LOW COST FLEXIBLE PAVEMENT DESIGNED BY USING SUBGRADE SOIL STABILIZATION TECHNIQUES

[1]MARISETTI RATNA KUMARI, [2]VOTHUJU AISHWARYA, [3]GUTTULA RAGA PRASANNA, [4]ADDANKI ASHA, CHINTHALAPUDI SIVA KRISHNA TEJA,[5]Y. REBKA

[1,23,4]Students, Department of Civil, Srinivasa Institute Of Engineering And Technology, Nh-214 Cheyyeru(V), Amalapuram

[5]Assistant Professor, Department of Civil, Srinivasa Institute Of Engineering And Technology, Nh-214 Cheyyeru(V), Amalapuram

ABSTRACT

Expansive soils, particularly Black Cotton soils, pose significant challenges in civil engineering due to their high swelling and shrinkage behavior under varying moisture conditions. These soils exhibit high strength in dry conditions but lose bearing capacity when saturated, leading to structural instability and pavement failure. This project focuses on improving the engineering properties of expansive soil through stabilization using fly ash, an industrial by-product from thermal power plants. The study aims to evaluate the effectiveness of fly ash in enhancing soil properties and reducing pavement construction costs. Laboratory experiments were conducted on locally available expansive soil mixed with varying percentages of fly ash (0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20%). Standard geotechnical tests, including grain size analysis, Atterberg limits, compaction tests, and California Bearing Ratio (CBR) tests, were performed. The results indicate that the addition of fly ash significantly reduces the liquid limit and plasticity index, thereby improving soil workability and reducing swelling potential. Furthermore, the CBR values under both soaked and unsoaked conditions showed substantial improvement with increasing fly ash content, indicating enhanced load-bearing capacity. The stabilized soil was further used in the design of flexible pavements as per IRC 37:2018 guidelines and analyzed using IITPAVE software. Comparative analysis between stabilized and unstabilized soil revealed that stabilization increases the resilient modulus of the subgrade, allowing a reduction in pavement thickness. The total pavement thickness was reduced by approximately 110 mm, leading to a cost reduction of about 24.2%. The study concludes that fly ash is an effective and economical stabilizing agent for expansive soils. Its utilization not only enhances soil performance but also promotes sustainable construction by utilizing industrial waste, thereby addressing environmental concerns and reducing overall project costs.

Keywords: Fly ash, Expansive soil, Soil stabilization, Black cotton soil, CBR, Pavement design, Plasticity index, Resilient modulus, Sustainable construction, Cost reduction.

I. INTRODUCTION

This project begins with the collection and preparation of materials required for soil stabilization. Representative samples of black cotton soil should be collected from a depth of 1.5 to 2 meters to ensure consistency in properties. Fly ash, used as a stabilizing agent, must be obtained from a nearby thermal power plant. Initial laboratory tests such as grain size analysis and soil classification should be conducted to understand the fundamental characteristics of the soil. After this, soil samples are to be mixed with varying percentages of fly ash, typically 0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20%. Proper mixing of soil and fly ash is essential to achieve uniformity. The mixtures should be prepared by adding calculated amounts of water and then stored in airtight containers for about 24 hours. This step ensures uniform moisture distribution and improves the reliability of test results. All preparation and handling procedures must follow standard guidelines such as IS codes to maintain accuracy and consistency. Care should be taken to avoid contamination and maintain proper labeling of samples. The prepared samples are then ready for further experimental testing. This stage lays the foundation for analyzing the impact of fly ash on expansive soil properties. Accurate sample preparation ensures reliable outcomes in subsequent tests. The overall objective of this phase is to create uniform and controlled soil mixtures that can be tested for improvement in engineering properties. This systematic preparation process is critical for achieving meaningful and consistent experimental results.

After preparing the soil-fly ash mixtures, the next step involves conducting detailed laboratory tests to evaluate the engineering properties of the stabilized soil. Atterberg limits tests, including liquid limit and plastic limit, should be performed to determine the plasticity index of the soil. These tests help in understanding the changes in consistency and workability due to the addition of fly ash. A reduction in plasticity indicates improved soil behavior, making it more suitable for construction purposes.Compaction tests, specifically the Proctor test, are carried out to determine the optimum moisture content (OMC) and maximum dry density (MDD). These parameters are essential for understanding how the soil behaves under compaction and for achieving maximum strength in field conditions. As fly ash content increases, variations in OMC and MDD should be carefully observed and recorded. Graphs must be plotted to analyze trends and identify the most effective proportion of fly ash. Further, the California Bearing Ratio (CBR) test is conducted under both soaked and unsoaked conditions to evaluate the strength of the stabilized soil. This test is crucial for pavement design as it indicates the load-bearing capacity of the subgrade. Results should be compared with untreated soil to determine the improvement achieved. The goal of this phase is to identify the optimum fly ash content that enhances strength while reducing plasticity and swelling behavior.

The final phase of the project involves applying the experimental results to flexible pavement design. Using the obtained CBR values, the resilient modulus of both stabilized and unstabilized soil should be calculated as per IRC 37:2018 guidelines. These values are essential for determining the structural capacity of the pavement layers. The pavement design should include different layers such as bituminous surface, base, sub-base, and subgrade. Each layer must be assigned appropriate thickness based on calculated parameters. Pavement analysis is then carried out using IITPAVE software. Input parameters such as wheel load, tyre pressure, Poisson's ratio, and layer moduli are used to determine stresses and strains in the pavement structure. The actual horizontal and vertical strains obtained from the software must be compared with permissible strain values. This comparison helps in determining whether the design is safe or requires modification. Multiple trial combinations of layer thickness should be analyzed to achieve an optimized design. Finally, a comparison between stabilized and unstabilized pavement sections should be made in terms of thickness and cost. It is observed that stabilization reduces pavement thickness and overall construction cost. Proper documentation of results, graphs, and conclusions should be maintained. This phase highlights the practical application of soil stabilization and demonstrates its benefits in improving performance and achieving economical pavement construction.

Figure 1: Expensive soil

II. LITRATURE REVIEW

Expansive soils are known for their swelling and shrinkage behavior due to moisture variation, which causes serious damage to pavements and structures. Researchers such as Bhuvaneshwari et al. (2013) highlighted that the presence of montmorillonite minerals significantly increases the swelling potential of soils. These soils lose strength when wet and become hard when dry, leading to cracks and differential settlements. Studies indicate that lightly loaded structures are more vulnerable to damage due to uplift pressure generated by expansive soils. Further, Sridharan and Prakash emphasized that the mineralogical composition of clay plays a crucial role in determining soil behavior. The higher the clay content, the greater the volume change. These findings underline the necessity of soil stabilization before construction.

The research concludes that understanding the properties of expansive soil is essential for selecting appropriate stabilization techniques to improve engineering performance.

Fly ash has been widely studied as a stabilizing agent for expansive soils due to its pozzolanic properties. According to Das (1990), fly ash contains silica, alumina, and other oxides that react with soil particles to improve strength and reduce plasticity. The classification of fly ash into Class C and Class F plays a vital role in stabilization performance, with Class C showing self-cementing properties. Research by Hausmann demonstrated that the addition of fly ash reduces plasticity index and increases compressive strength. It was also observed that fly ash works effectively when combined with lime or cement, especially for highly plastic soils. The study concludes that fly ash not only improves soil properties but also serves as an economical and environmentally friendly alternative to traditional stabilizers, promoting sustainable construction practices.

The influence of fly ash on strength characteristics of soil has been extensively investigated. Prabakar et al. reported that adding fly ash significantly improves shear strength, cohesion, and bearing capacity of soil. Their study showed that with increasing fly ash content, the California Bearing Ratio (CBR) values increased considerably, making the soil suitable for pavement applications. Similarly, Phani Kumar and Sharma found that fly ash reduces swelling pressure and plasticity while enhancing dry density and strength. The improved resistance to penetration indicates better load-bearing capacity. These results highlight the importance of optimizing fly ash content to achieve maximum benefits. The research concludes that fly ash stabilization is effective in improving both mechanical and physical properties of expansive soils, making it suitable for subgrade construction.

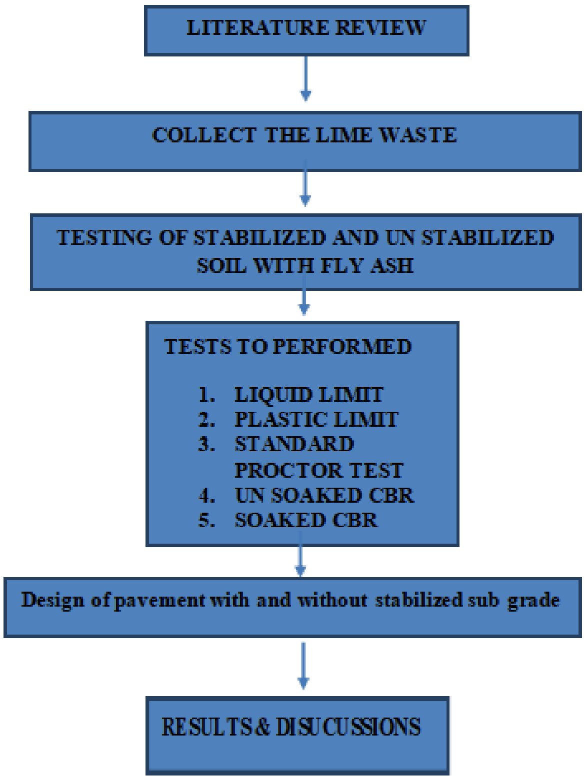
The role of curing and compaction in fly ash stabilization has been studied by several researchers. Misra observed that early hydration reactions in Class C fly ash lead to rapid strength gain when compaction is performed immediately after mixing. However, delayed compaction results in reduced density and strength. This indicates the importance of proper timing in construction practices. In another study, White and Gnanendran found that a delay between mixing and compaction can increase unconfined compressive strength and resilient modulus. The results suggest that controlled curing enhances long-term performance of stabilized soils. These studies emphasize that not only material composition but also construction methodology plays a vital role in achieving effective soil stabilization.

The effect of fly ash on compaction characteristics and density has also been explored. Nalbantoglu demonstrated that the addition of fly ash reduces clay-sized particles and improves soil structure through pozzolanic reactions. This leads to a decrease in plasticity and water absorption capacity. The study also showed that fly ash alters soil mineralogy, making it more granular. Additionally, Sezer et al. found that increasing fly ash content reduces maximum dry density while increasing optimum moisture content. This behavior is attributed to the lighter weight and porous nature of fly ash. The research concludes that fly ash significantly enhances compaction behavior and contributes to improved engineering performance of expansive soils.

Several studies have highlighted the application of fly ash in pavement design. Edil et al. reported that fly ash significantly increases the CBR value of fine-grained soils, making them suitable for subgrade layers. The study also indicated that stabilized soils exhibit higher stiffness and durability over time. Furthermore, Senol et al. demonstrated that fly ash improves both unconfined compressive strength and CBR values, allowing reduction in pavement thickness. This leads to cost savings in road construction. The findings confirm that fly ash stabilization not only enhances soil properties but also contributes to economical pavement design. Overall, the literature supports the use of fly ash as an effective and sustainable solution for improving subgrade performance in flexible pavements.

III. WORKING METHODOLOGY

The methodology for this project is structured in a systematic sequence to evaluate the effectiveness of fly ash in stabilizing expansive soil and its application in pavement design. Initially, representative samples of black cotton soil are collected from the field at a depth of about 1.5–2 meters to ensure uniformity. Fly ash is procured from a nearby thermal power plant and both materials are tested for basic properties. The soil is then mixed with varying proportions of fly ash such as 0%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, and 20%. Proper mixing is ensured by adding calculated moisture content and storing the mixtures in airtight containers for 24 hours to achieve uniform distribution.



In the next stage, laboratory tests are conducted on both untreated and treated soil samples. These tests include grain size analysis, Atterberg limits (liquid limit, plastic limit, and plasticity index), compaction test to determine optimum moisture content (OMC) and maximum dry density (MDD), and California Bearing Ratio (CBR) tests under soaked and unsoaked conditions. The results obtained from these tests are carefully recorded and analyzed using graphs and tables. The variation in engineering properties with respect to fly ash content is studied to determine the optimum percentage that provides maximum strength and reduced plasticity.

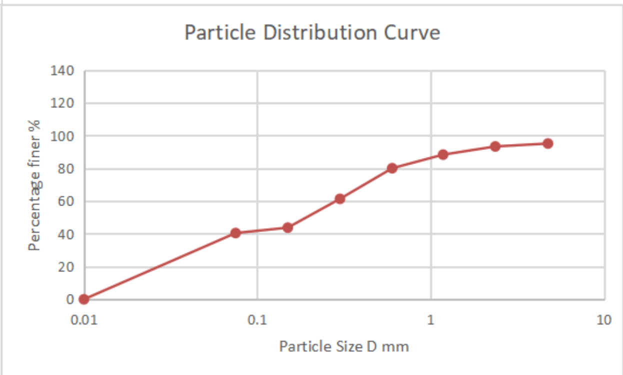


Fig. 2: Particle size distribution curve of Black cotton soil

The results obtained from a series of consistency tests, compaction tests, CBR tests conducted on expansive soils with and without additives have been presented in this chapter in the form of tables and figures. The effects of additives lime on the geotechnical properties of soils are studied thoroughly and discussed elaborately citing the results published in the literature.

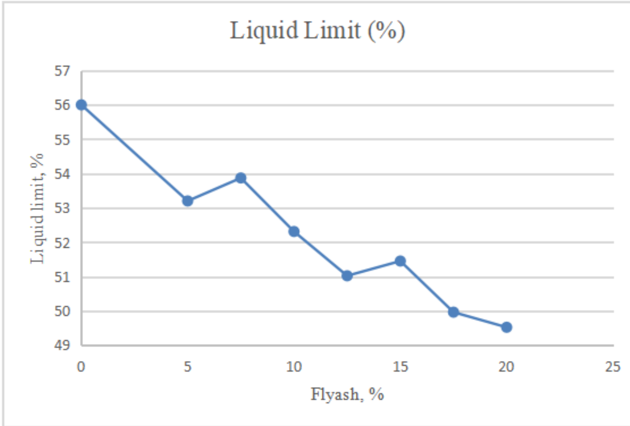


Fig. 3: Graph on Average Liquid limit values for fly ash as additive material

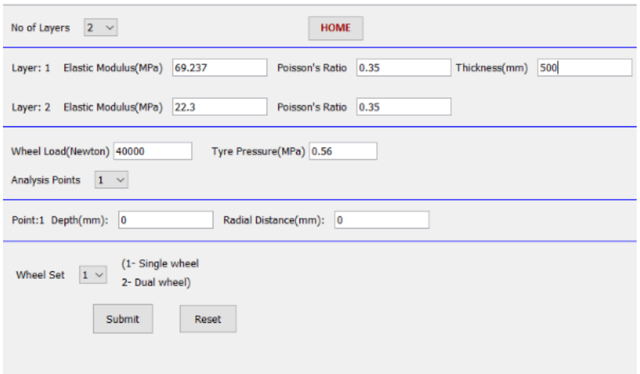


Figure 4: Combined modulus input

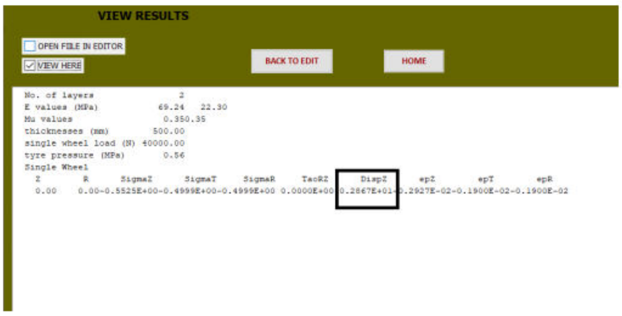


Figure 5: Combined modulus output

Finally, the obtained CBR values are used for flexible pavement design as per IRC 37:2018 guidelines. The resilient modulus of subgrade soil is calculated and pavement layers are designed. Analysis is carried out using IITPAVE software to evaluate stresses and strains. The design is validated by comparing permissible and actual strain values. A comparison between stabilized and unstabilized soil is performed in terms of pavement thickness and cost. The methodology concludes with identifying the most effective stabilization percentage and demonstrating its economic and engineering benefits.

IV.CONCLUSION

The generation of fly ash is more than its utilization. It can be used as an alternative material instead of conventional materials in the construction of geotechnical and infrastructures. If desired results are found in future studies on fly ash in soil stabilization, we could see large reductions in material costs. On the other hands, fly ash is a good material for use in geotechnical applications. The low unit weight of fly ash makes it acceptable for placement in soft soils. Addition of fly ash altered the physical and compaction characteristics of both granular and cohesive soils. Fly ash can create an adequate array of cations than under ionized conditions it can improve flocculation of dispersed clay particles. According to a cation exchange process, the influence of fly ash on expansive soils causes significant reduction of plasticity index. The combination of soil and fly ash improves liquid limit, plastic limit, and CBR values to acceptable limits. Fly ash increases strength of expansive soils. It can be concluded that fly ash treatment method can be used to stabilize expansive soils. Following conclusions are derived after a full-length study of soft soils using fly ash :

1. With the use of fly ash in soft soils of the Kompally, there is a great change in Index properties. It further leads to the stabilization of soil. With the help of this stabilization of soil, pavements can be designed economically such that sub-base thickness can be reduced with varying percentages of fly ash.
2. With addition of lime, the L.L. and P.I. of soils gradually decreases with the increase of fly ash contents. Maximum decrease is observed at 20% fly ash content.
3. CBR of soil-fly ash increases with the increase of fly ash content. The maximum increase being observed at 20% fly ash content. At 20% fly ash content, the 4 days soaked CBR of increase by 142% and un-soaked CBR of increase by 133%.
4. Since the more percentage gain in CBR values and MDD values of subgrade soils, reduction in pavement thickness can be achieved, by mixing fly ash waste. The Pavment layer thickness for construction of 4-lane flexible pavement as per IRC 37 -2018 designed those thickness are ; With fly ash stabilized soil 950mm and without stabilized soil 1060mm, the difference between both is 110mm. Around 0.11m

thickness of entire pavement reduced by stabilized of sub grade.

5. The 24% cost of stabilized sub grade reduced as compare to the un stabilized sub grade. Due to the saving in Pavement thickness is less quantity of material will be applicable so that, huge amount of money can be saved.
6. Use of it in highways and rural roads will certainly yield in terms of the economy because a large amount of fly ash can be made available from thermal Industries and a great problem of its disposal as well as environmental pollution would be solved.
7. It can be concluded that fly ash can be used as an effective additive for improving the physical properties of cohesive soils and it's suggested as low cost construction.

REFERENCES

1. S. and S. Mittal, Soil Testing for Engineers. Khanna Publishers, New Delhi, 2001.
2. Gulhati and Datta, Geotechnical Engineering. Tata MacGraw Hill Publications, New Delhi
3. M. H. Dr.Parker, AL Seyfferth, "Effect of common Soil anions and pH on the uptake and accumulation of perchlorate in lettice," Springer, vol. 302, pp. 139–148, 2008.
4. J. B. Oza and P. J. Gundaliya, "Study of Black Cotton Soil Characteristics with Cement Waste Dust and Lime," Procedia Eng., vol. 51, pp. 110–118, 2013, DOI: 10.1016/j.proeng.2013.01.017
5. K. Juwonlo Osinubi, "Stabilisation of Tropical Black Clay with Cement and Pulverised Coal Bottom Ash Admixture," in Advances in Unsaturated Geotechnics, Jul. 2000, pp. 289–302, DOI: 10.1061/40510(287)20.
6. T. Saravut J. Opas, S. and Pichai, "An investigation of lateritic Soil Cement for Sustainable Pavements," Indian J. Sci. Technol., vol. 5, 2012.
7. A. A. Araya, "Characterization of Unbound Granular Materials for Pavements," 2011.
8. J. James and P. Pandian, "A study on the early UCC strength of stabilized soil admixed with industrial waste materials," Int. J. Earth Sci. Eng., vol. 7, pp. 1055–1063, 2014.
9. C. Rajakumar and T. Meenambal, "Experimental Study on Utilization of Bottom Ash to Stabilize Expansive Soil Subgrades," 2015. Accessed: Feb. 17, 2019. [Online]. Available: http://sphinxsai.com/2015/ch_vol8_no3/1/(997-1005)V8N3.pdf.
10. V. Kaushal and S. Guleria, "Geotechnical Investigation of Black Cotton Soils," Int. J. Adv. Eng. Sci., vol. 5, 2015.

11. Recommended Practice for Stabilization of Subgrade Soils and Base Materials **National Cooperative Highway Research Program** **Dallas N. Little, Syam Nair** **Texas Transportation Institute, Texas A&M University College Station, Texas.**
12. WSDOT Research Report ,INTERPRETATION OF GEOTECHNICAL PROPERTIES OF CEMENT TREATED SOILS, Balasingam Muhunthan , Farid Sariosseiri, July 2008
13. Little, D. N., Males, E. H., Prusinski, J. R., and Stewart, B. (2000). Cementitious stabilization, Transportation in the New Millennium: State of the Art and Future Directions, Perspectives from Transportation Research Board Standing Committees.
14. White, W. G. and Gnanendran, C. T. (2005). "The influence of compaction method and density on the strength and modulus of cementitiously stabilized pavement material." The International Journal of Pavement Engineering, 6(2), 97-110.
15. Das, B. M. (1990). Principle of foundation engineering, PWS-KENT publishing company, Boston.
16. GRIFFIN, J. (1978) Guide to Stabilisation in Roadworks. NAASRA/ARRB Workshop on Stabilisation, held at Dept of Main Roads, New South Wales, April 1978.
17. Natt, G. S., and Joshi, R. C. 1984. "Properties of cement and lime-fly ash stabilized aggregate." Transportation Research Record 998, Transportation Research Board, Washington, D.C., 32–40
18. Hausmann, M. R. (1990). Engineering principles of ground modification. McGraw-Hill, New York.
19. Mirsa, A. (1998). Stabilization Characteristics of Clays Using Class C Fly Ash. Transportation Research Record 1611. 98-1025.
20. Cokca, E. Use of Class C fly ashes for the stabilization of an expansive soil (2001). Journal of Geotechnical and Geo environmental Engineering, 127(7), 568-573.
21. Phani Kumar, B. R., & Sharma, R. S. (2004). Effect of Fly Ash on Engineering Properties of Expansive Soils. Journal of Geotechnical and Geoenvironmental Engineering, 130(7), 764- 767.
22. Nalbantoglu, Z. (2004). Effectiveness of Class C fly ash as an expansive soil stabilizer.Construction and Building Materials, 18, 377–381.
23. Prabakara, J., Dendorkarb, N., & Morchhalec R.K. (2004). Influence of fly ash on strength behavior of typical soils. Construction and Building Materials, 18, 263–267.

24. Kate JM (2005) Strength and volume change behaviour of expansive soils treated with fly ash. Geo Frontiers 2005, ASCE, Geotechnical Special Publication.
25. Misra, A., Biswas, D., & Upadhyaya, S. (2005). Physico-mechanical behavior of self- cementing class C fly ash–clay mixtures. Fuel, 84, 1410–1422.
26. Parsons, R.L., & Kneebone, E. (2005). Field performance of fly ash stabilised subgrades. Ground Improvement, 9(1), 33–38.
27. Amo, O.O., Fajobi, A.B., & Afekhuai, S.O. (2005). Stabilizing potential of cement and fly ash mixture on expansive clay soil. Journal of Applied Sciences, 5(9), 1669-1673
28. T.B. Edil, H.A. Acosta & C.H. Benson. (2006). Stabilizing Soft Fine-Grained Soils with Fly Ash. Journal of Materials in Civil Engineering, 18(2), 283-294.
29. Senol, A., Edil, T.B., Shafique, Md.S.B., Acosta, H.A., & Benson, C.H. (2006). Soft subgrades stabilization by using various fly ashes. Resources, Conservation and Recycling, 46, 365–376.
30. Sezer, A., Inan, G., Yılmaz, H.R., & Ramyar, K. (2006). Utilization of a very high lime fly ash for improvement of Izmir clay. Building and Environment, 41, 150–155
31. Phani Kumar, B. R., & Sharma, R. S. (2007). Volume change behavior of fly ash-stabilized Journal of Materials in Civil Engineering, 19(1), 67–74.
32. Vizcarra1, G.O.C., Casagrande, M.D.T., & da Motta, L.M.G. (2014). Applicability of municipal solid waste incineration ash on base layers of pavements. Journal of Materials in Civil Engineering.
33. Athanasopoulou, A. (2014). Addition of lime and fly ash to improve highway subgrade soils. Journal of Materials in Civil Engineering, 26(4), 773-775.