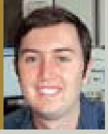

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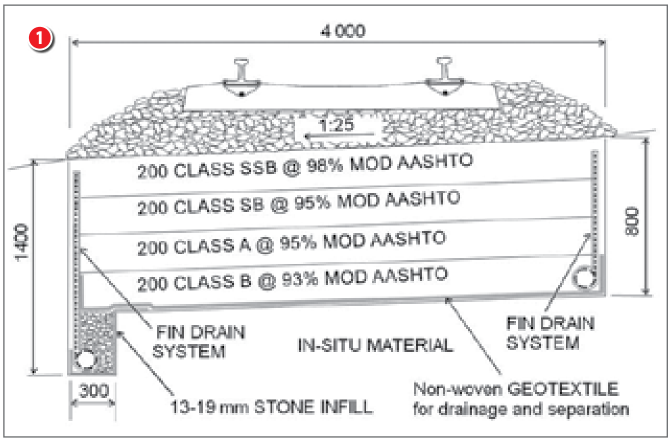
Axle load and track deflection on a heavy haul line

BACKGROUND

In the 21st century, the use of railways has grown to make them the preferred choice for the transportation of heavy freight. Thus new demands are constantly being placed on our understanding of rail track infrastructure performance. Track engineers are challenged to be more cost-effective and to base their designs on the design life of the entire track structure. It is therefore necessary to promote research that will evaluate the components that affect track foundation performance and expected service life. With the increase in annual freight demand, the need arises to increase the gross vehicle mass and, in turn, the axle load of freight wagons.

The performance of a track structure is dependent on the stress and strain levels present in the individual track components. As the track foundation is inaccessible after construction and is built from natural materials that are subject to environmental influences, the long-term behaviour of the foundation is often unknown and unpredictable. The Chair in Railway Engineering at the University of Pretoria is therefore focusing its research on measuring the performance of track structure components and, in this case, on measuring track deflection under train loading.

① Coal Line (Bloubank) railway formation design and layout



Track and foundation deflection therefore need to be measured more effectively and with greater ease. Measurement equipment such as particle image velocimetry (PIV) instrumentation, which is portable and does not cause disturbance of the track structure, should therefore be used (Bowness et al 2006).

Track deflection is a function of the foundation and the ballast support. With poor support the track may deform extensively as higher axle loads are imposed. Large deflections will decrease the riding quality and will also increase the maintenance needed for track components. This will result in a loss of revenue and will increase the costs of the rail track service life.

OBJECTIVES

The main objective of this research was to investigate the relationship between axle load and the total resilient deflection of conventional track under actual train loading. The focus was on the performance of the new Coal Line foundation design which incorporates the use of high-quality aggregates compacted to high densities, as well as an extensive drainage design. Figure 1 shows the details of the 26 t/axle formation design.

The study also enabled the researchers to compare the results of portable PIV instrumentation with the measurements obtained by using conventional in situ multi-depth deflectometers (MDDs).

PERMANENT AND RESILIENT DEFORMATION

In a track structure, two main types of deformation occur, namely permanent and resilient. Permanent, or plastic, deformation refers to the settlement of the track over time after repeated loading. Track foundations are designed to have the lowest possible permanent deformation (Esveld 2001; Selig & Waters 1994).

Resilient, or deflection, deformation refers to the elastic part of the track foundation deformation (i.e. being able to return to its original position). Most of the resilience in the system is provided by the ballast and rail pads (Cenery 2001).

Both of these parameters are important because excessive amounts of deformation lead to track structure failure and maintenance-related problems. Care should therefore be taken when designing track structure formation layers, limiting the predicted deformation to prescribed values (Li & Selig 1998a&b).

THE EFFECTS OF AXLE LOAD ON DEFORMATION

With an increase in axle load, deformation of the track structure also increases, the magnitude depending on the design and composition, as well as the interaction between track components (Korpanec et al 2005). According to research referred to by Esveld (2001), it has been found that an increase in axle load from 20 to 22,5 ton considerably increases deterioration of the track quality and geometry, but not the ballast stress. Maintenance costs are also expected to increase along with this increase in axle load. Also, in South Africa, high axle loads and formation problems have resulted in excessive sleeper movement and ballast failure (Maree 1993).

Another known effect of increased axle loading is increased resilient track deflection. Maximum vertical deflection occurs directly below the train axle and reduces with increasing depth of the track structure. Previous models have shown that, for a given subgrade, the ballast depth and sleeper spacing are the most important factors influencing vertical track deflection as a result of train loading. The selection of subgrade material is also important because with the increase in stress due to axle load, strain hardening may occur in the case of good, granular material, while strain softening may occur in the case of poor, cohesive (clayey) material (Craig 2007).

Higher axle loads in general require stronger infrastructure (i.e. larger rails and sleepers and also stronger bridge structures) in addition to high-quality subgrade materials. This will lead to higher investment costs, but will, however, produce a larger return on investment (Anderson & Harris 1993).

The literature on rail track performance does not indicate what the relationship between axle load and track deflection would be when the axle load is increased. Simple models (e.g. those used for track design) indicate a linear relationship as the axle load increases. This research aimed to determine the actual relationship between axle load and resilient track deformation on a well-designed track foundation.

PROJECT DESCRIPTION

This project focused on total track and formation resilient deformation with respect to axle load.

The range of axle loads investigated was from 6 to 28 ton. To compare the effect of axle load on resilient deformation, all other factors that could influence resilient deformation were kept constant. Therefore, a narrow speed range, between 35 and 45 km/h, was chosen.

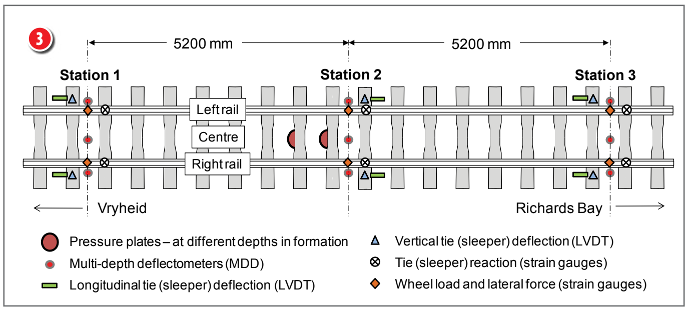
Two different types of deflection measurement device were used, namely MDDs and PIV. Strain gauge transducers installed on the rails were used to measure the axle load of the wagons.

The site chosen for the measurement of track deformation in response to axle load was at Bloubank near Vryheid on the Coal Line. This site was instrumented in 2004 when its formation was completely reconstructed due to formation failure. The new formation design is shown in Figure 1.

SITE DESCRIPTION AND FIELD SET-UP

The Bloubank test site is situated 60 km south of Vryheid, on the Vryheid–Ulundi track section. The geology of the area comprises weathered tillites forming part of the Vryheid geological formation. The test site is in a cut on a double line section of the track. Only the newly constructed number 1 line, carrying the loaded trains, was instrumented. This particular foundation was earmarked for complete rehabilitation and provided the ideal opportunity to carry out full-scale foundation research. A photo of the site is shown in Figure 2, depicting the two railway lines and the tunnel at km 60 on the Coal Line.

The formation that was constructed in 2004 was characterised by carrying out a number of geotechnical field tests. Table 1 provides a summary of the measured parameters. The strength parameters, soil foundation indicators and Young's modulus values are included in the table. The table shows the results of three methods by which the layer moduli were calculated, namely by back-calculation using the MDDs and GEOTRACK software, by carrying out falling weight apparatus (FWA) tests with a Zorn light drop-weight tester (unloaded) and by employing continuous surface wave (CSW) testing.



② Bloubank test site

③ Plan of the Bloubank test section showing the three measuring stations (redrawn from Shaw 2005)

④ Formation rod and the use of shielding to measure rail and formation resilient deformation

Table 1 Summary of the measured parameters (Shaw 2005)

Layer			SSB	SB	A	B	In Situ
Design Specifications	Minimum Compaction – % of Modified AASTHO Density		98	95	95	93	90
	Minimum Strength after Compaction – CBR		60	30	20	10	5
% Gravel			71	73	29	29	–
% Sand			21	18	56	56	–
% Silt			6	6	8	7	–
% Clay			2	3	6	7	–
Liquid Limit			Slightly Plastic	Slightly Plastic	29	29	–
Linear Shrinkage			0,5	1,5	5	5,5	–
Grading Modulus			2,46	2,5	1,87	1,83	–
Plasticity Index			Slightly Plastic	Slightly Plastic	4	4	–
Young's Modulus (MPa)	GEOTRACK (loaded)	St1	559	455	155	60	–
		St2	212,9	314,9	258,3	60,6	–
		St3	729,2	359	94,2	82,3	–
	FWA (no load)	St1	52,6		–	–	–
		St2	51,,6		–	–	–
		St3	60,7		–	–	–
	CSW (no load)	St3	321	107	67	39	596

Since construction, record has been kept of the permanent deformation of each formation layer. The site has three measuring stations, as shown in Figure 3, incorporating an array of instrumentation devices (Shaw 2005). For the purpose of this investigation, the following instrumentation was utilised:

- Three MDD holes, drilled just to the outside of the left and right rails and at the centre of the rail track, containing a string of six MDDs each. These MDDs were positioned at the layer interfaces. Individual measurements were used to back-calculate the Young's modulus of each layer while a summation of the layer deflections gave the total formation deflection of the track.
- Strain gauge transducers were installed on the left rail at the different locations to measure the vertical train wheel loads. These were calibrated before commencing with the tests.
- The PIV system, which incorporates the use of a video camera and targets fixed to the track components, was positioned next to the track, about 5 m from the left rail. Two video cameras were used, positioned at Station 2 and Station 3.

To measure the formation deflection with the PIV system, a copper peg was driven into the ground, through the ballast, into the top of the formation. One of the PIV system targets, as well as shielding, was attached to the rod with clamps. Figure 4 shows the two PIV targets, one attached to the rail and the other attached to the copper peg, enabling the simultaneous measurement of rail and formation resilient deformation.

RESULTS

The results gathered from Station 2 were used to derive the relationship between axle load and resilient deformation. Axle loads were taken as the average of the axle load of a bogie axle pair. Similarly, the reported deflections were taken as the average of the two peak deflections under the bogie axle pair.

Both ballast and foundation deflection were measured and found to contribute almost equally to the deflection of the total track structure. The total formation deflection was approximately 0,58 mm and the ballast deflection approximately 0,51 mm. An extract from a typical result is shown in Figure 5.

Figure 6 shows the relationships between total track deflection, formation deflection and axle load. The data obtained from the MDD instrumentation provided high-quality results with very little scatter. The data from the PIV system provided formation measurements scattered over a wider range than that of the MDD results. This could be as a result of the copper rod that was driven through the ballast into the top of the formation being affected by the vibrations in the ballast caused by the train. The total track deflection measurements show better quality than the formation deflection results. This can be attributed to the fact that the target for rail deflection was placed directly onto the rail and was not affected by the vibrations in other track components.

Formation deflection was measured by both the MDDs and the PIV instrumentation and ranged from 0 mm to approximately 0,7 mm for axle loads ranging from 0 to 28 t. The MDDs produced values that were approximately 85% of the PIV measurements (see Figure 6). Possible explanations for this difference include:

- The top MDD, positioned in the SSB layer does not measure the deflection of the entire layer and for practical reasons had to be positioned slightly lower than the top of formation.

- Differential movement could have occurred between the MDD modules, the flexible sleeve in which they were installed and the surrounding soil on the outside of the sleeve.

Despite this difference, the two measuring techniques, which are entirely different in terms of the technology and reference they use, nevertheless produced comparable and similar results.

The non-linear relationship between axle load and formation deflection is noted and emphasises the non-linear behaviour of soil as commonly accepted. Further research is planned in which similar instrumentation will be used to measure the same relationship at a site with poor formation material.

The general trend noticed was a logarithmic trend of the form $y = a \ln(x) + b$ where y is the resilient deformation, a and b are variables and x is the axle load. The resilient deformation therefore increases with an increase in axle load, but the rate of resilient deformation increase reduces as the axle load increases, especially when the axle load approaches 30 t. Axle loads beyond 28 t fall outside the scope of this study and the trend cannot be confirmed beyond this range. Regardless, the trend is unlikely to change drastically and it is not a linear relationship as suggested by the design models. These design models would lead to conservative and safe design of track structures at the expense of higher initial capital cost.

CONCLUSIONS

The following conclusions can be drawn from the resilient deflection study as described in this article:

- The PIV system is an accurate and cost-effective system to use for field measurements and compared well with the in situ MDD measurements. On average, the magnitude of the MDD measurement results was 85% of the PIV measurement results.
- Formation deflection was approximately 50% of the total track deflection (approximately 1,09 mm). This relatively high value

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⑤ Typical result showing PIV measurements: track and formation

⑥ Relationship between total track and formation deflection and axle load

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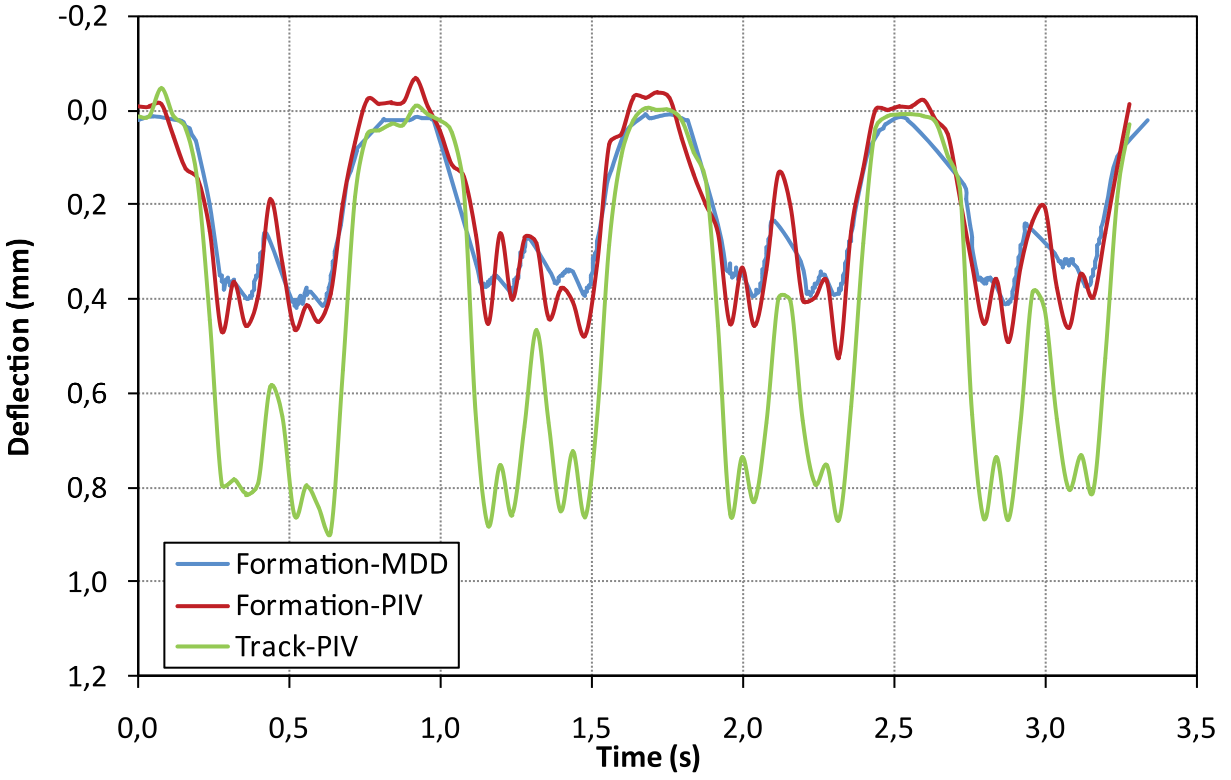

emphasises the importance of ballast quality and the role it will play in track quality measurements.

- The relationship between the total track and formation deflection with respect to axle load has a logarithmic shape for axle loads up to 28 t. The specific material at the site, which has good foundation properties, experiences strain hardening and the rate of increase in resilient deformation reduces as the axle load increases.
- Track structures designed with the linear model for axle loads exceeding 30 t will be conservative and safe but will result in higher capital costs.

RECOMMENDATIONS

Regarding further development of the PIV system, the following recommendations are made:

- Video imaging equipment that can measure at a higher frequency than the current 25 fps (frames per second) should be used.
- Remote triggering should be used to reduce movement of the reference when the testing is started manually.
- Lighting of the targets should be improved to reduce the negative effect of shadows.

For the measurement of resilient deformation with respect to axle load, the following are recommended:

- Further testing should be done at the site with axle loads exceeding 28 t.
- Similar testing should be done at a track on poor foundation material (e.g. cohesive clays).

ACKNOWLEDGEMENTS

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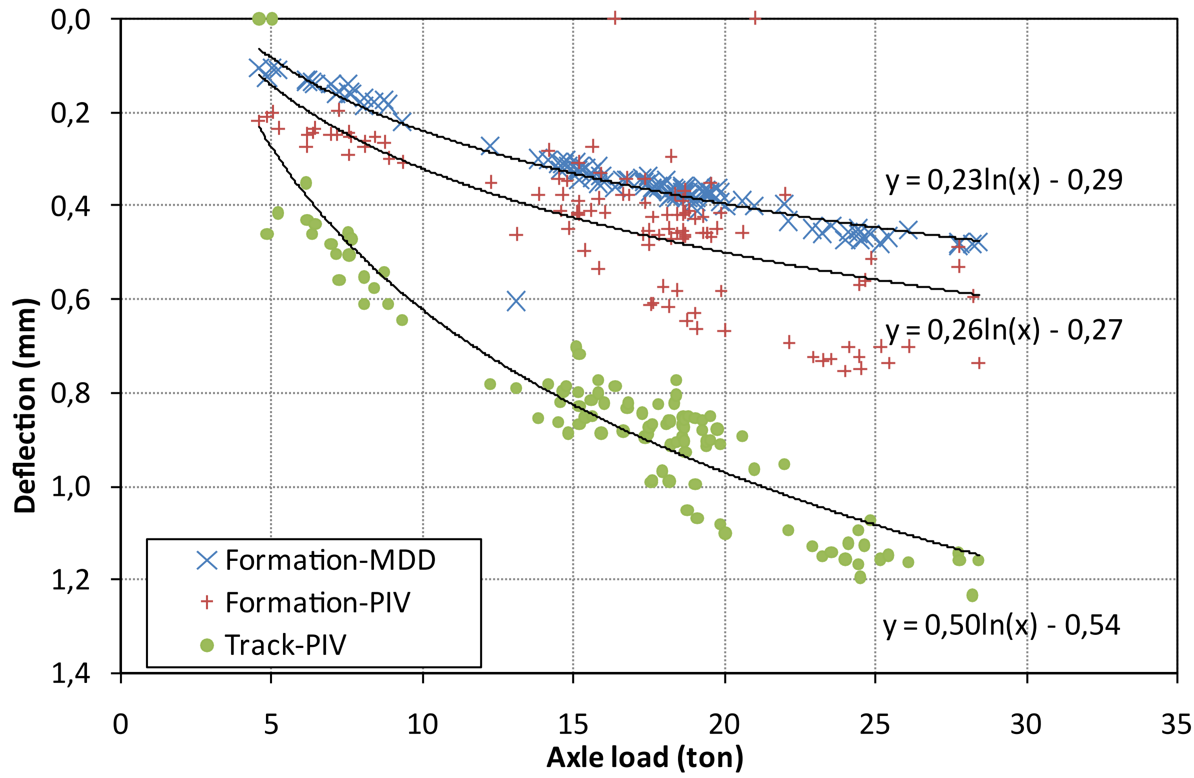

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