



**University of Brighton**

# **SEISMIC RESILIENCE of Structures**

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University of Patras, Greece***

*Brighton, May 2019*

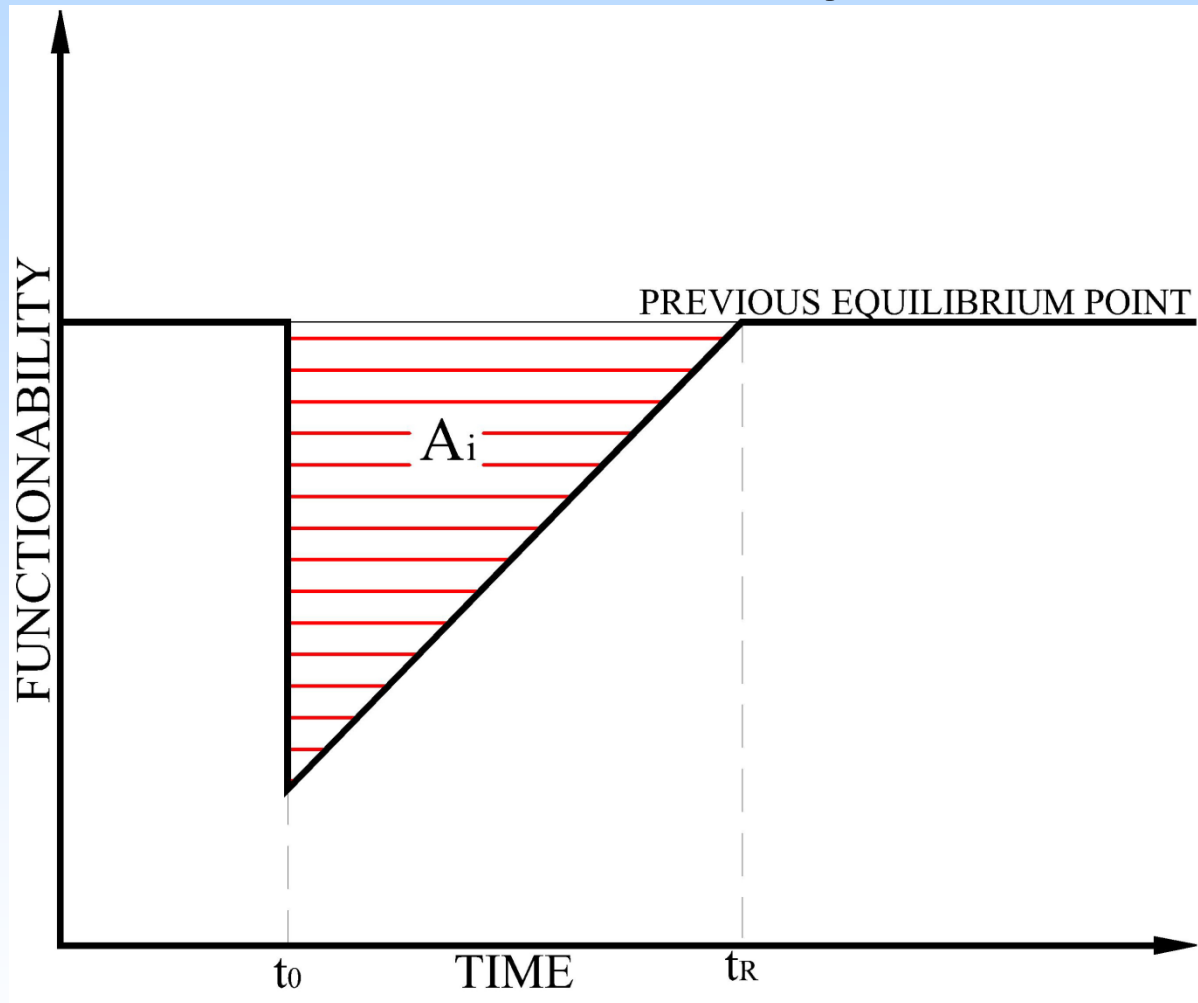
# **CONSEQUENCES OF DESTRUCTIVE EARTHQUAKES**

- **A whole region is affected**
- **Emergency services will be severely stretched**
- **There may be many high priority life threatening situations**
- **It may be several days if not weeks before a normal level of emergency services is restored**
- **It could take years if not decades before a region recovers from a severe earthquake**

# RESILIENCE

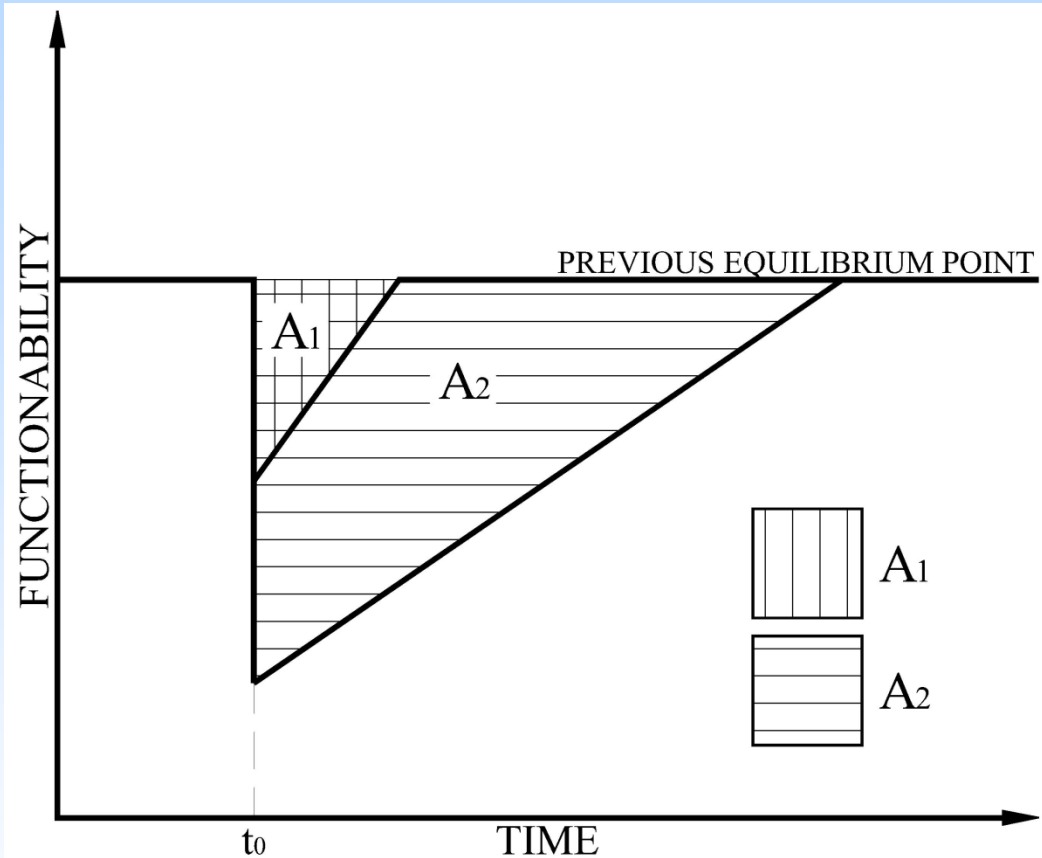
- **Need to assess resilience to disaster rather than vulnerability**
- **Resilience is the ability to cope with change and to “bounce back”**
- **Urban resilience involves preparing for, responding to and recovering from disaster**
- **A resilient society would be little affected by and would quickly recover from a catastrophe**

# RESILIENCE, R



For an event  $i$   
 $\max R_i$  when  $\min A_i$

# RESILIENCE

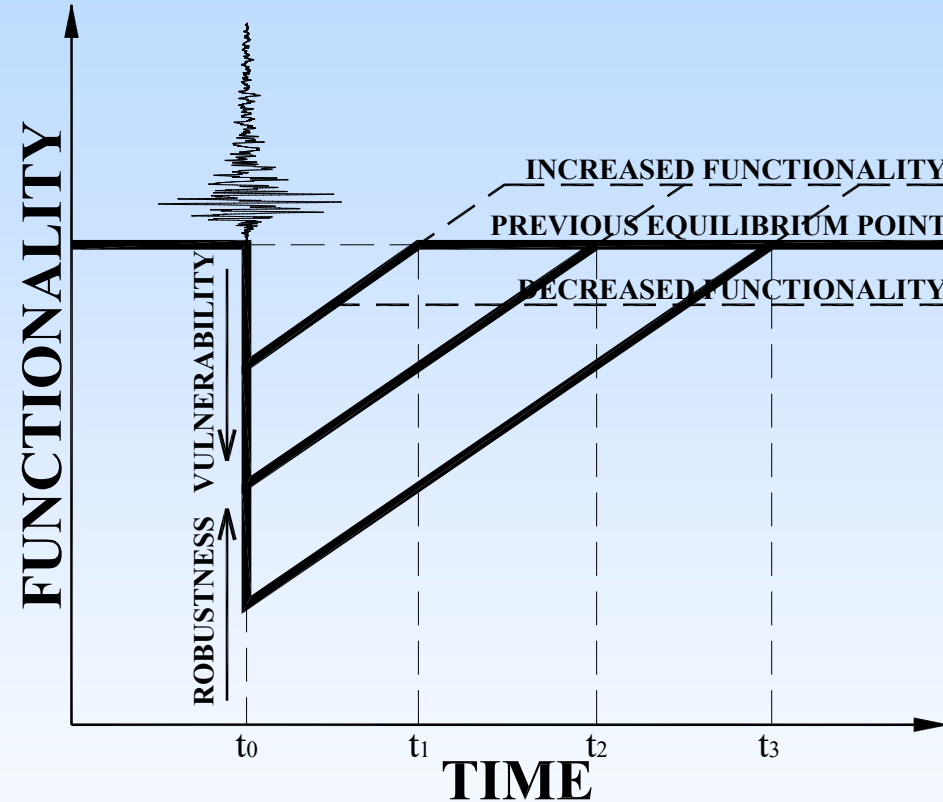


**RESILIENCE, R:**  
For event  $i$ ,  $R_i = f(1/A_i)$   
 $A_1 < A_2 \rightarrow R_1 > R_2$

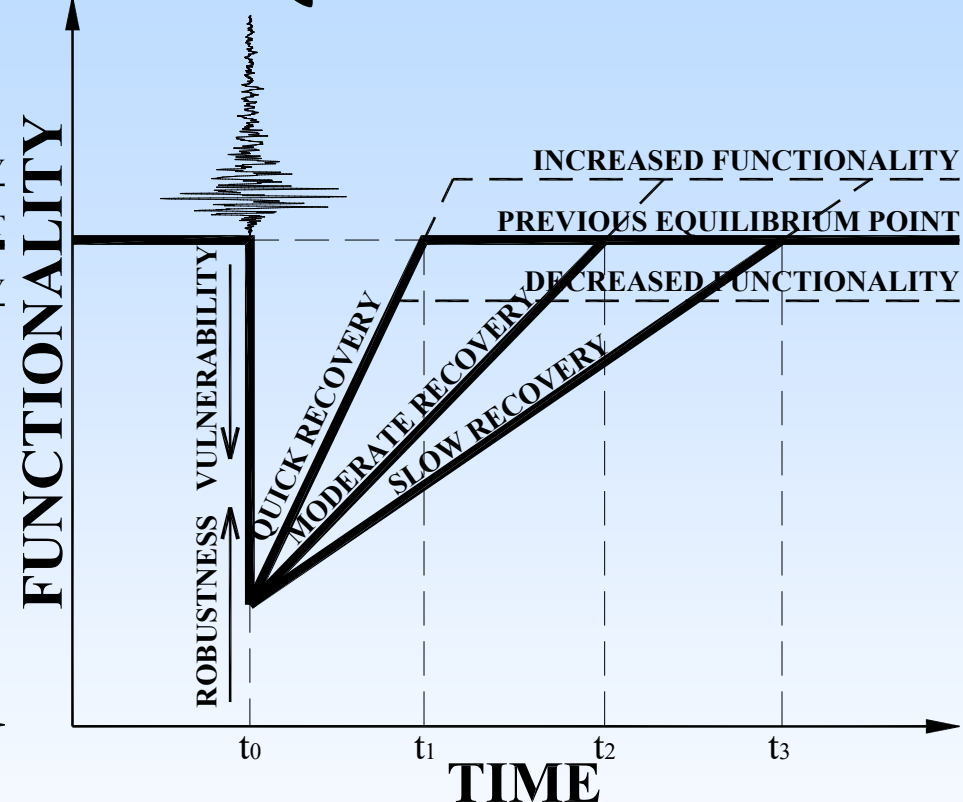
**A resilient system = little loss + quick recovery**

**A resilient society would be little affected by and would recover quickly from a disaster**

# RECOVERY AFTER AN EARTHQUAKE



loss of functionality variable



recovery rate variable

THE AREA OF THE TRIANGLES IS A MEASURE OF RESILIENCE,  
THE SMALLER THE TRIANGLE THE HIGHER THE RESILIENCE

# RECOVERY AFTER AN EARTHQUAKE

## SOME EXAMPLES OF INCREASED FUNCTIONABILITY

- **Volos, Greece, 1955 - devastated by a series of earthquakes - complete redesign of the city - now the third largest port in Greece**
- **2008 Sichuan earthquake, China - six and a half million buildings collapsed - the industrial base was rebuilt - now one of the leading manufacturing areas of China**
- **1986 Kalamata earthquake, Greece - brought a wind of change - now a modern provincial capital**

# **EARTHQUAKE RESILIENCE**

## **SOME CASES OF NON-RESILIENCE:**

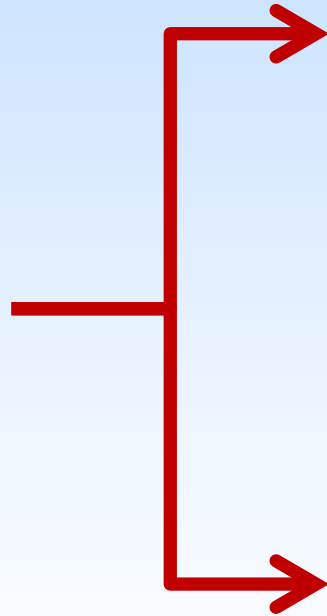
- **1755 Lisbon earthquake and tsunami severely affected Portugal's position as a colonial power, changing political, theological and philosophical thinking**
- **1908 Messina, Italy earthquake and tsunami considered as Europe's worst earthquake disaster, no anti-seismic design**
- **1953 Ionian earthquake, Greece was responsible for the exodus of the population of Cephalonia**
- **2010 Haiti earthquake reduced government and essential services to ineffectiveness - law and order broke down**

**LESSONS HAVE TO BE LEARNED**



# RESILIENCE

**HIGH  
RESILIENCE**



**High infrastructure  
performance  
(parameter 1)**

**High peoples' behaviour  
(parameter 2)**

# RESILIENCE

**Example: A ship sailing**

**Parameter 1: Infrastructure performance**

- the ship will be strong enough not sink or be affected by storms
- the ship will not sink even after capsizing (overturning), no loss of life through drowning, so that the situation can be easily recovered

**Parameter 2: peoples' behaviour**

- the best reaction of the crew and passengers

# **DESIGN FOR ALL**

**A CONCEPT CRITICAL TO DESIGN FOR RESILIENCE**

**The most vulnerable community groups suffer the most during and after an earthquake**

# DESIGN FOR ALL

New (?) Concept: **Design for all**

Consider

- Not only the general population
- All possible target groups



**Account for the most vulnerable part of the population or the vulnerability characteristics of the target groups**

# DESIGN FOR ALL

**As an example from engineering thinking:**

**If in a structure there exists a vulnerable element such as a column or a beam, then the vulnerability will affect the integrity of the whole structure**

**Similarly, if in a community there exists a vulnerable group such as people with disabilities, children, the aged, migrants, etc., then vulnerability will affect the integrity of the whole community. In the ship sailing example, we have in mind the priority “women and children first.”**

## **DESIGN FOR ALL: New Concept?**

**Part of a whole culture**

**Part of a holistic education**

**Part of a philosophy**

**In the Greek Language, “education” is expressed as:**

***Εκπαίδευση* (Ekpethefsi) or *Παιδεία* (Petheia)**

# EDUCATION as part of resilience

*Εκπαίδευση* (Ekpethefsi):

- mainly knowledge offered at schools
- also sometimes includes training

*Παιδεία* (Petheia):

- general way of thinking
- philosophical global education
- build culture
- build behaviour
- build character

More intense for the very young

*Παιδεία* (Petheia) = global education

*Παιδί* (Pethi) = child

And also *Παίζω* (Pezo) = to play

*Μόρφωση* (Morphosi) = to give shape, form (morphology)

**Design for all** → **Thinking as a community**

Not “**me** and **mine**” but “**us** and **ours**”

# **PARAMETERS**

**1: INFRASTRUCTURE PERFORMANCE**

**2: PEOPLES' BEHAVIOUR**



# Parameter 1: Infrastructure Performance

Urban planning and the built environment – design the whole city, provide open spaces, escape routes, increased resilience .....

## GOAL

**Earthquake resilient structures**

Design, Construct, Redesign, Retrofit, Reconstruct in order to minimise (attacking) effects of actions from possible disaster sources (earthquakes, floods, fires, windstorms, volcanoes, explosions as well .....

# Parameter 2: Peoples' Behaviour

## **AFTER A DESTRUCTIVE EVENT:**

- **A WHOLE REGION IS AFFECTED**
- **EMERGENCY SERVICES WILL BE SEVERELY STRETCHED**
- **THERE WILL BE MANY OTHER HIGHER PRIORITY LIFE THREATENING SITUATIONS**
- **IT MAY BE SEVERAL DAYS BEFORE A NORMAL LEVEL OF EMERGENCY SERVICES CAN BE PROVIDED**

# Parameter 2: Peoples' Behaviour

In General → Achieve the best effective reaction from people in any disaster

In Particular → Specific measures depending on:  
- the disaster source  
- the different capabilities of the population

TOOLS: EDUCATION and TRAINING

# **EARTHQUAKES FATALITIES**

## **MOST FATALITIES NOT FROM STRUCTURAL DAMAGE**

**It has been reported (Jones et al., 1990 for the Loma Prieta earthquake and Barque et al., 1991 for Whittier Narrows earthquake) that the majority of fatalities and injuries were mostly affected by how people behaved during or immediately after the earthquake and the fatalities and injuries were caused by people falling down or being hit by non structural elements and building contents.**

## Parameter 1: Infrastructure Performance



**Fatalities can also occur without serious damage to the building**

## Parameter 1: Infrastructure Performance



**Fatalities can also occur without damage to the building**

## Parameter 1: Infrastructure Performance



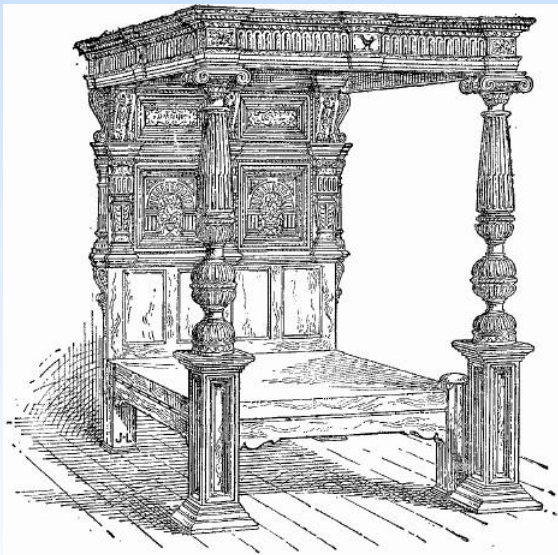
**Fatalities can also occur without damage to the building  
Mind to get under the table when you feel shaking from an earthquake**

Parameter 1: Infrastructure Performance

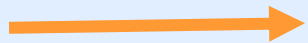
# EXAMPLE: EARTHQUAKE RESISTANT BED

Recommended for people with mobility impairments but also for other cases

Enclosed beds with a strong roof



CARVED OAK ELIZABETHAN BEDSTEAD.



Four poster bed



(<http://inhabitat.com/>)



([http://www.lifeguardstructures.com/order/index\\_24.php?dispatch=products.view&product\\_id=48](http://www.lifeguardstructures.com/order/index_24.php?dispatch=products.view&product_id=48))



# DESIGN FOR RESILIENCE

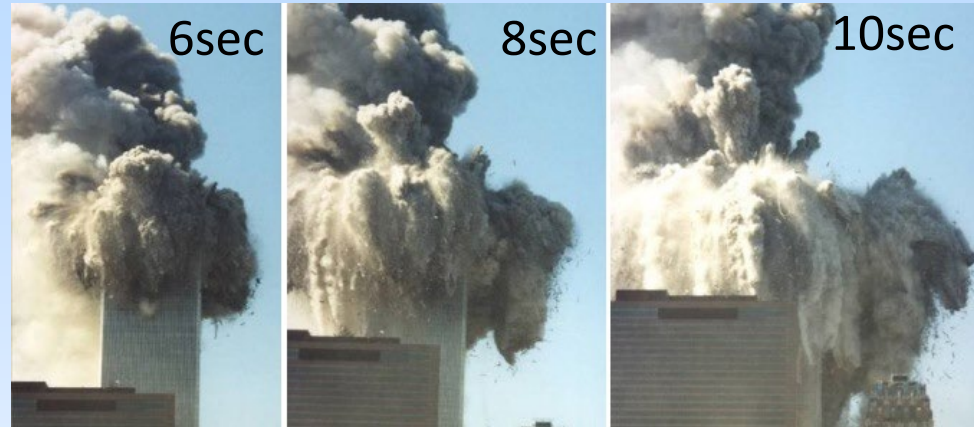
**Three examples of innovative design:**

- **Design for loss of column(s) due to unidentified accidental actions**
- **Seismic isolation as a design solution**
- **Rocking isolation as a design solution**

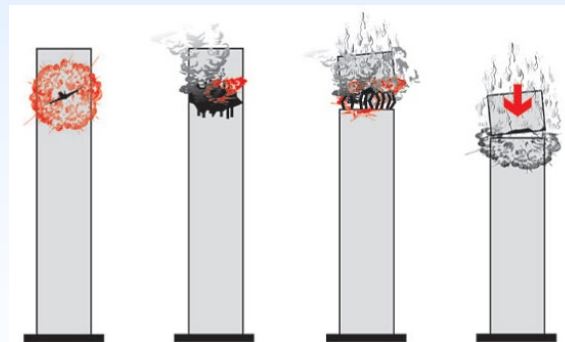
# A. Design for loss of column(s) due to unidentified accidental actions



**Ronan Point (London 1968)**  
**Gas explosion on 18<sup>th</sup> floor**



**World Trade  
Centre (2001)**



Buildings and Infrastructure Protection Series

## Preventing Structures from Collapsing

to Limit Damage to Adjacent Structures and Additional  
Loss of Life when Explosives Devices Impact Highly  
Populated Urban Centers

BIPS 05/June 2011



Homeland  
Security

Science and Technology

**Guidelines publication**

(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)

# EN 1990-1 (Basis of Structural Design)

(4)P A structure shall be designed and executed in such a way that it will not be damaged by events such as :

- explosion,
  - impact, and
  - the consequences of human errors,
- to an extent disproportionate to the original cause.

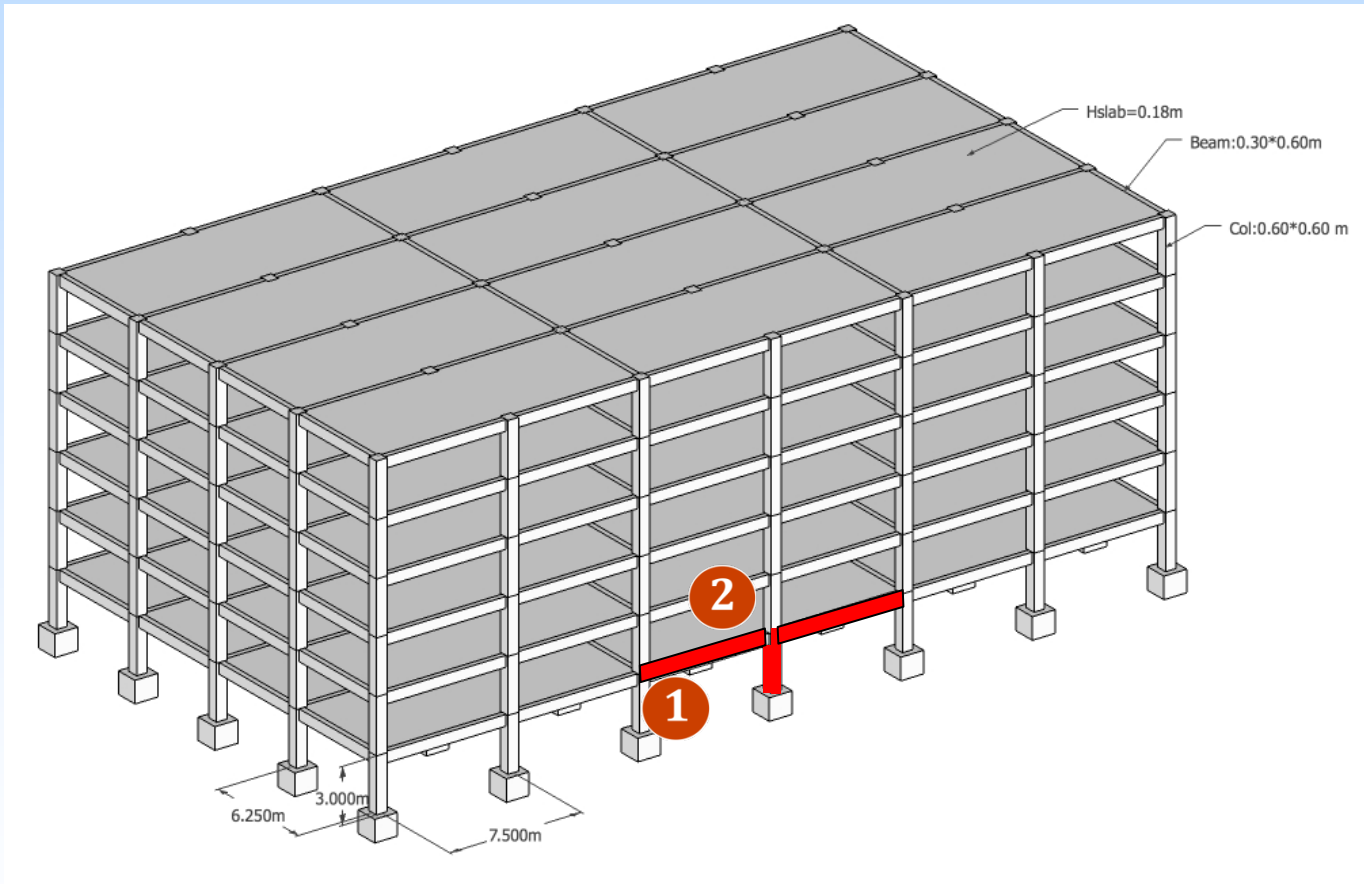
Further information is given in EN 1991-1-7 (Accidental Actions)

## EN 1991-1-7 (Accidental Actions)

The adoption of strategies for limiting the extent of localised failure may provide adequate robustness against those accidental actions identified in the code or any other action resulting from an unspecified cause

# Resistance to loss of support

## Alternative load paths?



(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)

# PRESCIENT University of Patras project

Paradigm for Resilient Concrete Infrastructures to Extreme Natural and Man-made Threats

Co-ordinator: Prof. M. Fardis

**PRESCIENT** ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ - ΤΜ. ΠΟΛΙΤΙΚΩΝ ΜΗΧΑΝΙΚΩΝ ΕΡΓΑΣΤΗΡΙΟ ΚΑΤΑΣΚΕΥΩΝ

Α+ Α Α- ΧΑΡΤΗΣ ΙΣΤΟΤΟΠΟΥ

ΤΟ ΠΡΟΓΡΑΜΜΑ ▾ ΕΡΕΥΝΑ ΔΗΜΟΣΙΕΥΣΕΙΣ ΕΡΓΑΣΤΗΡΙΑ ▾ ΕΠΙΚΟΙΝΩΝΙΑ

*"Paradigm for Resilient Concrete Infrastructures to Extreme Natural and Man-made Threats"*

*"Κατασκευές από σκυρόδεμα ανθεκτικές σε ακραίες φυσικές και ανθρωπογενείς απειλές"*

Ευρωπαϊκή Ένωση  
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ  
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ  
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ, ΕΡΕΥΝΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ  
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ  
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

ΕΣΠΑ  
2007-2013  
Ευρωπαϊκή Ένωση

ΜΑΘΕΤΕ ΠΕΡΙΣΣΟΤΕΡΑ

**Ανακοινώσεις**

Παράταση της ημερομηνίας λήξης του έργου  
Σεπτέμβριος 10, 2015  
Εγκρίθηκε αίτημα παράτασης της ημερομηνίας λήξης του έργου κατά ένα μήνα, ήτοι η λήξη του έργου μεταφέρεται στις 30 Σεπτεμβρίου 2015.

Το 4ο εξάμηνο αναφοράς του έργου ολοκληρώθηκε  
Ιούλιος 6, 2015

**Τελευταίες Δημοσιεύσεις**

Uplift of deck or footings in bridges with distributed mass subjected to transverse earthquake

Hybrid Simulation of Bridge Pier Uplifting

An Analytical Method for the Estimation of Radiation Heat Flux from Open pool Fires and pool Fires Im-pinging on Ceilings

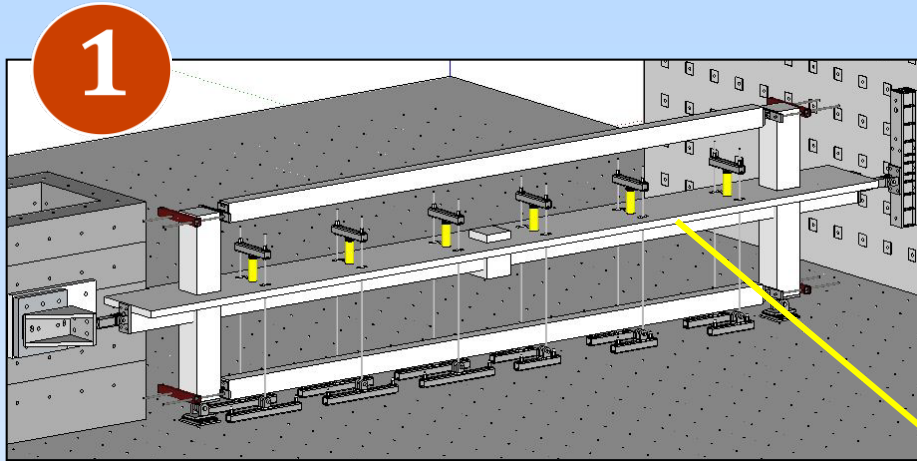
**Χρήσιμοι Σύνδεσμοι**

Σχετικά  
Ανακοινώσεις  
Δημοσιεύσεις

[www.prescient.upatras.gr](http://www.prescient.upatras.gr)

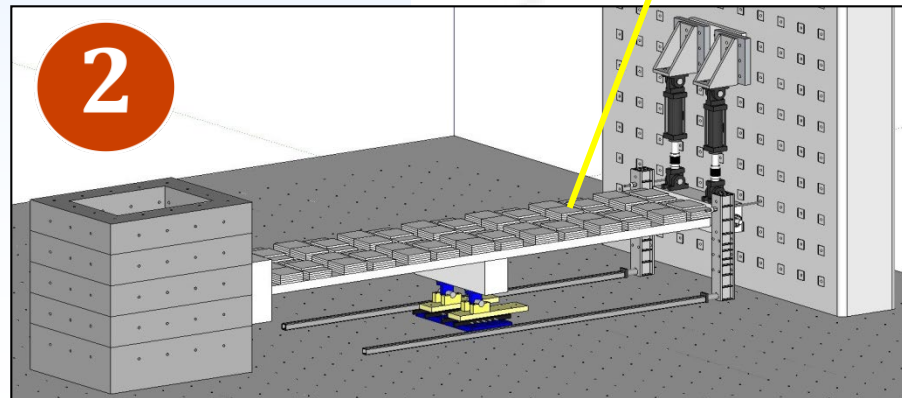
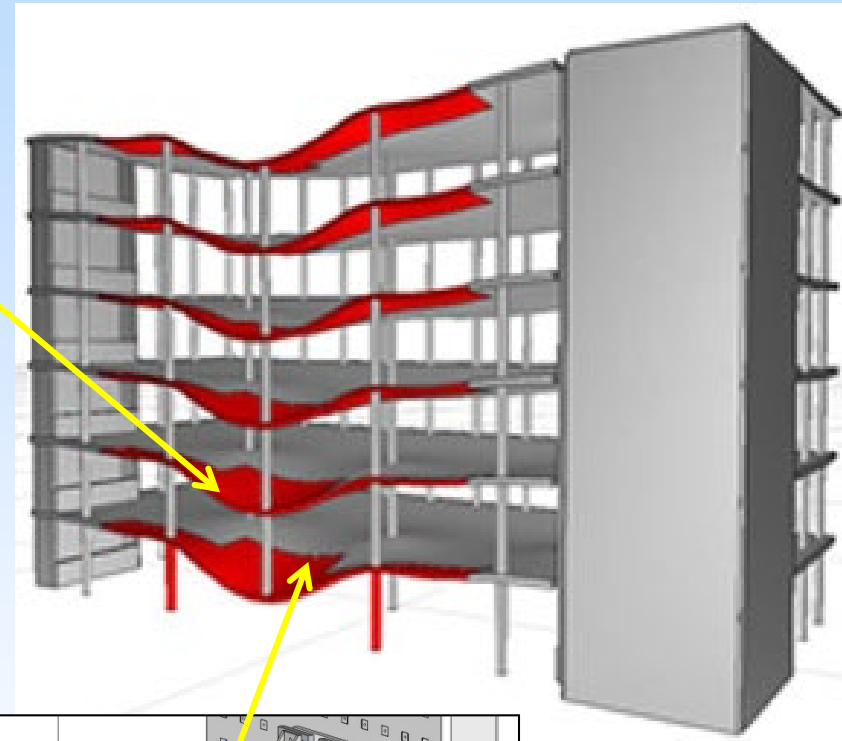


# Column failure



**How does the frame take the load?**

**Can the slab and the internal beam transfer the load to the external beams?**



(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)

# Earthquake damage

## Column loss



**Beneficial role of infill walls in the upper floor to resist progressive collapse following the loss of column(s)**

# Testing a building for loss of column

Scale 2:3

Investigate building behaviour designed to withstand earthquakes (according to Eurocode 8) with/without infill walls on the first floor during the instantaneous removal of:

- Perimeter column
- Corner column
- Central column

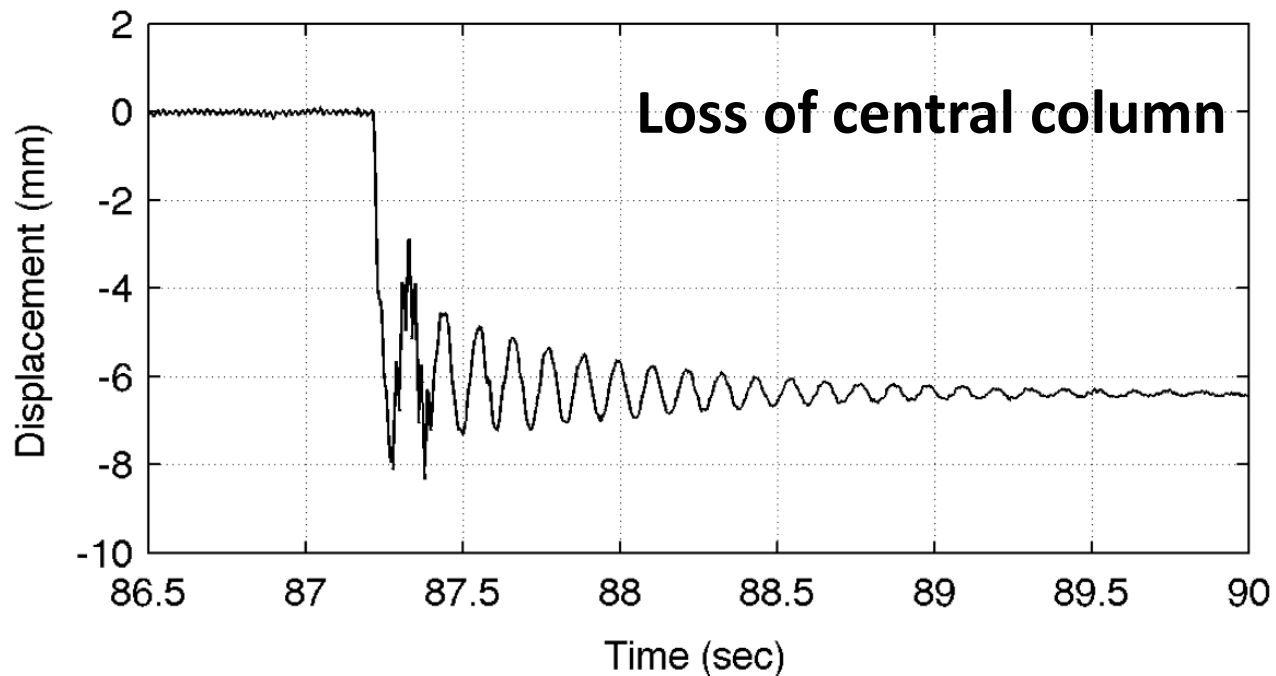
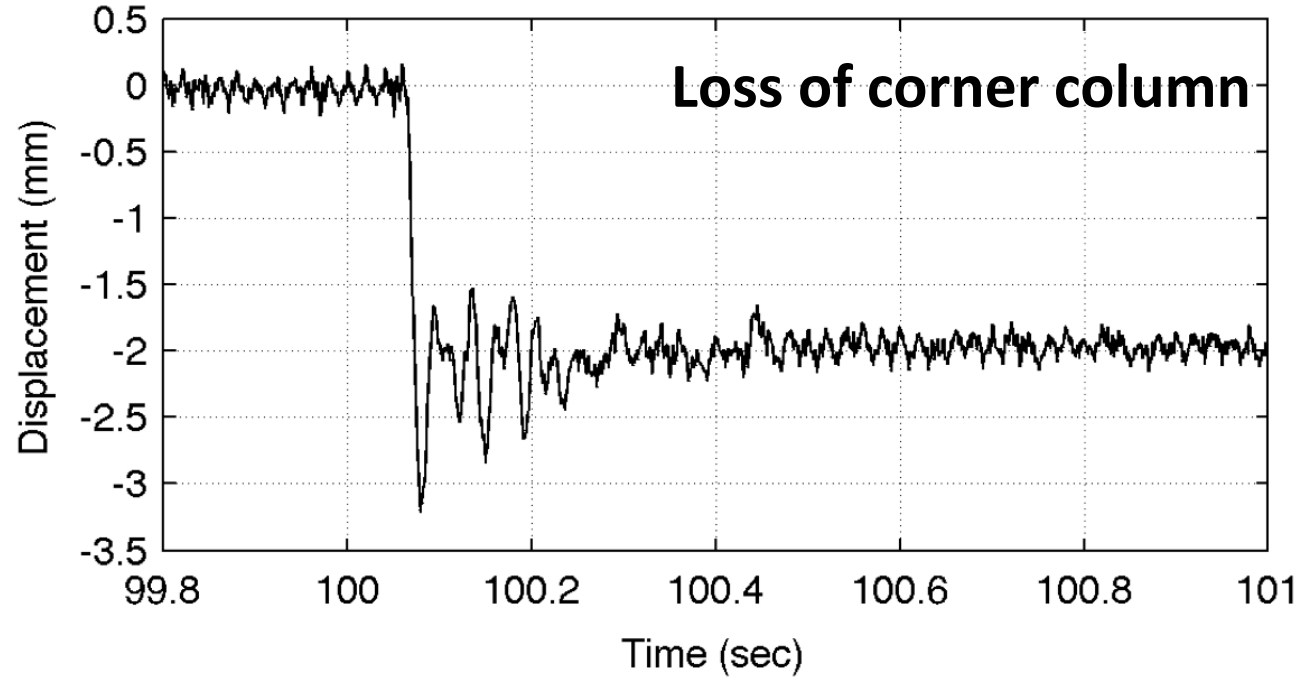


(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)





(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)



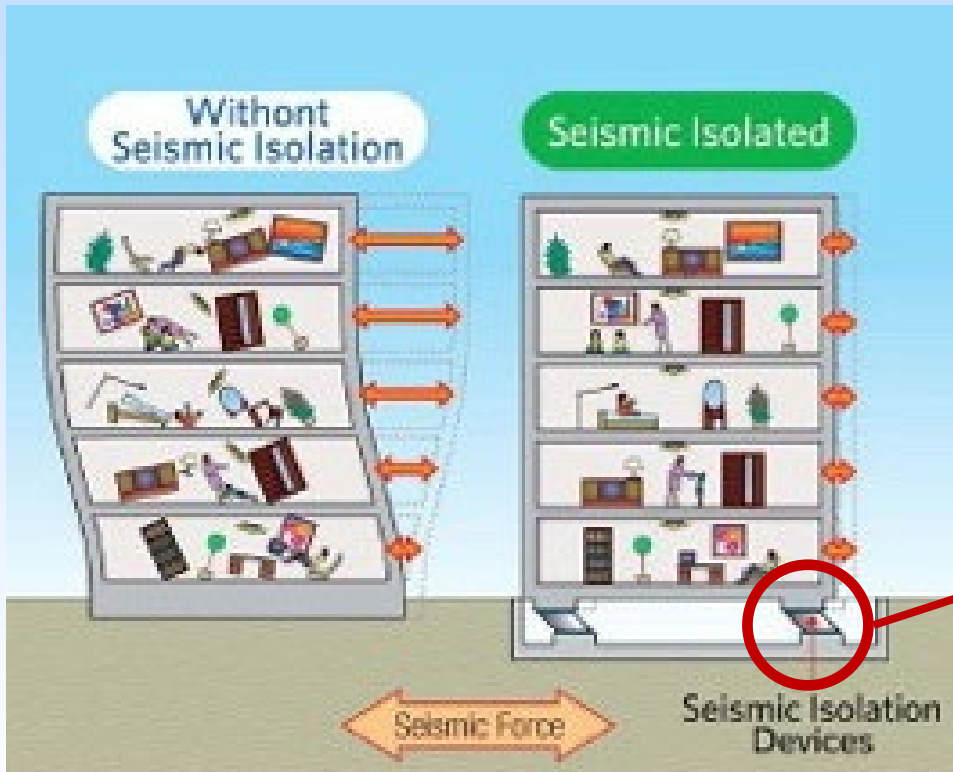
# The final test

- Remove infill walls
- Increase load (37 ton/floor  $\rightarrow$  70 ton/floor)
- Remove perimeter column



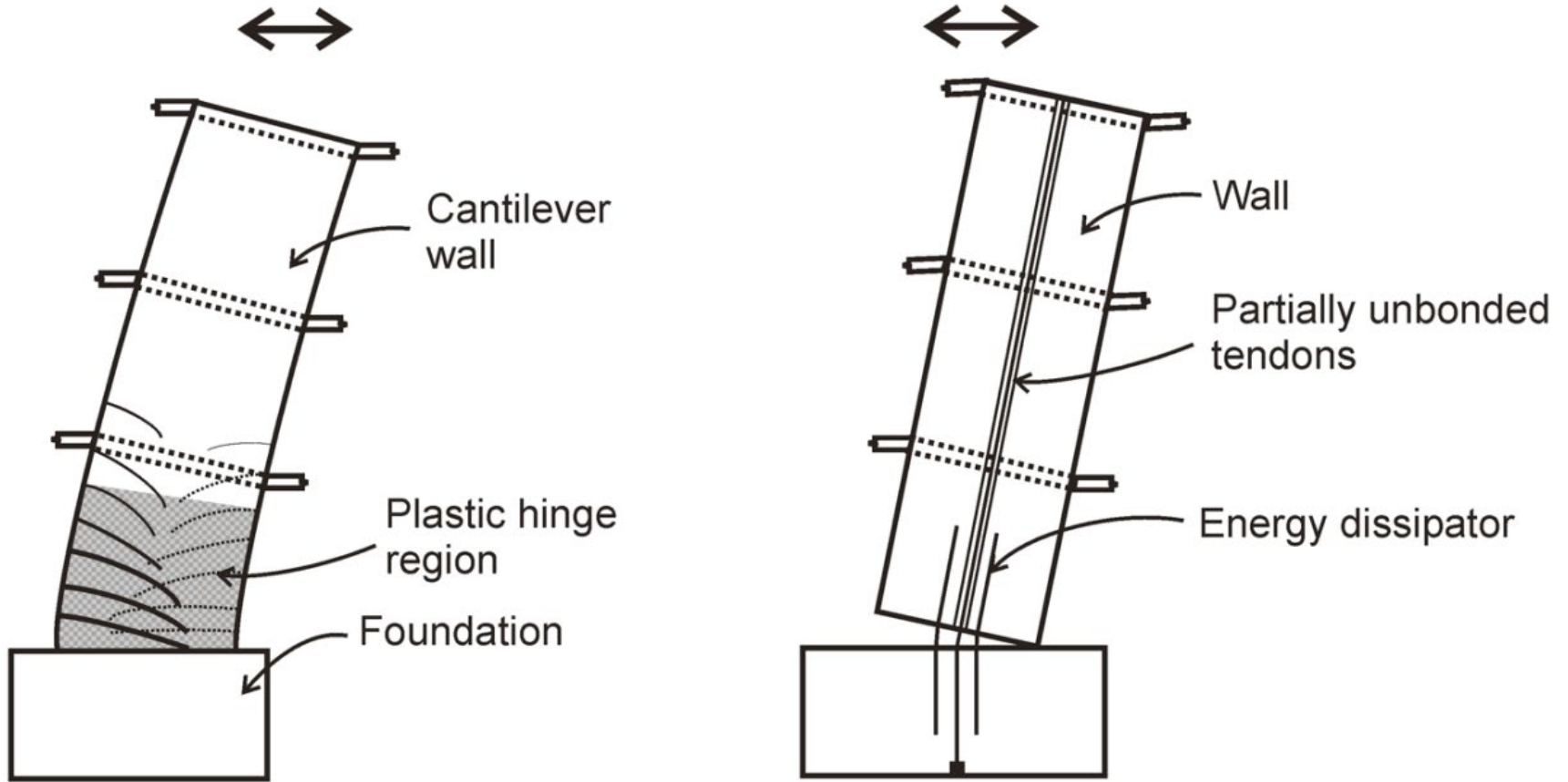
(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)

# B. SEISMIC ISOLATION





# B. ROCKING ISOLATION



An innovative design could be to allow rocking and expect an elastic response of the column.

→ Minimum damage (losses)

→ Recovery to original

→ **RESILIENCE**

(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)



## **ROCKING ISOLATION**

### **Seismic table tests**

**Dept. of Civil Engineering, Patras University**

(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)



## **ROCKING ISOLATION Pseudodynamic Tests**

**Structural Lab, Dept. of Civil Engineering, Patras University**

(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)



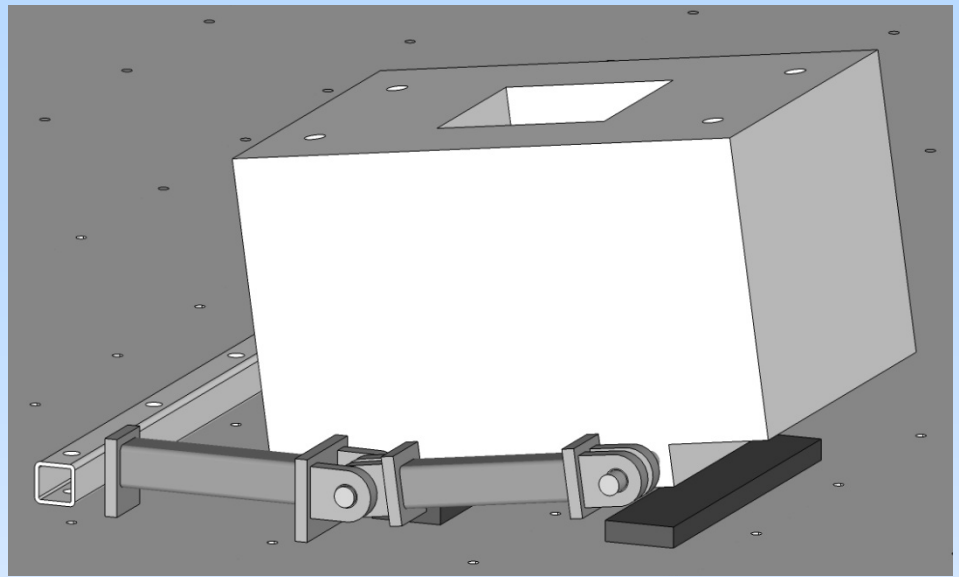
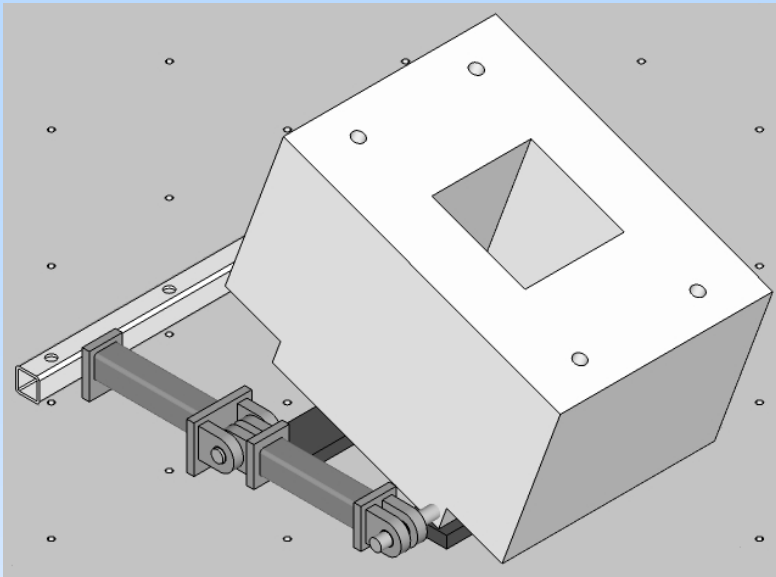
# **SIMULATION OF ROCKING ISOLATION**

## **Pseudodynamic Tests**

**Structural Lab, Dept. of Civil Engineering, Patras University**

(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)





## **SIMULATION OF ROCKING ISOLATION**

### **Pseudodynamic Tests**

**Structural Lab, Dept. of Civil Engineering, Patras University**

(Bousias, 22<sup>nd</sup> Students' Conference, Patras, 2016)

# LEARNING FROM ANCIENT GREECE

Resilience through unbonded sliding and rocking segmented columns



Still standing  
after 2500 years

(Galanopoulos, 1956)

# A GREEK MYTH

The ancient Greeks symbolised the earthquake as the chief of the Giants named Egelados, who was attacking and punishing the people. Goddess Athena beat Egelados in a battle and imprisoned him in Mount Etna in Sicily. This is the reason why Etna erupts from time to time, as Egelados tries to escape. As Athena was the goddess of wisdom and knowledge, the myth's message is that people should not be afraid. Wisdom and knowledge will win the battle with the earthquake.

# Find more .....

The screenshot shows the STRULAB website interface. At the top, there is a navigation bar with links for Home, Sitemap, Contact us, and a search box. Below this is a secondary navigation bar with categories: HOME, FACILITIES, RESEARCH / PROJECTS, PERSONNEL, EDUCATION, PUBLICATIONS, and RESOURCES. A breadcrumb trail indicates the user is in the Home / Photo Gallery section. The main content area is titled "Photo Gallery" and includes a sub-header "Click a thumbnail to see the full size photo". There are six photo thumbnails arranged in a 2x3 grid. The first two show pseudodynamic testing of a two-storey RC building frame. The third shows retrofitting with reinforced concrete jackets. The fourth shows damage at the base of a column. The fifth shows a cyclic test of a masonry-infilled RC frame. The sixth shows a workshop on earthquake engineering. To the right of the gallery is a "Quick links" section with "Software" and "Telepresence" links, and a "Latest News" section with several news items including "Latest experimental activities", "Tests on RC slabs", "First international distributed test", "First hybrid test between two research teams in Greece", "Strengthening of masonry infilled RC frame with Textile-Reinforced Mortar (TRM) - Completion of the experimental campaign", "Material from workshop on Earthquake Engineering Research Infrastructures now available", and "Cyclic test of three-storey masonry-infilled RC frame". At the bottom of the news section is a "News Archive" link.

[stulab.civil.upatras.gr](http://stulab.civil.upatras.gr)

[episkeves2.civil.upatras.gr](http://episkeves2.civil.upatras.gr)

The screenshot shows the episkeves2.civil.upatras.gr website. At the top, there is a header with the logo of the University of Patras and the text "ΕΠΙΣΚΕΥΕΣ & ΕΝΙΣΧΥΣΕΙΣ ΚΑΤΑΣΚΕΥΩΝ - ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ" and "REPAIR & STRENGTHENING OF STRUCTURES - UNIVERSITY OF PATRAS". Below the header is a navigation bar with links for HOME, COMMITTEES, CONTACT US, SPONSORS, and flags for the UK and Greece. The main content area features a grid of six news items, each with a thumbnail image and a title: "Student Conferences on Repair and Strengthening of Structures", "Greek Code of Structural Interventions (G.C.S.I)", "Jobs on Repair and Strengthening of Structures", "21st Student Conference on Repair and Strengthening of Structures", and two images showing structural repair work on concrete columns.