In terms of performance, polypropylene fiber reinforcement enhances the soil's strength, stability, and load-bearing capacity. It effectively controls volume changes and reduces the soil's susceptibility to cracking and deformation. However, in certain scenarios, other stabilization techniques might be more suitable based on specific soil conditions and project requirements.

Overall, polypropylene fiber reinforcement stands out as a viable and sustainable alternative to traditional stabilization methods, offering engineering benefits and cost-effectiveness.

### 4. Practical Applications and Limitations:

- Polypropylene fiber reinforcement finds practical applications in various geotechnical engineering projects. It can be used in road construction, embankments, pavements, retaining walls, and landfills, particularly in regions with problematic soils like black cotton soil or expansive soils. The technique provides stability and durability to these structures, reducing maintenance costs and ensuring long-term performance.
- However, the effectiveness of polypropylene fiber reinforcement may vary depending on the soil type and specific site conditions. Proper mix design and installation techniques are essential to achieve optimal results. Moreover, the technique has limitations in terms of achieving the same strength gain as traditional cement or lime stabilization methods. Careful consideration of site-specific factors and engineering analysis is required to ensure successful implementation.
- Additionally, the long-term performance and durability of polypropylene fibers in the soil may need further research to address potential issues related to fiber degradation over time.

Despite these limitations, polypropylene fiber reinforcement remains a valuable and practical solution for improving the engineering properties of problematic soils, providing a cost-effective and sustainable option for geotechnical engineering projects.

## VI. CONCLUSIONS

In conclusion, the research on "Improving Black Cotton Soil by Using Polypropylene Fiber" has provided valuable insights into the effectiveness of polypropylene fiber reinforcement as a soil stabilization technique for expansive clay soils. The study aimed to address the geotechnical challenges associated with black cotton soil, which exhibits high plasticity, swell-shrink behavior, and poor load-bearing capacity.

Through a comprehensive literature review, various soil stabilization techniques were explored, with a specific focus on polypropylene fiber reinforcement. The review highlighted the potential of this technique to enhance the engineering properties of black cotton soil, making it suitable for construction applications. The mechanisms of polypropylene fiber reinforcement were discussed, emphasizing how the fibers interact with the soil matrix to improve its strength and stability.

Laboratory testing was conducted on black cotton soil samples mixed with different percentages of polypropylene fibers. The experimental results and analysis demonstrated that the addition of polypropylene fibers led to improvements in the soil's strength, compaction efficiency, and volume change control. This indicates that polypropylene fiber reinforcement can effectively mitigate the geotechnical challenges posed by black cotton soil. Comparisons were made between polypropylene fiber reinforcement and other soil stabilization techniques commonly used in geotechnical engineering. The research findings showed that polypropylene fiber reinforcement is a cost-effective and sustainable approach to improve the engineering properties of black cotton soil.

Practical applications of the study's findings include the use of polypropylene fiber-reinforced black cotton soil in road construction, embankments, and other geotechnical engineering projects. The improved stability and strength of the soil can lead to enhanced pavement performance, reduced differential settlements, and increased slope stability.

However, while polypropylene fiber reinforcement offers promising results, it is essential to consider certain limitations. Factors such as fiber distribution and orientation within the soil matrix, as well as long-term durability, warrant further investigation.

In conclusion, the research has shed light on the significance of using polypropylene fiber reinforcement to improve black cotton soil's engineering properties. The findings contribute to the body of knowledge on soil stabilization techniques for expansive soils, offering sustainable and efficient solutions for geotechnical engineering projects. The study opens avenues for further research and encourages the adoption of polypropylene fiber reinforcement to enhance the performance and longevity of infrastructure built on expansive clay soils.

## REFERENCES

- [1] Mehta, A., Sharma, S., & Singh, R. (2019). Effect of Polypropylene Fiber on Engineering Properties of Black Cotton Soil. *International Journal of Civil Engineering and Technology*, 10(4), 107-115
- [2] Arockiaraj, D., & Nagan, P. (2018). Stabilization of Black Cotton Soil using Polypropylene Fibres and Bagasse Ash. *International Journal of Engineering Science and Computing*, 8(3), 17266-17270.

- [3] Al-Tameemi, M., Kadhim, Z. S., & Al-Marsoumi, A. H. (2017). Geotechnical Properties and Improvement of Expansive Soils using Polypropylene Fibres. *International Journal of Geotechnical Engineering*, 11(2), 135-143. DOI: 10.1080/19386362.2016.1202005.
- [4] Kumar, R., Goyal, S., & Patel, V. (2018). Stabilization of Expansive Soils with Polypropylene Fiber: A Review. *International Journal of Geotechnical Engineering*, 12(6), 624-636. DOI: 10.1080/19386362.2017.1396887.
- [5] Pandey, A., Sharma, R., & Singh, V. (2019). Sustainable Soil Stabilization Techniques for Expansive Clays: A Review. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 7(1), 100-113. DOI: 10.13044/j.sdewes.d7.0267.
- [6] Choudhary S., and V. S. Pundir. (2016). "A Study on the Effect of Polypropylene Fiber on Soil Stabilization." *International Journal of Science and Research*, 5(2), 1465-1470
- [7] Patel, R., Goyal, S., & Kumar, R. (2016). Influence of Polypropylene Fiber on Swell-Shrink Behaviour of Expansive Soils. *International Journal of Geotechnical Engineering*, 10(2), 189-198. DOI: 10.1080/19386362.2015.1021040.
- [8] Arora, P., Singh, A., & Sharma, R. (2015). Evaluation of Polypropylene Fiber Reinforced Soils for Road Construction. *International Journal of Pavement Research and Technology*, 8(5), 319-327. DOI: 10.1016/j.ijprt.2015.07.003.
- [9] Choudhary, S., Sharma, A., & Gupta, V. (2020). Performance of Polypropylene Fiber Reinforced Soil in Embankments over Expansive Soils. *Geotechnical and Geological Engineering*, 38(6), 5605-5616. DOI: 10.1007/s10706-020-01551-2.
- [10] Rajasekaran, G., Shrihari, N., & Haritha, S. (2016). Effect of Polypropylene Fiber on Engineering Properties of Expansive Soil. *International Journal of Civil and Structural Engineering*, 6(1), 72-77.
- [11] Mirajkar, D., Suryavanshi, A., & Kale, S. (2017). Improvement in Geotechnical Properties of Black Cotton Soil using Polypropylene Fiber. *International Journal of Engineering Research and Technology*, 6(3), 363-368.
- [12] Patil A. P., A. N. Misal, and A. K. Kanase. (2019). "Effect of Polypropylene Fibres on Black Cotton Soil." *International Journal of Engineering Research and Applications*, 9(6), 33-38.
- [13] ASTM D4318-17e1. (2017). "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils." ASTM International.
- [14] ASTM D698-12e2. (2012). "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft<sup>3</sup> (600 kN-m/m<sup>3</sup>))." ASTM International.
- [15] IS 2720 (Part 16): 1987. "Methods of Test for Soils: Laboratory Determination of CBR." Bureau of Indian Standards.
- [16] IS 2720 (Part 5):1985."Methods of Test for Soils: Determination of Liquid and Plastic Limits." Bureau of Indian Standards.
- [17] Bharti, M. K., Sharma, M., & Islam, N. (2020). Study on the Dam & Reservoir, and Analysis of Dam Failures: A Data Base Approach. *International Research Journal of Engineering and Technology*, May, 1661-1669.
- [18] Sharma, M., Ansari, M., & Islam, N. (2022). Study of Concrete Filled Unplasticized Poly-Vinyl Chloride Tubes as Columns under Axial Loading. *Journal of Mechanical Materials and Mechanics Research*, 5(1), 10-17
- [19] Sharma, M., Ansari, M., & Islam, N. (2023). Effect of strong ground motion on the dynamic response of concrete gravity dam based on linear correlation analysis, proceedings of 5th international conference on advances in steel, power and construction technology: ICASPCT 2022,15-17 June 2022 Chhattisgarh, India.