The Effect of Rubber Pads on The Stress Distribution for Concrete Railway Sleepers

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Abstract. A railway track system is comprised of several components such as rail, sleeper and ballast. Ballast is the weakest component in the track system and it is subjected to latent dynamic shifting. Constant and continuous loads lead to wear and breaking up of the ballast, thus, diminish the quality of track geometry. This causes unaccounted periodical tamping of track bed. A holistic solution to slow down this process is by installing rubber sleeper pads. Numerical investigation is performed using the general-purpose finite element software ABAQUS for the track system with varying rubber pad thickness and locality. The elastic properties of rubber are expected to lengthen the bending line of the rails and reduce the direct dynamic load on the ballast. Four separate models of the same load, sleeper and rail but with different rubber pad thicknesses is modelled using the finite element software ABAQUS to investigate the effect of the variation of rubber pad thickness in terms of the static stress distribution of the rail-sleeper. Spring supports are used at the bottom of the sleeper to represent the elastic stiffness of ballast bed and subgrade. The results indicate a reduction of sleeper stress along the depth of the cross-section of the concrete sleeper against increased thickness of rubber sleeper pad. Sleeper pad with 10mm exhibit a stress value of 2737kPa, whereas a stress reduction of approximately 10% and 17% was obtained if a 15mm and 20mm sleeper pad was used respectively. Nevertheless, the author concluded that the economics of using rubber sleeper pads is in the range between 22mm to 25mm. The suggested range was derived from the optimizing the behaviour of stress for both the concrete sleeper and rubber sleeper pads. The sleeper pads have the tendency to minimise excessive stress from developing within naked concrete sleepers.

1. Introduction

Rail transport has been in Malaysia since 19th century. At the beginning of its establishment, the rail transport is used to transport and service tin mining industry to ports located along the coast. At present, rail transport is one of the country’s most important transport mode. With the rapid technological
advancement more high-speed tracks have been introduced and axle load on the track has also been increased thus leading to higher stress in the railway track when the track is loaded by passing trains. The higher speed along with the heavier loads tends to speed up the track deterioration. As a result, the maintenance cost of the track has been increased by a significant amount. To keep the track deterioration (for example track settlement) and the maintenance costs low, a well-chosen vertical track stiffness is needed. But many railway tracks are very old and they were built without considering the soil stiffness. Therefore, the tracks are often built on a very soft soil. Also, the soil stiffness varies along a railway track. This leads to a varying vertical stiffness of the whole track. Elements of the track, like turnouts, hanging sleepers, embankments or bridges, influence the vertical track stiffness of the railway track as well. A changing vertical track stiffness causes higher contact forces between the wheels and the rails. Also vibrations are caused, as a result of this the track deterioration rate speeds up. To modify the vertical track stiffness Sleeper Pads may be used. These are elastic pads which are placed between the sleepers and the ballast. Sleeper pads are expected to reduce the influence of varying track stiffness on the wheel/rail contact force and to distribute the load of the train to a larger ballast area.

In this paper the effect of sleeper pads on the stress distribution of sleepers is evaluated numerically. One model without the sleeper pads and another three models with different sleeper pad thicknesses (10mm, 15mm and 20mm) are completed using the general finite element software ABAQUS. The primary objective of this study is to observe and analyze the stress distribution of sleepers for different sleeper pad thickness and sleepers without the pads.

2. Parameters used for modelling in ABAQUS

2.1. Concrete Sleepers
Concrete sleeper used in railway line is basically a transverse beam laid within on ballast and support to secure the rail and rail gauge, providing safe navigation of the rolling stock. The reason of the overwhelming popularity of concrete sleeper over the other kind of sleeper is because of it has a longer life and relatively cheaper than the other type of sleeper such as timber and steel sleeper. There are two types of concrete sleeper which are mono-block and twin-block. Twin-block sleeper consists of two separated concrete block connected through a steel beam and in the other hand mono-block sleeper is a whole concrete block pre-casted as one block. The significant of this study has been placed on the modeling of the mono-block sleeper using ABAQUS.

| Table 1 | The concrete properties [1] used for the modelling of the sleepers. |
|---------|------------------------------------------------------------------|
| Density (Kg/m$^3$) | Modulus of Elasticity (MPa) | Poisson’s Ratio | Compressive Strength (MPa) | Tensile Strength (MPa) |
| 2400 | 36406 | 0.2 | 60 | 2.85 |

2.2. Steel Properties for rail section
The properties of Steel, used as input data for the rail section as per shown below:

| Table 2 | The Steel properties used for the modelling of the Rails. |
|---------|----------------------------------------------------------|
| Density (Kg/m$^3$) | Modulus of Elasticity (GPa) | Poisson’s Ratio |
| 7850 | 210 | 0.3 |

2.3. Sleeper Pads
Sleeper pads are special pads which are placed between the sleepers and the ballast. They are about 10mm to 20mm thick and have been used for about 20 years in special applications for economic reasons [3]. In recent years the use of sleeper pads has increased, mainly in newly built high-speed railway tracks in Central Europe. According to Johansson [4], the sleeper pads often consist of a polyurethane
elastomeric material which has a foam structure. Often they consist of two materials, whereby an outer material protects an inner material from abrasive wear. The materials must be well chosen in order to get good damping and stiffness values. For the installation in the railway track, the sleeper pads are often glued onto the underside surface of the sleepers or put into the formwork before concreting. The main reason for using sleeper pads is to reduce the damage of the ballast by distributing the load evenly. A soft sleeper pad fits better with the stones, which can be pressed into the soft pad. Thereby the contact areas of the force-carrying stones get increased. According to Riessberger [5] normally only 3 to 4% of the sleeper’s area is in contact to stones. When using sleeper pads the contact area increases to nearly 30% of the sleeper’s area. This leads to a reduced contact pressure. Also the abrasive wear of the stones is expected to become less. By using sleeper pads the force of the train is expected to be distributed to more sleepers at the same time. This also reduces the contact pressure and the wear of the ballast and therefore the track settlement. Furthermore, it is expected that vibrations in the ballast and in the ground are reduced by using sleeper pads.

The vertical stiffness of a railway track can change very rapidly within a few meters. The railway track is seldom build on a homogeneous sub ground. Therefore, the sub ground changes its properties, including its stiffness, along the track. The change of track stiffness is more or less random. By using sleeper pads the variations of stiffness along the track can be compensated. These smoother stiffness variations lead to less maintenance work on the railway track. Also vibrations can occur at areas with a sudden change of the railway stiffness like for example at transition areas from an embankment to a bridge or at crossovers and switches. With sleeper pads these changes of stiffness can be made smoother and thereby the vibrations get reduced. Moreover, according to Riessberger [5] it is possible to reduce the thickness of the ballast layer when building a railway track with Under Sleeper Pads (USPs). The requirements for USPs are resistance against abrasive wear by the stones, especially against the sharp corners of the stones. Therefore, as mentioned above, a special outer layer is often used. The sleeper pads must also permanently withstand the loadings of the passing trains without losing their elastic properties. The vibration behaviour of the sleeper pads should also fit with the requirements for the track. Furthermore, with the installation of the sleeper pads, the periodical track maintenance with the use of tamping and other related machines will be minimum and long-term cost savings are possible. The material rubber properties used for modelling the sleeper pads in ABAQUS FEA are listed in Table 3.

| Table 3. The Rubber properties used for the modelling of the Sleeper Pads. |
|---------------------------------------------------------------|
| Density (Kg/m³) | Modulus of Elasticity (MPa) | Poisson’s Ratio |
| Sleeper Pads | 500 | 100 | 0.1 |

2.4. Load consideration

The rails are rigidly fastened to the concrete sleeper at 1 m spacing. Apart from the new East Coast Rail line (ECRL), most Malaysian railway system adopts the meter gauge spacing for rail. The locations on the top surface of the sleeper where the I-sectioned rails are positioned are called rail seats. There is a rubber dampener in between the rail and sleeper, which serves the purpose to dampen the impact, allows a little lateral movement, minimizes the friction between the rail and sleeper and distribute the load evenly onto the sleeper. We have ignored the effect of the rubber dampener to ease the modelling process, now the sleeper and the rail are just attached with together by their connecting surface. The total axle load of 30 metric tons is being considered for the modelling so it becomes 15 tonnes in each wheel. The analysis being done is a static analysis so the moving load effect and the impact loading effect (dynamic load) is ignored. As we know the wheel is a circular shaped object, the top of the rail is elliptic shape itself, as it is a static analysis and the moving load effect is being ignored, the contact patch between rail-wheel at an instance will be just a point. Therefore, a point load of 15 tones is applied at the top and the longitudinal and transverse center of each rail section.

2.5. Boundary Condition
In general, the sleeper is supported by ballast which acts as elastic cushion for the sleeper between the rails and the embankment. The sleeper model is supported by a viscously damped, massless elastic foundation with certain stiffness that simulates the simplified underlying ballast supports which allows the sleeper move up and down. According to Iwinicki [6] the ballast subgrade reaction should be 13MPa for soft beds and 26MPa for stiffer beds. Although the ballast pressure will change with time in a dynamic load situation [10], in our case for the sleeper and ballast interaction, instead of fixed support, discrete spring elements with uniform stiffness of 20 MN/m² are connected to the ground [2] with at the interval of 200 mm in the longitudinal direction and 140 mm in the transverse direction of the sleeper, which means with the total length of a sleeper, around 33 spring elements connected to the bottom of sleeper.

3. Finite Element Modelling and Validation

A three-dimensional finite element package (ABAQUS) has been used to establish all the 3D models, which is a numerical instrument used to show and simulate the mechanical behaviour of the steel rail under static loading condition, concrete sleeper and elastic rubber sleeper pads. At present it is very important to be able to use advanced mathematical solutions and methods for virtual analysis of large and complex elements or structures, of which the experimental work would be very expensive and time consuming. Therefore, Finite Element Analysis (FEA) has become a very useful tool in the recent years. It provides numerical answers for even extremely complex stress issues, which can now be acquired routinely using FEA packages.

ABAQUS CAE version 6.14 has been chosen as the finite element tool for this study. All solid component models have been created using ABAQUS. For this study four separate models with the same rail and sleeper sections have been created in the ABAQUS. At first the parts being used for modelling was done using AutoCAD 3D software and was imported into the ABAQUS CAE as. sat files. As shown in Figure 1 each model consists of five monoblock concrete sleepers and two steel rails seated at 1 m apart from each other. One model was done without any sleeper pads and the other three were created with 10mm, 15mm and 20mm thickness sleeper pads respectively. The rail is normally fastened to the sleepers with steel bolts, as the rail sleeper fastening joint is not the focus of the study during modelling the rails were connected with the sleepers using tie constraint function in ABAQUS [9]. The displacement and rotation DOF in every direction is considered restrained except the vertical displacement, to represent the sleeper ballast interaction spring constrained are used for the vertical displacement. The spring values being used in the model has been discussed in the previous chapter. In the three models with sleeper pads, the pads are attached at the bottom of the sleeper, using the tie constrained function in ABAQUS.
A sleeper subjected to constant impact loads is modelled and analysed [7]. By employing general purpose finite element analysis, ABAQUS, a three-dimensional concrete sleeper and rubber pad is established and simulated in static condition. The results from modelling are used to compare with experimental results from a full-scale static test. This was performed to validate the finite element model. The static test from Rikard [7] is carried out using a hydraulic jack, and the displacement at rail seat will increase at a constant rate. The support condition in this case is fixed where sleeper is tied on the ground on four locations. To validate the quality of the author’s FE model, its numerical results are compared with those from Rikard [7] after taking in consideration the stress-strain relation for concrete and steel and the load-vertical displacement diagram. The only difference to the model by Rikard [7] is the non-linear behaviour of concrete material because of lack of input data. In this FEM model concrete is modelled as elastoplastic material, while in Rikard’s model concrete is modelled as elastoplastic and brittle cracking material. From the validation, the results exhibit good agreement with experimental values [2].

The finite element investigation using ABAQUS was carried out for prestressed concrete sleepers with and without web openings and an experimental validation was done to verify the results of the FE models [1]. The experimental tests have been carried out as per British Standards [8]. From the load-deflection comparison curves for sleepers with no web openings, the elastic range of the curves shows a good correlation with failure, in addition the ultimate load from the FEA is 2.2% lower than the experimental one. That is because the only damage parameters applied are for reinforced concrete structures.

4. Results

Figure 3 illustrates the stress distribution of sleepers without any of the sleeper pads and stress at the top of the sleeper where its attached to the rail which is about 1092 kPa and at the bottom of the middle sleeper the maximum stress occurs (2155 kPa) and the stress gradually decreases in the outer sleepers, the maximum stress at the bottom of the outermost sleeper is about half of the value in the middle sleeper.

Figure 4 shows the stress distribution in sleeper and sleeper pads with a 10 mm thick sleeper pad attached at the bottom of the sleeper. Here the stress values at the bottom of all sleeper pads are almost equal, which is about 2737 kPa, Whereas, the stress at the top of the sleeper becomes 1617 kPa, which is almost same in all the sleepers.

Similarly, Figure 5 and 6 shows the stress distribution in sleeper and sleeper pads with pad thickness 15 and 20 mm respectively. Like the model with 10 mm pad the stress at the bottom of all five sleeper pads are almost equal which is about 2485 kPa and 2281 kPa for 15mm and 20mm sleeper pads respectively. The top sleeper stress is 1250 kPa and 1160 kPa for the 15 and 20 mm pads respectively.
Figure 3: Stress distribution of sleeper without any sleeper pads

Figure 4: Stress distribution of sleeper and sleeper pad with 10mm thick sleeper pad

Figure 5: Stress distribution of sleeper and sleeper pad with 15mm thick sleeper pad

Figure 6: Stress distribution of sleeper and sleeper pad with 20mm thick sleeper pad
Figures 7 to 10 shows a cross section of sleeper at vertical height of the point of load with and without sleeper rubber pads. The stress distribution without rubber pad in Figure 7 shows an increase of stress concentration at the bottom of the concrete sleeper up to 2155 kPa. Whereas, for 10mm, 15mm and 20mm rubber pad thickness, most stresses are being absorbed by the rubber pad. The similar region for bottom of sleeper has seen reduction of 25.8%, 42.0% and 46.1% respectively with rubber pads of 10mm, 15mm and 20mm respectively. In addition, the red region denotes the stress concentration of spring modelled to interact the sleeper to the earth ballast. Figure 11 and 12 exhibits the variation of stress with depth and rubber pad thickness respectively.
5. Conclusion

The author has concluded two prime findings in this study. The first is the overall stress distribution for a naked concrete sleeper which exhibits an immense stress contour at the top and bottom of the sleeper owing to the contribution of static load from the wheel. Secondly, the ability of rubber pads to reduce the stress contour for the concrete sleeper. Although the thickness of rubber pads played a vital role for the reduction of stress profile in concrete sleeper, nevertheless, it has an inverse impact of stress distribution in the rubber pad itself. The thicker rubber pad is capable to absorb more energy and dissipate the energy from the concrete sleeper whereas the thinner rubber pad has a lower tendency to absorb the energy and thus has a lower dissipation energy within the concrete sleeper.
6. References

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