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Railway Track Substructure: Recent Research and Future Directions

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Abstract- Railway transportation is one of the most important modes of transport for both passengers and goods, and its performance largely depends on the strength and stability of the track substructure. The substructure, which consists of ballast, sub-ballast, and subgrade, plays a vital role in distributing loads and maintaining track alignment under repeated loading conditions. In recent years, increasing axle loads, high-speed trains, and environmental concerns have created the need for improving the performance of railway track substructure using sustainable materials. This study focuses on the use of recycled and waste materials such as fly ash, construction and demolition (C&D) waste, plastic waste, and rubber waste to enhance the engineering properties of subgrade soil. An experimental investigation was carried out by preparing different soil mixes with varying proportions of these materials. Various laboratory tests including Atterberg limits, standard Proctor compaction test, California Bearing Ratio (CBR) test, permeability test, and direct shear test were conducted to evaluate the behavior of both natural and modified soil. The results indicate that the addition of recycled materials significantly improves soil properties. The plasticity index of soil decreases, which reduces swelling and shrinkage behavior. The maximum dry density increases while optimum moisture content decreases, indicating better compaction characteristics. The CBR value increases considerably, showing enhanced load-bearing capacity suitable for railway applications. The permeability of soil improves, ensuring better drainage, and shear strength parameters such as cohesion and angle of internal friction also increase, indicating improved stability. Among all the mixes, the combination of all materials shows the best performance in terms of strength, compaction, and drainage characteristics. The study concludes that recycled materials can effectively be used in railway track substructure to improve performance, reduce construction cost, and promote sustainable development. The findings of this study can be useful for engineers and researchers in developing eco-friendly and durable railway infrastructure systems.

Keywords: Railway Track, Ballast, Substructure, Sustainable Materials, Recycled Materials, Geosynthetics.

I. INTRODUCTION

Railway transportation is one of the most important and widely used modes of transport not only in India but also across the entire world, and it plays a very significant role in the overall development of a nation by supporting economic growth, industrial expansion, urbanization, and social connectivity between different regions. It is considered one of the most efficient, economical, and sustainable means of transportation, especially for long-distance travel and bulk goods movement, as it consumes less fuel compared to road transport, reduces traffic congestion, and provides a safer and more reliable system for both passengers and freight. In a developing country like India, where population density is high and transportation demand is continuously increasing, the railway network acts as the backbone of the transportation system by connecting rural areas to urban centers, facilitating trade and commerce, and supporting national integration. The continuous growth in railway infrastructure, introduction of high-speed trains, and increase in axle loads have further increased the importance of maintaining a strong and stable railway track system. A railway track system is a complex engineering structure that is designed to withstand repeated heavy loads under varying environmental conditions, and it is broadly divided into two main components, namely the superstructure and the substructure, both of which work together to ensure safe and smooth train operation. The superstructure consists of rails, sleepers, and fastening systems, which are directly responsible for carrying and transferring the loads imposed by moving trains. Rails provide a smooth-running surface for train wheels, sleepers maintain the correct gauge and alignment of rails, and fastenings hold the rails firmly in position. However, the efficiency and performance of the superstructure largely depend on the strength and stability of the underlying substructure, which acts as the foundation of the entire railway track system. The substructure includes ballast, sub-ballast, and subgrade layers, each having a specific function in supporting the loads transmitted from the superstructure and distributing them safely to the natural ground.

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The ballast layer, made of coarse granular materials such as crushed stones, helps in load distribution, drainage, and maintaining track alignment, while the sub-ballast layer acts as an intermediate layer that prevents the mixing of ballast with the underlying soil and provides additional strength and filtration. The subgrade, which is the natural soil layer at the bottom, ultimately bears the load and must possess adequate strength and stability to avoid excessive deformation. The proper functioning of these layers is very important because any weakness in the substructure can directly affect the performance of the entire track system. The performance, durability, and safety of railway tracks depend heavily on the condition and quality of the substructure, as it is continuously subjected to dynamic loads, vibrations, and environmental effects such as moisture variation, temperature changes, and repeated loading cycles. If the substructure is not properly designed or maintained, it can lead to various problems such as excessive settlement, track deformation, ballast fouling, poor drainage, and loss of track geometry, which ultimately increase maintenance costs and may lead to unsafe conditions. In modern railway engineering, where higher speeds and heavier loads are becoming common, the demand for a stronger and more durable substructure has increased significantly. Therefore, it becomes essential to study and improve the substructure using advanced materials and innovative techniques. In recent years, due to the depletion of natural resources and increasing environmental concerns, there has been a growing interest in the use of recycled and waste materials in railway construction, especially in the substructure layers. The use of materials such as fly ash, construction and demolition waste, plastic waste, and rubber waste not only helps in improving engineering properties but also promotes sustainable development by reducing environmental pollution and conserving natural resources. Hence, understanding the behavior of railway track substructure and exploring new materials for its improvement has become a major area of research in transportation engineering, which forms the basis of this study.

II. RESEARCH METHODOLOGY

Materials Used:
In this study, both conventional and recycled materials were used to prepare different mixes for experimental analysis. The materials selected are commonly available and suitable for railway engineering applications.

Natural Soil (Subgrade Material):
Natural soil was used as the base material representing subgrade conditions. The soil was collected from a nearby site and tested for its engineering properties. The soil mainly consisted of clay and silt particles with moderate plasticity. It was air-dried, pulverized, and sieved before testing.

Fly Ash:
Fly ash is a by-product obtained from thermal power plants. It is a fine powdery material and is widely used in soil stabilization due to its pozzolanic properties. It improves strength and reduces plasticity.

Construction and Demolition (C&D) Waste:
C&D waste includes broken concrete, bricks, and aggregates obtained from demolished structures. It was crushed and processed before use.

Plastic Waste:
Plastic waste was collected, cleaned, and shredded into small pieces. It was used in small proportions to enhance durability and reduce permeability.

Rubber Waste (Crumb Rubber):
Rubber waste was obtained from used tyres and converted into crumb form. It improves flexibility and shock absorption properties.

Geosynthetics (Geotextile):
Geotextiles were used as reinforcing material to improve strength and separation between layers.

Mix Proportions: Different combinations of materials were prepared to study their behavior. The percentage of recycled materials was varied to find the optimum mix.

Table 3.1: Mix Proportions

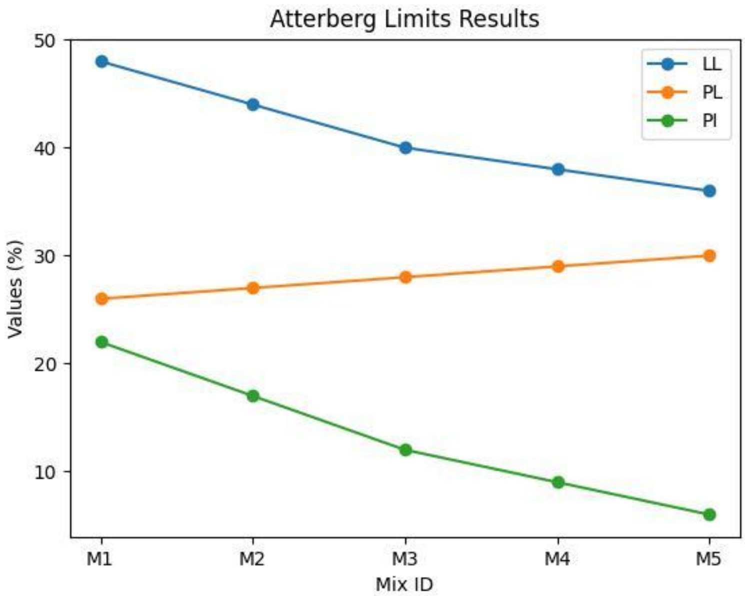
Mix ID	Fly Ash (%)	C&D Waste (%)	Plastic (%)	Rubber (%)
M1	0	0	0	0
M2	10	0	0	0
M3	15	10	0	0
M4	20	15	1	0
M5	15	20	1	2

III. RESULTS AND DISCUSSION

Atterberg Limits Results:

Table 4.1: Atterberg Limits Results

Mix ID	Liquid Limit (LL %)	Plastic Limit (PL %)	Plasticity Index (PI %)
M1 (Natural Soil)	48	26	22
M2 (+ Fly Ash 10%)	44	27	17
M3 (+ FA + C&D)	40	28	12
M4 (+ FA + C&D + Plastic)	38	29	9
M5 (+ All Materials)	36	30	6



Graph 4.1: Atterberg Limits Results

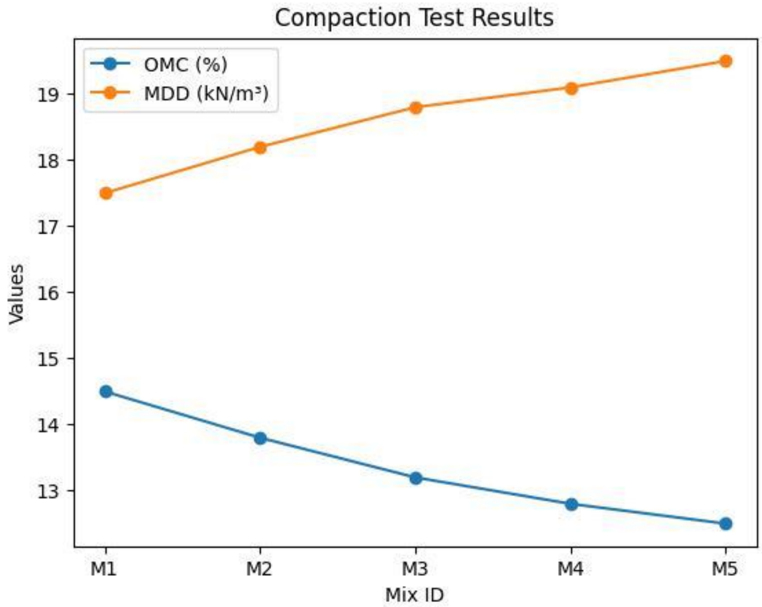
Discussion:

- Plasticity Index decreases with addition of recycled materials.
- Fly ash reduces soil plasticity significantly.
- Addition of plastic and rubber further improves soil behavior.
- Lower PI indicates reduced swelling and shrinkage.
- Modified soil becomes more stable and suitable for subgrade.

Compaction Test Results:

Table 4.2: Compaction Test Results

Mix ID	Optimum Moisture Content (OMC %)	Maximum Dry Density (MDD kN/m³)
M1	14.5	17.5
M2	13.8	18.2
M3	13.2	18.8
M4	12.8	19.1
M5	12.5	19.5



Graph 4.2: Compaction Test Results

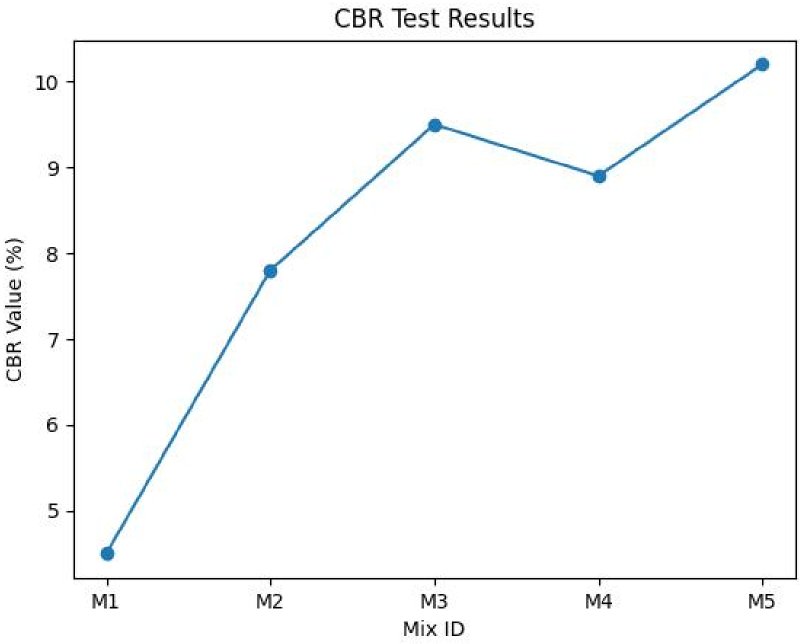
Discussion:

- MDD increases with addition of recycled materials.
- OMC decreases due to better gradation and packing.
- C&D waste improves compaction significantly.
- Plastic reduces water absorption.
- Modified soil shows better density and strength.

CBR Test Results:

Table 4.3: CBR Results

Mix ID	CBR Value (%)
M1	4.5
M2	7.8
M3	9.5
M4	8.9
M5	10.2



Graph 4.3: CBR Results

Discussion:

- CBR value increases with addition of recycled materials.
- C&D waste shows maximum improvement in strength.
- Rubber provides flexibility and reduces cracking.
- Highest CBR observed in M5 mix.
- Improved CBR indicates better load-bearing capacity.

Permeability Test Results:

Table 4.4: Permeability Results

Mix ID	Coefficient of Permeability (cm/sec)
M1	1.2×10^{-5}
M2	1.8×10^{-5}
M3	2.5×10^{-5}
M4	2.2×10^{-5}
M5	2.8×10^{-5}

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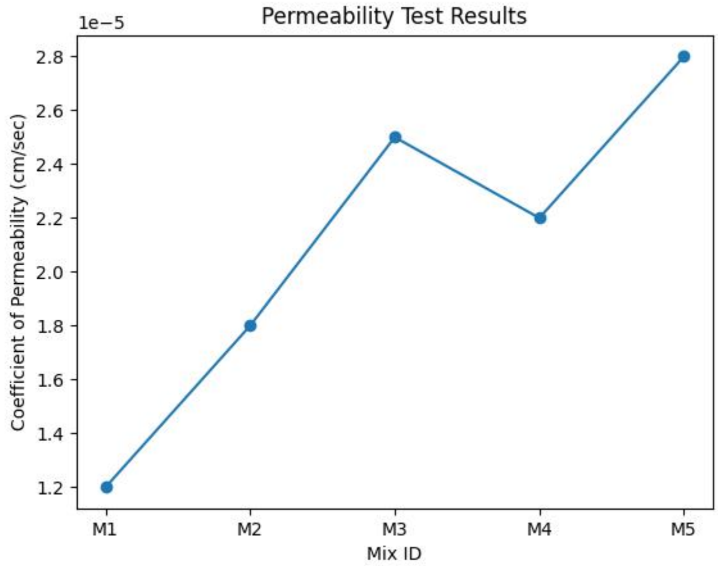
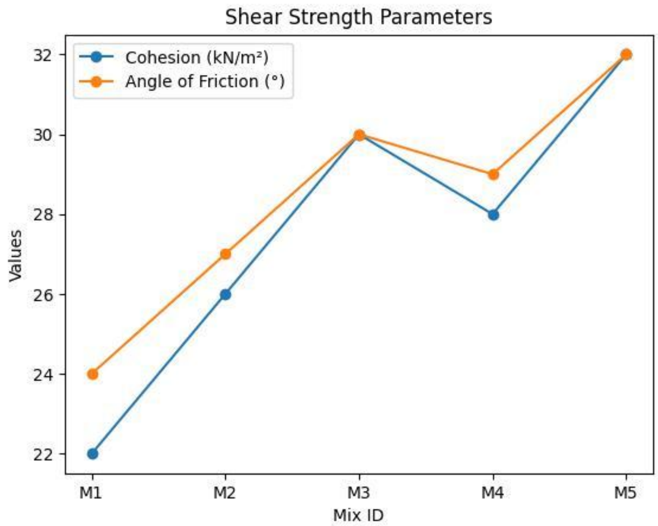


Graph 4.4: Permeability Results

Direct Shear Test Results:

Table 4.5: Shear Strength Parameters

Mix ID	Cohesion (c kN/m²)	Angle of Friction (φ°)
M1	22	24
M2	26	27
M3	30	30
M4	28	29
M5	32	32



Graph 4.5: Shear Strength Parameters

Discussion:

- Shear strength increases with recycled materials.
- Cohesion and friction angle both improve.
- C&D waste and fly ash enhance bonding.
- Rubber increases flexibility under load.
- M5 shows highest strength and stability.

CONCLUSION

The use of recycled materials significantly improves the engineering properties of soil used in railway substructure. The plasticity index (PI) of soil decreases with the addition of fly ash and other materials, which indicates reduced swelling and shrinkage behavior. The maximum dry density (MDD) increases and optimum moisture content (OMC) decreases, showing better compaction characteristics of modified soil. The California Bearing Ratio (CBR) value increases considerably, indicating improved load-bearing capacity and suitability for railway subgrade. The permeability of soil improves with the addition of coarse materials like C&D waste, which enhances drainage properties and reduces water-related problems. The shear strength parameters such as cohesion (c) and angle of internal friction (φ) increase, which indicates better stability and resistance to failure. Among all mixes, the combination of all materials (M5) shows the best performance in terms of strength, compaction, and drainage. The use of plastic and rubber waste improves flexibility and reduces the chances of cracking under repeated loading. Recycled materials can effectively replace conventional materials in railway substructure without compromising performance.

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