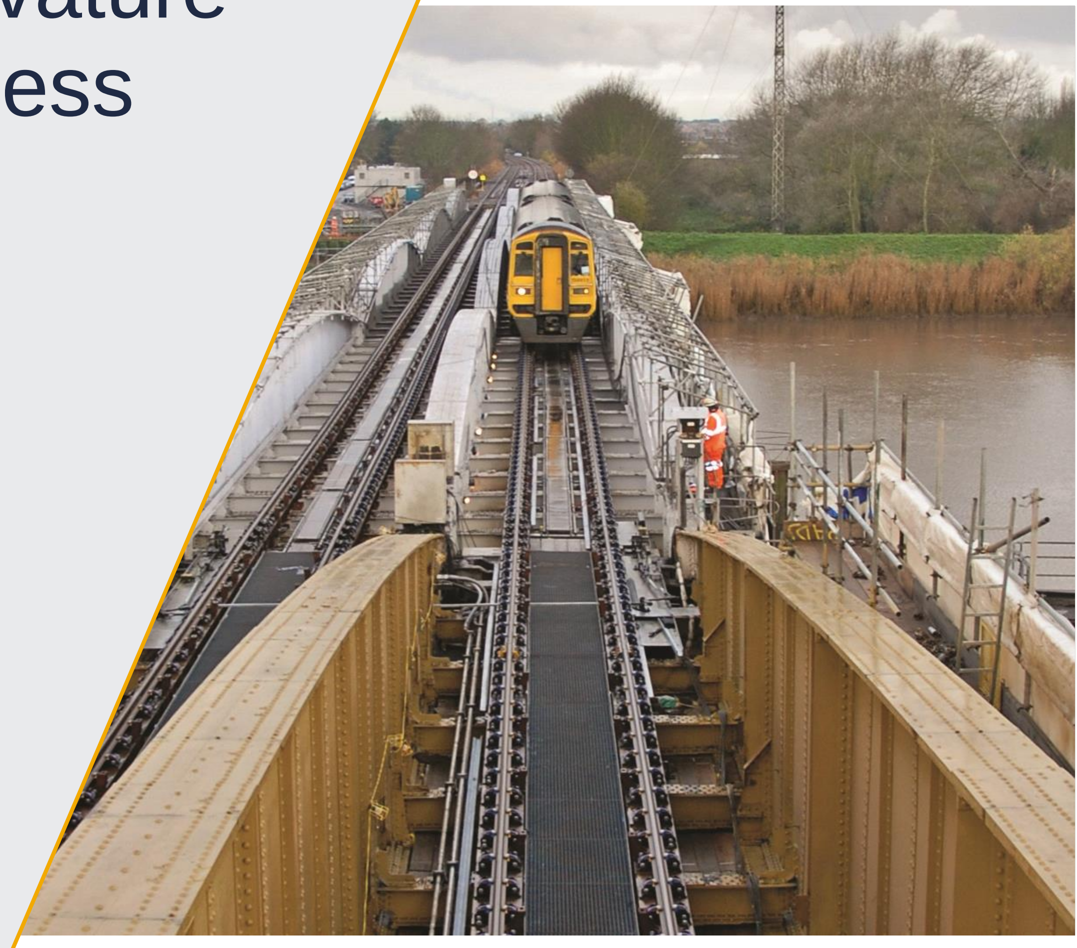
Bridge curvature and rail stress

TECHNICAL PAPER



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Partners in excellence

David Desmyter of Pandrol France reports on the findings of a recent analysis of rail stress on curved and straight bridges.

What factors increase rail stress on bridges? How can it be reduced?

When a track crosses over a bridge or viaduct, track/bridge interaction analysis is often needed to assess rail stress. In the case of straight bridges, the only issue is axial rail stress in the continuous welded rail (CWR) as a result of longitudinal displacement of the decks. However, when a bridge is curved, thermal variations of the CWR and the decks can cause radial, as well as longitudinal, displacements.

A recent Pandrol study used numerical simulations to analyse rail stress on curved and straight bridges. Bridges were modelled using finite element analysis (FEA) software.

1.1 The impact of lateral bridge support stiffness

The first simulations were based on a 40-metre bridge supporting one track (two rails), with CWR. The maximum axial and bending rail stress were calculated for different bridge radius values under bridge and rail temperature variations. The longitudinal bi-linear behaviour of the track was modelled with the track and spring elements between the rails and the bridge.

Table 1: Calculation parameters

Track section (mm^2)	15372
Ix rail (mm4); Torsion	35346200
Iy rail (mm4); Vertical bending	30550000
Iz rail (mm4); Lateral bending	5129000
Rail Young modulus (MPa)	210000
Rail thermal expansion coeff.	0.0000115
Rail foot width (mm)	150
Longitudinal fixed bearing stiffness (kN/m)	600000
Longitudinal free bearing stiffness (kN/m)	0
Lateral bearing stiffness K_{LB} (kN/m)	1E2 to 1E6
Bridge section (mm^2)	3.99 E5
Ix bridge (mm4); Torsion	1E8
Iy bridge (mm4); Vertical bending	2.53 E11
Iz bridge (mm4); Lateral bending	4.856 E12
Bridge Young modulus (MPa)	35000
Bridge thermal expansion coeff.	0.00001
Track resistance Fo (kN/m of track)	40
Uo (mm)	1
Rail support spacing (mm)	750
Lateral stiffness of the rail supports K_{LS} (MN/m)	100
Lateral & longitudinal pier stiffness (MN/m)	50

The results below show that when the lateral bridge support stiffness is high, the bridge curvature of a short deck has no significant effect on axial rail stress, whatever the variations in radius (R) and temperature (results would be the same for positive and negative temperature variations).

However, if the lateral bridge support stiffness is low, the bridge can move radially and drag the track with it. The axial tensile and compression rail stress is proportionate to the bridge radius and the lateral bridge support stiffness.

Table 2: Minimum and maximum axial rail stress (MPa)

K_{LB} (kN/m)	1 000 000		10 000		100	
ΔT bridge/ ΔT rail	**-35°C/0°C**	**-35°C/-50°C**	**-35°C/0°C**	**-35°C/-50°C**	**-35°C/0°C**	**-35°C/-50°C**
Alignment	-30.8 / +38.0	+89.9 / +158.7	-30.8 / +38.0	+89.9 / +158.7	-30.8 / +38.0	+89.9 / +158.7
R = 1500 m	-30.4 / +37.4	+90.3 / +158.1	-30.5 / +37.3	+90.2 / +157.9	-30.5 / +37.3	+90.0 / +157.6
R = 1250 m	-30.4 / +37.4	+90.3 / +158.1	-30.5 / +37.3	+90.1 / +157.8	-30.5 / +37.2	+89.9 / +157.3
R = 1000 m	-30.4 / +37.4	+90.3 / +158.1	-30.5 / +37.3	+90.0 / +157.6	-30.6 / +37.1	+89.6 / +156.9
R = 750 m	-30.4 / +37.4	+90.2 / +158.0	-30.5 / +37.2	+89.8 / +157.2	-30.7 / +36.9	+89.1 / +155.9
R = 500 m	-30.4 / +37.4	+90.2 / +157.9	-30.7 / +36.9	+89.1 / +156.0	-31.0 / +36.3	+87.3 / +153.2
R = 250 m	-30.5 / +37.3	+89.8 / +157.1	-31.5 / +35.5	+85.7 / +149.5	-32.7 / +33.2	+80.3 / +138.7
R = 100 m	-30.9 / +36.4	+86.9 / +151.6	-35.5 / +27.9	+68.9 / +120.7	-39.2 / +20.3	+57.8 / +120.8

It is important to note that when the bridge moves radially in under temperature variations, the axial tensile rail stress decreases.

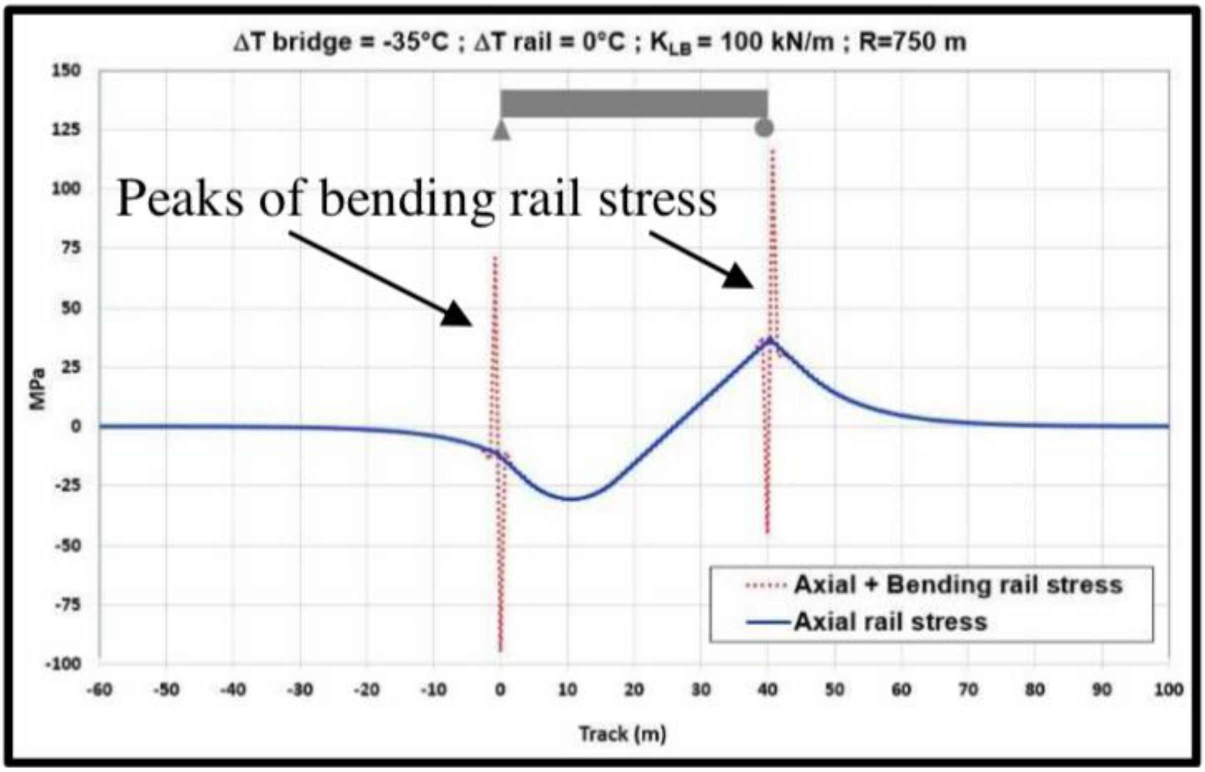
The lateral bridge support stiffness was also shown to have an influence on the bending rail stress at the abutments. If the lateral bridge support stiffness is low, the bridge can move in and out under temperature variations and there is relative lateral displacement between the bridge and the abutment.

Table 3: Maximum combined axial and lateral bending rail stress at the rail foot (MPa)

K_{LB} (kN/m)	1 000 000		10 000		100	
ΔT bridge/ ΔT	**-35°C/0°C**	**-35°C/-50°C**	**-35°C/0°C**	**-35°C/-50°C**	**-35°C/0°C**	**-35°C/-50°C**
Alignment	+38.0	+158.7	+38.0	+158.7	+38.0	+158.7
R = 1500 m	+38.0	+159.0	+52.8	+226.7	+76.9	+157.6
R = 1250 m	+37.6	+159.1	+56.4	+241.6	+85.5	+364.9
R = 1000 m	+37.6	+159.2	+61.1	+261.8	+97.4	+414.1
R = 750 m	+37.9	+160.4	+69.2	+295.8	+116.8	+497.3
R = 500 m	+38.0	+161.2	+86.5	+368.1	+156.5	+663.6
R = 250 m	+38.4	+164.3	+131.6	+557.2	+254.1	+1064.5
R = 100 m	+39.0	+165.4	+215.1	+865.2	+356.1	+1397.8

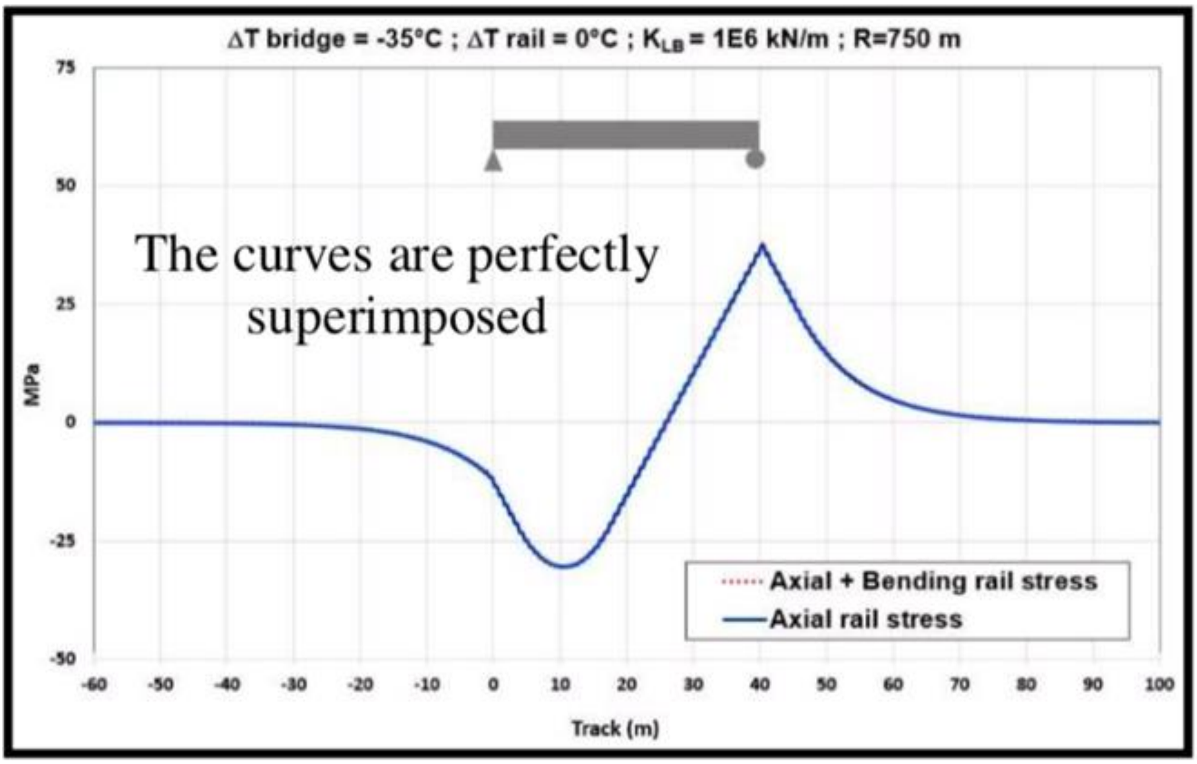
This relative lateral displacement causes peaks of bending rail stress at the structural joint between the deck extremity and the abutments, as shown below. The lower the bridge radius and the lateral bridge support stiffness, the higher the bending rail stress is at the abutment.

Figure 1: Rail stress for a bridge with low lateral bearing stiffness



Conversely, when the lateral bridge support stiffness is high, the bridge is restrained and can't move radially. As a result, there is no relative lateral displacement between the bridge and the abutment, and no peak of bending rail stress. As a result, the combined axial and bending rail stress is very close to the axial rail stress, as shown below.

Figure 2: Rail stress for a bridge with high lateral bearing stiffness



1.2 The impact of deck length

Additional simulations were done to evaluate the effect of deck length on rail stress.

A bridge with a single 234m long deck supported by five piers and two abutments was modelled, straight and curved, with a radius of 150m and 300m. The bridge and track parameters remained the same as for the previous analysis.

Our study showed that the axial tensile rail stress is lower on the sharp curved bridge. The lateral stiffness of the piers means that the bridge moves radially as a result of higher radial forces than on a bridge with a bigger radius.

Figure 3: Axial rail stress on the 234m long bridge

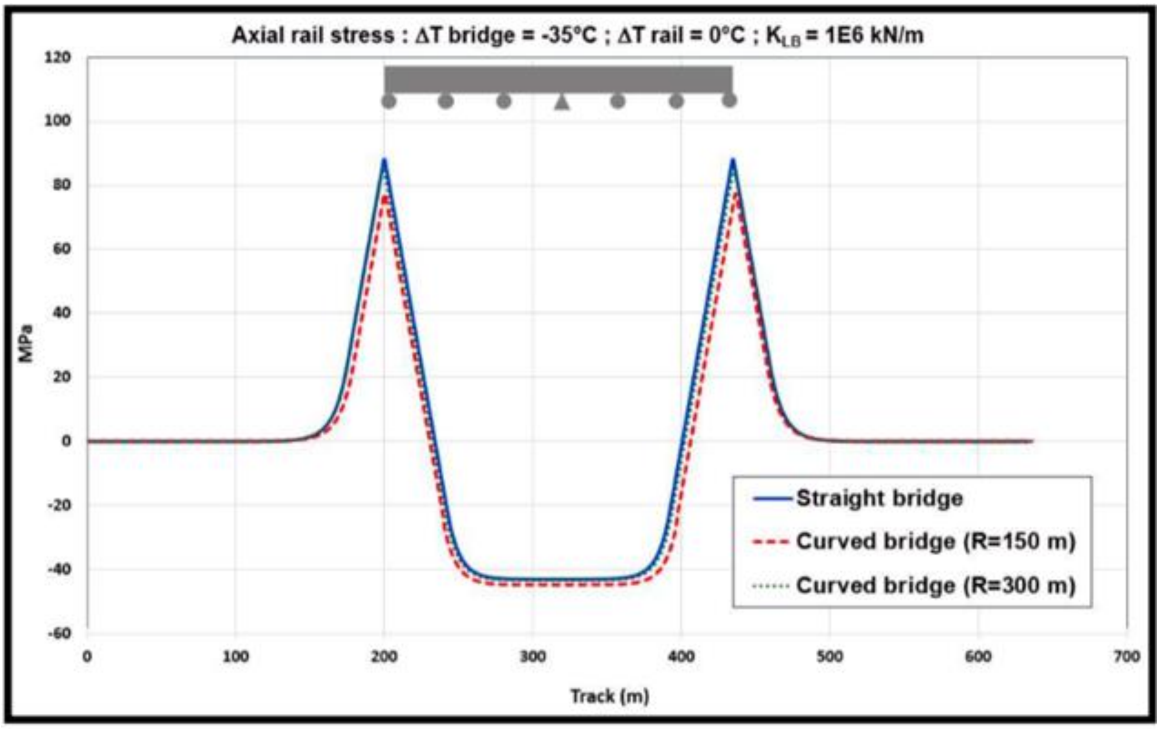


Table 4:

K_{LB} = 1E6	Axial rail stress (MPa)	
(kN/m)	Min	Max
Straight	-43.0	+87.9
R = 300 m	-43.5	+85.3
R = 150 m	-45.0	+77.2

The behaviour of long and short deck bridges is the same in terms of axial and bending rail stress under bridge and rail temperature variations. While the radial bridge displacement is contained, the axial rail stress is not affected.

1.3 Reducing bending rail stress peaks

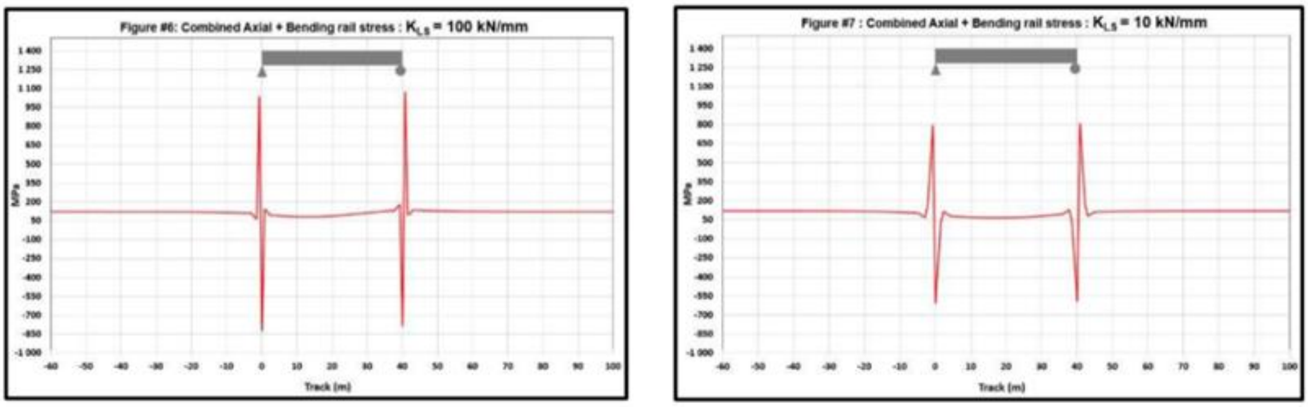
We also evaluated possible ways to reduce bending rail stress peaks at structural joints, in case of a sudden change in the lateral stiffness of the bridge support.

One option would be to reduce the lateral stiffness of the rail supports. The calculations below were done on the 40m single span bridge, with a radius of 250m and a lateral bridge support stiffness of 100 kN/m. When the lateral stiffness of the rail supports is reduced from 100 kN/mm to 10 kN/mm, the bending rail stress at the abutment is reduced by 25%.

Table 5:

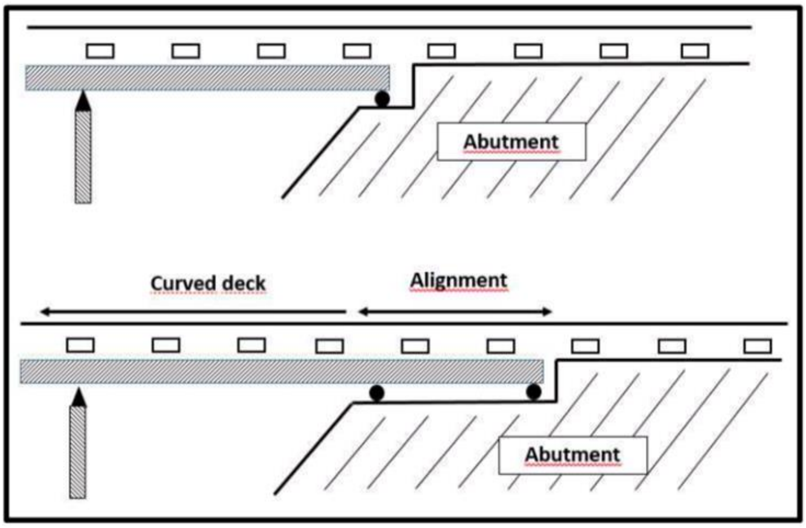
ΔT bridge = -35°C ; ΔT rail = -50°C R = 250 m ; K_{LB} = 100 kN/m	Axial rail stress (MPa)	Axial + bending rail stress at the rail foot (MPa)		
K_{Ls} (kN/mm)	**Min**	**Max**	**Mix**	**Max**
100	+80.3	+138.7	-819.2.0	+1064.5
10	+67.1	+120.7	-597.1 (-27.1%)	+802.6 (-24.6%)

Figure 4:



Another option would be to change the bridge design to extend the deck longitudinally onto the abutment, as shown below.

Figure 5: **Bridge design proposal to reduce bending rail stress at abutments**



Calculations were done with the 40m single span deck with a radius of 250m. The deck was extended onto the abutment by 10m and 20m on the free bearing side and bridge and rail temperature variations were considered.

As shown below, the bending rail stress decreases with the increasing length of the straight extended section, but the axial rail stress increases slightly. To achieve maximum reduction of the bending rail stress and minimum increase of the axial rail stress, an optimised deck extension length would have to be found.

Figure 6: Bending and axial rail stress with deck extension

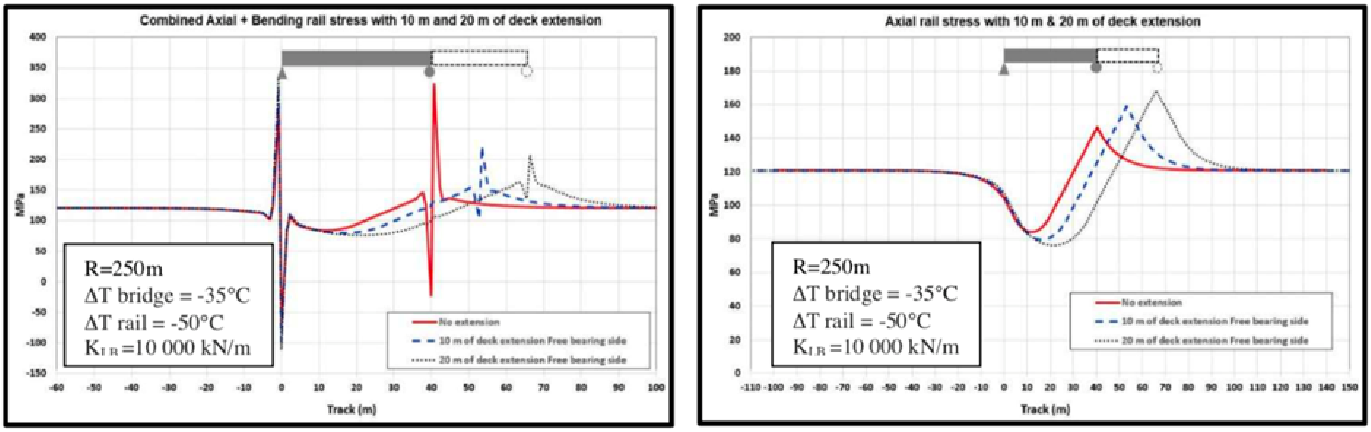


Table 6: Maximum rail stress with deck extension

ΔT bridge = -35°C ; ΔT rail = -50°C R = 250 m ; K_{LB} = 100 000 kN/m	Max. Axial tensile rail stress (MPa)	Max. Combined Axial + bending rail stress (MPa)
No extension	+146.4	+320.6
10 m extension	+159.0	+221.5
20 m extension	+168.3	+206.4

1.4 What do the findings show?

This study demonstrated that axial rail stress is not significantly affected by a bridge's curvature if the radial displacement is limited at bridge supports. If this is the case, the track/bridge interaction analysis for a curved bridge can be done as a straight bridge.

The main reason for doing track/bridge interaction simulations is to calculate whether it is necessary to use rail expansion devices or restraint clips to tackle longitudinal rail stress and longitudinal displacements. Whether the track is on a straight bridge or a curved bridge, this problem remains the same. The longitudinal rail stress must stay under control.

If the lateral bridge support stiffness is low, additional lateral bending rail stress can occur at the bridge abutments or between two consecutive decks. To reduce the effect of this, modifications in bridge and track design can be considered.

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