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Test Track Low Frequency Vibrations Reducing Measure Near Oosthuizen

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ABSTRACT

At the railway line north of Amsterdam the substructure of the track has been reconstructed to reduce vibrations at lower frequencies. Such a measure is sought for in the western Holland area where people are annoyed by railway traffic vibrations. Over a length of 300 m a 0.45 m thick concrete slab has been installed directly under the ballast layer. The thickness of the concrete plate has been determined by numerical calculations. To be able to compare the effect of the concrete slap a existing track with heavy passenger train traffic a representative weak soil profile has been chosen for a test site, which was found at the Oosthuizen. At this test site an extensive set of vibration measurements have been conducted to determine the effect of the taken measure and to validate the used numerical procedure to predict the vibrations.

KEYWORDS

numerical calculations, railway traffic, soildynamics, vibration measurements

INTRODUCTION

Dutch Rail manage and exploit all the main railways in the Netherlands. In the recent years Dutch Rail is more and more confronted with complaints of annoyance by perceptible vibrations due to railway traffic. These vibrations are caused by a more intense use of the current rail infrastructure by using heavier axle loads and increasing trainspeeds. In the near future the call for reducing vibrations for rail traffic will be larger when all the planned new railinfrastucture in the Netherlands has been completed. The vibrations originate from the dynamic forces induced by a train passing on the track. The vibrations will pass through the trackbed into the underlying soil and propagate to the dwellings next to the railway track. Immissions in buildings are normally harmless for the buildings as such, but they can be very annoying for the people living there.

In the western part of the Netherlands we have to deal with weak soil layers of organic peat and weak clay. Dominant frequencies under these conditions with heavy trains are around 5 Hz. Current vibration reducing methods, like resilient elements, rubber mats, etc., have no effect on these low frequencies. However, to be able to reduce vibrations from railway traffic in the future Dutch Rail is performing research into new measures specific for the Dutch situation.

By means of a prototype test at a test track nearby Oosthuizen, about 25 km north of Amsterdam, the effect of a new design of the trackbed has been investigated. The aim of new design is to reduce amplitude the low frequency vibrations significantly at the substructure of the track. The tested new design consisted of a concrete slab directly under the ballast layer of the track. In one weekend the existing track has been converted in the new design for a 300 m long stretch. Rebuilding the track in such a short period of time had special specifications to the design of the concrete slab.

The dimensions of the concrete slab have been determined by a series of numerical procedures in advance. With these calculations the effect of the concrete slab is determined in terms of reduction of the displacements at the trackbed and the reduction of the vibrations in the free field.

For the verification of the effect of the concrete slab in situ an extensive set of vibration measurements were taken. These measurements were taken at the track, the ballastlayer, at the interface of substructure and the ground and at several locations on the soil surface at several distances from the track. The vibrations have been measured before and after the construction of the concrete slap at the test site and at a reference site with comparable geotechnical profile.

In general the numerical results compare well with field measurements of the original situation and the new situation on the trackbed. However, the results of the measurements near the test track do not agree with the calculations.

DESIGN OF THE MEASURE

The basic principle of this trackbed design is to spread the stresses of an axle load over a larger area resulting in a smaller amplitude of the displacements. The spread of the stresses in the longitudinal direction has been realised by stiffening the substructure. The stiffening of the substructure has been realised by a concrete layer directly under the ballastlayer of the existing track. To ensure the spread of the trainload in the longitudinal direction no discontinuities in the concrete slab are allowed. Therefore slab is made as a continues construction.

For the test a 300 m long track has been reconstructed with a concrete slab under the ballastlayer. The construction of the concrete slab is complicated due to the fact the reconstruction is carried out in a existing track. The reconstruction of the track had to be done in one weekend, while the second track is still in service. The short construction period made it necessary to use a high quality concrete, which had enough strength to carry a trainload after 24 hours. Keeping the second track in service makes it difficult to work and special measures has to be taken to restrain the track in service from deforming. A sheet pile wall installed between the two tracks should hold the second track.

Figures 1 to 4 show different stages in the construction of the concrete slab. At the first stage the temporally sheet pile wall is installed between both tracks. In the next stage the rail, sleepers are removed together with the ballast and the sand of the substructure. The excavation is levelled, the shuttering is installed and the reinforcement is manually placed. In the third phase the concrete is poured and left to harden for 15 hours. In the last stage the ballast is brought back into place followed by the sleepers and the rails.

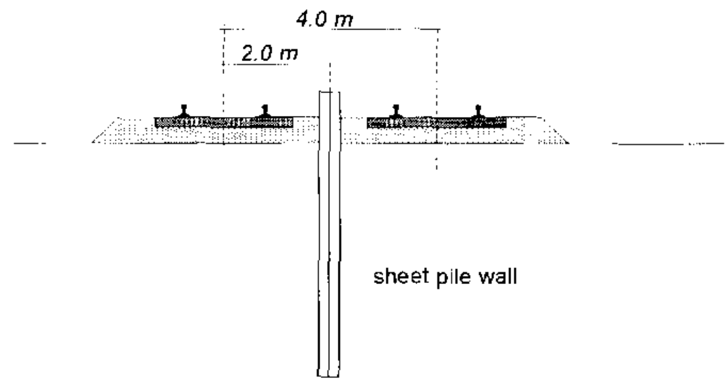

Fig. 1 Phase 1; installation of the temporary sheet pile wall

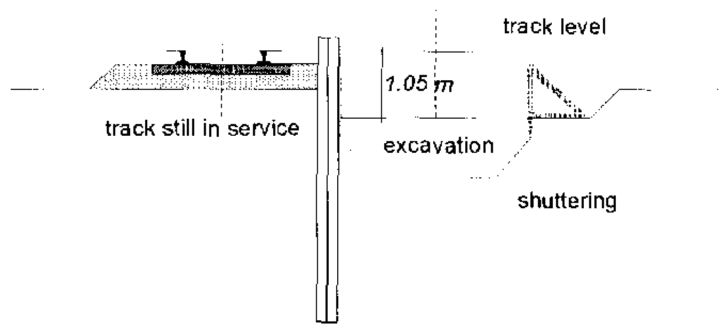

Fig. 2 Phase 2; removal of the track, excavation and shuttering

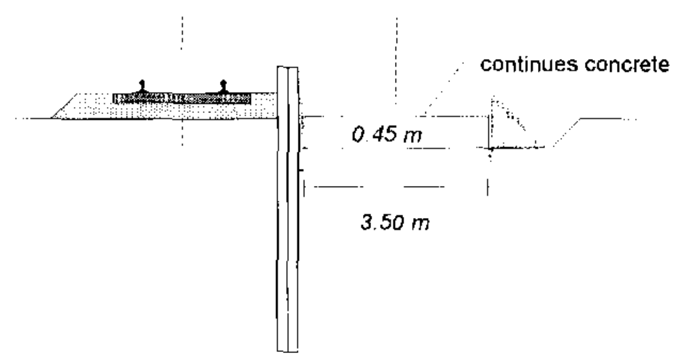

Fig. 3 Phase 3; pouring concrete, 0.45m thick, 3.50m wide and 300m long.

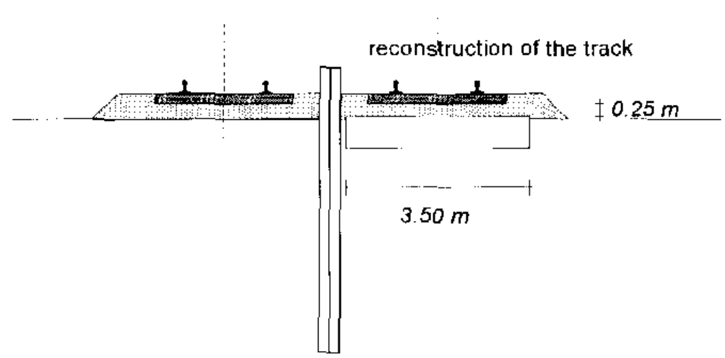

Fig. 4 Phase 4; reconstruction of the track.

With the sheet pile wall and the shuttering installed a space of 3.50 m remained for the concrete slab. This width was just wide enough to carry effectively the trainload by the concrete plate. The prediction calculations showed that a 0.45 m thick slab gives a significant effect in reducing the vibrations at the track. A 0.30 m thick plate gives at higher train speeds only a poor result. Thicker plates showed only a marginal increase of the effect of the trackbed stiffening.

GEOTECHNICAL PROFILE

To be able to compare the effect of the concrete slab two series of vibration measurements have been performed, one before and one after the reconstruction. To check the reproducibility of the two series, reference measurements have been performed at a 300 m reference track. For the reference track it is required that the geotechnical profile, with emphasis on the dynamical behaviour, is identical to the profile of the test track. For the test and reference track a total length of 600 m track with identical material parameters is required.

At Oosthuizen a track of 1.2 km was available. The profile at this location has been examined by CPT's.

The soil profile between track kilometres 23.0 and 23.6 is until a depth of 12 m identical. Table 1 gives an overview of the profile, which consists of 10 m thick weak soil profile representative for the Western part of the Netherlands. At lower depths the profile varies a bit along the selected track. From km 23.0 to km 23.4 runs sand layer, which absent along the rest of the track.

Table 1 Geotechnical profile for km 23.0 to 23.6.

depth soil layer in reference to surface level [m] from	to	soil type	dynamic elasticity modules [MN/m^2]
surface level	-0.30	ballast	150
-0.30	-1.3 to -1.9	sand	50
-1.3 to -1.9	-1.5 to -2.4	clay	
-1.5 to -2.4	-2.9 to -3.4	weak peat	2.1
-2.9 to -3.4	-10.4 to -11.2	clay	9.0
-10.4 to -11.2	-11.2 to -12.0	silty clay	
-11.2 to -12.0	∞	sand	

After the location the test and reference track have been selected, initial vibration measurements have been performed to verify the reproducibility of the selected track. These measurements show a good reproducibility. The variation in the soil profile at lower depths seems of no significant influence.

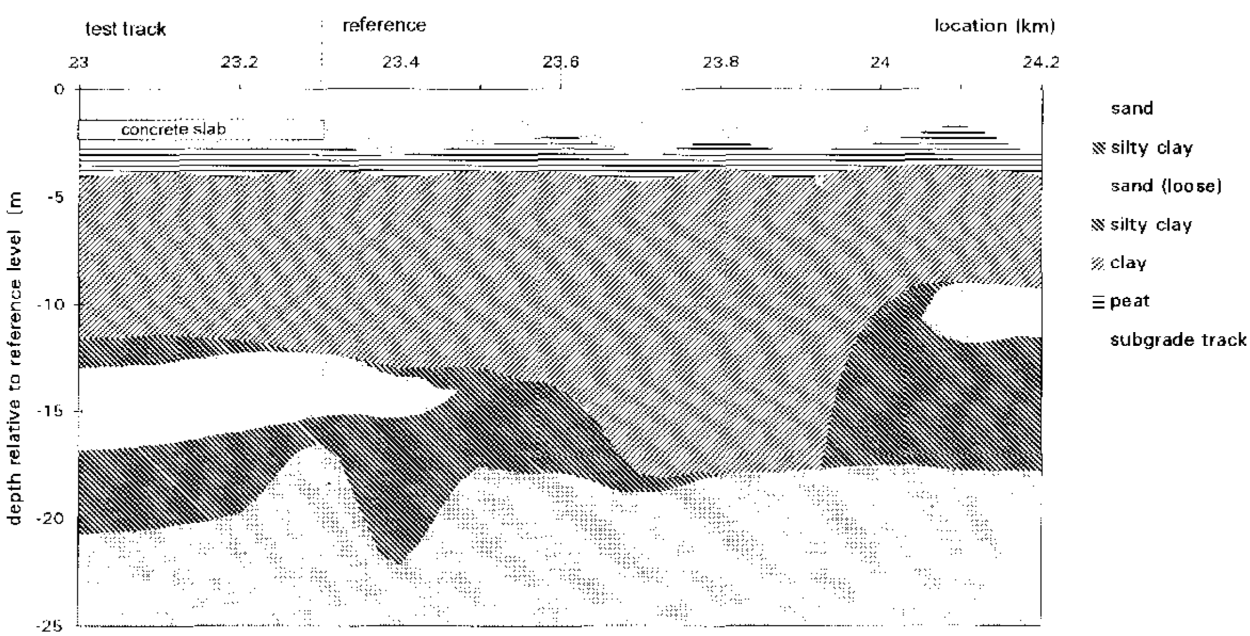

Fig. 5 Geotechnical soil profile

PREDICTION CALCULATIONS

Before the test a prediction of the effect of the concrete slab has been made by a series of numerical calculations. The calculations have also been used to determine the dimensions of the concrete slab.

With the current computer software and hardware it is not yet possible to make a complete three dimensional numerical analyses of the dynamic effects. Therefore the prediction calculation has been split in several numerical procedures, which are based on the different aspects which determine the propagation of the vibrations. The prediction calculation can be split globally in two parts, namely:

I. calculation of the dynamic displacement of a separate point at the railtrack;
II. calculation of the vibration immission of the railtrack at a certain distance from the track.

The dynamic displacement of a separate point at the railtrack (part I) have been analysed by modelling the track as a continues beam supported by springs and dampers. The parameters for the beam and the support have been determined by a three dimensional analysis of the track, substructure and soil profile. The continues beam loaded with a train with a certain speed. The result of this step is a displacement at one point at the track as a function of the time.

For the immission calculation (part II) first the immision of a single point has been determined by using a finite element model. The axial symmetric model incorporated a part of the trackstructure, and the surrounding soil profile. This model is loaded with the displacement versus time function from the first part. In case of a train there are multiple sources for vibrations along the track. To include this effect of the train, the responses of multiple points along the track are added together, taking into account the distance to the source and the time when the train passes the source location.

The calculations have been performed for 3 different track structures, one calculation with the original construction, one with a 0.30 m thick slab and one with a 0.45 m slab. Two trainspeeds have been analysed, namely 100 and 140 km/h. The results of the calculations are shown in Fig. 6 and Fig. 7 as effective vertical velocities at a certain distance from the track. The graphs in both figures have been determined by taking the maximum calculated effective velocity at a certain distance from the track. Due to inaccuracies in the summation method, especially for the greater distances, there will be some variability in the presented results.

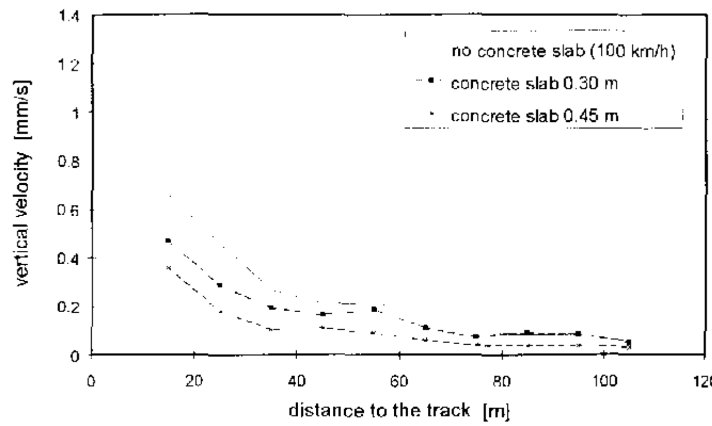

Fig. 6 Calculated effective vertical velocities at 100 km/h

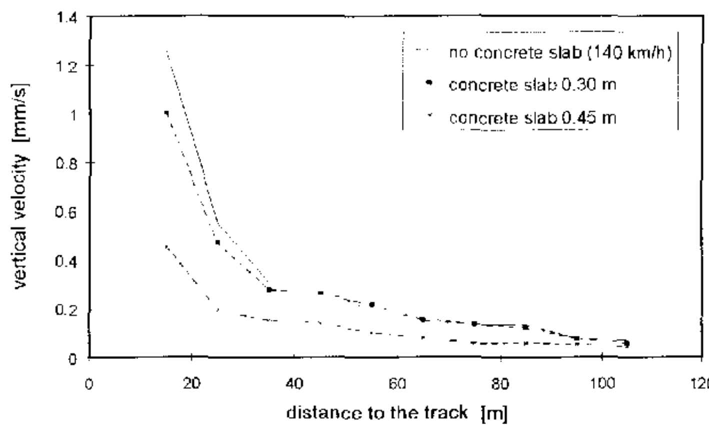

Fig. 7 Calculated effective vertical velocities at 140 km/h

Table 2 gives an overview of the reduction factor of a track with a 0.30 m or 0.45 m thick slab at 100 and 140 km/h. The calculations show that a 0.30 m thick concrete slab has a minimum effect at 140 km/h and gives a reduction of 25 % at lower trainspeeds. The reduction effect of a 0.45 m plate gives a lot more effect at both considered trainspeeds.

Table 2 Calculated reduction factors.

	Reduction factor compared the original situation			
train speed	100 km/h		140 km/h	
plate thickness	0.30 m	0.45 m	0.30 m	0.45 m
15 m	71 %	54 %	79 %	36 %
25 m	63 %	39 %	84 %	36 %
55 m	86 %	38 %	116 %	53 %
105 m	71 %	43 %	86 %	57 %
average	74 %	45 %	93 %	47 %

MEASUREMENTS

Program of measurements

To examine the effect of the concrete slab on the reduction of the vibrations in the free field a comprehensive series of measurements have been performed. Per cross-section accelerations have been measured at 4 different locations in the free field. The vertical and horizontal vibrations perpendicular to the track have been recorded. Four cross-sections at regular distances have been measured along the test track and four cross-sections along the reference track. Next to the vibrations in the field also the vertical vibrations of the top of the track and the bottom of the substructure at a depth of 1.75 m have been measured.

In the series before the reconstruction 25 trains have been measured and 27 after. The maximum passage speed at the track is 140 km/h and most of the trains passed at this speed the test site. Seven trains were asked to reduce their speed to 100 km/h. Furthermore a distinction has been made between the various types of trains with an emphasis on heavy trains.

The recorded signals are digital filtered with a bandpass filter between 1 and 80 Hz. From those filtered signals FFT have been made to determine the response frequency of the soil. Subsequently the velocities have been determined by integrating the accelerations. From those velocities the effective vibration velocity has been determined. The procedure to assess the effective velocity has been carried out according DIN 4150 [1992]. Further the effective velocities of different measurements are statistically processed to be able to compare the various series.

Results of the measurements

Reference track. The vibration measurements at the reference track show a good agreement for the two measuring series, the first set of measurements before the reconstruction and the second set after. Fig. 8 shows the average measured effective velocities of the reference field compared to the measurements at the test track location taken before the reconstruction. Besides some minor variations in the measurements with trainspeeds around 140 km/h are the results of the test track good comparable. These measurements confirm the conclusion from the geotechnical survey, were it was concluded that the soil profile along the test track is equal to the profile at the reference track.

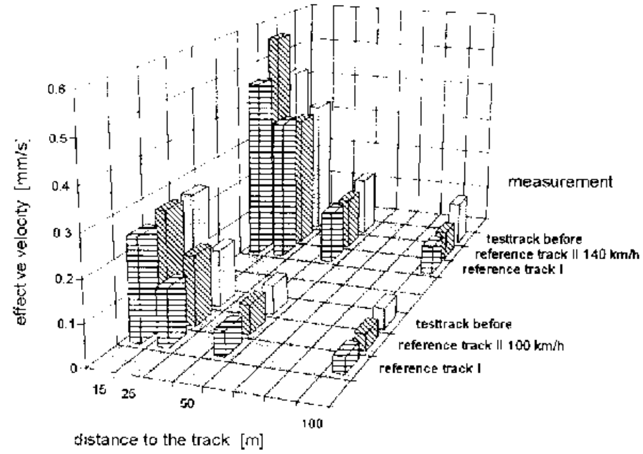

Fig. 8 Measurements at the reference track and the at the test track before reconstruction

Test track Table 3 gives the effective velocities in mm/s before and after the reconstruction with the concrete slab at the test track. For each measurement the vibrations in the measured directions are added together and the average measured effective velocities are given. The effect of the concrete is determined by the difference between the measurements before and after. The in Table 3 given values are also shown in the graph in Fig. 9, where the effective velocities are plotted against the distance from the track. The graph shows that in the free field the vibrations, measured in effective velocities, increase at 15 and 25 m from the track. From the measurements at 50 and 100 m it was hard to distinguish the vibrations caused by the train from the background noise. Therefore the results at these distances are less accurate.

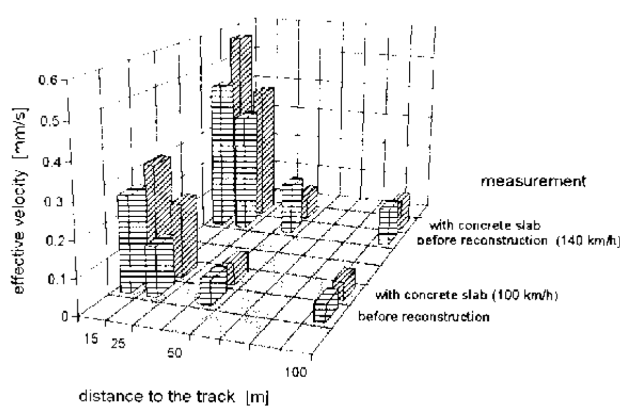

Fig. 9 Measurements of the test track before and after the reconstruction

Table 3 Results of the measurements.

	effective velocity, frequency range 1-10 Hz [mm/s]					
	100 km/h			140 km/h		
	before	after	effect	before	after	effect
track	3.78	1.94	51 %	5.76	3.85	67 %
15 m	0.27	0.31	114 %	0.44	0.57	130 %
25 m	0.14	0.21	150 %	0.35	0.40	114 %
50 m	0.07	0.06	86 %	0.15	0.08	54 %
100 m	0.05	0.05	100 %	0.11	0.09	82 %

Substructure Next to the measurements in the free field also the effect of the concrete slab has been measured at the ballast layer. The results of these measurements are shown in Fig. 10 at 100 km/h and Fig. 11 at 140 km/h. The results of these measurements are given in a frequency spectrum from 1 to 10 Hz, the intended range to reduce the train vibrations.

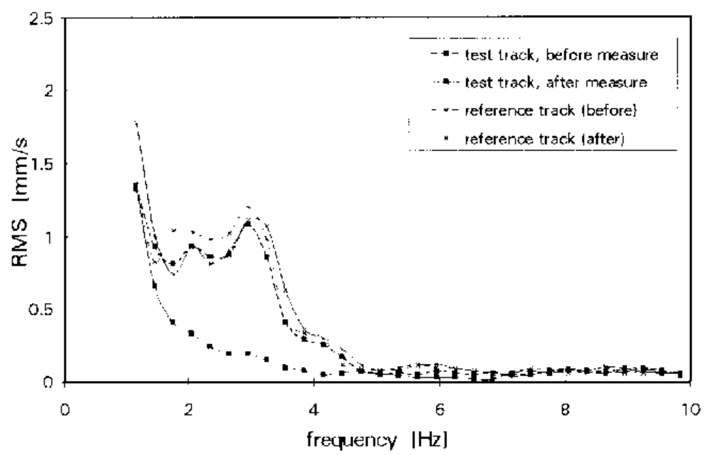

Fig. 10 Measurements at the track at 100 km/h

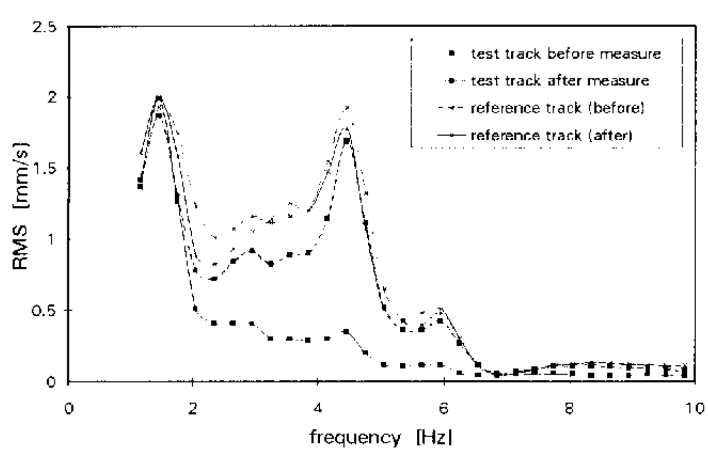

Fig. 11 Measurements at the track at 140 km/h

The lines with the black squares are the measurements at the reference track and the dashed line with the crosses the measurements at the test track before the measure. All these lines are in reasonable good agreement, indication again that the measurements reproduce well before and after the reconstruction. The graphs show also the effect of the concrete slab with the solid line with crosses. This curve indicates a significant reduction of the mainly dominant vibrations in the low frequency range from 2 to 7 Hz. For trainspeeds of 100 km/h the average reduction is 49 %, while at 140 km/h the average reduction is 33 %, see also Table 3.

VALIDATION

Before the reconstruction of the track the results of the initial measurements and the calculation results have been compared. Table 4 gives the effective velocities at 35 m from the track. In general the calculations and the measurements show a good fit. Furthermore the measurements showed a dominant frequency between 3 and 5 Hz, which was also found with the calculations. These results show that the chosen calculation method with the different model step leads to reliable results.

Table 4 Comparison measurements and calculations for the original situation

	effective velocities [mm/s]			
train speed	100 km/h		140 km/h	
	horizontal	vertical	horizontal	vertical
measurements	0.52	0.46	0.42	0.31
calculations	0.51	0.31	0.43	0.27

CONCLUSIONS

From the prediction calculations it is found that a 0.45 m thick concrete slab installed as a low frequency vibrations reducing measure a reduction of about 50 % of the effective velocity can be achieved. A 30 cm plate gives only a 25 % reduction for train speed at 100 km/h and less than 10 % at a train speed of 140 km/h.

The results of the prediction calculations without the concrete slab show a good agreement with the measured values in the free field.

The measurements before and after the reconstruction at the reference track show a good agreement, which indicates that the two series of measurements are reproducible.

Directly at the track and the substructure the new trackstructure with the concrete slab reduces the vibrations. Measurements show for trainspeeds around 100 km/h the effective velocity is about 50 % less than in the original situation. Trainspeeds around 140 km/h the effect is only 30 %. The aim of significantly reducing the low frequency vibrations at the track is fulfilled. The measured reductions for the different trainspeeds are in good agreement with the numerical calculations.

The dominant frequencies in the free field along the test track are mainly around 4 Hz and between 6 and 7.5 Hz.

Despite of the good results at the track, the vibration measurements in the free field (> 15 m) next to the test track show no significant difference between series taken before and after the reconstruction. The effective velocity at the dominant frequencies higher than 3.5 Hz show no clear reduction in the series after the reconstruction. At frequencies lower than 3 Hz the vibrations are significant reduced. At this point the measurements do not agree with the numerical calculations.

It is recommended evaluate in detail the used method to determine the vibrations in the free field and how to incorporate a concrete slab or any other track stiffening construction.

ACKNOWLEDGEMENT

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REFERENCES

DIN 4150-2 [1992]. *"Erschutterungen im Bauwesen, Einwirkungen auf Menschen in Behauden Teil 2."* (in German)

NS Technical Research [1995]. *"Verkennend trillingsonderzoek proeftraject Oosthuizen."* NSTO/6/10.556/0076, Utrecht, the Netherlands. (in Dutch).

NS Technical Research [1996]. *"Trillingsarme spoorconstructie Oosthuizen."* NSTO/96/9460044/002, Utrecht, the Netherlands (in Dutch).

TNO Bouw [1995]. *"Onderzoek naar de invloed op de trillingsemmissie van plaatverstijvingen in de bovenbouwconstructie"* 95-CON-R0860-02, Rijswijk, the Netherlands (in Dutch).