Structural conception and COllapse control performance based DEsign of multistory structures under aCcidental actions CODEC

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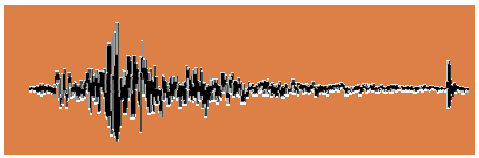


Design for reducing risk of collapse

- Modern society less and less accepts risk in civil engineering, but is not ready to increase the amount of funds to ensure a higher safety level to people (for new constructions, maintenance and strengthening of existing construction works)
- Robustness is an important issue

"A structure shall be designed and executed in such a way that it will not be damaged by events such as: explosion, impact, and the consequences of human errors, to an extent disproportionate to the original cause" - EN 1990

"The selected design situations shall be sufficiently severe and varied so as to encompass all conditions that can reasonably be foreseen to occur during the execution and use of the structure" - EN 1990

This Principle indirectly introduces the responsibility of the designer.

Accidental actions

- Natural hazards:
  - earthquake, wind, snow, temperature – beyond the code provisions
- Abnormal actions:
  - Fire, gas explosion, blast, impact or collision
  - Design / construction error
  - Occupant misuse

Consequences of localised failure

Gas explosions

Gas explosions

Gas explozion

- Four days ago a bog explosion in a block of flats
- Heavy damages, four walls have been completely removed injuries

Accidental explosion

- A truck loaded with 20 tons of ammonium nitrate rolled over.
- Soon after the accident, the truck caught fire, so the driver immediately called the emergency number.
- A small explosion took place in the cabin of the truck, followed 2 minutes later by a larger explosion, killing 7 firefighters, the TV crew, several villagers, and the truck driver, totaling 18 people. The explosion left behind a 6,5 m deep crater and 20 wide.

Views after the explosion

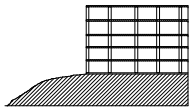
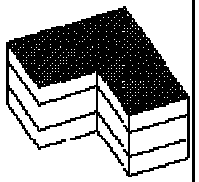
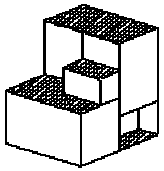
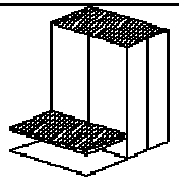
- Two adjacent buildings
  - 120x80m, 13.0m height
  - 180x80m, 9.5m height
- Snow drifting
- Accumulation up to 4.0m of snow
- Undrifted snow 1.0m
- Very large deformations of the roof, purlins and panels severely damaged
- Structural collapse prevented

- Snow was removed from the roof in the drifted area
- Repairing, upgrading necessary:
  - Purlins will be replaced
  - Panels will be replaced or strengthened
  - Local strengthening at main girders

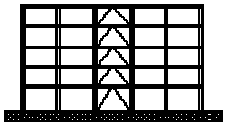
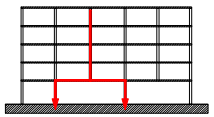
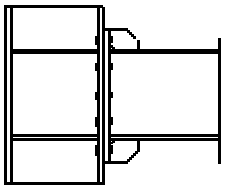
Identified problems

- There are no specific Guidelines for Robustness Performance Assessment of Buildings in Eurocodes
- Approaches in material related Eurocodes are different/absent
- EN1990, EN 1991-1-7 try to ensure robustness through accidental design situations
- CEN/TC 250 decided in 2009 to form an ad-hoc group on "Robustness", due to the concerns related to the limitations of the Eurocode provisions.
- The harmonised material is expected to be incorporated in the period 2013-2015

Multi-hazard design matrix

Site and building characteristics			Hazard					Interaction
			Seismic	Flood	Wind	Fire	Explosion	
1	Elevated building site		-	+	0	0	+	Highly beneficial for floods and external bomb explosion, not significant for wind or fire
2	Re-entrant corner plan forms		-	0	-	0	-	Stress concentration at corners, irregular behavior in case of earthquakes; localized wind pressures, amplification of shock wave in case of external blast
3	Very irregular buildings		-	0	-	-	-	Indirect load paths, stress concentrations in earthquakes, explosions. Localized high wind pressure, aggravates evacuation in case of fire
4	Large roof overhangs		-	0	-	-	-	Vulnerable to earthquakes (vertical motion), wind and also adjacent external blast. Mai pose risk also in case of fire evacuation

Multi-hazard design matrix

Site and building characteristics			Hazard					Interaction
			Seismic	Flood	Wind	Fire	Explosion	
5	Steel structural frame		+	+	+	-	+	When properly detailed, is recommended in seismic and high-wind zones. Good in flood with proper detailing. Vulnerable to fire if is not protected or well detailed and designed. Low vulnerability in case of blast and explosion, offers multiple paths.
6	Indirect load path		-	0	-	-	-	Very vulnerable for seismic, wind and explosion hazards because poor structural integrity increases likelihood of collapse. Fire may further weaken structure.
7	Ductile detailing of structure and connections		+	0	+	+	+	Provides good plastic response. The structure has large ductility and is more resistant to collapse in case of extreme loading

Strategies for risk mitigation

$$\lambda_{Collapse} = P(Collapse|D)\, P(D|H)\, \lambda_{H}$$

- Control occurrence of hazard
- Design structural elements to withstand load from hazard
- Design structural system to absorb local damage without collapse

Control hazard

$$\lambda_{Collapse} = P(Collapse|D)\, P(D|H)\, \lambda_{H}$$

- Limit access – stand-off distances
- Provide protective barriers, shields
- Install annunciators
- Install active control systems
- Minimize fuel loads
- Proscribe hazardous materials

Design key structural elements

$$\lambda_{Collapse} = P(Collapse|D)\, P(D|H)\, \lambda_{H}$$

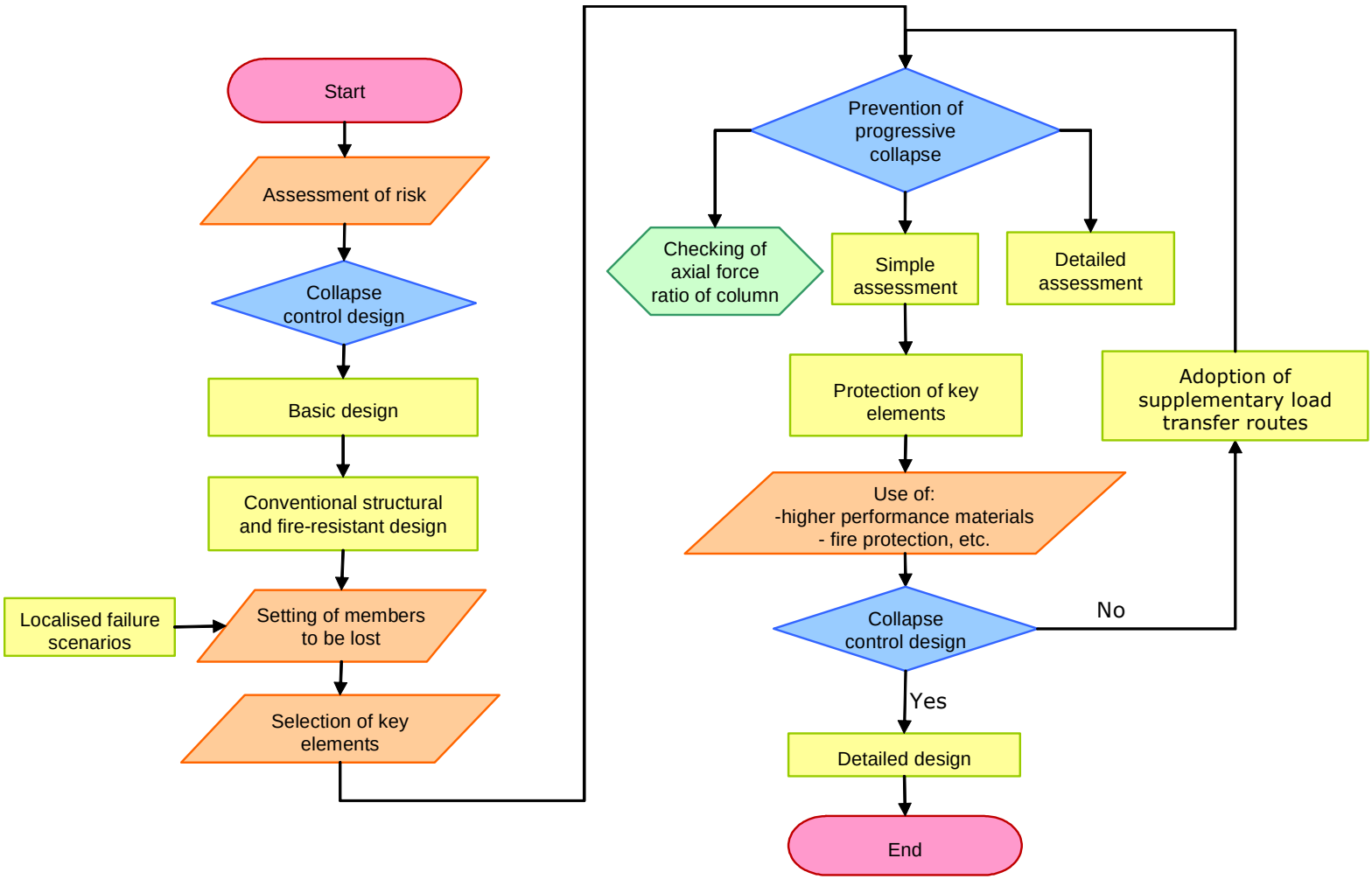
- Normative abnormal loads to prevent failures of essential structural elements
- Permit development of alternate paths

Design members to absorb damage

$$\lambda_{Collapse} \approx P(Collapse|H)\,\lambda_{H}$$

- Redundancy/overall stability
- Connectivity
- Ductility
- Shear strength
- Capability to withstand load reversals
- Compartmentation

Collapse control design flowchart



Research project CODEC

Title:
Structural conception and COllapse control performance based DEsign of multistory structures under aCcidental actions, 2012 – 2015, Contract no. 55/2012

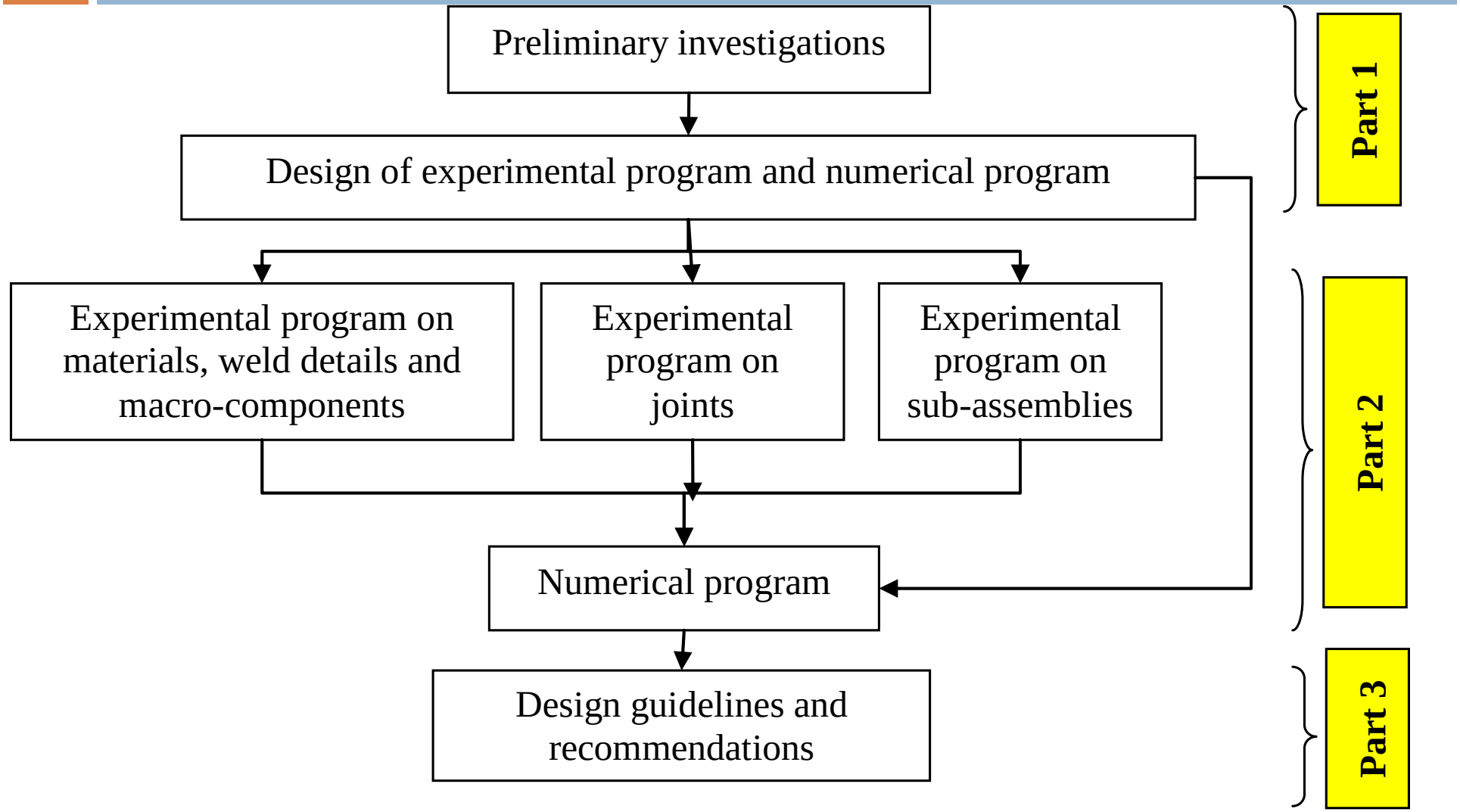
- Funded by The Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI), Romania
- Period: July 2012 – June 2015
- Budget: 600 k euro

Structural conception and COllapse control performance based DEsign of multistory structures under aCcidental actions, 2012 – 2015, Contract no. 55/2012

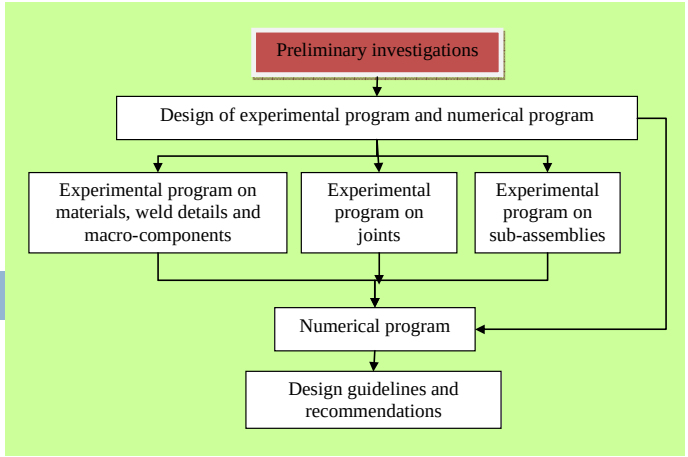
Partners

- Politehnica University of Timisoara - coordinator
- Tehnical University of Cluj Napoca
- URBAN-INCERC
- The National Institute for Research and Development in Mine Safety and Protection to Explosion : INCD – INSEMEX
- SC ACI CLUJ SA

Research plan



Preliminary investigations

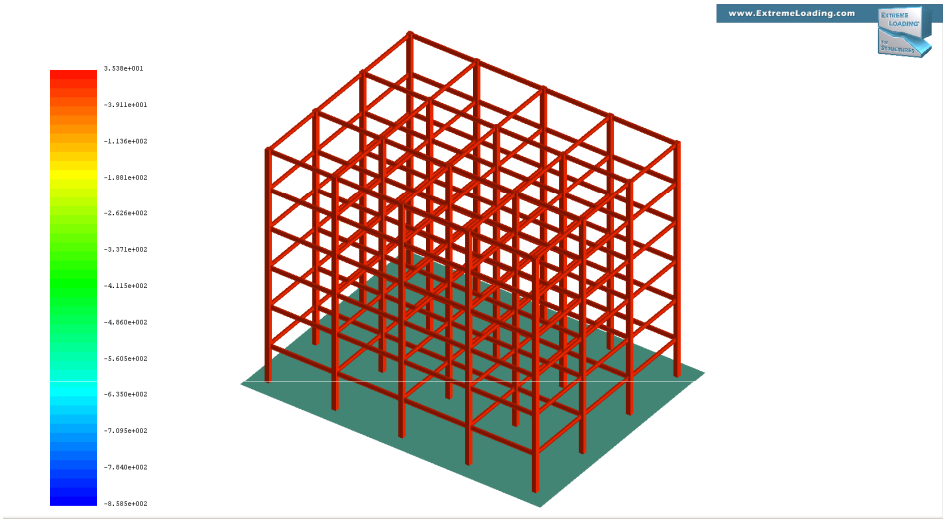


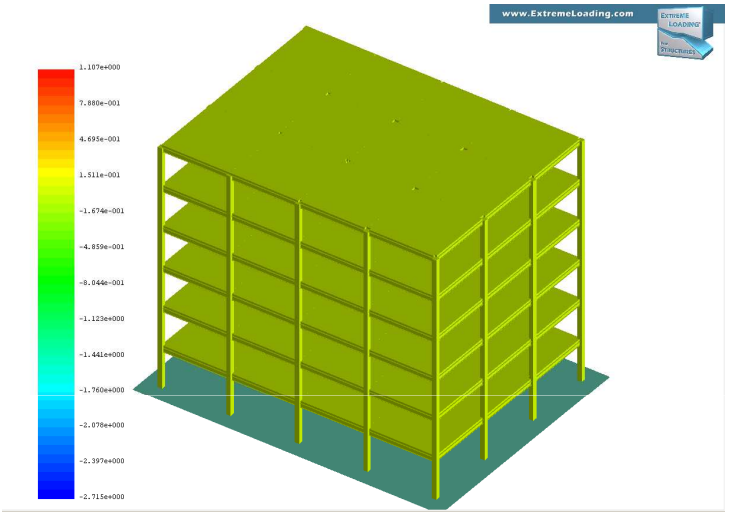
- Tasks:
  - review of existing methods, structural concepts and analytical tools for evaluating the progressive collapse potential of new and existing buildings, identification of gaps in knowledge
  - evaluation of effectiveness of collapse control based design for protection of building structures in case of accidental actions
  - Types of hazards, parameters characterising the action, modeling

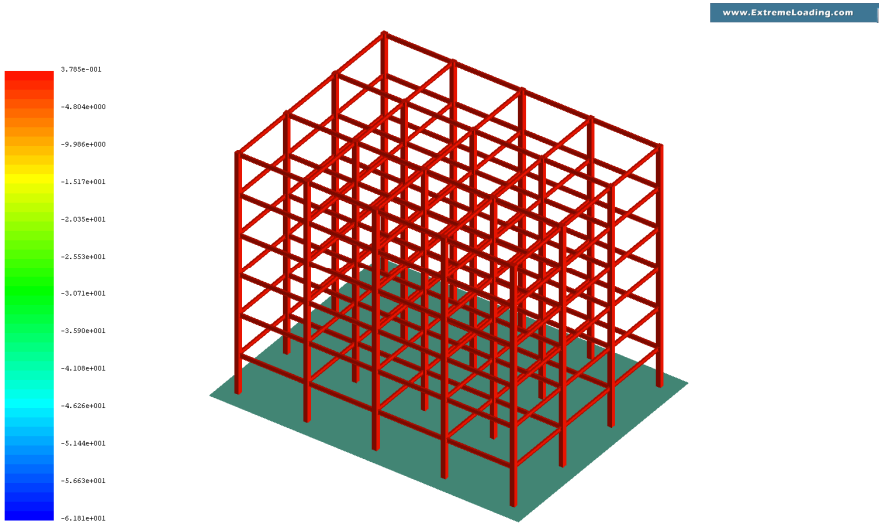
Preliminary investigations

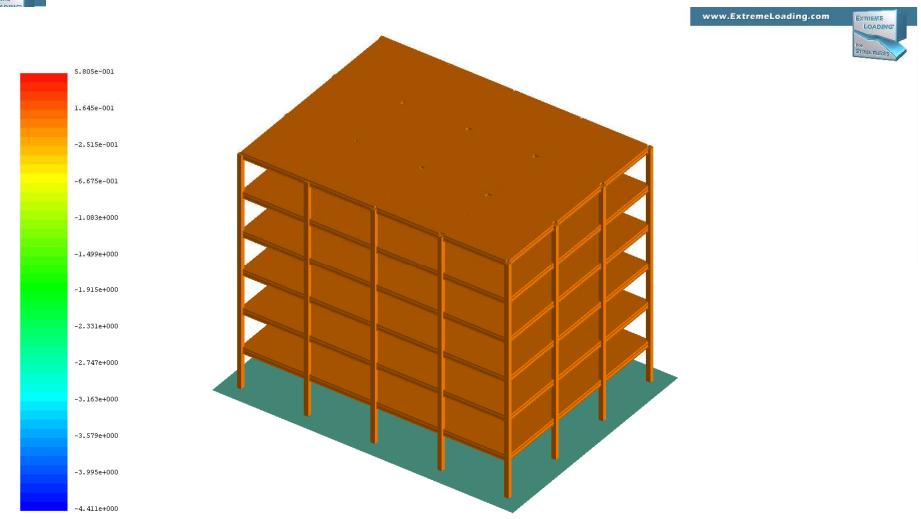
- Preliminary results:
  - Structural systems, tying effect
  - Steel structure – concrete floor interaction
  - Column loss scenarios – definition, modeling
  - Effect of fire on the ultimate capacity of connections

One-way vs. two-way systems, concrete floor contribution

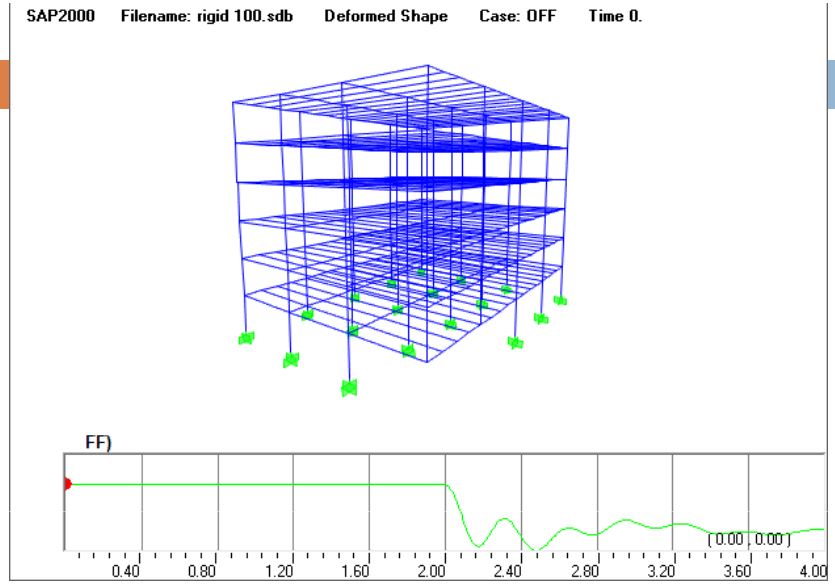


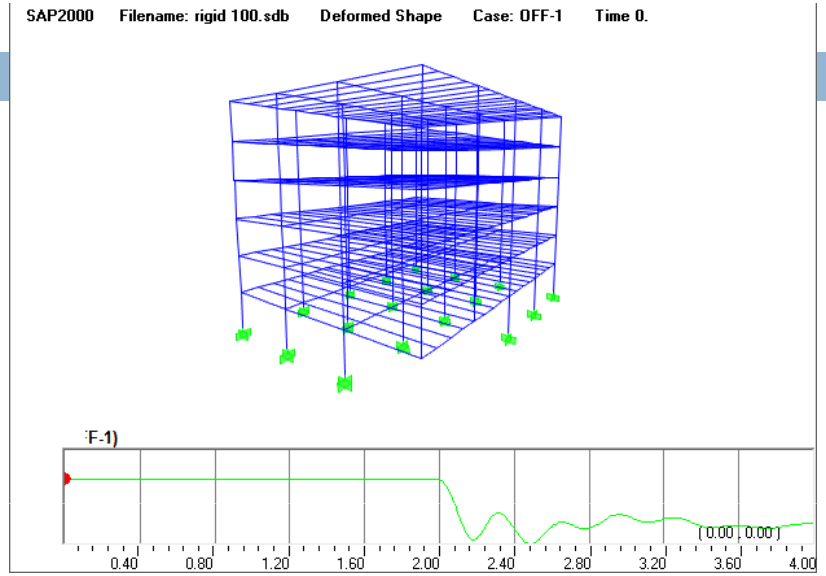


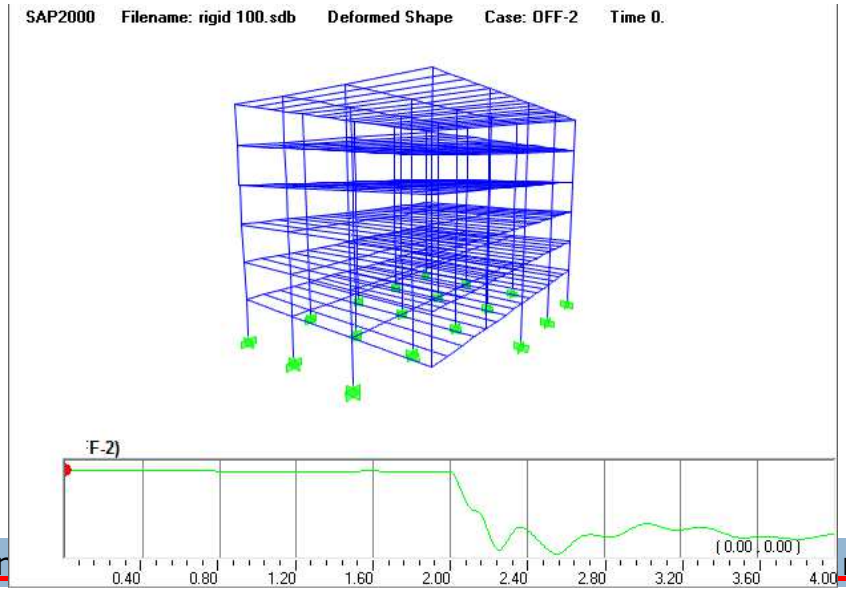




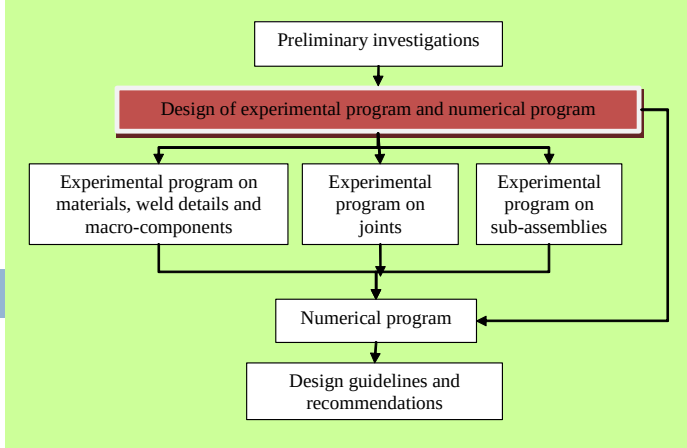
Column loss scenarios – definition, modeling



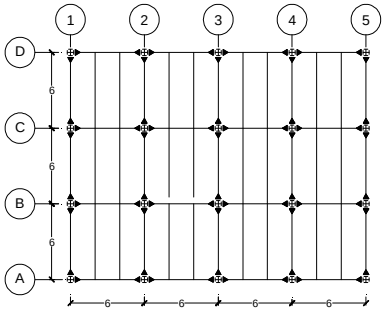


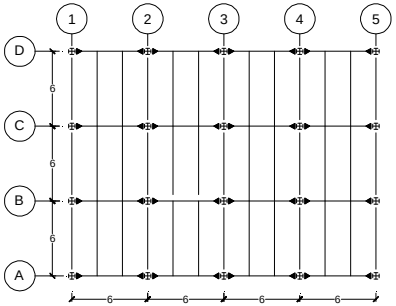


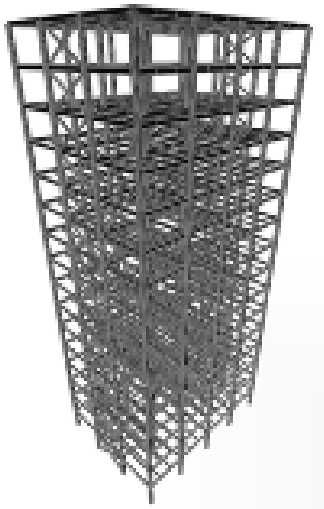
Design of experimental and numerical program



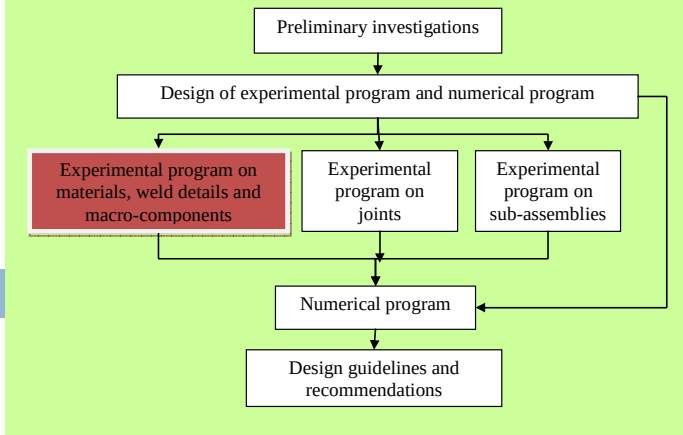
- Tasks:
  - design of specimens for experimental program, based on case study structures: typology, materials, technology of execution, loading parameters, data acquisition, rigs and test set-up, supply of materials and specimens.
  - design of numerical program



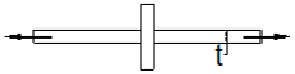




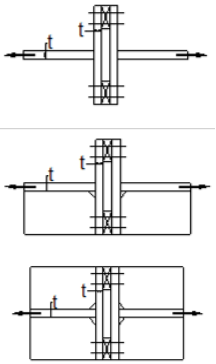
Experimental program on materials, welds details and macrocomponents



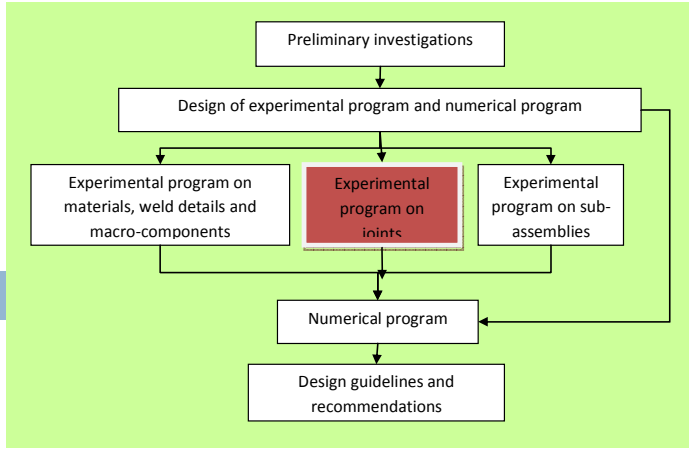
- Tasks:
  - Experimental tests on base materials and weld details

Weld detail	Weld	Thickness	Loading	Strain rate	Total
Butt weld 	Single bevel Double bevel	3	1M + 2C	2	36
Transversal cruciform weld 	Single bevel Double bevel Fillet	3	1M +2C	2	54

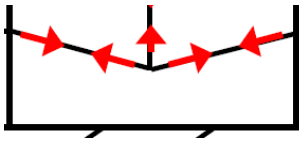
  - Experimental test on T-stub macro-components

T-stub	Loading	Strain rate	Temperature	Total
	2M+2C	2	2	48

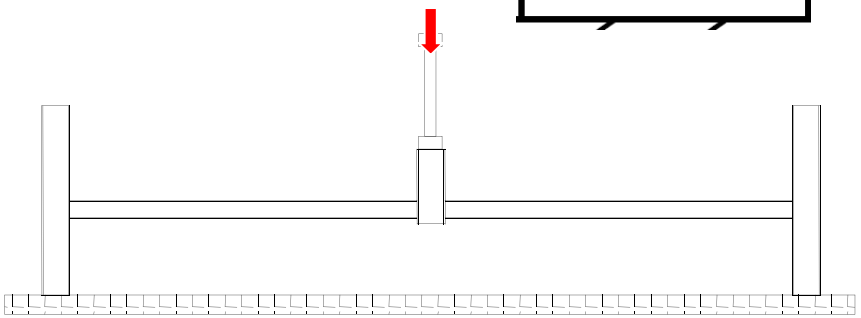
Experimental program on joints



- Tasks:
  - Experimental test on joint specimens

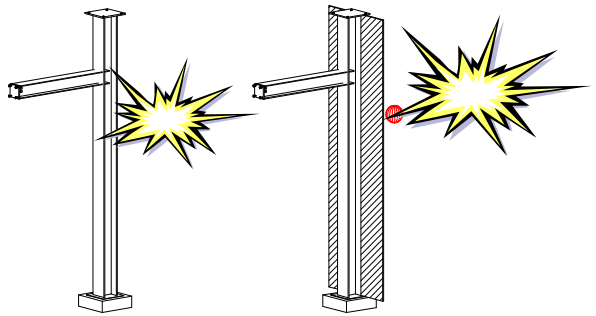


2 types x 3 capacity x 2 velocities = 12 specimens x2 = 24 specimens

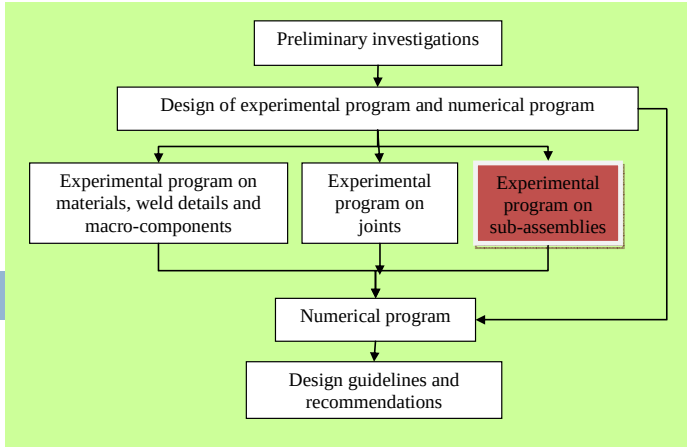


  - Testing on joints in blast conditions

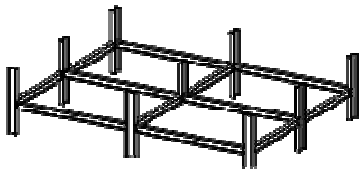
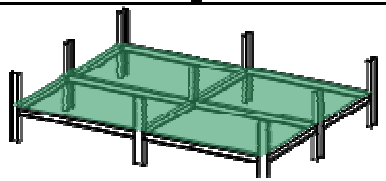
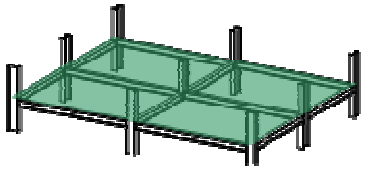
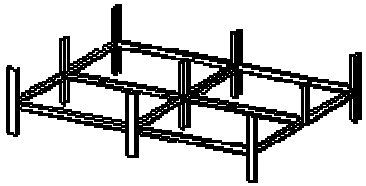
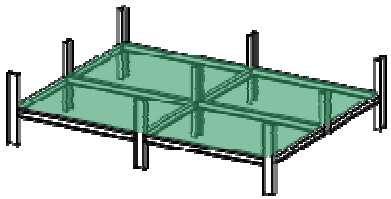
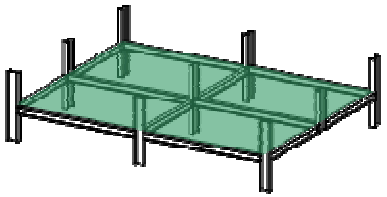
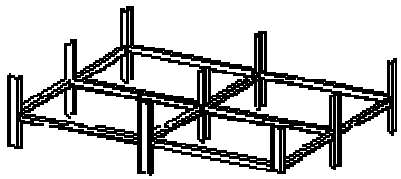
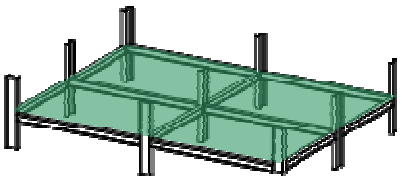
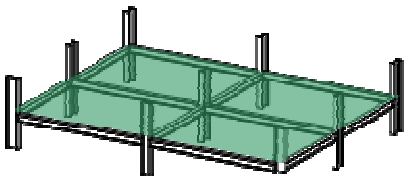
2 types x 2 stand-off distances = 4 specimens



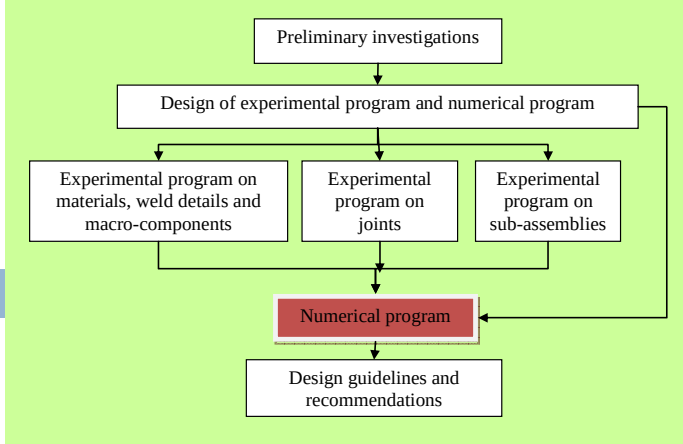
Experimental program on sub-assemblies



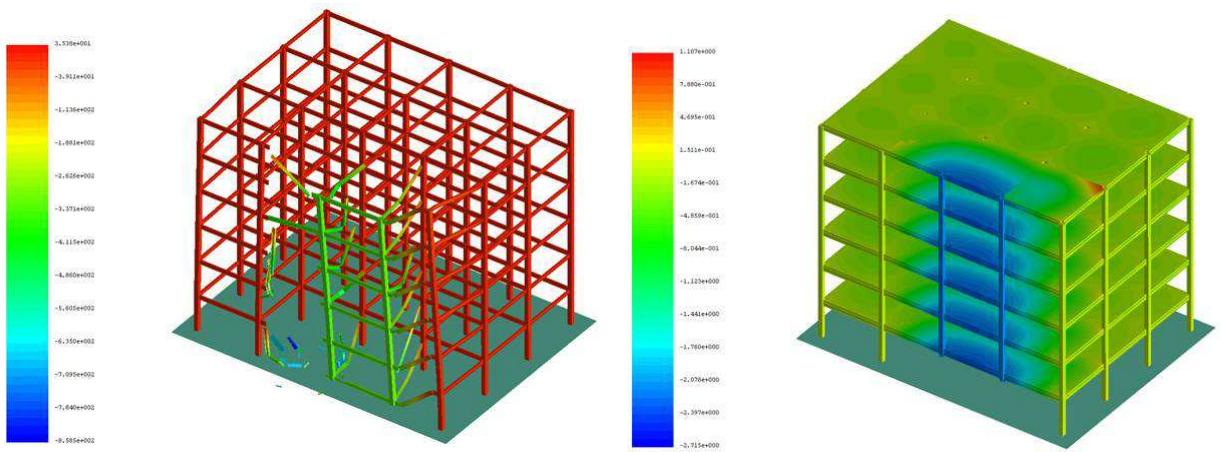
- Tasks:
  - Experimental test on subassembly specimens

Column loss	Specimen: No concrete slab Two-way action	Specimen: Concrete slab One-way action	Specimen: Concrete slab Two-way action	Total
Central				3
Penultimate				3
Corner				3

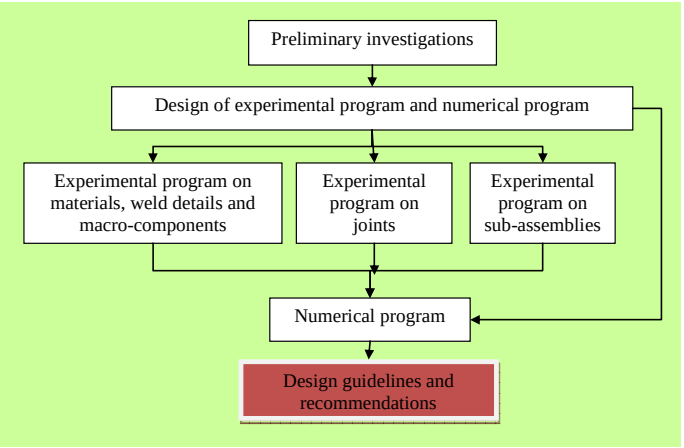
Calibration and validation of numerical models based on test results



- Tasks:
  - Calibration and validation of numerical models based on test results
  - Assessment of progressive collapse resistance by collapse control approach
  - Case studies



Design guidelines and recommendations



- Deliverables :
  - Synthesis of the results: A summary report on the results of the project will be provided. The most important findings and conclusions will be presented
  - Guidelines for the collapse control performance based design of multi-story frame buildings against accidental actions
  - Recommendations for best practice in selection of structural system, fabrication and material requirements for improving the robustness

Acknowledgement

- Funding of the research was made in the frame of the Partnerships Program Joint Applied Research Projects, contract PN II PCCA 55/2012 “Structural conception and COllapse control performance based DEsign of multistory structures under aCcidental actions” CODEC (2012-2015), between the “Politehnica” University of Timisoara and The Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI) , Romania.