Effect of Temperature Gradient on Highspeed track with Track-Bridge Interaction

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Abstract

Long Welded Rail (LWR) is inherent part of modern day high-speed railway track. Considerable longitudinal rail forces and axial compressive stresses may develop in LWR track on long-span bridges due to temperature variations. It plays pivotal role for selection of economic structure. For high-speed tracks, however, solving these problems by installing rail expansion devices in the track is not an attractive solution as these devices may cause a local disturbance of the vertical track stiffness and track geometry. Two actions are considered by the bridge loading standards, the uniform variation in the rail and deck temperature and the temperature gradient in deck. Generally, the effect of temperature gradient has been disregarded in the interaction analysis. This paper mainly deals with the effect of temperature gradient on the track-bridge interaction with respect to the Longitudinal force and axial compressive stress, rail stresses Railway codes are silent about the topic so far and so the same should be considered in the track-bridge interaction analysis and should be included in bridge code or LWR manual.

1. Introduction:

1.1 The demands on existing railway bridges regarding loads, speeds and robustness will continue to increase in future In order to fulfil the present and future demand to enhance capacities for passenger and freight traffic on the existing railway network, it is of vital importance to upgrade the existing railway bridges and ensure that

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they will behave properly under increased static and dynamic loads and higher speeds.

1.2 Long welded rails (LWR) have become an inseparable component of modern railway track structures due to their easy maintainability, safety and riding comfort. They are essential for high speed train operations. Residual stresses of various levels as well as mechanical stresses are present in the rails used in the construction of LWR track structures. The task of determining the longitudinal stresses acting in a rail of LWR track is not a simple technical problem. In a welded track the sleepers prevent displacement of rails through the track fastening elements. After the rails are clamped, any temperature change can cause additional thermal stresses in the rails due to restricted movement.

1.3 Continuing LWR track on bridges offers some additional advantages, but at the same time poses new challenges as from the point of understanding of the complex phenomenon of track-bridge interaction. Track is laid either in ballasted bed or rail is interlinked with girder by means of hook bolts with special type of sleepers. These interlinking causes behavioral changes to both track and bridge components.

1.4 It is important that the stress-free or neutral temperature be in the vicinity of the average of expected highest and lowest rail temperatures. If the discrepancy from that average is large, rail fracture may occur at low temperatures and buckling at high temperatures.

1.5 The UIC Leaflet 774-3R and Euro-code in 1991-2:2003 include the basic methodology for analysis of track-bridge interaction and describe the actions to be considered and the limit values to be complied with as regards both the stresses and displacements of the rails. These standards have been derived based upon prior researches on the related phenomena. According to UIC code 774-3R (2001), different longitudinal loading cases are analysed separately considering a nonlinear stiffness law of the ballast and the various effects are superimposed.

1.6 A few new studies also came into the picture dealing with various aspects of track bridge interaction effects. Some further cases discussed the new evolution for high speed rail line bridge design criteria and procedures. He shows that stiff piers may take more loads due to continuity of the track passing over simply supported spans. Some cases discussed the relevance of soil structure interaction stiffness on the braking load and thermal actions. Some research had been carried out for the track structure interaction under seismic conditions. It is recommended avoiding large variations in stiffness of adjacent piers.

1.7 Stability problems also arise in tracks due to the interaction. Further study suggests that as expansion of the rails in CWR track is restricted, a substantial temperature increase will result in high compressive stresses which are dangerous for track buckling. Buckling may start from a small misalignment in the track and then the track may move up to 1 m in lateral direction over a length of 10 to 20 m. It is extremely unsafe for trains to pass through the deflected track configuration, since such a passage may result in a catastrophic derailment. From 1992 to 1997 the ERRI (the European Rail Research Institute) Committee D 202 carried out an extensive study on the behavior of continuous welded rail track. This work consisted of the development of various programs, particularly for longitudinal force distribution and buckling analysis, amongst others. In all the aforementioned works only uniform temperature variation is considered.

1.8 All loading standards recognize the presence of temperature gradient in bridges; however, the same is not incorporated in the track-bridge interaction analysis. Hence in the present work, temperature gradient studies are carried out on LWR passing over bridges.

2. Track-bridge interaction phenomenon

The interaction between the track and the bridge, i.e. the consequences of the behavior of one subsystem on the behavior of other, occurs because both are connected through the wheel-rail contact that the relative vertical movement between the two is not permitted. Providing the LWR track over a bridge involve the transfer of forces and displacements of the bridge deck due to thermal expansion/contraction of the rail, longitudinal forces of traction and braking forces of the trains and locomotives from rails to bridge deck and partly to rails themselves. When the LWR is fixed to the sleepers with the aid of elastic fasteners, and rest on a bridge deck with or without a ballast cushion, interaction between the track and the bridge deck takes place as the two are not free to move respect to the other.

3. Associated factors affecting track-bridge interaction

In case of LWR, interaction between the track and the bridge takes place, as the two are assumed to be in perfect contact. This results in setting up of additional horizontal forces in the rails as well as in the bridge girders, which in turn will affect the design of bearings and substructures as well. Such forces are produced due to the following reasons:

- Temperature variation
  - (a) Thermal expansion of deck in the case of CWR.
  - (b) Thermal expansion of the deck and rails in the presence of expansion devices.
- Horizontal braking and accelerating forces.
- End rotations of the deck due to vertical traffic loads.
- Deformation of the supporting concrete structure due to creep and shrinkage.

4. Continuing LWR over bridges

If the effect of thermal variation alone is considered to be the cause of interaction between the girder and the LWR, the girder has a tendency to expand or contract being in connection with bearings. On the other hand, the central portion of the LWR is fixed in position irrespective of the temperature changes that occur. This results in an inter-play of forces between the girder and the LWR at the breathing length zone. Then, the magnitude of the force is dependent upon the nature of fastenings being provided between the rails and sleepers.

5. No interaction between rail and bridge

In case of rail free fastenings, whatever, the movement of the bridge deck due to temperature variations between the bridge and the track or the longitudinal force transferred to the rails are dissipated either by free movement of the rails over the sleepers or by providing expansion joints in rails at each pier. Here however, continuing LWR for a longer length is restricted by code. It is on account of the gap created by possible fracture of rails, which creates two breathing lengths at the point of fracture. The gap at the location is to be limited to 50 mm on Indian railways. So, with rail free fastenings on the track over bridge, the span length of the LWR can only be increased by isolating the LWR on the approaches from the bridge and by providing SEJ at each pier and at approaches or by allowing interaction between the bridge and the track by keeping the bridge on the central portion of LWR, i.e. away from the breathing lengths.

6. Interaction between rail/track and bridge deck

This raises certain issues of additional forces in the rails due to the relative movement of the bridge deck and track due to temperature variations, additional forces in the LWR due to longitudinal forces and bending of the decks. If the bridge settles under a LWR track, both the bridge and track able to move. Displacement that acts one of them would induce forces in the other. Therefore interaction takes place between the track and the bridge. There could be two interactions

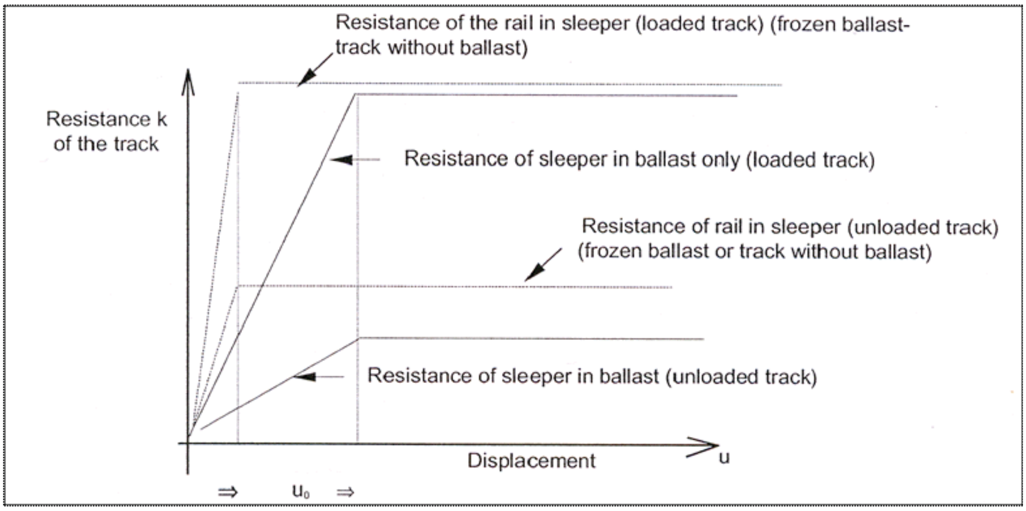

Figure 1 Bilinear relationship between resistance and displacement of track

1) LWR track induces additional force into the bearings of bridge deck.

2) Movement of deck induces an additional force on the LWR.

Following some factors can have an effect on the interaction. 1) Thermal expansion and contraction in track and/or bridge structure 2) tractive and braking force of a train 3) Translation of a structure 4) Lateral displacement of upper structure by wind load effect 5) temperature gradient in bridge girders. Especially the first two factors are dominant on the axial force of track. There are physical or geometrical parameters affecting the interaction 1) Support condition of decks. 2) Expansion length of deck 3) Stiffness of the girder 4) Cross-sectional area of rail 5) Flexural stiffness of pier 6) Soil spring co-efficient depending on the sort of soil in foundation. Here area of interest is to study effect of variation of temperature in structural components for track-bridge interaction.

1. Variations of temperature

The UIC code considers the following aspects of temperature variations:

- Changes in the uniform component of the temperature which causes a change in length in a free moving structure.
- Differences in temperature between the deck and the rails, in the case of track with expansion devices.

Generally, the effects of thermal gradients will be disregarded in the interaction analysis. Without expansion devices, the variation of temperature in the rail (TR) does not produce any relative displacements between the rails and the deck, thus the only variation of temperature to be considered is the change in temperature of the deck (TD). For the interaction analysis, the stresses in the rails due to the variation of temperature of the deck are considered as "additional stress", to be added to the stresses eventually due to the variation of temperature of the confined rail (R = R, TR . ER).

With expansion devices, the variation of temperature of the deck and the variation of temperature of the rails shall be taken into account. The difference in temperature between the deck and the track is assumed not to exceed ± 20°C.

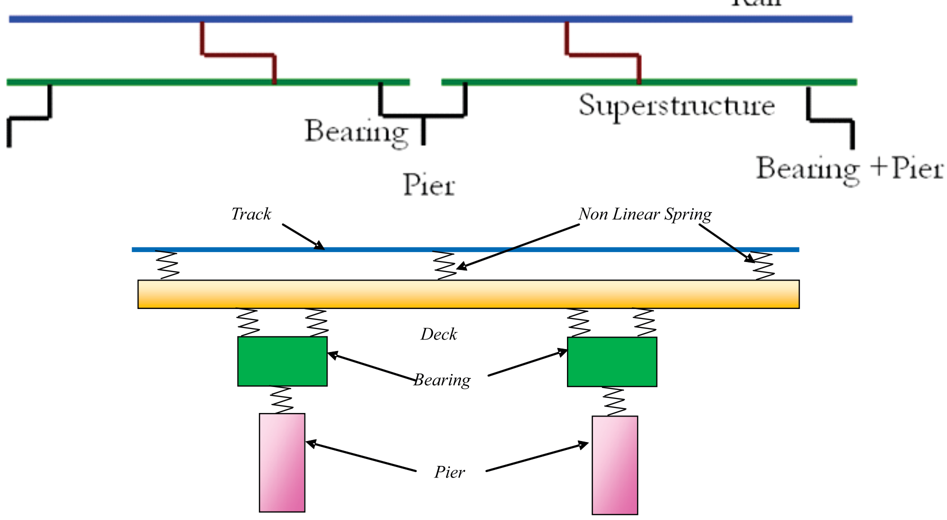

Figure 2 Model of track-bridge Interaction

8. Numerical modeling of track-bridge interaction

To carry out numerical studies on thermal gradient, a new numerical model has been created and the parametric investigations are carried out using this model. The model created for the track - bridge interaction has been shown below in Fig. 2.

The numerical models are developed to simulate the track–bridge interaction using the software STAADPRO which is based on stiffness approach. The bridge and rails are modeled using the beam elements and the connection between the two is modeled by springs (k_2). It is modeled as rigid element giving spring stiffness between deck slab and track. The bridge bearing stiffness is incorporated as (k_1 and k_3). On the other hand, pier stiffness (ksupport) is also incorporated in the model using springs. The model is developed by considering the track as a continuous beam supported on a number of discrete springs as shown in Fig. 2. The CWR track over a bridge means in fact that the CWR track is resting on a surface subjected to deformation and movements, hence causing displacement of the track. Details of various springs shown in Fig. 3 are defined as follows:

- k_1 and k_3 - spring stiffness to simulate the bridge bearing;
- k_2 - spring stiffness to simulate the stiffness of the medium between the track and the bridge. It accounts for the stiffness of sleepers and ballast, and is represented by a non-linear spring with stiffness dependent on the loading.
- $k_{support}$ - support stiffness of the deck. It includes the effect of following stiffness:
- Stiffness of the foundation;
- Stiffness of the piers;
- Stiffness due to displacement at the head of the support because of rotation of the foundation slab;
- Stiffness due to displacement of the support because of the horizontal movement of the foundation;
- Stiffness due to relative displacement between the upper and the lower parts of the bearings;

- Stiffness due to displacement at the head of the support due to elastic deformation;

  Since STAADPRO does not allow spring elements in the analytical model, the behavior of springs are simulated by providing axially loaded truss elements. The axial stiffness of a truss member is given by AE/L. The modulus of elasticity of truss is taken as 210 KN/m^2, Length is taken as 1.0m for track plus superstructure elements and 0.85m for elastomeric bearings. The sectional area of each element is therefore given by K*L/E.

9. Validation of the model

Furthermore, the UIC Leaflet 774-3R states that the numerical models used for the track-bridge interaction shall be validated before being actually used for performing numerical studies on them. The computing model presented in this paper and used for performing parametric investigations on thermal gradient has been validated with the help of manual calculations carried out using the charts provided in the UIC code of practice. During these studies the span of bridge is varied with two different combinations of support stiffness (K) and track-bridge connecting spring stiffness (k) i.e. K2 k20 and for K4 k20 (as defined in the UIC code) on models of deck lengths 16, 30, 60, 76 and 100 m with uniform variation of rail temperature 50°C and that of deck as 35°C, keeping all the other parameters like soil stiffness as constant. The horizontal support reaction for various deck-lengths has been plotted in Figure 3 and Figure 4.

From Figure 3 and Figure 4, it is clear that the model values and the UIC values are generally matching. The model values are slightly lower than the UIC values as their points are on the conservative side as expected. The theoretical values obtained by L. Fryba are higher than the present numerical values, as it is obvious. Hence the model has been validated with the UIC code of practice as well as with the literature and was used further to perform numerical studies on the effect of temperature gradient on the track-bridge interaction.

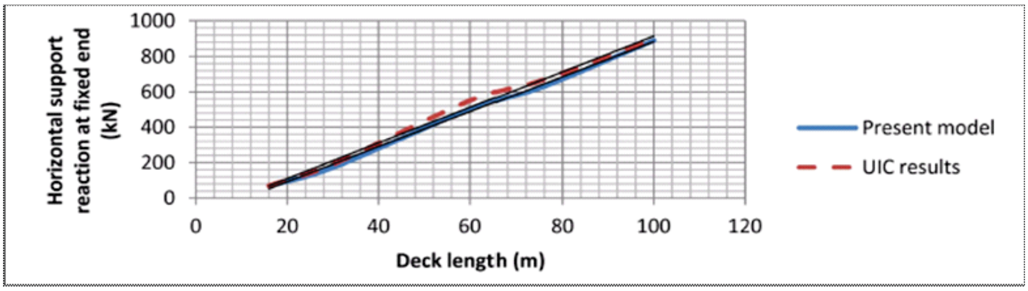

Figure 3 Variation of support reaction with deck length (K2 k20)

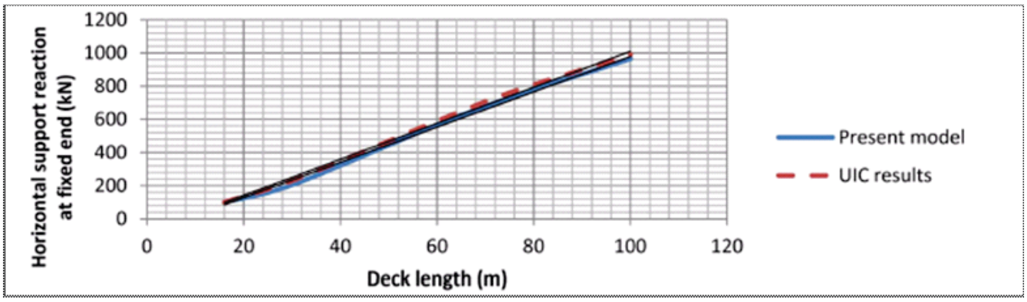

Figure 4 Variation of support reaction with deck length (K4 k20)

10. Numerical studies

Temperature gradient produces bending in the deck as well as in the rails as both are interlinked. In this paper, the numerical studies on the effect of temperature gradient are performed on continuous bridge model by changing the relative position of the rails and deck and also by changing the deck properties. The parametric studies are performed on the developed numerical models by allowing the temperature gradient to vary from -15°C to +15°C.

11. Effect of change in temperature gradient

The effect of variation in temperature gradient is investigated on a numerical model of 28 m deck span (continuous type) with pier column 9 m and by varying the temperature gradient (from top to bottom of the deck) at an interval of 5°C. T_{rail} = 50°C and T_{deck} = 35°C. Bearing size is taken as 560 mm x 560 mm x 96 mm. Diameter of pier column is 1.7 mtr. Grade of concrete is assumed as M40. This is real type model already used in Kolkata Metrorail Project. The results obtained are shown in Table 1.

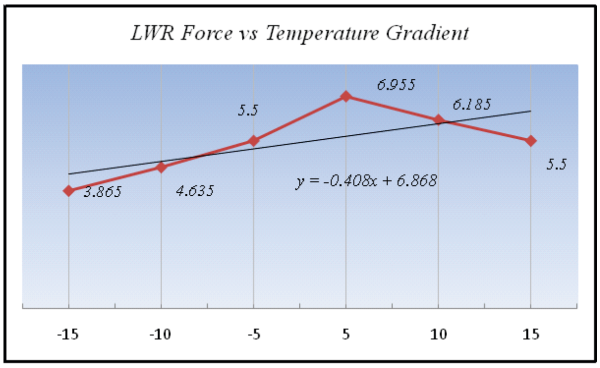

Figure 5 LWR Force with Temperature gradient variation

From Figure 5, it can be observed that the effect of temperature gradient is very prominent for LWR forces. When temperature gradient is less, LWR forces developed more. Table 1 and Table 2 show the results of the study.

Table 1:- Effect of temperature gradient (from 5°C to 15°C)

Temperature gradient (°C)	Design LWR force for each bearing (kN)	Percentage variation with respect to temperature gradient of +5°C
+5	6.955	-
+10	6.185	11.07
+15	5.500	12.45

Table 2:- Effect of temperature gradient (from -5°C to -15°C)

Temperature gradient (°C)	Horizontal support reaction (kN)	Percentage variation with respect to temperature gradient of -5°C
-5	5.500	-
-10	4.635	18.67
-15	3.865	19.92

An analysis of the results obtained in Tables 1 and 2 indicates that there is a remarkable effect of temperature gradient on lower temperature. The rate of decrease in LWR Force due to the decrease in temperature gradient is much higher than that of increase gradient. Longitudinal displacement of the support occurs under this effect between the top and bottom sides of the deck. At a particular value of temperature gradient, the LWR forces get reversed, i.e. from compression to tension and vice-versa. Bending is more predominant in the deck-type bridges than the continuous-type, which proves the significance of the present study.

12. Case Study-Honam high speed railway bridge

Track-bridge interaction analysis is carried out by Saman Engineering Corporation using LUSAS Bridge analysis software for preliminary design work on the Honam high speed railway on behalf of its client the Korea Rail Network Authority. As part of this work, a rail track/structure interaction analysis has been carried out for a 1.8km long viaduct bridge structure, with a 3-span centre section of steel box framed construction that carries the railway over the Mangyeong River near Iksan. Axial forces in the rails due to acceleration and braking forces caused by passing trains were evaluated and induced track displacements relative to the bridge deck were checked and found to be within the specified design limits.

Figure 6 Honam high speed railway bridge

12.1 Overview

The Honam high speed railway, when complete, will link South Korea's capital city, Seoul, with Mokpo, a southern port city in South Jeolla Province. It will be South Korea's second high speed railway. The first, the Seoul-Busan line, has been in operation since 2002. The Mangyeong River crossing, one of many structures on the new route, has a length of 1,875m and comprises a total of 50 spans of varying length and construction type. Three steel box framed spans of 60/75/60 metres over the river are flanked by steel girders of 50m span, and then by various numbers of 35m and 30m pre-stressed concrete box section spans for the remainder of the crossing's length.

12.2 Rail Track Analysis

To model the bridge Saman used the LUSAS Rail Track Analysis option. This allows rail track/bridge interaction analysis to be carried out to the International Union of Railways Code UIC 774-3. It builds models automatically from data defined in MS Excel spreadsheets, runs an analysis, and produces results in spreadsheet or LUSAS formats. To do this, the bridge is simplified and broken down into beam elements which represent the track and any supporting structure, with nonlinear springs being used to model the ballast and expansion joints. Bearings and foundations are modeled with simple springs. Temperature change in the rails and structure, and train loadings from acceleration and braking forces must also be defined. Changes in temperature and the passage of trains on different tracks accelerating or braking across the structure induce axial compressive forces in the rails and displacements in the rails relative to the bridge deck. These needed to be evaluated to ensure that they remain below specified design values for all in-service situations.

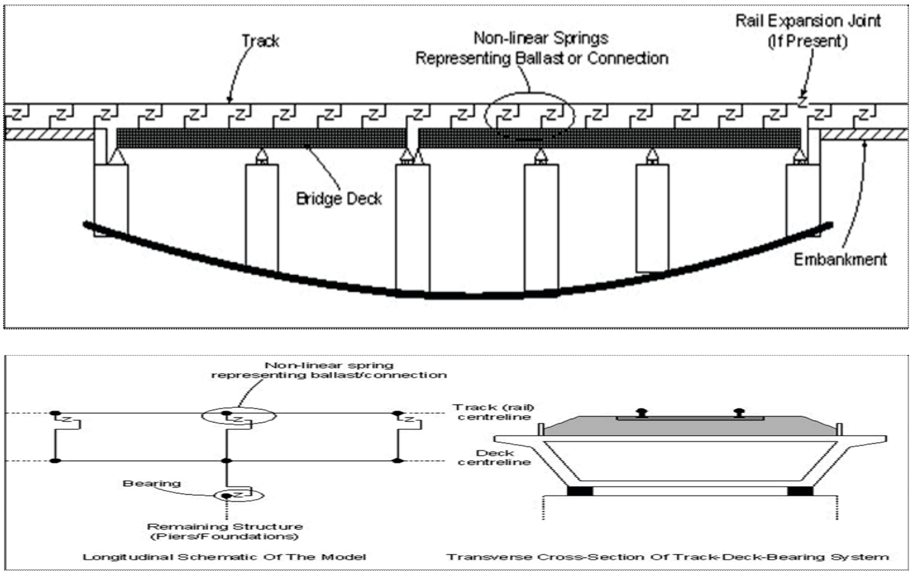

Figure 7 UIC 773-3 Structure System and Track/Deck Modeling

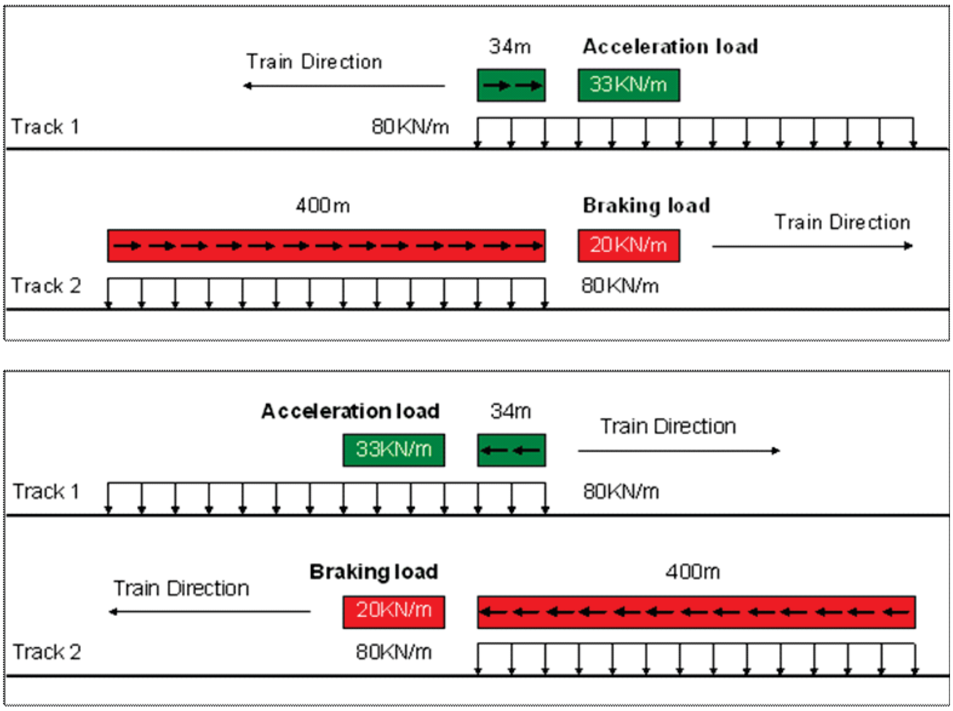

Figure 8 Train loading configuration straight and reverse directions

12.3 Modeling and Interpretation

For the Mangyeong River crossing, Saman created two LUSAS models to investigate the response of the structure. In one, automatically generated by the rail track analysis option, single beam elements modeled the deck and all spans of the structure. In the other, the initial rail track analysis-generated beam model was additionally edited to include the 3-span framed steel box members and included appropriate geometric and material properties for the added features. This somewhat unique method of increasing the accuracy of the UIC code analysis subsequently proved to be of real benefit when the results from both modeling methods were compared.

12.4 Results and analysis

From the results obtained from software analysis Saman created graphs for both the simple model (using beams only) and the full model (which additionally modeled the framed steel members). These showed the variation of axial compressive stress in the rails as a result of the temperature and acceleration / braking loading. From these graphs it was seen that full modeling of the steel framed members produced a reduced axial compressive stress in the track over that shown for the simple beam only model - reassuring Saman in its design.

Correct modeling of the nonlinear behavior of ballast, and of the interaction between the ballast and the rail track is not easy to do manually, so the LUSAS Rail Track analysis option, which handles this automatically, was very useful to us in this respect.

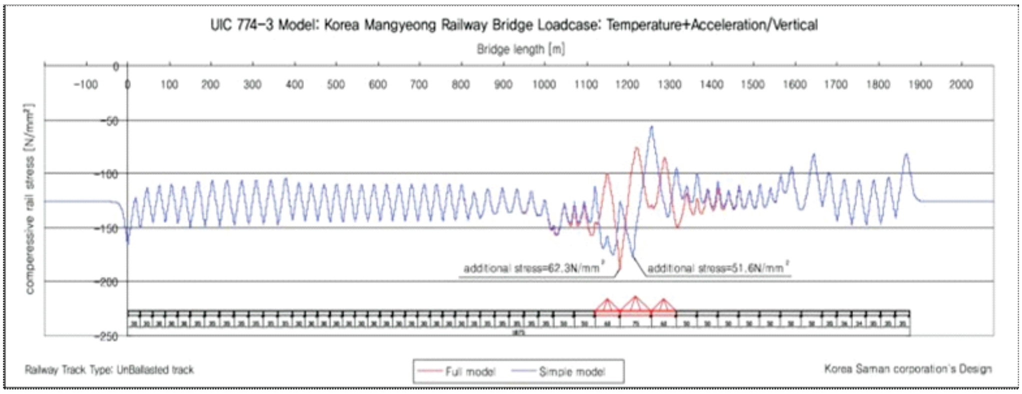

Figure 9 Compressive stresses in the rails from temperature and acceleration loading for both simple (beam only) and full (including framed steel members) models

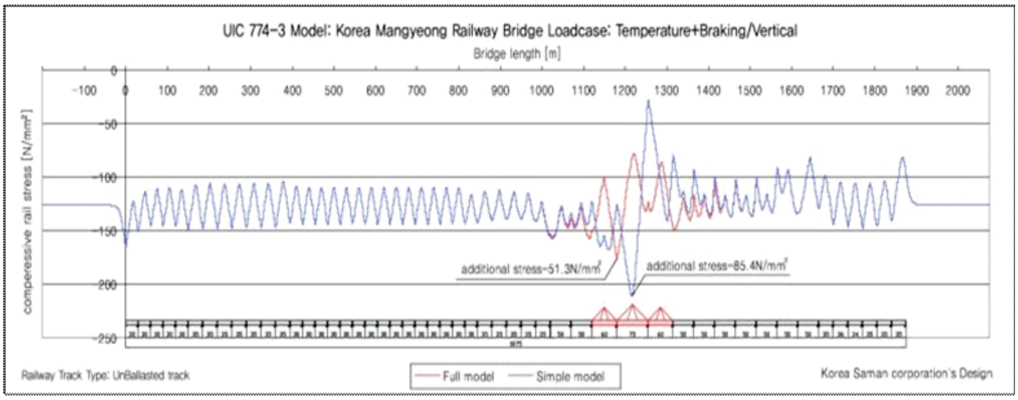

Figure 10 Compressive stresses in the rails from temperature and braking loading for both simple (beam only) and full (including framed steel members) models.

13. Conclusions

Long welded rail is inherent component of modern high speed railway track. The significance of track-bridge interaction studies has increased at present scenario. In the present study, the effect of temperature gradient on this phenomenon is studied by developing a numerical model by standard software package. The complex phenomenon is tried to understand by already performed numerical modeling and their results for Honam Railway Bridge From the parametric studies performed, the following conclusions can be drawn:

- The parametric study on temperature gradient shows that the influence of temperature gradient on the LWR Force is very significant and needs to be accounted for. The support reactions are influenced considerably
- The study shows the variation of axial compressive stress in the rails as a result of the temperature and acceleration / braking loading. It was seen that full modeling of the steel framed members produced a reduced axial compressive stress in the track It can save our material cost and will play a significant role for cost-benefit analysis.

DFCCIL and Metro Railway are already incorporated the track-bridge interaction in their design manual. But Railway codes are silent about the effect of temperature gradient in the design of bridges and so the same should be considered in the track-bridge interaction analysis and should be included in bridge code or LWR manual.

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