UNIVERSIDADE FEDERAL DO CEARÁ

UFOP, Departamento de Engenharia Civil
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PROGRAMA DE PÓS GRADUAÇÃO EM ENGENHARIA CIVIL

Nonlinear Multi-Scale Finite Element Modeling of the Progressive Collapse of Reinforced Concrete Structures

Lecture 1: Introduction

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CAPES

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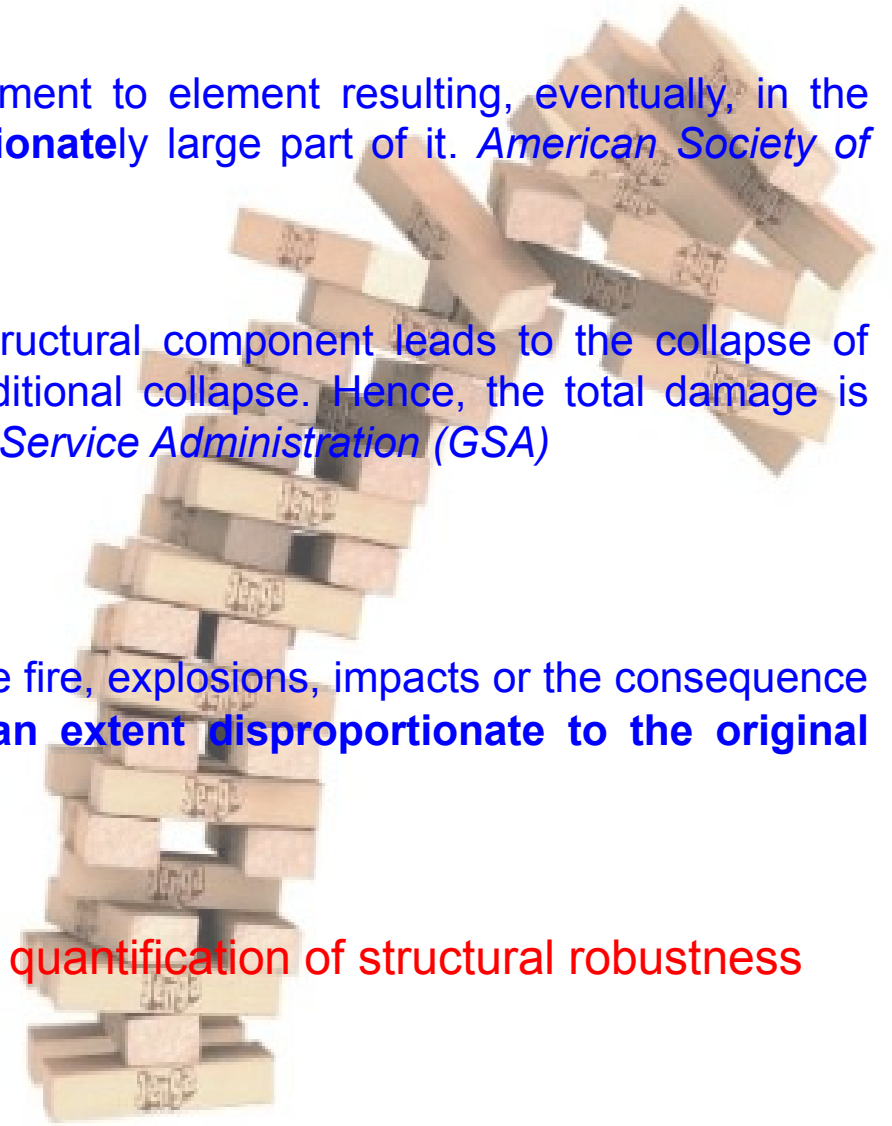
Progressive Collapse? Robustness?

Progressive collapse (PC):

The spread of an **initial local failure** from element to element resulting, eventually, in the collapse of an entire structure or a **disproportionate**ly large part of it. *American Society of Civil Engineers (ASCE)*

A situation where **local failure** of a primary structural component leads to the collapse of adjoining members which, in turn, leads to additional collapse. Hence, the total damage is **disproportionate** to the original cause. *General Service Administration (GSA)*



Structural robustness:

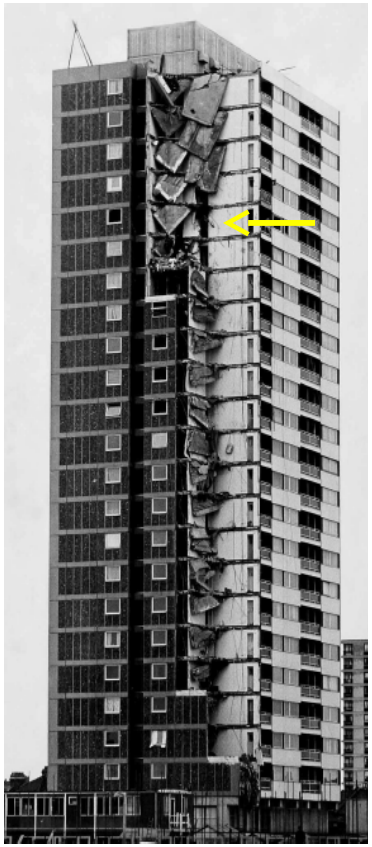
The ability of a structure **to withstand events** like fire, explosions, impacts or the consequence of human error, **without being damaged to an extent disproportionate to the original cause**. *Eurocodes*

Fundamental need:

In-depth understanding of PC, assessment, quantification of structural robustness and safety

Progressive Collapse? Robustness?

Progressive Collapse - Examples



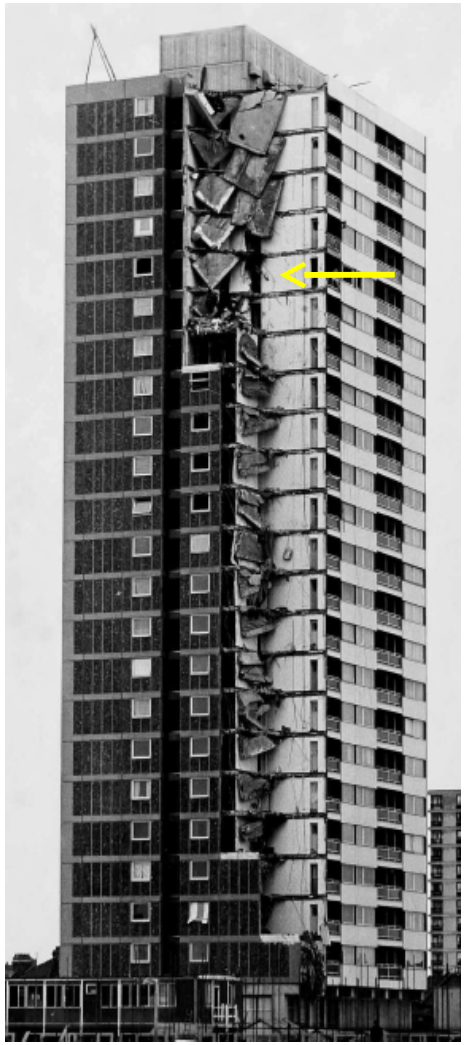
[Gas explosion, Ronan Point building, London, UK, 1968]

[Bomb attack, A.P. Murrah Federal Building, Oklahoma City, USA, 1995]

[WTC debris, Bankers Trust Building, New-York, 2001]

[The Real Class Building, Belém, Brazil, 2011]

Progressive Collapse - Characteristics



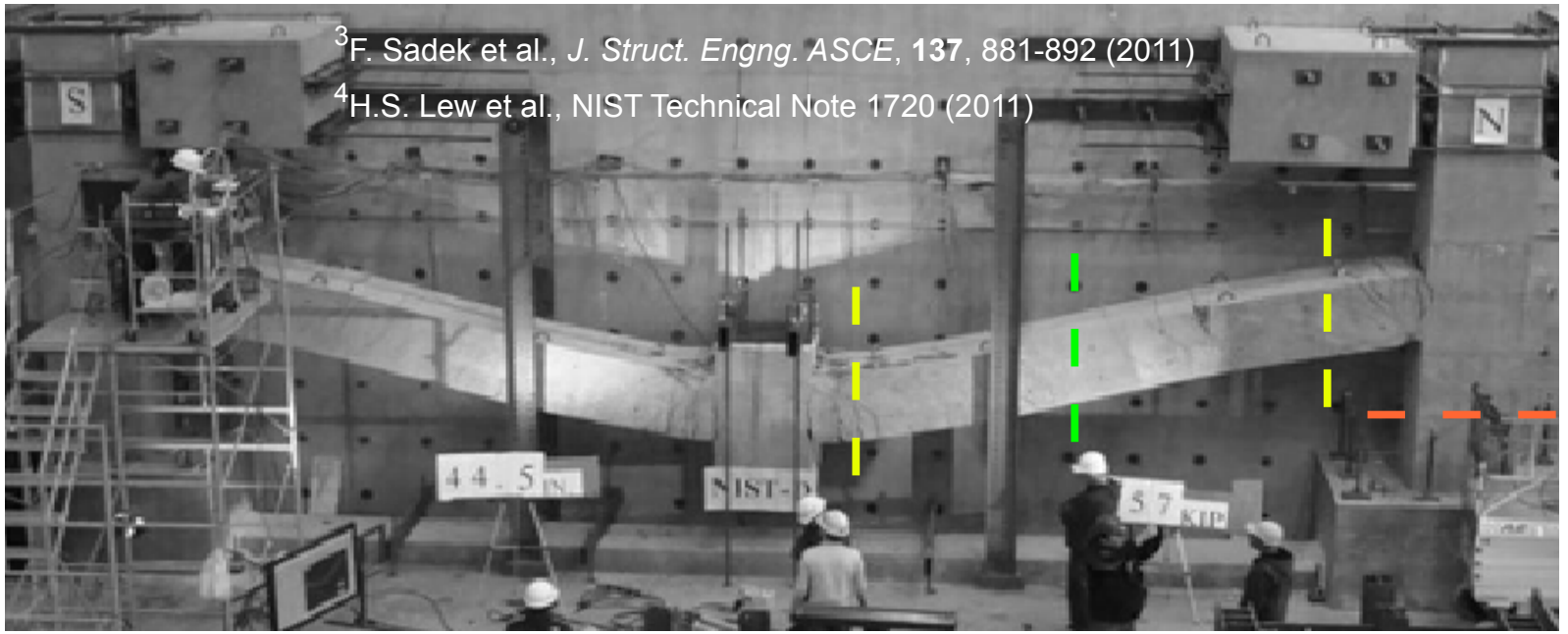
[Gas explosion, Ronan Point building, London, UK, 1968]

- Non-proportional (nonlinear - NL) material response
  - Permanent (plastic) deformation
  - Damage, cracking, failure
- Composite material ("microstructural" influence)
- Large changes in geometry (geometrical NL)
- Dynamics, high load rates, cyclic loads
- Highly **complex interaction of sources of NL**
- High number of design and material parameters
  - Concrete and steel grades
  - Reinforcement ratio and position
- Very high experimental costs...

⇩

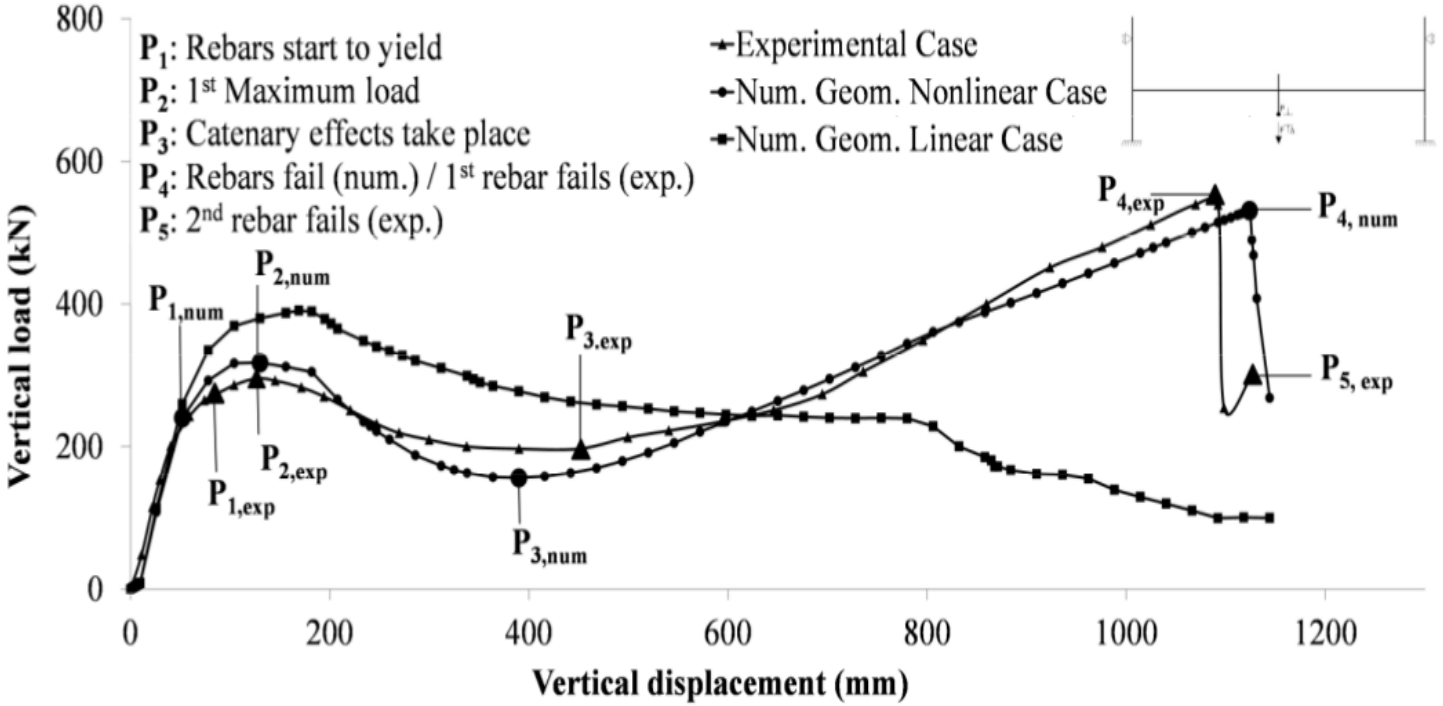
Computational simulation of the PC of structures, **using physically-based models** for an in-depth understanding of PC and for the quantification of structural robustness

Example of nonlinear structural response



[3] F. Sadek et al., *J. Struct. Engng. ASCE*, **137**, 881-892 (2011)

[4] H.S. Lew et al., NIST Technical Note 1720 (2011)



Course objectives and targeted competencies

- Awareness of computational approaches in Civil Engng.
- Understanding main principles of nonlinear modeling
- Get a glimpse of multi-scale approaches and applications
- Identify the limit of applicability of the proposed methods
- Develop a critical mind to computational results

Remarks

- Advanced topic subject of ongoing research
- This course is only an introduction
- There is **no** stupid question, interaction is crucial
- Constructive suggestions are welcome

Recommended literature

O.C. **Zienkiewicz and** R.L. **Taylor**, The Finite Element Method. **Volume 1**: The Basis. Butterworth-Heinemann, Linacre House, Jordan Hill, Oxford OX2 8DP, 225 Wildwood Avenue, Woburn, MA 01801-2041, England, 2000.

O.C. **Zienkiewicz and** R.L. **Taylor**, The Finite Element Method. **Volume 2**: Solid Mechanics. Butterworth-Heinemann, Linacre House, Jordan Hill, Oxford OX2 8DP, 225 Wildwood Avenue, Woburn, MA 01801-2041, England, 2000.

M.A. **Crisfield**, Non-linear Finite Element Analysis of Solids and Structures **Volume 1**: ESSENTIALS. John Wiley & Sons Ltd. Bafins Lane, Chichester West Sussex PO19 IUD, England, 1991.

B.S. Iribarren, P. Berke, Ph. Bouillard, J. Vantomme, T.J. Massart, Investigation of the influence of design and material parameters in the progressive collapse analysis of RC structures, *Engineering Structures*, Vol. 33, page 2805-2820, 2011.

J.-M. Battini, Corotational beam elements in instability problems, *Ph.D. Thesis*, Royal Institute of Technology, Department of Mechanics, Stockholm, Sweden, 2002.

C.E.M. Oliveira, A.G. Marchis, P.Z. Berke, R.A.M. Silveira, T.J. Massart, Computational analysis of a RC planar frame using corotational multilayered beam FE, correlated to experimental results, In Proceedings of XXXIV CILAMCE, 13 pages, 2013

Course planning

1. Newton-Raphson solution procedure for NL equations

   Global structure of a NL FE code

2. 1D computational plasticity

   Constitutive behavior and its numerical treatment

3. Geometrically NL Bernoulli beam FE

   Need for and treatment of geometrically NL framework

4. Introduction to multi-scale simulations

   Applied to composite Bernoulli beam

5. Applications – computer labwork