Parametric optimisation of railway track structures

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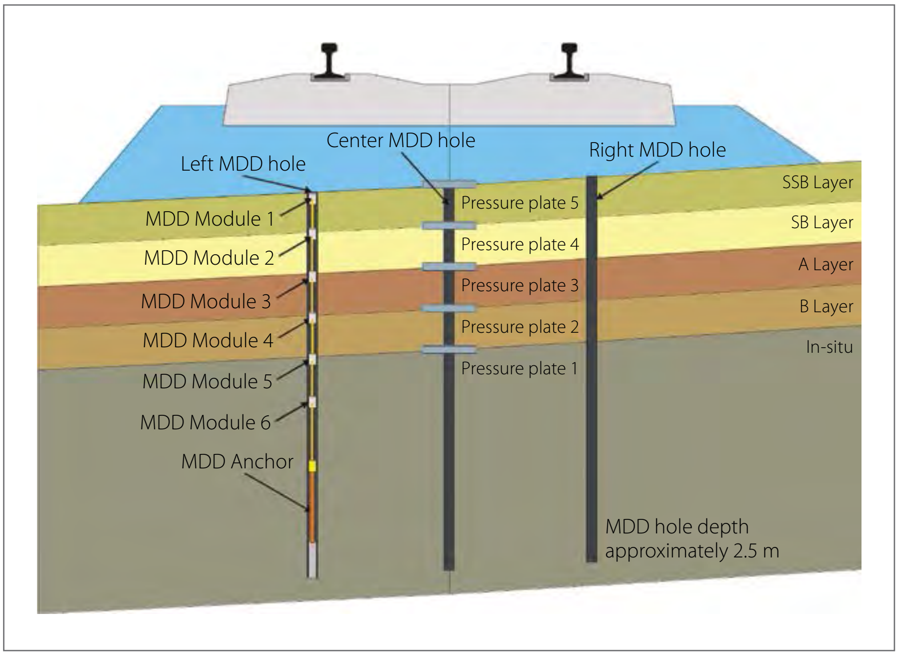

Figure 1 MDD positioning and formation layout structure

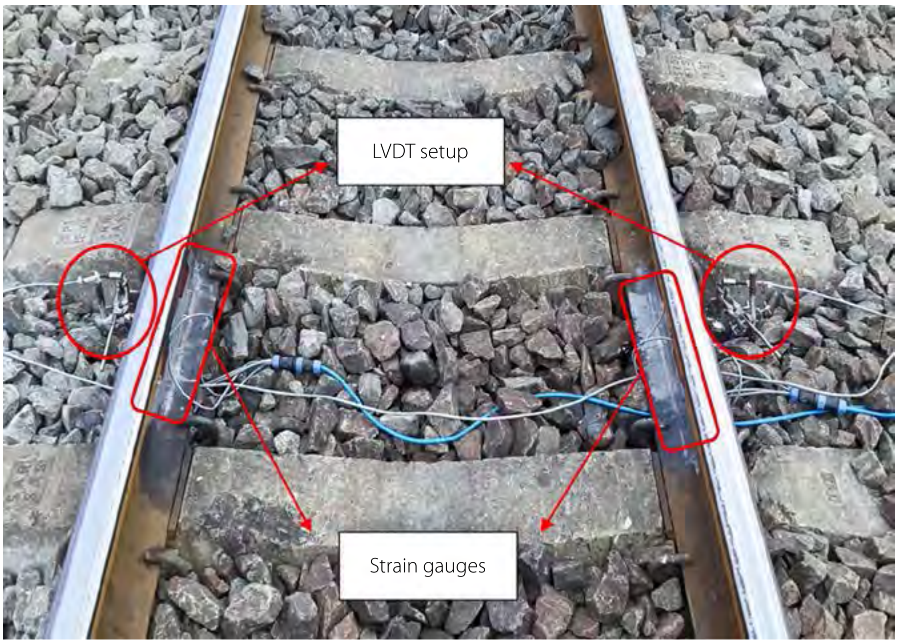

Figure 2 LVDTs and strain gauge setup

BACKGROUND

Railway track has been one of the most cost-effective and environmentally friendly modes of transportation for a number of years. The use of freight trains is an economical means of transporting natural resource commodities. South Africa is one of the richest countries in natural resources and exports 28% of its coal production, making it the fourth largest coal-exporting country in the world. Conventional ballasted railway track structures are still the most popular and universally adaptable method used today. Although the conventional track structure has been modified and altered over several years, little has been done to optimise the structure to its full potential.

OBJECTIVES

One of the objectives of the study was to find a way of optimising the conventional ballasted track structure whilst maintaining an acceptable level of vertical deflection. This was done by devising a method of modelling the track structure numerically and then calibrating the model against existing train load data to

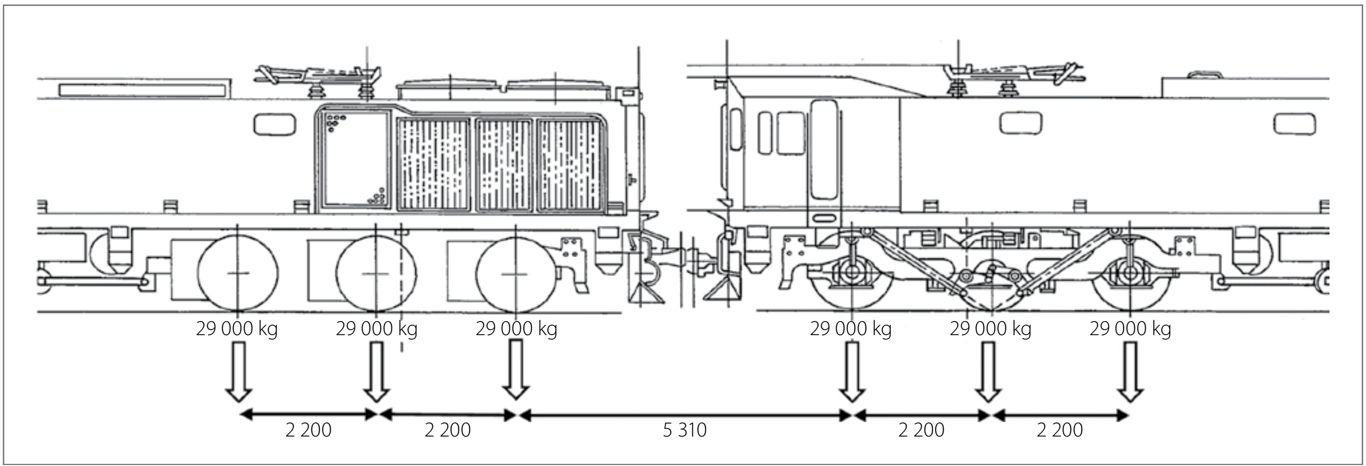

Figure 3 Coupled type 11E locomotive configuration

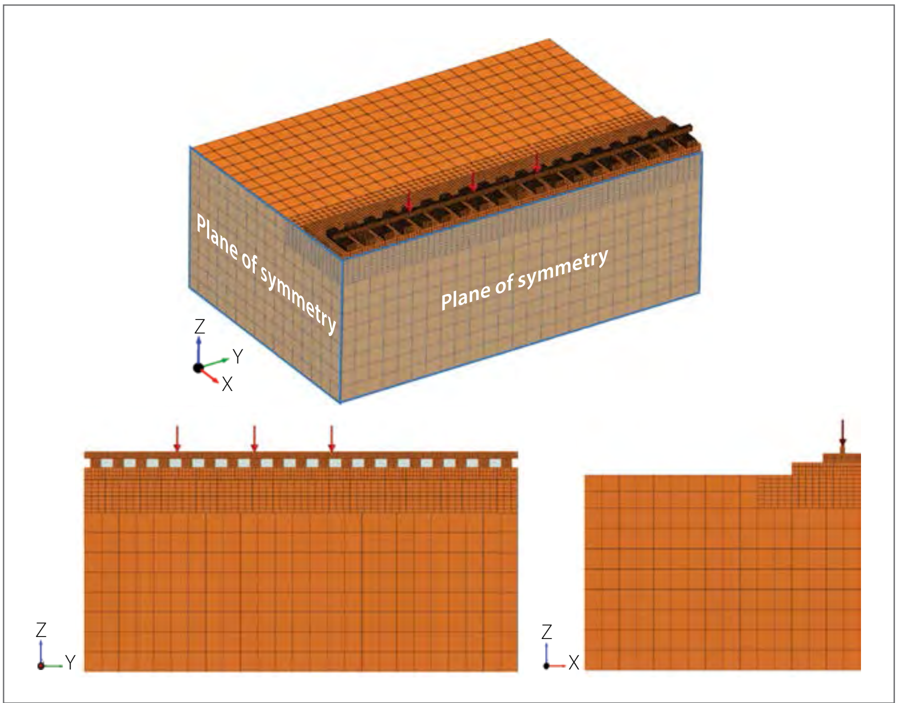

Figure 4 Meshed FEM indicating planes of symmetry

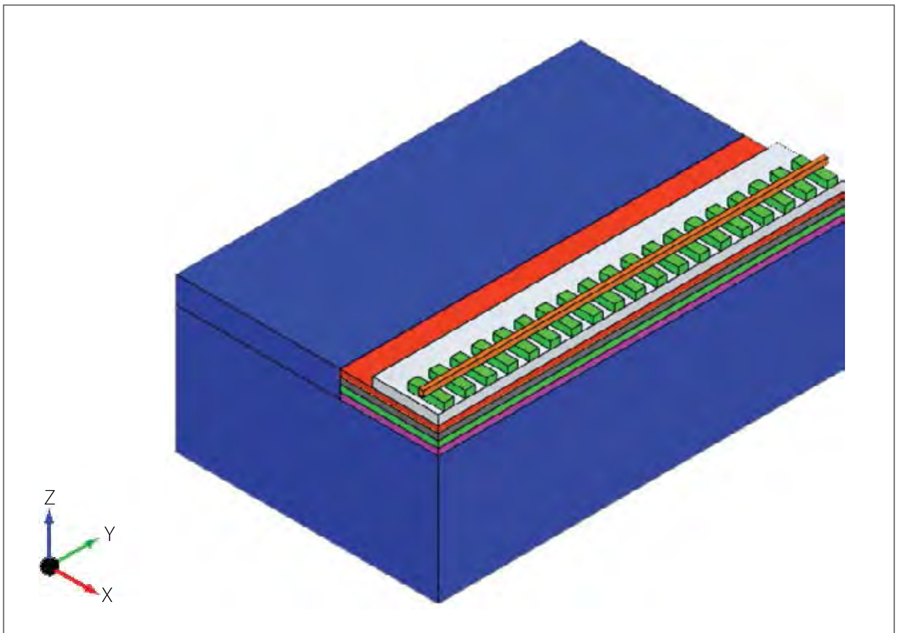

Figure 5 Isometric FEM indicating different components of the track structure

observe the effect that track parameter changes have on vertical deflection.

PROJECT DESCRIPTION

The test site used to capture the required data was located 60 km outside of Vryheid on the Richards Bay Heavy Haul Coal Line. The vertical deflection of each layer that makes up the railway track structure was recorded using multi-depth deflectometers (MDDs) and linear variable differential transducers (LVDTs) as the train wheel loads moved over the test site. An overview of the site setup can be seen in Figures 1 and 2.

A finite element model (FEM) of the track structure was created using CivilFEM 2016. The model structure was broken up into a finite number of smaller structural elements, and the interaction between the parts could be plotted and data extracted. The finer the mesh of elements in the model, the more accurate the results were. The FEM was then calibrated by changing the stiffness values of each formation layer of the track structure to replicate the same vertical deflection as that recorded in the field when exposed to a wheel load of two successive class type 11E locomotives. The wheel load configuration can be seen in Figure 3.

Strain gauges were used to measure the 14.5 ton wheel loads of the locomotives, and the same loads were applied to the FEM in a similar wheel configuration layout. The wheel loads on the track structure were assumed to be symmetrical along the axis parallel to the steel rails and therefore only half of the track structure was modelled using the FEM. The MDD positions and track structure formation layers can be seen in Figure 1. The meshed FEM of the track structure can be seen in Figures 4 and 5.

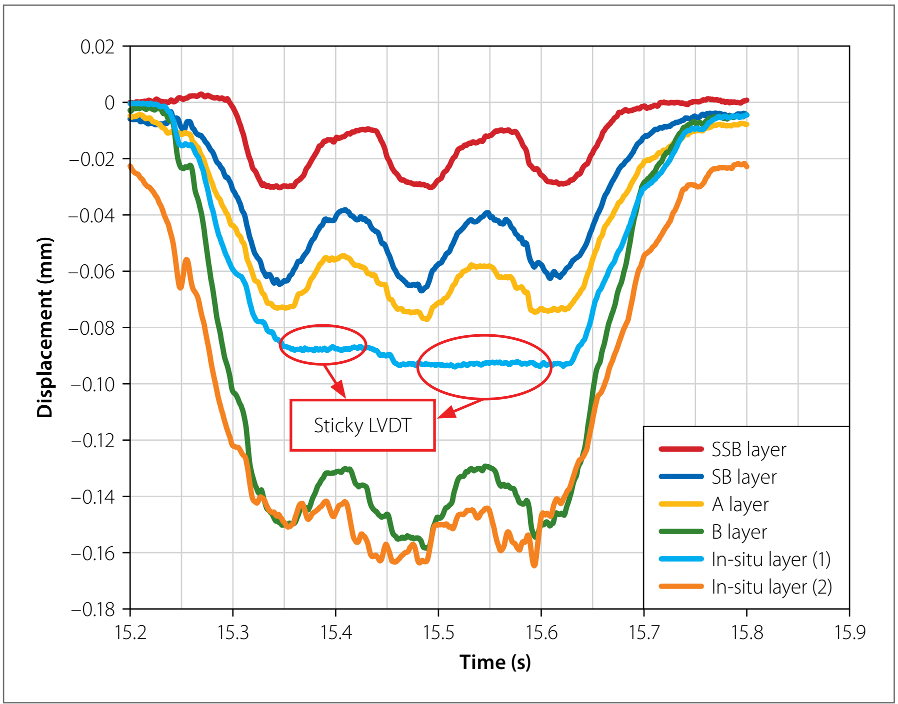

Figure 6 Graph showing the measured deflections of the formation layers

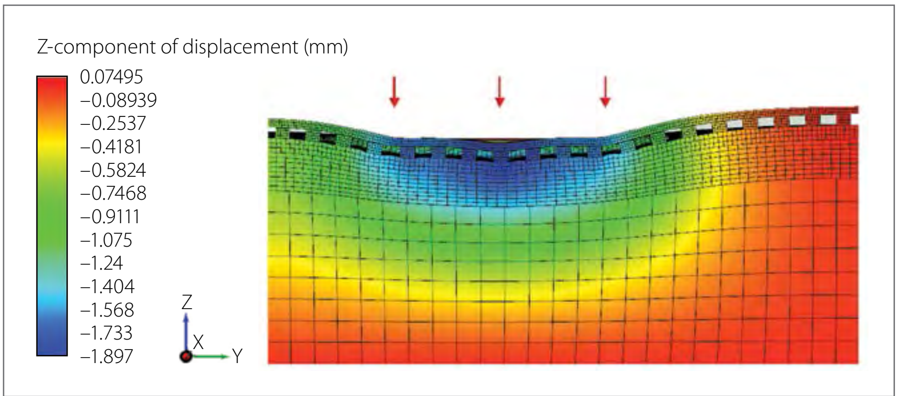

Figure 7 FEM showing the exaggerated deflections experienced by the track structure

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DISCUSSION OF RESULTS

To calibrate the FEM proved to be challenging, as the stiffness of each formation layer of the railway track had to be estimated until the deflection of that layer matched the measured deflection of the coal line track structure recorded at the test site. The existing MDD units have remained in-situ for a number of years and the data captured using the LVDT units was somewhat unreliable due to the presence of seating strain and hanging sleepers in the ballast layer. This gave the impression that some of the units recorded data that appeared to be "sticky" in nature. This is illustrated in Figure 6, with the measured deflection in mm versus the time in seconds as the three wheels of the train passed the instruments.

Once the FEM was calibrated, three parameters were considered to optimise the railway track structure:

1. The spacing of sleepers
2. The depth of the ballast layer
3. The size of the steel-rail profile.

Figure 7 shows the exaggerated vertical deflection experienced by the track structure under the load conditions, while Figure 8 shows the anticipated deflection experienced on the track structure under the given static wheel loads. The results were as follows:

- By changing the sleeper spacing from 500 mm to 800 mm, the total track deflection increased by 9.8%.
- By changing the rail profile size, in terms of its moment of inertia, from 3 949 cm^4 to 1 368 cm^4, an increase in total track deflection of 7.6% was recorded.
- By altering the ballast layer depth from 500 mm thick to 200 mm thick, an increase of 2.5% in total track deflection was recorded.

CONCLUSION

It was therefore found that a more conservative railway track structure could be built using a 54 kg/m rail profile, a sleeper spacing of 800 mm and a ballast depth of 200 mm. The result was an overall increase in total track deflection of 5.6% when compared to the original track structure parameters. The total deflection would amount to 1.3 mm which was deemed to be acceptable. It was also found that, by implementing the optimised railway track structure over a 600 km long railway line, there could be a potential saving of 443 000 sleepers, 180 000 m^3 of ballast, and a cheaper rail profile could be implemented.

Although this proved to be a more efficient railway track structure in terms of total vertical deflection, the scope of the study was too narrow to conclude that the optimised track structure is an acceptable alternative to the existing structure. Factors such as sufficient provision of lateral resistance in the railway track structure when a sleeper spacing of 800 mm is utilised, were not considered in this study. It is also known that the smaller the rail profile, the greater the bending stress and fatigue experienced by the rail. The stresses in the rail profile were also not considered in this study.

Similarly, the increase in sleeper spacing has a significant effect on the bending stress experienced by the rail and it is recommended that further investigation be conducted to establish a more suitable railway track structure. The ballast layer thickness of 200 mm is also not recommended for heavy-haul lines,

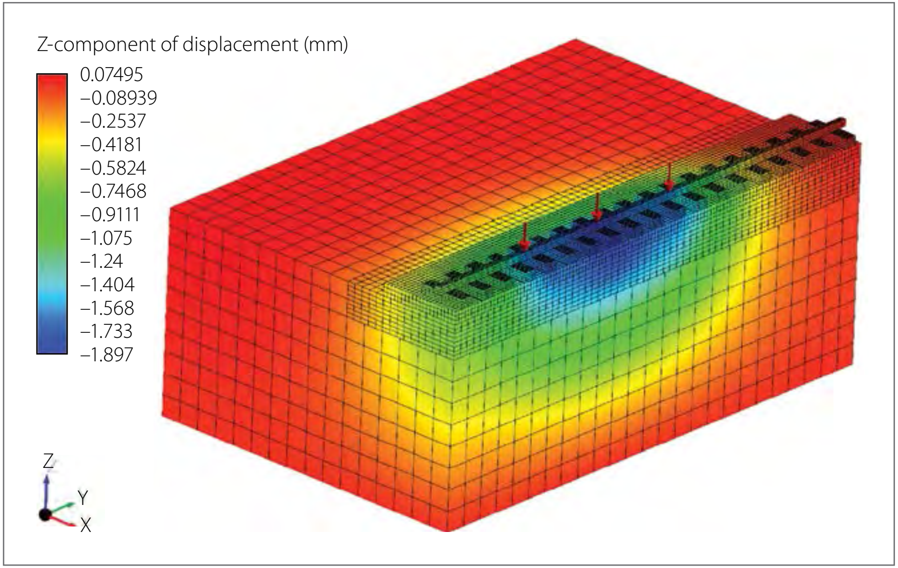

Figure 8 FEM showing the deflection distribution in the track structure

as it will interfere with the maintenance of the track structure, among other things. Without carefully considering and investigating the known factors that make a railway track structure safe and durable, it is not recommended that the proposed optimised railway track structure be considered for future design. It is, however, possible that an acceptable and optimal design exists with track parameters somewhere between the current design and the optimised track structure described in this article. This research also provides an indication of the sensitivity of track parameter changes to the structural performance of the optimised designs. □

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