Multi-objective optimization of irregular RC bridge infrastructures based on evolutionary algorithms

Overview of thesis structure, developed work and work in progress

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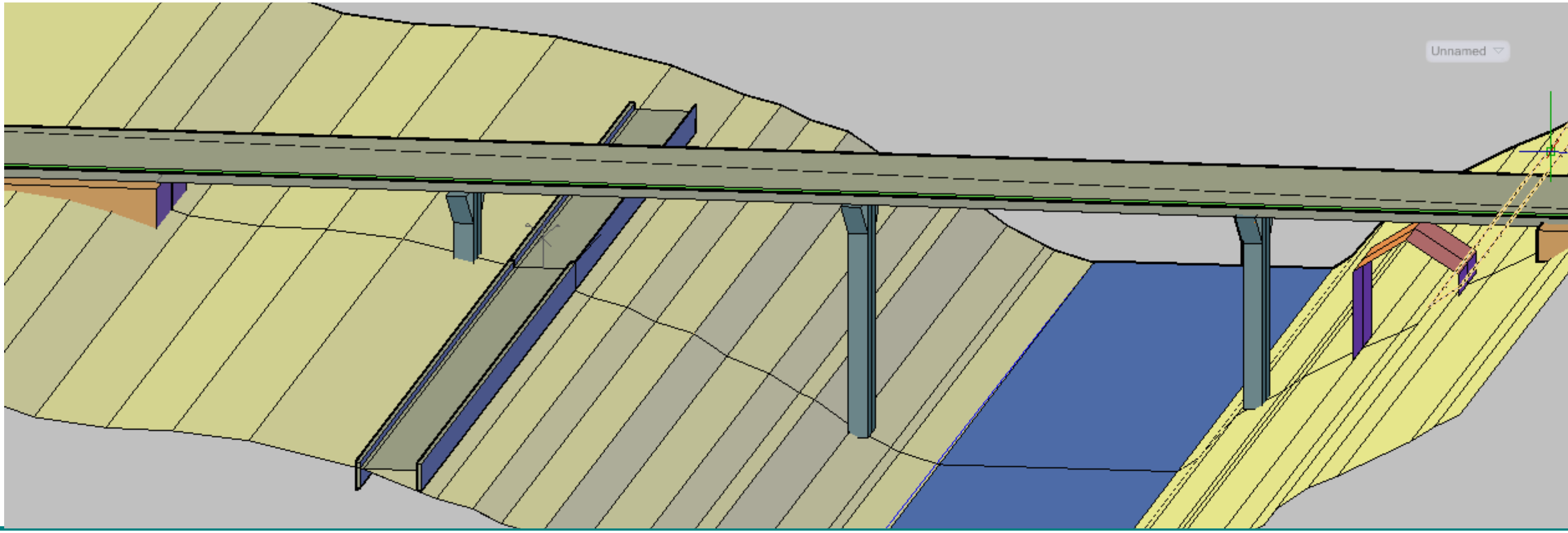


Presentation layout

- Thesis overview – Index
- What has been done this past year
- Revision of behaviour factors for elastic seismic design with MOEA
  - Definition of expression for real q-factor value.
- Irregular bridges – length, irregularity layout and optimization
  - Indicators RSI and L/Ktotal as predictors for dynamic behaviour.
- What is still left to do

Thesis Index

1. Introduction
2. Objectives, bibliography and basic concepts
    - Factors that influence ductility
    - Concepts on short and long bridges
3. Optimization
    - Meta-heuristic optimization algorithms
    - Multi-objective optimization and application to structural engineering
4. Short bridges – longitudinal direction
    - Study on behaviour factors and sensibility analysis of the parameters that influence ductility
    - Normalization/Standardization of irregular bridge design. Limits of redistribution.
5. Long bridges – longitudinal + transversal direction
    - Standardization profiles associated to different irregularities. Similarity between longitudinal and transversal peak responses.
    - Stiffness based-design. Reduced degree-of-freedom (RDOF) approximate peak response for bridges.
    - Steel hysteretic dampers. – qualitative discussion. State-of-art review.
    - IDA and design for different damage states. Cases where design for serviceability limits is important.
6. Spatial variability of earthquake action for long viaducts. Implications in design.
7. Conclusions.

What was done this past year

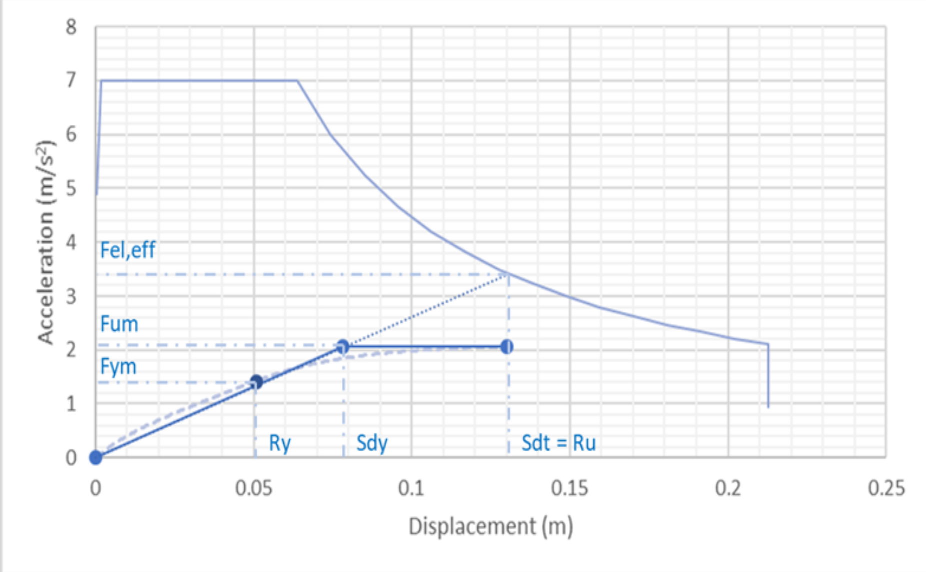
- Revision of behaviour factors for elastic seismic design with MOEA. Definition of irregularity measure and function for estimation of real behaviour factor.
- Analysis of case-studies for irregular bridges. Sensitivity analysis for various irregularity layouts.
- Evaluation of a few irregularity and stiffness indicators as predictors for bridge THDP (transverse horizontal displacement profile)
- Application of GAs for the optimization of steel distribution for long bridges. Impact of steel distribution for different irregularity layouts and bridge length.
- Definition of a RDOF methodology for the prediction of peak response. Similarity of peak response in longitudinal and transverse direction.

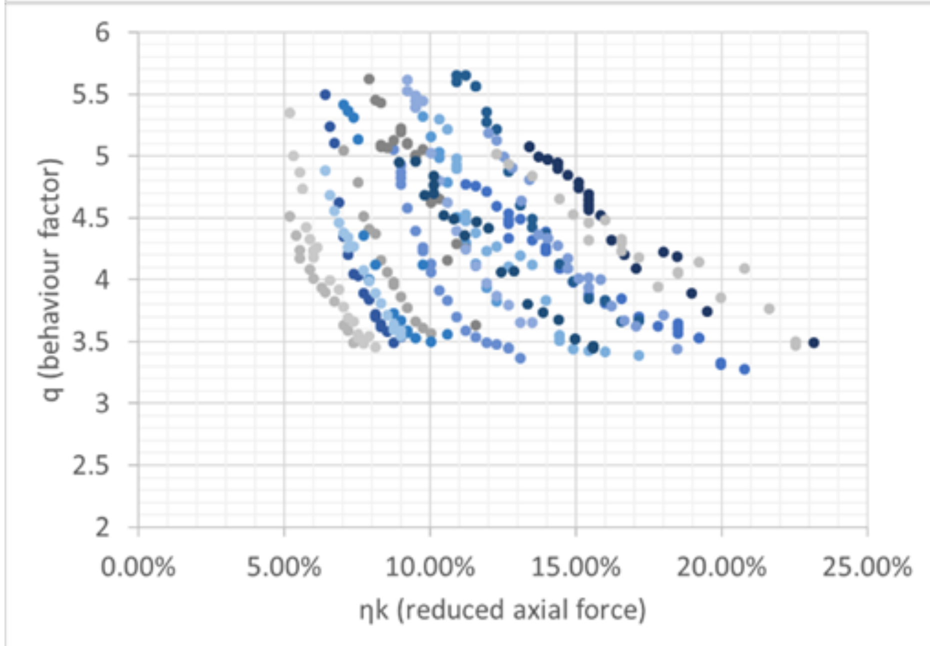
Revision of behaviour factors for elastic seismic design with MOEA

Longitudinal direction of irregular bridges:

- 29 case-studies covering many combinations of irregularities with varying length diferences between piers.
- For each case-study, optimization of pier variables (cross-section diameter and flexural steel reinforcement)
- The optimization minimizes the amount of material and maximizes use of available ductility.
- N2 method is applied at the analysis and evaluation step of the optimization procedure:
  - Calculation of q-factor:

$$q = F_{el,eff}/F_{yd} = 1.5 \cdot q_s \cdot q_\mu$$





Revision of behaviour factors for elastic seismic design with MOEA

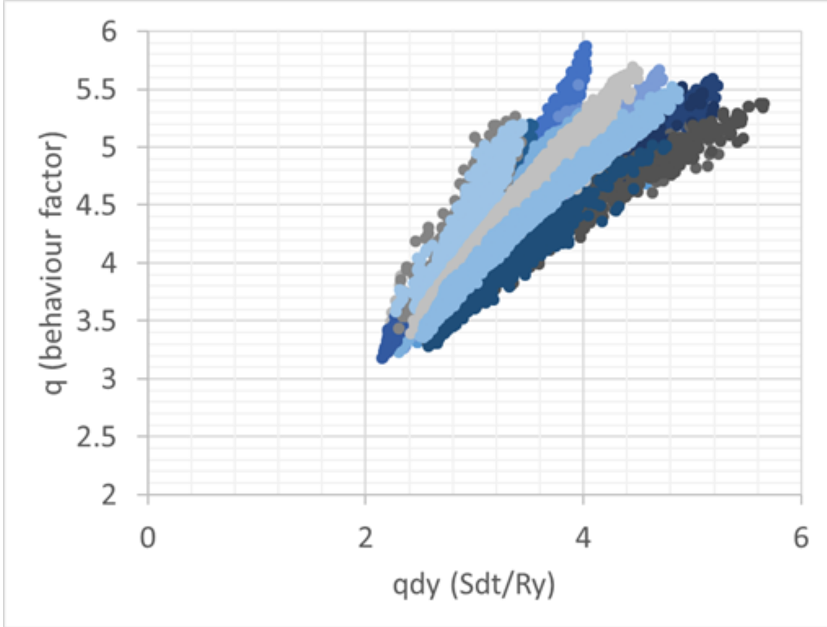
Comparison of results for each case-study regarding the irregularities:

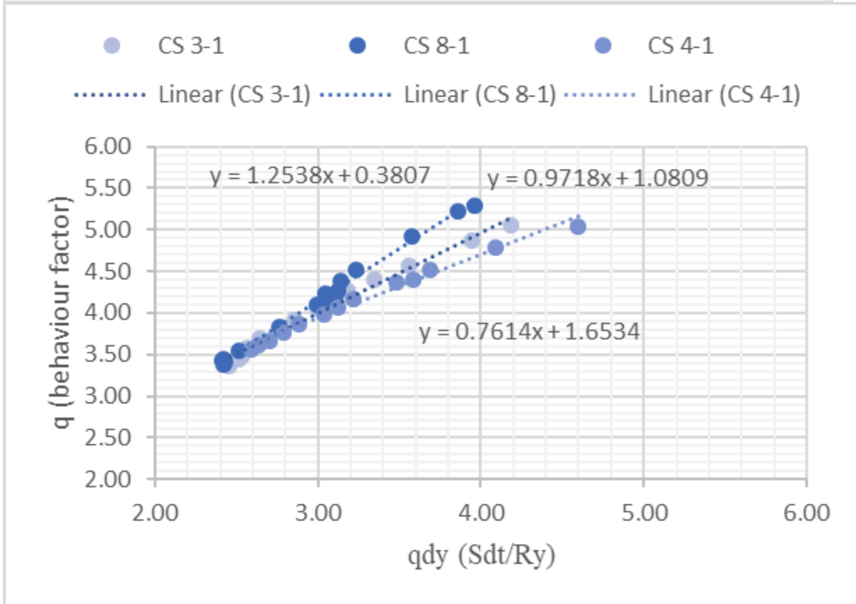
- Linear relationship between q-factor and qdy (Sdt/Ry):
  - Sdt – Structure's target displacement
  - Ry – yield displacement of stiffest pier

- The linear relationship depends on the irregularity level: more irregularity implies smaller slope of linear regression.

- Measure of irregularity inspired in the coefficient of variation (CoV) of yield displacements of the piers:

$$PIrr = \sqrt{\frac{\sum_{i=1}^{n}(Ry_i - minRy)^2}{n \cdot minRy^2}}$$





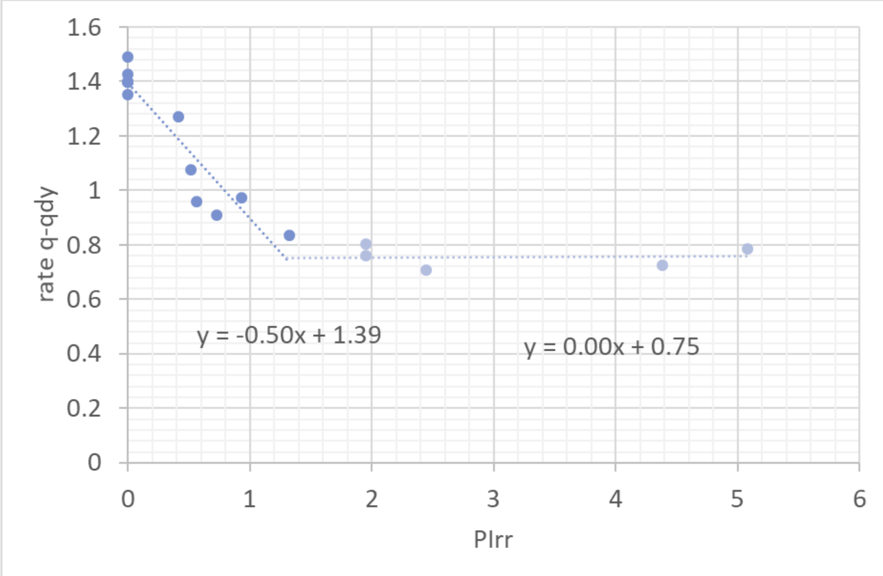
Revision of behaviour factors for elastic seismic design with MOEA

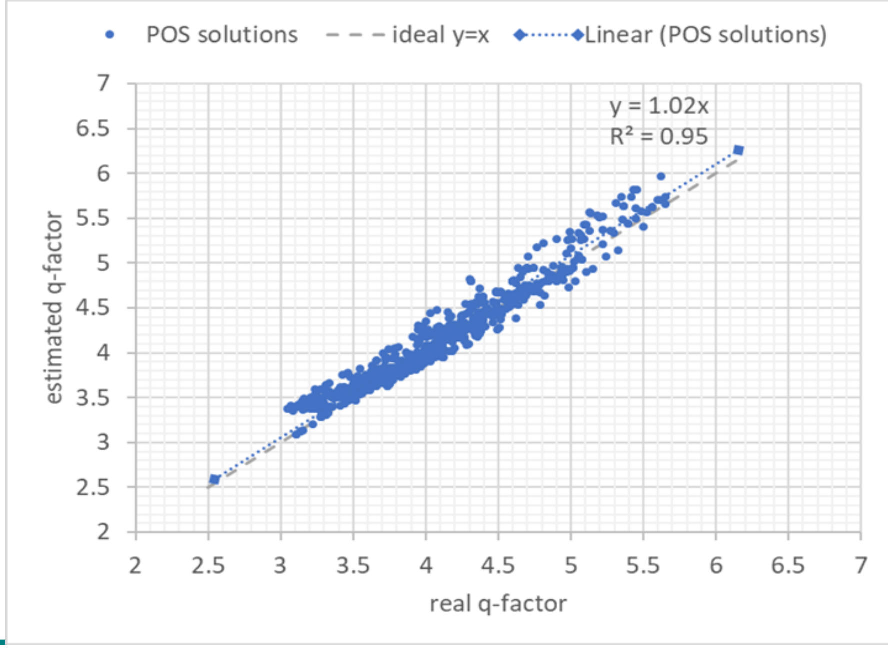
- Expression for irregularity (Pirr) compared with the slope of the linear approximations.

- Expression estimating the actual q-factor is defined, independent of confinement level and level of axial force.

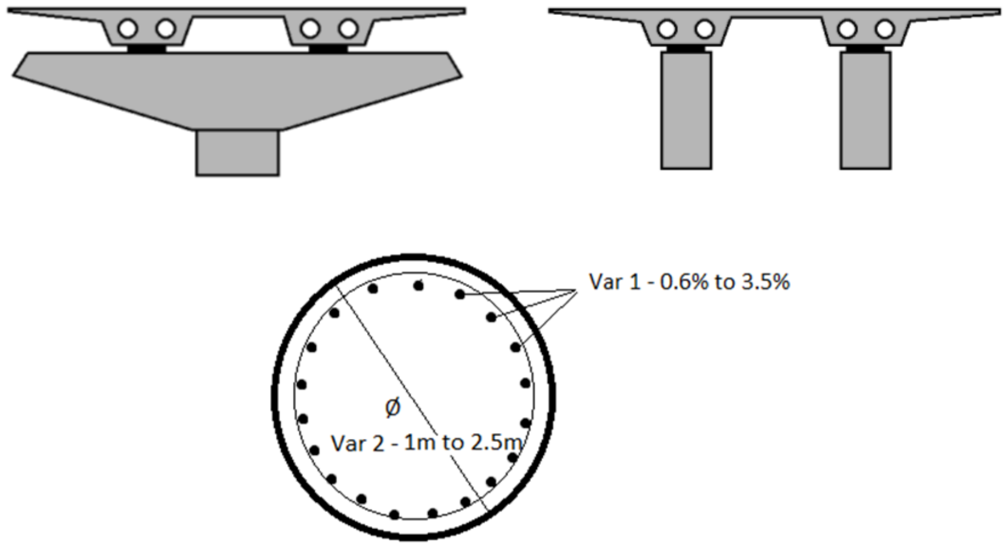
$$\begin{cases} mq = -0.50 \cdot PIrr + 1.39, if\ PIrr \leq 1.28 \\ mq = 0.75, if\ PIrr > 1.28 \end{cases}$$

$$q = mq(PIrr) \cdot \frac{Sdt}{Ry} + c$$





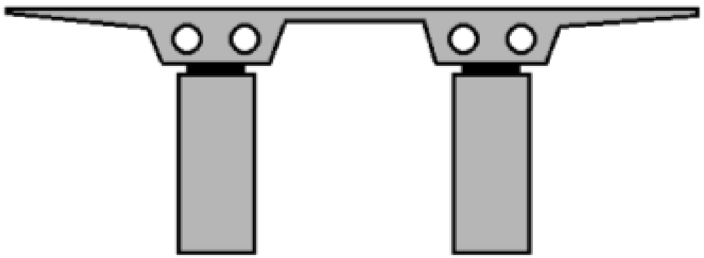
Irregular bridges – length, irregularity layout and optimization

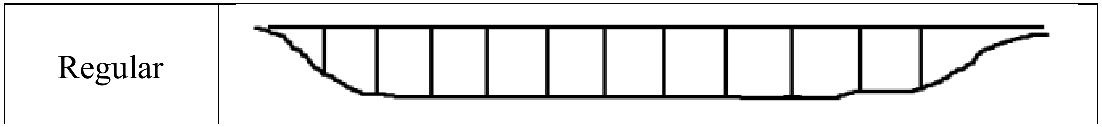


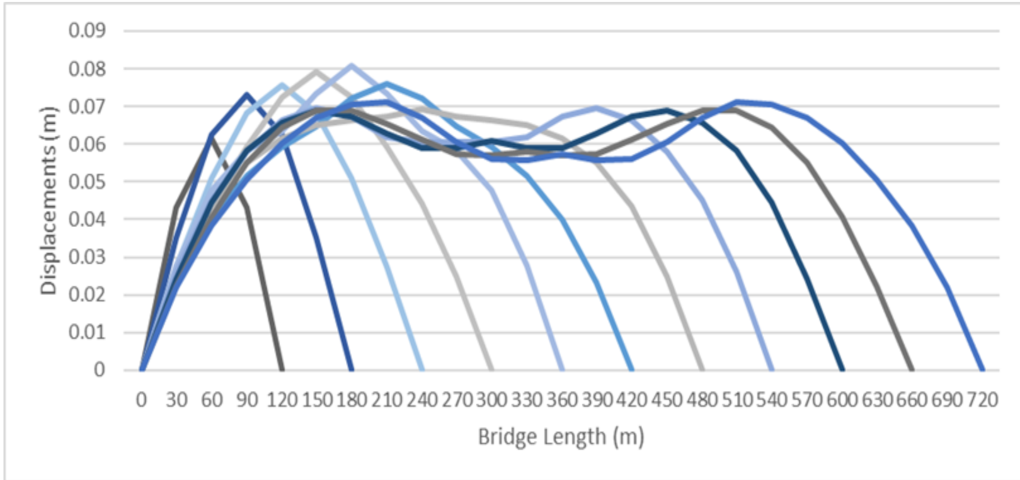
Category	*Explanatory figure*
Regular	
Irregularity 1	
Irregularity 2	
Irregularity 3	

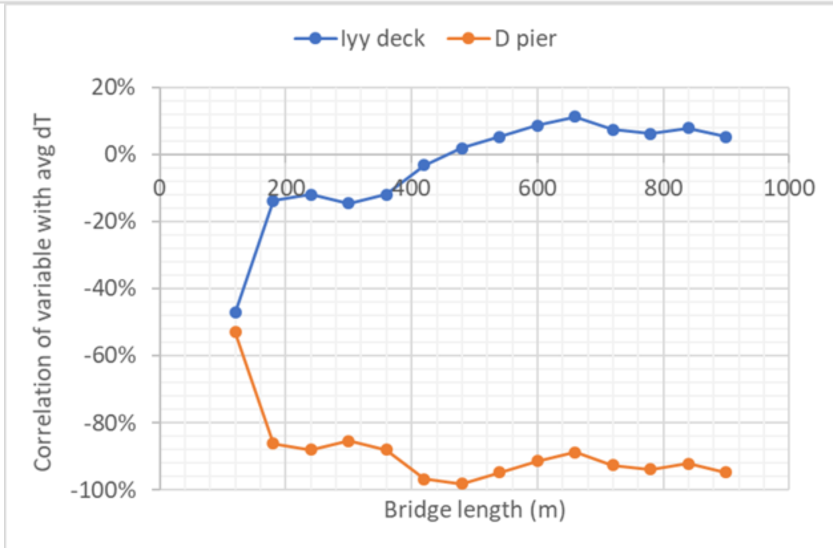
- Four irregularity profiles and two superstructure types
- The two deck solutions are common and have relevant differences in terms of dynamic behaviour in the transversal direction associated to diferences in torsion.
- The irregularity profiles have different impact on the bridge transverse horizontal displacement profile (THDP)

Irregular bridges – length, irregularity layout and optimization





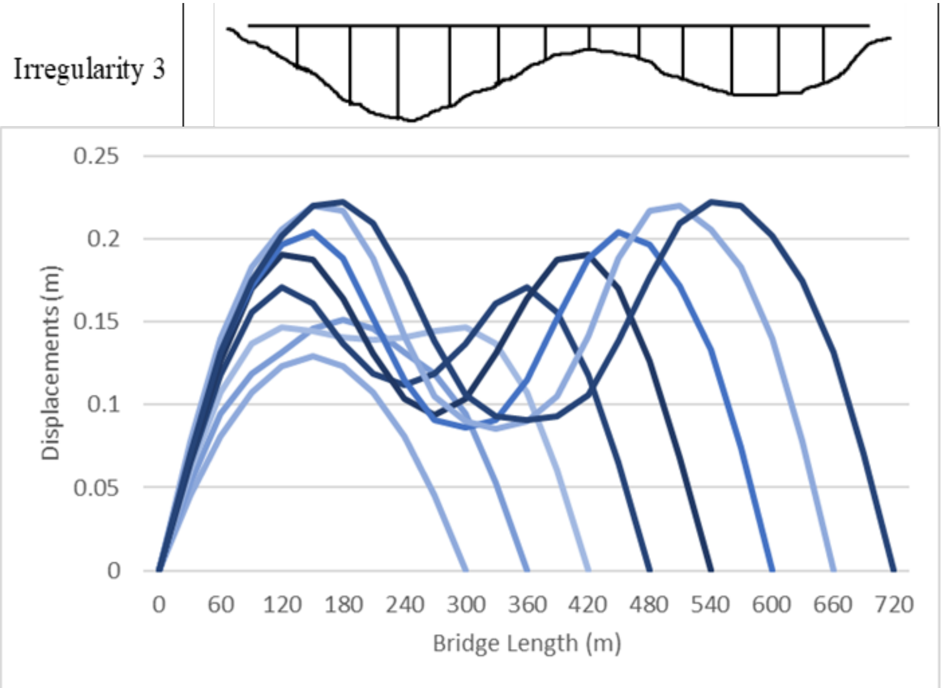




- The ratio between superstructure stiffness and infrastructure stiffness is very significant on the THDP of the bridge

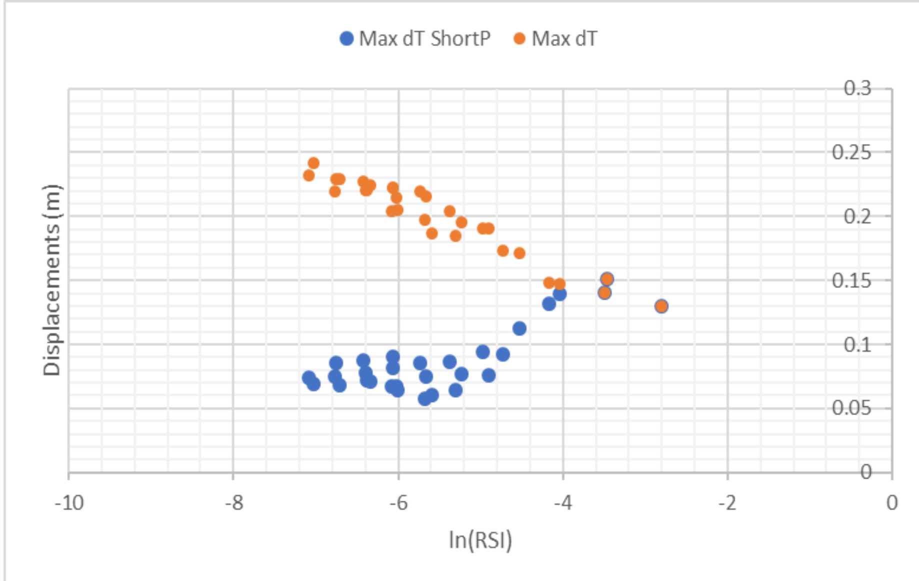
- However, the impact of that indicator on average displacement is only noticeable for short bridges.

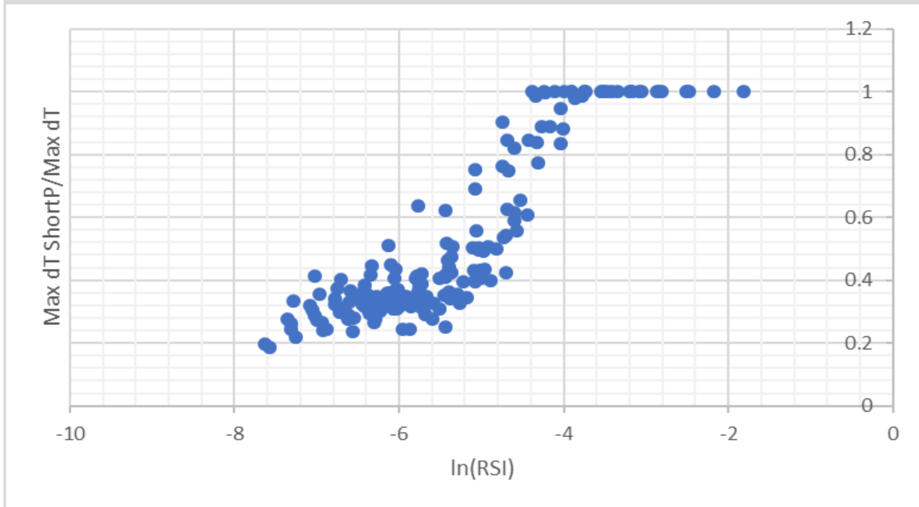
Irregular bridges – length, irregularity layout and optimization



flexible deck, stiff pier

Stiff deck, flexible pier





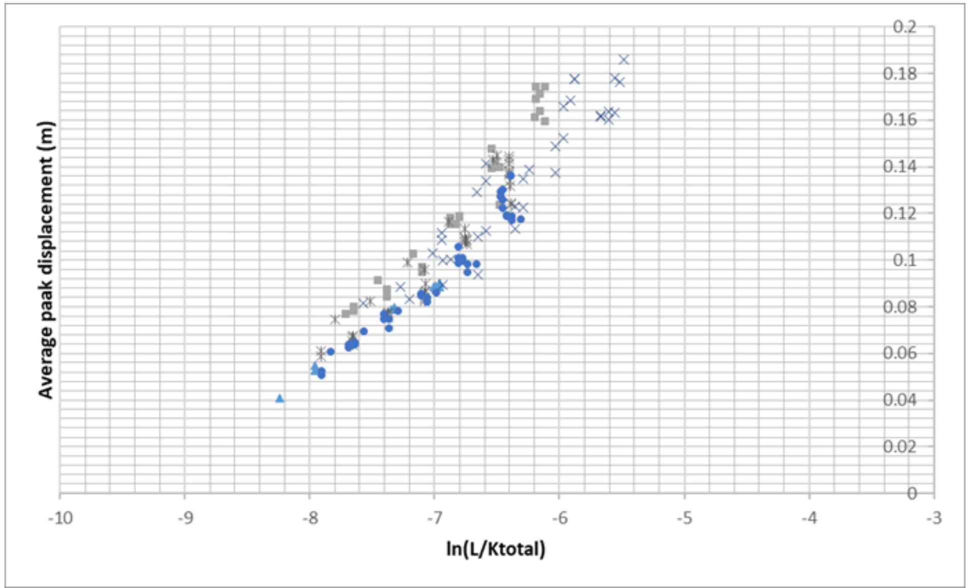
- Relative Stiffness Index (Priestley, Seible, & Calvi, 1996):

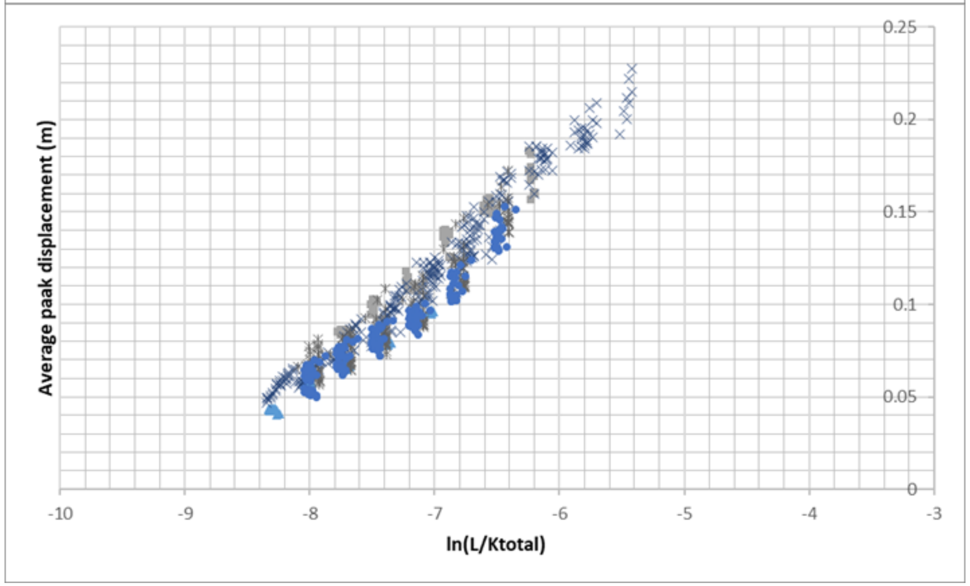
$$RSI = \frac{K_{Ss}}{K_{Is}} = \frac{\frac{385/_{5} \cdot EI_{Ss}}{L^3}}{\sum_{p=1}^{np} K_p}$$

Irregular bridges – length, irregularity layout and optimization

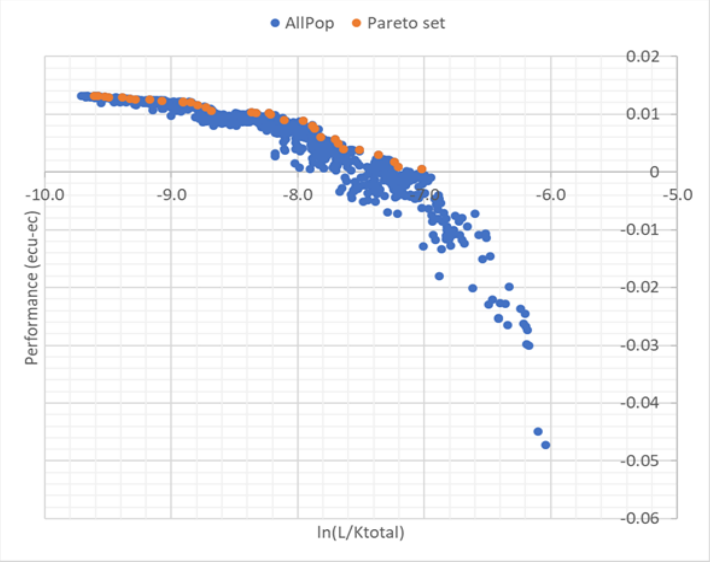
- Average peak displacement is well correlated with L/Ktotal (bridge length / pier stiffness), regardless of irregularity profile.

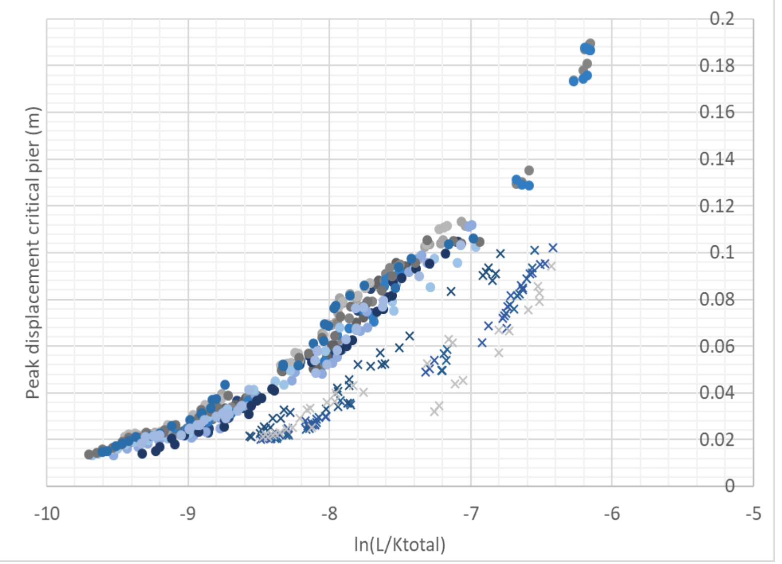
- Although different between short bridges (high RSI) and long bridges (low RSI)





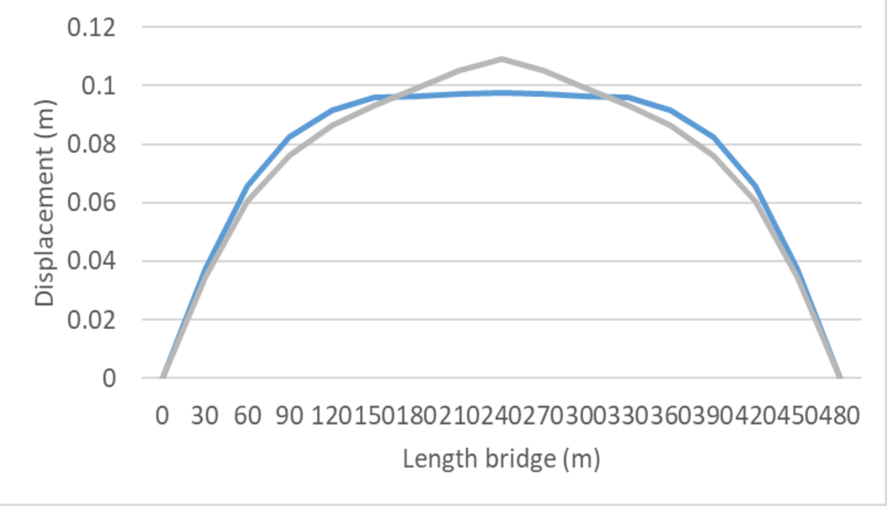
Irregular bridges – length, irregularity layout and optimization





- In bridges with smaller RSI values (long bridges), the peak response of the critical pier can change by redistributing the stiffness of the piers, even though the average displacement is the same.

Flex. Steel P1-P2-P3	Avg dT(m)	Max dT(m)
2.25%-3.45%-3.05%	0.072	0.098
3%-3%-3%	0.072	0.109



What is still left to do

- Performing optimization runs for other types of superstructure and damage states. Definition of global rules according to each superstructure and each irregularity layout.

- Spatial variability of earthquake action for long viaducts. (This study is initiated and has already been implemented in the algorithm).

Thank you for your attention!