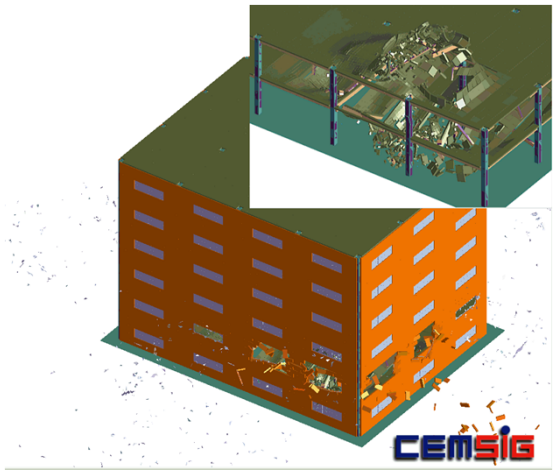
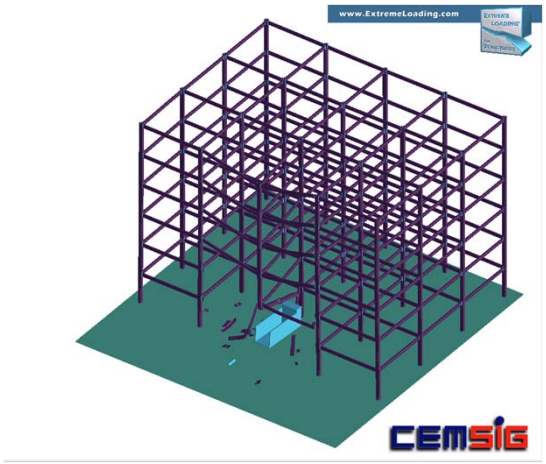
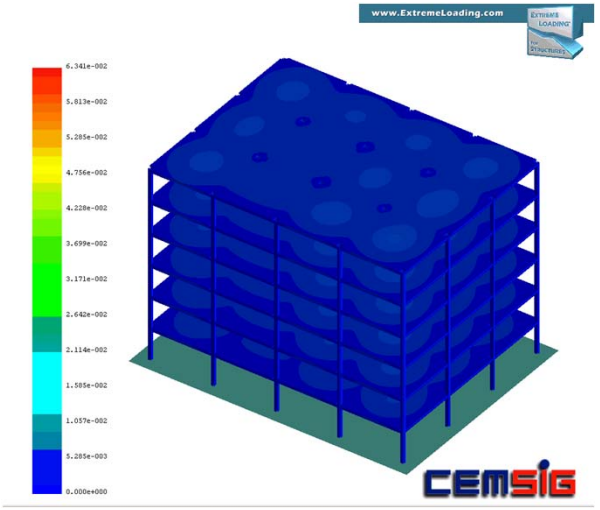
Application







Florea Dinu

European Erasmus Mundus Master Course

Sustainable Constructions

under Natural Hazards and Catastrophic Events

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

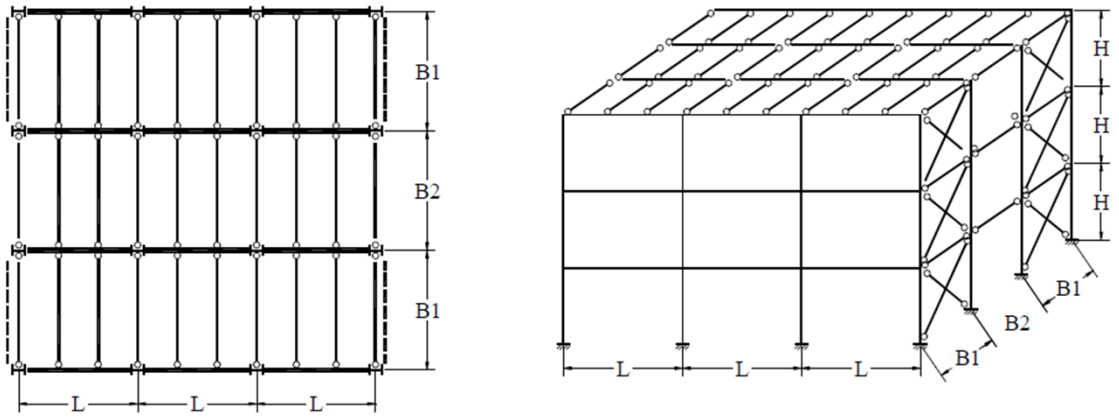
Universitatea Politehnica Timişoara

Objective: Application of « simple » method:

- Indirect method: tying method
- Direct method:
  - Key element method – Impact of a vehicle
  - Alternate path method
- Studied building: 3D steel structures

1. Multi-story buildings - Design of a multi-story building

Design of multi-story building



Considered combinations:

- « Normal » situation: 1,35 G + 1,5 Q
- « Accidental » situation: G + 0,5 Q

Content:

- Preliminary computations
- Application of different methods:
  - Tying method
  - Key element method
  - Alternate path method

Applied loads

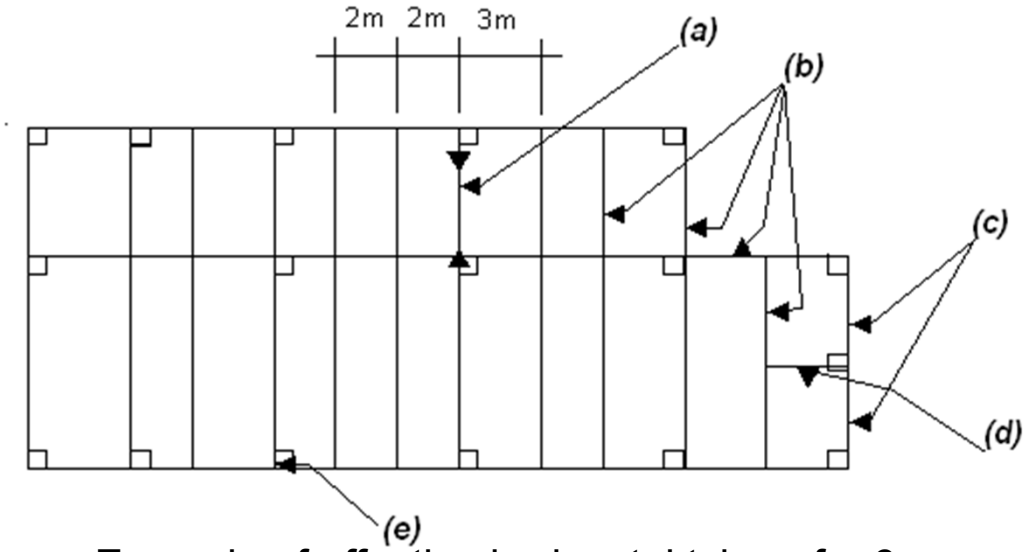
- Considered combinations:
  - « Normal » situation: 1,35 G + 1,5 Q
    - ➔ combination used for the design of the building at ULS

Normal (permanent) situation: see 2C08

  - « Accidental » situation: G + 0,5 Q
    - ➔ combination used for the verification of the structure in case of exceptional event

Application of first method: Tying method

- Ties have to be placed:
  - Around the perimeter at each level and;
  - Internally in two perpendicular directions for the tying of the columns and the walls



Example of effective horizontal tying of a 6 storey framed office building

(a) 6 m span beam as internal tie
(b) All beams designed to act as ties
(c) Perimeter ties
(d) Tie anchoring column
(e) Edge column

- Effective horizontal ties may comprise rolled steel sections, steel bar reinforcement in concrete slabs, or steel mesh reinforcement and profiled steel sheeting in composite steel/concrete floors (if directly connected to the steel beams with shear connectors). The ties may consist of a combination of the above types.
- Each continuous tie, including its end connections, should be capable of sustaining a design tensile load of “Ti” for the accidental limit state in the case of internal ties, and “Tp” , in the case of perimeter ties, equal to the following values:

for internal ties, $T_i = 0{,}8\,(g_k + \psi q_k)\,sL$ or 75 kN, whichever the greater.

for perimeter ties $T_p = 0{,}4\,(g_k + \psi q_k)\,sL$ or 75 kN, whichever the greater.

Where :

s is the spacing of ties.

L is the span of the tie.

ψ is the factor according to the accidental load combination (ie. ψ_1 or ψ_2).

EXAMPLE Calculating the accidental design tensile force T_i in 6 m span beam.

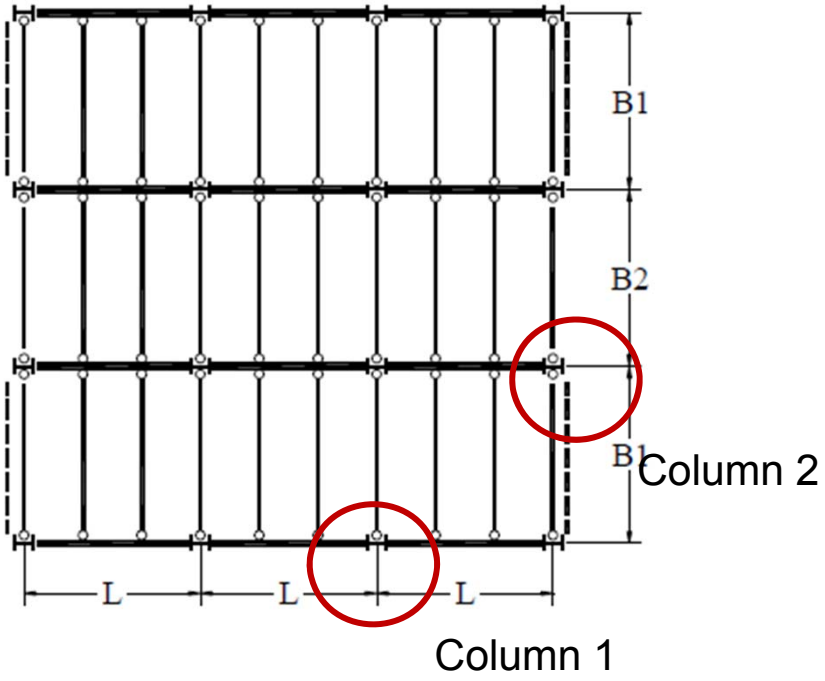
Characteristic loading : q_k = 5, 0 kN/m^2 and g_k = 3, 0 kN/m^2

$$T_i = 0{,}8\,(3{,}00 + 0{,}5 \times 5{,}00)\frac{3+2}{2} \times 6{,}0 = 66\,kN$$ (being less than 75 kN)

Verification of the joints

Application of second method: Key element method

- Considered exceptional event: impact of a vehicle
- Two façades at proximity of the roads:



Action associated to the impact

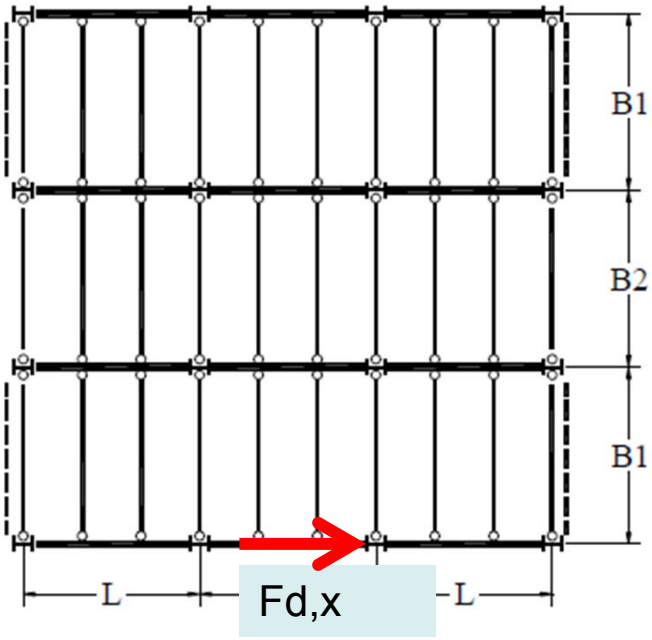
- Structures for which the energy is mainly dissipated by the impacting object:

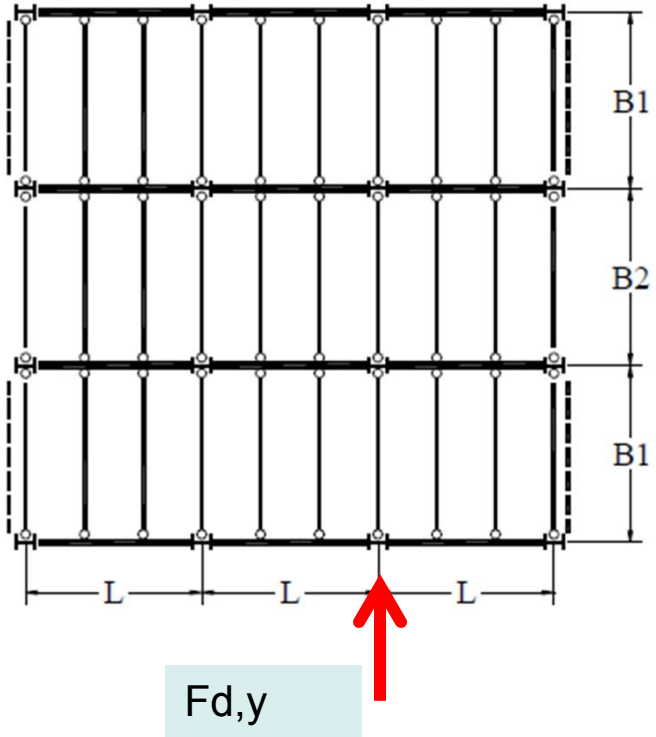
Caterory	Minimum Force $F_{d,x}$ [a] [kN]	Minimum Force $F_{d,y}$ [a] [kN]
Motorways and country national roads	1000	500
Country Roads in rural area	750	375
Roads in Urban area	500	250
Court yards and parking garages with access to: - Cars - Lorries [b]	 50 150	 25 75

[a] x = direction of normal travel, y = perpendicular to the direction of normal travel.
[b] The term 'lorry' refers to vehicles with maximum gross weight greater than 3.5 ton.

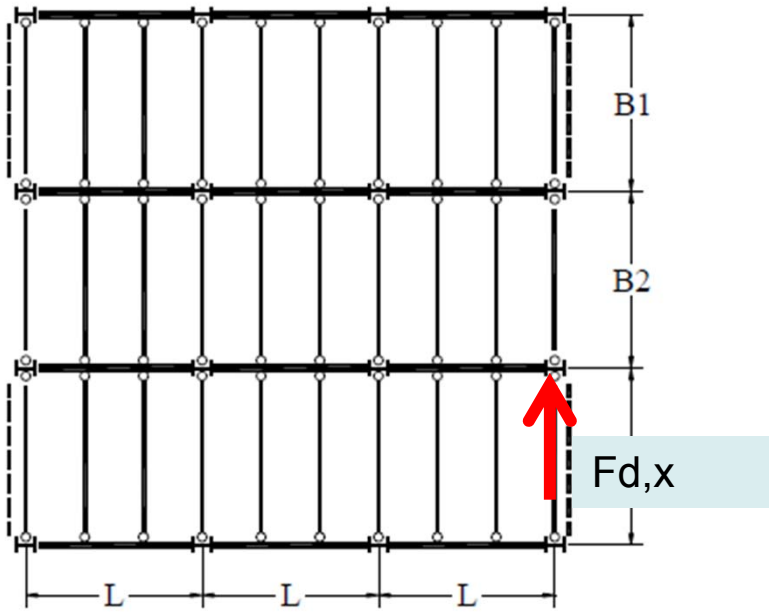
- Recommended equivalent static loads for the design
- Fd,x and Fd,y have not to be considered at same time
- *h*, position of the impact load Fd , varying from *0,5 m* (cars) to *1,5 m* (trucks)

Impact on column 1:





- Impact on column 2:



Three situations to be considered:

- Column 1 under Fd,x (= 500 kN) at 1,5m – Major axis bending
- Column 1 under Fd,y (= 250 kN) at 1,5m – Minor axis bending
- Column 2 under Fd,x (= 500 kN) at 1,5m – Minor axis bending

Verifications

- Verification of the element:
  - Beams
  - Columns
  - Risk of instability to be taken into account

Application of third method: Alternate load path method

- Study of the load redistribution within the structure following an extreme loading
- Each supporting member is notionally removed one at a time to ensure that the limit of admissible local damage is not exceeded and that the building remains stable.
- Upon the notional removal of any single member, the structure must remain stable as a whole.
- Complex problem to be dealt with as different phenomena have to be taken into account:
  - Material non linearities, geometrical non linearities
  - Dynamic effects
  - Needs generally the use of sophisticated finite element software

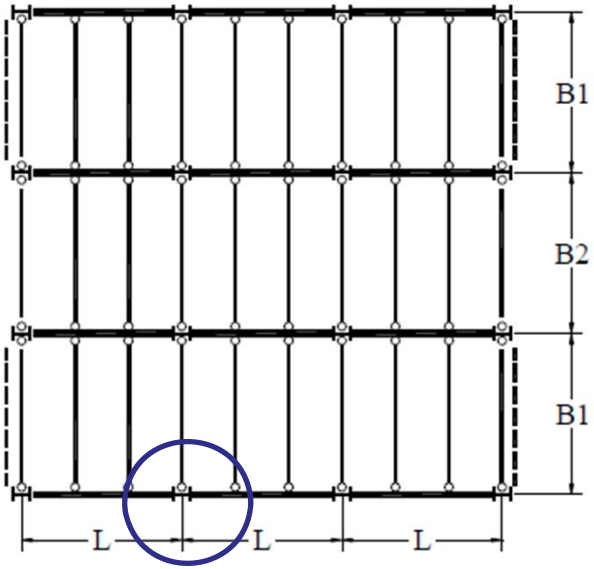
- First study: an idealised secondary frame in order to apply simplified analytical methods

  → Objective: to put into sight the developpement of membrane forces

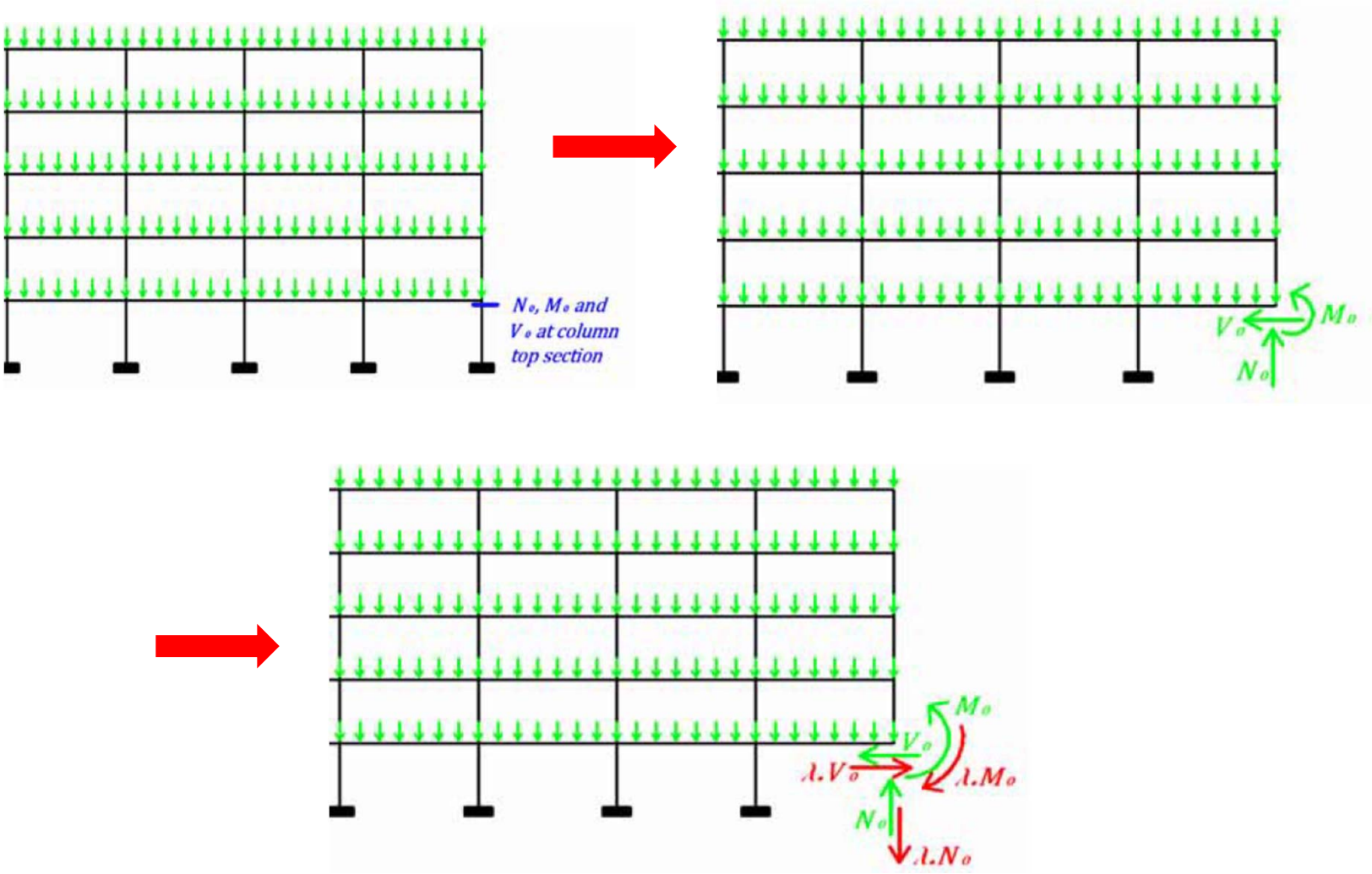
- Study of a primary frame through the use of a FEM Software
  → Objective : analysis of the load distributions and of the solution allowing this redistribution

Simplified approach

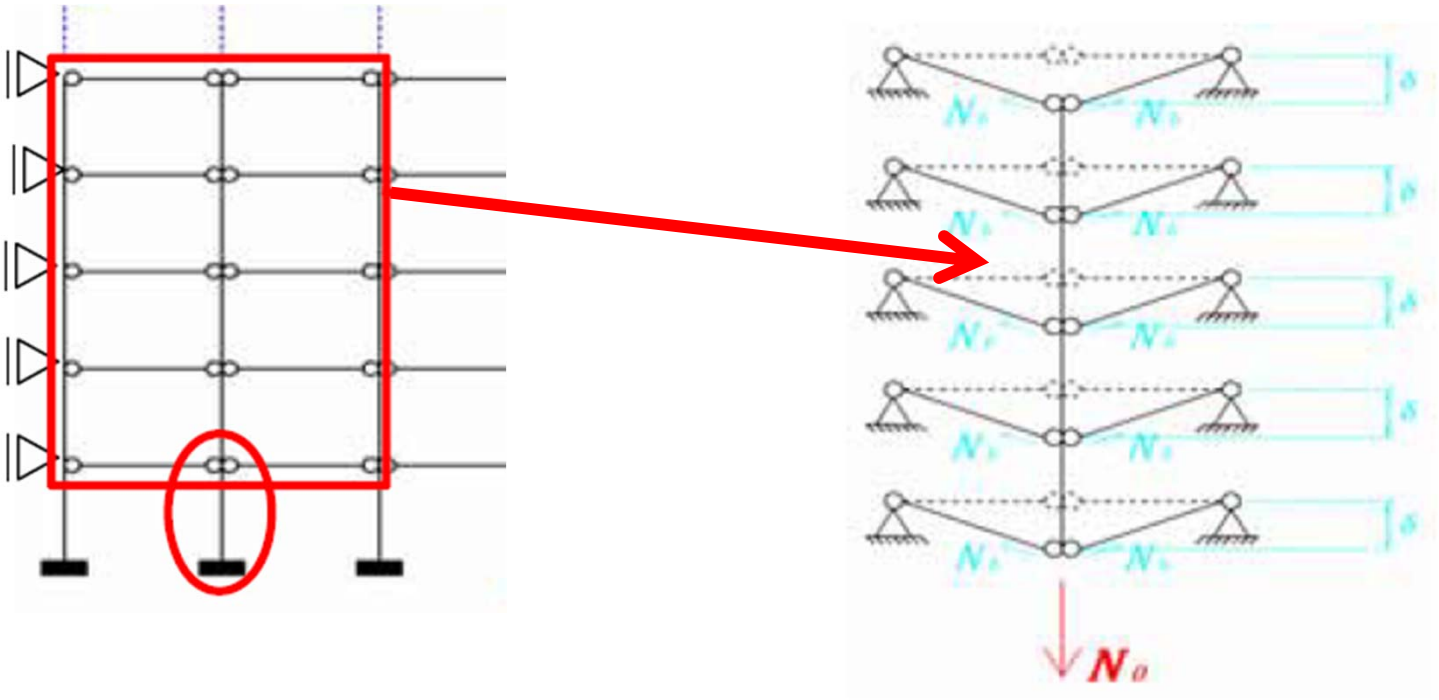
Scenario: Consider 1 column loss



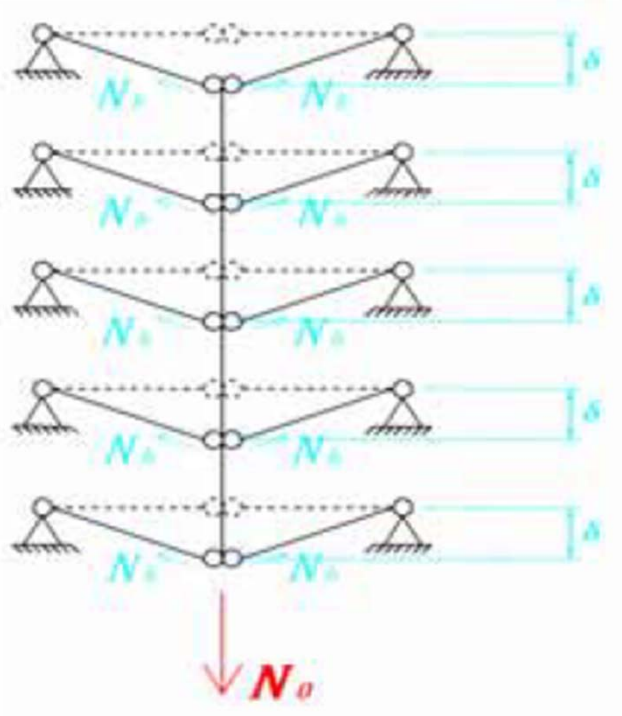
Column 1


N₀, M₀ and V₀ at column top section
V₀
M₀
N₀
M₀
V₀
λ.V₀
λ.M₀
N₀
λ.N₀

Definition of the idealised structure



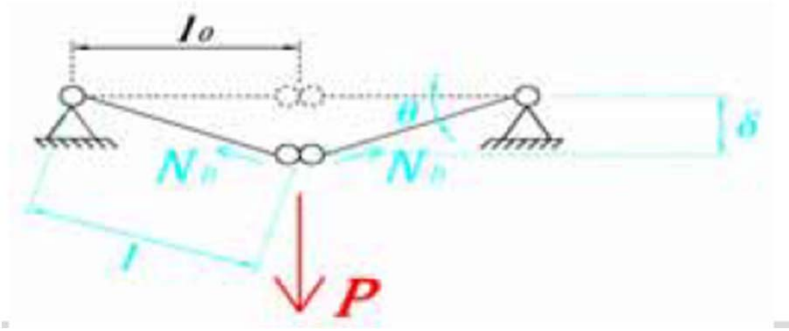
Distribution of No :

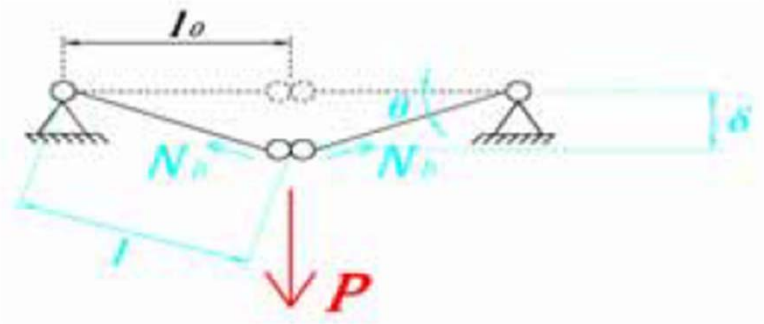


5 identical floors with identical restraints at their extremities:

→ Load N_0 will be distributed equivalently between the floors

→ Each floor will support a load $P = N_0/5$



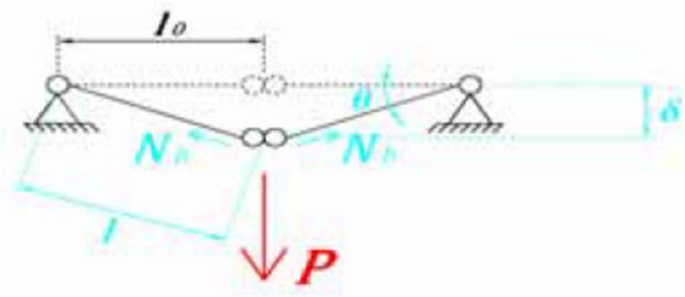


- Equilibrium in the deformed configuration (static theorem):

$$P = 2\, N_b \sin\theta$$

- Compatibility of displacement (cinematic theorem):

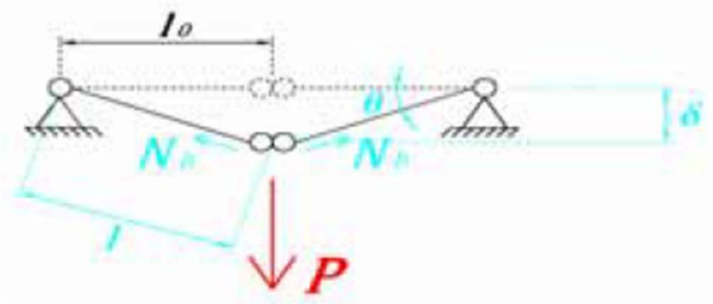
$$l = l_o / \cos\theta$$



- Elongation of the beam:

$$\Delta l = N_b \cdot \frac{l0}{E.A}$$

$$l = l_o/\cos\theta \quad \rightarrow \quad N_b = \frac{1-\cos\theta}{\cos\theta} \cdot EA$$



- System of two equations with two unknowns:

$$N_b = \frac{1-\cos\theta}{\cos\theta} \cdot EA$$

$$P = 2.N_b \sin\theta$$

→ Possible to compute N_b and the associated rotation θ

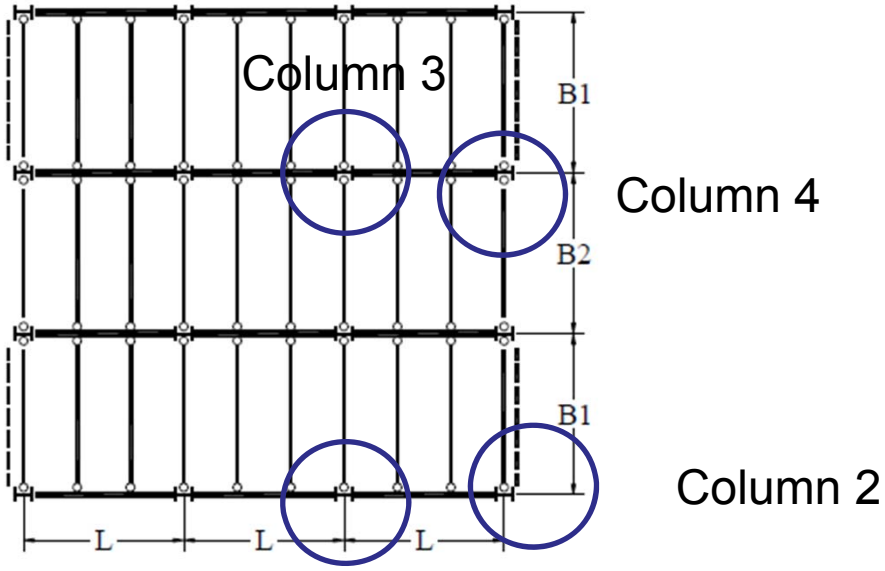
Verifications:

- Axial resistance of the beams and of the joints
- Capacity of rotation of the joints
- Resistance of the columns close to the lost column which have to support additional compression loads

Numerical approach

Scenario:

- Consider a perimeter column loss scenario



Standards	Load combinations after notional member removal	Accidental load
BS	$(1\pm0.5)\ D + L/3 + W_n/3$	34 kPa (5 psi)
Eurocode 2003 draft		20 kPa (3 psi)
Canada 1977	$D + L/3 + W_n/3$	
ASCE 7-98, 02, 05	(0.9 or 1.2) D + (0.5 L or 0.2 S) + 0.2 W_n (with member removal) 1.2 $D + A_k$ + (0.5 L or 0.2 S) (specific local resistance method) (0.9 or 1.2) $D + A_k$ + 0.2 W_n (specific local resistance method)	A_k
DOD UFC 4-010-01	D + 0.5 L net floor uplift	
DOD UFC 4-023-03	D +0.5 L net floor uplift (0.9 or 1.2) D + (0.5 L or 0.2 S) + 0.2 W_n (nonlinear dynamic analysis) 2.0 [(0.9 or 1.2) D + (0.5 L or 0.2 S)] + 0.2 W (static analysis)	
NYC 1998, 2003	2 D + 0.25 L + 0.2 W_n	
GSA	2 (D + 0.25 L) static analysis D + 0.25 L dynamic analysis	
Sweden	$G_k + \Psi Q_k$	Q_{ak}

D, L, W_n, S = dead, live, wind and snow loads;
Q_{ak} = characteristic value of accidental action;
G_k , Q_k = characteristic dead, imposed loads per unit area of the floor or roof; Ψ is a load reduction factor which, when multiplied with Q_k , gives the frequent value of a variable action.
A_k = extraordinary load.

- **Inelastic static**
  - The non-linear equivalent static approaches generally simulate the dynamic load through a load factor.
  - The gravity load reaction of the removed column are incrementally applied to generate a “push-down curve” of the structural behavior.
  - Acceptance criteria for member performance are based on deformation limits

Loads

$GN = \Omega N\,[(0.9 \text{ or } 1.2)\,D + (0.5\,L \text{ or } 0.2\,S)]$

Amplified load in all floors above the removed element

$G = (0.9 \text{ or } 1.2)\,D + (0.5\,L \text{ or } 0.2\,S)$

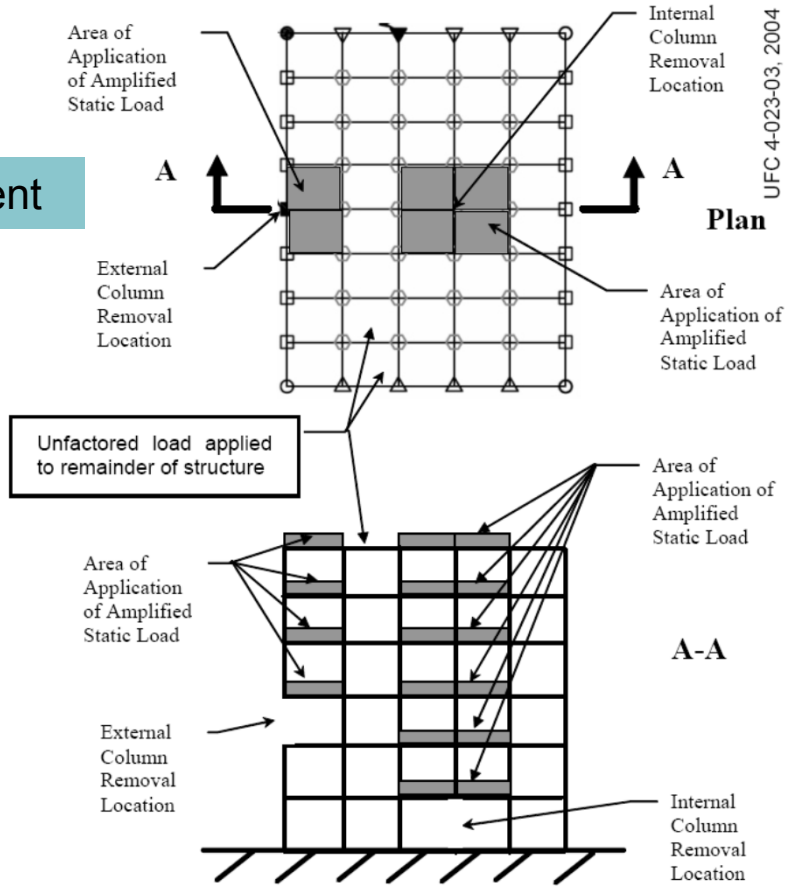
Unfactored load in the rest of the structure

Lateral Loads Applied to Structure

$LLAT = 0.002\Sigma P$

where

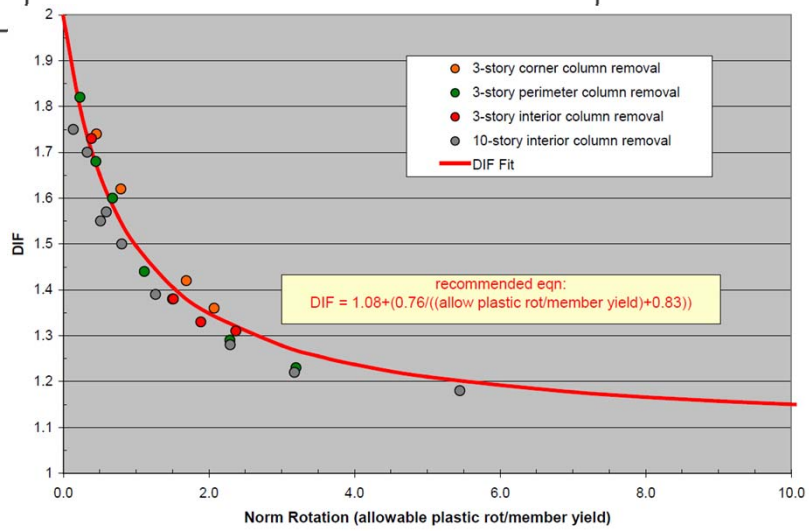
L_{LAT}	=	Lateral load
$0.002\Sigma P$	=	Notional lateral load applied at each floor; this load is applied to every floor on each face of the building, one face at a time (i.e., four load combinations must be assessed for a rectangular building)
ΣP	=	Sum of the gravity loads (Dead and Live) acting on only that floor; dynamic increase factors are not employed.



Load Application for Alternate Path Analysis (UFC 4-023-03, 2004)

Dynamic Increase Factors for Nonlinear Static Analysis

Material	Structure Type	Ω_N
Steel	Framed	$1.08 + 0.76/(\theta_{pra}/\theta_y + 0.83)$
Reinforced Concrete	Framed	$1.04 + 0.45/(\theta_{pra}/\theta_y + 0.48)$
	Load-Bearing Wall	2
Masonry	Load-bearing Wall	2
Wood	Load-bearing Wall	2
Cold-formed Steel	Load-bearing Wall	2



UFC 4-023-03, 2010

- **Inelastic dynamic**
  - A more rigorous approach for evaluating progressive collapse
  - This approach should be used by structural engineers with knowledge and experience in structural dynamics
  - Acceptance criteria for the performance of structural members are in terms of deformation limits.

Loads

Apply the following gravity load combination to the entire structure.

G = (0.9 or 1.2) D + (0.5 L or 0.2 S)

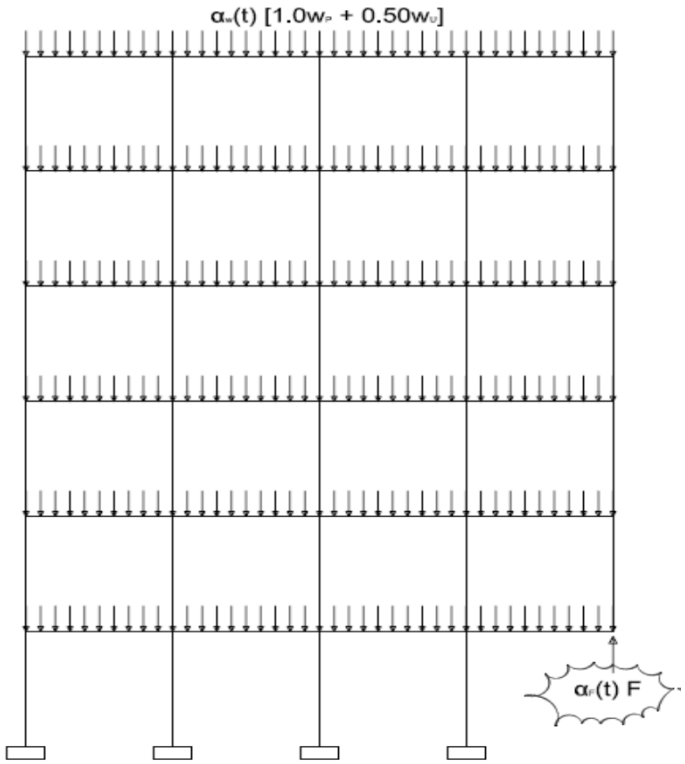
Lateral Loads Applied to Structure

LLAT = 0.002ΣP

where

L_{LAT}	=	Lateral load
0.002ΣP	=	Notional lateral load applied at each floor; this load is applied to every floor on each face of the building, one face at a time (i.e., four load combinations must be assessed for a rectangular building)
ΣP	=	Sum of the gravity loads (Dead and Live) acting on only that floor; dynamic increase factors are not employed.

- It is preferable to remove the column instantaneously
- Otherwise the duration for removal must be less than one tenth of the period associated with the structural response mode for the vertical motion of the bays above the removed column, as determined from the analytical model with the column or wall section removed.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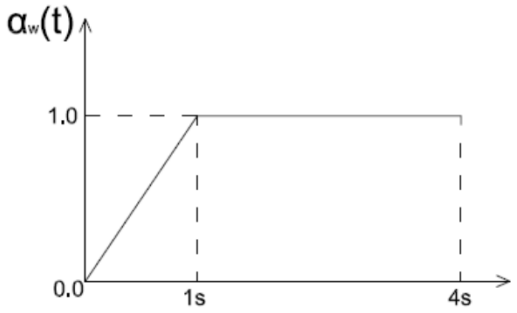
αF(t) F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1s
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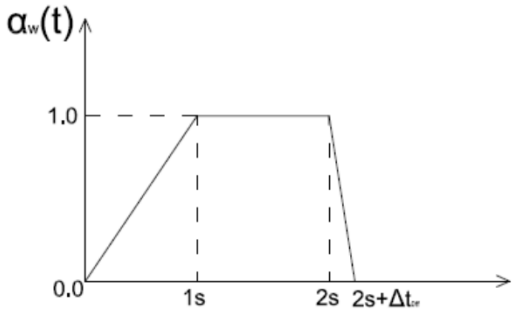
αw(t)
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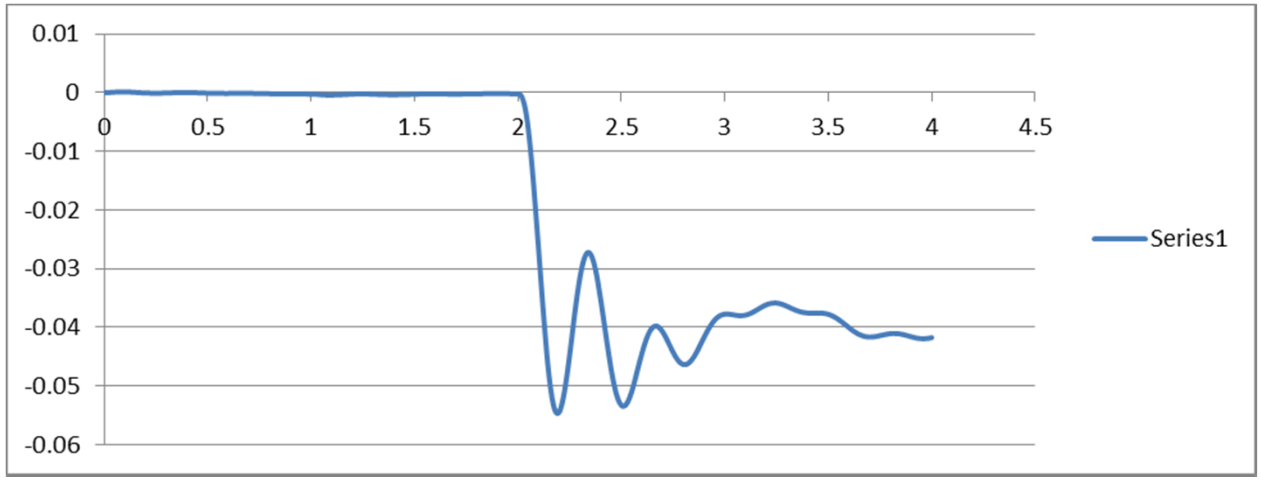
0.0
1s
2s
2s+Δtcr

Example:


0.01
0
-0.01
-0.02
-0.03
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2
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3
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4
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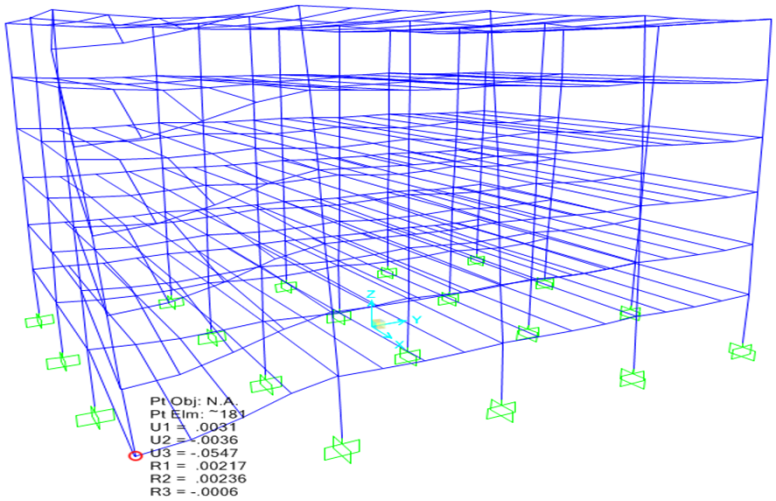
Series1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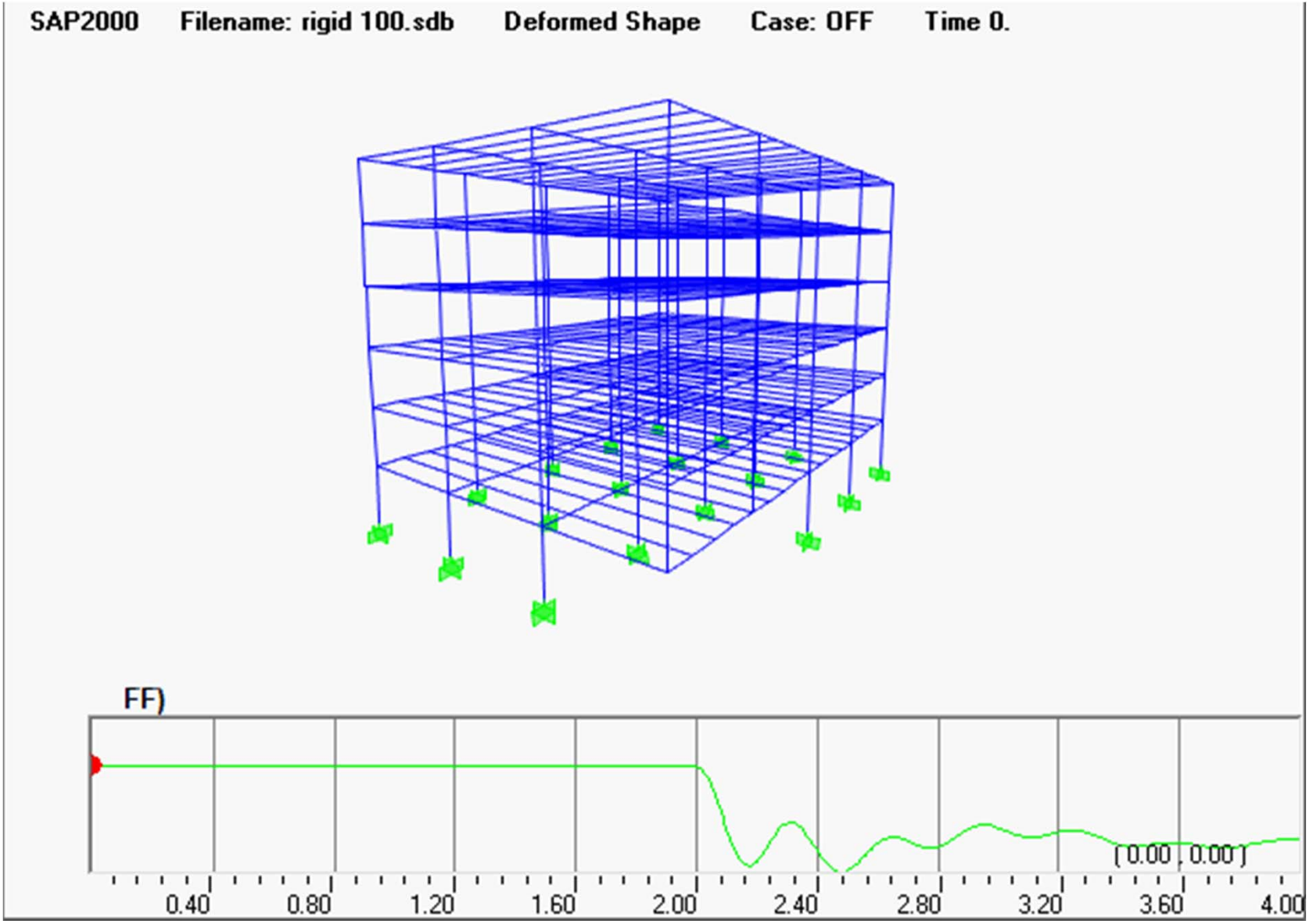
U2 = -.0036
U3 = -.0547
R1 = .00217
R2 = .00236
R3 = -.0006


SAP2000 Filename: rigid 100.sdb Deformed Shape Case: OFF Time 0.
FF)
0.40
0.80
1.20
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2.40
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3.60
4.00
[0.00 , 0.00]

This lecture was prepared for the 1st Edition of SUSCOS (2012/14) by J.-F. Demonceau & J.-P. Jaspart, ULg

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

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