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Measured Dynamic Loading of Railway Underground

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ABSTRACT: Some in-situ measurements related to dynamic stress, velocity and acceleration in the substructure and subsoil from railway traffic are reported. The dependency of these parameters on train speed and superstructure is revealed. The measured maximum dynamic stress increases linearly with train speed between 150 and 300 km/h. Based on these, a stress amplification factor k_{dyn} is introduced. In addition, a correlation of the measured maximum dynamic stress with vibrating acceleration is illustrated.

KEYWORDS: railway foundation, dynamic stress, vibrating velocity, vibrating acceleration

1 INTRODUCTION

Generally speaking, the dynamic loading of railway foundation is affected by many factors, such as wheel set loads, super- and substructure, train speed, depth and the type of subsoils. The dynamic loads can be calculated based on a theoretical analysis of stress wave propagation in soils. Such analyses have been made possible by using numerical methods, e.g. Hanazato et al (1991), and Müller & Huber (1991). These analytical models are based on elastic half-space theory. Some of them even consider different soil layers and can simulate the stress waves produced by a passing train. However, they have for the most part not been calibrated using in-situ measurements.

An altenative for determining the dynamic loading in subsoil is the direct measurement of dynamic stress, vibrating velocity, and other parameters induced by passing trains. This method is certainly very expensive, it may provide a more realistic picture of the dynamic loading in the substructure and subsoil. Furthermore, the measured results can be used to calibrate the existing analytical models.

In this paper, the data of seven measuring projects conducted in Germany related to the dynamic stress, vibrating velocity and acceleration are reported. The influence of different boundary conditions on the loading behaviour in the substructure and subsoil are revealed. The results can be used for the design of railway foundation.

2 DYNAMIC STRESS

In Table 1, a survey of seven measuring projects is given. The measurements were made under very different boundary conditions, such as different superstructures, different subsoils and different train speeds. This provides a broad spectrum for the analysis.

The measurements of dynamic stress in the substructure and subsoil on the Hannover-Würzburg/Germany railway line were carried out in 1987/1988, see Schwarz (1989). The superstructure was exclusively conventional ballasted track. The subsoil has different compositions and varies from gravelly sand, silty sand to clayey sand. The measurements were made with train speeds up to 400 km/h. To measure the dynamic stress induced by passing trains, numerous pressure gauges were installed at three different levels in the substructure and subsoil.

To illustrate some of the results, the measured dependency of the maximum dynamic vertical stress on train speed for the pressure gauges 102 and 202 (measuring cross section 1 and 2) is presented in Fig. 1. A clear increase of the resulting dynamic stress in the substructure and subsoil can be observed within the range of the train speed between 150 and 300 kph.

The measured distribution of the maximum dynamic vertical stresses with depth is illustrated in Fig. 2. They are given in the form of a band-width for all measurements with train speeds of 10 and 280 km/h, respectively.

TABLE 1. The Analyzed Measuring Projects

Project	Superstructure	Subsoil	Measuring components
Hannover-Würzburg	Ballast	Gravelly sand, silty sand and clayey sand	Dynamic stress and vibrating acceleration
Kutzenhausen	Slab and ballast	Silts and sandy silts	Dynamic stress and vibrating velocity
Hösbach	Slab and ballast	Fill: fine sandy clay	Dynamic stress and vibrating velocity
Schwarzenbek	Ballast	Soil exchange with sand	Dynamic stress and vibrating velocity
NLfB	Ballast	Peat	Vibrating velocity
Wittenberge-Dergenthin	Slab	Fine and middel sand with organic bands	Settlement and vibrating velocity
Waghäusel	Slab and ballast	Gravelly sand and sandy gravel	Dynamic stress and vibrating velocity

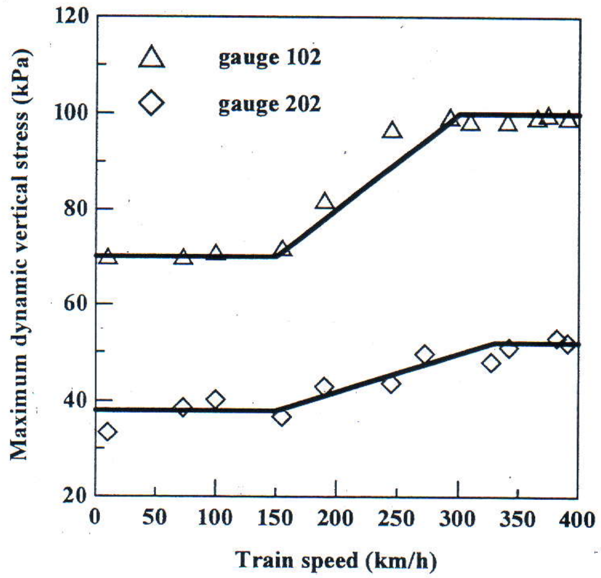

Figure 1. Measured maximum stress versus train speed, Project Hannover-Würzburg.

The influence of the superstructure on the dynamic stress in the substructure and subsoil is revealed by analyzing the measured results of the project Kutzenhausen (see Table 1), because in this project three different superstructures, namely conventional ballasted track as well as asphaltic and concrete slab tracks, were tested by passing trains. The existing subsoil under the railway line is composed of silts and sandy silts. The speeds of the passing trains were between 95 and 160 km/h.

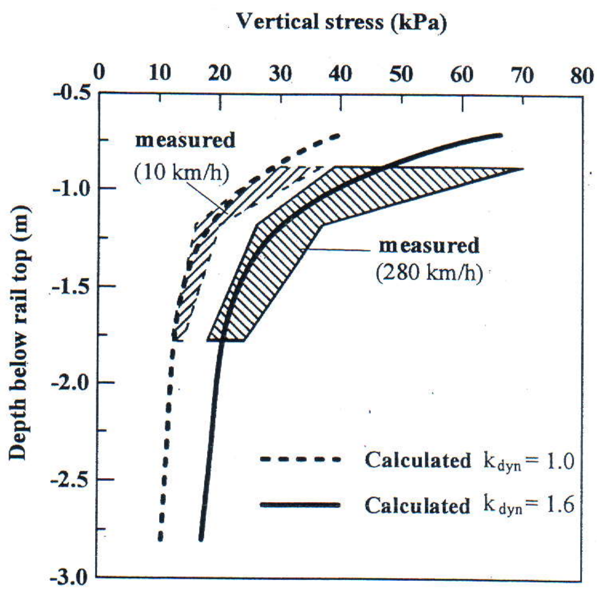

Figure 2. Comparison of measured and calculated maximum dynamic stress with depth

As illustrated in Fig. 3, the installed pressure gauges are located on the track axis, the rail axis and at a location off the rail axis. They are arranged at two levels, 0.86 m and 1.48 m below the rail top, corresponding to the substructure and subsoil, respectively.

The average values of all measured maximum dynamic stresses are presented in Fig. 3. From the ballasted track to the asphaltic and concrete slab tracks, the resulting maximum dynamic stresses become smaller. This means that the superstructure has considerable influence on the dynamic loading of the substructure and subsoil. The stiffer the superstructure, the smaller the resulting dynamic stresses in the substructure and subsoil.

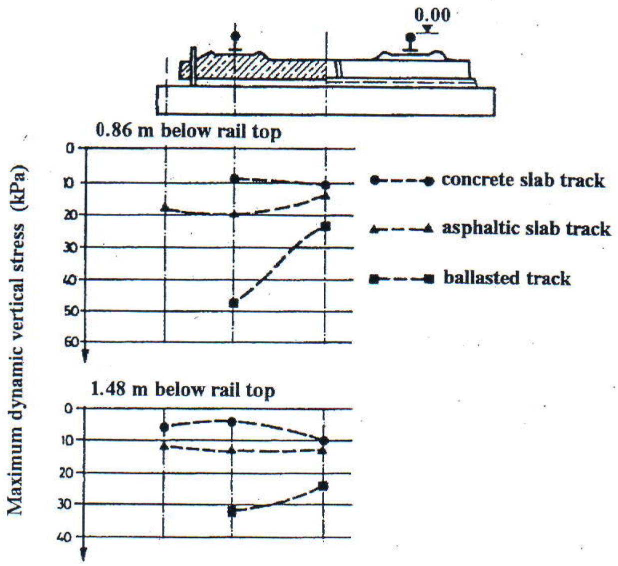

Figure 3. Dependency of maximum dynamic stress in substructure and subsoil on superstructure (Project Kutzenhausen)

On the basis of the above analysis, it can be concluded that the resulting dynamic stress in the substructure and subsoil from railway traffic is, largely dependent on train speed and superstructure in addition to wheel set loads and measuring depth. The dependency of dynamic stress on train speed and superstructure can be described by using a stress amplification factor k_{dyn} illustrated in Fig. 4. With reference to the static stress σ_s determined from the wheel set loads, the stress amplification factor $k_{dyn} = \sigma_d/\sigma_s$ is 1.0 up to a train speed of 150 km/h. Beyond that point, the factor increases linearly with train speed until it reaches a maximum at 300 km/h. Then, k_{dyn} becomes independent of the train speed again. Based on our analysis of the existing in-situ measurements, the maximum factor k_{dyn} was determined to be about 1.3 for the substructure and subsoil under slab tracks, and 1.7 under ballasted tracks.

With the help of this introduced factor k_{dyn}, a static back-analysis using finite element method was carried out for the measurements illustrated in Fig. 2. In these calculations the wheel set loads were applied under consideration of the stress amplification factor k_{dyn} (1.0 and 1.6 for train speed 10 and 280 km/h respectively). The comparision between the calculated and the measured results indicates a good conformity.

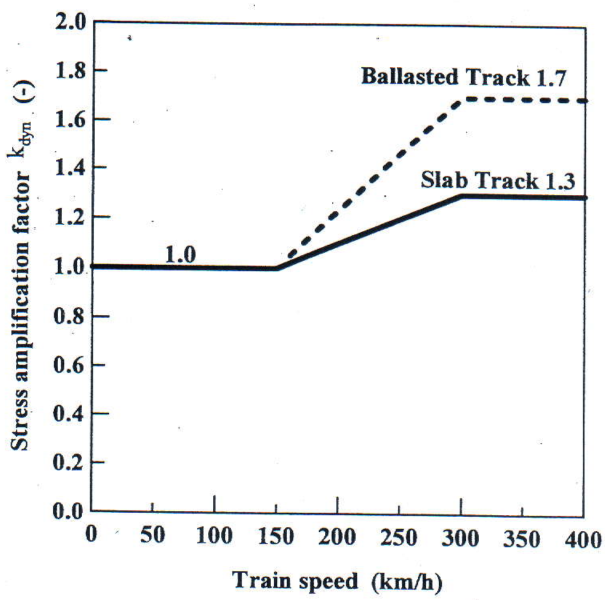

Figure 4. Stress amplification factor k_{dyn} depending on train speed and superstructure

3 VIBRATING VELOCITY

Similar to dynamic stress, the measured vibrating velocities are also largely dependent on superstructure and train speed. In Fig. 5, the measured results of project Kutzenhausen are illustrated in the form of a band-width for passing trains with speeds between 95 and 160 km/h. It can be seen that the higher vibrating velocities appear in the substructure and subsoil under conventional ballasted track. For the same gauges, the measurements in 1990 indicate higher velocities than those in 1988. This can be put down to the compaction effect of dynamic loading.

The distribution of the measured vibrating velocity with depth can best be illustrated by analyzing the measurements of the project Waghäusel (see Table 1), because geophones were installed 5 m below the rail top. In Fig. 6, the measured vibrating velocities with depth are illustrated for ballasted track and asphaltic slab track for a passing train with a speed of 156 km/h.

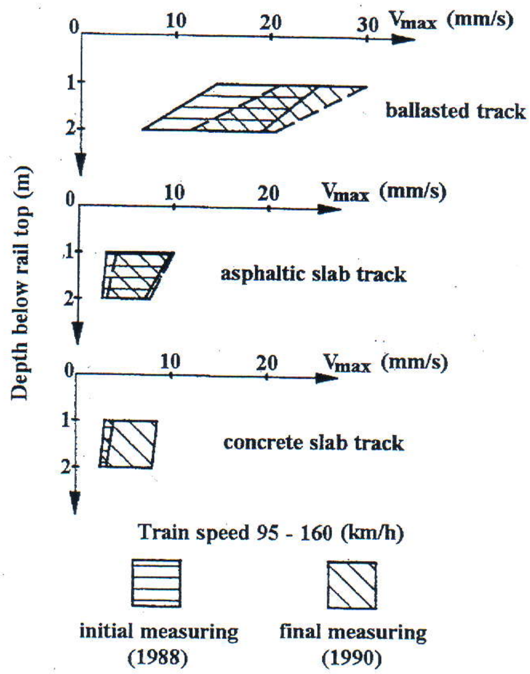

Figure 5. Influence of superstructure on measured maximum vibrating velocity (Project Kutzenhausen).

4 VIBRATING ACCELERATION

Measurements of the vibrating acceleration in the substructure and subsoil were obtained in the project Hannover-Würzburg (see Table 1). The accelerometers were installed in the pressure gauges. This makes the correlation between the measured dynamic stress and the acceleration possible.

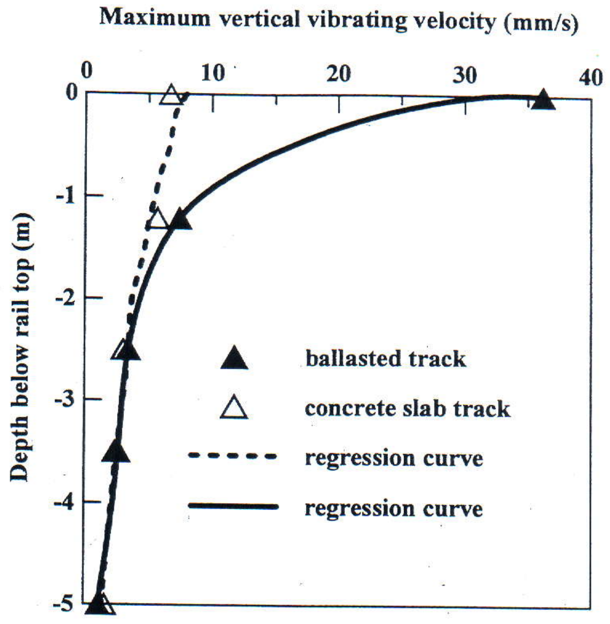

Figure 6. Maximum vertical vibrating velocity versus depth (Project Waghäusel)

By using the available measurements the relationship between the measured vibrating acceleration and train speed has been established, see Fig. 7. The illustrated regression curves for two different measuring points pass through the origin. This indicates the linear dependency of vibrating acceleration upon train speed.

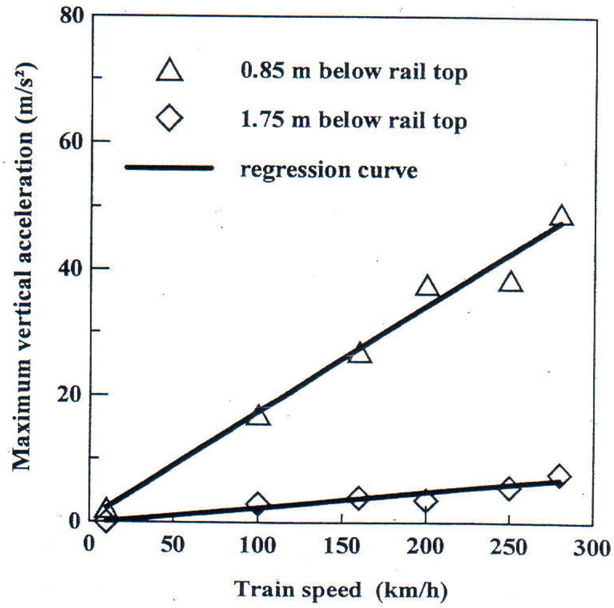

Figure 7. Maximum vibrating acceleration versus train speed.

In Fig. 8, the measured maximum dynamic stresses are expressed as a function of the measured maximum accelerations. Clearly, linear relationships between the maximums of dynamic stress and acceleration exist. Here, the intersections of the lines on the ordinate correspond to the static stresses resulting from the passing train with very low speed.

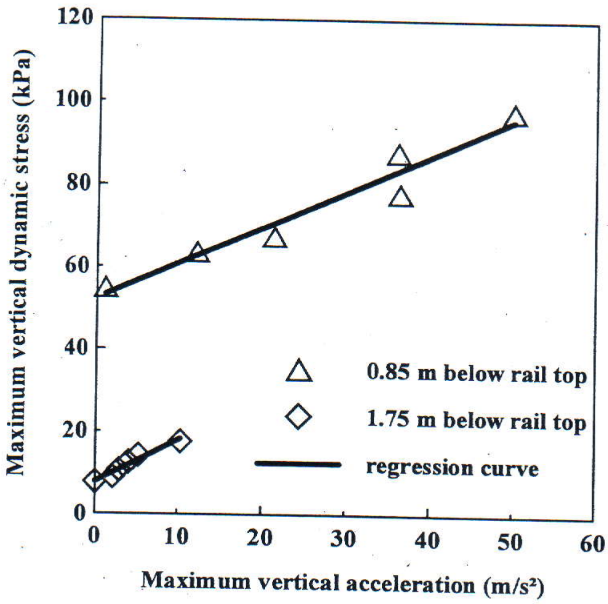

Figure 8. Correlation between measured stress and vibrating acceleration.

5 CONCLUSIONS

The analysis of some in-situ measurements indicates that, in addition to wheel set loads and measuring depth, the dynamic loading in the substructure and subsoil from railway traffic depends largely on train speed and superstructure. The quantitative analysis shows that for train speeds between 0 and 150 km/h, the resulting maximum dynamic stress remains nearly unchanged, whereas it increases linearly with train speed between 150 and 300 km/h. Beyond this point, the measured values remain constant up to the 400 km/h limit of the data. The increase in stress resulting from the dynamic effect can be considered by introducing a stress amplification factor k_{dyn}. With reference to the static stress calculated from wheel set loads, the maximum k_{dyn} was found to be 1.7 under conventional ballasted track and 1.3 under slab track. The distribution of the measured maximum dynamic stresses with depth can be evaluated by using a static finite element model along with the stress amplification factor k_{dyn}.

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