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INNOVATION FOR THE CONTROL OF INFRASTRUCTURE MAINTENANCE

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1. INTRODUCTION

This paper addresses the control of infrastructure maintenance, primarily focusing on track, as indicated in figure 1, and examining the subject from the safety and maintenance cost optimization angles.

- rails
- fasteners
- sleepers
- ballast
- subballast
- subgrade

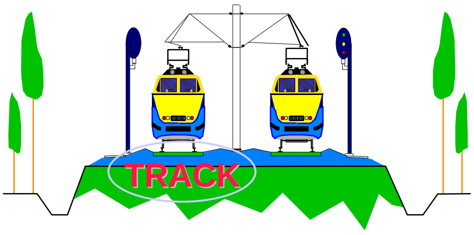

Figure 1: Track as part of the railway infrastructure

2. EXISTING METHODS

Railways use various kinds of inspection tool to plan track maintenance and renewal. In the early days, only visual inspection data and manual measurements were available. Safety control was, and to a large extent still is, dependent on visual inspection. Nowadays however, most railways use track recording cars for measuring track geometry. Initially the output simply consisted of strip charts, which were interpreted visually. Indeed, only local defects were monitored.

Modern recording cars use non-contacting transducer technology, based on laser components and inertia systems. The measurement signals are analyzed by a computer and the output consists of standard deviations for planning track maintenance and exceedances for monitoring local track defects to be dealt with by hand equipment.

Today's more accurate measurements allow the comparison of successive recording campaigns and the carrying out of trend analyses. This, however, requires proper synchronization of records, for which NS, for example, use track magnets at intervals of approximately 10 km.

For safety reasons, and to facilitate planning of rail and track renewals, ultrasonic inspection, both with manual equipment and special testing vehicles, is common practice. It has recently been possible to increase the inspection speed of special inspection vehicles to 80-100 km/h.

3. SAFETY REQUIREMENTS

The basic safety limits laid down in the railway standards are specified in terms of forces between wheel and rail and loads exerted on the track. Well-known examples include the limits for lateral track forces induced by a vehicle:

$$SY_{2m} < b\ [10 + \frac{2Q}{3}]$$

in which:

- SY_{2m} is the sum of the lateral forces exerted on the rails, cleared from components of less than 2 m wavelength.
- Q is the vertical wheel load;
- b is a factor normally having a value of 0.85.

Another parameter is the derailment ratio:

$$\frac{Y}{Q} < g$$

where Y being the lateral wheel/rail force and Q the vertical wheel/rail force. The factor g generally falls in the range 0.8-1.2.

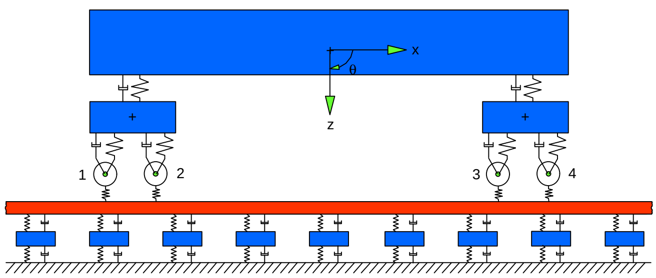

Figure 2: Model describing vehicle/track interaction.

Passenger comfort is normally specified in terms of coach body accelerations, weighted according to human perception criteria, defined, amongst others, in ISO standard 2631.

Not all these data are produced by a track recording car. Direct measurement of these vehicle reactions is difficult and the results would only pertain to that particular vehicle at the current running speed. In order to produce data on vehicle response, NS implemented the VRA system (Vehicle Response Analysis) [1], which calculates forces and accelerations in real time for a number of vehicles at different speeds. The current track geometry serves as vehicle excitation. In the early nineties DB implemented a similar system based on a linear vehicle model consisting of a coach body on two bogies according to figure 2. Obviously this is the way to proceed. However, the models should be extended further, in particular with respect to the non-linear calculation of the Y force and ratio Y/Q.

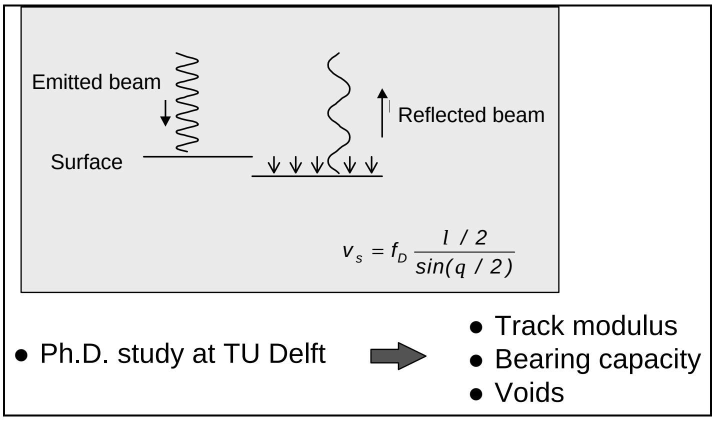

Figure 3: HSD (High Speed Deflectograph)

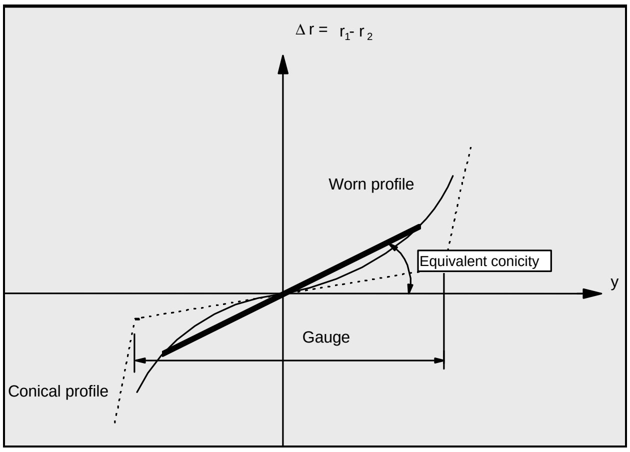

Figure 4: Equivalent conicity

Moreover, the models should be supplemented with track and subgrade properties, with emphasis to the vertical stiffness. At TU Delft a Ph.D. study has started on the measurement of actual track stiffness and related track modulus with the aid of laser Doppler techniques [2]. In the measuring system advantage is taken from the difference in wavelength created when an emitted laser beam is reflected by a surface, as outlined in figure 3. The reflected beam normally has a longer wavelength due to the Doppler frequency shift. From the thus obtained surface velocities, displacements can be derived. With the aid of mathematical models, such as a beam on an elastic foundation, or multi-layer systems, quantities representing the vertical track stiffness, such as the track modulus, can then be derived.

ERRI is currently undertaking a major study into the safety aspects of CWR [3]. A large number of parameter studies with the newly developed program CWERRI, together with experimental data, have revealed that one of the most important parameters is the lateral track resistance. For a better estimation of the real safety margins it is necessary to measure the current lateral resistance of the track. Plasser & Theurer [4] have recently developed a method, in combination with the Dynamic Track Stabilizer (DTS), which allows lateral resistance values along the track to be determined.

4. HIGH SPEED OPERATIONS

The equivalent conicity plays an important role as a criterion for running stability, particularly at high speeds. The conicity follows from the difference in rolling radius of right and left wheel as a function of the lateral wheelset displacement, as indicated in figure 4, by taking the first derivative. The equivalent conicity is a representative value, based on the anticipated wheel excursion, normally obtained as a weighted average, or just as the angle of the secant line through zero and the maximum displacement. Experience has shown that the equivalent conicity should stay below 0.4 for not violating vehicle stability.

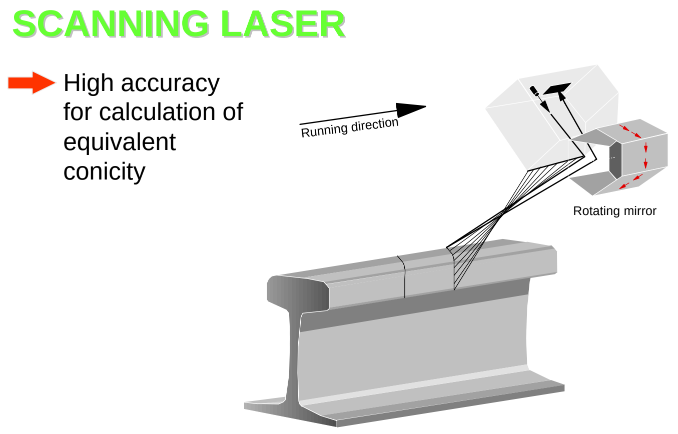

Figure 5: Laser scanner

Facilities to obtain information on current values along the track are still lacking, even with modern track recording cars. It is therefore recommended that the cross sectional railhead profile be measured to a high degree of precision with high tech laser scanners, the principle of which is illustrated in figure 5. With this information, and a standard wheelset, with representative wheel profile, the equivalent conicity can be determined, and thus the margins for stable train operation.

Another important issue related to high speed train operation is the propagation speed of surface waves, which governs the critical train speed [5]. These so-called Rayleigh waves propagate with about a 10 % lower speed than shear waves, having a propagation speed of:

$$c_T = \sqrt{\frac{G}{r}} ,$$

in which G is the shear modulus and r is the density. Especially in delta areas, such as in The Netherlands and in Japan the subgrade often consists of weak soils with critical speeds far below the intended operational speed. In such cases measures for increasing the vertical stiffness are inevitable. Possible solutions are soil improvements, deep mixing, grouting and piles. In this respect a combination with slab track has great advantages. In anyway the critical speed should be increased to a level which is at least 50 % higher than the operational speed, certainly when anticipating future speed boosts.

Returning to the subject of measuring track data, actual critical train speeds can well be estimated from measured vertical track stiffness, adopting the Laser Doppler principle discussed previously together with a wave propagation model. The resulting data are of particular importance for the detection of local dangerous situations.

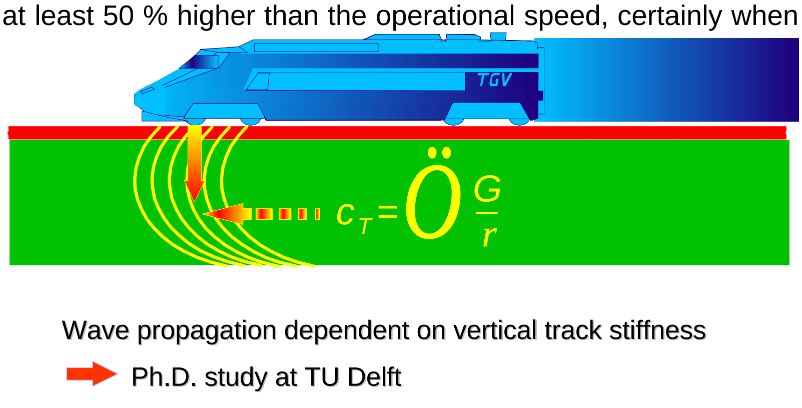

Figure 6: Critical train speed

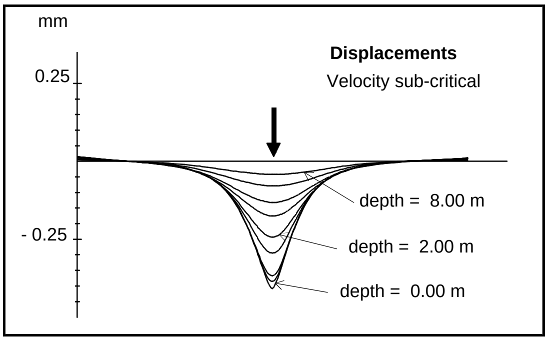

Figure 6.b. Displacements under subsonic steady state load

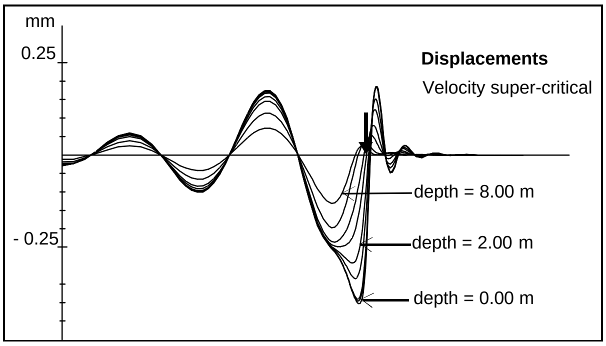

Figure 6.c. Displacements with supersonic velocity

5. INSPECTION FREQUENCY ON HIGH SPEED LINES

On traditional lines, recording frequencies of once per 4 to 6 months are considered sufficient. However, for high speed lines, and, to some extent, also for freight lines carrying dangerous goods, this might not be enough. Local track defects, associated with disturbances of the rail running surface, can develop into dangerous situations in 12 to 24 hours under high speed operations. From this point of view it is recommended to monitor the track irregularities continuously with relatively simple measuring units on board of a representative number of vehicles in service. These measuring units could comprise, for example, of accelerometers mounted on the axle box, or bogie frame. At least three units per rail are required to distinguish between railborne and wheelborne defects. Measurement data might be stored on board the train, or in a central computer. In that case data transfer via radio, or GSM, is the obvious solution, preferably with the aid of ETCS (the European Train Control System) [6], presently under development at ERRI.

6. MAINTENANCE REQUIREMENTS

Most of the measuring data mentioned can be used for track maintenance and renewal purposes. Additional data to be collected for control of maintenance include:

- Position and cross-sectional area of overhead wires, using ultra-fast precision laser technology;
- Clearance gauge and infrastructure-bound objects, using vision technology;
- Detection of cables and pipe lines that could obstruct track maintenance, possibly using radar sensing technology.

All relevant data for maintenance decision support has to be stored in a database such as the ECOTRACK system [7] developed by ERRI. Life cycle cost considerations should be an integral part of all such decision support systems.

7. CWR FORCES

A recognized high-priority issue is the non-destructive measurement of longitudinal rail forces in CWR track. Methods based on ultrasonic principles to measure stresses at the rail surface indeed exist. However, the rail contains huge residual stresses and so the integration of the total axial stresses over the rail cross sectional area is required to find the resulting longitudinal force. A number of attempts in the USA and recently by DB, together with the Fraunhofer Institute, have been unsuccessful [8].

8. CONCLUSIONS

At present, control of infrastructure maintenance and of track quality are suffering from a number of shortcomings, which are directly related to safety.

In view of this, the following measures are proposed:

1. Calculate Q force, Y force, Y/Q and ΣY_{2m};
2. Measure vertical track stiffness and voids;
3. Determine critical train speeds;
4. Determine the current safety margins to track buckling based on ERRI's CWERRI program;
5. Point 4 requires systematic measurement of lateral track resistance.

For safety reasons at high speed operations, development of an acceleration-based on-board system to monitor rapidly-growing track defects is strongly recommended.

For a better control of track stability, from the perspective of safety, it is recommended to pursue attempts to develop a method for non-destructive measurement of longitudinal rail forces in CWR track.

From the economical point of view better systems for track maintenance and renewal decision support should be developed, emphasizing minimization of total life cycle costs.

A number of the subjects mentioned in this paper could be proposed as an EU project.

9. REFERENCES

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