Curing of subgrade problems in railway tracks

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In the last few years the development of new methods to cure subgrade problems in a railway track has accelerated. Qualitatively and quantitatively increased demands in regard to functional efficiency, operational reliability, as well as a longer trouble-free service life of a railway system have in many cases also compelled the use of new materials. Among these, geotechnical fabrics always play an important role. This paper deals with the analysis of the railway subgrade problems and addresses new remedial techniques to solve such problems.
مازالت عمليات التطور فى طرق علاج أساس السكة بالسكك الحديدية مستمرة، فبسبب زيادة الطلب -كما ونوعا- على النقل بالسكك الحديدية، وبغرض زيادة الطاقة الإنتاجية وتجنب عوائق التشغيل لهذا النوع من النقل، تم البحث عن مواد جديدة لعلاج وتقوية هذا النوع من الأساسات. ومن بين هذه المواد Geotechnical Fabric والتى تلعب دورا أساسيا فى هذا المجال. ولذلك فإن هذا البحث يهدف بصورة أساسية الى تحليل مشاكل أساس السكة بالسكك الحديدية، وتحديد استعمالات هذه المواد فى علاج المشاكل المناسبة لها.

Keywords: Subgrade Problems, Geotechnical Fabrics, Geogrids, Paved Track.

1. Introduction

While the most-visible portions of the track structure (rail, ties, and ballast) often receive the most attention, the subgrade represents a major source of both short- and long-term track maintenance problems, and can not be ignored. The subgrade usually consists of original or fill material located beneath the track structure, ballast and subballast. Many researches indicate that the significant portion of poor track performance is caused by subgrade problems. Also, ballast problems are often interrelated and closely associated with subgrade problems. However, they often make problems at the subgrade level.

This paper is divided into three major sections. The first section identifies and analyzes the main subgrade problems. The second section presents and analyzes the factors affecting these problems. The final section addresses new remedial technique to cure such subgrade problems.

2. Subgrade problems

The Subgrade is permanently subjected to various static and dynamic loads. At the same time, it is subjected to variations of temperature and humidity, infiltration effect, evaporation effect, and the effect of ground water level change. All these factors can result the subgrade degradation and track instability. The major subgrade problems may be classified into:

- Subgrade erosion ,
- Rapid ballast settlement rate,
- Subgrade stability problems, (sliding, distortion of the slopes of the embankments),
- Progressive shear failures (subgrade squeeze),
- Subgrade surface subsidence,
- Subgrade spots,
- Liquefaction,
- Swelling and shrinkage, and
- Soil collapse.

Table 1 Main subgrade problems and their characteristics.

Type	Causes	Characteristics
Subgrade erosion.	• Repeated over stresses. • Fine-grained soil. • High water content.	• Depression under ties. • Heaves in crib and/or shoulder.
Rapid ballast settlement rate .	• Repeated loading • Soft or loose soils	• Differential subgrade settlement. • High elastic strain. • Ballast settlement and pockets. • Track irregularities. • Deterioration of vertical track geometry.
Subgrade stability problems.	• Repeated loading • Contact between ballast and subgrade • Water presence • Clay rich rocks or soils	• Sliding . • Settlement.
Progressive shear failure (subgrade squeeze).	• Soil and train weight • Inadequate soil strength	• Squeezing near subgrade surface. • Often triggered by increase in water content.
Subgrade surface subsidence	• Repeated loading. • Soft or loose soil.	• High elastic strain deterioration of vertical track geometry.
Subgrade spots	• Repeated loading • Vibrations • Weak strength of soil	• Track irregularities. • Degeneration of the ballast into fine grains.
Liquefaction	• Repeated loading. • Saturated silt and fine sand.	• Large displacement. • More severe with vibration. • May happen in subballast.
Swelling/Shrinkage	• Highly plastic soils. • Changing moisture content.	• Rough track surface.
Soil collapse	• Water inundation of loose soil deposits.	• Ground settlement.

Table 1 illustrates the major subgrade problems and their characteristics. This table shows that the main causes of such subgrade problems are the high water content and the weakness of the soil itself.

3. Factors affecting subgrade problems

There are three main categories of causes of subgrade problems and associated failures [1]:

- Load-related factors,
- Soil-related factors, and
- Environmentally-related factors.

Load-related factors include both the loading due to the weight of the track structure and the subgrade materials, and loading caused by traffic. While the weight of material can be significant in consolidation and consolidation-related long-term settlement, it is the traffic loading that is of greatest concern, particularly repeated traffic loading. Both the magnitude of the individual wheel loads and the repeated nature of the loading are important from the point of view of subgrade degradation.

Researches indicated that there is a significant effect of the increased axle loading on the subgrade degradation, and this effect depends on the soil type and strength as well as the load itself [2].

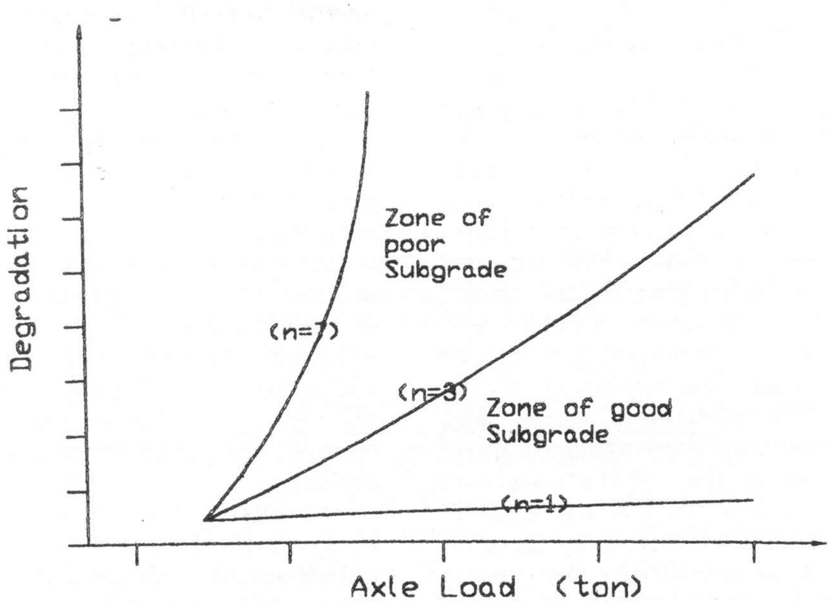

Fig. 1. The relationship between track degradation and axle load [2].

They differentiated between the quality of the subgrades according to its rate of deterioration. For good subgrades, the rate of deterioration is approximately linear with load (n; degree of the algebraic function = 1). For poor subgardes, the rate of deterioration is much more rapid, following an exponential growth rate with the load (the exponential rate is between 3 and 7). Figure 1 shows the relationship between track degradation and the axle load

The vibrations of track elements produced from the running trains is an other factor that affects track formation problems. The radius of the action of the forced vibrations in the form of a live load caused by the traffic depends on the weight of the trains, their speed, and the frequency of passing and it may be greater in dry coherent soil than in non-coherent soil.

The type and the strength of the associated soil are the second main factor that affects the subgrades problems. A fine grained soils like silts and clay will experience significantly greater degradation than a coarse grained soil subgrades like gravel and sands [3].

The third factor that strongly affects the development of subgrade problems is the environmental condition, which is related to both moisture content and freeze/thaw cycle. The presence of water and the corresponding moisture content of the soil strongly affect both the strength and the stiffness of the subgrade, and thus the track structure.

The climatic factors affect not only the stability of track formation but also the slopes of the railway embankment. The action of water may affect the track subgrade in the following forms:

- Infiltration by gravity through the ballast in the track formation, and through the lining in the slopes,
- Underground water-bearing stratum, both beneath the track subgrade and in the body of the soil in the slopes of embankments, and
- Capillary, threatening both the track formation and the slopes of embankments by the possibility of the formation of ice under low temperatures.

The action of high temperatures and wind causes shrinkage cracks especially in the slopes of the embankments.

4. Curing techniques

4.1. Curing of subgrade problems

The recent methods to cure subgrade problems are those which use the geotechnical fabrics. The Geotechnical fabrics can be used in a railway track with four basic operational functions: separation, filtration, reinforcement (both vertical and lateral), and drainage in the plan of the fabric.

Separation enables the fabric to pass water while retaining fines, thus stopping subgrade intrusion and / or pumping. Filtration retains soil particles of differing sizes and composition, for instance separating silts and clays. Reinforcement is the characteristic of increasing the strength of the track structure. This can be accomplished vertically through membrane support, or laterally by restraining the tendencies of the ballast and /or subballast to displace transversely. Drainage is provided by fabric's ability to improve the internal lateral transport of the moisture in the subgrade.

4.2. Curing of subgrade erosion

The old traditional cure method for a subgrade erosion problem is to lay filtering layer, which is commonly called a blanket, to protect the formation. The filtering layer material that have been tried in the past included fine sands, stone dust, slag dust, crushed stone, and river gravel [4]. The ideal material has been found, in that time, to be a well grade sand which contain sufficient fine particles, to act as a filter barrier against the fine grained subgrade, together with a larger fraction which has been found to give increased resistance to shearing [5]. However, due to its wide availability and low cost, stone dust was also used extensively.

In recent years, membrane sheeting and geotextiles are used to cure subgrade erosion. Polythene sheeting and bitumen spray are the most used material form of membrane. The membrane is usually laid above the susceptible subgrade. When using the polythene, some protection is required to prevent puncturing of the material. Normally, sand is laid as a blinding layer before placing the polythene, which is then covered with a further layer of sand to prevent penetration of ballast particles (Fig. 2).

The advantage of using geotextiles to cure subgrade erosion is that they are easy and quick to install and would be useful in situations where the time available for installation is short. Geotextiles are often used in two ways. The first involves placing the geotextiles directly on the subgrade, to act as a barrier between the subgrade and ballast, while the second involves placing the material on top of a filtering blanket layer to act as a separator between this layer and the overlying ballast.

Finally, the most effective way of preventing subgrade erosion in a track substructure underlain by a fine-grained subgrade is to install over the subgrade a sand or stone dust filtering layer (blanket) of appropriate thickness. Then, a geotextile can be used as a separator beneath the ballast layer to provide protection to the underlying filter material.

As a comparison between the polythene method and the geotextile method. Polythene can treat the subgrade erosion in which it is specified as a waterproofing layer to keep water away from the subgrade and to arrest the upward movement of slurry from the subgrade into the ballast. However, the basic functional requirements of a geotextile in track substructure are: to drain water away from the track on a long-term basis, to filter or hold back soil particles while allowing the passage of water, to separate two types of soils of different sizes and gradings that would readily mix under the influence of load and water migration, and to withstand the abrasive forces of moving aggregates caused by tamping compaction process during track maintenance, by the tamping during initial compaction, and by passage of train on a frequent basis.

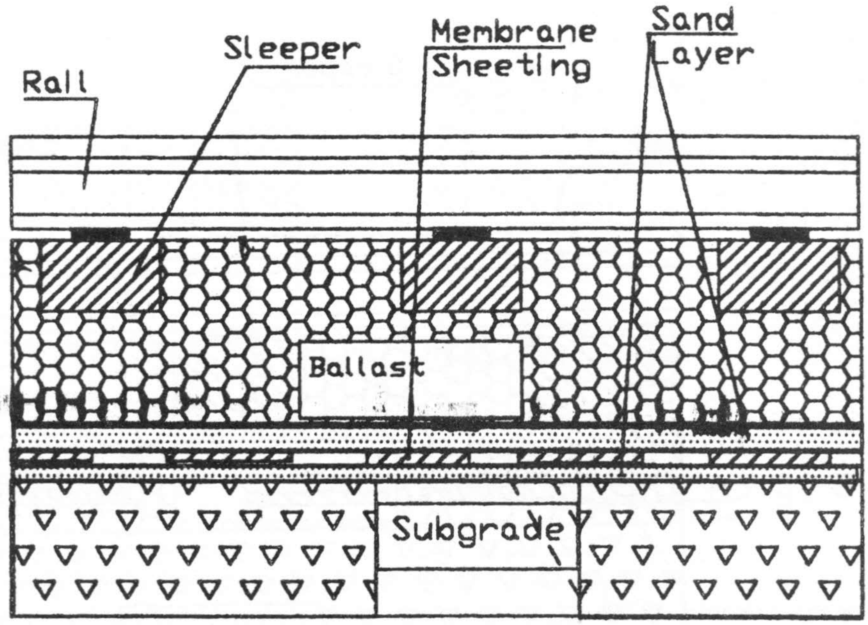

Fig. 2. Membrane sheeting (Polythene) for curing subgrade erosion.

4.3. curing of ballast settlement rate on soft substructure

Track laid on a soft substructure experiences high elastic strains, resulting in more rapid settlement of the track. The old traditional cure method of track settlement over soft substructure is to increase the depth of ballast, or to use the process of chemical stabilization. The new method to reduce the ballast settlement rate and consequently the track maintenance requirements , is to use the geogrids [6,7]. Researches indicated that the use of geogrids with high profile ribs, which provide a good interlock with the ballast, can limit the lateral creep of the ballast particles, reduce the settlement and the rate of deterioration of the vertical track geometry, increase the stiffness of the track, and reduce its elastic deflections [7]. Using the geogrid within the ballast structure can reinforce the granular material by the mechanism of interlock. When a granular material is compacted onto the geogrid, some of the granular material penetrates the geogrid apertures to form a positive interlock. This mechanical interlock produces a flexural stiff platform which distributes load evenly, and minimizes differential settlement.

The use of geogrids in the railway must have three basic characteristics :

- Good stiffness at low strain, since the strain at which the geogrid is working in the reinforcement of granular layers is very low (generally less than 2%), and it is necessary that the geogrid is able to give a good strength response at this strain level [6].
- High junction strength, since the interlock mechanism depends on the ribs of the grid restraining the stone and preventing movement. Therefore, the ribs must not only be strong in themselves, but should also have good integrity at the junctions.
- A good rib profile. The ribs of the geogrid should be rectangular and therefore present a positive profile to the stone.

Figure 3 illustrates an example to use the geogrids to cut ballast settlement rate on soft substructure.

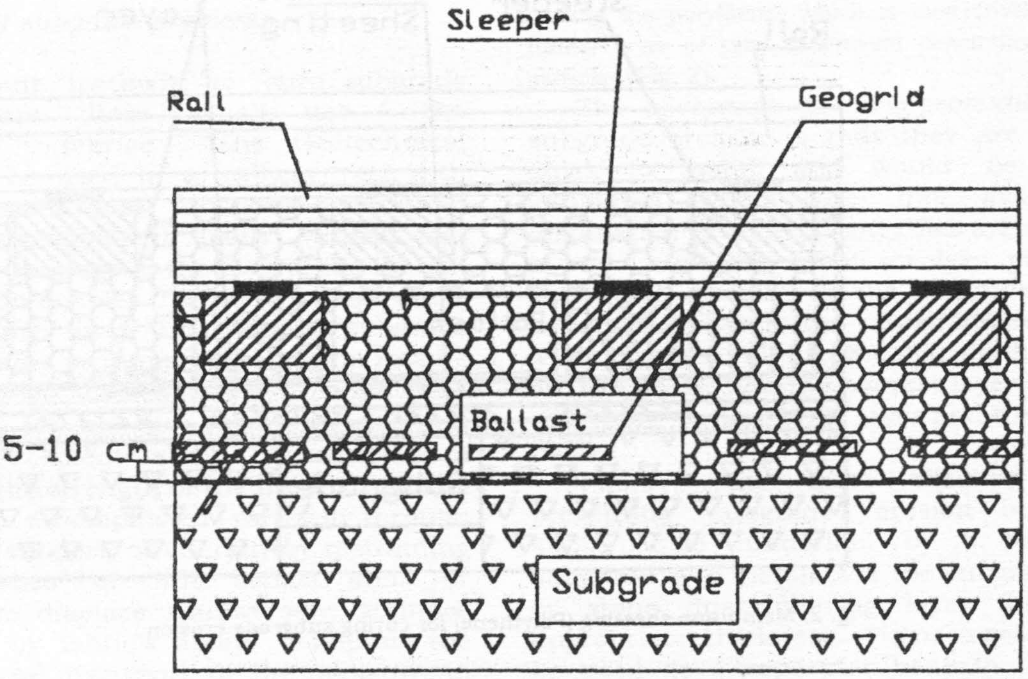

Fig. 3. The use of geogrids to reduce the ballast settlement rate on soft substructures.

4.4. Stabilization of the Subgrade

The old traditional cure method for formation stabilization is to use the process of chemical stabilization. Recently, polymer materials have been used as an effective method of stabilizing of track formations. Subgrade stabilization in this concern refers mainly to the protection against the effect of water using foils or layers on a basis of polymer materials below the ballast bed. The following material can be considered: polyvinyl-chloride, polyethylene, and synthetic fibers (polyamide), whereby impermeability to water increased.

4.5.Curing of the progressive shear failure of the subgrade (subgrade squeeze)

The hot mix asphalt (HMA) may be considered as a new application, which can be used in the railway track as a ballast underlayment, sharing the location and some of the functions of the sub-ballast. The main advantage of using such layer in the railway track is the greater stiffness, which decrease the stresses transmitted to the lower, weaker layers. The amount of subgrade stress reduction provided by HMA can vary considerably depending on the position of the asphalt layer relative to the other substructure layers and the thickness of these layers. Most of this stress reduction is limited to the upper portion of subgrade. Therefore, HMA may provide an effective remedy when the failure is due to weakness in the upper few meters of subgrade, such as in a progressive shear failure (subgrade squeeze). Researches indicated that, in terms of subgrade stresses, 10 cm of HMA equivalent to 30 cm of ballast [8]. These researches compared between track with 25 cm of ballast, 10 cm sub-ballast layer, and 10 cm of HMA layer with another with 55 cm ballast and 10 cm sub-ballast layer. Figure 4 shows the equivalence of two track construction in terms of subgrade stresses.

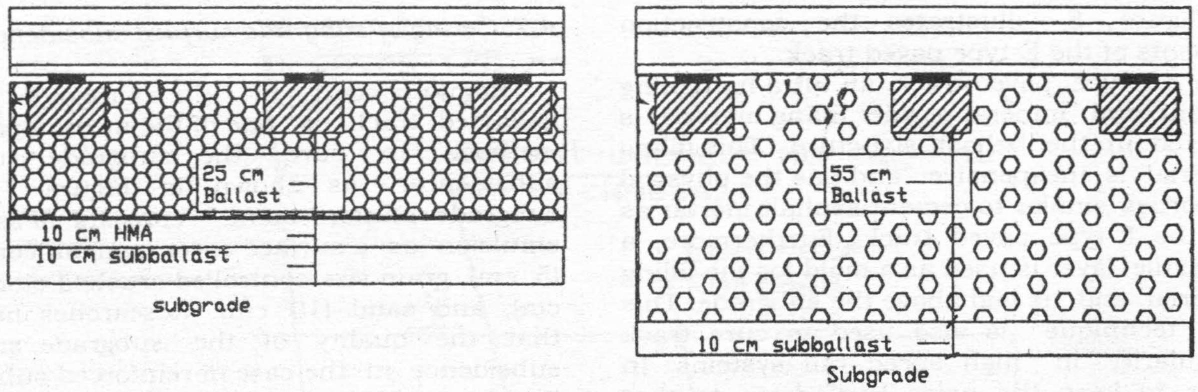

Fig. 4. The equivalence of two track construction in terms of subgrade stresses.

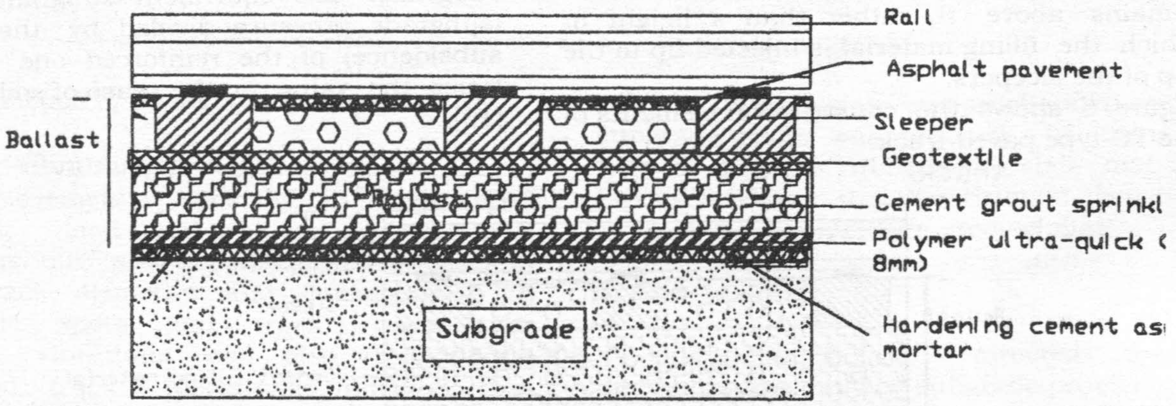

Fig. 5. Construction elements of the E-type paved track.

4.6. Curing of track irregularities

The main causes of track irregularities are the ballast settlement and the degeneration of the ballast into fine grains. The grouted ballasted track (ballasted track filled with heated asphalt), or paved track, is a modern remedial technique which has been used recently as an effective method of curing track irregularities, and reducing track maintenance [9]. There are five types of paved track, A-type, B-type, C-type, D-type, and E-type paved track. An asphalt-based filling material is used in all of these cases. By the types A, B, C, and D, filling material is injected into the ballast. The filling material is injected into the ballast. The filling material is made from ordinary cement, a hardening accelerator, a special asphalt emulsifier, sand, water, a setting modifier and an aluminum powder. The filling material is changed from the heated asphalt used for the B-type paved track to polymer ultra-quick hardening cement asphalt mortar in the E-type paved track (to be handled at ordinary temperatures, and to secure simple injection and quick strengthening) . In the E-type paved track, a geotextile is used to form a mold in the ballast area and the filling material is also injected into the mold. This creates support for large pre-stressed concrete sleepers. Researches indicated that track irregularities index improves for the E-type paved track and the maintenance required by E-type paved track is about 0.2 of that for ballasted track using pre-stressed concrete sleepers [9].

Figure 5 illustrates the construction elements of the E-type paved track.

In a TC-type paved track, an ultra hardening cement and mineral powder filling material is injected in the ballast structure. This filling material is inexpensive and has the physical properties similar to cement asphalt mortar as in the E-type paved track. Furthermore, a geotextile layer is used as a mold for the filling material and is laid above the subgrade. This new technique is also used to cure track irregularity in high speed rail systems. In order to keep the noise level down to that equivalent to ballasted tracks, and to prevent cracking resulting from drying and shrinkage of the filling material, the height of the filling material must be injected so that some ballast remains above it, rather than a height in which the filling material is injected up to the top of the sleepers.

Figure 6 shows the construction elements of the TC-type paved track.

4.7. Curing of subgrade surface subsidence

Reinforcement of the subgrade in a ballasted track, is one of the most important methods to cure the subgrade surface subsidence. As shown in Figure 7, the subgrade reinforcement consists of asphalt emulsion as a surface cover, asphalt concrete (5 cm), grain size-controlled crushed stone (45 cm), and sand (10 cm). Researches indicate that the quality of the subgrade surface subsidence in the case of reinforced subgrade is about 30% of that in the case of non-reinforced subgrade (soil subgrade). The related subsidence of the rail level in this case is approximately 70% of that in the case of soil subgrade. The equivalent subgrade reaction (subgrade pressure divided by the subgrade subsidence) of the reinforced one is about 5 times the value in the case of soil subgrade [10].

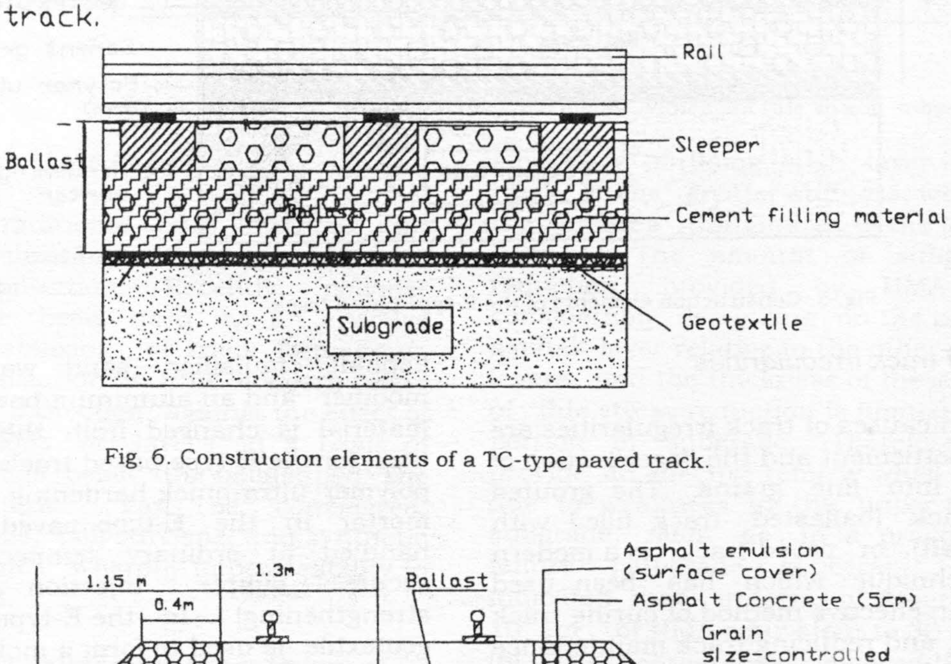

Fig. 6. Construction elements of a TC-type paved track.

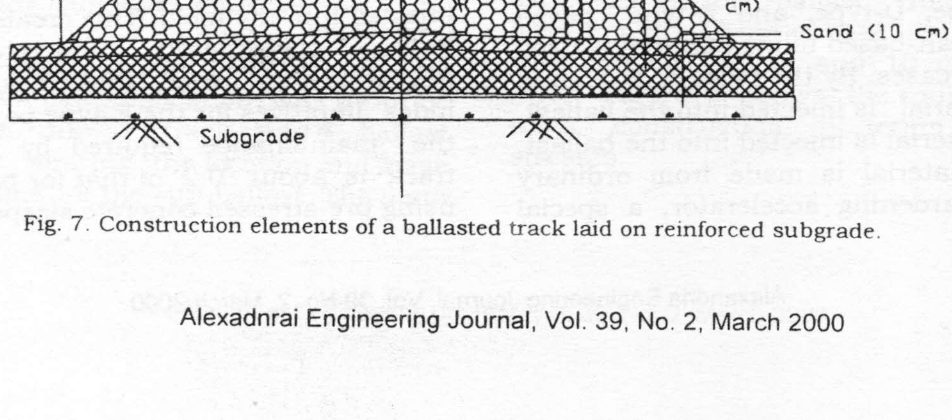

Fig. 7. Construction elements of a ballasted track laid on reinforced subgrade.

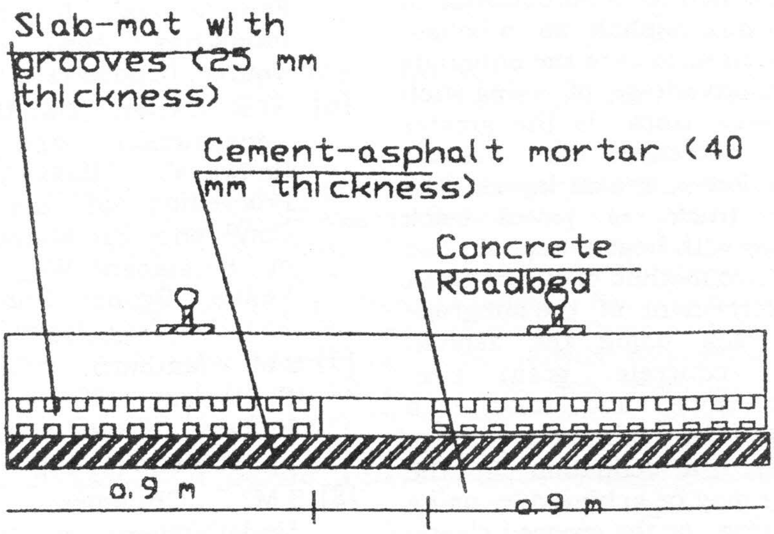

Fig. 8. Construction elements of the slab track on elastic grooved mat..

4.8. Reduction of the subgrade vibrations

The vibrations of track elements due to train movements, specially in high speed systems, lead not only to environmental problems but also to considerable stresses in the track elements and consequently to subgrade spots and track irregularities. Ground vibrations can also destroy the ballasted track. Researches indicate that such spots are caused by resonance between axle load and the subgrade [11]. The vibration caused by train axles can be reduced or amplified through the ground, and resonance occurs only when the frequency characteristics of the train loads and those of the ground match each other.

It was found that the resonance can be effectively stopped by changing the frequency characteristics of the subgrade. For this purpose, chemical grouting was found to be a very effective, economical and practical measure to reduce the subgrade vibrations [11].

The slab track on elastic mat with grooves (type G) is other remedial technique to reduce the subgrade vibrations and consequently spots. The slab-mat is effective for the increase of free surface of deformation, and may be used only in the packed length of the track (0.9 m from the end of the sleeper). It is made of pulverized rubber. It was found that the stresses distribution was ameliorated and the subgrade spots was reduced by using this type of grooved rubberized slab- mat [12]. Figure 8 shows the construction elements of the slab track on elastic grooved mat.

5. Conclusions

This paper is directed towards understanding railway subgrade problems and addressing their new curing techniques. Causes and characteristics of subgrade problems, such as subgrade erosion, rapid track settlement rate, subgrade stability problems, progressive shear failure, subgrade surface subsidence, and subgrade spots, are demonstrated. Different factors that affect these problems such as load-related, soil-related, and environmentally-related factors are analyzed. New techniques, using new materials, used to cure such problems are introduced.

Subgrade erosion can be solved by using membrane sheeting and geotextile. The advantage of this method is that geotextiles are easy and quick to install. Geogrids may be used to reduce the ballast settlement rate. The use of geogrids with high profile ribs can limit the lateral creep of the ballast particles, reduce the settlement and the rate of deterioration of the vertical track geometry, increase the stiffness of the track, and reduce its elastic deflections. Polymer material can be used as an effective method of stabilization of the subgrade. Hot mix asphalt as a ballast under-layer may be used to cure the subgrade squeeze. The main advantage of using such layer in the railway track is the greater stiffness, which decrease the stresses transmitted to the lower, weaker layers. The grouted ballasted track or paved track (ballasted track filled with heated asphalt) can be used as an effective method of curing track irregularities. Reinforcement of the subgrade in a ballasted track using the asphalt emulsion, asphalt concrete, grain size-controlled crushed stone, and sand is a remedial technique for subgrade surface subsidence. Finally, a reduction in the subgrade vibrations may be achieved by using the chemical grouting , or the grooved elastic slab mat.

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