

The Behaviour of the Embedded Rail in Interaction with Bridges

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Abstract. Since the introduction of the direct fastening system, Embedded Rail System (ERS) is probably one of the most spectacular and innovative developments in railway engineering. The development has become more rapid, especially in the last decade due to competitive advantages in comparison to other systems with respect to higher speed, cost effectiveness, environmental-material sustainability and others. But still there is a lack of specific interaction model, especially when it comes to bridges equipped with ERS system. Previous studies on ERS by Estzer Ludvigh² found out some important coefficients (vertical and longitudinal bedding coefficient) and compared the longitudinal resistance of ERS with flexible fastening systems. Other studies on ERS do not specifically deal with the evaluation of longitudinal resistance of such a system. With a view to establish the typical behaviour pattern of ERS, this paper is dedicated to find out the interaction of a specific Embedded Rail System with bridges. A small scale test was conducted on a sample of ERS in the laboratory under different combinations of vertical and longitudinal track loads and subsequently a Finite Element Model (FEM) was developed to simulate the test. The paper presents the FEA result validation with test results, the interaction pattern, longitudinal resistance of ERS track for both loaded and unloaded conditions, design load distribution for such systems and some specific influences of ERS on simply supported bridge systems.

1. Introduction

The primary component of an ERS in railway tracks is the embedding material used, which compensates for the use of traditional ballast along with the sleeper. Elastic embedment does the main work of providing the necessary longitudinal resistance against the wheel load along with better lateral stability, noise and vibration reduction, less influence of dynamic forces and a lot of other advantages [1, 2]. The properties of embedding material may change depending on manufacturer but the primary

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objective fulfillment will be the same for all ERS. In this paper, the study is made on Edilon Sedra ERS (see figure 1), a widely known manufacturer of ERS. The numerical results found from the analysis are primarily Edilon Sedra embedding Corkelast VA-60 specific. Edilon Sedra Corkelast VA-60 is solvent and plasticizer free, two component, self-leveling casting elastomer system based on the state-of-the-art polyurethane resins with cork granulate and mineral fillers.

Other important features used in the system influencing track resistance are the use of hyperelastic resilient strip at the bottom interface of embedding, the steel angle and base plate bounding the embedding material and PVC pipes for space filling in the embedding.

An asymmetric steel I girder with a height of 300mm (see figure 1) was used with the ERS to represent a simply supported single span bridge system.

For connection, the top flange of the girder was directly bolted to the base plate and the steel angles of the ERS assembly. The bolts of 20mm diameter at 150mm spacing were used.

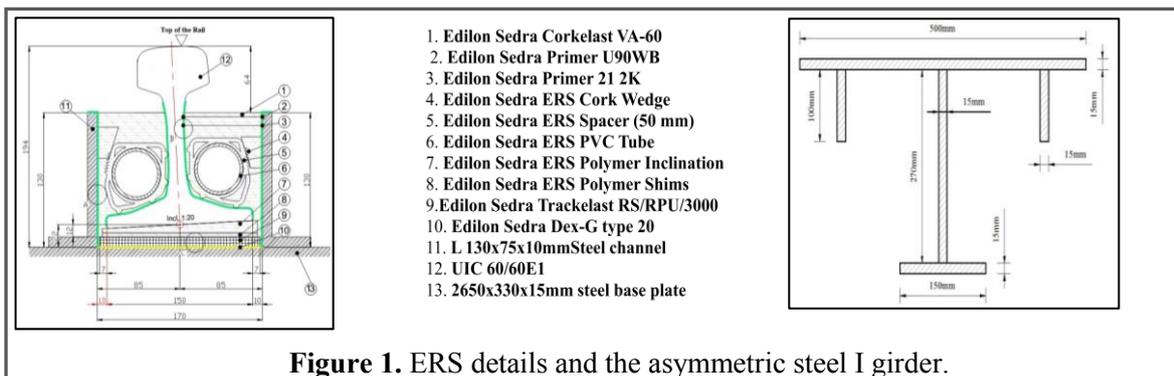


Figure 1. ERS details and the asymmetric steel I girder.

2. Laboratory Test for ERS Track

The static scheme of the whole assembly of ERS with Steel I girder is shown in figure 2. The idea was to impose longitudinal load on the rail only and to represent the ideal length of the rail i.e., the continuously welded rail (CWR) on the bridge deck. The test specimen was arranged for undergoing several stages of vertical and horizontal loading. The vertical load cell was positioned above the center of the girder to impose vertical load at the top of the rail and was supported by the steel beam and column. For the longitudinal load cell, the vertical support was provided by a steel cross beam at the rear end of the specimen. The horizontal support of the load cell was ensured by steel sections welded at the front end of the girder cross section. The final assembly of the test is shown in figure 3.

Four stages of vertical point load were considered up to maximum. And as the test was conducted on a single rail only, these were 0, 40, 80 and 125 kN respectively.

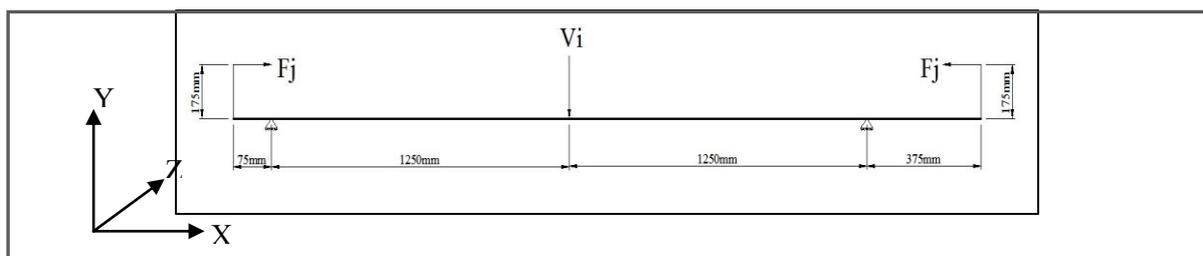


Figure 2. The static scheme of the test.

According to UIC-774R, the maximum longitudinal displacement for embedded rail is recommended as maximum 6mm for unloaded and 7mm for the loaded track [6]. Eurocode [7] has no recommendation on embedded rail. Hence, the maximum longitudinal load applied during the test was monitored according to the longitudinal displacement of the rail (not to exceed too much beyond 7mm) and it had never exceeded the maximum design longitudinal force value).

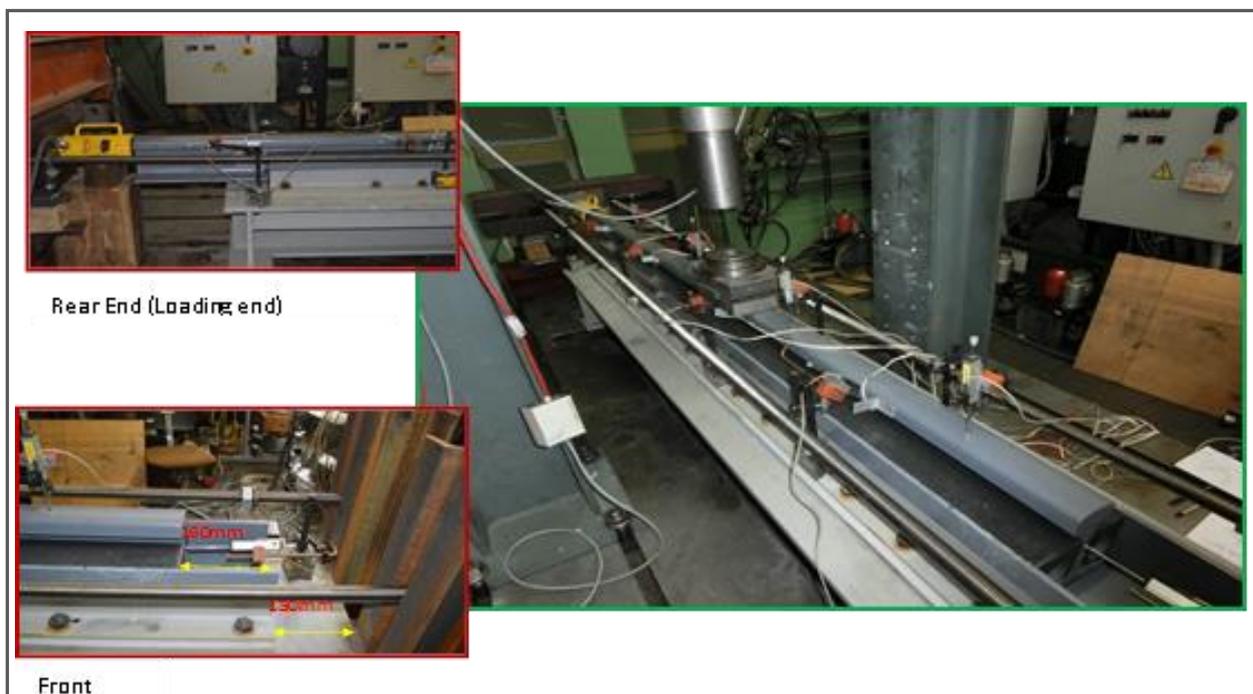


Figure 3. The final test assembly for the ERS on steel girder.

2.1. Test output

The relationship between the longitudinal resistance of the ERS in response to longitudinal displacement was found slightly curvilinear and can be approximated as a linear one, see figure 4.

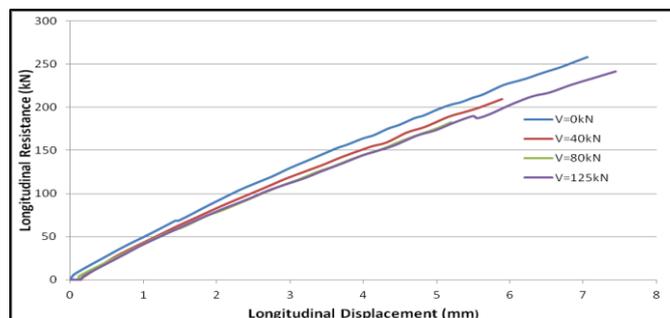


Figure 4. Longitudinal resistance of ERS against longitudinal displacement from the test data.

Although for the loaded track higher longitudinal resistance of track has been obtained as compared to the unloaded track in various studies of ballasted and non-ballasted track (UIC-774R & Euro Codes) [6,7], the test data obtained from the testing of ERS has shown slight decrease of longitudinal resistance with the higher vertical load combinations. Other than the longitudinal resistance and displacement data, the data were recorded for vertical displacements and horizontal stresses along the length of the rail. Stresses at the mid-span of the girder were also recorded.

3. Numerical FEM model Simulation and Validation

3.1. Numerical simulation

To accurately represent the real test specimen and to quantify the accuracy of the numerical solutions to experimental data, a 3-D finite element model was developed with the help of ANSYS APDL version 14.0. The model was composed of quadratic elements and thus hexahedral meshing was done. The lower order (SOLID185) for regular shapes and higher order (SOLID186) elements for irregular shapes elements were used.

One of the challenges was the choice of material for connecting different physical parts in the model. The adhesive materials used for contact between the embedding material and steel angle as well as the base plate have high adhesive strength (greater than 10 MPa and 35 MPa for steel angle and base plate respectively) that has been suggested to be enough to restrict any slippage between them by Edilon Sedra and the test observation attested that. However, the response from the laboratory test was recorded and the separation of physical parts of the arrangement was found only in two cases;

- Between the PVC pipe and the embedding material at the front and rear end.
- Between elastomer and the underlying steel girder at the rear end.

The two separations were modeled manually and the model was analyzed both for the glued and partially unglued regions, taking into consideration different length of separation. The main reason of such consideration was to identify possible influence of the separation on the results.

Both the embedding and the elastomer material show bimodular material properties[3]. Therefore, before picking the result from an analysis, a trial run was given to find out the tension and compression zone of these materials. Then the corresponding volumes were cut into parts to assign different material properties prior to the final run. Hyperelastic material model (Arruda-Boyce) was used for resilient strip in compression.

3.2. Validation

Mainly 3 parameters: longitudinal stress on rail, longitudinal displacement of rail and stresses on girder were used for the validation of the FEM. Longitudinal displacement values from FEA were found close to the experimental result for higher vertical load and showed lower displacement for the last load case (figure 5). The maximum deviation was 15.04% for unloaded condition and, most importantly, the pattern of displacement along the increment of vertical load was found similar.

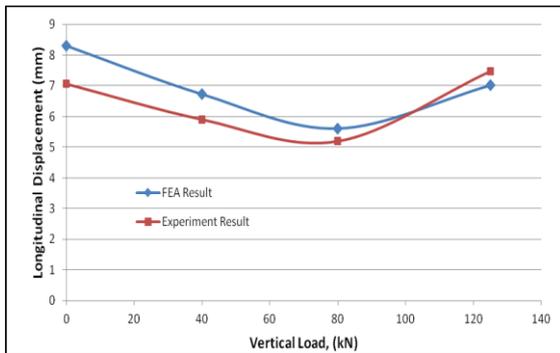


Figure 5. Longitudinal Displacement of Rail with the increment of vertical load.

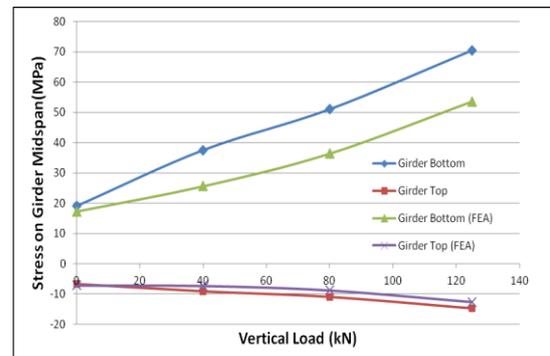
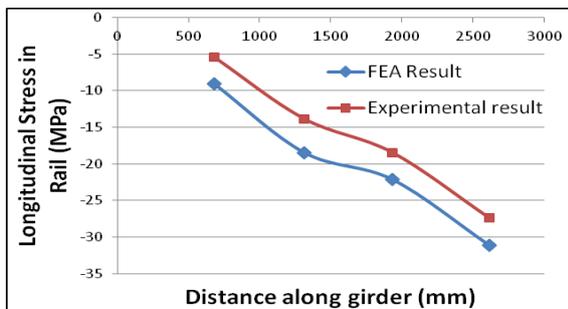
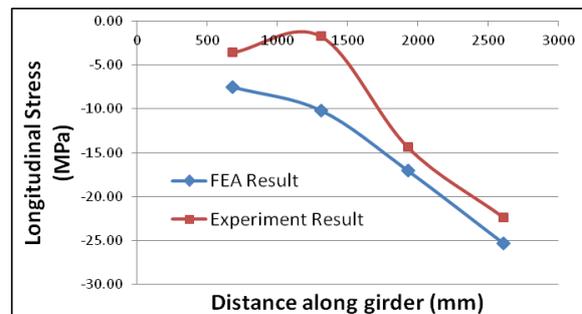


Figure 6. Comparison of stresses on girder.

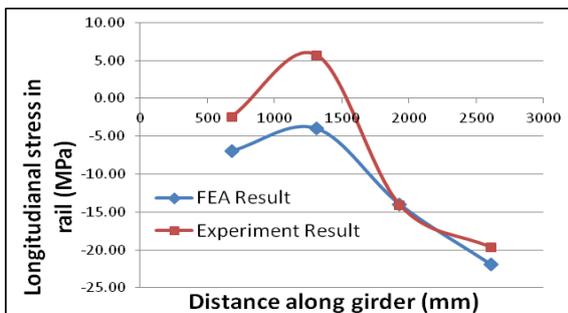
Girder stresses in the top and bottom fibers in the mid span were found growing at similar pattern for both test and FEA. And for both tension and compression the results for FEA were found lower than test results (figure 6). The behavior of longitudinal stress in rail was found to be of similar pattern under the vertical load application zone (figure 7). This was considered more as a local behavior not impacting much the global behavior or quality of the whole experiment. It was found after a parametric study that higher Poisson’s ratio of embedding material and shifting of the vertical load application point from the center can well describe the specific local variation of results.



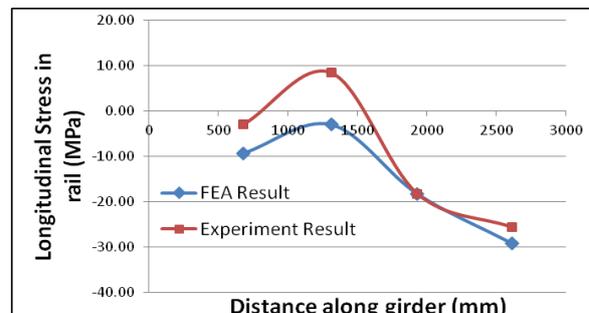
Combination 1: V=0 kN



Combination 2: V=40 kN



Combination 3: V=80 kN



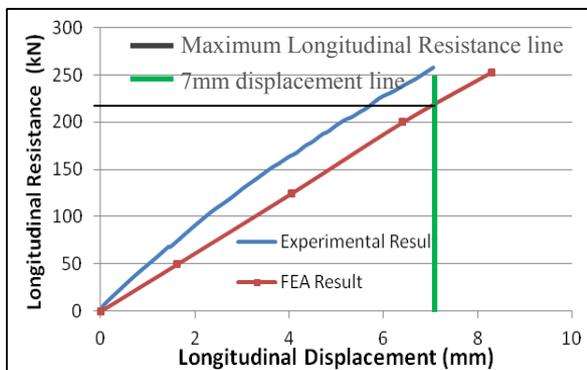
Combination 4: V=125 kN

Figure 7. Longitudinal Displacement of Rail with the increment of vertical load.

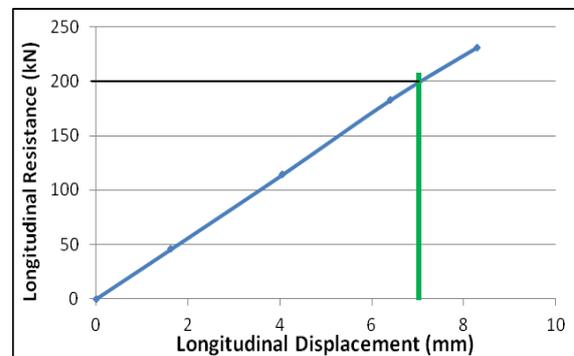
4. Evaluation of the longitudinal resistance of ERS track

4.1. Unloaded Track

The comparison of coupling relationship for 2190mm of embedding on a single rail was plotted first. Then converting the resistance for a 1 m track assembled with ERS system was suggested (figure 8). The result found in FEA is conservative in contrast to the experimental result for the unloaded track. Given the maximum allowable longitudinal displacement of 7mm in UIC-774-3R [7] for embedded rail, maximum longitudinal resistance have been found to be 200 kN for the unloaded track in FEA.



On single rail with 2190mm of ERS

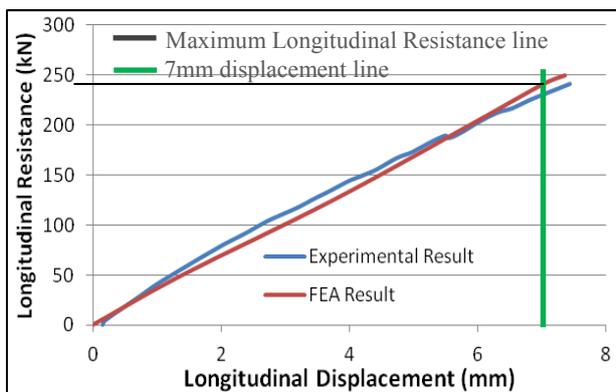


On 1m of ERS track

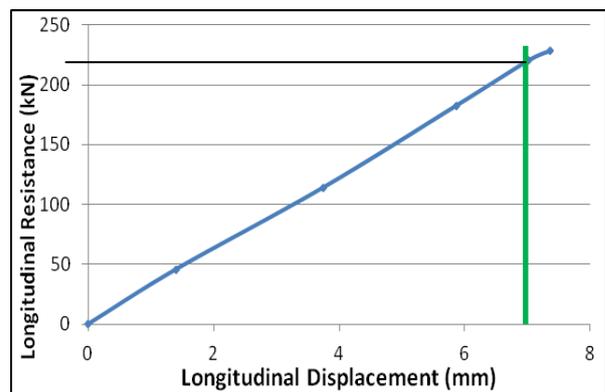
Figure 8. Longitudinal resistance of ERS track (unloaded condition).

4.2. Loaded Track

The result found in FEA is not conservative in contrast to the experimental result for the loaded track (figure 9) and matches the recommendation of UIC-774-3R [6], see table1.



On single rail with 2190mm of ERS



On 1m of ERS track

Figure 9. Longitudinal stress of ERS track (loaded condition).

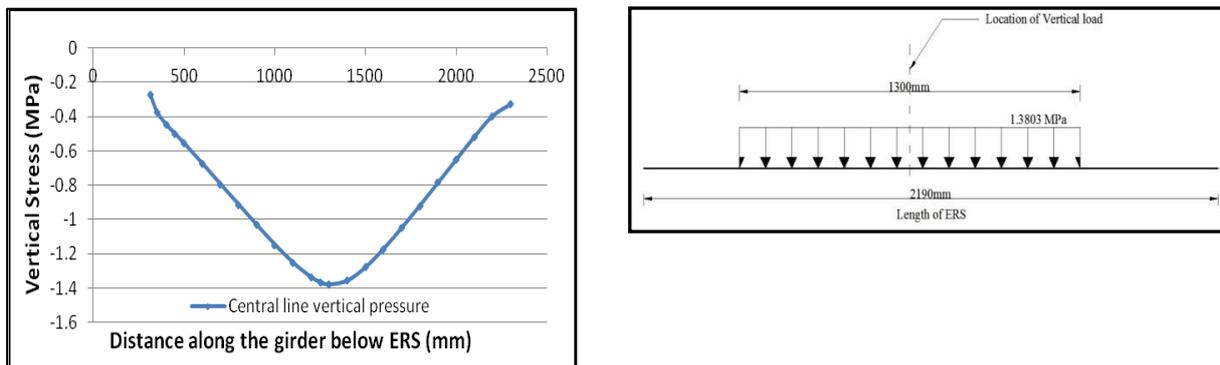
Table 1. Comparison of resistance k value of track (UIC 774-3 vs FEA & experimental result).

| | Unloaded track (kN/mm) | Loaded track(kN/mm) |
|--------------------------|------------------------|---------------------|
| UIC 774-3 Recommendation | 13 | 19 |
| FEA | 28.57 | 31.42 |
| Experiment Result | 33.01 | 30.66 |

5. Evaluation of design stress on bridge deck

5.1. Distribution of vertical pressure along the length of ERS

The pressure under the sleepers in the ballasted track is widely known. However, the same information for ERS (essential for the analysis of the supporting structure) is not given anywhere. To find out the vertical pressure distribution beneath the ERS, FEA was done for vertical load 125 kN only and pressure distribution was found along the longitudinal central line of the girder. From the idea of effective width of stress distribution, an attempt was made to find out the general shape of this distribution. The peak pressure found was recorded as 1.38 MPa. The area under the pressure curve was calculated as 1792.44 N/mm.

**Figure 10.** Vertical Stress distribution along the length of the girder (central line).

5.2. Transverse distribution of vertical pressure along length of ERS

The distribution of the vertical pressure in transverse direction was checked along the plane of peak stress as well as along two other intermediate planes. The vertical pressure in transverse direction can be also be idealized as distributed over an effective length. This information is important for the design of the bridge deck plate.

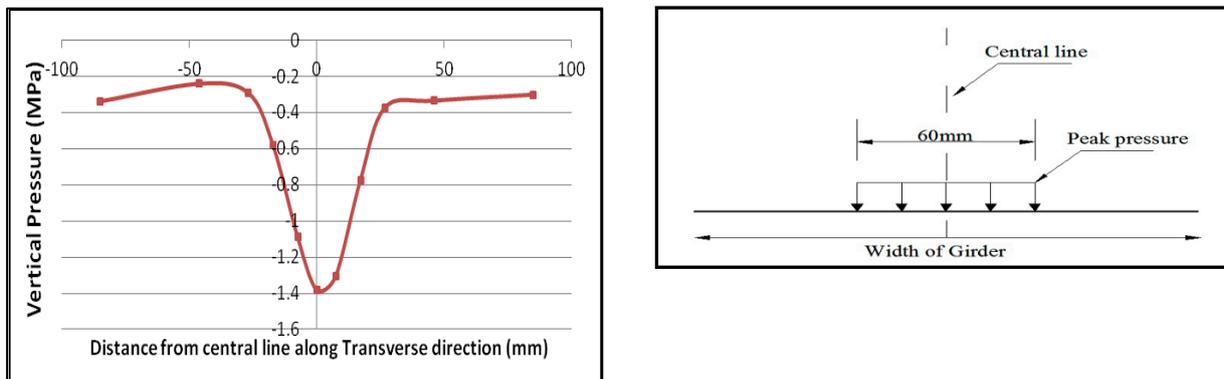


Figure 11. Vertical Stress distribution along transverse direction.

6. Effect of ERS on girder stress

The stiffness of the ERS system can have an impact on the stresses in the steel structure, due to its high stiffness. To analyze this effect, further analysis was performed with and without the ERS assembly for the loaded track condition. The reduction of girder stress was found for ERS application especially in the top fibers of the steel structure. On ERS track, the vertical point load is distributed over the length of the girder whereas for typical ballasted track the point load is applied on 3 adjacent points (to 3 adjacent sleepers) i.e., 50% load at the midpoint (directly under the wheel) and the rest equally divided to either side [7].

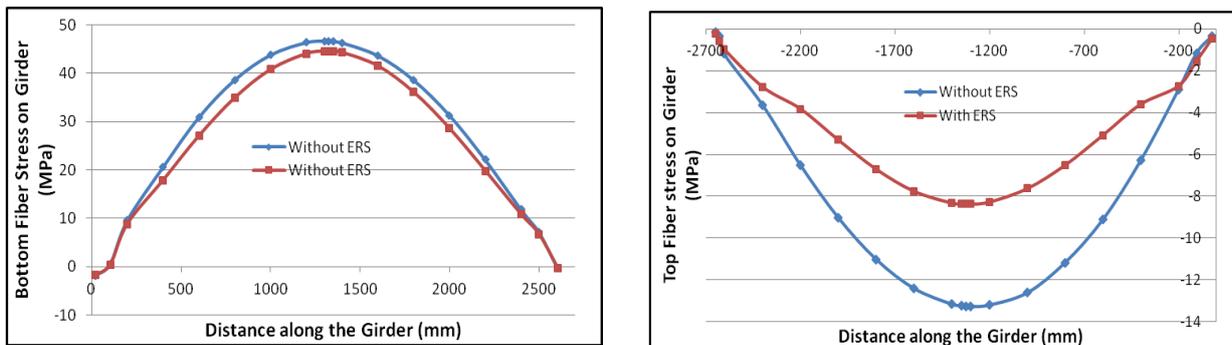


Figure 12. Reduction of girder stress due to ERS application.

7. Conclusion

The limitation to assigning bimodular material properties of embedding and elastomer material precisely (for highly irregular distribution of compression and tension elements) was verified in the analysis and little impact of the assumptions was identified.

It has been found that the resistance of the rail track is decreasing with the increment of vertical load while the same has been found increasing in FEA. This is a different and important conclusion, in contrast to the existing UIC recommendations. Also, the longitudinal resistance depends significantly on the speed of the loading. This is important for the proper analysis of the rail-bridge interaction actions like temperature and the brake/acceleration forces.

It is evident that gradual elastic softening of the material elasticity will lead to higher displacement under the same load and will influence the subsequent behavior of the other parts adjoin to that material. The last important conclusion is that the stiffness of the fastening is significantly higher than the value adopted in the UIC 774-3, which can lead to underestimation of the rail interaction stresses.

8. References

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