PROJET STRATEGIQUE RISQUES NATURELS (ATTIVITA' B6)

EDIFICI IN MURATURA
Analisi Statica Nonlineare (Pushover)

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METODO PUSHOVER : COME E QUANDO NASCE

Nasce come metodo semplificato per studiare il comportamento di telai piani in c.a. (all' inizio degli anni '80)

Ne esistono diverse versioni a seconda delle semplificazioni ed ipotesi introdotte

Nell' Ordinanza é descritta la versione di Fajfar e Gaspersic del 1996

TELAI IN CA MODELLATI COME SDOF

Saiidi, Mete, Sozen "Simple nonlinear seismic analysis of R/C structures", J. Struct. Engrg., ASCE, 107(5), 937-951, (1981).

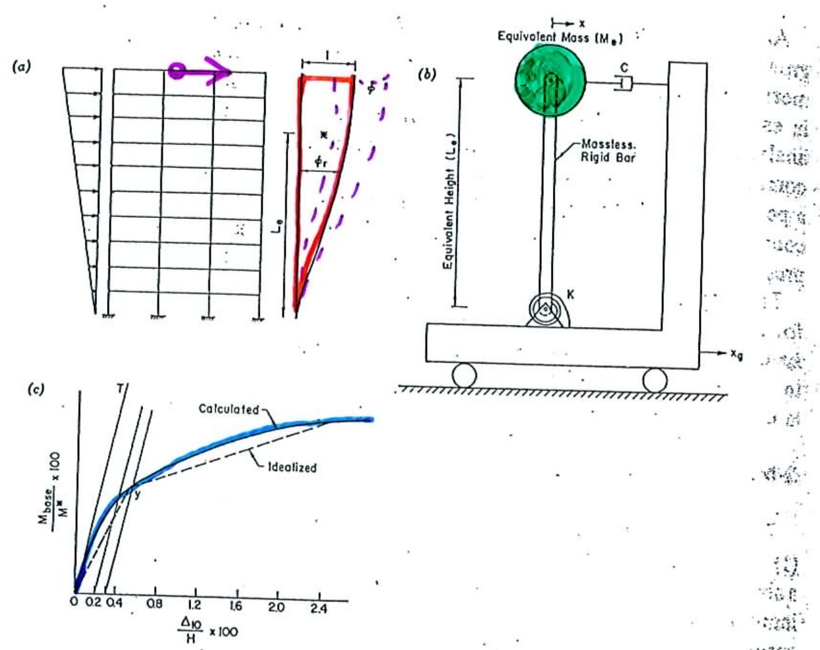


FIG. 1.—Relationship of Q-Model to Multistory Structure: (a) Static Lateral Loads; (b) Q-Model; (c) Force-Displacement Relationships

E' molto complicato integrare nel tempo le eq. del telaio in c.a (MDOF non lineare)

Q - model
- riduzione del telaio MDOF ad un oscillatore elasto-plastico SDOF
- Approssimazione della rigidezza variabile incrementale del telaio con una singola molla non-lineare

L'equazione dell'oscillatore elastoplastico viene integrata nel tempo

IL LAVORO E' LA BASE DEL METODO PUSHOVER !!!

Q-MODEL : TELAI PROVATI

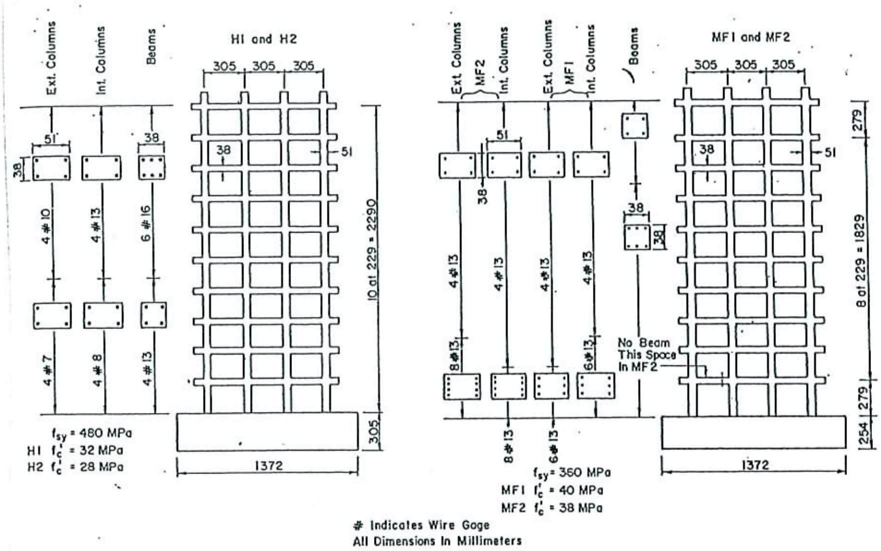


FIG. 3.—Test Structures H1, H2, MF1, and MF2

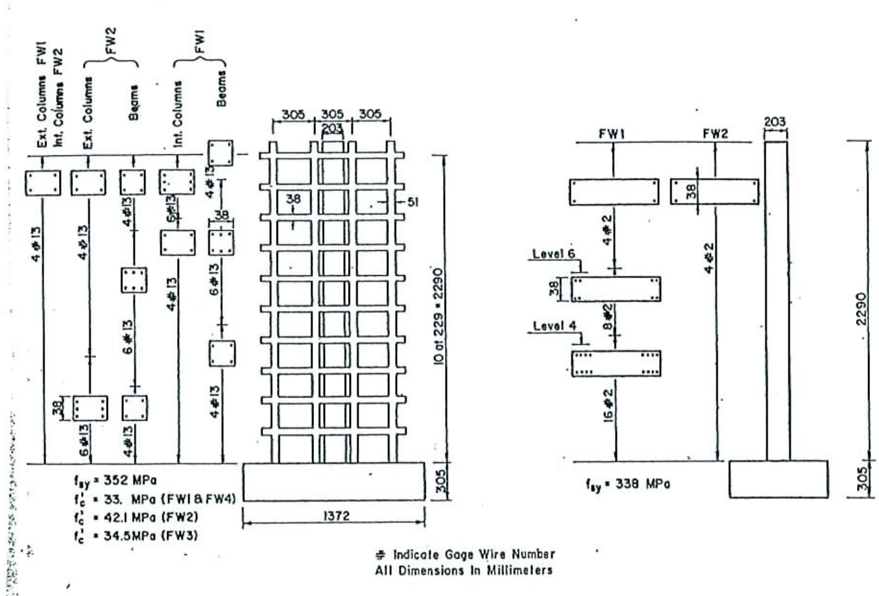


FIG. 4.—Test Structures FW1, FW2, FW3, and FW4

Q-MODEL : CONFRONTI

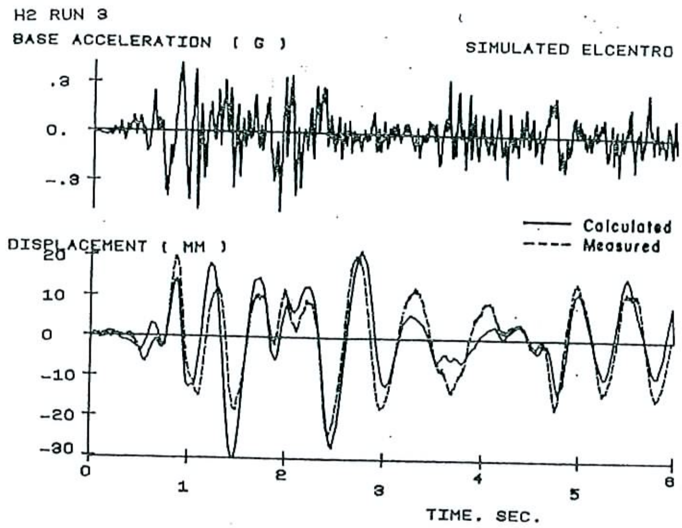
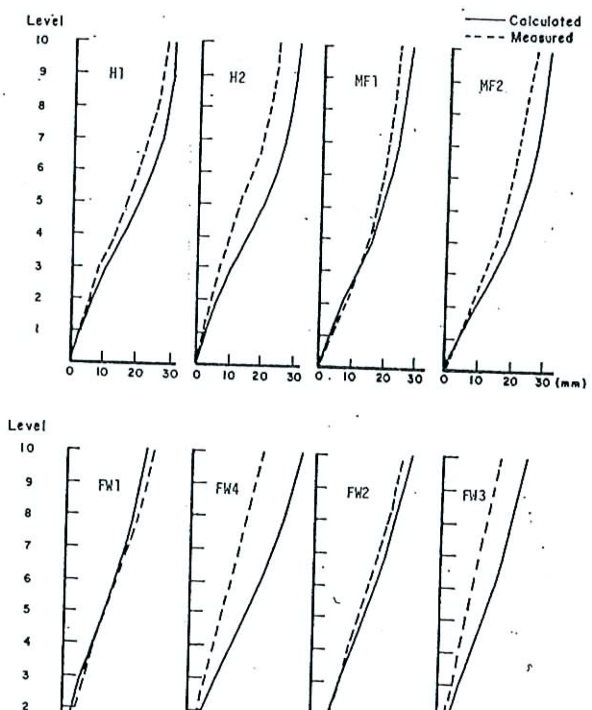
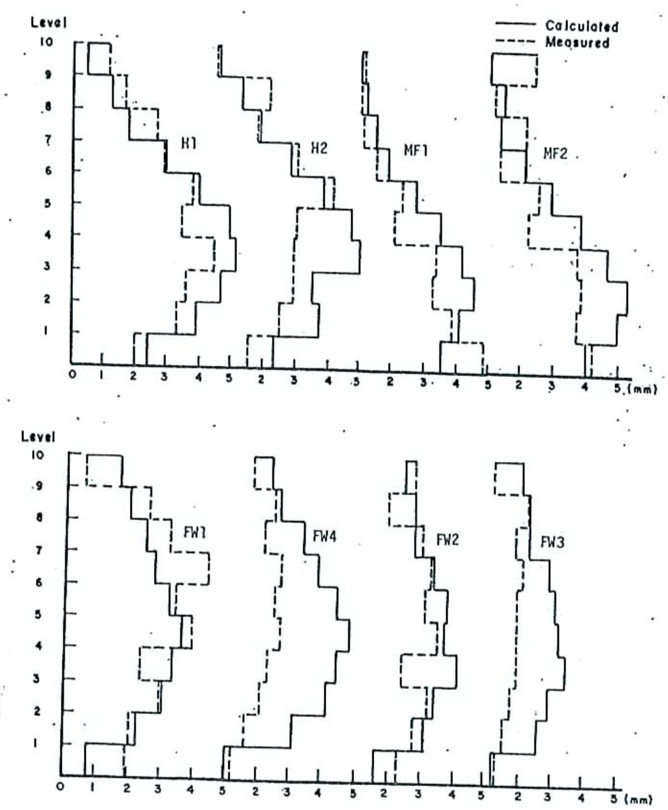


FIG. 6.—Base Acceleration and Displacement Histories for Test Structures H1 and H2



—Distribution of Floor Displacements at Instant of Maximum Displacement



—Distribution of Story Drift at Instant of Maximum Displacement at Level

OSCILLATORE ELASTICO MDOF

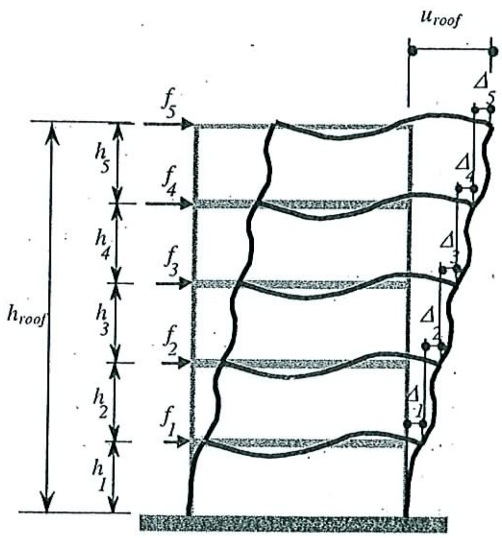
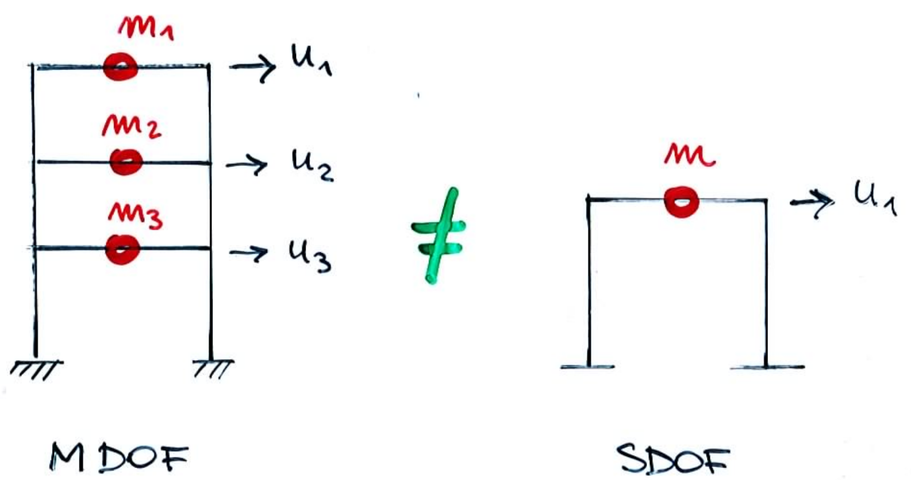


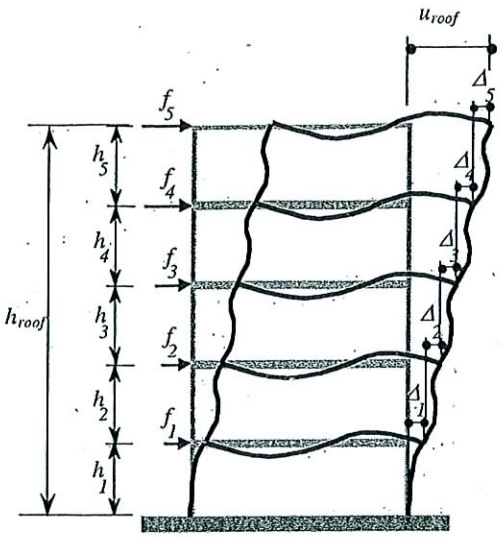
Fig. 3-31: Story Drift Definition

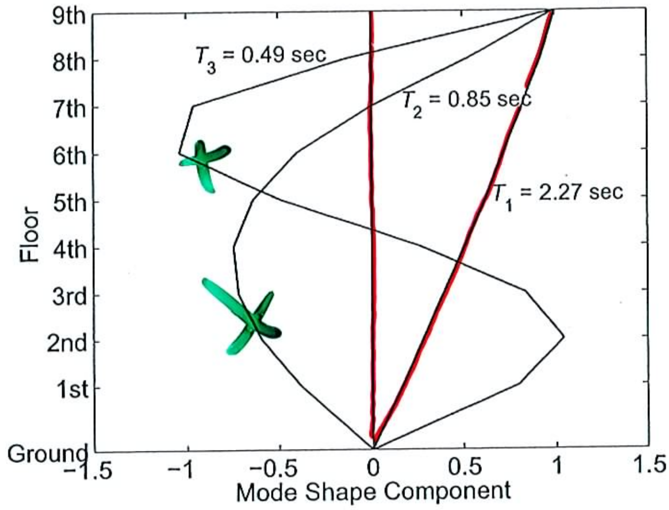
- *Global displacement* represents the displacement relative to the base of an equivalent SDOF system representing the structure. In this chapter, it has been consistently described by the variable u.
- *Roof displacement* refers to the lateral displacement of the roof of the building with respect to the base. The term u_{roof} has been used here to describe it.
- *Interstory drift* is the relative horizontal displacement between two adjacent floors bounding the story. The term Δ_i is used here to describe its value at story i.
- *Drift ratio* corresponds to the interstory drift divided by the story height Δ_i/h_i, with h_i being the vertical distance between the floors.
- *Average drift* refers to the roof displacement divided by the total height of the building $\Delta_{ave} = u_{roof}/ h_{roof}$.



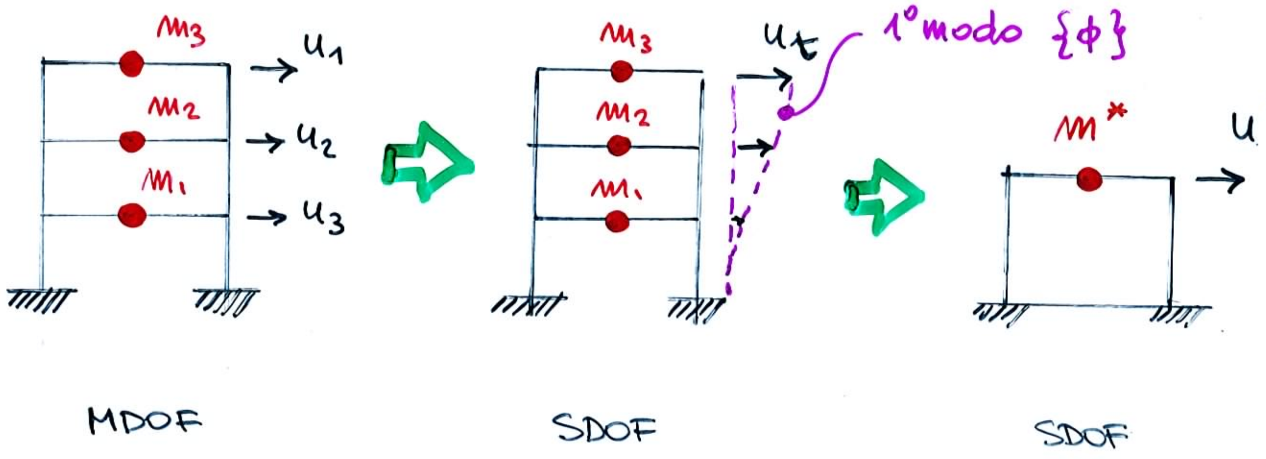
PASSAGGIO DA MDOF A SDOF

SISTEMA MDOF $\begin{cases} N \text{ d.o.f.} \\ N \text{ modi di vibrare} \\ N \text{ periodi } T_1, T_2, \dots T_5, \dots T_N \end{cases}$



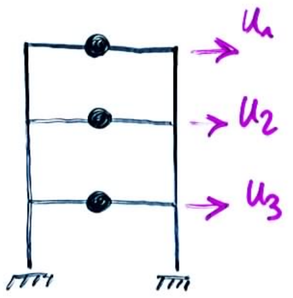


Se $m^{(1)} > 85\%\, m$ ⇝ posso lavorare con il 1° modo e trascurare gli altri .... il sistema si comporta come se fosse un SDOF.



MODELLO SDOF EQUIVALENTE

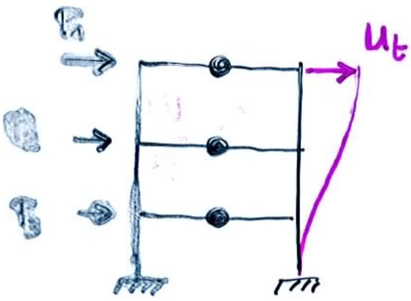
Sono state proposte $\neq$ procedure per definire le caratteristiche del sistema SDOF. ⤳ Fajfar



$\rightarrow a$

$$\boxed{M\ddot{U} + R = -M1a} \quad \textbf{MDOF}$$

$$U = \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix}$$



$\leftarrow V$

$$U = \phi^{(1)} u_t \qquad \phi^{(1)} = \begin{Bmatrix} 1 \\ \cdots \\ \cdots \end{Bmatrix}$$

$$R = P = M\phi^{(1)} p$$

$$\phi^{T(1)} M \phi^{(1)} \ddot{u}_t + \phi^{T(1)} M \phi^{(1)} p = -\phi^{T(1)} M 1 a$$

$$\frac{\phi^T M 1}{\phi^T M 1} \underbrace{\phi^T M \phi}_{1/\Gamma} \ddot{u}_t + \frac{\phi^T M 1}{\phi^T M 1} \phi^T M \phi \, p = -\underbrace{\phi^T M 1}_{m^*} a$$

$$\Gamma = \frac{\phi^T M 1}{\phi^T M \phi} = \frac{\Sigma m_i \phi_i}{\Sigma m_i \phi_i^2}$$

FATTORE DI PARTECIPAZIONE MODALE

$$m^* = \phi^T M 1 = \Sigma m_i \phi_i$$

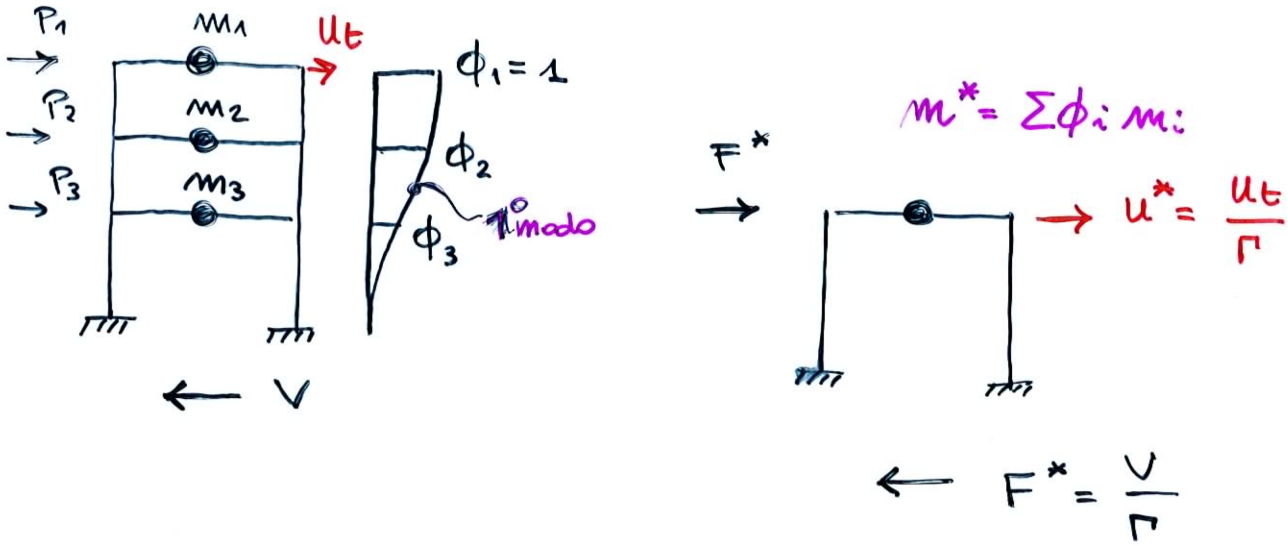
$$m^* \underbrace{\left(\frac{\ddot{u}_t}{\Gamma}\right)}_{\ddot{u}^*} + \underbrace{\frac{m^*}{\Gamma} p}_{F^*} = -m^* a$$

$$\boxed{m^* \ddot{u}^* + F^* = -m^* a}$$

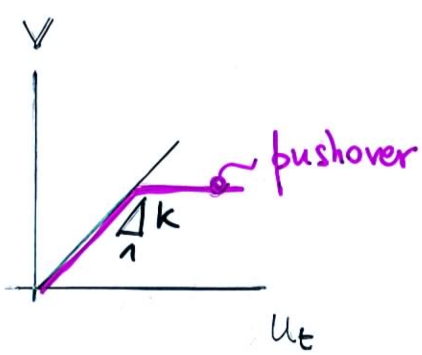
EQUAZIONE SDOF EQUIVALENTE **SDOF**

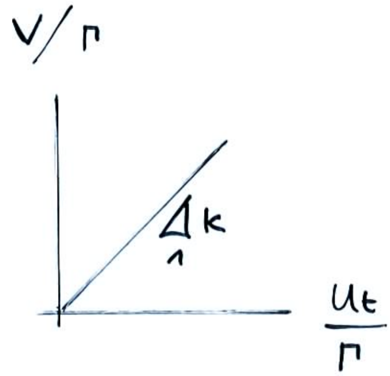
$$u^* = \frac{u_t}{\Gamma}$$

$$F^* = \frac{p\, m^*}{\Gamma} = \frac{\phi^T M 1 p}{\Gamma} = \frac{\sum P_i}{\Gamma} = \frac{V}{\Gamma}$$



$$\boxed{\text{MDOF}} \xleftrightarrow{\ \Gamma\ } \boxed{\text{SDOF}}$$



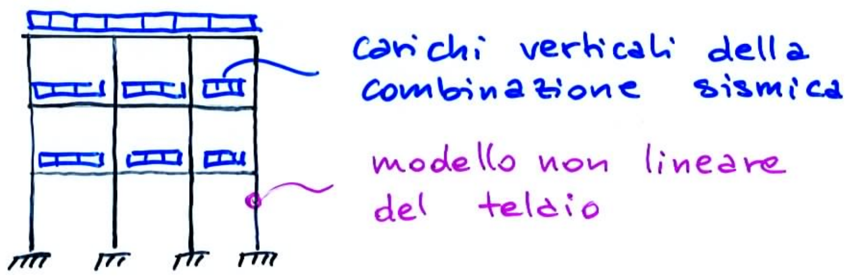


PUSHOVER : MODELLO N2 < CAPACITA' / DOMANDA

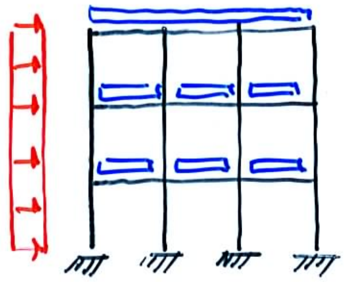
Fajfar, Gašperšič " The N2 method for the seismic damage analysis of RC buildings" Earth Eng ... (1996)

CAPACITA' : CURVA DI PUSHOVER

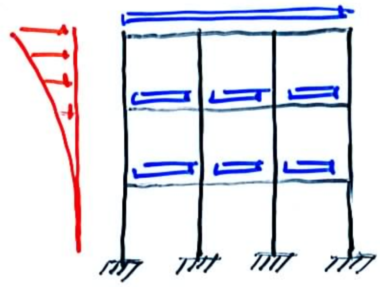
1. Modello non lineare della struttura e carichi verticali



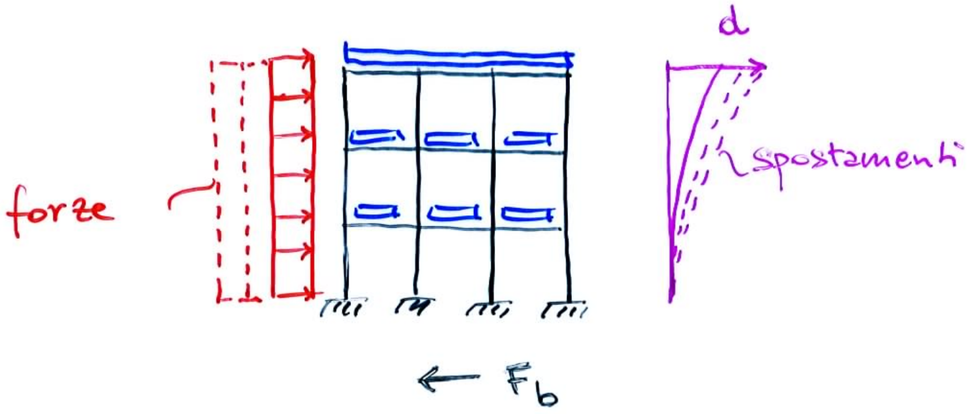
2 Analisi statica non lineare per tracciare la curva di pushover



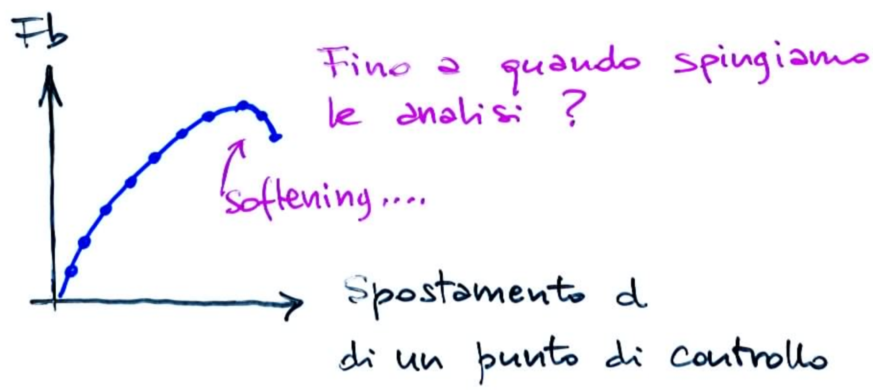
Forze ∝ masse

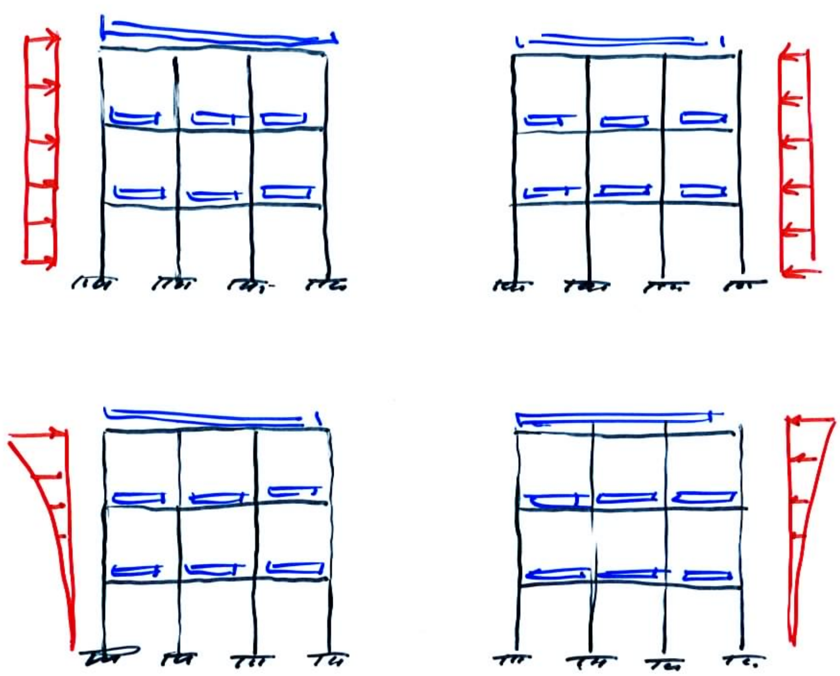


Forze ∝ masse x deformata 1°modo



La curva di capacità è tracciata per punti al crescere delle azioni sismiche mediante analisi statica non lineare della struttura

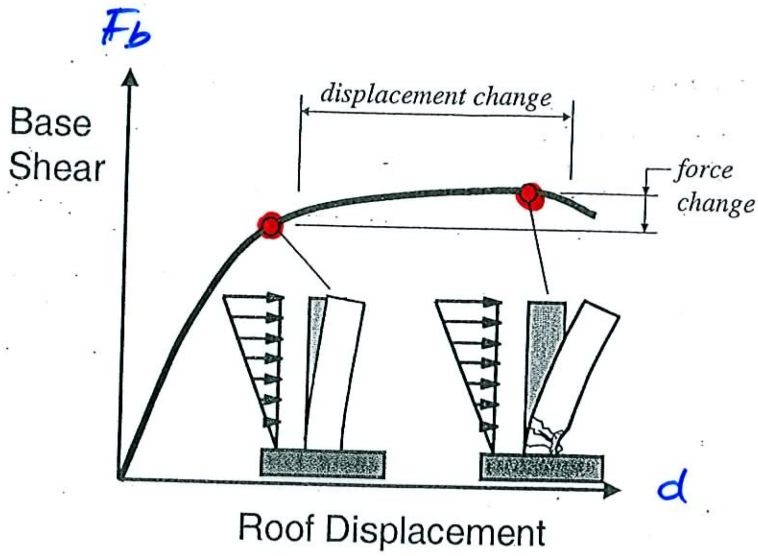




4 CASI PER CONSIDERARE IL ≠ VERSO DEL SISMA ...

⇓

4 CURVE DA ANALIZZARE SEPARATAMENTE



The relation between displacement and damage

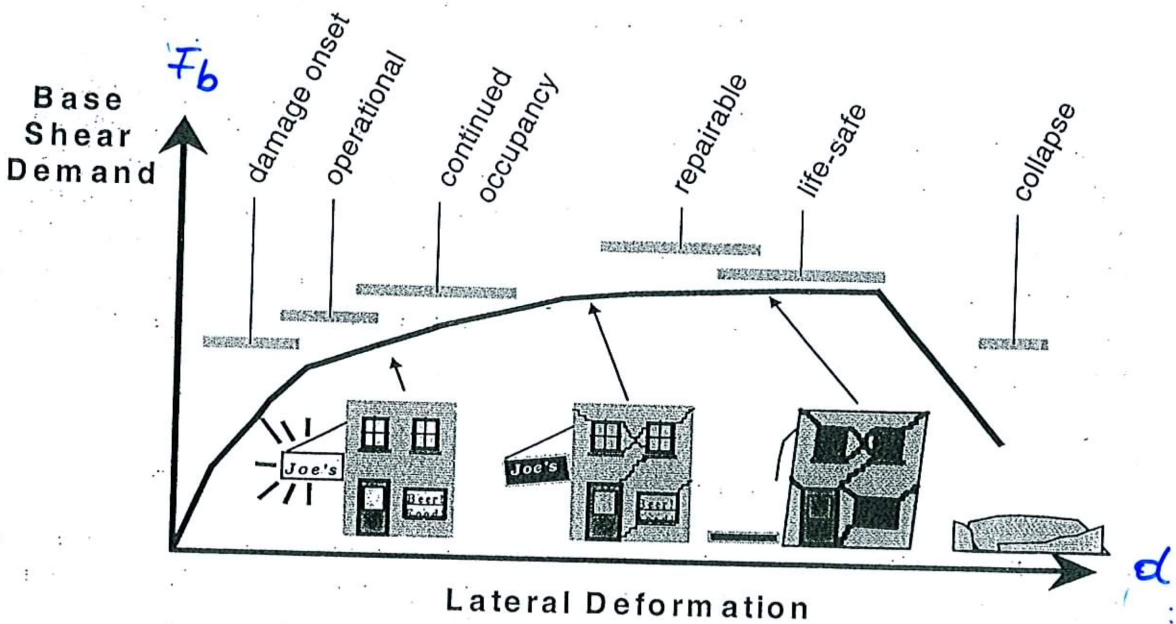
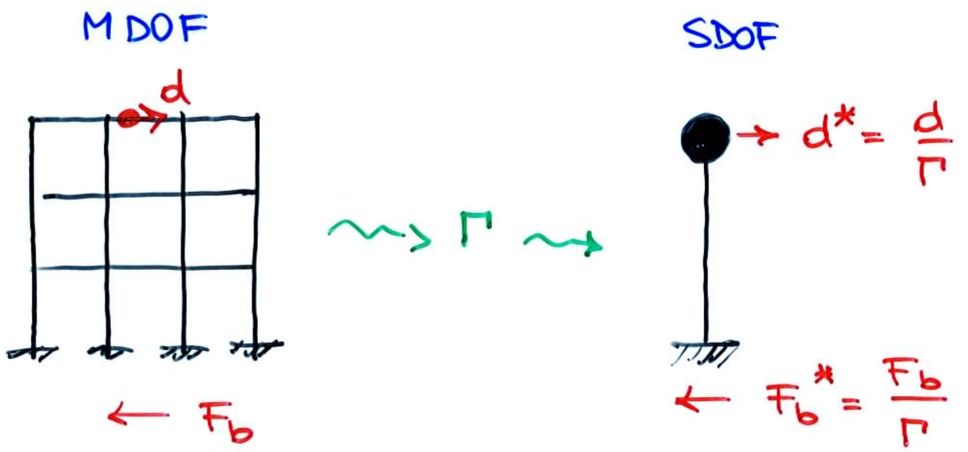
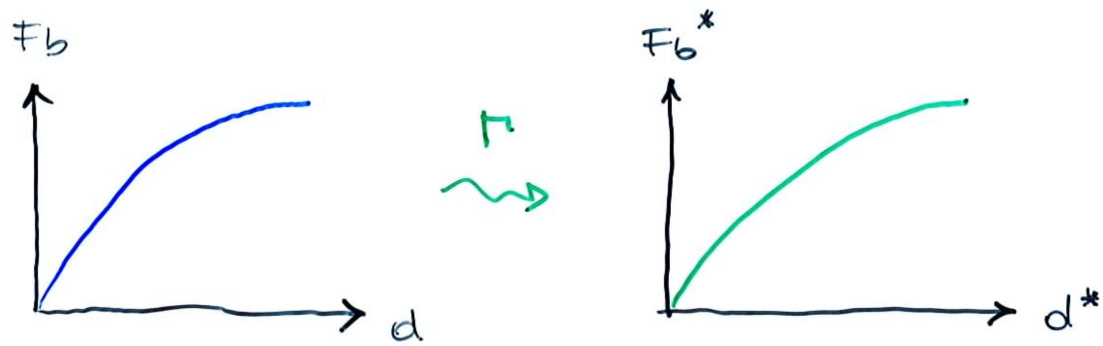


Figure 2-1: Performance levels and relative damage (Joe's cartoon by permission of Ron Hamburger)

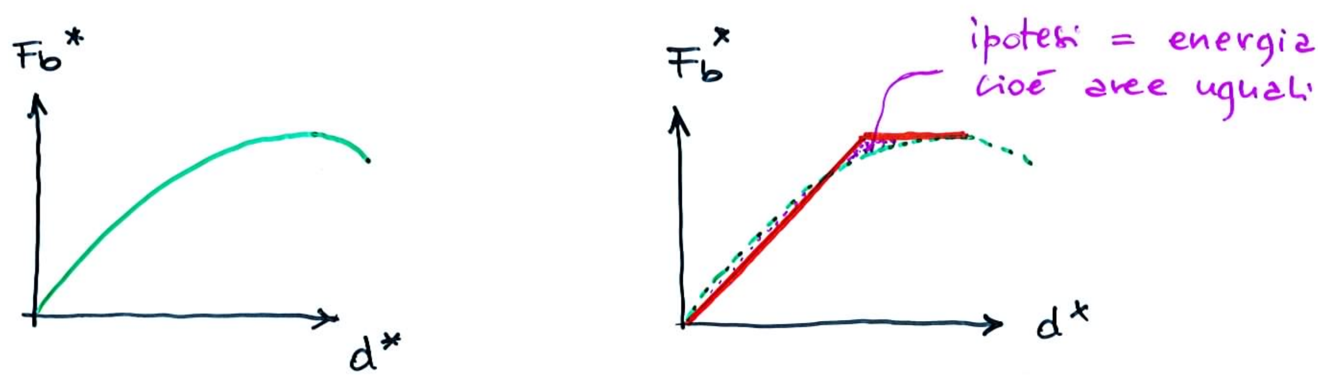
3 • Riduzione del sistema ad 1 grado di libertà





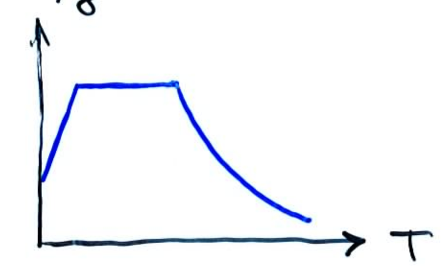
$$\Gamma = \frac{\phi^T M R}{\phi^T M \phi}$$ (già visto prima)

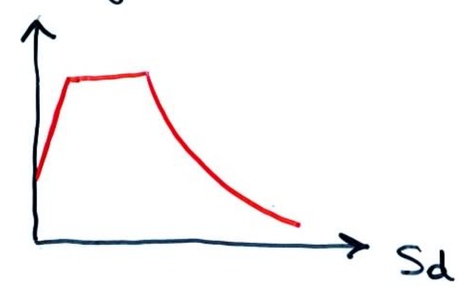
4 bilinearizzazione



DOMANDA : SPETTRO

1. Trasformo lo spettro in formato ADRS



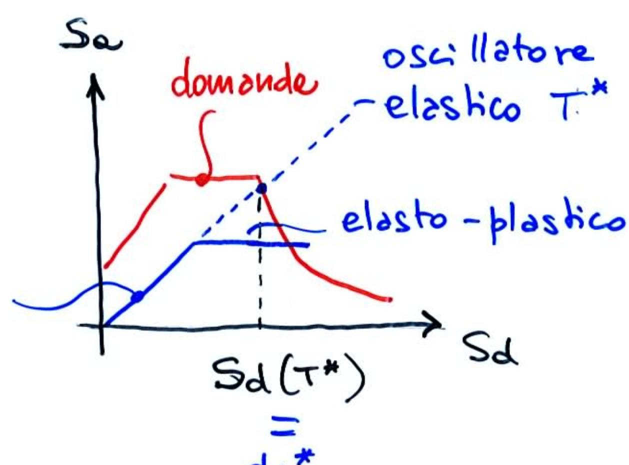


$\hookrightarrow \omega = \frac{2\pi}{T} \leadsto Sd = \frac{Sa}{\omega^2} \nearrow$

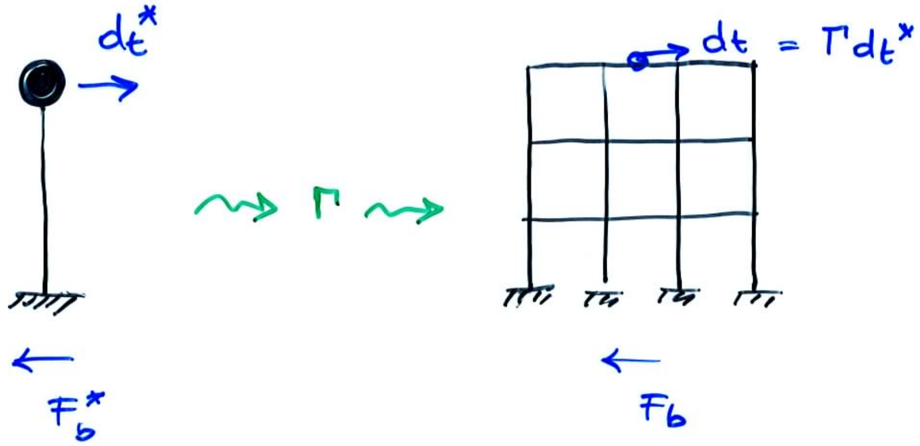
Spettro elastico

Spettro ADRS

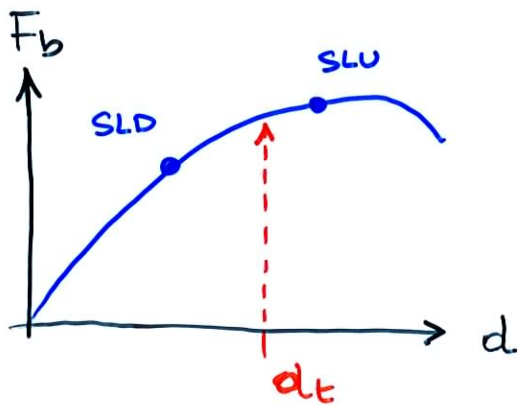
VERIFICA



Sfruttando i legami tra oscillatore elastico ed oscill. elasto-plastico visti prima, trovo lo spostamento $Sd(T^*) = d_t^*$ dell'oscillatore elasto plastico (sullo spettro dell'oscill. elastico!)

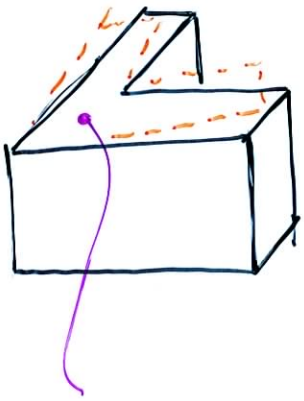


Valuto il corrispondente spostamento $d_t = \Gamma d_t^*$ sul telaio e controllo, sulla curva di capacità, che le verifiche SLU o SLD siano soddisfatte



Verifica soddisfatta

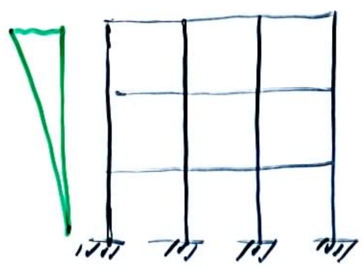
ALCUNE CONSIDERAZIONI



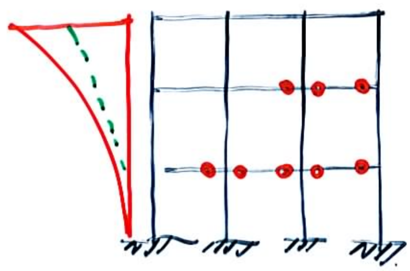
Quale punto di controllo ?

L'analisi pushover può sottostimare fortemente gli spostamenti di una struttura con modi torsionali prevalenti

1° modo



1° modo

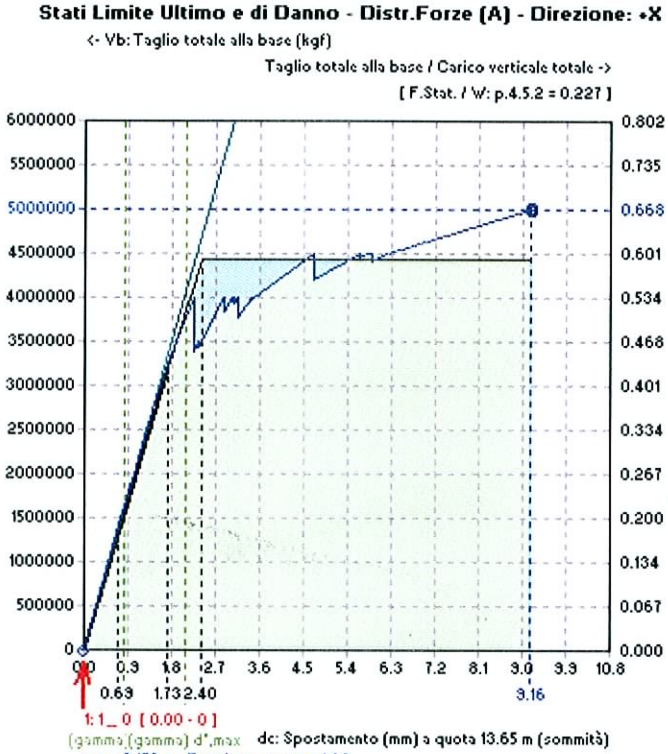


Quando la struttura si danneggia cambia la rigidezza e quindi il 1° modo di vibrare

Sono stati proposti metodi adattativi che modificano le azioni orizzontali agenti.

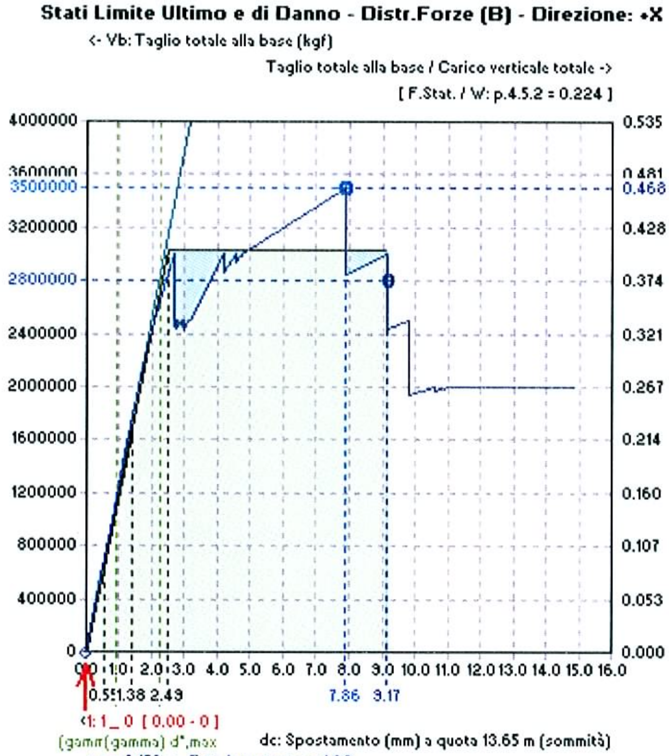
ANALISI PUSHOVER SCUOLA COCCONI: CURVE DI PUSHOVER

Stati Limite Ultimo e di Danno - Distr.Forze (A) - Direzione: +X



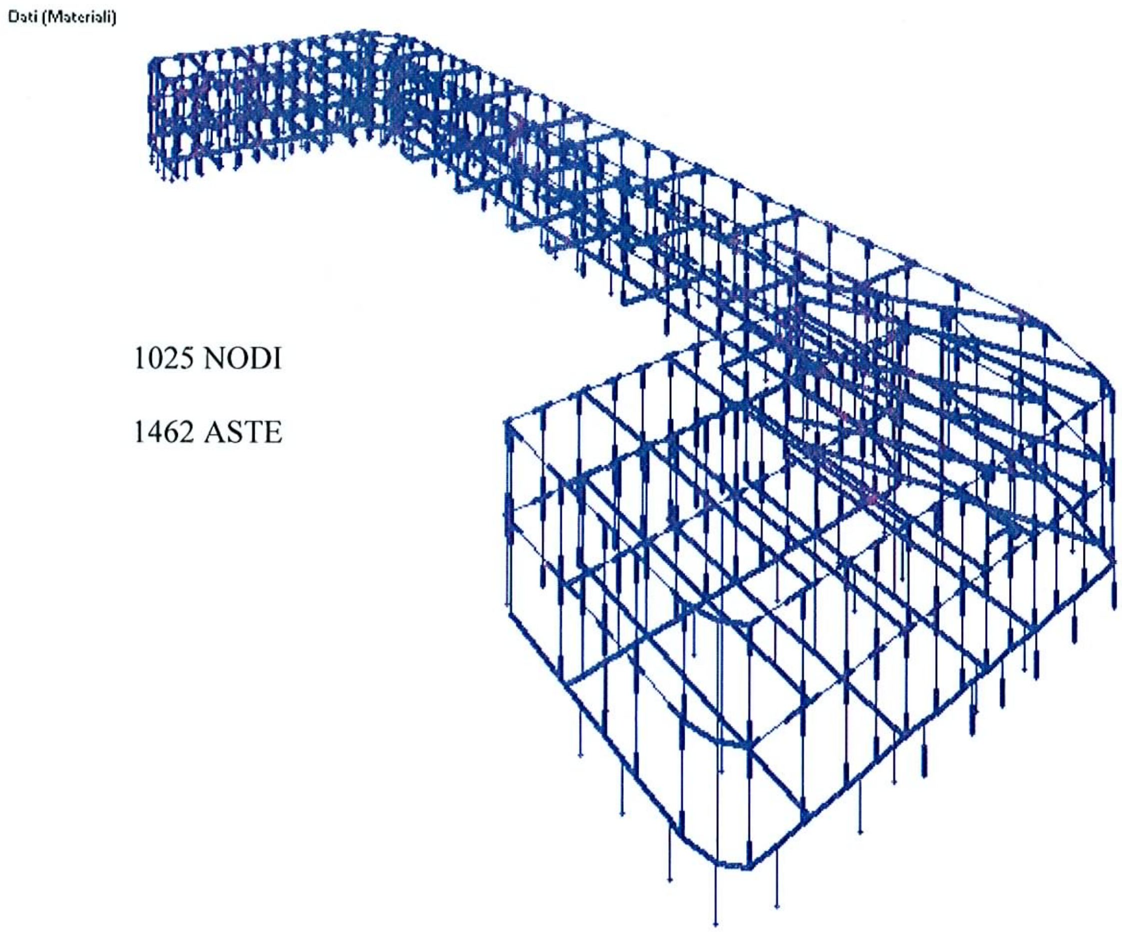
a,g = 0.150 g - Fatt. Importanza = 1.20
SLU: Capacità / Domanda = 9.16 / 2.07 = 4.42
PGADS (= PGA per danno severo = a,g sostenibile per SLU) = 0.324 g

Stati Limite Ultimo e di Danno - Distr.Forze (B) - Direzione: +X



a,g = 0.150 g - Fatt. Importanza = 1.20
SLU: Capacità / Domanda = 9.17 / 2.27 = 4.04
PGADS (= PGA per danno severo = a,g sostenibile per SLU) = 0.348 g

ANALISI PUSHOVER SCUOLA COCCONI: TELAIO EQUIVALENTE



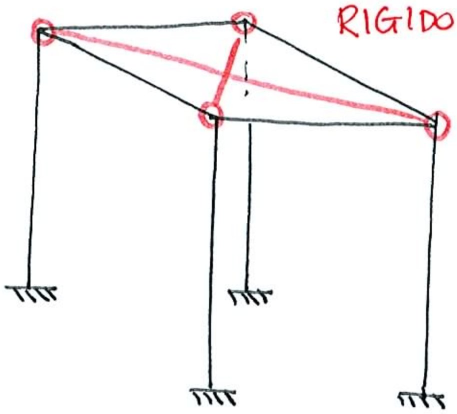
1025 NODI

1462 ASTE

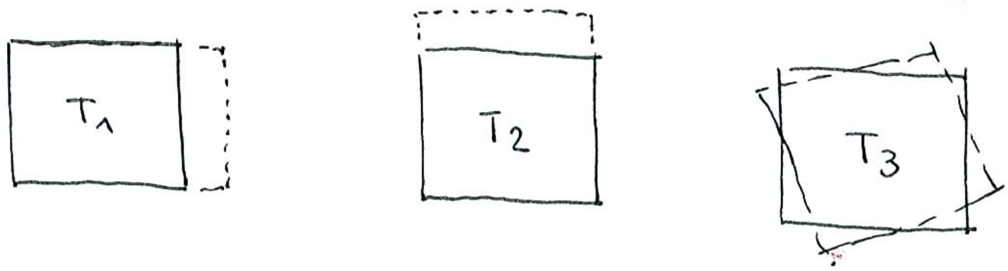
RIASSUNTO CAPACITA'/DOMANDA:

DISTR "A"	LUNGO X	4.42
DISTR "B"	LUNGO X	4.04
DISTR "A"	LUNGO Y	5.96
DISTR "B"	LUNGO Y	1.92

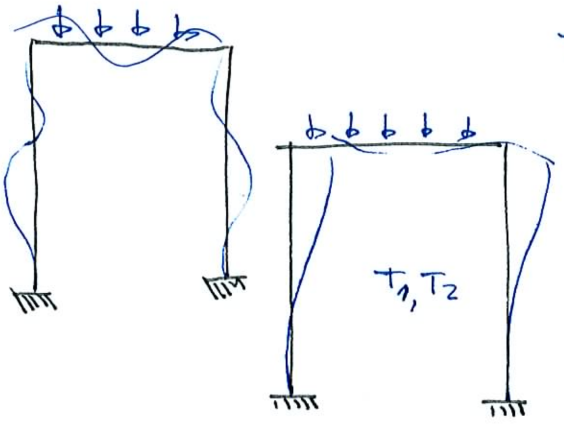
— RIGIDO



RIGIDO + RESISTENTE

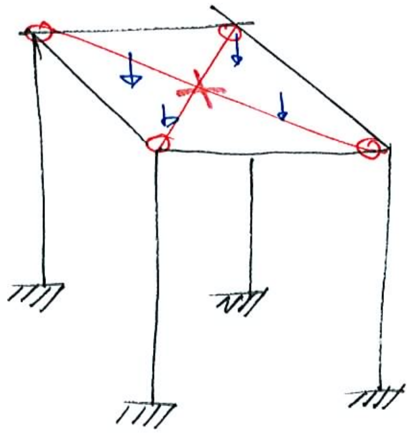


— DEFORMABILE



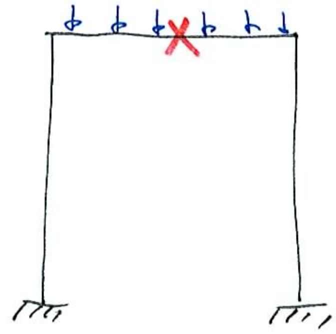
$T_1, T_2, T_3, \ldots T_\infty$

Massa partecipante
molto piccola



RIGIDO

P. controllo



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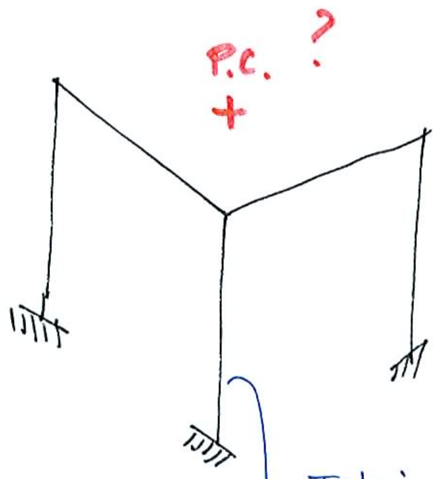

Telai ammorsati

Lateral Load Tests on a Two-Story Unreinforced Masonry Building

Tianyi Yi[1]; Franklin L. Moon[2]; Roberto T. Leon[3]; and Lawrence F. Kahn[4]

Abstract: A full-scale two-story unreinforced masonry (URM) building was tested in a quasistatic fashion to investigate the nonlinear properties of existing URM structures and to assess the efficiency of several common retrofit techniques. This paper presents the main experimental findings associated with the nonlinear properties of the original URM structure. The test structure exhibited large initial stiffness and its damage was characterized by large, discrete cracks that developed in masonry walls. Significant global behavior such as global rocking of an entire wall, and local responses such as rocking and sliding of each individual pier were observed in the masonry walls with different configurations. In addition, formation of flanges in perpendicular walls and overturning moments had significant effects on the behavior of the test structure. A comparison between the experimental observations and the predictions of *FEMA 356* provisions shows that major improvements are needed for this latter methodology.

DOI: 10.1061/(ASCE)0733-9445(2006)132:5(643)

CE Database subject headings: Masonry; Seismic effects; Failure investigations; Full-scale tests; Retrofitting.

Introduction

Unreinforced masonry (URM) construction has shown poor performance in past earthquakes. This type of construction, which has been widely used in the United States, therefore presents a large threat to life safety and regional economic development in seismic areas. While numerous experimental investigations have been conducted on URM elements, particularly piers (Epperson and Abrams 1989; Abrams and Shah 1992; Magenes and Calvi 1992; Anthoine et al. 1995; Manzouri et al. 1995; ATC 1999 to name a few), relatively few have been carried out on complete URM structural systems (Costley and Abrams 1996; Paquette and Bruneau 2003). Although these studies provided valuable insight into the nonlinear properties of URM structures and resulted in guidelines for the evaluation of existing structures (*FEMA 356*, ATC 2000), much work is still needed to characterize the true three-dimensional (3D) behavior of URM buildings.

In order to develop strength evaluation and rehabilitation strategies for URM buildings in the mid America region, several coordinated research projects were conducted in the 1996–2002 period under the sponsorship of the Mid-America Earthquake (MAE) center. Those projects included the characterization of URM building inventory in mid America (Project SE-1, French and Olshansky 2001), quasistatic in-plane strength and retrofit tests on URM piers (Project ST-6, Franklin et al. 2003), and their analyses (Project ST-4, Craig et al. 2002), shake table tests on URM out-of-plane walls (Project ST-10, Simsir et al. 2002) and their analyses (Project ST-9, Goodno et al. 2002), and testing of flexible wood diaphragms (Project ST-8, Peralta et al. 2000) and their analyses (Project ST-5, Kim and White 2002). As a capstone of those projects, a full-scale quasistatic test on a two-story URM structure was conducted at Georgia Tech (Project ST-11). In parallel, a 1/2-scale shaking table test of the same structure was conducted at the US Construction Engineering Research Laboratory (CERL) (Project ST-22).

Based on the component behavior found from other related MAE center projects, the full-scale test was aimed at evaluating the global nonlinear properties of URM structures and investigating appropriate rehabilitation approaches at the structure rather than the component level. This paper is the first of a series presenting the findings of this experimental research, and it describes the findings related to the nonlinear properties of existing URM structures. Two other papers, including one on numerical simulation and one on design implications and recommendations for changes of current *FEMA 356* provisions, have also been submitted for publication (Moon et al. 2006; Yi et al. 2006). The outcome of the associated retrofit approaches can be found in Moon (2004).

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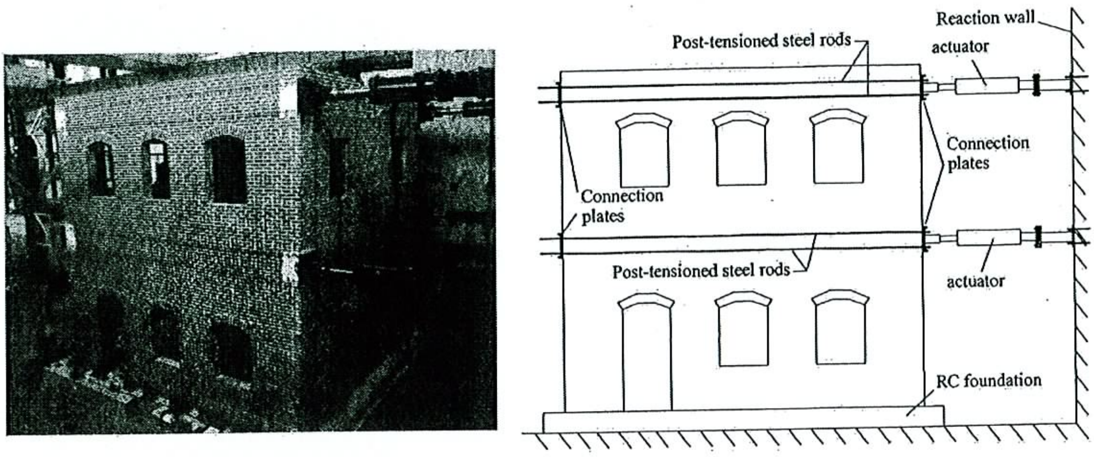
Objectives

Previous research has revealed that URM piers are the most important structural components of a URM building (Bruneau 1994). The nonlinear behavior of a URM pier is dependent primarily on its material properties, aspect ratio (the height divided by the width), and vertical stress. Based on a review of previous experimental research results, evaluation guidelines have been proposed (ATC 2000). These guidelines provide strength evaluation equations for the basic failure mechanisms for a URM pier:



(a) Photograph (b) loading system

Fig. 1. Unreinforced masonry test structure

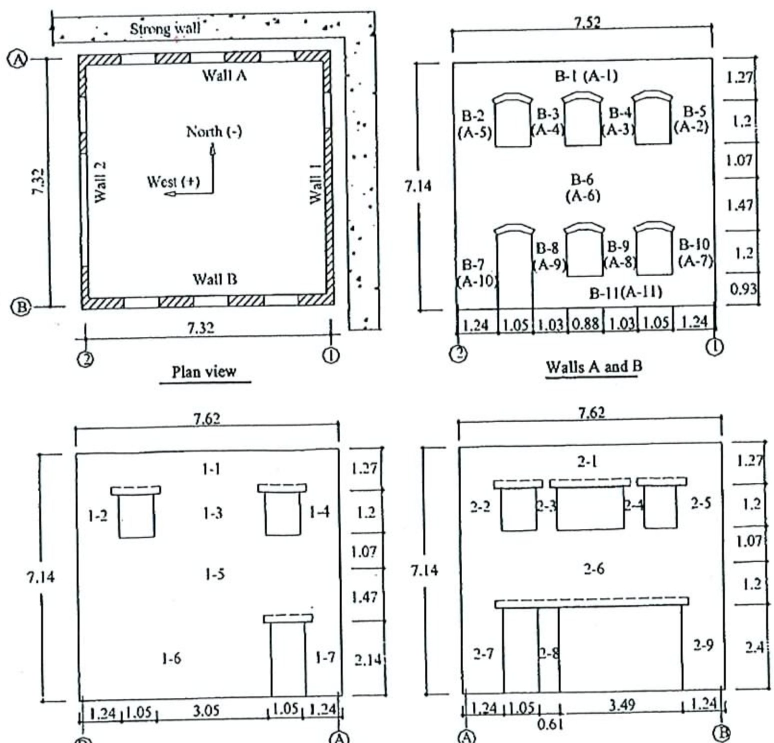


Fig. 2. Plan view and elevation of test structure (dimensions in meter)

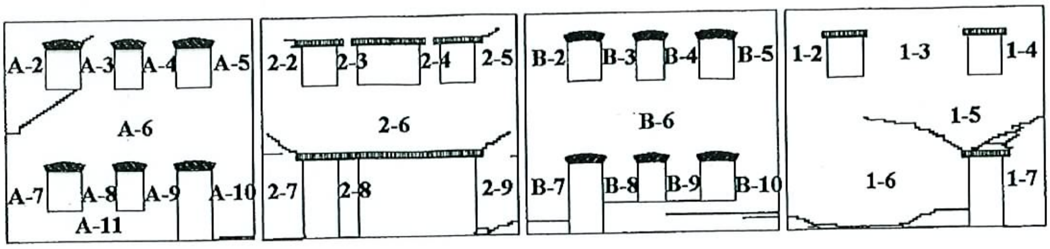


Fig. 5. Final crack pattern for test structure after in-plane wall tests parallel to Walls 1 and 2

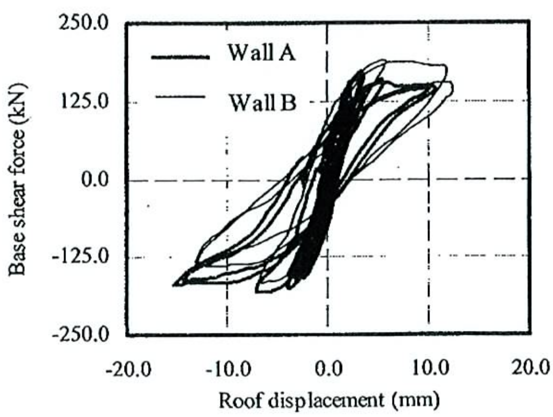


Fig. 9. Force–displacement relationship for Walls A and B

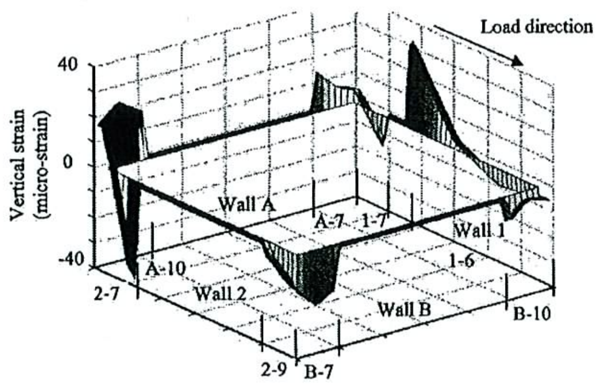


Fig. 10. Vertical stress distribution at base of wall (with roof lateral displacement of 0.43 mm)