Optimization of the seismic design of reinforced concrete bridges using evolutionary algorithms

Overview and application example

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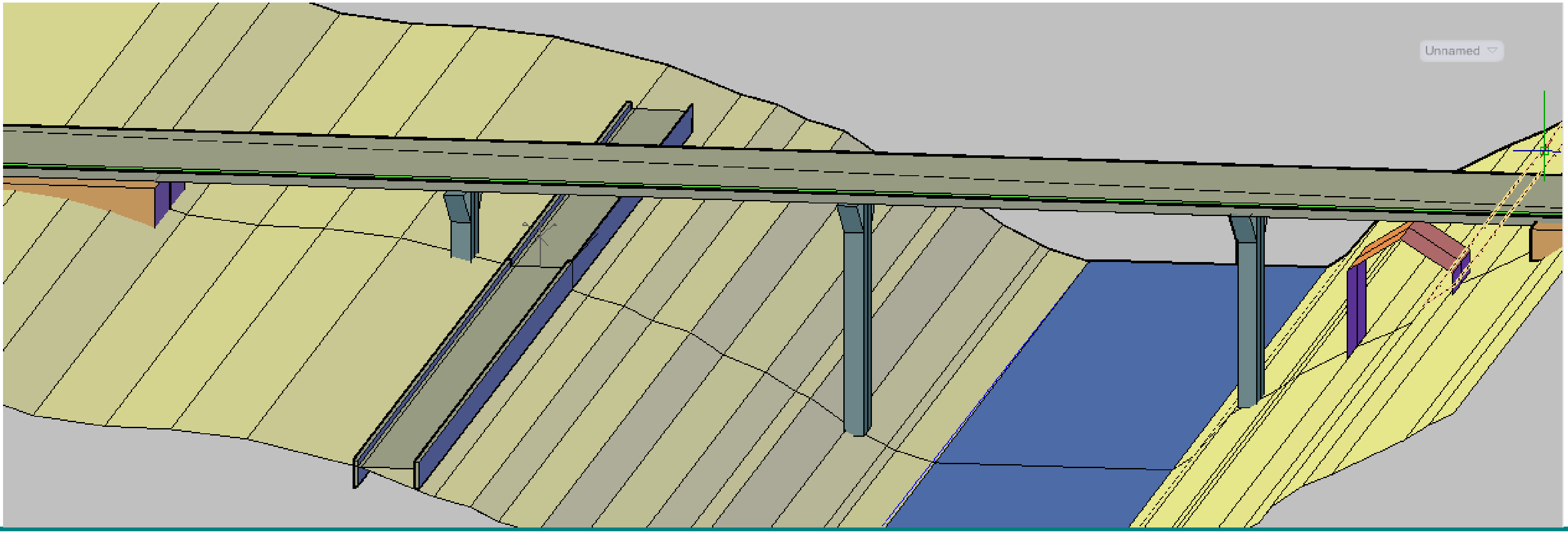


Presentation layout

- Thesis Overview
- Resulting Publications
- Introduction to Structural Optimization using Evolutionary Algorithms (EA) and possible applications
- Example of an EA application from the thesis
- Future Works

Thesis Overview

1. Introduction
2. General concepts of seismic design and ductility of reinforced concrete elements
3. **Seismic structural optimization**
4. **Optimizing earthquake design of reinforced concrete bridges based on evolutionary computation techniques**
5. Revision of behaviour factors
6. **Multivariate analysis of regular and irregular RC bridges and characterization of earthquake behaviour according to stiffness-based indexes**
7. Effect of spatial variability of seismic strong motions on long regular and irregular RC bridges
8. Final Remarks and Future Works

Resulting Publications

Journals:

- Camacho, V. T., Guerreiro, L., Oliveira, C. S., & Lopes, M. (2020). Effect of spatial variability of seismic strong motions on long regular and irregular slab-girder RC bridges. Bulletin of Earthquake Engineering. https://doi.org/10.1007/s10518-020-01002-y
- Camacho, V. T., Horta, N., Lopes, M., & Oliveira, C. S. (2020). Optimizing earthquake design of reinforced concrete bridge infrastructures based on evolutionary computation techniques. Structural and Multidisciplinary Optimization. https://doi.org/10.1007/s00158-019-02407-3
- Camacho, V. T., Lopes, M., & Oliveira, C. S. (2020). Revising seismic behaviour factors for reinforced concrete bridge design in the longitudinal direction using multi-objective evolutionary algorithms. Bulletin of Earthquake Engineering, 18(3), 925–951. https://doi.org/10.1007/s10518-019-00739-5
- Camacho, V. T., Lopes, M., & Oliveira, C. S. (2021) Multivariate analysis of regular and irregular RC bridges and characterization of earthquake behaviour according to stiffness-based indexes. Bulletin of Earthquake Engineering. **Accepted on the 3rd of September 2021.**
- Camacho, V. T., Horta, N. Multiobjective seismic optimization of RC bridges' piers and use of machine learning to obtain surrogate models for structural seismic performance. **Currently under review.**

Conferences:

- Camacho, V. T., Horta, N., Lopes, M. Multiobjective optimization of long irregular RC bridges' piers subjected to strong motions and definition of classification tree surrogate models. 9EWICS, December 2020, Lisbon, Portugal. To be published as a chapter in "Seismic Behaviour and Design of Irregular and Complex Civil Structures IV".

Structural Optimization

- Optimization is about obtaining the best solutions according to our chosen objectives. The choice of the objectives defines the solutions that will be obtained. Optimization does not imply that the obtained solutions have no safety margins.

- How to optimize a problem that does not have an analytical expression and has a non-convex, non-differentiable nature?

- Traditional, gradient-based methods easily get stuck in local optima, or can't deal very well with constraints and discrete variables.

- One possible solution is to resort to metaheuristic optimization methods, such as Evolutionary Algorithms.
  - These algorithms are population-based approaches which allow to deal with multiple contradictory objectives, thus outputting multiple solutions that provide trade-offs between said objectives.

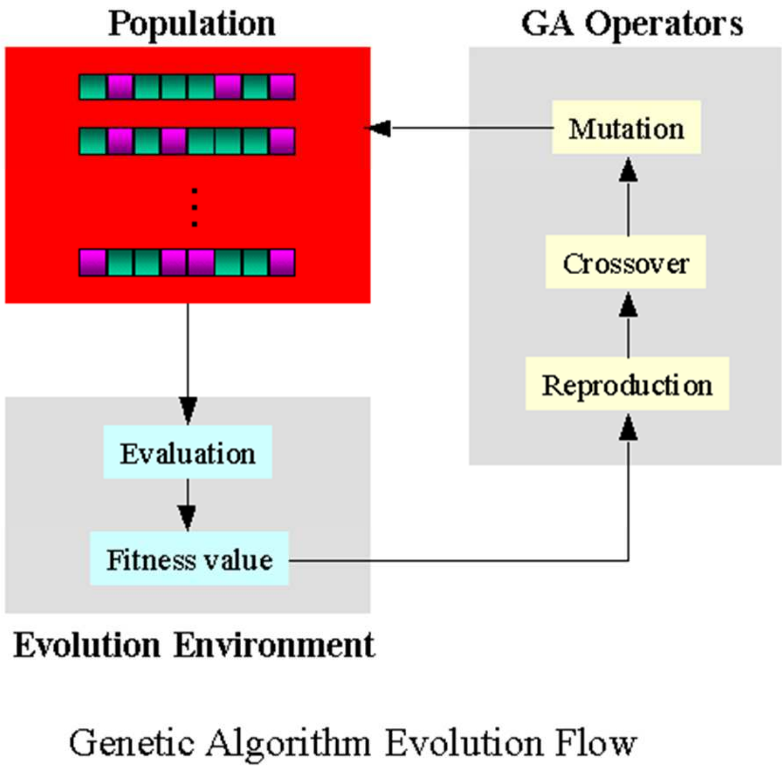
Structural Optimization

$$(MO)\begin{cases} \quad minimize\ f_i(x) \\ subjected\ to\ \begin{cases} g_1(f) \le 0 \\ g_2(x) = 0 \end{cases} \\ L_d \le x_d \le U_d, 1 \le d \le n \end{cases}$$

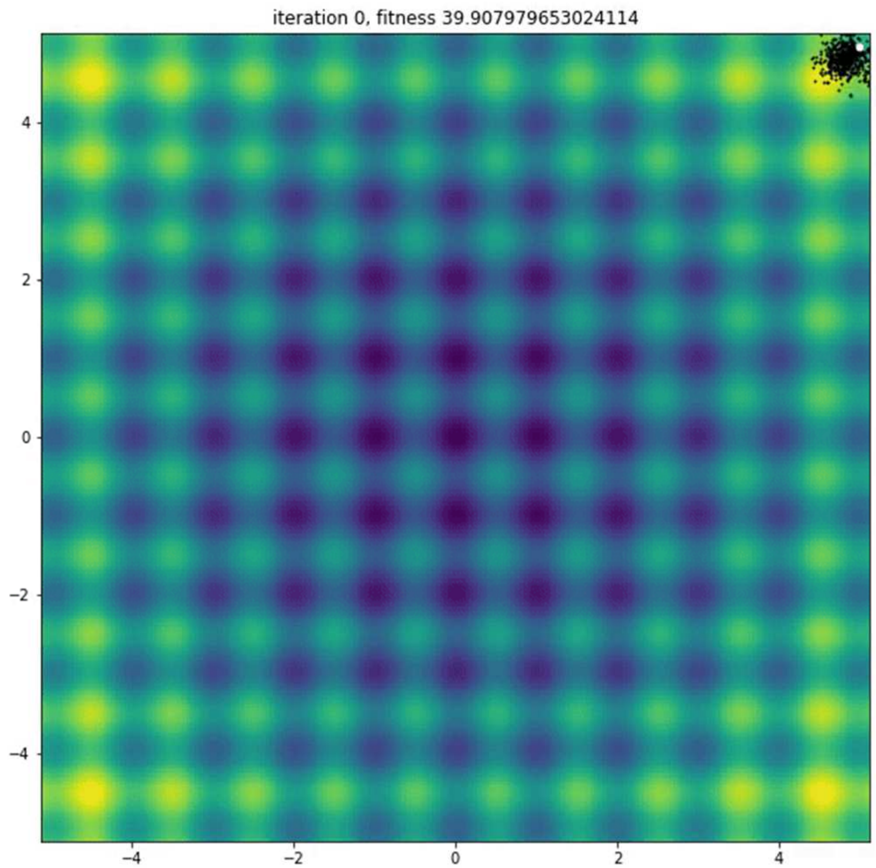
- What constitutes an optimization problem formulation:
  - Objective functions, $f_i(x)$.
  - Equality and Inequality constraints, $g_1(f), g_2(x)$.
  - Decision space – composed by variables with lower and upper boundaries, x_d.

Structural Optimization

Evolutionary algorithms – *Population-based methods inspired by nature*

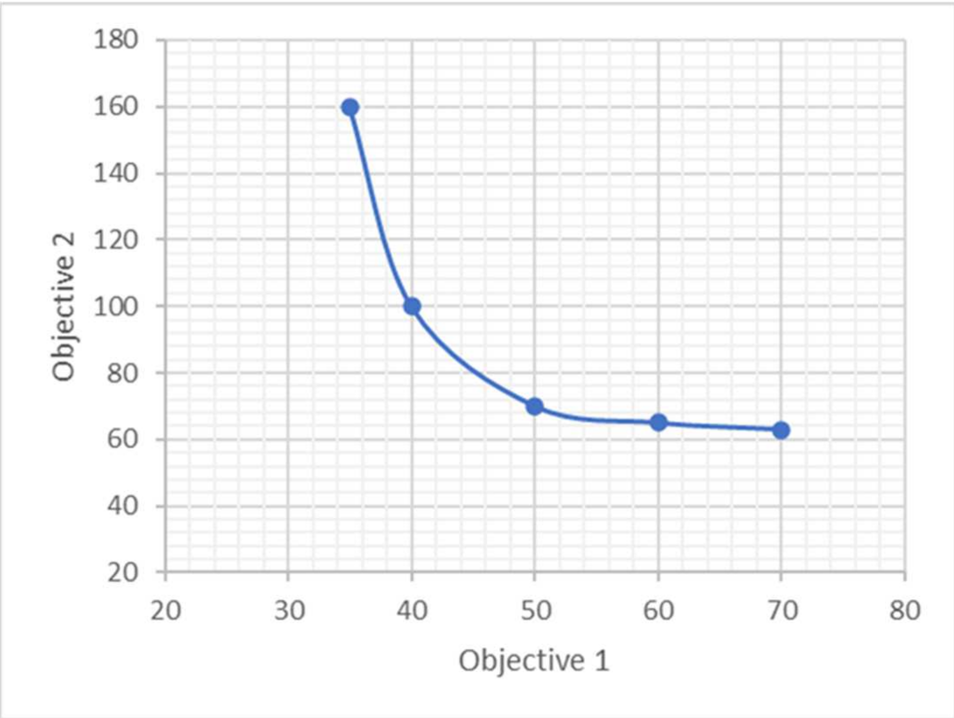


Non-convex objective space – *how population-based solutions converge towards the global optimum.*

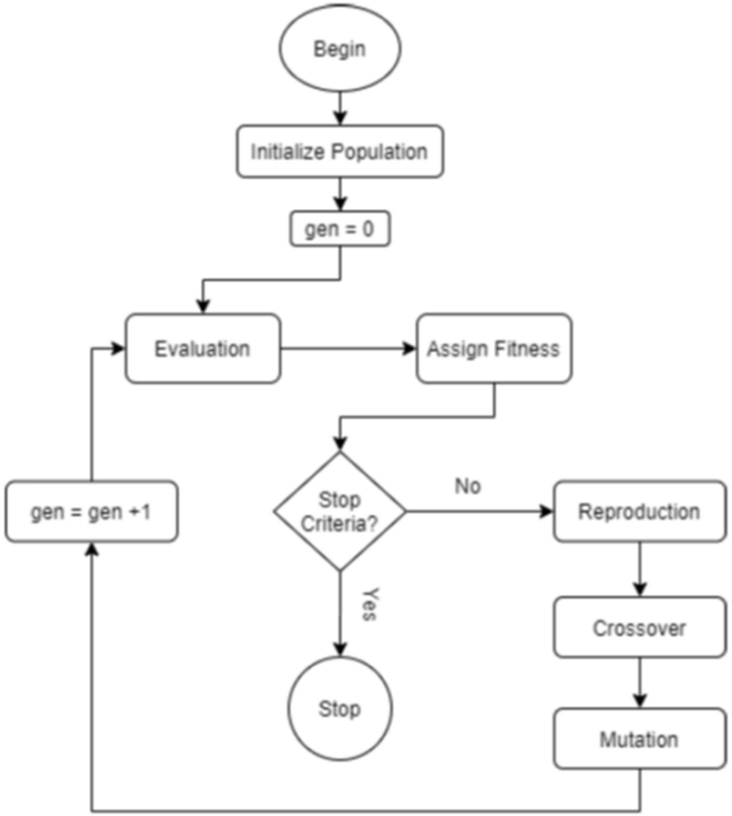


Structural Optimization

Multiobjective optimization – *Pareto fronts and "knee regions"*

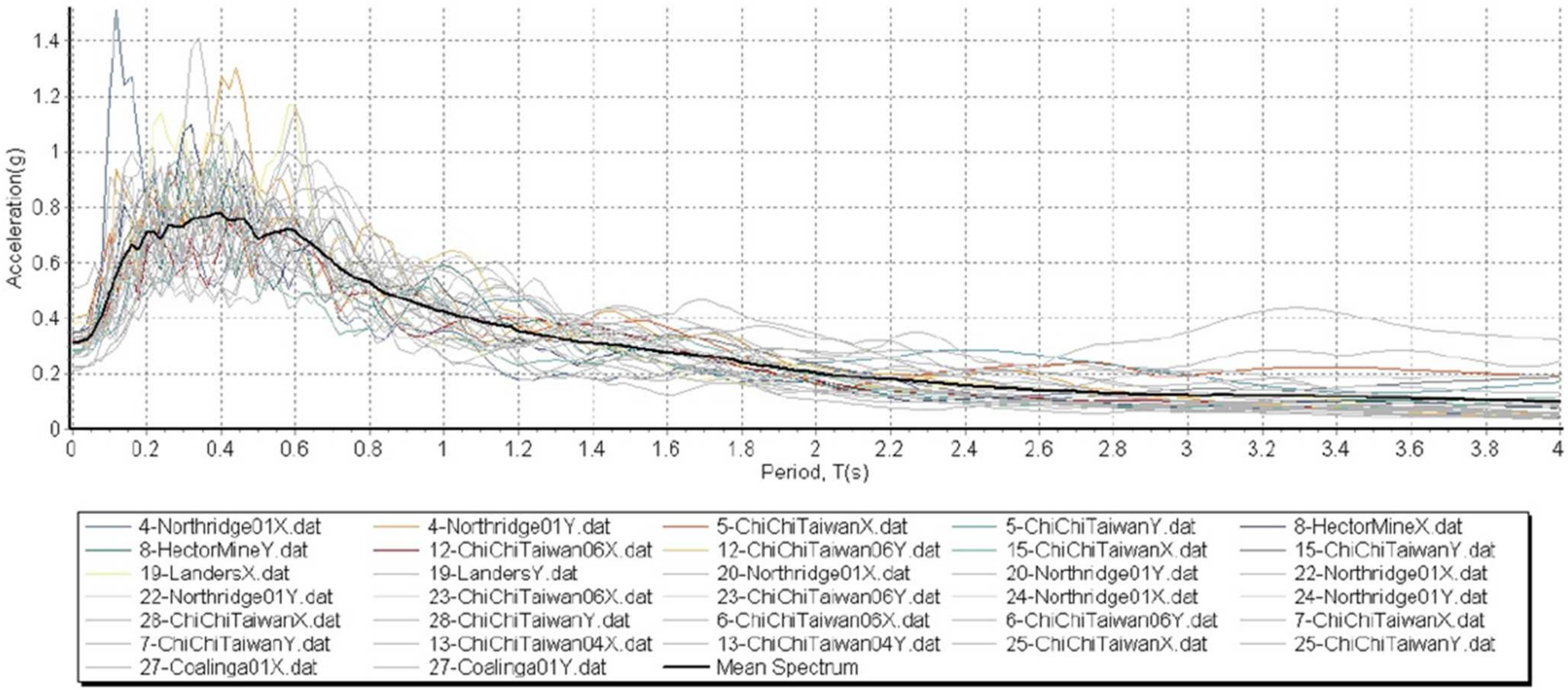


Evolutionary algorithms – *Population-based methods inspired by nature*



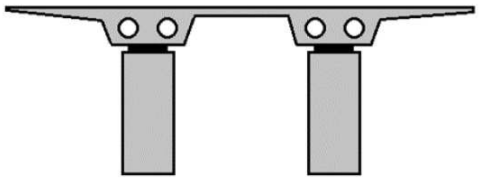
Example of an EA application from the thesis

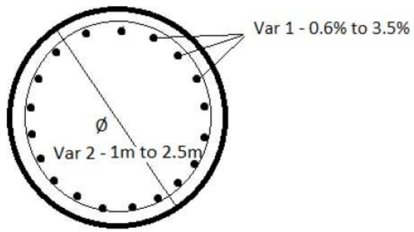
- Initial set of 16 pairs of strong motions scaled and matching design seismic action type 1, zone 2, soil C



Example of an EA application from the thesis

- Case-study to observe the effects of changing pier cross-section variables on the seismic behaviour of long bridges, particularly irregular bridges.

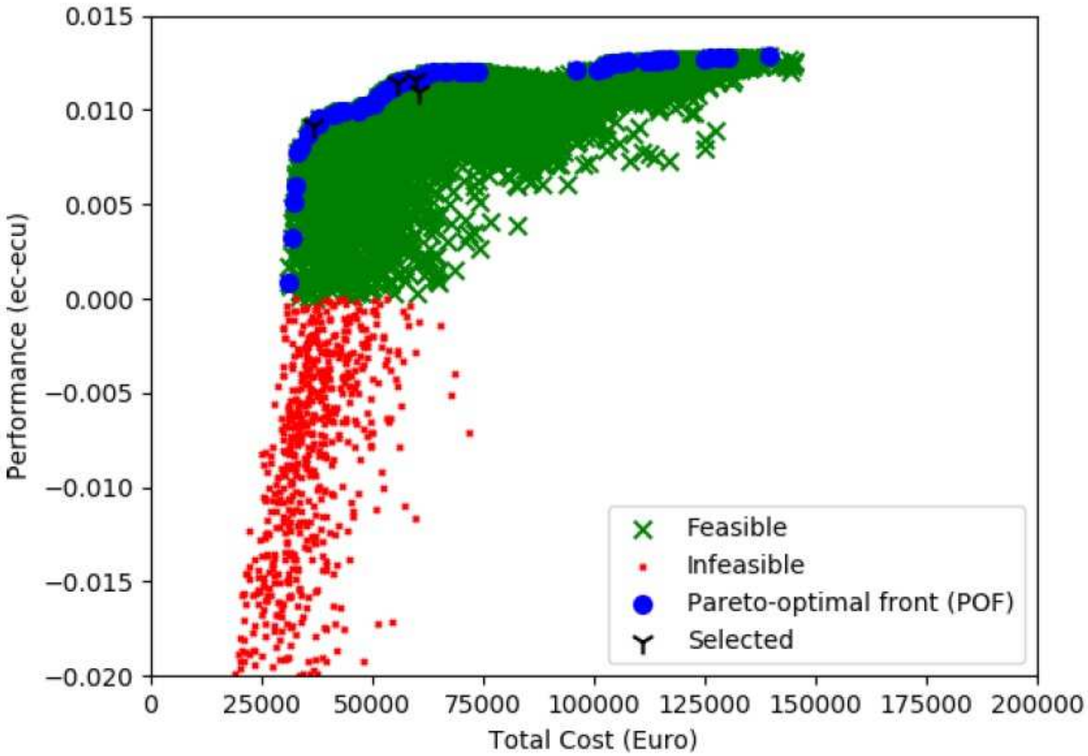




Pier Lengths (m)	Pier Groups
11 11 14 14 11 11 7 7 7 11 11 14 14 11 11	(1 2 14 15) (3 4 12 13) (5 6 10 11) (7 8 9)

Example of an EA application from the thesis

- Optimization run based on performance and cost objectives. The output are different possible design modes, which provide different strategies of design, and show how differential stiffness affects seismic behaviour.



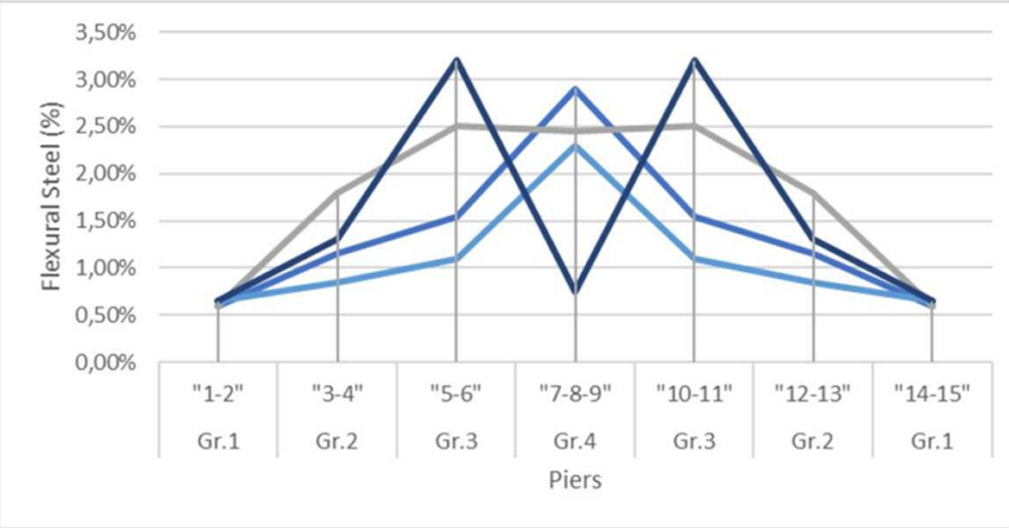
Example of an EA application from the thesis

	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.

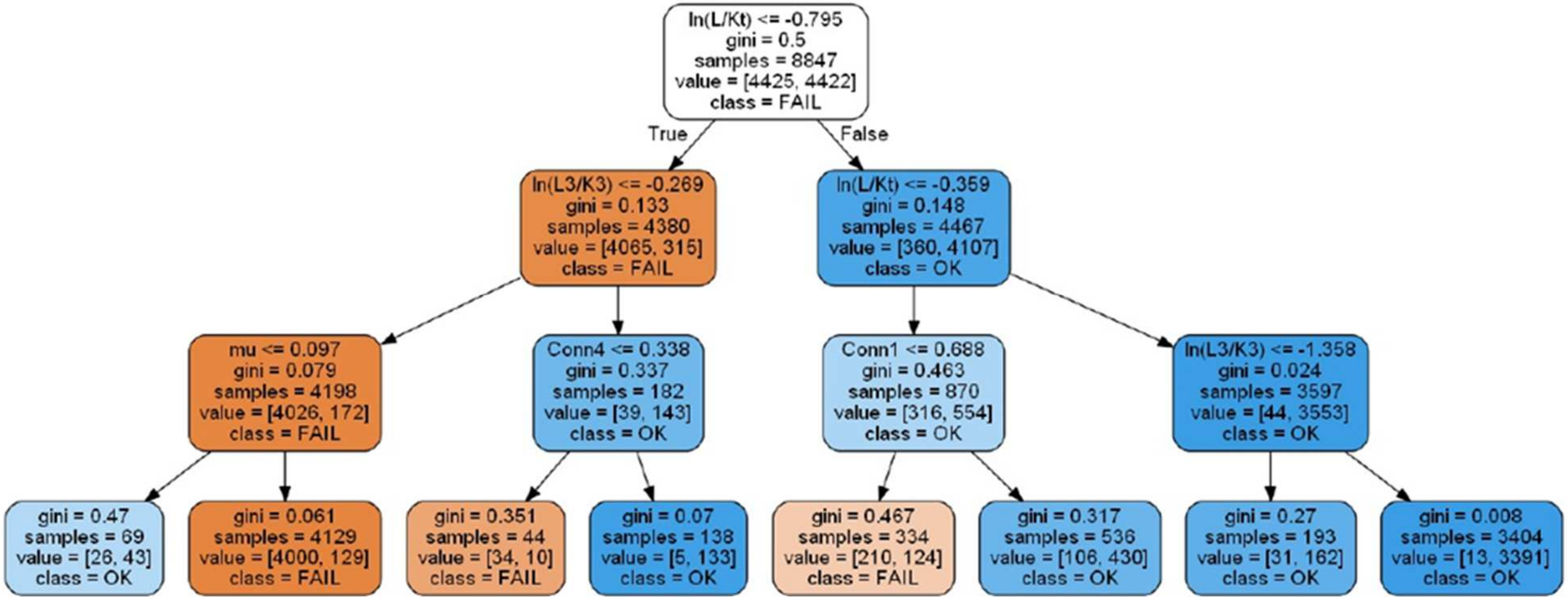


Example of an EA application from the thesis

- 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.

- Many Machine Learning techniques can be employed for this information extraction and also to build **surrogate models**. One of such techniques are **classification trees**.

- The **classification tree** chooses the **best features to separate the two labels/classes (FAIL and OK)**, where ln(L/Kt) is the main one and is a measure of bridge length normalised by the total effective stiffness of the piers.



Future Works

- The **systematic application of these methodologies** and of classification trees and/or other surrogate models in the **analysis of different case studies can be used to compose a set of rules for different bridges**, according to different irregularity layouts and length classifications.
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- The study of **other earthquake intensities** and **performance-based design for other levels of damage** than the collapse prevention level used in this thesis would be of interest and should be studied.
- The study of optimization with the addition of **dissipation devices in bridges**, such as steel hysteretic dampers.
- The application of evolutionary algorithms and other techniques such as machine learning algorithms should also start being applied for **other types of structures and should start to complement more the work of the design engineer**.

Thank you for your attention!