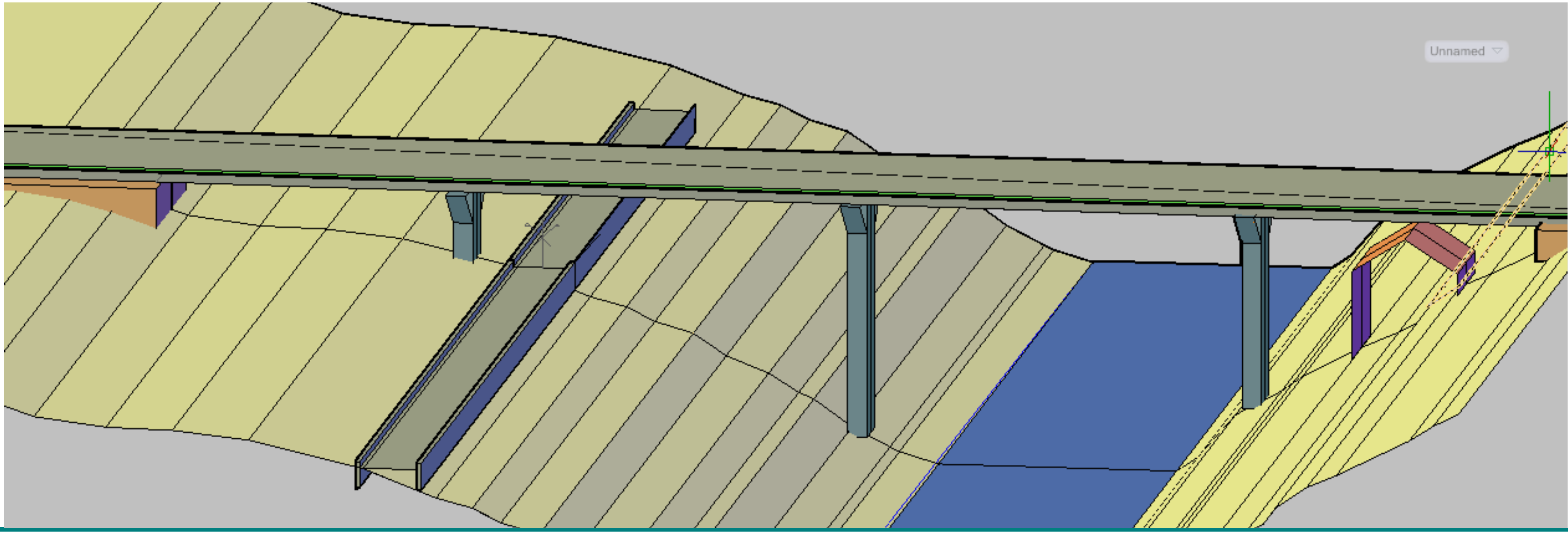
Optimization methodology for the design of reinforced concrete bridge infrastructures based on evolutionary algorithms

Overview of thesis structure, developed work and future work

Vítor Teixeira Camacho – PhD student at Instituto Superior Técnico (IST)
Prof. Mário Lopes – thesis supervisor (IST)
Prof. Carlos Sousa Oliveira – thesis co-supervisor (IST)



Presentation layout

- Thesis overview – Index
- What has been done this past year
- Applications of Multi-Objective Evolutionary Algorithms (MOEA):
    - For irregular bridges, using multiple objective sets
    - For calibration of behaviour factors for seismic design
- What will be done next year

Thesis Index

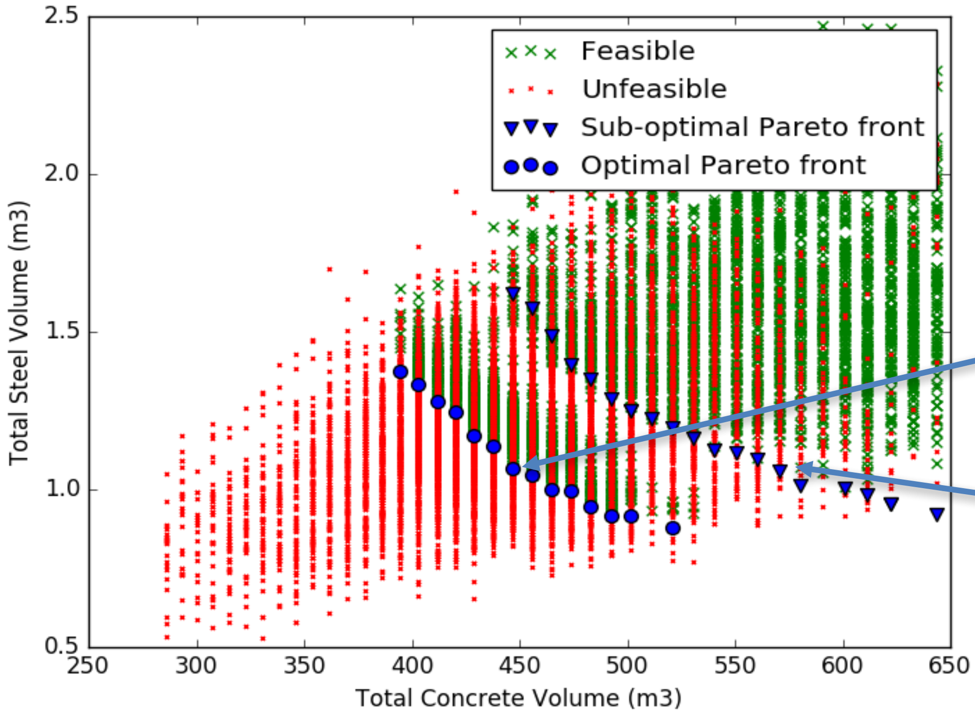
1. Introduction
2. Objectives, bibliography and basic concepts
   - Factors that influence ductility
   - Concepts on short and long bridges
3. Optimization
   - Meta-heuristic optimization algorithms
   - Multi-objective optimization and application to structural engineering
4. Short bridges – longitudinal direction
   - Study on behaviour factors and sensibility analysis of the parameters that influence ductility
   - Normalization/Standardization of irregular bridge design. Limits of redistribution. Design method based on standardization
5. Long bridges – longitudinal + transversal direction
   - Standardization profiles associated to different irregularities.
   - Steel hysteretic dampers
   - IDA and design for different damage states
6. LCA – life-cycle cost assessment? Qualitative criterium analysis. Case-study application
7. Signal compatibility in very long viaducts? Soil heterogeneity?
8. Conclusions.

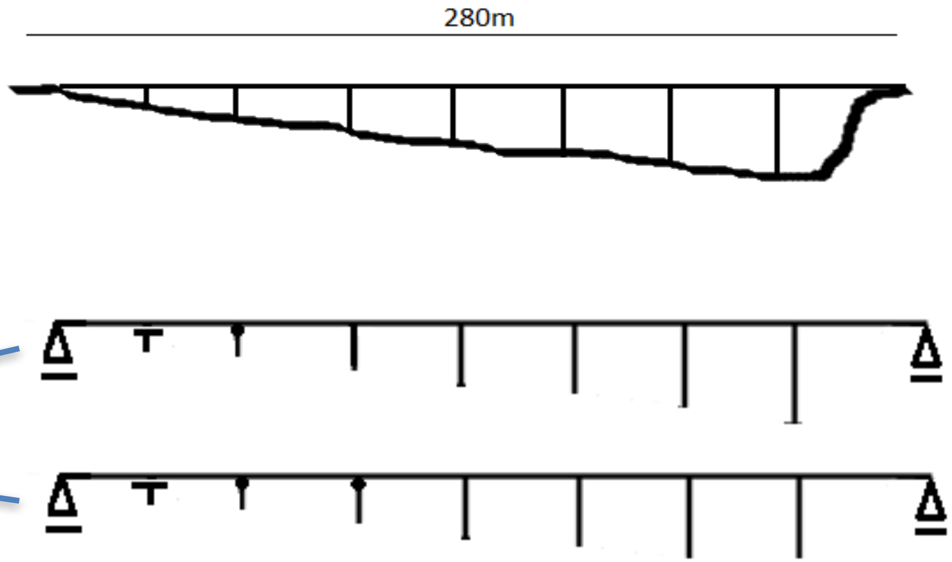
What was done this past year

- Enhancement of the code for structural optimization, with improvement of the algorithm. Course attended on Multi-objective evolutionary algorithms (MOEA)
  - Other algorithms tested besides the NSGA-II, resulting in a modified version of the NSGA-II. Journal paper submitted on application of MOEAs for structural seismic optimization.
- Modification of the code for running in parallel machines and optimization of the procedures in terms of computation overhead – cloud computing
  - This provided a huge speed-up of around 3000% from 3 hours to 6 minutes per generation run, with AMD 1950X processors.
- Application to a case study of an irregular bridge
- Revision of behaviour factors for elastic seismic design with MOEA
- Measuring redistribution limits for steel reinforcement in irregular bridges - standardization
- Final definition of thesis index after the CAT (thesis overview committee) presentation

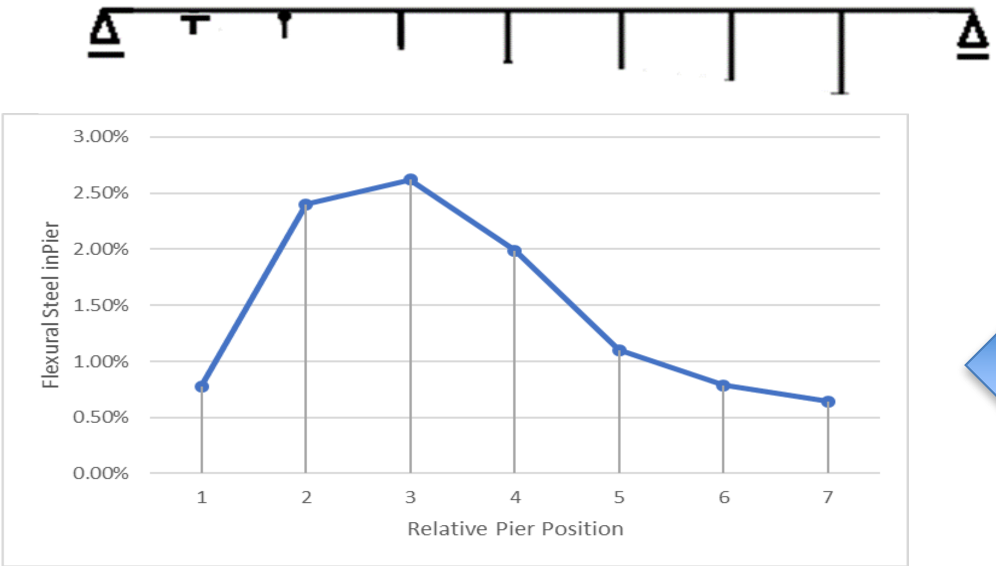
Application of MOEA to a case study of an irregular bridge

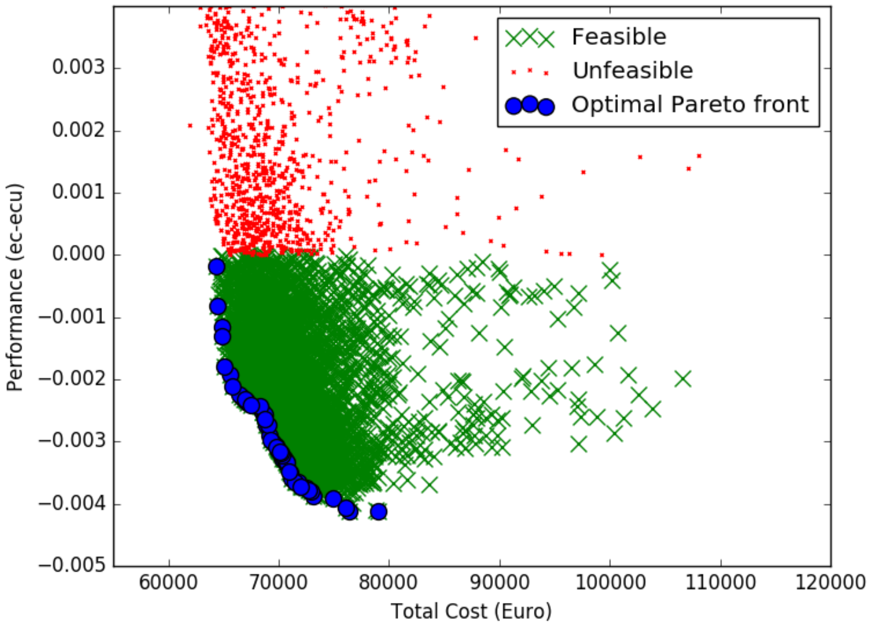
	Pier 1 – 7m	Pier 2 – 9m	Pier 3 – 11m	Pier 4 – 13m	Pier 5 – 15m	Pier 6 – 17m	Pier 7 – 19m
Connection to deck	X1	X2	X3	X4	X5	X6	X7
Longit. Reinf. steel	X8	X9	X10	X11	X12	X13	X14
Section Diameter	X15	X15	X15	X15	X15	X15	X15
Transv. Reinf. steel	X16	X17	X18	X19	X20	X21	X22





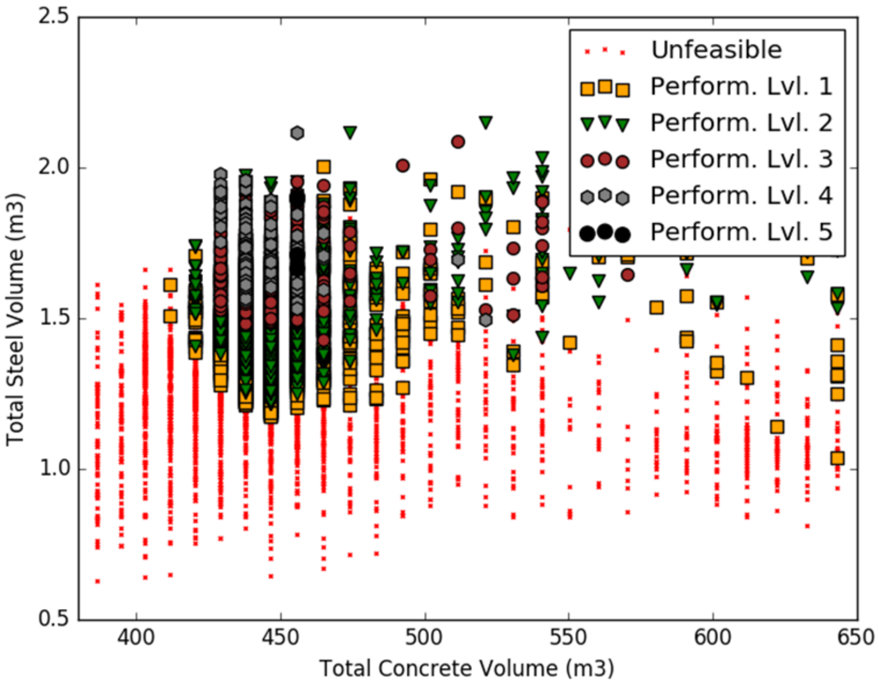
Application of MOEA to a case study of an irregular bridge





- First optimization performed with cost minimization objectives. Results in a set of results with a pattern for all variables.
- Second optimization run with performance objectives and using previous results as starting iteration.

Application of MOEA to a case study of an irregular bridge



	P1	P2	P3	P4	P5	P6	P7
Perform. Lev.(ecu-ec)	CoV Flexural Steel						
0.0-0.0015	41%	23%	13%	17%	35%	36%	42%
0.0015-0.003	52%	24%	15%	18%	38%	46%	38%
0.003-0.0035	51%	25%	13%	17%	35%	45%	42%
0.0035-0.004	51%	28%	9%	19%	29%	39%	41%
>0.004	45%	24%	6%	16%	23%	23%	39%
Perform. Lev.(ecu-ec)	CoV Pier Confinement						
0.0-0.0015	40%	22%	13%	22%	73%	62%	70%
0.0015-0.003	39%	26%	14%	24%	65%	59%	71%
0.003-0.0035	38%	16%	10%	21%	39%	54%	63%
0.0035-0.004	39%	14%	6%	18%	22%	32%	62%
>0.004	38%	9%	2%	12%	10%	26%	40%

- The second optimization run uses the information gain from the first run associated to variable patterns, and optimizes according to performance/risk and cost. The result is a tradeoff between cost and performance/risk
- The entire search space can be divided into performance levels which can then be used to identify critical variables, which vary the least inside each performance level.

Revision of behaviour factors for elastic seismic design with MOEA

- The MOEA procedure can also be applied to calibrate behaviour factors.
- This is done by varying factors that influence ductility and running the optimization procedure.

Concrete	B35	B50	
Pier length (m)	7-7-7	7-11-9	7-14-11
Self-weight (deck) (ton)	3900	6240	
Steel post-yield stiffness (MPa)	1000 (0.5%Es)	3000 (1.5%Es)	
Maximum confinement	ϕ16//10	ϕ16//5	

- The factors were combined to make 24 case-studies
- For each case the optimization variables were the usual associated to pier design: confinement, pier-deck connection, section diameter and flexural reinforcement steel

Revision of behaviour factors for elastic seismic design with MOEA

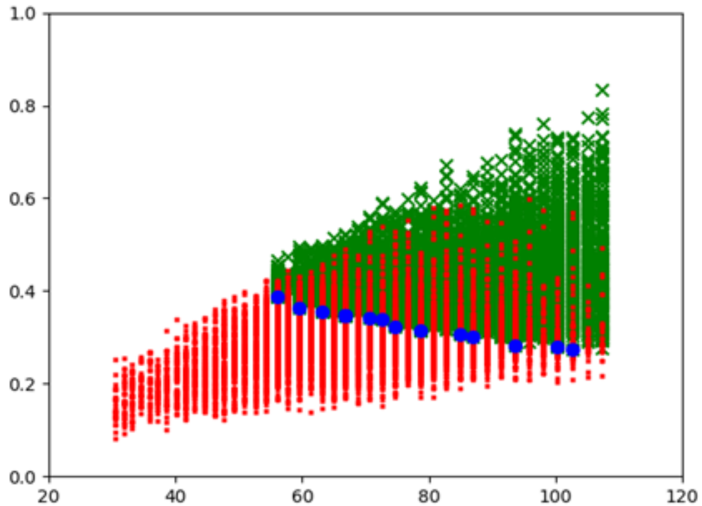
- The optimization procedure simultaneously maximizes available ductility and ductility demand. The optimized solutions correspond to maximum behaviour factors for each particular case-study.

- In the end the solutions obtained with the optimization procedure, calculated with non-linear analysis methods, are checked with elastic analysis.

- The result of the elastic analysis is compared with the real capacity curve and the behaviour factors calculated.

Revision of behaviour factors for elastic seismic design with MOEA

- Example: pier lengths 7m-11m-9m, B35 concrete, 3900-ton deck, max confinement ϕ16//5 and 1000MPa post-yield steel stiffness



flex. steel(cm2)	D(m)	Ftot_Resist	F Inertia_eff	F Inertia_elast	q_Ec8	q_eff	q_elast	μ	EC8 Ductility class	ecu1	Ry	Sdt	Ru	qdy=Sdt/Ry	qeff/qdy
752.1	1.2	4826.7	10660.3	14153.6	**3.5**	**2.21**	**2.93**	23%	Ductile	-0.0221	6.98	**18.53**	**18.73**	2.655	0.832
693.4	1.25	5059.9	11130.8	15357.6	**3.5**	**2.20**	**3.04**	21%	Ductile	-0.0215	6.48	**17.5**	**17.74**	2.701	0.815
603.9	1.3	5050.8	11418.3	16610.8	**3.5**	**2.26**	**3.29**	19%	Ductile	-0.0210	6.23	**16.69**	**16.99**	2.679	0.844
536.8	1.35	4936.7	11336.7	17913.1	**3.5**	**2.30**	**3.63**	18%	Ductile	-0.0205	5.74	**16.53**	**16.74**	2.880	0.797
484.9	1.4	4972.9	11507.5	19264.6	**3.5**	**2.31**	**3.87**	17%	Ductile	-0.0201	5.24	**16.01**	**16.25**	3.055	0.757
437.6	1.45	4978.9	11634.4	20665.2	**3.5**	**2.34**	**4.15**	16%	Ductile	-0.0197	4.75	**15.5**	**15.75**	3.263	0.716
379.9	1.5	4940.7	11746.1	22114.9	**3.5**	**2.38**	**4.48**	15%	Ductile	-0.0193	4.25	**15**	**15.25**	3.529	0.674
365.3	1.525	4983.5	11861.0	22858.2	**3.47**	**2.38**	**4.59**	14%	Ductile	-0.0191	4	**14.75**	**15**	3.688	0.645

- Simillar results were obtained for other 23 combinations of initial variables associated to ductility: pier normalized axial force; concrete quality; steel post-yield stiffness; pier irregularity; concrete confinement; flexural steel ratio

What will be done next year

- Performing optimization runs for other case studies representing different irregularity profiles.
- Performing optimization resorting to steel hysteretic dampers for case-study of long bridge with short central piers. Comparing with optimization without steel hysteretic dampers.
- Optimization design performed for several damage states. Special emphasis on Eurocode directives for seismic service limit states with reduced behaviour factors. Comparing elastic design with design obtained through optimization with non-linear analysis.
- Optimization design for multiple earthquake intensities. Incremental dynamic analysis.
- Signal compatibility for very long viaducts, especially with soil variation. Importance of such issues on design.

Thank you for your attention!