

RESEARCH AND PRACTICE IN ENGINEERING

The Rion-Antirion Bridge foundation design

Alain PECKER

- Finance
- Design
- Build
- Own
- Operate
- Transfer



OUTLINE OF PRESENTATION

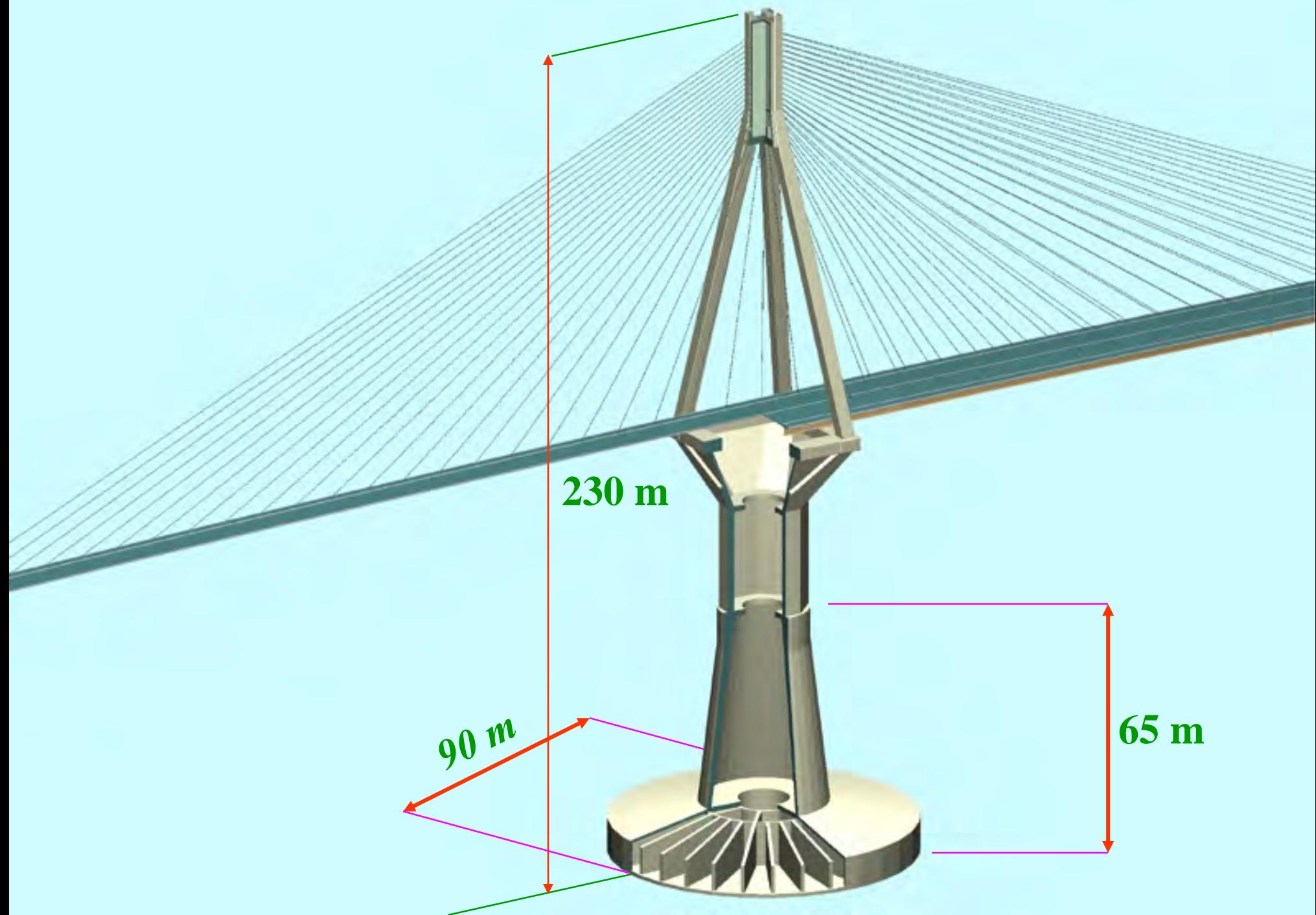
- Overview of Project
- Geotechnical and environmental conditions
- Adopted solution for foundations
- Design methodology
- Pictures of construction
- A last question

KEY DATES

- Launch of tender : 1992
- Contract award : December 1997
- Start of construction : End 1999
- Date of completion : August 2004
- Total cost : 770 Mi Euros (630 construction)







GEOTECHNICAL CONDITIONS

GEOTECHNICAL SOIL PROFILE



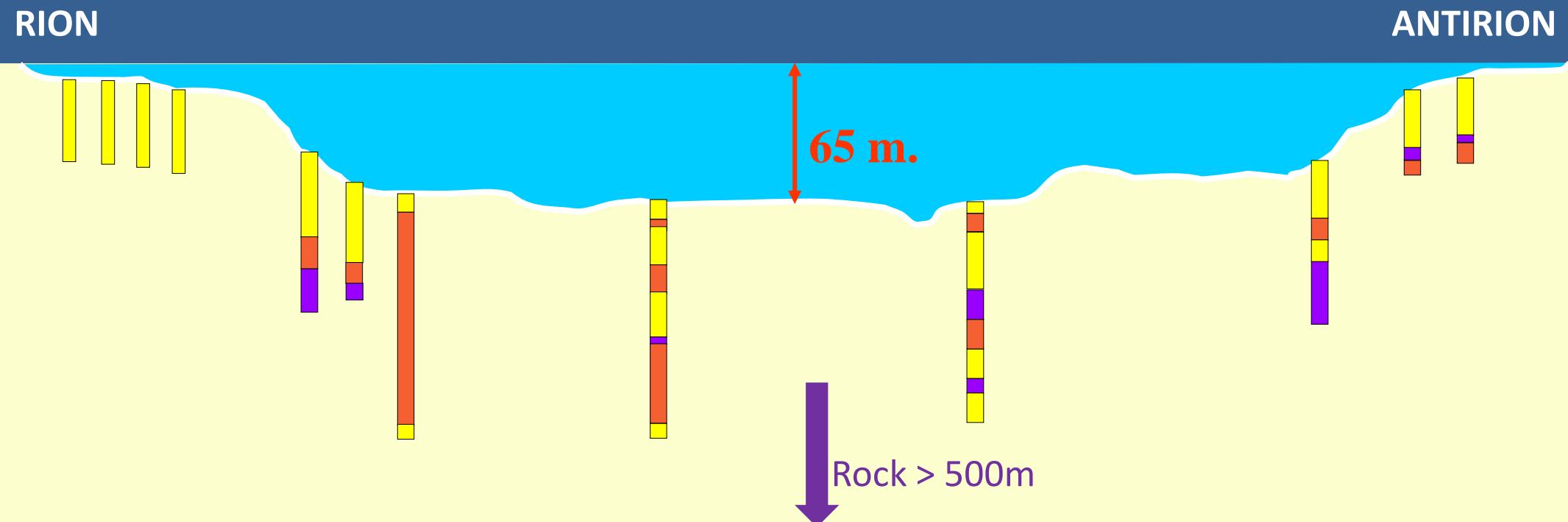
SAND AND GRAVEL



CLAY



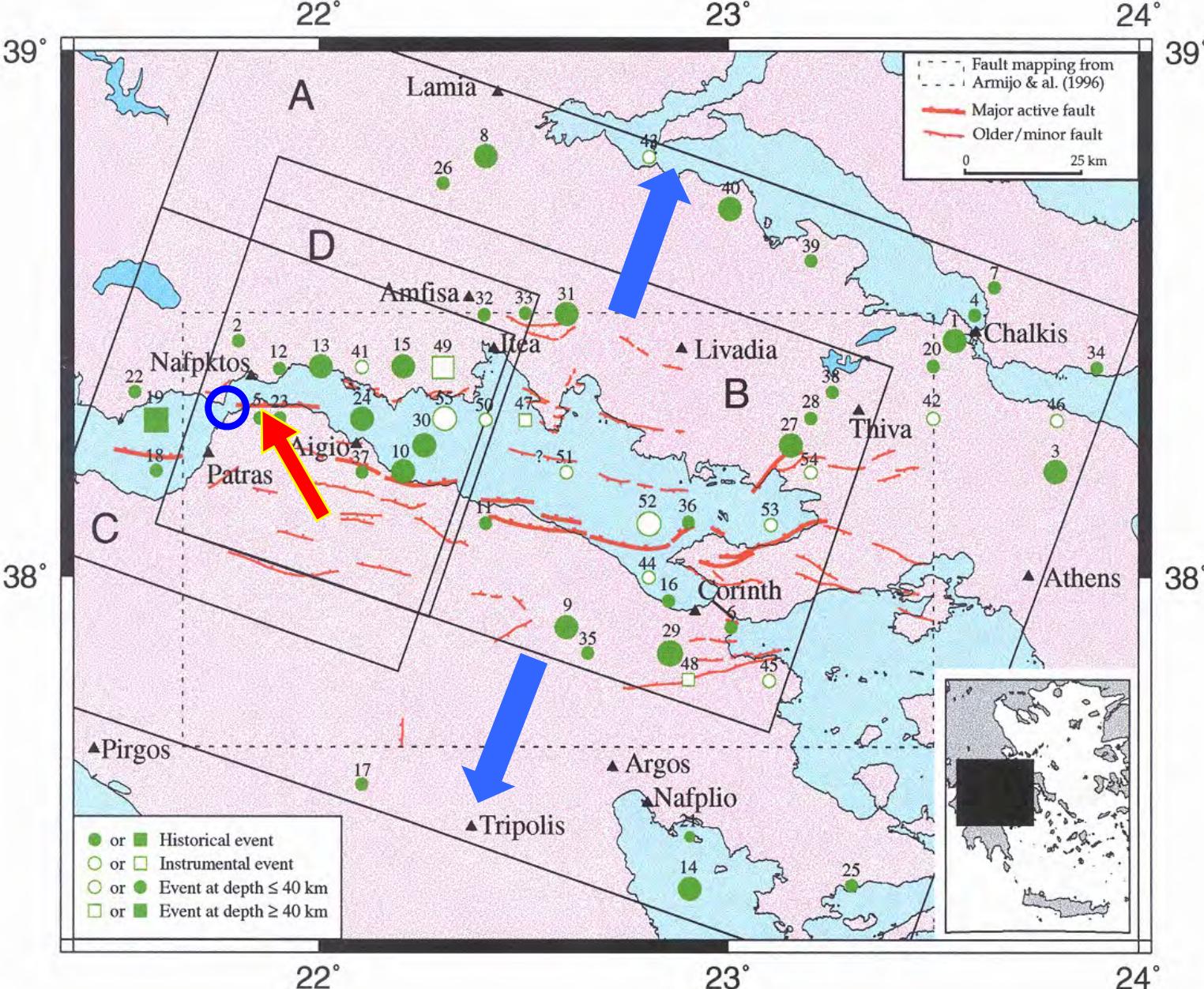
SILT



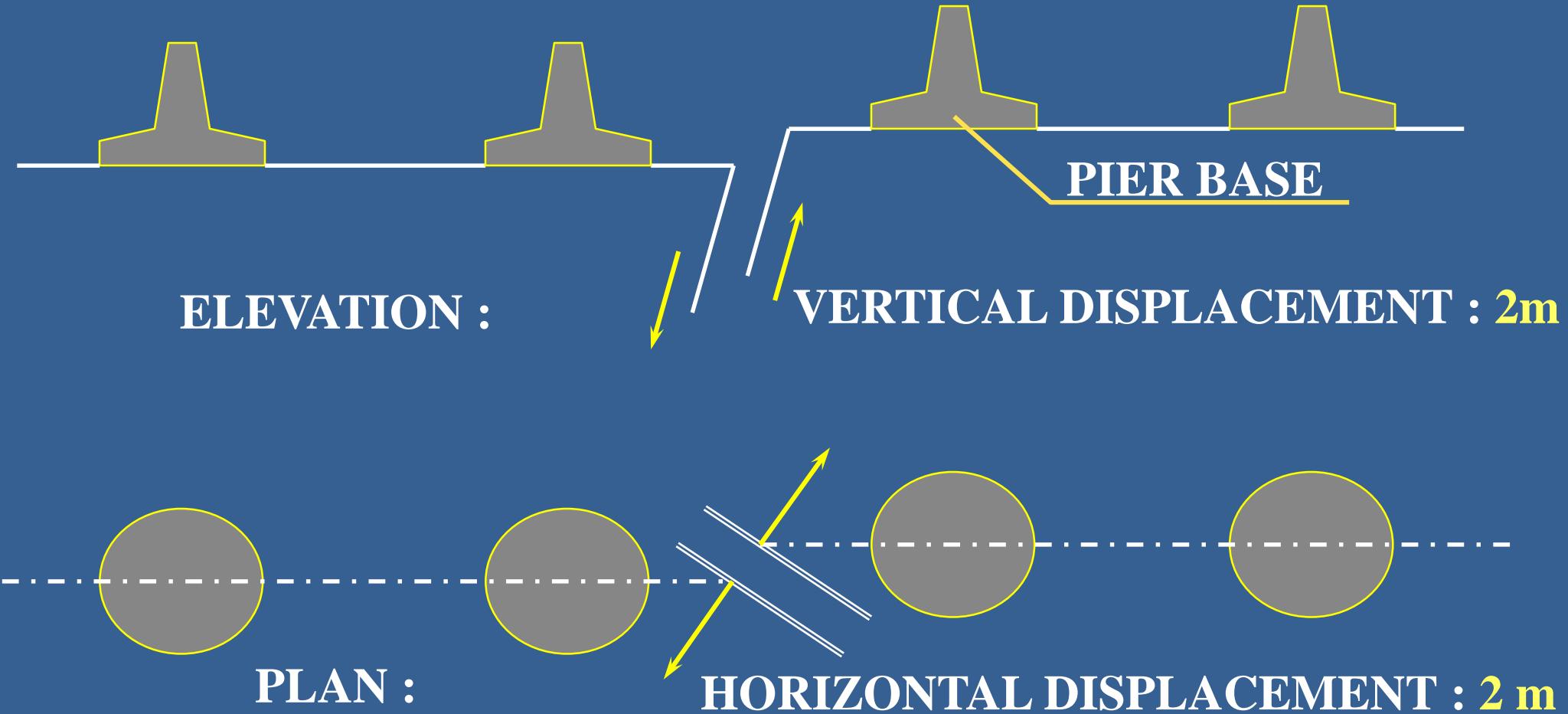
ENVIRONMENTAL CONDITIONS

Seismic design conditions

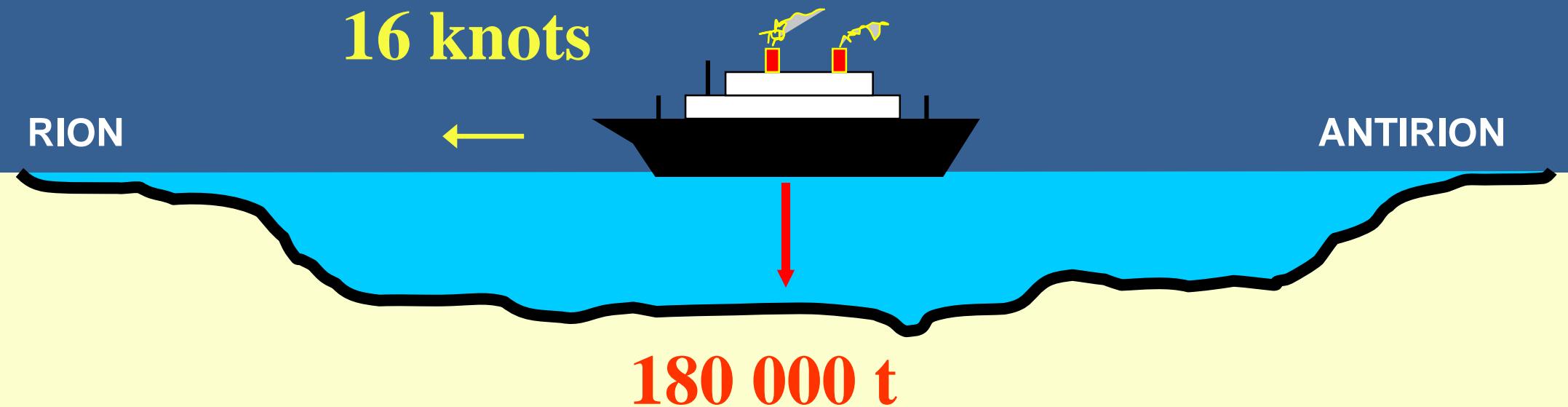
Magnitude 7.0
Max acceleration: 0.5g
 $P = 0.05\% / \text{year}$



TECTONIC MOVEMENTS



SHIP IMPACT



CHALLENGES

- No rock formation at less than 600 m
- Large water depth : 65 m
- Performance objectives (2000 year return period):
 - ⇒ Damages acceptable but bridge repairable
 - horizontal sliding acceptable ; tilt prohibited (<0.1 %)

INVESTIGATED FOUNDATION SOLUTIONS

- ➡ PILES
- ➡ EMBEDDED CAISONS
- ➡ SOIL SUBSTITUTION
- ➡ SHALLOW FOUNDATION

Many advantages : constructability, celerity, cost
Behavior in high seismic areas on soft soil ?

EXAMPLES OF FOUNDATION BEHAVIOUR

Shallow foundations

- Post earthquake observations
 - Mexico city (1985)
 - Loma Prieta (1989)
- Confirmation by small scale experiments
 - Shake table tests (CEA, Cambridge, PWRI)
 - Centrifuge tests (UC DAVIES, IFSSTAR)
 - Pseudo dynamic tests (JRC)

MEXICO

(Michoacan, 1985)



FOTODECLINICA
FOTOGRÁFICA MEDICA
TRANSPARENCIAS PARA CONFERENCIAS
ARTICULOS FOTOGRÁFICOS
FOTOSTATICOS TEL:

PO. REY

MINOLTA XD-5

HORARIO
LUNES A VIERNES
1000 A
1600 A



MEXICO
(Michoacan, 1985)

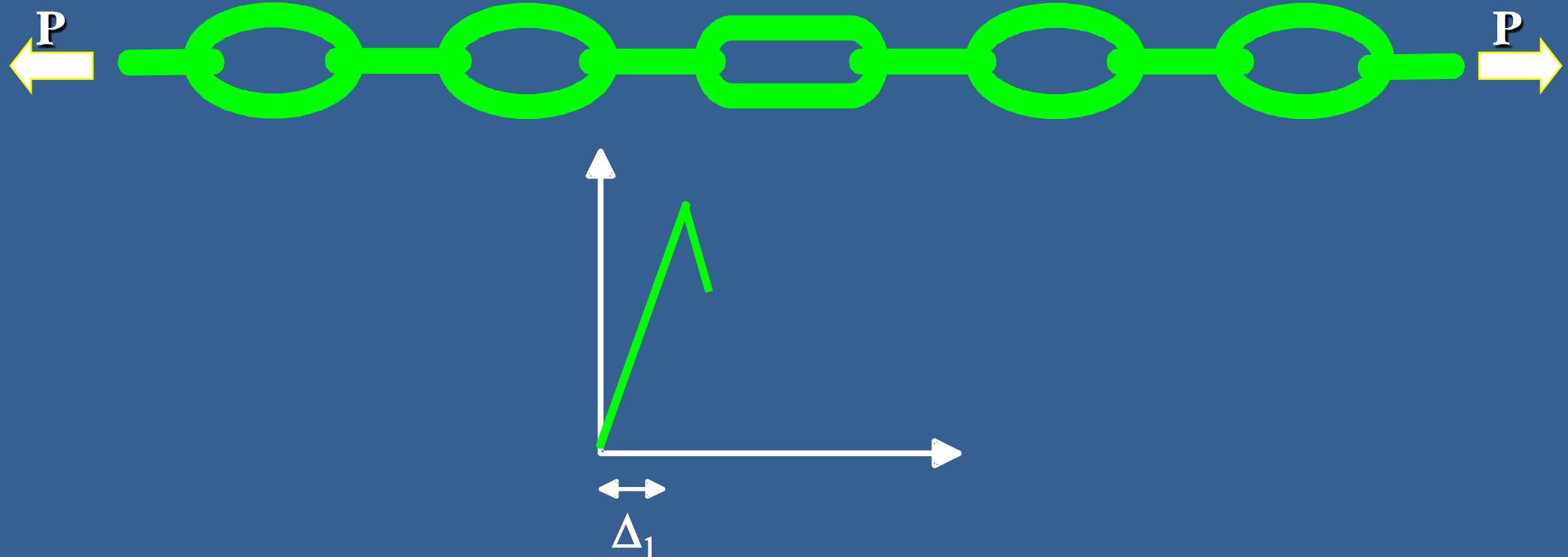
MOSS LANDING (Loma Prieta, 1989)



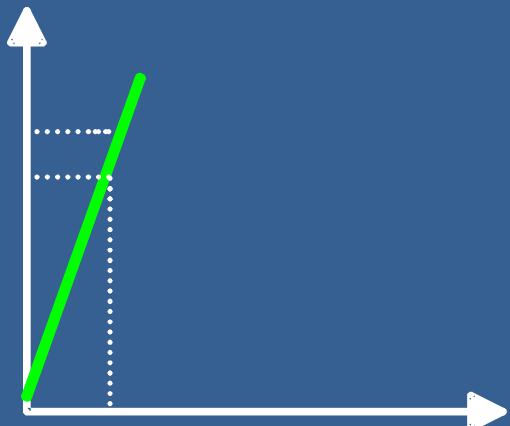
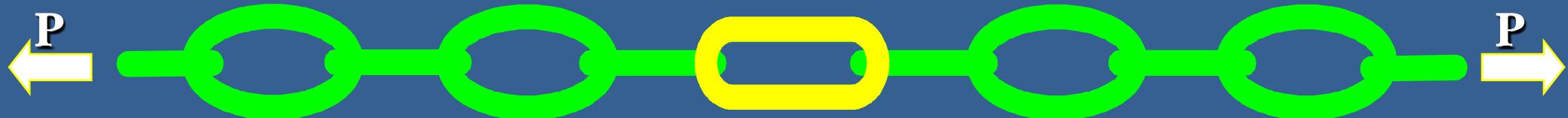
STRATEGY

- Use the concepts of previous research on:
 - ⇒ Seismic bearing capacity of shallow foundations
Salençon-Pecker (1991)
 - ⇒ Analyses of nailed structures
Salençon-De Buhan (1993)
- Introduce new aspects to develop an innovative solution
 - ⇒ Shear force contribution in resistance of inclusions
 - ⇒ Introduce a capacity design philosophy

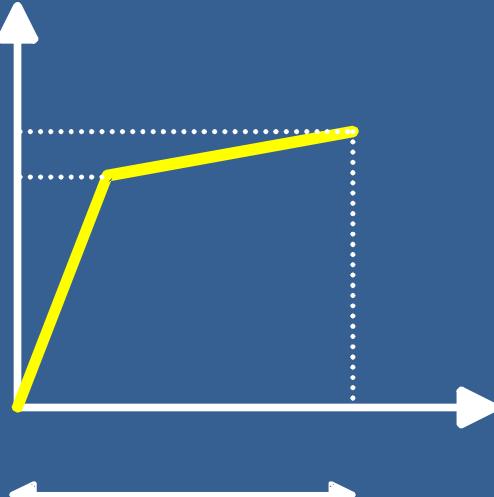
CAPACITY DESIGN (Paulay, 1997)



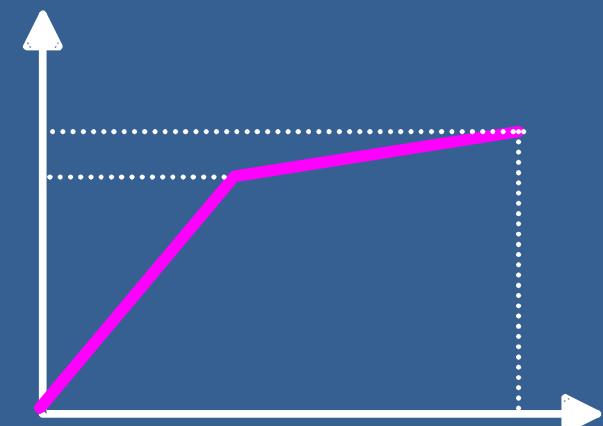
CAPACITY DESIGN (Paulay, 1997)



$$\Delta_1$$



$$m \Delta_1$$



$$n \Delta_1 + m \Delta_1$$



$$\mu^* = \frac{n + \mu}{n + 1}$$

N Brittle links

+ Ductile link

= Ductile chain

SOIL REINFORCEMENT

- Driven steel pipes
 - ⇒ Diameter 2 m, Thickness 20 mm
 - ⇒ Length 25 m to 30 m
 - ⇒ Spacing 7 m x 7 m
- Gravel layer : 3m thick



200 INCLUSIONS UNDER EACH FOUNDATION

FOUNDATION CROSS SECTION

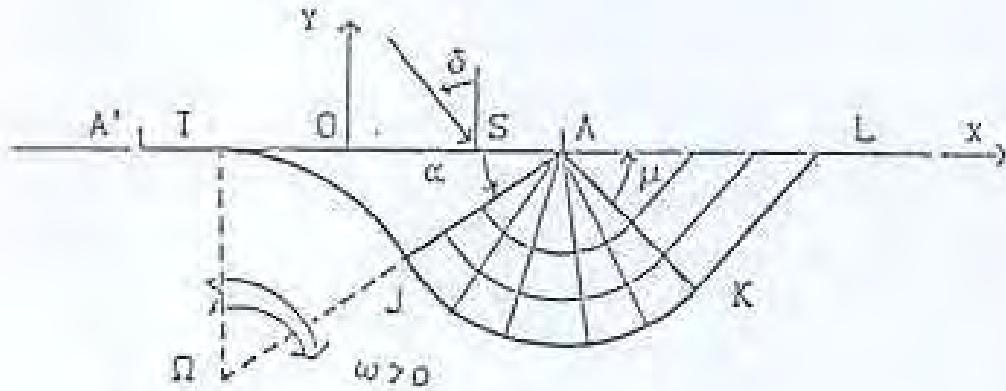


Gravel layer : $h=3m$

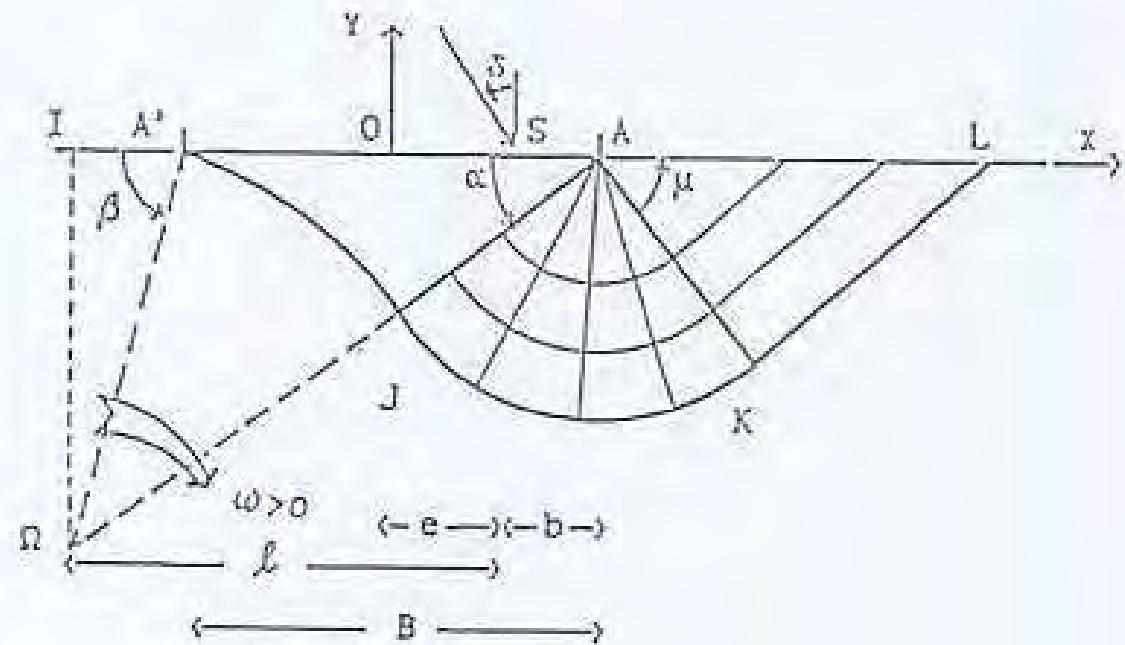
Inclusions : $s=7mx7m$
 $h=30m$
 $\phi=2m$

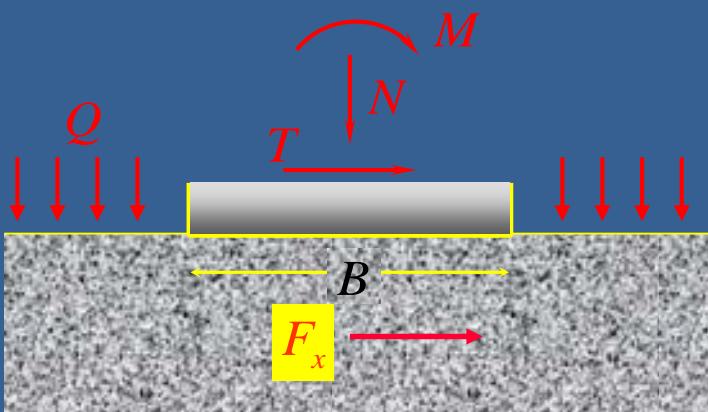


CENAPRED WORKSHOP (1991)



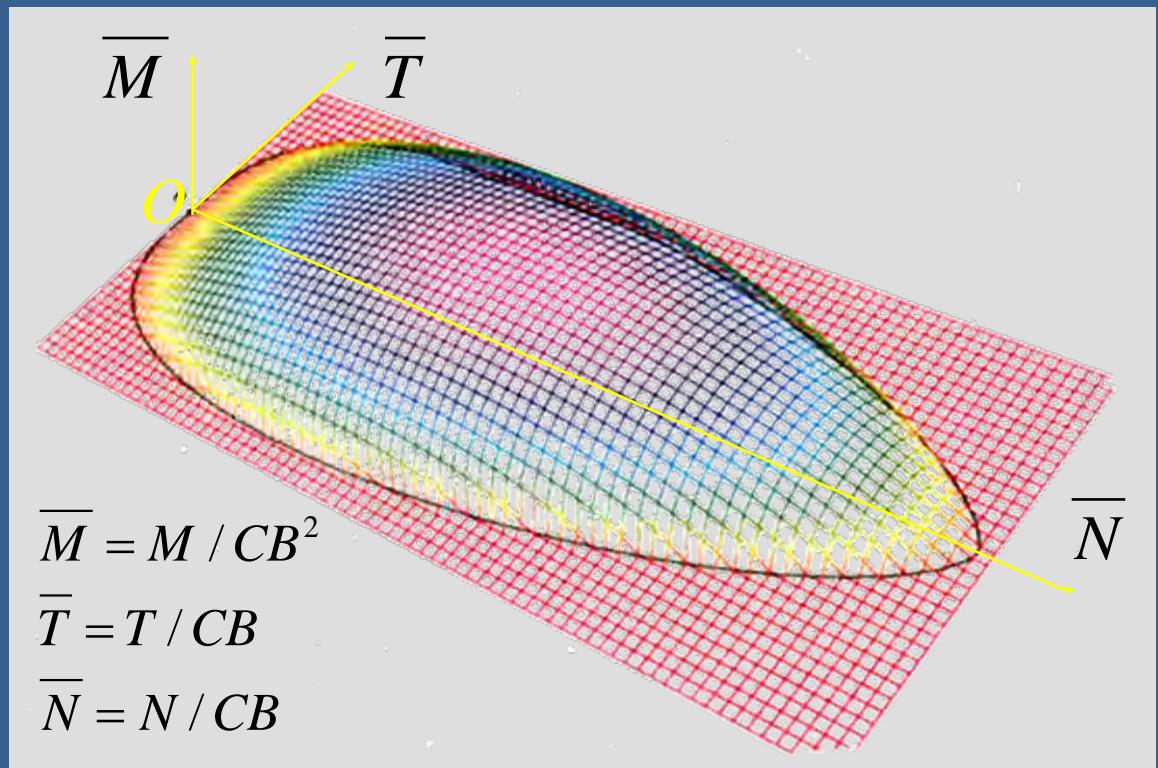
$$\begin{array}{c} \leftarrow e \rightarrow \leftarrow b \rightarrow \\ \leftarrow l \rightarrow \\ \leftarrow B \rightarrow \end{array}$$



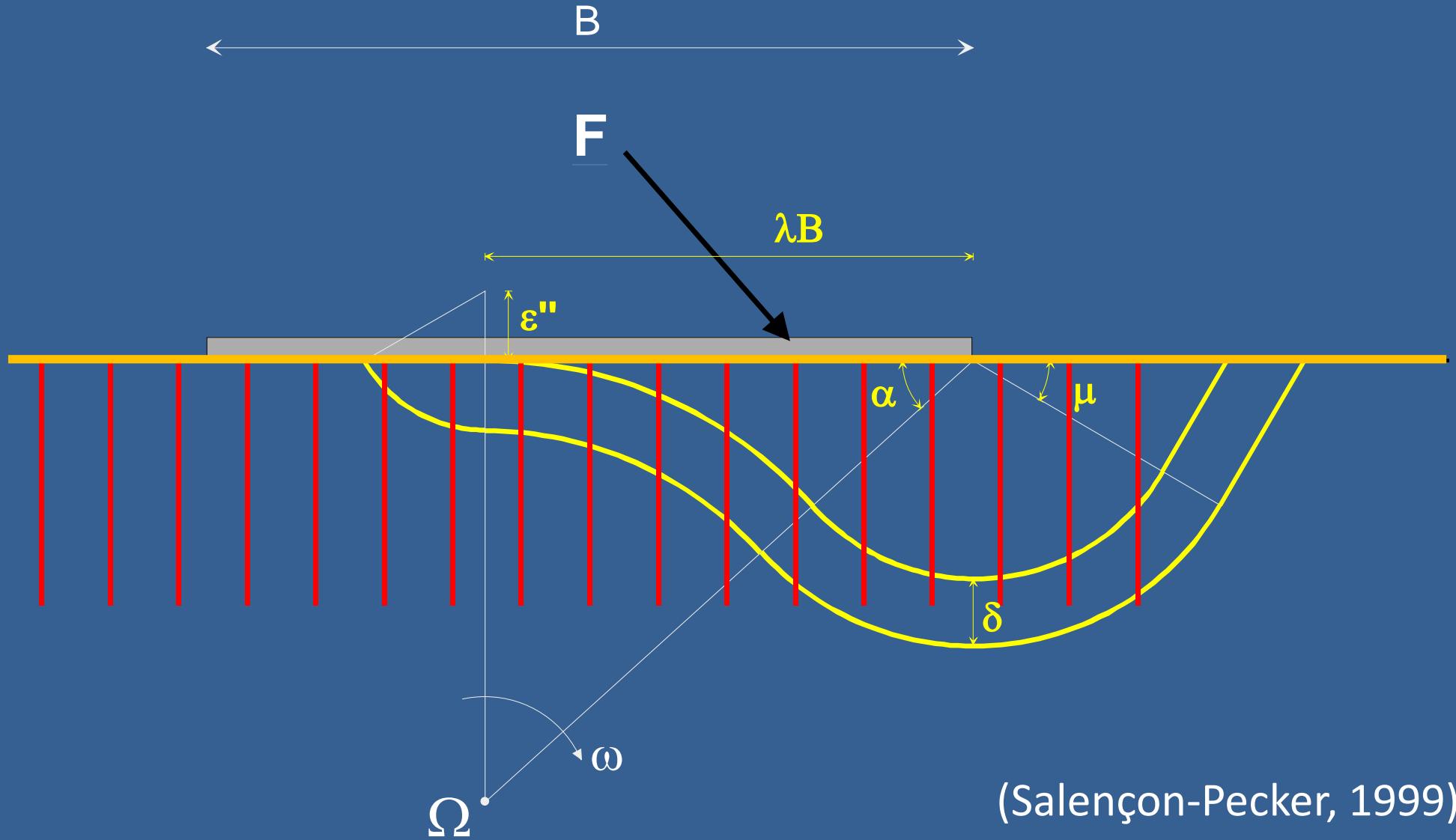


BEARING CAPACITY under COMBINED LOADS

Yield design theory (1983)



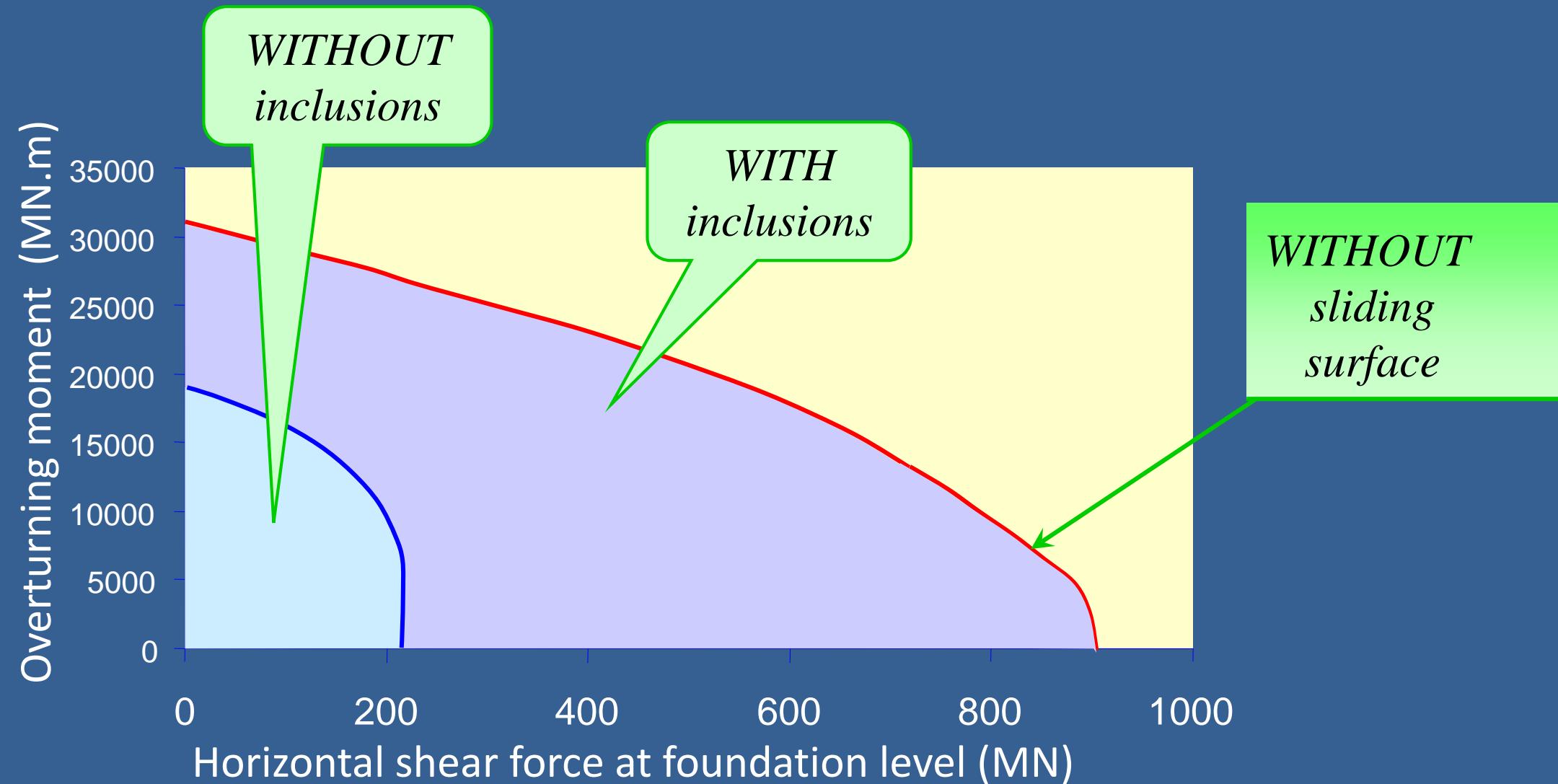
REINFORCED SOIL



(Salençon-Pecker, 1999)

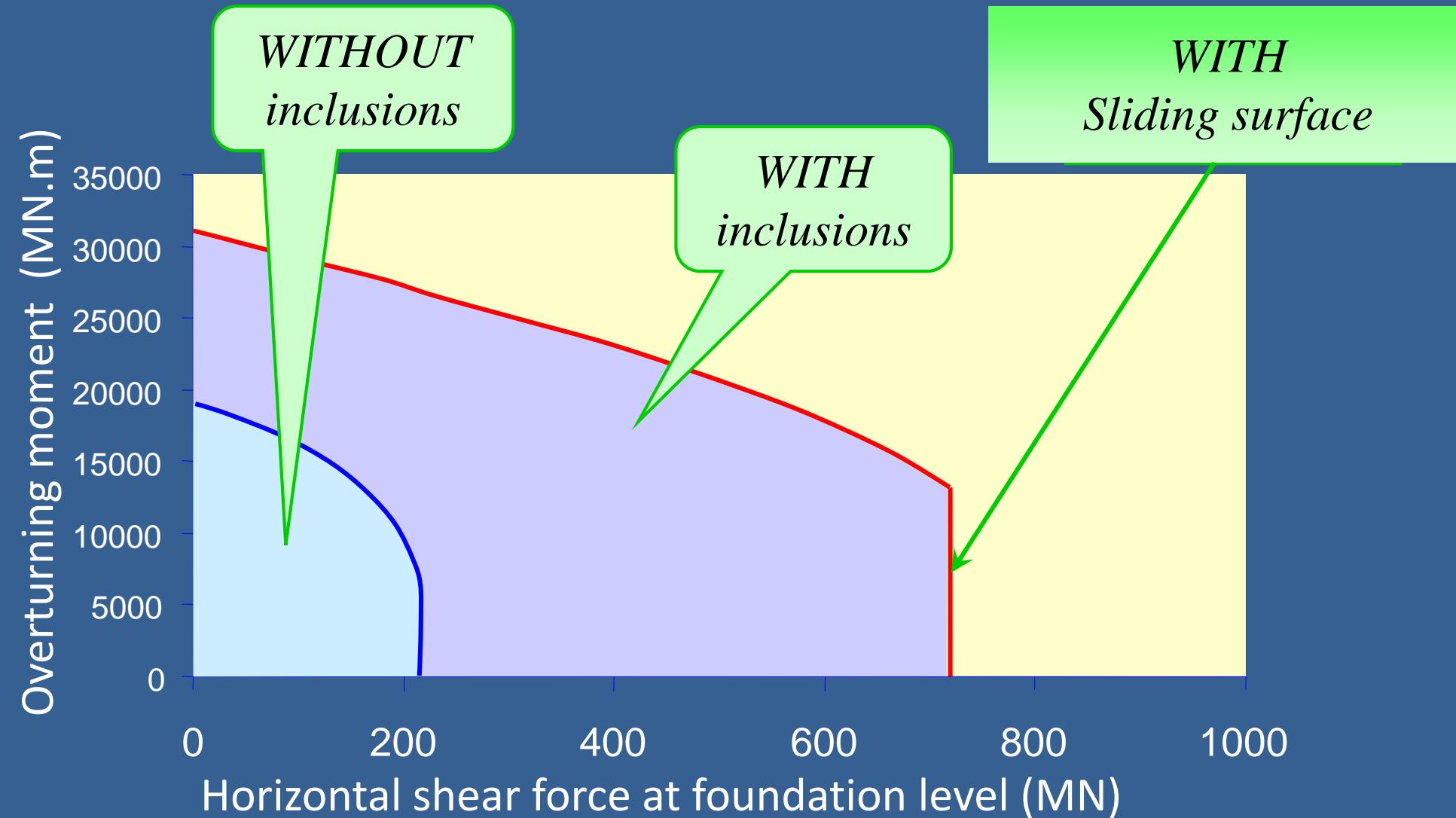
BOUNDING SURFACE

$$N = 860 \text{ MN} - L = 25 \text{ m} - S = 7 \text{ m}$$



BOUNDING SURFACE

$$N = 860 \text{ MN} - L = 25 \text{ m} - S = 7 \text{ m}$$



CAPACITY DESIGN PHILOSOPHY

Plastic link (hinge) = Gravel bed

Overstrength = Reinforced soil

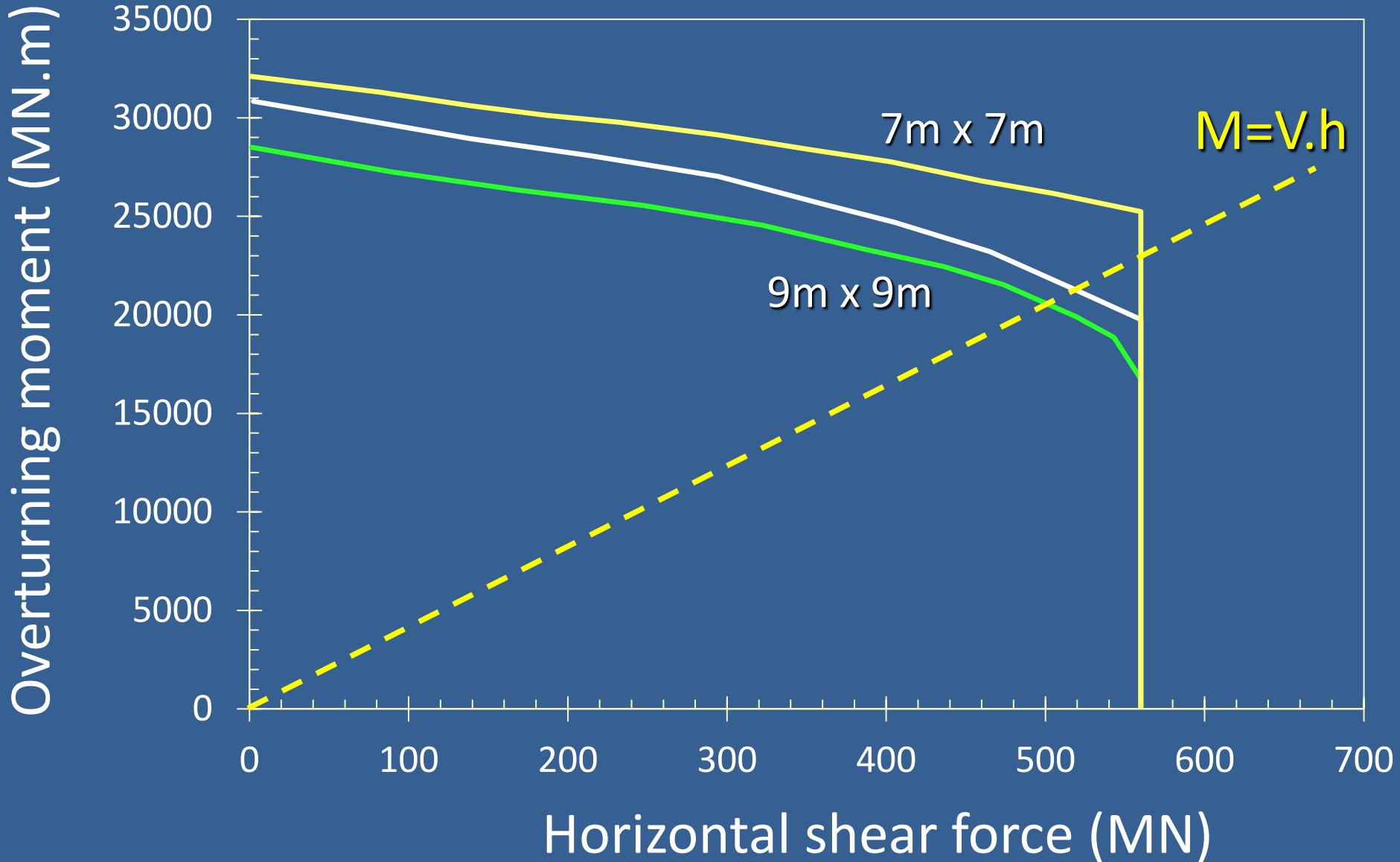
COMBINED EFFECT PROVIDES

- Bounds for forces in the superstructure
- Control of failure mode (*horizontal sliding*)

DESIGN STRATEGY

- Facing a new design situation
 - ⇒ Keep things as simple as possible
- Four steps process
 - ⇒ Conceptual design : New tools (Yield Design Theory)
 - ✓ Amenable to parametric studies
 - ⇒ Validation : Physical modeling (centrifuge)
 - ⇒ Final design : non linear finite element models
 - ⇒ Development of a dynamic macro element (structural analyses)

INCLUSIONS SPACING



EXPERIMENTAL VALIDATION

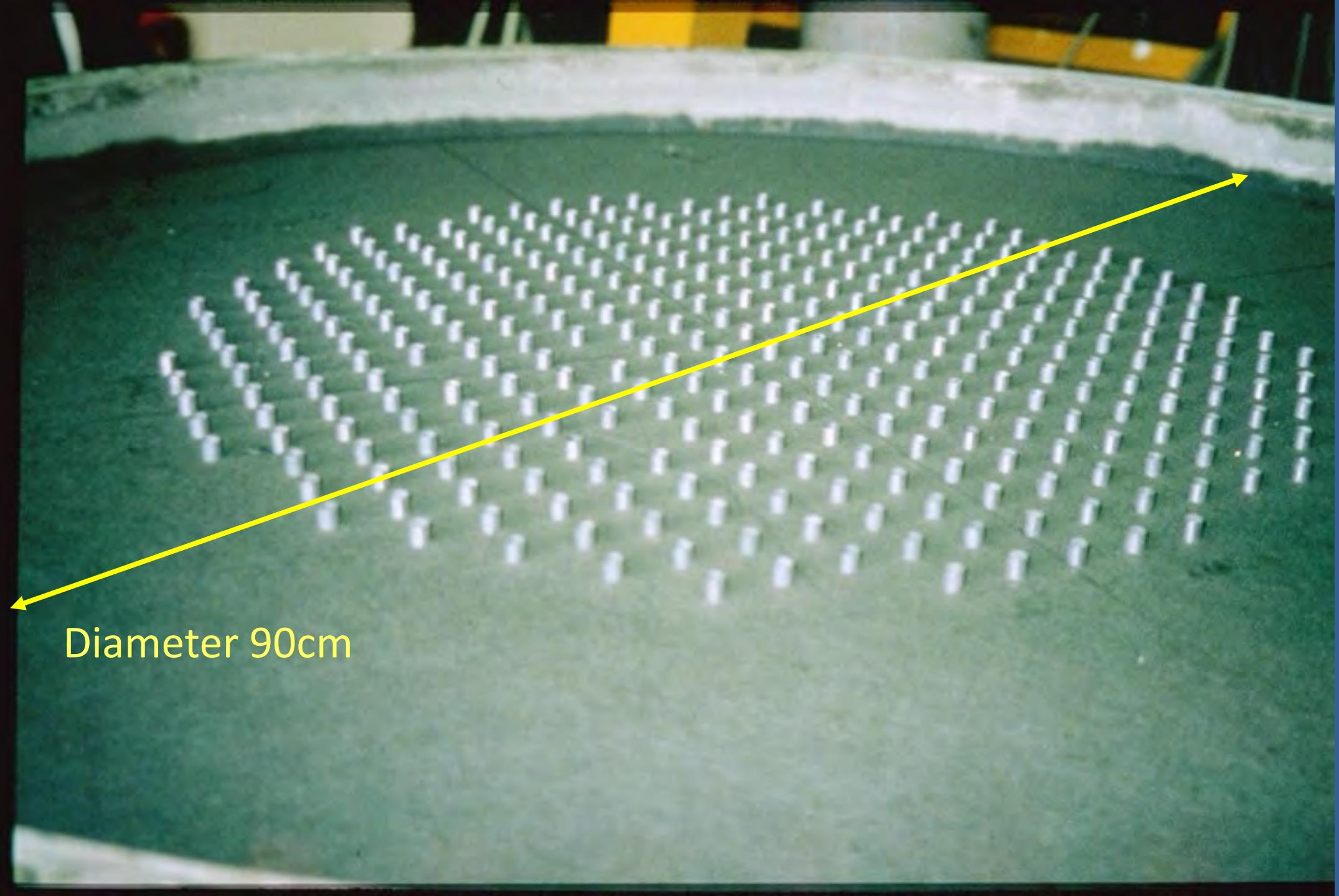
- Centrifuge tests

⇒ Ultimate failure loads → Monotonic tests

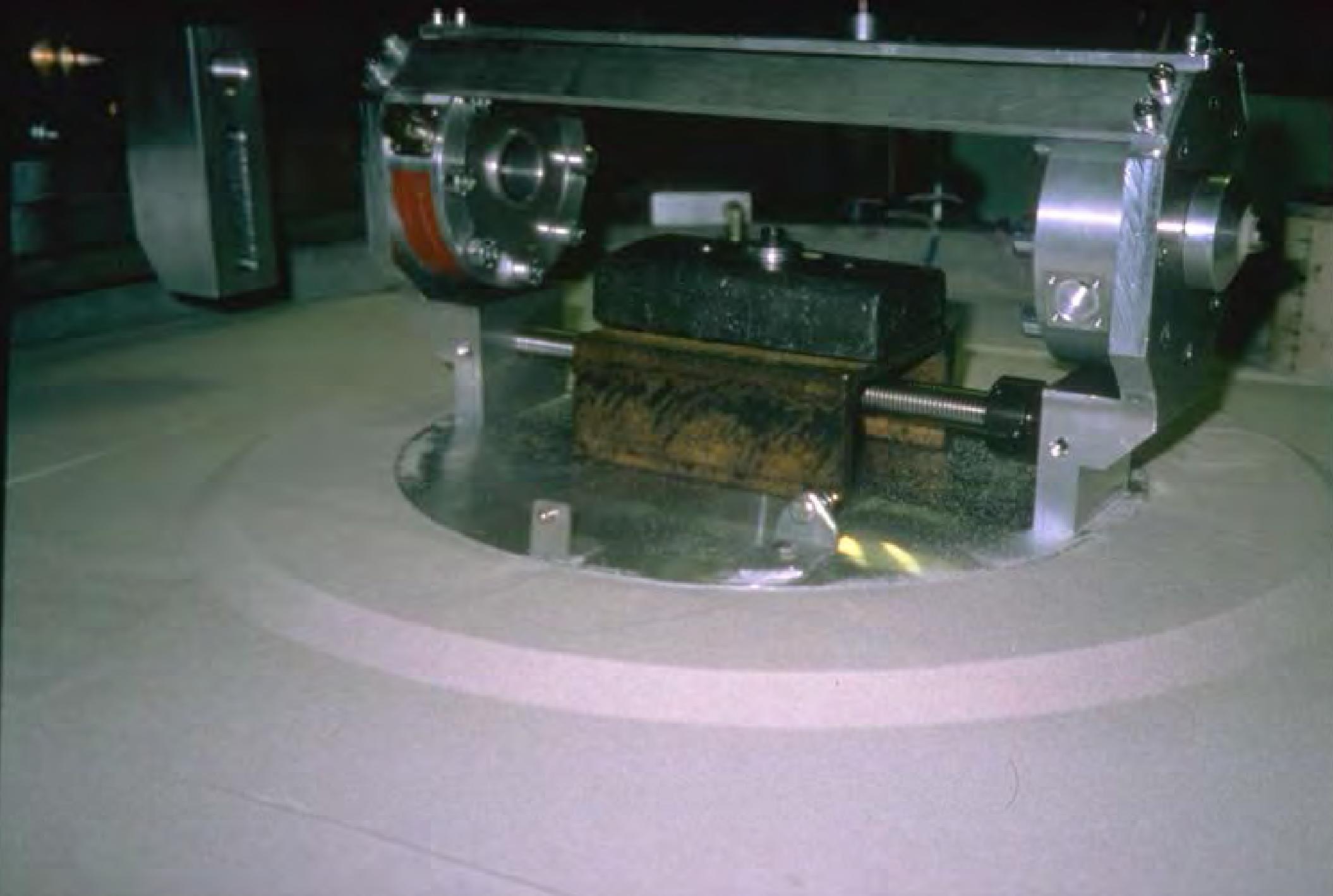
✓ Push over test

⇒ Cyclic behavior → Cyclic tests



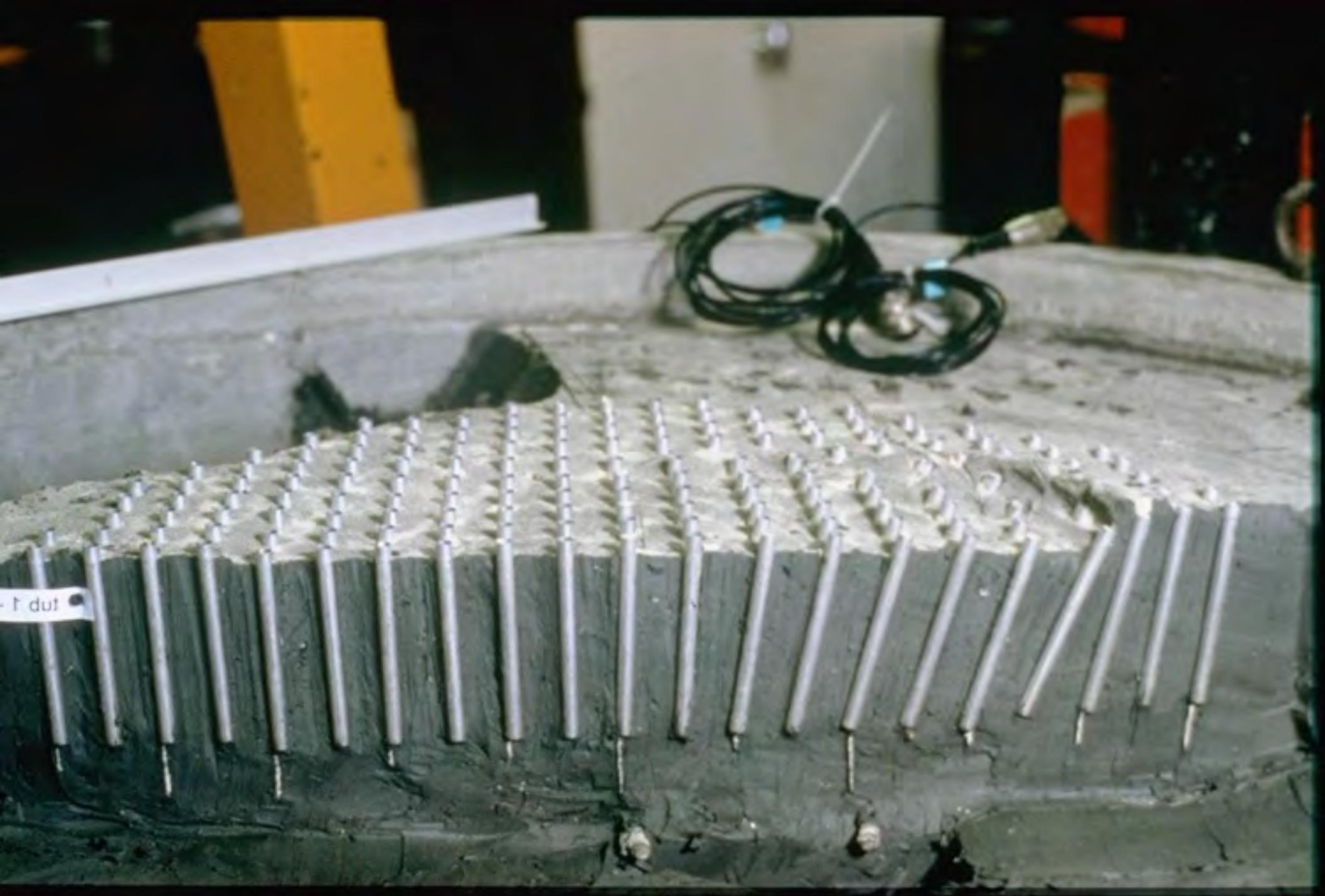


Diameter 90cm



MONOTONIC FAILURE LOAD



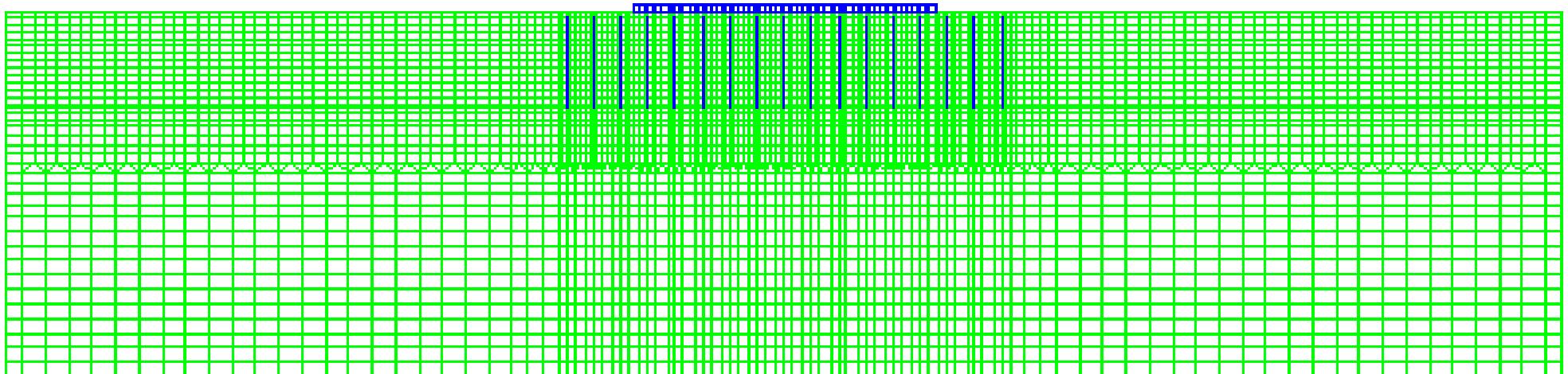


FINITE ELEMENT ANALYSES

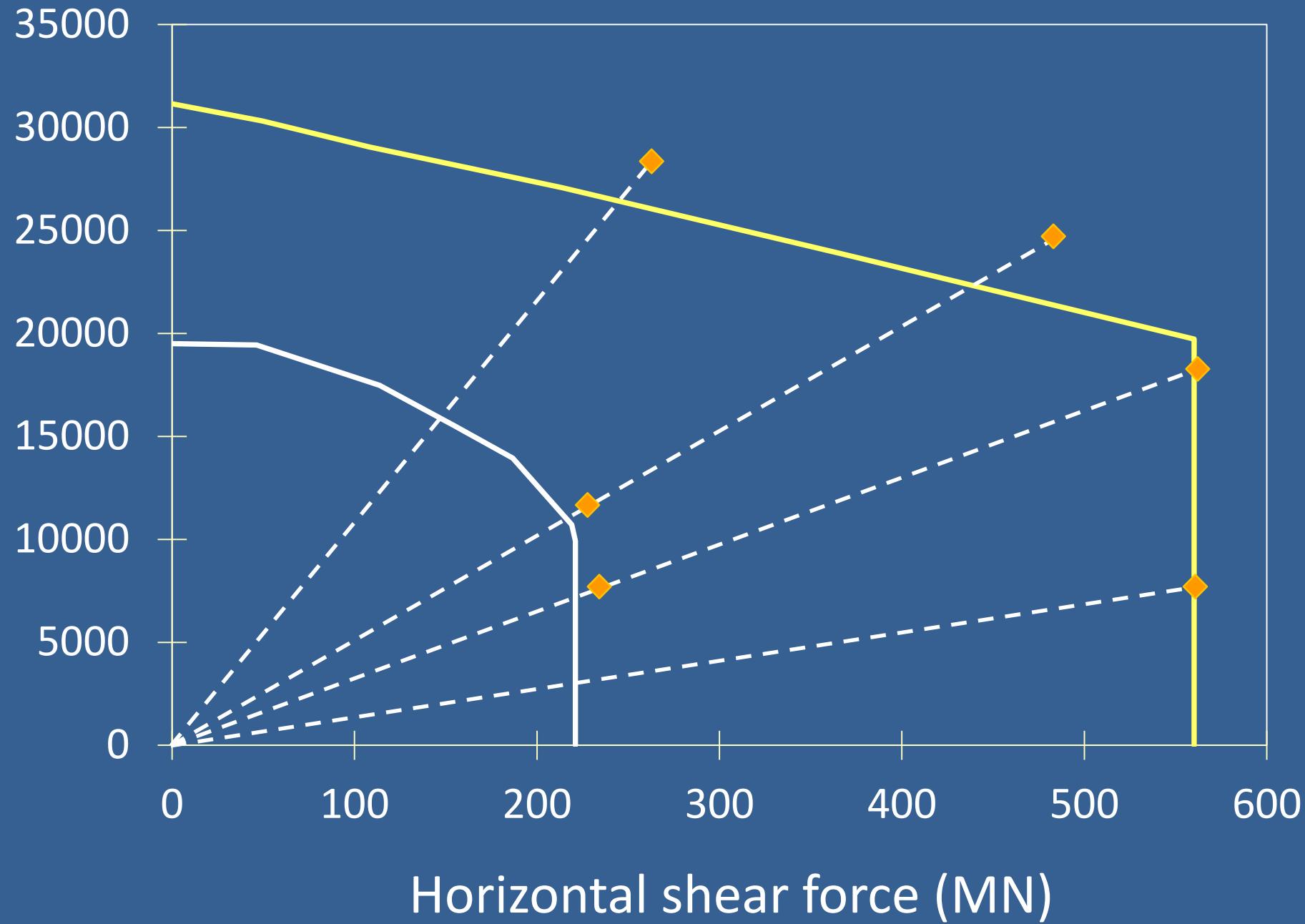
- Soil
 - ⇒ Continuum elements
 - ⇒ Elastoplastic constitutive law
- Inclusions
 - ⇒ Beam elements
 - ⇒ Linear elastic
- Interface : Soil-Raft & Soil-Inclusions
 - ⇒ Limited shear capacity
 - ⇒ No tensile capacity (soil-raft)

FINITE ELEMENT MODEL

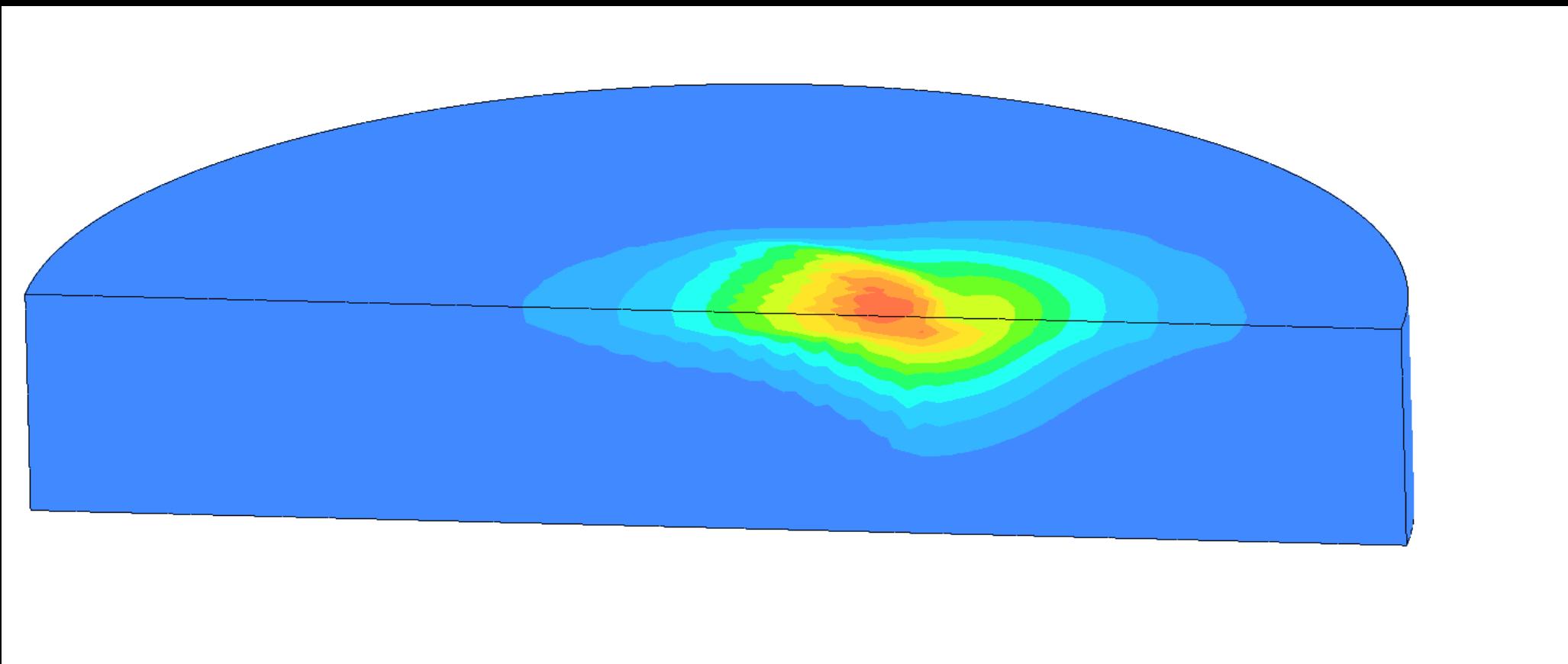
Foundation



Overshielding moment (MN.m)



FAILURE MECHANISM



GRAVEL BED DESIGN

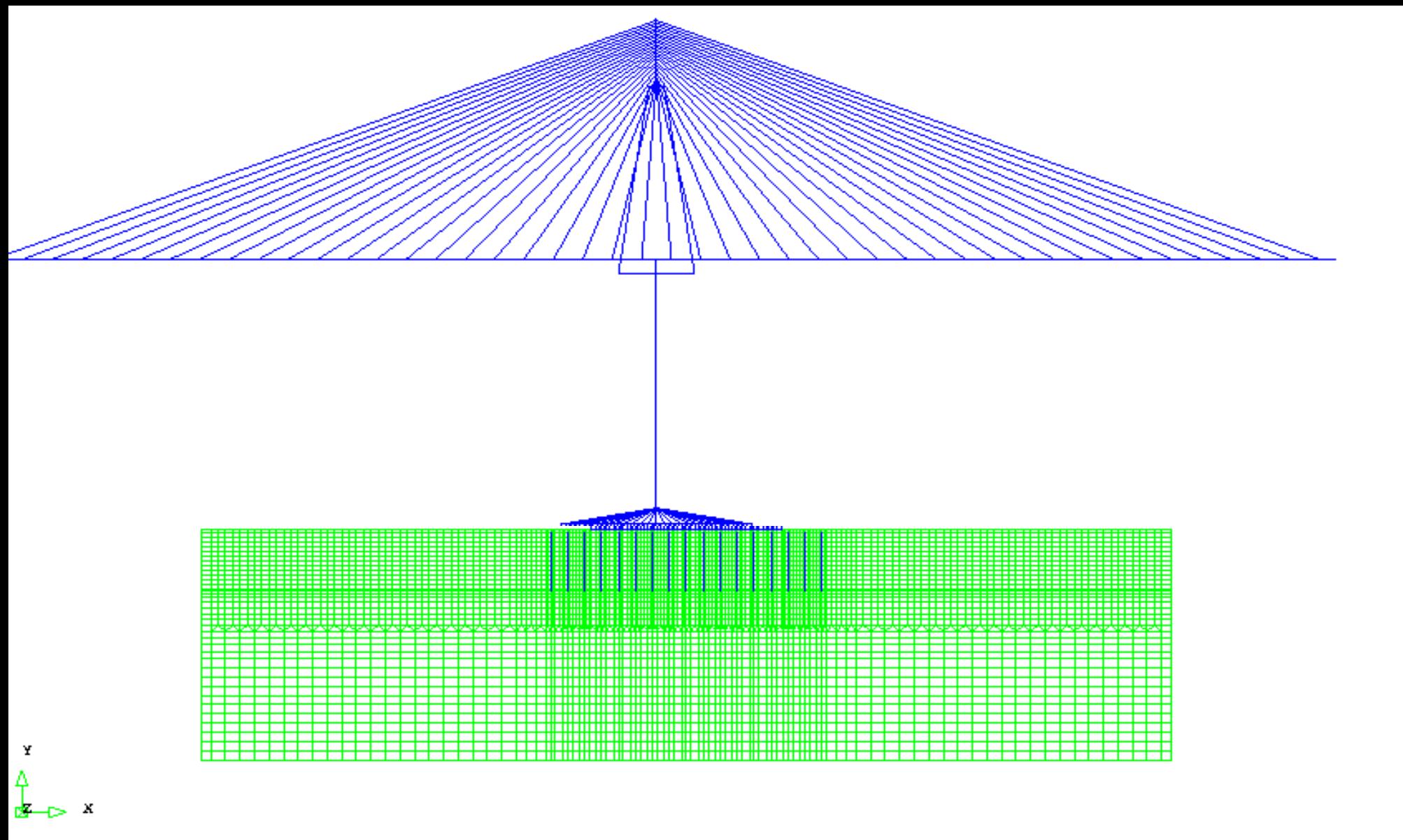
- Role
 - ⇒ Act as a plastic link (hinge)
- Requirements
 - ⇒ Large **permeability** to control pore pressure build up
 - Theoretical analysis (Pecker-Dormieux-Prevost, 2001)
 - ⇒ Adequate **friction angle** to bound forces and limit displacements
 - Field tests

19.
29.800
TON

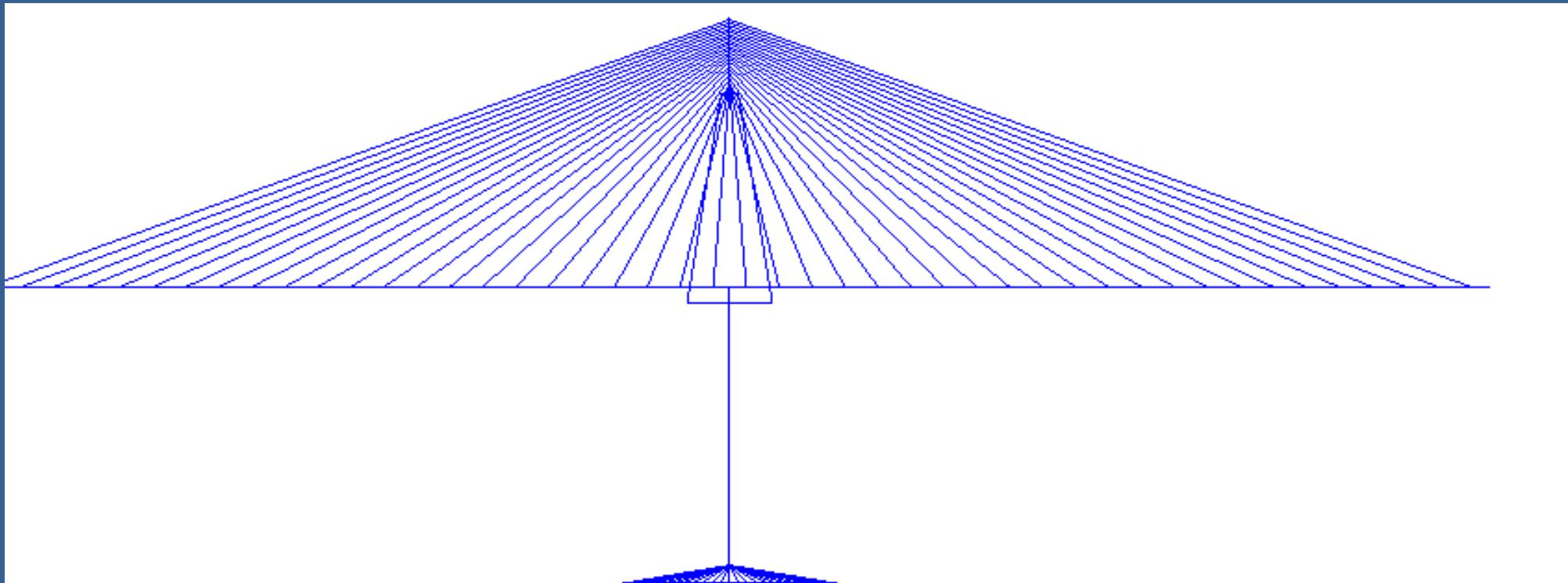
T/NE
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SEISMIC SOIL STRUCTURE INTERACTION

FINITE ELEMENT MODEL

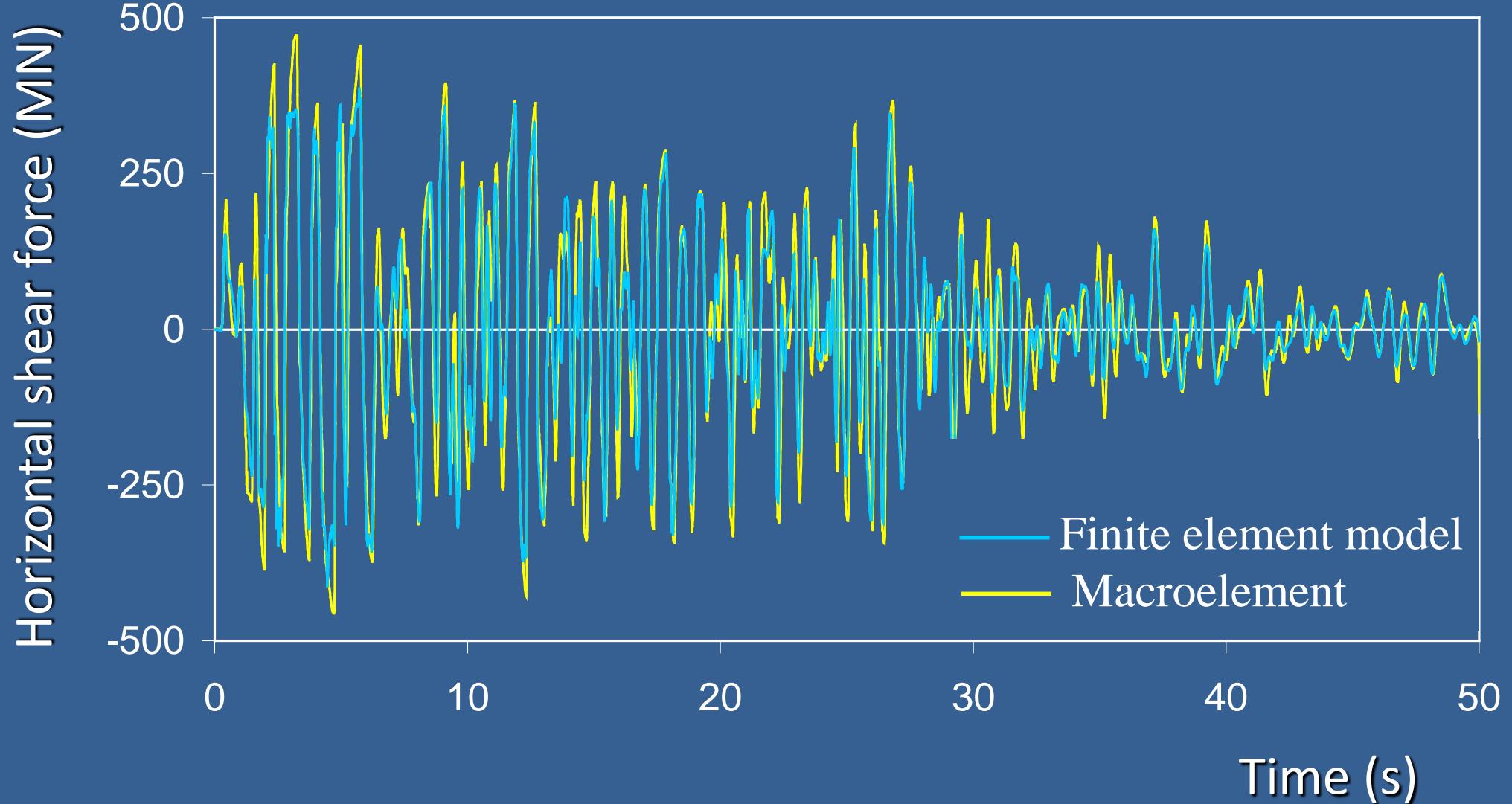


FINITE ELEMENT MODEL

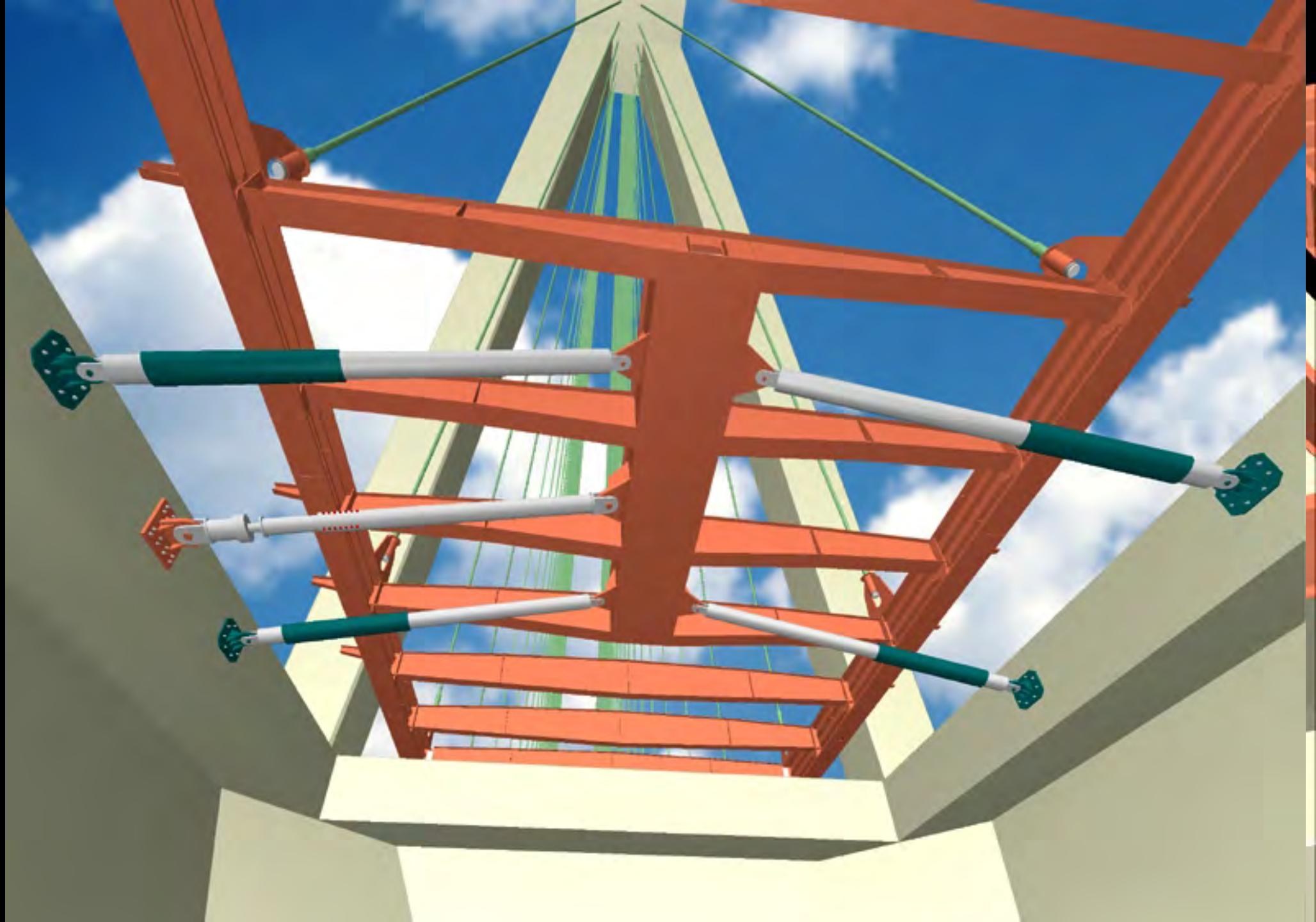


Macroelement

SOIL STRUCTURE INTERACTION



TECTONIC DISPLACEMENT



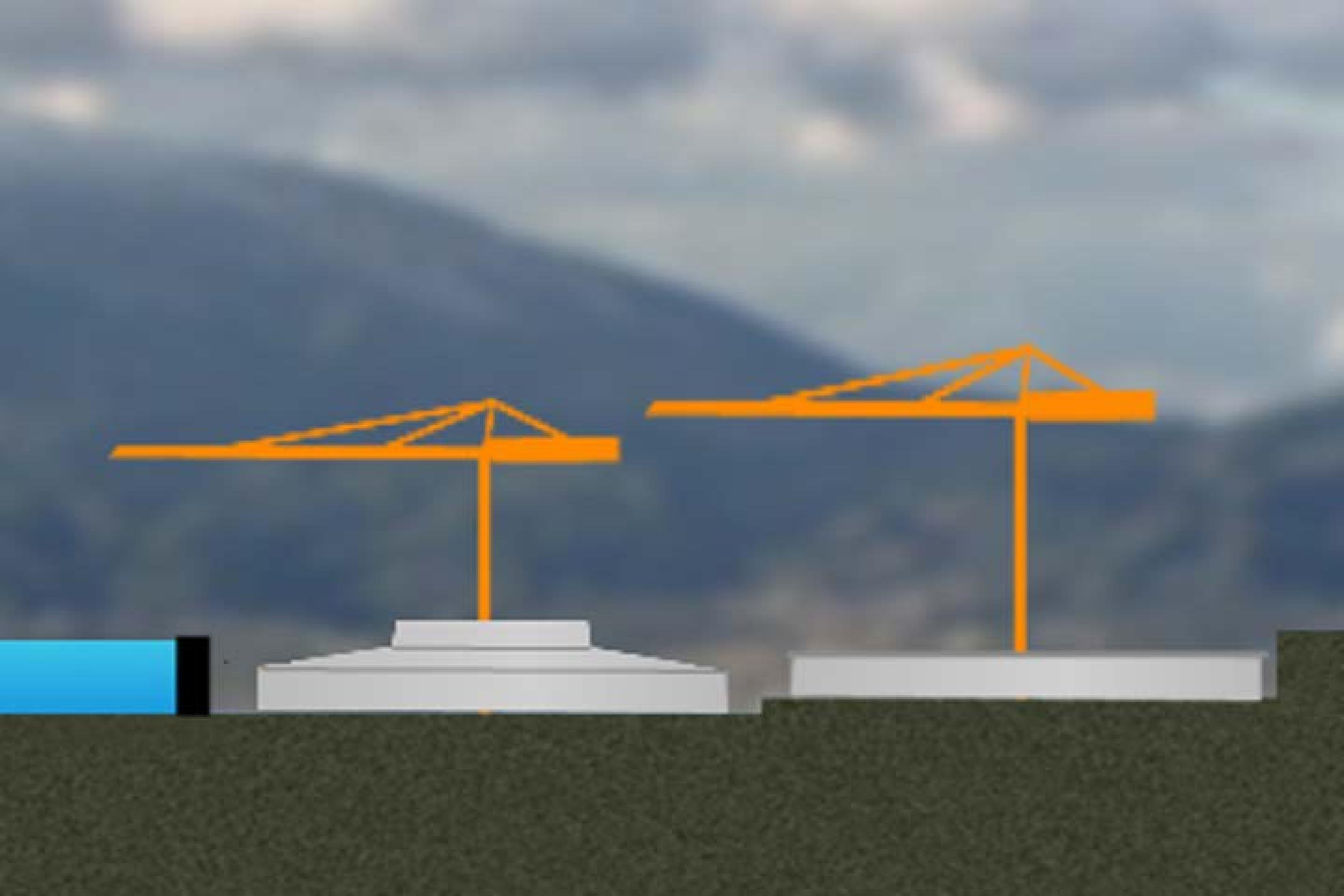






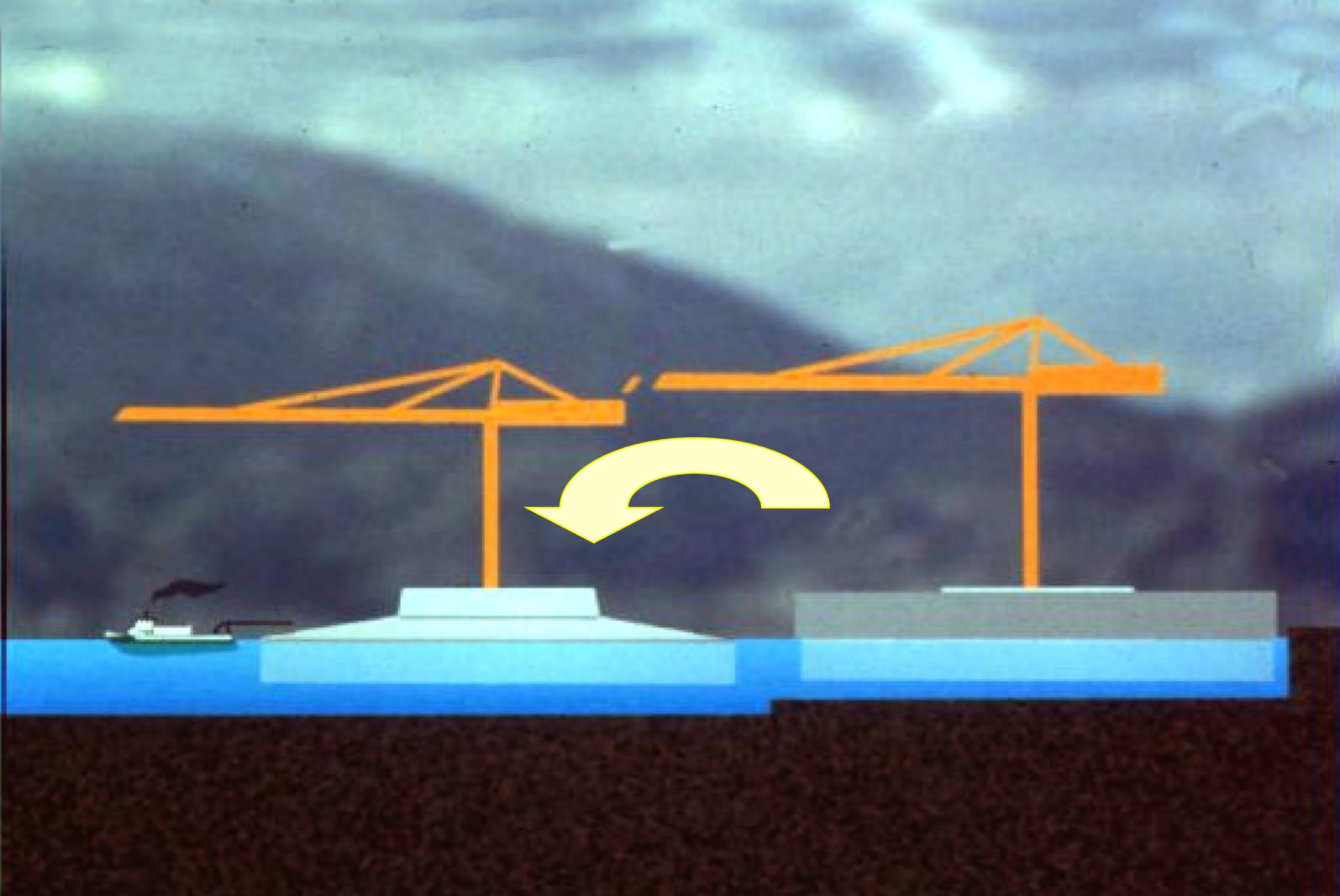
PICTURES OF CONSTRUCTION





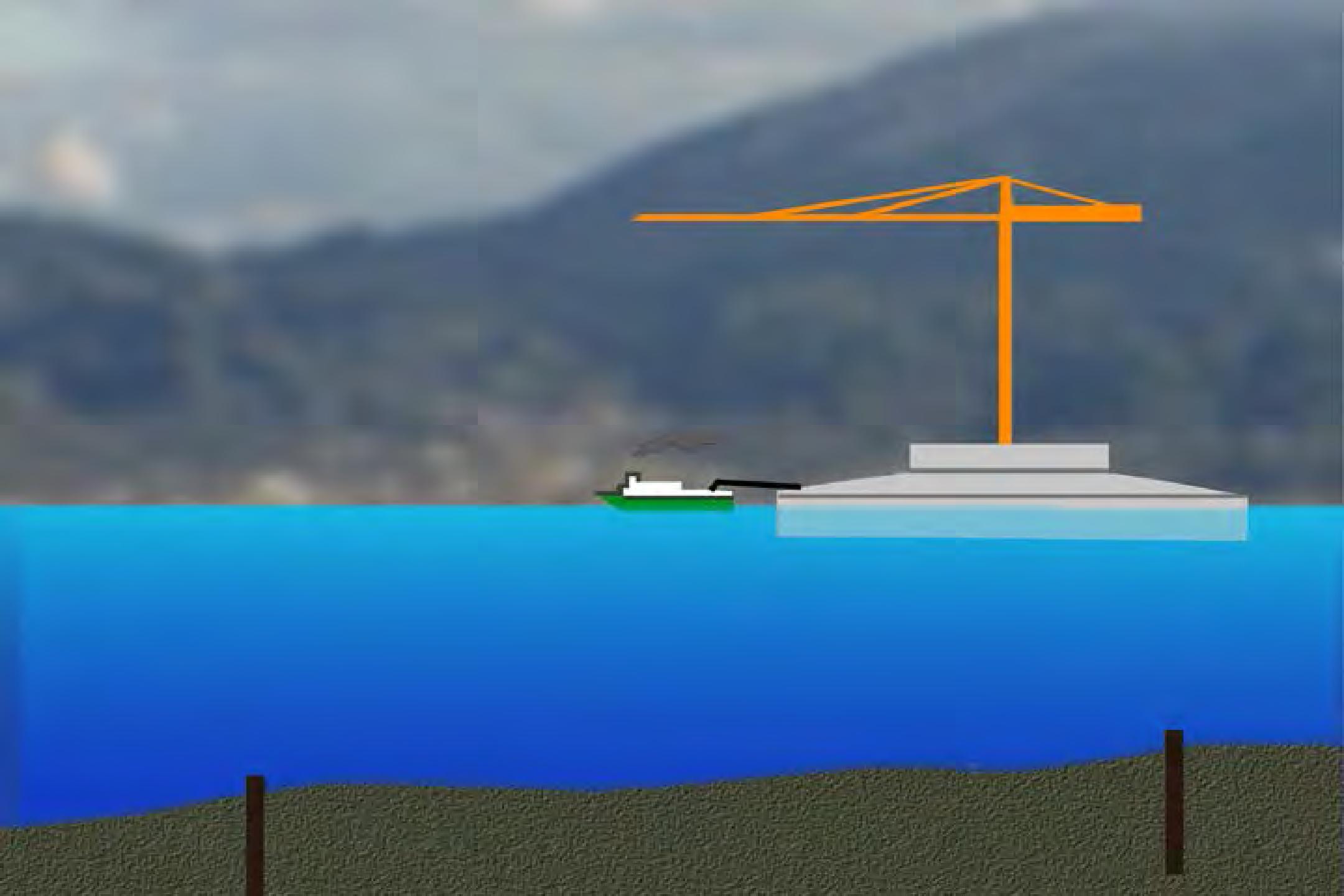




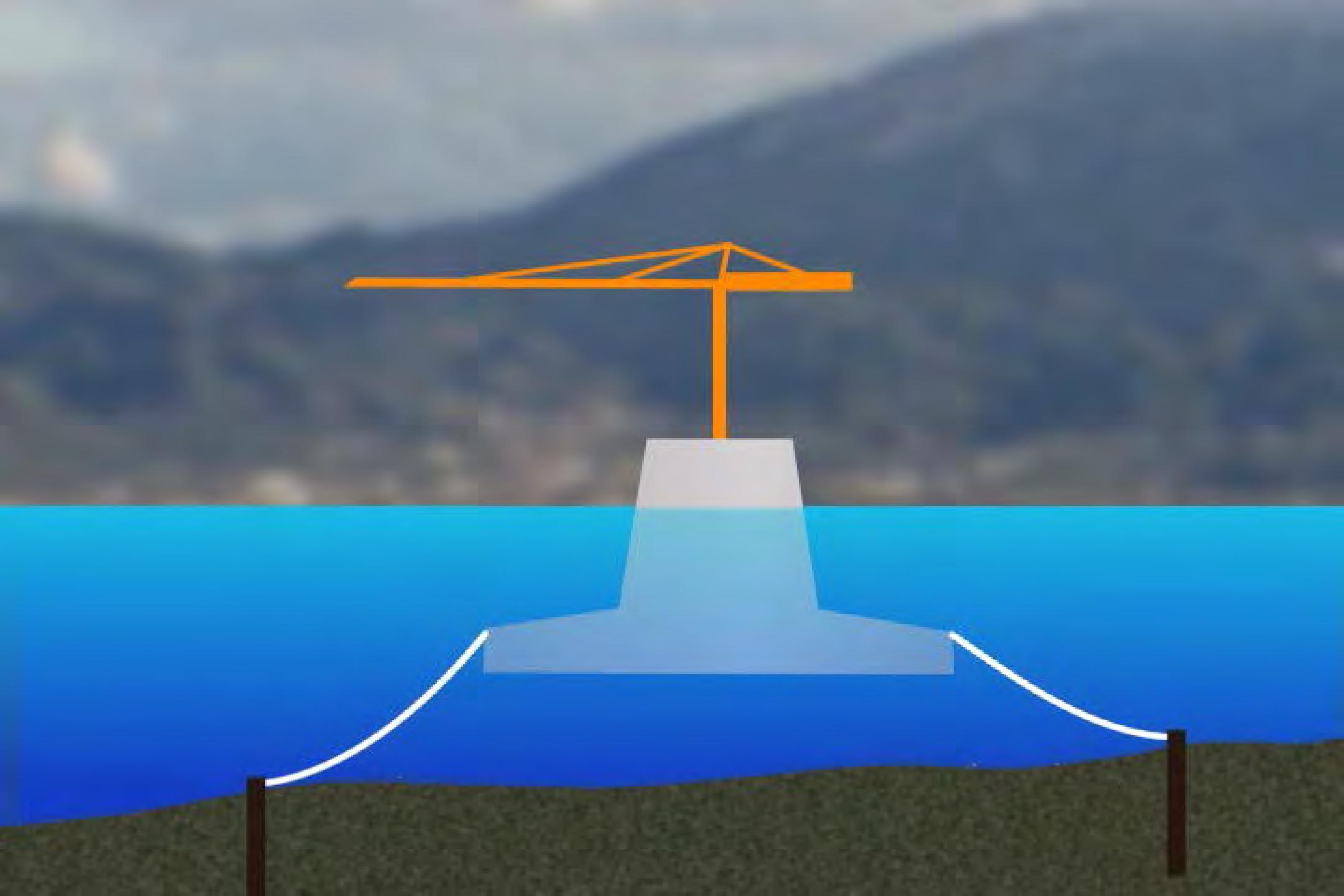






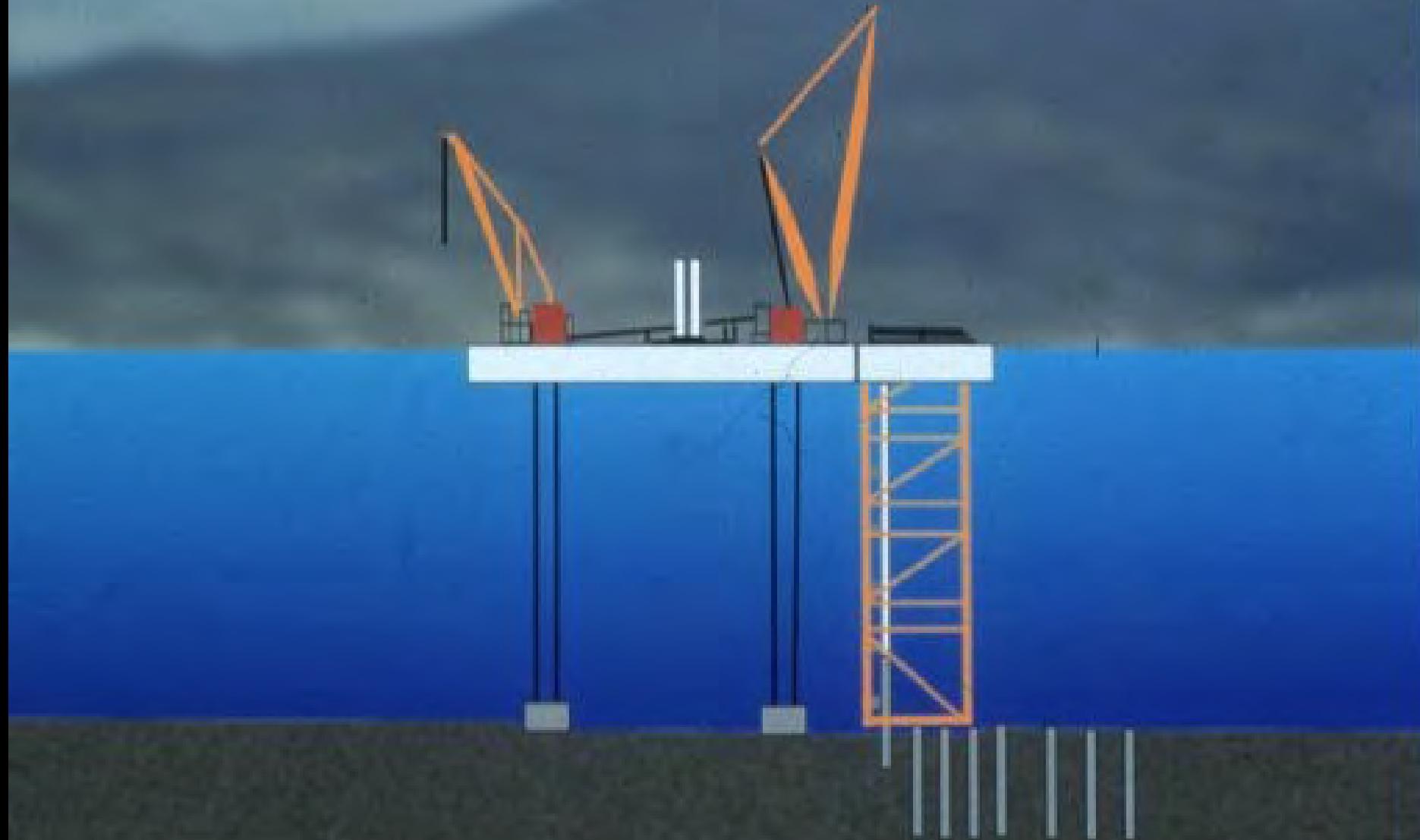






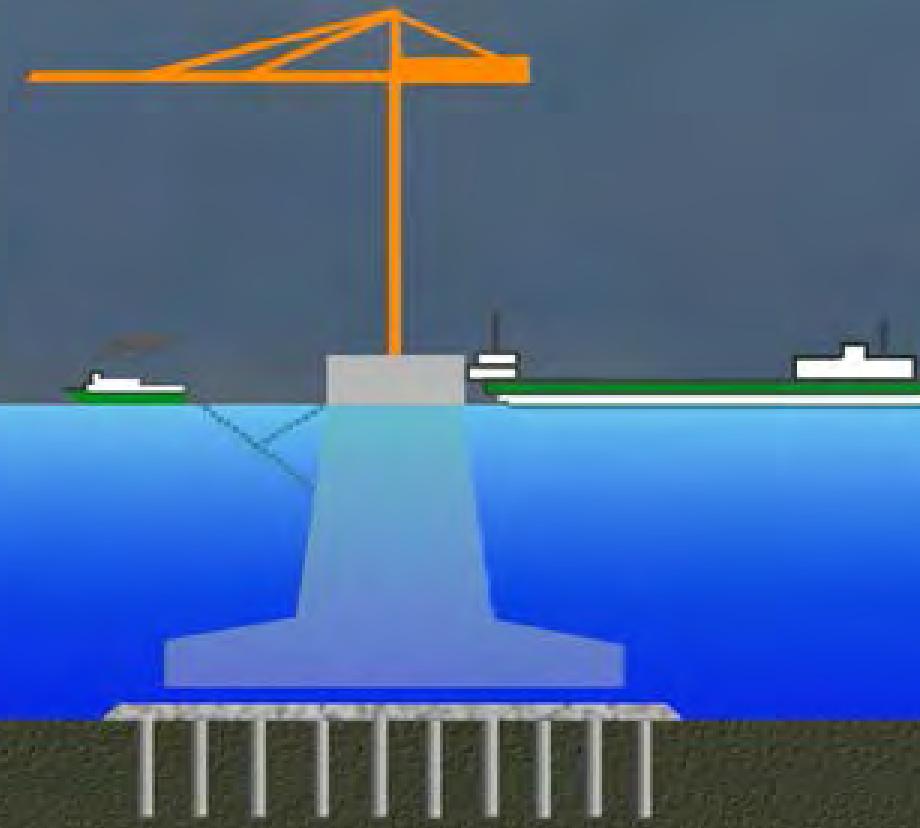


Inclusions



Steel Pipe Driving & Gravel Bed Installation

















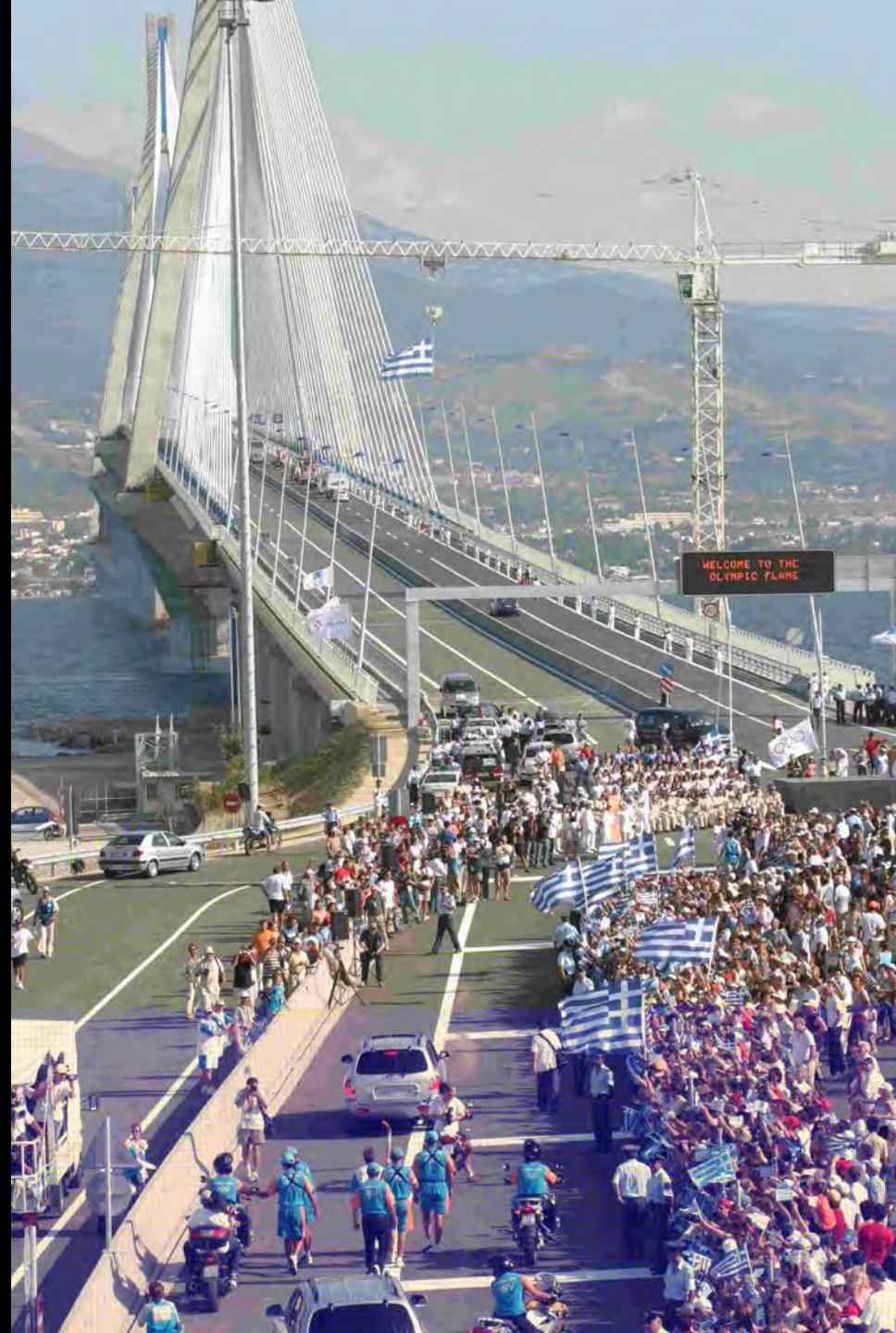




A photograph of a female torchbearer smiling while holding the Olympic torch. She is wearing a white t-shirt with the number 054 and a blue wreath design. The torch has the Olympic rings logo on it.

AUGUST 8th, 2004

END OF AN EXCEPTIONAL
TECHNICAL CHALLENGE
AND HUMAN ADVENTURE



CONCLUSIONS

Key factors to the success

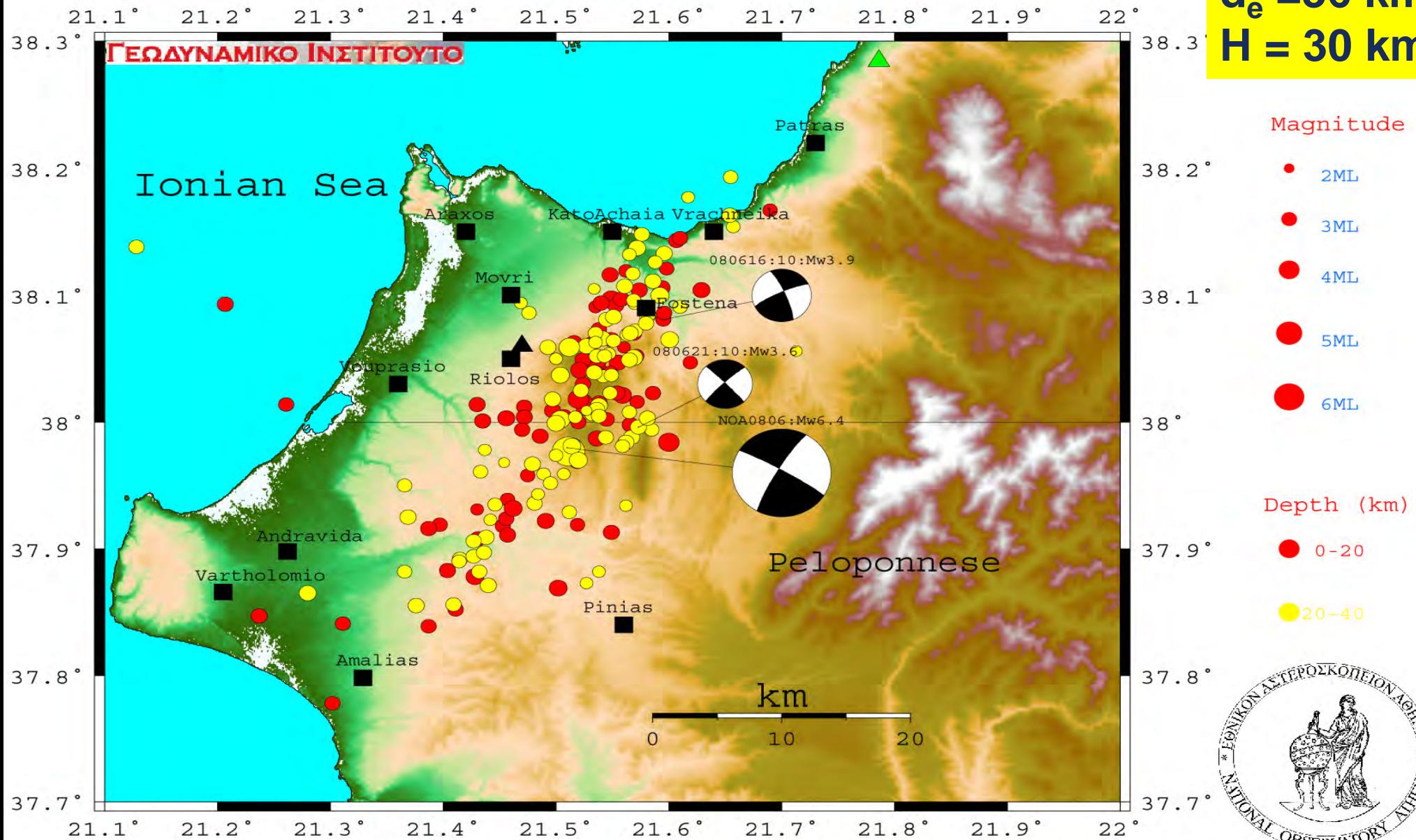
- Correct assessment of foundation performance criterion
- Time allowed for design
- Close collaboration and **confidence** between all parties:
 - ✓ Owner, Contractor, Design team, Checker

HOW WILL THE BRIDGE BEHAVE DURING AN EARTHQUAKE ?

8 June 2008 aftershock sequence from NOAGI network

185 events > 2.3 ML until 11 June 0320 UTC

M = 6.5
d_e = 36 km
H = 30 km



FOOTINGS SETTLEMENTS

	M1	M2	M3	M4
Immediately due to the earthquake	0.021 [m]	0.016 [m]	0.011 [m]	0.000 [m]
Total (from footing landing up to immediately after the earthquake)	0.202 [m]	0.247 [m]	0.283 [m]	0.161 [m]

Total displacements are similar to theoretical ones

Earthquake induced displacements are less than 10% of total





"Often engineers are bound to solve problems although on those specific issues science is not achieved. Gentlemen, you must find practical solutions, even facing uncompleted science"

Louis PASTEUR

