Continuous, non-destructive measuring of lateral resistance of the track

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Abstract

The recreation of the required lateral resistance after track works is an important factor of safety and economy. Since the introduction of the Dynamic Track Stabilizer in 1975 a method of the immediate proof of the re-achieved lateral resistance was searched. For the lateral resistance of the track a certified measuring method which is integrated into the Dynamic track stabilizer is now available. It is based on the energy input by the machine into the track.

AEA Technology Rail, Bam Rail BV and Stukton Rail Infra, together with Plasser & Theurer performed tests and the validation procedure in the Netherlands. The results of these test runs show a good correlation between the traditional manual measurements and those with a the Dynamic Track Stabilizer, DGS 62 N and were certified by the Technical University of Delft, Professor Esveld.

Conclusion: For the first time the lateral resistance of the track can be measured in real time. Further it was proved, that the Dynamic Track Stabilizer recreates the required lateral resistance.

1. Dynamic continuous measurement of resistance to lateral displacement (RLD)

1.1. Influencing parameters

The following parameters influence the effect of track stabilisation (and therefore also the settlement to be achieved):

- stabilizer frequency,
- vertical static load applied to the stabilising units by hydraulic cylinders,
- working speed and
- dynamic power of impact.

While the first three parameters can be freely adjusted during work, the dynamic power of impact is predetermined by the eccentric masses of the stabilizer unit. However, it also depends in squared form on the size of the frequency. Each stabilising unit is equipped with 4 eccentric oscillators. Each pair of oscillators works in opposite directions so that their effect is cancelled out in vertical direction and amplified in horizontal direction.

1.2. Spatial compaction achieved by the DTS

While tamping, sleeper-end compaction and sleeper crib consolidation have a local effect only, the dynamic track stabilizer produces the effect of stabilization and homogenization throughout the entire ballast bed. This is called "*comprehensive spatial"* compaction [1]. Stabilization is performed in all three dimensions, as shown in Figure 1. This increases the track's resistance to lateral displacement as well as to longitudinal displacement. The ballast bed becomes homogeneous in vertical direction and the cavities under the sleepers are reduced.

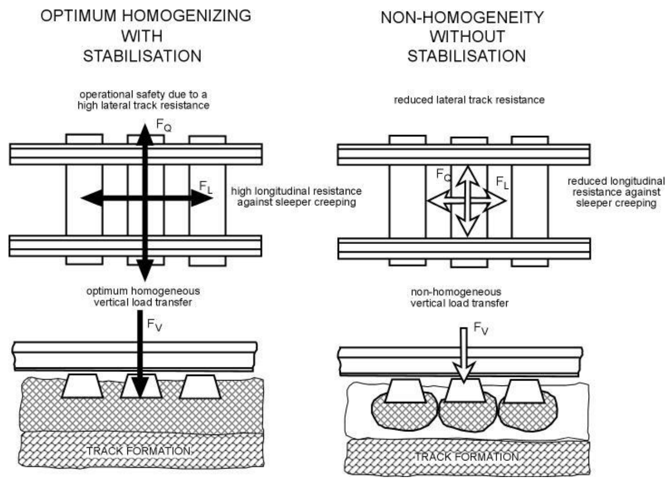

Figure 1: Spatial compaction achieved by the DTS

The roller clamps of the *DTS* oscillating unit 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 *Graz University of Technology* in 1983 [2] served to determine the optimum settings for the vertical static load, oscillating frequency, duration of application and amplitude. These studies also proved that compaction of the ballast stones by horizontal vibration is up to seven times more effective than vertical vibration.

The vibration frequency range between 30-37 Hz has proven to be ideal regardless of the type of permanent way. If work is carried out with far lower frequencies, there will be higher vibration amplitudes of the entire system "machine – track grid". These lead to settlements which are difficult to control and therefore this frequency range is avoided. At higher frequencies the plasto-elastic (liquefying) properties of the ballast increase, also leading to track settlement caused by the machine which is difficult to control. If it is intended to reach a maximum settlement value, the maximum constant vertical static load is applied.

1.3. Resistance to Lateral Displacement (*RLD*)

The value of the resistance to lateral displacement is of decisive importance for the geometric stability to withstand buckling. The RLD is influenced by the following factors:

- type, weight, dimensions and spacing of the sleepers,
- granular composition of the ballast bed,
- quantity of ballast bed material between and at the ends of the sleepers (ballast bed shoulder) and the
- compaction of the ballast bed.

1.3.1 Methods of measuring the *RLD*

The resistance to lateral displacement can be measured using the following methods:

- the panel displacement method,
- the single sleeper shifting method,
- the mechanical track shifting method,
- the method using a derailment wagon and
- **the continuous dynamic measurement of the resistance to lateral displacement**.

1.3.2. Theory of the continuous, dynamic measurement of resistance to lateral displacement (RLD)

The device requires a *DTS* in order to function. During the stabilisation process it measures the track's continuous dynamic resistance to lateral displacement . The device is based on the notion of measuring the output required to drive the stabilisation units and equating it with the frictional power for "rubbing" the track grid into the ballast bed. The following will apply:

$$P_{\mathrm{supp}l} = p_p \cdot V_p \cdot f = F_v \cdot \mu \cdot A \cdot f + P_{loss}$$

The introduction of a standardising reference vertical static load F_N (resistance to lateral displacement at a normal force of 100 kN) produces the following equation:

$$p_p \cdot V_p \cdot f \cdot \frac{F_N}{F_v} = F_N \cdot \mu \cdot A \cdot f + P_{loss} \cdot \frac{F_N}{F_v} = QVW \cdot A \cdot f + P_{loss} \cdot \frac{F_N}{F_v}$$

The term μ * F_N now corresponds to the standardised frictional power, the so-called *RLD* at a normal force of 100 kN. It follows that:

$$RLD = \frac{p_p \cdot V_p \cdot f \cdot \frac{F_N}{F_v} - P_{loss} \cdot \frac{F_N}{F_v}}{A \cdot f}$$

p_p	…	working pressure of the driving hydraulic pump [Pa]
V_p	…	pump filling volume [m³]
f	…	vibration frequency [Hz]
F_N	…	standardising normal force [N]
η	…	efficiency of the pump
F_v	…	vertical force applied on the stabilising units [N]
A	…	vibration amplitude of the stabilising units [m]
μ	…	coefficient of friction between sleeper and ballast bed

The pump volume of the hydraulic pump driving the stabilising units is constant, the standardised reference vertical static load is defined as 100 kN. The pump working pressure occurring due to the frictional force and the vibration amplitude are measured continuously. With the help of the empirically determined stabilizer formula, the device defines the settlement value to be expected at the measured parameters and the prospective gain in lateral track resistance in % after tamping. Furthermore, the device monitors the plausibility limits of the measured working parameters of the *DTS* and gives visual and audible signals about critical changes in the resistance to lateral displacement. The continuous, dynamic resistance to lateral displacement (with a 2 mm displacement – corresponds to the typical vibration amplitude of the *DTS*) as well as the expected gain in RLD and the expected settlement can be recorded by a data recorder. Figure 2 shows the composition of the device.

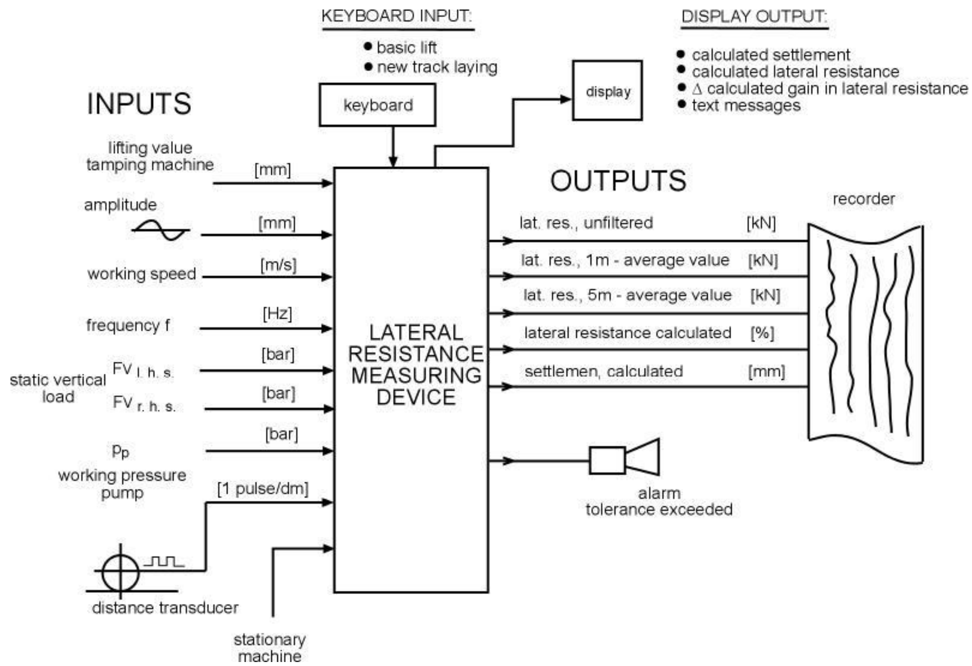

Figure 2: Composition of the dynamic, continuous RLD measuring device

2. Verification of the dynamic continuous RLD measurement

2.1. Reference

Following renewal and maintenance work on the track ballast bed, the infrastructure manager demands a minimum resistance of the track to lateral displacement. The Inframanager has laid down this demand in specifications, such as that, for example, laid down by ProRail in the Netherlands in the specification "ISV00001" for proof of resistance to lateral displacement following ballasting work. The track contractors performing the maintenance work have to fulfil these specifications and provide documentary evidence.

Plasser & Theurer has developed a measuring system for the DGS 62N dynamic track stabilizer which measures the RLD during operation of the stabilizer. It is intended to validate this method of measuring under a variety of conditions on different types of permanent way.

AEA Technology Rail BV (AEAT) provided a measuring method in order to measure the RLD of individual sleepers which is recognised by ProRail.

At the request of Plasser & Theurer, AEA Technology Rail BV performed a series of tests in cooperation with the contractor Strukton Railinfra in search of the correlation between the results supplied by the DGS 62N RLD method and the actual resistance of the individual sleepers to lateral displacement.

2.2. Test series

The measurements were taken on the new line of the Betuwe route in nine different sections of track. The reference measurement was carried out with maximum vertical load, a vibration frequency of 30 Hz and at a speed of 1.5 km/h. For each section of line one parameter (vertical load, speed, vibration frequency) was changed each time. Measurements were also taken at the ballast bed with minimum ballast around the sleeper ends, before and after tamping, and after stabilisation.

2.3. Manual measurements

Altogether 18 series of manual measurements were performed. Each measuring series contains 30 to 35 manual measurements. In these measurements the force is measured in comparison to the displacement of the sleepers. For this so-called single-sleeper method the rail fastenings are removed and using a hydraulic screw-jack the sleeper is displaced against the rail by about 5 to 10 mm.

Figure 3: Manual measurements

The manually measured sleepers lie in each case 4.8 metres apart (eight sleeper spacings). Figure 4 shows as an example the force-distance graph of a manual measurement taken.

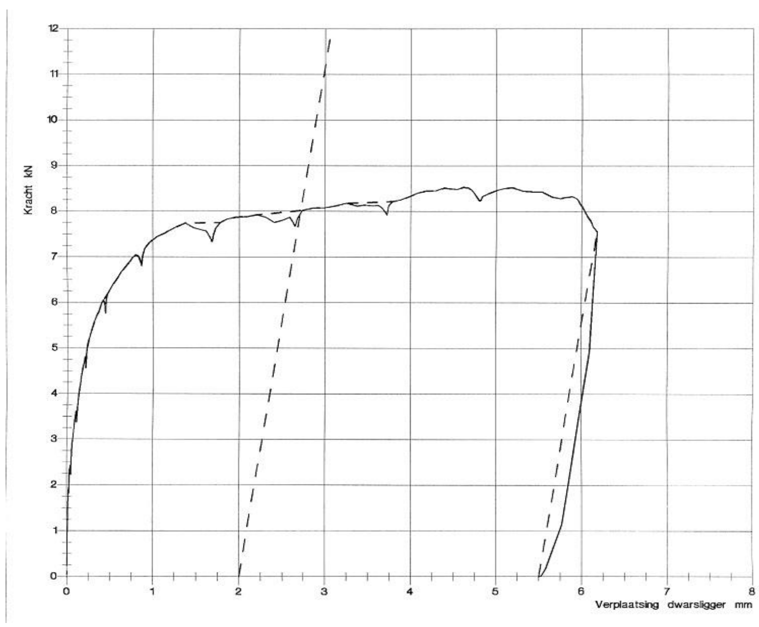

Figure 4: Force-distance graph of a manual RLD measurement

The zero offsets of the measuring signals were removed from the measurements taken by hand at the individual sleepers with the help of the calculation program DIAWIN illustrated in the force-distance graph (Figure 4).

Primarily, the following coefficients were established from the force-distance graphs:

a. the maximum displacement and the associated force;
b. the slope coefficient of the diminishing section of the force-distance graph;
c. the force which coincides with 2 mm remaining displacement. This value is the resistance to lateral displacement according to the definition given by ProRail.

2. Results of the manual measurements

Figure 5 shows in graph form the average, resistance to lateral displacement measured manually of varying measuring sections before and after stabilisation. The threshold value of 4 kN required by ProRail is shown here as a red dotted line. From this diagram it can be seen that when the ballast bed has been tamped, dynamic stabilisation raises the RLD to approximately the same level as before tamping.

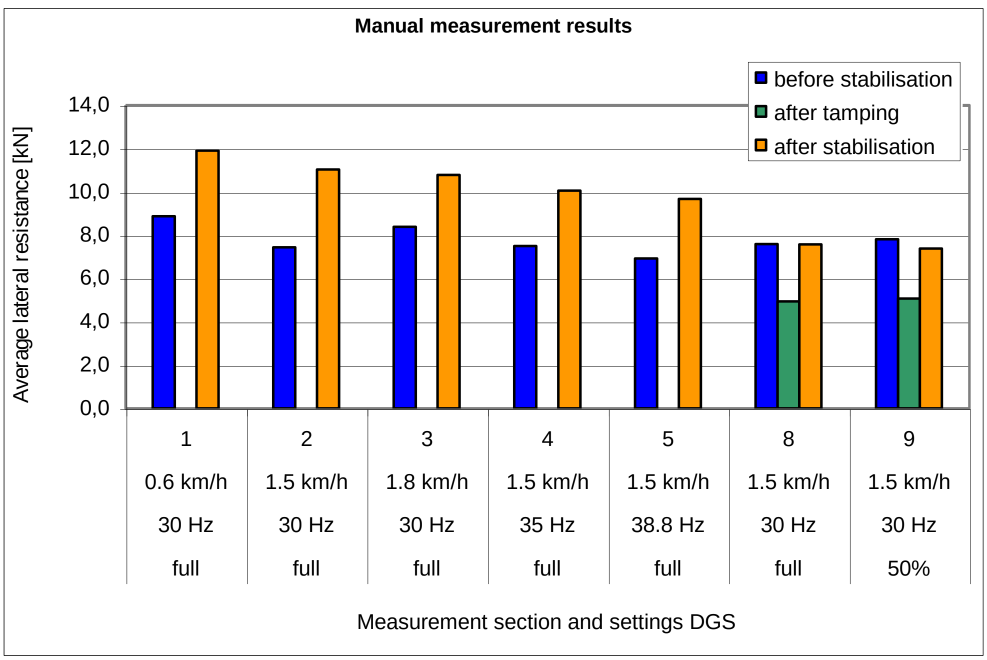

Figure 5: RLD values before and after tamping and following dynamic track stabilisation

In Figure 6 the RLD of the various sleepers measured manually for a variable section of track are shown in graph form. It can be seen from this graph that in the starting situation and after 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 the track not yet stabilised, the RLD is critical compared to this threshold value.

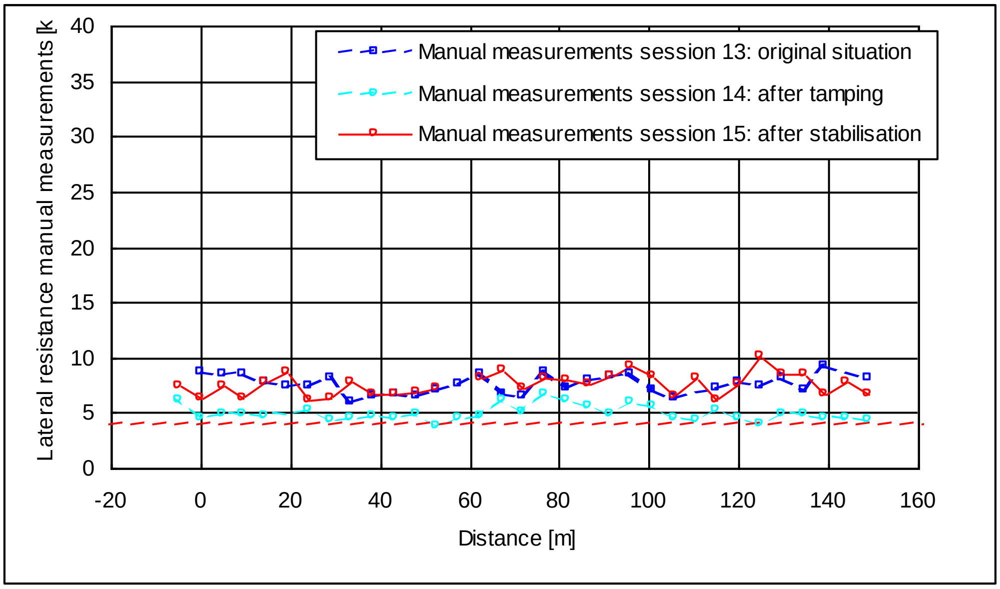

Figure 6: Manual RLD measurements

3.1. Comparison of DGS 62N measurements and manual measurements

Figure 7 shows the results of the measurements taken manually together with the results produced by the DGS 62N RLD measuring system. The results of the manual measurements are shown here by a red line. The scaling of the vertical axis for manual measurements is shown on the left-hand side of the graph. The scaling of the vertical axis is shown on the right-hand side of the graph for the DGS 62N RLD measurement. The relative position of the values of the left and right hand vertical axes of the graph was laid down on the basis of the many measured data of the reference measurements. The threshold value of 4 kN required by ProRail is shown as a dotted red line.

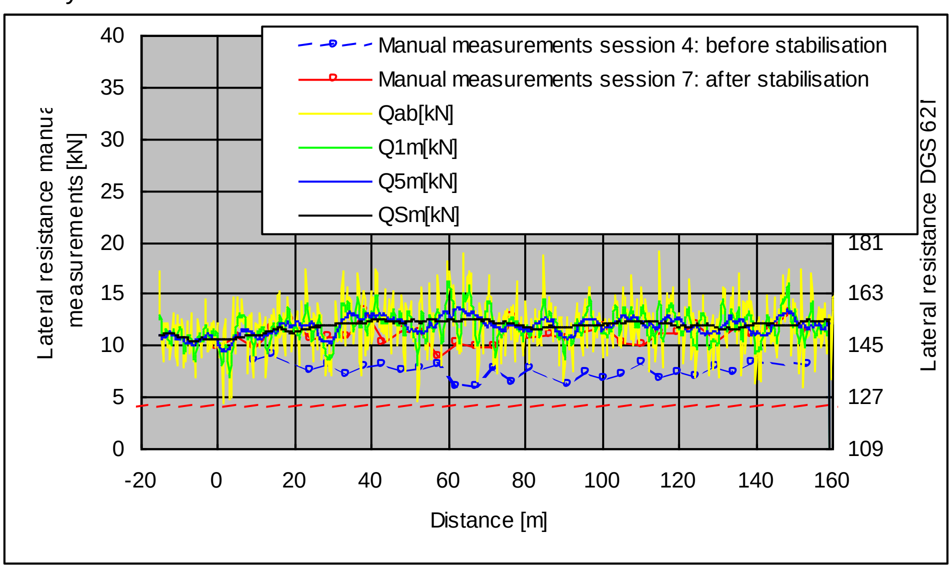

Figure 7: Comparison of RLD manual measurements and dynamic continuous measurement of RLD

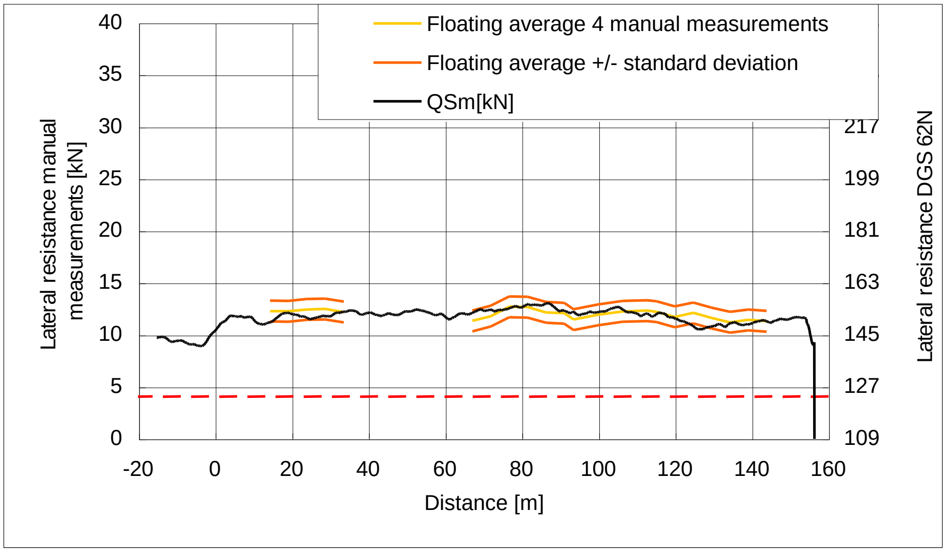

Figure 8: Comparison of average values of manual measurement and mechanical measurement

To make it easier to compare the results of the manual measurements and the DGS 62N measurements, Figure 8 shows the signal “Q_{Sm}” of the DGS 62 RLD measuring system (the floating average value of the signal Q_{ab} over 20 metres), together with the floating average value of the manual measurements following stabilisation. This floating average value was determined with a window size of 4 measurements = 19.2 metres and represented by an orange line. For each measuring section the standard deviation of the manual measurements with this floating average value is added and subtracted from the floating average value. The resulting values are shown as two red lines.

The relative position of the DGS 62N measuring results compared to the results of the manual measurements coincides more or less for the various measuring sections. On the measurements with minimum vertical static load, the measured values produced by the DGS 62N measuring system are much higher than in all other cases. When there is a rise in the vibrating frequency of the stabilizer over 35 or 38.8 Hz, this causes a rise of around 10% in the DGS 62N measuring results but not a rise in the RLD values measured manually. Therefore, when determining a clear correlation between the DGS 62N measured values and the manual measurements, a specific vibration frequency should be laid down as a framework condition.

3.2. Determining the correlation

Using the measured values shown in Figure 9 a linear regression line was calculated which is illustrated in Figure 9.

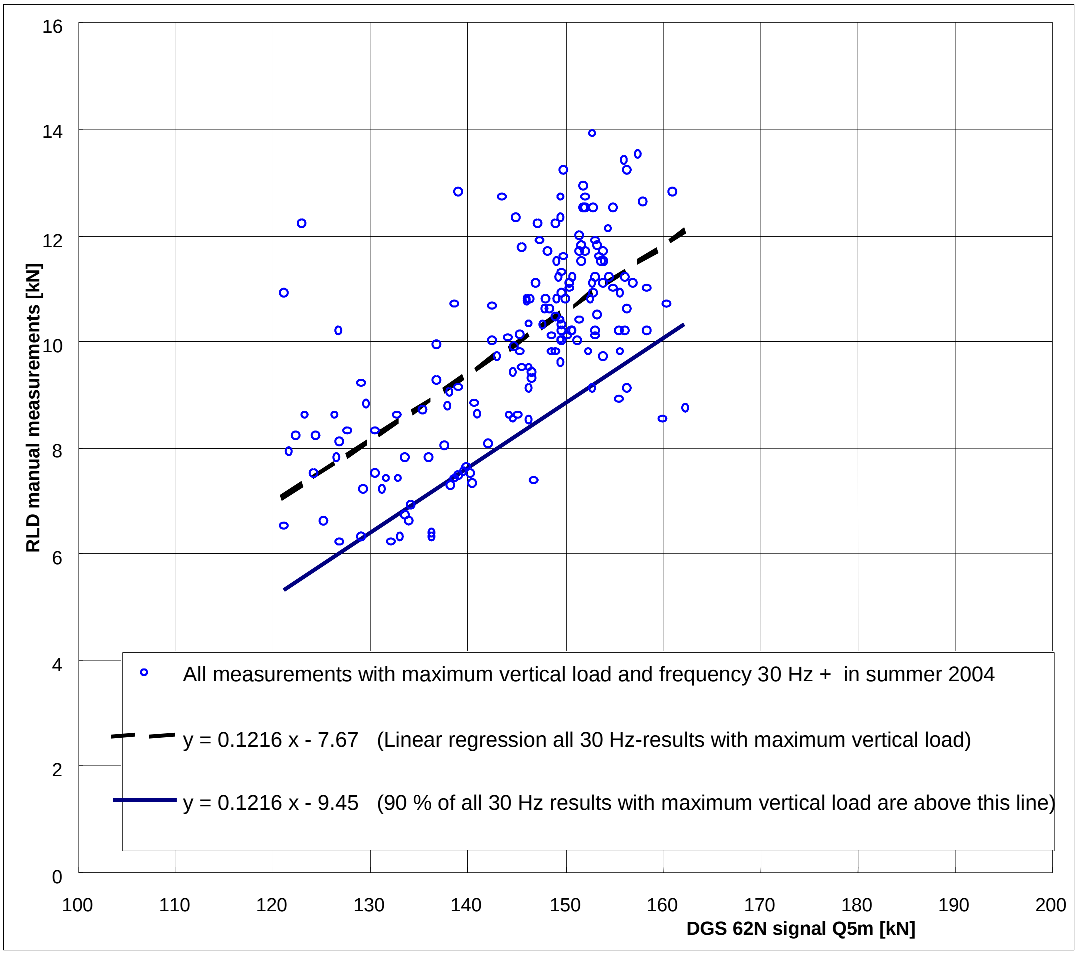

Figure 9: Correlation between manual measurements and DTS

3.3. Conclusions

a. In the starting situation and after 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 the track not yet stabilised, the RLD is critical compared to this threshold value.

b. The results of the RLD measurements carried out by the Plasser & Theurer DGS 62N and the manual RLD measurements carried out by AEAT show a correlation. The relation between the DGS 62N measured values and the RLD values measured manually can be approximated by the formulae:

$$QVW_{single\ sleepers} = 0.1216 * result_{DGS\ 62N} - 7.67$$

c. When the RLD value is calculated with the formula (90% line)

$$QVW_{single\ sleepers} = 0.1216 * result_{DGS\ 62N} - 9.45$$

d. The results should correspond to the threshold value of 4 kN laid down by ProRail.

e. The formulae apply only for the reference values: full vertical load and a stabilising frequency of 30 Hz.

f. With a stabilising frequency of 35 Hz the $\text{result}_{\text{DGS 62N}}$ is approx. 20% higher than with an impulse frequency of 30 Hz. This is taken into account automatically in the device performing the continuous dynamic RLD measurement.

g. The results are independent of the speed.

The results have been approved by Professor Dr. ir. Coenraad Esveld, Delft University of Technology, Netherlands.

Literature

[1] Schubert, Egon: Die räumliche Wirkung der Verdichtung des Gleisschotters, ETR Eisenbahntechnische Rundschau (37) 1/1988, S. 71-74

[2] Fischer, Johann: Einfluss von Frequenz und Amplitude auf die Stabilisierung von Oberbauschotter, Dissertation, TU Graz, Juni 1983