Non-destructive continuous dynamic measurement of lateral track resistance offers real-time results directly after track maintenance

The ballast bed is a very important element of the track. A poor quality of the ballast or a not well stabilised ballast bed can lead to high safety risks, such as track buckling or even a train derailment. For over 30 years, Netherlands Railways (NS) has invested in research concerning ballast material, ballast quality and ballast behaviour under operating conditions, as well as during and after track maintenance and renewal. The research was conducted by the research institute of NS which, in 2000, became a subsidiary of the British company AEA Technology Rail and, since Autumn 2006, is called DeltaRail BV. In this article, the non-destructive continuous dynamic measurement of lateral track resistance after track maintenance is addressed.

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FUNCTIONS OF THE BALLAST BED

The most important functions of the ballast bed are [1]:

— as part of the track system, to transfer the axle load to the subsoil and to secure the position of the sleepers by establishing lateral and longitudinal resistance to track displacement;
— as a mass-spring system, to guarantee the elasticity of the track, in order to minimise the dynamic forces in the rails;
— as part of the drainage system, to guarantee a good permeability of water and air, in order to avoid frost heaves and wet spots.

If there are wet spots in the track, it is a sign that the drainage of the ballast bed is inadequate. In Fig. 1, an example of a wet spot is shown.

Fig. 1: Wet spot in the ballast bed

As can be observed, in Fig. 1, all cavities between the ballast stones are filled with water and mud. Such a defect in the ballast bed leads to a decrease in lateral and vertical resistance to track displacement.

Fig. 2: Track buckling

One of the most important functions of the ballast bed is to ensure that the track skeleton is anchored and remains in place, under both loaded and unloaded circumstances. When the lateral resistance of the ballast bed is insufficient, track buckling will occur (Fig. 2).

LATERAL RESISTANCE TO TRACK DISPLACEMENT AFTER TRACK MAINTENANCE

Just after ballast cleaning or track renewal, the density of the ballast is very low and the ballast bed does not offer sufficient lateral resistance to track displacement. Thus, in order to secure a safe track infrastructure after maintenance, a temporary speed restriction would be required, until the ballast has reached sufficient lateral resistance. Since 1975, the research institute of NS which, in 2000, became a subsidiary of the British company AEA Rail Technology and, since Autumn 2006, is called DeltaRail BV, has conducted research projects to determine the lateral resistance of the ballast bed, the effects of the various maintenance activities on the lateral resistance of the ballast bed, and the stabilisation effect of regular train traffic. The results of these research projects have led to a more precise determination of the duration of temporary speed restrictions.

However, due to the separation between infrastructure and operations, in accordance with European Union directives, new infrastructure access regulations, including a performance guarantee by the infrastructure manager, ProRail, have been established. This has led to pressure on the infrastructure manager to avoid temporary speed restrictions and, thus, ProRail has laid down the requirement of a minimum lateral resistance to track displacement after maintenance of 4 kN.

Dynamic track stabilisation
Dynamic track stabilisation has a significant effect on the lateral resistance to track displacement, in that it raises the lateral resistance to such an extent that the track can be opened to rail traffic immediately after track maintenance.

Principle of dynamic track stabilisation
While tamping, sleeper-end compaction and sleeper-crib consolidation have a local effect only, the dynamic track stabiliser produces the effect of stabilisation and homogenisation throughout the entire ballast bed. This is called "comprehensive spatial" compaction [2]. Stabilisation is performed in all three dimensions, which increases the resistance of the track to both lateral and vertical displacement (Fig. 3). The ballast bed becomes homogeneous in vertical direction and cavities under the sleepers are reduced.

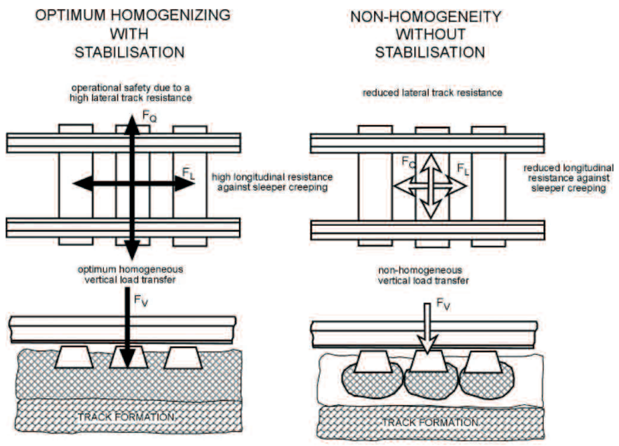

Fig. 3: "Comprehensive spatial" compaction achieved by the dynamic track stabiliser

Work method of the dynamic track stabliser
The roller clamps of the oscillating unit of the dynamic track stabiliser grip both rails and cause the track to vibrate horizontally under vertical static load. The vertical static load is applied by two hydraulic cylinders per stabilising unit. The horizontal vibration is produced by two flyweights rotating in the unit. Two flyweights at a time are linked to each other in their rotating movement, so that their vertical components cancel each other out. Extensive studies carried out by TU Graz, Austria, in 1983 [3], which served to determine the optimum settings for vertical static load, oscillating frequency, duration of application, and amplitude, also proved that compaction of the ballast stones by horizontal vibration is up to seven times more effective than by vertical vibration.

The vibration frequency range of between 30 and 37 Hz has proven to be ideal, regardless of the type of track. At lower frequencies, there will be higher vibration amplitudes of the entire system "machine-track grid", leading to settlements that are difficult to control and, therefore, this frequency range is to be avoided. At higher frequencies, the plasto-elastic (liquefying) properties of the ballast increase, also leading to track settlements caused by the machine that are difficult to control.

If it is intended to reach a maximum settlement value, the maximum constant vertical static load is applied.

The significant effect of dynamic track stabilisation
In Fig. 4, the decrease in lateral resistance to track displacement after ballast cleaning and tamping, as well as the increase due to dynamic track stabilisation and regular train traffic for a standard Dutch track (UIC 54 rails and concrete sleepers) is shown.

From Fig. 4, it can be observed that the lateral resistance is lower after tamping than just before tamping, and that the effectiveness of dynamic track stabilisation on the lateral resistance is significant.

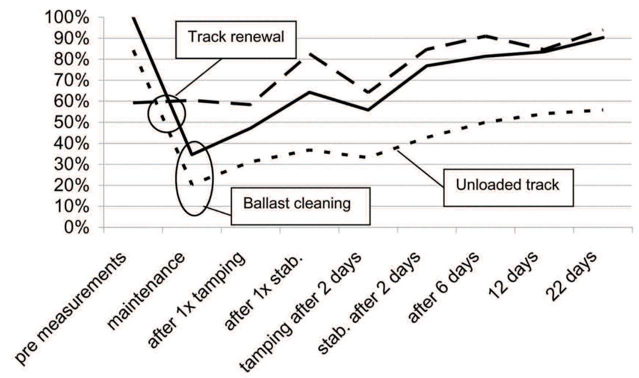

Fig. 4: Lateral resistance after track maintenance

MEASURING LATERAL RESISTANCE TO TRACK DISPLACEMENT: METHODS

The lateral resistance to track displacement can be measured by means of:
— the track panel displacement method;
— the manual single-sleeper shifting method;
— the mechanical track shifting method;
— the method using a derailment wagon;
— the non-destructive continuous dynamic measurement method.

Continuous dynamic measurement of lateral resistance to track displacement
The non-destructive continuous dynamic measurement method, when integrated in a dynamic track stabiliser, offers real-time results directly after track maintenance. It enables the maintenance contractor to hand over the evidence to the infrastructure manager that the track meets the minimum lateral resistance required.

VALIDATION OF THE NON-DESTRUCTIVE CONTINUOUS DYNAMIC MEASUREMENT METHOD

In 2005, the non-destructive continuous dynamic measurement method, developed by Plasser & Theurer, has been validated in The Netherlands against the manual single-sleeper shifting method. For this, measurements were conducted at nine different sections of the new Betuwe Line.

A well stabilised track gives a certain value for lateral resistance, which serves as a standard for all other measurements. Thus, first of all, a reference measurement was carried out at maximum vertical load, a vibration frequency of 30 Hz and a speed of 1.5 km/h. For each of the nine track sections, each time one of the parameters (vertical load, vibration frequency, speed) was changed. Measurements were also taken at the ballast bed with minimum ballast around the sleeper ends, before and after tamping, and after dynamic track stabilisation.

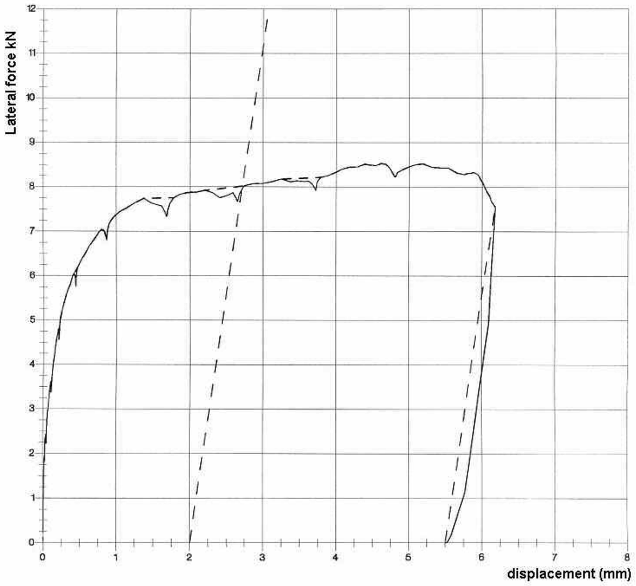

Fig. 5: Force-distance graph of a manual measurement

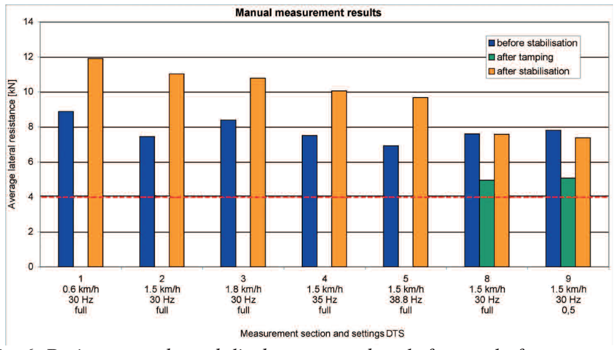

Fig. 6: Resistance to lateral displacement values before and after tamping, and following dynamic track stabilisation

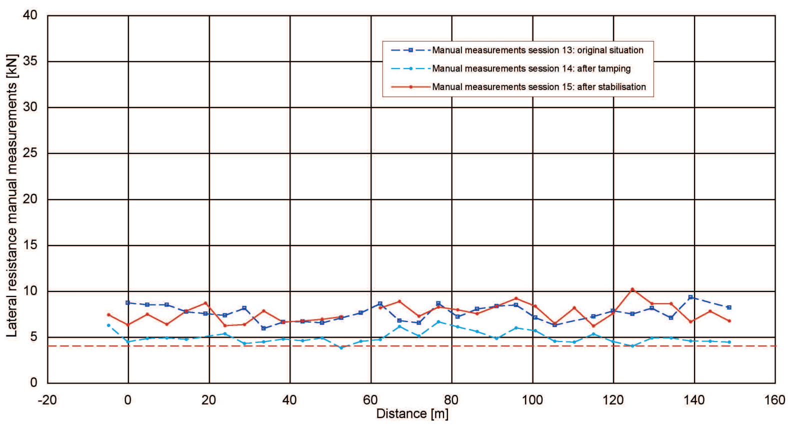

Fig. 7: Results of manual resistance to lateral displacement measurements

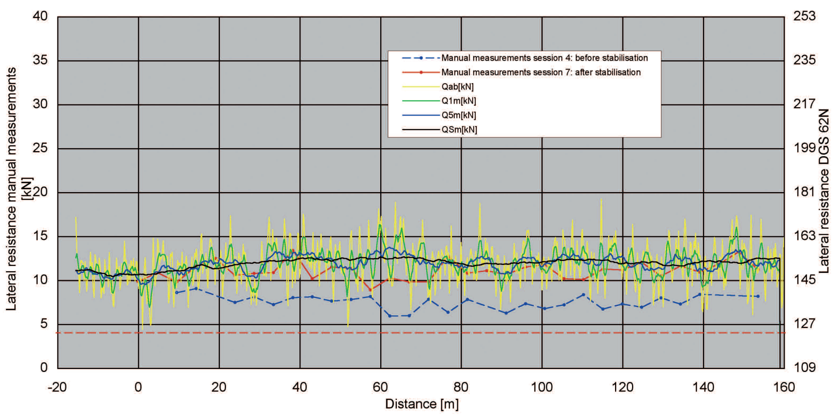

Fig. 8: Comparison of manual measurement and dynamic continuous measurement results

Manual single-sleeper shifting method

Altogether 18 series of manual measurements were performed, with each series embracing 30 to 35 measurements. In these measurements, the force required to displace the sleepers was measured. For this so-called single-sleeper shifting method, the rail fastenings were removed and, using a hydraulic screw-jack, the sleepers were displaced against the rail by about 5 to 10 mm. In each case, the manually measured sleepers were 4.8 m apart (eight sleeper spacings). In Fig. 5, the force-distance graph of one of these measurements is shown. With the help of the calculation program DIAWIN, the zero offsets of the measuring signals were removed.

Measurement results: single-sleeper shifting method

In Fig. 6, the average resistance to lateral displacement measured at seven of the nine different sections of the Betuwe Line, using the manual single-sleeper shifting method, both before and after dynamic track stabilisation, is shown. The threshold value of 4 kN required by ProRail is shown here as a red dotted line.

From Fig. 6, it can be observed that when the ballast bed had been tamped, dynamic track stabilisation raised the resistance to lateral displacement to approximately the same level as before tamping.

In Fig. 7, the resistance to lateral displacement of the various sleepers in a variable track section, measured manually, is shown.

From Fig. 7, it can be observed that in the starting situation and after dynamic track stabilisation, the resistance to lateral displacement of the sleepers observed is always higher than the threshold value of 4 kN laid down by ProRail. When the ballast bed has been tamped but not yet been stabilised, the resistance to lateral displacement is critical compared to this threshold value.

Comparison of results of the manual single-sleeper shifting method and the continuous dynamic measurement method

In Fig. 8, the results of measurements taken manually, together with those produced by the continuous dynamic measurement method of the dynamic track stabiliser (DGS 62N) are shown.

On the left-hand side of the graph, the scaling of the vertical axis for the manual measurements is shown, and that for the continuous dynamic measurement method on the right-hand side.

The relative position of the values of the left and the right-hand vertical axes of the graph was determined on the basis of the many measured data of the reference measurements. The threshold value of 4 kN laid down by ProRail is shown as a red dotted line.

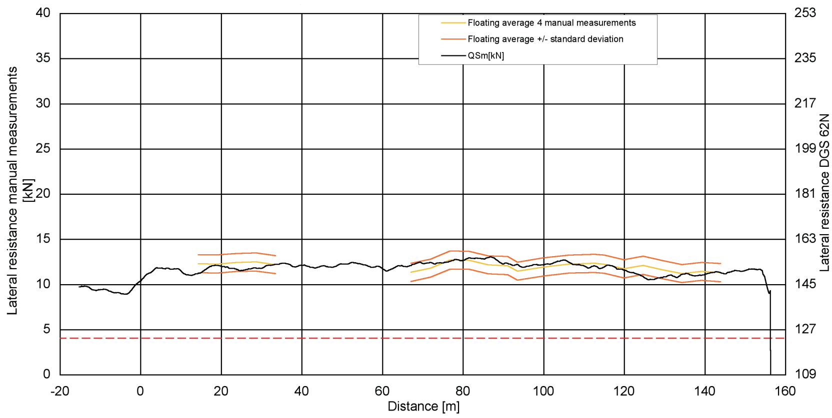

Fig. 9: Comparison of average values (the two red lines represent the confidence interval of lateral resistance for a given distance)

To make it easier to compare the results of the manual measurements with those produced by the continuous dynamic measurement method, the black line in Fig. 9 shows the signal "QSm" of the continuous dynamic measurement method (the floating average value of the signal Qab over 20 m), together with the floating average value of the manual measurements following dynamic track stabilisation (yellow line), which was determined for four measurements = 19.2 m. As can be observed, the relative position of the measurement results of the continuous dynamic measurement method compared to those of the manual measurements coincides, more or less, for the various measurement sections.

From the measurement results, which have been verified by TU Delft, The Netherlands, it can be observed that in the starting situation and after dynamic track stabilisation, the lateral resistance to track displacement is always higher than the threshold value of 4 kN laid down by ProRail. Whereas, when the ballast bed has been tamped but not yet stabilised, the resistance to lateral displacement is critical compared to this threshold value. Therefore, it is of great importance that the ballast bed is stabilised after track maintenance, in order to achieve the highest lateral resistance to track displacement.

CONCLUSIONS

The advantage of the continuous dynamic measurement method of the dynamic track stabiliser lies in the fact that it is a non-destructive method that offers real-time results directly after track maintenance, and enables the contractor to hand over the evidence to the infrastructure manager that the track meets the minimum lateral resistance required.

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