SEISMIC RESILIENCE of Structures

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Brighton, May 2019

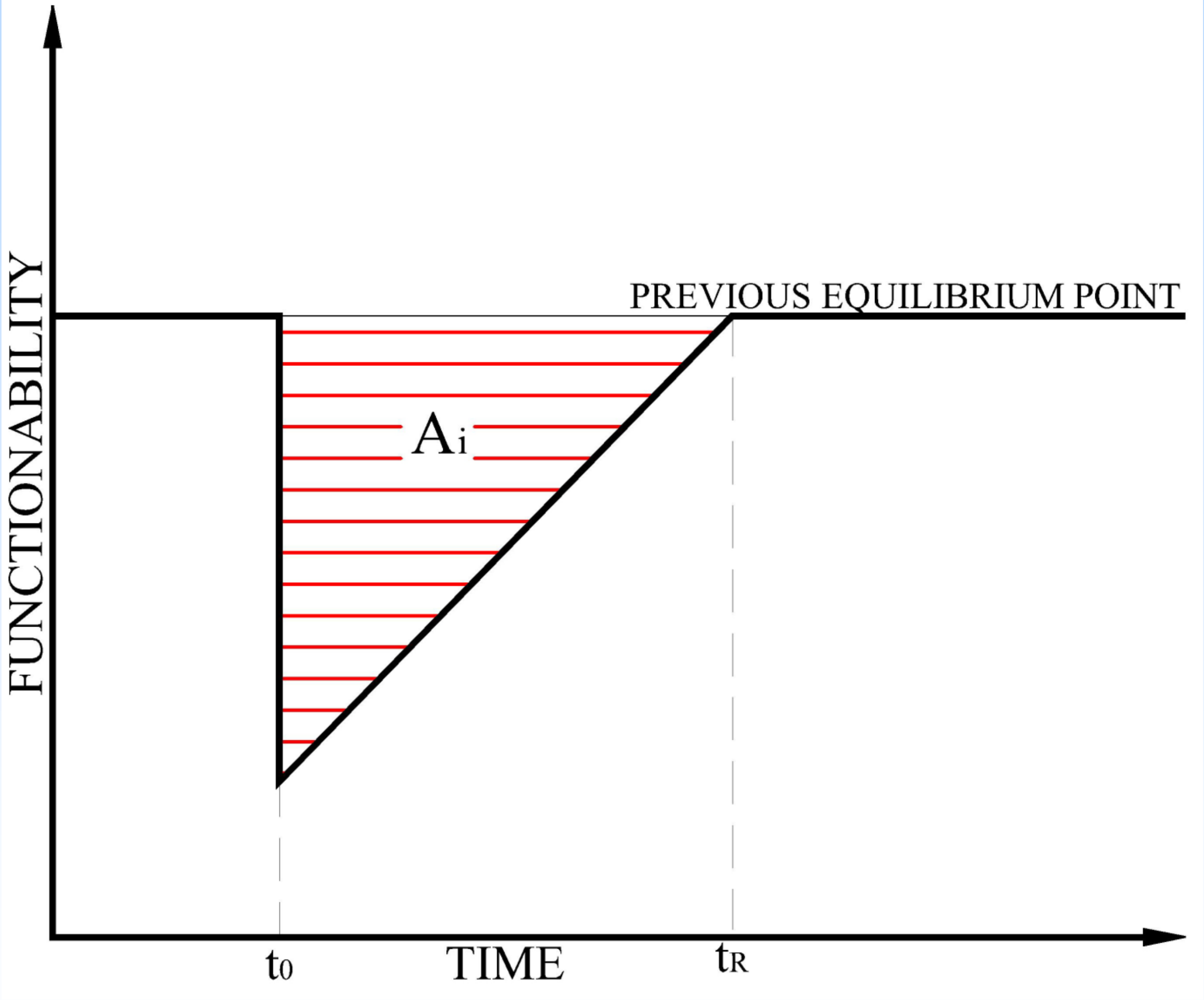
CONSEQUENCES OF DESTRUCTIVE EARTHQUAKES

- **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**

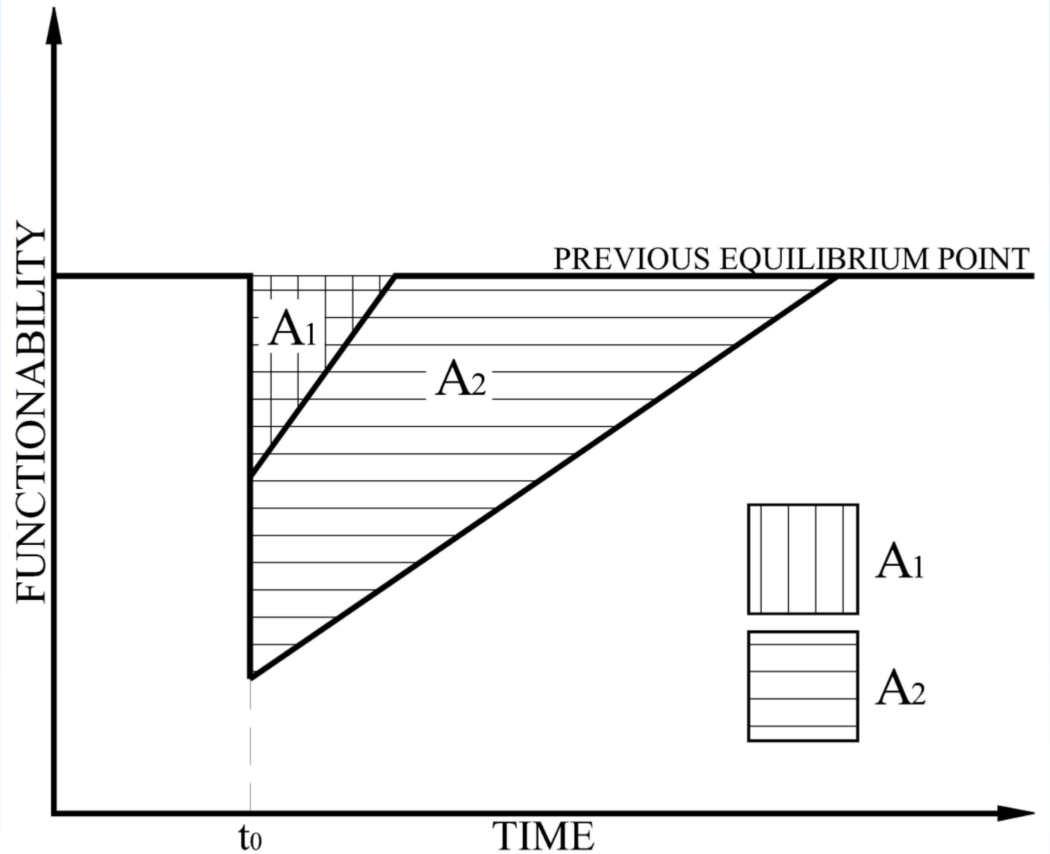
RESILIENCE, R



For an event i

$maxR_i$ when $minA_i$

RESILIENCE



RESILIENCE, R:

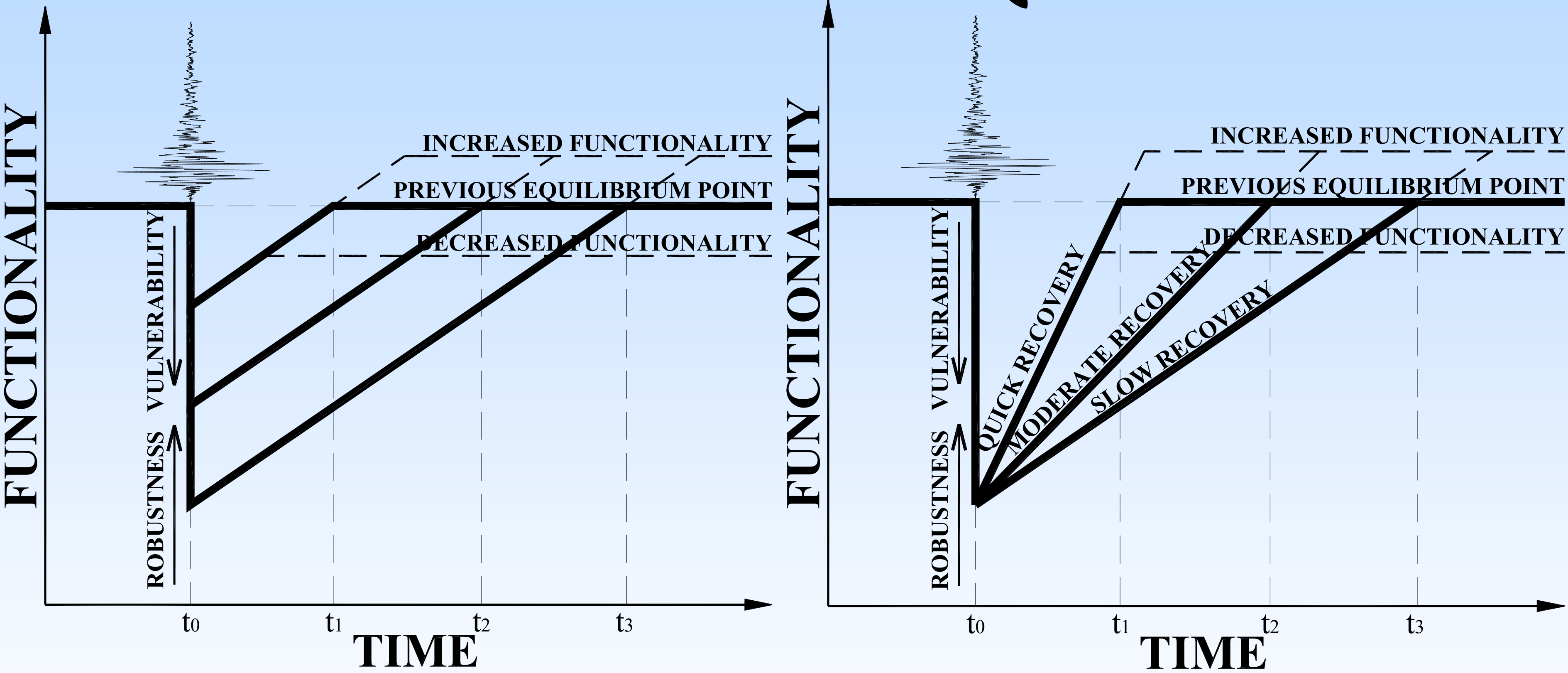
For event i, $R_i = f(1/A_i)$

$A_1 < A_2 \rightarrow R_1 > R_2$

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 expessed 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

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

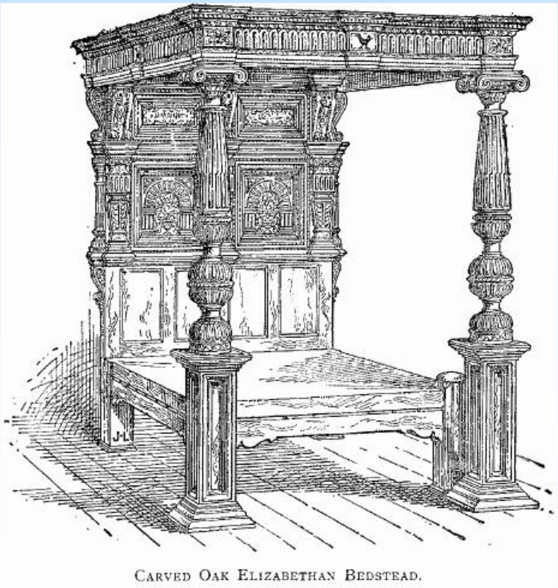
Mind to get under the table when you feel shaking from an earthquake

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



(http://inhabitat.com/)

Four poster bed

(http://www.lifeguardstructures.com/order/index.php?dispatch=products.view&product_id=48)

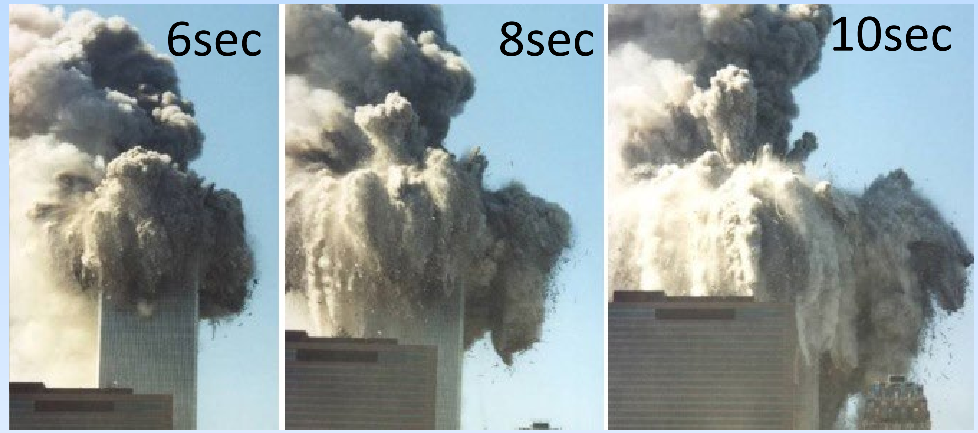
DESIGN FOR RESILIENCE

Three examples of innovative design:

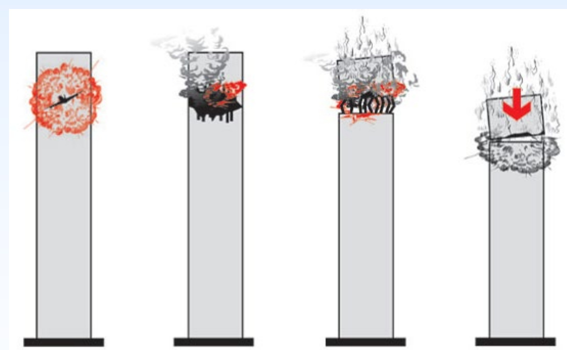
- **Design for loss of column(s) due to unidentified accidental actions**
- **Seismic isolation as a design solution**
- **Rocking isolation as a design solution**

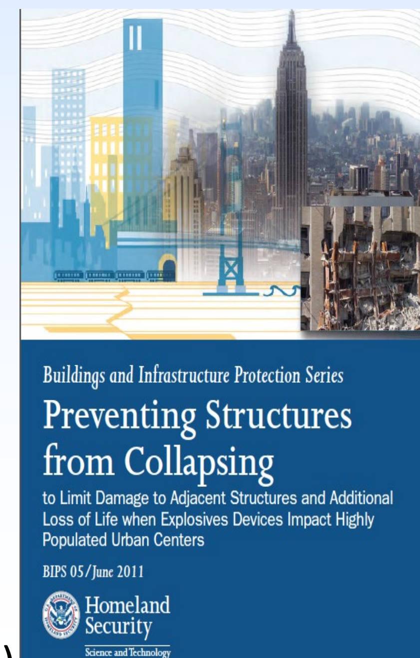
A. Design for loss of column(s) due to unidentified accidental actions

Ronan Point (London 1968)
Gas explosion on 18th floor



World Trade Centre (2001)





Guidelines publication

(Bousias, 22nd 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,

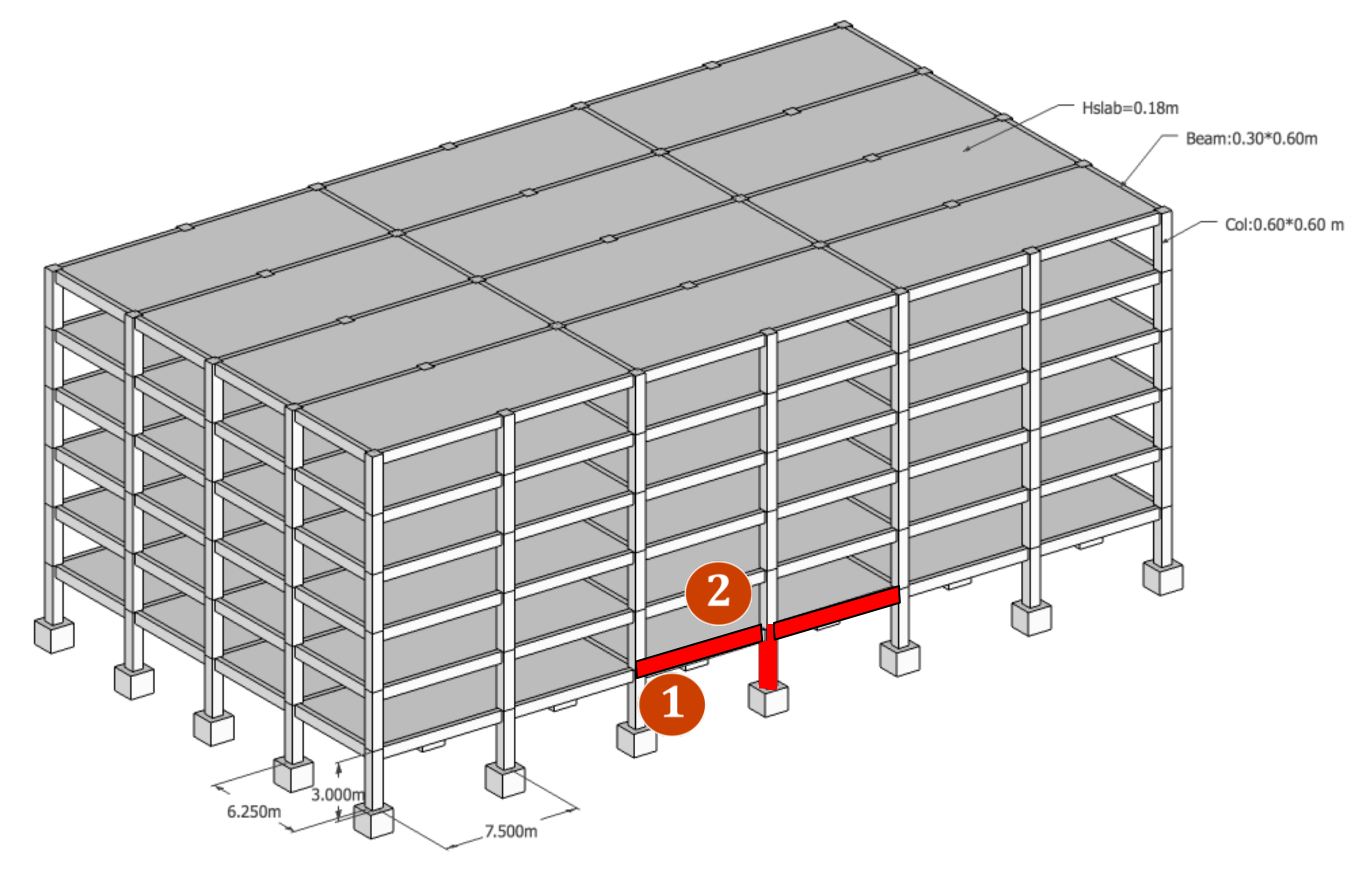
to an extent disproportionate to the original cause.

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?

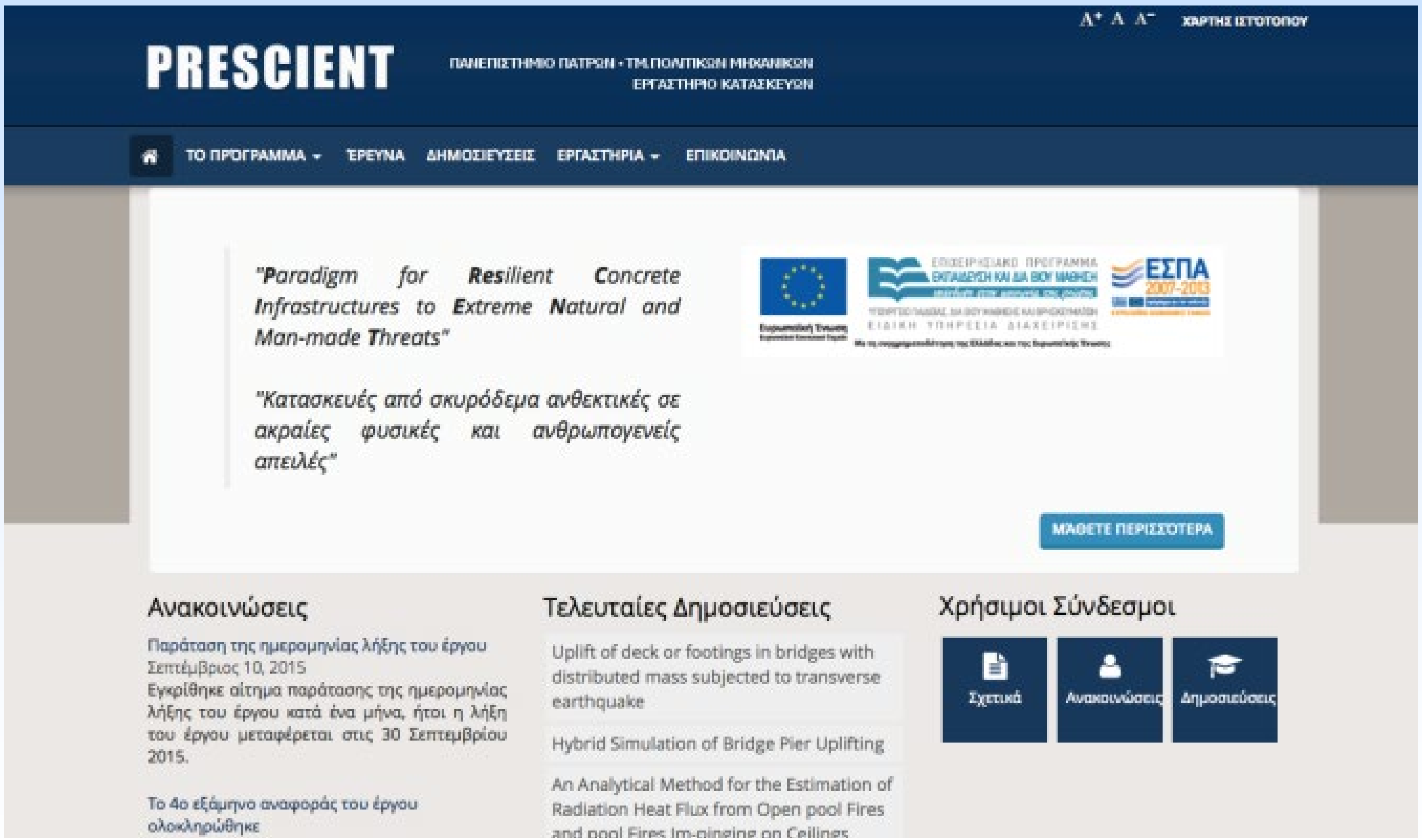


(Bousias, 22nd Students' Conference, Patras, 2016)

PRESCIENT University of Patras project

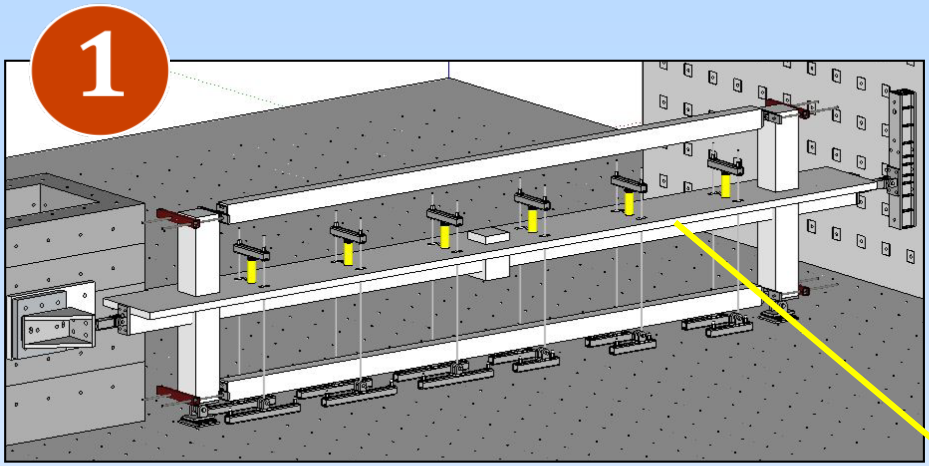
Paradigm for **Res**ilient **C**oncrete **I**nfrastructures to **E**xtreme **N**atural and **M**an-made **T**hreats

Co-ordinator: Prof. M. Fardis

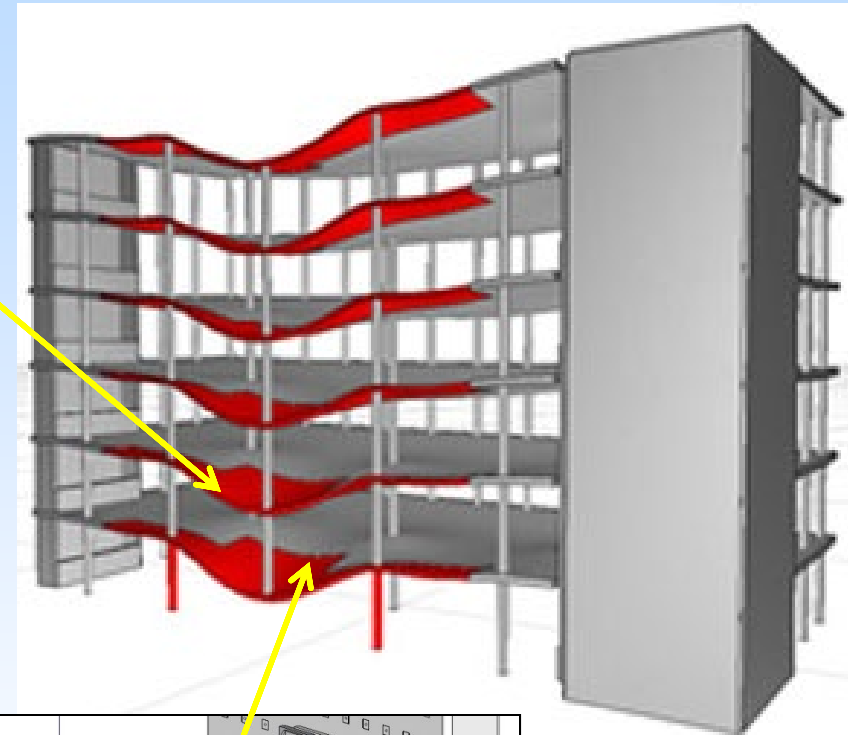


www.prescient.upatras.gr

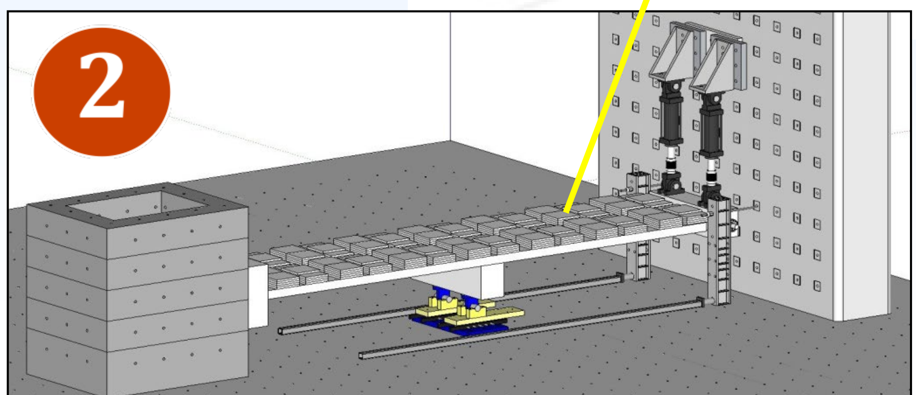
Column failure



How does the frame take the load?



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



(Bousias, 22nd 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)

(Bousias, 22nd Students' Conference, Patras, 2016)

Testing a building for loss of column

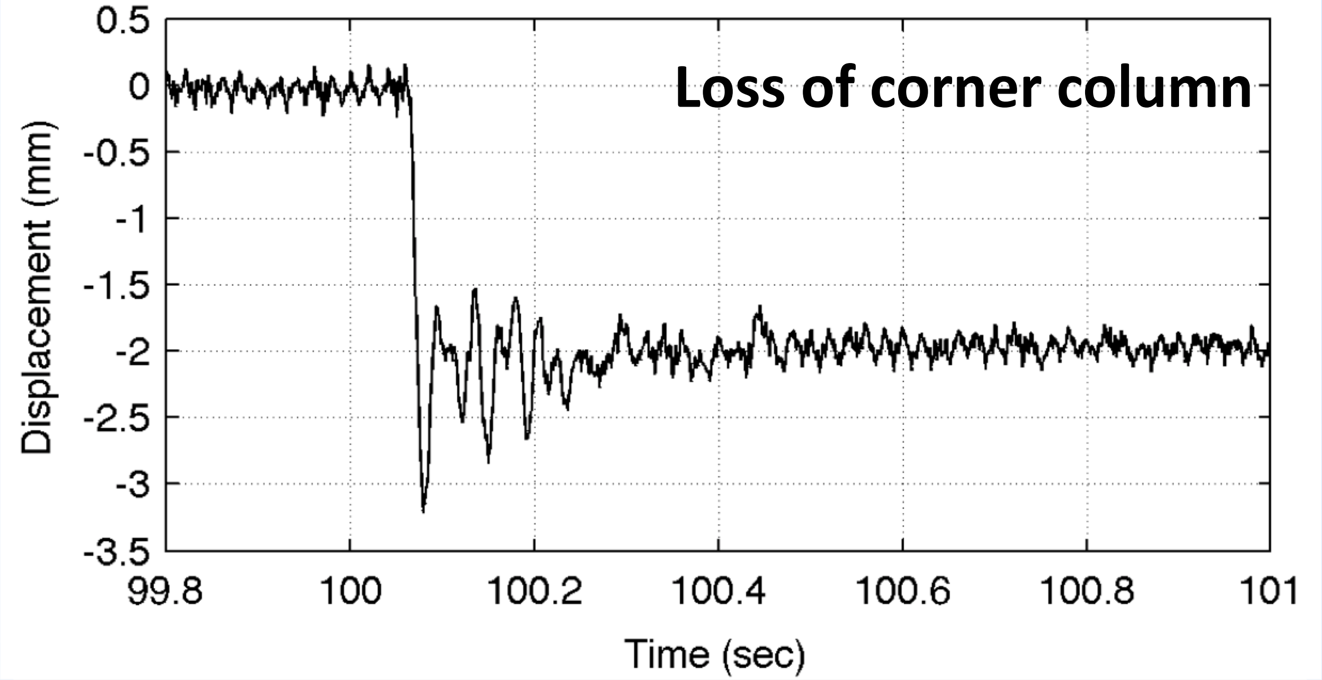
Scale 2:3

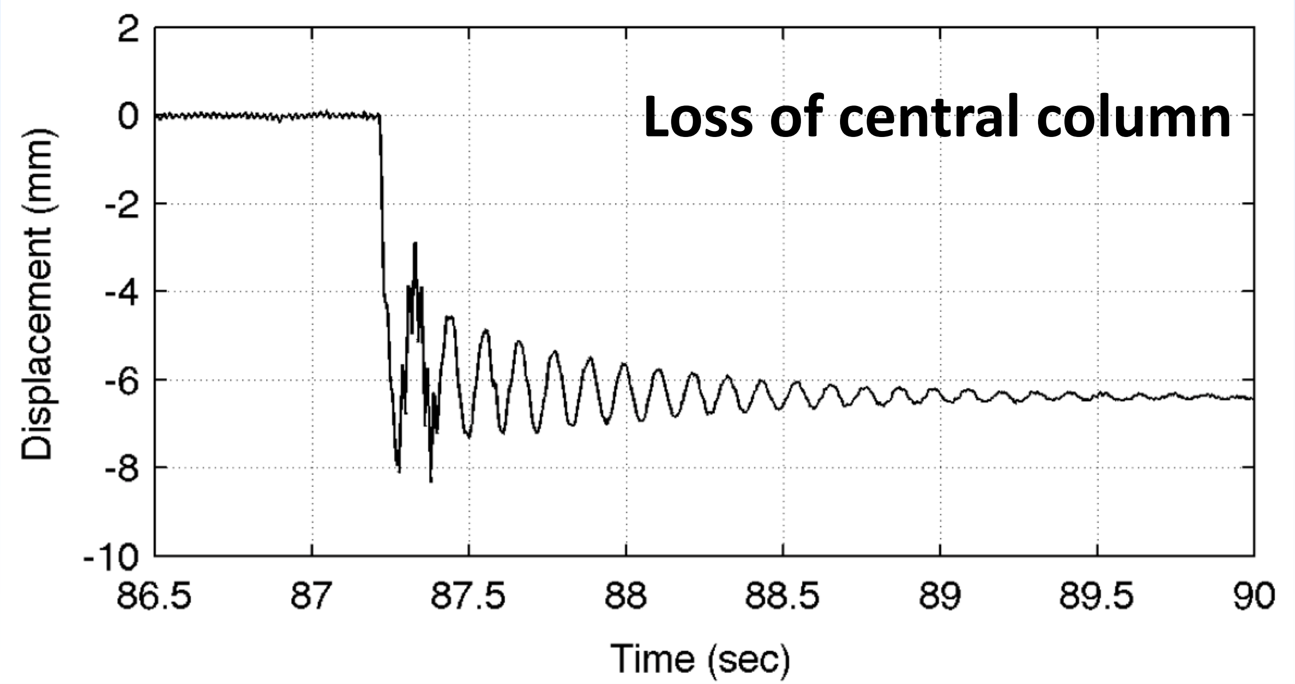
Investigate building behaviour designed to withstand earthquakes (according to Eurocode 8) with/without infill walls on the first floor during the instantaneous removal of:

- **Perimeter column**
- **Corner column**
- **Central column**

(Bousias, 22nd Students' Conference, Patras, 2016)

(Bousias, 22nd Students’ Conference, Patras, 2016)





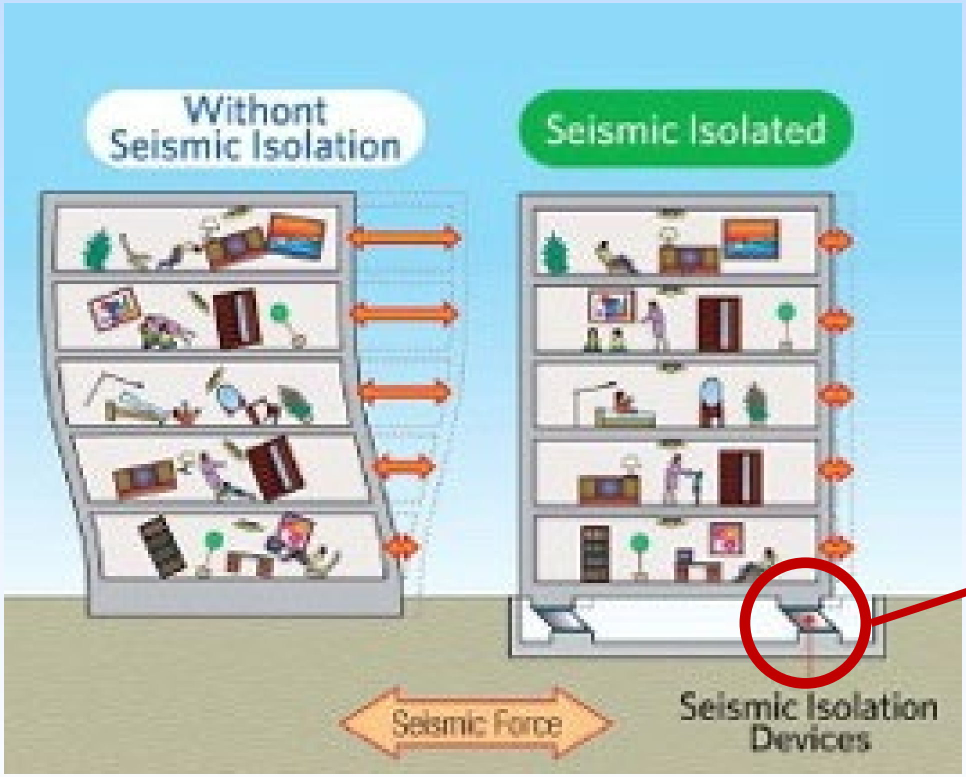
(Bousias, 22nd Students' Conference, Patras, 2016)

The final test

- **Remove infill walls**
- **Increase load (37 ton/floor → 70 ton/floor)**
- **Remove perimeter column**

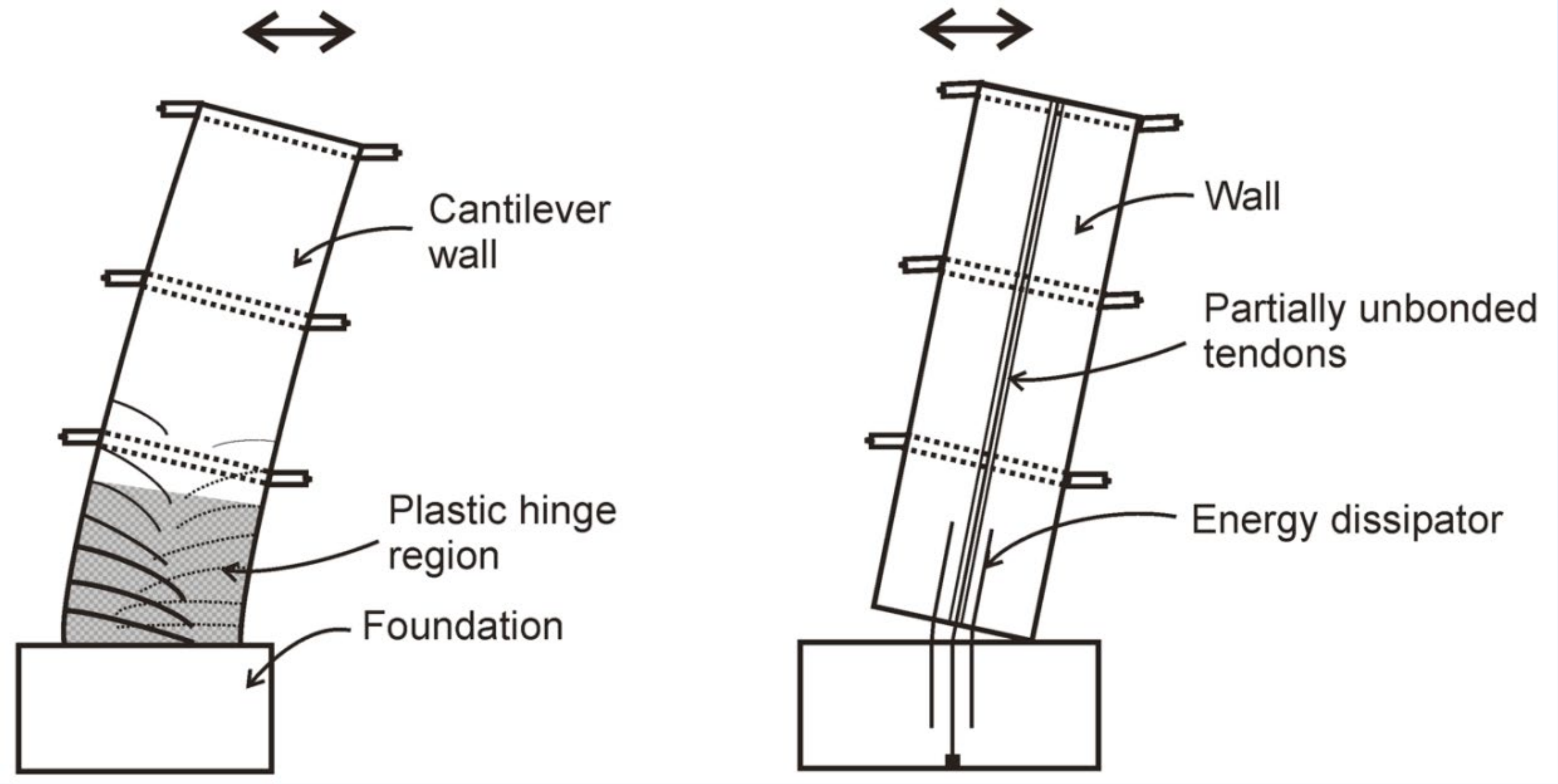
(Bousias, 22nd Students' Conference, Patras, 2016)

B. SEISMIC ISOLATION



(https://mathspig.wordpress.com/category/topics/differentiation/)

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, 22nd Students' Conference, Patras, 2016)

ROCKING ISOLATION

Seismic table tests

Dept. of Civil Engineering, Patras University

(Bousias, 22nd Students' Conference, Patras, 2016)

ROCKING ISOLATION

Pseudodynamic Tests

Structural Lab, Dept. of Civil Engineering, Patras University

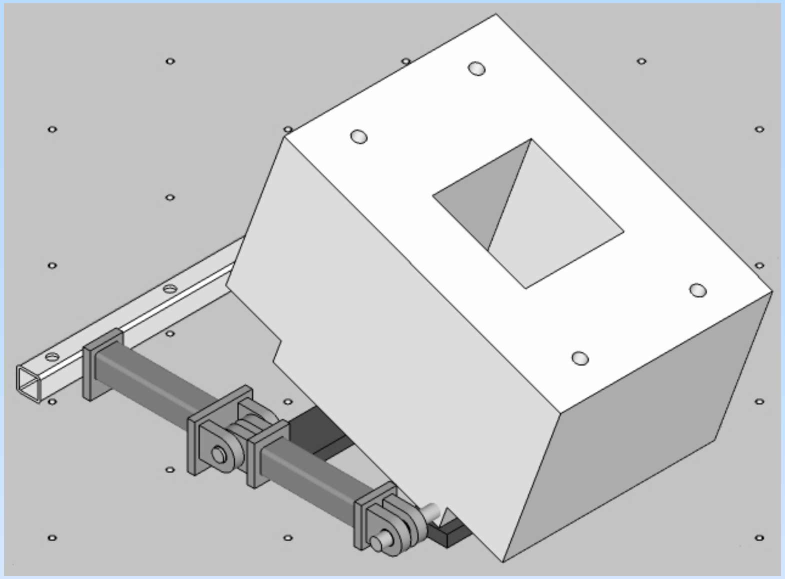
(Bousias, 22nd Students' Conference, Patras, 2016)

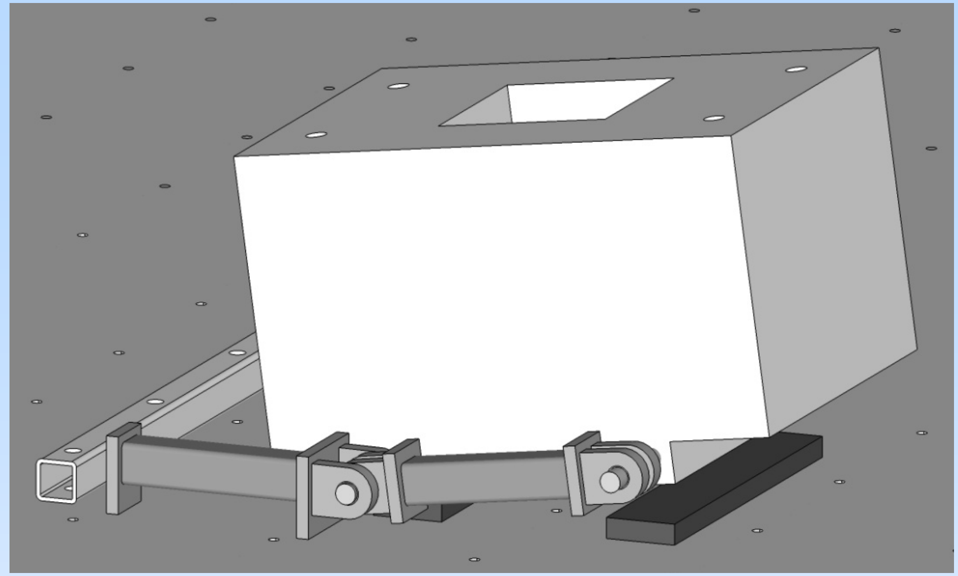
SIMULATION OF ROCKING ISOLATION

Pseudodynamic Tests

Structural Lab, Dept. of Civil Engineering, Patras University

(Bousias, 22nd Students' Conference, Patras, 2016)





SIMULATION OF ROCKING ISOLATION

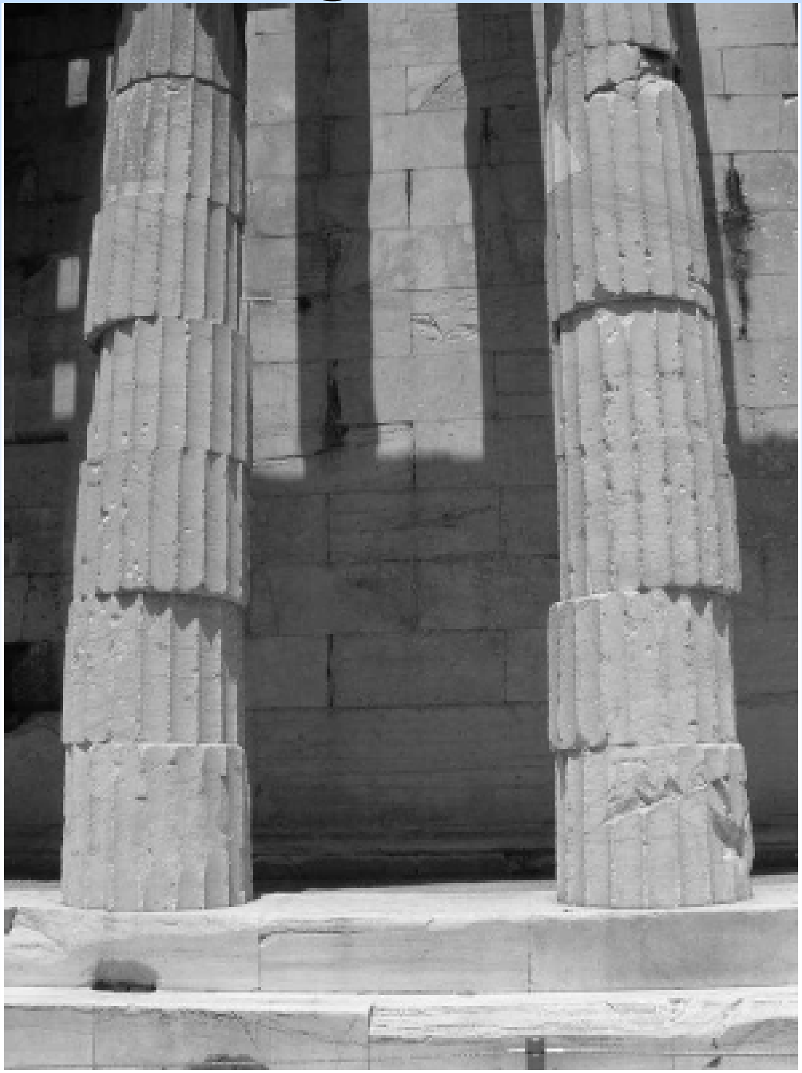
Pseudodynamic Tests

Structural Lab, Dept. of Civil Engineering, Patras University

(Bousias, 22nd Students' Conference, Patras, 2016)

LEARNING FROM ANCIENT GREECE

Resilience through unbonded sliding and rocking segmented columns



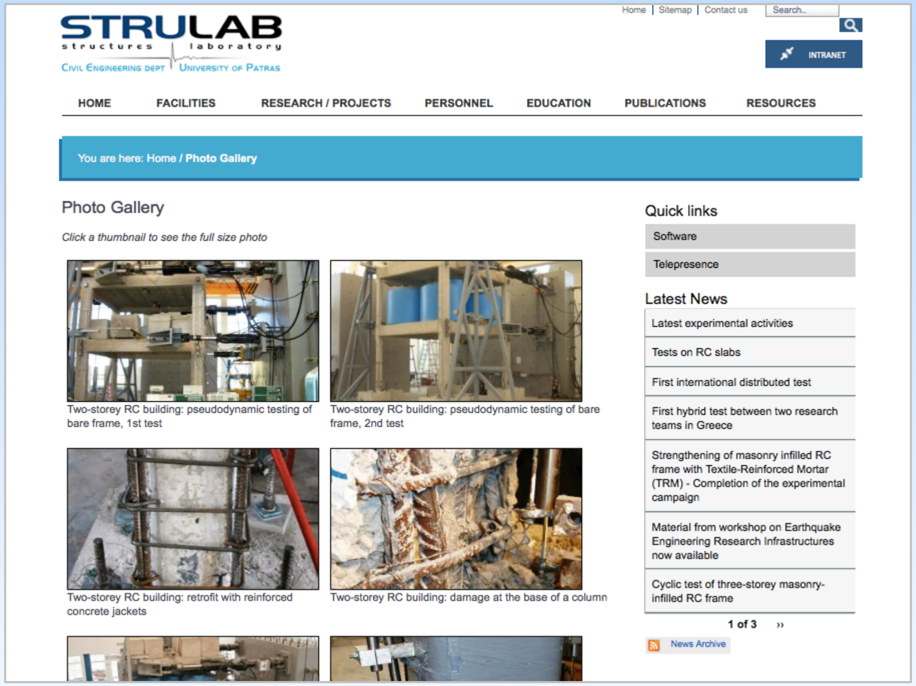
Still standing after 2500 years

(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 ....



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