9th EWICS

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Multiobjective optimization of long irregular RC bridges' piers subjected to strong motions and definition of classification tree surrogate models

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Complexities of the seismic design of long irregular bridges

- Long irregular (pier length) bridges can be difficult to analyse and design, due to uncertain seismic behaviour.

- Some cases, due to heavy influence of higher vibration modes, may only be analysed through nonlinear dynamic analysis.

- For this reason, many design methodologies are not easy to employ for such bridges, which leads to these bridges being designed through trial and error based on the experience of the design engineer.

Bridge seismic design optimization

- When designing a structure, one attempts to optimize some aspect of the structure, even if implicitly. Usually, a trade-off is procured between structural resistance and some economical aspect (material quantities, standardization, etc.)

- The more complex the structural behaviour is, the more difficult and less likely it is to attain some form of optimization, due to the number of necessary iterations and the type of analysis needed.

- Traditional optimization methods (gradient-based) struggle with structural optimization, and even more so with seismic optimization, due to the non-convex, non-differentiable nature, as well as the existence of discrete variables and design code limits.

Genetic algorithms for seismic design

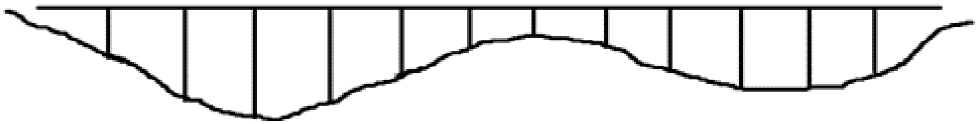
- Genetic/Evolutionary algorithms and other metaheuristic methods are good alternatives for structural optimization because they are not hindered by the non-convex and discontinuous nature of the optimization problem.

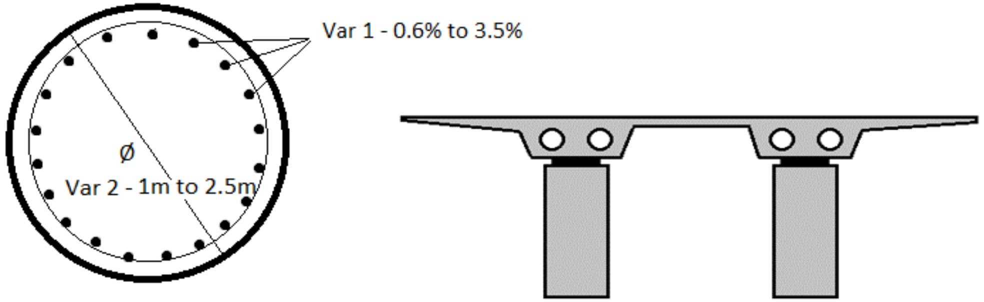
- They can be applied to any type of problem, and they can optimize more than one objective function simultaneously.

- In previous works, these techniques were used to define a multiobjective optimization methodology for the seismic design of bridges.

Genetic algorithms for seismic design – long irregular bridge case study

- In this work, the methodology is applied to a long irregular bridge with short central piers, and the search history is then used for knowledge/rule extraction using machine learning techniques.
- Decision variables – pier diameter, flexural steel reinforcement, pier-deck connection.





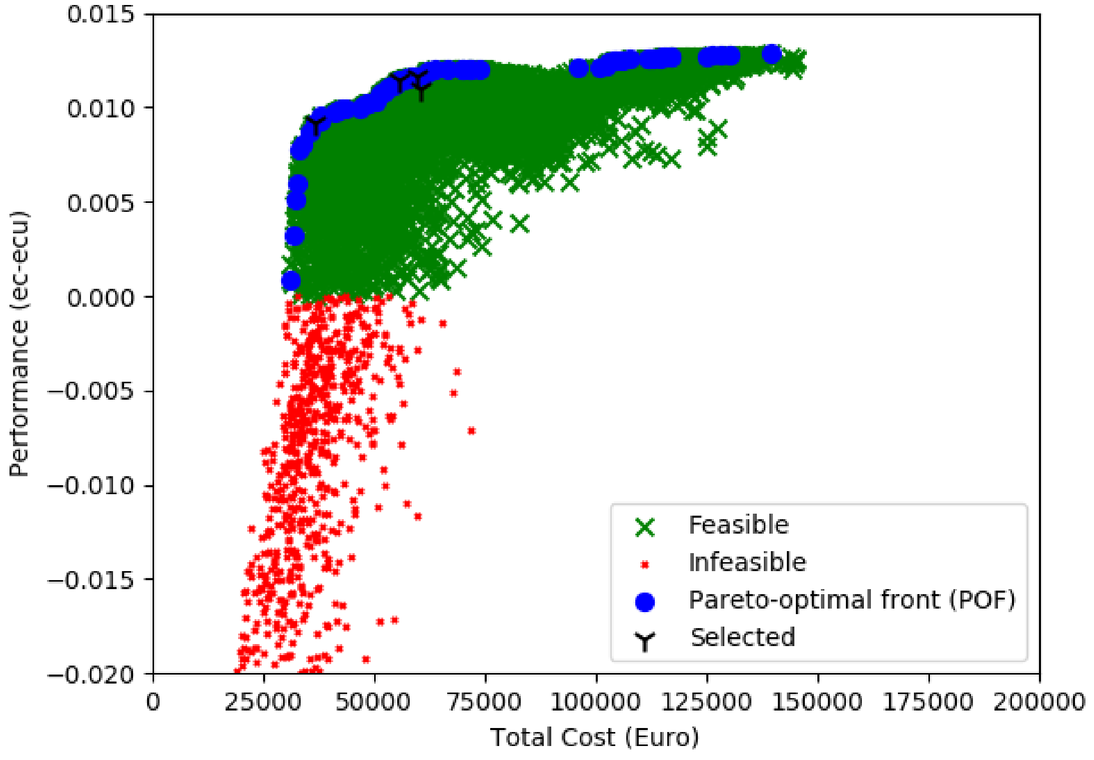
Pier Lengths (m)	Pier Groups
11 11 14 14 11 11 7 7 7 11 11 14 14 11 11	(1 2 14 15) (3 4 12 13) (5 6 10 11) (7 8 9)

Multiobjective optimization

- Optimization objectives:
  - Maximization of performance (concrete compressive strain in each pier < maximum admissible strain)
  - Minimization of cost (material quantities in the piers)

- Method of analysis – Nonlinear dynamic analysis with real strong motions

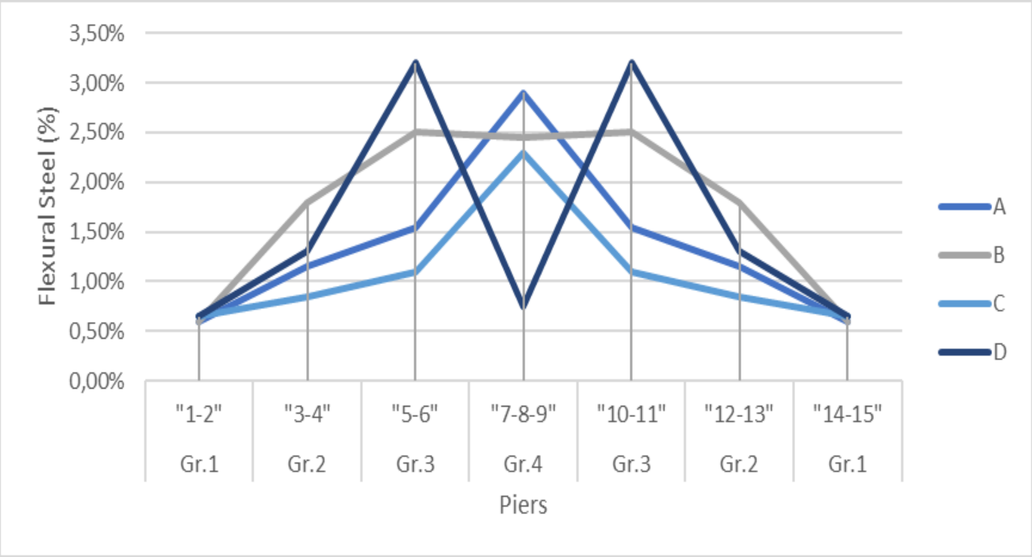
- OpenSEESMP with parallel computing of different bridge instances.



Multiobjective optimization – Pareto front (best trade-offs)

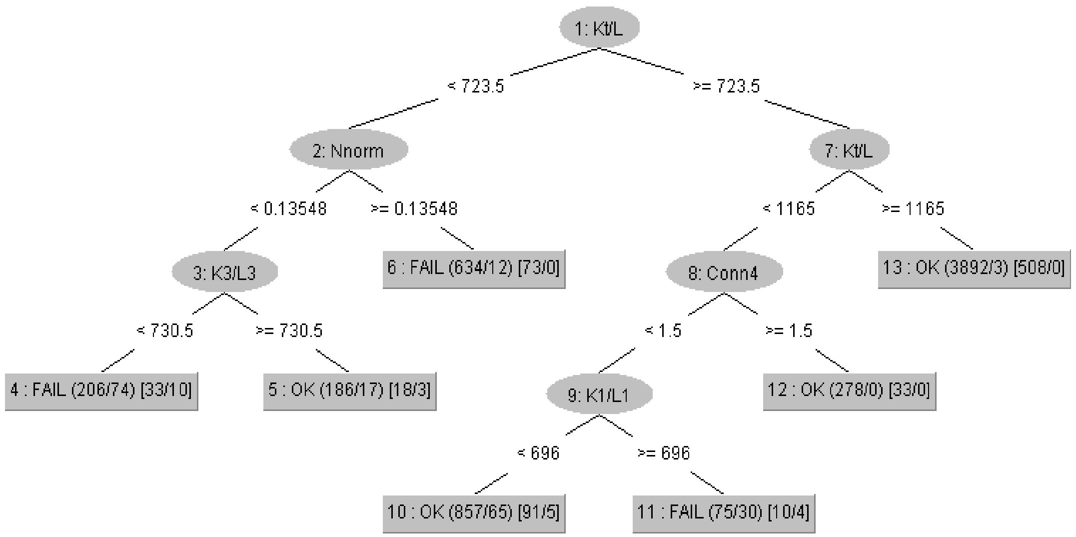
	Pier-deck connections				Flex. Steel (%)						
Id	Gr.1	Gr.2	Gr.3	Gr.4	Gr.1	Gr.2	Gr.3	Gr.4	D (m)	Cost (euros)	Perf. (ecu-ec)
A	2	1	1	1	0.60	1.15	1.55	2.90	1.525	55844	0,0114
B	2	1	1	1	0.60	1.80	2.50	2.45	1.475	59761	0,0117
C	2	1	1	1	0.65	0.85	1.10	2.30	1.3	36588	0,0092
D	1	1	1	2	0.65	1.30	3.20	0.75	1.525	60292	0,0110

- The genetic algorithm's search is not biased by structural design preconceptions and so it is ideal to search different design solutions.
- Two design schema were found in the results with similar performance but different distribution of flexural steel reinforcement between piers.
- The resulting bridges with different design schema have different dynamic behaviour. In one, the irregularity is reduced by reducing the central piers' stiffness, and in the other it is increased which increases the importance of higher vibration modes.



Classification tree

- The genetic algorithm's search analyses many instances, in this case thousands of instances, before reaching a final Pareto front. This generated data can be used to extract information about what variables are critical for the earthquake resistance.
- The use of classification trees are ideal, because the instances from the genetic algorithm are labelled as Ok (Feasible) or Fail (Infeasible), according to their ability to sustain the earthquake action.
- The classification tree chooses the best features to separate the two labels, having found that Kt/L – total stiffness divided by length, Nnorm – reduced axial force and Conn4 – pier/deck connection of the central piers.



Classification tree accuracy

- The tree's accuracy is high with 96% of correctly classified instances. This was attained with relatively shallow depth.

Correctly classified instances	6620	96.03%
Incorrectly classified instances	274	3.97%

- The confusion matrix shows how instances were classified by the trees where each row correspond to a label and each column correspond to how the instances were classified.

a	b	← classified as
838	156	a = Fail
118	5782	b = OK

Thank you for your attention!