Interaction between Ballastless Track and Bridge structures on High Speed Lines

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The old way:
“Rigid” bridge structure with short spans;
“Flexible” track structure with jointed rails, wooden sleepers and ballast.
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The new way:
“Flexible” bridge structure with long spans;
“Rigid” track structure with continuous rails, on concrete slabs.
Back to basics........

Bridge decks are different. They are longer on hot days than they are on cold days. (They also bend when a train is on them and they shift when the train driver applies the brakes....)

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In cold weather the bridge deck contracts – the longer the bridge, the more the free end of the deck moves.

If there is enough “give” between the rail and the bridge deck, there is no displacement of the rail, and no extra stress in the rail.

(Note that the relative displacement between the rail and the bridge deck is equal to the displacement of the bridge deck).
In real life, there is never enough “give” and so the bridge deck drags the rail with it, but that generates an additional stress in the rail.
The less flexible the connection between the rail and the bridge deck, the more severe the effect – hence the special significance with ballastless tracks.
What can the *track* engineer do about it?

OPTION 1. Put in a rail expansion device wherever there is a discontinuity in the structure.

Expensive to install
Expensive to maintain
Possible source of noise.......  
**To be avoided on high speed ballastless tracks!**
What can the track engineer do about it?

OPTION 2. Accept locally increased rail stresses.

..... but there must be some limit to the stress which can be accepted.

Either...

put a limit on the length of bridge over which CWR can be laid without using a rail expansion device

...or ...

put a limit on the extra stress which can be accepted in the rail (over and above the stress which would be in the rail with the same track form, the same traffic, the same weather, etc... but not on the bridge).
Acceptable “additional rail stress”

Calculation method and limiting stress values published in UIC774-3R for
• 60E1 rail grade R260 or better
• Concrete sleepers at 650mm spacing in good ballast
• Straight track or very large radius curves

Maximum additional stress in tension = 92MPa (to avoid rail fatigue failures)
Maximum additional stress in compression = 72MPa (to avoid track buckling)

This data has also been copied into the Eurocode for bridge design
(EN1991-2:2003 §6.5.4)

Note: UIC Leaflets are advisory, but
(for the structure designer), compliance with the Eurocode is mandatory.
CEN Task Group on Track-Bridge Interaction

Work is now in progress to produce a more detailed technical report to supersede UIC774-3R (which was last revised in 2001) and to improve the relevant section of the Eurocode.

A CEN Technical Report is expected to be published in 2017 dealing with ..

• Background technical information
• Ballastless tracks
• Curves, S&C, lighter rail sections
• Calculation methods for track and bridge engineers
• Case studies and worked examples
• Recommendations for Standards development
• Recommendations for future R&D
Introduction

A typical railway structure carries ballasted track with simply-supported decks 20 to 40m long which are fixed at one end and free at the other.

Expansion of each deck unit is unlikely to exceed a few mm therefore there is no effect on rail stress during expansion and contraction of the structure.

The advent of high speed trains has resulted in longer and more complex railway structures due to the more severe alignment constraints.
The use of Long Welded and Continuously Welded Rails (CWR) required the introduction of Rail Expansion Joints (REJ) at the ends of long structures in order to avoid a significant increase in rail stress resulting from the movement of the deck structure during diurnal and annual temperature changes.

The rail stress will be either compressive or tensile depending on the change in the temperature and whether the rail is located behind or in front of the structural expansion joint.

Compressive stress in the rail is a particular concern with ballasted track due to the risk of track buckling but this phenomenon is unknown with ballastless track.

Rail Expansion Joints must be avoided due to their high capital and maintenance costs and the need to avoid any discontinuity in the rails particularly with high speed train operations.
Additional forces act on the rails from above (in addition to those caused by thermal movements of the structure below). They are more significant with high speed trains:

- **Forces from above**
  - Train acceleration and braking forces along the rails
  - Vertical (dynamic) loading
  - Nosing forces; lateral wind loading

- **Forces from below**
  - Bending and torsion effects of long viaduct decks
  - Thermal movements of the supporting structure

Distribution of forces along the rails into (and from) the deck is a function of the toe load (clamping force) of the rail fastenings and the length of the deck. The use of ZLR fastenings can reduce the friction (and hence the load transfer) between them and the rail at peak stress locations.
Ballastless Track

- The ‘late arrival’ of HS2 puts it at a major advantage over upgraded railways in the UK, particularly in terms of track design. With a ‘green field’ site, the opportunity to incorporate **ballastless track and components** on continuous structures that have already been proven in extensive service under high speed rail conditions overseas, must be taken, preferably for the whole of HS2!

- A trackform basically free from maintenance for its design life has immeasurable environmental benefits, the economic implications of which should be incorporated into any economic evaluation.

- The avoidance of ‘ballast flight’ occurring in train speeds exceeding ~250km/h also has major track and rolling stock maintenance and operational advantages.

- Environmental benefits for ballastless track also occur during construction wrt to reduced noise and dust and the avoidance of the ‘long haul’ transport of ballast.
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Ballastless Track: Advantages

• The KEY advantage of Ballastless Track is that it is a Linear Structure comprising engineering materials (basically reinforced concrete, steel rails and fastening components and rubber/neoprene resilient rail supports) which can be subjected to detailed structural analysis.

• Ballast is not an engineering material; it is subject to variable performance depending on its physical condition, the presence of moisture, fines or organic matter and its status in the tamping cycle. Factors of Safety which may exist in the present EN standards to allow for these variations in the track supporting material are not required to the same extent for ballastless track.

• The first, and most obvious change, which has already been applied by myself (for the ballastless track design on structures in Bangkok) was the revision of the UIC Code 774-3 (EN1991-2) for permissible rail compressive stress to be up-graded from 72MPa to 92MPa as track buckling cannot occur on ballastless track.
Major Supporting Structure

- Another factor which works to the advantage of the ballastless track designer is a phenomenon rarely investigated until recently which has resulted from the increased requirement for long structures for high speed and other new railway lines. This involves the coefficient of expansion for large concrete structures. It had been assumed that the expansion of a viaduct deck is basically a function of the coefficient of expansion of the structural concrete $[9.8 \times 10^{-6} \text{m/m K}] \times$ the ‘free’ length of the deck (ie beyond the last fixed bearing or encastre pier).

- However, observations and recent measurements in the field show that the actual expansion is considerably less. This is probably due to the length of time required for a major structure to reach the increased air temperature during the day. Further, only parts of the deck structure can be exposed to the heat of the sun at any one time. (Figure 2)

- Reduced expansion of the deck will result in lower stress transmission to the rails.
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Figure 2: Cross-Section of Typical Railway Viaduct

Area: 3.75 m²
Moments of inertia: X: 2.17 m⁴
Y: 17.95 m⁴
Z: 4.54 m⁴
New Metro Lines in Bangkok

• My interest in the subject of continuous decks for railway viaducts was stimulated after meeting a Norwegian structural engineer in Bangkok in 2010 who was very keen to develop a series of continuous viaduct beams for the new metro lines then being planned throughout the city.

• I had previously read an article in the annual Pandrol magazine which featured the use of ZLR fastenings to avoid REJs on a long span steel lattice girder bridge in the USA and was already considering how to incorporate this ingenious concept in long span pre-stressed concrete railway structures in the Far East.

• We persevered, and with detailed analysis of the rail stresses provided by Pandrol’s dedicated software were able to confirm that long structures were feasible by the application of ZLR fastenings at specific high stress areas in the rails. An example of a long structure is shown later.
‘Decoupling’ of the Track and Structure

• The KEY to this problem is understanding that the track and the supporting structure must be ‘decoupled’ from each other, at least over the ‘high rail stress’ areas along the deck, to enable the expansion and contraction of the deck to proceed without inducing additional forces into the rails. The length of the decoupling is limited to avoid major gaps occurring in the event of a rail break. [However, the vertical and lateral loading conditions in Slide 14 still apply.]

• The application of ZERO LOAD RAIL (ZLR) fastenings enables decoupling to be achieved without affecting the integrity of the rail support. (ZLR fastenings only allow horizontal displacement of the structure; no torsion or lateral displacement of the rail is possible).

• An example of the recent analysis of a balanced cantilever structure on the new Purple metro line in Bangkok is now given.
Modelling Longitudinal Track Forces

- The main longitudinal forces applied to the rails are due to:
  - Expansion and contraction of the concrete deck
  - Traction and braking from the trains (can occur simultaneously on adjacent tracks)

- These values may be obtained from the relevant EN Design Standards specifically the UIC leaflet 774-3 and EN1991-2.

- The software analysis also includes for:
  - Bending and torsion of the deck
  - (Side) Wind loading (on the trains)
  - Nosing forces on the track
  - Creep and shrinkage effects of the concrete deck
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Figure 3: The proposed balanced cantilever structure under analysis
Case Study: Data

Please note! The data provided in the case study are for the purposes of this presentation only and must not be divulged to outside parties. Copyright is held by the structural consultants.

Data entered into the Pandrol C_VOIE programme:

- **Structural properties of the Viaduct Structure**
  - Box girder cross-section (min) = 5.1m² (max) = 8.1m²
  - Box Girder Young’s Modulus = 33.5GPa
  - Columns: Longitudinal Stiffness = 16.7MN/m
  - Integrated Bearing Stiffness = 1013kN/mm
  - Free Bearing Stiffness = 0kN/mm
  - Neutral Temperature = 28°C
  - Thermal beam ends: Contraction (18°C) = 22mm. Expansion (12°C) = 15mm

- **Structural properties of the Trackwork**
  - The Trackwork comprises 4 x 60E1 rails continuously welded:
    - Cross-section = 7687 x 4 = 30 748mm²
    - Young’s Modulus = 210GPa
    - Rail fastening PANDROL e2007 VIPA DRS. Spacing = 650mm
    - Max longitudinal restraint (e2007) = 13kN/fastening
    - Max longitudinal displacement of rail = 1mm
Case Study: Results

- Based on the output data from the Pandrol C_VOIE programme (Figure 4) the allowable rail stress is only exceeded when the rail is subject to the combination of ‘structural contraction’ and ‘train traction’ load case.

- There is a peak rail stress of 106MPa ie > 92MPa over the LHS column; due to symmetry, there is a similar peak stress over the RHS column. Therefore ZLR fastenings must be provided over the length of rail obtained from the area of the graph above the 92MPa limit.
Figure 4: Combined Loads without ZLR Fasteners
Case Study: Implementation

- The installation of Pandrol VIPA DRS baseplate assemblies with ZLR modifications were recommended on the rails located within a 16m zone either side of both the column centres in order to reduce the maximum rail stress from 106MPa to 88MPa (Figure 5) with e2007 clips.
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Figure 5: Combined Loads with ZLR Fastenings
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Case Study: Comparative Stresses
Case Study: ZLR Fastenings

• ZLR versions of the Pandrol e2000 series fastenings are achieved by placing the appropriate size of shim between the clip and the baseplate which reduces the clip loading to zero but still prevents rail rotation.

• The location of this shim can be seen in Figure 6; the shim is located adjacent to the rail foot.
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Figure 6: Pandrol VIPA DRS with ZLR Fastening
Continuous Structures

- Some examples of continuous railway structures installed on the Blue and Purple Lines are shown in the next few slides:
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Balanced cantilever deck bridge over Chao Phraya River, Bangkok
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Bangkok Metro Blue Line Structures (Depot Connection)
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Bangkok Metro Blue Line structures
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Bangkok Metro Purple Line Structures
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Bangkok Metro Purple Line Structures
Interaction between ballastless track & bridge structures on high speed lines

Pandrol base plates with e-clips on p.c. plinth track, Purple Line Bangkok
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E-clips on Purple Line viaduct
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Colourful Clips! High toe load (grey); Medium toe load (green) and ZLR clips (yellow) on the MTR South Island Line in Hong Kong
Thank you for your
ATTENTION!
Danke für Ihre
AUFMERKSAMKEIT!!