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Research Paper

EFFECT OF RAILWAY TRACK ELEMENTS PROPERTIES ON STRESSES DISTRIBUTION

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The railway track elements (iron rail bars, concrete sleepers, crushed stone layers, base or ballast layer and the subgrade layer) play an important role to resist the stresses resulting from the movement of trains on this track line, the basic purpose for the railway components to transfer resulting stresses safely to earth's natural layer. In this paper we use the Track 3.1 program developed by US army crops engineers to calculate the rail bending stresses and tie bending stresses as well as shear stresses or layers reaction of load hanging from the train and on the assumption that the material of installation layer (ballast) behavior as in elastic materials. Several attempts to study the effect of changing the thickness of the installation layer (ballast), the distance between the sleepers (tie spacing), sectional area of the installation panel and modulus of elasticity calculated from the value of CBR test (California bearing ratio) as well as the number of bolts(spike number) , on the rail bending stresses , tie bending stresses and the vertical stresses at the surface of installation layer (ballast) , and subgrade layer as well as reaction (shear) for the sleepers. From the results obtained we note that the rail bending stresses is less when increasing the thickness of the installation layer (ballast) ,when increase ballast grade size (aggregate gradation) and increase the modulus of elasticity of the subgrade layer. While the tie bending stresses increases with increasing distance (tie spacing) between them and the number of screws which fasten it with the installation layer, and less with increase the modulus of elasticity of the subgrade layer and the sectional area of the panel installation.

Keywords: Railway track element, Track 3.1 program, Rail bending stress, Tie bending stress

INTRODUCTION

The railway track system plays an important role in providing a good transportation system in a country. A very large portion of the annual budget to sustain the railway track system goes into track maintenance. In the past, most attention has been given to the track superstructure consisting of the rails, the fasteners and the sleepers, and less

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attention has been given to the substructure consisting of the ballast, the subballast and the subgrade.

Even though the substructure components have a major influence on the cost of track maintenance, less attention has been given to the substructure because the properties of the substructure are more variable and difficult to define than those of the superstructure (Selig and Waters, 1994).

Ballast is the most important component of the substructure because it is the only external constraint applied to the track in order to restrain it. Ballast is also important for providing the fastest and most economical method of restoring track geometry, especially at a subgrade failure situation. However, ballast is also one of the main sources of track geometry deterioration (Tutumluer *et al*., 2006).

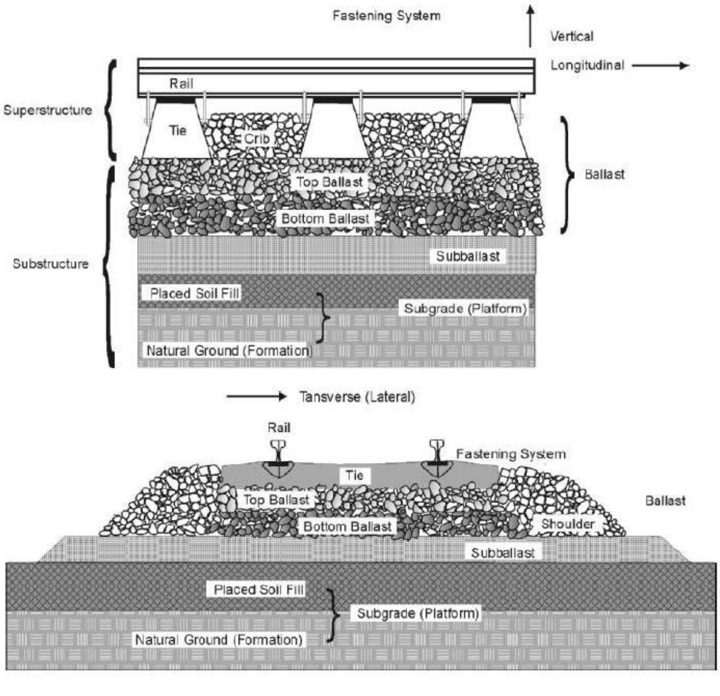
RAILWAY TRACK ELEMENTS

Track components are grouped into two main components: The superstructure and substructure as shown in Figure 1. The superstructure refers to the top part of the track that is the rails, the fastening system and the sleepers, while the substructure refers to the lower part of the track: that is the ballast, the subballast and the subgrade (Selig and Waters, 1994).

Ballast

Ballast has many functions. The most important functions are to retain track position, reduce the sleeper bearing pressure for the underlying materials, store fouling materials, provide drainage for water falling onto the track, and rearrange during maintenance to restore track geometry. Thus, ballast materials are required to

Figure 1: Typical Standard Railway Track Element



be hard, durable, and angular, free from dust and dirt, and have relatively large voids. Since ballast is a type of granular material, behavior of such a material is well documented in granular materials literature (Fong, 2006).

Railroad ballast is the aggregate layer usually installed between crosstie and subgrade. It transfers the load impact from the tie and distributes over the low strength subgrade soil.

Many factors may influence the ballast behavior before and after tamping such as aggregate gradation, shape, angularity, tie surface texture, and ballast compaction level.

According to the American Railway Engineering and Maintenance of Way Association (AREMA), ballast aggregate should be open graded with hard, angular shaped particles providing sharp corners and cubical fragments with a minimum of flat and elongated pieces (maximum 5% by weight over 3 to 1 ratio) (Tutumluer *et al*., 2006).

Several studies in the last decade have linked coarse aggregate size and shape properties to pavement performance (Aursudkij, 2007; Fair, 2003). In the pavement unbound aggregate base courses, while compaction is important from a shear resistance and strength point of view, the shape, size and texture of coarse aggregates are also important in providing stability [6]. Field tests of conventional asphalt pavement sections with two different base thicknesses and three different base gradations showed that crushed-stone bases gave excellent stability because of a uniform, high degree of density and little or no segregation (Rose *et al*., 2006). Rounded river gravel with smooth surfaces was found to be twice as susceptible to rutting compared to crushed stones (Talbot, 1980).

Ballast is the crushed granular material placed as the top layer of the substructure, in the cribs between the sleepers, and in the shoulders beyond the sleeper ends down to the bottom of the ballast layer. Traditionally, good ballast materials are angular, crushed, hard stones and rocks, uniformly graded, free of dust and dirt, not prone to cementing action. However, due to the lack of universal agreement on the specifications for ballast materials, availability and economic considerations have been the main factors considered in the selection of ballast materials. Thus, a wide range of ballast materials can be found, such as granite, basalt, limestone, slag and gravel. One of the main functions of ballast is to retain track position by resisting vertical, lateral and longitudinal forces applied to the sleepers. Ballast also provides resiliency and energy absorption for the track, which in turn reduces the stresses in the underlying materials to acceptable levels. Large voids are required in the ballast for storage of fouling materials and drainage of water falling onto the track. Ballast also needs to have the ability to rearrange during maintenance level correction and alignment operations (Tutumluer *et al*., 2006).

Sleeper or Ties

The main functions of sleepers are to distribute the wheel loads transferred by the rails and fastening system to the supporting ballast and restrain rail movement by anchorage of the superstructure in the ballast (Fong, 2006).

Subgrade

Subgrade is the foundation for the track structure. It can be existing natural soil or placed soil. The main function of the subgrade is to provide a stable foundation for the track structure. Thus, excessive settlement in the subgrade should be avoided (Fong, 2006).

Stresses on Railway Track

There are two main forces which act on ballast. These are the vertical force of the moving train and the "squeezing" force of maintenance tamping. The vertical force is a combination of a static load and a dynamic component superimposed on the static load. The static load is the dead weight of the train and superstructure, while the dynamic component, which is known as the dynamic increment, depends on the train speed and the track condition. The high squeezing force of maintenance tamping has been found to cause significant damage to ballast. Besides these two main forces, ballast is also subjected to lateral and longitudinal forces which are much harder to predict than vertical forces.

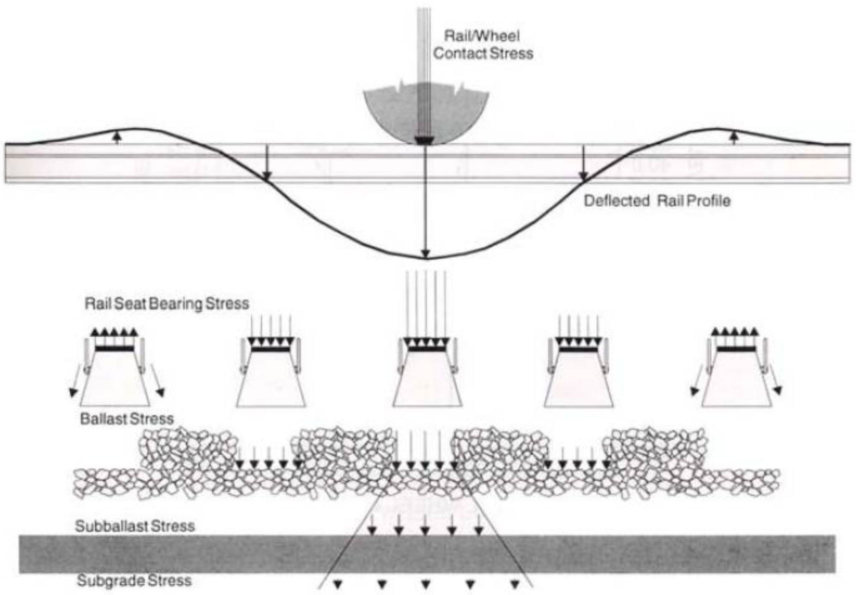
The dead wheel load can be taken as the vehicle weight divided by the number of wheels. The static load from the dead weight of the train often ranges from about 53 kN for light rail passenger services to as high as 174 kN for heavy haul trains in North America. The dynamic increment varies with train section as it depends on track condition, such as rail defects and track irregularity.

The static wheel load distribution was obtained by dividing known individual gross car weights by the corresponding number of wheels, and the dynamic wheel load distribution was measured by strain gauges attached to the rail.

The vertical wheel force is distributed through a number of sleepers. The number of sleepers involved is highly dependent on the sleeper spacing and the rail moment of inertia.

The vertical downwards force at the rail-wheel contact points tends to lift up the rail and sleeper some distance away from the contact point, as shown in Figure 2.

Figure 2: Uplift of Rails



Source: Selig and Waters (1994)

The uplift force depends on the wheel loads and self-weight of the superstructure. As the wheel advances, the lifted sleeper is forced downwards causing an impact load, which increases with increasing train speed. This movement causes a pumping action in the ballast, which increases the ballast settlement by exerting a higher force on the ballast and causing "pumping up" of fouling materials from the underlying materials in the presence of water.

It is also noted that the impact load increases with the increase in track irregularity or differential settlement (i.e., impact load increases with the increase in the size of the gap underneath the sleeper). The increase of impact load would then lead to an increase in ballast settlement and lead to a larger gap underneath the sleeper. Thus, track geometry tends to degrade in an accelerating manner.

The lateral force is the force that acts parallel to the long axis of the sleepers. The principal sources of this type of force are lateral wheel force and buckling reaction force. The lateral wheel force arises from the train reaction to geometry deviations in self-excited hunting motions which result from bogie instability at high speeds, and centrifugal forces in curved tracks. These types of forces are very complex and much harder to predict than vertical forces. The buckling reaction force arises from buckling of rails due to the high longitudinal rail compressive stress which results from rail temperature increase. The longitudinal force is the force that acts parallel to the rails. The sources of this force are locomotive traction force including force required to accelerate the train, braking force from the locomotive cars, thermal expansion and contraction of rails, and rail wave action.

The vertical wheel force is distributed through a number of sleepers. The number of sleepers involved is highly dependent on the sleeper spacing and the rail moment of inertia. Conducted a parametric study using the GEOTRACK computer program, which is a three-dimensional, multi-layer model for determining the elastic response of the track structure. They found that as the sleeper spacing increased from 250 mm to 910 mm, the load applied to the sleeper beneath the wheel increased by a factor of about 4. They also found that for an increase of rail moment of inertia from 1610 cm^4 to 6240 cm^4, the load applied to the sleeper beneath the wheel decreased by 40% (Selig and Waters, 1994).

TYPES OF STRESSES EFFECT ON RAILWAY

1. Bending stress
2. Ballast surface stress
3. Tie bending stress
4. Tie reaction
5. Subgrage stress

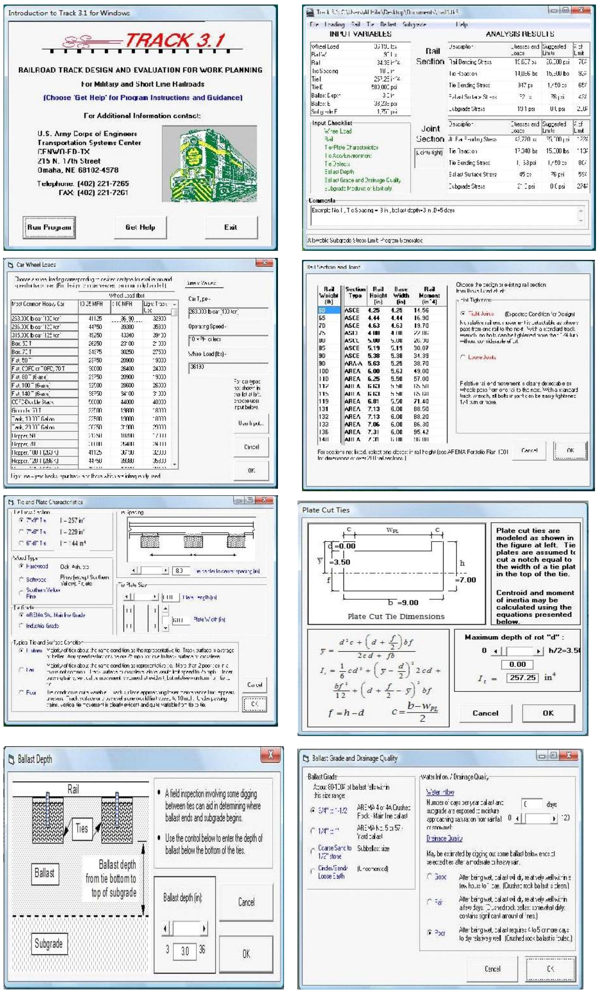
TRACK 3.1 PROGRAMS

The program which is used to calculate railway track element is called "Track 3.1" developed by US army Corps of engineers, transportation system center, more details are shown on the Plate 1 and input variables shown in Table 1.

SENSITIVITY ANALYSIS

Sensitivity analysis has been made to illustrate the effect of various parameters on pavement structural design. Due to the complex interactions among the large number of parameters, it is difficult to present a concise but accurate picture

Plate 1: Track 3.1 Program Menu



Introduction to Track 3.1 for Windows

TRACK 3.1

RAILROAD TRACK DESIGN AND EVALUATION FOR WORK PLANNING

For Military and Short Line Railroads

(Choose 'Get Help' for Program Instructions and Guidance)

For Additional Information contact:

U.S. Army Corps of Engineers
Transportation Systems Center
CENWO-ED-TX
215 N. 17th Street
Omaha, NE 68102-4978

Telephone: (402) 221-7265
FAX: (402) 221-7261

Plate Cut Ties

Plate cut ties are modeled as shown in the figure at left. Tie plates are assumed to cut a notch equal to the width of a tie plat in the top of the tie.

Centroid and moment of inertia may be calculated using the equations presented below.

$$\bar{y} = \frac{d^2c + \left(d + \frac{f}{2}\right)bf}{2cd + fb}$$

$$I_t = \frac{1}{6}cd^3 + \left(\bar{y} - \frac{d}{2}\right)^2 2cd + \frac{bf^3}{12} + \left(d + \frac{f}{2} - \bar{y}\right)^2 bf$$

$$f = h - d \qquad c = \frac{b - w_{PL}}{2}$$

Maximum depth of rot "d" : 0 h/2=3.50

0.00

I_t = 257.25 in^4

Ballast Depth

- A field inspection involving some digging between ties can aid in determining where ballast ends and subgrade begins.
- Use the control below to enter the depth of ballast below the bottom of the ties.

Ballast depth (in): 3 3.0 36

on the effect of a given parameter. This is because the effect of such variable depends not only on the parameter itself but also on other parameters. Conclusions based on a set of parameters may not be validated if some of the other parameters are changed. The best approach is to fix all other parameters at their most reasonable values while varying the parameter in question to show its effect as shown in the following Table.

DATA ANALYSIS

Effect of Ballast Thickness, it can be noticed from Figure 3

Rail Section

1) The bending stresses at rail decreased with increased ballast thickness.

2) The tie reaction force increased with increased ballast thickness.

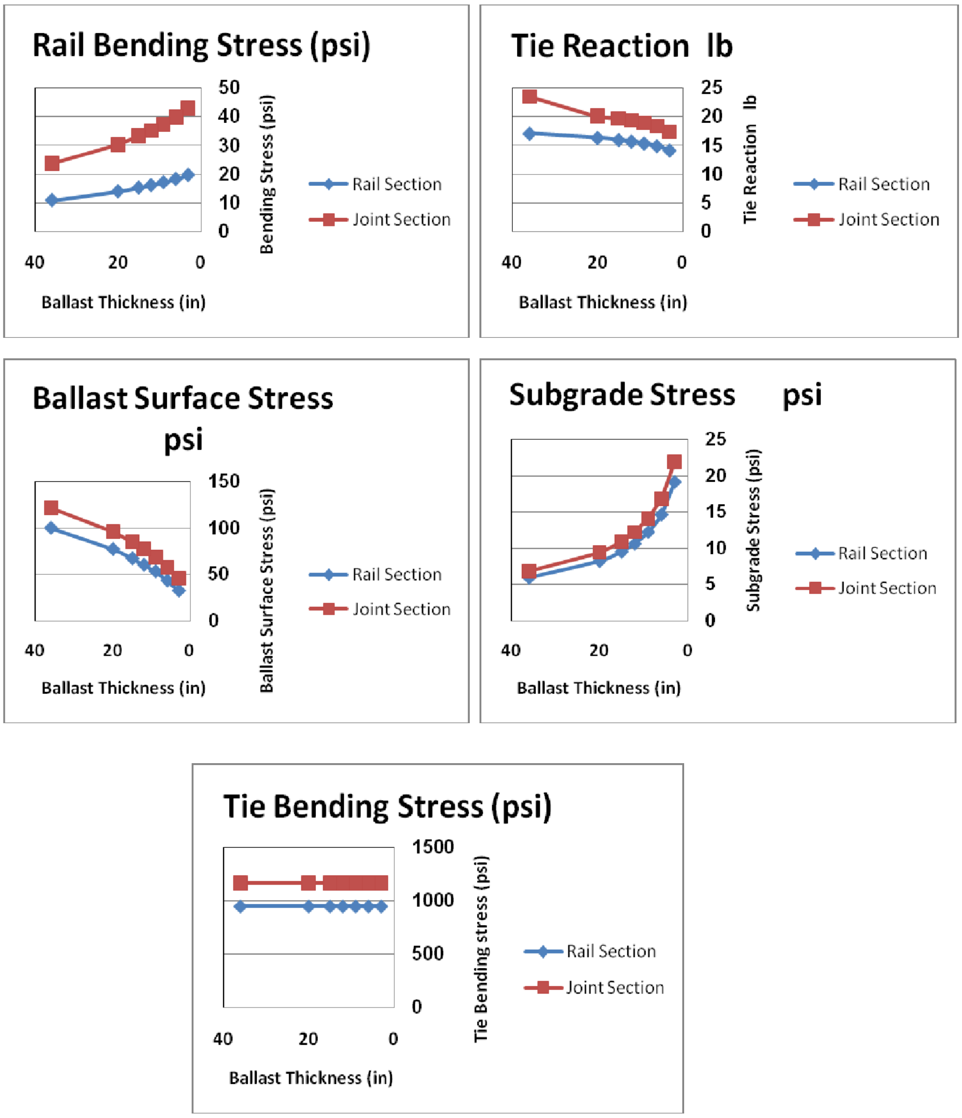
3) The vertical stress at surface of the ballast layer increased with increased ballast thickness.

4) The vertical stress at the top of the subgrade layer decreased with increased ballast thickness.

Table 1: Input Variables

Railway Track Element	Effect of Ballast Depth (in)	Effect of Tie Spacing (in)	Effect of Tie Cross-Section (I, in^4)	Effect of Ballast size (in)		Effect of Subgrade Modulus (psi)		Effect of Spike No.
						CBR	Es = 1750*CBR	
Variables (No. of Trials)	3	18	7"*9"=257	1	¾	1	1750	0
	6	20	7"*8"=229	2	½	5	8750	1
	9	22	6"*8"=144	3	¼	10	17500	2
	12	24		4	loose earth	20	35000	3
	15					30	52500	4
	20					40	70000	
	36					50	87500	

Figure 3: Effect of Ballast Thickness



5) The tie bending stresses not significant effect by ballast thickness.

Joint Section

Generally; the response behavior is the same in rail section but less than it.

Effect of Tie Spacing , it can be seen from Figure 4

Rail Section

1) The bending stresses at rail not significant effect with tie spacing.

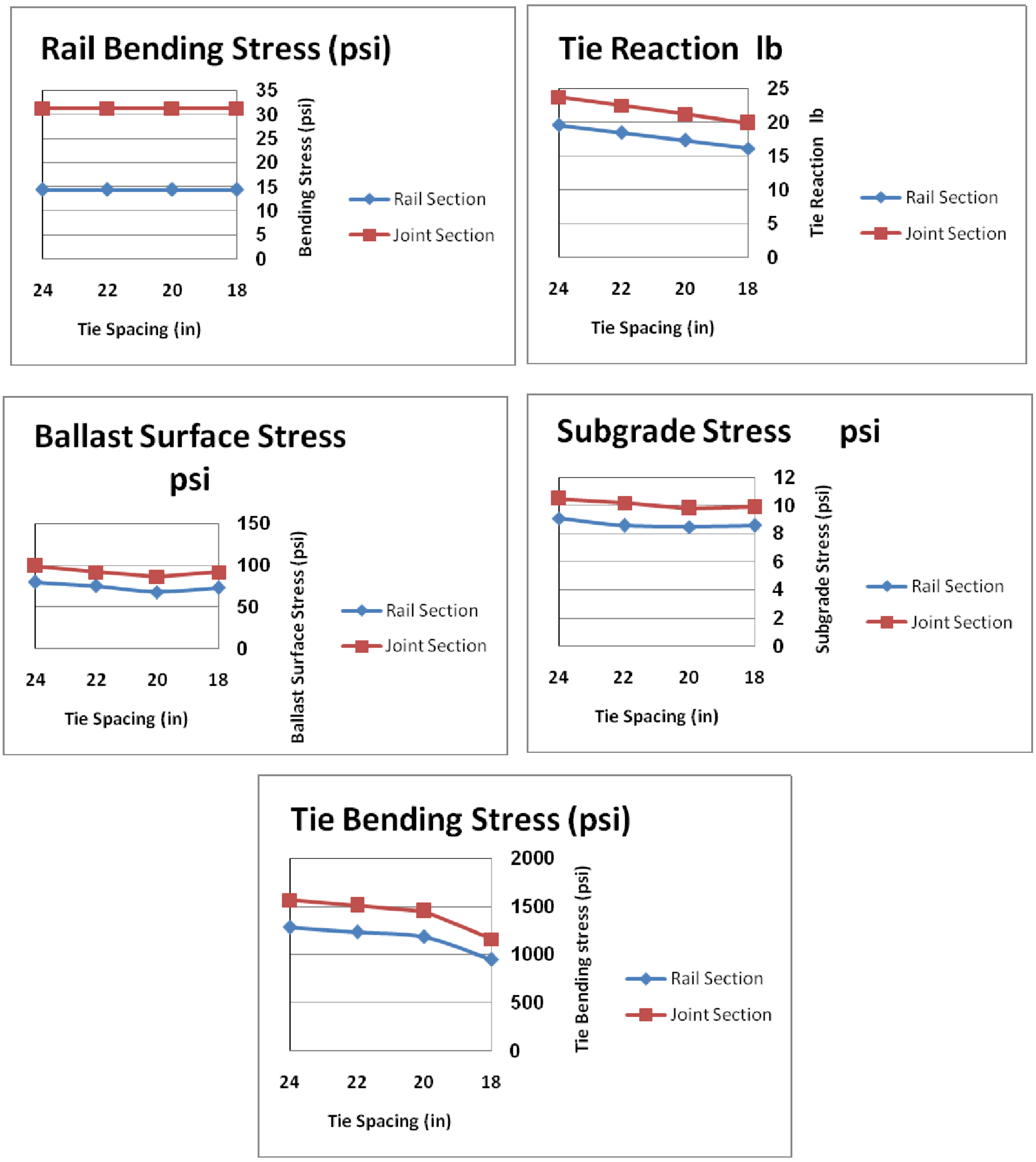
2) The tie reaction force increased with increased tie spacing.

3) The vertical stress at surface of the ballast layer increased with increased tie spacing.

4) The vertical stress at the top of the subgrade layer increased with increased tie spacing.

5) The tie bending stresses increased with increased tie spacing.

Figure 4: Effect of Tie Spacing



Joint section

Generally; the response behavior is the same in rail section but less than it.

Effect of Changing Tie Cross Section , it can be noticed from Figure 5

Rail Section

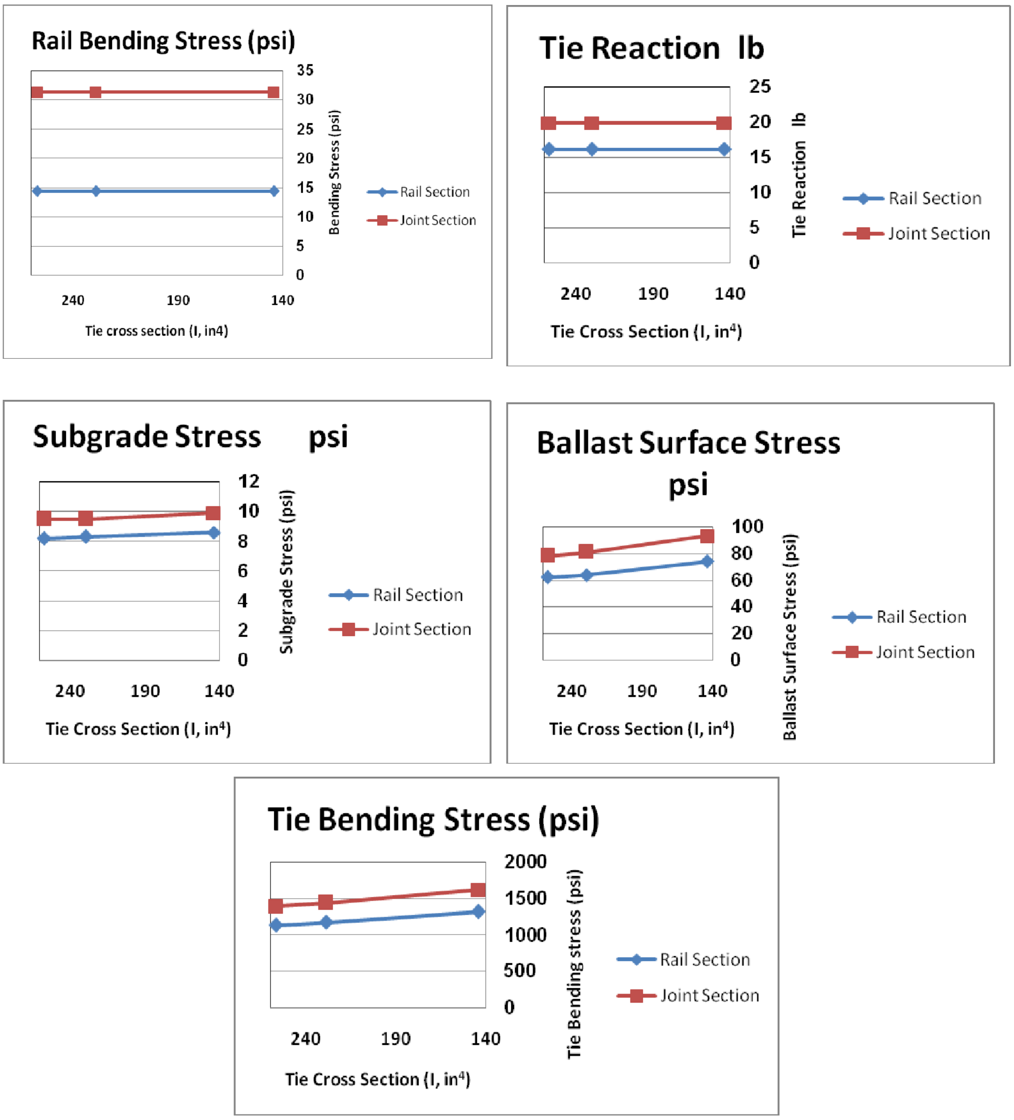
1) The bending stresses at rail not significant effect with changing tie cross section.

2) The tie reaction force not significant effect with changing tie cross section.

3) The vertical stress at surface of the ballast layer decreased with increased tie cross section.

4) The vertical stress at the top of the subgrade layer decreased with increased tie cross section.

Figure 5: Effect of Tie Cross-Section


Rail Bending Stress (psi)

Tie Reaction lb

Subgrade Stress psi

Ballast Surface Stress psi

Tie Bending Stress (psi)

5) The tie bending stresses decreased with increased tie cross section.

Joint Section

Generally; the response behavior is the same in rail section but less than it.

Effect of Changing Ballast Grade Size, it can be seen from Figure 6

Rail Section

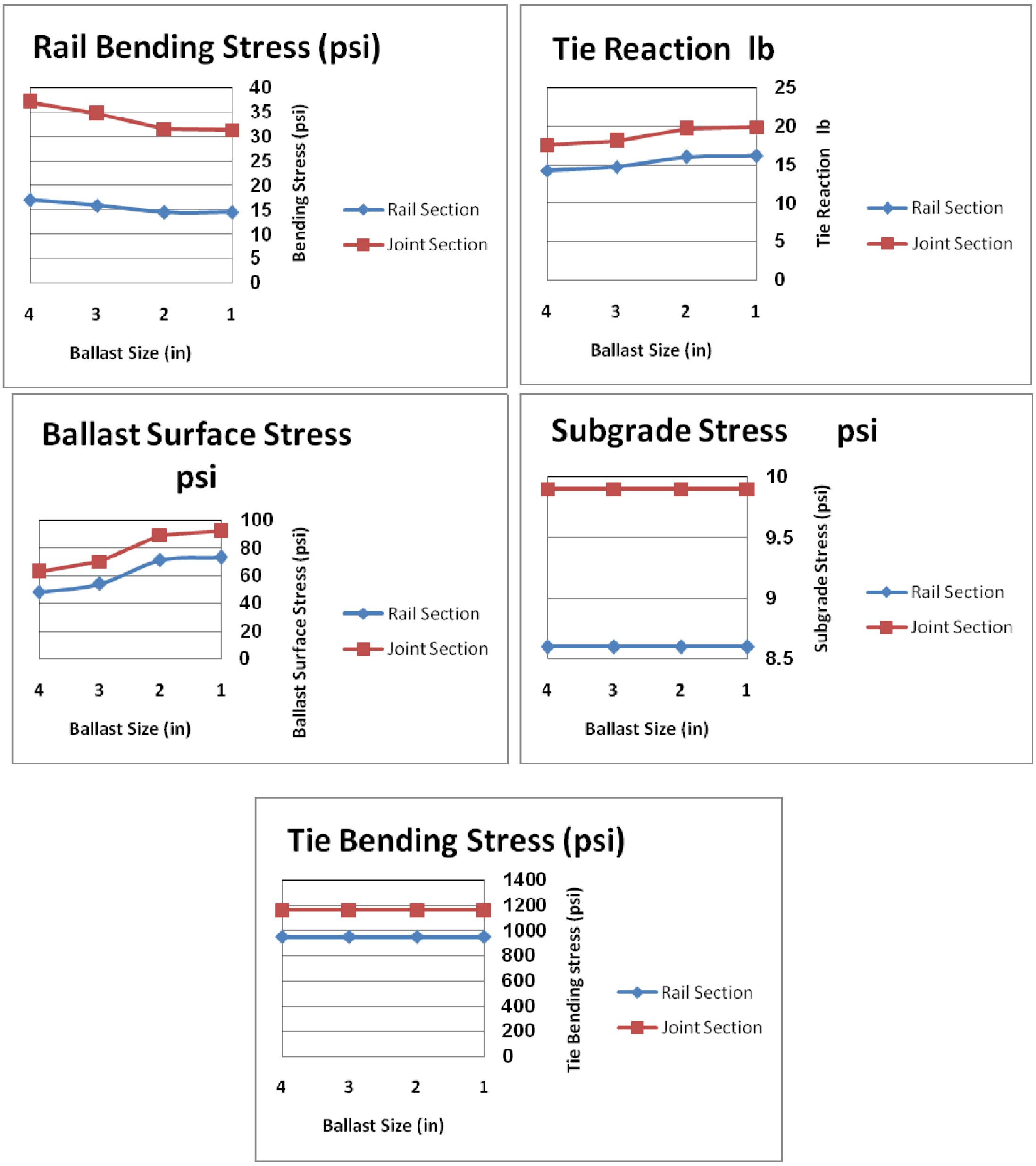
1) The bending stresses at rail reduced with increasing ballast grade size due to increased aggregate stiffness.

2) The tie reaction force increased with increased ballast grade size due to increased ability of ballast layer to resist.

3) The vertical stress at surface of the ballast layer decreased with reduced ballast grade size due weak in ballast layer.

4) The vertical stress at the top of the subgrade

Figure 6: Effect of Ballast Grade Size



layer not significant effect with changing in the ballast grade size.

5) The tie bending stresses not significant effect with changing in the ballast grade size.

Joint Section

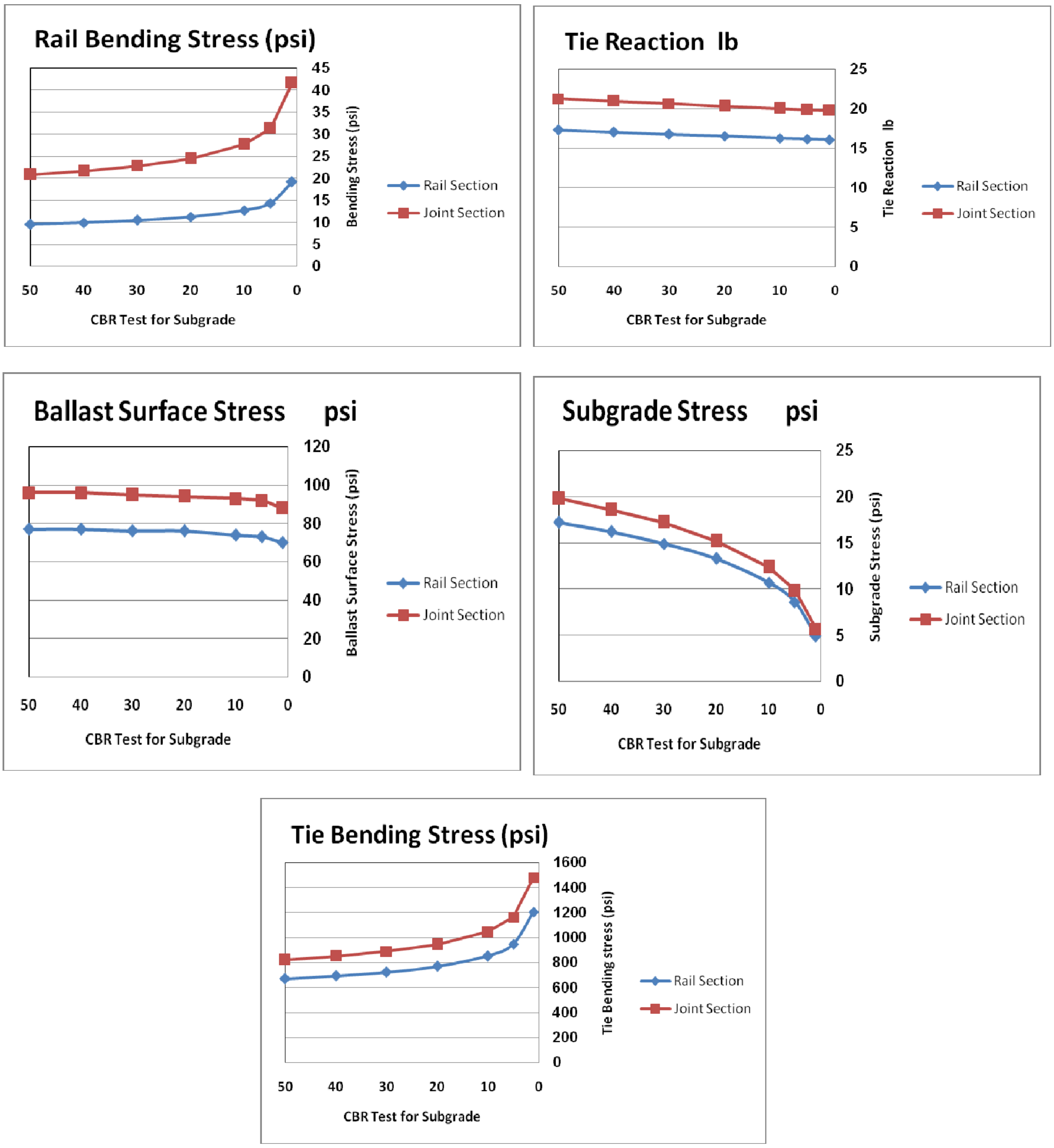
Generally; the response behavior is the same in rail section but less than it.

Effect of Strength of Subgrade it can be noteced from Figure 7

Rail section

1) The bending stresses at rail reduced with increasing strength of subgrade (increasing CBR value) due to increased subgrade stiffness.

Figure 7: Effect of Subgrade Strength



2) The tie reaction force increased with increased subgrade strength due to increased ability of subgrade layer to resist.

3) The vertical stress at surface of the ballast layer increased with increased subgrade strength due strong in subgrade layer.

4) The vertical stress at the top of the subgrade layer increased with increased subgrade strength.

5) The tie bending stresses decreased with increased subgrade strength.

Joint Section

Generally; the response behavior is the same in rail section but less than it.

Effect of Spike Number, it can be seen from Figure 8

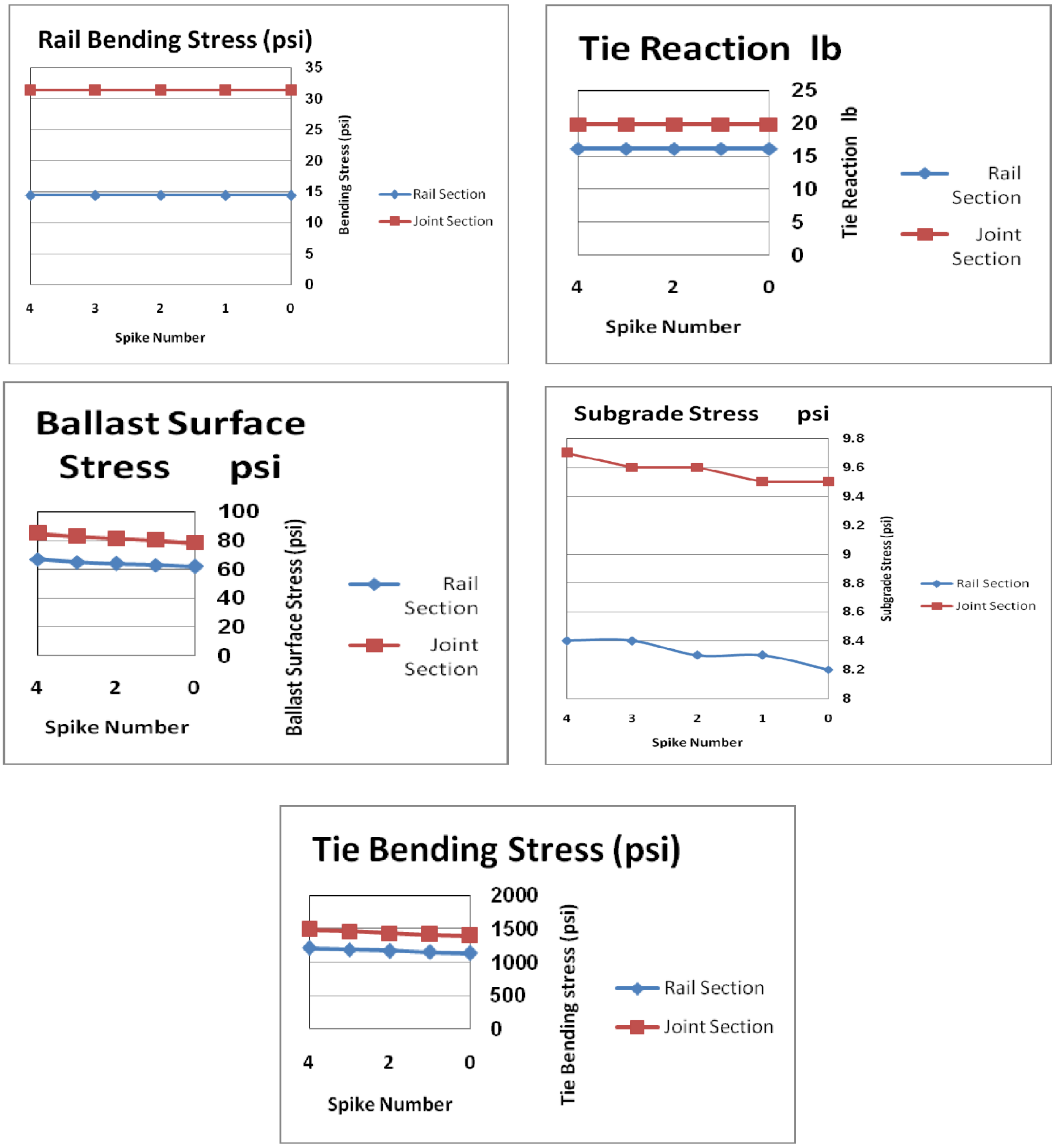
Rail Section

1) The bending stresses at rail not significant effect with increasing spike number.
2) The tie reaction force not significant effect with increasing spike number.
3) The vertical stress at surface of the ballast layer increased with increased spike number due to stable of tie plate.
4) The vertical stress at the top of the subgrade layer increased with increased spike number.
5) The tie bending stresses increased with increased spike number.

Joint Section

Generally; the response behavior is the same in rail section but less than it.

Figure 8: Effect of Spike Number



CONCLUSION

From the data analysis can be conclude:

1) The bending stresses at rail increased with decreased ballast thickness and reduced with increased ballast grade size and so reduced with increased subgrade strength (CBR value).
2) The tie reaction force increased with increased ballast thickness, tie spacing, ballast grade size and subgrade strength.
3) The vertical stress at surface of the ballast layer increased with increased ballast thickness, tie spacing, subgrade strength and spike numbers but reduced with increased tie cross section and ballast grade size.
4) The vertical stress at the top of the subgrade layer decreased with increased ballast thickness, tie cross section but increased with increased subgrade strength, spike number and tie spacing.
5) The tie bending stresses increased with increased tie spacing, spike number but decreased with increased tie cross section and subgrade strength.
6) The response parameters in rail section are more than in joint section.

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