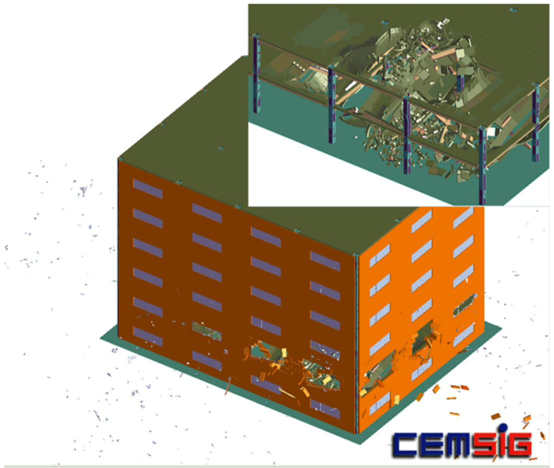
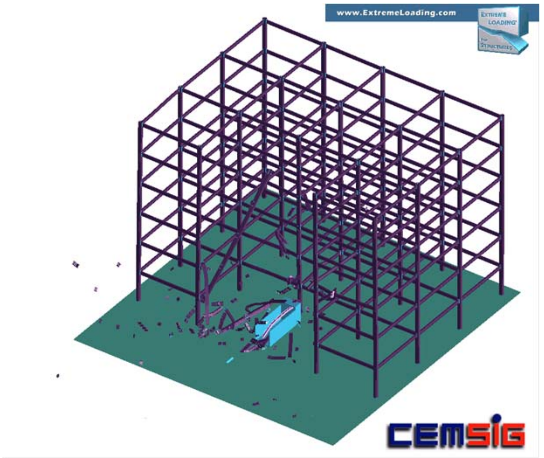
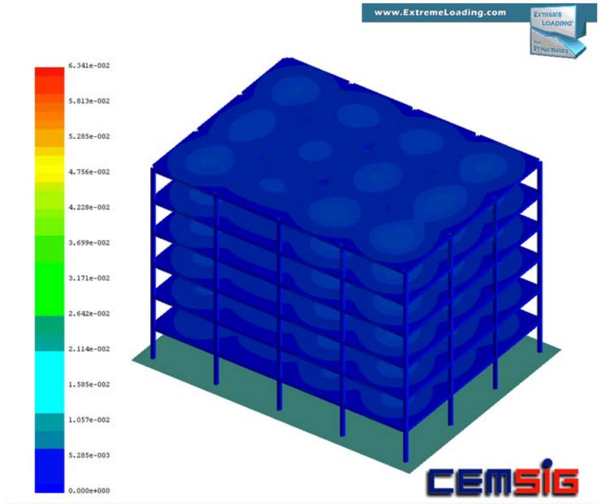
Robustness of structures. Local and global response







Florea Dinu

Lecture 11: 07/04/2014

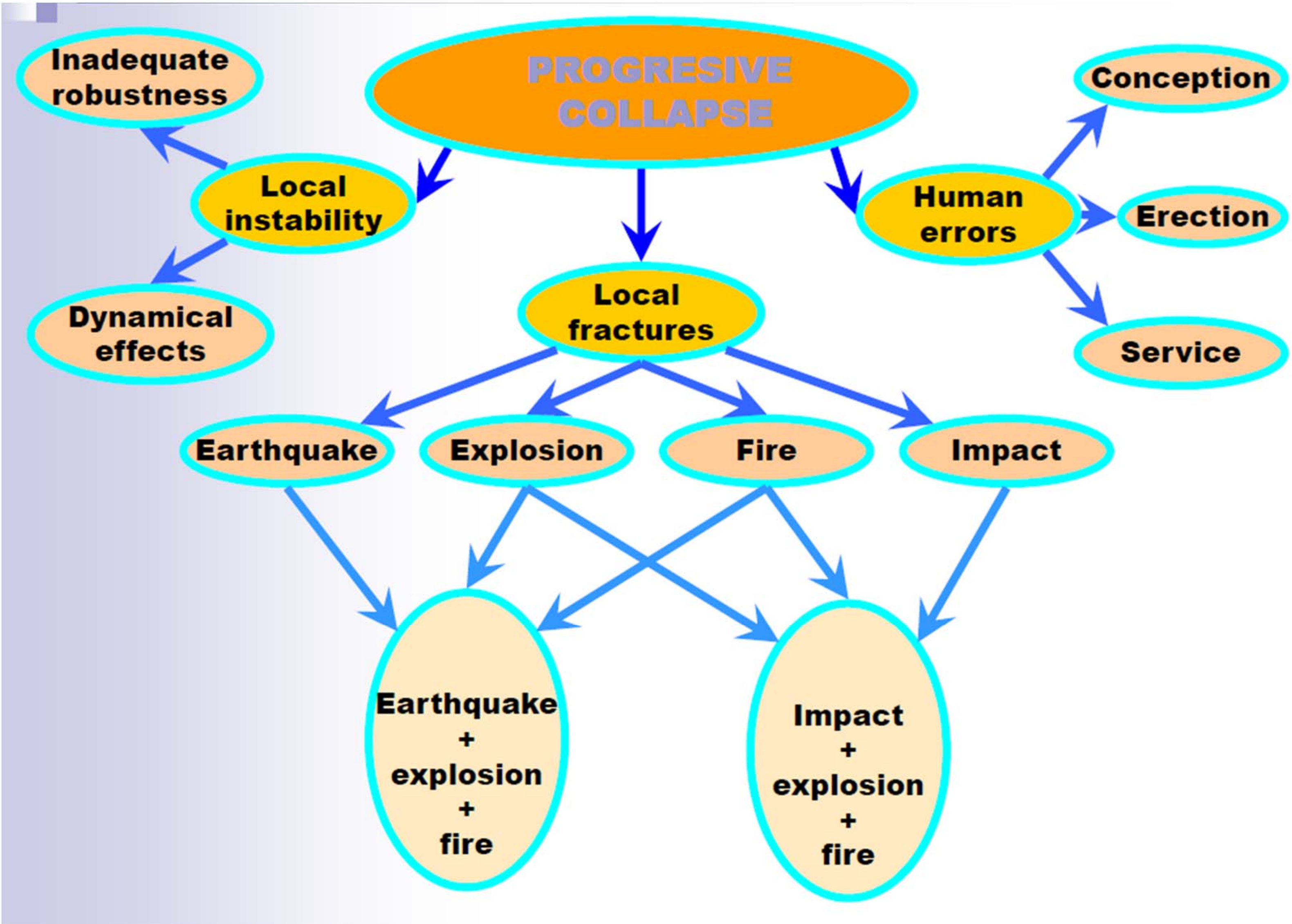
European Erasmus Mundus Master Course

Sustainable Constructions

under Natural Hazards and Catastrophic Events

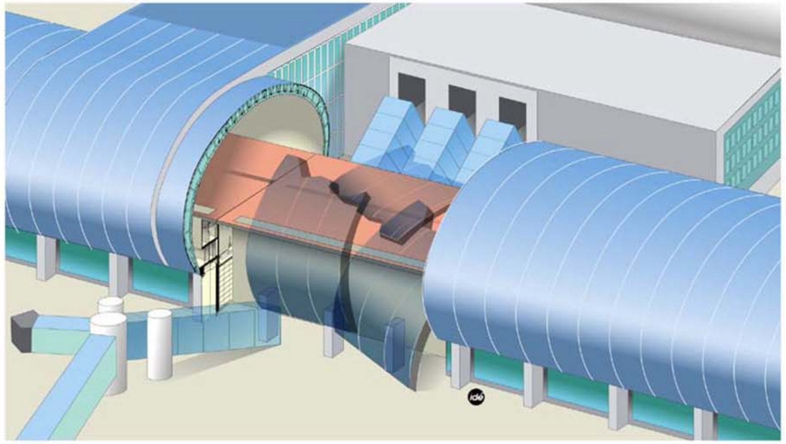
520121-1-2011-1-CZ-ERA MUNDUS-EMMC

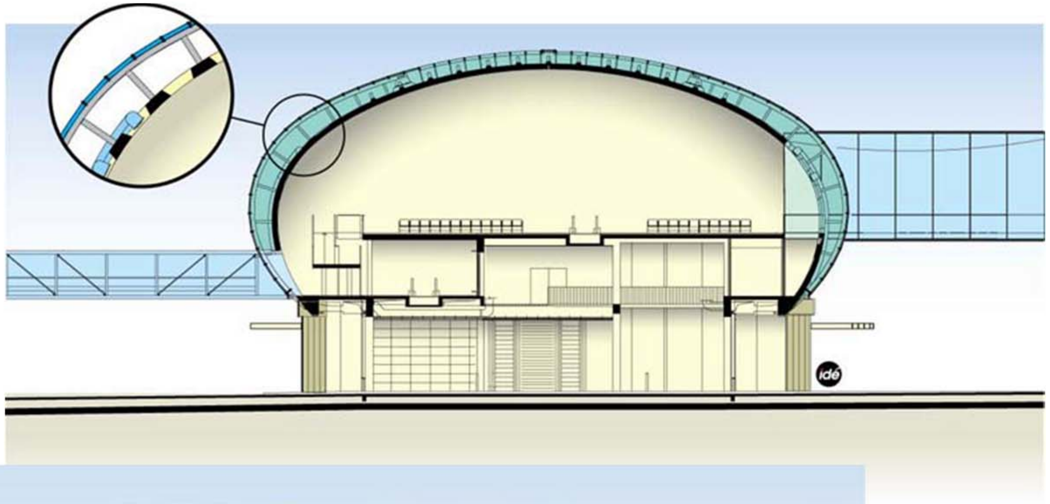
Universitatea Politehnica Timişoara

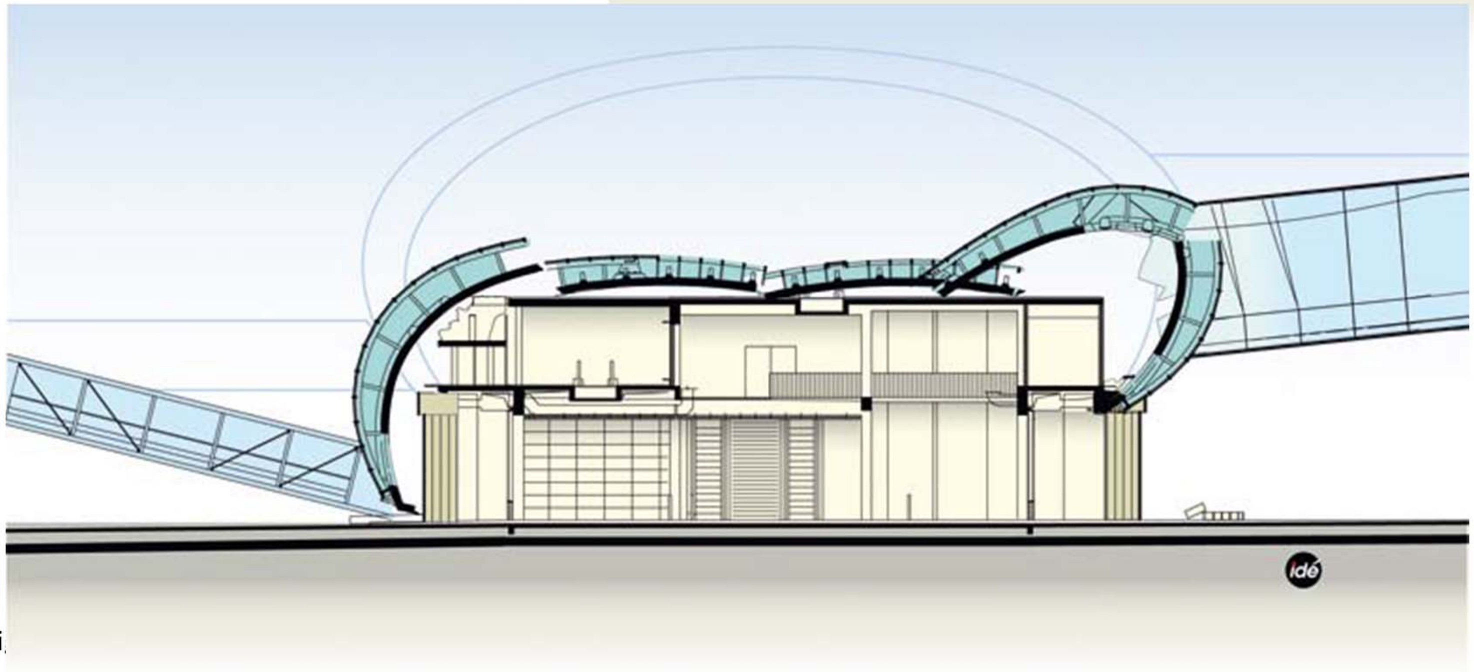


Victor GIONCU, Progressive collapse and explosions, COST C26 seminar, 26-27 October 2007 Timisoara

Collapse of Paris Airport Terminal 2E, 2004








121.925
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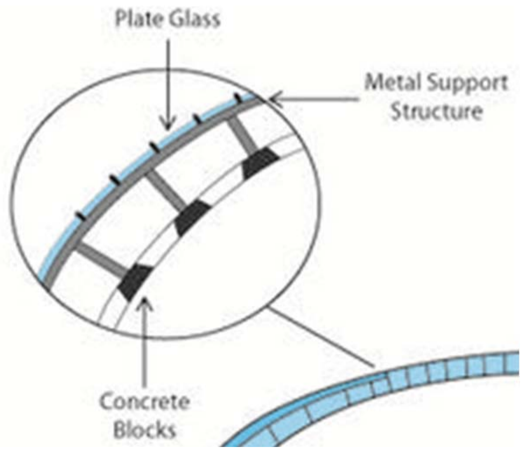
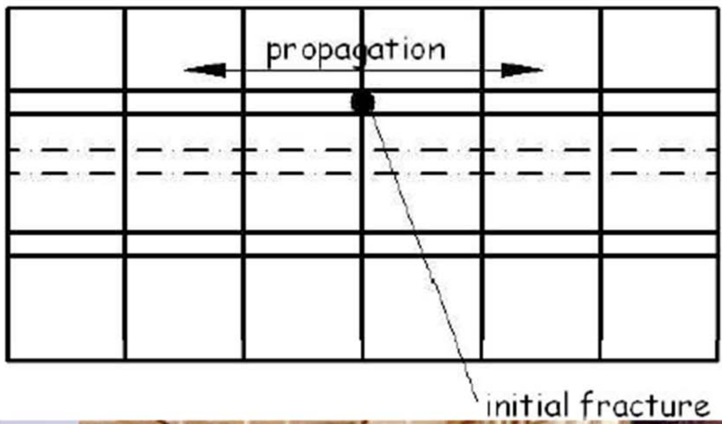
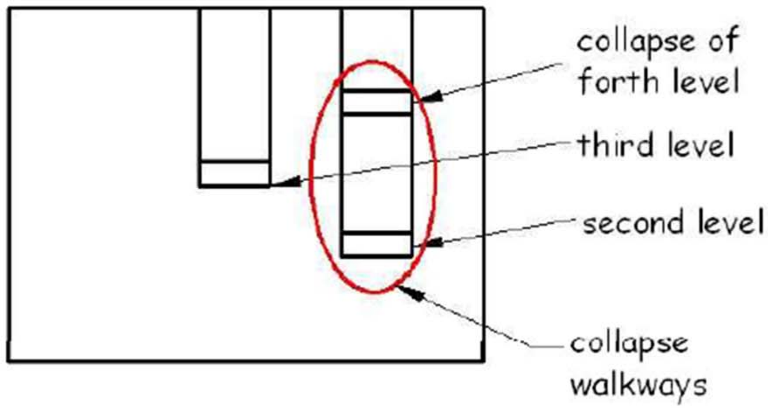
Causes of the Failure

- *The metal support structure of the shell was found to be too deeply embedded into the concrete blocks*
- *This most likely caused cracking in the concrete layer/blocks, which led to the weakening of the roof, which then decreased the stability of the structure.*
- *The concrete supports/blocks, in many reports, was also considered to be insufficiently reinforced during pre-fabrication or the reinforcements could have been badly positioned during construction.*
- *"The horizontal concrete beams on which the shell rested were weakened by the passage of ventilation ducts"(Downey).*
- *Finally, one of the biggest factors that led to the collapse was the fact that rapid thermal expansion happened upon the outer metal structure, made the metal support structure to contract and expand the concrete.*

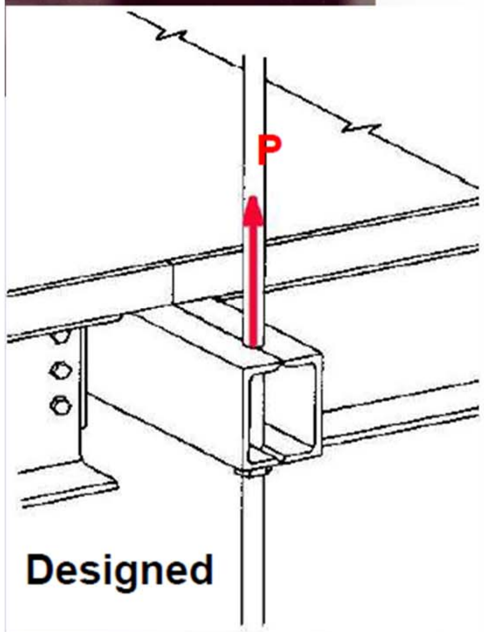


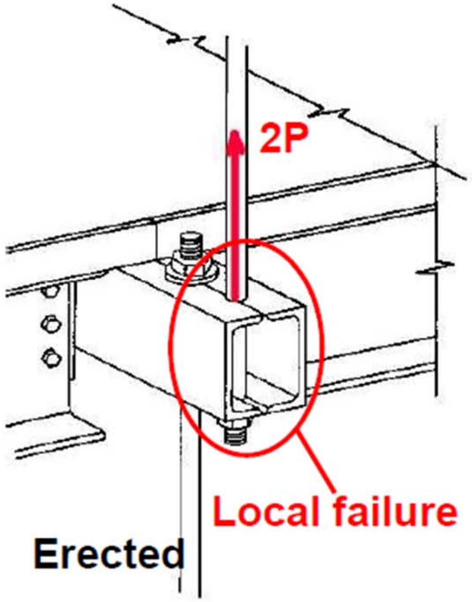
Collapse of Hyatt Regenary (Kansas City) walkways, 1981 due to modification of suspension details





Changing of designed solution.





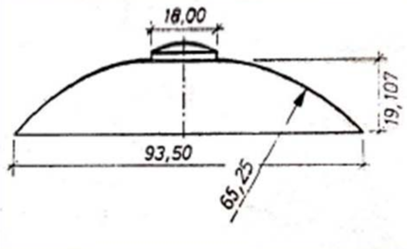
Skyline Plaza, Bailey's Crossroads, Virginia

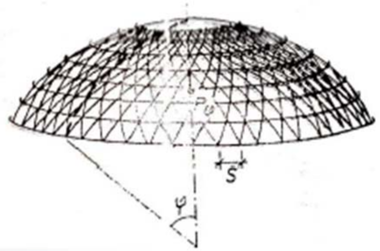
The collapse occurred because of the premature removal of shoring from beneath newly poured floors

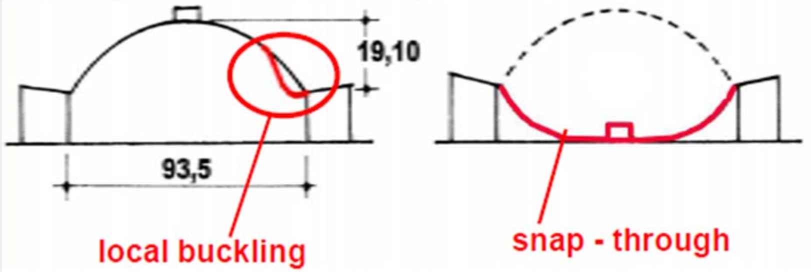
Building Collapse In Baku 2007

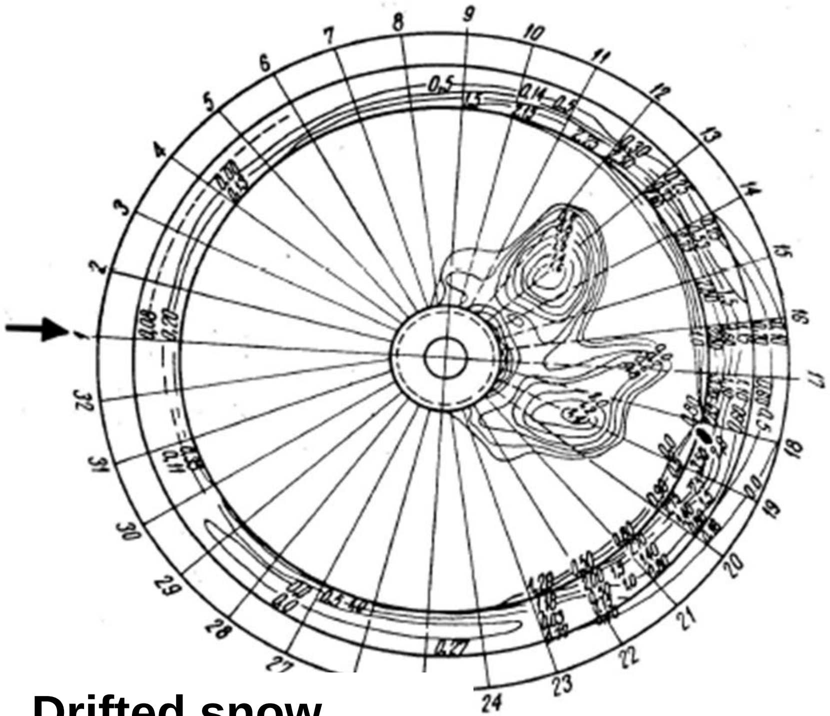
Building collapse caused by violation of safety rules

COLLAPSE OF EXPOSITION HALL, Bucharest, 1963

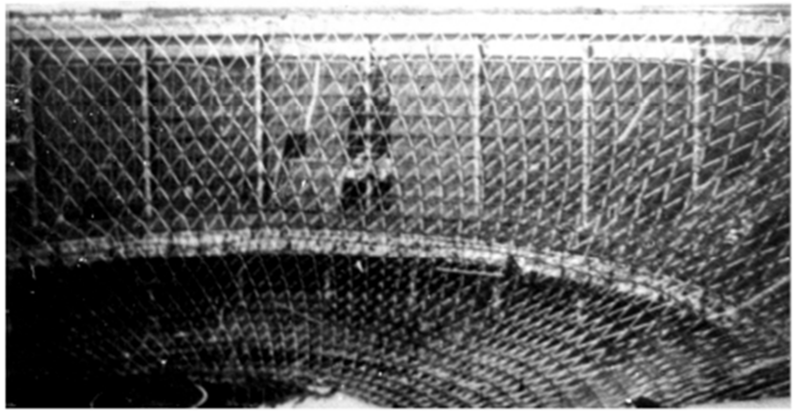








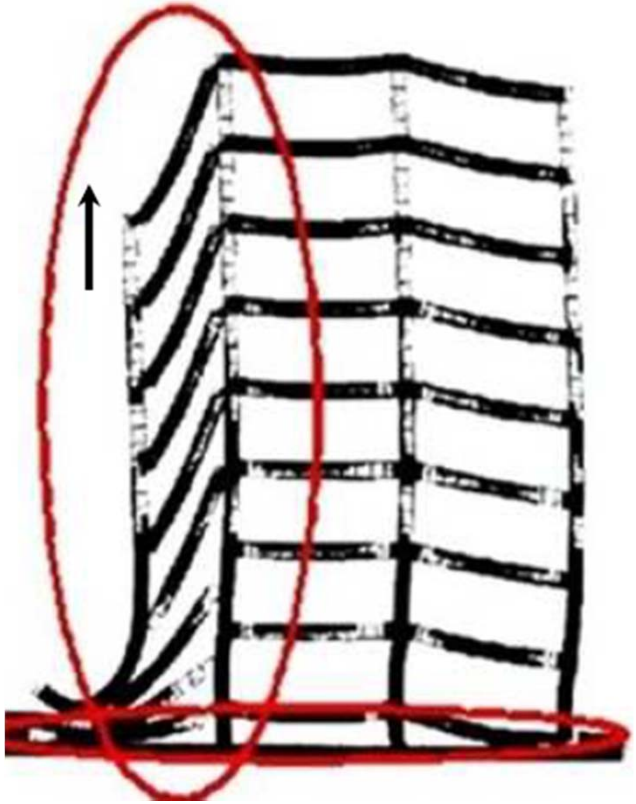
Drifted snow



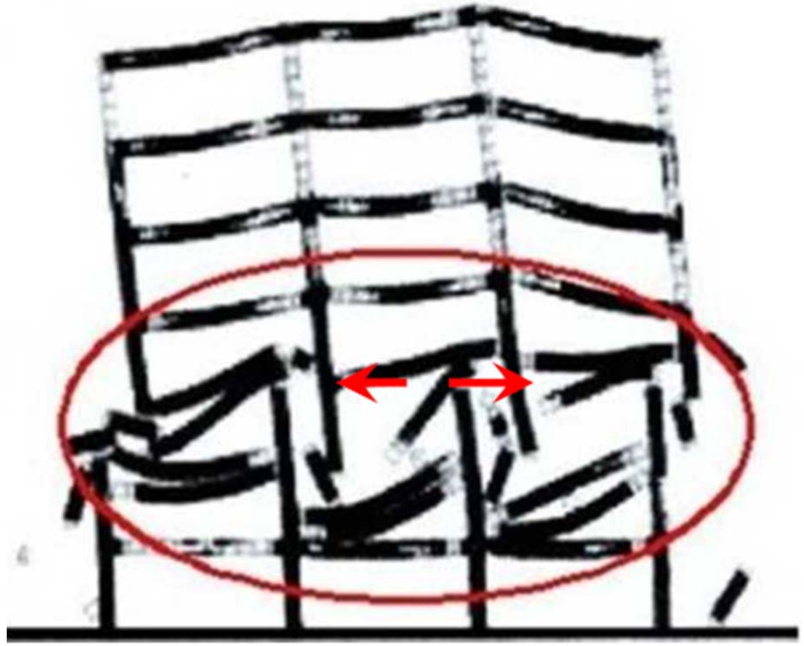
LOCAL FRACTURE

Collapse of Pino Suarez building, Mexico City - 1985

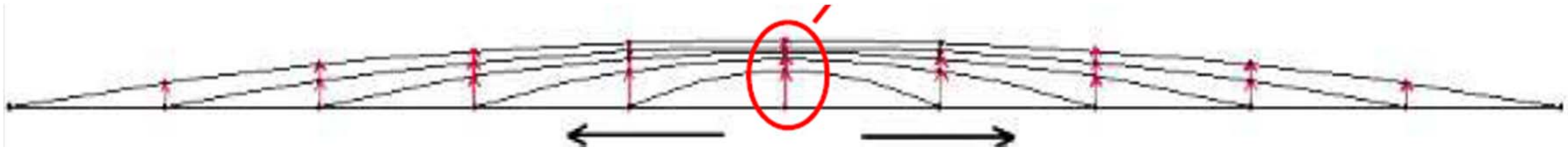
Vertical Progressive Collapse of a building during the Kobe earthquake, 1995

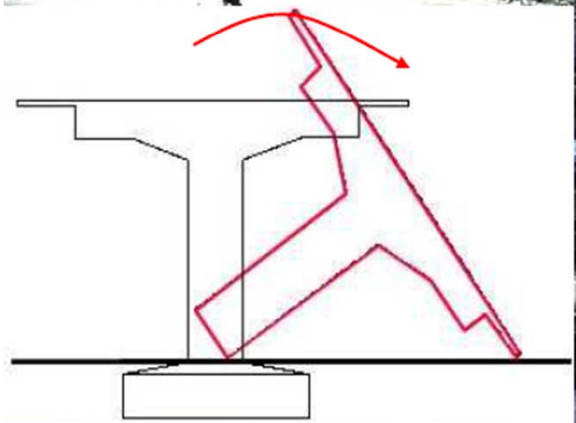


Horizontal Progressive collapse of an intermediate storey during the Kobe earthquake, 1995

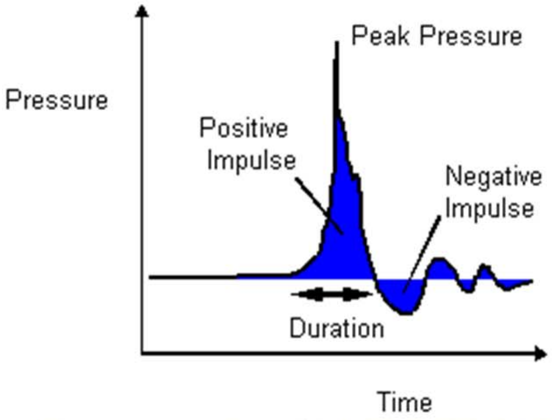


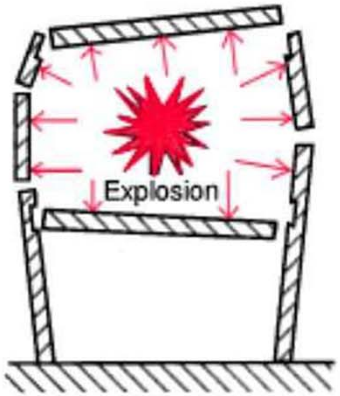
COLLAPSE OF HANSHIN EXPRESSWAY – KOBE, 1995
initial collapse

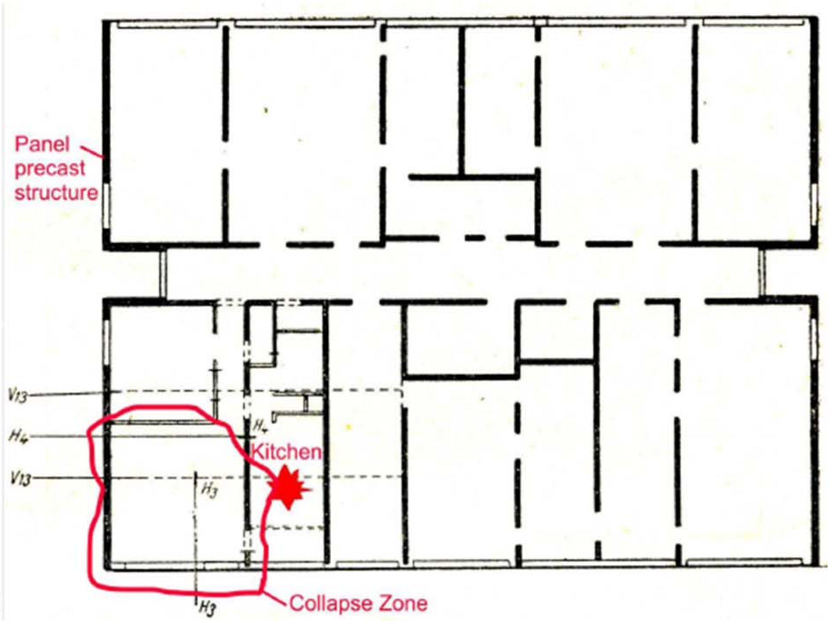


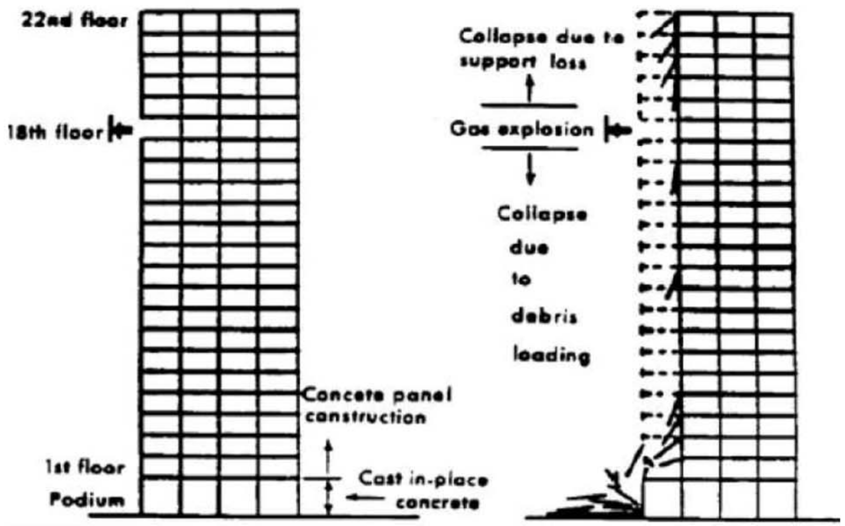


EXPLOSIONS
Inner explosion – ROMAN POINTBUILDING, England 1968



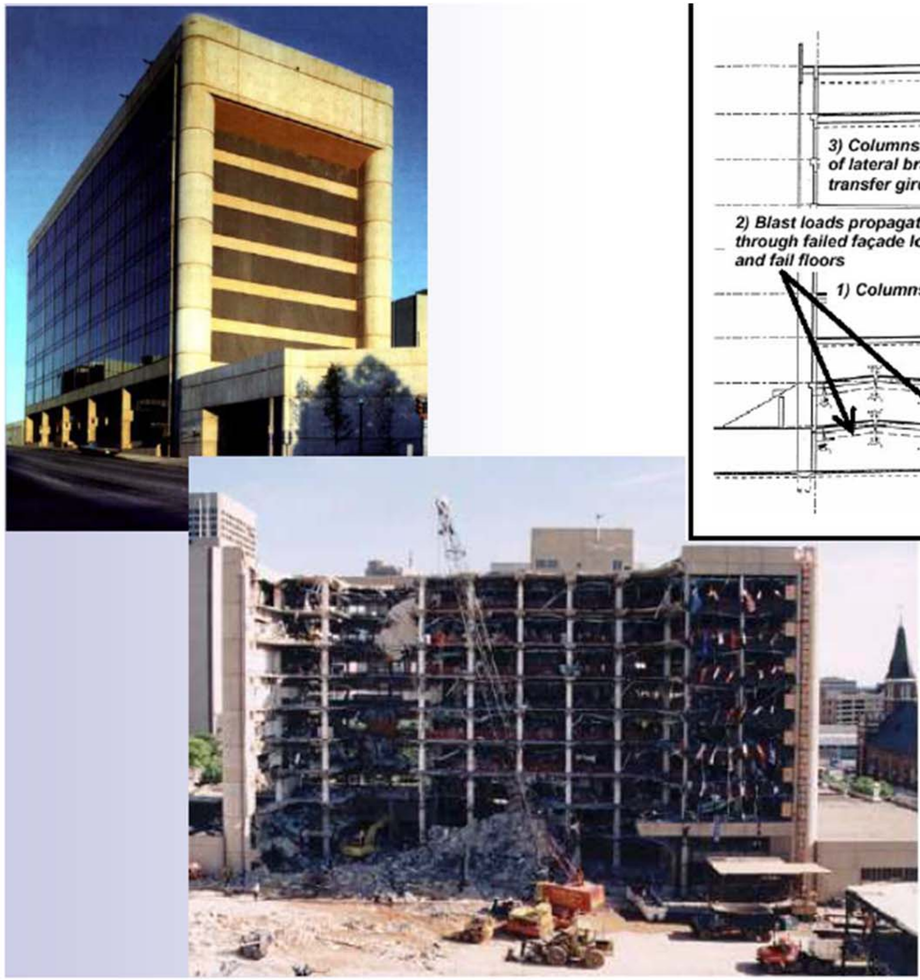


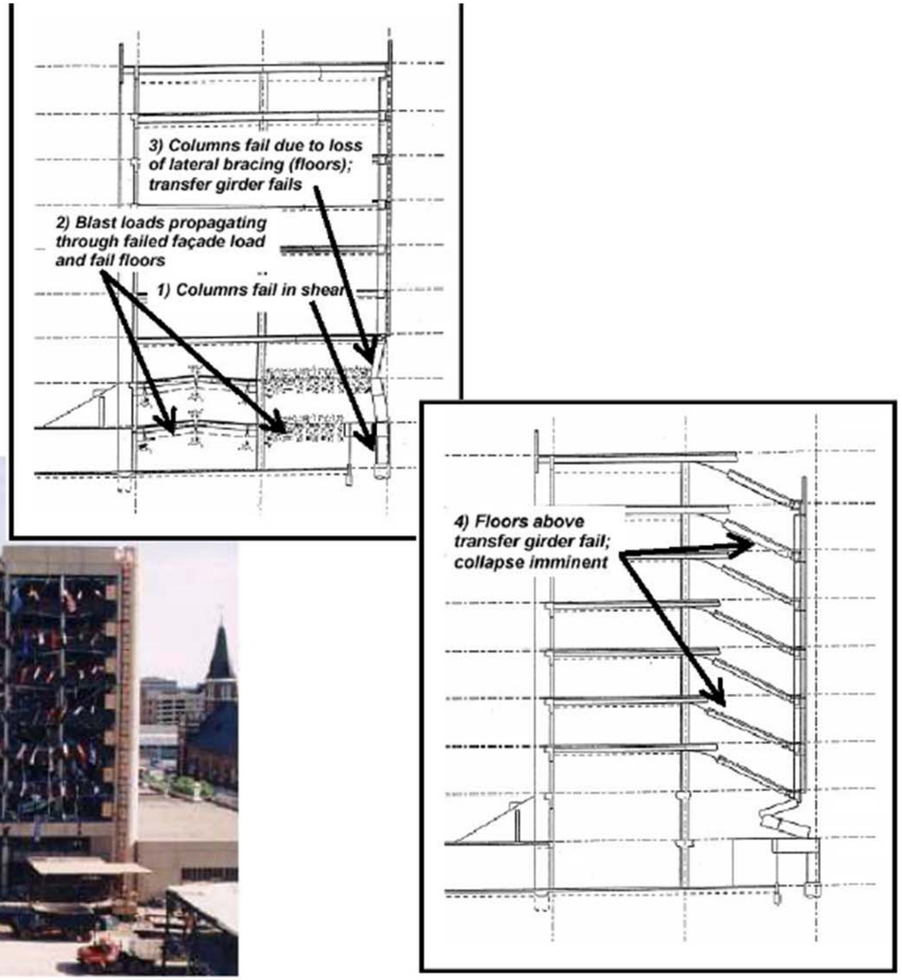




Blast

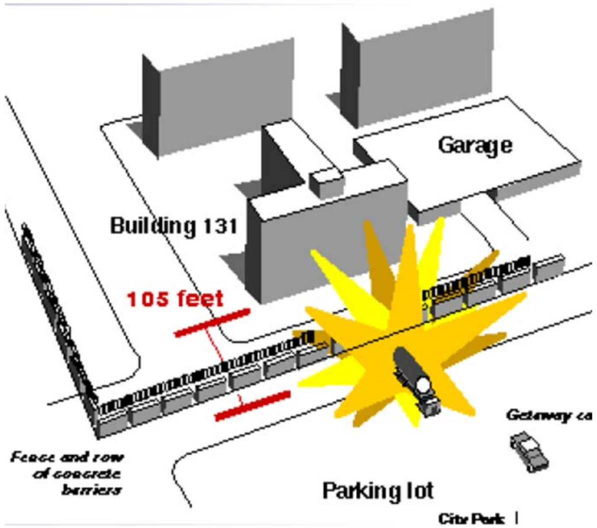
Murrah Federal Building, Oklahoma City, 1995





KHOBAR TOWERS – SAUDI ARABIA, 1996

place of explosion



LONDON 1992

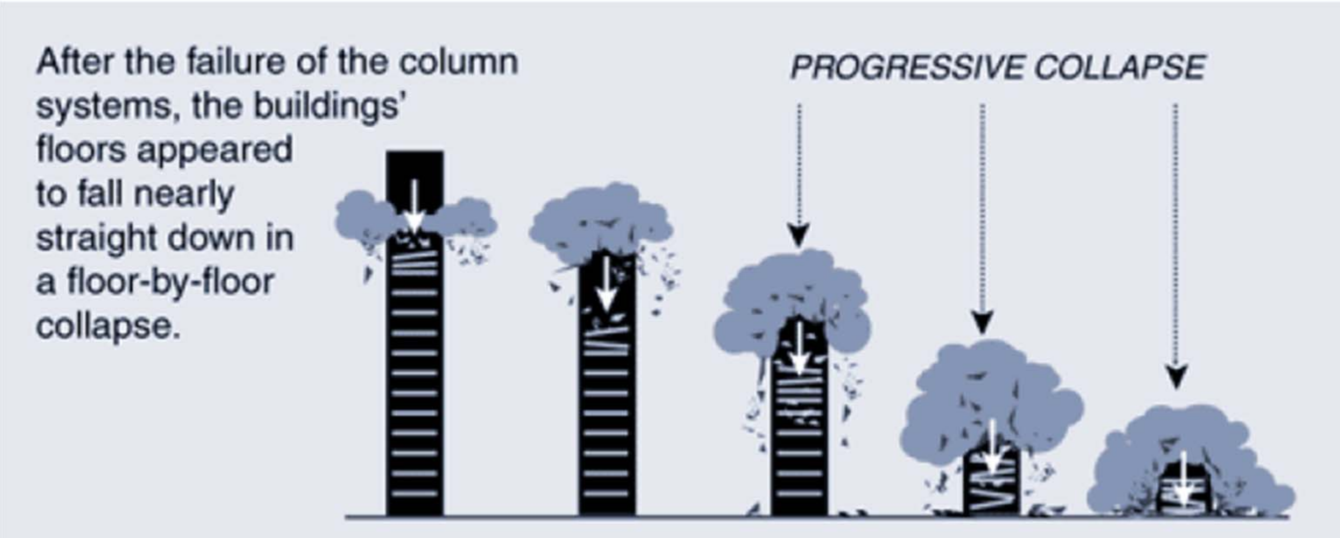
LONDON 1993

IMPACT+EXPLOSION+FIRE

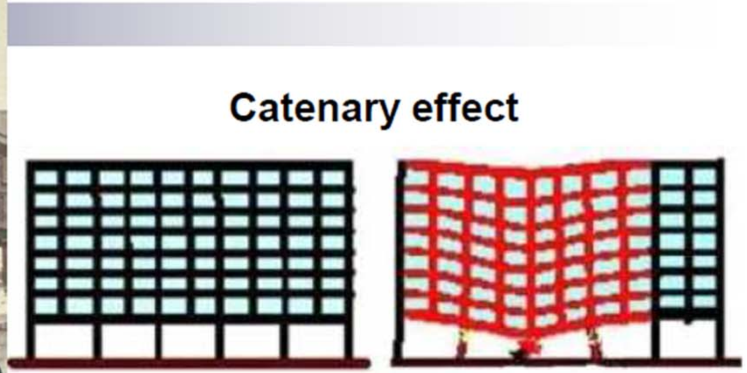
WORLD TRADE CENTER PROGRESSIVE COLLAPSE
11September 2001
New - York

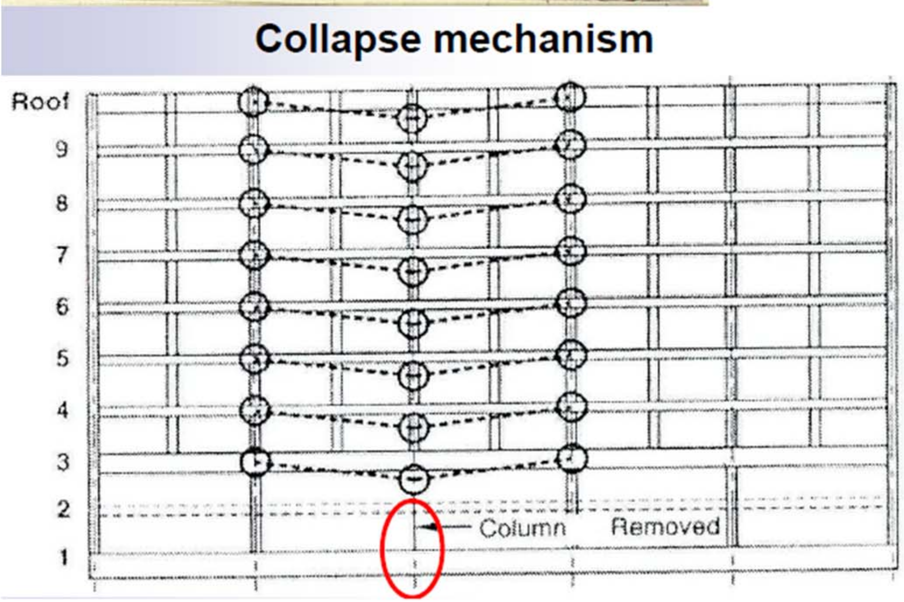
PROGRESSIVE COLLAPSE

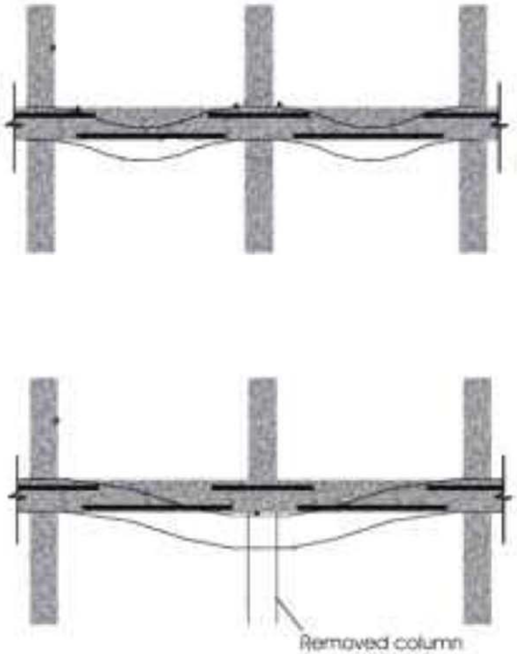
Collapse of beams



Bombing


Catenary effect


Collapse mechanism
Roof
9
8
7
6
5
4
3
2
1
Column Removed


Removed column

- Structural systems should be designed to be robust so as to avoid extensive damage (that may lead to the progressive collapse) under extreme events
- The basic strategies to reduce the probability of structural collapse may be expressed using the following equation:

$$P(C) = P(C|LD)\,P(LD|H)\,\lambda_H$$

where
λ_H = rate of occurrence of the abnormal load or hazard,
$P(LD|H)$ = probability of local damage given that the abnormal load occurs, and
$P(C|LD)$ = probability of collapse given that local damage occurs.

Robustness measures can be categorized into ([1]):

- Local measures: focus on local values reaching critical levels when a member is lost, e.g.:
    1. the force demand-to-capacity ratio exceeds a threshold at a particular location
    2. the displacement or rotation at a given point exceed some prescribed limits.
- Global measures: are more comprehensive in their assessment, e.g.:
    1. pushdown methods, in which robustness is expressed as a ratio of the load carried by the damaged structure to the nominal gravity loads
    2. energy-based methods in which the vulnerability of the structure is assessed in terms of its ability to absorb energy before collapse after member loss.
    3. other global measures can be proposed, e.g., a redundancy measure, in which the number of adjacent members that must be removed to precipitate collapse is an indirect measure of overall robustness.

(1) El-Tawil, S. et al., 2013, Computational Simulation of Gravity-Induced Progressive Collapse of Steel-Frame Buildings: Current Trends and Future Research Needs, Journal of Structural Engineering.

The force demand-to-capacity ratio approach

- The demand-capacity ratio (*DCR*) may be defined as:

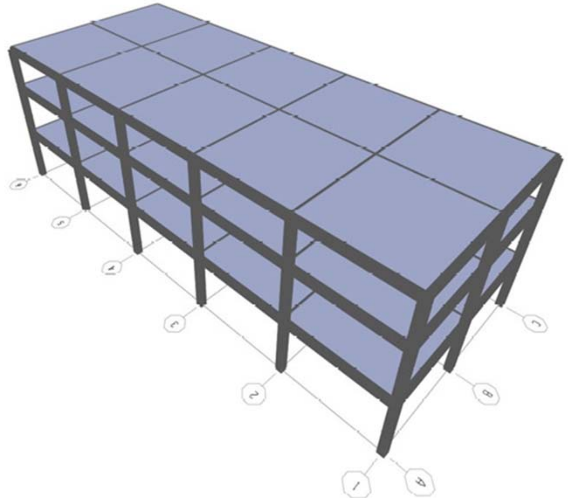
$$DCR = \frac{Q_{UD}}{Q_{CE}}$$

where
Q_{UD} = acting force on structural member or joint, and
Q_{CE} = expected ultimate, unfactored capacity

- Using static, linear-elastic analysis, the designer identifies the magnitude and distribution of potential, inelastic demands on primary and secondary structural elements.
- The Design Guidelines limit the values of *DCR (*2 or less for typical structural configurations, and to 1.5 or less for atypical structural configurations.
- If the *DCR* cannot be limited to these values, then the structural member or connection in question is considered to have failed

Example

- Two spans and five bays of 6.0m each



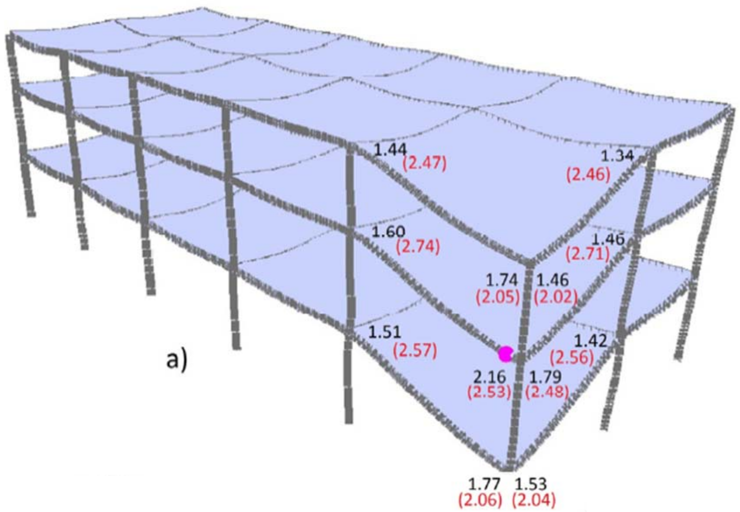
Structure	Column [mm]	Beam [mm]	Slab [mm]
3 -story	400 x 400	250 x 450	150

- Linear Static Analysis

$$Load = 2(DL + 0.25LL)$$

- SAP2000 structural analysis software

a)

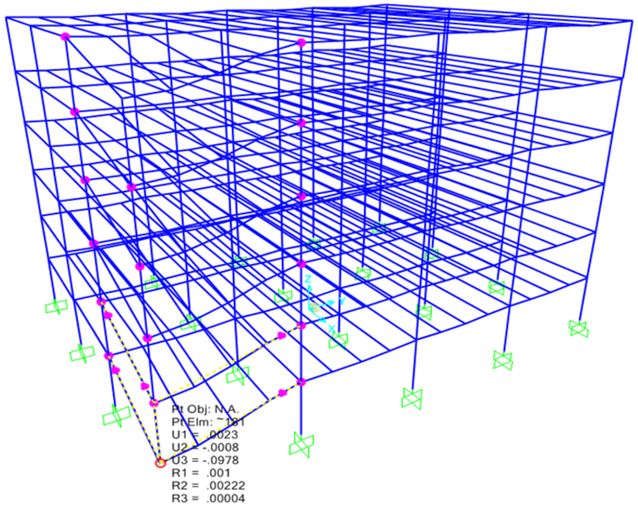


Limitation of displacement or deformation demands

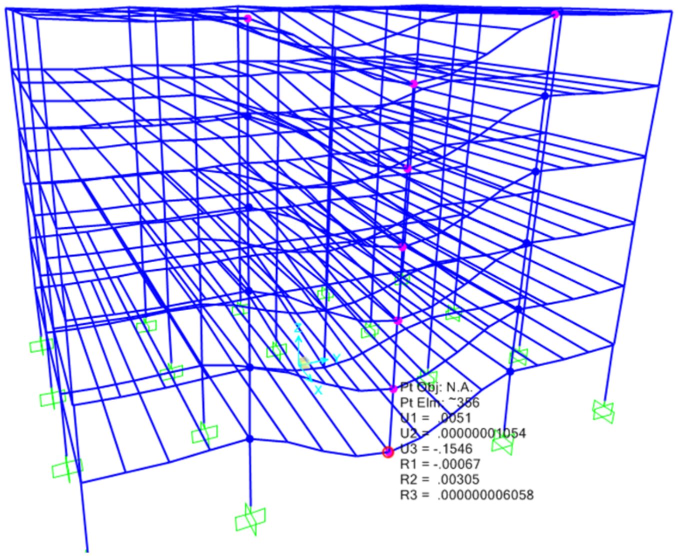
- The deflection and deformations that are calculated must be compared against the deformation limits that are specific to each structural component
- If any structural element or connection violates an acceptability criteria, modifications must be made to the structure

Component	AP for Low LOP		AP for Medium and High LOP	
	Ductility (μ)	Rotation, Degrees (θ)	Ductility (μ)	Rotation, Degrees (θ)
Beams--Seismic Section[A]	20	12	10	6
Beams--Compact Section[A]	5	-	3	-
Beams--Non-Compact Section[A]	1.2	-	1	-
Plates	40	12	20	6
Columns and Beam-Columns	3	-	2	-
Steel Frame Connections; Fully Restrained				
Welded Beam Flange or Coverplated (all types)[B]	-	2.0	-	1.5
Reduced Beam Section[B]	-	2.6	-	2
Steel Frame Connections; Partially Restrained				
Limit State governed by rivet shear or flexural yielding of plate, angle or T-section[B]	-	2.0	-	1.5
Limit State governed by high strength bolt shear, tension failure of rivet or bolt, or tension failure of plate, angle or T-section[B]	-	1.3	-	0.9

Acceptability Criteria and Deformation Limits for Steel Members (UFC Criteria)

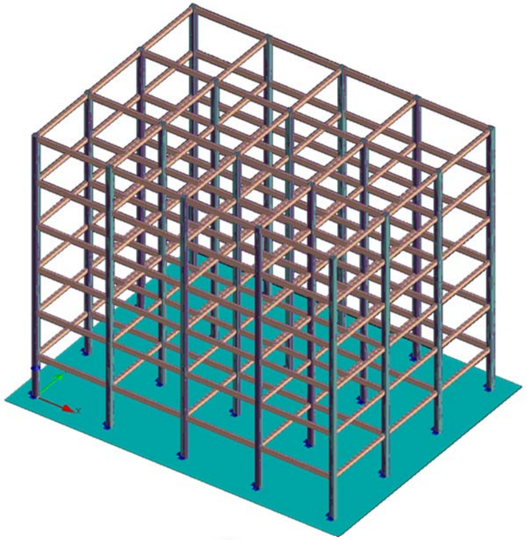


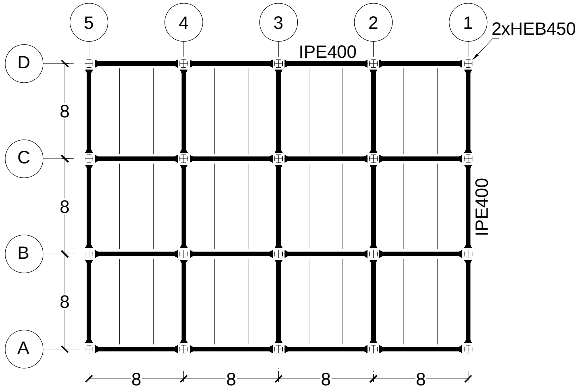
Scenario	Vertical displacement [mm]	Rotation [rad]
Corner column	97.8	0.00395

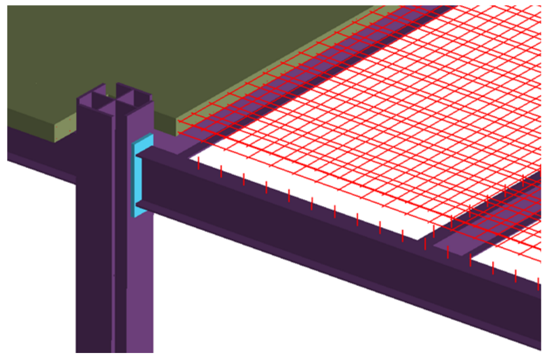


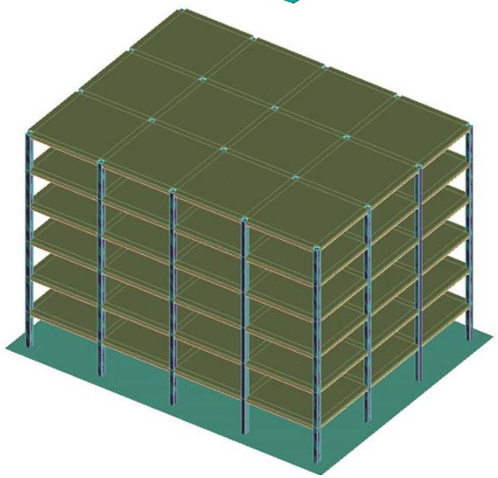
Scenario	Vertical displacement [mm]	Rotation [rad]
Perimeter + internal column	183	0.015

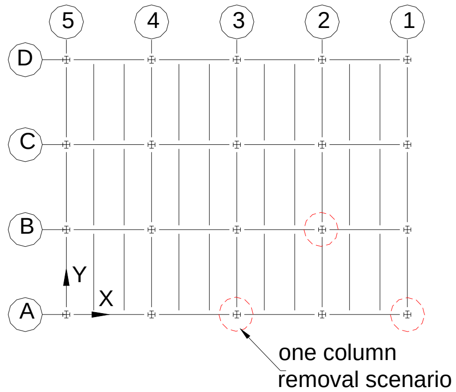
Pushdown methods: robustness is expressed as a ratio of the load carried by the damaged structure to the nominal gravity loads

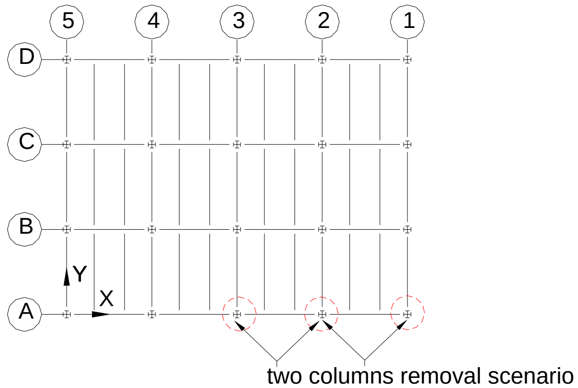


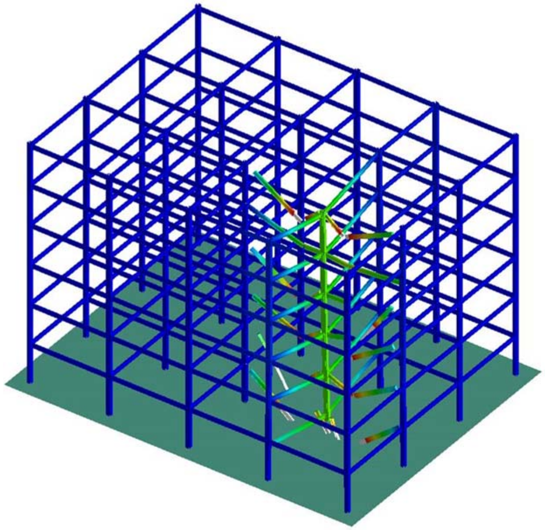


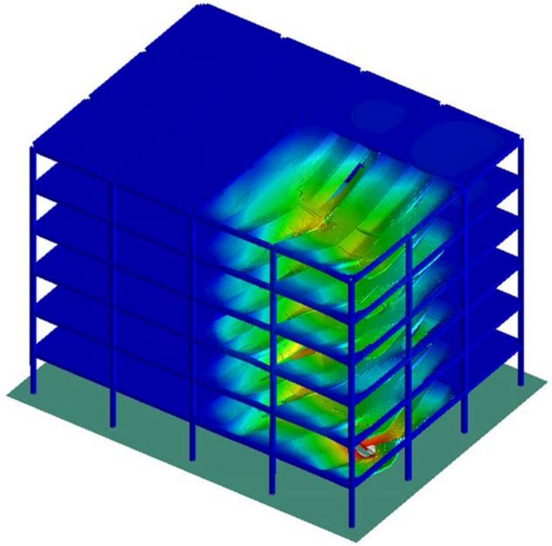


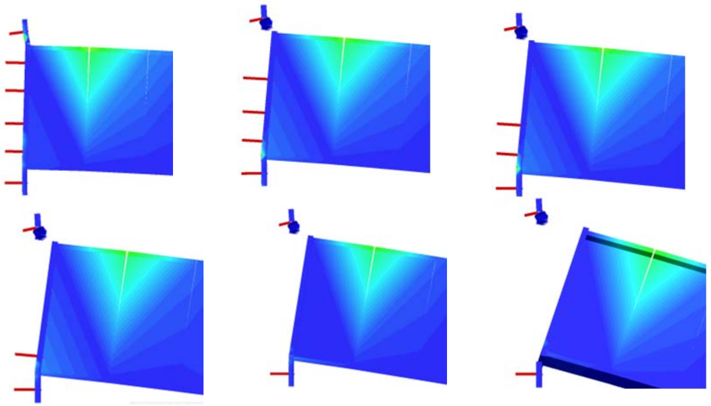


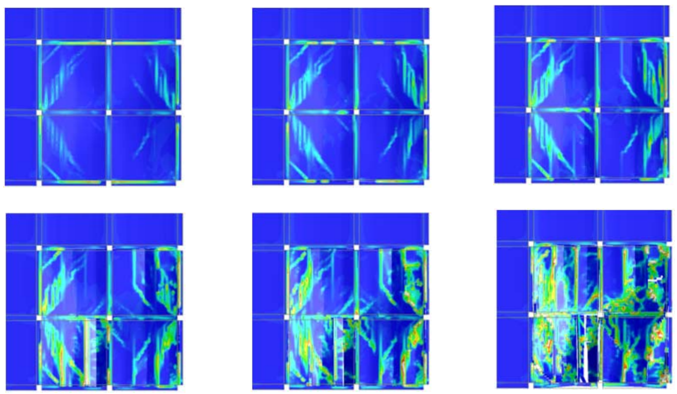




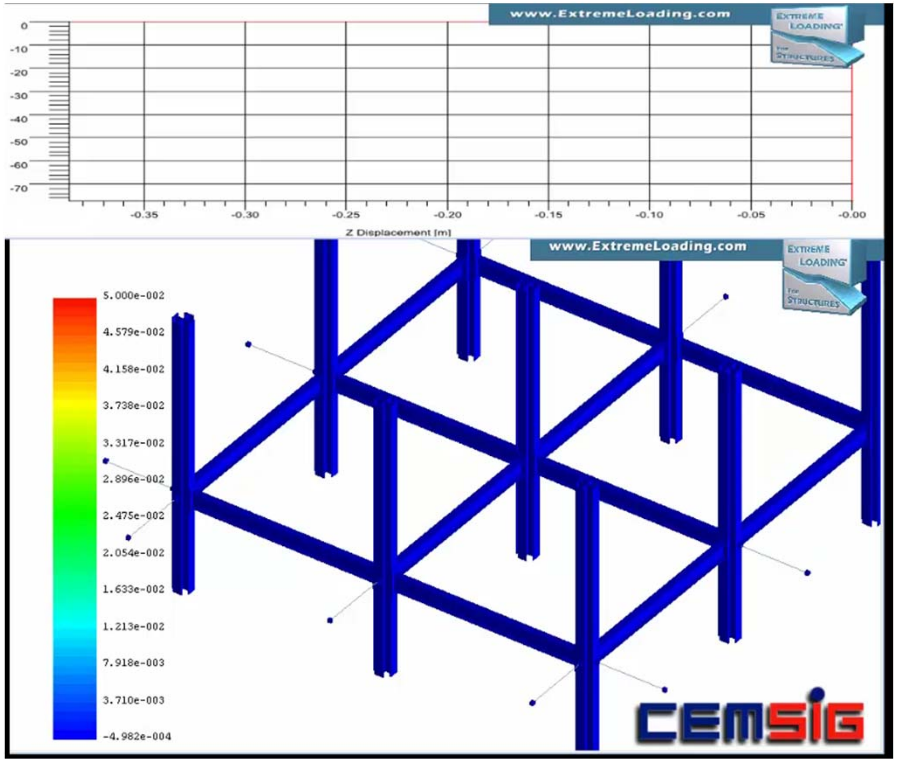








Scenario	Overload factor, Ω
	Dynamic analysis, Ω_D
S-I-A1	2.3
S-I-A3	1.8
S-I-B2	1.2
S-I-A12	1.2
S-I-A23	1.15
C-I-A1	2.83
C-I-A3	2.83
C-I-B2	2.91
C-I-A12	1.60
C-I-A23	1.94
S-II-A1	2.05
S-II-A3	1.6
S-II-B2	1.05
S-II-A12	1.1
S-II-A23	1.15
C-II-A1	2.66
C-II-A3	2.75
C-II-B2	2.58
C-II-A12	1.58
C-II-A23	1.91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EXTREME LOADING FOR STRUCTURES
0
-10
-20
-30
-40
-50
-60
-70
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
-0.00
Z Displacement [m]
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5.000e-002
4.579e-002
4.158e-002
3.738e-002
3.317e-002
2.896e-002
2.475e-002
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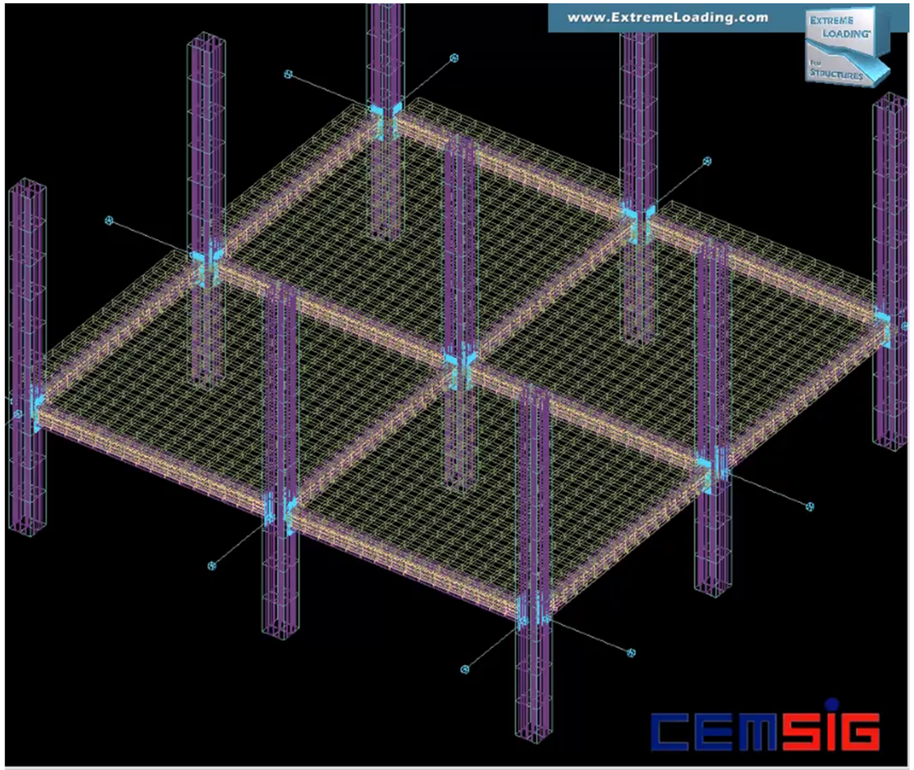
1.633e-002
1.213e-002
7.918e-003
3.710e-003
-4.982e-004
CEMSIG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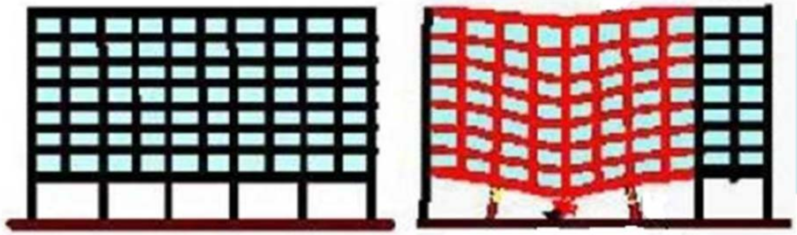
CEMSIG

Other measures to enhance robustness

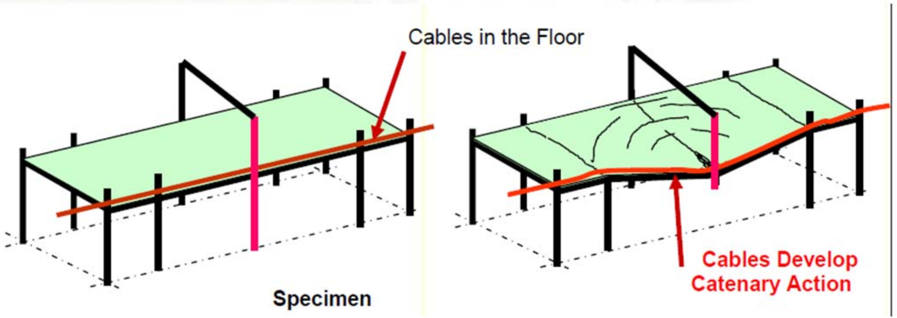
- Prediction of progressive collapse (worst case scenarios)
- Enhancing redundancy (to ensure that alternate load paths are available in the event of local failure of structural):
  - structure framing (two-way redundancy)
  - catenary action of floor (may be improved by using cables)
  - introduction of secondary trusses
  - relying on Vierendeel action
  - creation of "strong floors" in buildings
  - introduction of means to hang portions of the structure from above

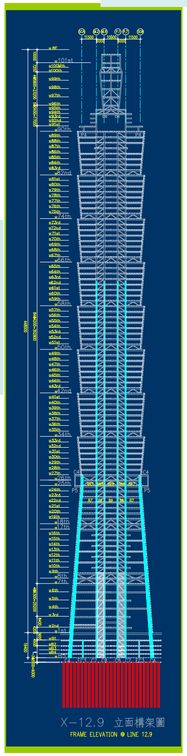
THE TAIPEI 101

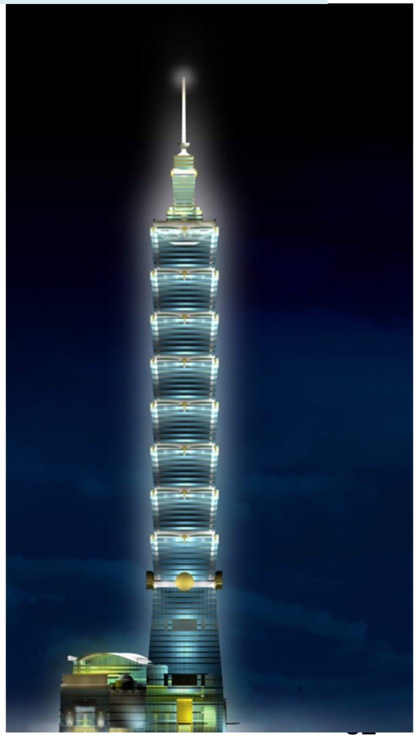
10 very strong mfloors



Catenary action of floor may be improved by using cables







This lecture was prepared for the 1st Edition of SUSCOS (2012/14) by Kang-Hai TAN, Nanyang Technological University, Singapore and ULg

Adaptations brought by Florea Dinu, PhD (UPT) for 2nd Edition of SUSCOS

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http://steel.fsv.cvut.cz/suscos

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