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Learning from Observations of Geotechnical Performance in Earthquakes

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Observations in Earthquakes

- 1. Simple visual inspections**
- 2. Inspections with measurements**
- 3. Inspection and recorded accelerations, displacements, performance**
- 4. Documentation of case histories for post-seismic back analyses**

BENEFITS

from Observations

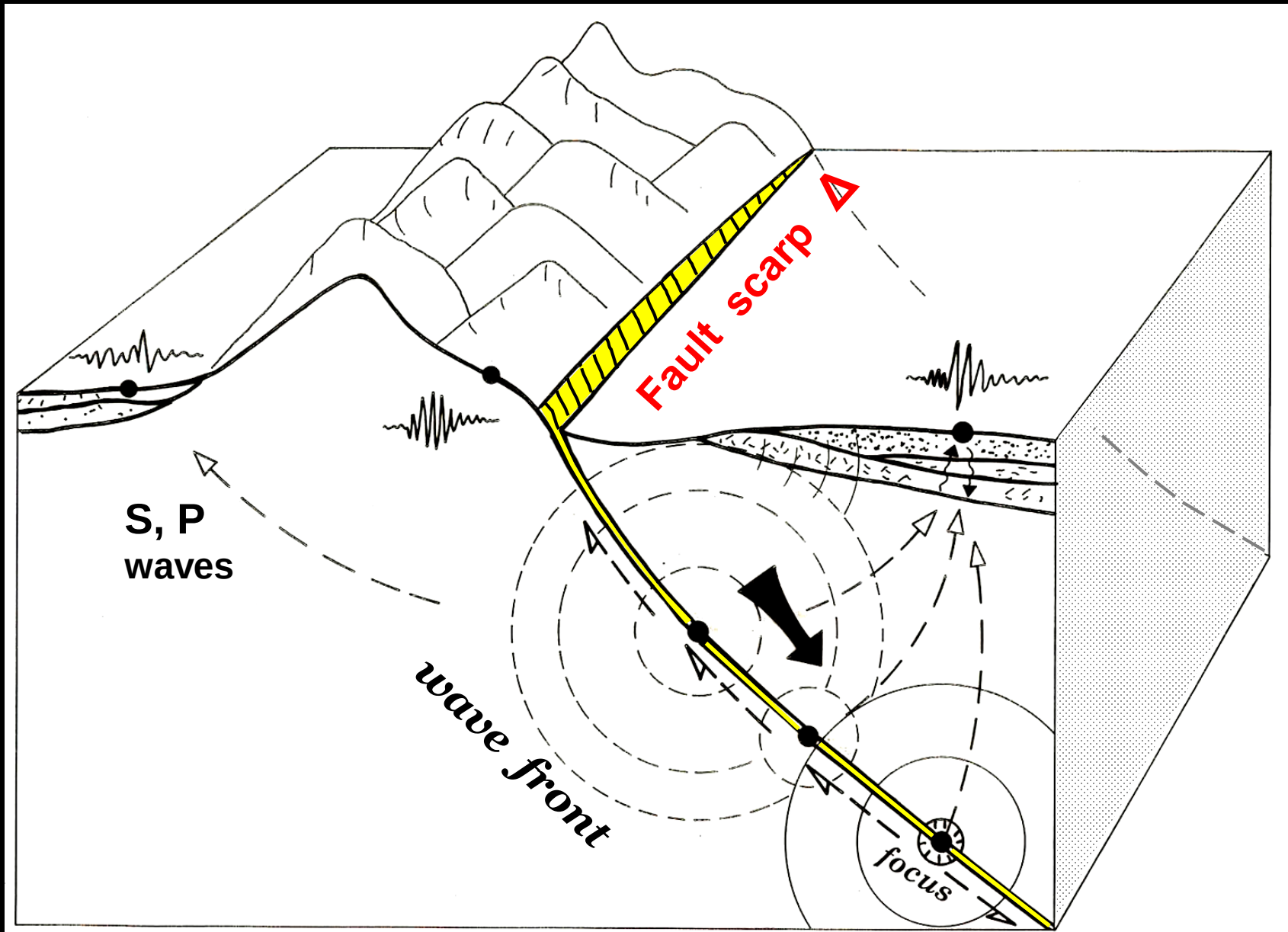
- 1. Obtain Valuable Experience, even if Qualitative..**
- 2. Verify or Refute Methods, Theories, ...**
- 3. Develop NEW Approaches for Seismic Design**
- 4. Implement CHANGES in Seismic CODES
or in Established Practices**

3 CASE HISTORIES

from Kocaeli 1999 and Kobe 1995 Earthquakes

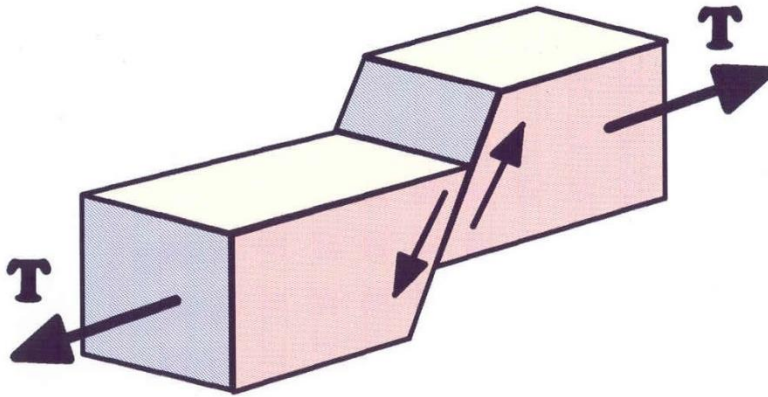
- 1. Fault Rupture Under Buildings**
- 2. Damage to Caisson Harbor Quaywalls**
- 3. Collapse of Underground Metro Station**

NORMAL FAULT Earthquake: the 2 components

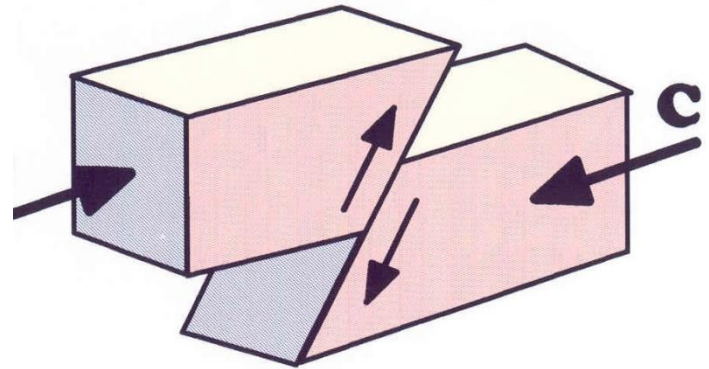


Types of Faulting

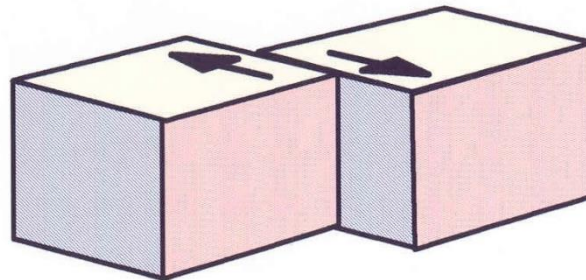
1. NORMAL



2. REVERSE or THRUST



3. STRIKE-SLIP



Kocaeli, Turkey, 1999

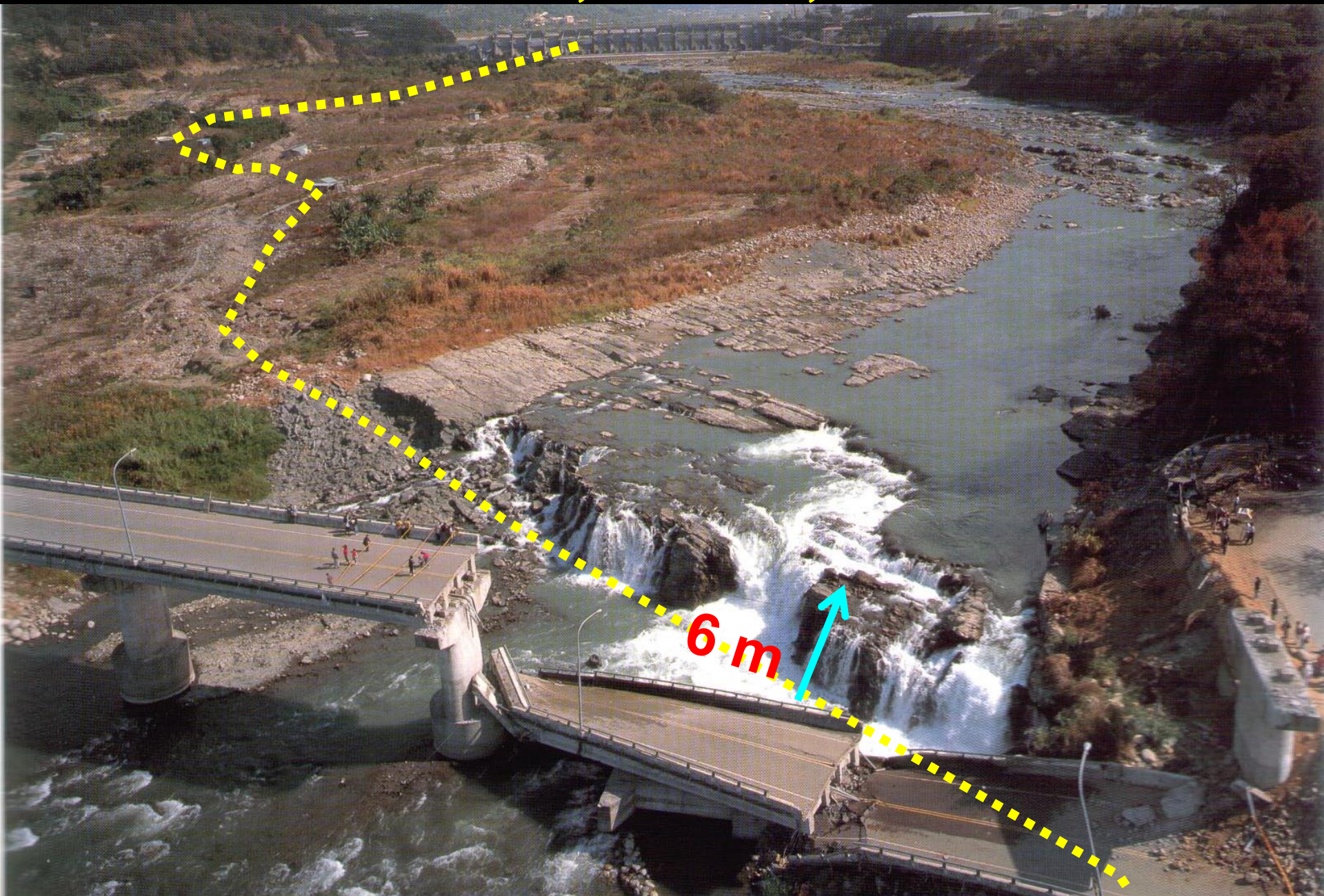


**5 – storey building
collapse**



Deflection (offset) of rail

Chi-Chi, Taiwan, 1999



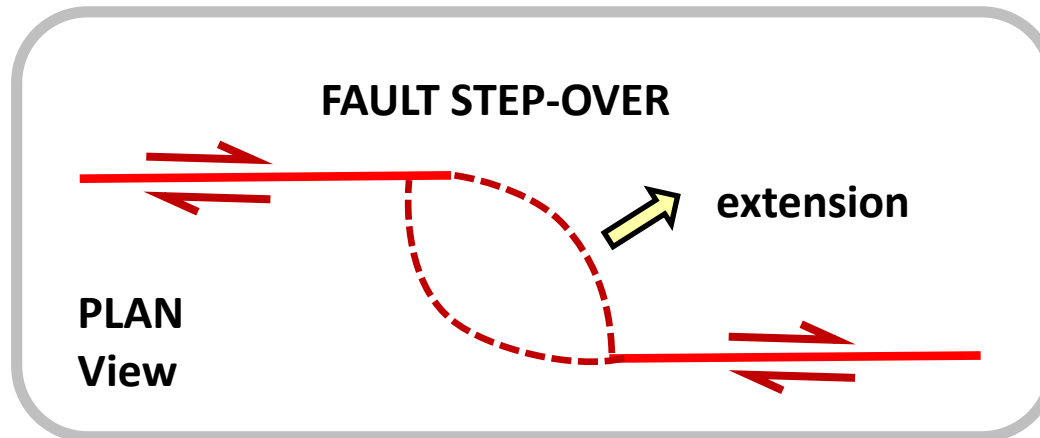
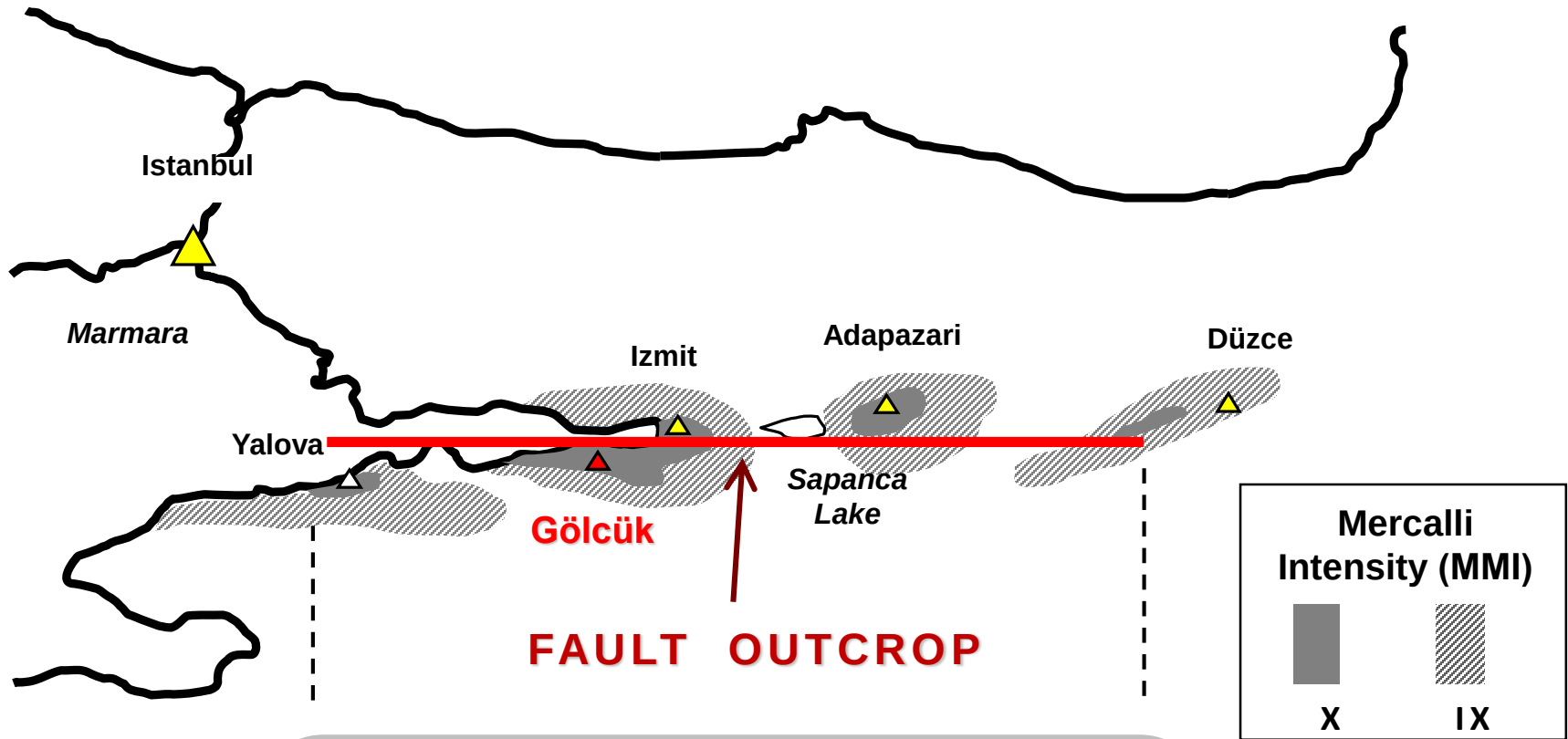


9 m

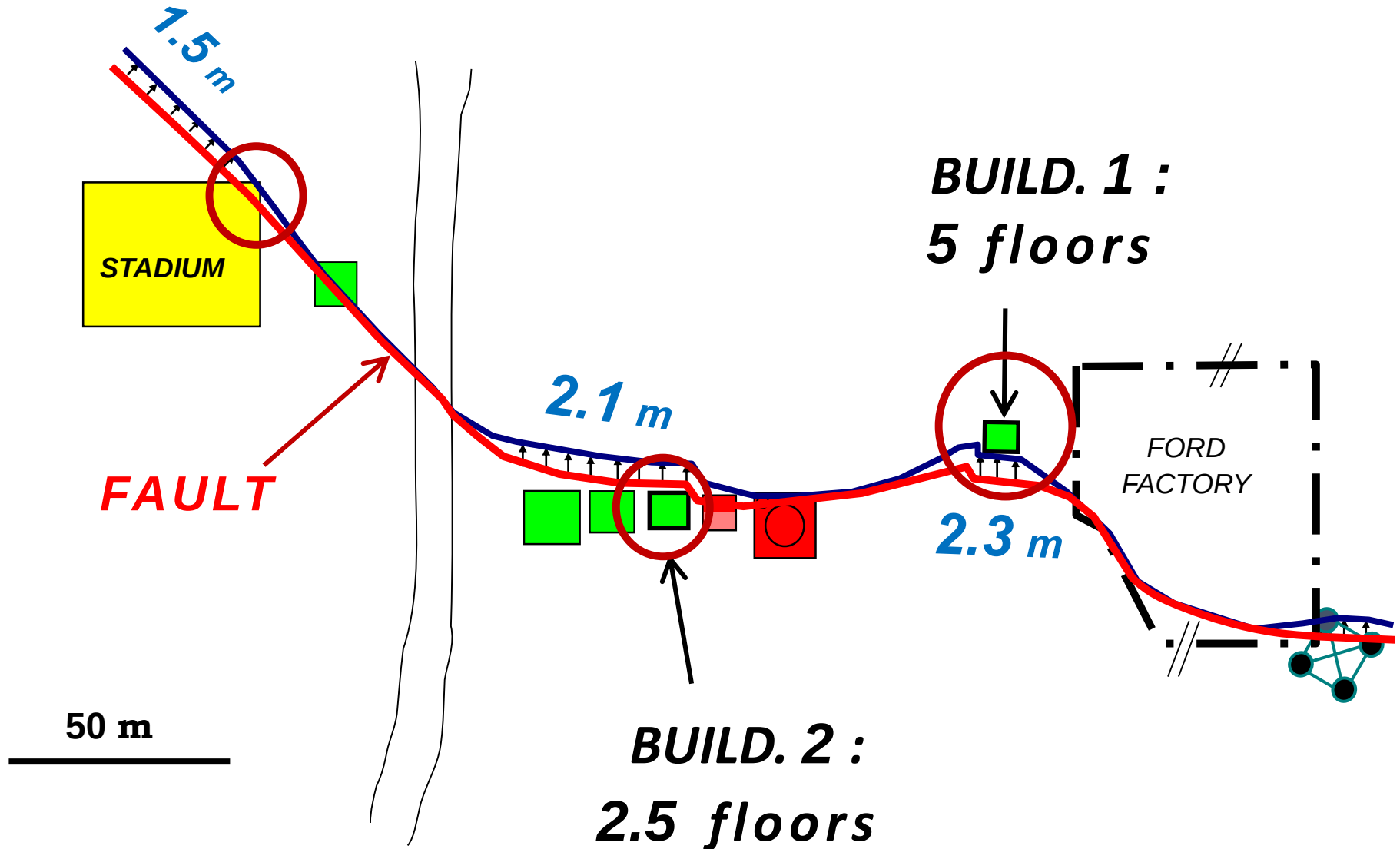
(“OLD”) SEISMIC CODES

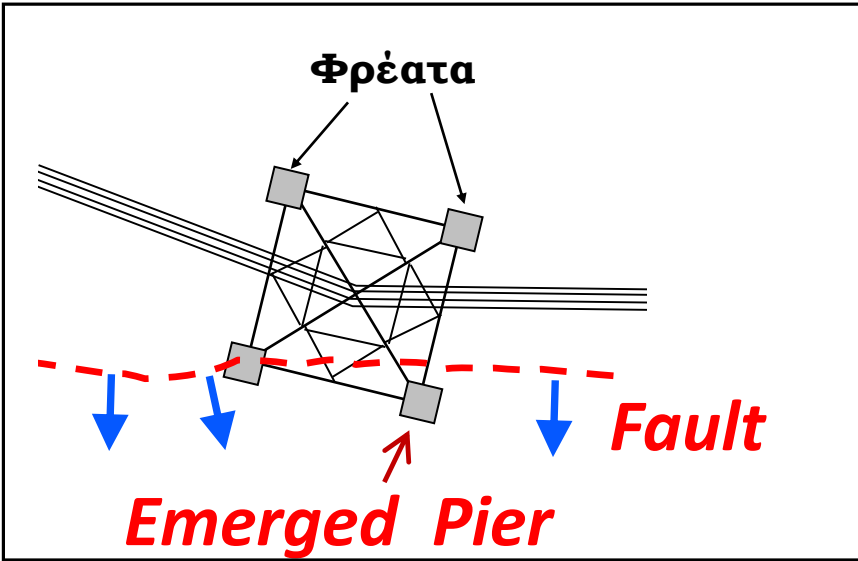
*“Important Structures
shall not be erected in
the IMMEDIATE VICINITY
of active faults...”*

KOCAELI 1999 Earthquake M = 7.5

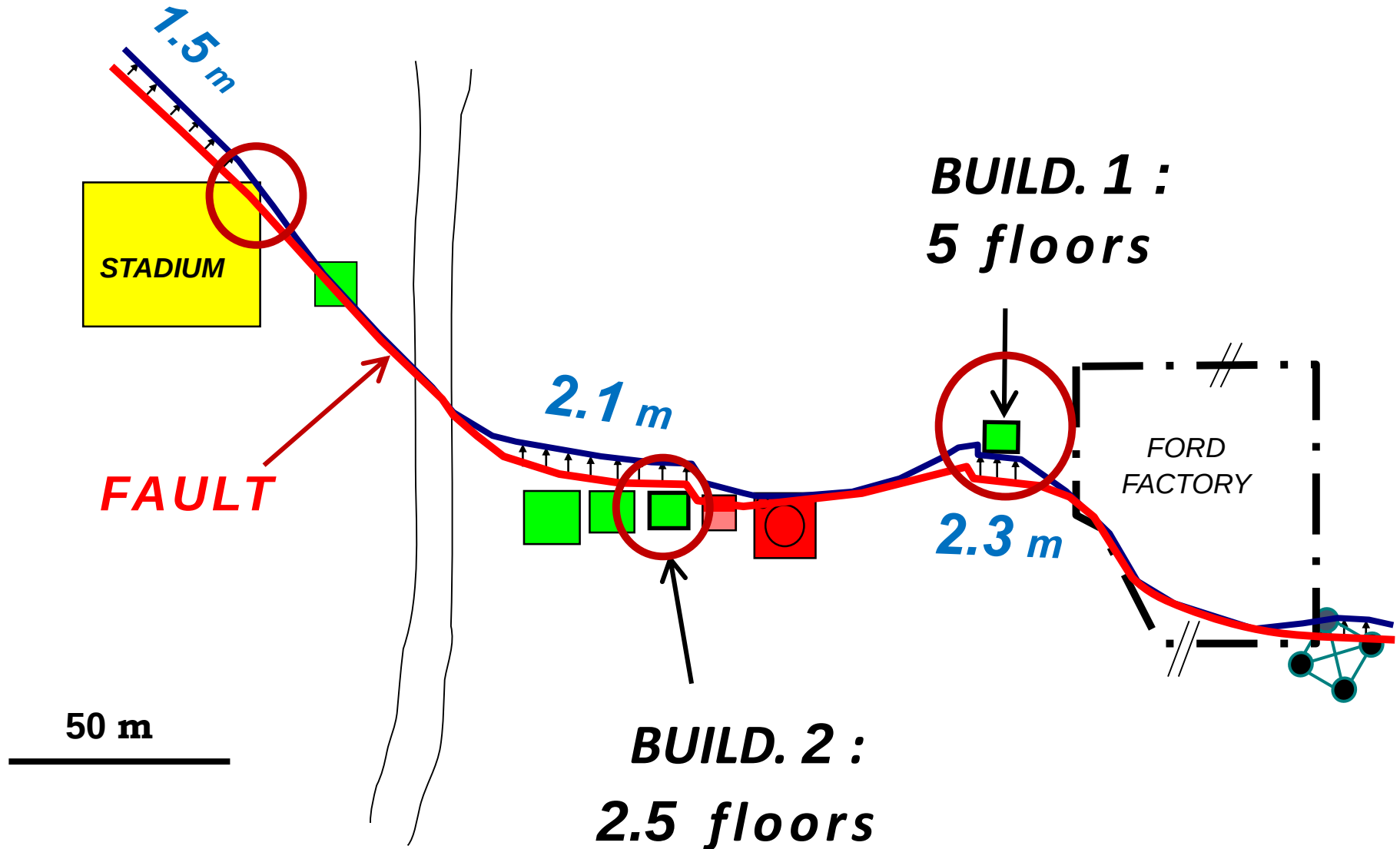


Normal Surface Rupture, Denizevler (east of Gölçük)





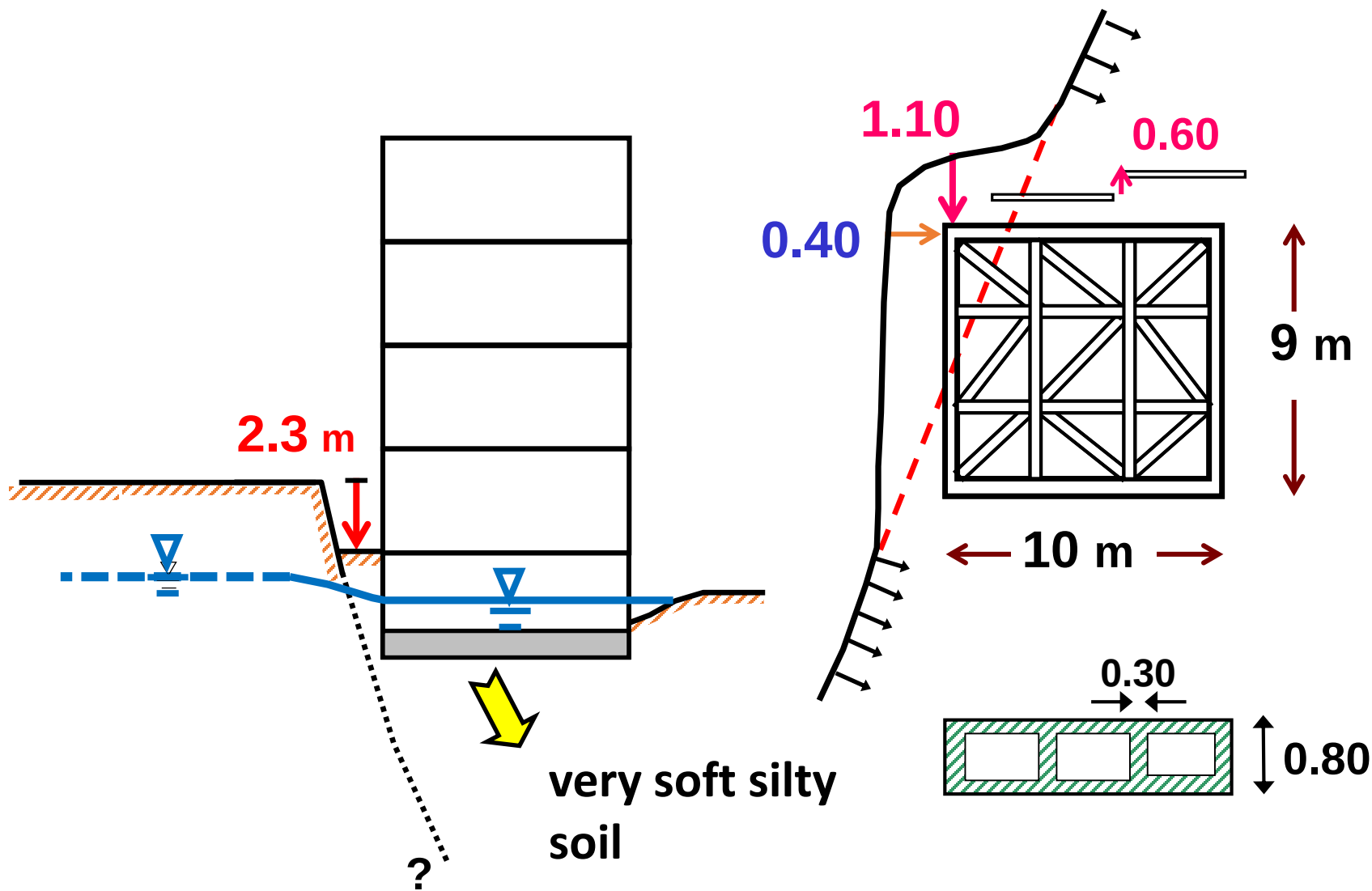
Normal Surface Rupture, Denizevler (east of Gölçük)



5-storey Building 1 : NO Damage

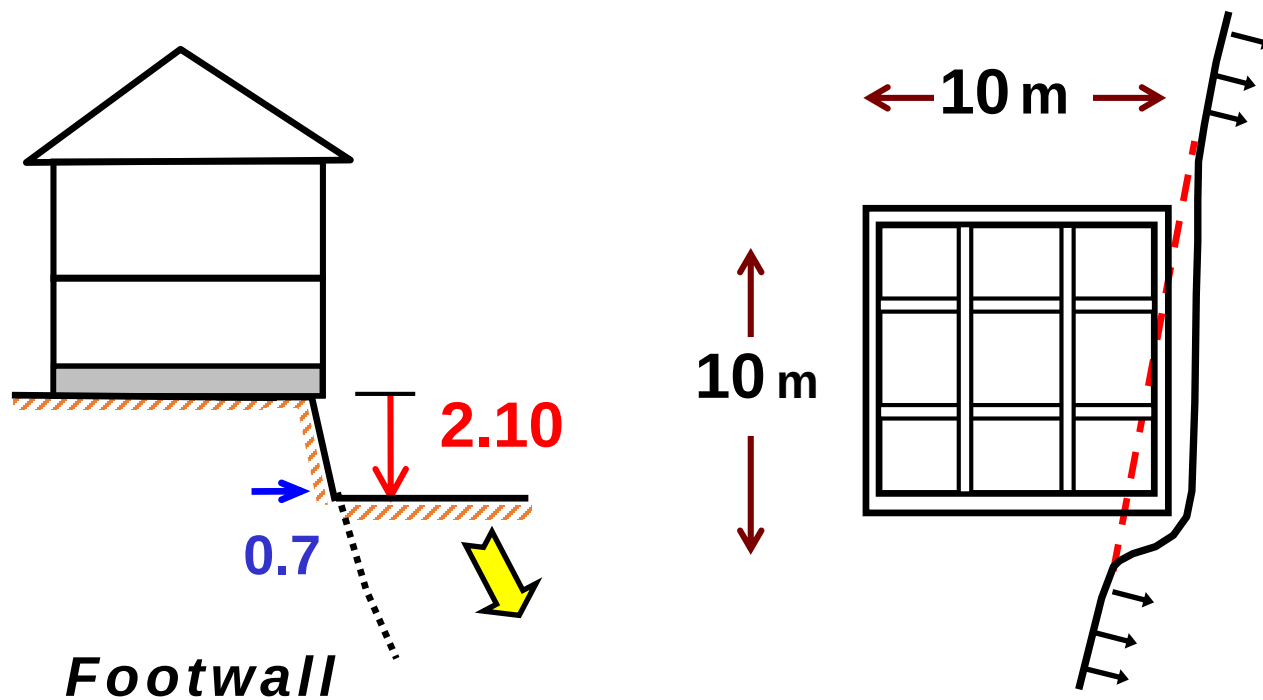




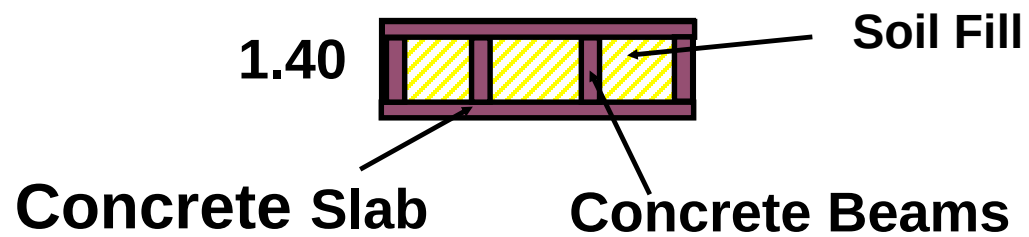


2.5 storey Building 2 : NO Damage





Footwall

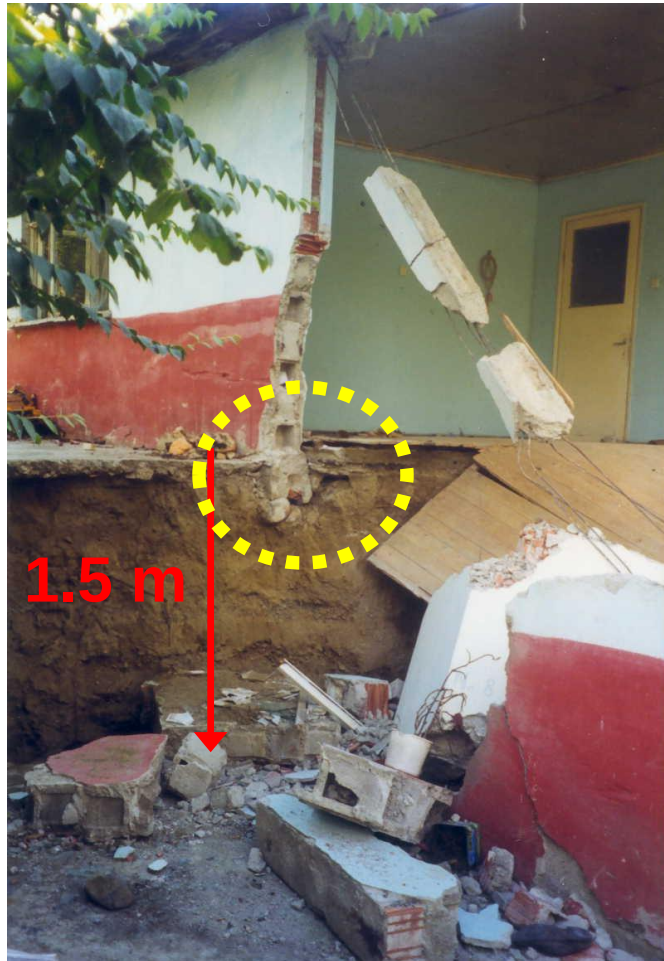


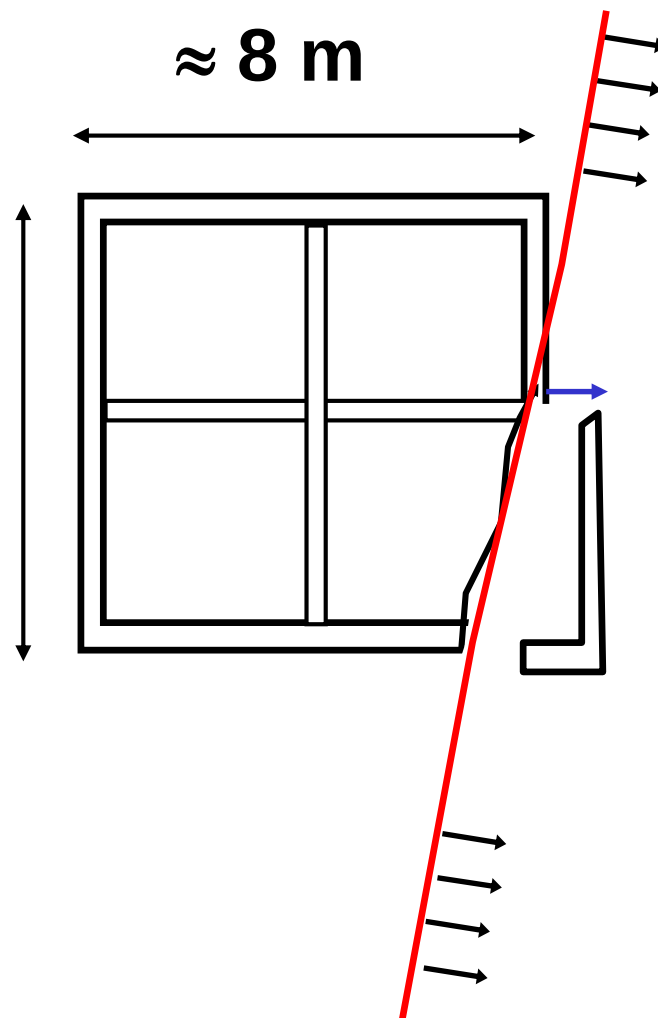
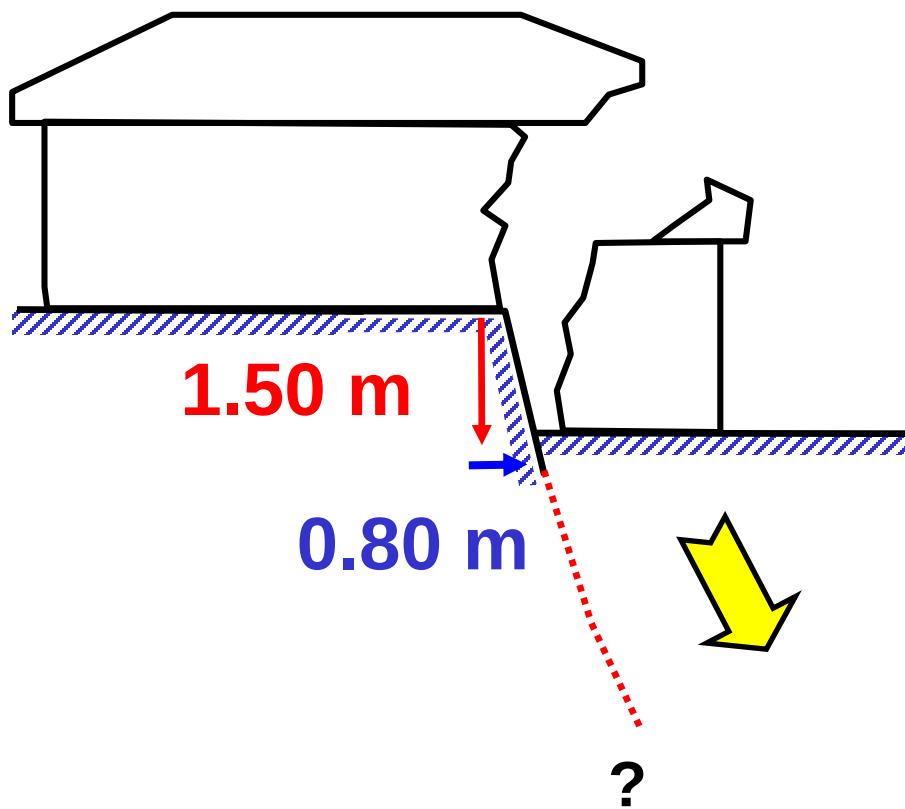
Wenchuan, China, 2008

Success
amid Destruction



1-floor building: **Partial Destruction**





The Engineering Question :

Can we design

foundations + structures

to withstand

FAULT RUPTURING *underneath ?*

*Positive Answer, for Two
Potentially Beneficial Reasons*

1. Beneficial Role of Soil

*Above the Base-Rock,
Reducing Fault Scarp*

*2. The Presence of a Rigid
Foundation / Structure*

Diverts and Diffuses the Rupture

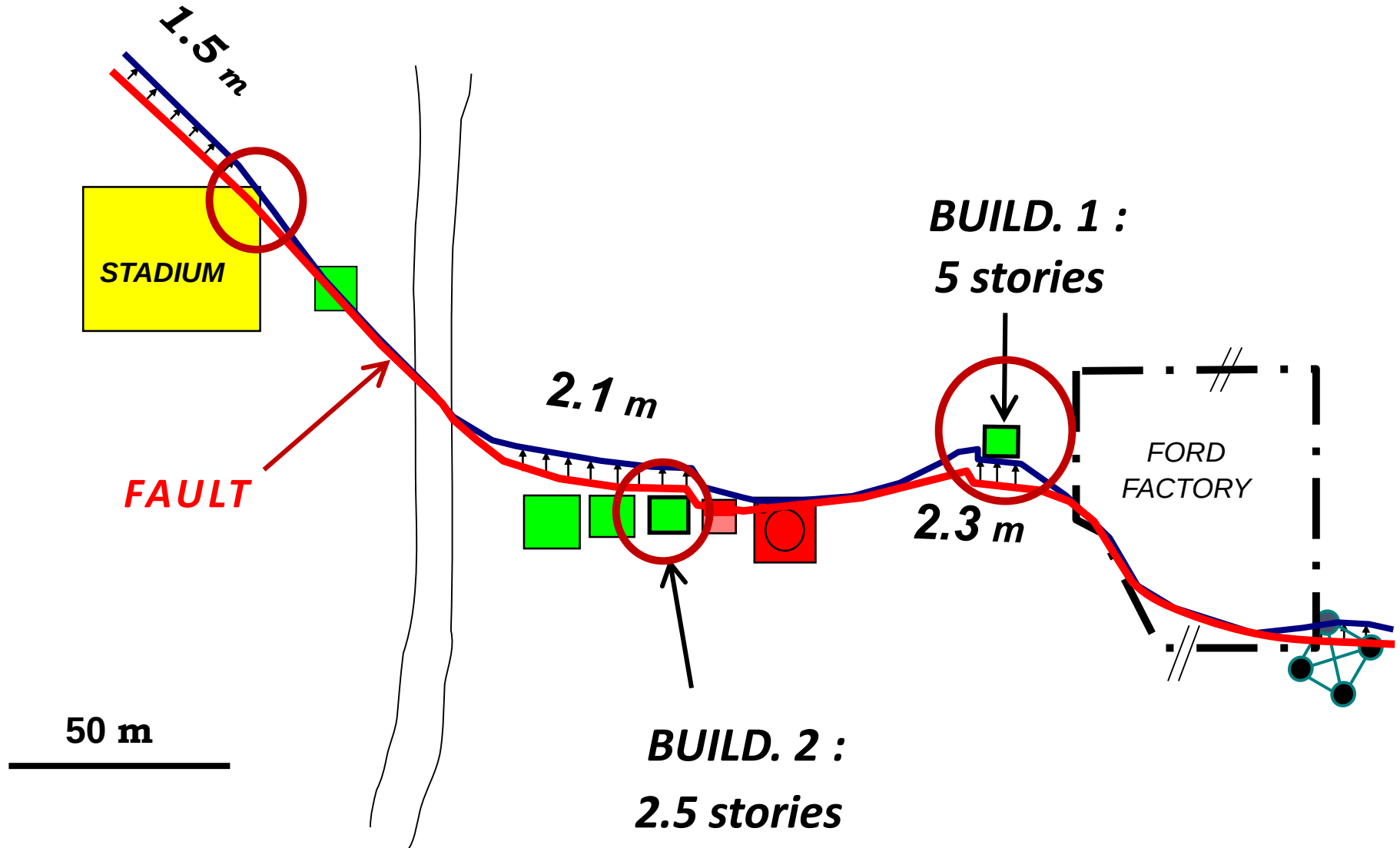
Theoretical and Experimental Studies:
Interaction of Fault Rupture
with the
Soil – Foundation – Structure
System

NEW EC 8 , Part 5

B 1.1 Potentially active seismic faults

- (1) In the presence of active tectonic faults, ... structures ... should only be constructed if :
- (i) a continuous stiff foundation is designed, *and*
 - (ii) a soil cover exceeding a certain thickness *H* exists above the rock formation .

Normal Surface Rupture, Denizevler (east of Gölçük)



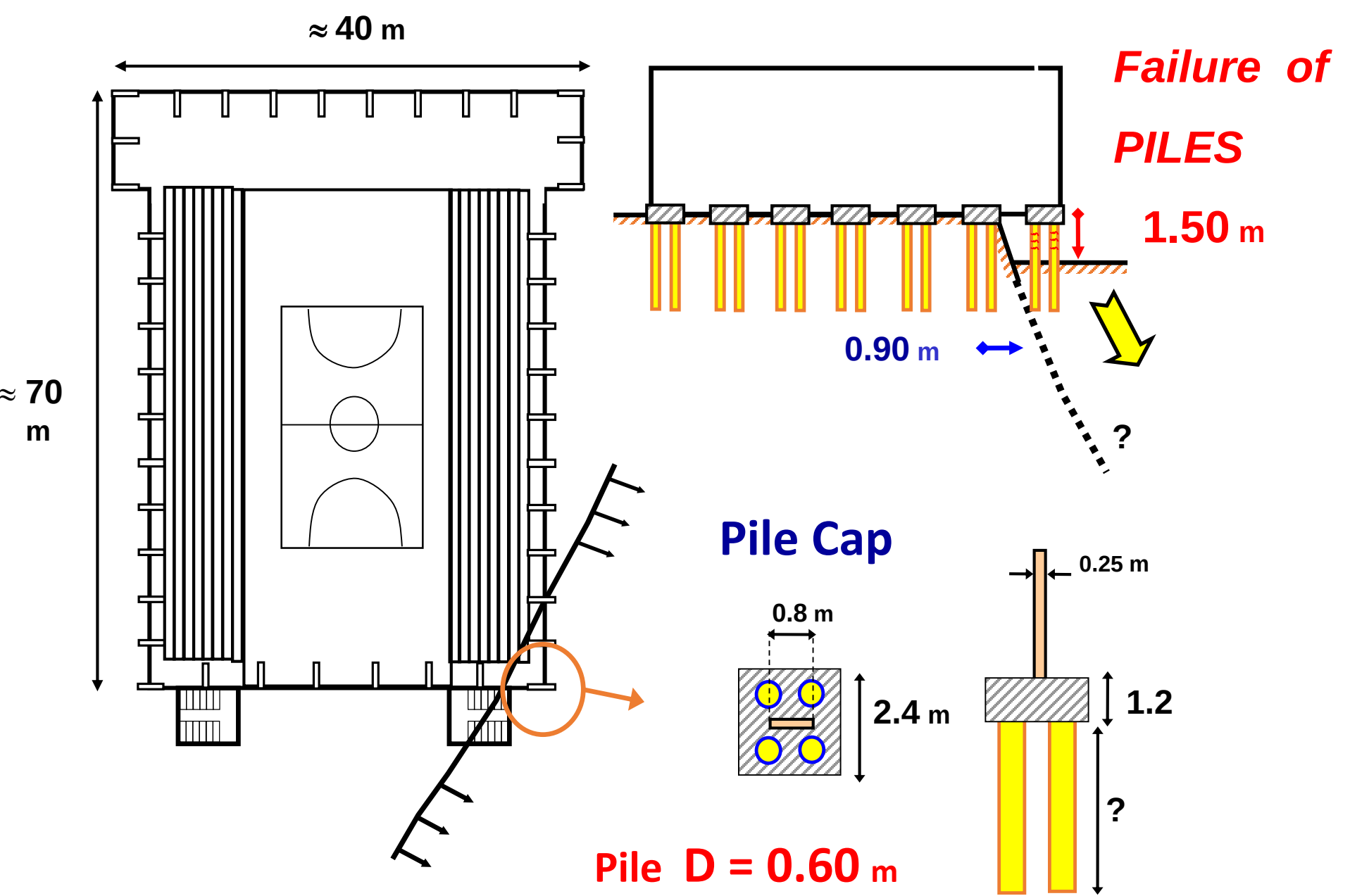
Devizevler ATATURK STADIUM



STADIUM : DAMAGE

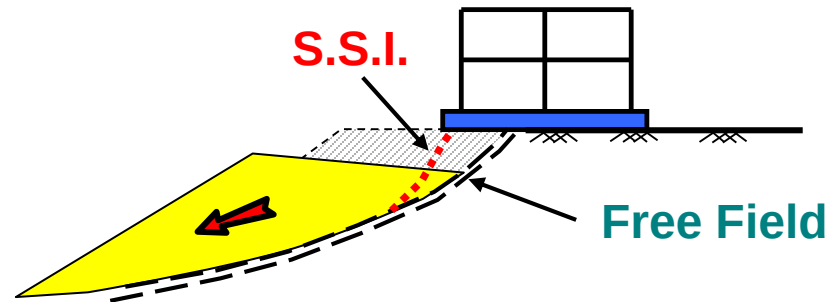




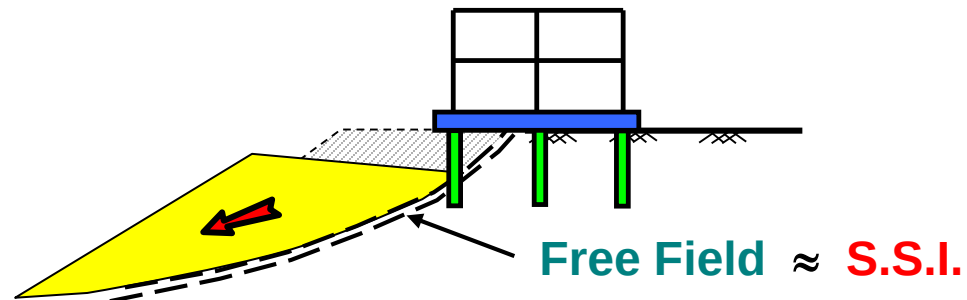


STRUCTURE “on top” of **LANDSLIDE**

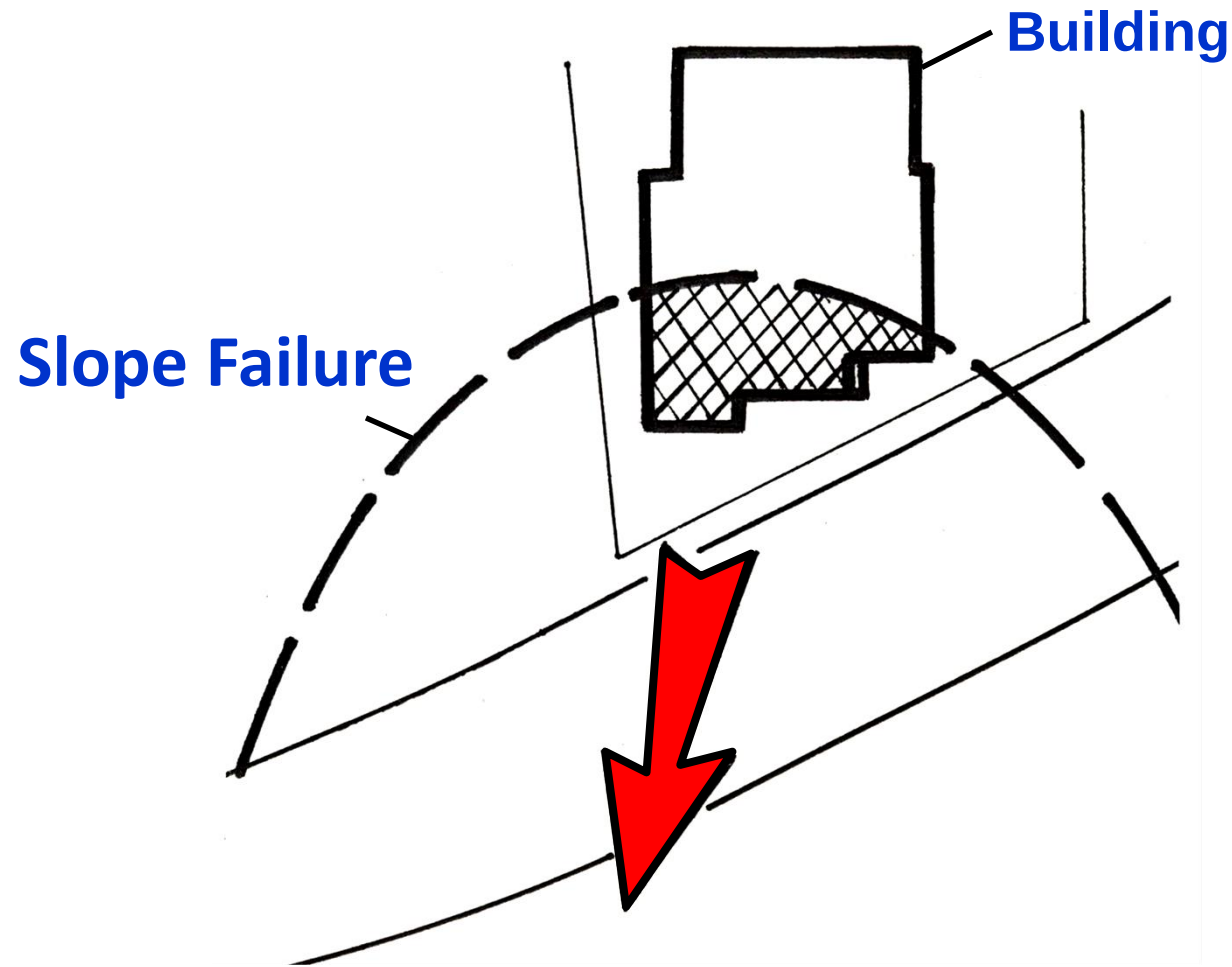
*Raft
Foundation*



*Piled
Foundation*



Shukugawa Landslide – Kobe, Japan 1995







***Seismic Performance of
Gravity Quay-Walls***

Gravity and Flexible RETAINING Walls

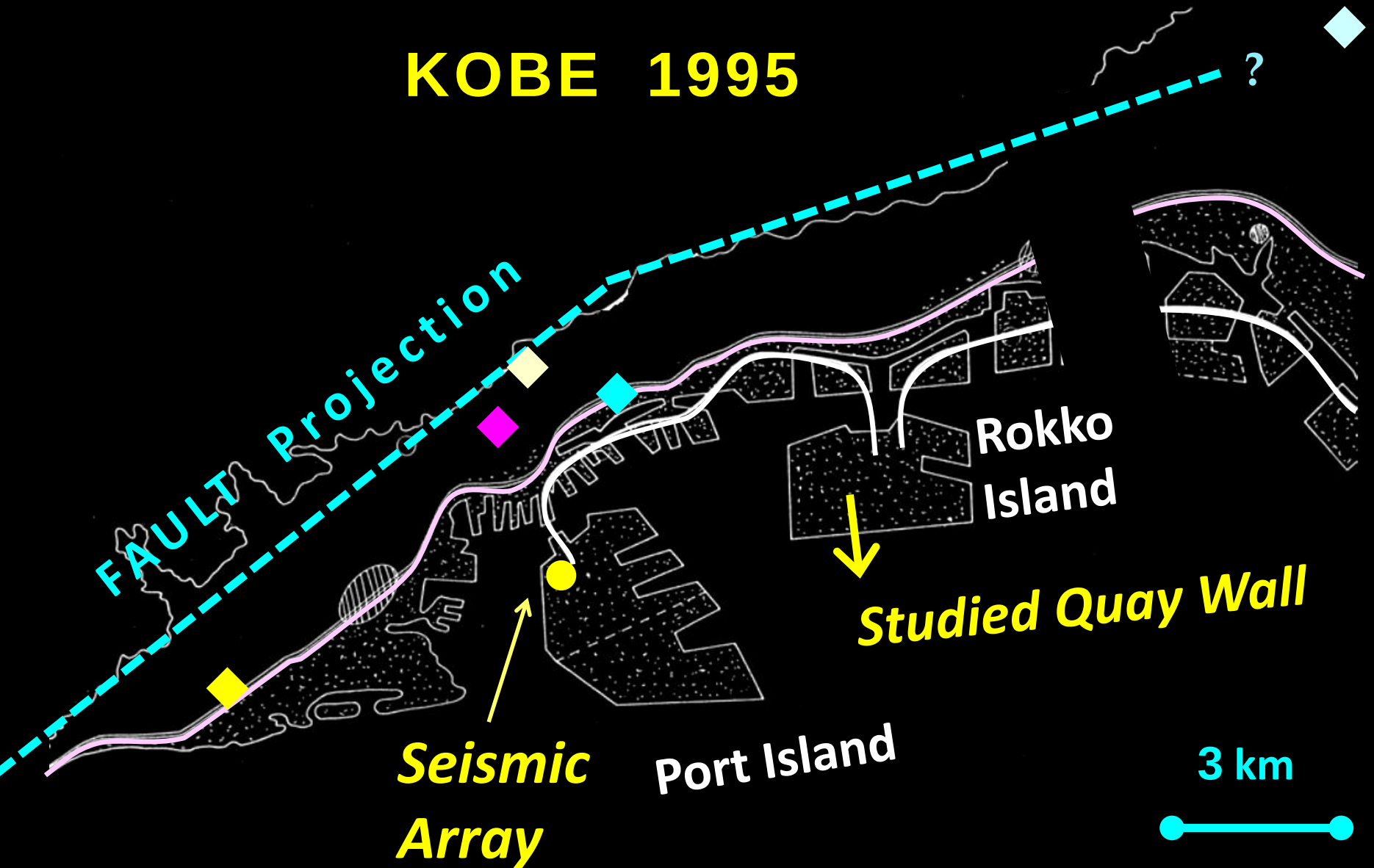
Supporting “DRY” Soil

*have not suffered much even in strong
seismic shaking*

Exception:

Harbour Quay-Walls

KOBE 1995





≈ 4 m

KOBE 1995

KOBE 1995

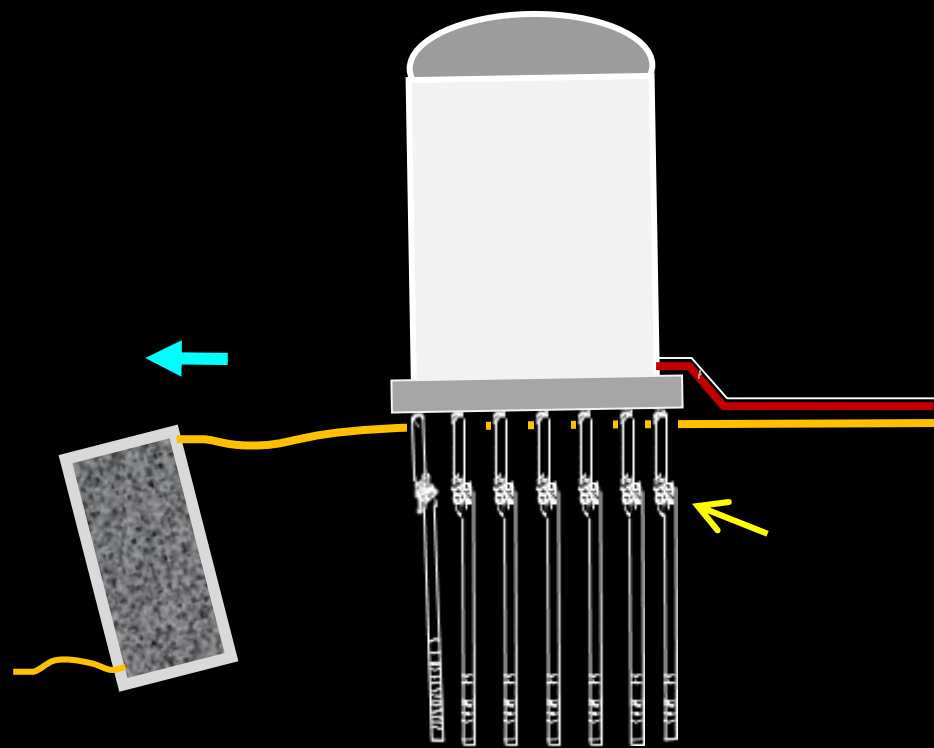






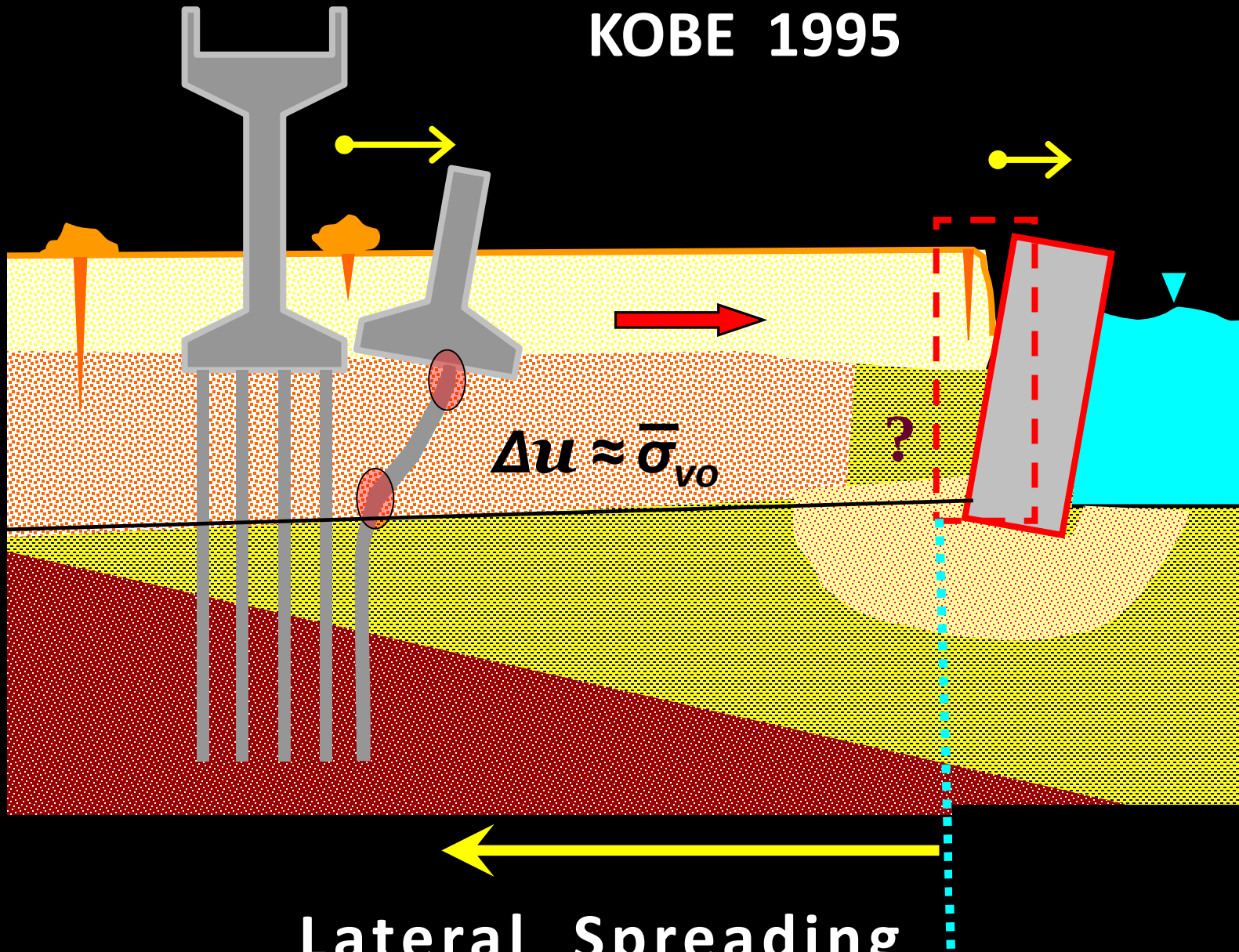


KOBE 1995



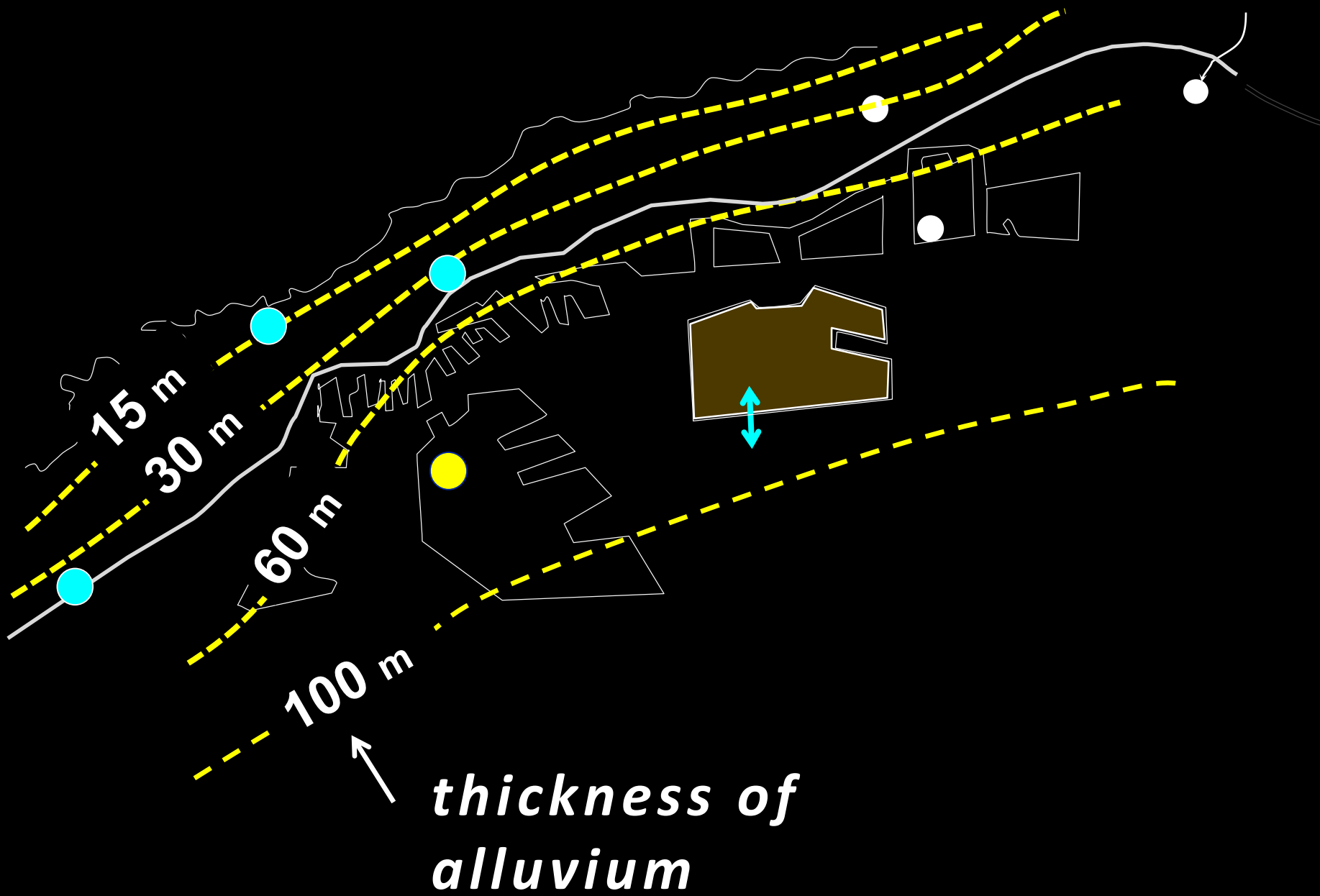
PILE FAILURE

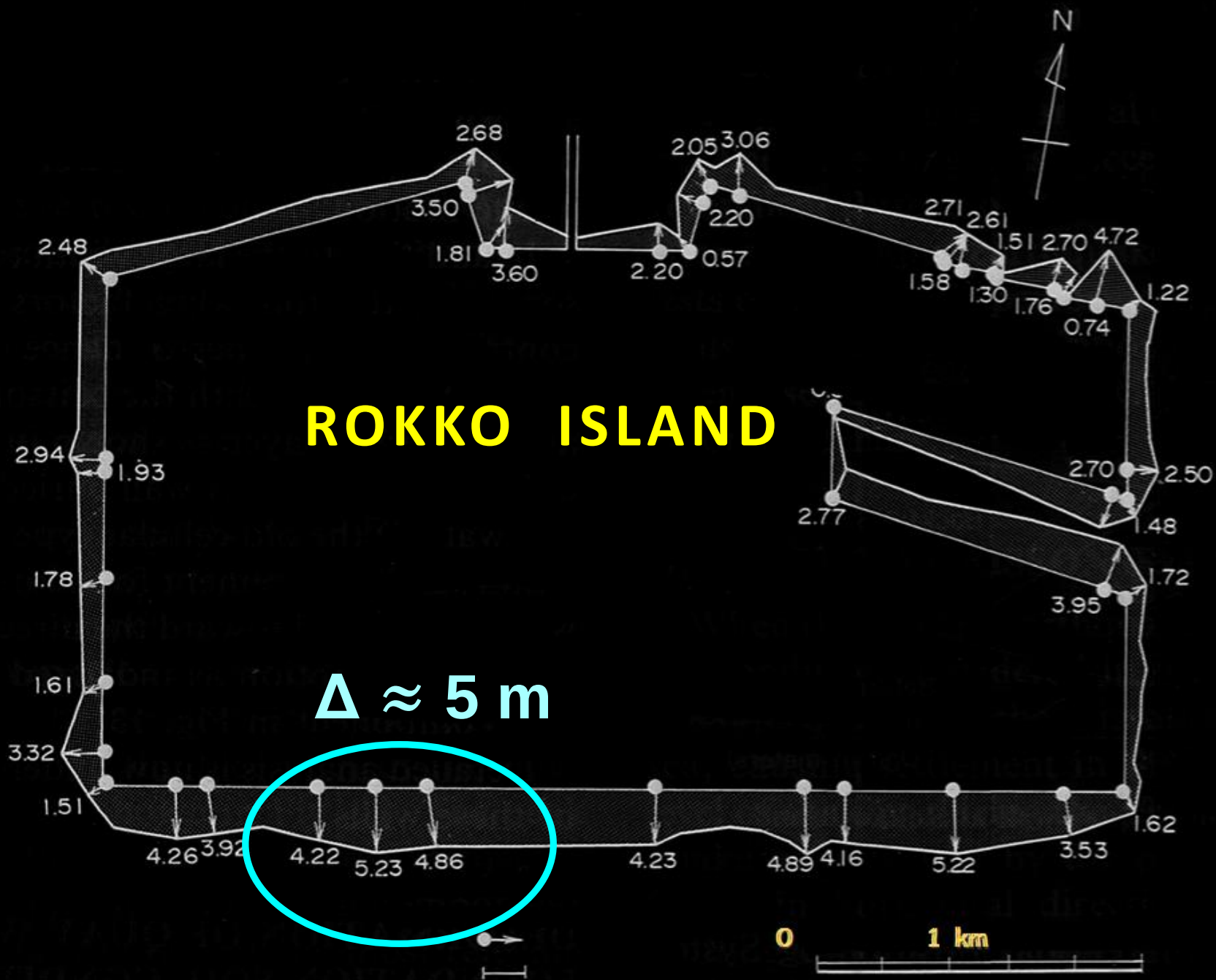
KOBE 1995



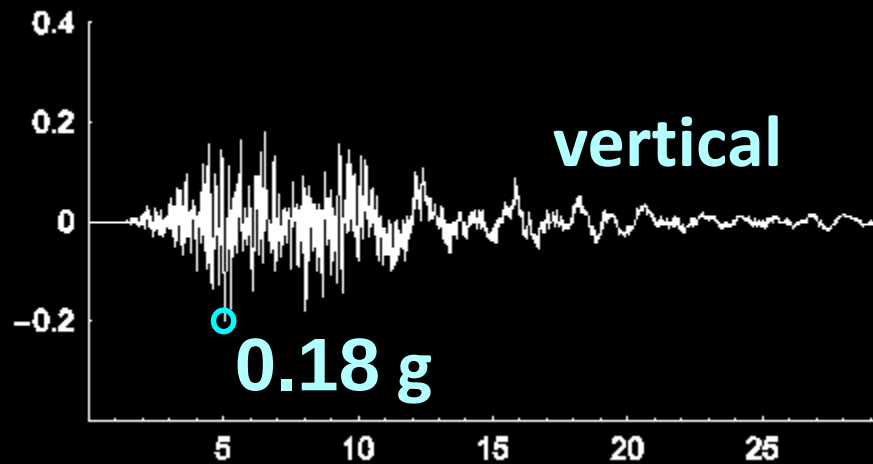
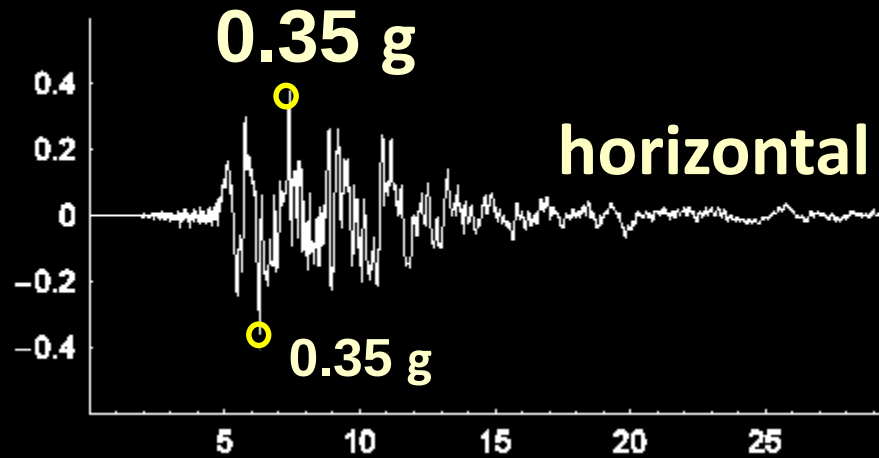


Nishinomiya-ko bridge
Kobe 1995

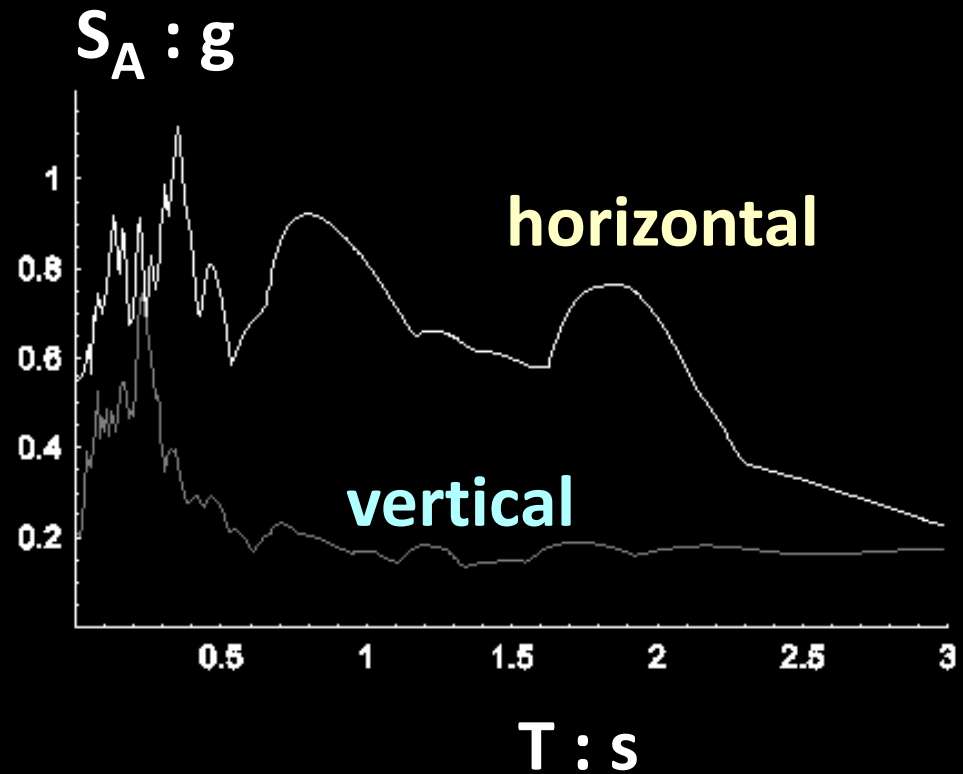




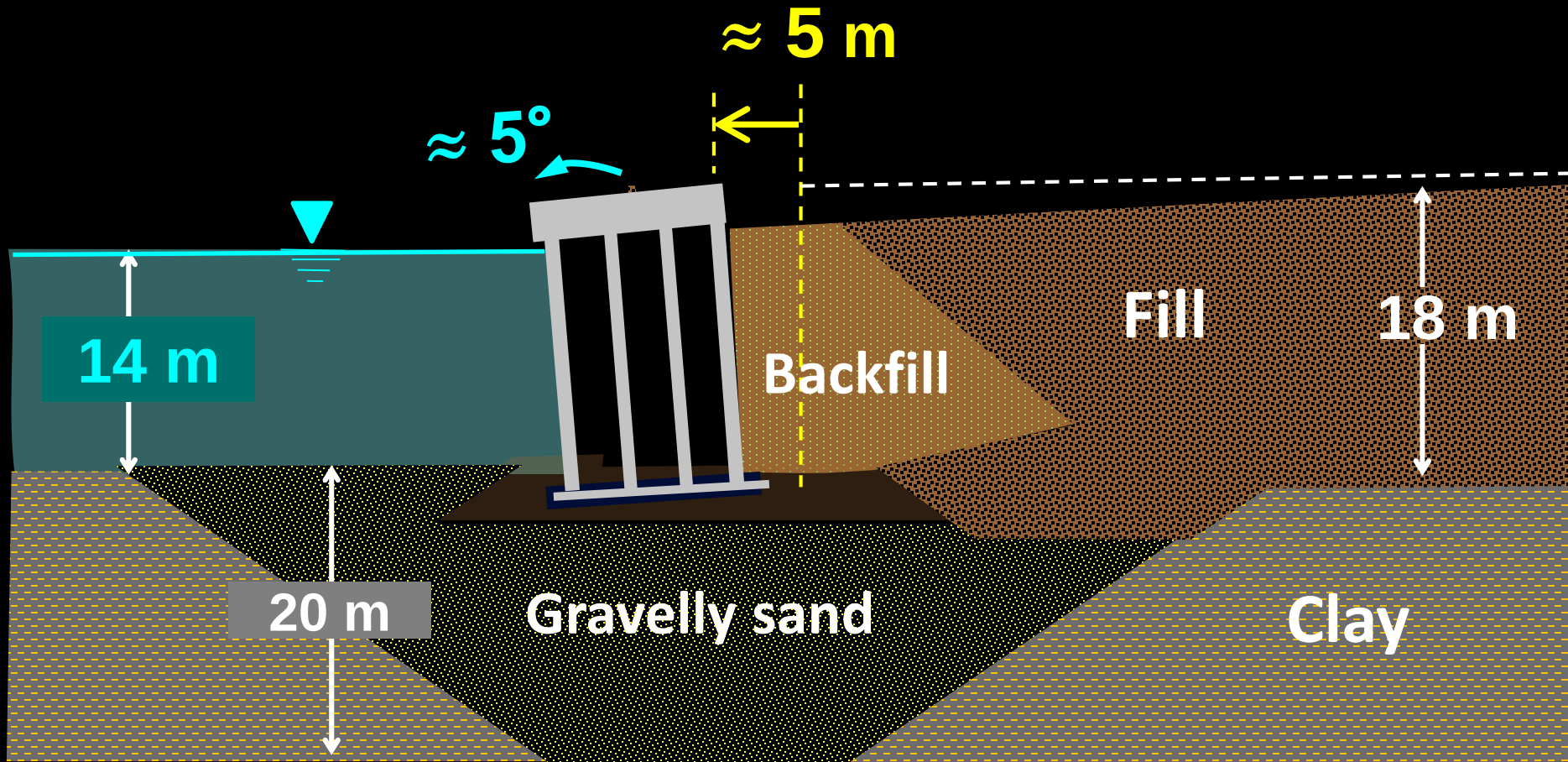
Port-Island Record at **-32 m**



$t: s$



Kobe 1995, Rokko Island: Iai 1996, 1998



Max settlement behind the wall 2.5 m

Presumed Causes of “Failures”

(a) Backfill seismic soil pressures

(b) Wall inertia

(c) Soft inelastic foundation soil

(d) Liquefaction

For proper modelling:

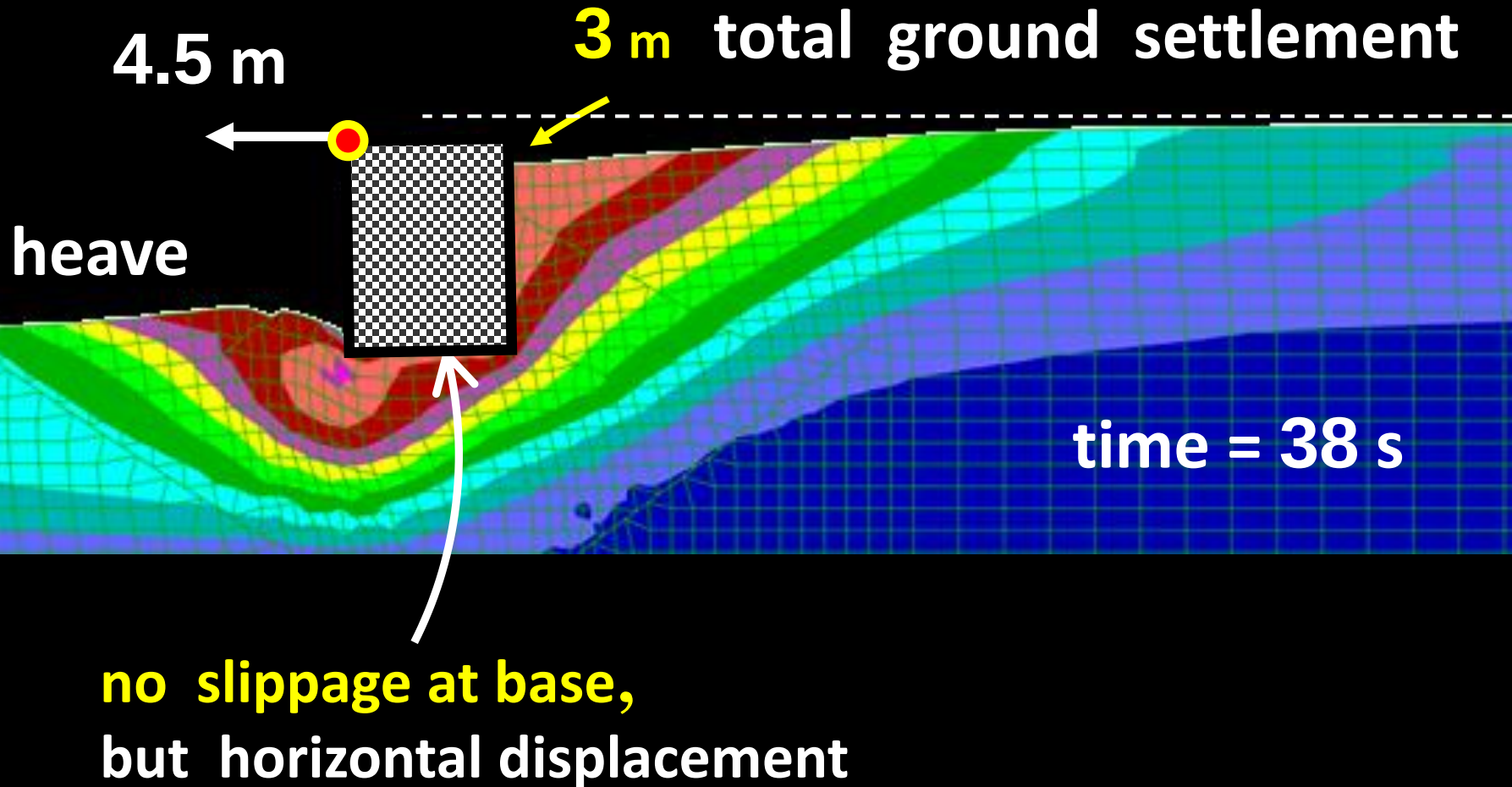
Effective–Stress Dynamic Analysis

(using FLAC)

with suitable constitutive material relations

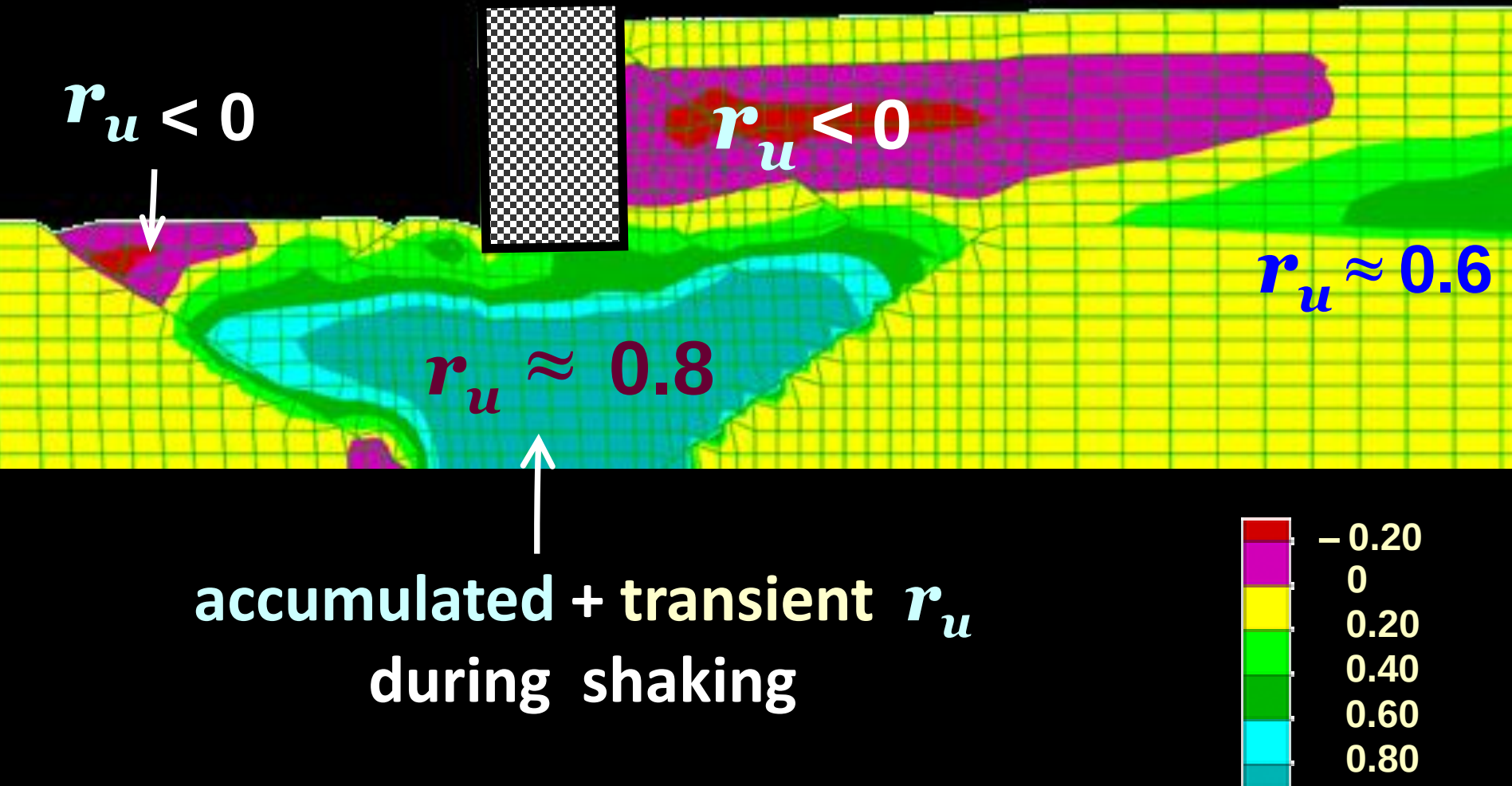
(Pastor & Zienkewitz)

Contours of Horizontal Displacements



Excess Pore Water Pressure Ratio

$$r_u = \Delta u / \sigma'_{om} \text{ at time } \underline{t = 10 \text{ s}}$$



Development of excess pore-water pressures, Δu

► *Two competing mechanisms*

Cyclic Simple Shear

POSITIVE Δu

(Liquefaction ?)

*Dominates in Free Field
and Foundation Soil*

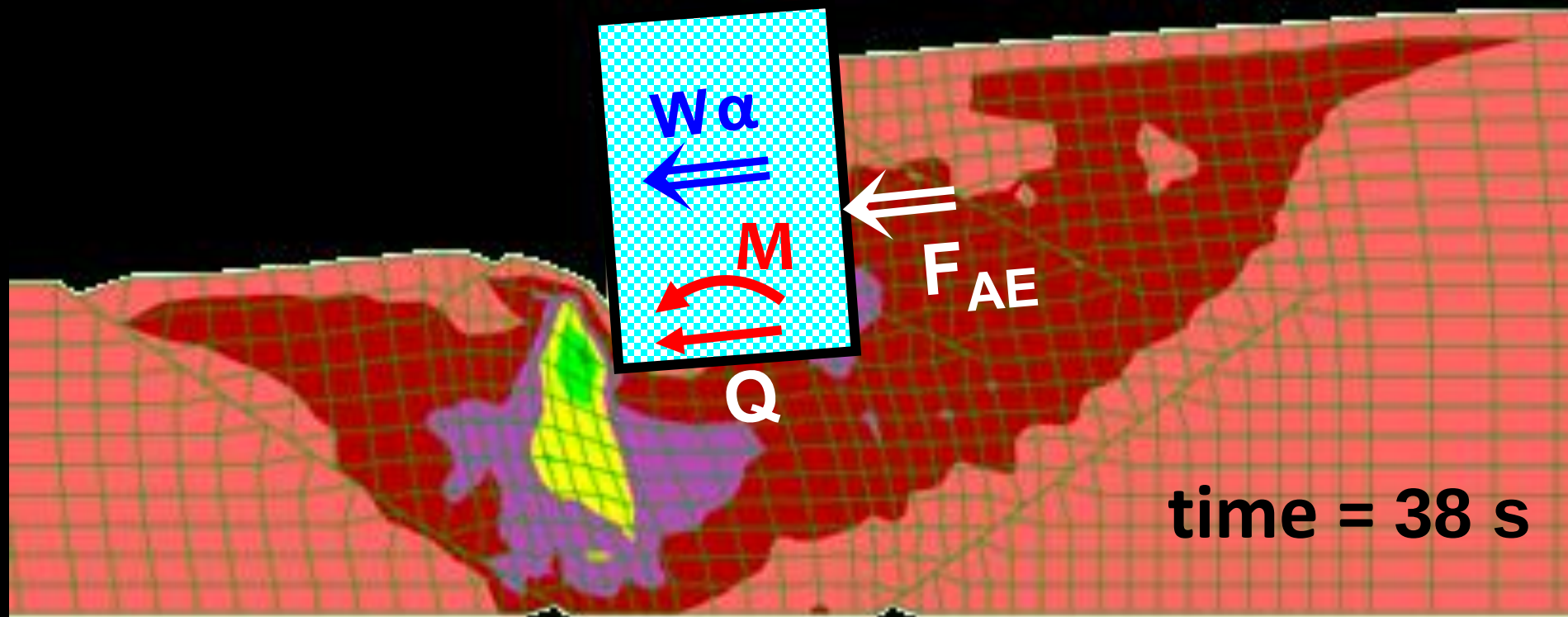
Large Seaward

Displacement :

NEGATIVE Δu

Dominates Behind Wall

Accumulation of Plastic Shear Strains



mobilised **bearing capacity** under **M** and **Q** from
(a) the **WALL INERTIA**, $W\alpha$, and
(b) the **Active Earth Pressures**, F_{AE}

Check the relative contribution:

Backfill Active Soil Pressures

versus

Wall Inertia Force

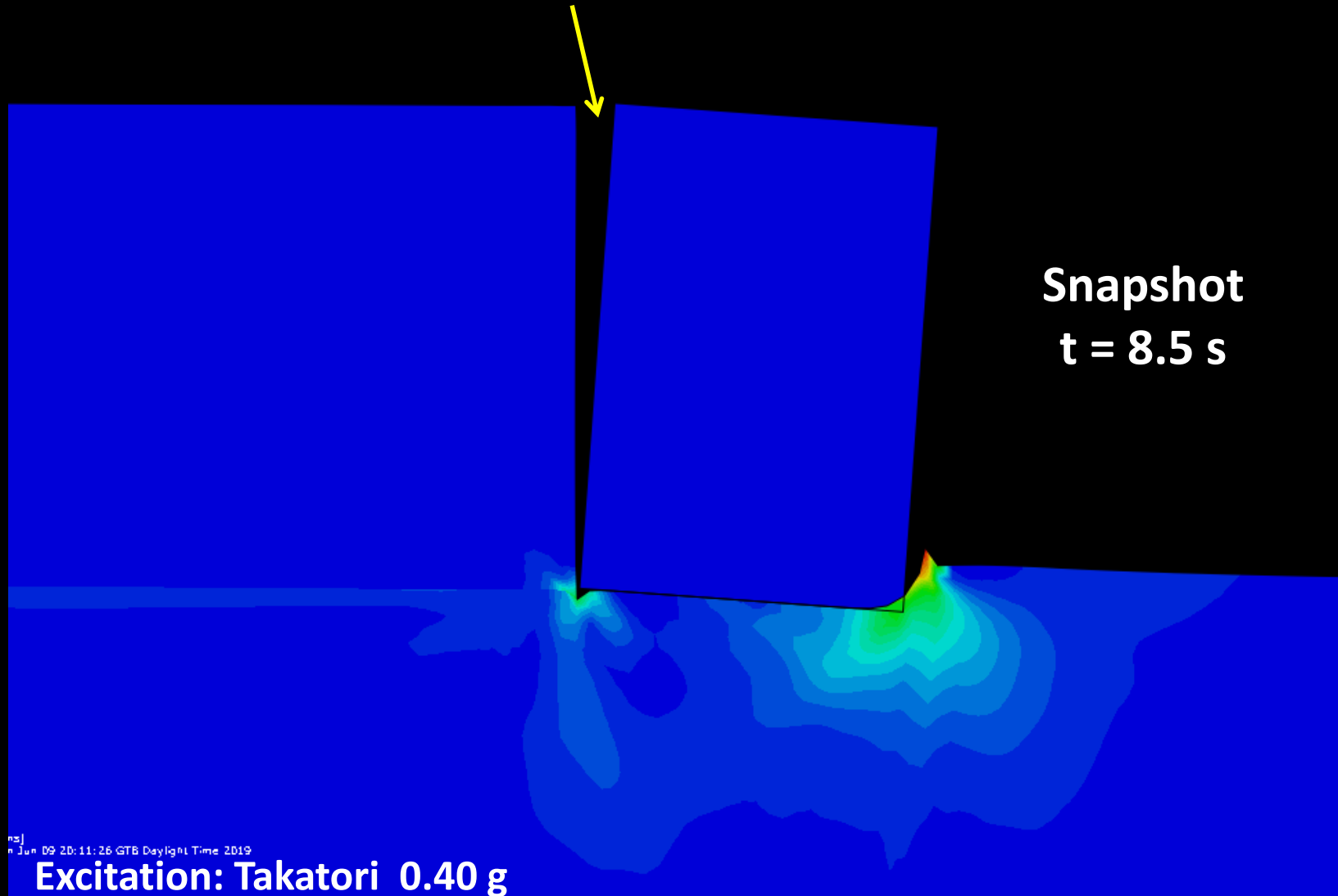
A simple way:

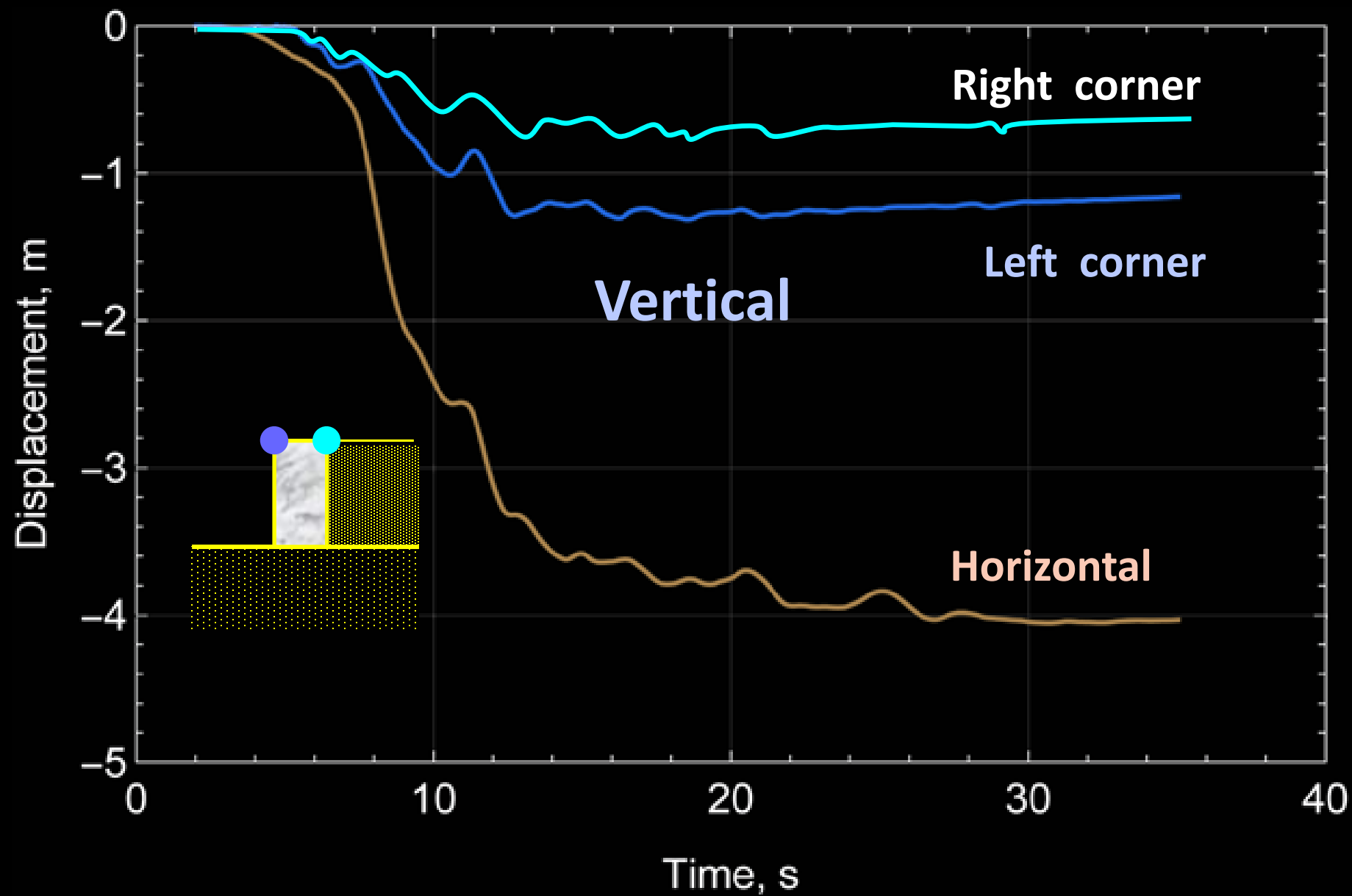
*Artificially minimise
the backfill Active Soil Pressures, F_{AE}*

*For example, by increasing
the cohesion of the backfill to **50 kPa**,
and re-analyzing the system
(with all other conditions unchanged)*

Retaining soil with $c_1 = 50$ kPa

Soil **separates from** the rotated wall





Presumed MAIN Causes of “Failure”

(a) ~~Backfill seismic soil pressures~~

(b) Wall inertia ✓

(c) Soft inelastic foundation soil ✓

(d) ~~Backfill-Liquefaction~~

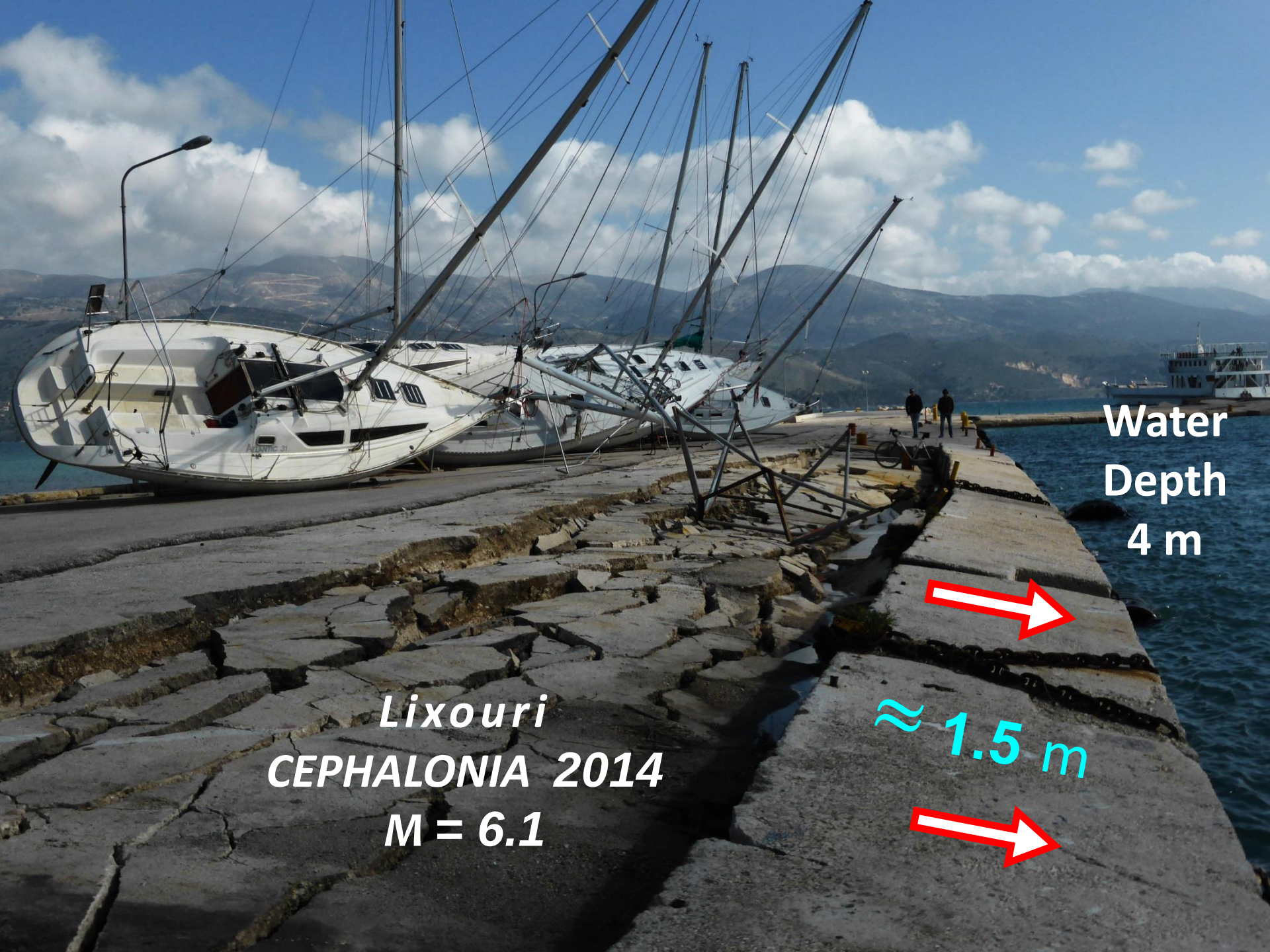
ONLY of the FOUNDATION SOIL !

CONCLUSION

All types of gravity quay walls are sensitive to seismic ground shaking, experiencing large seaward movements, but rarely overturning failures.

“ Increasing the wall dimensions
is a losing game,
as the inertia of the wall eventually
exceeds the active soil thrust ”...
leading to excessive rocking and
sliding

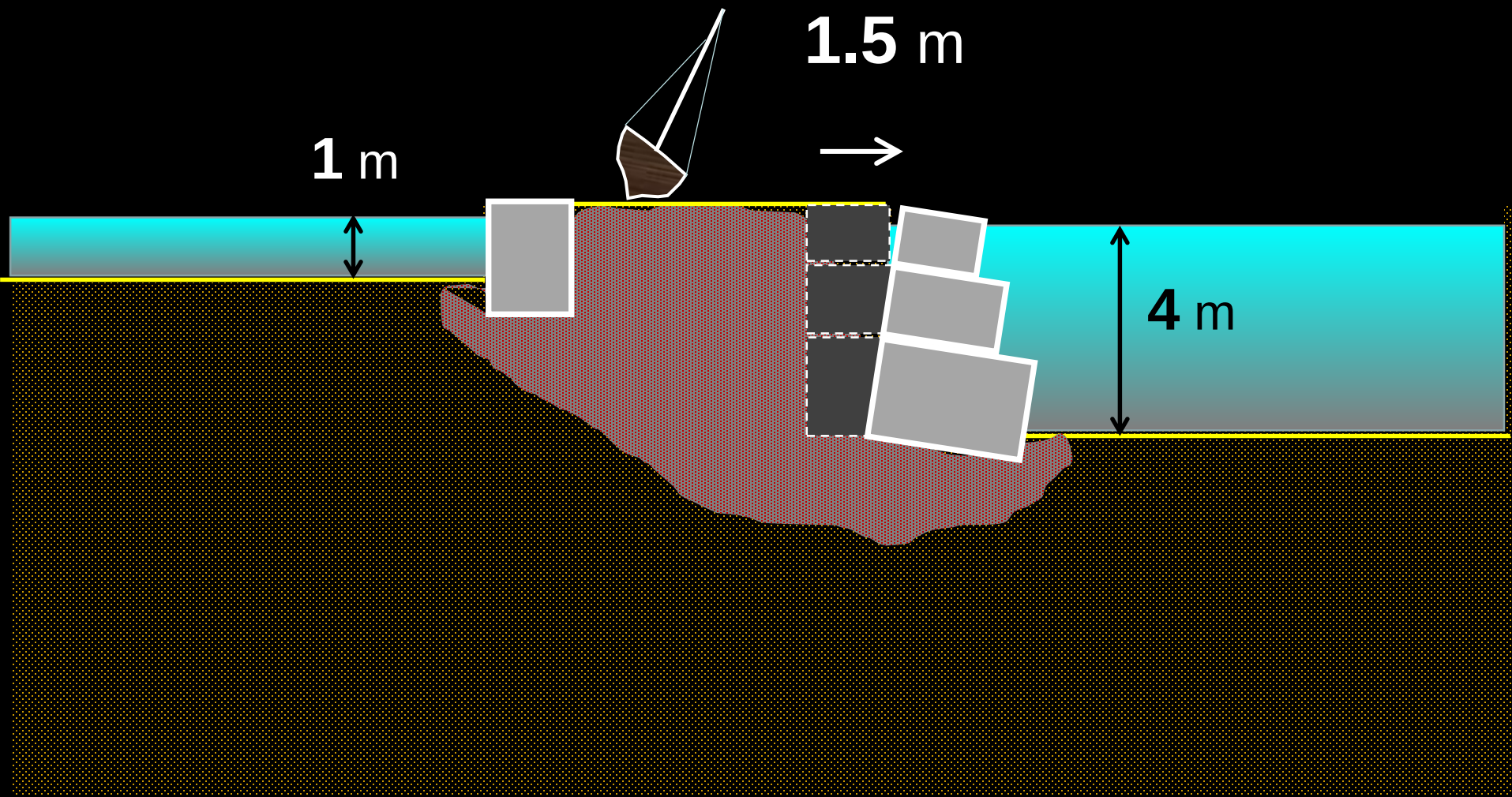
(Pender 2019)



Water
Depth
4 m

Lixouri
CEPHALONIA 2014
M = 6.1

≈ 1.5 m



Seismic Failures

Daikai Underground Station, Kobe 1995

TUNNELS in ROCK

***are considered safe even in very
strong shaking***

But not in SOIL or even in Fractured Rock

EXAMPLES

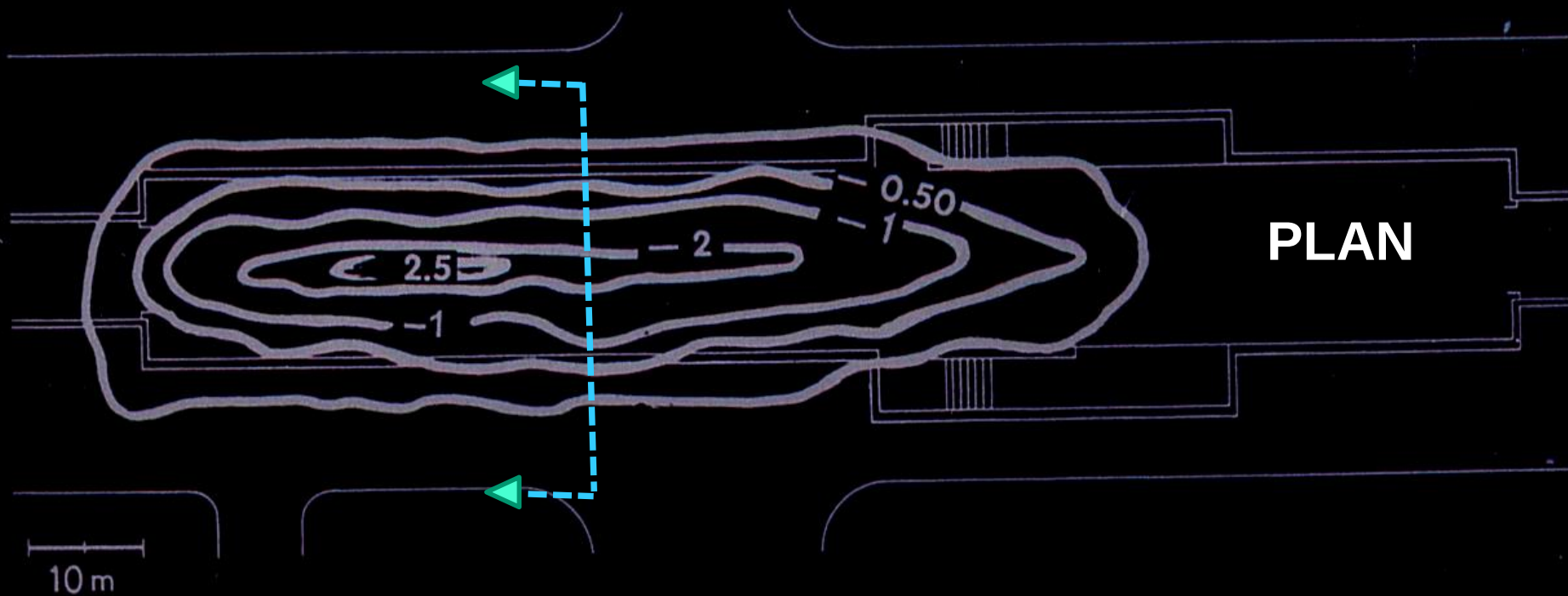
Daikai Station in Kobe, 1995

Duzce-Bolu, 1999

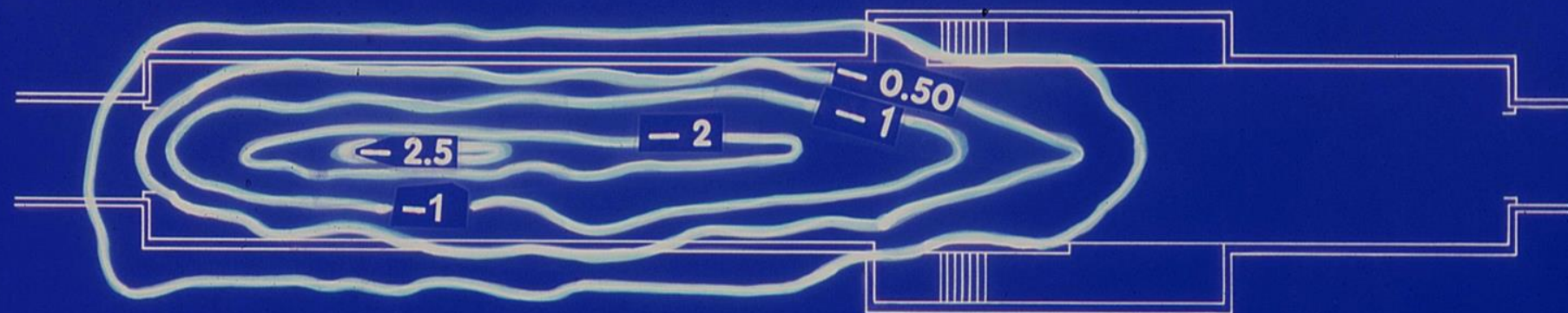


自動車をのみこむように氾濫した道路の
管が破裂、水が溢れた。西宮市内では越
水堤が機能しなくなった(17日、神戸市
区大開通)



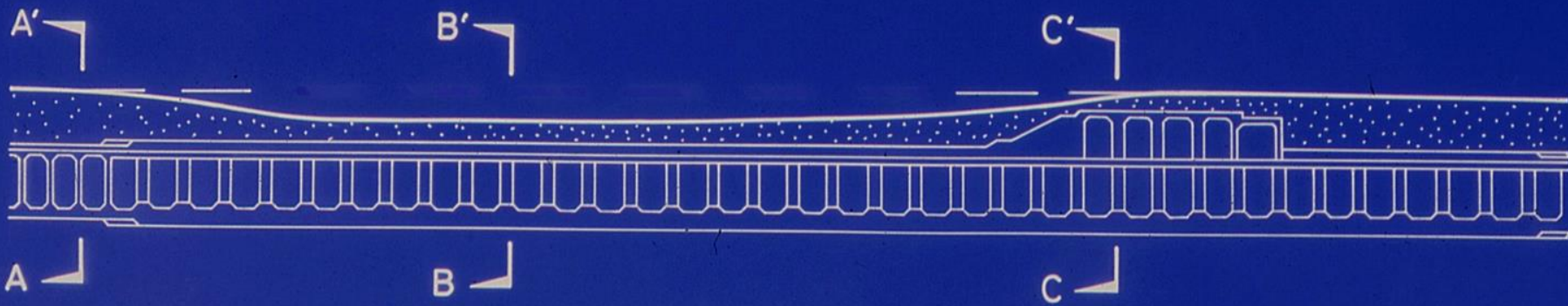


КАТОШ



10 m

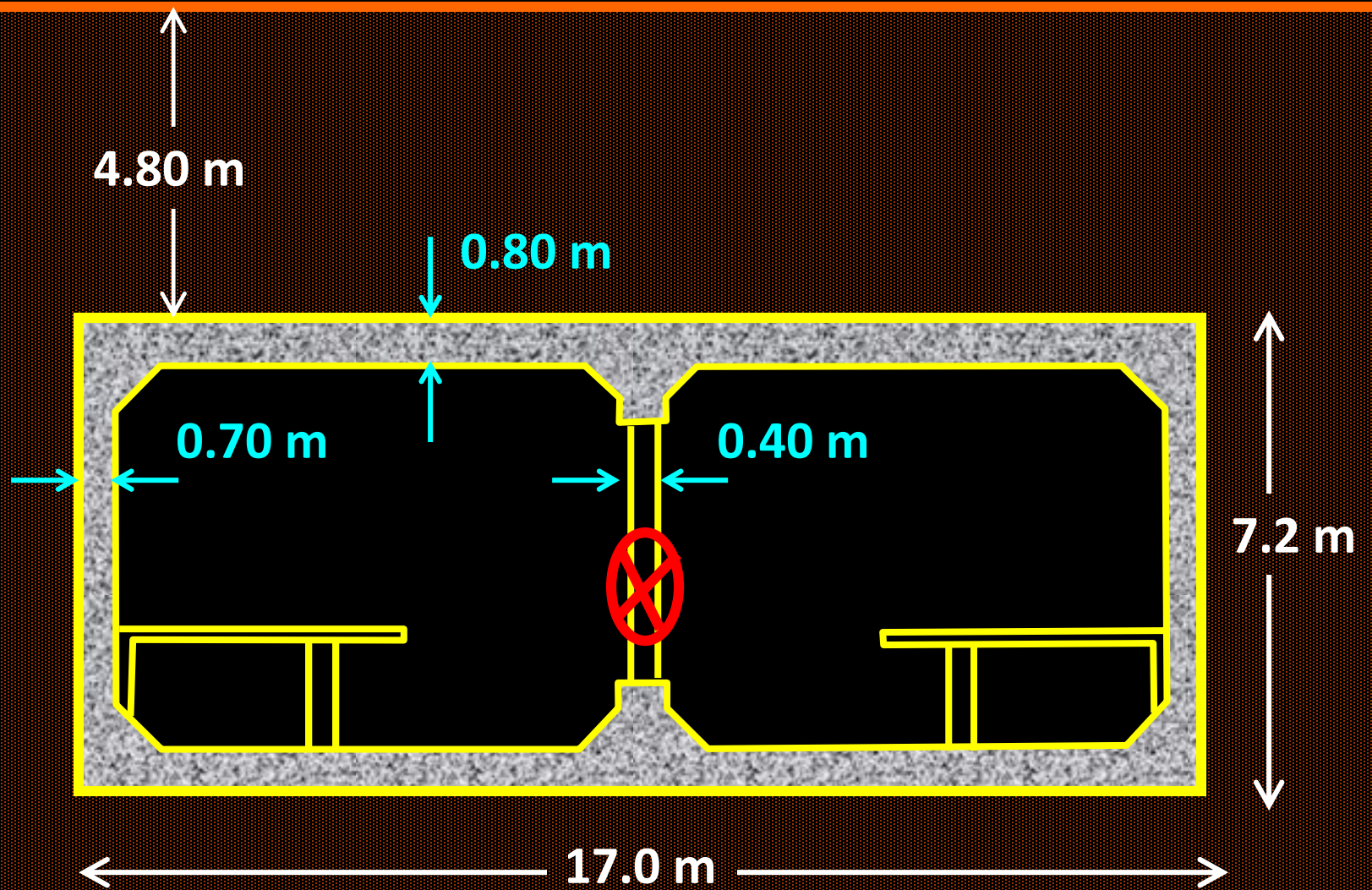
МНКТОМН

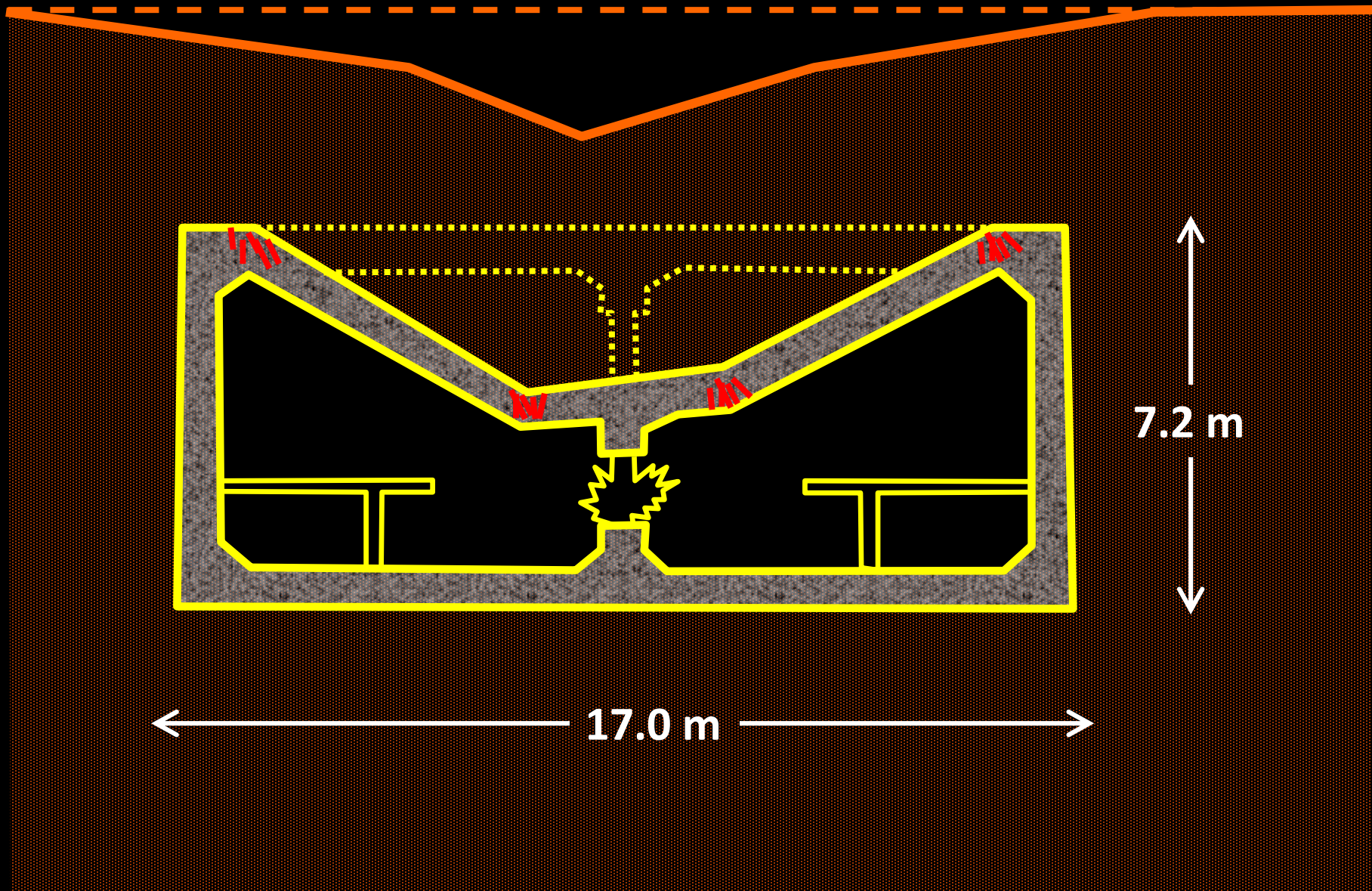












- *Strong Shaking (PGA > 0.60 g)*
 - *(Medium) Soft / Loose Soil*
- *Poor Structural Concept / Reinforcement*

CAUSES OF FAILURE :

Large A (> 0.60 g) and Large Overburden:

Excessive Inertia Force:

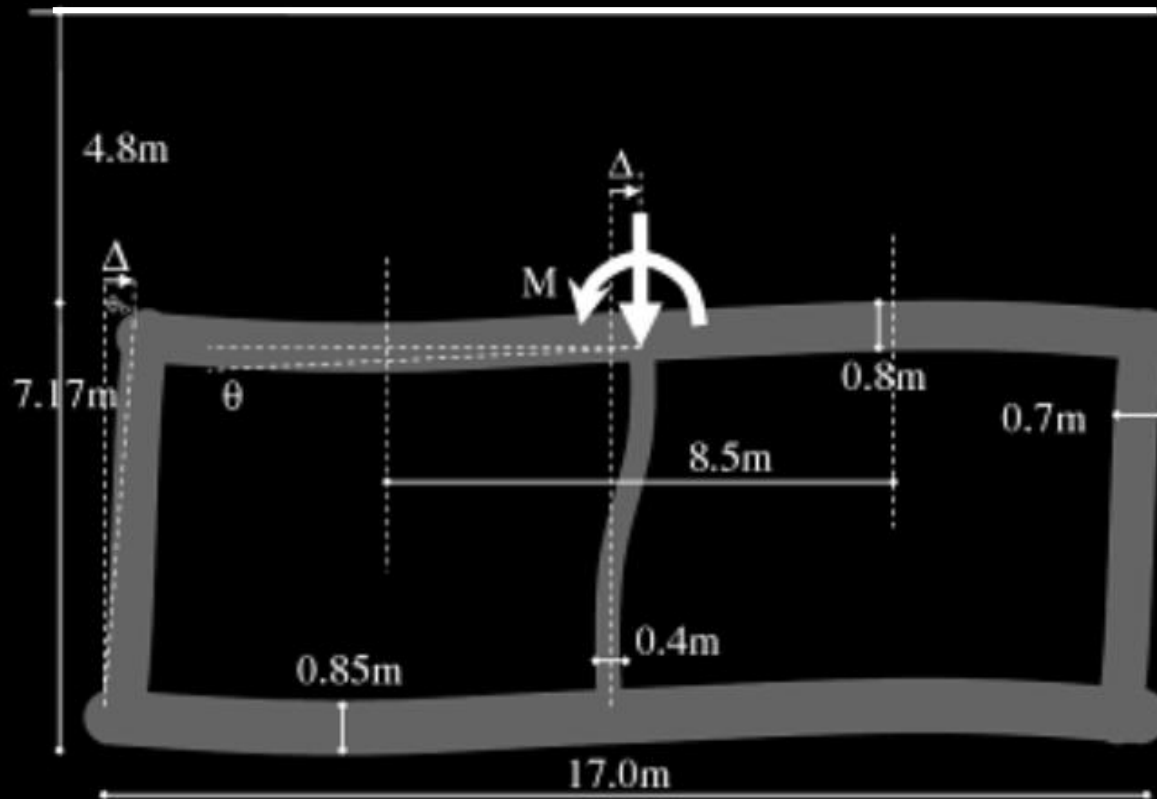
Horizontal: $0.60 \times 20 \times 5 \times 17 = 1020 \text{ kN}$

Shear on Column $\approx 150 \text{ kN}$

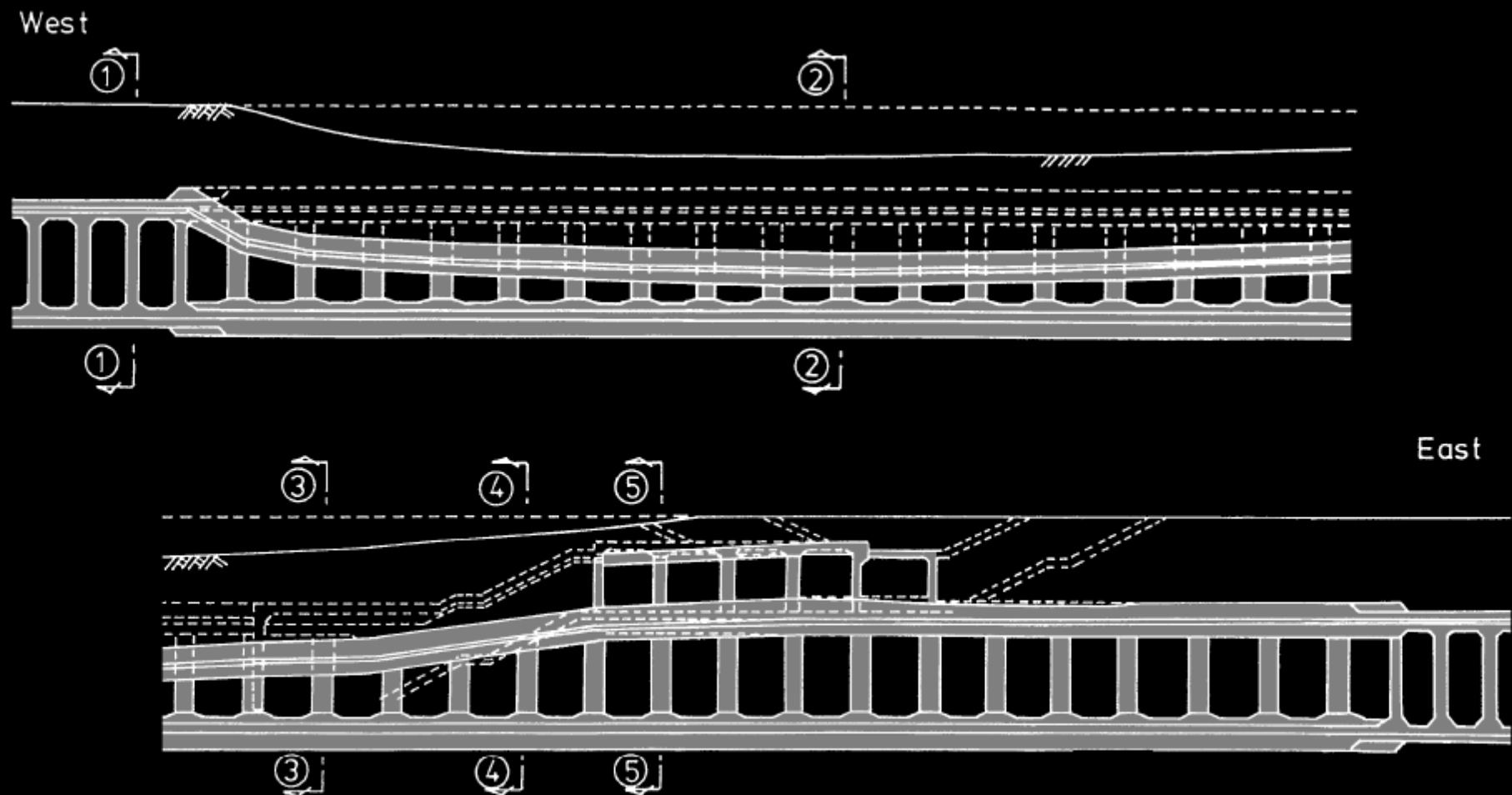
Bending Moment $\approx 540 \text{ knm}$

Axial Load $\approx 850 \text{ kN}$

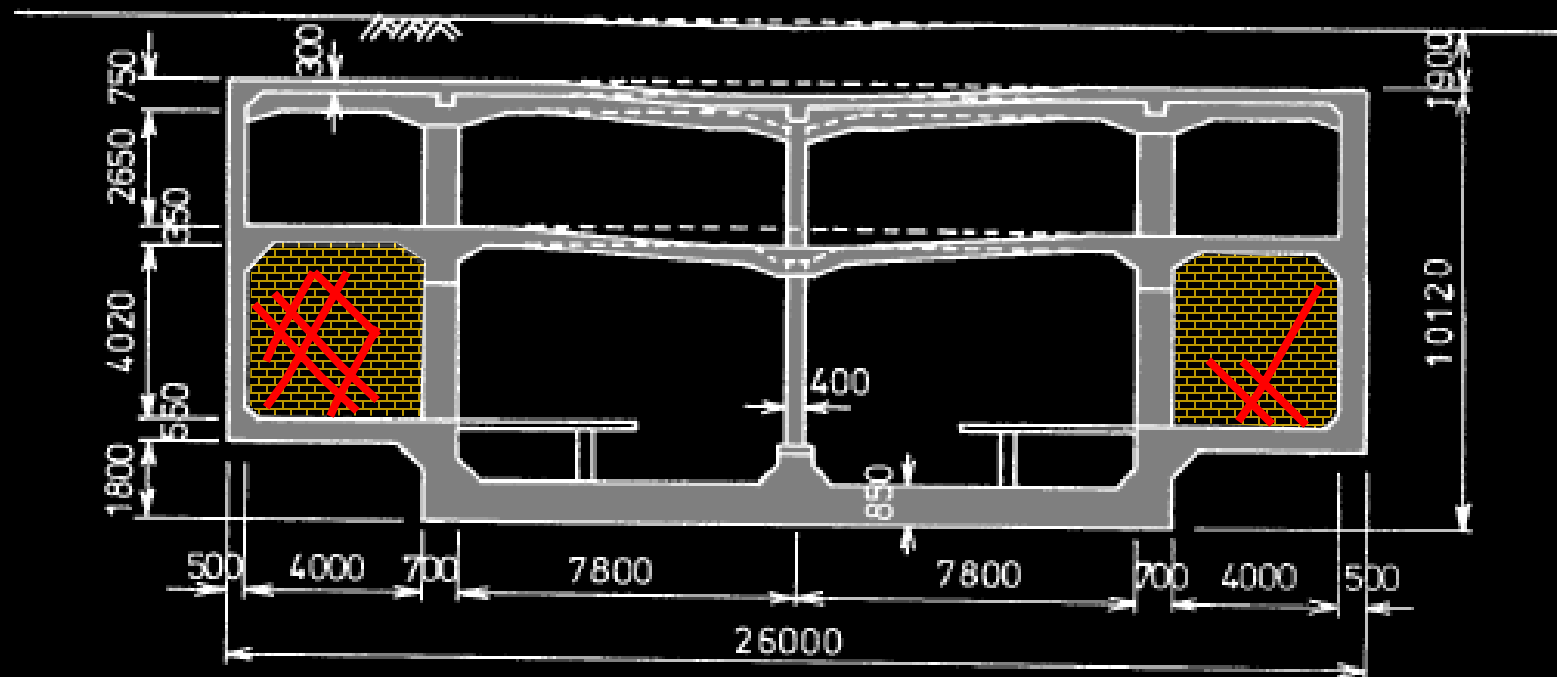
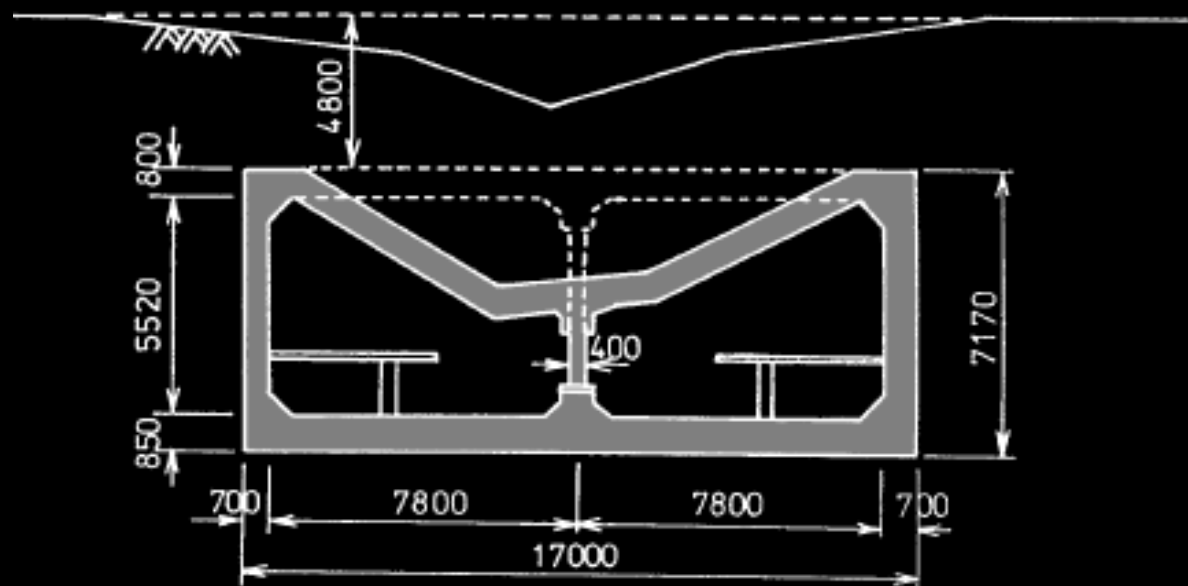
Needed: excessive ductility of concrete column



Then $P-\Delta$ effects lead to collapse



(a) Longitudinal section



Lessons from the Daikai Collapse

- 1. C&C Stations are not immune to strong seismic shaking*
- 2. Large embedment and Soft/Loose Soil can be disastrous*
- 3. Poor Structural Concept / Reinforcement can lead to failure*

The BENEFITS
from Earthquake Observations
are Invaluable



The End





Son

*Dikkatiniz için
Teşekkür ederim*

