CONSTRUCT

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Seismic behavior of precast piers on high speed railway bridges

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2016

1. PhD framework:

- Main work developed on the scope of the SIPAV project.
- Challenged proposed by *Mota-Engil, Betões e Prefabricados*:
  - Full-scale application viable for high-speed railway bridges (HSRL);
  - Precast solution for fast construction;
  - Reinforced concrete (RC) based layout;
  - Focus on the piers for seismic behavior assessment;
- State-of-art of relevant areas reviewed accordingly:

HSRL + Precast solution + RC + Piers = Virtually non-existent

- Opportunity to address the shortcoming by aiming to apply common precast solutions for HSRL Piers as well.

2. HSRL Bridge Piers:

- Common Layouts for HSRL Bridge piers:

Single Column Pier
(often with flare)

Tall viaducts

Wall Pier

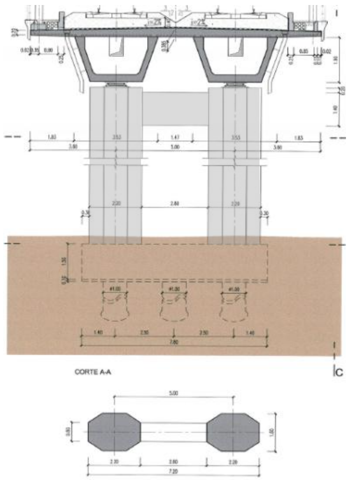
Multiple Column Pier
(Bent-type column)

Long/short viaducts

- **Increased stiffness** relative to equivalent motorway bridge piers.
- Strict deformation limits for HSRL running safety limit state, e.g.:
  – Maximum radius for lateral deflection of 1.50 x 10^{-3} rad;
  – Maximum longitudinal displacement of 5.00 mm;
- **High seismic forces** are expected.

3. Base Structure for Study:

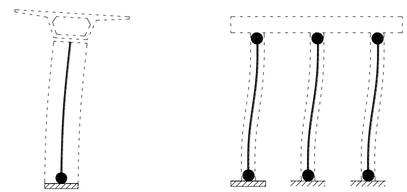
- Poceirão – Caia HSRL proposal for long and low height viaducts:



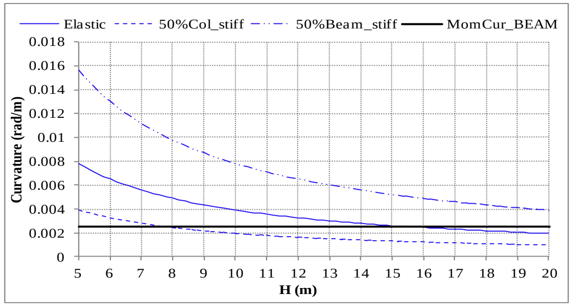
  - Double Column RC Pier (5.00m < H_{pier} < 20.00m);
  - Short span coupling beam (α_s = 1.0);
  - High stiffness columns;

Seismic design guidelines:

  - Plastic hinges;
  - High ductility;

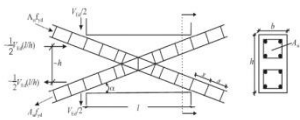
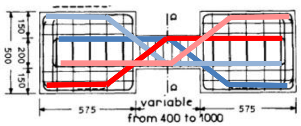


- Height dependent stiffness ratios lead to difficulty in evaluating suitable locations for inelastic deformations.
- Possibility for high shear ductility demand in the beams.



4. Prototype Solutions:

- Beam reinforcement layouts based on applications for coupling beams of shear walls:

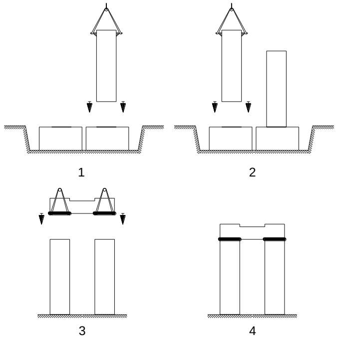




Bi-diagonal layout (Eurocode 8 / ACI318).

Rhombic truss (Tegos and Penelis (1988)).

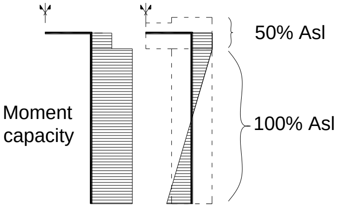
Dowel Rhombic truss (adapted from Tassios *et al.* (1996)).

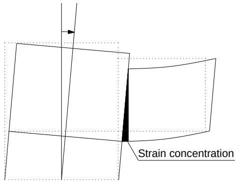
- Precast system based on a top-down assembly (2 columns + beam), enforcing reinforcement yielding at the joint.



Assembly Procedure

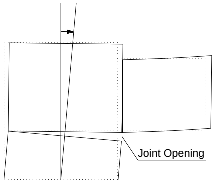
Precast Joint Reinforcement Design:





Monolithic Scenario

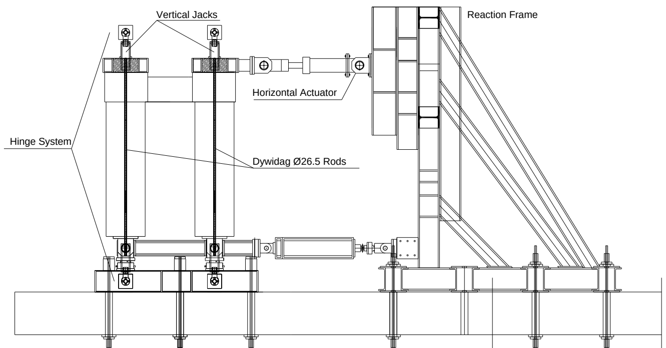
vs.

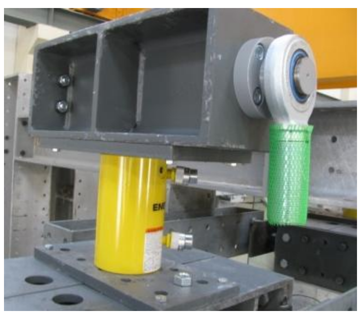


Idealized Precast Scenario

5. Experimental Campaign

- Test setup designed and installed in LESE accounting for:
  - Constant axial loading on both columns (300 kN);
  - Free rotation on column bases;
  - Cyclic loading applied through shear;




Vertical Jacks

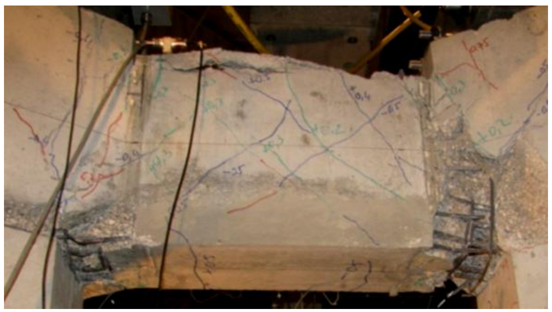

Threadbar Connection


Shear Loading Plates


Rotation Hinge

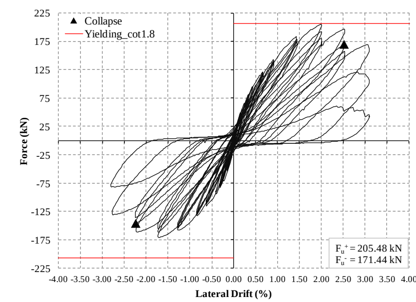
6. Main Observations

- Monolithic Specimens largely influenced by beam shear, providing generally low ductility capacity.



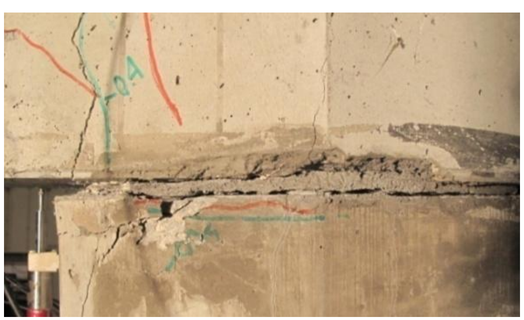
Sliding shear

Diagonal splitting

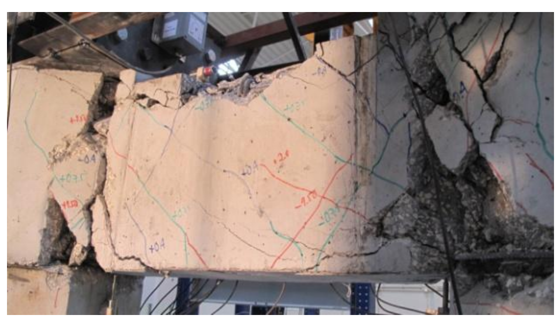


Low ductility and energy dissipation

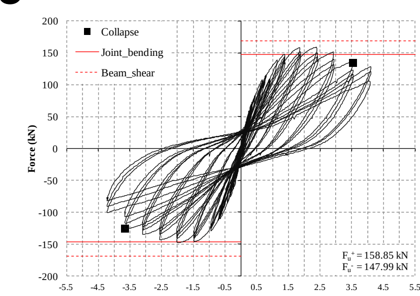
- Precast Specimens benefitting from the flexibility provided by the joint, although still subjected to heavy damage.



Large joint displacements



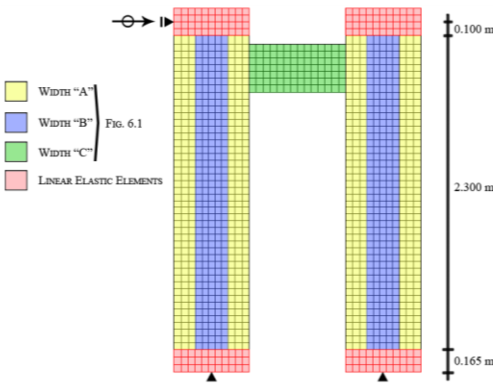
Heavy damage on larger drifts



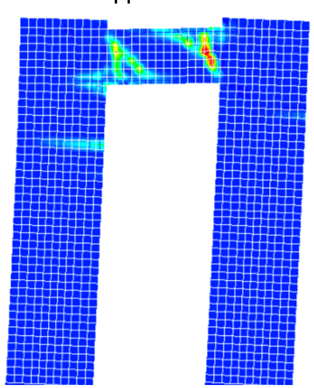
Increased ductility and energy dissipation

7. Numerical Modelling

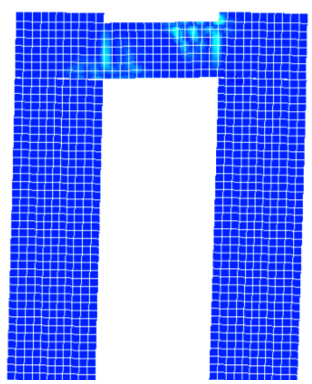
- 2D FEM based plane stress approach on Cast3m, with individual constitutive characterization of:
  - Concrete (Faria, R. and Oliver, J. (1993));
  - Steel reinforcement (Menegotto, M. and Pinto, P. (1973));
  - Bond-slip behavior (Eligehausen *et al.* (1982));
  - Joint behavior (Snyman *et al.* (1991));



ε_{11} strains at first yielding:

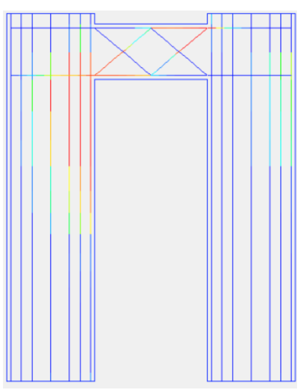


Monolithic specimen

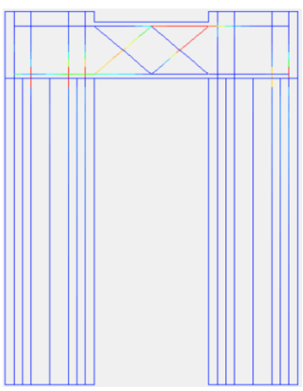


Precast specimen

Rebar stresses:

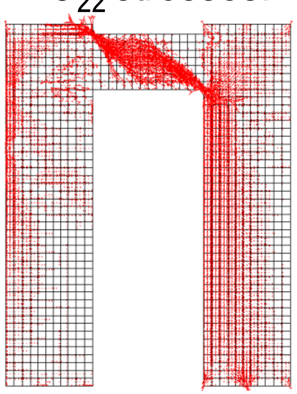


Monolithic specimen



Precast specimen

σ_{22} stresses:



Both specimens

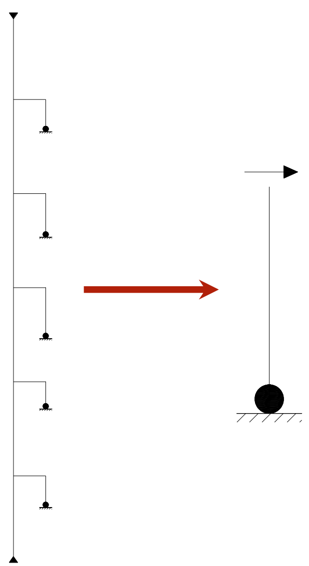
8. Seismic Performance

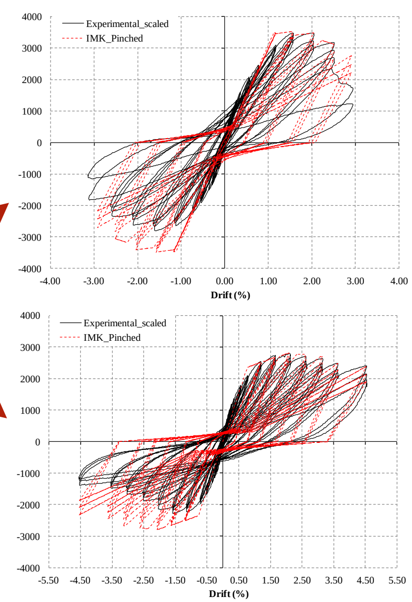
- Experimental data used to calibrate global modelling tools for seismic performance assessment:

– Viaduct modelling using 2D characterization in OpenSees;

– Lumped plasticity at the base of each pier calibrated accordingly, for Monolithic and Precast specimens (Ibarra *et al.* (2005));

– IDA procedures (Vamvatsikos, D. and Cornell, C.A. (2002));



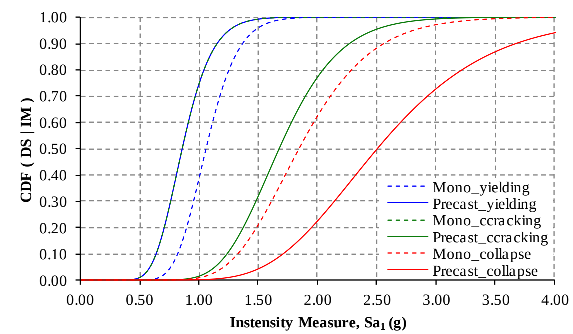


Comparison of different Damage Measures:

DM #1 - Structural Damage;

DM #2 – Lateral Deflection;

DM #3 – Spectral Intensity;



DM #1 – Structural Damage

Conclusions

- A double column bent pier system was studied for precast application;
- There is a high shear ductility demand in the beam of the structural system, requiring unconventional reinforcement layouts;
- Experimental evidence showed that the precast system helps with increasing overall ductility and energy dissipation;
- Numerical analyses confirm that the precast system is able to globally improve the seismic performance of the studied viaducts;

Thank you!