Railway Bridge to EUROCODE

Presenter:
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- Q&A

Sutong Bridge
Relevant Documentation

- **EN 1991-2** Actions on structures – Traffic loads on bridges:
  - Section 6 Rail traffic actions and other actions specifically for railway bridges;
  - Annex C Dynamic factors $1+\varphi$ for real trains;
  - Annex D Basis for the fatigue assessment of railway structures;
  - Annex E Limits of validity of load model HSLM and the selection of the critical universal train from HSLM-A;
  - Annex F Criteria to be satisfied if a dynamic analysis is not required;
  - Annex G Method for determining the combined response of a structure and track to variable actions;
  - Annex H Load models for rail traffic loads in transient situations.

- **EN 1990** - Annex A2 Basis of structural design – Application for bridges:
  - Section A2.2.4 Combination rules for railway bridges;
  - Section A2.4.4 Verifications regarding deformations and vibrations for railway bridges.
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Stonecutters Bridge
Railway Actions

- Actions considered by the Moving Load Analysis:
  - Vertical loads: Load Models 71, SW (SW/0 and SW/2), “unloaded train” and HSLM;
  - Dynamic effects.

- Actions to be considered separately:
  - Vertical loading for earthworks;
  - Centrifugal forces;
  - Nosing force;
  - Traction and braking forces;
  - Aerodynamic actions from passing trains;
  - Actions due to overhead line equipment and other railway infrastructure and equipment;
  - Actions for non-public footpaths.
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Vertical Loads – Load Model 71

- The characteristic values shall be multiplied by a factor $\alpha$, on lines carrying rail traffic which is heavier or lighter than normal rail traffic. When multiplied by the factor the loads are called "classified vertical loads". This factor $\alpha$ shall be one of the following:

  $0.75 - 0.83 - 0.91 - 1.00 - 1.10 - 1.21 - 1.33 - 1.46$

- The actions listed below shall be multiplied by the same factor $\alpha$:
  - Equivalent vertical loading for earthworks and earth pressure effects;
  - Centrifugal forces;
  - Nosing force (multiplied by $\alpha$ for $\alpha \geq 1$ only);
  - Traction and braking forces;
  - Combined response of structure and track to variable actions;
  - Derailment actions for Accidental Design Situations;
  - Load Model SW/0 for continuous span bridges.

- For checking limits of deflection classified vertical loads and other actions enhanced by $\alpha$ shall be used (except for passenger comfort where shall be taken as unity).
Vertical Loads – Load Models SW/0 and SW/2

- Load Model SW/0 represents the static effect of vertical loading due to normal rail traffic on continuous beams.
- Load Model SW/2 represents the static effect of vertical loading due to heavy rail traffic.
- Load Model SW/0 shall be multiplied by the factor $\alpha$.

<table>
<thead>
<tr>
<th>Load Model</th>
<th>$q_{vk}$ [kN/m]</th>
<th>$a$ [m]</th>
<th>$c$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW/0</td>
<td>133</td>
<td>15.0</td>
<td>5.3</td>
</tr>
<tr>
<td>SW/2</td>
<td>150</td>
<td>25.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>
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Load Considerations – Eccentricity of Vertical Loads (LMs 71 and SW/0)

- The effect of lateral displacement of vertical loads shall be considered by taking the ratio of wheel loads on all axles as up to 1.25:1.00 on any one track.

- Eccentricity of vertical loads may be neglected when considering fatigue.

Key:
(1) Uniformly distributed load and point loads on each rail as appropriate
(2) LM 71 (and SW/0 where required)
(3) Transverse distance between wheel loads

\[ \frac{q_{v1}}{Q_{v1}} + \frac{q_{v2}}{Q_{v2}} = 1.25 \]  
\[ \frac{q_{v1} + q_{ve}}{Q_{v1} + Q_{ve}} = (2) \]
\[ \frac{q_{ve}}{q_{v1}} \approx 1.25 \]
\[ e \approx \frac{r}{18} \]
\[ r = (3) \]
Load Considerations – Longitudinal distribution of a point force or wheel load by the rail

- A point force in Load Model 71 and HSLM (except for HSLM-B) or wheel load may be distributed over three rail support points.

Key:
- $Q_{vi}$ is the point force on each rail due to Load Model 71 or a wheel load of a Real Train in accordance with 6.3.5, Fatigue Train or HSLM (except for HSLM-B)
- $a$ is the distance between rail support points
Load Considerations – Longitudinal distribution of load by sleepers and ballast

- Generally the point loads of Load Model 71 only or an axle load may be distributed uniformly in the longitudinal direction;
- For the design of local floor elements etc. the load distribution beneath sleepers should be taken as in the figure.
- Not considered in the program.

Load Considerations – Transverse distribution of actions by the sleepers and ballast

- Transversely loads shall be distributed accounting for cant, consolidation of ballast and sleepers system.

Load Considerations – Equivalent vertical loading for earthworks and earth pressure effects

- Not considered in the program.
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Dynamic Effects

- Factors influencing dynamic behaviour:
  - the speed of traffic across the bridge;
  - the span L of the element and the influence line length for deflection of the element being considered;
  - the mass of the structure;
  - the natural frequencies of the whole structure and relevant elements of the structure and the associated mode shapes along the line of the track;
  - the number of axles, axle loads and the spacing of axles;
  - the damping of the structure;
  - vertical irregularities in the track;
  - the unsprung/sprung mass and suspension characteristics of the vehicle;
  - the presence of regularly spaced supports of the deck slab and/or track (cross girders, sleepers etc.);
  - vehicle imperfections (wheel flats, out of round wheels, suspension defects etc.);
  - the dynamic characteristics of the track (ballast, sleepers, track components etc.).

- The dynamic enhancement of load effects shall be allowed for by multiplying the static loading by the dynamic factor $\Phi$. If a dynamic analysis is necessary, the results of the dynamic analysis shall be compared with the results of the static analysis enhanced by $\Phi$ and the most unfavourable load effects shall be used for the bridge design;

- The dynamic effects of a Real Train may be represented by a series of travelling point forces. Vehicle/structure mass interaction effects may be neglected. For spans less than 30 m dynamic vehicle/bridge mass interaction effects tend to reduce the peak response at resonance. Account may be taken of these effects by:
  - carrying out a dynamic vehicle/structure interaction analysis;
  - increasing the value of damping assumed for the structure.
Dynamic Effects - Dynamic Factor $\Phi$

- A static analysis shall be carried out with the load models (LM71 and where required Load Models SW/0 and SW/2). The results shall be multiplied by the dynamic factor $\Phi$ (and if required multiplied by $\alpha$).

- The dynamic factor takes account of the dynamic magnification of stresses and vibration effects in the structure but does not take account of resonance effects.

- Structures carrying more than one track should be considered without any reduction of dynamic factor $\Phi$.

- Generally the dynamic factor is taken as either 2 or 3 according to the quality of track maintenance as follows:

  (a) For carefully maintained track:

  $$\phi_2 = \frac{1.44}{\sqrt{L_{\Phi} - 0.2}} + 0.82$$

  with: $1.00 \leq \phi_2 \leq 1.67$

  (b) For track with standard maintenance:

  $$\phi_3 = \frac{2.16}{\sqrt{L_{\Phi} - 0.2}} + 0.73$$

  with: $1.00 \leq \phi_3 \leq 2.0$

  $L_{\Phi}$ – Determinant Length

- The dynamic factor shall not be used with:
  - Loading due to Real Trains;
  - Loading due to Fatigue Trains;
  - Load Model HSLM;
  - Load model “unloaded train”.

### 6.4.5.4 Reduced dynamic effects

(1) In the case of arch bridges and concrete bridges of all types with a cover of more than 1.00 m, $\phi_2$ and $\phi_3$ may be reduced as follows:

$$red\ \phi_{2,3} = \phi_{2,3} \cdot \frac{h - 1.00}{10} \geq 1.0 \quad (6.8)$$
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Load Application

- The required **number and position(s)** of the tracks may be specified for the **individual project**.
- The **minimum spacing of tracks** and **structural gauge clearance** requirements may be specified for the **individual project**.
- The effects of all actions shall be determined with the traffic loads and forces placed in the **most unfavourable positions**. Traffic actions which produce a **relieving effect** shall be **neglected**.

- **Influence Line Dependent Point** option:

- **All Points** option:
Load Application

- **Load Model 71:**
  - any number of lengths of the uniformly distributed load $q_{uk}$ shall be applied to a track and up to four of the individual concentrated loads $Q_{vk}$ shall be applied once per track;
  - for structures carrying two tracks, Load Model 71 shall be applied to one track or both tracks;
  - for structures carrying three or more tracks, Load Model 71 shall be applied to one track or to two tracks or 0.75 times Load Model 71 to three or more of the tracks.

- **Load Model SW/0:**
  - the loading shall be applied once to a track;
  - for structures carrying two tracks, Load Model SW/0 shall be applied to one track or both tracks;
  - for structures carrying three or more tracks, Load Model SW/0 shall be applied to one track or to two tracks or 0.75 times Load Model SW/0 to three or more of the tracks.

- **Load Model SW/2:**
  - the loading shall be applied once to a track;
  - for structures carrying more than one track, Load Model SW/2 shall be applied to one track only with Load Model 71 or Load Model SW/0 applied to one other track.

- **Load Model “unloaded train”:**
  - any number of lengths of the uniformly distributed load $q_{uk}$ shall be applied to a track;
  - generally Load Model “unloaded train” shall only be considered in the design of structures carrying one track.

- **All continuous beam structures** designed for Load Model 71 shall be checked additionally for Load Model SW/0.

- Where a **dynamic analysis** is required all bridges shall also be designed for the loading from Real Trains and Load Model HSLM where required.

- For the verification of **deformations** and **vibrations** the vertical loading to be applied shall be:
  - Load Model 71 and where required Load Models SW/0 and SW/2;
  - Load Model HSLM where required;
  - Real Trains when determining the dynamic behaviour in the case of resonance or excessive vibrations of the deck where required.

- For bridge decks carrying one or more tracks the checks for the limits of deflection and vibration shall be made with the number of tracks loaded with all associated relevant traffic actions. Where required classified loads shall be taken into account.
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Lazarevsky Bridge
### Groups of Loads and Load Combinations

<table>
<thead>
<tr>
<th>number of tracks on structure</th>
<th>Groups of loads</th>
<th>Vertical forces</th>
<th>Horizontal forces</th>
<th>Comment</th>
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<tr>
<td>number of tracks loaded</td>
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<td>SW/2 (1) (3) Unloaded train</td>
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<td>Tractive, Braking (1)</td>
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<tr>
<td>Centrifugal force (1)</td>
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<tr>
<td>Nosing force (1)</td>
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<tr>
<td>1</td>
<td>gr11 T1</td>
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<td>Max. vertical 1 with max. longitudinal</td>
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<td>gr12 T1</td>
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<td>Max. vertical 2 with max. transverse</td>
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<td>Max. longitudinal</td>
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<td>Lateral stability with “unloaded train”</td>
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<td>SW/2 with max. longitudinal</td>
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<td>SW/2 with max. transverse</td>
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<td>gr21 T1 T2</td>
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<td>Max. vertical 1 with max. longitudinal</td>
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<tr>
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<td>gr22 T1 T2</td>
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<td>Max. vertical 2 with max. transverse</td>
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<tr>
<td>2</td>
<td>gr23 T1 T2</td>
<td>1 (4)</td>
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<td>Max. longitudinal</td>
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<td>gr24 T1 T2</td>
<td>1 (4)</td>
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<td>gr26 T1 T2</td>
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<td></td>
<td>SW/2 with max. longitudinal</td>
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<tr>
<td>2</td>
<td>gr27 T1 T2</td>
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<td></td>
<td></td>
<td>SW/2 with max. transverse</td>
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<td>gr31 T1</td>
<td>0.75</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Additional load case</td>
</tr>
</tbody>
</table>
Groups of Loads and Load Combinations

- **Ultimate Limit State:**

  - \( \gamma_{G, sup} = 1.35 \).
  - \( \gamma_Q = 1.45 \) when \( Q \) represents unfavourable actions due to rail traffic, for groups of loads 11 to 31 (except 16, 17, 26 and 27), load models LM71, SW/0 and HSLM and Real Trains, when considered as individual leading traffic actions.
  - \( \gamma_Q = 1.20 \) when \( Q \) represents unfavourable actions due to rail traffic, for groups of loads 16 and 17 and SW/2.
  - For rail traffic actions for groups of loads 26 and 27 \( \gamma_Q = 1.20 \) may be applied to individual components of traffic actions associated with SW/2 and \( \gamma_Q = 1.45 \) may be applied to individual components of traffic actions associated with load models LM71, SW/0 and HSLM, etc.

- **Serviceability Limit State:**

  - The \( \psi_1 \) factor varies depending on the number of loaded tracks, which can be considered in the moving load analysis.
  - The \( \psi_0 \) factor does not rely on the number of loaded tracks, which can be considered in the Load Combination.
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Traffic Loads for Fatigue

- For normal traffic based on characteristic values of Load Model 71, including the dynamic factor, the fatigue assessment should be carried out on the basis of the traffic mixes, "standard traffic", "traffic with 250 kN-axles" or “light traffic mix” depending on whether the structure carries mixed traffic, predominantly heavy freight traffic or lightweight passenger traffic in accordance with the requirements specified.

- Each of the mixes is based on an annual traffic tonnage of 25×106 ton passing over the bridge on each track.

- For structures carrying multiple tracks, the fatigue loading shall be applied to a maximum of two tracks in the most unfavourable positions.

- The fatigue damage should be assessed over the design working life. 100 years is recommended.

- Vertical rail traffic actions including dynamic effects and centrifugal forces should be taken into account in the fatigue assessment. Generally nosing and longitudinal traffic actions may be neglected in the fatigue assessment.
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Dynamic Analysis

- Real Train or HSLM vehicles are used for dynamic analysis.
- Calculation of natural frequency of bridge.
- Dynamically moving loads with different arrival times and varying positions of loads.
- Time history analysis with peak acceleration vs time plots.
- Check for max vertical deflection for passenger comfort.
- Check whether load effects exceed static load effects from LM71 or SW/0.
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Live Demonstration
# Live Demonstration

<table>
<thead>
<tr>
<th>No</th>
<th>Moving Load Case</th>
<th>Rail Traffic Load</th>
<th>Load Combination</th>
<th>( \varphi_1 )</th>
<th>( \gamma_Q )</th>
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<td>1</td>
<td>LM71_ULS</td>
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<td>ULS</td>
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<td>LM71_SLS C</td>
<td>Load Model 71</td>
<td>SLS-Characteristic</td>
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<td>SLS-Frequent</td>
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<td>4</td>
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<td>Load Model SW/0</td>
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<td>1.45</td>
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<td>5</td>
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<td>SLS-Characteristic</td>
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<tr>
<td>6</td>
<td>SW/0_SLS F</td>
<td></td>
<td>SLS-Frequent</td>
<td>0.8 one track loaded 0.7 two tracks loaded</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>SW/2+LM71_ULS</td>
<td>Load Model SW/2</td>
<td>ULS</td>
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<td>1.2 SW/2 1.45 LM71</td>
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<td>Load Model 71</td>
<td>SLS-Characteristic</td>
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<td>SLS-Frequent</td>
<td>0.8 one track loaded 0.7 two tracks loaded</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Thank you!

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For any questions send an e-mail at:

uksupport@midasuser.com