Track Settlement Prediction using Computer Simulation Tools

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TRACK SETTLEMENT PREDICTION USING COMPUTER SIMULATION TOOLS

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SUMMARY

A project is being carried out at Manchester Metropolitan University to examine the effects of different vehicles on track deterioration and consequent maintenance costs. A number of track settlement models have been investigated including those published by Prof. Sato in Japan and a model based on laboratory experiments at the Technical University of Munich.

The MEDYNA simulation package has been used to generate the equations of motion for the vehicles being studied and time stepping integration routines used to predict motions and forces as required. The ADAMS/Rail package has also been used to assist with the visualisation of the models and the predicted behaviour. Inputs to the model were made at each wheelset. These were either idealised discrete events such as dipped rail joints or measured values from real sections of track.

The results are presented here for three vehicles with different types of suspension and for two of the track settlement models. All of the settlement models used predict that the suspension characteristics have a large effect on the rate of track deterioration. The general trends in predicted track settlement rate agree between the two settlement models but there are also some very significant variations in the relative rates for some cases.

1. INTRODUCTION

As the railway industry in the UK is changing, new types of vehicles are being introduced and higher operating speeds and axle loads are being proposed. It is therefore particularly important to be able to assess the effects of these vehicles when deciding on levels of track maintenance and on design of new infrastructure. As an example a new three-piece freight bogie of a type not previously operated in the UK is now being introduced and an understanding of the likely levels of expected track damage and comparison with existing freight vehicles and also with passenger vehicles and locomotives is clearly useful.

This paper reports on the methods that have been used in a project to predict rate of track settlement likely as vehicles with different suspension characteristics are run on track with various irregularities. The resulting values are not intended to be absolute indicators of damage but can be used in a comparative way to assess the effects of different suspension designs.

2. THE VEHICLE MODELS

The 3-piece bogie, although not common in Western Europe, is widely used in North America, Australia, Africa and Russia and a modern version is currently being introduced into Britain. The wheelsets support two side frames that in turn support a bolster (figure 1). Connection from the bolster to the car body is via a central pivot and side bearers with sliding surfaces. Vertical and lateral suspension between the side frames and the bolster is provided by a spring unit which consists typically of 7 sets of concentric springs (figure 2). The resulting unsprung mass is higher than for a vehicle with a primary suspension between the wheelset and the bogie.

Damping is achieved by spring loaded snubbing wedges acting between the ends of the bolster and each side frame. These wedges are arranged such that a proportion of the car body weight is passed through the wedges causing the normal force at the friction surfaces, and therefore the damping, to vary with vehicle load.

The main difficulties for the modeller are the clearances which are present between the axleboxes and the side frames and between the side frames and the bolsters and also the friction surfaces which see normal forces which vary with the vehicle motion. MEDYNA has friction elements included for sliding in one plane or in two and allows consideration of a dynamically varying normal force. The normal force is taken from the force in the spring underneath the snubbing wedge and applied to the element. A vector of the relative motion of the two surfaces is calculated and the friction force calculated, checking at each step for saturation.

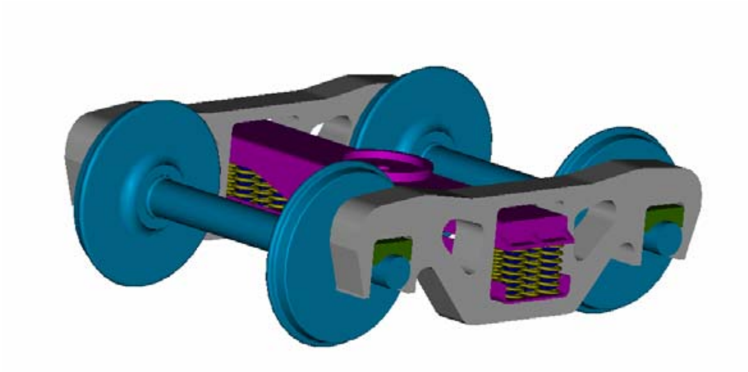

Figure 1. A typical '3-piece' bogie

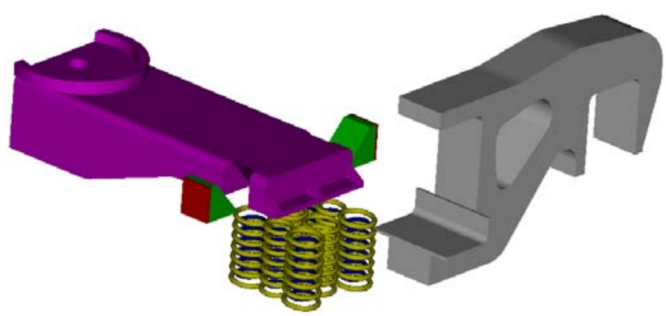

Figure 2. A detail of part of the secondary suspension of the 3-piece bogie model

As a comparison, a two axle coal wagon with leaf spring suspension is used (figure 3). Multi-leaf springs are very common and in addition to giving the necessary compliance they provide part or all of the required damping as friction between the leaves dissipates energy. MEDYNA, as with other packages, allows this to be modelled with the user being required to specify the number of leaves and stiffness of each and also to estimate the coefficient of friction between the leaves. The later is often the most difficult aspect to quantify.

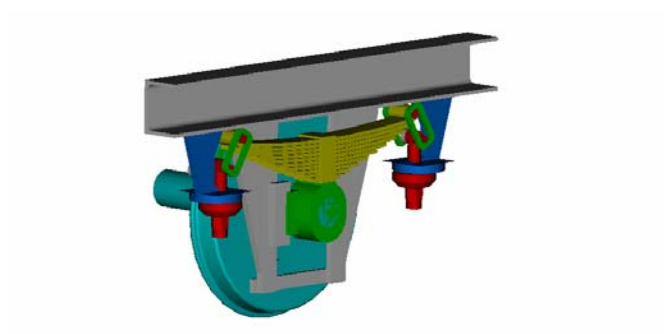

Figure 3. A typical leaf spring suspension

A common passenger vehicle used on British track is the Mk3 coach with BT10 bogies. These bogies have a welded steel frame with swing arm axle-boxes and primary coil springs and hydraulic dampers. Secondary vertical suspension is by air springs with levelling valves to maintain constant body height. The air springs sit on a spring plank which is hung on long pendulum links from the bogie frame. The model arrangement is shown in figure 4.

Figure 4. Model of the BT10 passenger bogie

3. THE TRACK MODEL

A relatively simple vertical track model is used for this work and is shown in figure 5. The track model includes representation of the rails, the rail pads, the sleepers and the ballast. All parameters for the rail model have been taken from the Eurobalt study [3]. The Eurobalt work included measurements of typical track on German and French lines as well as in Britain.

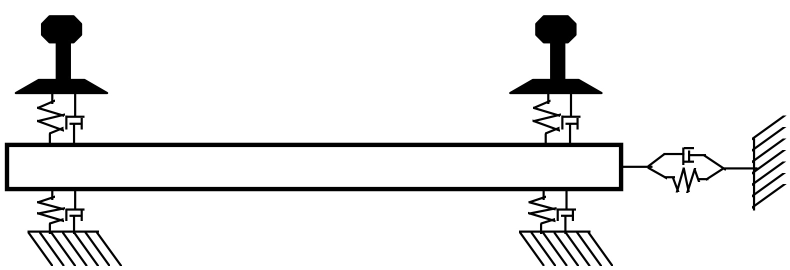

Figure 5. The simple track model used

4. TRACK SETTLEMENT

Settlement of ballasted track occurs in two major phases as seen in figure 6. Directly after tamping the settlement rate is very fast until the gaps between the ballast particles are reduced and the ballast is consolidated. The second phase shows a slower and more linear rate of settlement.

Vertical track geometry deteriorates much faster than lateral track geometry under traffic so that although modern automatic tamping machines adjust lateral as well as vertical alignment, the trigger for tamping is almost always deterioration in the vertical geometry.

If every section of track experienced the same rate of settlement then the level of irregularities would not change but the track would just sink down evenly into the ballast. In practice due to uneven support conditions and due to variations in the load pattern along the track this is not the case. Irregularities develop and this can also cause changes in the load distribution. In this work we are attempting to evaluate the effect on the rate of track settlement that can be related to the passage of different vehicles rather than due to changes in support along the track. The maximum settlement due to the peak vertical force has therefore been taken as being indicative of the rate of geometry deterioration

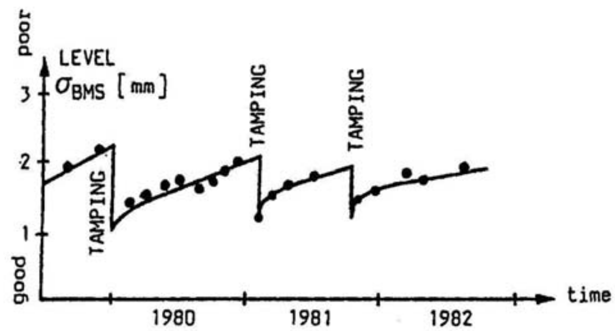

Figure 6. Track settlement over a period of time (from Shenton [6])

Frederick and Round [5] have shown that the deterioration is proportional to the peak force and they point out that this peak force should be calculated using the envelope of pressure distribution as the wheel moves along the track. If the dynamic forces are small compared with the static force the total force will be almost the same as that calculated assuming that the maximum forces occur directly under the wheelset. If, however, the dynamic forces are large the force envelope method must be used. In the case of a single discrete defect such as a dip the peak force will occur where the wheelset force also reaches a peak.

A number of models have been used to predict track settlement. A good review of some of these is given in [14]. They include statistical and empirical models based on records or measurements made on track. A simple power law is used by several railway organisations where ballast pressure is evaluated and raised to the 2^{nd} (optimistic) or 4^{th} (pessimistic) power. The ORE deterioration model is a statistical model with no track parameters and which uses traffic volume, dynamic axle load and speed raised to the power of empirically derived factors. Japanese experience has led to an empirical track settlement model based on quasi-static ballast pressure and ballast acceleration together with vehicle speed and tonnage and factors for track type (Sato[1]). Experiments at the Technical University of Munich led to a series of equations predicting settlement rate from ballast pressure [2]. Other models have been developed by Li and Selig, Ford, Mauer, Frohling and Shenton [6] to [13].

4.1 The Sato track damage model

Japanese measurements from track recording vehicles over many years have led to an empirical track settlement model. Rail vibrations are used to predict ballast settlement and growth of irregularities using the following equation:

$$S = 2.09.10^{-3}.T^{0.31}.V^{0.98}.M^{1.1}.L^{0.21}.P^{0.26} \qquad [1]$$

where:

S	= average growth in irregularity (mm/100 days)
T	= passed tonnage (million tonnes/year)
V	= average running speed (km/hr)
M	= structure factor
L	= rail influence factor (=1 for CWR =10 for jointed rail)
P	= influence factor for subgrade (1 = good 10 = bad)

The structure factor contains the influence of the forces on the track and is calculated as follows:

$$M = P_b y_z S\text{i} \qquad [2]$$

where:

P_b = the quasi-static ballast pressure
y_z = the rail acceleration
Si = the impact coefficient (a function of the rail properties)

For vehicles running on similar track, equation [1] can be reduced to:

$$S \propto V^{0.98}.T^{0.31}.M^{1.1} \qquad [3]$$

and therefore for an equal number of vehicle passes a track damage factor can be defined:

$$D = V^{0.98}w^{0.31}.(Q.y_z)^{1.1} \qquad [4]$$

where:
V = velocity [km/hr]
w = vehicle weight [tonnes]
Q = the axle load [tonnes]
y_z = the rail acceleration [ms^{-2}]

4.2 British Rail Research track deterioration models

In the UK ballast settlement has been studied in the laboratory [5] and the results incorporated into a package called 'MARPAS'. The track geometry deterioration model used in MARPAS is extremely complex and was developed as a result of fundamental research over a period of approximately 30 years. This package does not include a model for the vehicle dynamics but uses two coefficients to calculate the ride force (forces in the frequency range realted to the vehicle sprung mass motions). These coefficients are called the ride force constant and the ride force coefficient and they need to be found for each vehicle being studied.

4.3 TU Munich settlement model

Experiments under well controlled laboratory conditions at the Technical University of Munich representative of vehicles passing a dipped joint have been used to establish equations to calculate rate of settlement. Ballast pressure is multiplied by the log of the number of axle passes as follows:

$$S_{opt} = 1.57.p.\Delta N + 3.04.p^{1.21}.\ln N$$
$$S_{pess} = 2.33.p.\Delta N + 15.20.p^{1.21}.\ln N \qquad [6]$$
$$S_{med} = 1.89.p.\Delta N + 5.15.p^{1.21}.\ln N$$

The first part of the equation relates to the initial settlement immediately after tamping and the second part relates to the longer term and more gradual settlement after about 10,000 axle passes.

Ballast pressure is calculated using the Zimmermann method which involves a theoretical equivalent longitudinal sleeper placed under the track.

5. SIMULATIONS

The vehicle models were run over a variety of idealised track defects and also over measured track data. One type of track defect that is often used to analyse the vertical forces is a dipped joint. The forces at a discrete irregularity of this type have been extensively modelled and measured (for example [13]) and the behaviour is well understood. For this work dipped joints with included angles at the dip of 5, 10 and 20 mrad were used as representative of the population. Track with a cyclic vertical irregularity with various wavelengths was also used but this was found not to cause significant levels of force compared with the dipped joint cases. Measured track data from a track recording coach was also available from a number of locations on high speed main lines and branch lines.

The simulations were run with each vehicle model over a range of speeds. The peak force in the spring element representing the ballast was used as input for the TU Munich settlement model and the rail acceleration for the Sato model. For the discrete events the peak force was used, for the measured track data runs the 99.85th percentile of the force peaks was used. The equations were set up in a spreadsheet allowing the results to be presented graphically and all results were normalised to the case of the HAA coal wagon on a 7mm dip at 20 m/s for ease of comparison.

6. RESULTS

The simulation results have been used to calculate track damage or settlement factors using several of the models described above. The results presented here show the track damage factor from the Sato model and the settlement factor from the T.U. Munich model normalised to the case of the HAA wagon running on a 7mm (5mrad) dip at 20 ms-1 (45 mph) (set at 2). Results for the freight vehicles are given for the laden condition. Figure 7. and figure 8. show the vehicles running over a 7mm dip. Figure 9. shows the track settlement factor from the T.U. Munich model on a section of measured track.

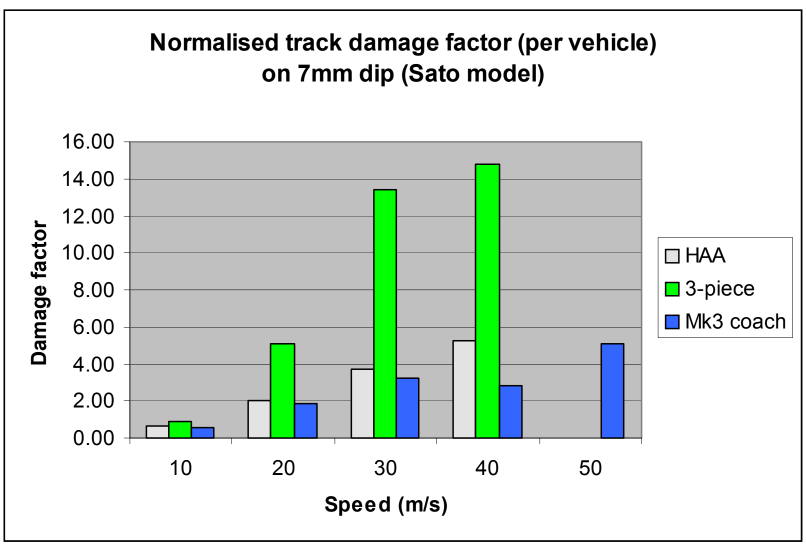

Figure 7. Predicted track damage factors on 7mm dip (Sato model)

The results show that the track damage and settlement factors for the 3-piece bogie vehicle are generally much higher than for the HAA car (although the 3-piece bogie vehicle modelled carries a much higher payload). The passenger coach has a lower factor in all cases. The factor for all vehicles increases very significantly with speed but again this seems greater for the 3-piece bogie than for the other vehicles.

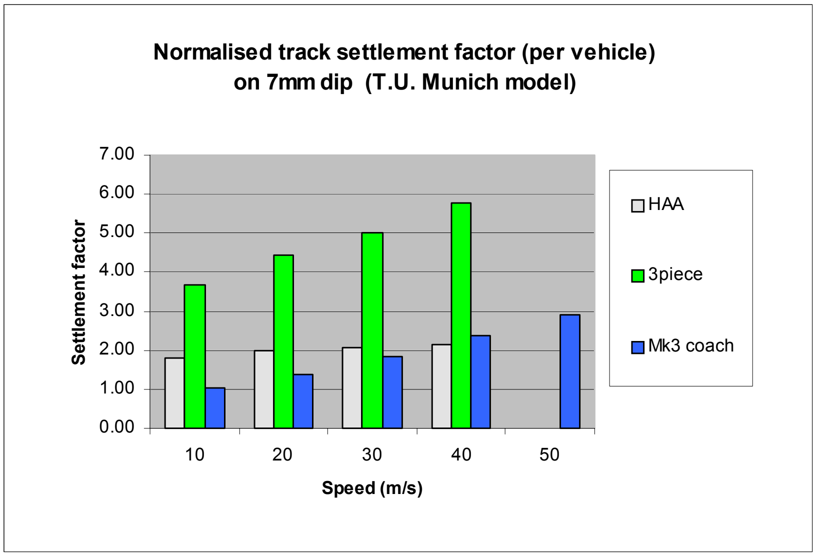

Figure 8. Predicted track damage factors on 7mm dip (T.U. Munich model)

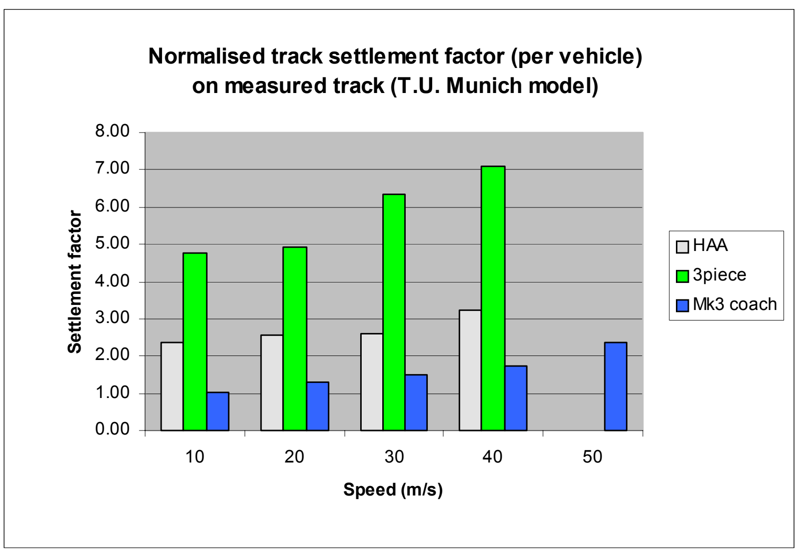

Figure 9. Predicted track damage factors on measured track data (T.U. Munich model)

The results from the Sato model and the TU Munich model are generally consistent in the trends shown for vehicle type and for speed but there are significant differences in the rates of these changes. This results in a significantly higher predicted differential rate after the normalisation.

The results on the 7mm (5mrad) dip and the measured track data show quite similar levels of predicted track settlement factors. This indicates that a dip may be used to approximate the damage carried out by vehicles running on typical track.

7. CONCLUSIONS

A number of typical British railway vehicles have been simulated and the models used to predict the vehicle behaviour at typical track defects. These results have been used to indicate the relative effects on rate of track deterioration by means of a number of published track deterioration models.

The results show large differences in the predicted rates of track deterioration for different suspension types even when axle loads are similar. The various deterioration models used show good agreement in the general trends of predicted settlement rate as speed and suspension type are varied but do not compare well in the precise relative values predicted.

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January, 2004
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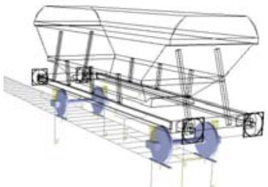
(RTU Manager)



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