

Laboratory and Field Testings of the New Concrete Friction Sleeper

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ABSTRACT: In summer the temperature stresses in the rails may become very high and induce lateral distortion of the track with risk of derailment. In small radius curves ($R < 300$ m) there are restrictions on use of CWR due to the risk of track buckling. This requires fishplated rail-joints with their many drawbacks. To improve safety and reduce maintenance costs it was found essential to find a practical way of improving the lateral resistance of ballasted track with concrete sleepers. The new concrete Friction Sleeper was designed with cross-wise ridges at the under-side to form a coarse cogging with adequate dimensions to utilise more of the high internal friction potential of the crushed stone ballast. By lateral displacement of this sleeper a completely continuous layer of ballast material will be held fixed to the sleeper under-side by hooking, wedging and granular interlock, and give a very high friction resistance. In performed field tests the Friction Sleepers provided a considerably larger lateral displacement resistance than the standard concrete and wood sleepers. Based on the observation data in these tests, the track with Friction Sleepers obtained the highest absolute and relative lateral resistance values for all three axle load levels. A very important result was that the unloaded track with Friction Sleepers had a very high lateral resistance, 35 and 110 % higher than obtained by the track with the standard concrete and the wood sleepers respectively. Based on the field and laboratory test results the new concrete *Friction Sleeper* has a considerable potential to yield higher safety against rail buckling, increased use of CWR tracks and less strict requirements on ballast quality and ballast profile.

KEY WORDS: Railway sleeper, track stability, lateral stability

1 FUNDAMENTAL IDEA

The lateral displacement resistance of a monoblock concrete sleeper consists mainly of three components: the passive ballast pressure at the end of the sleeper, the frictional resistance at the side surfaces, and the frictional resistance between the ballast and the under-side of the sleeper, see the illustration in Figure 1.

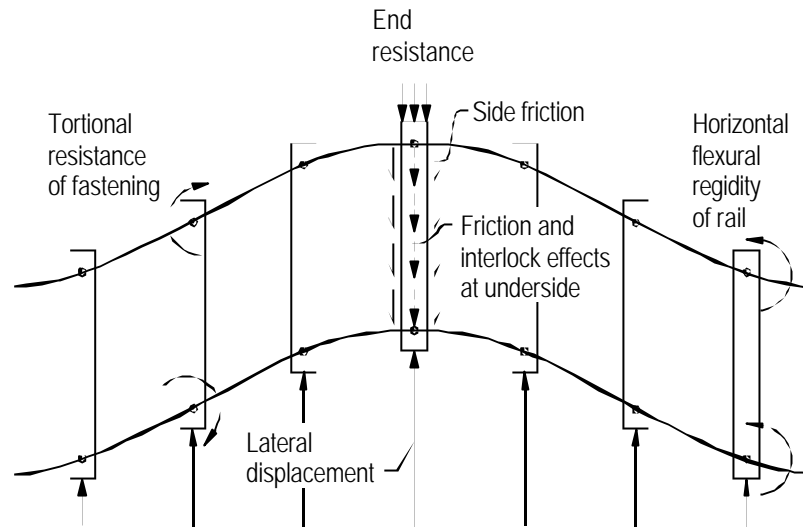


Figure 1: Main resistance force components on a sleeper and in the track panel that buckle under constrained thermal expansion forces in the continuous welded rails.

The frictional resistance at the under-side of the sleeper is normally the largest resistance component. Typical conditions at the under-side of a standard concrete sleeper are illustrated in Figure 2.

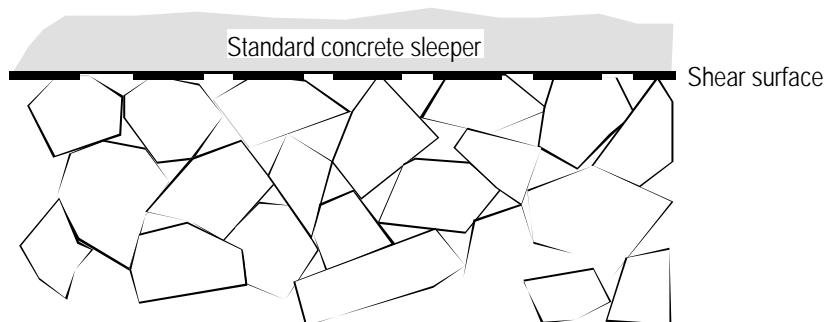


Figure 2: Detail of the under-side of a standard concrete sleeper in crushed stone ballast.

Lateral displacement forces are transferred from the sleeper to the ballast bed via shear stresses at the shear surface. The displacement resistance consists mainly of the friction by ballast stones sliding at the contact points on the relative smooth concrete surface. Full-scale tests with concrete sleepers and ballast material (25 mm - 63 mm) under static load yielded friction coefficients of around 0.5.

It is, however, well known that the internal friction of crushed stone ballast is much higher. By triaxial compression testing there are measured friction coefficients in the range of 0.9-1.4, depending on material quality, grading and degree of compaction. This shows that the under-side of standard concrete sleepers utilises less than around half of the available internal friction of common crushed stone ballast.

In order to exploit more of the high friction potential of the crushed stone ballast an entirely new principle for fixation of the sleeper under-side into the ballast bed must be developed and utilised. This principle forms the basis for the Friction Sleeper.

2 DESIGN OF THE FRICTION SLEEPER

The Friction Sleeper is a new concrete sleeper designed with a coarse cogging at the under-side (figure 3).

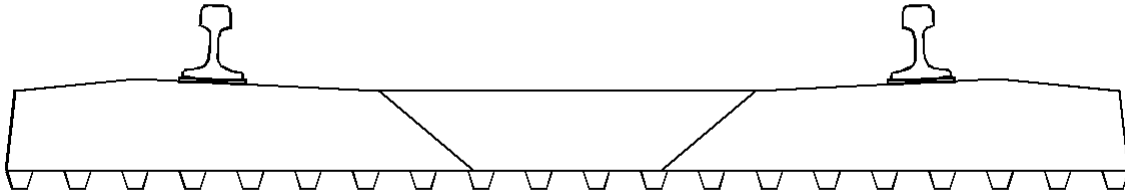


Figure 3: The Friction Sleeper with a coarse cogging at the under-side to exploit the high internal friction of the crushed stone ballast material.

The cogging provides the possibilities for an effective grip (fixation) of the sleeper in the ballast bed, and thereby yields an especially high resistance against lateral displacement of the sleeper. This is obtained by the crushed stone ballast being forced up into the cogging by tamping, traffic loads and vibrations, and where it becomes hooked up and wedged in between the ridges.

By lateral displacement of the sleeper a more or less completely continuous layer of ballast material will be held fixed to the sleeper under-side by hooking, wedging and granular interlock. This forces the shear-zone to pass underneath this layer and through the ballast material itself, see Figure 4. In that shear-zone the potential of the granular interlock and the internal friction of the ballast material can be utilised to give high resistance against lateral displacement of the sleeper. As mentioned the internal friction of crushed stone ballast is about twice as large as the friction in the shear surface between the relative smooth under-side on a standard concrete sleeper and the ballast stones.

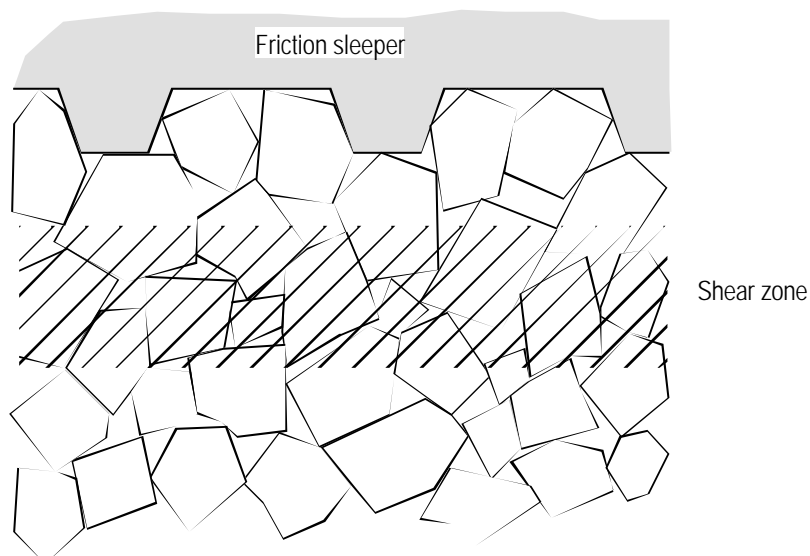


Figure 4: Underneath the Friction Sleeper an upper layer of ballast material is held rather well fixed to the sleeper under-side. It forces the shear-zone to pass through the ballast material underneath where the high potential of resistance against lateral displacement will be mobilised.

3 LABORATORY TESTS

To study the lateral displacement resistance of sleepers imbedded in ballast it was found most appropriate to carry out laboratory experiments with full size sleepers. A test rig containing a short section of a railway track with three sleepers was built, and furnished with loading equipment and instrumentation to study the lateral resistance of the middle sleeper. The loading equipment consisted of two hydraulic actuators; one for applying vertical, static and dynamic loads on the sleeper and a horizontal one to test the lateral resistance.

Laboratory tests were carried out on several types of sleepers. With the general aim of developing an improved sleeper for rehabilitation of railway lines with small radius curves ($R < 300\text{m}$) the standard concrete monobloc sleeper in Norway NSB 90 was found appropriate to use as the main reference sleeper. The Friction Sleepers for laboratory testing were manufactured by pouring a thin layer of concrete and concrete ridges on to the under-side of standard concrete sleepers (NSB 90).

For testing a standard superstructure section for small radii ($R = 250\text{ m}$) curves with 150 mm cant was installed in the test rig. For the sleeper in the centre the axial displacement resistance, with and without vertical loading, was measured.

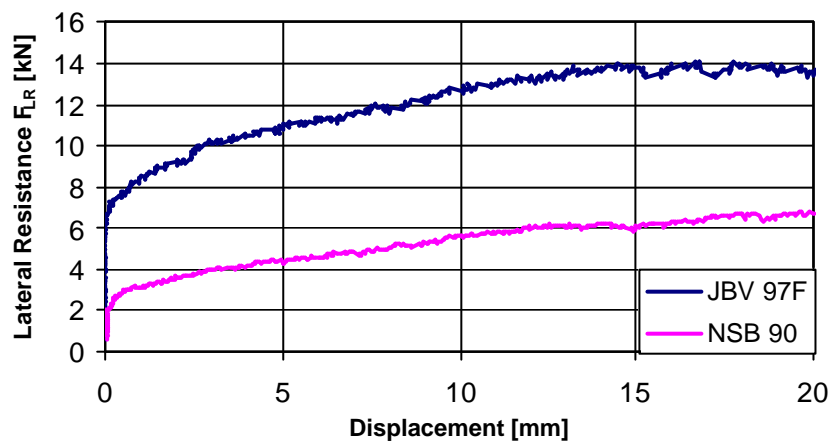


Figure 5: Lateral resistance as function of displacement for a standard concrete (NSB 90) and a Friction Sleeper(JBV 97F).

The horizontal resistances of a standard concrete sleeper NSB 90 and a Friction Sleeper under dead weight only are shown in Figure 5. It is easily seen that the lateral resistance of the Friction Sleeper is more than twice that of the standard concrete sleeper.

The means of the test results in Figure 6, obtained by the laboratory testing, show that the lateral displacement resistance of the Friction Sleepers is considerably higher than that obtained for the standard concrete sleepers. The stipulated lateral resistance of the Friction Sleepers under zero vertical load and also under the load of the dead weight of the track, is also much higher than that of the NSB 90 sleepers. This is of much importance for the lateral stability of track and especially for critical conditions occurring in small radius curves.

Altogether the results of the laboratory testing were very promising. They indicated that the Friction Sleeper provided considerably higher lateral displacement resistance than our standard concrete sleepers. It would therefore be of considerable interest to study their usefulness in practice.

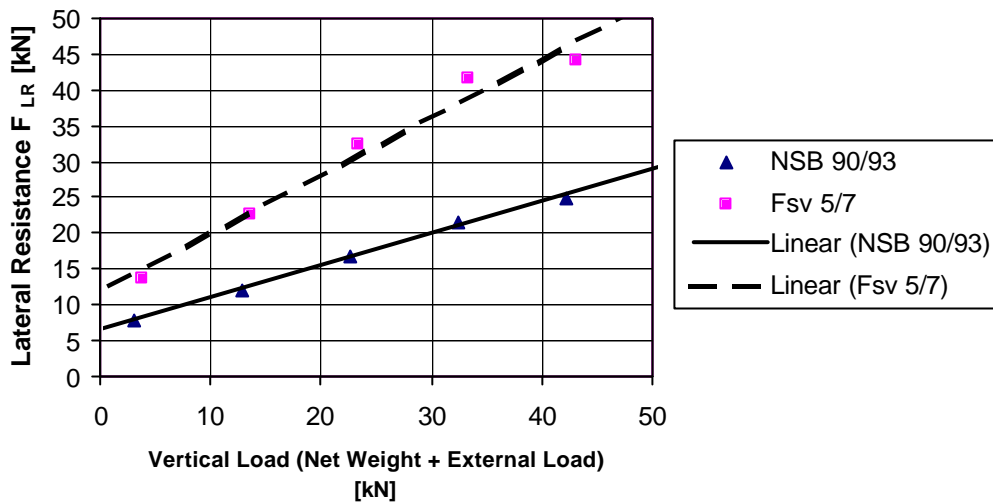


Figure 6: Mean lateral displacement resistance for the tested standard concrete sleepers and for the Friction Sleepers.

4 FIELD TESTING

The preliminary analyses and laboratory testing performed to develop the Friction Sleeper were successful. However, such investigations have their limitations. Therefore field installations with in situ testing were needed to supplement and verify the laboratory investigations.

A test site was selected on the Røros line, near to Koppang in a curve with radius 250 m and axle load limit of 22.5 tons. 200 Friction Sleepers were installed in the selected test section of the track in August 2003. This section with Friction Sleepers was placed in between an existing section of wood sleepers at one side and a section of NSB90 concrete sleepers at the other side. With this layout the testing could easily be carried out simultaneously and under similar weather conditions.

The testing was carried out in August 2004 by use of a Swedish Track Loading Vehicle (Figure 7).

The lateral resistance of the track was measured on five selected sleepers, evenly distributed within each of the three test sections. At each measuring point three tests with different axle loads were carried out according to the test procedure adopted by ORE (Office of Research and Experiments of the International Union of Railways). Under applied axle loads of 40, 70 and 100 kN a gradually increasing lateral load was applied to the track until a displacement of respectively 0.4, 0.7 and 1.0 mm was obtained. The three resulting lateral resistance/displacement - loops are shown in Figure 8.



Figure 7: Arrangement of loading and measuring equipment at one of the test sleepers.

In addition the unloaded track was likewise subjected to a gradually increasing lateral load until a displacement of 2.0 mm was obtained. This is shown as the fourth test loop in the diagram.

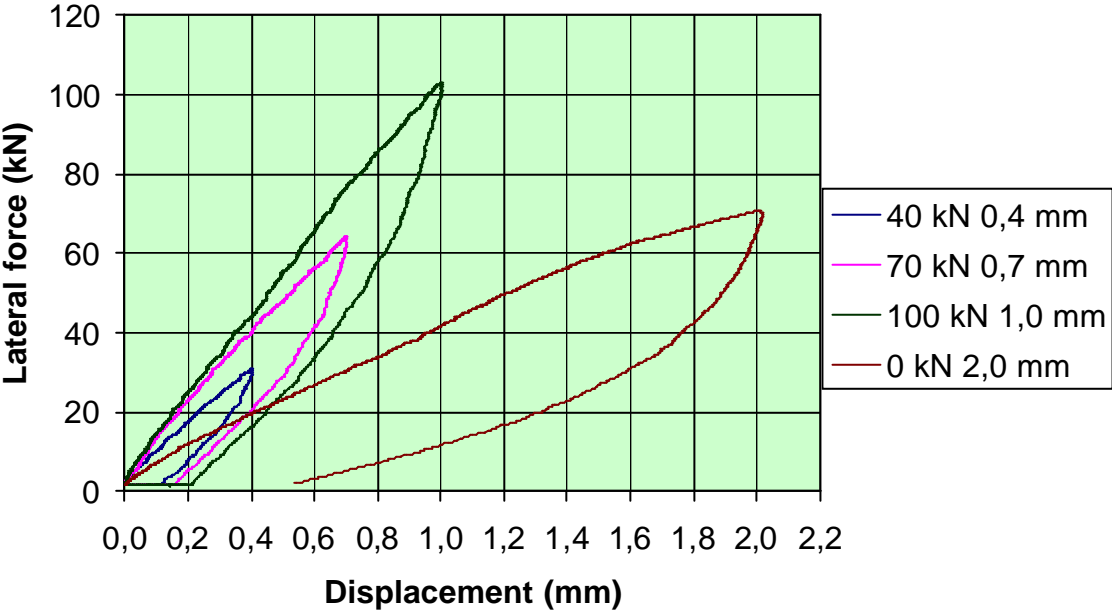


Figure 8: Recordings of the lateral force (resistance) as a function of the displacement for Friction Sleeper No 0+20.

All the measurements of lateral track resistances for the five selected Friction Sleepers are presented in the bar chart in Figure 9, together with the mean values, the standard deviations and the S-lim value according to the Prud'hommes formula for the lowest lateral resistance required for a loaded track with wood sleepers.

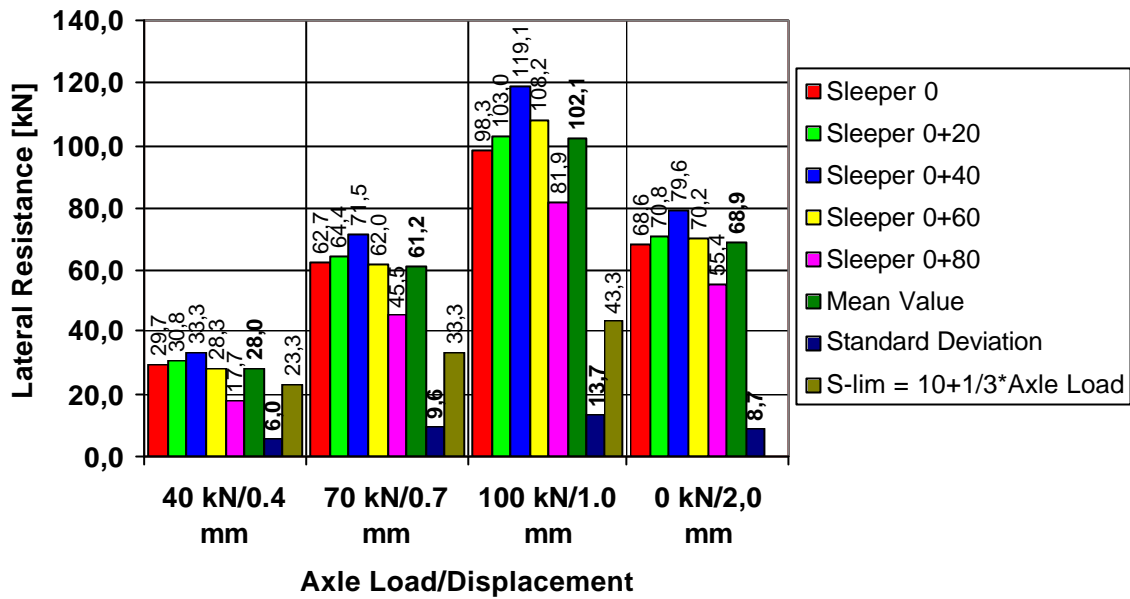


Figure 9: Measured lateral resistances for the 5 Friction Sleepers.

A main object of the field testing was to measure the lateral resistances of the track with Friction Sleepers and to compare them with the neighbouring track structures having wood and NSB90 concrete sleepers.

The lateral resistance of a track, as measured according to the ORE-test procedure, is a function of a complex system containing several variables: ballast, ballast profile, sleepers, rails, fastenings and applied axle load. The measured lateral resistances of different tested sleepers and those of tracks containing these sleepers are not directly comparable. In practise they must be assessed separately on their more or less empirical background, or otherwise analysed by advanced track behaviour models.

In Figure 10 the mean values of the measured lateral resistances for the tracks with wood, NSB90 concrete and Friction Sleepers are compiled in the bar chart. Further the relative resistance values of the tracks when relating them to the tracks with wood and NSB90 sleepers are presented in the in Figure 11.

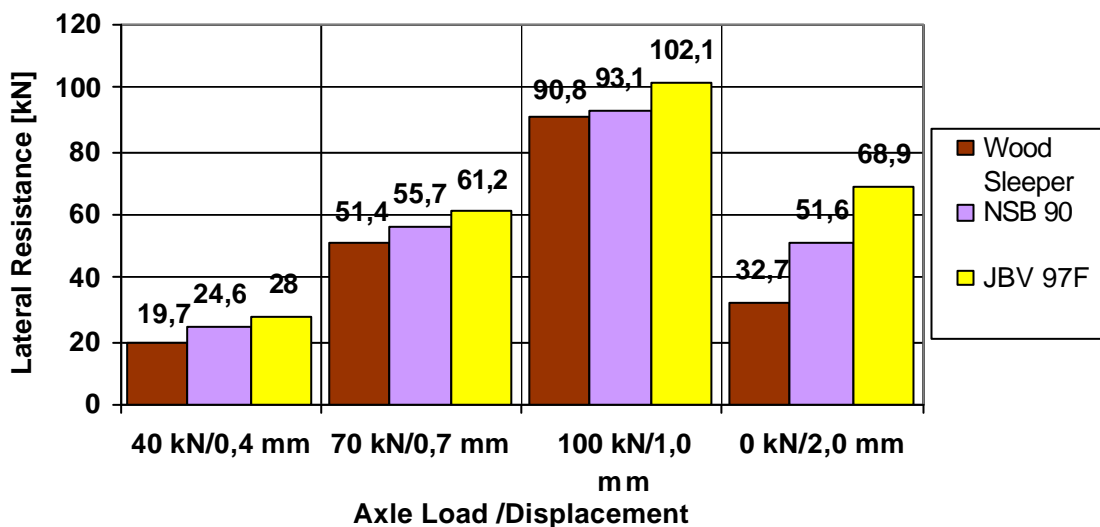


Figure 10: Mean values of the measured lateral resistances for loaded and unloaded tracks with wood sleepers, standard concrete NSB90 and Friction Sleepers.

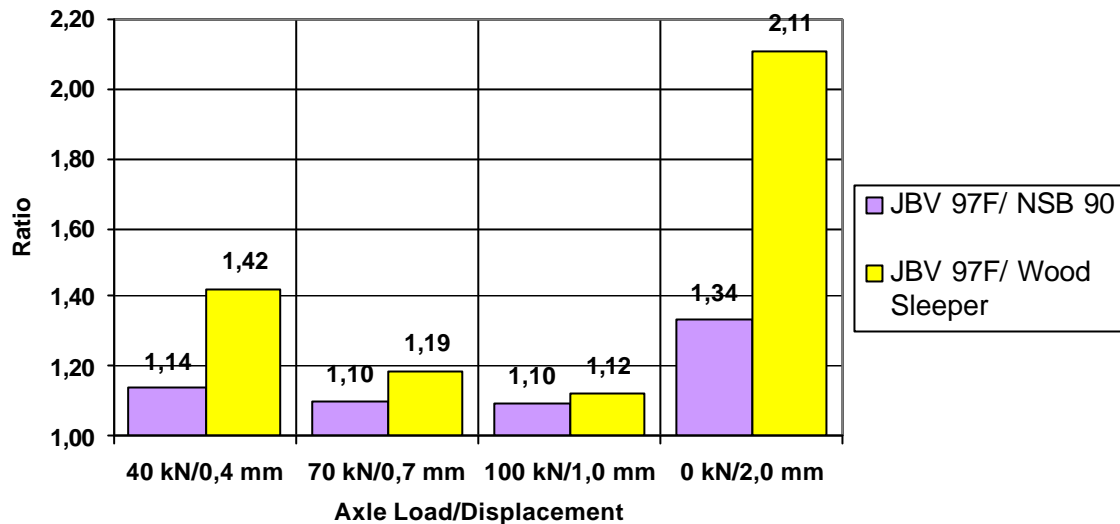


Figure 11: Relative lateral resistances of the tracks.

Based on the raw observation data in these tests, the track with Friction Sleepers obtained the highest absolute and relative lateral resistance values for all three axle load levels.

In the cases of unloaded track the lateral resistance for the track with Friction Sleepers was especially high: around 35 % and 110 % higher than for the track with standard concrete and wood sleepers respectively. High lateral resistance of the unloaded track is very important both in small-radius curves and on long straight tracks to prevent buckling of the track under high temperature stresses.

It was originally hoped to test the lateral track resistances under approximately equal conditions for the important variables. This also was the case as to rail profile, type and quality of ballast, track geometry, weather conditions and temperatures. However, the important factor, the width of the ballast shoulders, was quite different: The width of the shoulder of the track section with NSB 90 concrete sleepers being around 95 cm; for the section with wood sleepers the shoulder width was 60 cm and the shoulder width for the section with Friction Sleepers 45 cm whereas the standard shoulder width for this type of track should be 55 cm. We plan now to find corrections for the deviating shoulder widths by means of theoretical analyses. Based on a rough estimate the measured lateral resistances for the track with NSB 90 and wood sleepers might be reduced by 5 – 10 %, and the lateral resistance of the track with Friction Sleepers should also be corrected upward. Together these corrections may increase the relative lateral resistance of the track with Friction Sleepers considerably.

Other factors that are not taken into consideration as to their influence on the measured lateral resistances are: location of the track on fill and cut sections, other local differences in the old substructure and superstructure, differences between the three types of fastenings and potential differences in consolidation of the track sections.

5 ASSESSMENT OF BENEFITS OF THE FRICTION SLEEPER

The new Friction Sleeper, JBV 97F, is designed with a coarse cogging on the under-side, adapted to the grading of the ballast. The purpose of this cogging is to obtain an increased lateral displacement resistance by exploiting the high internal friction and the granular interlock of crushed stone ballast.

Rail uplift forces influence the lateral stability of the track. They occur in front of and behind the deflection waves under the moving loads. This leads to a corresponding reduction of the lateral displacement resistance. Where the rail uplift forces locally may fully balance the dead weight of the track, there will, in case of standard concrete sleepers, be no lateral resistance component at the under-side of the sleepers in question. However, the coarse cogging of the under-side of the Friction Sleeper will to a fairly large degree maintain the grip of its ridges in the ballast bed even in uplift zones, and maintain a corresponding component of its lateral resistance. These sleepers will give an important increase to the safety against track buckling also in connection with moving traffic loads.

The Friction Sleeper, with its coarse cogging, will also prevent the forming of a slip plane, which otherwise may develop between the under-side of a standard concrete sleeper and fouled ballast during spring thaw. This sleeper will be less sensitive than a standard concrete sleeper to the content of fines and worn particles in the ballast in view to reduction of the lateral displacement resistance.

Narrow formation on railway lines will result in narrow ballast shoulders with reduced lateral displacement resistance. If use of Friction Sleepers it may now be possible to obtain sufficient lateral track stability for the use of CWR on these lines without widening the formation.

The higher lateral displacement resistance obtained with the Friction Sleeper may particularly improve the track stability in curves. These sleepers will make it possible to use CWR in curves with radii less than tolerated to day. The fishplated joints can be replaced with welded joints in narrow curves and the general track standard will be improved, giving better travel comfort and reduced noise and vibrations. The elimination of the rail joints also reduces the costs for track construction and maintenance and gives longer intervals between track adjustments. In addition the Friction Sleepers are expected to give a faster re-establishment of the track stability after maintenance works like tamping. This means shorter periods with speeds restrictions and better regularity of the traffic. Other benefits for the traffic companies seem to be reduced wear and maintenance costs for the rolling stock.

As regards maintenance equipments the design of the Friction Sleeper does not require changing of the packing rods on the tamping machines.

All this show that the use of the Friction Sleeper may in practice gives a series of savings and benefits even there are important questions related to production and installation that still need to be answered.

6 SUMMARY

In summer the temperature stresses in the rails may get very high and induce lateral distortion of the track. In small radius curves ($R < 300$ m) there are restrictions on use of CWR due to the risk of track buckling. This requires fishplated rail-joints which are expensive to maintain, and they initiate impact loads which damage the superstructure and cause high wear on the rolling stock.

To improve safety and reduce maintenance costs it is essential to find a practical way of improving the lateral resistance of a ballasted track. The fundamental idea of the Friction Sleeper is to mobilize more of the high internal friction and the granular interlock of the crushed stone ballast to increase the lateral resistance of the sleeper. The new concrete Friction Sleeper is designed with a coarse cogging at the under-side. The crushed stone ballast is forced upwards into the cogging by tamping and traffic loads where it becomes hooked up and wedged in between the ridges. Under lateral loads a layer of ballast material will be held fixed to the sleeper under-side. This forces the shear-zone to pass lower through the ballast

material itself. In the lowered shear-zone the potential of the granular interlock and the internal friction of the ballast material can be utilised to give high resistance against lateral displacement of the sleepers.

The Friction sleeper was tested in a laboratory before a number of Friction Sleepers were installed at a test site north of Koppang on the Røros line in a small radius curve ($R = 250$ m) in August 2003. During the summer 2004 a Swedish Track Loading Vehicle was used to test the lateral resistance of the track and to check and verify the previously obtained laboratory results. In all the measurements the track with the Friction Sleepers gave the highest lateral displacement resistance. A very important result was that the unloaded track with Friction Sleepers had a very high lateral resistance, 35 and 110 % higher than obtained by the track with the NSB 90 and the wood sleepers respectively. Theoretical analyses of the recorded test data are to be carried out.

Patent for the Friction Sleeper is applied for.

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