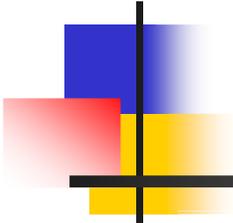


Ordine degli Ingegneri della Provincia di Pistoia  
Corso sulla Vulnerabilità Sismica



# Modelli evolutivi per la verifica del rischio di edifici esistenti

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## Quaderno 3 Esempi applicativi

**Prof. Enrico Spacone**

Dipartimento di Ingegneria e Geologia  
Università degli Studi "G. D'Annunzio" Chieti-Pescara

DIPARTIMENTO DI

INGEGNERIA  
E GEOLOGIA

*31 Maggio 2012*



# SOMMARIO

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- **Edificio di Bonefro**
- **Ponte di Humbolt Bay**
- **Modellazione Taglio (Per ponti ed edifici)**
- **Esempio di modellazione ed analisi in MidasGen**
- **E-ELT Telescope**

# SOMMARIO

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# APPLICAZIONE 1: EDIFICIO DI BONEFRO

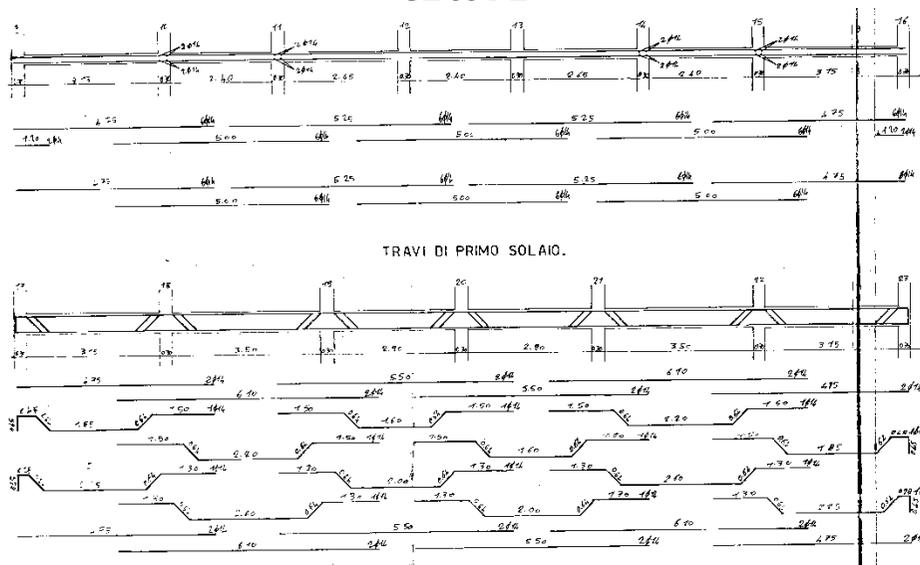
Edificio danneggiato dal sisma del Molise 2002



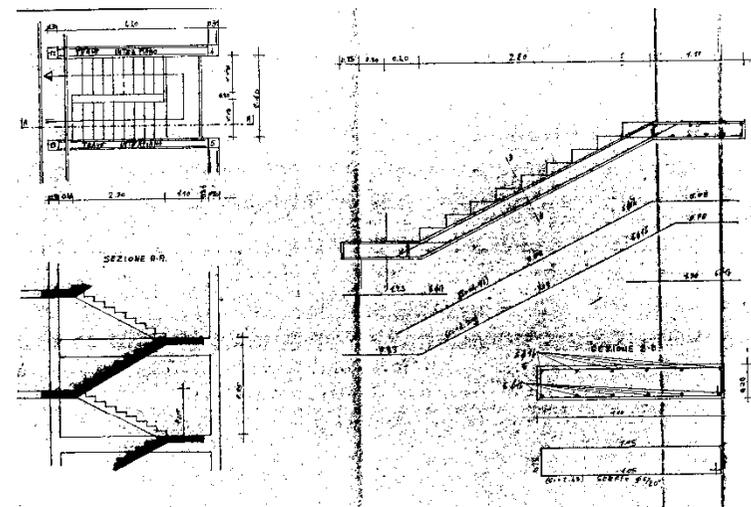


# APPLICAZIONE 1: EDIFICIO DI BONEFRO

## travi

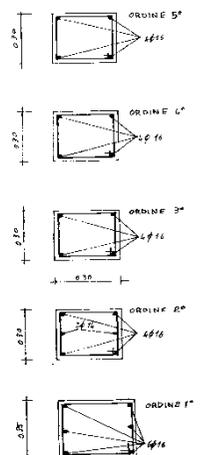


## scala

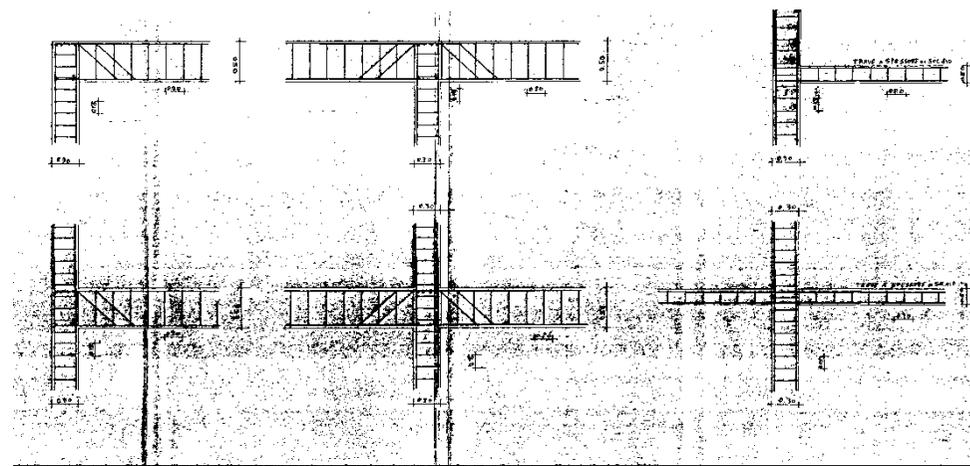


## pilastri

PILASTRI	1-3-5-7-9	4-6-8-10-12
ORDINE	5°	6°
DIMENSIONI	30x30	30x30
ARMATURA	4φ16	4φ16
STAFFE	φ10/10	φ10/10
ORDINE	4°	5°
DIMENSIONI	30x30	30x30
ARMATURA	4φ16	4φ16
STAFFE	φ10/10	φ10/10
ORDINE	3°	4°
DIMENSIONI	30x30	30x30
ARMATURA	4φ16	4φ16
STAFFE	φ10/10	φ10/10
ORDINE	2°	3°
DIMENSIONI	30x30	30x30
ARMATURA	4φ16	4φ16
STAFFE	φ10/10	φ10/10
ORDINE	1°	2°
DIMENSIONI	30x30	30x30
ARMATURA	4φ16	4φ16
STAFFE	φ10/10	φ10/10



## nodi

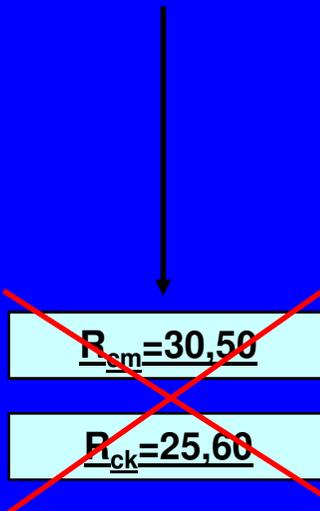


# APPLICAZIONE 1: EDIFICIO DI BONEFRO

## MODELLAZIONE DEL CLS

### RESISTENZA A COMPRESSIONE DEL CLS

**LUGLIO 1984**  
**PROVINI CUBICI**  
**CERTIFICATI**



DEVIAZ. STAND. = 2,3

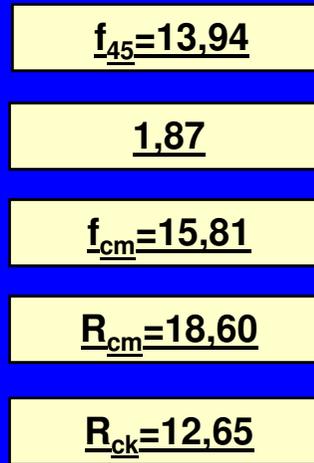
MEDIA CILINDRICA SU  
10 MICROCAROTE

RESISTENZA  
CILINDRICA MEDIA

RESISTENZA  
CUBICA MEDIA

RESISTENZA CUBICA  
CARATTERISTICA

**FEBBR. 2003**  
**MICROCAROTE**  
**CILINDRICHE**



### MICROCAROTAGGIO

- diametro di 28mm
- diametro di 45mm
- diametro di 70mm

EFFETTO SCALA DOVUTO AL  
MICROCATOTAGGIO (45mm)

$$f_{cm} = 1,048 + 1,058 f_{45}$$

*"MATERIALS AND*  
*STRUCTURES"*  
*(F. INDELICATO)*

*ACI MATERIALS JOURNAL*

### MODULO ELASTICO

$$E_c = 4700 \sqrt{f_{cm}} = 18688 \text{ Mpa}$$

# APPLICAZIONE 1: EDIFICIO DI BONEFRO

<b>Piani 1-2-3</b>	
Peso Proprio soletta	2.82 KN/m <sup>2</sup>
Carichi Permanenti	2.80 KN/m <sup>2</sup>
Carichi Variabili	2.00 KN/m <sup>2</sup> 4.00 KN/m <sup>2</sup> (balcone)

<b>Piano 4 (sottotetto)</b>	
Peso Proprio soletta	2.82 KN/m <sup>2</sup>
Carichi Permanenti	0.3 KN/m <sup>2</sup>
Carichi Variabili	2.00 KN/m <sup>2</sup> 4.00 KN/m <sup>2</sup> (balcone)

<b>Copertura</b>	
Peso Proprio soletta	3.25 KN/m <sup>2</sup>
Carichi Permanenti	2.07 KN/m <sup>2</sup>

# APPLICAZIONE 1: EDIFICIO DI BONEFRO

---

$$\sum G_{k,j} + \sum \Psi_{Ej} Q_{Kj}$$

$\Psi_{Ei}$  = coeff. di combinazione dell'azione variabile (EC8)

$$\Psi_{Ej} = \varphi \cdot \Psi_{2j} (SLU)$$

---

	$\Psi_{2i}$
abitazioni, uffici	0.30
Tetti e coperture con neve	0.20

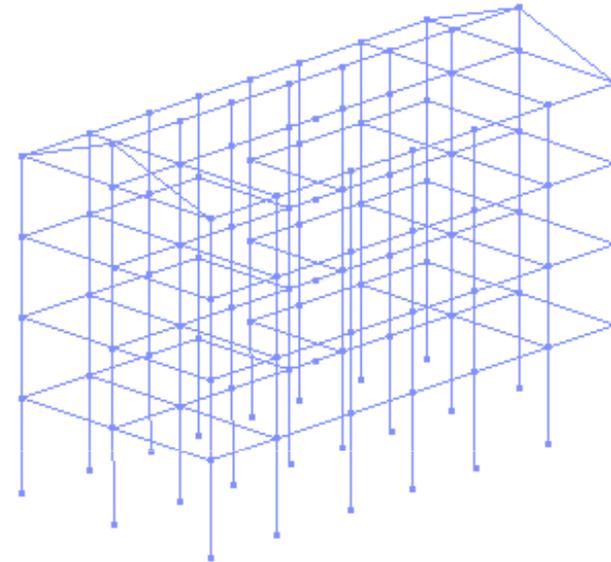
---

Carichi indipendenti	$\varphi$
Ultimo piano	1.00
Altri piani	0.50

---

# APPLICAZIONE 1: EDIFICIO DI BONEFRO

	<b><math>M = W/g</math> (t)</b>
<b>Piano 1</b>	164
<b>Piano 2</b>	175
<b>Piano 3</b>	175
<b>Piano 4</b>	107
<b>Copertura</b>	69



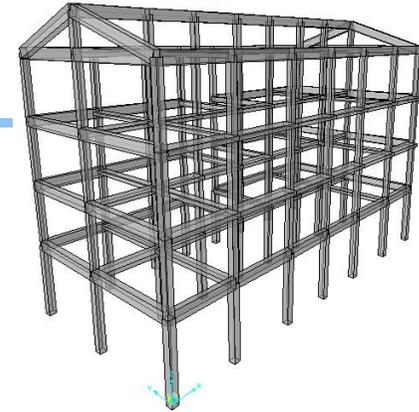
$$M_{tot} = 692 t$$

Le masse di piano vengono ripartite ai nodi  
(diaframma infinitamente rigido)

N.B. non e' stato incluso il carico neve

# ANALISI MODALE 1

EDIFICIO DI BONEFRO:  
SOLAIO "RIGIDO"  
SENZA TAMPONAMENTI E SCALE (EI intero)

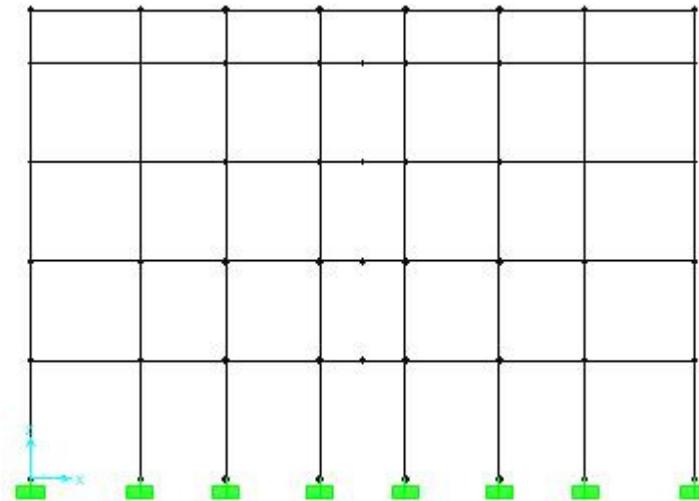
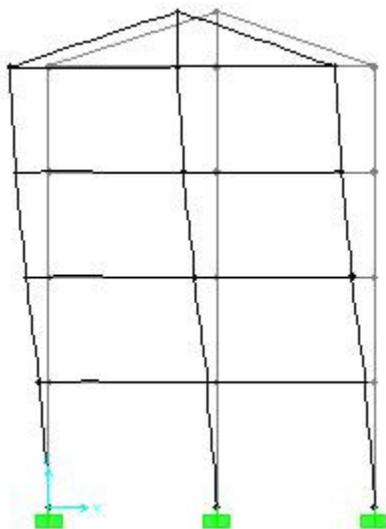
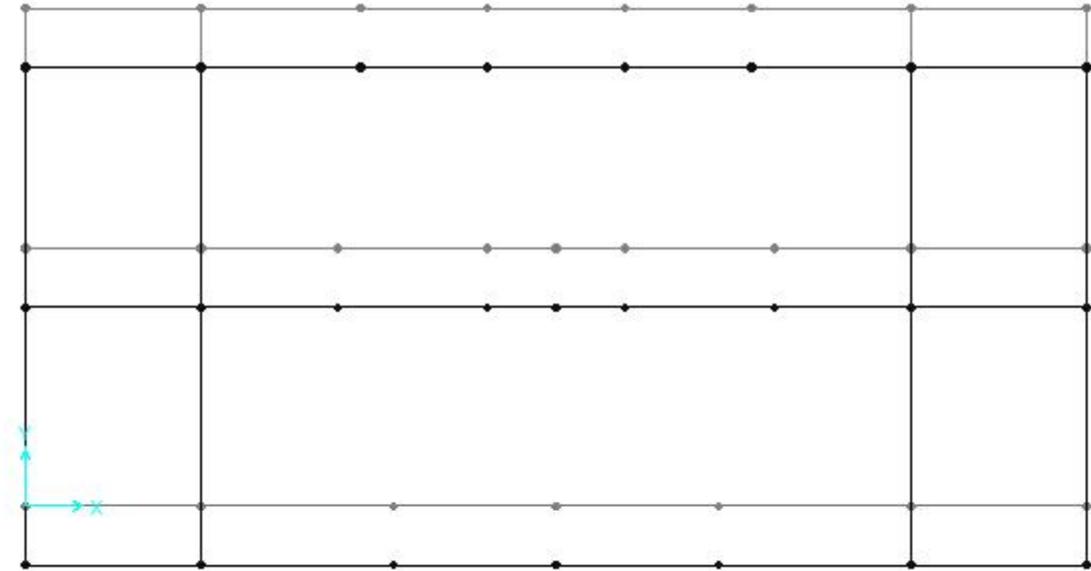
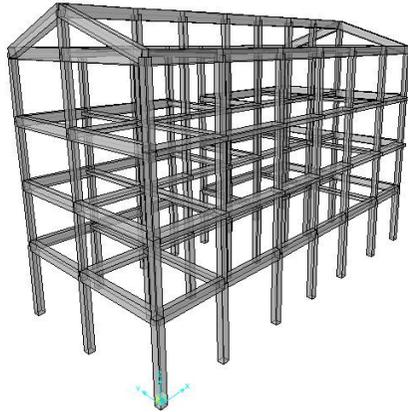


Modo	Periodo (Sec)	UX	UY	RZ	SumUX	SumUY	SumRZ
1	0,902	0,00000	0,83935	0,00000	0,00000	0,83935	0,00000
2	0,685	0,27868	0,00000	0,57195	0,27868	0,83935	0,57195
3	0,642	0,57923	0,00000	0,29194	0,85791	0,83935	0,86389
4	0,299	0,00000	0,09731	0,00000	0,85791	0,93666	0,86389
5	0,228	0,04963	0,00000	0,05925	0,90753	0,93666	0,92314
6	0,214	0,05334	0,00000	0,03701	0,96087	0,93666	0,96015
7	0,176	0,00000	0,03990	0,00000	0,96087	0,97656	0,96015
8	0,139	0,01032	0,00000	0,02018	0,97119	0,97656	0,98033
9	0,134	0,01947	0,00000	0,00762	0,99066	0,97656	0,98795
10	0,119	0,00000	0,02071	0,00000	0,99066	0,99727	0,98795
11	0,108	1.86E-02	0,00000	0,01169	0,99068	0,99727	0,99964
12	0,106	0,00932	0,00000	3.18E-02	100,000	0,99727	0,99967

**E' FORTEMENTE CONSIGLIABILE FARE UN'ANALISI MODALE PRIMA DI UNA  
QUALUNQUE ANALISI NONLINEARE**

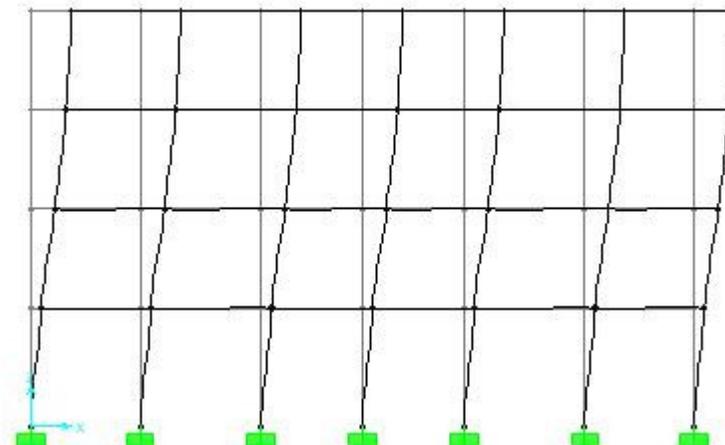
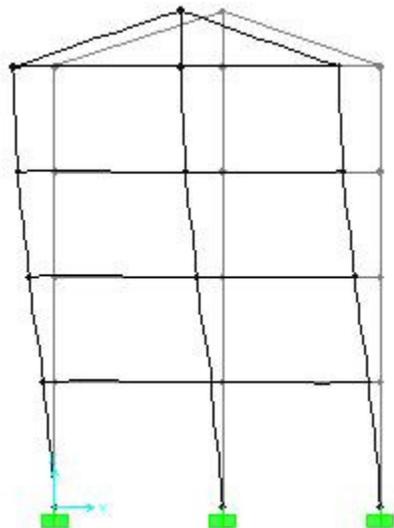
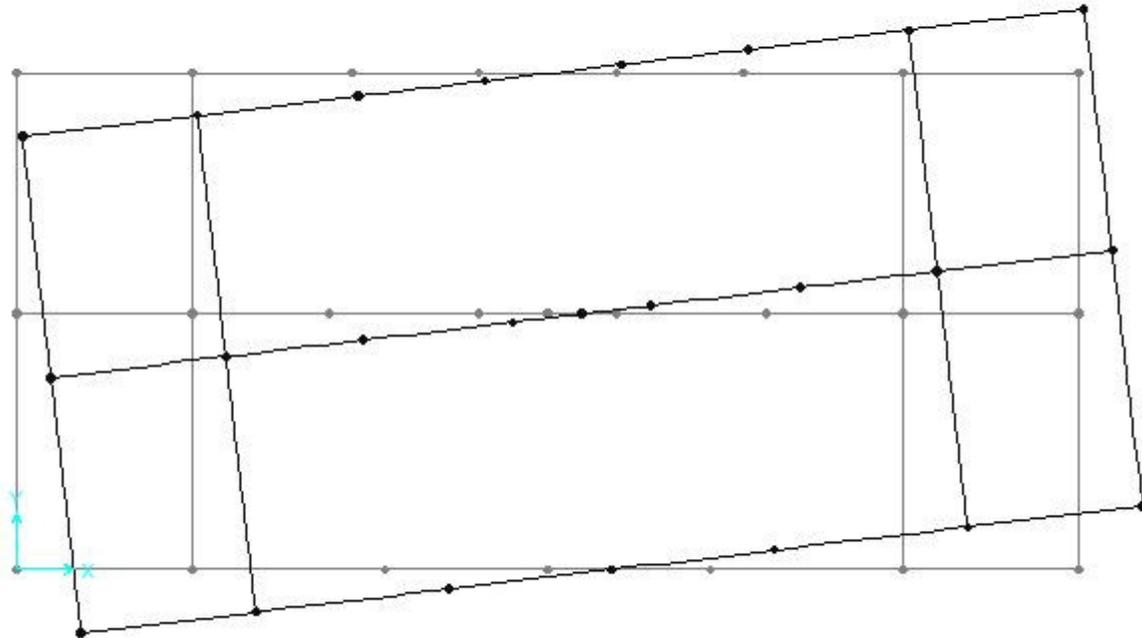
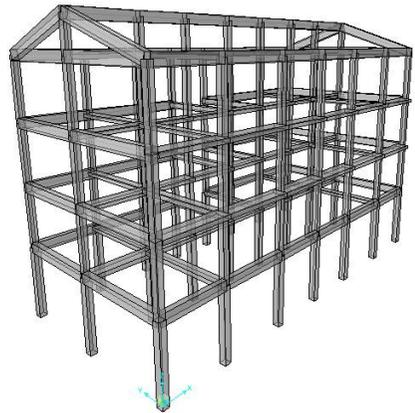
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
1	0,902	0,00000	0,83935



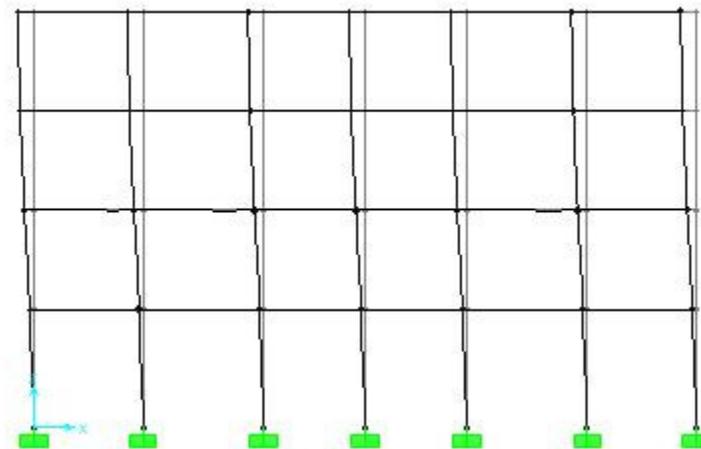
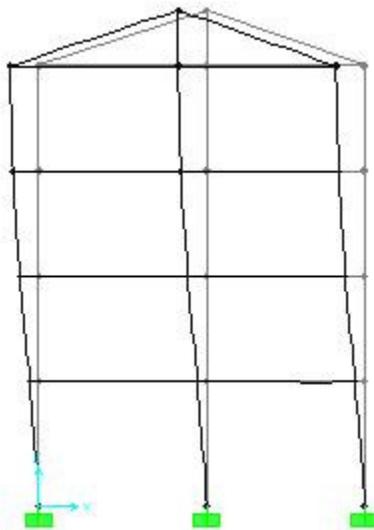
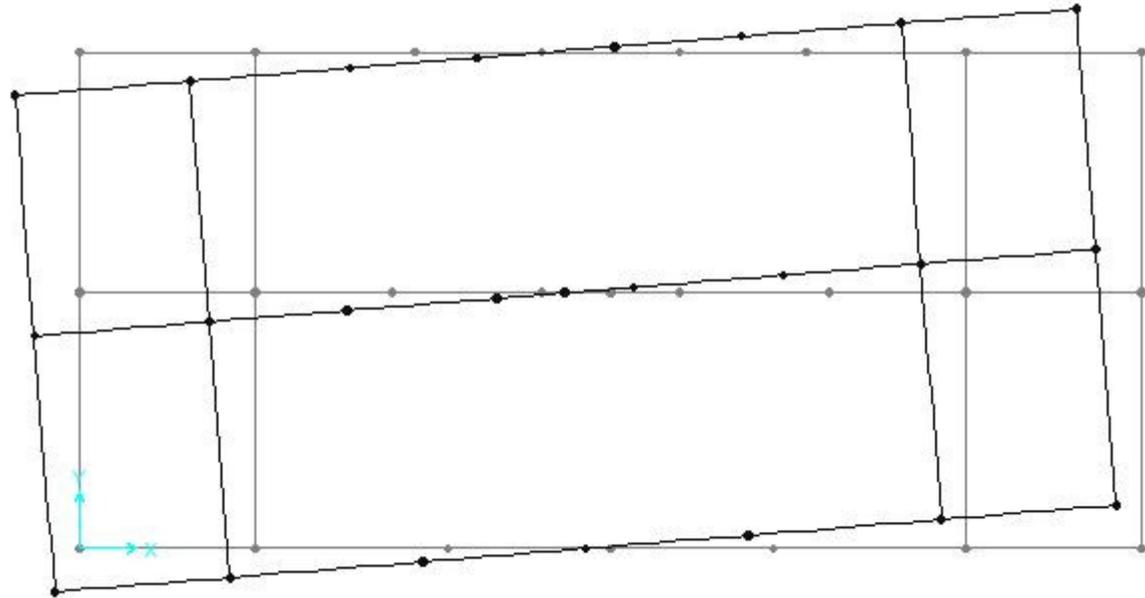
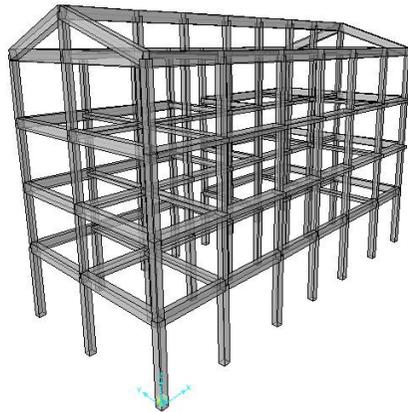
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
2	0,685	0,27868	0,00000



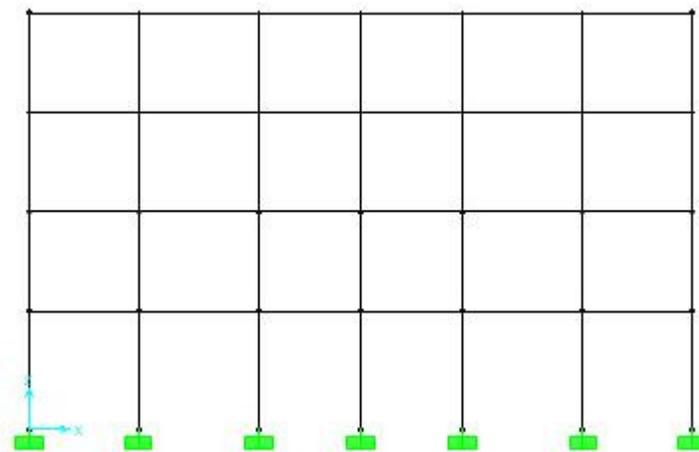
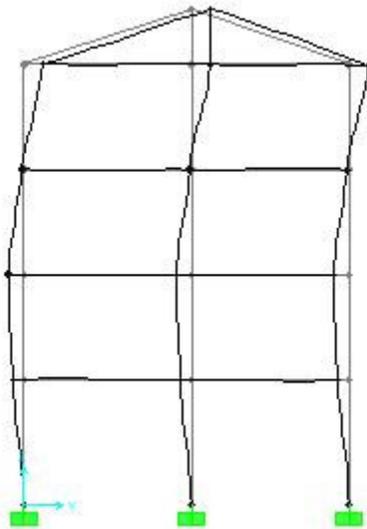
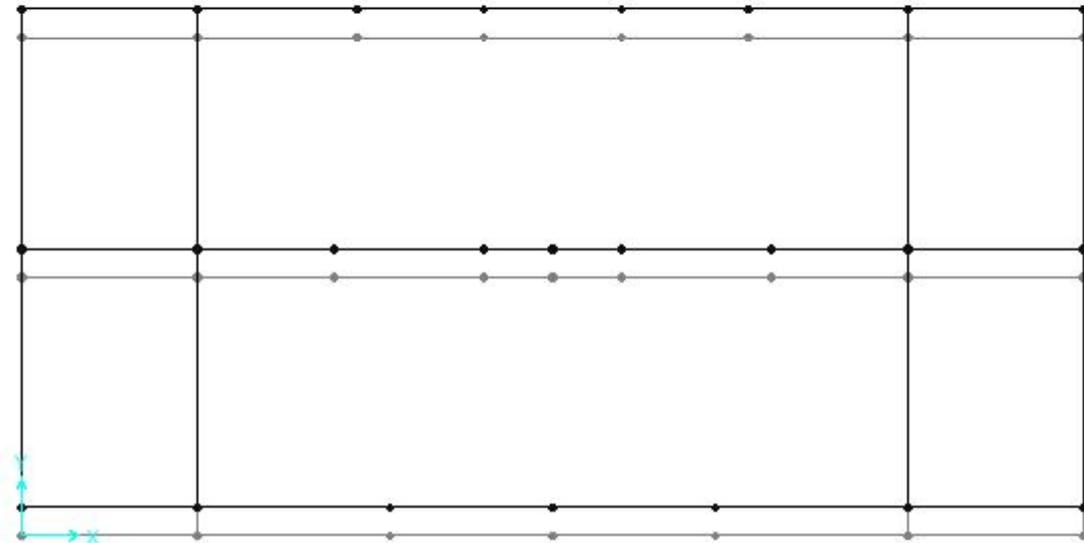
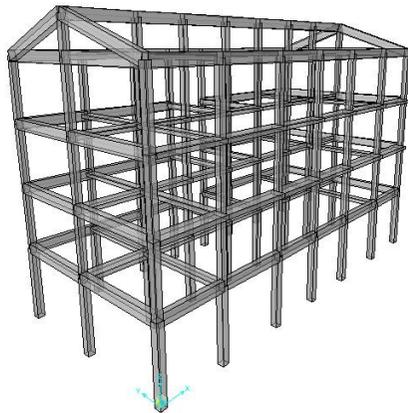
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
3	0,642	0,57923	0,00000



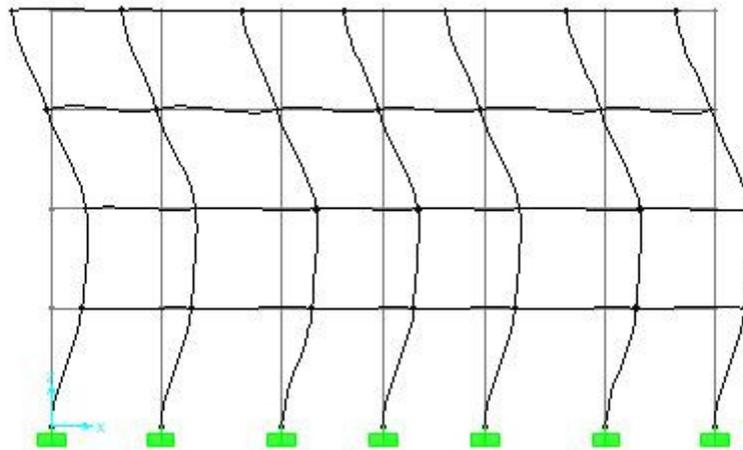
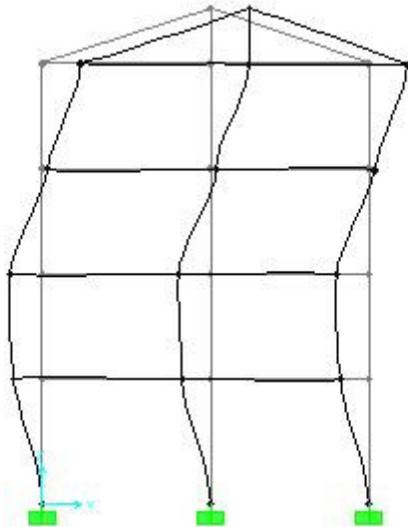
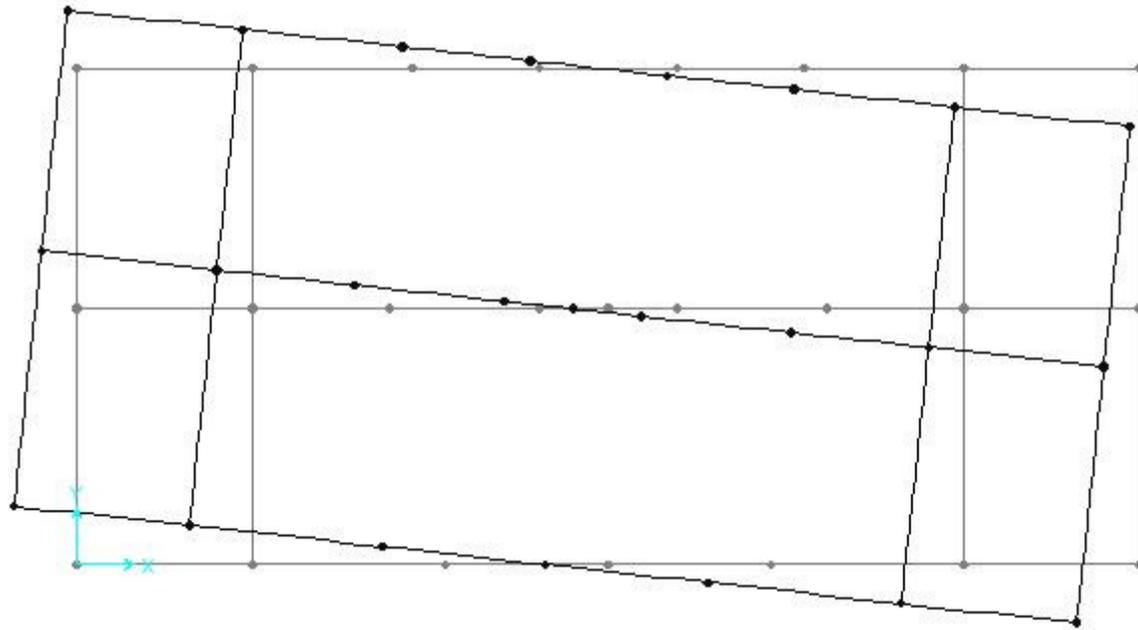
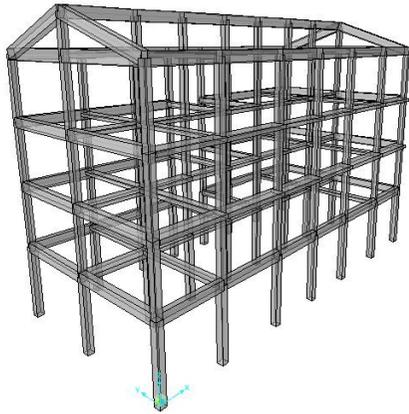
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
4	0,299	0,00000	0,09731



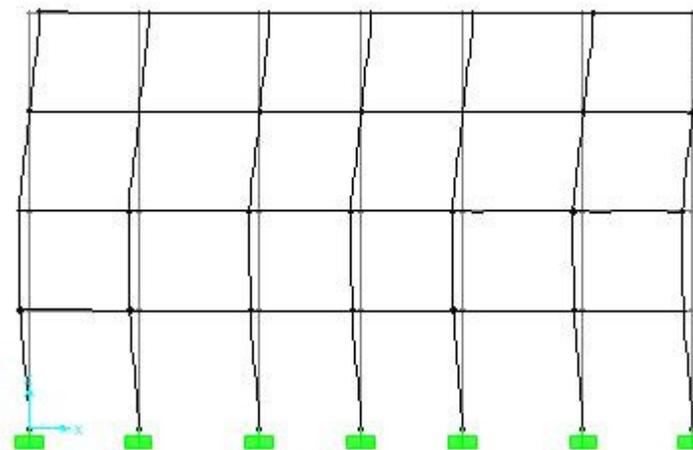
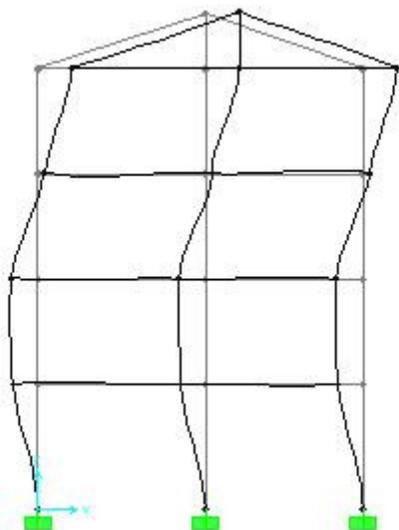
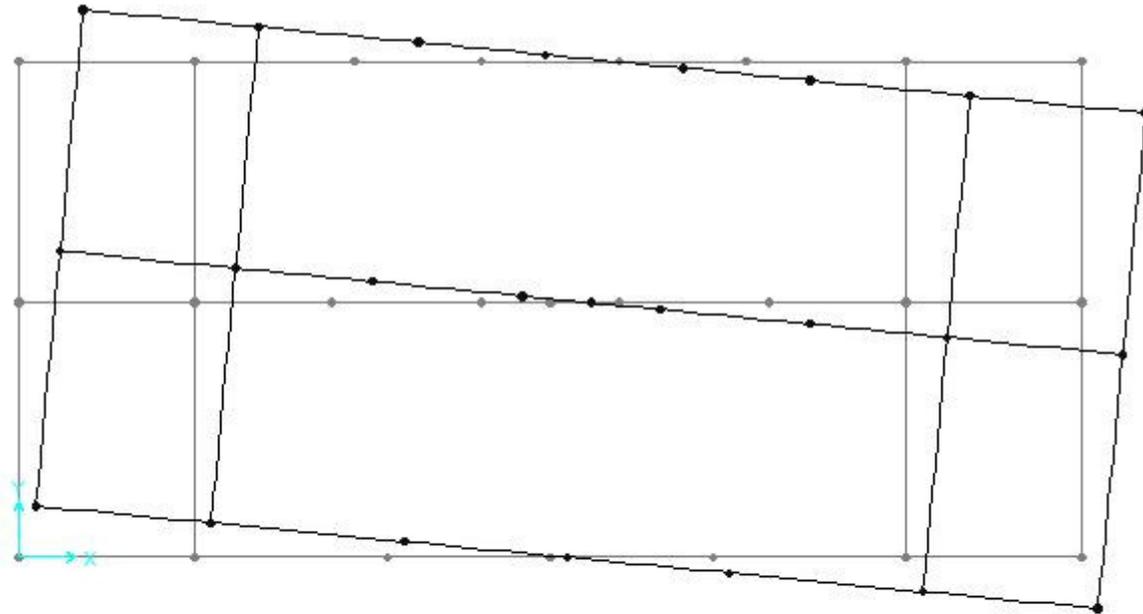
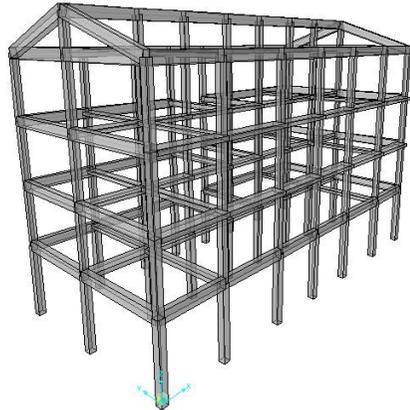
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
5	0,228	0,04963	0,00000



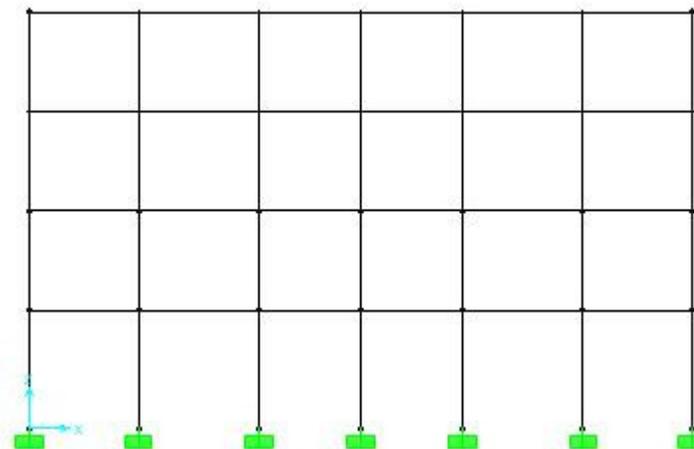
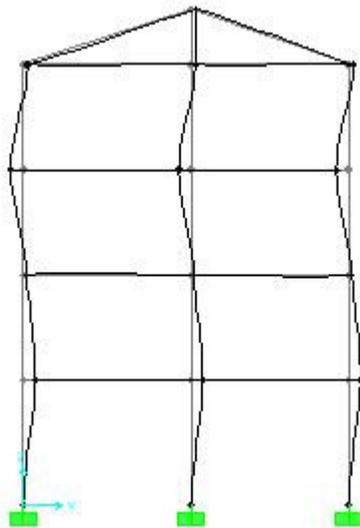
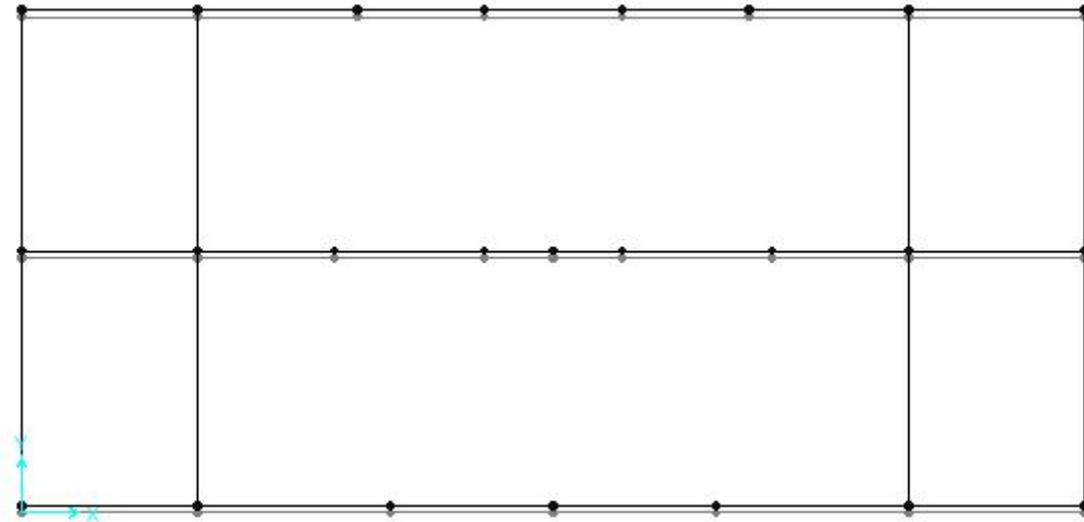
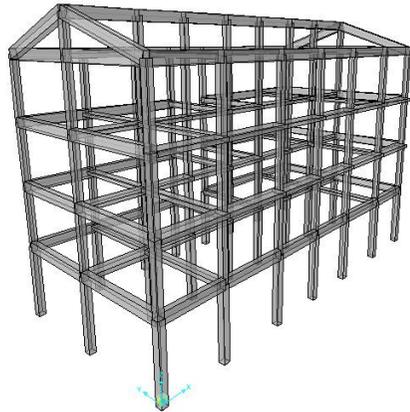
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
6	0,214	0,05334	0,00000



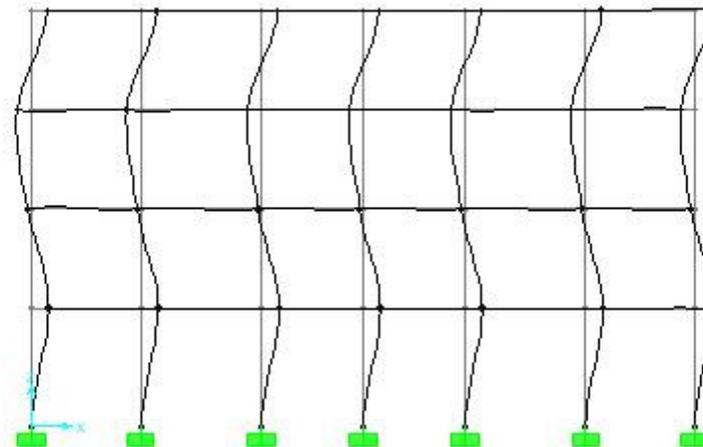
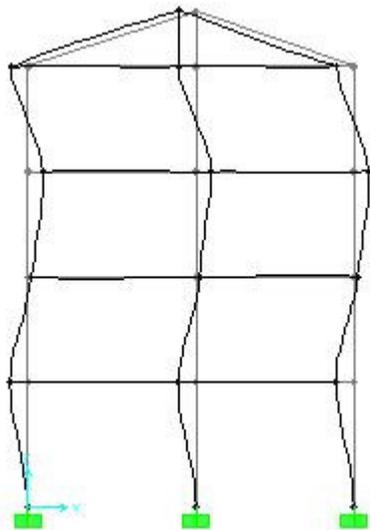
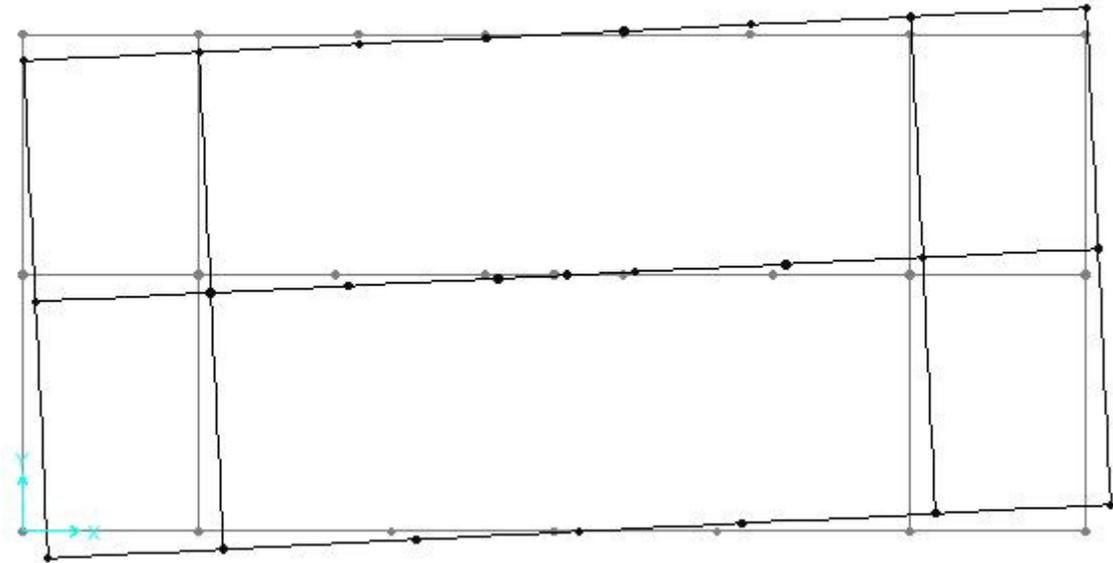
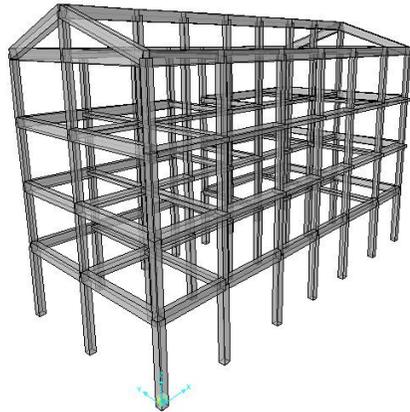
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
7	0,176	0,00000	0,03990



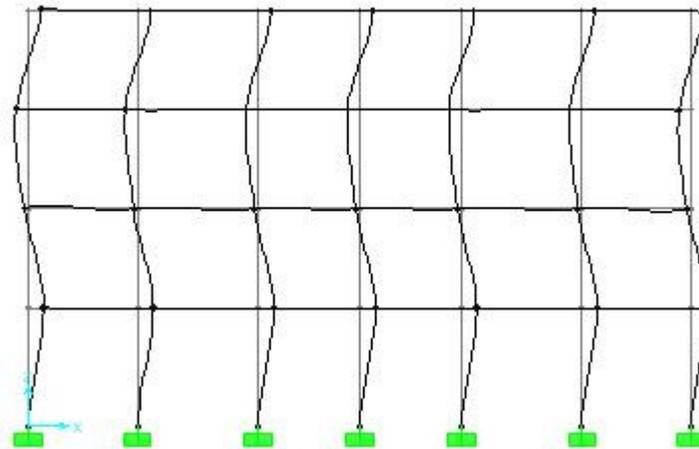
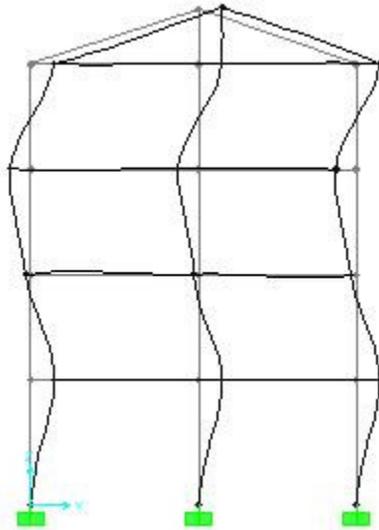
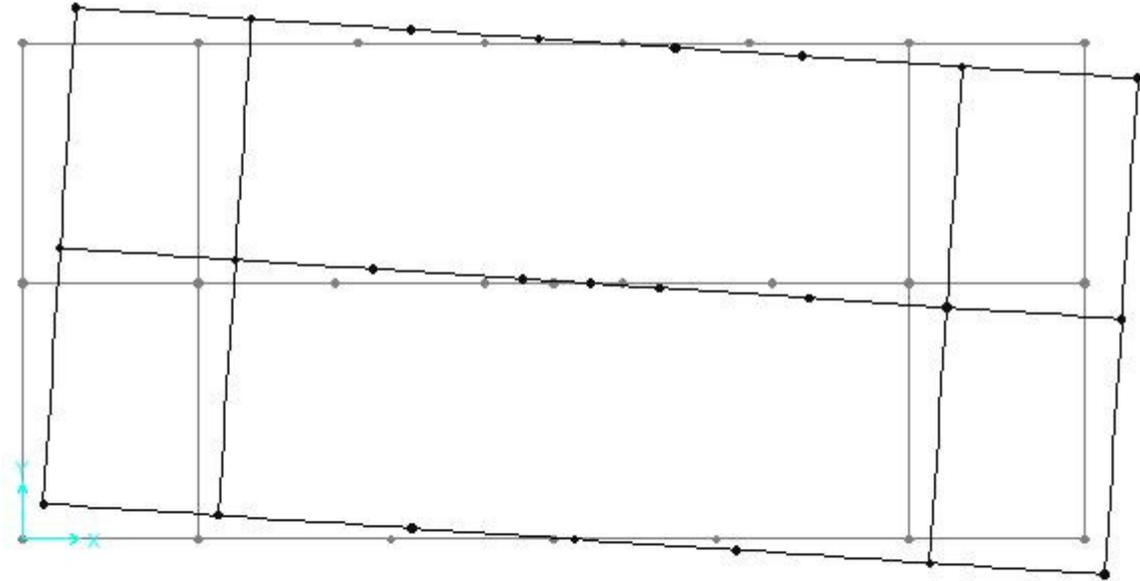
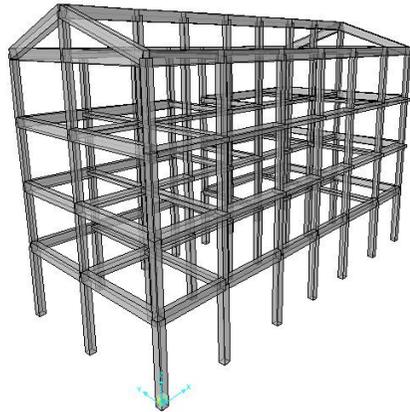
# ANALISI MODALE 1

Modo	T (sec)	UX	UY
8	0,139	0,01032	0,00000



# ANALISI MODALE 1

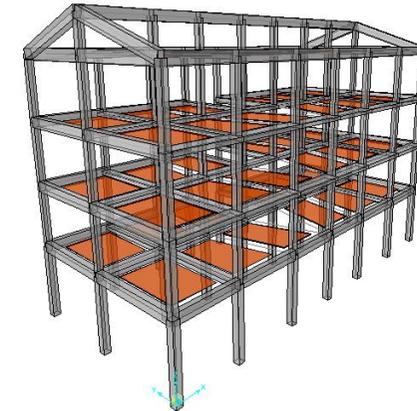
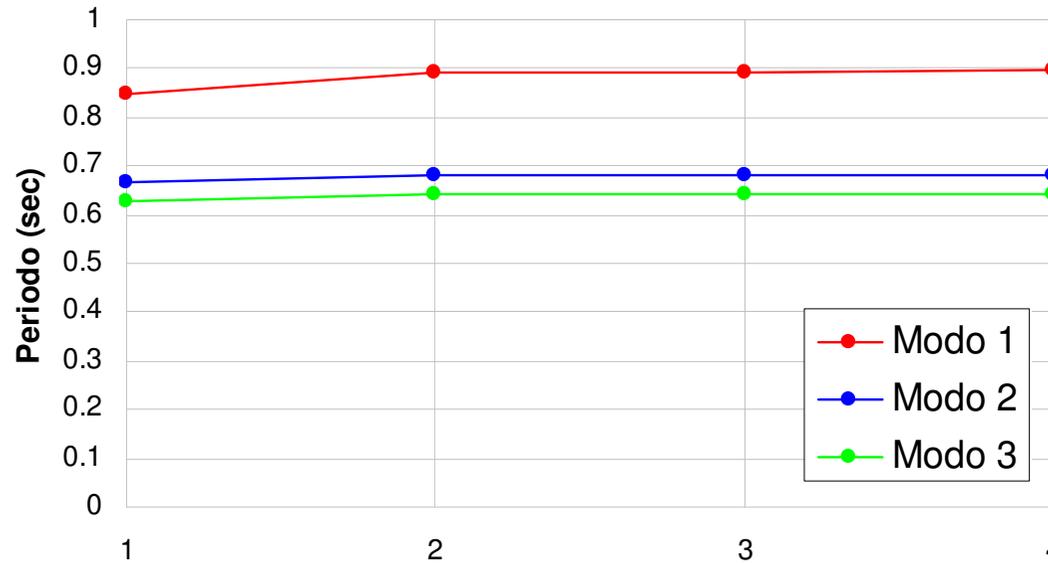
Modo	T (sec)	UX	UY
9	0,134	0,01947	0,00000



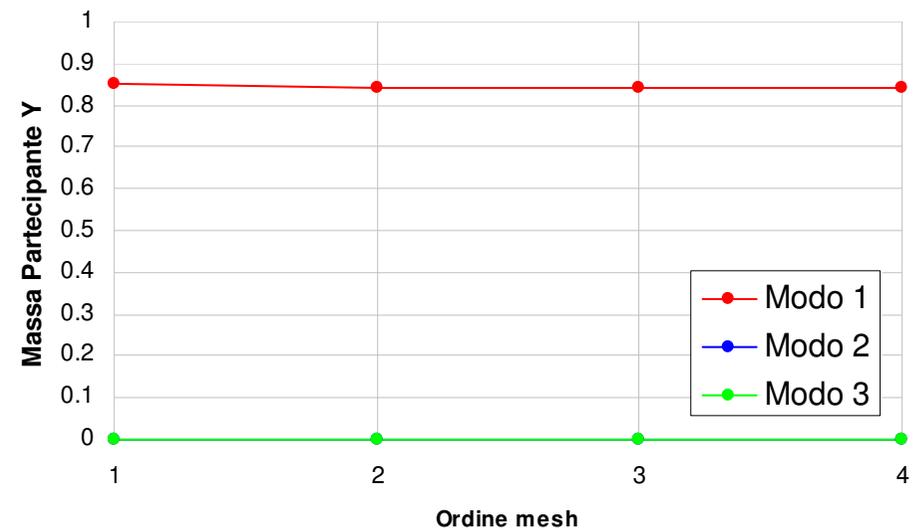
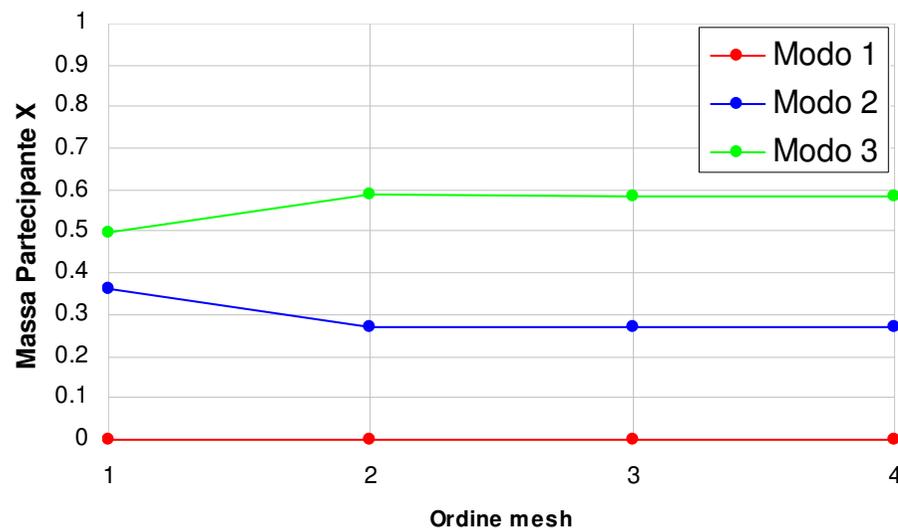
# ANALISI MODALE 2

## EDIFICIO DI BONEFRO: SOLAIO NON "RIGIDO"

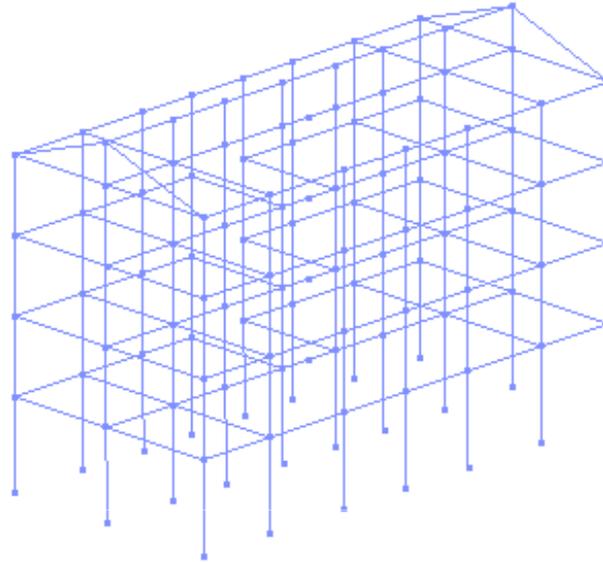
SENZA TAMPONEMENTI E SCALE (EI intero)



**EFFETTO DISCRETIZZAZIONE SOLAIO**



# MODELLO NON LINEARE DELLA STRUTTURA

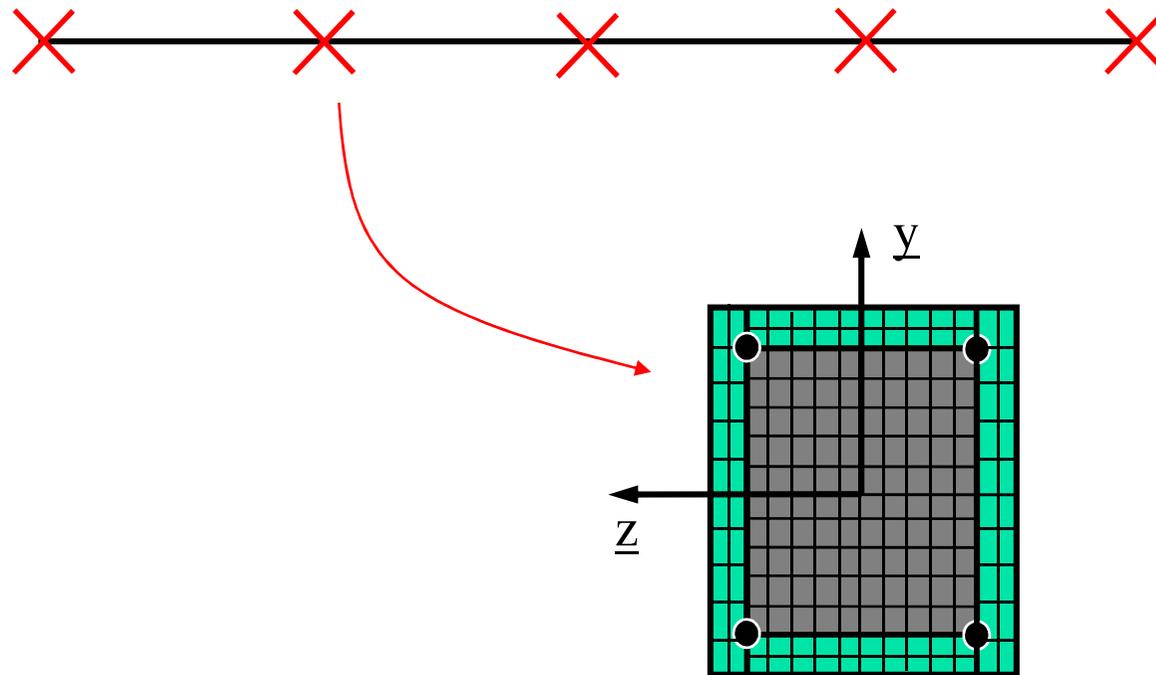


- a) costruire il modello è la parte più importante ed impegnativa
- b) un elemento “frame” in forza/trave o pilastro
- c) elemento “frame” a plasticità distribuita
- d) punti di integrazione (sezioni) a fibre
- e) leggi costitutive materiali
- f) stesso modello sia per pushover che per TH
- g) diaframma di piano rigido
- h) masse distribuite
- i) scala al momento non inclusa

# MODELLO NON LINEARE DELLA STRUTTURA

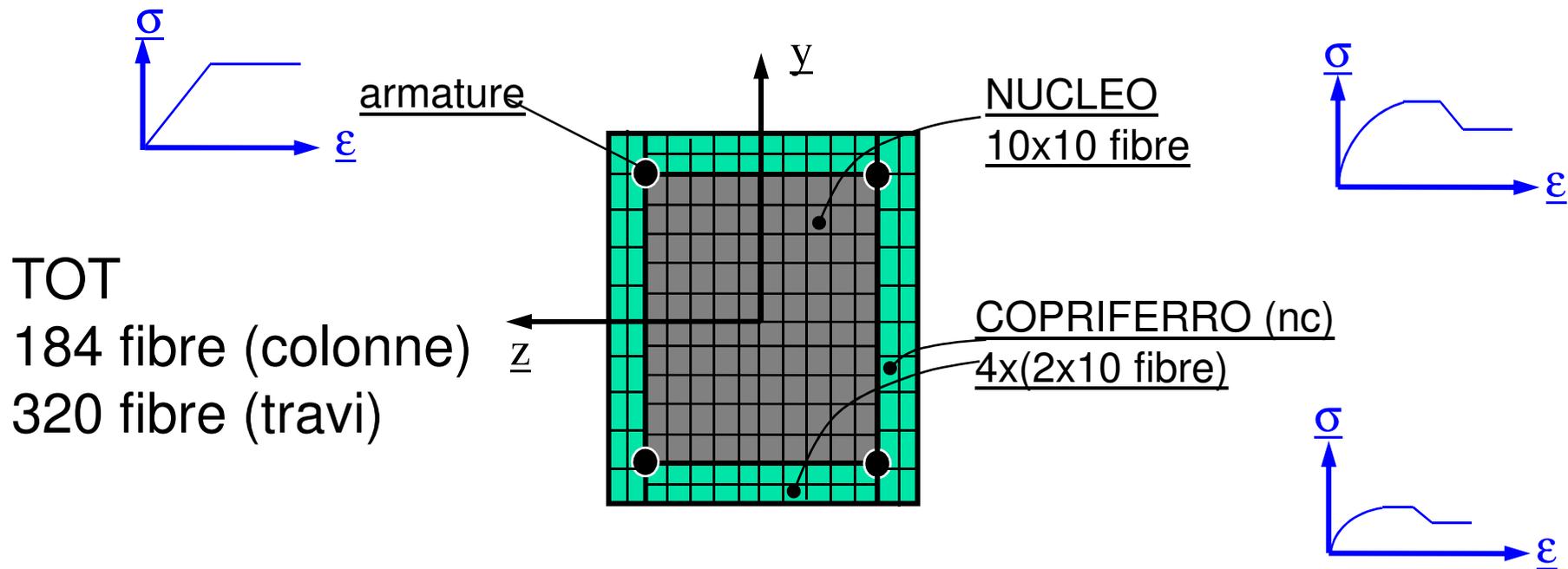
## 1) Elementi in forze

- ✓ 5 punti di Integrazione di Gauss-Lobatto
- ✓ Sezioni a fibre



# MODELLO NON LINEARE DELLA STRUTTURA

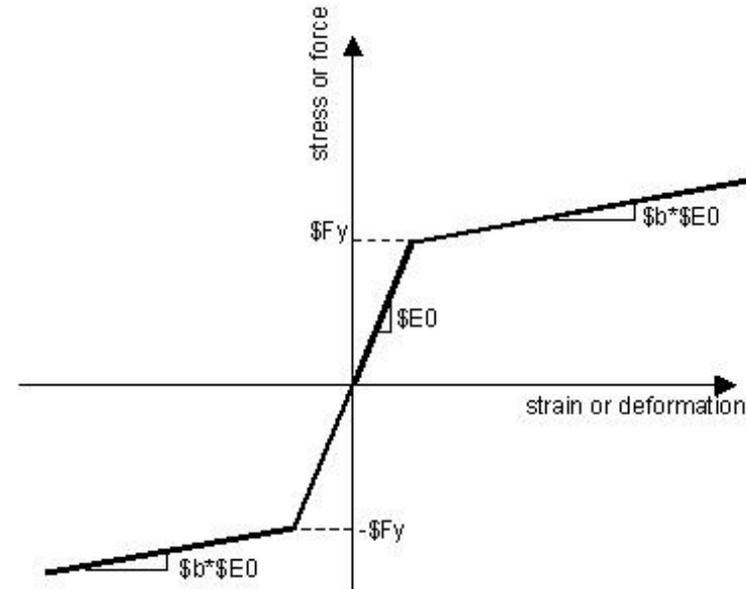
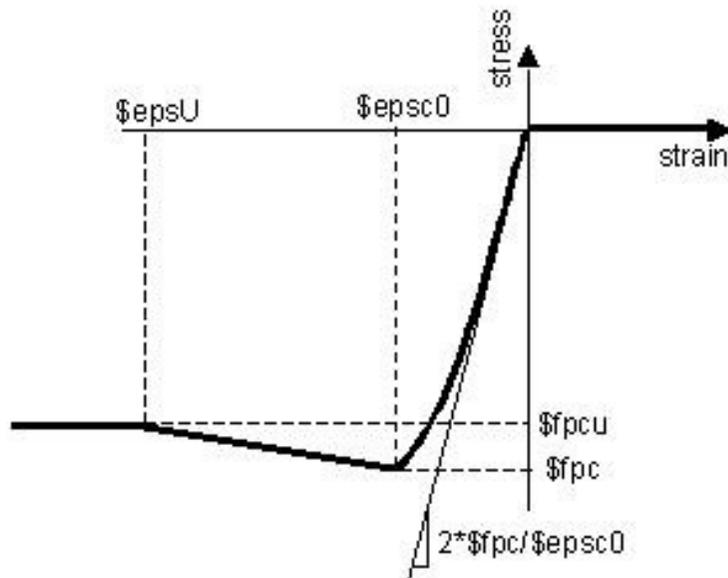
Modello NL a fibre



**CIs del nucleo: modello di confinamento di Kent-Scott-Park**

# MODELLO NON LINEARE DELLA STRUTTURA

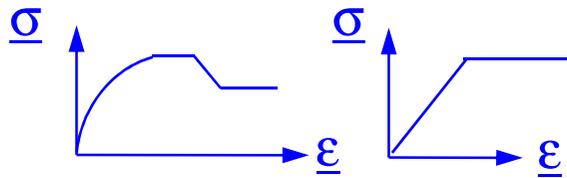
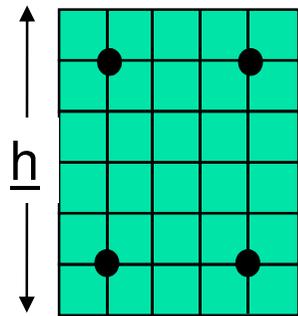
## Leggi costitutive dei materiali



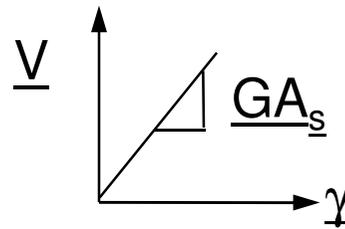
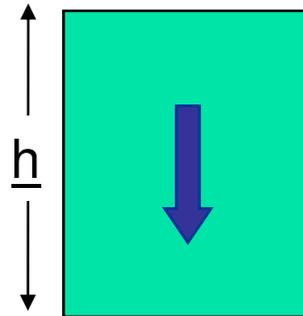
#			$f_{pc}$	$\epsilon_{psc0}$	$f_{pcu}$	$\epsilon_{pscu}$
uniaxialMaterial	Concrete01	1	-30	-0.002	-6	-0.01
uniaxialMaterial	Concrete01	2	-25	-0.002	0	-0.005
#		tag	$f_y$	$E0$	$b$	
uniaxialMaterial	Steel01	3	340	210000	0.01	

# MODELLO NON LINEARE DELLA STRUTTURA

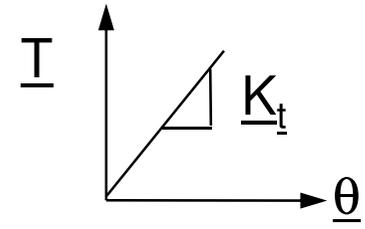
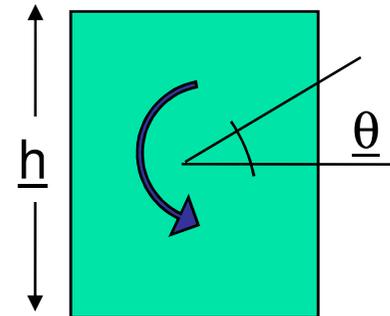
flessione  
NL fibre  $\sigma$ - $\varepsilon$   
 $\leftarrow \underline{b} \rightarrow$



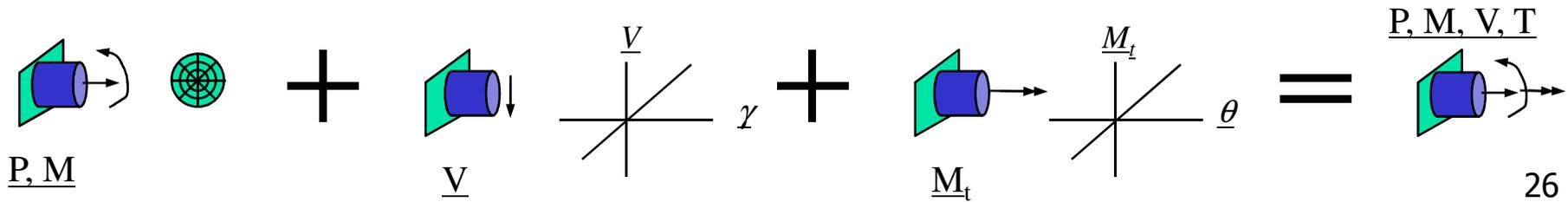
taglio  
Lineare  $V$ - $\gamma$   
 $\leftarrow \underline{b} \rightarrow$



torsione  
Lineare  $T$ - $\theta$   
 $\leftarrow \underline{b} \rightarrow$



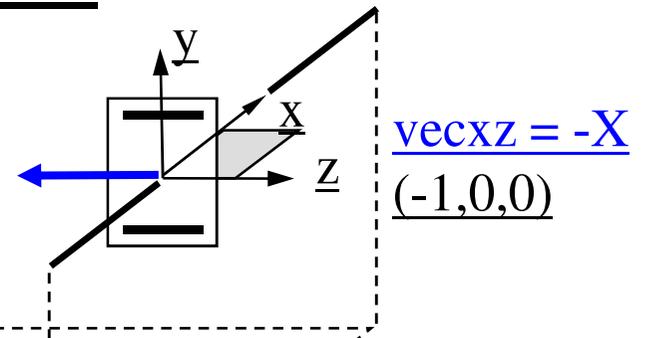
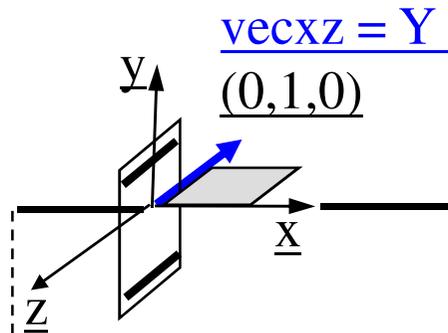
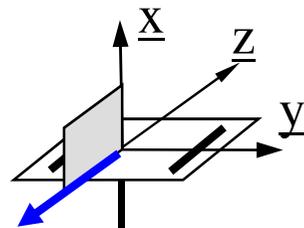
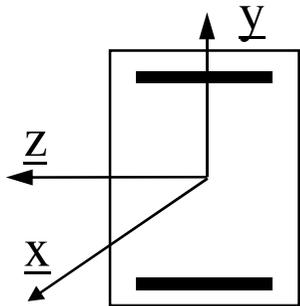
$$K_T = \frac{GJ}{L} = \frac{Gc_2hb^3}{L} \quad (h > b)$$



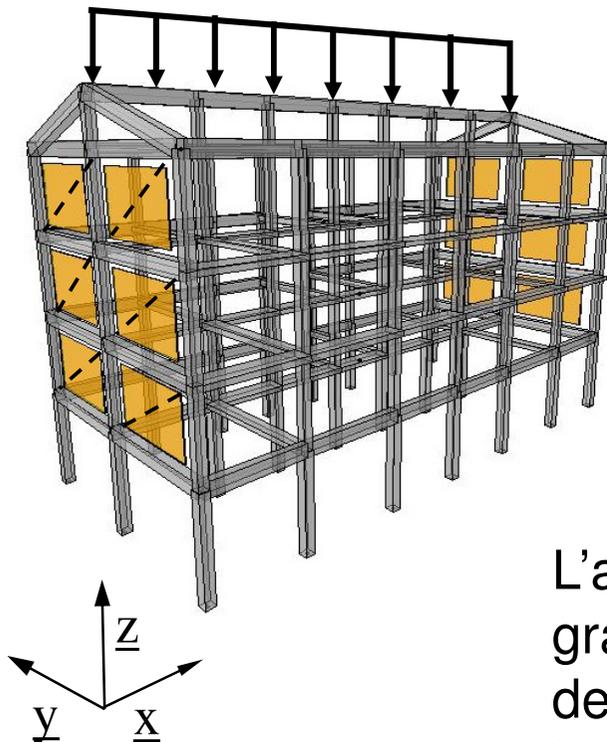
# MODELLO NON LINEARE DELLA STRUTTURA

## Orientamento elementi

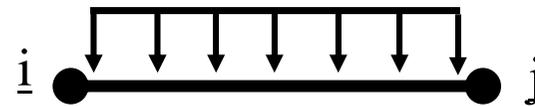
Rif. LOCALE



# APPLICAZIONE DEI CARICHI NON SISMICI



$$G_k + P_k + \sum_i (\psi_{2i} Q_{ki})$$



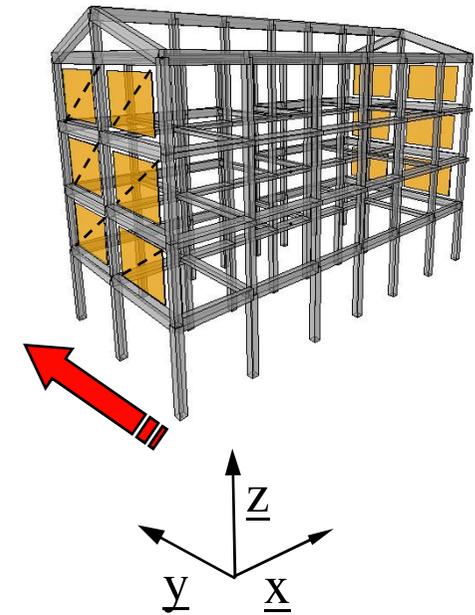
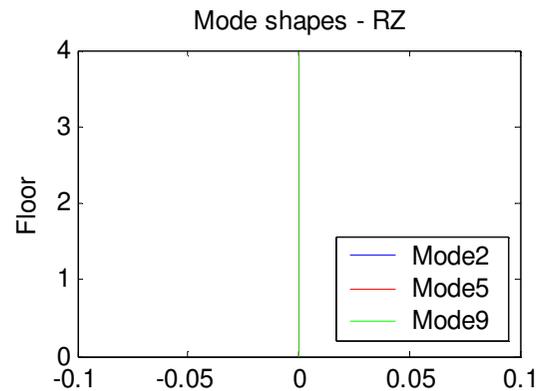
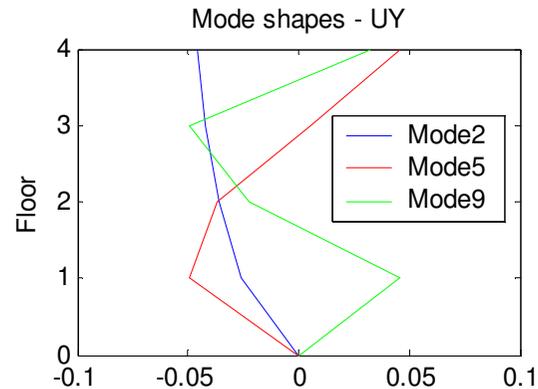
Travi: carichi verticali uniformemente distribuiti

L'applicazione dei carichi gravitazionali cambia le caratteristiche della struttura, in particolare le travi si fessurano. A questo punto si consiglia un'analisi modale (confrontare con analisi modale su modello elastico)

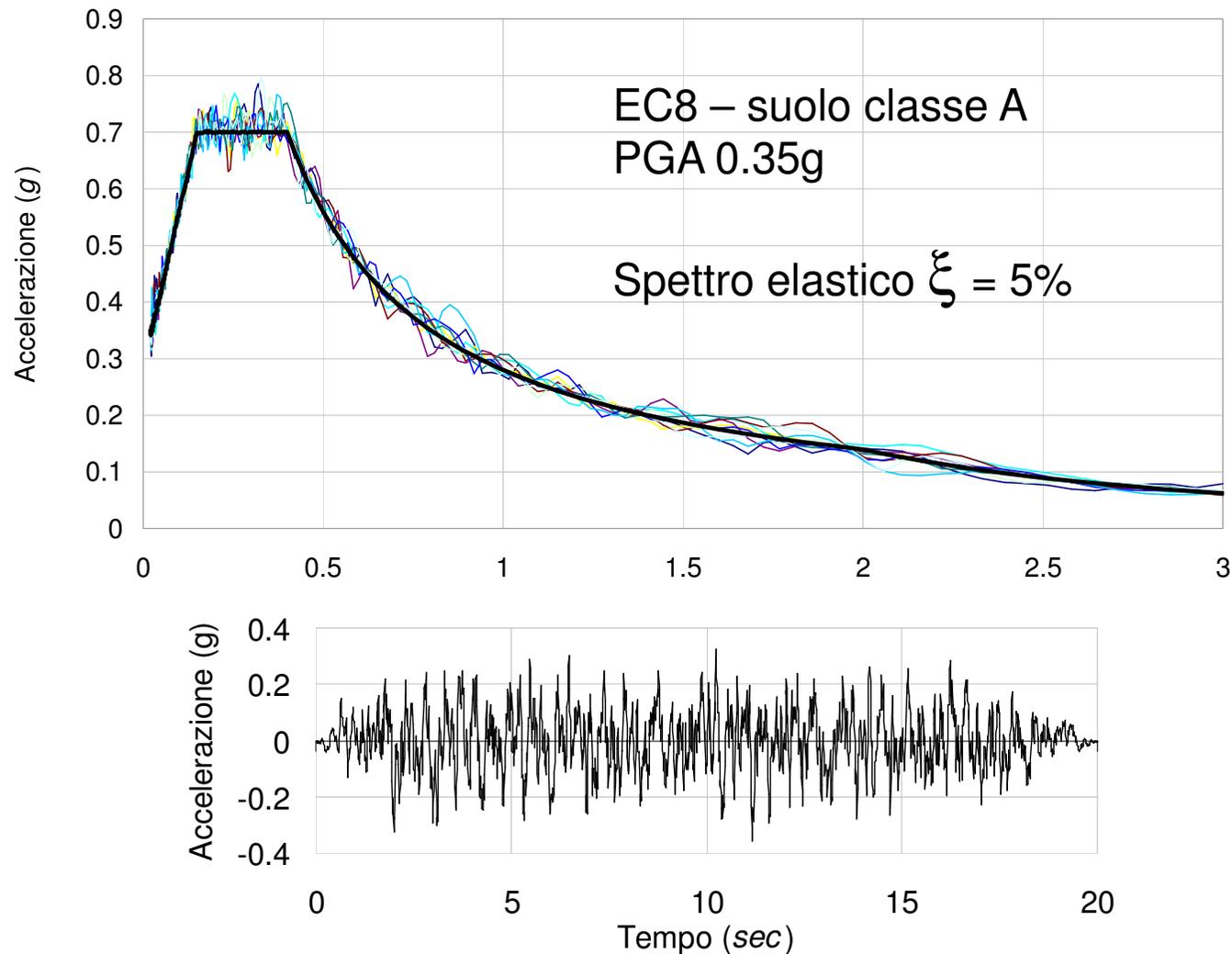
# APPLICAZIONE DEI CARICHI NON SISMICI

Periodi modali prima e dopo l'applicazione dei carichi gravitazionali

Mode	$T_{in}$ (sec)	$T_{fin}$ (sec)	$\Delta T$
1	0,765	0,872	14%
<b>2</b>	<b>0,630</b>	<b>0,668</b>	<b>6%</b>
3	0,527	0,557	6%
4	0,249	0,282	13%
<b>5</b>	<b>0,183</b>	<b>0,190</b>	<b>4%</b>
6	0,146	0,161	10%
7	0,143	0,148	3%
8	0,109	0,114	5%
<b>9</b>	<b>0,099</b>	<b>0,102</b>	<b>3%</b>
10	0,078	0,080	2%
11	0,072	0,074	2%
12	0,058	0,059	2%



10 accelerogrammi generati con SIMQKE (pesante x la struttura, ok perché stiamo testando il metodo): discussione ancora aperta su come generare terremoti



# ANALISI TIME HISTORY

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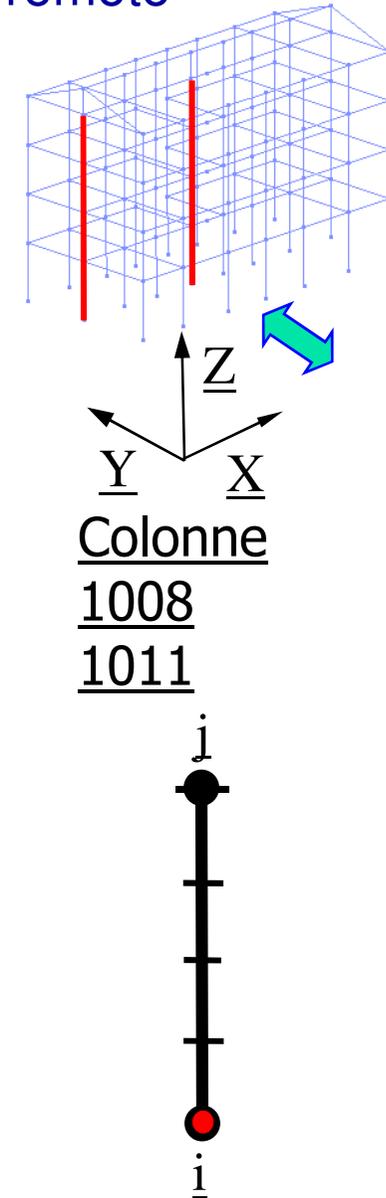
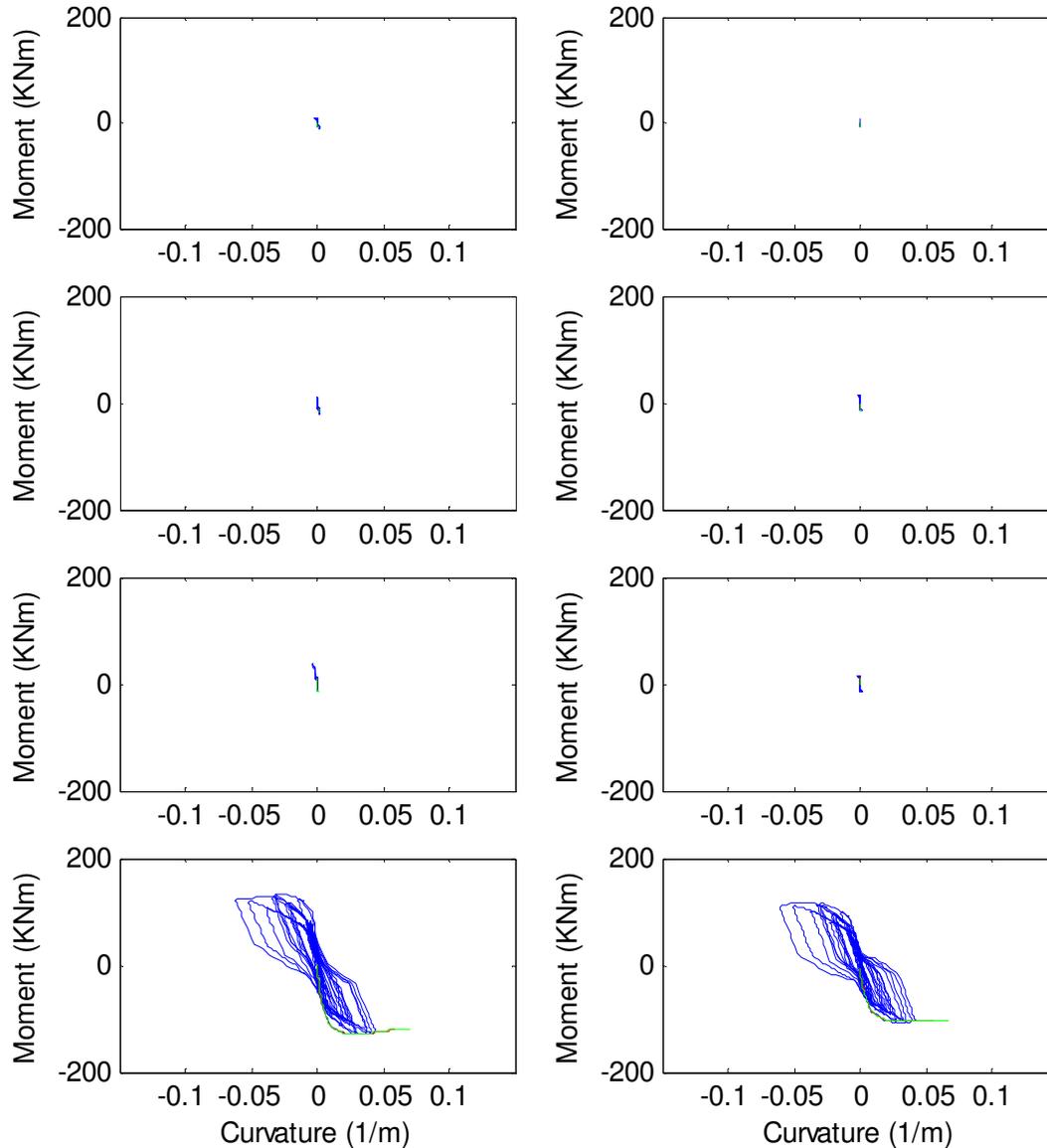
Discussione ancora aperta su quali accelerogrammi usare:

- Naturali, Artificiali, Generati?
- Ma sono veramente naturali, free-field?
- Come sceglierli
- I programmi disponibili generano accelerogrammi realistici?
- Fra poco saranno disponibili in Italia un database di accelerogrammi naturali e delle linee guide per la generazione di accelerogrammi ([www.reluis.unina.it](http://www.reluis.unina.it))
- Al momento alcuni “esperti” consigliano accelerogrammi generati per testare i metodi (ricerca) mentre per la verifica di edifici consigliano terremoti naturali (meno gravosi sulla struttura)

Smorzamento viscoso 3% nei modi 1 e 6 (ragionevole?)

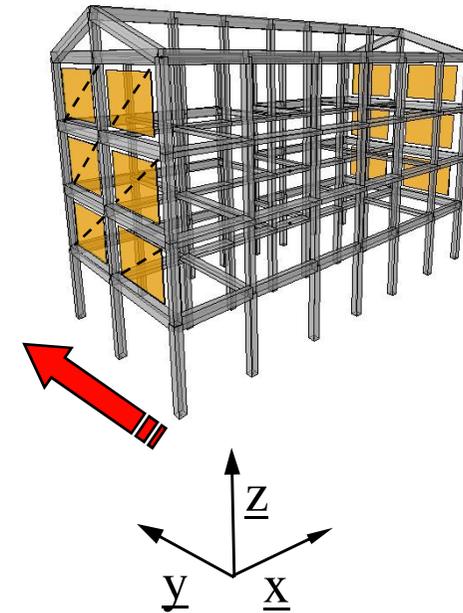
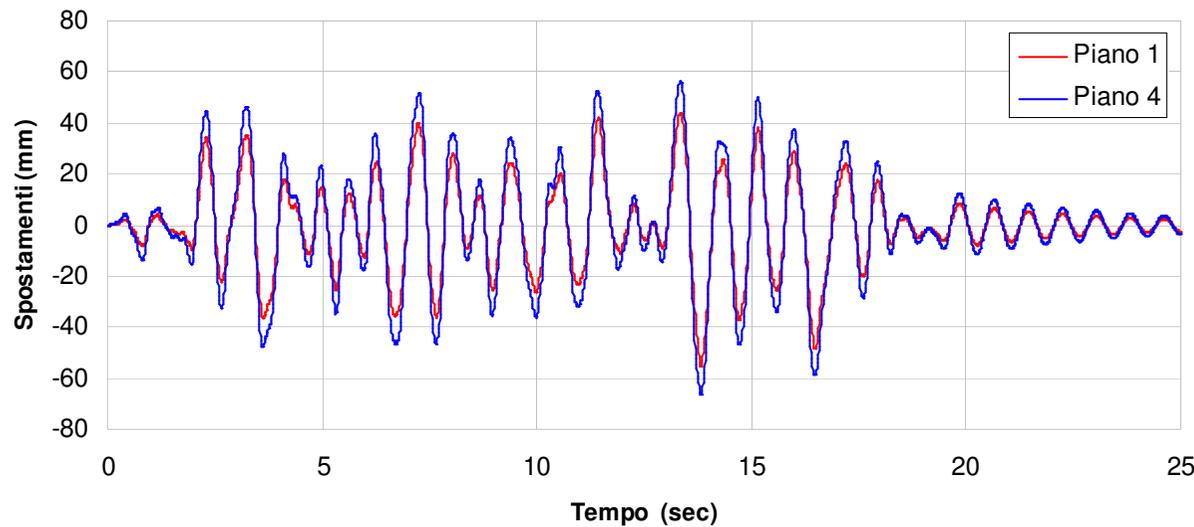
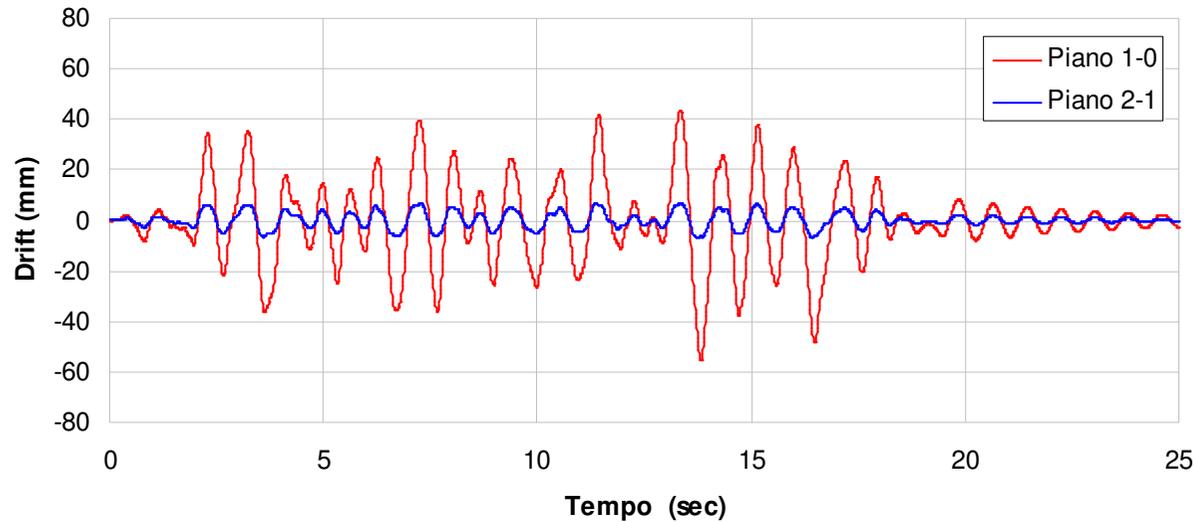
# ANALISI TIME HISTORY

## Telaio con tamponamenti Singolo terremoto



# ANALISI TIME HISTORY

## Telaio con tamponamenti Singolo terremoto



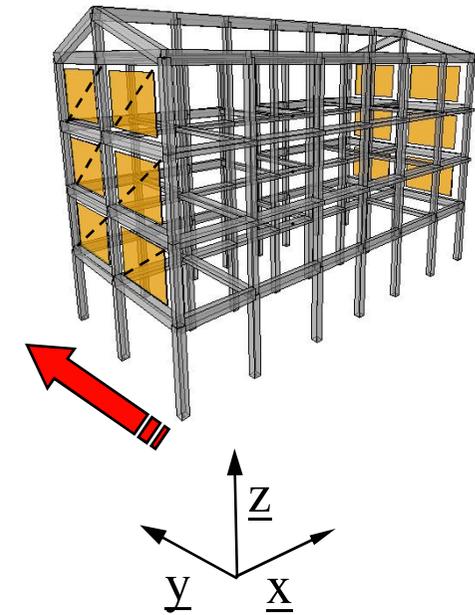
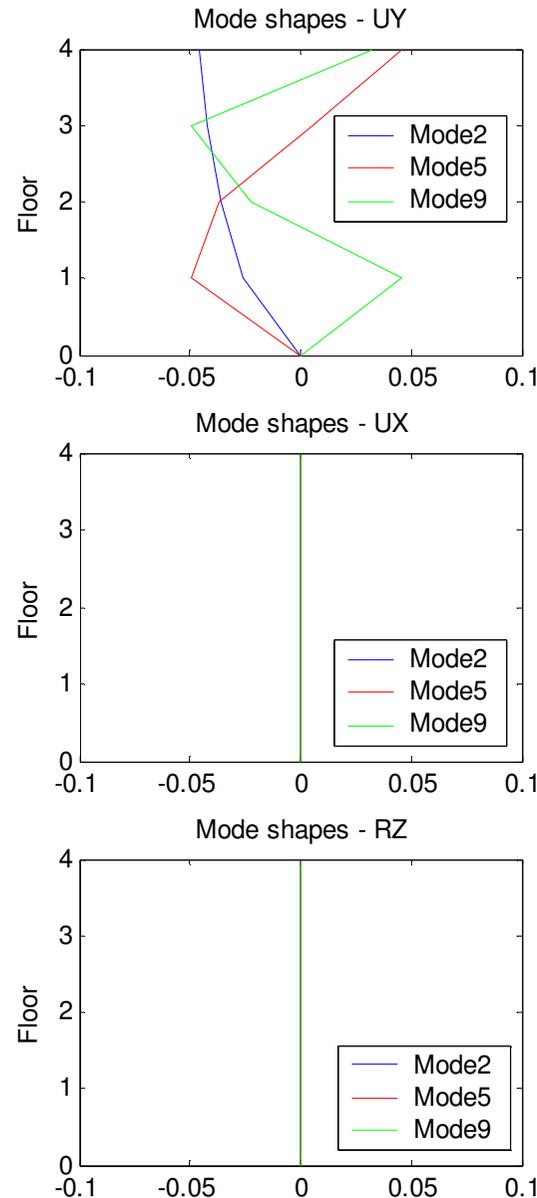
Non vi è spostamento residuo nonostante la plasticizzazione delle colonne a piano terra.  
Dipende dai materiali usati!

# PUSHOVER E TIME HISTORY

## Telaio con tamponamenti

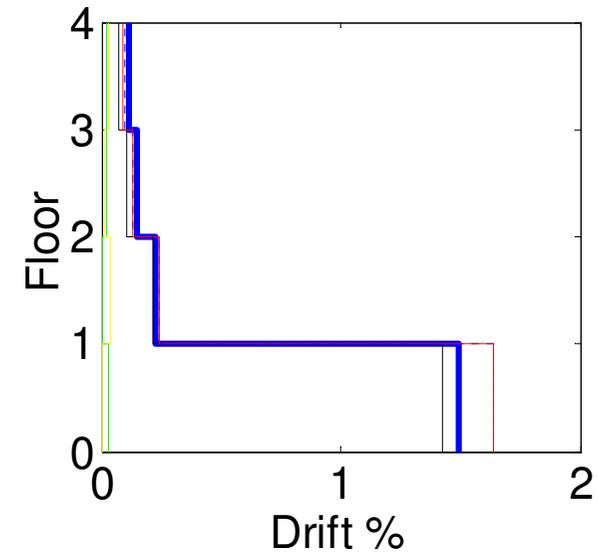
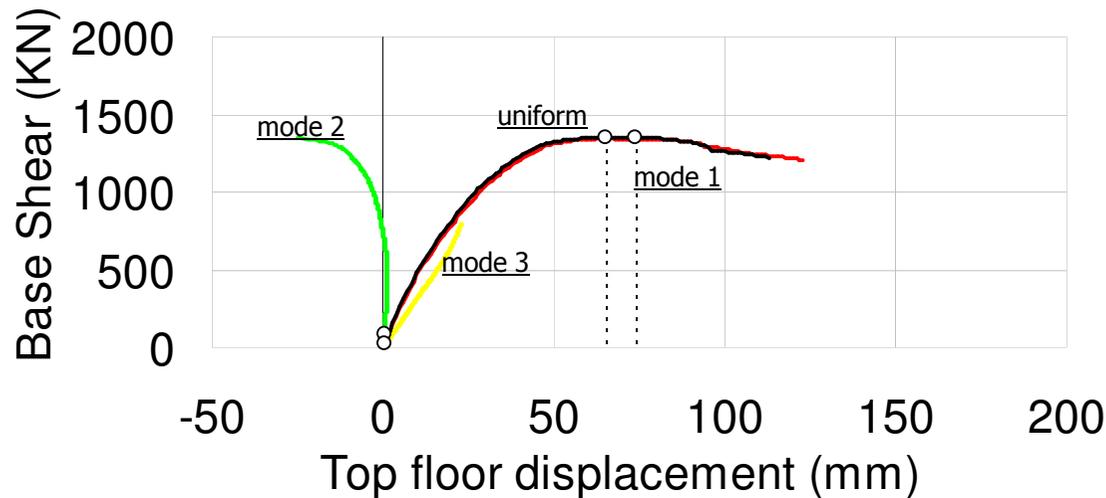
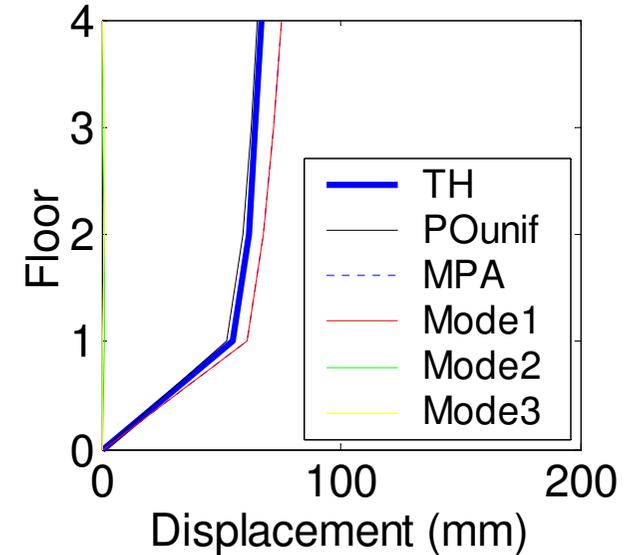
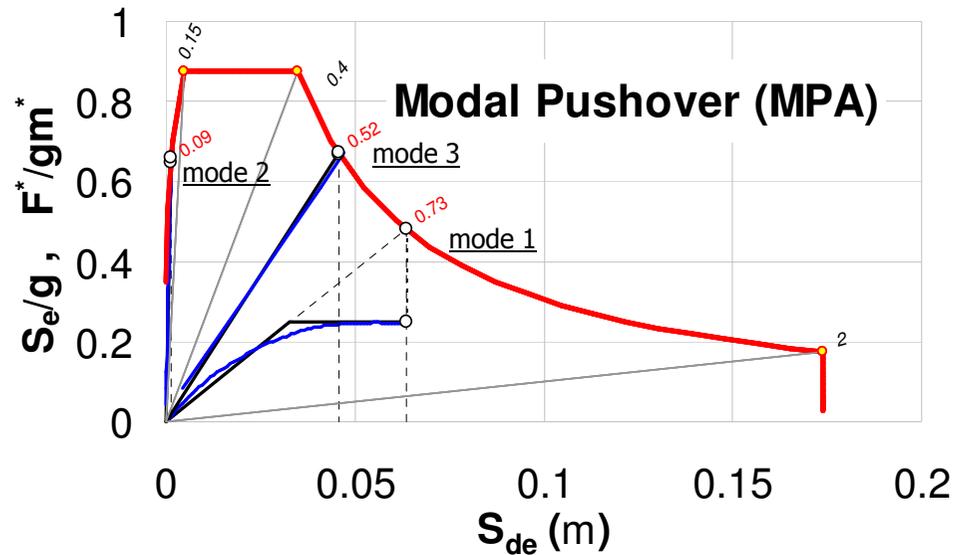
Periodi modali prima e dopo l'applicazione dei carichi gravitazionali

Mode	$T_{in}$ (sec)	$T_{fin}$ (sec)	$\Delta T$
1	0,765	0,872	14%
<b>2</b>	<b>0,630</b>	<b>0,668</b>	<b>6%</b>
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<b>5</b>	<b>0,183</b>	<b>0,190</b>	<b>4%</b>
6	0,146	0,161	10%
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<b>9</b>	<b>0,099</b>	<b>0,102</b>	<b>3%</b>
10	0,078	0,080	2%
11	0,072	0,074	2%
12	0,058	0,059	2%



# PUSHOVER E TIME HISTORY

Telaio con tamponamenti  
Singolo terremoto



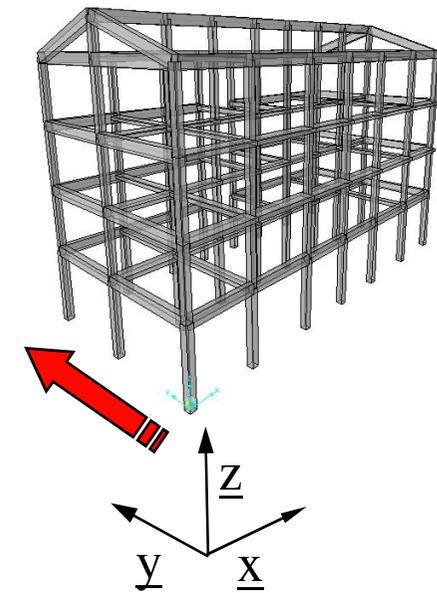
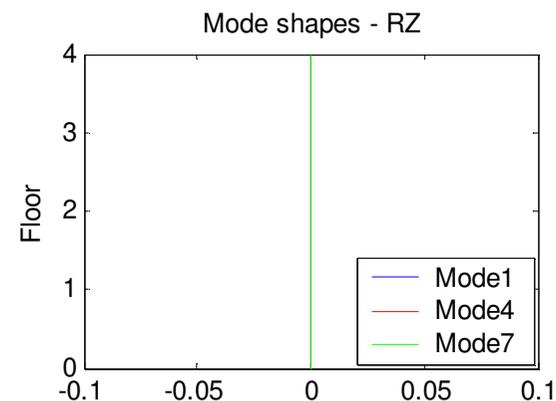
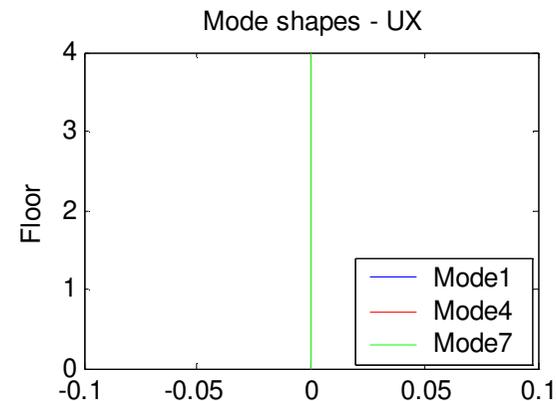
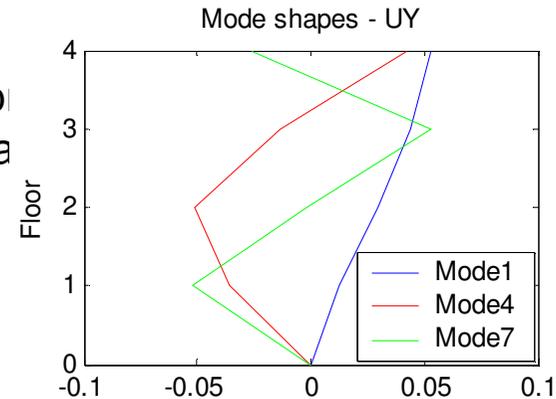
Analisi TH con un solo terremoto: non significativa!

# PUSHOVER E TIME HISTORY

Telaio senza tamponamenti

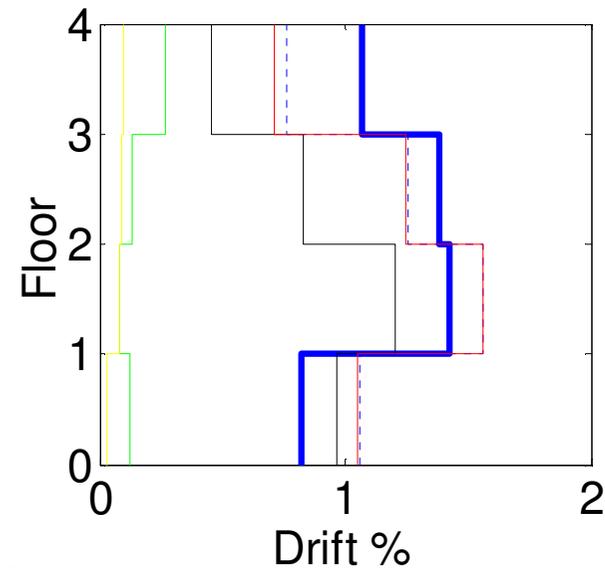
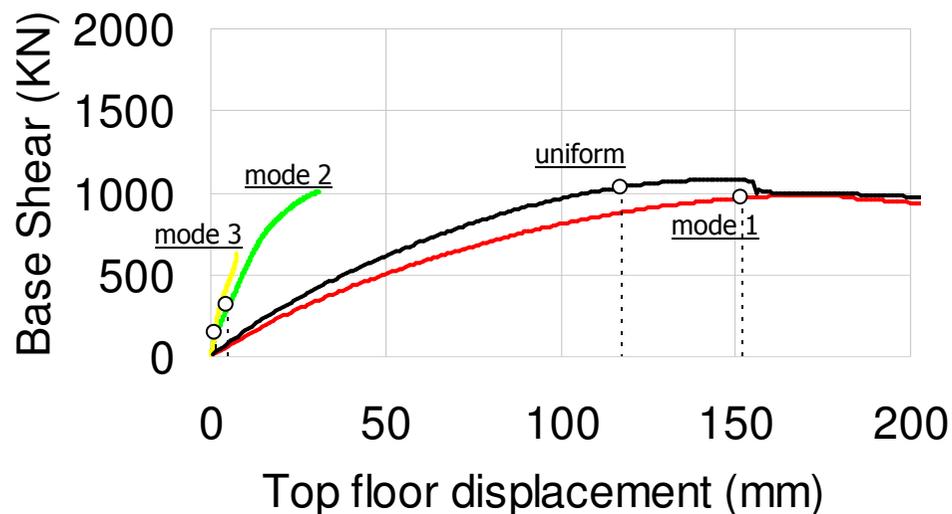
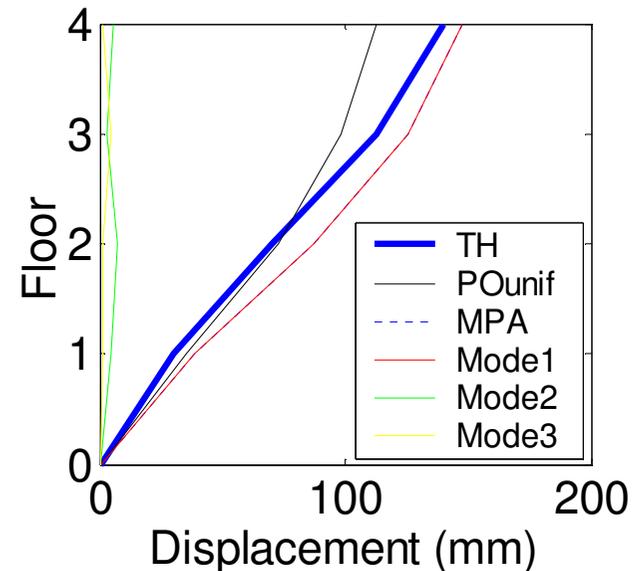
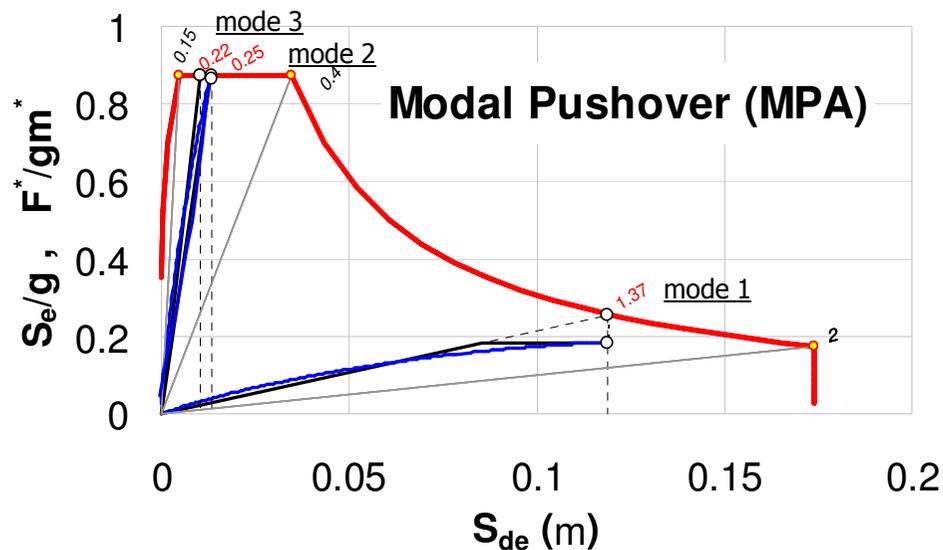
Periodi modali prima e dopo l'applicazione dei carichi gravitazionali: manca la scala

Modo	$T_{in}$ (sec)	$T_{fin}$ (sec)	$\Delta T$
<b>1</b>	<b>1,002</b>	<b>1,185</b>	<b>18%</b>
2	0,818	0,950	16%
3	0,817	0,851	4%
<b>4</b>	<b>0,316</b>	<b>0,369</b>	<b>17%</b>
5	0,265	0,303	14%
6	0,245	0,276	12%
<b>7</b>	<b>0,171</b>	<b>0,190</b>	<b>12%</b>
8	0,153	0,173	13%
9	0,145	0,159	10%
10	0,116	0,122	6%
11	0,111	0,119	7%
12	0,109	0,114	5%



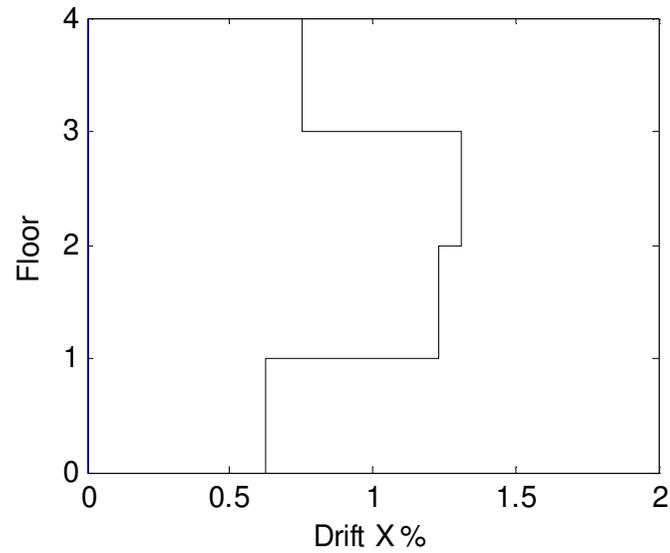
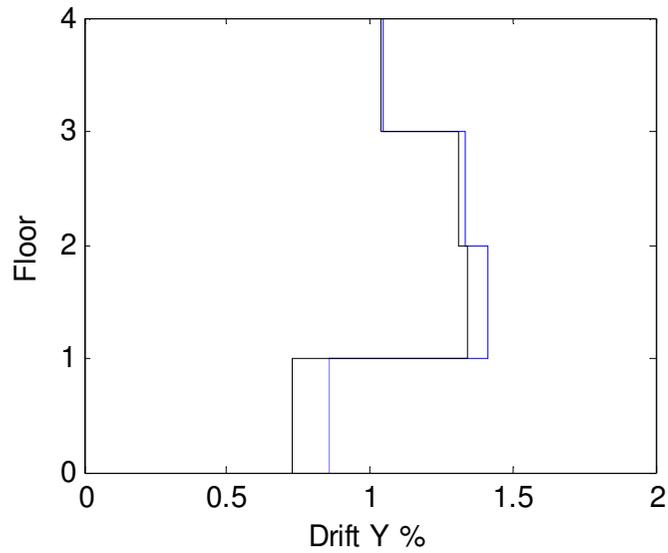
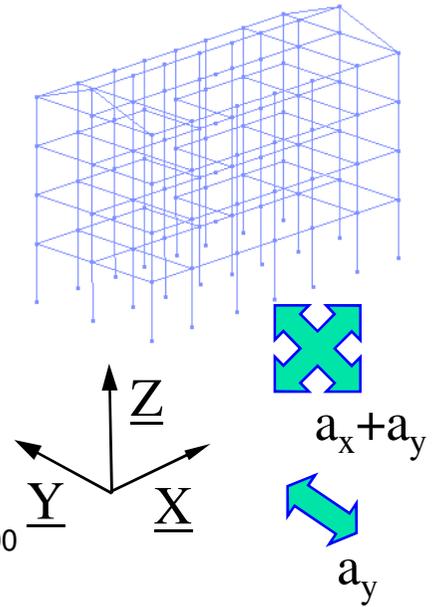
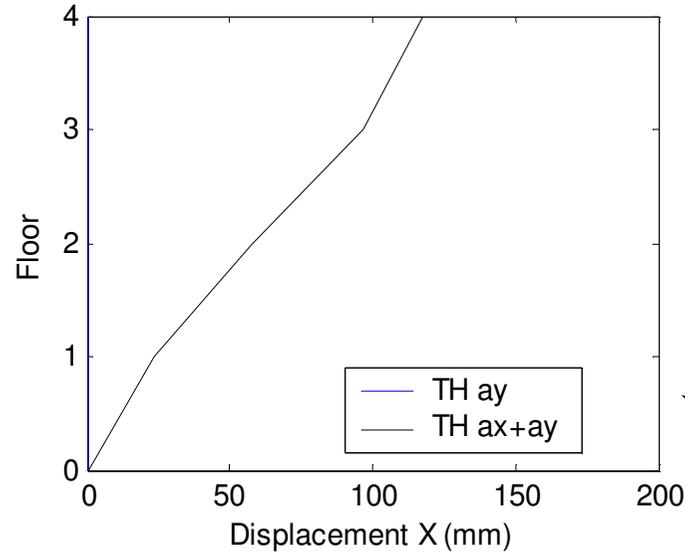
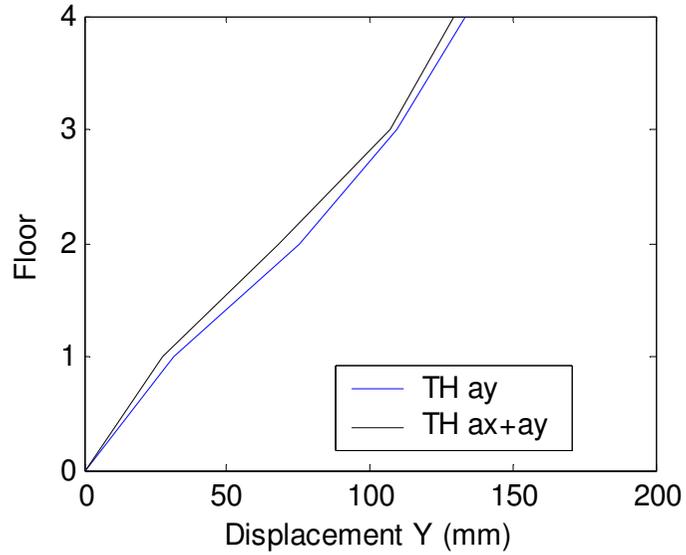
# PUSHOVER E TIME HISTORY

Telaio senza tamponamenti



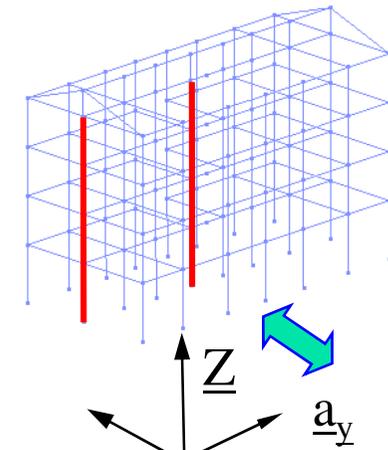
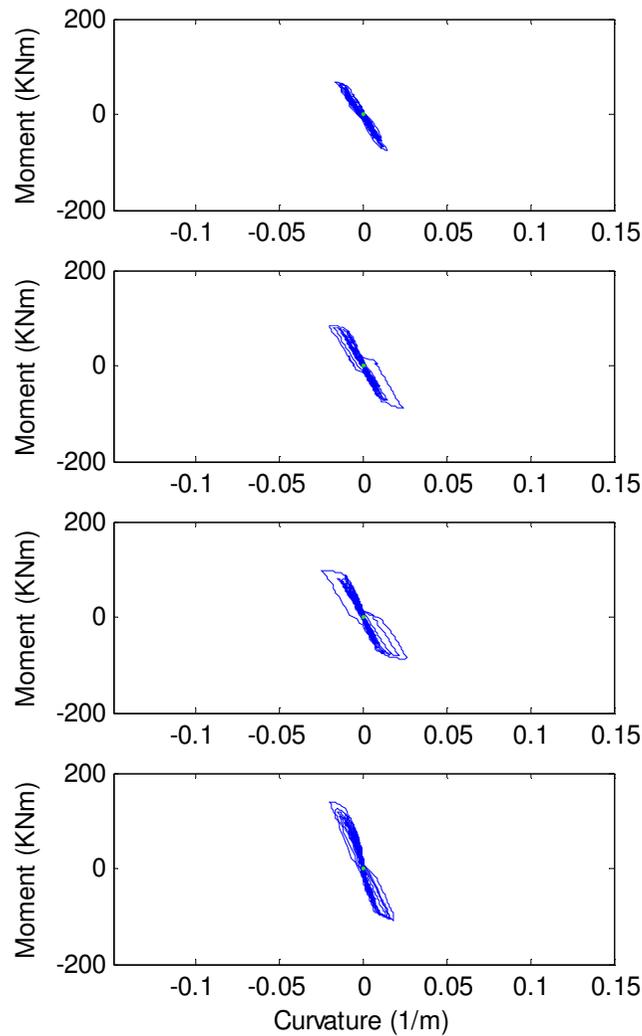
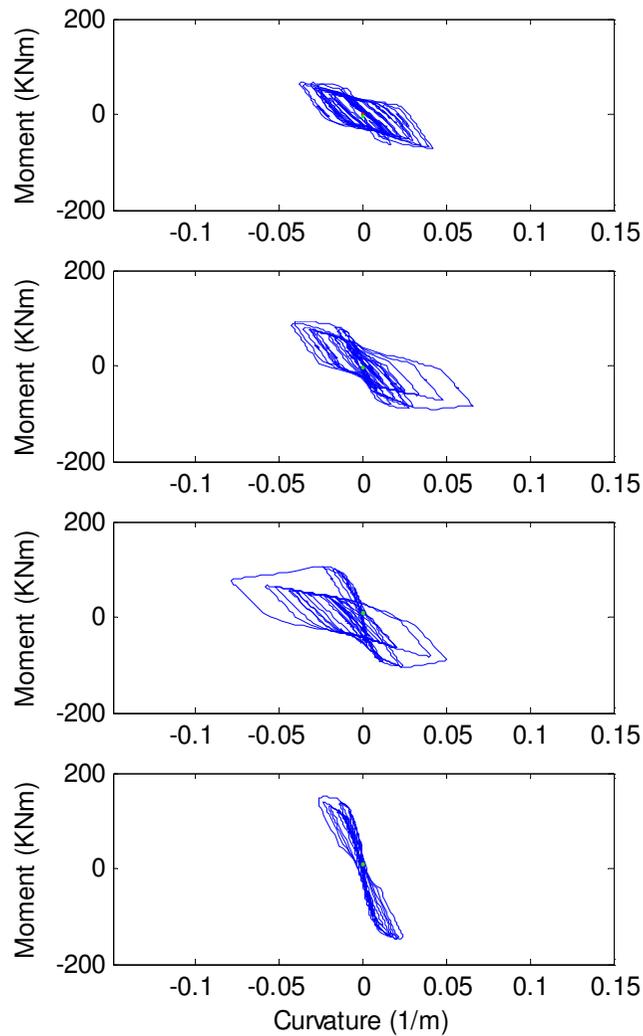
**10 terremoti: valori medi risposta**

# TIME HISTORY 3D

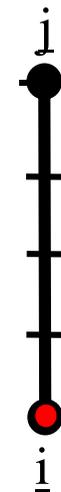


# TIME HISTORY 3D

$M_{z, ay}$

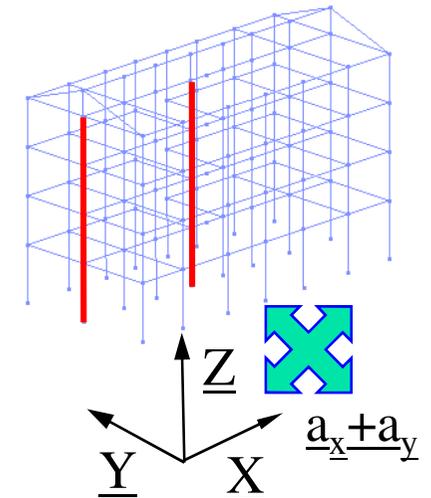
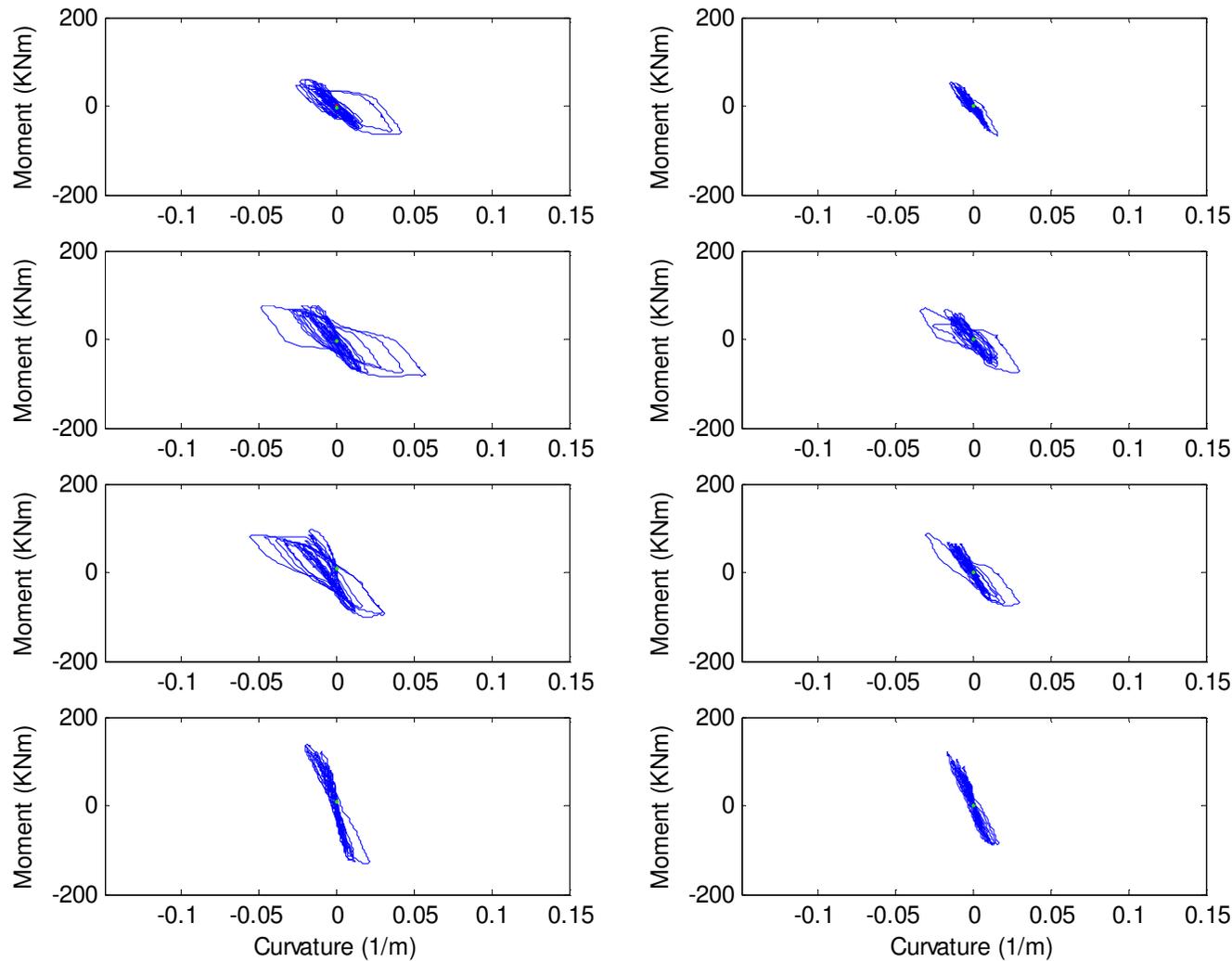


Columns  
1008  
1011



# TIME HISTORY 3D

$$M_y, a_y+a_x$$



Columns

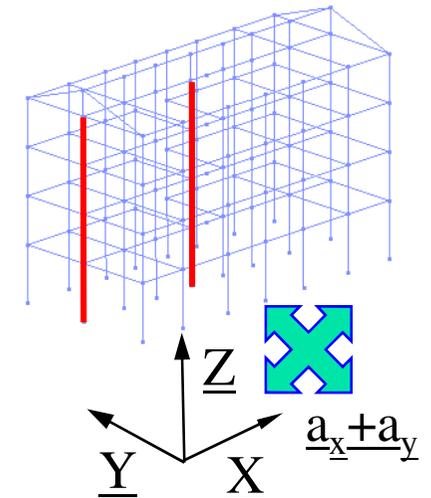
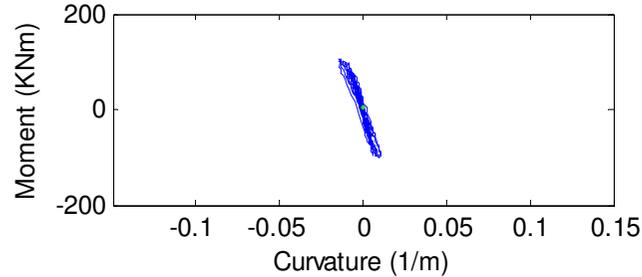
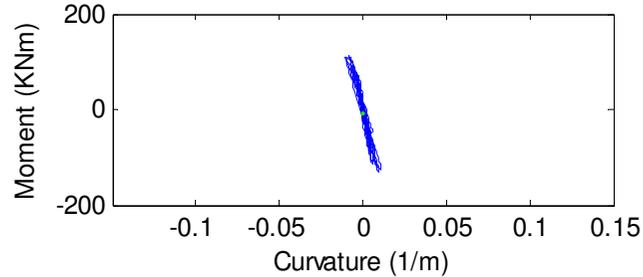
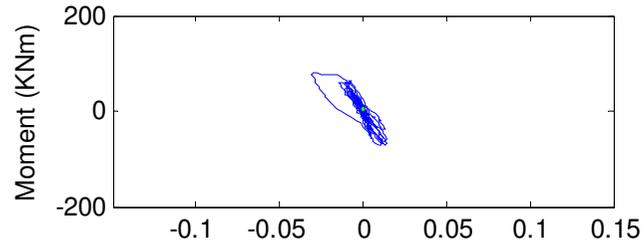
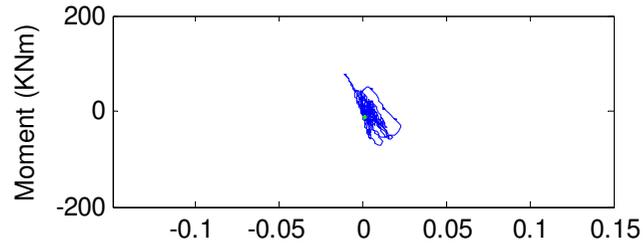
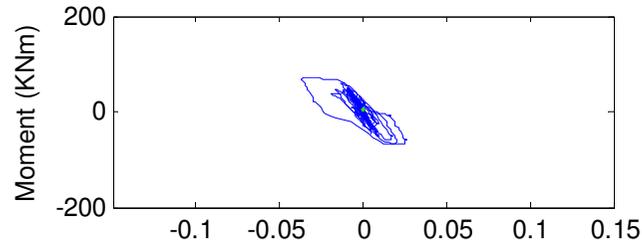
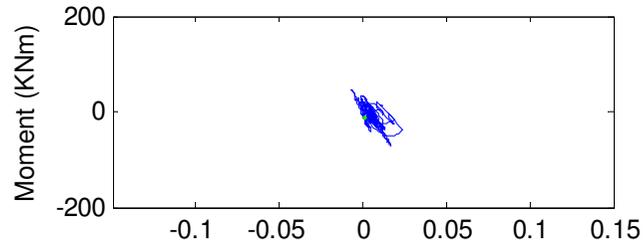
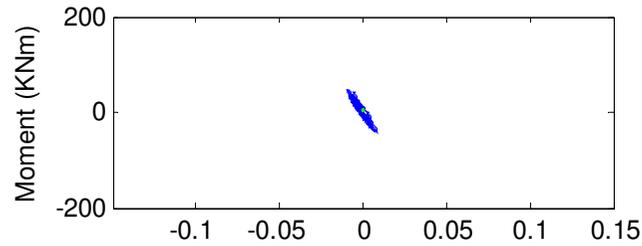
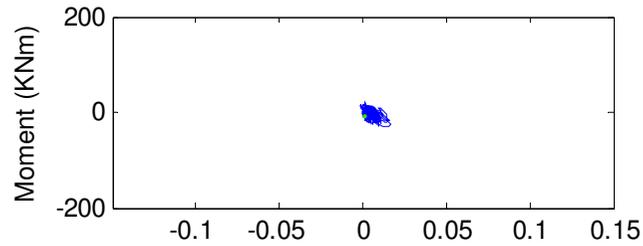
1008

1011



# TIME HISTORY 3D

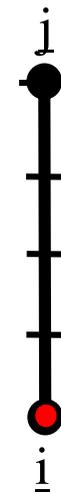
$$M_{x, ay+ax}$$



Columns

1008

1011



# BREAKDOWN DELLE COMPONENTI STRUTTURALI

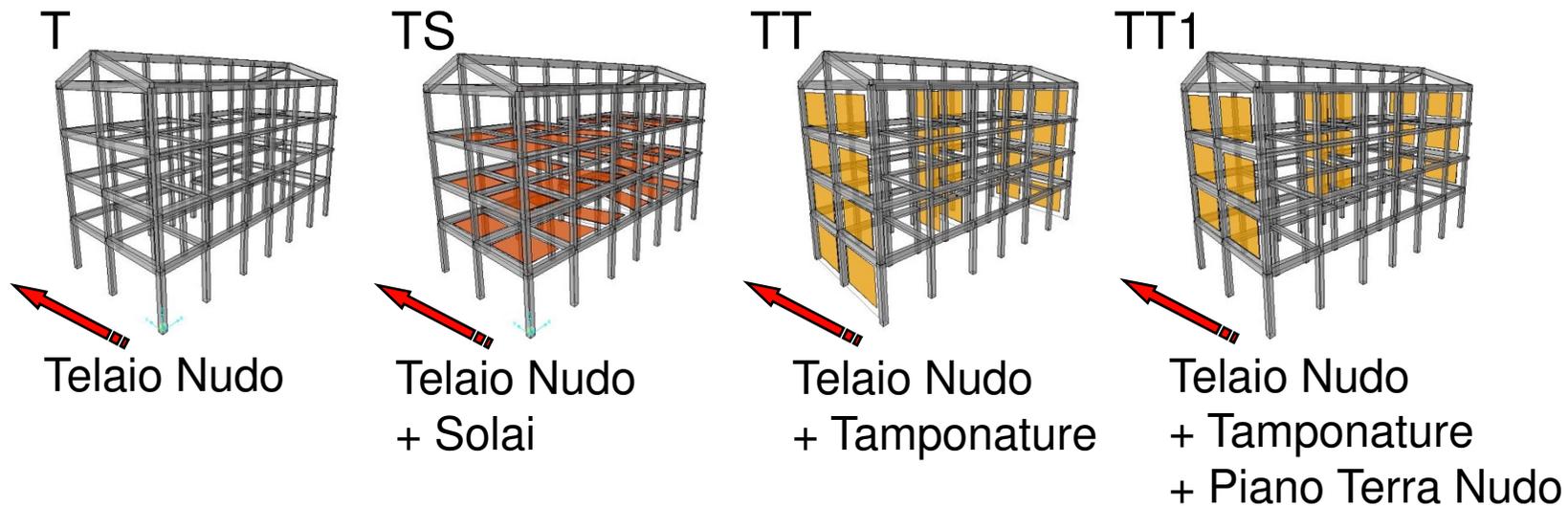
Edificio esistente  
Modello a fibre  
Direzione Y

## Sistema strutturale completo



## Breakdown delle componenti strutturali – singoli contributi

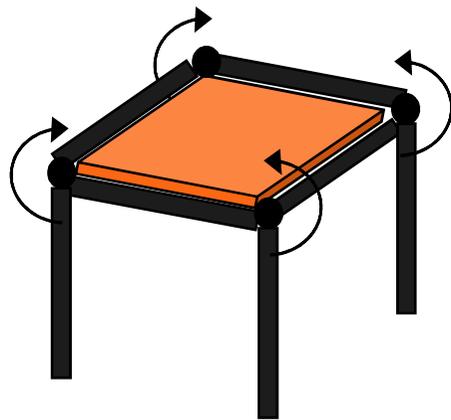
M. Faggella, E. Spacone, J.P. Conte, J. Restrepo 13ECEE, Ginevra 2006



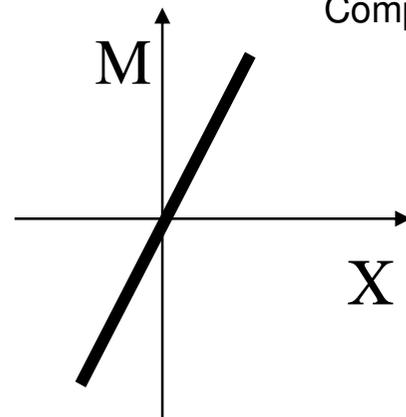
# BREAKDOWN DELLE COMPONENTI STRUTTURALI

Edificio esistente  
Modello a fibre  
Direzione Y

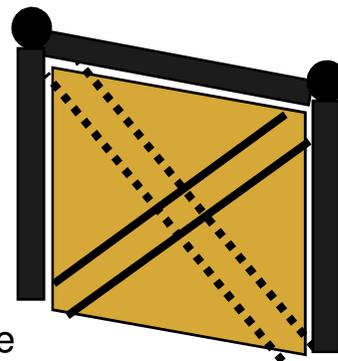
## Modelli per le singole componenti



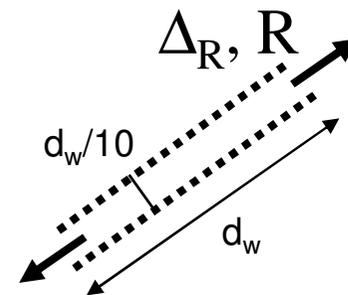
Shell Elastico



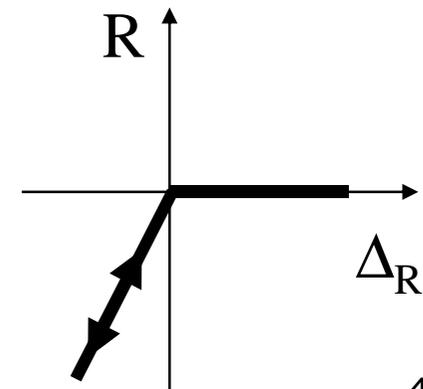
Campi di solaio:  
Comportamento Lastra-Piastra



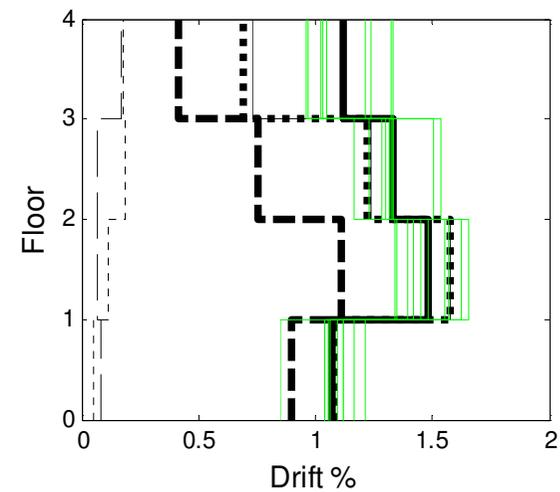
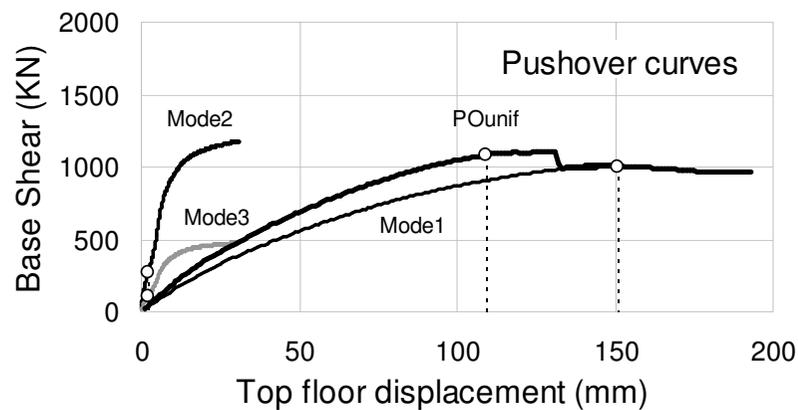
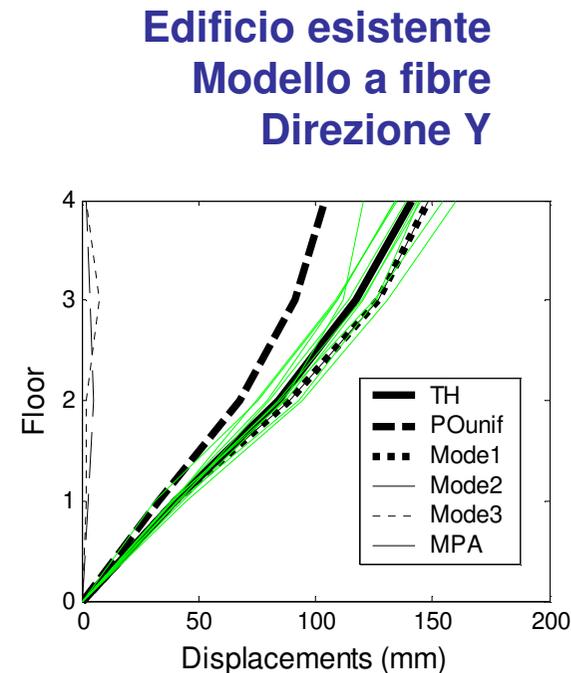
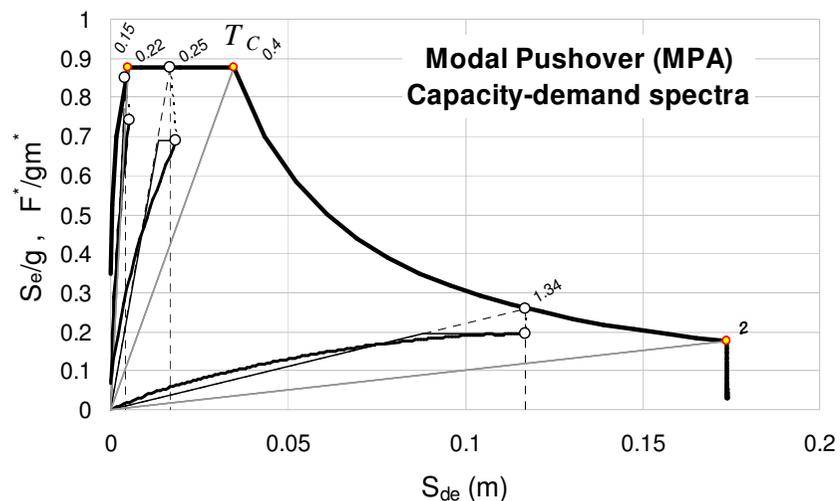
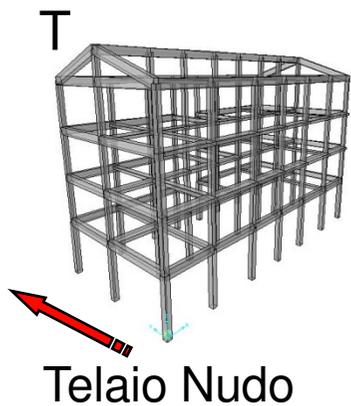
Tamponature:  
Modello a Biella Equivalente



Elastico,  
non reagente a trazione

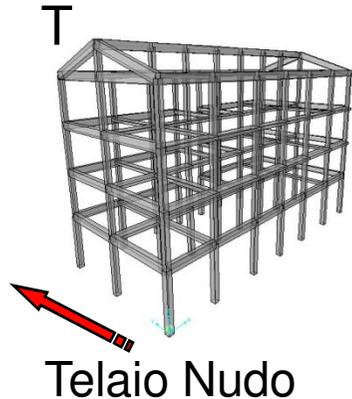


# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO T



# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO T

Edificio esistente  
Modello a fibre  
Direzione Y

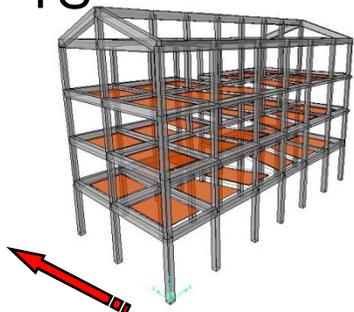


**Risultati dei diversi metodi di analisi nonlineare (TH, PO, MPA):**

- Alta flessibilità della struttura in esame.
- PO Modo1 e media TH in accordo sugli spostamenti massimi.
- PO Modo1 e media TH in disaccordo sui max drift (specie ai piani alti).
- MPA con combinazione SRSS non migliora la corrispondenza con la media TH.
- Il grado di nonlinearietà della risposta determina dispersione dei risultati delle singole TH.
- Telaio nudo: max spostamenti e drift, minimo taglio di base alla massima richiesta PO.

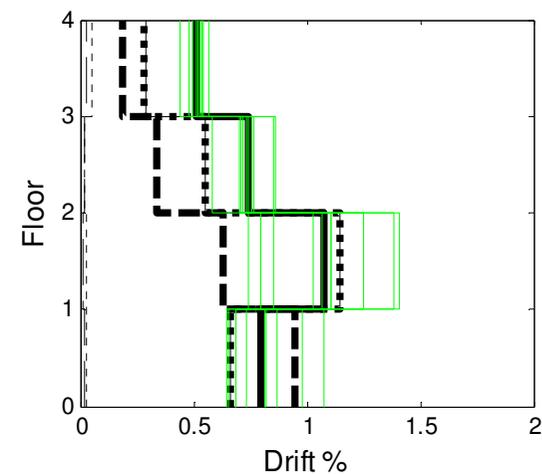
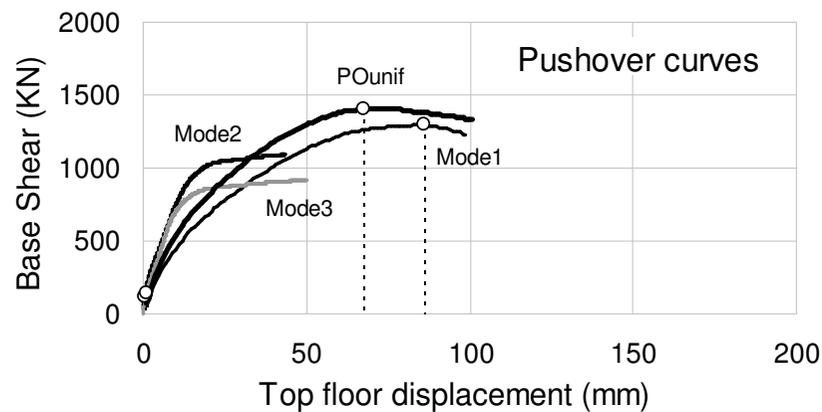
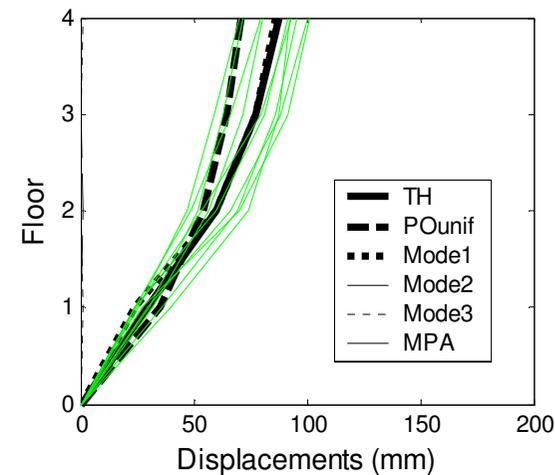
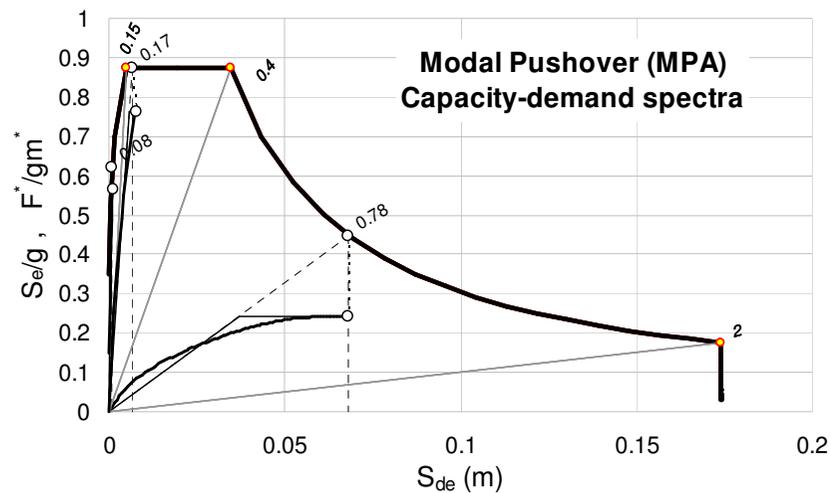
# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO TS

TS



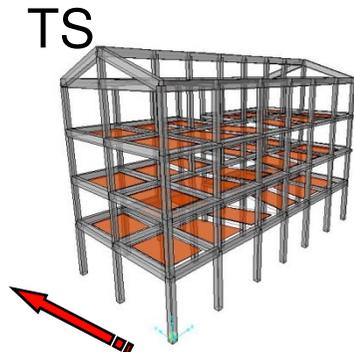
Telaio Nudo + Solai

Edificio esistente  
Modello a fibre  
Direzione Y



# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO TS

Edificio esistente  
Modello a fibre  
Direzione Y

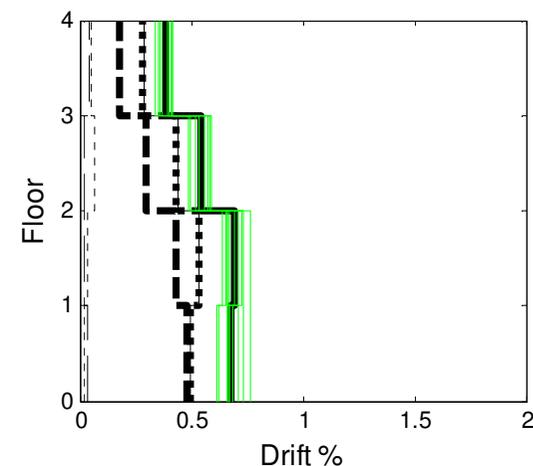
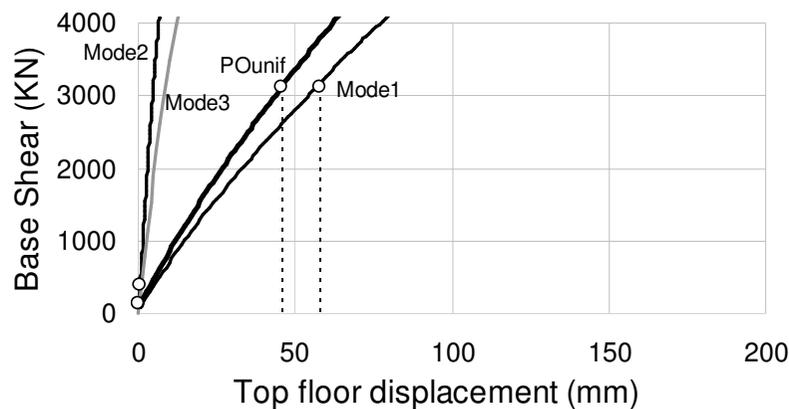
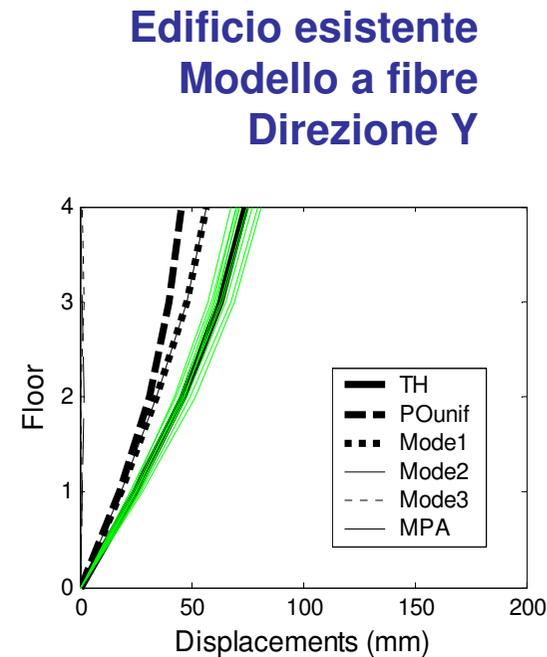
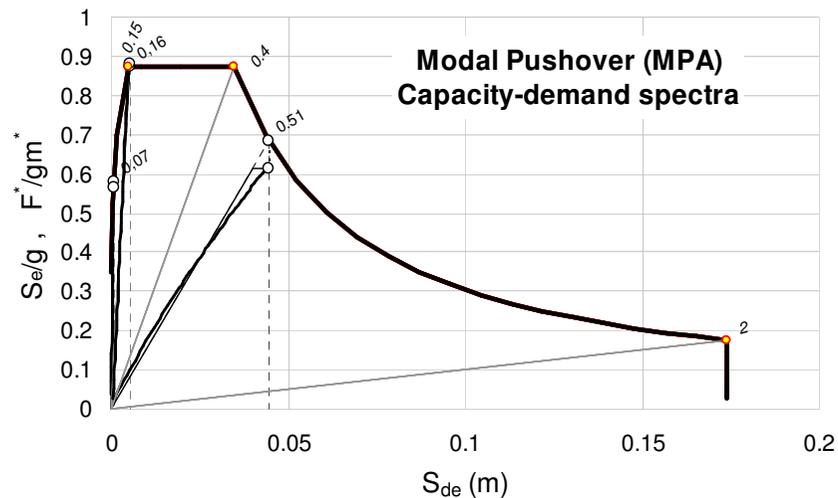
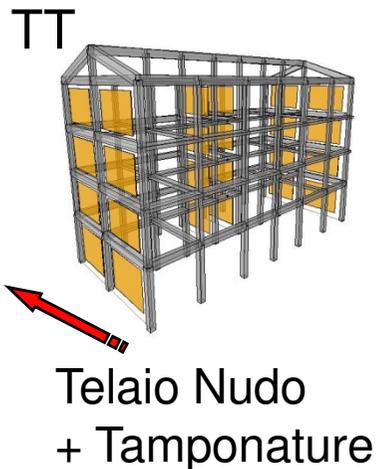


Telaio Nudo  
+ Solai

**Risultati dei diversi metodi di analisi nonlineare (TH, PO, MPA):**

- L'aggiunta della rigidezza flessionale dei solai riduce spostamenti complessivi e drift
- La maggiore rigidezza iniziale ottenuta sembra produrre un comportamento generalmente più duttile.
- L'aggiunta di elementi resistenti a flessione scarica le travi, e favorisce ancor più il meccanismo a colonne plasticizzate
- MPA con combinazione SRSS non migliora la corrispondenza con la media TH.
- Il grado di non linearità della risposta determina dispersione dei risultati delle singole TH.

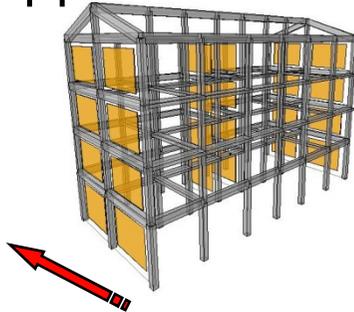
# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO TT



# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO TT

Edificio esistente  
Modello a fibre  
Direzione Y

TT



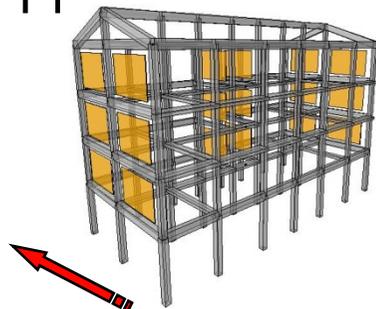
Telaio Nudo  
+ Tamponature

**Risultati dei diversi metodi di analisi nonlineare (TH, PO, MPA):**

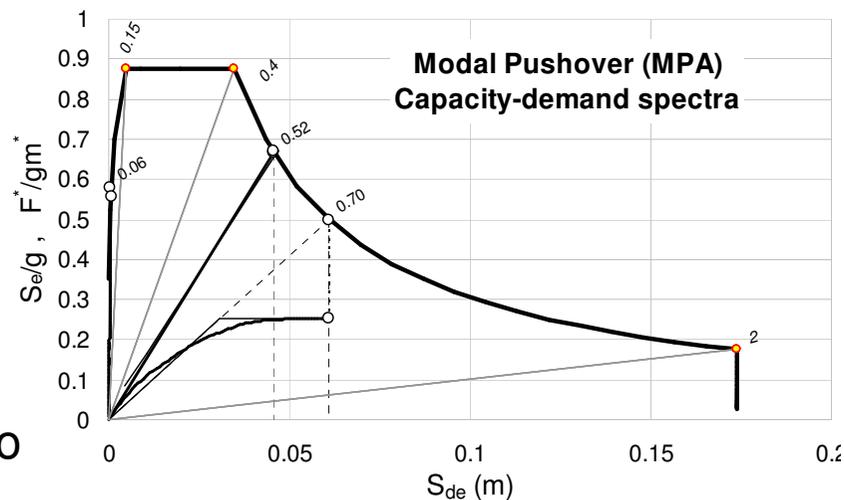
- Tamponature elastiche: elevato abbattimento della risposta in spostamenti e drift.
- Bassa partecipazione modi superiori → TH e PO dovrebbero coincidere, ... ma ...
- ... questa struttura resta elastica, andrebbe usato il 5% anche nella TH (come per il PO).
- La risposta resta abbastanza in campo lineare → bassa dispersione sulle TH

# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO TT1

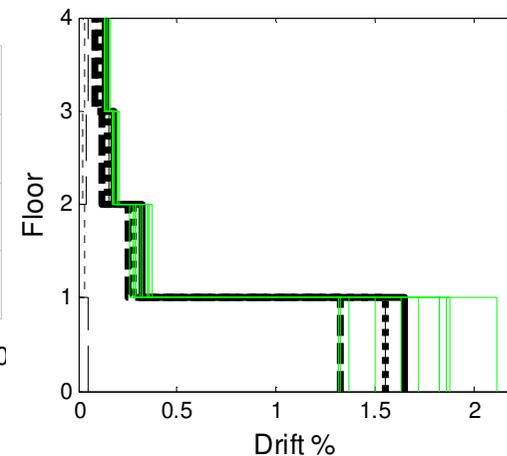
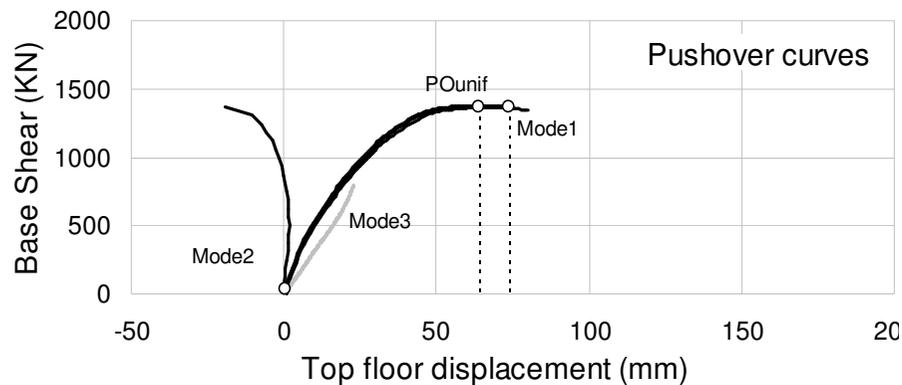
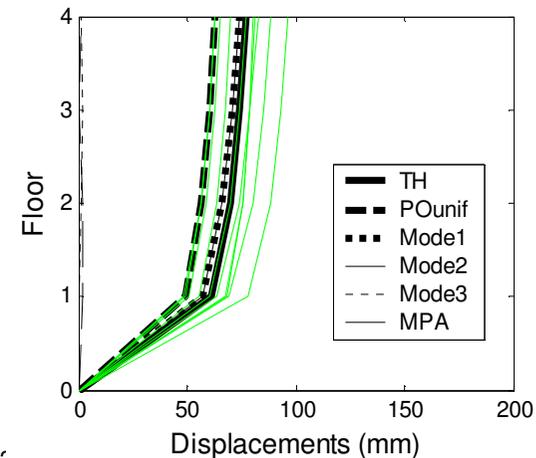
TT1



Telaio Nudo  
+ Tamponature  
+ Piano Terra Nudo



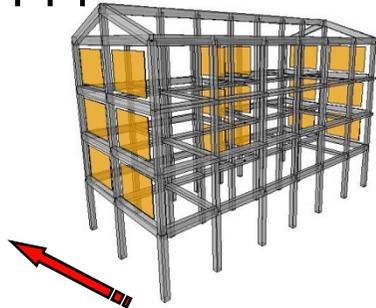
Edificio esistente  
Modello a fibre  
Direzione Y



# BREAKDOWN DELLE COMPONENTI STRUTTURALI – MODELLO TT1

Edificio esistente  
Modello a fibre  
Direzione Y

TT1



Telaio Nudo  
+ Tamponature  
+ Piano Terra Nudo

**Risultati dei diversi metodi di analisi nonlineare (TH, PO, MPA):**

- Piano Terra Nudo → compare un meccanismo di piano.
- I piani superiori subiscono deformazioni limitate. Tamponature lineari OK.
- Risposta altamente nonlineare → alta dispersione nei risultati TH

# ULTERIORI ANALISI DINAMICHE NONLINEARI SU EDIFICIO BONEFRO

➤ **INSERIRE QUI LAVORO NICOLA**

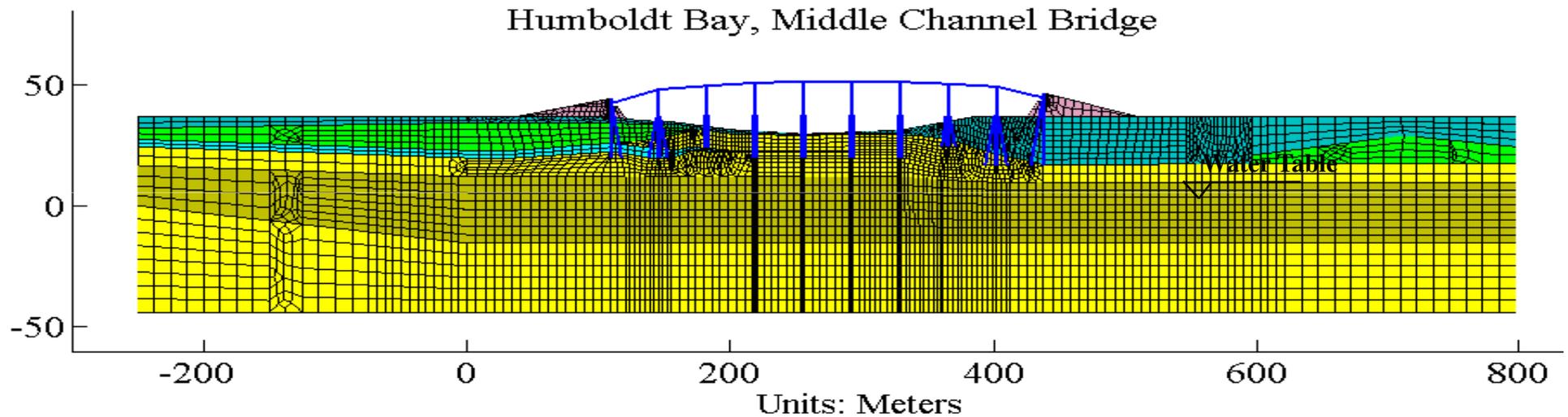
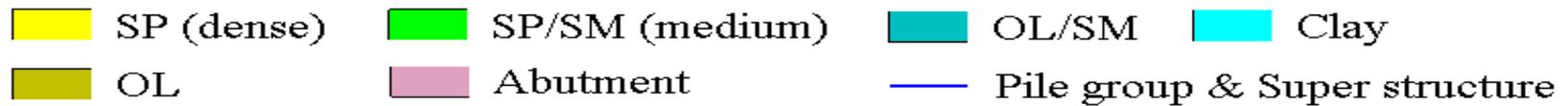
# SOMMARIO

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- Edificio di Bonefro
- **Ponte di Humbolt Bay**
- Modellazione Taglio (Per ponti ed edifici)
- Esempio di modellazione ed analisi in MidasGen
- E-ELT Telescope

# HUMBOLDT BAY BRIDGE

## Profilo terreno



SP: Poorly graded sand; gravely sand

SM: Silty sand; sand-silt mixtures

OL: Organic silt; organic silty clays of low plasticity

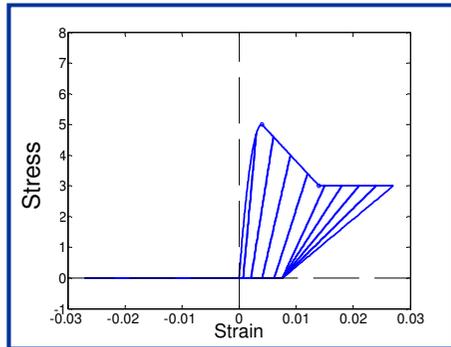




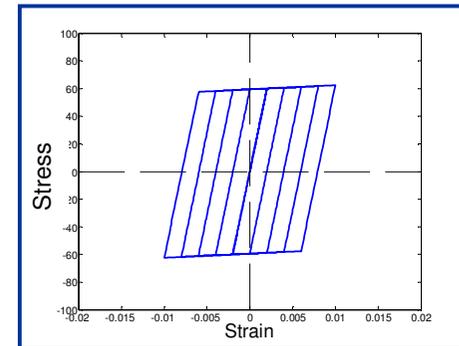


# HUMBOLDT BAY BRIDGE

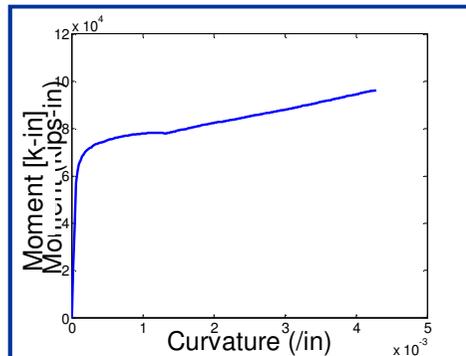
## Pila: sezione a fibre



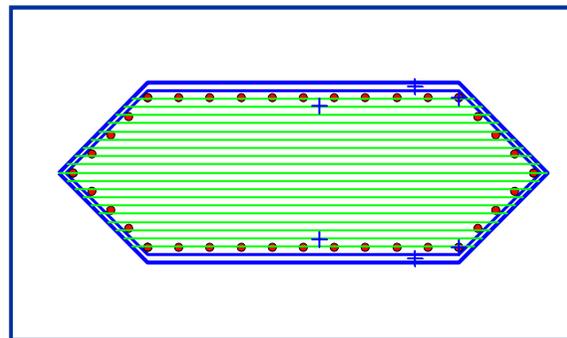
Concrete: Kent-Scott-Park Model



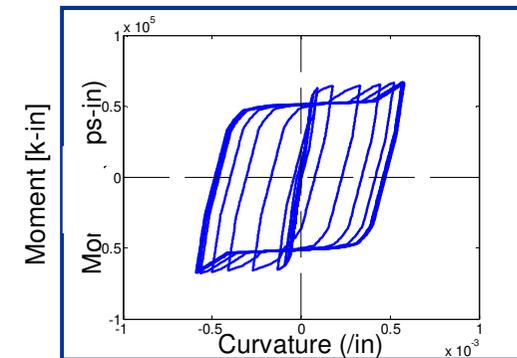
Steel: Bilinear Model



Monotonic Pushover (Single Column on Fixed Base)



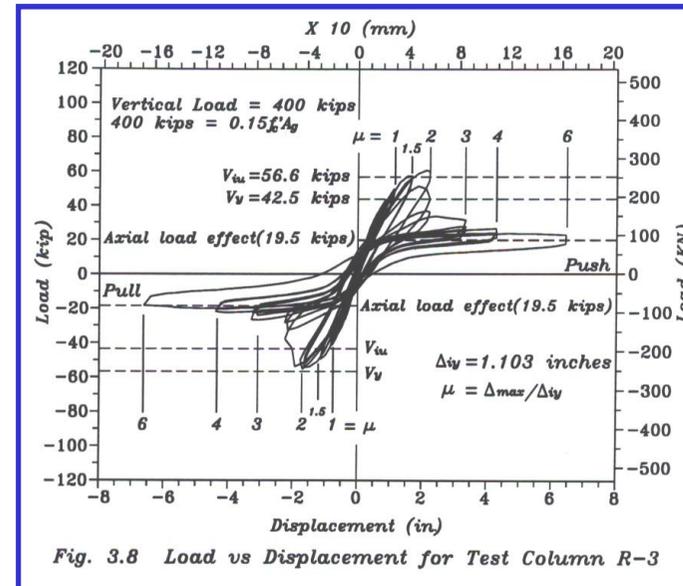
Fiber Discretization of Column Cross-section



Cyclic Pushover (Single Column on Fixed Base)

# HUMBOLDT BAY BRIDGE

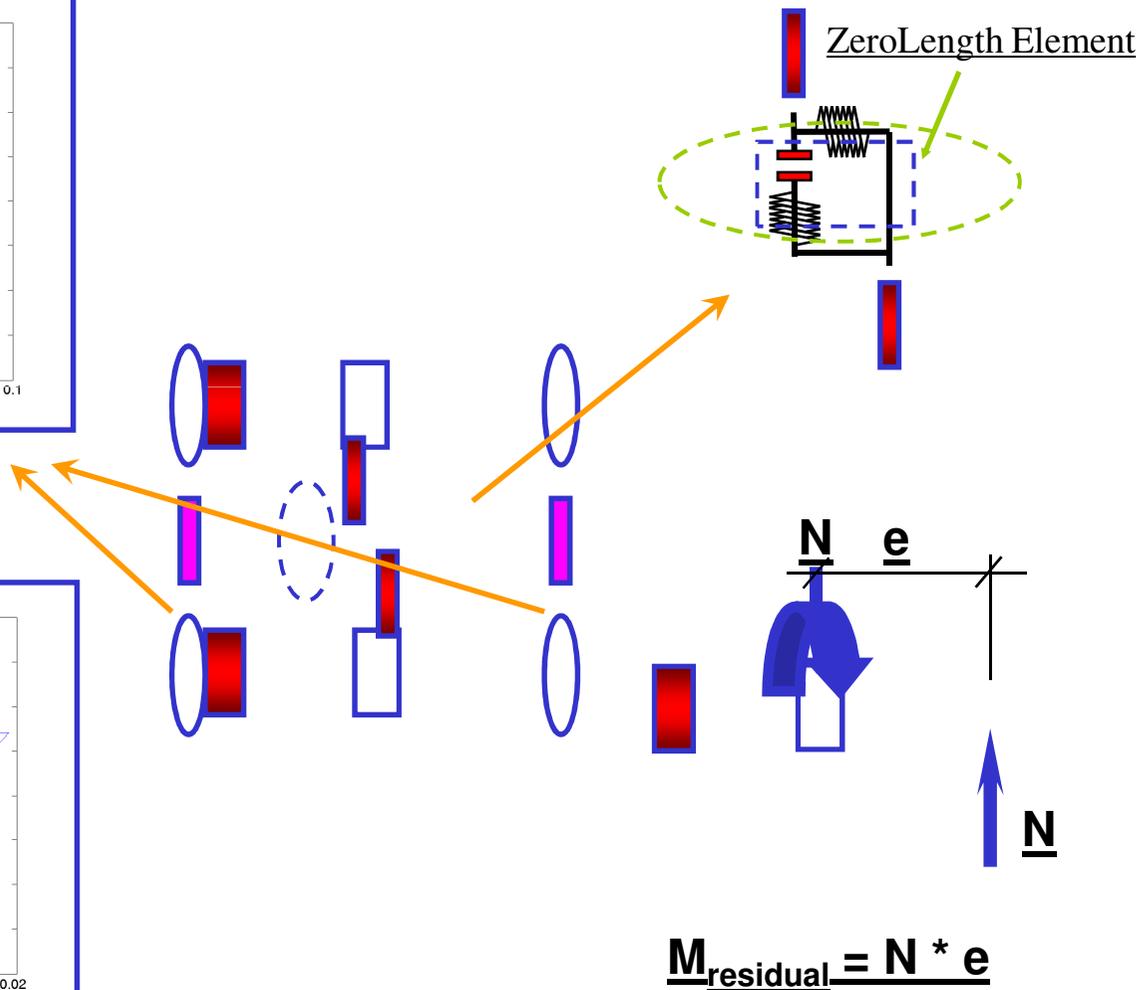
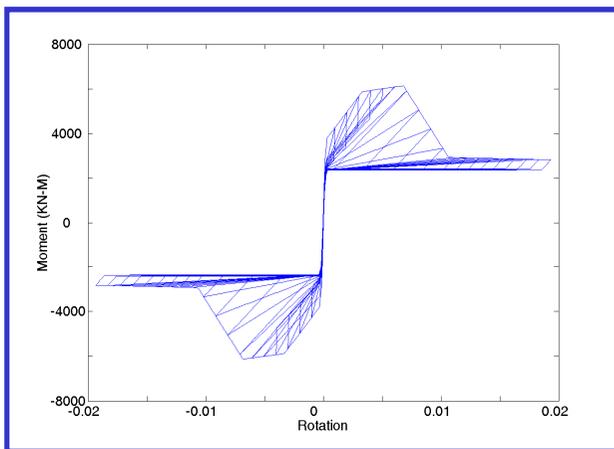
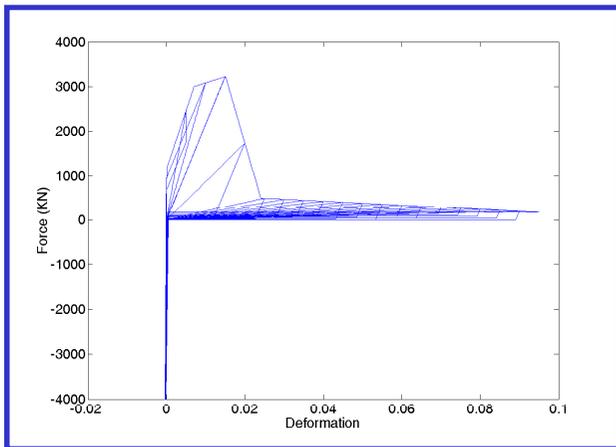
## Pila: modello sezione con ripresa ferri



Professor Priestley, UCSD 1991

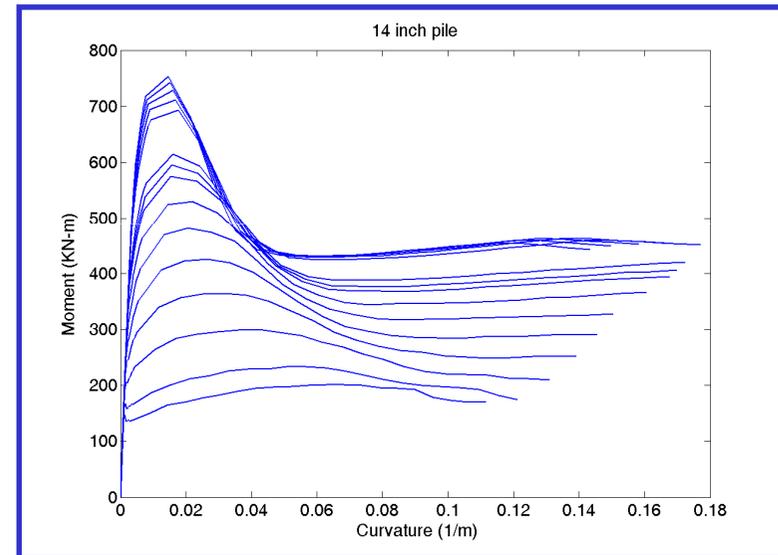
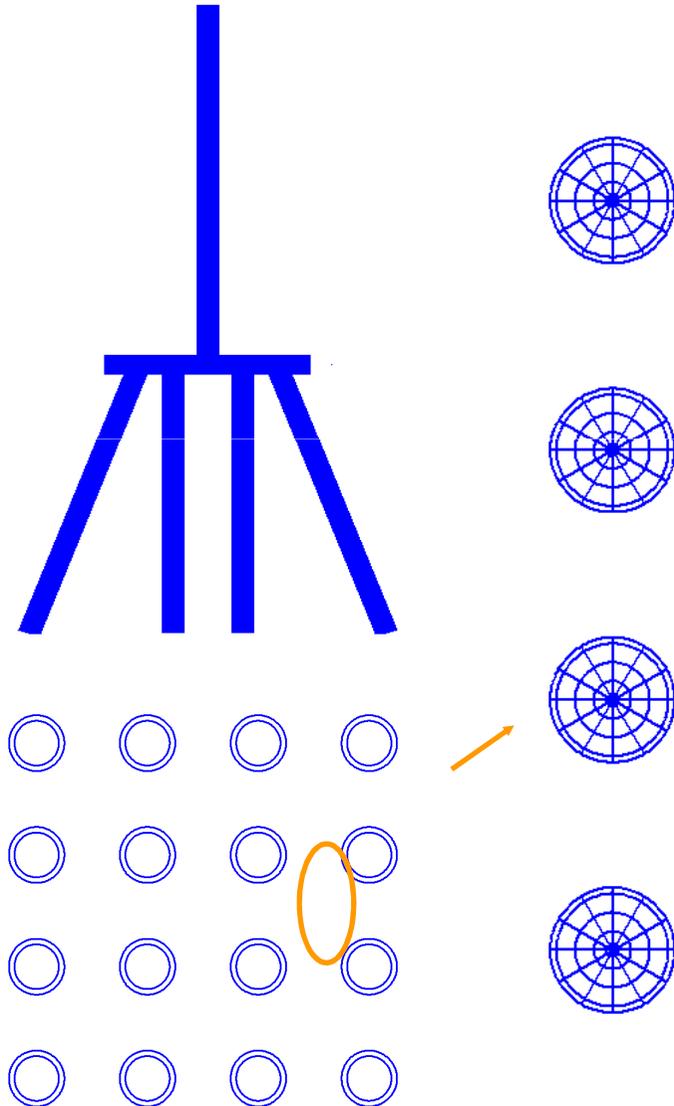
# HUMBOLDT BAY BRIDGE

## Pila: modello sezione con ripresa ferri



# HUMBOLDT BAY BRIDGE

## Fondazioni a pali

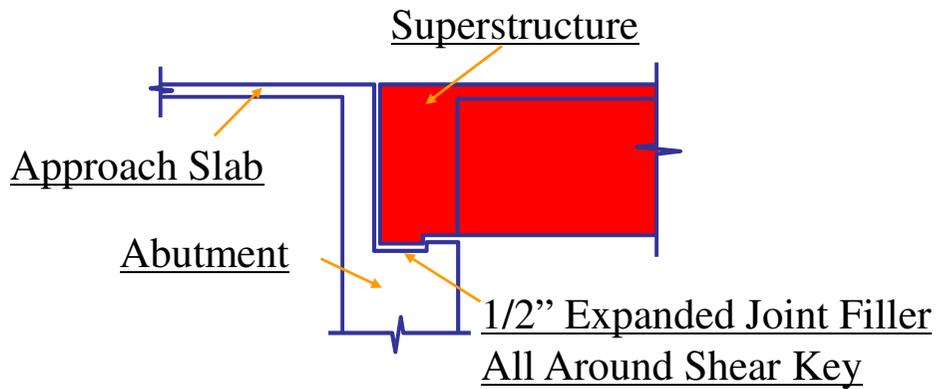


# HUMBOLDT BAY BRIDGE

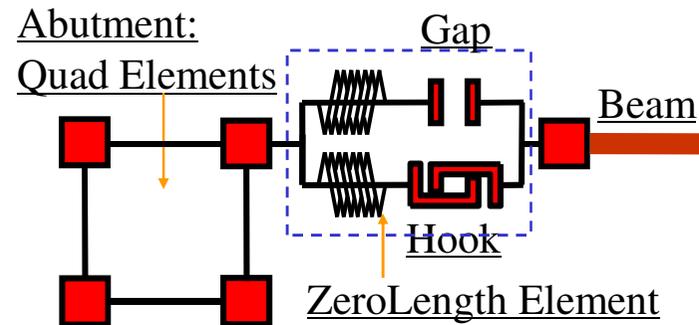
## Spalle: Giunto di espansione



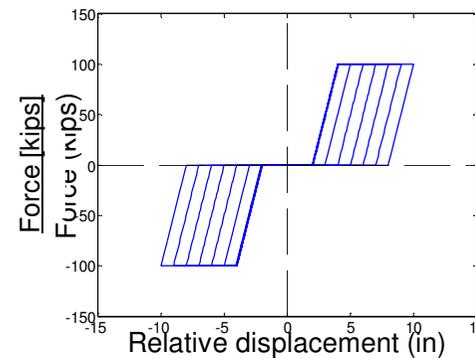
As Built



Finite Element Model

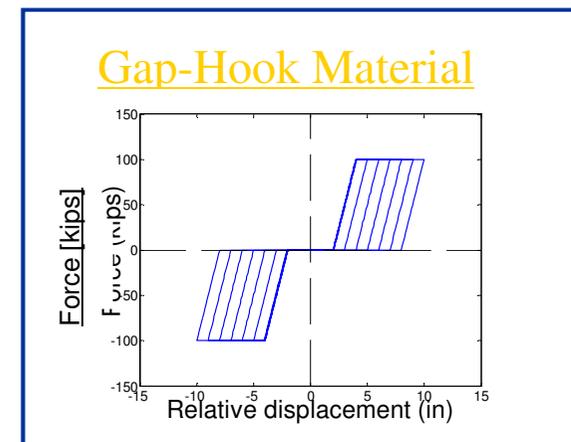
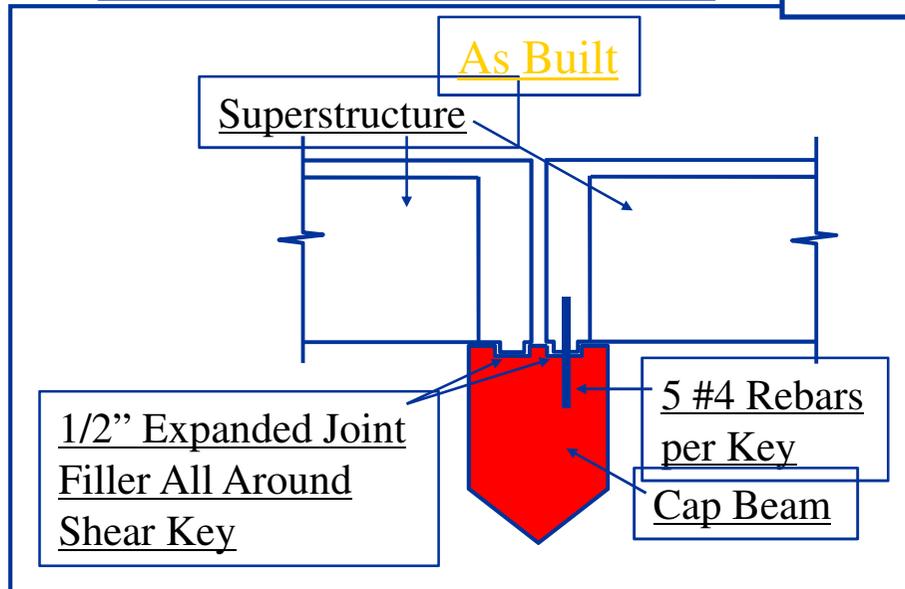
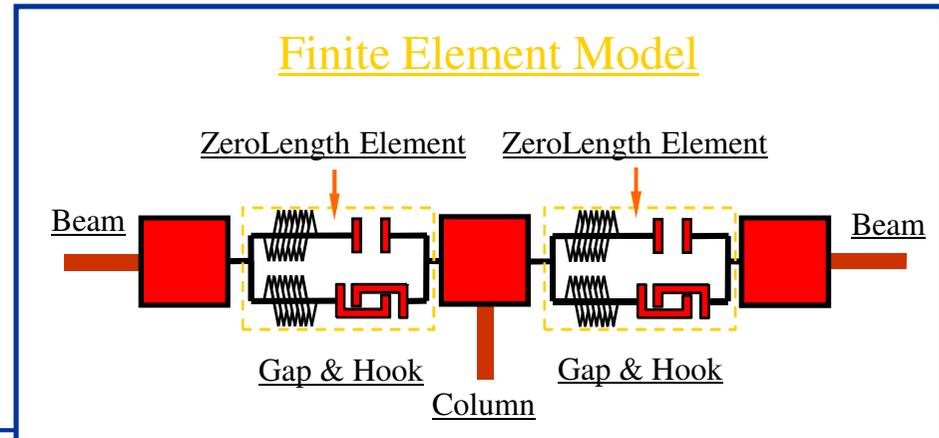


Gap-Hook Material



# HUMBOLDT BAY BRIDGE

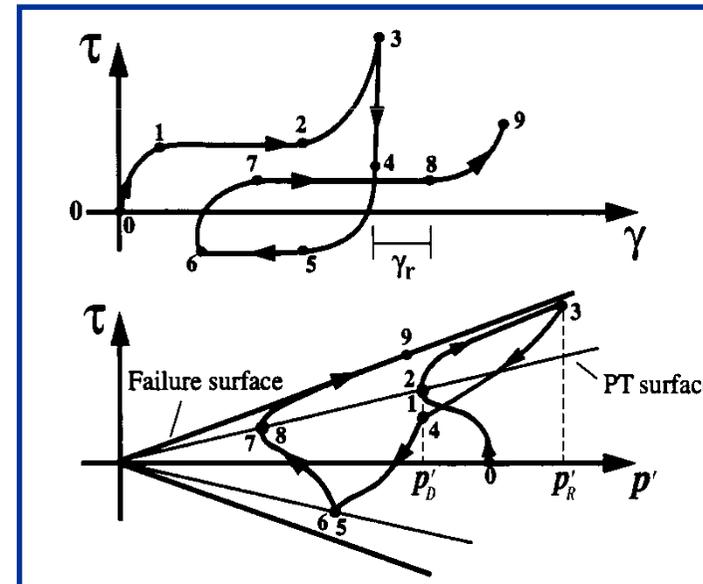
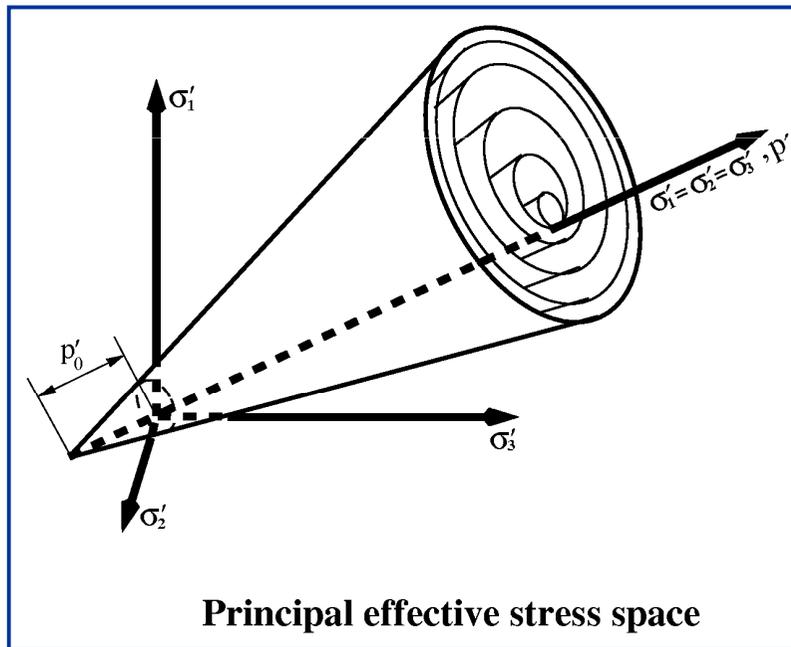
## Testa pila: Giunto di espansione



# HUMBOLDT BAY BRIDGE

## Modelli suolo 1

Soil: pressure-dependent, multi-surface, non-associative plasticity model (for gravel, sand, and silt), incorporating liquefaction effects

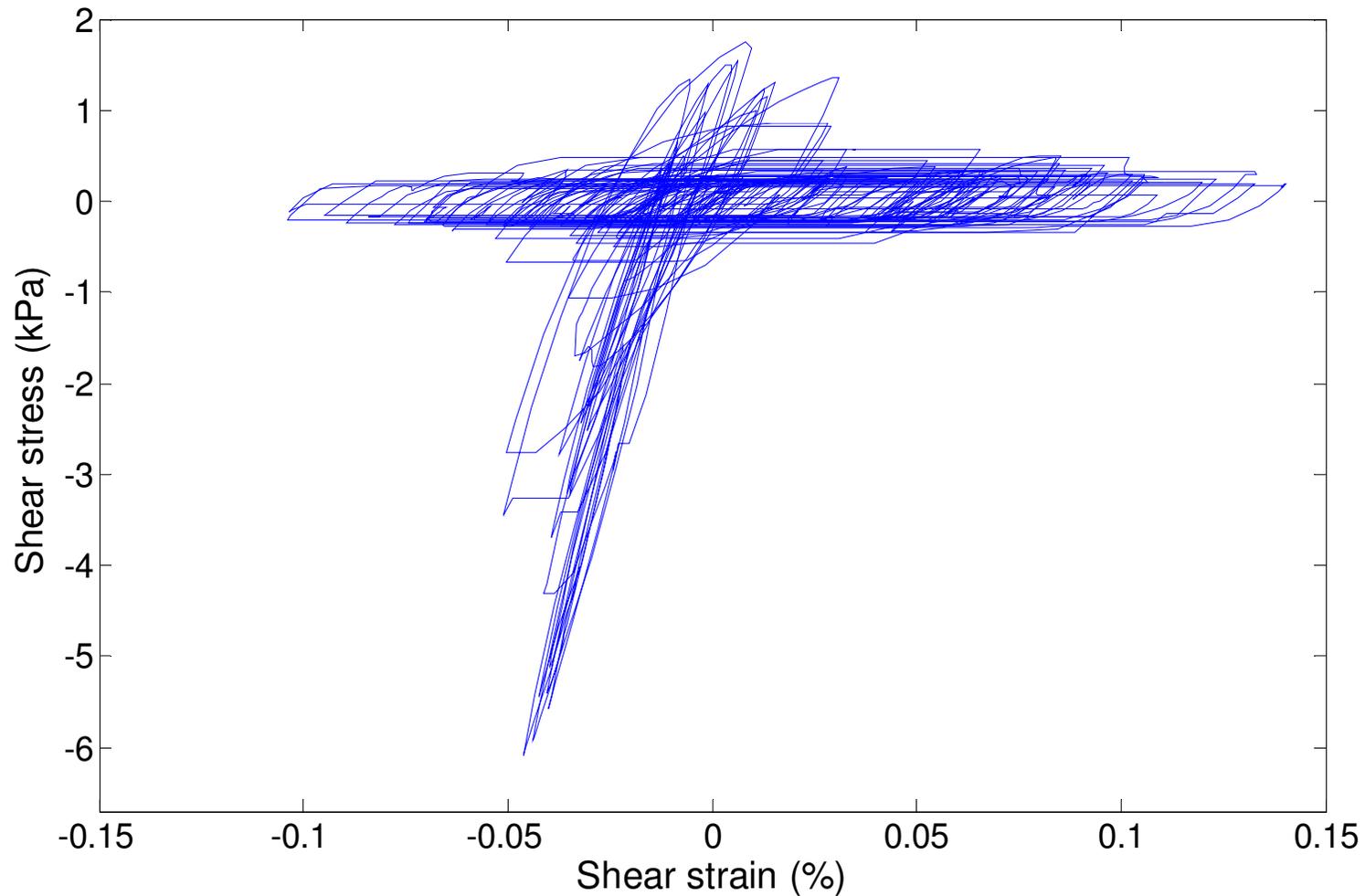


# HUMBOLDT BAY BRIDGE

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## Modelli suolo 1

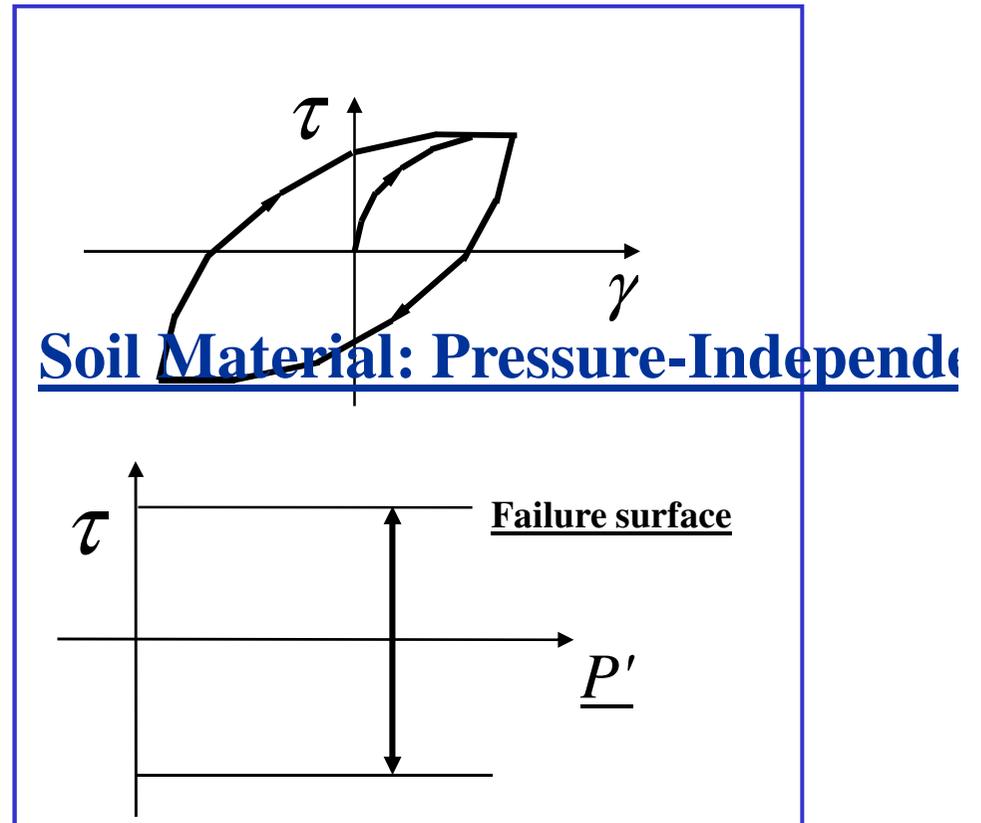
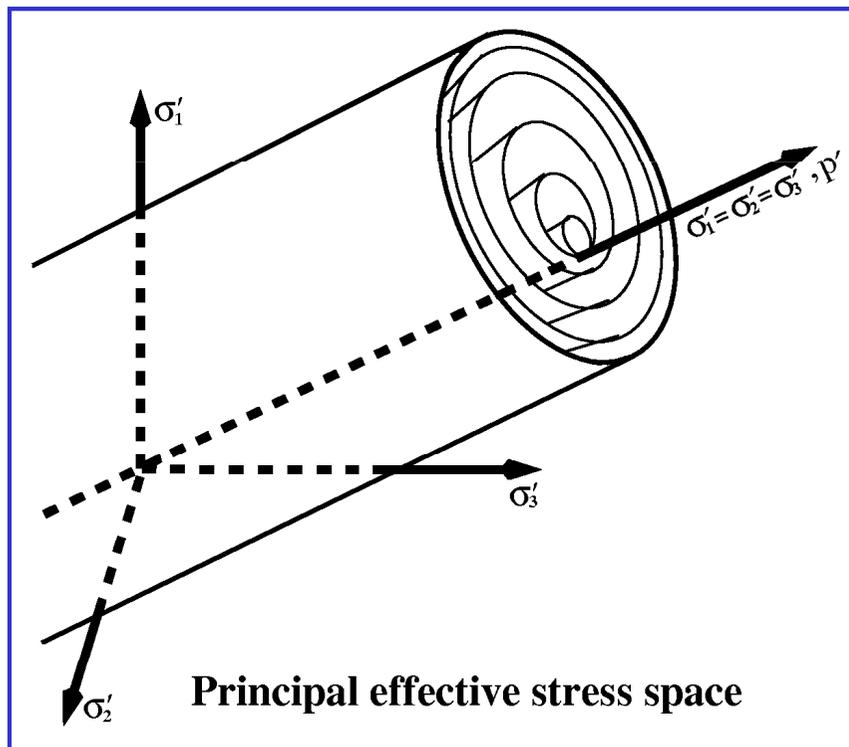
Sample Undrained Sand Response (medium dense)



# HUMBOLDT BAY BRIDGE

## Modelli suolo 2

**Soil Material: Pressure-Independent Model**  
multi-surface, associative plasticity model (for clay and silt)

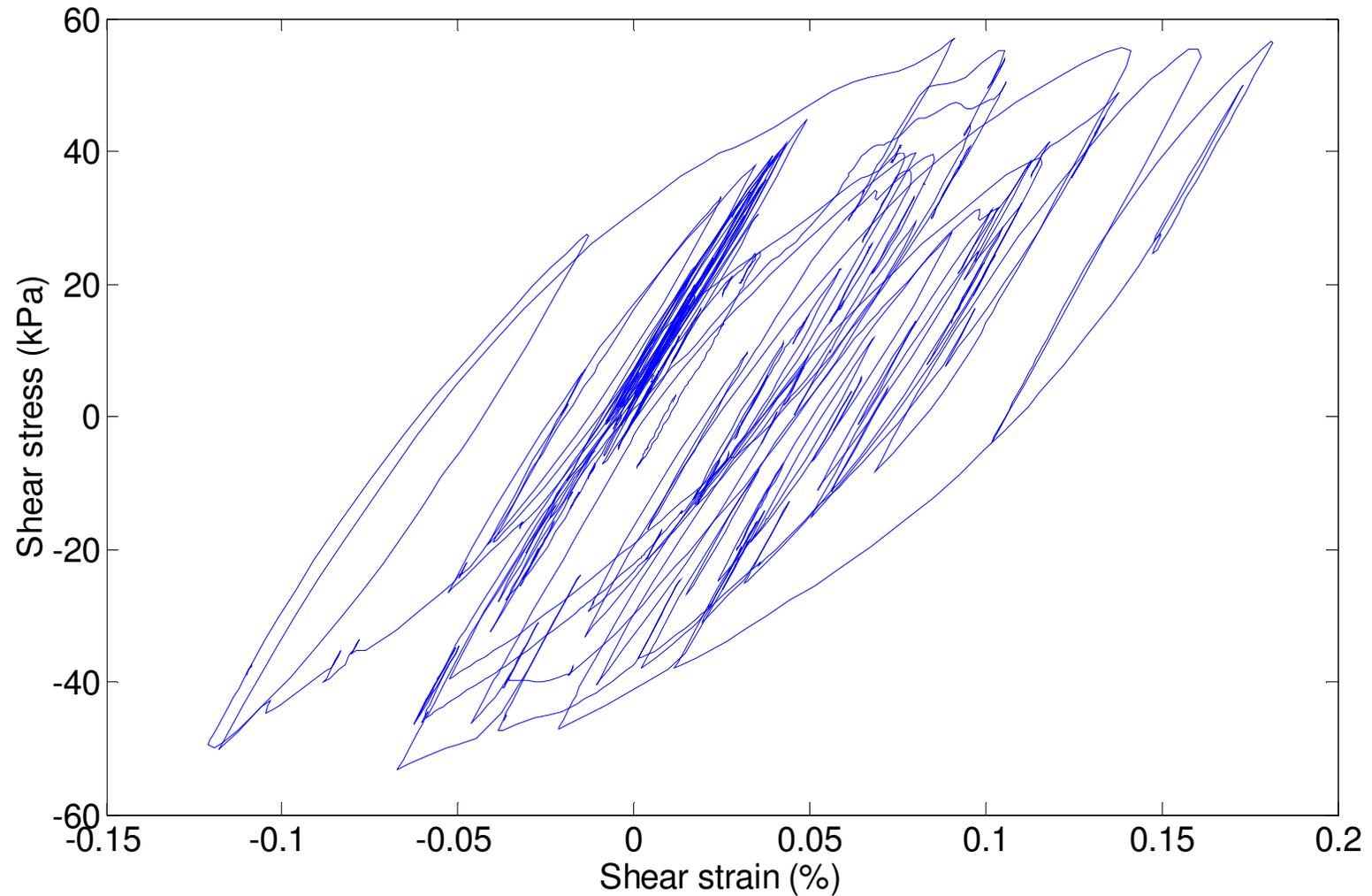


# HUMBOLDT BAY BRIDGE

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## Modelli suolo 2

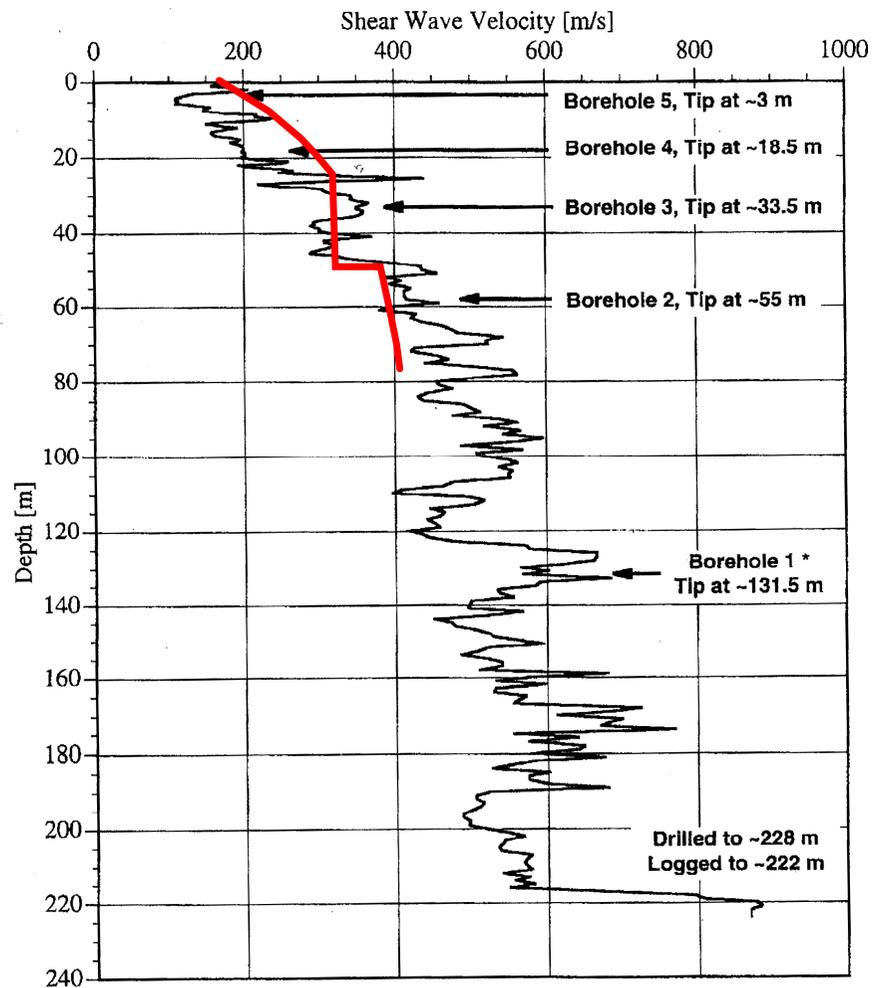
### Sample Clay Response



# HUMBOLDT BAY BRIDGE

## Dati terreno

### Caltrans' Somoa Bridge (Rte 255) Geotechnical Array Preliminary PS-Logging Data (Borehole 1)



# HUMBOLDT BAY BRIDGE

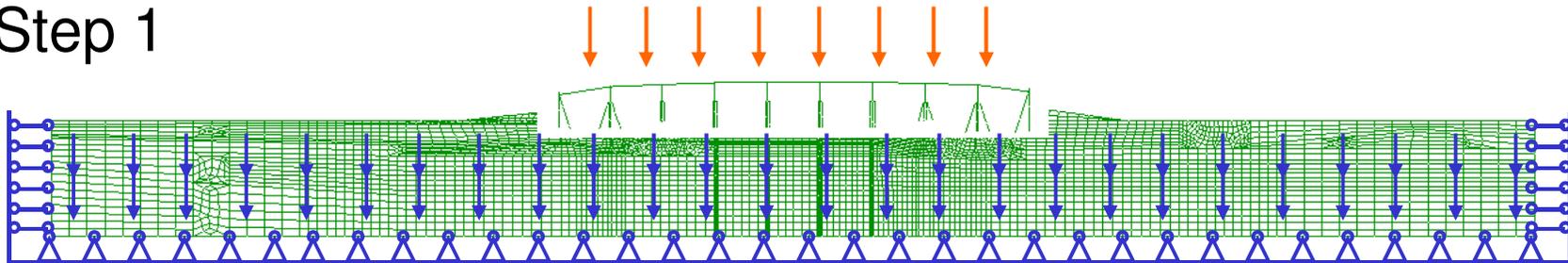
## Dati terreno

Soil Type	Description	Average ( $N_1$ ) <sub>60</sub>	Unit weight (t/m <sup>3</sup> )	Relative density	Friction angle (degrees)	Cohesion (kPa)	Gmax (kPa) at 80 kPa mean confinement
SP	Dense to very dense, fine to medium grained sand	50	2.1	90	45	0	1.2e5
SP/SM	Medium, fine to medium grained sand	20	1.9	50	35	0	0.6e5
OL/SM	Organic silt, silty sand	7	1.9		0	35	0.6e5
CL	Very stiff clay	20	1.8		0	100	1.e5
OL	Organic silt	14	2.0		0	70	1.0e5
Abutment fill	Compact medium sand		1.9	50	35	25	0.6e5

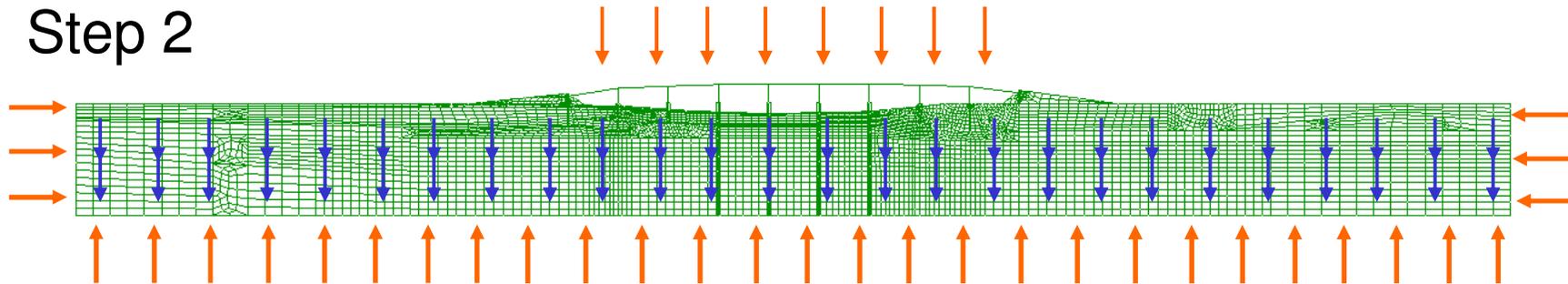
# HUMBOLDT BAY BRIDGE

## Passi analisi

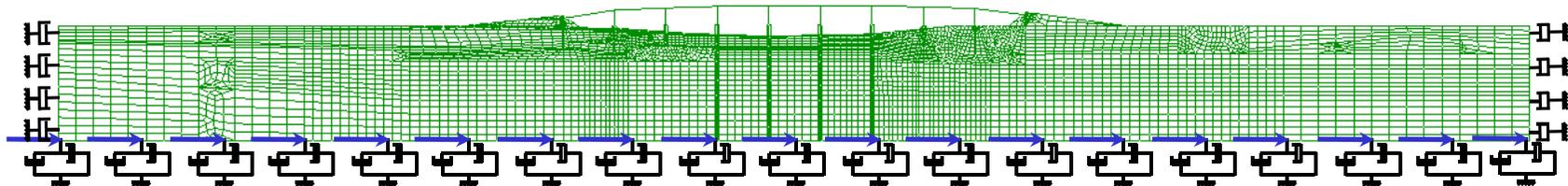
Step 1



Step 2



Step 3

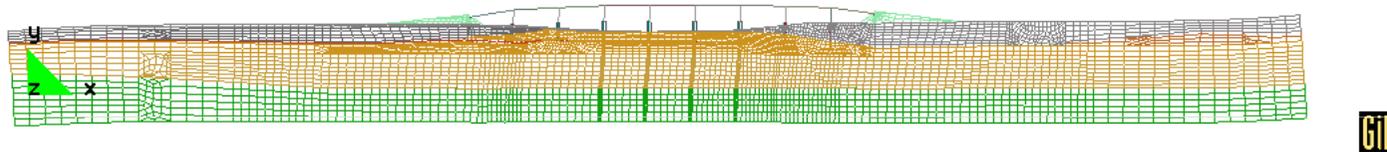


# HUMBOLDT BAY BRIDGE

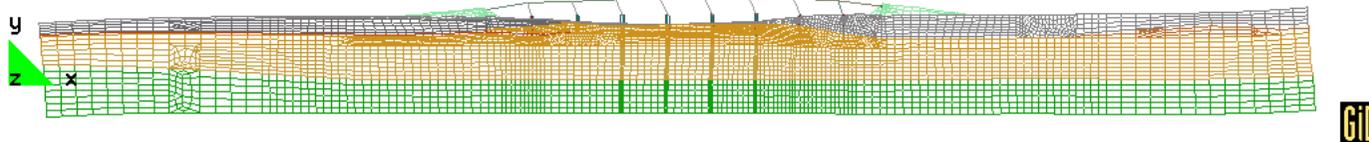
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## Modi

**Mode 1 ( $T_1 = 1.25$  sec): Bridge structure in phase with soil media**

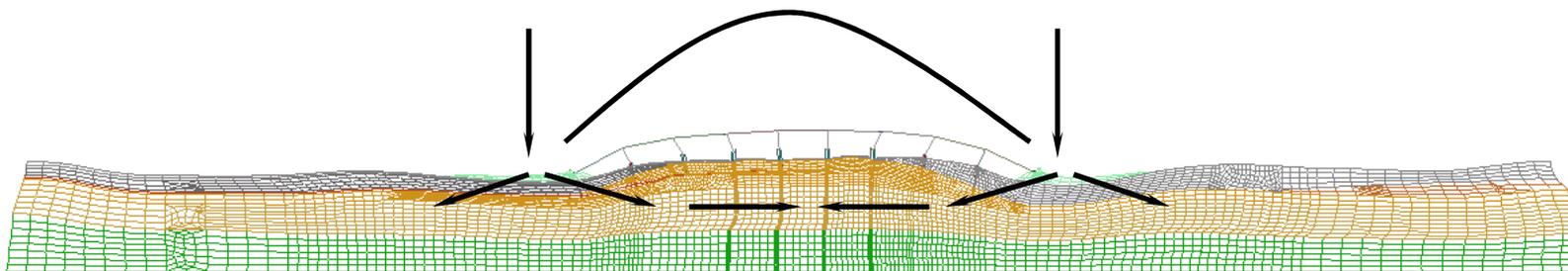
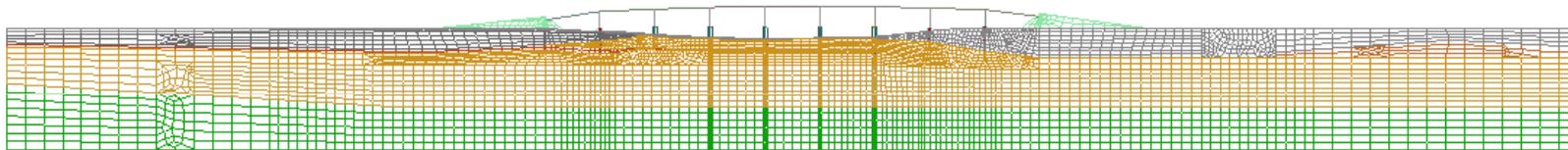


**Mode 2 ( $T_2 = 0.64$  sec): Bridge structure out of phase with soil media**



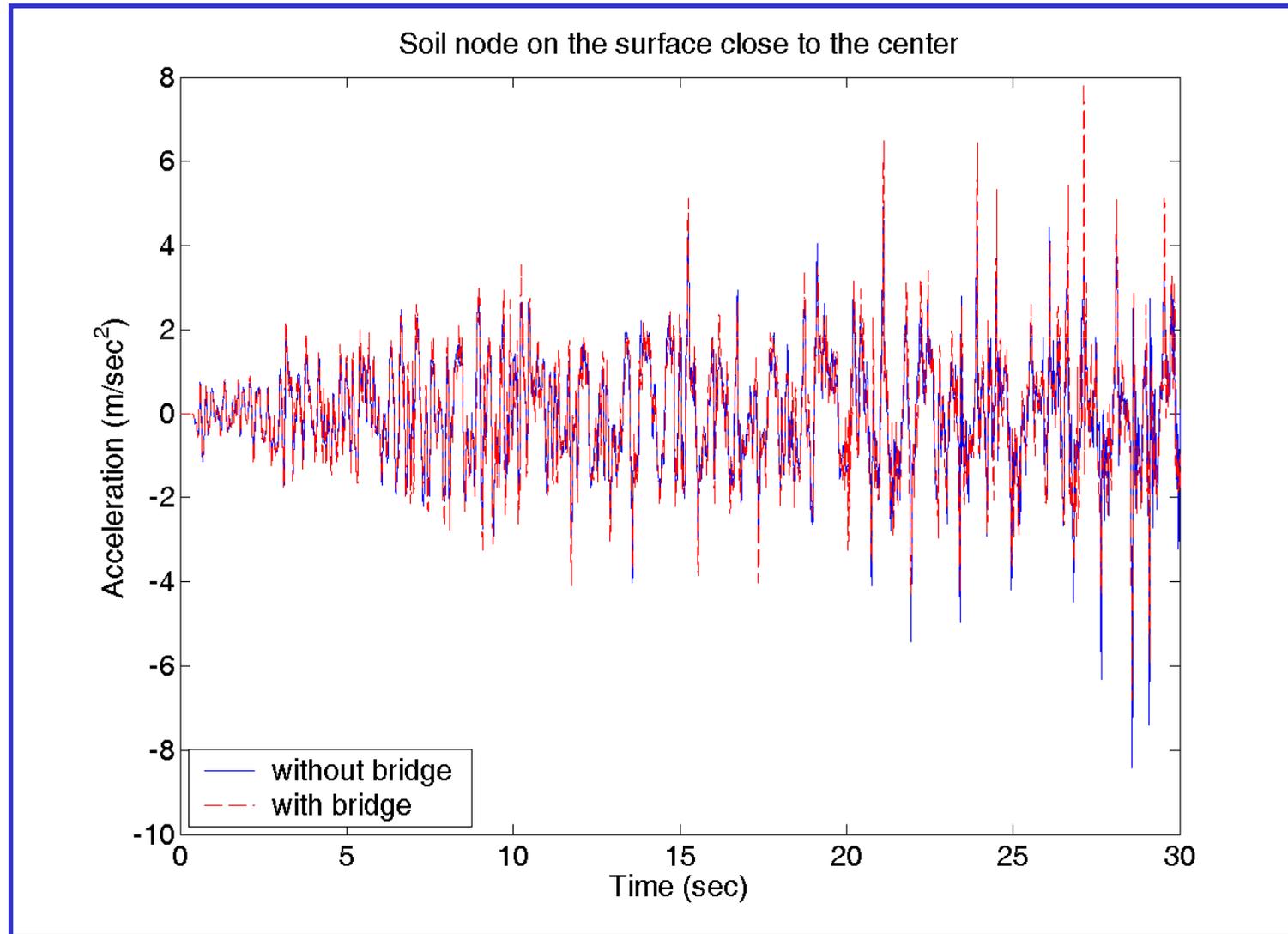
# HUMBOLDT BAY BRIDGE

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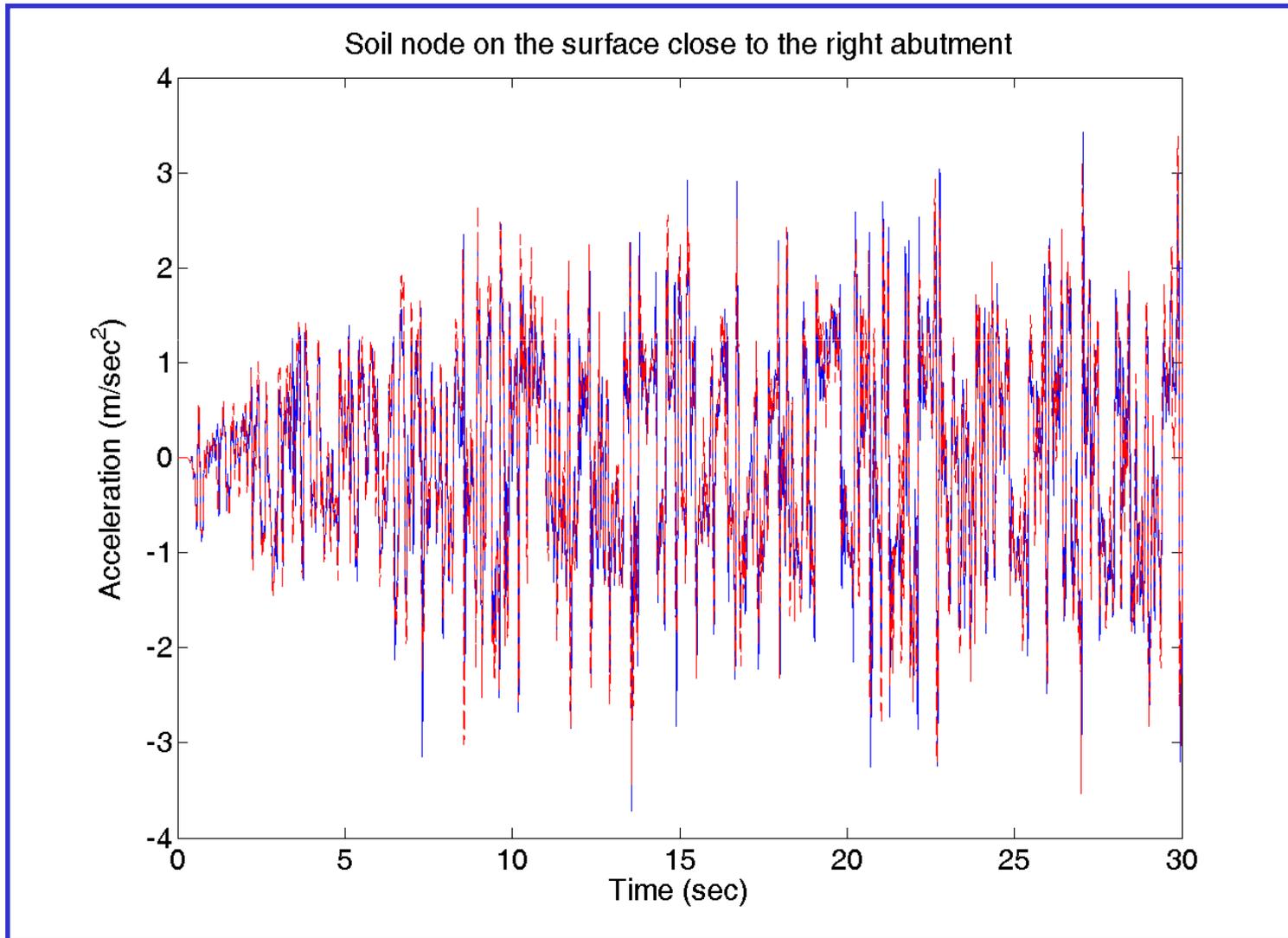
# HUMBOLDT BAY BRIDGE

## Interazione Suolo-Struttura



# HUMBOLDT BAY BRIDGE

## Interazione Suolo-Struttura



# SOMMARIO

---

- **Edificio di Bonefro**
- **Ponte di Humbolt Bay**
- **Modellazione Taglio (Per ponti ed edifici)**
- **Esempio di modellazione ed analisi in MidasGen**
- **E-ELT Telescope**

# SOMMARIO

---

- **Modellazione Taglio (Per ponti ed edifici)**
  - **Motivazione**
  - **Cerniera plastica**
  - **Plasticità distribuita**

# SOMMARIO

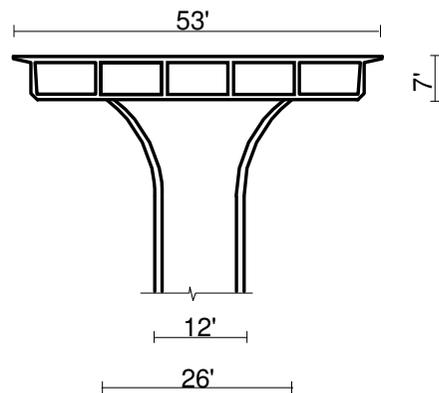
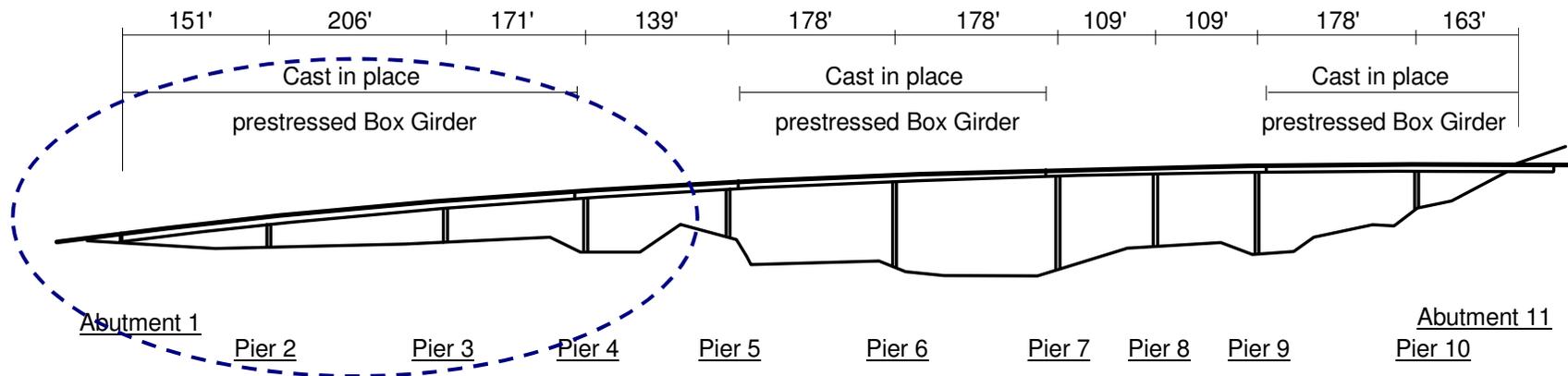
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- **Modellazione Taglio (Per ponti ed edifici)**
  - **Motivazione**
  - **Cerniera plastica**
  - **Plasticità distribuita**

# MODELLAZIONE TAGLIO

## PONTE “IRREGOLARE” a Los Angeles

### RTE 14/5 Intersection - SOUTH CONNECTOR



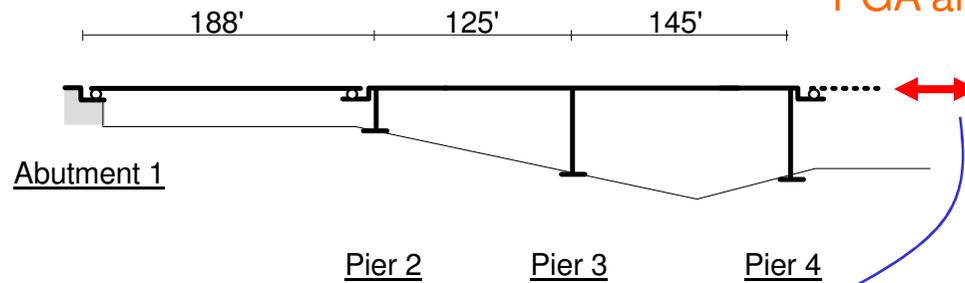
TYPICAL SECTION

In fase di costruzione colpito dal terremoto di San Fernando, 1971

# MODELLAZIONE TAGLIO

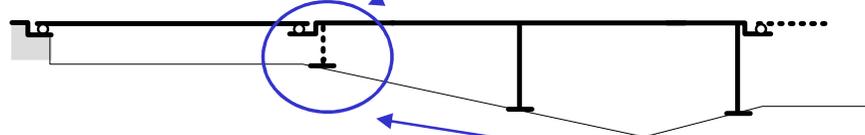
A) North Connector before Northridge earthquake

Terremoto di Northridge, 1994  
PGA al raccordo 0,5 g



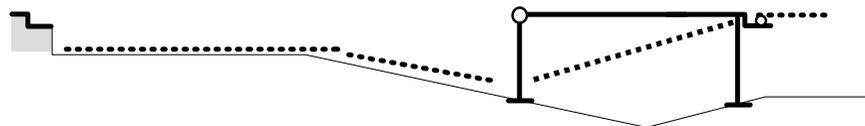
La forza sismica è attratta dalla pila corta, più rigida

B) Pier 2 column fails

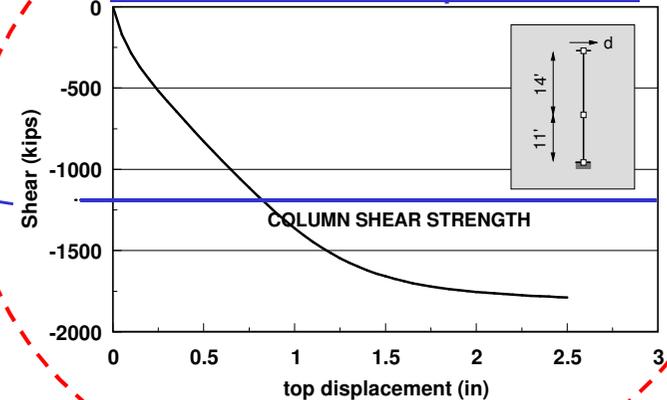


resistenza a taglio insufficiente

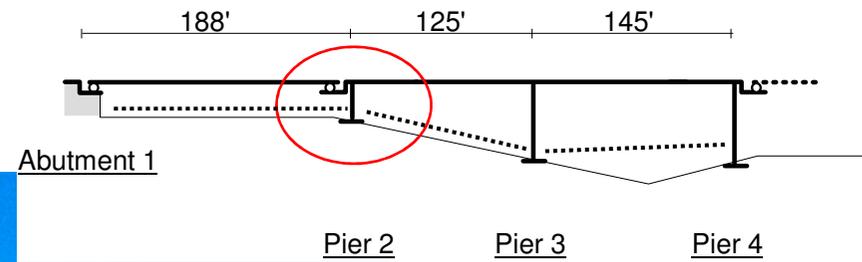
C) Simple span falls off seat abutment;  
Box girder forms a hinge at bent 3 and tears off



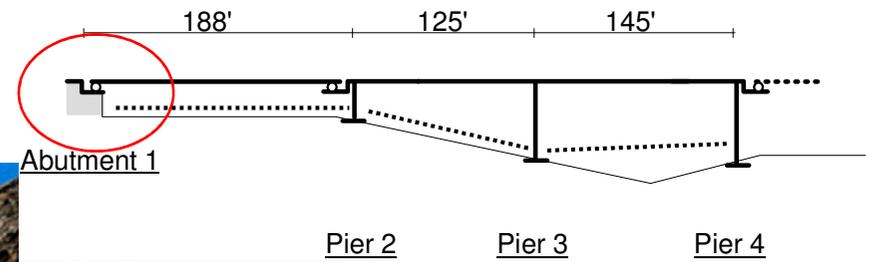
Pier 2: curva di pushover



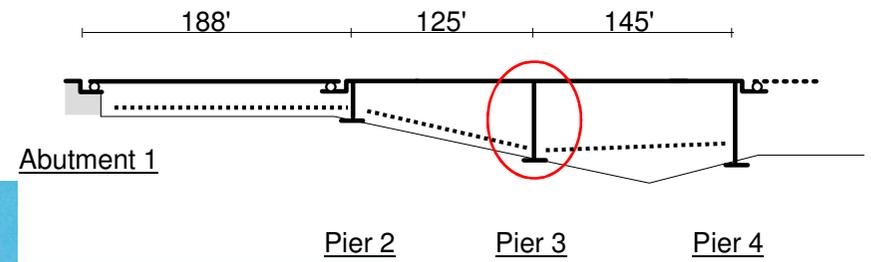
# MODELLAZIONE ROTTURA A TAGLIO



# MODELLAZIONE ROTTURA A TAGLIO



# MODELLAZIONE ROTTURA A TAGLIO



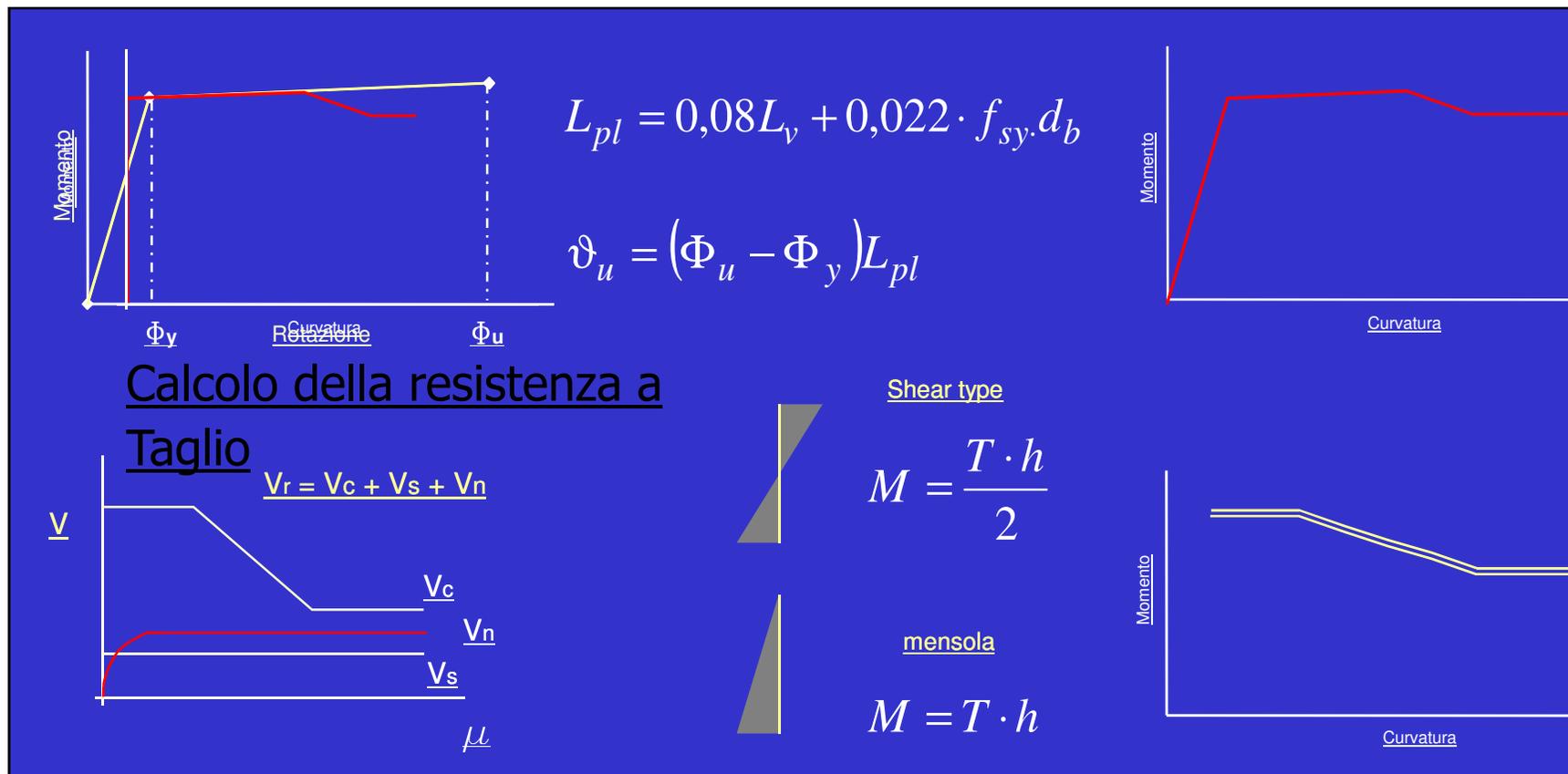
# SOMMARIO

---

- **Modellazione Taglio (Per ponti ed edifici)**
  - **Motivazione**
  - **Cerniera plastica**
  - **Plasticità distribuita**

# MODELLAZIONE ROTTURA A TAGLIO METODO PER CERNIERA PLASTICA

- A partire dai legami costitutivi dei materiali si determina il legame Momento-Rotazione relativa delle cerniere plastiche
- Definizione del legame costitutivo Momento-Curvatura della sezione
- Definizione del comportamento plastico delle cerniere

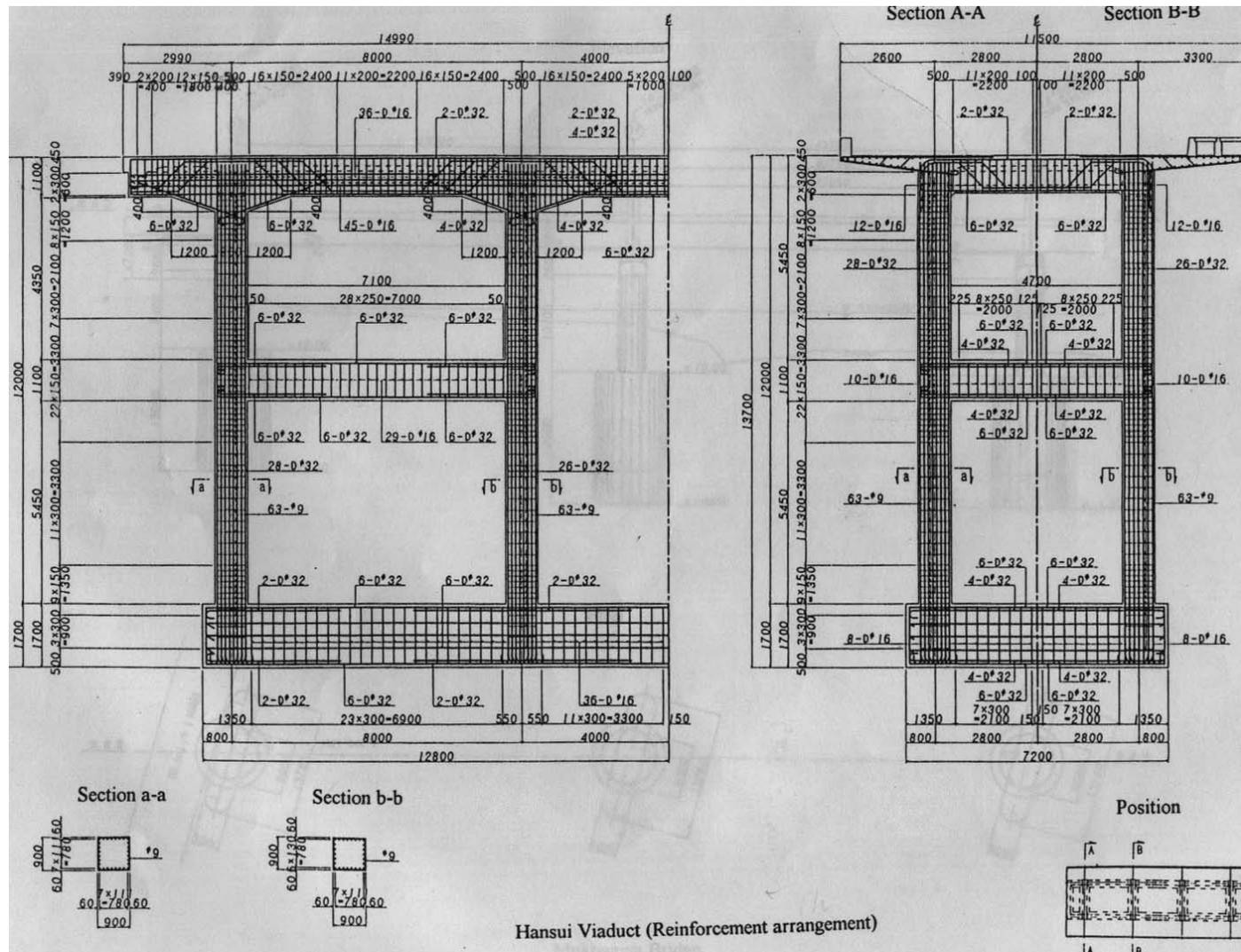


# SOMMARIO

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- **Edificio di Bonefro**
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- **Modellazione Taglio (Per ponti ed edifici)**
  - **Motivazione**
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  - **Plasticità distribuita**

# PONTE HANSUI (GIAPPONE)



**COLLASSO PER TAGLIO – TERREMOTO KOBE 1995**

# PONTE HANSUI

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- **Necessità di modellare la risposta nonlineare N-V-M**
- **Elemento in Forze di Timoshenko**

**Sezione a fibre:** matrice di rigidezza completa calcolata in base alla risposta

$$\mathbf{k}(x) = \begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{12} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{bmatrix}$$

Petrangeli, M., Pinto, P.E. and Ciampi, V. (1999). "Fiber element for cyclic bending and shear of R/C structures. I: theory", *ASCE Journal of Engineering Mechanics*, 125(9), 994-1001

# PONTE HANSUI

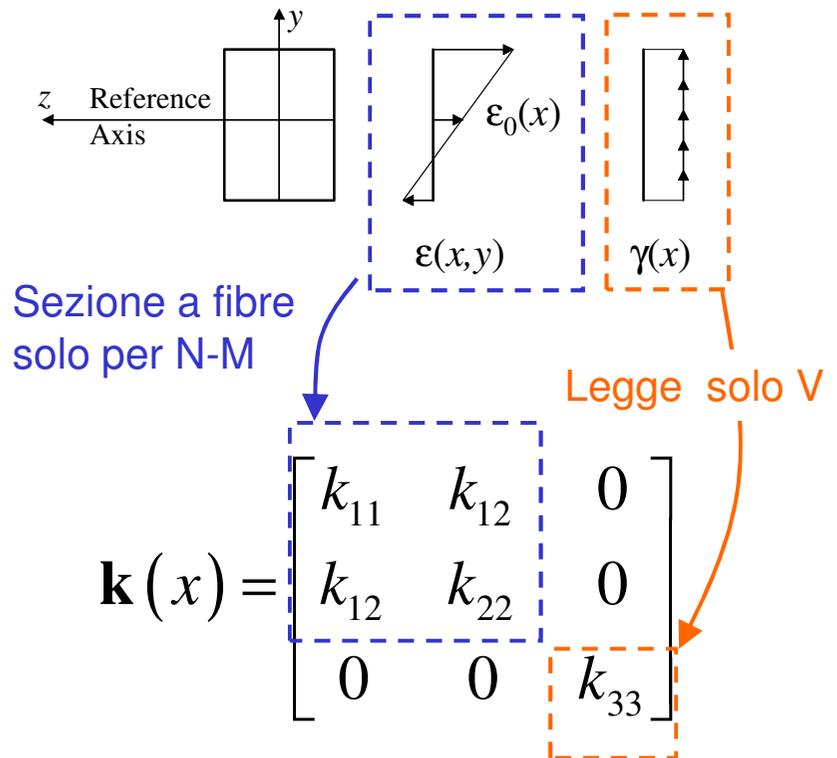
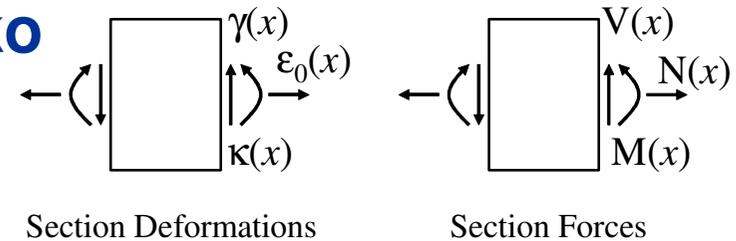
## Elemento in Forze di Timoshenko

### Sezione a fibre semplificata

Marini, A., Spacone, E. (2006). Analysis of R/C Elements Including Shear Effects, *ACI Structure Journal*, in stampa

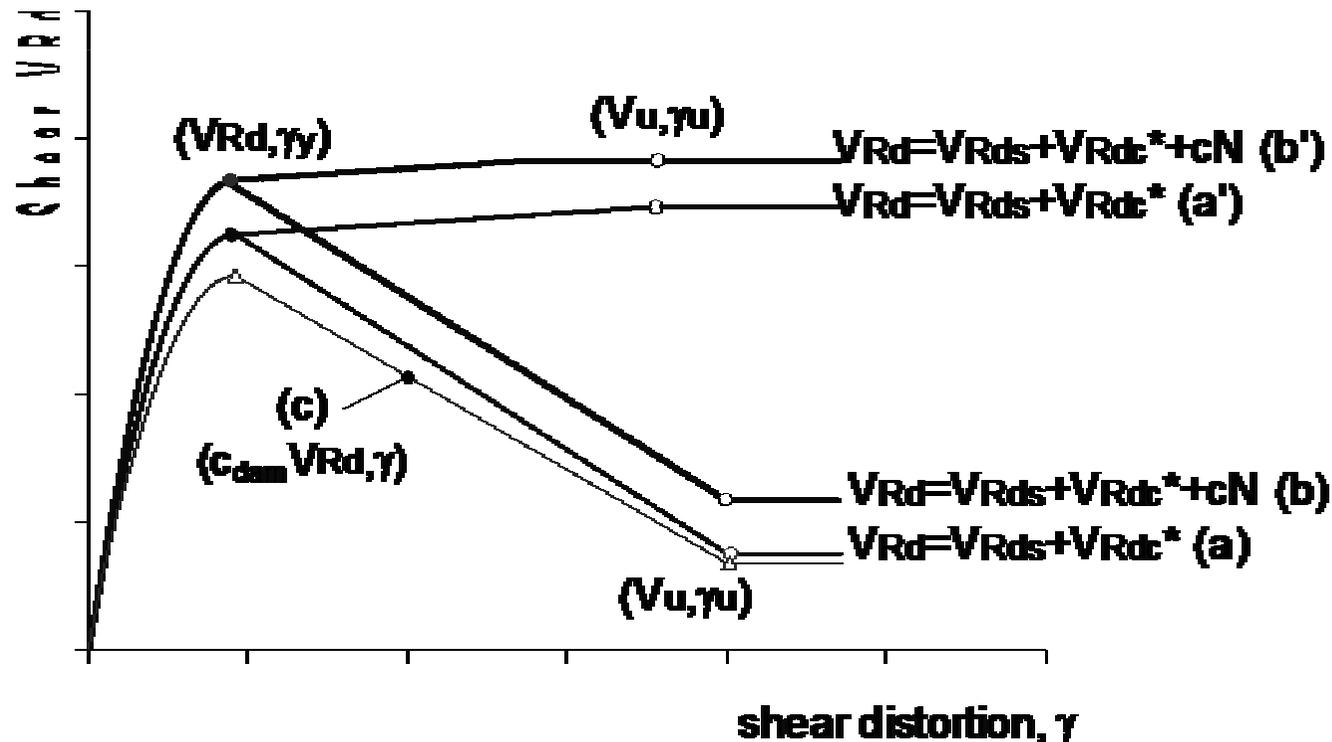
$V$  ed  $M$  sono collegati dall'equilibrio puntuale,  $V = dM/dx$ . L'eventuale rottura a taglio impedisce al momento di aumentare!

Serve una legge  $V-\gamma$



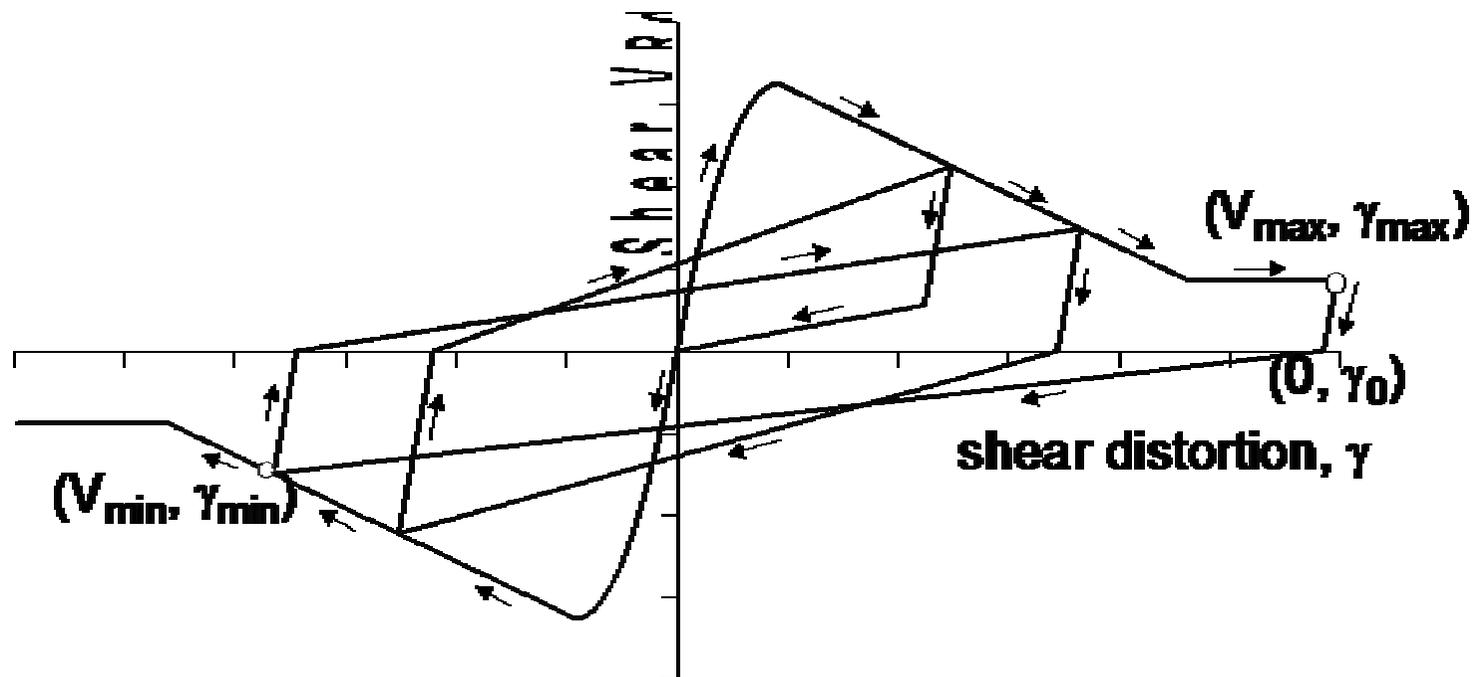
## Modello Ponte

- Elementi telaio in forze (tipo Timoshenko)
- Sezioni a fibre per N-M
- Modello a taglio V- $\gamma$  – Equilibrio con M,  $V=dM/dx$  (“esatto”)



## Modello Ponte

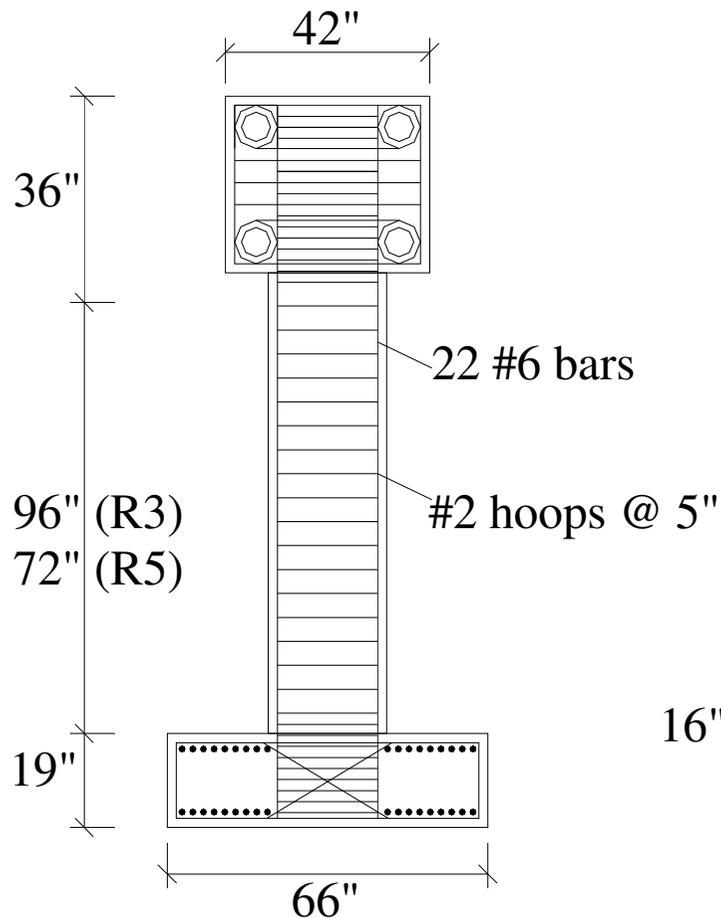
- Comportamento ciclico a taglio (con danno)



# PONTE HANSUI

## Modello Ponte

Taratura modello taglio



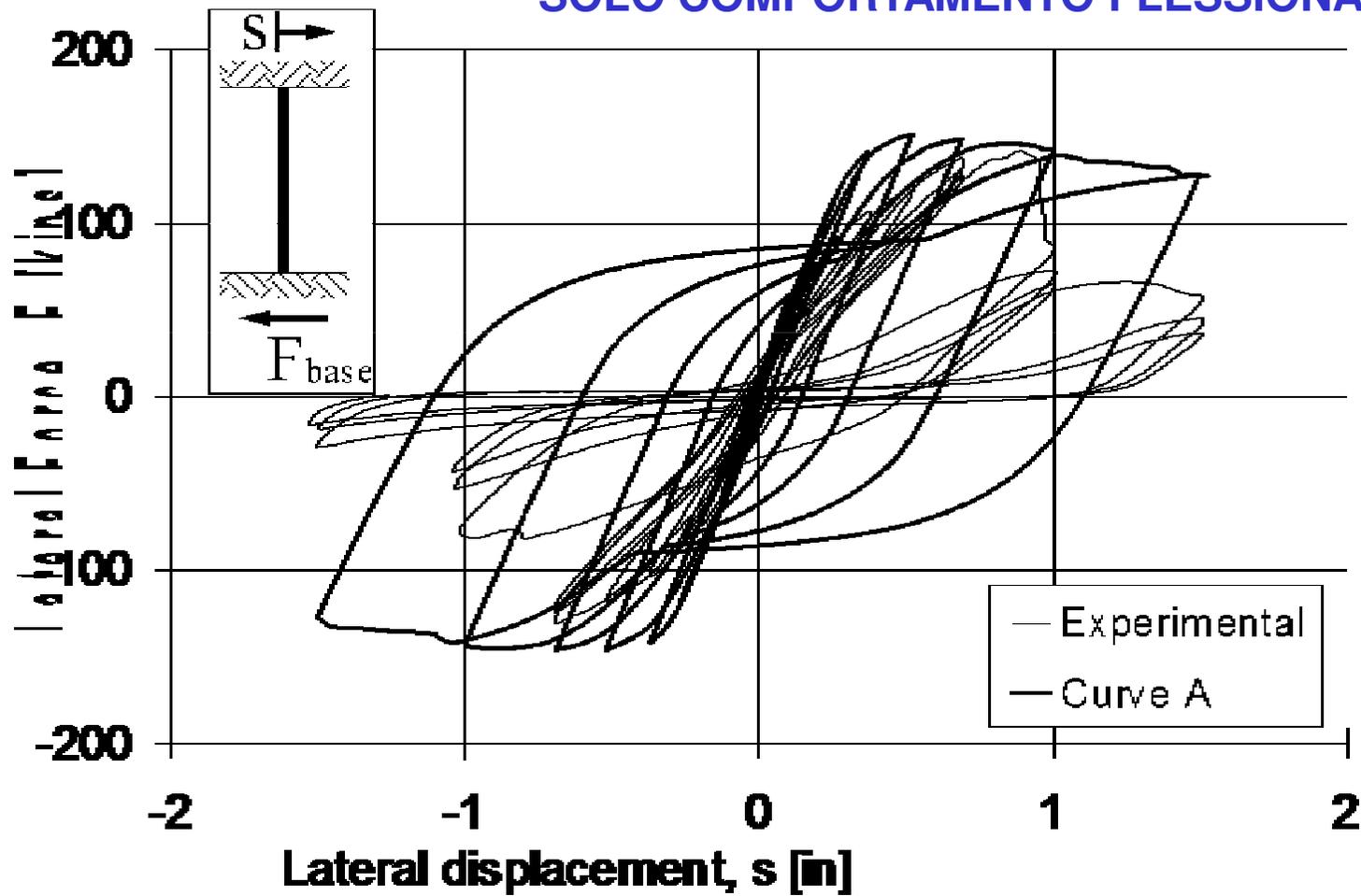
**Colonna provata in laboratorio** (UC San Diego, USA):

Xiao, Y., Priestley, N., Seible, F. (1993). "Steel jacket retrofit for enhancing shear strength of short rectangular reinforced concrete columns", *Report n. SSRP-92/07, University of California, San Diego, Structural Systems Research Project.*

# PONTE HANSUI

## Modello Ponte

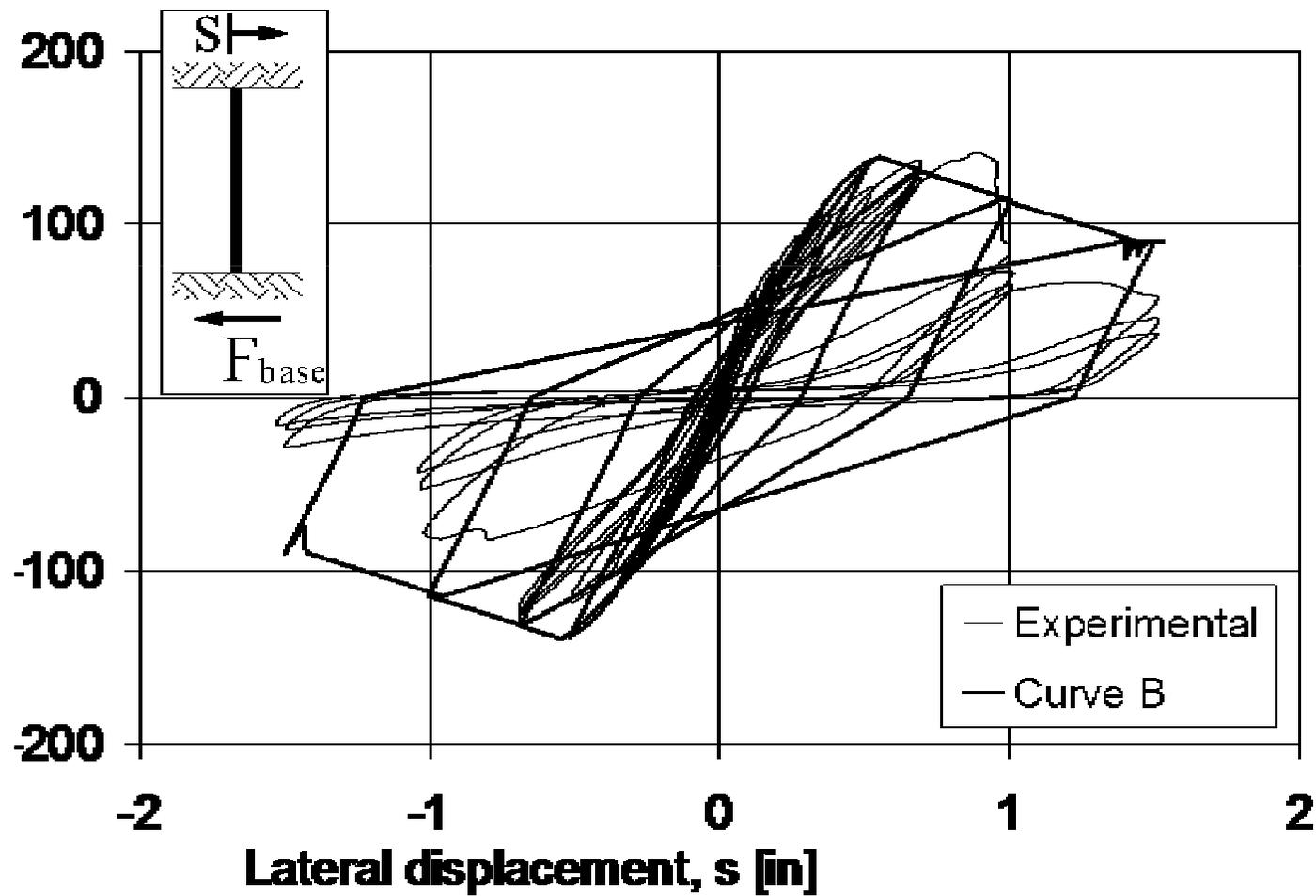
SOLO COMPORTAMENTO FLESSIONALE



# PONTE HANSUI

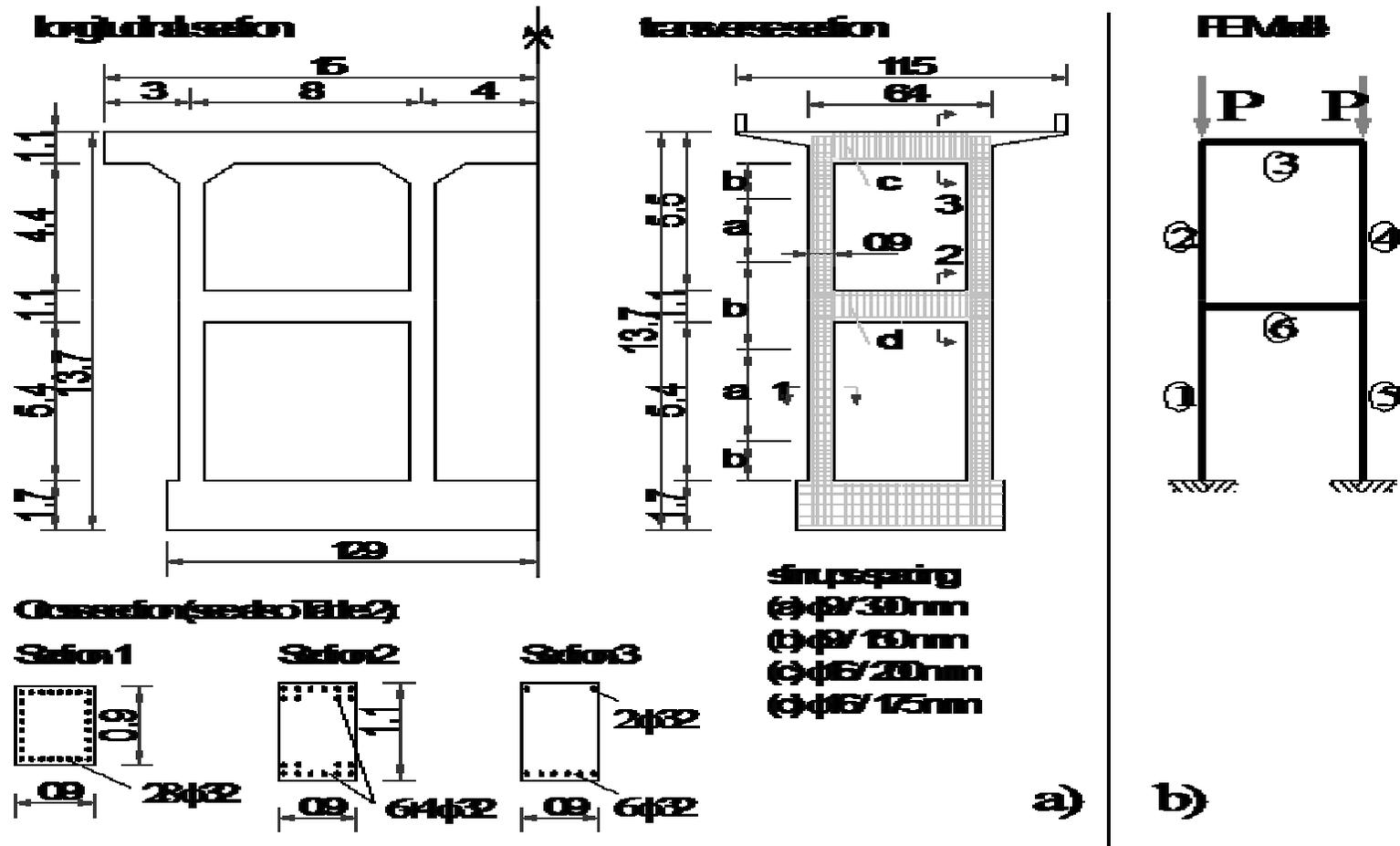
## Modello Ponte

### FLESSIONE E TAGLIO (SECONDO EC2)



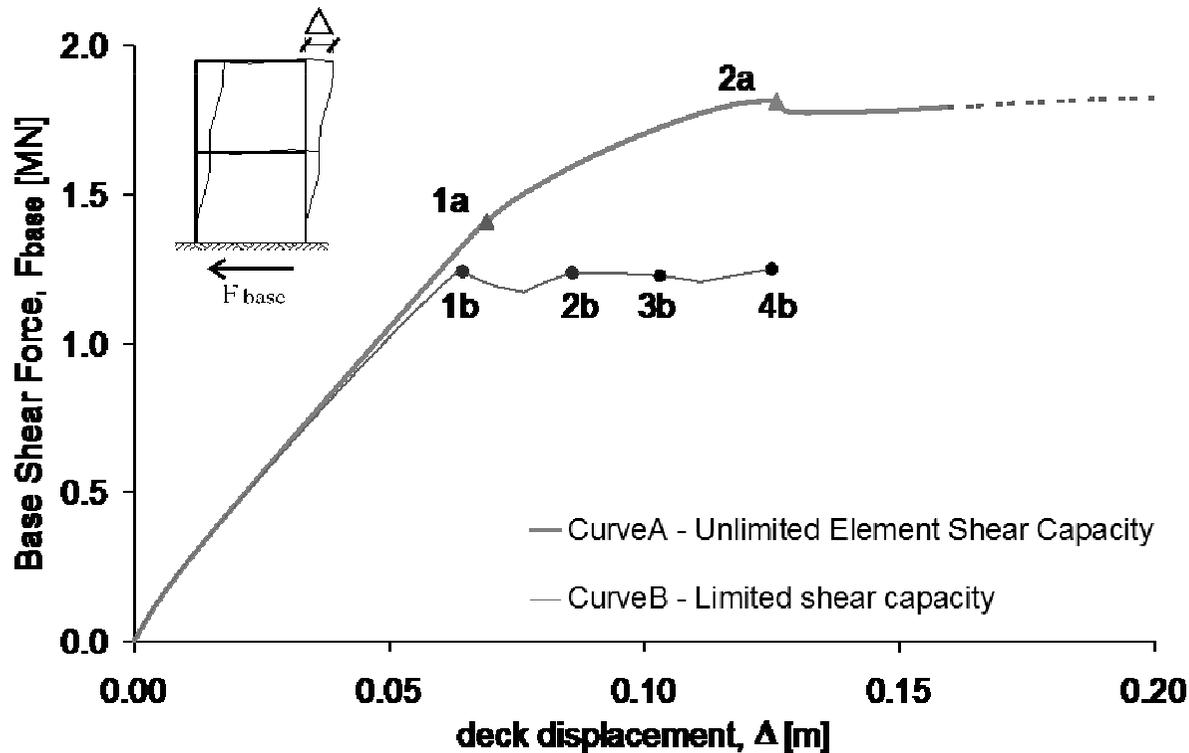
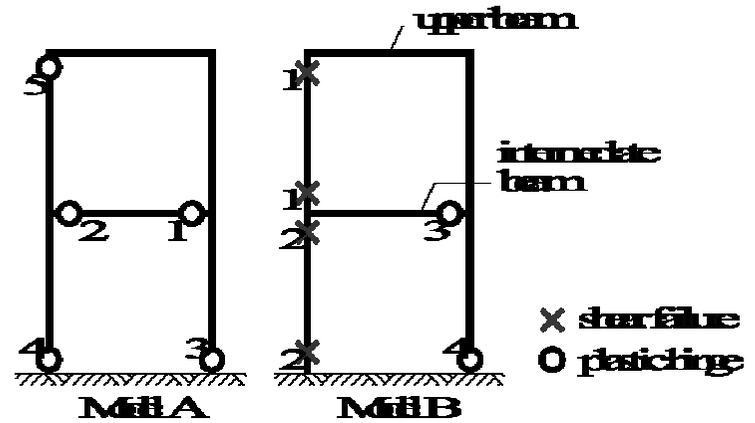
# PONTE HANSUI

## Modello Ponte



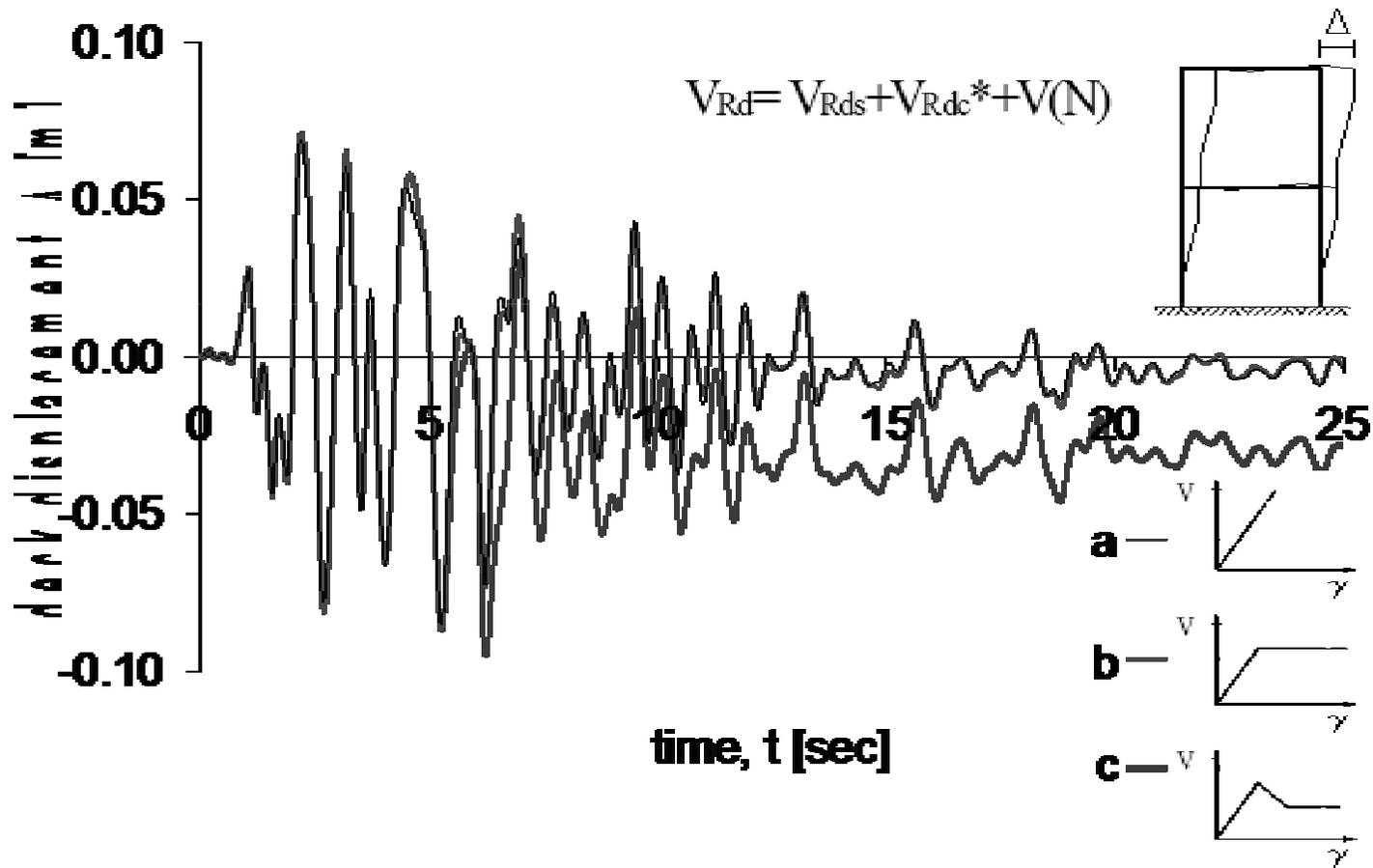
# PONTE HANSUI

## Risultati Analisi Ponte (PO)



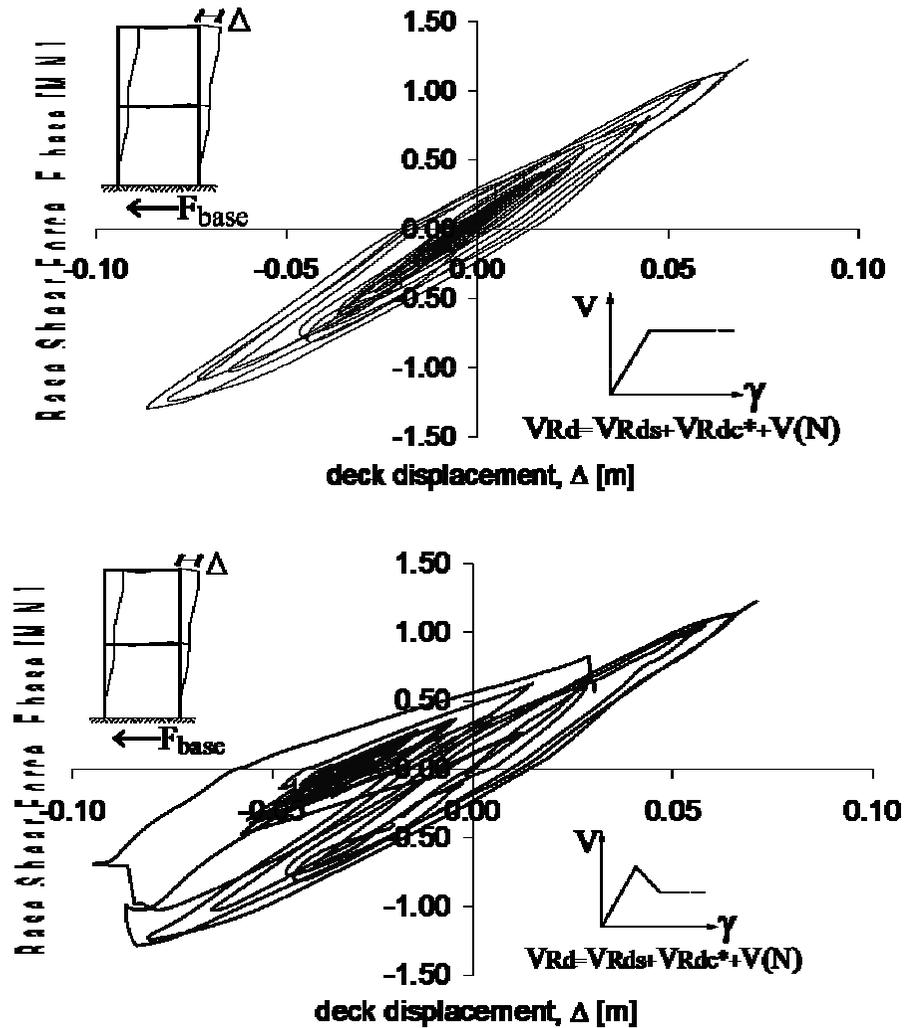
# PONTE HANSUI

## Risultati Analisi Ponte (TH terremoto Kobe)



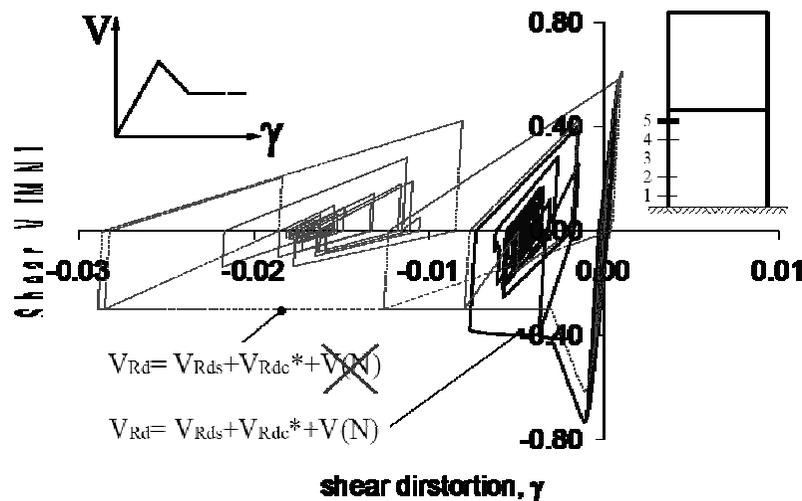
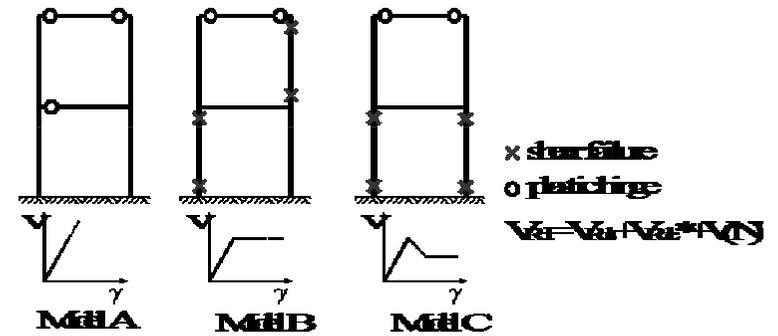
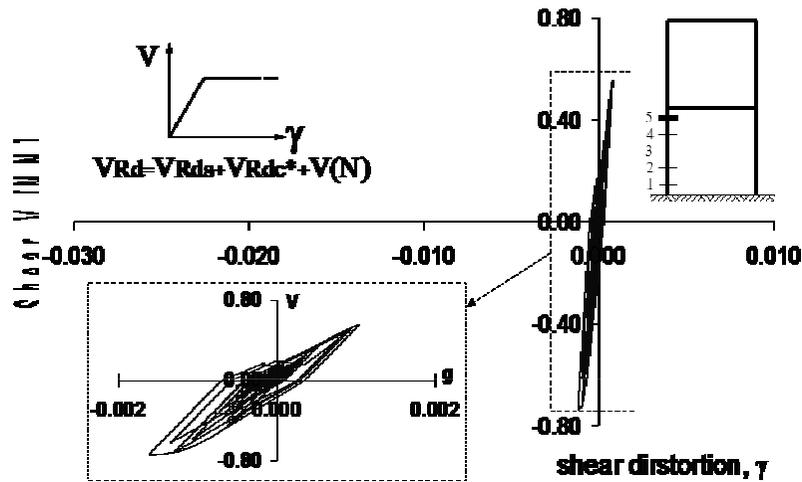
# PONTE HANSUI

## Risultati Analisi Ponte



# PONTE HANSUI

## Risultati Analisi Ponte



# CONCLUSIONI SUI TRE ESEMPI

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- Effettuare delle analisi nonlineari è oggi possibile anche sui normali PC
- PUNTO CENTRALE: scelta di un modello accurato
- In molti si domandano il perché delle analisi di PO (e quindi approssimate) piuttosto che analisi TH
- Non esistono ancora confronti completi fra PO e TH tridimensionali, con confronto critico dei risultati
- La fase di verifiche non è ancora applicativa (da norma). O ci sono programmi che specificano il raggiungimento di tutti gli SL cercati (rotture a flessione, taglio, etc.) o il controllo diventa pesante
- Servono inoltre indicazioni sul come stabilire il raggiungimento di uno SL. Per esempio, il fatto che si formi (al target displacement) una singola cerniera plastica in una trave non è un problema, mentre un meccanismo di piano è sicuramente un fatto più serio.
- Alcune normative indicano l'interstory drift come misura di controllo (sicuramente più semplice, forse meno precisa)

# SOMMARIO

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- **Edificio di Bonefro**
- **Ponte di Humbolt Bay**
- **Modellazione Taglio (Per ponti ed edifici)**
- **Esempio di modellazione ed analisi in MidasGen**
- **E-ELT Telescope**

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Carichi:

Primo e secondo Livello:

$$G_k = 3 \text{ kN/m}^2$$

$$Q_k = 2 \text{ kN/m}^2$$

Terzo Livello:

$$G_k = 6 \text{ kN/m}^2$$

$$Q_k = 4 \text{ kN/m}^2$$

## Materiali:

$$f_{ck} = 20 \text{ N/mm}^2$$

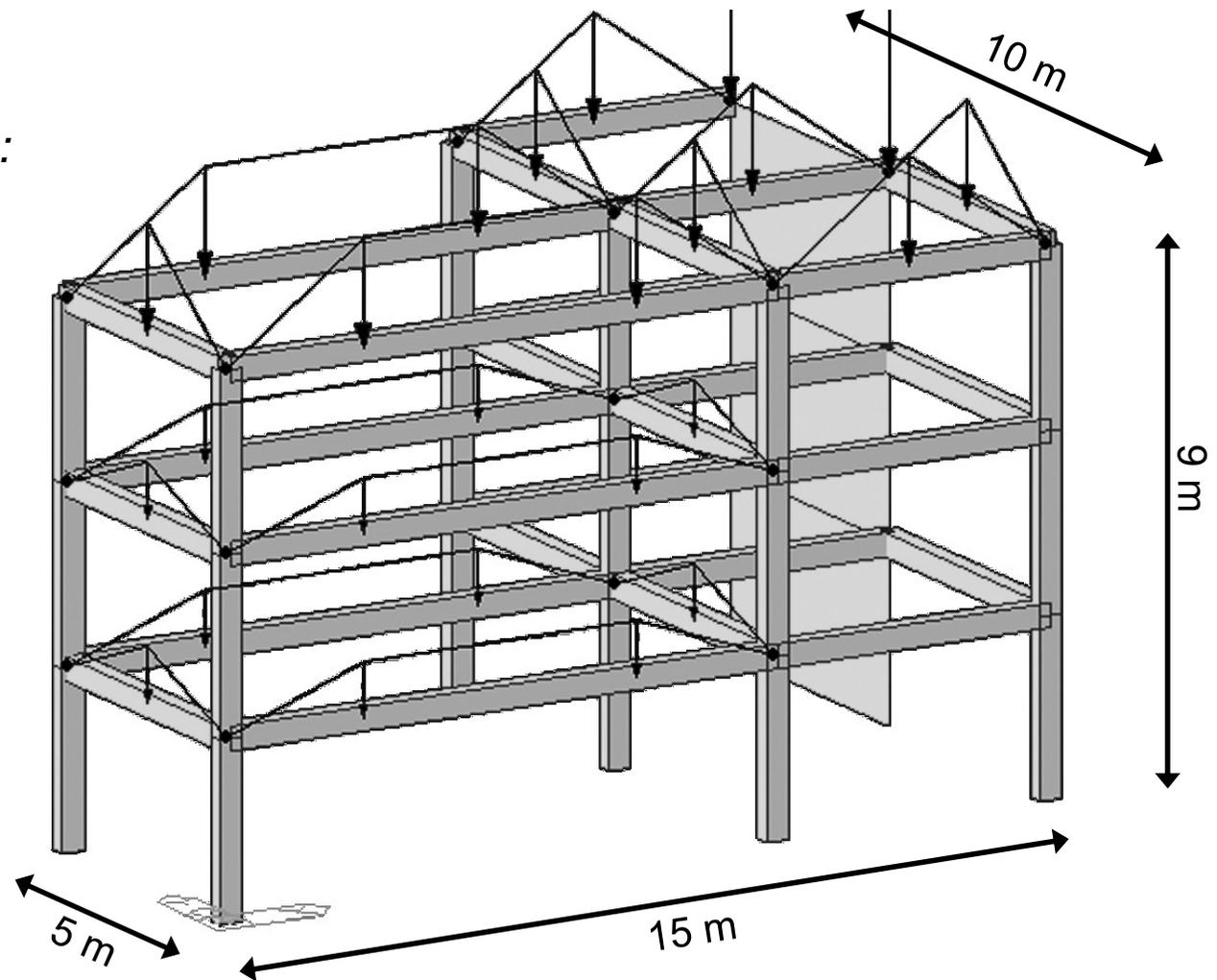
## Sezione:

Travi e Colonne:

$$b = 40 \text{ cm}$$

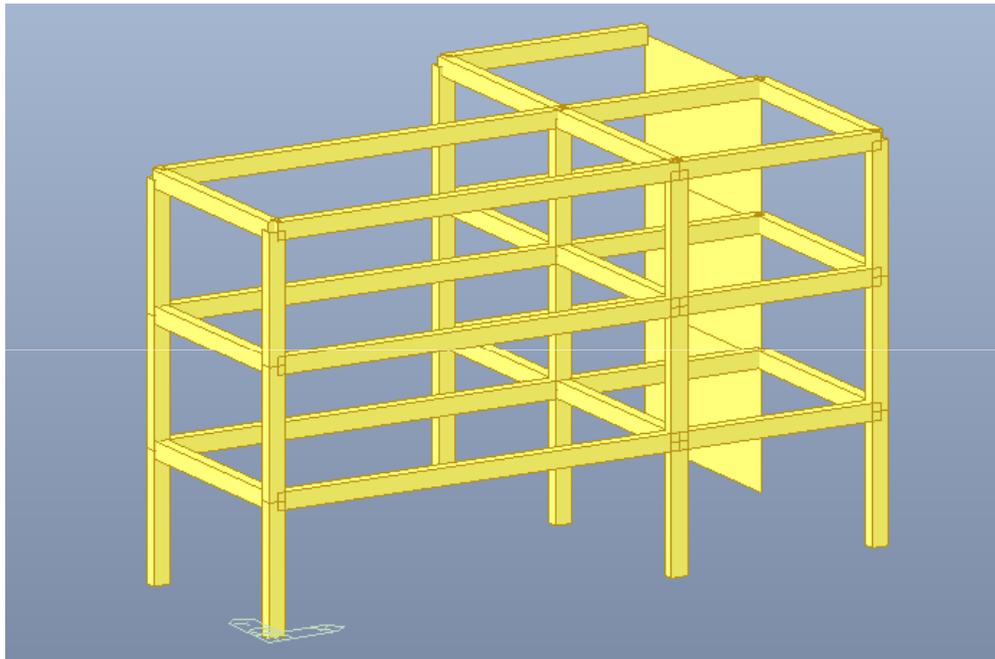
$$h = 30 \text{ cm}$$

$$\text{Wall: } s = 30 \text{ cm}$$



# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Definizione del modello lineare ed analisi modale



Mode No	Period (sec)	TRAN-X		TRAN-Y		TRAN-Z		ROTN-Z	
		MASS(%)	SUM(%)	MASS(%)	SUM(%)	MASS(%)	SUM(%)	MASS(%)	SUM(%)
1	0.6742	65.12	65.12	10.11	10.11	0.00	0.00	10.69	10.69
2	0.5977	20.39	85.51	33.24	43.35	0.00	0.00	34.18	44.87
3	0.1747	2.15	87.66	3.50	46.85	0.00	0.00	3.86	48.73
4	0.1571	9.28	96.94	0.59	47.44	0.00	0.00	0.94	49.67
5	0.1036	0.00	96.94	40.71	88.15	0.01	0.01	34.81	84.48

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 1: Selezione delle registrazioni spettro-compatibili

<http://esse1.mi.ingv.it/>



### I dati *online* della pericolosità sismica in Italia

#### Mappe dinamiche

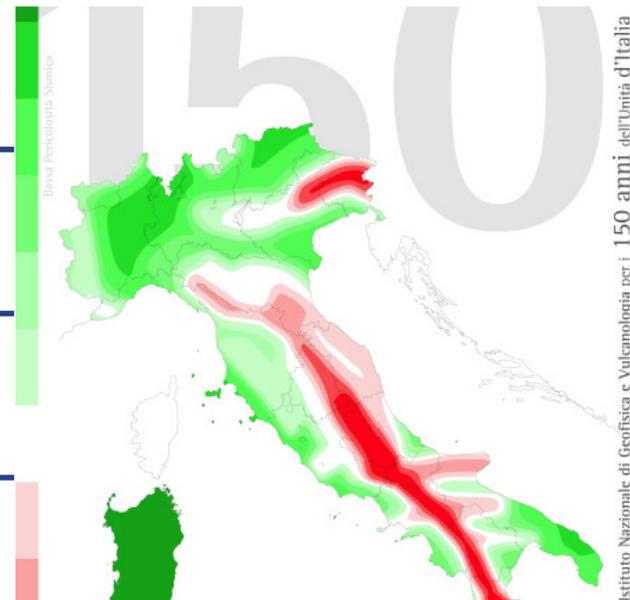
-  [Mappe interattive della pericolosità sismica \(WebGis\)](#)
-  [Interactive Maps of Seismic Hazard \(WebGis\)](#)

#### Mappe statiche e download dati

- [PGA per varie probabilità di eccedenza in 50 anni](#)
- [Accelerazioni spettrali per varie probabilità di eccedenza in 50 anni](#)

#### Norme Tecniche per le Costruzioni

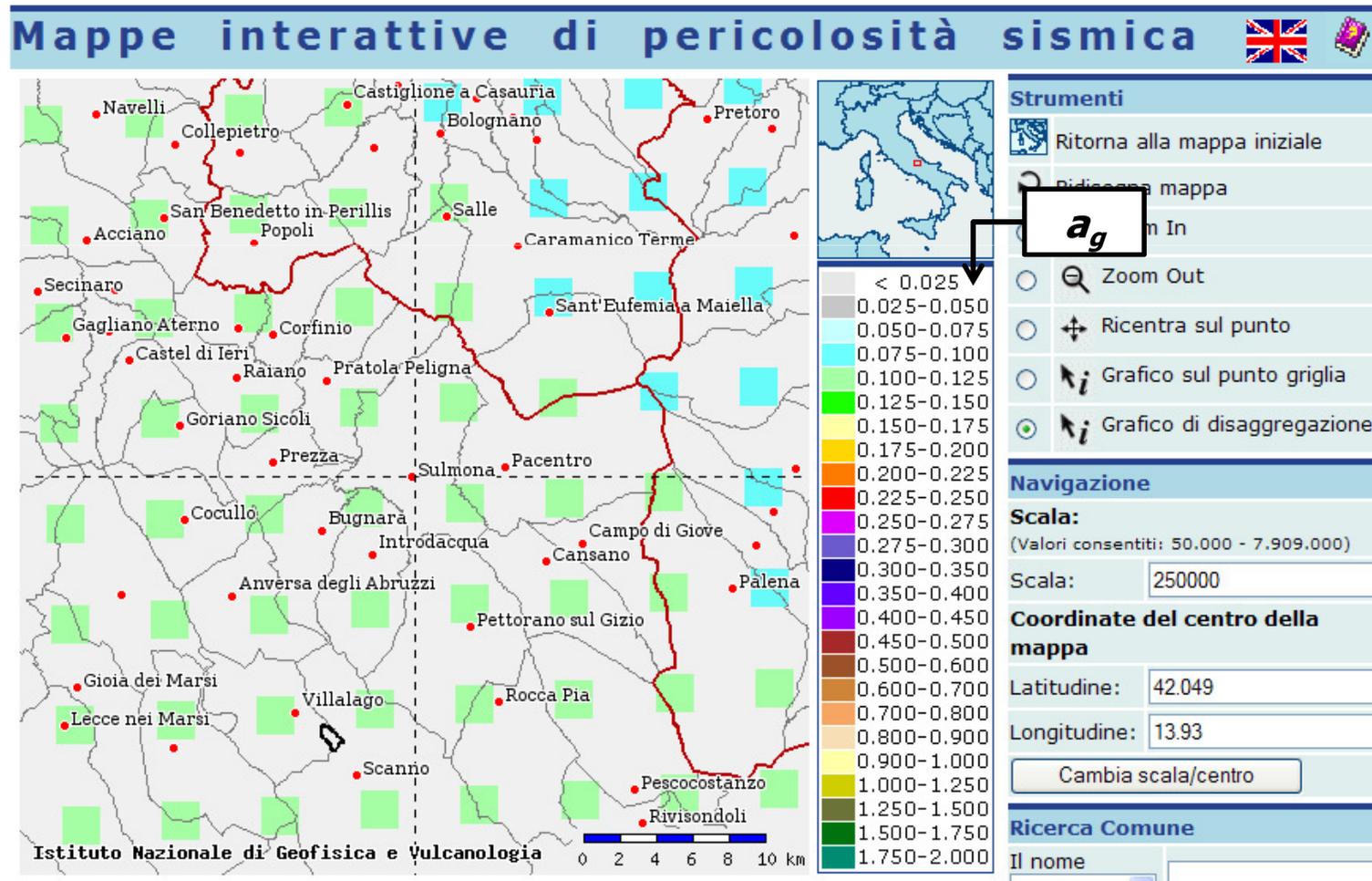
- [DM 14/01/2008 - Allegato A](#)



# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

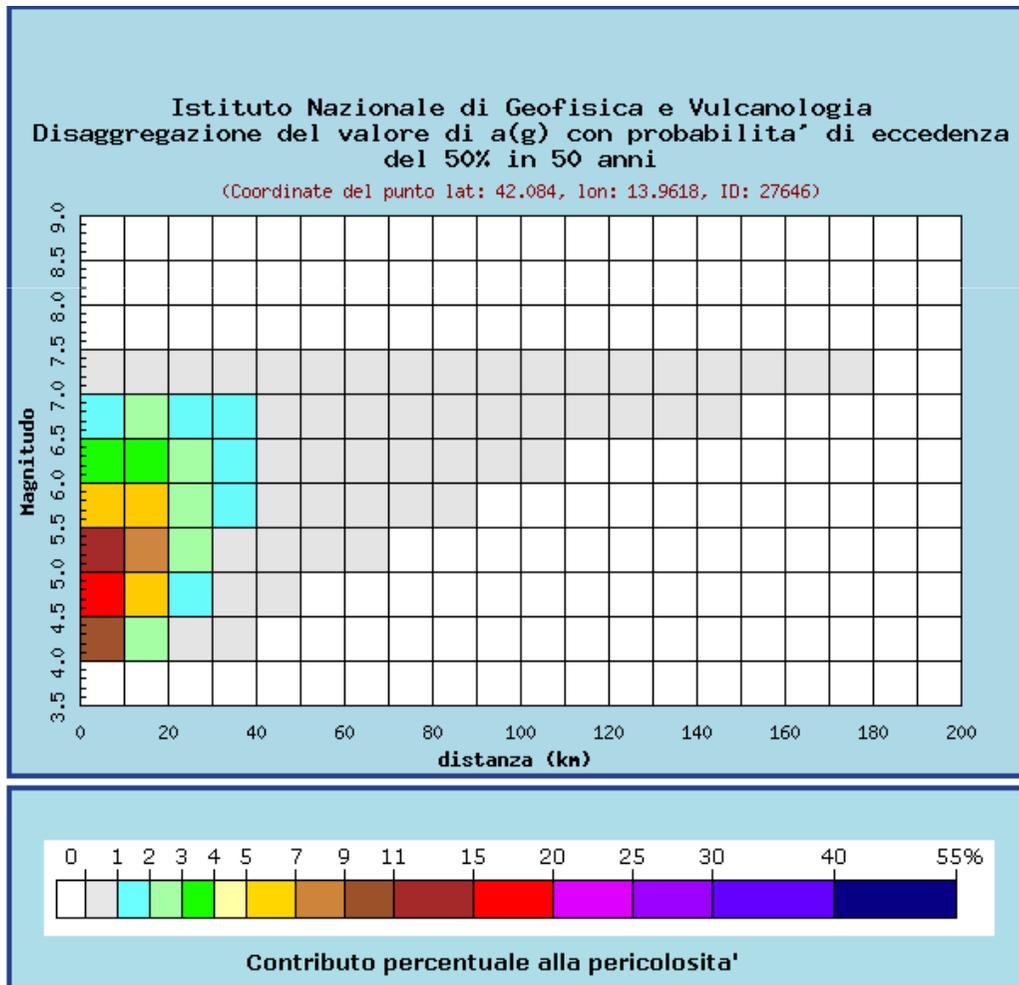
## Step 1: Selezione delle registrazioni spettro-compatibili

*Probabilità di Eccedenza 50% in 50 anni*



# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili



**Selezione da Disaggregazione della Pericolosità Sismica (Probabilità di Eccedenza 50% in 50 anni):**

$$5.5 \leq M_w \leq 6.5$$

$$0 \leq d_{ep} \leq 30 \text{ km}$$

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

$$5.5 \leq M_w \leq 6.5$$

$$0 \leq d_{ep} \leq 30 \text{ km}$$

Distanza in km	Disaggregazione del valore di a(g) con probabilita' di eccedenza del 50% in 50 anni (Coordinate del punto lat: 42.084, lon: 13.9618, ID: 27646)										
	Magnitudo										
	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0	8.0-8.5	8.5-9.0
0-10	0.000	9.320	18.600	11.800	6.440	3.120	1.350	0.443	0.000	0.000	0.000
10-20	0.000	2.310	6.830	7.040	5.840	3.910	2.000	0.784	0.000	0.000	0.000
20-30	0.000	0.211	1.300	2.260	2.720	2.470	1.590	0.770	0.000	0.000	0.000
30-40	0.000	0.001	0.114	0.600	1.070	1.280	1.070	0.619	0.000	0.000	0.000
40-50	0.000	0.000	0.001	0.092	0.372	0.594	0.646	0.435	0.000	0.000	0.000
50-60	0.000	0.000	0.000	0.005	0.112	0.266	0.358	0.278	0.000	0.000	0.000
60-70	0.000	0.000	0.000	0.000	0.026	0.123	0.208	0.184	0.000	0.000	0.000
70-80	0.000	0.000	0.000	0.000	0.004	0.044	0.100	0.100	0.000	0.000	0.000
80-90	0.000	0.000	0.000	0.000	0.001	0.015	0.056	0.062	0.000	0.000	0.000
90-100	0.000	0.000	0.000	0.000	0.000	0.004	0.030	0.038	0.000	0.000	0.000

**Selezione da Disaggregazione della Pericolosità Sismica (Probabilità di Eccedenza 50% in 50 anni)**

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

**1. Target Spectrum**

Italian Building Code 2008

ag [g] 0.17

Longitude [°] 13.93

Latitude [°] 42.049

Map

Site class EC8 A

Topographic category T1

Nominal life 50 yea...

Functional type II

Limit state SLV (...)

Horizontal  Vertical

Disaggregation for (Italian sites only) Sa(T = ...)

**2. Preliminary database search**

Based on M, R

M minimum 6 M maximum 7

R minimum [km] 0 R maximum [km] 30

T [s] 1 Epsilon minimum -3 Epsilon maximum 3

Database European Strong-motion Data...

Site class Same as target spectrum

**3. Spectrum matching**

Lower tolerance [%] 10

Upper tolerance [%] 30

T1 [s] 0.15

T2 [s] 2

Plot spectral bounds

**4. Analysis options**

Scaled records  (PGA-normalized records' search)

I'm feeling lucky  (Returns only the first combination found)

Set size

Individual record

7 records

30 records

1 component

2 components

3 components

Build code spectrum User-defined spectrum

Look at disaggregation ID conditional hazard

NEW SEARCH EXIT

Iervolino I., Galasso C., Cosenza E., REXEL: computer aided record selection for code-based seismic structural analysis, Bull Earthquake Eng (2010) 8:339–362

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

The screenshot displays the REXEL v 3.3 (beta) software interface. The 'Mappa' window is open, showing a map of Italy with a selected site marked by a yellow star at longitude 13.93° and latitude 42.049°. The main interface includes sections for '1. Target Spectrum' (Italian Building Code 2008) and '2. Preliminary database search' with various search parameters like M minimum, R minimum, T [s], and Database. A 'Map' button is visible between the two sections.

Definizione del sito selezionato mediante latitudine e longitudine

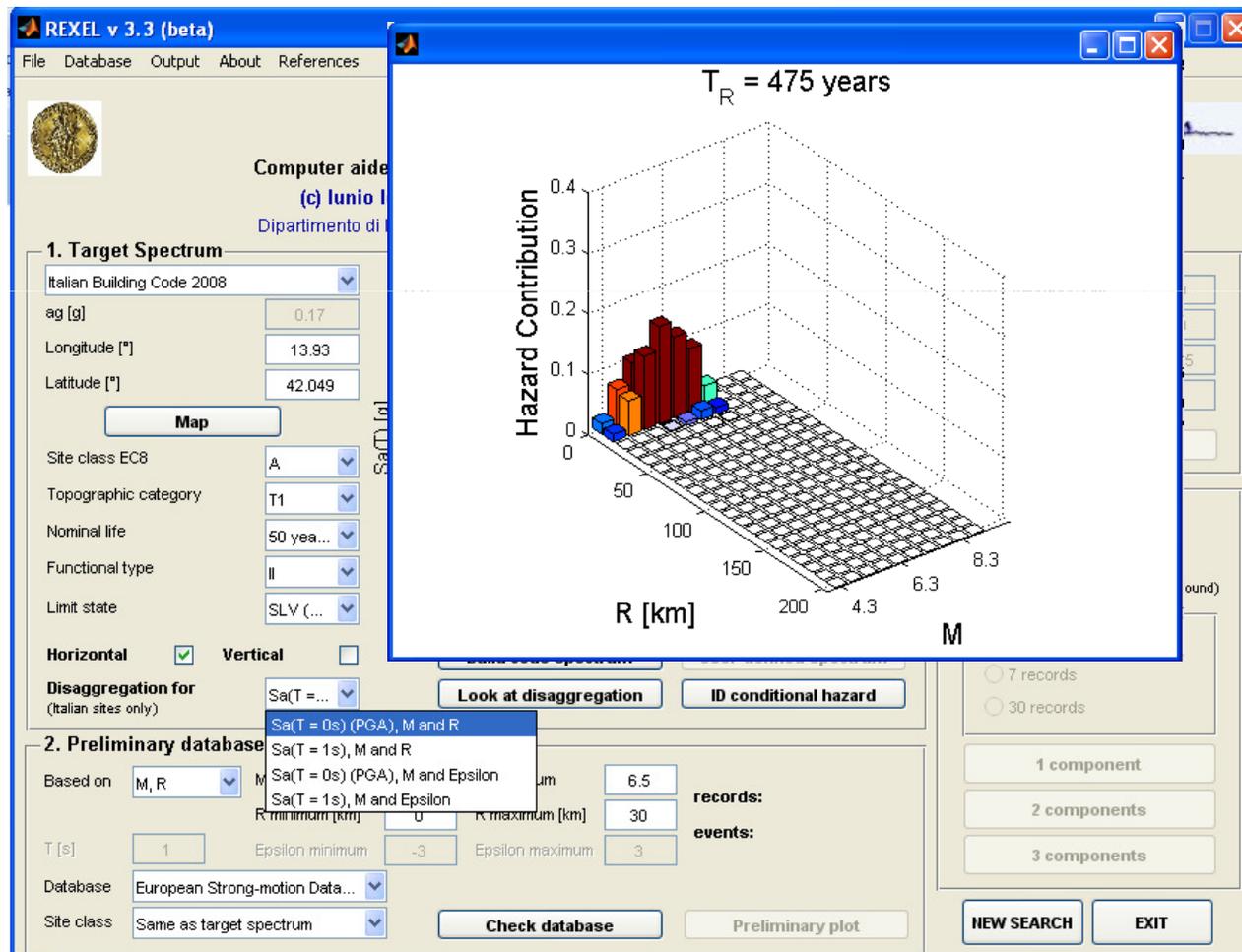
# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

Definizione dello spettro di risposta elastico NTC2008 (target spectrum) in funzione del sito selezionato

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili



Visualizzazione dell'analisi di disaggregazione in PGA per magnitudo M e distanza epicentrale R

Epsilon is defined as a measure of the difference between the spectral acceleration of a record and the mean of a ground motion prediction equation at the given period

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

The screenshot displays the REXEL v 3.3 (beta) software interface. The main window is titled "REXEL v 3.3 (beta)" and includes a menu bar (File, Database, Output, About, References) and a logo for "reluis". The interface is divided into several sections:

- 1. Target Spectrum:** Includes input fields for "Italian Building Code 2008", "ag [g]" (0.17), "Longitude [°]" (13.93), "Latitude [°]" (42.049), "Site class EC8" (A), "Topographic category" (T1), "Nominal life" (50 yea...), "Functional type" (II), and "Limit state" (SLV (...)). It also has checkboxes for "Horizontal" (checked) and "Vertical", and a "Disaggregation for" dropdown. A central graph shows the "Acceleration elastic response spectrum" with a blue curve for "horizontal component,  $T_p = 475$  years,  $\xi = 5\%$ ".
- 2. Preliminary database search:** Features a dropdown for "Based on" (M, R), input fields for "M minimum" (5.5), "M maximum" (6.5), "R minimum [km]" (0), "R maximum [km]" (30), "T [s]" (1), "Epsilon minimum" (-3), and "Epsilon maximum" (3). It also includes a "Database" dropdown (European Strong-motion Data...) and a "Site class" dropdown (Same as target spectrum). A blue arrow points from the "Based on" dropdown to the search results.
- 3. Spectrum matching:** Includes input fields for "Lower tolerance [%]" (10), "Upper tolerance [%]" (30), "T1 [s]" (0.15), and "T2 [s]" (2). A "Plot spectral bounds" button is present.
- 4. Analysis options:** Includes checkboxes for "Scaled records" (checked) and "I'm feeling lucky" (checked), and a "Set size" dropdown with options for "Individual record" and "7 records".

At the bottom right, a summary box shows "records: 2x 65" and "events: 29". A blue arrow points from the search results area to this summary box. The interface also includes buttons for "Build code spectrum", "User-defined spectrum", "Look at disaggregation", "ID conditional based", "Check database", and "Preliminary plot".

Determinazione della coppia M, R per effettuare la selezione e verifica del numero di records con tali caratteristiche contenuti nel database

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

The screenshot displays the REXEL v 3.3 (beta) software interface, which is used for seismic record selection. The main window is titled "REXEL v 3.3 (beta)" and includes a menu bar (File, Database, Output, About, References) and a toolbar. The interface is divided into several sections:

- 1. Target Spectrum:** This section allows users to define a target spectrum based on the Italian Building Code 2008. It includes input fields for  $ag$  [g] (0.17), Longitude [°] (13.93), and Latitude [°] (42.049). A "Map" button is provided. Other parameters include Site class EC8 (A), Topographic category (T1), Nominal life (50 years), Functional type (II), and Limit state (SLV). There are checkboxes for "Horizontal" (checked) and "Vertical" (unchecked), and a "Disaggregation for" dropdown set to "Sa(T=...)". Buttons for "Build code spectrum", "User-defined spectrum", "Look at disaggregation", and "ID conditional hazard" are visible.
- 2. Preliminary database search:** This section allows users to search for records based on magnitude (M) and distance (R) criteria. The search is based on "M, R" with M minimum 5.5 and M maximum 6.5, R minimum 0 km and R maximum 30 km. The search results show 2x 65 records and 29 events. A large blue arrow points from the "events" count to the "Preliminary plot" button. Other search parameters include T [s] (1), Epsilon minimum (-3), and Epsilon maximum (3). The database is set to "European Strong-motion Data..." and the site class is "Same as target spectrum". Buttons for "Check database" and "Preliminary plot" are present.
- Preliminary plots:** Two plots are shown on the right side of the interface. The top plot is titled "Preliminary plot of horizontal unscaled spectra" and shows  $Sa(T)$  [g] versus  $T$  [s]. It displays multiple individual spectra (grey lines) and a thick black line representing the "Average spectrum", along with a dashed black line for the "Target spectrum". The bottom plot is titled "Preliminary plot of horizontal non-dimensional spectra;  $SF_{mean} = 4.6143$ " and shows  $Sa(T)/PGA$  versus  $T$  [s]. It also displays individual spectra (grey lines), an "Average spectrum" (thick black line), and a "Target spectrum" (dashed black line).
- Component Selection:** A panel on the right side of the interface allows users to select the number of components for the analysis. It includes a radio button for "30 records" and three buttons for "1 component", "2 components", and "3 components". Below these are "NEW SEARCH" and "EXIT" buttons.

Andamento delle registrazioni selezionate in funzione di M ed R

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## **Step 0: Selezione delle registrazioni spettro-compatibili**

### NTC2008; 3.2.3.6 Impiego di accelerogrammi

L'ordinata spettrale media non deve presentare uno scarto in difetto superiore al 10%, rispetto alla corrispondente componente dello spettro elastico, in alcun punto del maggiore tra gli intervalli  $0,15s \div 2,0s$  e  $0,15s \div 2T$ , in cui  $T$  è il periodo fondamentale di vibrazione della struttura in campo elastico, per le verifiche agli stati limite ultimi

$$T_1 = 0.67s$$

$$2T_1 = 1.34s$$

$$\max \{0.15s \div 2.0s; 0.15s \div 2.0T_1\}$$

$$\max \{0.15s \div 2.0s; 0.15s \div 1.34s\} = 0.15s \div 2.0s$$

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

Definizione dei parametri di coerenza spettrale e selezione delle opzioni di analisi (registrazioni NON scalate; 2 componenti)

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

REXEL v 3.3 (beta)

Computer aided code-based real record selection for seismic analysis of structures  
(c) Iunio Iervolino, Carmine Galasso and Eugenio Chioccarelli, 2008-2011  
Dipartimento di Ingegneria Strutturale, Università degli Studi di Napoli Federico II, Naples, Italy.

### 1. Target Spectrum

Italian Building Code 2008

ag [g] 0.17

Longitude [°] 13.93

Latitude [°] 42.049

Site class EC8 A

Topographic category T1

Nominal life 50 yea...

Functional type II

Limit state SLV (...)

Horizontal  Vertical

Disaggregation for (Italian sites only) Sa(T = ...)

### 2. Preliminary database search

Based on M, R M minimum 5.5 M maximum 6.5 records: 2x 65

R minimum [km] 0 R maximum [km] 30 events: 29

T [s] 1 Epsilon minimum -3 Epsilon maximum 3

Database European Strong-motion Data...

Site class Same as target spectrum

### 3. Spectrum matching

Lower tolerance [%] 10

Upper tolerance [%] 10

T1 [s] 0.15

T2 [s] 2

### 4. Analysis options

Scaled records (PGA-normalized records' search)

I'm feeling lucky

Set size

Individual record

7 records

30 records

1 component

2 components

3 components

NEW SEARCH EXIT

Build code spectrum User-defined spectrum

Look at disaggregation ID conditional hazard

Plot spectral bounds

Acceleration elastic response spectrum

horizontal component,  $T_R = 475$  years,  $\xi = 5\%$

Sa(T) [g]

T [s]

Ricerca  
accelerogrammi  
SCALATI  
(normalizzati  
alla PGA)

Maximum number of compatible sets to find:  
100000

Maximum mean scale factor:  
2

OK Cancel

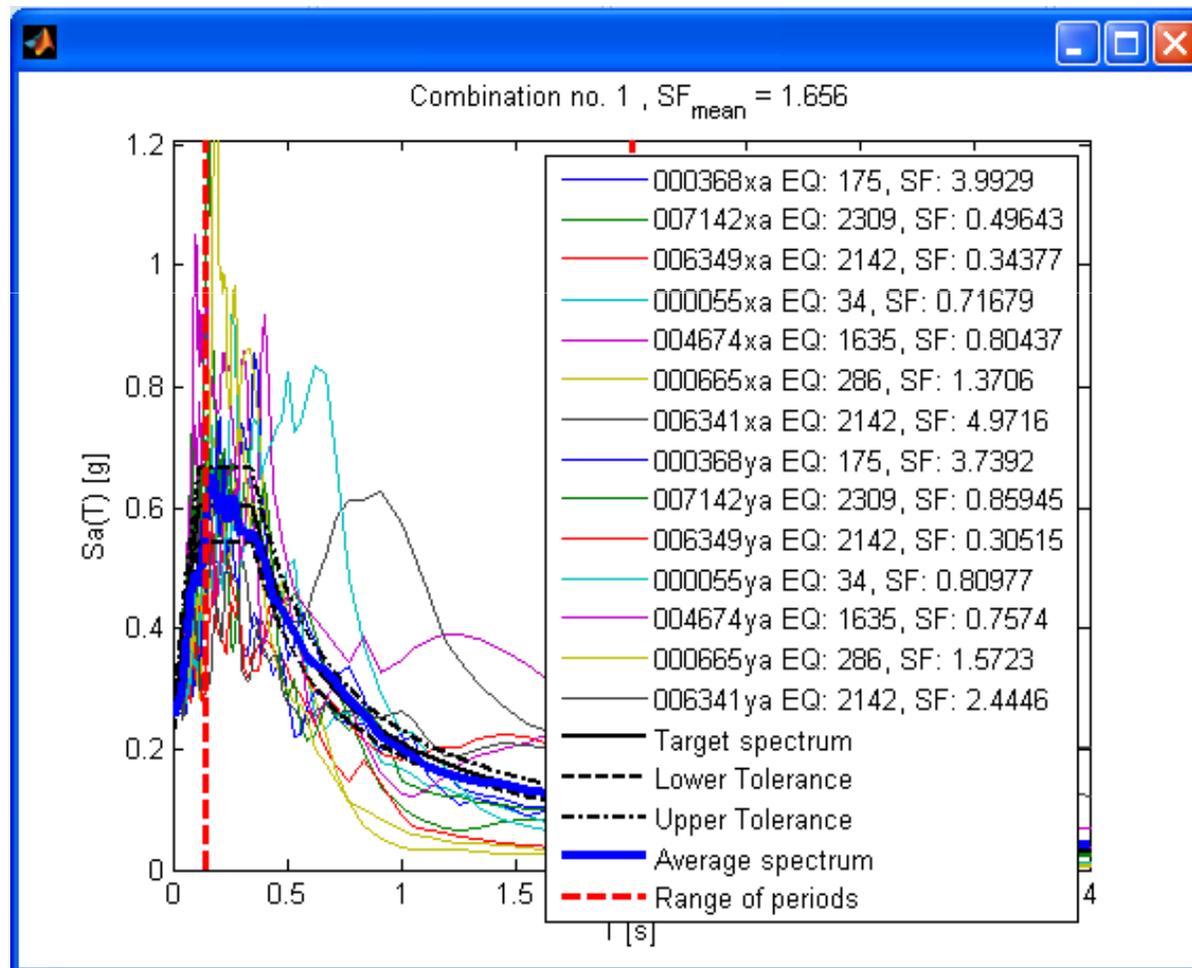
Result

73 compatible sets found

OK

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili



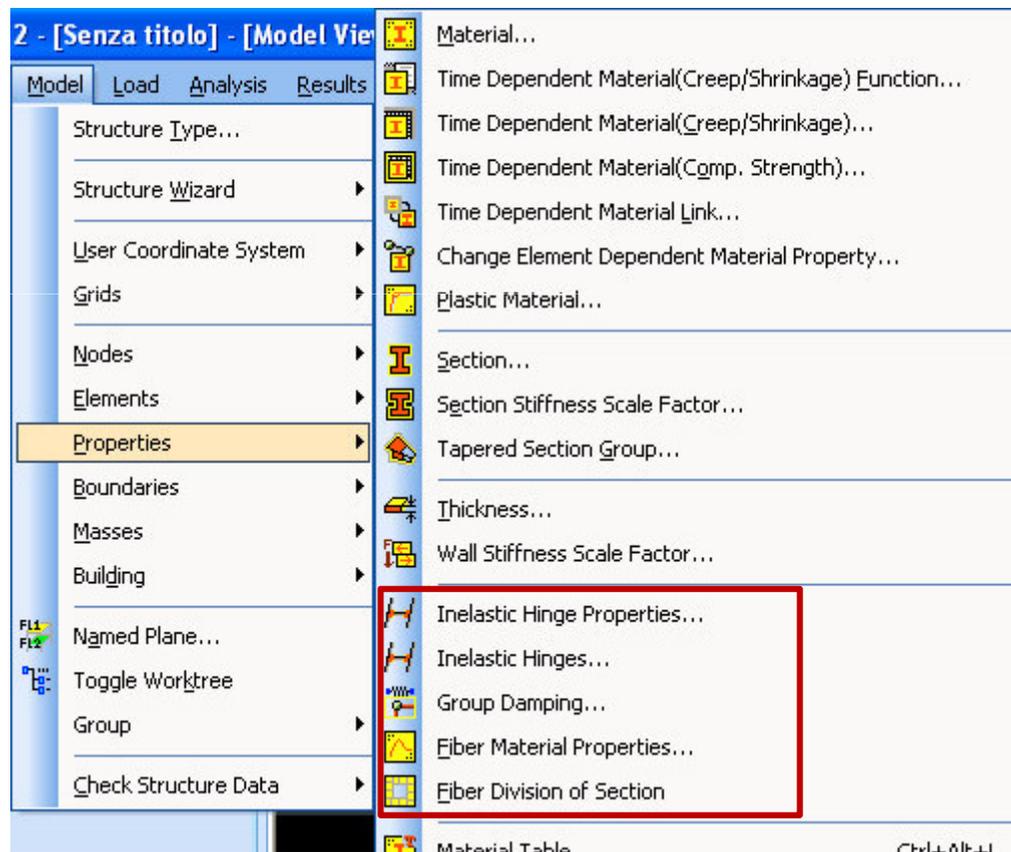
# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 0: Selezione delle registrazioni spettro-compatibili

Waveform ID	Earthquake ID	Station ID	Earthquake Name	Date	Mw	Fault Mechanism	Epicentral Distance [km]	PGA_X [m/s <sup>2</sup> ]	PGA_Y [m/s <sup>2</sup> ]	EC8 Site class
368	175	ST143	Lazio Abruzzo	07/05/1984	5.9	normal	22	0.628	0.6706	0.2564
7142	2309	ST539	Bingol South	01/05/2003	6.3	strike slip	14	5.0514	2.9178	4.427
6349	2142	ST2558	Iceland (aftershock)	21/06/2000	6.4	strike slip	5	7.2947	8.218	4.1405
55	34	ST20	Friuli	06/05/1976	6.5	thrust	23	3.4985	3.0968	2.6227
4674	1635	ST2486	South Iceland	17/06/2000	6.5	strike slip	5	3.1176	3.3109	2.6815
665	286	ST238	Umbria Marche	26/09/1997	6	normal	21	1.8296	1.5949	0.7392
6341	2142	ST2497	South Iceland (aftershock)	21/06/2000	6.4	strike slip	20	0.5044	1.0258	0.393
<b>mean:</b>					<b>6.29</b>		<b>15.71</b>	<b>3.13</b>	<b>2.98</b>	<b>2.18</b>

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

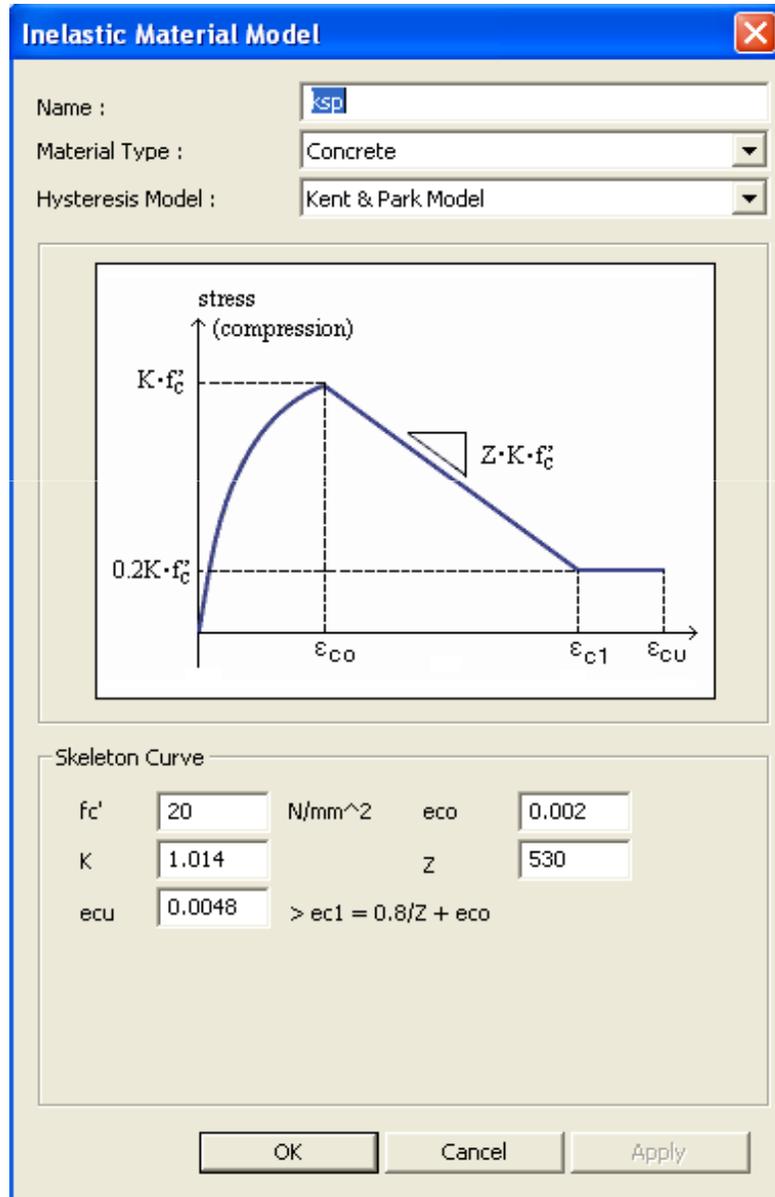
## Step 2: Definizione del modello non lineare



Lista dei comandi per operare con il modello a fibre

*Model > Properties > Fiber Material Properties*

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN



## Step 2: Definizione dei materiali a comportamento non lineare

Il modello di Kent e Park (1973) e in seguito esteso da Scott et al. (1982) è definito come segue:

$$\text{per } \epsilon_c \leq \epsilon_0 \quad \sigma_c = K f'_c \left[ 2 \left( \frac{\epsilon_c}{\epsilon_0} \right) - \left( \frac{\epsilon_c}{\epsilon_0} \right)^2 \right]$$

$$\text{per } \epsilon_0 \leq \epsilon_c \leq \epsilon_u \quad \sigma_c = K f'_c [1 - Z (\epsilon_c - \epsilon_0)] \geq 0.2 K f'_c$$

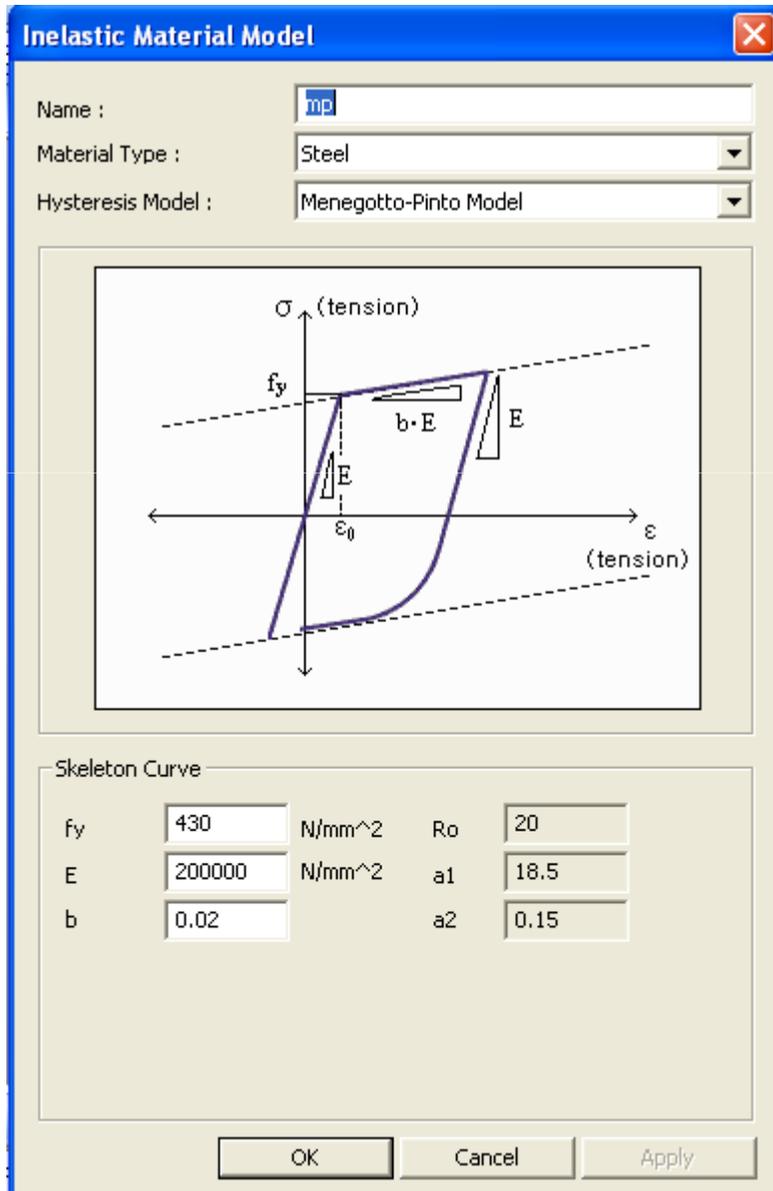
$$\epsilon_0 = 0.002 K$$

$$K = 1 + \frac{\rho_s f_{yh}}{f'_c}$$

$$Z = \frac{0.5}{\frac{3 + 0.29 f'_c}{145 f'_c - 1000} + 0.75 \rho_s \sqrt{\frac{h'}{s_h}} - 0.002 K}$$

Model > Properties > Fiber Material Properties <sup>119</sup>

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN



## Step 2: Definizione dei materiali a comportamento non lineare

Il legame costitutivo Menegotto-Pinto è espresso da questa relazione

$$\sigma^* = b \varepsilon^* + \frac{(1-b) \varepsilon^*}{(1 + \varepsilon^{*R})^{1/R}}$$

dove:

$$\varepsilon^* = \frac{\varepsilon - \varepsilon_r}{\varepsilon_0 - \varepsilon_r}$$

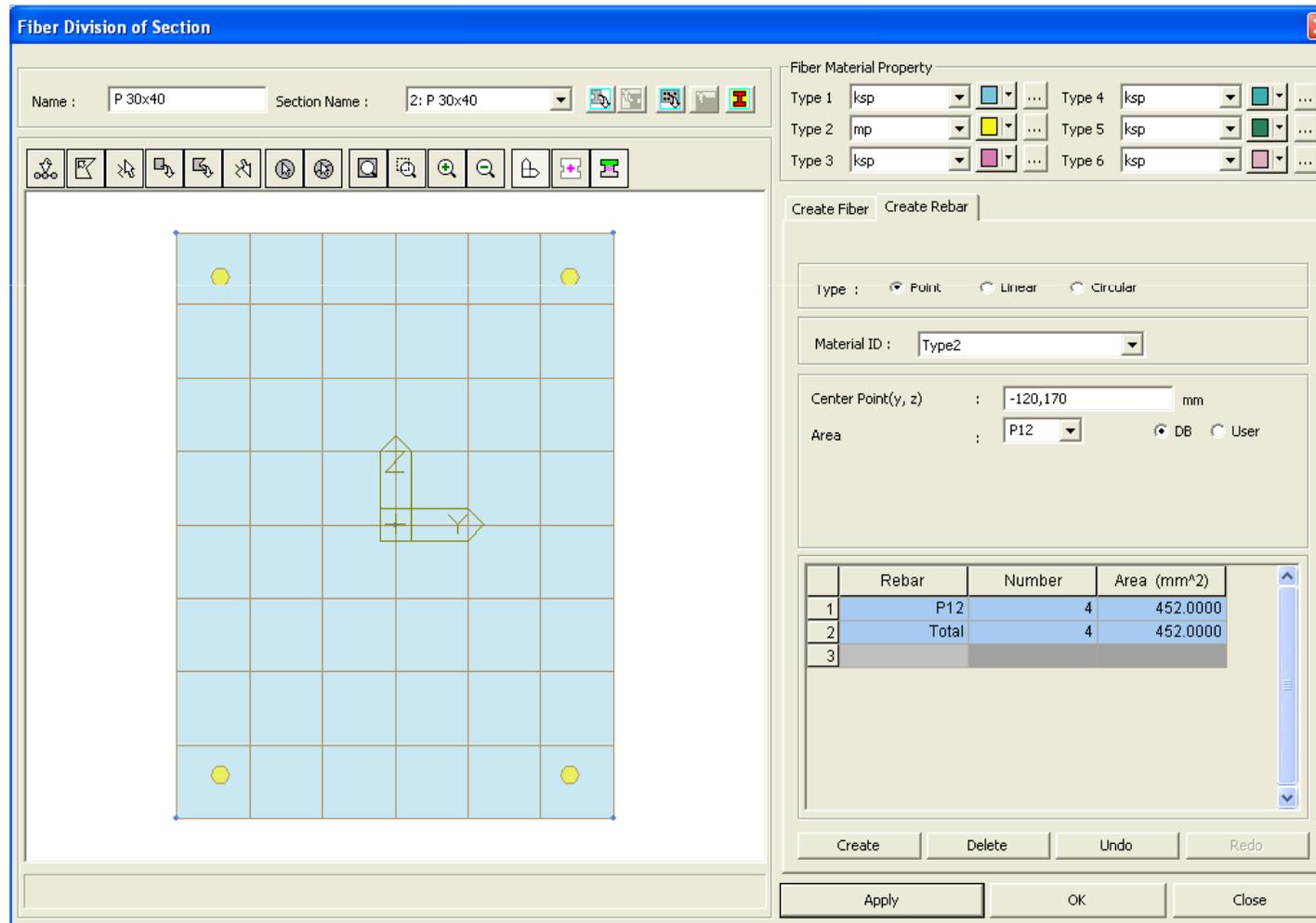
$$\sigma^* = \frac{\sigma - \sigma_r}{\sigma_0 - \sigma_r}$$

$$R = R_0 - \frac{a_1 \xi}{a_2 + \xi}$$

Model > Properties > Fiber Material Properties <sup>120</sup>

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 3: Definizione della geometria delle sezioni a fibre



*Model >  
Properties >  
Fiber Division of  
Section*

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 4: Definizione e assegnazione delle sezioni a fibre

*Model > Properties > Define Inelastic Hinge Properties*

*Model > Properties > Inelastic Hinge*

The image displays two overlapping dialog boxes from the MIDASGEN software. The background dialog is 'Assign Inelastic Hinges', and the foreground dialog is 'Add/Modify Inelastic Hinge Properties'.

**Assign Inelastic Hinges Dialog:**

- Option:  Add / Replace,  Delete
- Element Type:  Truss,  Beam,  Wall
- Inelastic Hinge Property: P 30x40
- Material: [Empty]
- Member Type: [Empty]
- Element Position: [Empty]
- Section: [Empty]

**Add/Modify Inelastic Hinge Properties Dialog:**

- Name: P 30x40
- Description: [Empty]
- Yield Strength(Surface) Calculation Method:  User Input,  Auto-Calculation
- Type:  Beam-Column,  Lumped,  Distributed,  Spring,  Truss
- Definition:  Skeleton,  Fiber
- Interaction Type:  None,  P-M in Strength Calculation,  P-M-M in Status Determination
- Material Type:  Steel,  RC
  - SRC(filled)
  - SRC(encased)
  - User Defined
- Code: AISC
- Name: [Empty]
- Member Type:  Beam,  Column,  Brace
- Element Position:  I,  M,  J
- Section Name: [Empty]
- Component Properties Table:

Component	No. of Sections	Hysteresis Model	Properties...
<input checked="" type="checkbox"/> Fx	4	Kinematic Hardening	Properties...
<input type="checkbox"/> Fy	3	Kinematic Hardening	Properties...
<input type="checkbox"/> Fz	3	Kinematic Hardening	Properties...
<input type="checkbox"/> Mx	3	Kinematic Hardening	Properties...
<input checked="" type="checkbox"/> My	4	Kinematic Hardening	Properties...
<input checked="" type="checkbox"/> Mz	4	Kinematic Hardening	Properties...
- Yield Surface Properties...: [Empty]
- Fiber Name: P 30x40

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 5: Definizione dei casi di carico Time History

Si definisce un caso di carico per ogni registrazione (non per ciascuna componente!!!!)

**Add/Modify Time History Load Cases**

General  
Name : TH\_1 Description :  
Analysis Type :  Linear  Nonlinear  
Analysis Method :  Modal  Direct Integration  Static  
Time History Type :  Transient  Periodic  
End Time : 30 sec Time Increment : 0.01 sec  
Step Number Increment for Output : 1

Order in Sequential Loading  
 Subsequent to  Initial Element Forces(Table)  
Load Case : ST : TOT  
 Cumulate D/V/A Results  Keep Final Step Loads Constant

Damping  
Damping Method : Mass & Stiffness Proportional  
Mass and Stiffness Coefficients  
Damping Type :  Direct Specification : 0  Calculate from Modal Damping : 0.29684339527  
Mass Proportional :  0 Stiffness Proportional :  0.0030226907E  
Coefficients Calculation  
 Frequency [Hz] : Mode 1: 0 Mode 2: 0  
 Period [sec] : Mode 1: 0.67 Mode 2: 0.6  
Damping Ratio : Mode 1: 0.03 Mode 2: 0.03  
Show Damping Ratio ...

Time Integration Parameters  
Newmark Method : Gamma 0.5 Beta 0.25  
 Constant Acceleration  Linear Acceleration  User Input

Nonlinear Analysis Control Parameters  
 Perform Iteration Iteration Controls...  
Damping Matrix Update :  No  Yes

OK Cancel Apply

*Load > Time History Analysis Data > Time History Load Cases*

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 5: Inserimento delle funzioni time-history

The main dialog box, titled "Add/Modify/Show Time History Functions", contains the following elements:

- Function Name:** TH\_1X
- Time Function Data Type:** Acceleration (selected), Normalized Accel., Force, Moment, Normal.
- Scale Factor:** Scale Factor (selected) with value 0.716, Maximum Value with value 0 mm/sec^2.
- Gravity:** 9806 mm/sec^2
- Graph Options:** X-axis log scale, Y-axis log scale, F.F.T (all unchecked).
- Buttons:** Import, Earthquake, Heel Drop.
- Table:**

	Time (sec)	Function (mm/sec^2)
1	0.0000	0.0049
2	0.0100	0.0135
3	0.0200	0.0208
4	0.0300	0.0148
5	0.0400	0.0009
6	0.0500	-0.0048
7	0.0600	0.0042
8	0.0700	-0.0034
9	0.0800	-0.0501
10	0.0900	-0.1092
11	0.1000	-0.1285
12	0.1100	-0.0979
13	0.1200	-0.0514
14	0.1300	-0.0130

The graph shows a red line representing the time history data, with a peak around 0.04 seconds and a trough around 0.10 seconds. The Y-axis is labeled "Time History Data" and ranges from -3 to 4. The X-axis is labeled "Time" and ranges from 0 to 12.

The smaller dialog box, titled "Time History Functions", contains a table with the following data:

Forcing Function	Function Type	Data Type
TH_1X	Time	Accel

Buttons on the right side of the smaller dialog box include: Add Time Function, Add Sinusoidal, Modify/Show, Delete, and Close.

*Load > Time History Analysis Data > Time Forcing Functions*

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 5: Inserimento delle funzioni time-history

**Add/Modify/Show Time History Functions**

Function Name: TH\_1Y

Time Function Data Type:  Normalized Accel.  Acceleration  Force  Moment  Normal

Scale Factor:  Scale Factor: 0.716  Maximum Value: 0 mm/sec<sup>2</sup>

Gravity: 9806 mm/sec<sup>2</sup>

Graph Options:  X-axis log scale  Y-axis log scale  F.F.T

	Time (sec)	Function (mm/sec <sup>2</sup> )
1	0.0000	-0.0038
2	0.0100	-0.0102
3	0.0200	-0.0160
4	0.0300	-0.0133
5	0.0400	-0.0028
6	0.0500	0.0078
7	0.0600	0.0048
8	0.0700	-0.0102
9	0.0800	-0.0173
10	0.0900	-0.0017
11	0.1000	0.0205
12	0.1100	0.0194
13	0.1200	-0.0056
14	0.1300	-0.0224

Description:

Generate Earthquake Response Spectrum...

OK Cancel Apply

*Load > Time History Analysis Data > Time Forcing Functions*

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 6: Definizione delle componenti che costituiscono la registrazione

Time History Analysis Data

Ground Acceleration

Time History Load Case Name  
TH\_1

Function for Direction-X  
Function Name : TH\_1X  
Scale Factor : 1  
Arrival Time : 0 sec

Function for Direction-Y  
Function Name : TH\_1Y  
Scale Factor : 1  
Arrival Time : 0 sec

Function for Direction-Z  
Function Name : NONE  
Scale Factor : 1  
Arrival Time : 0 sec

Angle of Horizontal Ground Acc.  
0 [deg]

Case Name	Angle of Acc.
TH_1	0

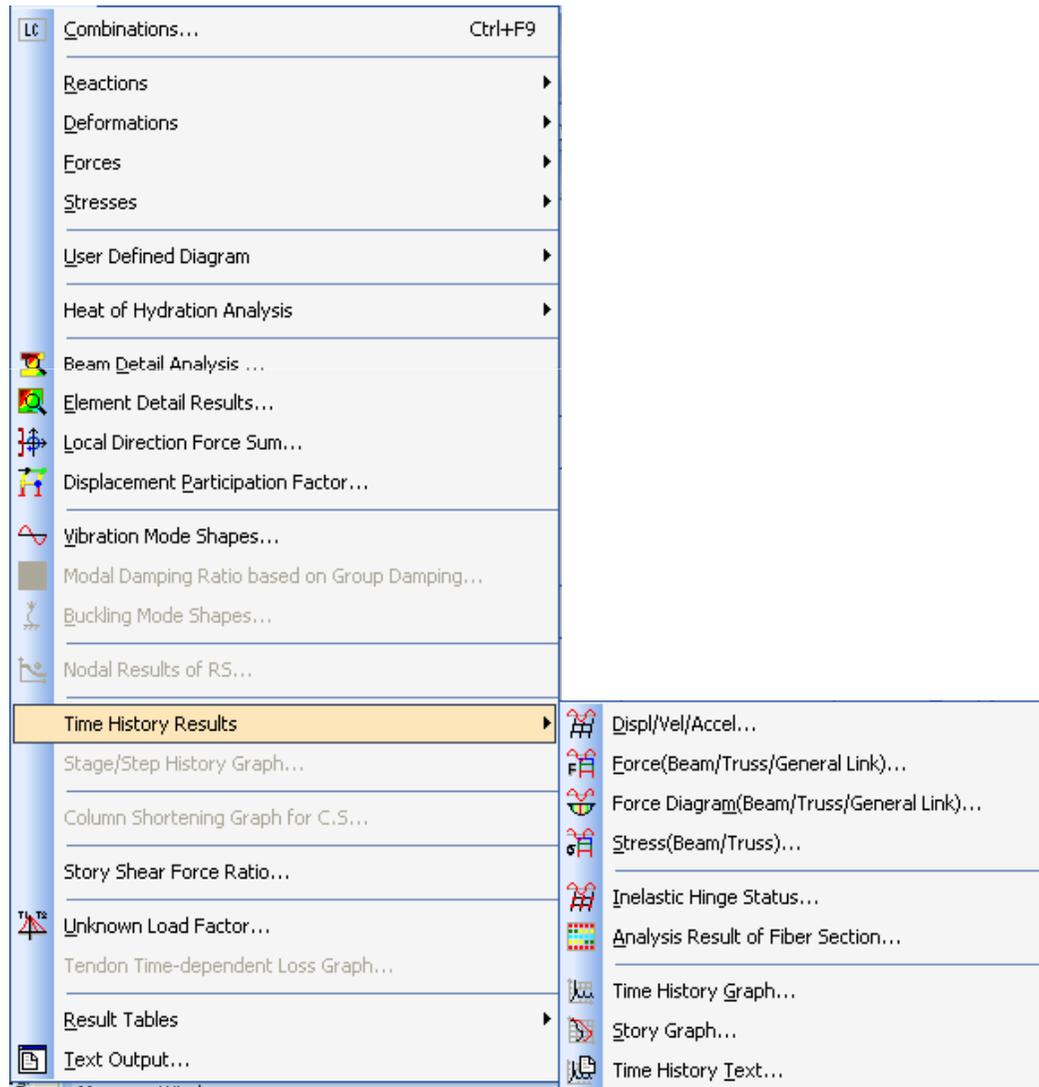
Operations  
Add Modify Delete

Close

*Load > Time History Analysis Data > Ground Acceleration*

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

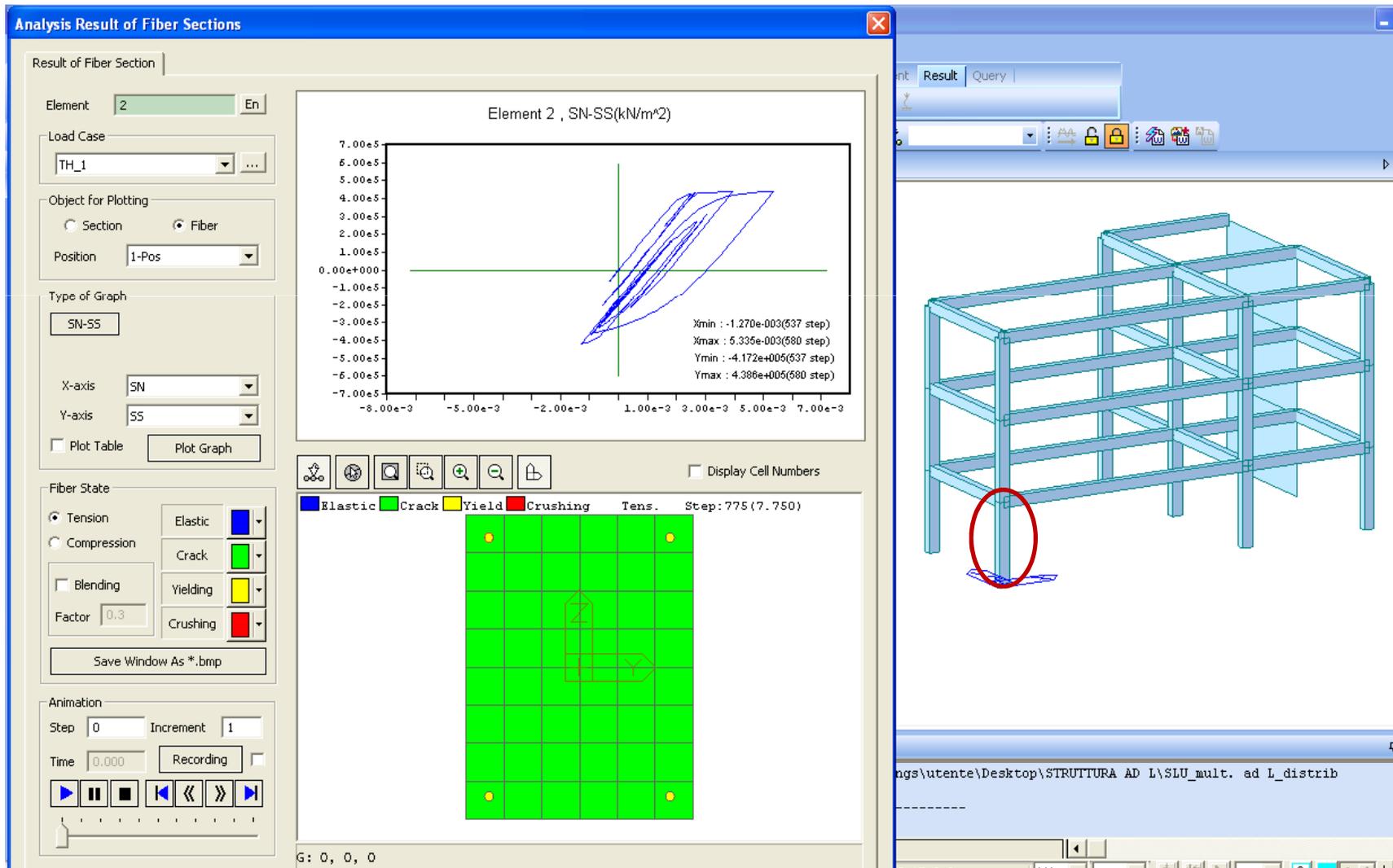
## Step 7: Analisi ed interpretazione dei risultati



Lista dei comandi per interpretare l'analisi dinamica non lineare

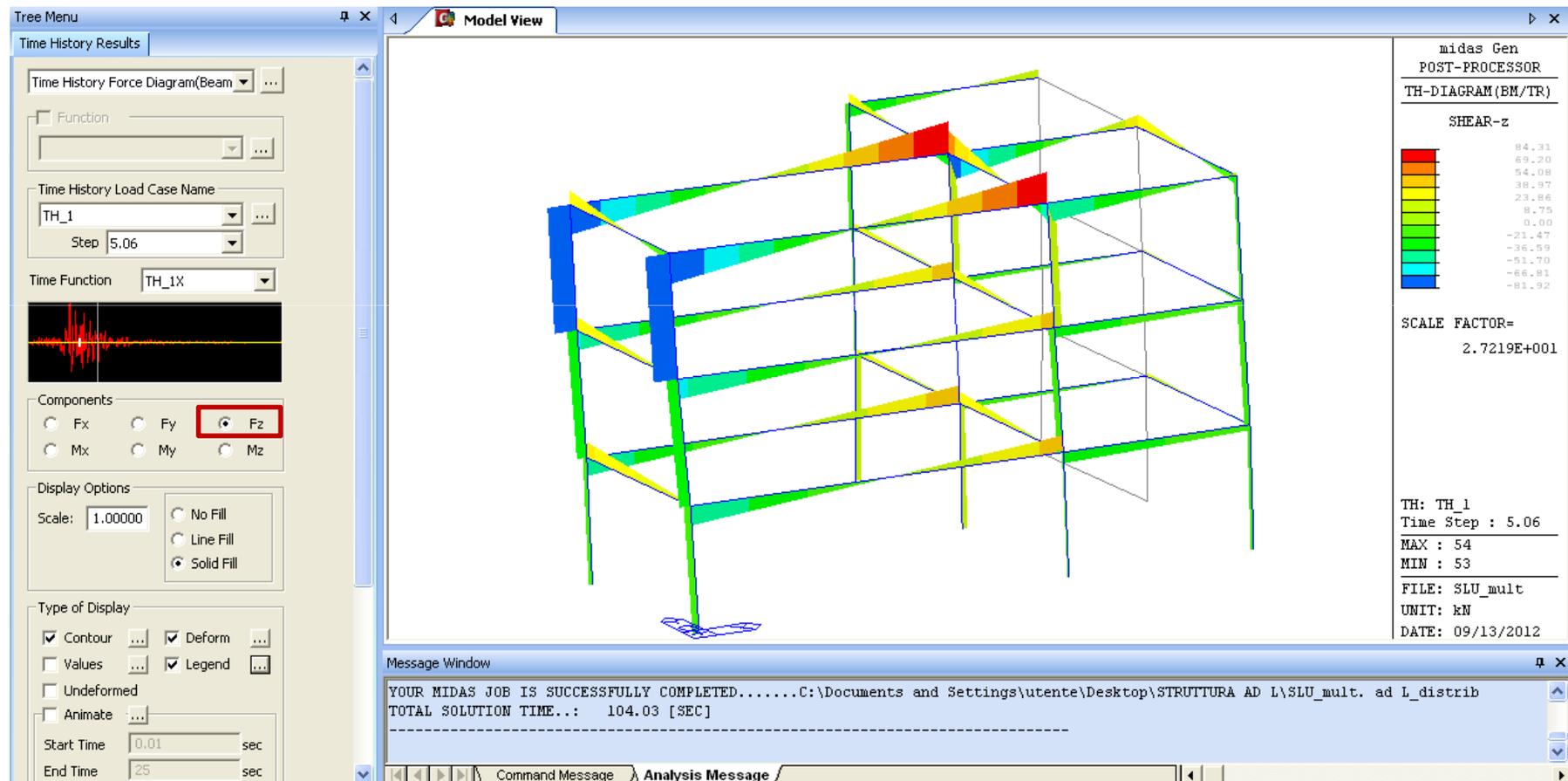
# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 7: Analisi ed interpretazione dei risultati



# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 7: Analisi ed interpretazione dei risultati



taglio

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 7: Analisi ed interpretazione dei risultati

The screenshot displays the MIDAS Gen software interface. The main window shows a 3D model of a metal frame structure. The left panel, titled 'Time History Results', contains the following settings:

- Time History Disp/Vel/Accel: [Dropdown]
- Function: [Dropdown]
- Time History Load Case Name: TH\_1
- Step: 5.55
- Time Function: TH\_1X
- Time Function Graph: [Graph showing a red waveform]
- Display Type:  Displ.,  Vel.,  Accel.
- Components:  DX,  DY,  DZ,  DXY,  DYZ,  DXYZ
- Type of Display:  Deform,  Undeformed,  Values,  Legend,  Animate
- Start Time: 0.01 sec
- End Time: 25 sec
- Increment: 0.01 sec
- Set Default Time button

The right panel displays the analysis results:

```
midas Gen
POST-PROCESSOR
TH-DISPL/VEL/ACCEL
RESULTANT
X-DIR= 1.699E-002
NODE= 29
Y-DIR= -7.666E-003
NODE= 5
Z-DIR= 1.039E-003
NODE= 29
COMB.= 1.710E-002
NODE= 25
SCALE FACTOR=
4.502E+001
TH: TH_1
Time Step : 5.55
MAX : 25
MIN : 1
FILE: SLU_mult
UNIT: m
DATE: 09/13/2012
```

The bottom panel, titled 'Message Window', shows the following text:

```
YOUR MIDAS JOB IS SUCCESSFULLY COMPLETED.....C:\Documents and Settings\utente\Desktop\STRUTTURA AD L\SLU_mult. ad L_distrib
TOTAL SOLUTION TIME... 104.03 [SEC]
```

spostamento

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 7: Analisi ed interpretazione dei risultati

The screenshot displays the MIDASGEN software interface during a time history analysis. The main window shows a 3D model of a frame structure. The 'Results' menu is open, and the 'Time History Results' option is selected, which has opened a sub-menu. The sub-menu options include: Displ/Vel/Accel..., Force(Beam/Truss/General Link)..., Force Diagram(Beam/Truss/General Link)..., Stress(Beam/Truss)..., Inelastic Hinge Status..., Analysis Result of Fiber Section..., Time History Graph... (highlighted), Story Graph..., and Time History Text....

The 'Tree Menu' on the left side of the interface shows the following structure:

- Works
  - Analysis Control Data
    - Eigenvalue Analysis [Type=Eigenvectors]
  - Structures
    - Nodes : 35
    - Elements : 48
  - Properties
    - Material : 1
    - Section : 1
    - Thickness : 1
    - Inelastic Hinge Properties : 1
    - Inelastic Hinges : 18
    - Inelastic Material Properties : 2
    - Fiber Division of Section : 1
  - Boundaries
    - Supports : 8
  - Masses
    - Loads to Masses : 3
  - Static Loads
    - Static Load Case 1 [PP ; ]
    - Static Load Case 2 [Gk ; ]
    - Static Load Case 3 [Qk ; ]
    - Static Load Case 4 [TOT ; ]
  - Time History Analysis
    - Time History Load Cases : 1
    - Time Forcing Functions : 2
    - Ground Acceleration : 1

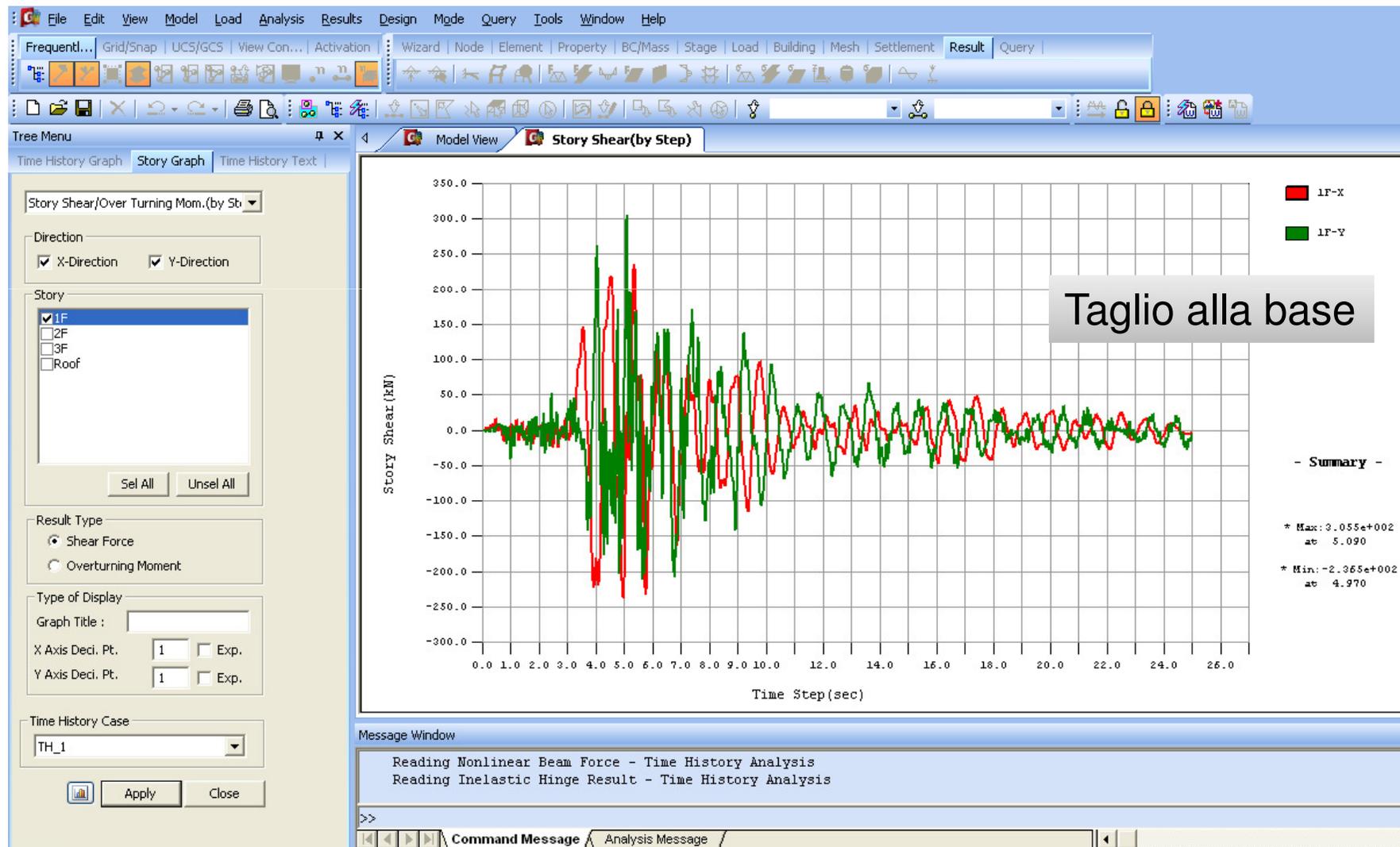
The 'Message Window' at the bottom displays the following text:

```
Reading Nonlinear Beam Force - Time History Analysis
Reading Inelastic Hinge Result - Time History Analysis
```

The status bar at the bottom shows: Time History Graph, Node-26, U: 0, 5, 9, G: 0, 5, 9, kN, m, nonk, 131, 2.

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 7: Analisi ed interpretazione dei risultati



# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 7: Analisi ed interpretazione dei risultati

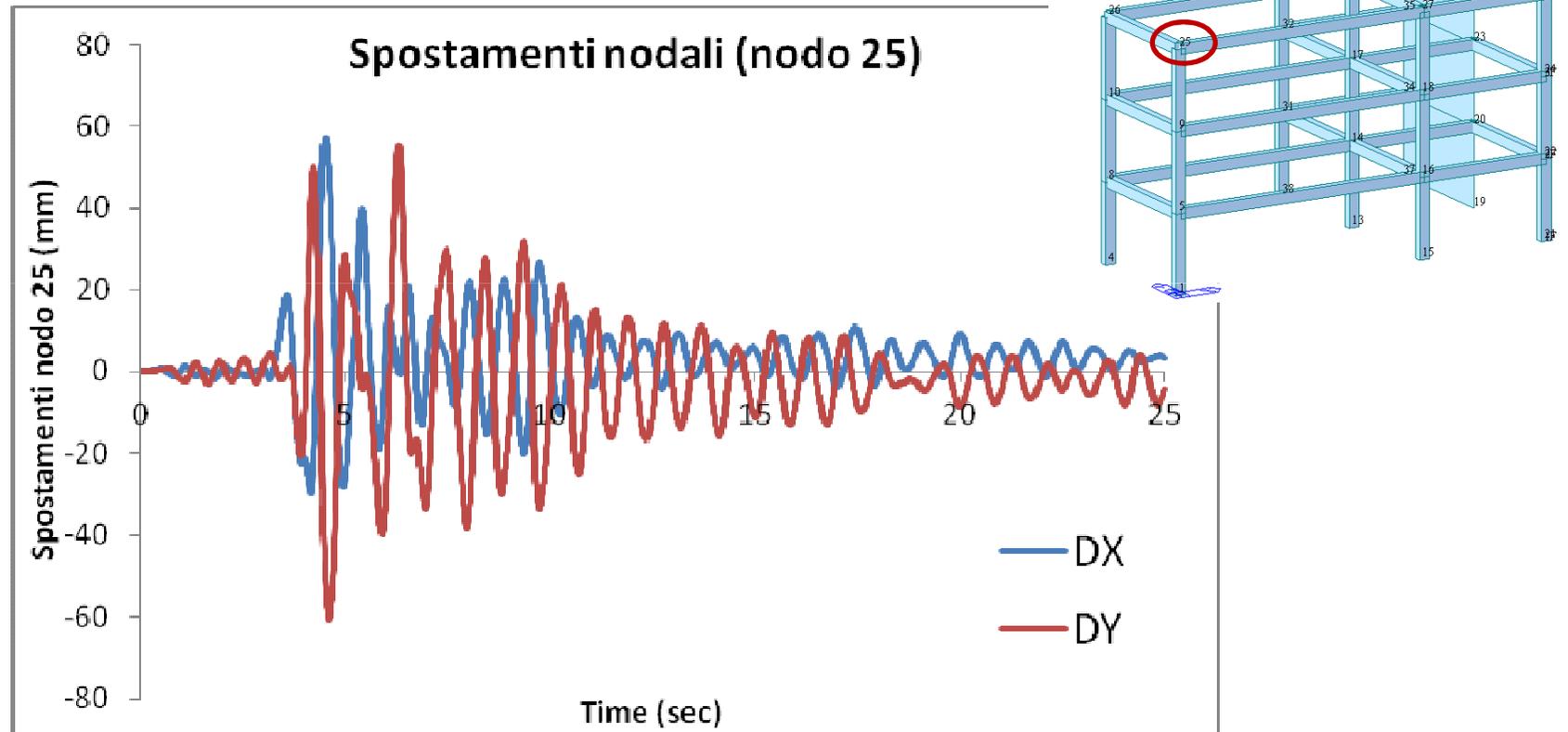
The screenshot displays the MIDAS Gen software interface. The main window shows a 3D model of a multi-story frame structure with nodes numbered 10 through 36. A text box labeled "Spostamenti nodali" (Node Displacements) is overlaid on the model. A tooltip for Node 25 shows its coordinates: X=0, Y=0, Z=9. On the left, the "Time History Text" panel is open, showing "Node Result" set to "Displacement" and "Output Type Selection" set to "Time Step". The "Output Time Step" is set from 0.01 to 25. The "Node Selection" is set to "User Input" with node 25 selected. The "Reference Point" is set to "Ground". The "Time History Case" is "TH\_1".

The "MIDAS/Text Editor - [TimeHistoryResult]" window shows the following output data:

```
00001
00002  ** midas Gen Time-history Output Data **
00003
00004
00005
00006  NODE =    25  Displacement History      UNIT SYSTEM ...: m, kN, sec
00007  -----
00008
00009
00010
00011  TIME      DX      DY      DZ      RX      RY      RZ
00012  0.010    -3.329e-007  2.525e-007  -3.394e-009  1.171e-009  -4.539e-010  -9.996e-010
00013  0.020    -1.644e-006  1.243e-006  -1.951e-008  4.678e-009  9.560e-009  -1.131e-008
00014  0.030    -4.337e-006  3.295e-006  -5.213e-008  1.119e-008  4.237e-008  -5.570e-008
```

# ESEMPIO DI MODELLAZIONE ED ANALISI IN MIDASGEN

## Step 7: Analisi ed interpretazione dei risultati



# SOMMARIO

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- **Edificio di Bonefro**
- **Ponte di Humbolt Bay**
- **Modellazione Taglio (Per ponti ed edifici)**
- **Esempio di modellazione ed analisi in MidasGen**
- **E-ELT Telescope**

- **Introduzione**

Questo progetto concettuale rivoluzionario, chiamato E-ELT, ovvero **European Extremely Large Telescope**, sarà il più grande telescopio ottico/vicino-infrarosso del mondo con uno specchio primario del diametro di 42 m.

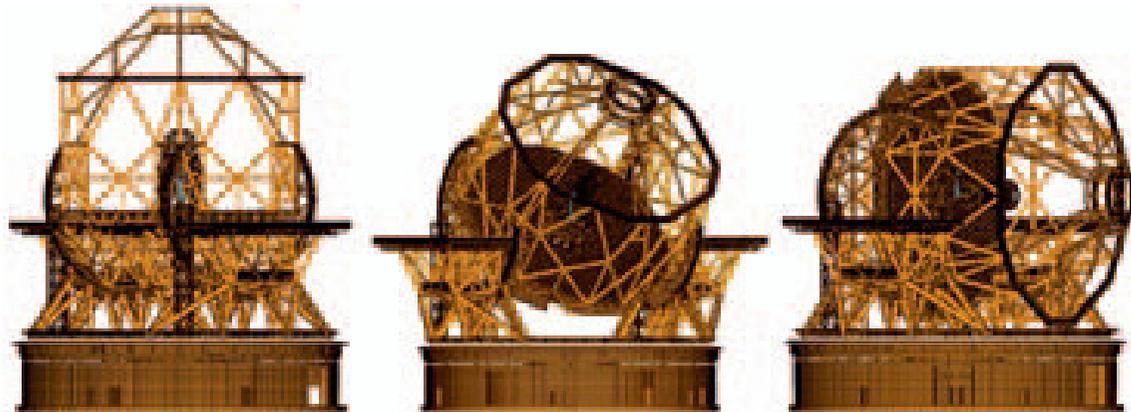


*E-ELT Telescope, [www.eso.org](http://www.eso.org) ESO/L. Calçada*

L'obiettivo di questo lavoro era la progettazione di un sofisticatissimo **sistema di isolamento tridimensionale** che fosse in grado da un lato di garantire la rigidità delle fondazioni durante l'operatività del telescopio e dall'altro di ridurre di almeno il 50% le accelerazioni negli specchi nel caso di evento sismico. Lo sviluppo dei dispositivi è stato fatto in collaborazione con Alga Spa.

- **Modellazione strutturale**

Sono stati realizzati diversi modelli utilizzando il software Midas Gen per valutare le accelerazioni per diverse configurazioni del telescopio.



*Modelli numerici del telescopio sviluppati con Midas Gen*

I modelli consistono in

- 31773 **elementi trave**
- 4576 **elementi shells**
- 6062 **equazioni lineari di vincolo** utilizzate per connettere gli specchi alla struttura (schematizzano la rigidità degli attuatori)

- ***Tipologia di analisi***

Il sistema è stato studiato tramite analisi non lineari con integrazione.

- ***Selezione dell'input sismico***

Si è scelto in questo caso di applicare contemporaneamente triplette di **accelerogrammi artificiali** alla base del modello.

Sarebbe stato preferibile utilizzare accelerogrammi naturali ma poiché l'intensità dell'accelerazione attesa al suolo nel sito in esame è molto elevata (**PGA = 0.72g**, ASDEA 2010) non è stato possibile reperire accelerogrammi naturali spettrocompatibili senza dover scalare eccessivamente le accelerazioni.

- **Smorzamento**

Per quanto riguarda lo smorzamento si è utilizzata la **formulazione classica della matrice di smorzamento  $\mathbf{C}$  di Rayleigh** che assume lo smorzamento proporzionale alla massa e alla rigidezza in accordo con la formula seguente:

$$\mathbf{C} = a_0 \mathbf{M} + a_1 \mathbf{K}$$

I coefficienti  $a_0$  e  $a_1$  possono essere calcolati assegnando lo smorzamento  $\xi_m$  e  $\xi_n$  a due specifiche frequenze  $\omega_m$  e  $\omega_n$ .

$$\begin{Bmatrix} a_0 \\ a_1 \end{Bmatrix} = 2 \frac{\omega_m \omega_n}{\omega_n^2 - \omega_m^2} \begin{bmatrix} \omega_n & -\omega_m \\ -1 / \omega_n & 1 / \omega_m \end{bmatrix} \begin{Bmatrix} \xi_m \\ \xi_n \end{Bmatrix}$$

- **Smorzamento**

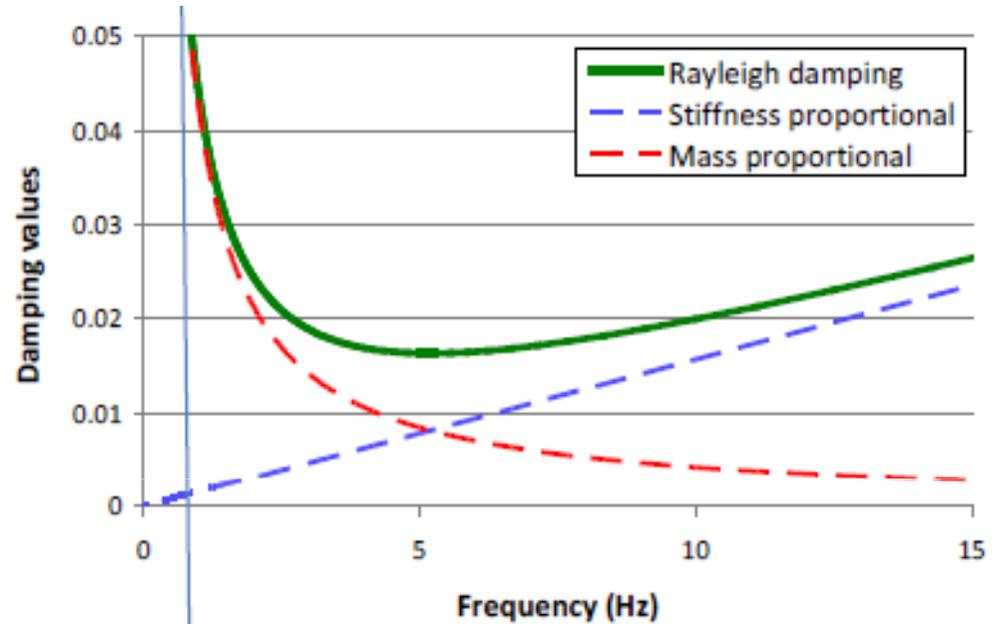
Le due frequenze utilizzate per definire  $\xi$  devono considerare tutti i modi di vibrazione che hanno masse partecipanti significative per la risposta del telescopio.

L'analisi modale del telescopio a base fissa mostra che per eccitare l'85% della massa totale servono più di **600 modi**.

$$\begin{Bmatrix} a_0 \\ a_1 \end{Bmatrix} = 2 \frac{\omega_m \omega_n}{\omega_n^2 - \omega_m^2} \begin{bmatrix} \omega_n & -\omega_m \\ -1 / \omega_n & 1 / \omega_m \end{bmatrix} \begin{Bmatrix} \xi_m \\ \xi_n \end{Bmatrix}$$

- **Smorzamento**

Nelle analisi non lineari si considera un **valore dello smorzamento** inferiore al convenzionale 5% usato nelle analisi lineari, **tipicamente compreso tra lo 0% e il 2%**. Questo perché parte della dissipazione è considerata direttamente nel modello.

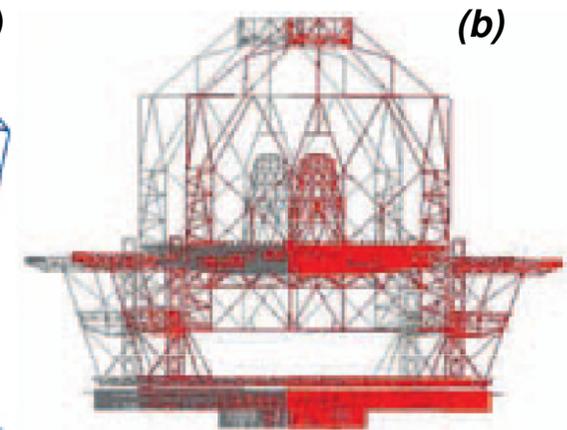
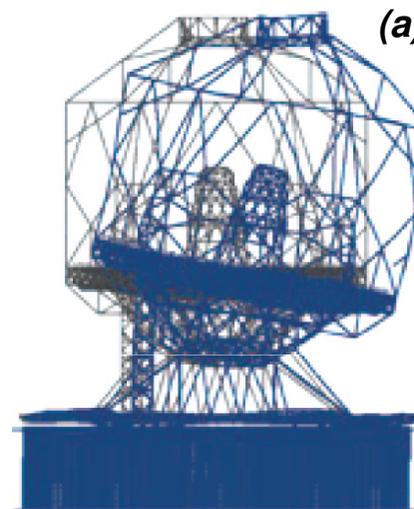
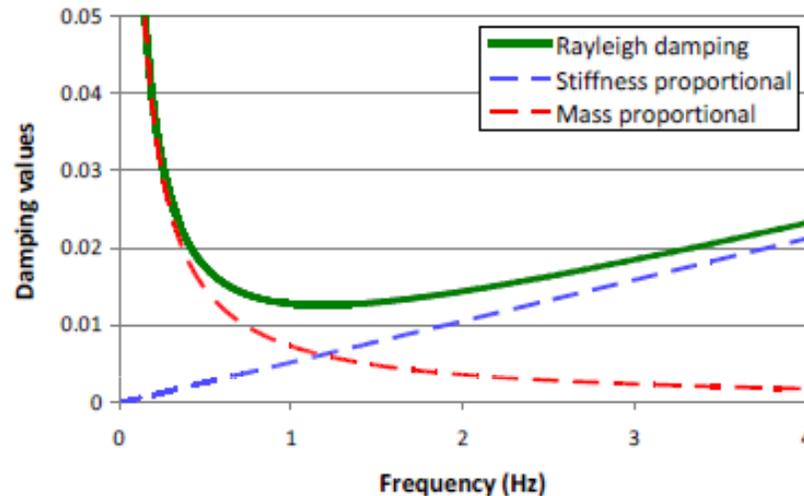


*Base fissa - smorzamento*

Il range di frequenze da coprire è molto ampio, si è scelto di fissare lo **smorzamento al 2%** per frequenze pari a 2.7 e 10 Hz.

È importante valutare con attenzione se vi sono masse partecipanti importanti oltre i 10 Hz poiché verrebbero smorzate più di quanto richiesto riducendo artificialmente le accelerazioni di output.

- **Smorzamento**



**Sistema isolato - smorzamento**

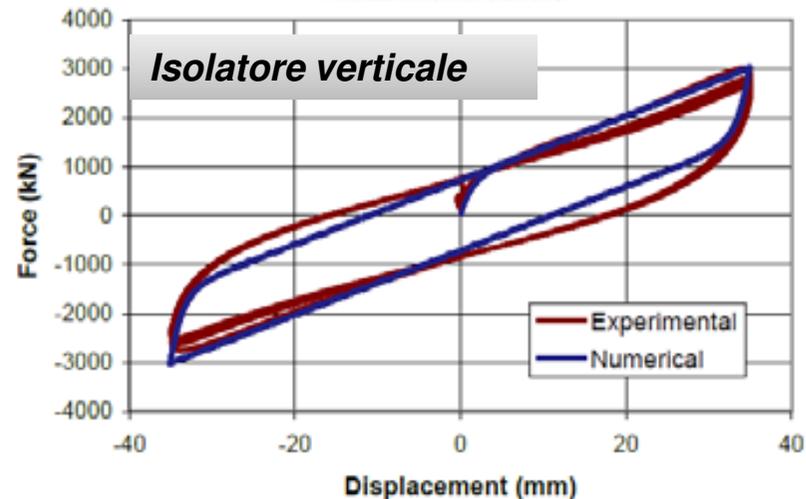
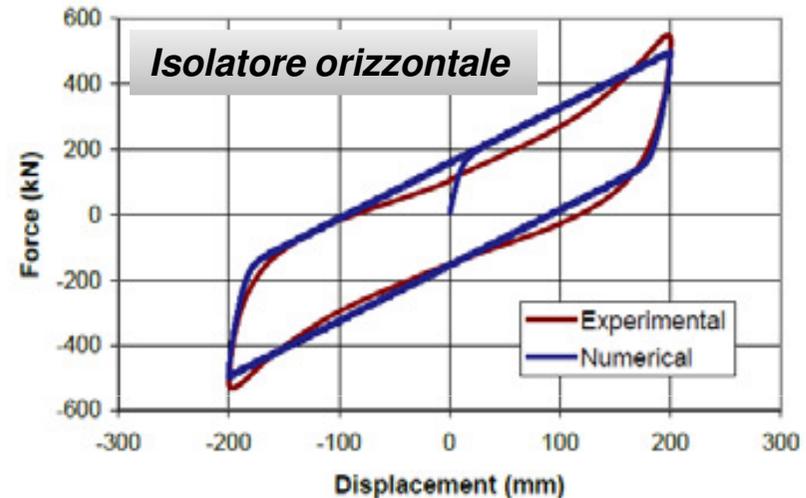
**(a) Base fissa - 1° modo di vibrare (b) Sistema isolato - 1° modo di vibrare**

La scelta delle frequenze per la **soluzione isolata** è molto più semplice poiché l'isolamento governa il periodo proprio della struttura e il 99% della massa orizzontale è associata a una frequenza pari a 0.42 Hz, mentre quella verticale ad una frequenza di 3.33 Hz

- **Taratura degli isolatori**

Per modellare il comportamento è stato utilizzato l'elemento link non lineare chiamato: "*Hysteretic System*", che modella l'energia dissipata attraverso un comportamento isteretico.

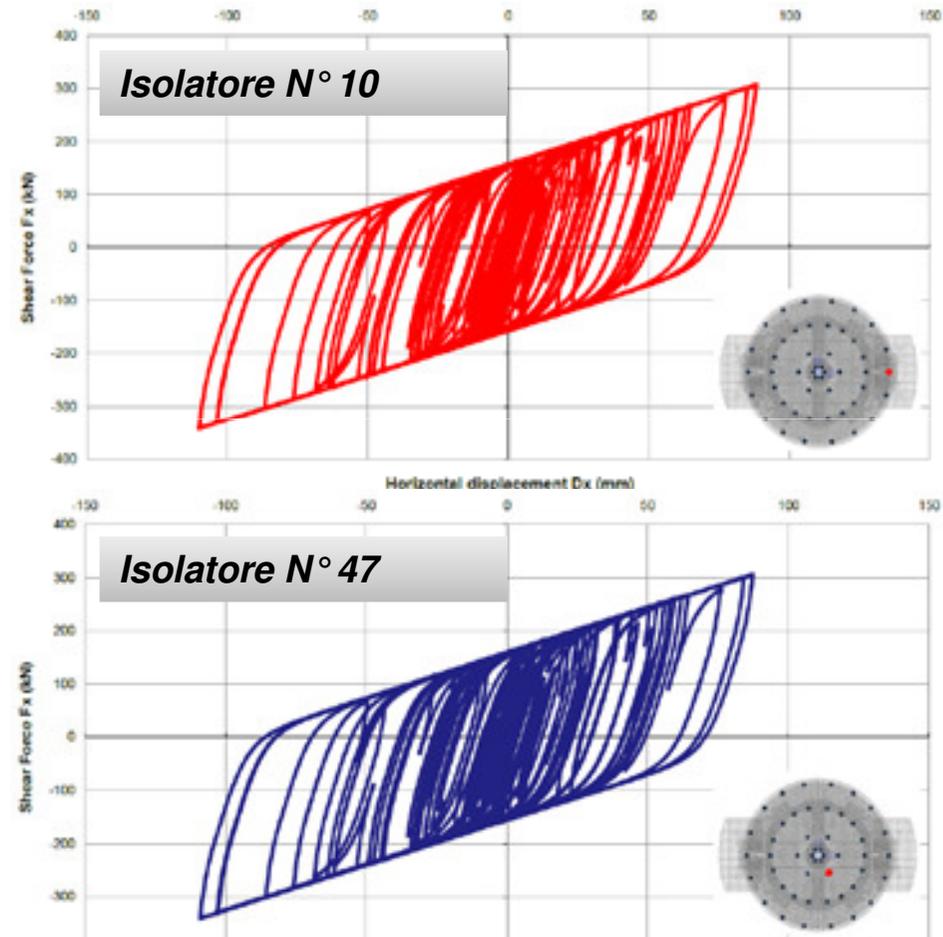
Il modello numerico tarato riproduce fedelmente il comportamento sperimentale ciclico degli isolatori



**Confronto tra il comportamento sperimentale e numerico dell'isolatore orizzontale e verticale**

- **Comportamento ciclico degli isolatori**

La valutazione critica del comportamento ciclico degli isolatori durante il sisma permette di valutare se vi sono degli isolatori sottoposti a forze di trazione che potrebbero generare un **effetto di rocking** incontrollabile ed estremamente pericoloso.



**Risposta orizzontale nella direzione X-degli isolatori soggetti alla massima (isolatore N° 10) e minima (isolatore N° 47) forza assiale (configurazione a 0°gradi)**

# E-ELT TELESCOPE

- **Risultati**

Le accelerazioni sia orizzontali che verticali sono state ridotte sostanzialmente grazie all'inserimento degli isolatori

