FINAL REPORT

Numerical simulation of train-track dynamics

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Final Report

Numerical simulation of train/track dynamics: Computer models and verifications, track settlement, hanging sleepers, and track stiffness variations

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Summary

This report describes the development of some computer models by which the vertical dynamic interaction between a railway train and the track can be simulated. High-speed railway lines in Spain and France have been modelled and the models have been verified versus in-field measurements. The computer models have been exploited in calculating railway track settlements, in studying track dynamics due to suspended (hanging) sleeper(s), and in investigating train/track dynamics due to track stiffness variations.

The computer models simulating the dynamic train/track interaction were verified versus field measurements performed at the Spanish Madrid-Zaragoza high-speed line. Validations were performed both for static loading of the track and for dynamic loading with a wheelset travelling at high speed on the track. Field measurements with a locomotive loading the track statically and with a train passing the measurement site at high speed were performed, and good agreement between calculated and measured responses was achieved.

Some capabilities of the program developed are presented. The dynamic wheel/rail contact force is determined. Due to its irregularity, this force will induce track degradation, of which track settlement due to non-elastic deformations in the ballast and subground is one important part. Track settlement can be simulated using a simple elastic-plastic material model of the ballast.

Due to irregular track settlements in the ballast and in the sub-ground, hanging sleepers may appear, and these sleepers will induce an irregularity of the track stiffness giving an increased dynamic loading of the track. Using the numerical model developed, track dynamics due to one or several unsupported sleepers have been investigated.

Variations of track stiffness along a track cannot always be avoided (for example at a transition area from an embankment to a bridge). A study on how to optimally select the track stiffness variation at a transition zone has been performed and some results are presented.

1 INTRODUCTION

In recent years the experience from high-speed train traffic has revealed that even if high-speed trains have a relatively low axle load, the high-speed traffic may cause severe track settlement problems at certain sections of the high-speed lines. The dynamic loading of the high-speed traffic leads to degradation of the ballast and underlying layers. Track alignment and track level will deteriorate due to this track settlement. Loss of track level and alignment require maintenance. The track is lifted and aligned, and new ballast material is injected under the sleepers. The degradation thus burdens railway companies with extensive maintenance work.

In the European FP5 project SUPERTRACK (SUstained PErformance of Railway TRACKs) one objective was to investigate the dynamic train/track interaction forces and to investigate their effect on track degradation. Less degradation will, of course, reduce maintenance costs.

Track models and model validations

Computer models, developed with the purpose of investigating track dynamics due to high-speed traffic loading, have been developed. One of the models was verified versus measurements performed in Spain on the Madrid-Zaragoza high-speed line. Calculated track responses, such as rail deflections, contact pressure between sleeper and ballast, and stresses in the ballast and subballast, were compared with measured results. Considering that the track was newly built and not fully stabilized, the agreement between calculated and measured results was acceptable.

Track settlement

Track settlements are caused by the dynamic loading of the high-speed trains. The dynamic loading leads to degradation of the ballast and underlying layers. The settlement follows from permanent deformations in the ballast and in the underlying soil. The severity of the settlement depends on the quality and the behaviour of the ballast, the subballast, and the subgrade. As soon as the track geometry starts to degenerate, the variations of the dynamic train/track interaction forces increase, and this speeds up the track deterioration process. Very often the ballast bed becomes uneven, and, because the sleepers are fastened to the rails, this results in loss of the full contact between the sleepers and the ballast bed; some sleepers become hanging (suspended) in the rails. This phenomenon can be investigated by the model developed. A literature review and a Bibliography on track settlements have been presented in the SUPERTRACK project, see Dahlberg [1].

Hangings sleepers

A study of the influence of an unsupported sleeper (hanging in the rails) on the train/track dynamics has been performed, see reference [2]. In an ideal case, the sleepers provide support of the rails and preserve gauge, level, and alignment of the track. The sleepers transmit vertical, lateral and longitudinal forces from the rail down to the ballast bed. They should also provide electrical insulation between the two rails. In the study performed, one sleeper was not in contact with the ballast (for the unloaded track). A gap of 0.5 mm or 1mm was introduced between the sleeper and the ballast bed, and the increase of dynamic forces due to this gap was investigated. Some results are presented in Section 4.2 below. More results, with two or three hanging sleepers, were presented in reference [2]

Transition area with change of track stiffness

The stiffness of a track may change from one value to another at different parts of a track; an embankment-to-bridge transition is an example. A study on how to select the track stiffness at a transition zone between two parts with different stiffness was performed and reported in reference [3]. The study focused on optimization of the track stiffness at the transition area (booted sleepers, for example, can be used to control track stiffness). In the model, the transition area was divided into five short sections with one stiffness (to be optimized) in each section.

As an objective of the optimization, the variation of the wheel/rail contact force was selected. The force variation (the irregularity of the force) should be as small as possible when the wheel passed the transition area. It was found that with a transition length of 15 sleepers only, the amplitude of the wheel/rail contact force could be reduced by a factor 3 or 4 as compared to the case with no transition area at all. This investigation is summearized in Section 4.3 below.

2 NUMERICAL MODELLING OF DYNAMIC TRAIN/TRACK INTERACTION AND MODEL VERIFICATION

The compound train and track system plays an important role when train and track dynamics are investigated. The interaction of the two dynamic systems generate dynamic forces that produce vibrations leading to track deterioration, such as track settlements (inducing hanging sleepers), railhead corrugation growth, damage to track components (railpads, sleepers, ballast), and so on.

Structures subjected to moving loads can be analysed by many different methods. A survey of railway track dynamics and modelling of the train/track interaction is given in Dahlberg [4]. Basically, the methods can be divided into two groups: methods for calculations in the frequency domain and methods for calculations in the time domain. Use of numerical methods, and improvements of computer capacity, have made it possible to make more detailed models of the track structure. Using the finite element method, a larger part of the subground may be modelled in a rational manner. Also non-linear behaviour of track components, such as railpads and ballast, can be modelled using the finite element method. Hertzian contact stiffness (also non-linear) at the wheel/rail contact patch can be modelled. Phenomena like loss of contact and recovered contact between wheel and rail as well as loss of contact between sleeper and ballast may be included in the finite element models without large difficulties.

Literature on finite element modelling of railway vehicles and tracks, and their dynamic interaction, may be found in, for example, Knothe and Grassie [5], Popp *et al.* [6], Popp and Schielen [7], Nielsen [8], Oscarsson [9], and Andersson [10]. A textbook dealing with vibration of solids and structures under moving loads is Fryba [11].

Two track models have been developed in the SUPERTRACK project. The “small” model (Figure 1) assumes longitudinal symmetry of a single track and of the loading. Only half a wheelset, one rail, and half of the sleepers and the ballast/subground bed were included in that model. The “large” model contains a full double-track railway line loaded with one or several moving wheelsets on one track or on both. The track models can be used to simulate the short-term behaviour of the dynamic train and track systems when a wheel or a train runs on the track. The long-term behaviour of the track due to many wheel passages can (so far) be studied in the small model only. A simple material model to simulate the permanent ballast and subground deformation was implemented into that model.

The models were built-up using the pre-processor TrueGrid [12], and the commercial finite element program LS-DYNA [13] solved the dynamic train/track interaction problem. An explicit solver with a small time step was used for obtaining an accurate representation of high-frequency load variations.

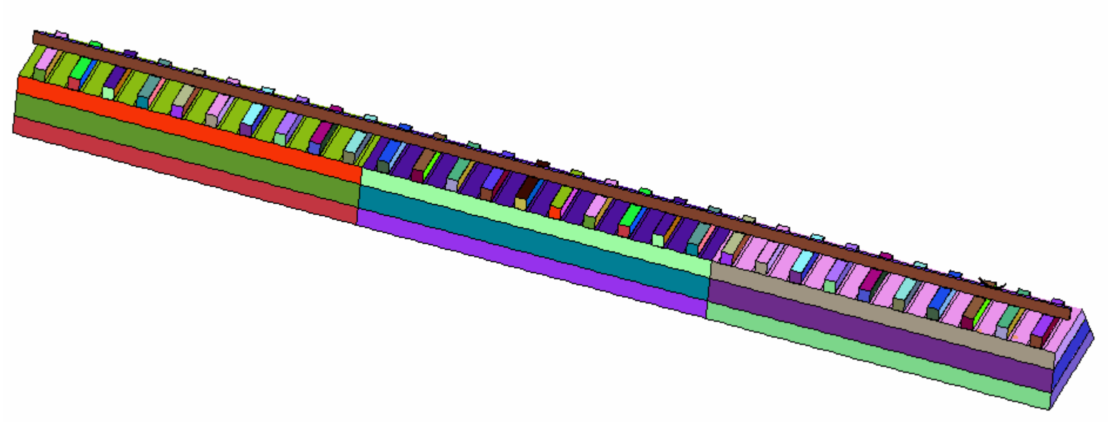

Figure 1 Track model (symmetry used) with ballast bed of elastic and elastic-plastic material (here in three sections and three layers). A moving wheelset (not shown) loads the model.

The models used in the SUPERTRACK project were built-up of three-dimensional solid elements. The smaller model was composed of half a wheelset, one rail (symmetry with respect to the centre line of the track was assumed), railpads, sleepers, and ballast bed. The ballast bed was modelled as a continuum with elastic or elastic-plastic material properties. To avoid wave reflections at the ends of the ballast bed, non-reflecting boundary conditions were used. The wheel was modelled as rigid, and the sleepers could be either rigid or flexible. The railpads were modelled using a predefined rubber material.

The loading of the track came from a wheelset of a train moving on the track. A constant force representing the dead load of the car body and the bogie frame loaded the wheelset. The mass of the wheelset, i.e., the wheel mass and half of the axle mass, was taken into account. This means that the inertia force from the unsprung mass, i.e., from the wheel and the axle, was taken into account. The passage of a full train can then be simulated as the passage of a sequence of wheelsets. I this study, only one wheelset representing the train load was used. Only in a study of the long-term behaviour of the track several wheelset passages were applied to the track.

When studying the short-term behaviour of the track, normally only the maximum track deflection and maximum stresses in rails, sleepers, and ballast, and other extreme values, are of interest. In that case it is sufficient to load the track with one wheelset only. The influence of one wheelset of a bogie on the deflections, etc, at the nearby wheelset is negligible. This can be concluded from the fact that much of the track deflection rebounds between the two wheels. The loading from one wheelset on the track is spread out over a few (say three or four) sleepers only below the wheelset, but the distance to the next wheelset is several sleeper spans. Therefore the influence of one wheelset at the location of the other wheelset can be neglected and it is concluded that one wheelset represents well the local loading of the train on the track.

Regarding the influence of the car body motion and the bogie frame motion, the load variations from these parts are of a relatively low frequency. A wheelset is surrounded by two “springs”: one upwards to the bogie frame (the primary suspension) and one downwards to the rail (the elasticity in the wheel/rail contact patch). The primary suspension (spring to bogie frame) has a much lower stiffness than the contact “spring” (the stiffness at the contact patch). This indicates that the primary suspension will induce a frequency in the system that is much lower than the frequency induced by the contact spring (the so-called Hertzian spring). A low-frequency load variation requires a very long model. For example, a speed v = 60 m/s and a frequency f = 1 Hz gives a load variation with wavelength $\lambda = v/f$ = 60 m, and that long models were not feasible in this study. Therefore, the influence of the car body and the bogie frame on the track dynamics was, in this study, taken care of as a static load on the wheelset only. Thus, when calculating the dynamic wheel/rail contact force, inertia effects from the wheelset and the track structure (rails, sleepers, ballast, etc) were included, but inertia effects of car body and bogie frame were excluded; only their dead load was accounted for. This implies that higher frequencies, such as the sleeper-passing frequency and the pinned-pinned frequency of the rail are captured in the model, but low frequencies, giving a wavelength longer than the model itself, cannot be dealt with.

2.1 Complete double-track models

Two models of double-track lines were developed. One of them, the model of the Madrid-Zaragoza line, was used to simulate measurements that were performed in the SUPERTRACK project. This track model is shown in Figure 2. Some calculations with moving wheelsets loading the track were performed to verify that the models work correctly. Single wheelsets have run on the two tracks (one track at a time). Also, two “trains”, i.e. two wheelsets, running simultaneously in opposite directions or in parallel on the two tracks were tested, and the results were promising.

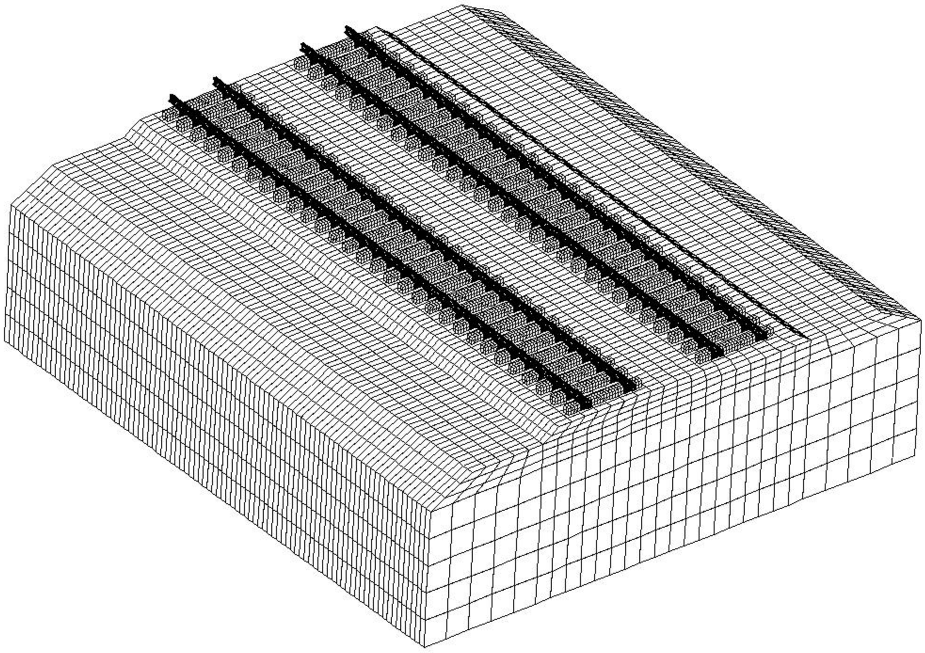

Figure 2 Finite element model of a double-track Spanish line.

2.2 Computer program

The finite element models of the railway tracks were built-up using the pre-processor TrueGrid. Input files to the solver (LS-DYNA) were generated. Besides building the FE mesh in TrueGrid, one must designate what kind of output result one wants, one has to implement contacts, assign material properties to the different parts of the track, and give boundary conditions. The TrueGrid file for this model is attached in Appendix 4.

The solver is a general-purpose finite element code for analysing large deformation dynamic responses of structures, including structures coupled to fluids. The main solution methodology is based on explicit time integration. The contact force is calculated by a penalty method (contacts appear between wheel and rail and between sleeper and ballast).

The non-reflecting boundary condition is important when dealing with geomechanical problems because one wants to limit the size of the model. Instead of having an enormous model it is possible to make a much smaller model and still obtaining the same results but with a shorter calculation time. The non-reflecting boundary condition absorbs the shear and pressure waves so that no reflections occur at the boundaries. However, the bending wave in the rail is still reflected.

The postprocessor used is LSPOST. Using this postprocessor one can analyse the output results from LS-DYNA. Animations and graphs can easily be created in the postprocessor.

2.3 Model verifications

The double-track finite element model has been verified by use of measured results from a Spanish test site at a newly built track. Track deflection was measured when a six-axle locomotive was loading the track. Results are presented in Figure 3. The passage of the six axles can clearly be seen in the figure. The axles pass the sleeper where the measurements were performed. The axles arrive in groups of three, with three axles on the first bogie, and after a while, another three axles on the second bogie pass the measurement site. When performing these measurements, the six-axle locomotive loaded the track statically; it passed the measurement site by advancing just one sleeper distance at a time. The measurements gave a maximum track deflection of 1.9 mm, see Figure 3.

Calculations performed for this case give displacements of the same size (1.5 mm) as the measured displacements, see Figure 3. Track data provided within the SUPERTRACK project for this site were used in the numerical model. The difference between the measured and the calculated deflections that can be seen in the figure may depend on the fact that the track was very new so that the track structure (rails and sleepers) had not yet settled firmly onto the ballast. Most probably there are some small gaps between the sleepers and the ballast, so that even at a very low loading of the track, the track will have some deflection due to closing of these gaps (such “gaps” are not included in this model). It can be seen from the measured curve that the rail does not return to its original position even when the bogies are not close to the measurement site. The distance between the last axle in the first bogie and the first axle in the second bogie is about 5 m, but although the axles are so well separated, the rail will not be pushed back to zero displacement by the support. This implies that the sleeper support must be very soft at low loading of the track. Thus, small “gaps” between the sleepers and the ballast could explain this very low stiffness at low loads. As soon as these “gaps” have been closed, the track will have its ordinary stiffness. In the numerical model, the track will be pushed back to its initial level also between the bogies, implying that the track stiffness in the model is not sufficiently low at low loadings of the track, see Figure 3.

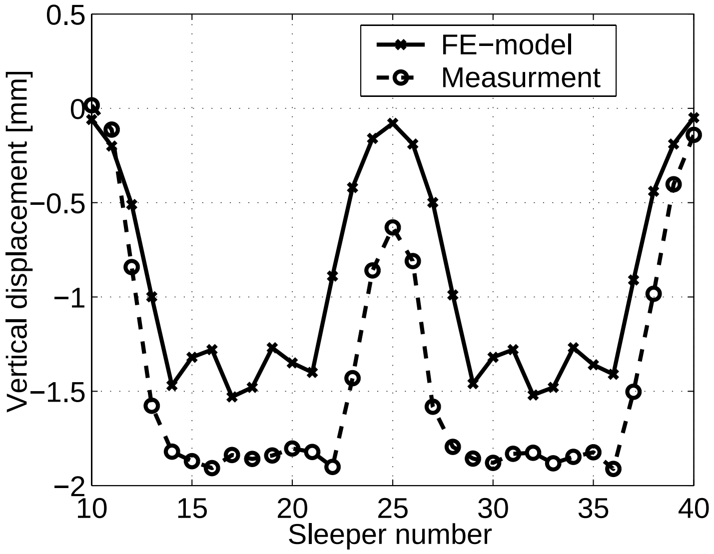

Figure 3 Validation of track model. Calculated track deflection using FE-model of Spanish track (full-line curve) compared to measured deflection (dotted curve) when six-axle locomotive was loading the track.

At another measurement campaign performed on the Madrid-Zaragoza line, also stresses in the ballast bed and in the interface between ballast and subballast were measured.

The computer model resembled the measurement site as close as possible. There were five different material layers: the ballast layer, the subballast, the form layer, the embankment, and the natural ground. Characteristics of each layer are given in Table 1.

Table 1 Characteristics of the five layers of the track bed.

Layer	Depth (m)	Modulus of elastici (MPa)	Poisson’s ratio	Weight (kN/m^3)
ballast	0.35	70	0.15	15
subballast	0.225	70	0.3	20.5
form layer	0.60	60	0.3	20.8
embankment	3.0	50	0.3	21
natural ground	13.0	700	0.3	20

The computer model used for this validation had a length of 30 sleepers. Five sleepers in the centre of the model were elastic and the remaining sleepers were rigid. All results were extracted from the centre of the model close to sleeper 15 (sleepers 13 to 17 were elastic).

One wheelset moved over the model at a speed of 200 km/h. The static (dead) load on the wheelset was 123.911 kN (which was the maximum wheel load measured). The stiffness of the railpad was adjusted so that its deformation became 0.4 mm when the wheel with the load given above passed.

Comparing calculated results with measured ones gave the following:

- Calculated maximum rail deflection at wheel passage was 1.9 mm and the measurements gave 2.4 mm.
- Calculated maximum stress below the outer end of the sleeper was 0.0737 MPa and the measurements gave 0.0633 MPa.
- Calculated maximum stress below the centre of the sleeper was 0.0694 MPa and the measurements gave 0.0272 MPa.
- Calculated maximum stress at the interface between ballast and subballast at the outer end of the sleeper was 0.0516 MPa. The measurements gave 0.0493 MPa.
- Calculated maximum stress at the interface between ballast and subballast at the centre of the sleeper was 0.0590 MPa. The measurements gave 0.0115 MPa.

As can be seen, the rail displacements differ by 0.5 mm. The same phenomenon as discussed at Figure 3 may apply here. At the centre of the track (below the centre of the sleeper) the computer model indicated too high stresses. One explanation may be that in the model the sleeper was supported along its full length, whereas in practice the ballast was more compacted below the rails and less at the sleeper centre. This may explain the big difference found for the stresses in the ballast at the centre of the track. At the sleeper end, the agreement between calculations and measurements is good (or even excellent) both at the sleeper/ballast interface and at the ballast/sub-ballast interface.

Some explanations of the differences are:

- Material data was taken from a site situated a few metres from the measurement site.
- The ballast compaction needs not be constant along the track and along a sleeper. Normally, the ballast is less compacted at the centre of the sleeper. This can be seen in the measured results. The model could, of course, be modified to account for lower ballast stiffness at the centre, but this was not done because no data was available.
- The wheel load was measured a few metres from the measurement site. The maximum wheel load used in the calculations need not be the same at the measurement site as at the place where it was measured. An irregularity of the track stiffness (for example a hanging sleeper) may greatly influence the wheel/rail contact force to give large local variations of the contact force.
- Measurements were performed with a full train but calculations were performed with one wheelset only.

From these validations of the numerical model it could be concluded that the dynamic train/track interaction could be simulated with an acceptable accuracy.

3 Critical aspects of track response

The research work performed and some capabilities of the computer program developed in this project are presented in this section. The research concerns track settlement due to non-elastic deformation of the ballast bed and the subground, hanging sleepers, and a smooth transition between two parts of the track with different stiffness.

3.1 Track settlement

Regarding track settlement, not many numerical models to simulate the settlement can be found in the literature. In a research programme in Germany track settlement and deterioration of ballast and subgrade materials were examined, reference [7]. The German project aimed at better understanding the dynamic interaction between vehicle and track, and at understanding the long-term behaviour of the components of the entire track system.

In many track models the track stiffness, the damping, and the track mass are discretized. The mass of the track (sleepers, ballast, etc.) is modelled by use of rigid masses. The track stiffness and damping are modelled by use of spring and damper elements. In a model proposed by Dahlberg [14] it was assumed that also the track settlement could be discretized; the settlement of the track was collected in a settlement element in the track model. That model contained one rail (longitudinal symmetry was assumed), railpads, rigid sleepers, ballast stiffness (spring elements), ballast damping (damper elements), and an element beneath the ballast stiffness to take care of the permanent deformation of the ballast. In this element the track settlement was accumulated. Using that model it was possible to simulate so-called differential settlement. A local track settlement was achieved at some sleepers that were supported by “bad” ballast material.

The elastic-plastic continuum material model used in the study presented here to model the ballast material was predefined in the computer program (material MAT SOIL AND FOAM was used). According to the User’s Manual [15] this material behaves like a fluid. It should be used only in situations “when soils and foams are confined in the structure”. When loading the material, it behaves like a linear elastic, deformation hardening material. If the yield limit of the material is exceeded, permanent plastic deformations will remain in the ballast after it has been unloaded. When the track bed is composed of several layers with different function and characteristics (ballast, subballast, formation), different material models for the different layers will be used, see Figure 1.

As an example, the SOIL AND FOAM material was used for the ballast layer in Figure 1. The yield limit of the ballast material was selected so that the stress beneath sleepers 11 to 20 (30 sleepers in the model) would exceed the yield limit of the ballast material when the wheel passed.

In the calculations it was found that the contact force between the ballast and sleeper 11 (the first sleeper in the section with “bad” ballast, i.e., a low yield strength) became zero after the first wheel passage. This indicates that the ballast bed has undergone that large plastic deformation that Sleeper 11 has become hanging in the rail. Sleeper 12 gets a lower (static) sleeper/ballast contact force after the first wheel passage, and the contact disappears after the second wheel passage. Sleepers 13 to 18 never lose contact during these cycles, but the permanent deformation (settlement) increases during the loading, see Figure 4. The settlement rate after each wheel passage is, however, decreasing. Figure 4 also shows how the rail and sleeper move upwards a small amount just before the wheel arrives and also after the wheel has passed. Further details on this work can be found in Lundqvist and Dahlberg [16].

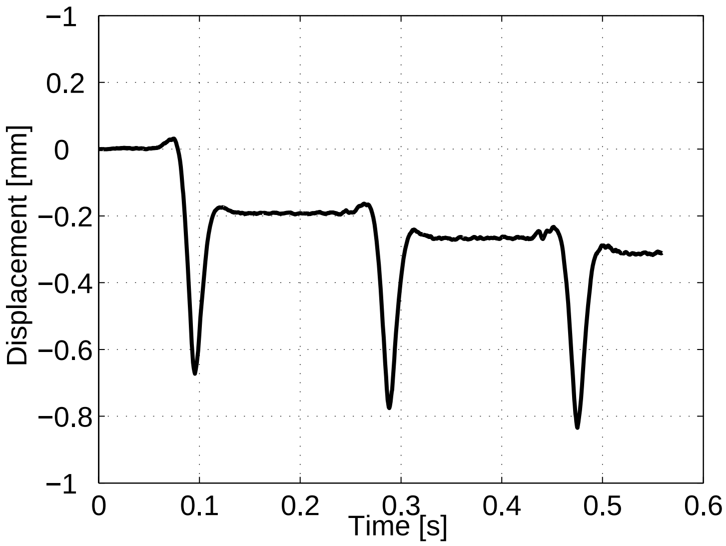

Figure 4 Displacement of sleeper 15 (see Figure 1) during three wheel passages. The settlement (permanent deformation after a wheel passage) increases for each load cycle, but settlement rate decreases.

3.2 Dynamic forces due to unsupported sleeper

A study of the influence of an unsupported (or “hanging”) sleeper on the train/track dynamics has been performed. In an ideal case, the sleepers should rest on the ballast bed to provide support of the rails and transmit vertical, lateral and longitudinal forces from the rail down to the ballast bed. In the calculated results presented here, one sleeper was not in contact with the ballast (i.e. when the track was unloaded). A gap of 0.5 mm or 1mm was introduced between the sleeper and the ballast, and the increase of dynamic forces due to this gap was investigated. The model shown in Figure 1 was used. The hanging sleeper and the two adjacent sleepers were made flexible, while the other sleepers of the track model were rigid. The ballast bed was fully elastic. Further details on this study were presented in Lundqvist and Dahlberg [2]. In reference [2] also two and three hanging sleepers were investigated.

Some calculated results for a track with one hanging sleeper (No 15) are shown in Figures 5 and 6. The wheelset loading the track moved at speed 90 m/s going from the left (sleeper 1) to the right (sleeper 30). The gap between sleeper 15 and the ballast bed was 0.5 mm and 1 mm. For comparison, the contact force when there was no gap at sleeper 15 is also shown.

The sleeper/ballast contact force at sleeper 14, when sleeper 15 was hanging, increased by about 20 percent. If the gap at sleeper 15 was 0.5 mm or 1.0 mm did not matter. At sleeper 15 there was some contact between the sleeper and the ballast if the gap was 0.5 mm, but at a gap of 1 mm no contact occurred between the sleeper and the ballast.

Sleeper 16 became the most loaded sleeper when sleeper 15 was hanging. In Figure 5 the sleeper/ballast contact force at sleeper 16 is shown. It can be seen in the figure that the sleeper/ballast contact force at this sleeper increases a lot (at vehicle speed 90 m/s). The figure shows that the sleeper/ballast contact force at sleeper 16 increased by 70 percent when sleeper 15 was hanging in the rail with a gap of 1 mm down to the ballast. Such a large overload of the ballast bed might, of course, result in non-elastic deformations of the ballast and subground at that sleeper. A process that results in track settlements might have been initiated.

In Figure 6 the wheel/rail contact force is shown. It is seen that the contact force goes down when the wheel passes sleeper 15 (and also the wheel moves downwards) and it is also seen that there is a large impact when the wheel reaches sleeper 16 (where the wheel moving downwards should be turned to move upwards). It is concluded that a hanging sleeper will induce large dynamic forces in the track.

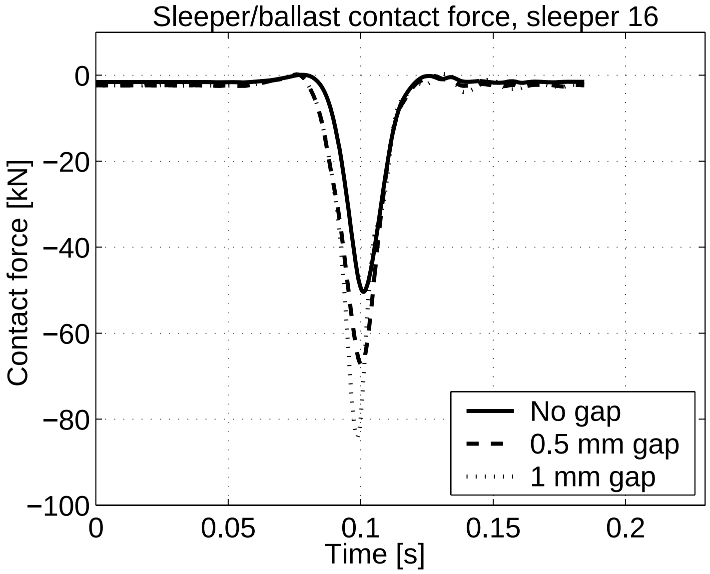

Figure 5 Sleeper/ballast contact force at sleeper 16 when sleeper 15 is hanging. The gap between sleeper 15 and the ballast is 0.5 mm and 1 mm. For comparison, the contact force at sleeper 16 when there is no gap at sleeper 15 is also shown (solid line).

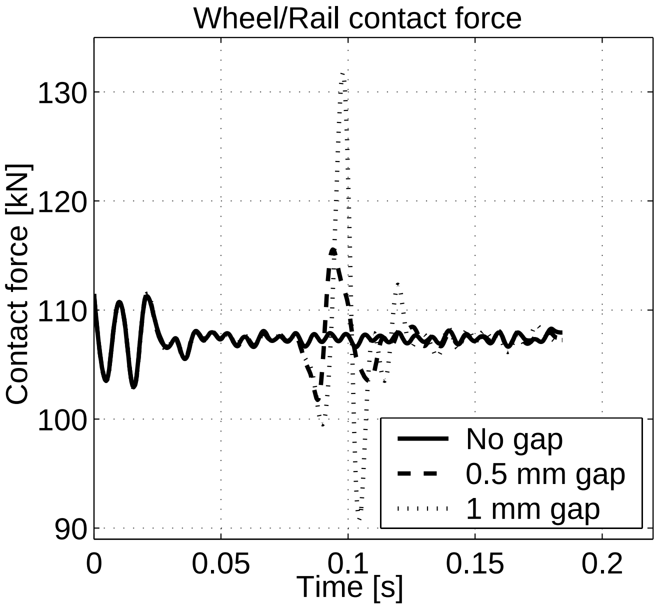

Figure 6 Wheel/rail contact force obtained when wheel passes over hanging sleeper. The hanging sleeper (No 15) is passed at time 0.085s (approximately), and a large dynamic impact is seen when the wheel reaches sleeper No 16.

3.3 Optimal track stiffness

The stiffness of a track will change from one value to another at different parts of a track; an embankment-to-bridge transition is an example. Therefore, a study on how to select the track stiffness at a transition zone between two parts with different stiffness has been performed [3]. The study focuses on optimization of the track stiffness at the transition area (booted sleepers, for example, can be used to control track stiffness). In the model, the transition area is divided into five short sections with one stiffness (to be optimized) in each section, see Figure 7.

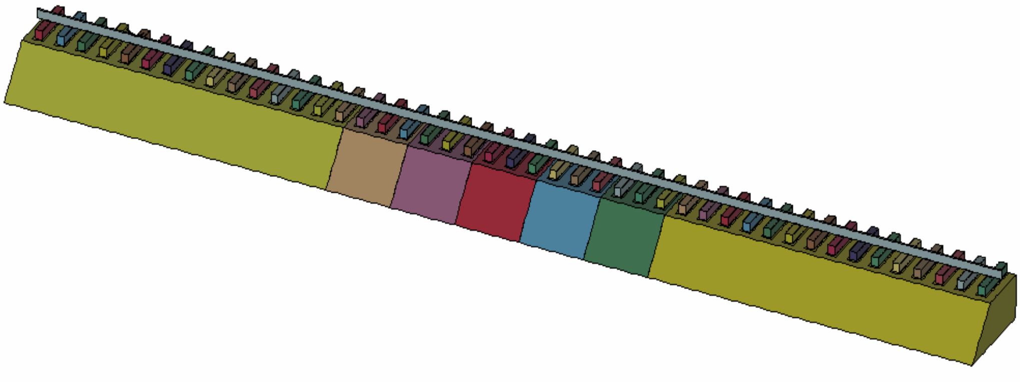

Figure 7 Track stiffness transition zone (five sections) from stiff to soft track, or vice versa.

As an objective of the optimization, the wheel/rail contact force was selected. The force variation (the irregularity of the force) should be as small as possible when the wheel passed the transition area. Optimal track stiffness variations in the transition area, as obtained from the optimization procedure, are shown in Figure 8a,b. The track stiffness at one end of the track model was 90 kN/mm and at the other end the stiffness was 45 kN/mm (different stiffnesses were obtained by changing the modulus of elasticity of the ballast material). It is seen in Figure 8a,b that the optimal stiffness variation depends on the travelling direction of the train.

The improvement of the wheel/rail contact force variation can be seen in Figure 9a,b. The results show that by selecting the track stiffness suitably, a wheel/rail contact force can be achieved that does not differ very much from the force obtained at the constant-stiffness track. This will, of course, improve the dynamic performance of the train and less damage will be induced to the track.

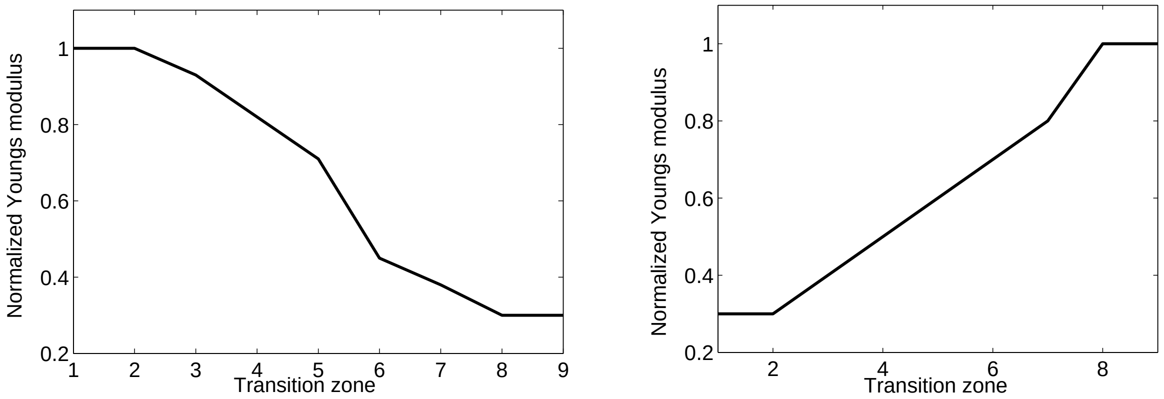

Figure 8 Optimum track stiffness variation along transition area when wheelset is moving from stiff to soft track (left figure), and when moving from soft to stiff track (right figure)

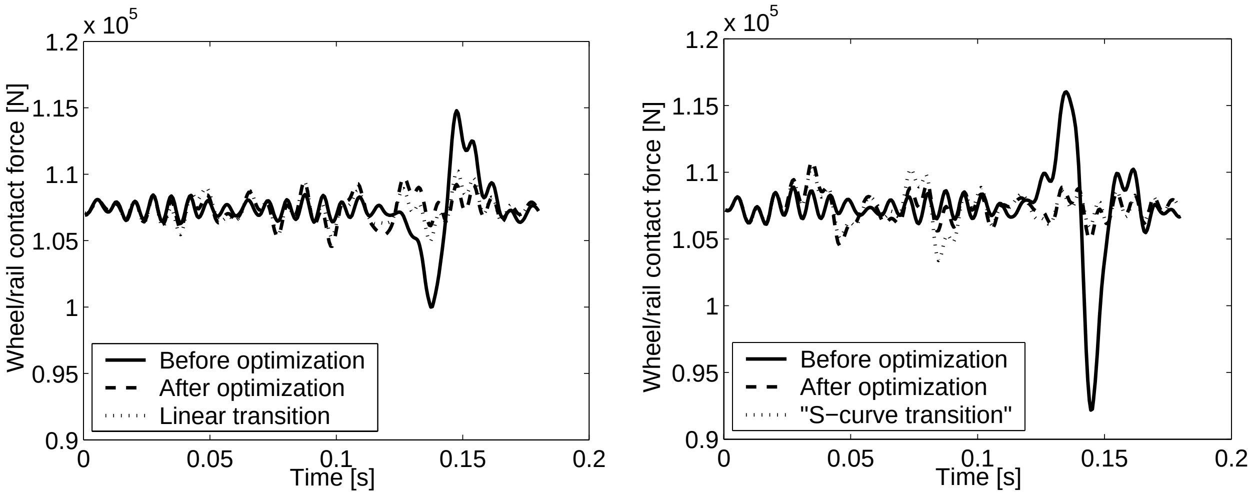

Figure 9 Wheel/rail contact force at track stiffness transition area before optimization and after optimization for transition from stiff to soft track (left figure) and from soft to stiff track (right figure).

4 SUMMARY AND CONCLUSIONS

Numerical models to simulate the dynamic interaction between a railway train and the track have been presented. The models were developed at Linkoeping University, and they were verified versus field measurements performed by the Centro de Estudios y Experimentacion de Obras Publicas (CEDEX) on the high-speed line between Madrid and Zaragoza. The finite element model of the high-speed double-track line gave calculated results that agree fairly well with the measured ones.

The dynamic wheel/rail interaction force can be simulated by the program. Due to irregularities of this force, track degradation will occur. Track settlement due to non-elastic deformations in the ballast and subground is one important part of the degradation. Track settlement has been simulated using a simple elastic-plastic material model of the ballast. Due to track settlement, hanging sleepers may appear, and these sleepers will induce an irregularity of the track stiffness giving an increased dynamic loading of the track. Using the model developed, track dynamics due to one or several unsupported sleepers can be investigated.

Variations of track stiffness along a track cannot always be avoided (a transition from an embankment to a bridge is an example). A study on how track stiffness should be selected to obtain an as smooth transition as possible between two parts of the track with different stiffness was undertaken. It was demonstrated that a transition can be achieved that gives almost the same wheel/rail contact force as one has at a constant-stiffness part of the track.

5 REFERENCES

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6 APPENDICES

Appendix 1 - Presentations given at meetings and conferences

Meetings, seminars, and conferences where Linköping University has presented the work performed in the SUPERTRACK project are listed. Presentations at SUPERTRACK meetings are not included.

11th *Nordic Seminar on Railway Mechanics*, Copenhagen, Denmark, Mar 31 to Apr 1, 2003.

18th IAVSD Symposium *Dynamics of Vehicles on Roads and Tracks*, Atsugi, Kanagawa, Japan, Aug 24-30, 2003.

12th *Nordic Seminar in Railway Mechanics*, Luleå, Sweden, June 1-2, 2004

The *Abetong seminar* at Chalmers, Gothenburg, March 21, 2005

SVIB Conference *Nordic Vibration Research*, KTH Stockholm, June 3-4 2004

13th *Nordic Seminar in Railway Mechanics*, Hamar, Norway, May 10-11, 2005

The *"Under-sleeper-pad" seminar* at Chalmers, Gothenburg, May 19, 2005

Meeting at Banverket, Borlänge, June 27, 2005

19th IAVSD Symposium *Dynamics of Vehicles on Roads and Tracks*, Milano, Italy, Aug 29 to Sept 2, 2005.

Elmia Nordic Rail 2005, Jönköping, Oct 4-6, 2005.

Appendix 2 - Published papers and reports

Papers and reports presented by Linkoeping University are listed. Progress (and other) reports to the SUPERTRACK consortium are listed separately.

1. Lundqvist A and Dahlberg T: Verification of track model versus Spanish measurements. Report for the EU project SUPERTRACK, Solid Mechanics, IKP, Linköping University, Linköping, Sweden, 2005, 18 pp. *To be published.*

2. Dahlberg T: *Railway track settlements - a literature review and a Bibliography.*
Report for the EU project SUPERTRACK, Solid Mechanics, IKP, Linköping University, Linköping, Sweden, 2002, 41 pp.

3. Lundqvist A and Dahlberg T: Dynamic train/track interaction including model for track settlement evolvement. Proceedings 18th IAVSD Symposium at Atsugi, Japan, August 24-29, 2003. *Vehicle System Dynamics,* Vol 41(Supplement) 2004, 667-676.

4. Lundqvist A and Dahlberg T: Dynamic train/track interaction including model for track settlement evolvement. Presented at *Eleventh Nordic Seminar in Railway Mechanics,* Copenhagen, March 2003.

5. Lundqvist A and Dahlberg T: Load impact on railway track due to unsupported sleepers. Proc IMechE *Journal of Rail and Rapid Transit,* Vol 219 Part F, 67-77, 2005

6. Lundqvist A and Dahlberg T: Dynamic forces in railway track due to unsupported sleepers. *Twelfth Nordic Seminar in Railway Mechanics*, June 1-3, 2004, Luleå.

7. Lundqvist A and Dahlberg T: Dynamic forces in railway track due to unsupported sleeper. *Proceedings, Nordic Vibration Research 2004,* KTH, Stockholm, June 3-4, 2004.

8. Lundqvist A and Dahlberg T: Railway track stiffness variations – consequencies and countermeasures. Presented at 19th *IAVSD Symposium on Dynamics of Vehicles on Roads and Track,* Milan, Italy, Aug 29 to Sept 2, 2005.

9. Lundqvist A and Dahlberg T: Railway track stiffness variations – consequencies and countermeasures. *Thirteenth Nordic Seminar in Railway Mechanics,* May 10-11, 2005, Hamar, Norway.

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11. Dahlberg T: Railway track dynamics - a survey. To appear in *Handbook on Railway Vehicle Dynamics*, Swetz & Zeitlinger, 2005 (or 2006?), 50 pp.

12. Lundqvist A: *Dynamic train/track interaction – Hanging sleepers, track stiffness variations, and track settlement*. Thesis for the degree of licentiate, Solid Mechanics, IKP, Linköping University, Linköping, Sweden, 2005.

13. Dahlberg T: Numerical simulation of train/track dynamics, railway track settlement, unsupported sleepers, and track stiffness irregularities.
Presented at the Abetong seminar at Chalmers, Gothenburg, March 21, 2005.

Appendix 3 - Progress reports to SUPERTRACK consortium

1. Progress report August 2003 (SUPERTRACK progress report: Dynamic train/track interaction including model for track settlement evolvement)

2. Progress report March 2004 (Dynamic train/track interaction including model for track settlement evolvement)

3. Progress report July 2004 (Dynamic train/track interaction model:
verification, modelling of track settlement, hanging sleeper(s), and varying track stiffness)

4. Progress report May 2005 (Numerical simulation of train/track dynamics, railway track settlement, unsupported sleepers, and track stiffness irregularities - Progress Report Year 3)

5. Final report October 2005 (Numerical simulation of train/track dynamics: Computer models and verifications, track settlement, hanging sleepers, and track stiffness variations)

Appendix 4

Input file to TRUEGRID

```
title wheel on rail
lsdyna
keyword

c
c Here all output quantities one wants from the model are
c declared. It could be, for exazmple, displacements of nodes and
c rigid bodies, speeds  and accelerations, stresses in elements,
c energies, etc. Also, how often the data should be
c stored is declared here:
c
c
para tterm 6e-2 nplt 20;
lsdyopts hgen 2 slnten 2 itrist 1 endtim %tterm
glstat [%tterm/(5*%nplt)]
matsum [%tterm/(5*%nplt)]
hgen 2
rwen 2
rylen  2
slnten 2
sleout [%tterm/(5*%nplt)]
nodout [%tterm/(5*%nplt)]
rbout [%tterm/(5*%nplt)]
rcforc [%tterm/(5*%nplt)]
gceout [%tterm/(5*%nplt)]
elout [%tterm/(5*%nplt)]
d3plot dtcycl [%tterm/%nplt] ; strflg 1 ;
c lsdyopts nrcyck 100 drtol 0.006 drfctr 0.995 drterm 0 tssfdr 0 irelal 0 edttl
c 0.04 idrflg 1 ;

c ------------------------------------------------------------------------------
c ballast-sleeper contacts
c ------------------------------------------------------------------------------
c Here all contacts between sleepers and ballast are declared and
c which type of contact that is used. Here a node-to-surface
c contact is used under all 60 sleepers:
c

sid 1 lsdsi 5 scoef 0.1 ; ;
sid 2 lsdsi 5 scoef 0.1 ; ;
sid 3 lsdsi 5 scoef 0.1 ; ;
sid 4 lsdsi 5 scoef 0.1 ; ;
sid 5 lsdsi 5 scoef 0.1 ; ;
sid 6 lsdsi 5 scoef 0.1 ; ;
sid 7 lsdsi 5 scoef 0.1 ; ;
sid 8 lsdsi 5 scoef 0.1 ; ;
sid 9 lsdsi 5 scoef 0.1 ; ;
sid 10 lsdsi 5 scoef 0.1 ; ;
sid 11 lsdsi 5 scoef 0.1 ; ;
sid 12 lsdsi 5 scoef 0.1 ; ;
sid 13 lsdsi 5 scoef 0.1 ; ;
sid 14 lsdsi 5 scoef 0.1 ; ;
sid 15 lsdsi 5 scoef 0.1 ; ;
sid 16 lsdsi 5 scoef 0.1 ; ;
sid 17 lsdsi 5 scoef 0.1 ; ;
sid 18 lsdsi 5 scoef 0.1 ; ;
sid 19 lsdsi 5 scoef 0.1 ; ;
sid 20 lsdsi 5 scoef 0.1 ; ;
sid 21 lsdsi 5 scoef 0.1 ; ;
sid 22 lsdsi 5 scoef 0.1 ; ;
sid 23 lsdsi 5 scoef 0.1 ; ;
sid 24 lsdsi 5 scoef 0.1 ; ;
sid 25 lsdsi 5 scoef 0.1 ; ;
sid 26 lsdsi 5 scoef 0.1 ; ;
sid 27 lsdsi 5 scoef 0.1 ; ;
sid 28 lsdsi 5 scoef 0.1 ; ;
sid 29 lsdsi 5 scoef 0.1 ; ;
sid 30 lsdsi 5 scoef 0.1 ; ;
sid 101 lsdsi 5 scoef 0.1 ; ;
sid 102 lsdsi 5 scoef 0.1 ; ;
sid 103 lsdsi 5 scoef 0.1 ; ;
sid 104 lsdsi 5 scoef 0.1 ; ;
sid 105 lsdsi 5 scoef 0.1 ; ;
sid 106 lsdsi 5 scoef 0.1 ; ;
sid 107 lsdsi 5 scoef 0.1 ; ;
sid 108 lsdsi 5 scoef 0.1 ; ;
sid 109 lsdsi 5 scoef 0.1 ; ;
sid 110 lsdsi 5 scoef 0.1 ; ;
sid 111 lsdsi 5 scoef 0.1 ; ;
sid 112 lsdsi 5 scoef 0.1 ; ;
sid 113 lsdsi 5 scoef 0.1 ; ;
sid 114 lsdsi 5 scoef 0.1 ; ;
sid 115 lsdsi 5 scoef 0.1 ; ;
sid 116 lsdsi 5 scoef 0.1 ; ;
sid 117 lsdsi 5 scoef 0.1 ; ;
sid 118 lsdsi 5 scoef 0.1 ; ;
sid 119 lsdsi 5 scoef 0.1 ; ;
sid 120 lsdsi 5 scoef 0.1 ; ;
sid 121 lsdsi 5 scoef 0.1 ; ;
sid 122 lsdsi 5 scoef 0.1 ; ;
sid 123 lsdsi 5 scoef 0.1 ; ;
sid 124 lsdsi 5 scoef 0.1 ; ;
sid 125 lsdsi 5 scoef 0.1 ; ;
sid 126 lsdsi 5 scoef 0.1 ; ;
sid 127 lsdsi 5 scoef 0.1 ; ;
sid 128 lsdsi 5 scoef 0.1 ; ;
sid 129 lsdsi 5 scoef 0.1 ; ;
sid 130 lsdsi 5 scoef 0.1 ; ;

c ------------------------------------------------------------------------------
c parameters
c ------------------------------------------------------------------------------
c Here two parameters are given: the sleeper distance (should be
c an integer multiple of 100 mm) and the number of sleepers.
```

```
para
a 600   c sleeper distance (in steps of 100 mm)
s 30;   c number of sleepers (maximum 30)


c -----------------------------------------------------------------------------
c sleepers
c -----------------------------------------------------------------------------
c Material data for all sleepers
c


lsdymats 1 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5;
lsdymats 2 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5;
lsdymats 3 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5;
lsdymats 4 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 5 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 6 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 7 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 8 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 9 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 10 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 11 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 12 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 13 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 14 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 15 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 16 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 17 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 18 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 19 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 20 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 21 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 22 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 23 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 24 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 25 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 26 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 27 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 28 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 29 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 30 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 101 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 102 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5;
lsdymats 103 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5;
lsdymats 104 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 105 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 106 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 107 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 108 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 109 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 110 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 111 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 112 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 113 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 114 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 115 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 116 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 117 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 118 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 119 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 120 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 121 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 122 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 123 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 124 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 125 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 126 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 127 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 128 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 129 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
lsdymats 130 20 hgqt 1 brick elfob i8b rho 2.5e-9 e 2.1e+5 pr 0.3 cmo con 6 5 ;
c lmi 1
c block 1 2;1 2;1 2;0 1250;0 200;250 450;
c mseq i 99
c mseq j 3
c mseq k 3

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;

c sii 1 2;-1;1 2;1 s ;

c mate 1
c si 1 1 1 2 1 2 1 s ;
c lct [%s-1] mz [%a] ; repe [%s-1];
c lrep 0 1 2 3 4  5 6 7 8 9 10 11 12 14 15 16 17 18 19 20 21 22 23 24;
c merge


c For each sleeper the geometry and the FE mesh are given.
c The material data given above are connected to the
c corresponding sleeper. Nodes involved in contacts are
c declared.

c -----------------------------------------------------------------------------
c hanging sleeper 1
c -----------------------------------------------------------------------------
lmi 100
lsii 100
block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250] [450];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1
c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;1 s ;
lct 1 mx 4500 ryz;
lrep 0 1;
mate 1
merge
c -----------------------------------------------------------------------------
c hanging sleeper 2
c -----------------------------------------------------------------------------
block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+1*%a]
[450+1*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;2 s ;
mate 2
c lmi 100
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 3
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+2*%a]
[450+2*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;3 s ;
mate 3
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 4
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+3*%a]
[450+3*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;4 s ;
mate 4
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 5
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+4*%a]
[450+4*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;5 s ;
mate 5
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 6
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+5*%a]
[450+5*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;6 s ;
mate 6
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
```

```
merge

c -----------------------------------------------------------------------------
c hanging sleeper 7
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+6*%a]
[450+6*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;7 s ;
mate 7
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 8
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+7*%a]
[450+7*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;8 s ;
mate 8
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 9
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+8*%a]
[450+8*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;9 s ;
mate 9
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 10
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+9*%a]
[450+9*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;10 s ;
mate 10
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 11
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+10*%a]
[450+10*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;11 s ;
mate 11
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 12
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+11*%a]
[450+11*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;12 s ;
mate 12
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 13
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+12*%a]
[450+12*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;13 s ;
mate 13
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 14
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+13*%a]
[450+13*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;14 s ;
mate 14
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 15
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+14*%a]
[450+14*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;15 s ;
mate 15
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge


c -----------------------------------------------------------------------------
c hanging sleeper 16
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+15*%a]
[450+15*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;16 s ;
mate 16
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c hanging sleeper 17
c -----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+16*%a]
[450+16*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;17 s ;
mate 17
c lmi 0
lct 1 mx 4500 ryz;
```

```
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 18
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+17*%a]
[450+17*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;18 s ;
mate 18
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 19
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+18*%a]
[450+18*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;19 s ;
mate 19
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 20
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+19*%a]
[450+19*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;20 s ;
mate 20
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 21
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+20*%a]
[450+20*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;21 s ;
mate 21
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 22
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+21*%a]
[450+21*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;22 s ;
mate 22
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 23
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+22*%a]
[450+22*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;23 s ;
mate 23
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 24
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+23*%a]
[450+23*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;24 s ;
mate 24
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 25
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+24*%a]
[450+24*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;25 s ;
mate 25
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 26
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+25*%a]
[450+25*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;26 s ;
mate 26
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 27
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+26*%a]
[450+26*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;27 s ;
mate 27
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c hanging sleeper 28
c ---------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+27*%a]
[450+27*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;28 s ;
mate 28
c lmi 0
lct 1 mx 4500 ryz;
```

```
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c hanging sleeper 29
c ----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+28*%a]
[450+28*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;29 s ;
mate 29
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c hanging sleeper 30
c ----------------------------------------------------------------------------

block 1 2 3 4 5 6;1 2;1 2;-1250 -850 -650 650 850 1250;0 200;[250+29*%a]
[450+29*%a];
mseq i 3 15 12 15 3
mseq j 1
mseq k 1

c bi -1;1 2;1 2;dx 1 ry 1 rz 1 ;
sii 1 6;-1;1 2;30 s ;
mate 30
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge


c ----------------------------------------------------------------------------
c contact shell
c ----------------------------------------------------------------------------
c To speed up the contact search algorithm, so-called null-shells
c are used. Their material propertiea are declared here.

control
lsdymats 31 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 32 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 33 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 34 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 35 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 36 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 37 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 38 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 39 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 40 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 41 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 42 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 43 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 44 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 45 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 46 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 47 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 48 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 49 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 50 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 51 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 52 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 53 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 54 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 55 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 56 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 57 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 58 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 59 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 60 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 131 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 132 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 133 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 134 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 135 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 136 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 137 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 138 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 139 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 140 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 141 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 142 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 143 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 144 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 145 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 146 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 147 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 148 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 149 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 150 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 151 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 152 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 153 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 154 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 155 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 156 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 157 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 158 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 159 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
lsdymats 160 9 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 2.5e-9 ;
c lmi 0
c block 1 2;-1;1 2;0 1300;0;200 500;
c mseq i 12
c mseq k 2
c orpt + 0 100 0
c n 1 1 1 2 1 2
c sii ; ; ;1 m ;

c mate 26

c lct [%s-1] mz [%a] ; mz [2*%a] ; mz [3*%a] ; mz [4*%a] ; mz [5*%a] ;
c mz [6*%a];mz [7*%a];mz [8*%a];mz [9*%a];mz [10*%a];mz [11*%a];
c mz [12*%a];mz [13*%a];mz [14*%a]; mz [15*%a]; mz [16*%a];mz [17*%a];
c mz [18*%a];mz [19*%a];mz [20*%a];mz [21*%a];mz [22*%a];mz [23*%a];
c mz [24*%a];
c lrep 0 1 2 3 4 5 6 7 8 9 10 11 12 14 15 16 17 18 19 20 21 22 23 24;
merge


c Geometry and element mesh for the null-shells are given, and
c that these contacts refer to the sleeper-ballast contacts.
c
c ----------------------------------------------------------------------------
c contact between shell and sleeper 1
c ----------------------------------------------------------------------------



block 1 2;-1;1 2;-1478 1478;0;[150] [550];
mseq i 6
```

```
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;1 m ;

mate 31
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 2
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+1*%a] [550+1*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;2 m ;

mate 32
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 3
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+2*%a] [550+2*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;3 m ;

mate 33
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 4
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+3*%a] [550+3*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;4 m ;

mate 34
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 5
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+4*%a] [550+4*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;5 m ;

mate 35
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 6
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+5*%a] [550+5*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;6 m ;

mate 36
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 7
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+6*%a] [550+6*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;7 m ;

mate 37
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 8
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+7*%a] [550+7*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;8 m ;

mate 38
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 9
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+8*%a] [550+8*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;9 m ;

mate 39
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 10
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+9*%a] [550+9*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;10 m ;

mate 40
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 11
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+10*%a] [550+10*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;11 m ;

mate 41
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 12
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+11*%a] [550+11*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;12 m ;

mate 42
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
```

```
c contact between shell and sleeper 13
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+12*%a] [550+12*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;13 m ;

mate 43
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 14
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+13*%a] [550+13*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;14 m ;

mate 44
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 15
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+14*%a] [550+14*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;15 m ;

mate 45
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 16
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+15*%a] [550+15*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;16 m ;

mate 46
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 17
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+16*%a] [550+16*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;17 m ;

mate 47
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 18
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+17*%a] [550+17*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;18 m ;

mate 48
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 19
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+18*%a] [550+18*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;19 m ;

mate 49
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 20
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+19*%a] [550+19*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;20 m ;

mate 50
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 21
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+20*%a] [550+20*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;21 m ;

mate 51
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 22
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+21*%a] [550+21*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;22 m ;

mate 52
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 23
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+22*%a] [550+22*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;23 m ;

mate 53
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ---------------------------------------------------------------------------
c contact between shell and sleeper 24
c ---------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+23*%a] [550+23*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;24 m ;

mate 54
```

```
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c contact between shell and sleeper 25
c ----------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+24*%a] [550+24*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;25 m ;

mate 55
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c contact between shell and sleeper 26
c ----------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+25*%a] [550+25*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;26 m ;

mate 56
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c contact between shell and sleeper 27
c ----------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+26*%a] [550+26*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;27 m ;

mate 57
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c contact between shell and sleeper 28
c ----------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+27*%a] [550+27*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;28 m ;

mate 58
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c contact between shell and sleeper 29
c ----------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+28*%a] [550+28*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;29 m ;

mate 59
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c contact between shell and sleeper 30
c ----------------------------------------------------------------------------

block 1 2;-1;1 2;-1478 1478;0;[150+29*%a] [550+29*%a];
mseq i 6
mseq k 1
orpt + 0 100 0
n 1 1 1 2 1 2
sii ; ; ;30 m ;

mate 60
c lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c ----------------------------------------------------------------------------
c railpads
c ----------------------------------------------------------------------------
c Material properties and geomerty for the railpads
c

control
lsdymats 61 7 hgqt 1 brick elfob i8b rho 2.0e-9 g 1.02e+2 ;
lmi 0
block 1 2;1 2;1 2;675 825;200 210;250 450;
mseq i 11
mseq k 1
mate 61
lct [%s-1] mz [%a] ; mz [2*%a] ; mz [3*%a] ; mz [4*%a] ; mz [5*%a] ;
mz [6*%a];mz [7*%a];mz [8*%a];mz [9*%a];mz [10*%a];mz [11*%a];
mz [12*%a];mz [13*%a];mz [14*%a]; mz [15*%a];mz [16*%a];mz [17*%a];
mz [18*%a];mz [19*%a];mz [20*%a];mz [21*%a];mz [22*%a];mz [23*%a];
mz [24*%a];mz [25*%a];mz [26*%a];mz [27*%a];mz [28*%a];mz [29*%a];
lrep 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29;
merge

lmi 0
block 1 2;1 2;1 2;-825 -675;200 210;250 450;
mseq i 11
mseq k 1
mate 61
lct [%s-1] mz [%a] ; mz [2*%a] ; mz [3*%a] ; mz [4*%a] ; mz [5*%a] ;
mz [6*%a];mz [7*%a];mz [8*%a];mz [9*%a];mz [10*%a];mz [11*%a];
mz [12*%a];mz [13*%a];mz [14*%a]; mz [15*%a];mz [16*%a];mz [17*%a];
mz [18*%a];mz [19*%a];mz [20*%a];mz [21*%a];mz [22*%a];mz [23*%a];
mz [24*%a];mz [25*%a];mz [26*%a];mz [27*%a];mz [28*%a];mz [29*%a];
lrep 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29;
merge

lmi 0
block 1 2;1 2;1 2;-3825 -3675;200 210;250 450;
mseq i 11
mseq k 1
mate 61
lct [%s-1] mz [%a] ; mz [2*%a] ; mz [3*%a] ; mz [4*%a] ; mz [5*%a] ;
mz [6*%a];mz [7*%a];mz [8*%a];mz [9*%a];mz [10*%a];mz [11*%a];
mz [12*%a];mz [13*%a];mz [14*%a]; mz [15*%a];mz [16*%a];mz [17*%a];
mz [18*%a];mz [19*%a];mz [20*%a];mz [21*%a];mz [22*%a];mz [23*%a];
mz [24*%a];mz [25*%a];mz [26*%a];mz [27*%a];mz [28*%a];mz [29*%a];
lrep 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29;
merge

lmi 0
block 1 2;1 2;1 2;-5325 -5175;200 210;250 450;
mseq i 11
mseq k 1
mate 61
lct [%s-1] mz [%a] ; mz [2*%a] ; mz [3*%a] ; mz [4*%a] ; mz [5*%a] ;
mz [6*%a];mz [7*%a];mz [8*%a];mz [9*%a];mz [10*%a];mz [11*%a];
mz [12*%a];mz [13*%a];mz [14*%a]; mz [15*%a];mz [16*%a];mz [17*%a];
mz [18*%a];mz [19*%a];mz [20*%a];mz [21*%a];mz [22*%a];mz [23*%a];
mz [24*%a];mz [25*%a];mz [26*%a];mz [27*%a];mz [28*%a];mz [29*%a];
lrep 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29;
merge

c ----------------------------------------------------------------------------
c rail 1
c ----------------------------------------------------------------------------
c Material properties, geomety, and element mesh for the rail
c

control

lsdymats 62 1 struct hgqt 1 brick elfob i8b rho 7.723e-9 e 2.1e+5 pr 0.3 ;
c block 1 2;1 2; 1 2;700 750;210 404;0 [200*%s+500+(%s-1)*(%a-200)];
block 1 2 3 4 5 6;1 2 3 4;1 2;675 712.5 737.5 762.5 787.5 825;210 222.5
 347.5 385;-50 [200*%s+500+(%s-1)*(%a-200)+50]
mseq i 2 1 1 1 2
mseq j 0 3 1
mseq k [(600+200*%s+(%s-1)*(%a-200))/100-1]
dei 1 2; 2 4; 1 2;
dei 5 6; 2 4; 1 2;
dei 2 3; 2 3; 1 2;
dei 4 5; 2 3; 1 2;

c ----------------------------
c Boundary conditions and non-reflecting boudaru conditions for the rail
c -----------------------------

mate 62
bi 1 -6;1 4;-2;dz 1 rx 1 ry 1 ;
```

```
bi 1 -6;1 4;-1;dz 1 rx 1 ry 1 ;
nri 1 -6;1 4;-2;
nri 1 -6;1 4;-1;
lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge



c -----------------------------------------------------------------------------
c wheel 1
c -----------------------------------------------------------------------------
c Material properties, geomety, and element mesh for the wheel
c

control
lsdymats 63 20 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 7.8e-9 cmo con 1 7;
c lsdymats 29 20 hgqt 1 brick elfob i8b rho 7.8e-9 e 2.1e+5 pr 0.3 cmo con 1 7;
block 1 2;-1;1 2;712.5 787.5;375;600 1300;
sd 1 cyli 0 685 950 1 0 0 300
mseq k 69
mseq i 4
sfi 1 2; -1; 1 2;sd 1

mate 63
merge

c -----------------------------------------------------------------------------
c rail 2
c -----------------------------------------------------------------------------

control

c block 1 2;1 2; 1 2;700 750;210 404;0 [200*%s+500+(%s-1)*(%a-200)];
block 1 2 3 4 5 6;1 2 3 4;1 2;-825 -787.5 -762.5 -737.5 -712.5 -675;210 222.5
 347.5 385;-50 [200*%s+500+(%s-1)*(%a-200)+50]
mseq i 2 1 1 1 2
mseq j 0 3 1
mseq k [(600+200*%s+(%s-1)*(%a-200))/100-1]
dei 1 2; 2 4; 1 2;
dei 5 6; 2 4; 1 2;
dei 2 3; 2 3; 1 2;
dei 4 5; 2 3; 1 2;

mate 62
bi 1 -6;1 4;-2;dz 1 rx 1 ry 1 ;
bi 1 -6;1 4;-1;dz 1 rx 1 ry 1 ;
nri 1 -6;1 4;-2;
nri 1 -6;1 4;-1;
lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c ballast, part 1, section 1
c -----------------------------------------------------------------------------
c Material properties, geomety, and element mesh for one of the
c material layers in the embankment. Also boundary conditions
c and non-reflecting boundary conditions are given
c

control
lsdymats 64 1 struct hgqt 1 brick elfob i8b rho 1.55e-9 e 1.18e+2 pr 0.15 ;

block 1 2;1 2;1 2;-1900 1900;-350 0;-50 [200*%s+500+(%s-1)*(%a-200)+50];
sd 2 plan 0 -350 0 0 1 0
sd 3 plan 1900 0 0 1 1 0
sd 4 plan -1900 0 0 -1 1 0
sfi -2; 1 2; 1 2;sd 3
sfi 1 2; -1; 1 2;sd 2
sfi -1; 1 2; 1 2;sd 4
mate 64
mseq i 8
mseq j 1
mseq k [(600+200*%s+(%s-1)*(%a-200))/200-1]
bi 1 2;1 2;-2;dz 1 rx 1 ry 1 ;
bi 1 2;1 2;-1;dz 1 rx 1 ry 1 ;
nri 1 2;1 2;-1;
nri 1 2;1 2;-2;

lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c ballast, part 1, section 2
c -----------------------------------------------------------------------------

control
lsdymats 65 1 struct hgqt 1 brick elfob i8b rho 2.25e-9 e 2.74e+2 pr 0.20 ;

block 1 2 3;1 2;1 2;-2250 2250 4350;-550 -350;-50
[200*%s+500+(%s-1)*(%a-200)+50];
sd 5 plan 0 -550 0 0 1 0
sd 6 plan 4350 -350 0 1 1 0
sfi -3; 1 2; 1 2;sd 6
sfi 2 3; -1; 1 2;sd 5
mate 65
mseq i 8 3
mseq j 0
mseq k [(600+200*%s+(%s-1)*(%a-200))/200-1]
bi 1 3;1 2;-2;dz 1 rx 1 ry 1 ;
bi 1 3;1 2;-1;dz 1 rx 1 ry 1 ;
nri 1 3;1 2;-1;
nri 1 3;1 2;-2;

lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c ballast, part 1, section 3
c -----------------------------------------------------------------------------

control
lsdymats 66 1 struct hgqt 1 brick elfob i8b rho 2.27e-9 e 2.88e+2 pr 0.20 ;

block 1 2 3 4;1 2;1 2;-2250 2250 4550 4750;-1050 -550;-50
[200*%s+500+(%s-1)*(%a-200)+50];
sd 7 plan 0 -1050 0 0 1 0
sd 8 plan 4750 -550 0 1 1 0
sfi -4; 1 2; 1 2;sd 8
sfi 3 4; -1; 1 2;sd 7
mate 66
mseq i 8 3 0
mseq j 1
mseq k [(600+200*%s+(%s-1)*(%a-200))/200-1]
bi 1 4;1 2;-2;dz 1 rx 1 ry 1 ;
bi 1 4;1 2;-1;dz 1 rx 1 ry 1 ;
nri 1 4;1 2;-1;
nri 1 4;1 2;-2;

lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge



c -----------------------------------------------------------------------------
c ballast, part 1, section 4
c -----------------------------------------------------------------------------

control
lsdymats 67 1 struct hgqt 1 brick elfob i8b rho 2.00e-9 e 23.04e+2 pr 0.40 ;

block 1 2 3 4;1 2;1 2;-2250 2250 4550 5250;-1350 -1050;-50
[200*%s+500+(%s-1)*(%a-200)+50];
mate 67
sd 9 plan 0 -1350 0 0 1 0
sfi -4; 1 2; 1 2;sd 8
sfi 3 4; -1; 1 2;sd 9
mseq i 8 3 0
mseq j 0
mseq k [(600+200*%s+(%s-1)*(%a-200))/200-1]
bi 1 4;1 2;-2;dz 1 rx 1 ry 1 ;
bi 1 4;1 2;-1;dz 1 rx 1 ry 1 ;
nri 1 4;1 2;-1;
nri 1 4;1 2;-2;

lmi 0
lct 1 mx 4500 ryz;
lrep 0 1;
merge

c -----------------------------------------------------------------------------
c ballast, part 1, section 5
c -----------------------------------------------------------------------------

control
lsdymats 67 1 struct hgqt 1 brick elfob i8b rho 2.00e-9 e 23.04e+2 pr 0.40 ;
lmi 0
block 1 2 3 4;1 2;1 2;-2250 2250 4550 5550;-5050 -1350;-50
[200*%s+500+(%s-1)*(%a-200)+50];

mseq i 8 3 0
mseq j 6
mseq k [(600+200*%s+(%s-1)*(%a-200))/200-1]
bi 1 4;-1;1 2;dx 1 dy 1 dz 1 rx 1 ry 1 rz 1 ;
nri 1 4;-1;1 2;
bi 1 4;1 2;-2;dz 1 rx 1 ry 1 ;
bi 1 4;1 2;-1;dz 1 rx 1 ry 1 ;
nri 1 4;1 2;-1;
nri 1 4;1 2;-2;
nri -4;1 2;1 2;

lct 1 mx 4500 ryz;
lrep 0 1;
mate 67
merge
```

```
c -----------------------------------------------------------------------------
c wheel 2
c -----------------------------------------------------------------------------

control
lsdymats 68 20 hgqt 1 shell elfor fibt shear 0.833 tsti 3 shth 0.1 e 2.1e5 pr
0.3 rho 7.8e-9 cmo con 1 7;
c lsdymats 29 20 hgqt 1 brick elfob i8b rho 7.8e-9 e 2.1e+5 pr 0.3 cmo con 1 7;
block 1 2;-1;1 2;-787.5 -712.5;375;600 1300;
sd 1 cyli 0 685 950 1 0 0 300
mseq k 69
mseq i 4
sfi 1 2; -1; 1 2;sd 1

mate 68
merge

c
c Here all separate parts of the model are joined into one single
c model. Here it is a complete double-track line with
c embankement that is 30 sleeper spans long
c

bptol 1 31 0
bptol 1 68 0
bptol 2 32 0
bptol 2 68 0
bptol 3 33 0
bptol 3 68 0
bptol 4 34 0
bptol 4 68 0
bptol 5 35 0
bptol 5 68 0
bptol 6 36 0
bptol 6 68 0
bptol 7 37 0
bptol 7 68 0
bptol 8 38 0
bptol 8 68 0
bptol 9 39 0
bptol 9 68 0
bptol 10 40 0
bptol 10 68 0
bptol 11 41 0
bptol 11 68 0
bptol 12 42 0
bptol 12 68 0
bptol 13 43 0
bptol 13 68 0
bptol 14 44 0
bptol 14 68 0
bptol 15 45 0
bptol 15 68 0
bptol 16 46 0
bptol 16 68 0
bptol 17 47 0
bptol 17 68 0
bptol 18 48 0
bptol 18 68 0
bptol 19 49 0
bptol 19 68 0
bptol 20 50 0
bptol 20 68 0
bptol 21 51 0
bptol 21 68 0
bptol 22 52 0
bptol 22 68 0
bptol 23 53 0
bptol 23 68 0
bptol 24 54 0
bptol 24 68 0
bptol 25 55 0
bptol 25 68 0
bptol 26 56 0
bptol 26 68 0
bptol 27 57 0

c ---------------------------
c End of data
c ---------------------------
```