# Non linear probabilistic analysis of reinforced concrete structures

**Jose Campos e MATOS**
PhD Student / Lecturer
Minho University
Guimaraes, Portugal
*jmatos@civil.uminho.pt*

Jose Matos, born 1979, received the civil engineering degree from University of Porto. Within cooperation between Porto and Catalonia University, obtained the degree of MSc in civil engineering. PhD student and Lecturer at School of Engineering of University of Minho.

**Isabel Brito VALENTE**
Assistant Professor
Minho University
Guimaraes, Portugal
*isabelv@civil.uminho.pt*

Isabel Valente, born in 1974, graduated and concluded the MSc in civil engineering, at Porto University. Obtained PhD in civil engineering at University of Minho. Is Assistant Professor at School of Engineering of University of Minho. Works with composite structures.

**Paulo Sousa CRUZ**
Full Professor
Minho University
Guimaraes, Portugal
*pcruz@arquitectura.uminho.pt*

Paulo Cruz, born in 1964, graduated in civil engineering and concluded the MSc in civil engineering, by the Porto University. Obtained the PhD in civil engineering at University of Catalonia. Full Professor at School of Architecture of University of Minho.

## Resume

When evaluating the behaviour of a reinforced concrete structures it is, in many situations, desirable to develop a non linear numerical analysis, due to the non linearity of the behaviour of existent materials. On other way, and in order to consider the uncertainty of main parameters, probabilistic techniques should be also introduced on such kind of analysis, leading so to a full probabilistic non linear analysis. This analysis is divided on following steps: 1) Develop a numerical model; 2) Execute a sensitivity analysis to identify critical structural parameters; 3) Determine a random distribution function and correlation coefficient between each parameter; 3) Develop a full probabilistic non linear analysis; 4) Determine the probabilistic density function for both numerical and experimental results; 5) Calculate approximation index ($\theta$), which relates the proximity of both results. In this paper this analyses is realized using SARA platform, which is a combination of software ATENA (non linear structural analysis software) [1] and FREET (reliability analysis software) [2, 3].

Such analyzes falls upon the evaluation of the behaviour of two batches of reinforced concrete beams, tested, in laboratory, up to failure. Those beams intend to represent real reinforced concrete structures, like bridges, in which this analysis can be applied. The first batch of laboratory tested beams were four point loaded, till failure. The test scheme, present at Figure 1, was also the same for all beams. Although the repeatability of developed tests is achieved, each beam presents a specific longitudinal reinforcement and space between transversal reinforcement, belonging so, to one particular typology. Four different typologies are studied within this paper. The second battery of laboratory tested beams, simply supported in one side and partially clamped on the other, were loaded, in laboratory, till failure. The test scheme, present at Figure 1, was the same for all beams. Although the repeatability of developed tests is achieved, each beam presents a specific longitudinal reinforcement, space between transversal reinforcement and longitudinal concrete cover, belonging so, to one particular typology. Taking this into consideration, tested beams were divided by typologies. In this paper it is analyzed one specific typology.

A deterministic numerical model is firstly developed, calibrated and simplified. A sensitivity analysis, with the aim of identifying most important parameters, is then executed. Afterwards, and once characterized the probabilistic density function and the correlation coefficients of those parameters, a full probabilistic non linear analysis is developed. From such analysis, the probabilistic density function of each output parameter is obtained. Experimental data was grouped by beam typologies and characterized by a probabilistic density function also. The approximation

index ($\theta$), which characterizes, in a more rigorous way, the approximation between both curves, is then defined. Table 1 and 2 presents the results obtained from such analysis for the case of simply supported and mixed supported beams, respectively.
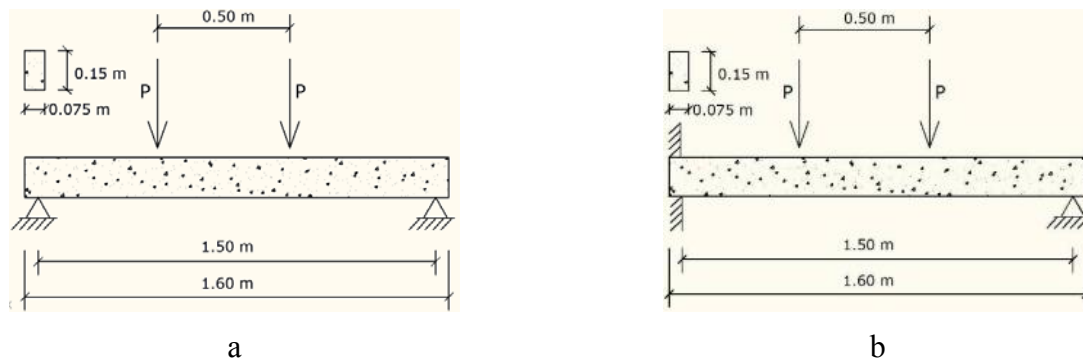


Fig. 1: Scheme of laboratory tests: a) Simply supported beams b) Mixed supported beams.

Table 1: Results from probabilistic non linear analysis of simply supported beams.

| Typology | Experimental failure load [kN] | | | Numerical failure load [kN] | | | Approximation index ($\theta$) |
|---|---|---|---|---|---|---|---|
| | Distribution law | Average value [kN] | Standard deviation [kN] | Distribution law | Average value [kN] | Standard deviation [kN] | |
| 1 | Normal | 24.805 | 0.247 | Normal | 24.572 | 1.028 | 0.220 |
| 2 | Normal | 29.983 | 1.333 | Normal | 28.606 | 1.191 | 0.772 |
| 3 | Normal | 41.278 | 4.522 | Normal | 36.642 | 3.568 | 0.807 |
| 4 | Normal | 44.007 | 2.104 | Normal | 37.863 | 3.613 | 1.473 |

Table 2: Results from probabilistic non linear analysis of mixed supported beams.

| Parameter | Experimental data | | | Numerical results | | | Approximation index ($\theta$) |
|---|---|---|---|---|---|---|---|
| | Distribution law | Average value | Standard deviation | Distribution law | Average value | Standard deviation | |
| Failure load [kN] | Normal | 29.390 | 1.598 | Normal | 30.013 | 1.918 | 0.250 (-) |
| Bending moment [kN.m] | Normal | 6.904 | 0.674 | Normal | 4.346 | 1.856 | 1.299 |

Main conclusions of this analysis are: 1) The applicability of the developed method through the analysis of the behaviour of reinforced concrete structures, as bridges; 2) The comparison between numerical and experimental data, using this method, is made in a consistent way, as the variability of most important parameters is considered; 3) For these two batches of tested beams, the obtained numerical results are near the experimental data; 4) In some situations, like the ones related to shear failure modes, even in the presence of a detailed numerical model, the variability of responses is so high that it is very difficult to evaluate the structural behaviour.

## References

[1]     ČERVENKA, V., "Computer simulation of failure of concrete structures for practice", *Proceedings of the 1st fib Congress Concrete Structures in 21 Century*, Osaka, Japan. 2002, pp. 289 - 304.

[2]     NOVÁK, D., VOŘECHOVSKÝ, M. and RUSINA, R. "Small-sample Probabilistic Assessment – Software *FReET*", *Proceedings of ICASP 9*, San Francisco, USA, 2003, pp. 91 – 96.

[3]     PUKL, R., JANSTA, M., ČERVENKA, J., VOŘECHOVSKÝ, M., NOVÁK, D. and RUSINA, R. "Spatial variability of material properties in advanced nonlinear computer simulation", *Proceedings of the EURO-C Conference*, Mayrhofen, Austria, 2006, pp. 891 – 896.