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PROGRESSIVE COLLAPSE ASSESSMENT INCLUDING RATE SENSITIVITY

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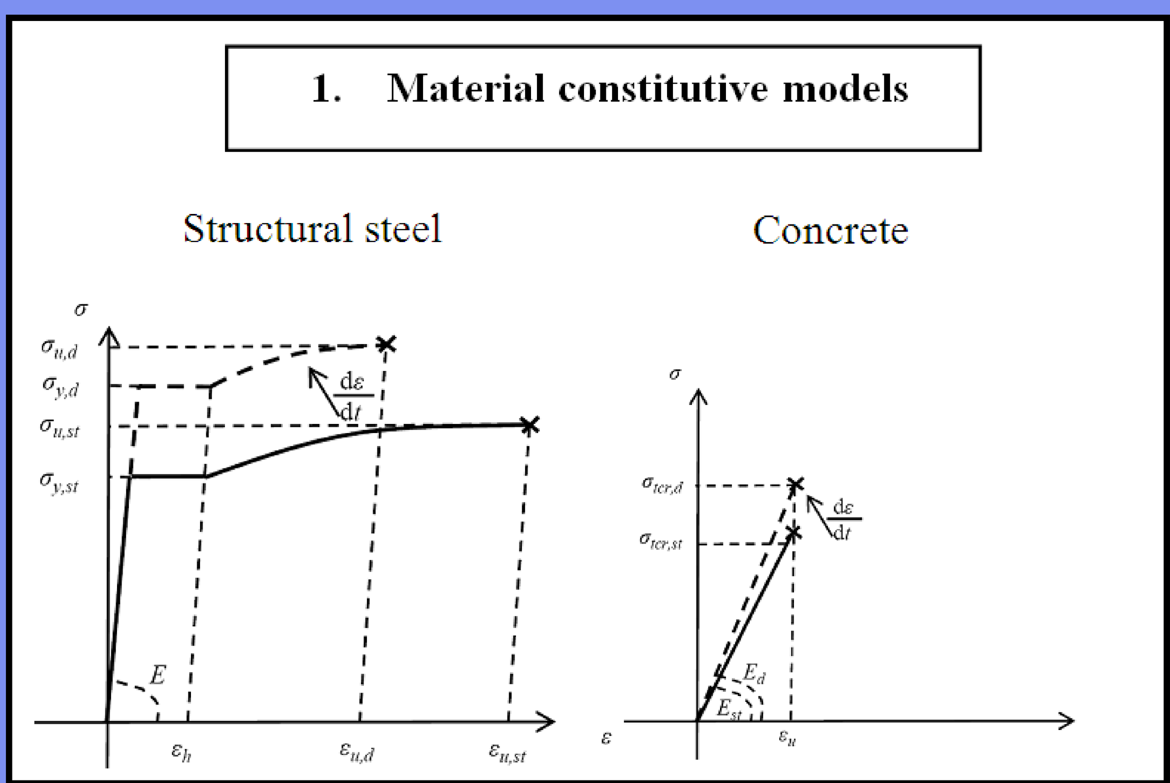
INTRODUCTION

Nearly a decade after the historical event of the collapse of the WTC towers in New York, the understanding of progressive collapse of tall buildings has greatly evolved. A design-oriented framework for design against progressive collapse of such structures has been proposed by Izzuddin *et al.*, which, for the first time, quantitatively considered ductility, redundancy and energy absorption in a structural system affected by a sudden column loss. However, the original framework ignored the change in material behaviour for such a short duration scenario.

MATERIAL RATE SENSITIVITY

Structural materials such as concrete and steel present a rate sensitivity to their stress-strain behaviour (Figure 1).

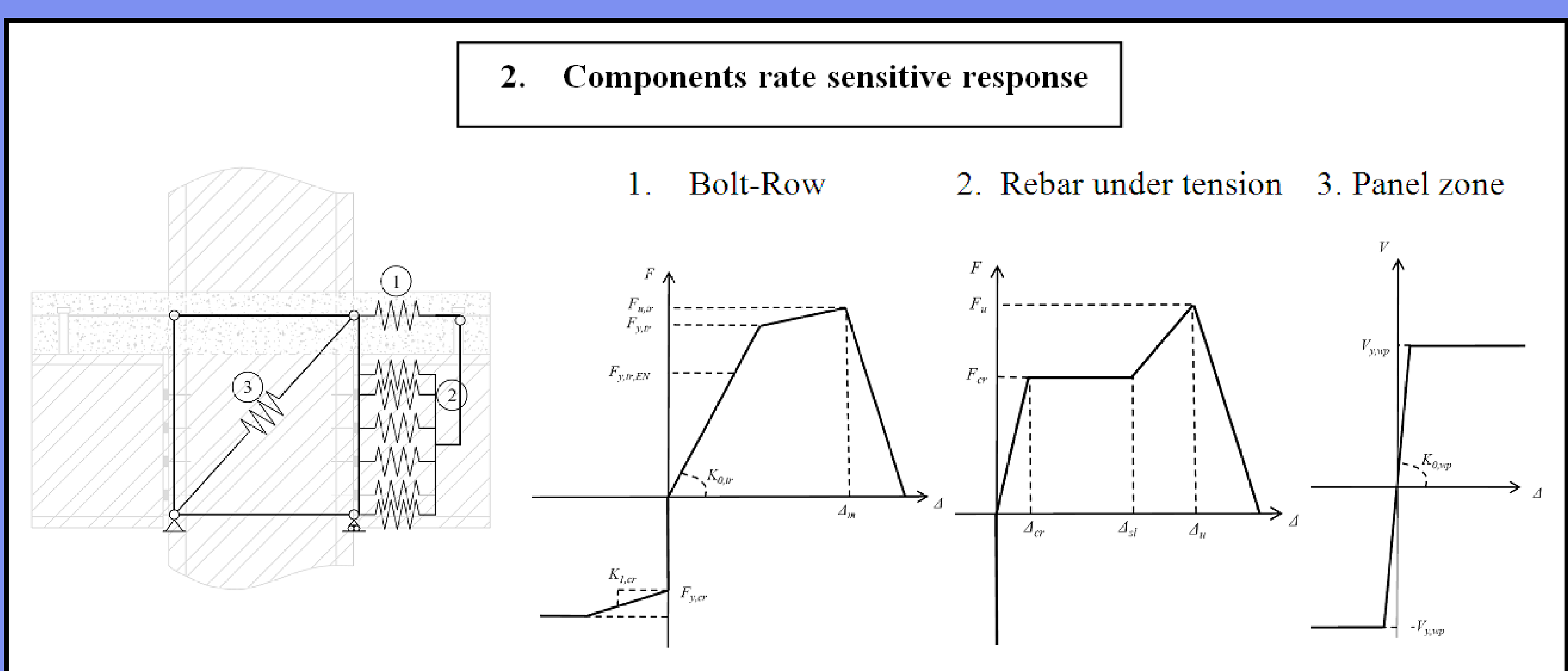
Rate sensitivity in concrete is restricted to viscoelasticity, showing an increase in the tensile and compressive strengths with strain rate. Steel also experiences an increase of yield and ultimate strengths, though this is accompanied with a reduction in material toughness with strain rate, leading to a decrease in the ultimate strain.



COMPONENT RATE SENSITIVITY

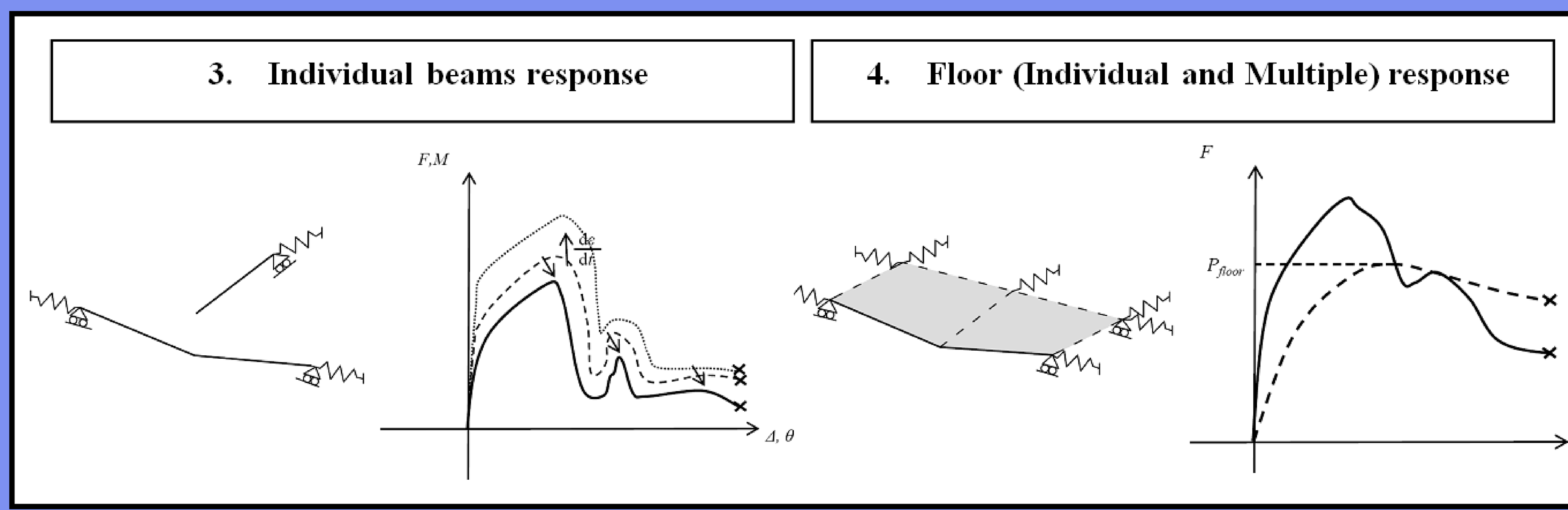
Steel and composite structures with partial-strength connections experience great rotations in their joints in order to achieve large displacements. Joint rotation capacity is, in its turn, a function of the ductility of components. Hence, there is a need to account for rate sensitivity in a scenario where component ductility may be drastically reduced due to steel ultimate strain rate sensitivity.

Joint modelling follows the component method from the Eurocode 3 with consideration of the full nonlinear rate sensitive response for each component (Figure 2).

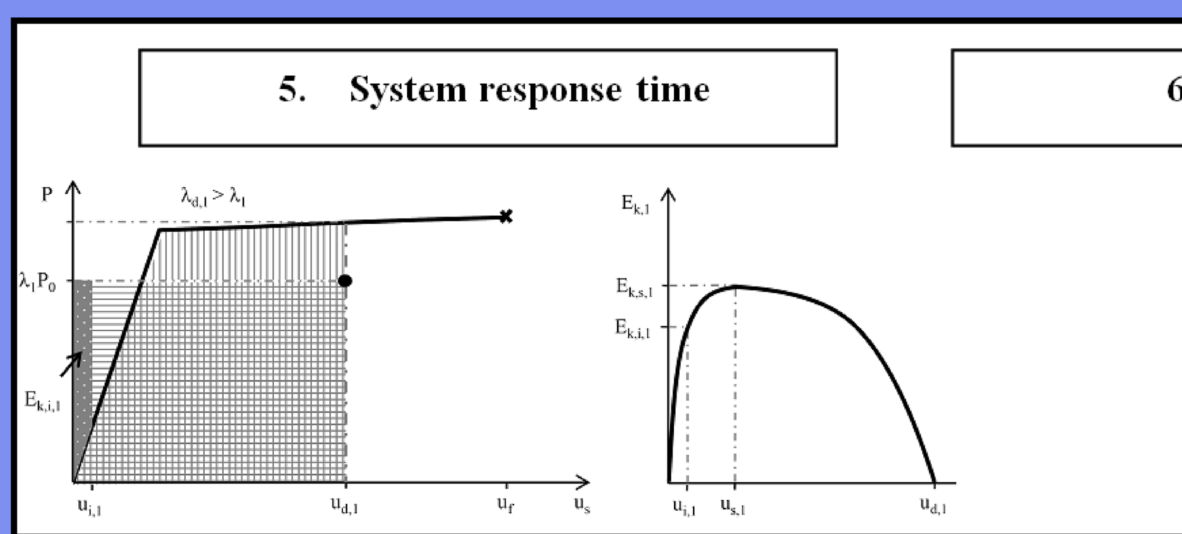


MULTI-LEVEL MODIFIED FRAMEWORK

The original framework defines the principles of sub-structuring the multiple floors above the lost column into lower levels of idealisation that can be successively assembled in a simplified manner based on energy balance (Figures 3 & 4).



In order to account for material rate sensitivity, the total time to arrest the dynamic deformation is also required. This should be performed at the highest level of structural idealisation, utilising time prediction techniques based on the kinetic energy profile of the overall structure (Figure 5).The maximum rate sensitive pseudo-static capacity of the structure can at the last stage be compared to the service load in order to verify the safety against progressive collapse (Figure 6).



$$P_{floor} > \gamma_{DL} DL + \gamma_{LL} LL$$

APPLICATION STUDY

The demonstration of rate sensitivity effects on structural robustness is undertaken for the benchmark application study of Vlassis *et al.*, which is a seven storey office building subjected to a sudden peripheral column loss. The results show a residual increase of 5% in average in the structural load capacity when accounting for rate sensitivity. However, since the modified framework considers the joint ductility implicitly in the component response instead of using the original rational maximum rotation approach, in the end an average 20% lower overall structural load capacity is estimated, highlighting the insufficiency of current code design provisions against progressive collapse.

CONCLUSIONS

The analysis of the rate sensitive response of a structural system undergoing a gravity-driven loading revealed the significance of over strength and ductility reduction in the component response and its repercussions on the overall structural response. The importance of connection optimisation for robustness design is also emphasised by parametric variation of the joint configuration. This has motivated the proposal of an experimental validation of component rate sensitivity to be shortly undertaken in collaboration with the University of Trento.

REFERENCES

Izzuddin, B.A., Vlassis, A.G., Elghazouli, A.Y., and Nethercot, D.A. (2008). *Progressive Collapse of Multi-Storey Buildings due to Sudden Column Loss – Part I: Simplified assessment framework.* Engineering Structures. Vol. 30, 1308-1318.

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