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REINFORCED RAILWAY SLEEPERBED
BALLASTAGE ARME EN CONSTRUCTION FERROVIAIRE
ARMIERTES SCHOTTERBETT IM EISENBAHNBAU

Traditionally constructed railway sleeperbeds suffer from imperfections in rail level due to breakage and displacement of ballast material caused by railway traffic. Therefore, frequent maintenance is necessary. To avoid such maintenance Enka, jointly with the Railway Engineering Institute of the University of Technology of Graz and with Austrian Railways, has developed a system in which specially designed bags made of polyester woven fabric are filled with rounded material (gravel or sand), which is then compacted. The post-stressed bags are connected with the sleepers by woven polyester straps.
Extensive investigations have shown very promising properties of the reinforced sleeperbed, viz.:
- very low settlement under heavy railway traffic;
- attractive elasticity, remaining at a constant level during the lifetime of the system;
- strong reduction of vibrations caused by railway traffic.
This article deals with the results of laboratory investigations and the data obtained from the test track.

1. INTRODUCTION

About mid-1979 Enka was requested by the Austrian Railways (OBB) to find out to what extent the cost of maintenance of existing and planned railway lines could be reduced by using polymer materials.
The OBB declared that, if a preliminary investigation should show that positive results might be expected from a possible new construction, they would be prepared to participate in the cost of further investigations and to finance a test track in due time.
In close co-operation with OBB's civil engineering management a study and research team was formed, in which Enka and the Railway Engineering Institute of the University of Technology of Graz participated. Enka contributed its polymer and conversion know-how and the University of Technology of Graz made available its know-how in the field of railway engineering as well as research facilities. The research activities resulted in a solution in which the traditional sleeper-ballast-bed construction was replaced by a construction in which the sleeper is connected by straps with post-stressed bags filled with rounded material like gravel or sand.
The first phase of the investigation resulted in a small test track, which was constructed near Graz (1982). On the basis of the results of further investigations and the experiences gained with the small test section, the OBB decided to construct a 1-km long test section near Vienna. This section was realized in the autumn of 1984 and will be closely observed in the coming years (Fig. 1)
The system has been patented world-wide.

Dynamische Belastungen des Eisenbahnverkehrs führen in traditionell gebauten Schotteroberbausystemen zu unzulässigen Gleishöhenlagefehlern, die auf seitliches Auspressen oder auf Zermalmen des Schotters zurückzuführen sind. Das macht eine regelmässige Unterhaltung notwendig. Als Problemlösung hat ENKA in Zusammenarbeit mit der Technischen Universität Graz und den Oesterreichischen Bundesbahnen ein einzigartiges System entwickelt, bei dem Kies in speziell entwickelten Säcken verfüllt und verdichtet wird. Die Säcke werden mit Gurten stramm an den Schwellen verankert. Umfassende Laboruntersuchungen, sowie die ersten Ergebnisse von Versuchsstrecken in GRAZ (1982) und WIEN (1984) zeigen drei vielversprechende Eigenschaften des kunststoffbewehrten Schotterbettes:
- sehr geringe Setzungen unter schwerem Eisenbahnverkehr
- sehr günstige, immer constante Elastizität während der Lebensdauer der Konstruktion
- starke Reduzierung der durch den Eisenbahnverkehr verursachten Körperschall.

Fig. 1 The Vienna test section

2. PROBLEM DESCRIPTION

2.1 Maintenance

Railway sleepers are traditionally embedded in gravel or crushed rock. The dynamic load of passing trains transmits considerable vibrations through the rails to the sleepers, causing the gravel or crushed stone bed to shift and break, so that the entire construction is liable to subside. This not only affects the level of the rails, but seriously reduces bearing capacity as well as drainage capability. The process is accelerated in railways which are subjected to heavier axle loads, increased train frequency and high speeds. (Fig. 2)
In order to keep railway security and reliability up to standard, regular and thorough maintenance is required. This is expensive particularly in areas where high axle loads accelerate the settlement of the ballast bed and where little time is available for maintenance due to high train frequency.

2.2 Ballast

In areas where crushed rock is scarce and has to be transported from distant places or even has to be imported at very high cost, a construction system using locally available material such as sand or rounded gravel can bring a practical and economic solution and accelerate the realization of a railway infrastructure.

2.3 Vibrations

Areas near railway tracks suffer from vibrations and noise, especially in tunnels, on fly-overs and on bridges.

Fig. 2 Shifting of ballast

3. PROBLEM SOLUTION

"The bag-reinforced sleeperbed system"

In collaboration with the Railway Engineering Institute of the University of Graz and Austrian Railways, Enka has developed a unique system to solve the problems described in section 2. Specially designed bags woven from high-modulus yarns are filled with rounded gravel or similar material with a high degree of compaction. When filled, the tubular bags are extremely compact. Woven straps anchor them to sleepers.
To optimize bearing capacity, the filled bags are flattened before being fitted with assembly rails and prepared for installation (Fig. 3)

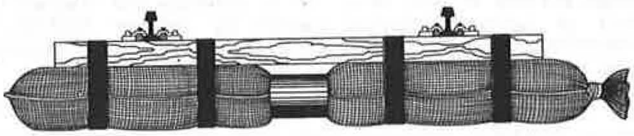

Fig. 3 Module

3.1 Selection of yarns for the fabrics

In order to function optimally for a very long time, the bags and anchoring straps should meet three requirements within a temperature range from -40° C to +70° C:
- high bearing capacity in the prestressed state
- permanent elasticity
- mechanical and chemical stability.

These requirements can only be met by synthetics with extremely low creep and long time to fracture under prolonged dynamic loading.
In view of the selection criteria high modulus polyester shows the best price-performance behaviour.
Polypropylene, polyethylene and polyamide do not come under consideration due to poor creep under dynamic loading and thermal stability (1).
In addition, tests have been made to determine the influence of micro-organisms in the soil. It has been found that polyester does not lose strength at all under severe fungus attack. (2)

3.2 Synthetic bags and straps

A special loom is needed for production of the fabric. The bags must be made of a heavy-duty fabric with low stretch in both directions. To prevent mechanical damage to the reinforcing fibres, the bags have an outer and inner protective layer made of a polyester non-woven fabric. The outer layer also withstands ultraviolet radiation during storage and installation on the spot.
The tests performed by the University of Graz and measurements made during filling the bags for the Vienna test section have shown that the permanent stress in the fabric of the bags will be about 25 kN/m' and about 10 kN in the anchor straps.
In connection with creep behaviour, possible mechanical damage during construction, and modulus requirements a fabric has been chosen for the bags with a breaking strength of 100 kN/m' in both directions, while the straps have a breaking strength of 120 kN. Both stretch approx. 12% to counteract rupture. The elongation at working load is about 5%. This elongation is fully absorbed during filling and compaction of the bags.

3.3 Filling and shaping of the bags

The bag is suspended in a framework already holding the sleeper. Whilst the bag is being filled, a powerful pneumatic vibrator is applied to the material in order to compress it as densely as possible. (Fig. 4)
The vibrator must have the possibility to vary the frequency and the amplitude because each fill material has its own frequency and amplitude at which optimal compaction can be reached. For rounded gravel (20 - 60 mm) as used for the Vienna test track the optimal frequency seems to be 17-19 Hz at an amplitude of 1 mm.
The filling mechanism is constructed in such a way that during filling and compaction the sleeper is anchored firmly to the bag by means of the straps. When full, the bag is tied up with a stout cord. In order to make the round shape slightly flatter, the filled bag is placed in a mould, where a heavy vibrating road roller presses it into the desired shape. Together with the sleeper, the bag is ready to carry the rail construction. The reinforced sleeperbed module is ready now. (Fig. 5)

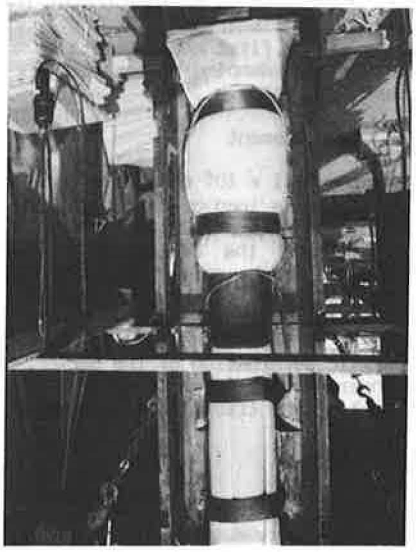

Fig. 4 Filling the bags

Fig. 5 The shaped bags taken out of the mold

4. BUILDING THE 1-KM VIENNA TEST TRACK

4.1 Construction

Modules were combined to form construction elements by means of assembly rails. (Fig. 6) These elements were prepared and transported to the track by railway vans. The length of the construction elements was limited to nine modules, with a total weight of about 10 tonnes, in connection with the lifting power of the hoisting tackle available. (Fig. 7)

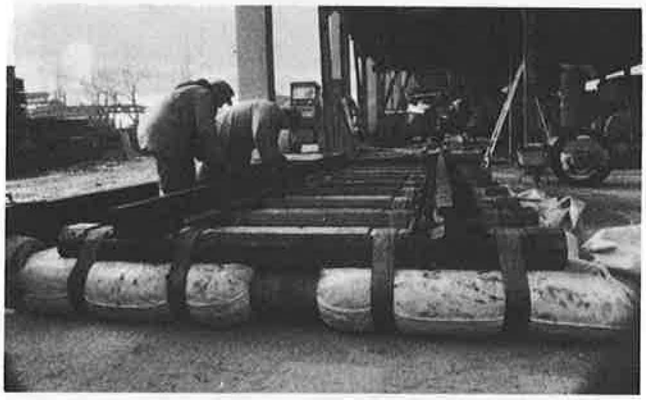

Fig. 6 Assembling of modules to elements

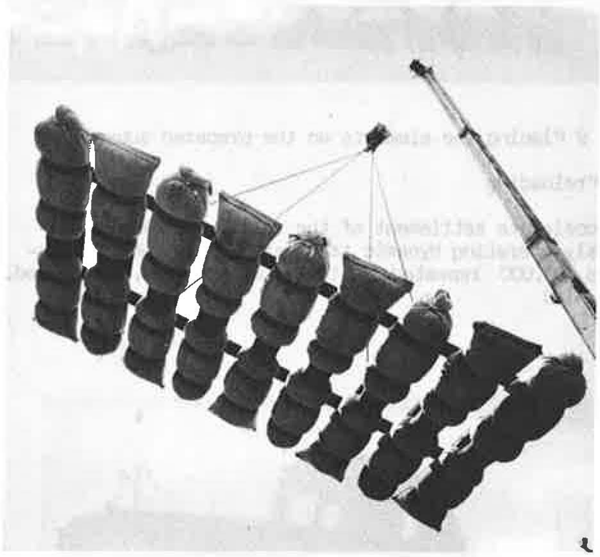

Fig. 7 Building elements

To construct the track the construction elements were taken simply from the railway vans with the building crane and placed on the prepared subsoil (Fig. 8 + 9). Afterwards the assembly rails were replaced by the permanent rails.

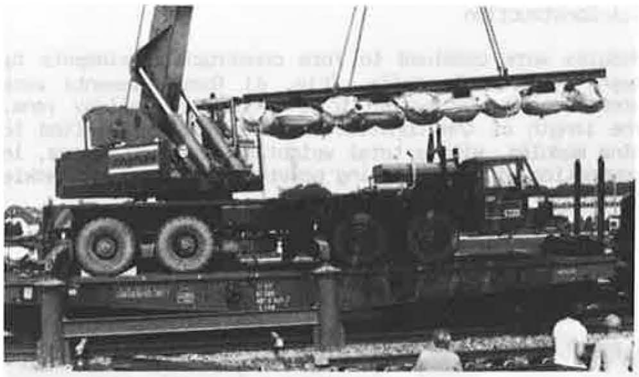

Fig. 8 Taking the elements form railway-vans

Fig. 9 Placing the elements on the prepared subsoil

4.2 Preloading

To accelerate settlement of the railway track a continuously operating dynamic track stabilizer, which simulates 10,000 repeated 20-tonne axle loads, was used. (Fig. 10)

Fig. 10 Preloading by track stabilizer

4.3 Levelling

After the dynamic stabilizer had passed over the track, the required level was reached by applying, in some places, plates of various thicknesses between bags and subsoil. The exact height was reached by using very thin plates between rail and sleeper.

4.4 Finishing

After levelling, the bag-sleeper system was covered with ballast, so that the reinforced sleeperbed closely resembled the traditional construction.

5. RESULTS OF TEST PROGRAMMES

An extensive research programme has been carried out by Graz University (Austria), including theoretical analyses and tests on fill material and fabrics. But most tests were made on the system to gather information on plastic and elastic deformation, horizontal resistance and load-distribution of the new system. These tests were performed on a 1 : 1 scale.(1) (3) (4) (5)
Later on the University of Karlsruhe (Germany) confirmed the good results of Graz University in an independent 1:3 model study. (6)
The most striking results of the first measurements on the test track are the vibration damping properties of the bag reinforced sleeperbed system.

5.1 Plastic deformation or settlement

In a dynamic loading machine 22.1 x 10^6 changes of axle loads were realized up to an axle load of 36 tonnes, corresponding to 464 x 10^6 tonnes of traffic load. After applying this number of loads the measurements were stopped because further settlements proved to be linear (Fig. 11). Following the usual prediction rules, predictions of the settlement behaviour can be made up to 221 x 10^6 changes of axle loads or 4640 x 10^6 tonnes of traffic load. The plastic deformation of the bag-reinforced sleeperbed under these extreme loading conditions was only 10% of that of the traditional sleeperbed (1).

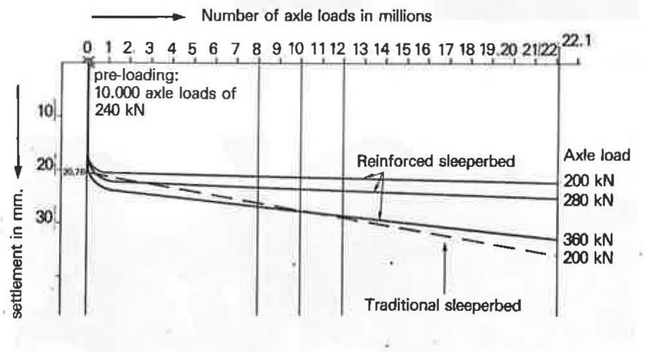

Fig. 11 Plastic deformation (settlement)

5.2 Elastic deformation

During the settlement tests to determine the permanent deformation of the bag-reinforced sleeperbed under varying axle loads, the elastic deformation of the system was also measured by means of step-by-step loading and unloading. The elastic deformation was found to be very uniform from the beginning of the settlement test up to

21.3 x 10^6 axle loads, varying from 1.6 to 2.6 mm at different axle loads. For example at 28-tonne axle load the bag-reinforced sleeperbed shows an elastic deformation of 1.9 mm compared with 0.7 mm for a traditional construction. This aspect exerts a positive influence on the stability and vibration damping properties of the sleeperbed (4).

5.3 Horizontal and vertical resistance of the bag system

Temperature variations may cause pressure forces in the rail because of extension of the steel, so that the rail with sleepers may buckle horizontally or vertically under collapsing load.
Vertical buckling is rarely reported and the bag system prevents this vertical buckling because the sleepers are connected with the filled bags, together weighing more than 1000 kg. Therefore, vertical buckling forces must exceed 17 kN/m' before collapsing occurs.

Transversal buckling, however, is the most critical and measurements have been made at the University of Graz to determine transversal buckling resistance. Fig. 12 shows the results compared with the results of tests on the traditional system using wooden or concrete sleepers.

The values of transversal buckling resistance have also been measured in the Vienna test track, using a tamping machine. The correlation of these results with the values presented in Fig. 12 is striking.

From this figure it can be derived that in the most critical situation, - the unloaded rail - the buckling resistance for the bag reinforced sleeperbed system is 9 kN/m' sleeperbed at a transversal movement of 2 mm (1.67 sleepers per m' sleeperbed).
Führer (7) mentions a value of 6 kN/m' as sufficient.

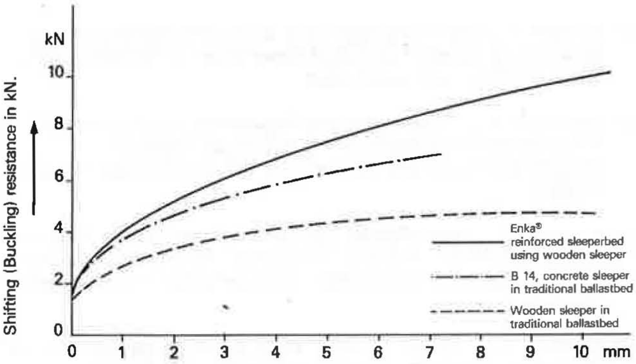

Fig. 12 Buckling resistance of several types of constructions

5.4 Load-distributing action

To verify the load-distributing action of the reinforced ballast bed, soil pressure cells incorporated under the bags in the test machine during the dynamic settling test were loaded statically as well as dynamically, after which the load distribution was measured.
The difference between the dynamic and static load figures was very small. The compressive stresses measured under the bag were 30 N/cm² at an axle load of 28 tonnes and 33 N/cm² at an axle load of 36 tonnes.

Although these values seem to be high, it should be noted that in the test set-up the pressure cells form a very rigid underground, which leads to a reduction of the load-distributing action of the layer above.
Also Eisenmann (8) found very high compressive stresses for traditional constructions. At an axle load of 24 tonnes and a ballast bed thickness of 50 cm, for example, he mentions a compressive stress of 19 N/cm², whereas in practice under the same construction and load conditions a soil pressure of $\leq$ 10 N/cm² was measured.
With a view to the relatively high soil stresses to be expected, the geometry of the bag model for the Vienna test section was changed in such a way as to create a larger contact surface between bag and subsoil so as to improve the load-distributing action.
The stresses in the model are expected to drop to 25 N/cm² so that a soil stress $<$ 20 N/cm² will become probable.

Because of the soil stresses to be expected high demands will have to be made on the stability and the degree of compaction of the subsoil to prevent bags from being pressed into it.
Moreover, it will be clear that its very good elastic properties permit the reinforced ballast bed to be placed on very rigid subsoils.

5.5 Fill material

One of the problems of the traditional sleeperbed is the fact that crushed rock or crushed gravel will break due to bending forces under loading conditions causing settlement of the rail. Wear-off in the long run gives drainage problems and instability of the ballast bed. To avoid these problems in the bag model, rounded quartz gravel (16-50 mm) was used from the outset as fill material, mainly having pressure forces in compacted condition and having a high abrasion and wear-off resistance.
To formulate future selection criteria for fill material separate tests were carried out concerning:
- elastic and plastic behaviour of the fill under repeated loading
- compaction possibilities
- abrasion and wear-off
- cementation.

The tests concerning the elastic behaviour of the fill material have shown that rounded gravel has a better elastic behaviour than crushed materials and that the similarity in elastic behaviour between rounded gravel and desert sand from North Africa is striking (Fig. 13).

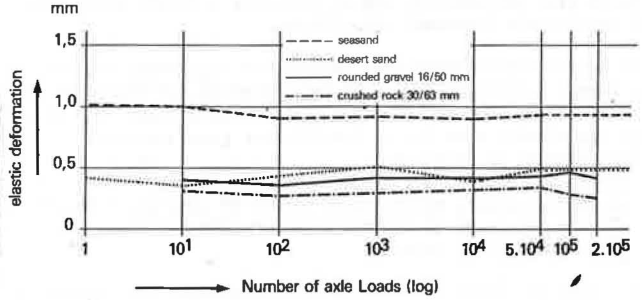

Fig. 13 Elastic behaviour of fill material

5.6 Vibration damping

The Federal Austrian Research Institute "Arsenal" has determined the vibration damping properties of the bag system in comparison with the traditional construction in the Vienna test section. The results indicate a slight improvement in the ranges of 0-10 Hz and 10-40 Hz but an impressive improvement of 10-20 dBv in the range of 40-200 Hz (Fig. 14) in favour of the bag system (9). Especially in urban areas where railway traffic passes tunnels, bridges and fly-overs, this improvement means a substantial contribution to noise abatement.

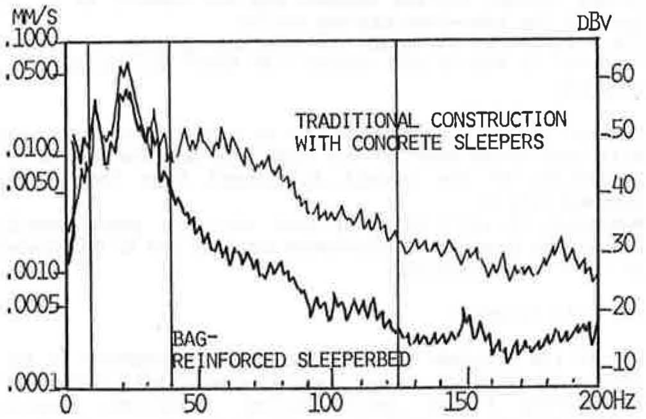

Fig. 14 Vibration damping properties

6. ECONOMICS

Integral maintenance costs, including costs of traffic interruptions, vary with different conditions of subsoil and traffic load. Our present information on the level of these maintenance costs is limited to Western European conditions which vary from:
- 7 NLG/m average per year, in case of very good subsoil, high quality ballast, light traffic, to
- 20 NLG/m average per year, in case of very heavy traffic.

Savings on integral maintenance costs may well justify higher investments in a low maintenance superstructure. The meaning of these savings in terms of present value, pay-out time or return on investment should be investigated in detail for each individual project/country.
We have calculated that the costs of the new bag-reinforced sleeperbed construction for commercial projects will be 20%-25% higher than for a traditional construction for European conditions.

Professor Riessberger has calculated (10) that the investment (=present value of the expected savings) for an alternative, low maintenance cost construction may be up to 25% higher than for a traditional construction.
This figure is based on:
- daily track load of 30,000 - 40,000 tonnes
- averaged yearly maintenance costs of approx. 7 NLG/m
- 6% interest and 3% increase maintenance cost
- life-time of 45 years.

In case of noise and vibration abatement we expect to have found an economically favourable solution.

7. DEVELOPMENTS

Although the results of the laboratory tests and the field tests are very promising for the bag-reinforced sleeperbed, more field tests have to be carried out to obtain additional information under extreme heavy load concerning:
- load distribution on subsoil
- irregularity in level from sleeper to sleeper
- vibration damping aspects
- rail stresses.

Optimization of the construction method for commercial application is under way such as:
- filling and shaping units
- mechanical levelling devices
- track-laying machines.

8. ACKNOWLEDGEMENTS

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