Stabilization of Gravelly Soil Using Cationic Bitumen Emulsion and Cement for Enhanced Subgrade Strength

Dr. T, Kiran Kumar[1], Dhupam Sonika [2]
[1]Department of Civil Engineering St. Ann's College of Engineering & Technology, Chirala
[2]Professor, Department of Civil Engineering St. Ann's College of Engineering & Technology, Chirala

Abstract—**Soil, being one of the most abundant natural construction materials, forms the foundation for nearly all types of civil engineering structures. In road construction, the performance of a pavement system is largely governed by the strength of the subgrade soil. Weak subgrade conditions necessitate stabilization or replacement to enhance load-bearing capacity and overall pavement durability.**

Improvement in subgrade strength can significantly reduce pavement thickness, thereby resulting in economic benefits. Conventional stabilizing agents such as cement, lime, fly ash, and fibers are widely used for this purpose. This experimental study focuses on improving the engineering properties of gravelly soil through the incorporation of bitumen emulsion. The primary objective is to enhance subgrade strength, evaluated in terms of California Bearing Ratio (CBR), using cationic bitumen emulsion (CMS). A small percentage of cement is also introduced as a filler material to further improve the binding characteristics and strength performance of the soil matrix. The investigation includes detailed laboratory testing to determine the basic properties of soil, compaction characteristics, and strength behaviour under varying mix proportions. Different combinations of gravel soil, CMS bitumen emulsion, and cement were analysed to study their influence on maximum dry density and CBR values. The results indicate that the inclusion of cationic bitumen emulsion, in conjunction with a minimal quantity of cement, significantly enhances the strength properties of gravelly soil. Optimal mix conditions were identified, demonstrating the potential of this stabilization technique as an economical and effective solution for subgrade improvement.

Index Terms—**Gravelly soil, Soil stabilization, Cationic bitumen emulsion, Cement stabilization, California Bearing Ratio, Subgrade strength, Pavement engineering, Compaction characteristics, Bituminous stabilization, Geotechnical improvement.**

I. INTRODUCTION

Subgrade soil plays a vital role in determining the structural performance and service life of pavement systems. The strength and stability of the subgrade directly influence the load distribution characteristics and thickness requirements of pavement layers. Weak and poorly graded soils often exhibit low bearing capacity, excessive deformation, and poor resistance against moisture variations, which may lead to premature pavement failures such as rutting, cracking, and settlement. In highway engineering, stabilization techniques are commonly adopted to improve the engineering properties of weak soils and to enhance their suitability for pavement construction. Conventional stabilizing agents such as cement, lime, fly ash, and chemical additives have been extensively utilized for increasing the California Bearing Ratio (CBR), improving compaction characteristics, and reducing moisture susceptibility. Among these methods, bituminous stabilization has gained increasing attention because of its ability to improve cohesion, water resistance, and flexibility within soil matrices (Ingles and Metcalf, 1972; Sherwood, 1993). Bitumen emulsions are particularly suitable for soil stabilization because they can be mixed with moist aggregates at ambient temperatures without requiring heating. Cationic bitumen emulsions exhibit strong adhesion properties due to their positive charge, which enhances bonding with negatively charged soil particles. When combined with small quantities of cement, the stabilization process produces a dense and durable soil structure capable of resisting moisture infiltration and repeated loading. Cement acts as a filler and hydraulic binder, while the bitumen emulsion improves flexibility and waterproofing

characteristics. Previous investigations reported that the combined use of bitumen emulsion and cement significantly improves Maximum Dry Density (MDD), Optimum Moisture Content (OMC), unconfined compressive strength, and CBR values of granular and gravelly soils. Despite the promising performance of bitumen stabilized soils, limited research has focused on the stabilization behaviour of gravelly soils using cationic bitumen emulsion and cement under varying mix proportions. Therefore, the present study investigates the influence of CMS bitumen emulsion and cement on the compaction and strength characteristics of gravelly soil intended for subgrade applications (Little and Nair, 2009; Reddy and Reddy, 2010; IRC: SP:89-2010).

II. MATERIALS AND METHODS

The gravelly soil used in the present investigation was collected from a local borrow area intended for road construction purposes. The collected soil was air dried and sieved to remove oversized particles before laboratory testing. Preliminary index tests including grain size distribution, specific gravity, Atterberg limits, and compaction tests were conducted according to relevant IS standards. Cationic bitumen emulsion of CMS grade was selected as the primary stabilizing agent because of its superior adhesion and coating properties. Ordinary Portland Cement of 43 grade was incorporated in small percentages as a filler material to enhance the binding and strength characteristics of the stabilized soil matrix.

Different combinations of gravelly soil, CMS bitumen emulsion, and cement were prepared to evaluate their influence on Maximum Dry Density and California Bearing Ratio values. Bitumen emulsion content was varied from 2% to 8% by weight of dry soil, while cement content ranged from 1% to 4%. Modified Proctor compaction tests were conducted to determine Optimum Moisture Content and Maximum Dry Density for each mix proportion. California Bearing Ratio tests were performed on soaked specimens after curing to assess subgrade strength characteristics. The laboratory results were analysed to identify the optimum mix combination capable of providing maximum strength improvement and compaction efficiency for pavement subgrade applications.

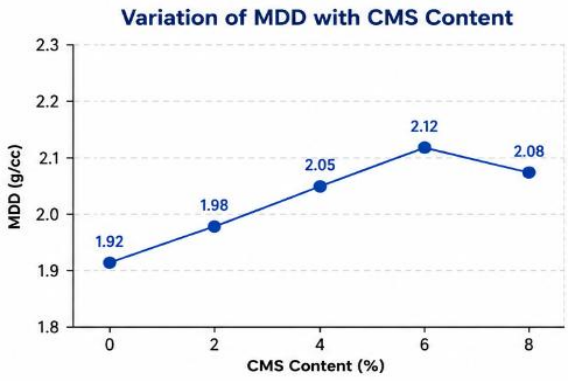
III. RESULTS AND DISCUSSION

The incorporation of cationic bitumen emulsion and cement significantly influenced the compaction characteristics of gravelly soil. Initially, the addition of bitumen emulsion increased the Maximum Dry Density because of improved particle lubrication and better packing efficiency. However, excessive emulsion content resulted in a slight reduction in density due to increased coating thickness around soil particles. Cement addition further enhanced compaction characteristics by filling voids and promoting stronger interparticle bonding within the soil matrix.

Table 1. Compaction Characteristics of Stabilized Gravelly Soil

CMS Content (%)	Cement Content (%)	MDD (g/cc)	OMC (%)
0	0	1.92	8.4
2	1	1.98	8.1
4	2	2.05	7.8
6	3	2.12	7.5
8	4	2.08	7.7

The results indicate that the optimum compaction characteristics were achieved at 6% CMS and 3% cement content, where the Maximum Dry Density reached 2.12 g/cc. The reduction in Optimum Moisture Content with increasing stabilizer content can be attributed to the lubricating effect of bitumen emulsion and improved particle rearrangement during compaction.

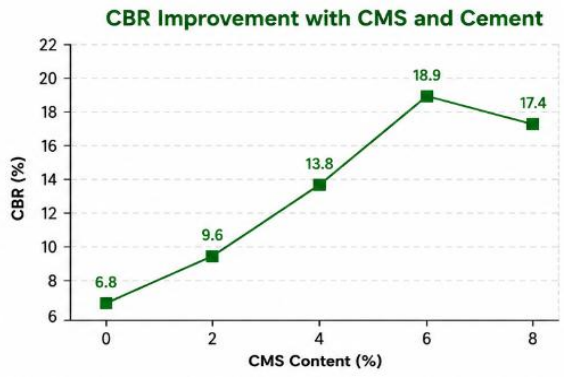


California Bearing Ratio values increased substantially with the incorporation of cationic bitumen emulsion and cement. The untreated gravelly soil exhibited relatively low bearing capacity because of poor particle bonding and moisture sensitivity. The addition of CMS improved cohesion and waterproofing properties, while cement contributed to the formation of stronger cementitious bonds. The combined stabilization mechanism resulted in a denser and more stable soil structure capable of resisting penetration and deformation under loading conditions.

Table 2. CBR Values of Stabilized Gravelly Soil

CMS Content (%)	Cement Content (%)	Soaked CBR (%)
0	0	6.8
2	1	9.6
4	2	13.8
6	3	18.9
8	4	17.4

The highest soaked CBR value of 18.9% was observed for the mix containing 6% CMS and 3% cement. Beyond this optimum dosage, a slight reduction in CBR was observed because of excessive bitumen coating, which reduced frictional resistance between soil particles. The stabilized mixes exhibited improved resistance against moisture penetration and maintained structural integrity under soaked conditions.

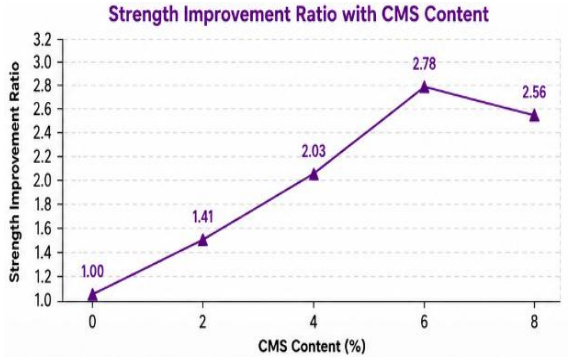


The interaction between cationic bitumen emulsion and cement significantly improved the overall stability and durability characteristics of the gravelly soil. Cement hydration products enhanced particle interlocking and rigidity, while the bitumen emulsion formed a flexible waterproof coating around soil particles. This dual stabilization mechanism reduced moisture susceptibility and improved resistance against repeated traffic loading. The improved subgrade strength can effectively reduce pavement thickness requirements, leading to considerable savings in construction costs.

Table 3. Strength Improvement Ratio of Stabilized Soil

CMS Content (%)	Strength Improvement Ratio
0	1.00
2	1.41
4	2.03
6	2.78
8	2.56

The stabilized soil mixes demonstrated excellent suitability for pavement subgrade applications because of their improved load bearing capacity and compaction efficiency. The findings are consistent with previous studies reporting the beneficial effects of bituminous stabilization in granular soils. The combination of cationic bitumen emulsion and cement provides a practical and economic stabilization approach for rural and low volume road construction projects.



IV. CONCLUSION

The present investigation demonstrates that the stabilization of gravelly soil using cationic bitumen emulsion and cement significantly improves subgrade strength and compaction characteristics. The inclusion of CMS enhanced cohesion, waterproofing behaviour, and particle bonding, while cement contributed to improved rigidity and structural integrity of the

stabilized soil matrix. Maximum Dry Density increased and Optimum Moisture Content decreased with increasing stabilizer content up to the optimum level. The highest soaked California Bearing Ratio value of 18.9% was achieved at 6% CMS and 3% cement content, indicating substantial improvement in load bearing capacity compared to untreated soil. Beyond the optimum dosage, excessive bitumen coating slightly reduced strength characteristics because of lower frictional resistance. The stabilized mixes exhibited improved resistance against moisture susceptibility and deformation under loading conditions. The study confirms that the combined use of cationic bitumen emulsion and cement provides an economical, durable, and effective solution for enhancing gravelly soil performance in pavement subgrade applications.

REFERENCES

[1] Ingles, O. G., and Metcalf, J. B. (1972). Soil Stabilization Principles and Practice. Butterworths, Sydney.
[2] IRC: SP:89-2010. Guidelines for Soil and Granular Material Stabilization Using Cement, Lime and Fly Ash. Indian Roads Congress, New Delhi.
[3] IS 2720 Part 16. (1987). Laboratory Determination of CBR. Bureau of Indian Standards, New Delhi.
[4] IS 2720. (1985). Methods of Test for Soils. Bureau of Indian Standards, New Delhi.
[5] Little, D. N., and Nair, S. (2009). Recommended practice for stabilization of subgrade soils and base materials. National Cooperative Highway Research Program, Report 144.
[6] Reddy, K. R., and Reddy, M. A. (2010). Utilization of bitumen emulsion in soil stabilization for road construction. International Journal of Engineering Science and Technology, 2(9), 4564–4571.
[7] Sherwood, P. T. (1993). Soil Stabilization with Cement and Lime. Transport Research Laboratory, HMSO, London.