9.7 A CURRENT STUDY ON BALLASTED RAIL TRACKS IN SRI LANKA

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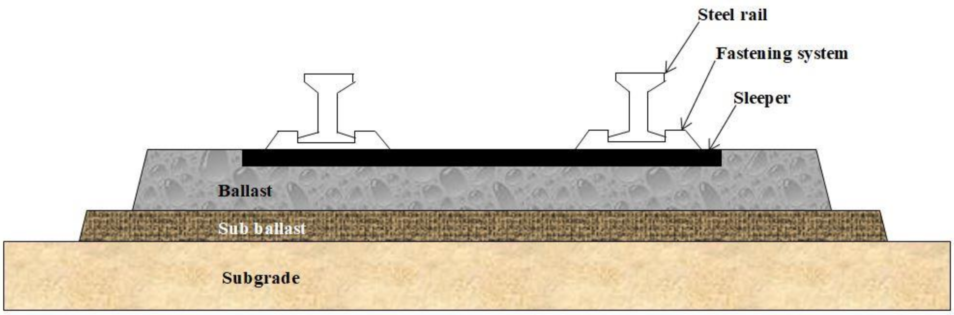
1. Introduction

Rail transport was introduced in Sri Lanka in the early 1860s for transporting coffee from estates to the port. Sri Lanka Railways (SLR) is the only rail transport organization in Sri Lanka which was established in 1864 under the name of Ceylon Government Railway. The total route length of ten main lines and three spur lines is 1,607 km. The track gauge is 1676 mm and the sleeper length is 2790 mm. Generally, rail tracks are made of either using ballast or concrete. The initial construction cost for slab tracks is much higher than that for ballasted tracks. Most of the tracks in Sri Lanka are also ballasted rail tracks. The primary components in ballasted tracks are steel rail, concrete or timber sleeper, fastening system, ballast layer, sub-ballast layer, and compacted subgrade (See Figure 1(a) and (b)). The ballast layer is the largest layer by volume and weight. Ballast is a coarse granular material with various-sized particles, highly angular corners, high bearing capacity, a large number of voids, and superlative resiliency. Sub-ballast is commonly a mixture of broadly graded sand and gravel. Ballast particles are obtained by crushing and blasting parent rocks such as basalt, gneiss, dolomite, granite, graphite, and so on. Commonly in Sri Lanka, ballast material is obtained from biotite gneiss. Ballast absorbs the loads and vibration exerted by moving trains and transmits and distributes it to underlying layers in a wide area at an acceptable level. It also acts as a level and hard bed for sleepers and holds sleepers in place. The ballast layer holds the rail track in position by giving longitudinal and transverse stability and makes small alterations in the level and the alignment of the track. It drains the rainwater instantly through its interconnected larger voids, also hindering the growth of vegetation in tracks.



(a)

(b)

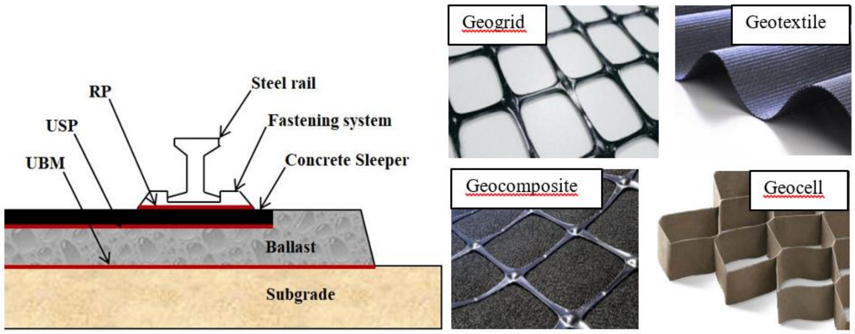
Figure 1: Components of a ballasted rail track shown in a (a) schematic diagram; (b) photograph

2. Ballast degradation and remedial actions

The ballast layer undergoes deterioration with time under recurring cyclic and impact loadings due to less confinement and its highly angular corners. Accordingly, the service lifespan of rail track reduces as differential settlement and fouling result from ballast deterioration. Aggregates become rounded as the corners continuously get broken, thus reducing particle interlocking of the ballast layer. This leads to excessive total and differential settlement hence discomfort and safety issues in train transport. Ballast fouling is a phenomenon where the voids in the ballast layer are partially or fully filled with foreign materials such as sand, coal, silt, dust, clay, and by its own degradation. Ballast fouling reduces permeability, decreases the energy-absorbing capacity, and leads to vegetation growth, therefore affecting the track function and its longevity. This track deterioration forces regular monitoring and high-cost maintenance activities such as ballast tamping and stone blowing.

To overcome these issues, the application of artificial inclusions such as energy-absorbing rubber elements namely rail pads (RPs) under sleeper pads (USPs) and under ballast mats (UBMs), and geosynthetics such as geogrids, geotextile, geocomposite, and geocell is an established practice in many countries. Figure 2(a) shows the insertion locations of rubber elements and Figure 2(b) shows the different types of geosynthetics used in railway applications.

RP disconnects the direct contact between the rail and the concrete sleeper and acts as a resilient fastener. USP increases the contact area between the sleeper and ballast. This leads to a significant reduction of the stress on the ballast layer. Sleepers with USPs also improve the lateral resistance of the track. UBM is used in slab tracks where the ballast layer is laid on top of the concrete slab. UBM acts as a soft bed to the ballast layer and reduces the ballast breakage. Manufacturing these rubber elements using end-of-life tyres reduces the amount of waste rubber that goes into the spoil tip while giving a significant advantage in improving the track performance. Merits of geosynthetics are the provision of economical and sustainable solutions for critical problems, machinery is not necessary for the installation, and unskilled labor can be employed. Geogrids are flexible, tensile elements that are strong in tension. When geogrids are inserted into the ballast layer, it mechanically interlocks ballast aggregates into its open apertures and provides lateral support by resisting the free movement of distinct particles. Geotextile acts as a separation and filtration layer in the rail track application. It is normally placed at the interface of the subgrade and granular layer. Geocomposite is a combination layer where geogrid is bonded with geotextile. It functions as a reinforcement layer and as a separation layer simultaneously. Geocells are cellular geosynthetics and are laid inside the sub-ballast or subgrade layer.



(a) (b)

Figure 2: (a) Different types of rubber elements used in rail tracks; (b) Various types of geosynthetics

3. Large-scale testing facilities

Strength, deformation, and drainage properties of fine-grained materials can be obtained by conducting standard direct shear, triaxial, and permeability tests. But the sizes of ballast particles used in rail tracks range from about 20 - 65 mm. Therefore, the load-bearing capacity of ballast and its stress, degradation, and drainage characteristics can be effectively studied using large-scale testing. Figure 3 illustrates the large-scale testing facilities designed and designated at the Department of Civil Engineering, University of Peradeniya.

The large-scale direct shear test apparatus (Figure 3(a)) is used to study the shear, dilation, and breakage behavior of rail track ballast under shearing. It has a circular shear plane and it can accommodate a cylindrical test specimen of 400 mm diameter and 300 mm height. The shear plane is kept at the middle by separating the specimen into two equal halves. The vertical load is applied using a static lever arm technique and shearing is applied using a hydraulic jack. A data logger is used to obtain the results digitally using two Linear Variable Displacement Transducers (LVDTs) and a load cell.

The large-scale constant head permeability test apparatus (Figure 3(b)) is used to study the permeability behavior of fresh and fouled ballast. The cylindrical chamber has dimensions of 400 mm diameter and 1000 mm height. The gap between the piezometer outlets is 400 mm. The constant head tank has a capacity of 500 liters.

The large-scale cyclic test apparatus (Figure 3(c)) is used to study the stress-strain and degradation behavior of ballast under cyclic loading. A ballast box was designed and built to represent the unit cell of Sri Lankan rail track. A servo-hydraulic dynamic actuator with a dynamic load capacity of 100 kN and 25 Hz frequency was purchased and installed at a heavy-duty steel frame.

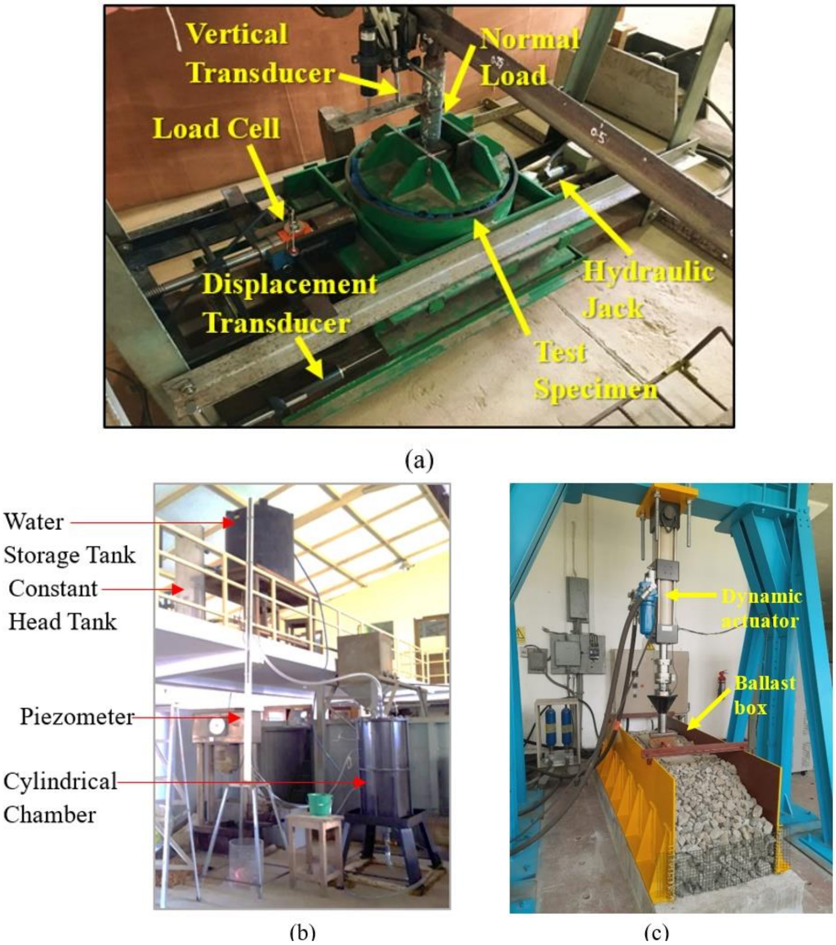


Figure 3: (a) Large-scale direct shear test apparatus; (b) Large-scale permeability test apparatus; (c) Large-scale cyclic load test apparatus

4. Numerical Analysis

A high amount of ballast materials are consumed and it is labor-intensive work when conducting large-scale laboratory tests to study the shear, degradation, and permeability behavior of ballast. In recent years, numerical studies are adopted by many researchers to reduce the usage of human resources and materials. And also, numerical studies enable extended analysis through conducting a parametric study using the validated model. The common types of numerical approaches are the Finite Element Method (FEM) and the Discrete Element Method (DEM). FEM is a continuum numerical method that has domains with boundary conditions whereas DEM is a discrete approach that analyses the macroscopic behavior of the system from individual particle interactions. DEM is more suitable to analyze the mechanical behavior of granular discrete particles by incorporating their shapes and sizes preciously. So using these distinct approaches, the above-mentioned large-scale testing facilities can be modeled and models can be calibrated and validated using the laboratory results. Then, validated models can be used to conduct a parametric study to predict the behavior of ballast under various loading, materials, and type of artificial inclusions conditions.

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