The interaction of normal fault ruptures and shallow foundations: (failles normale et fondations)

Centrifuge modelling

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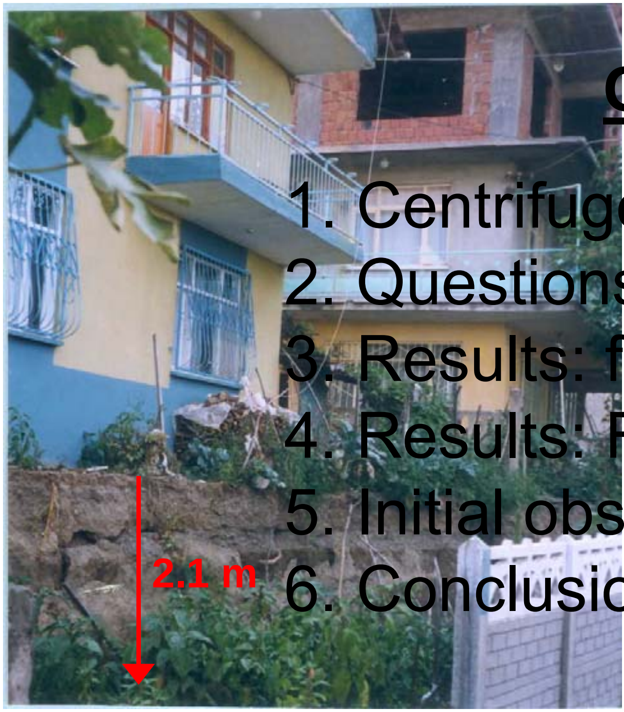

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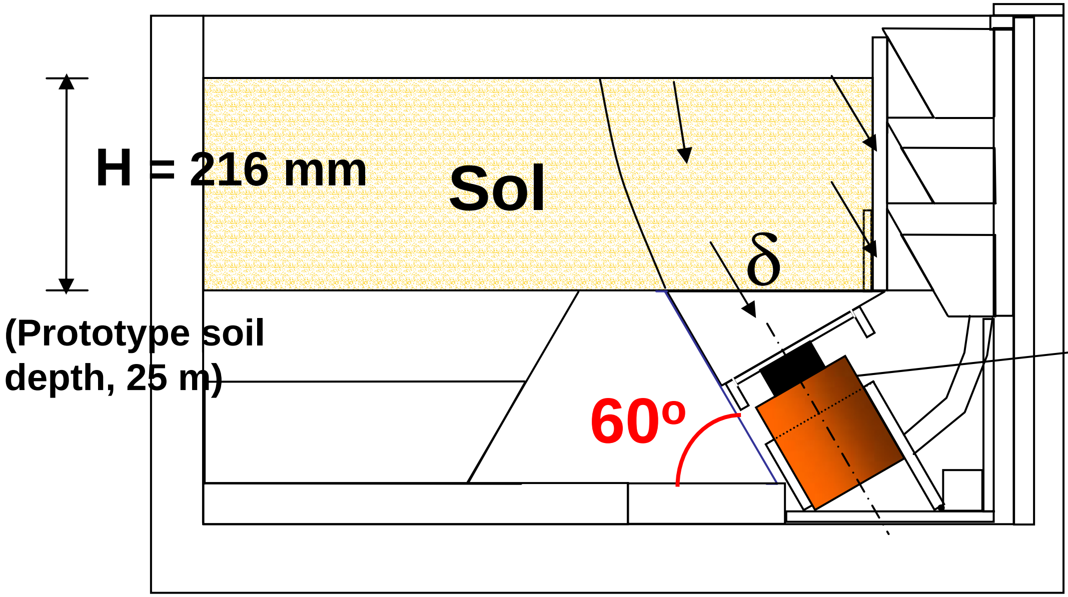
Photos from George Gazetas, NTUA

1. Centrifuge modelling:

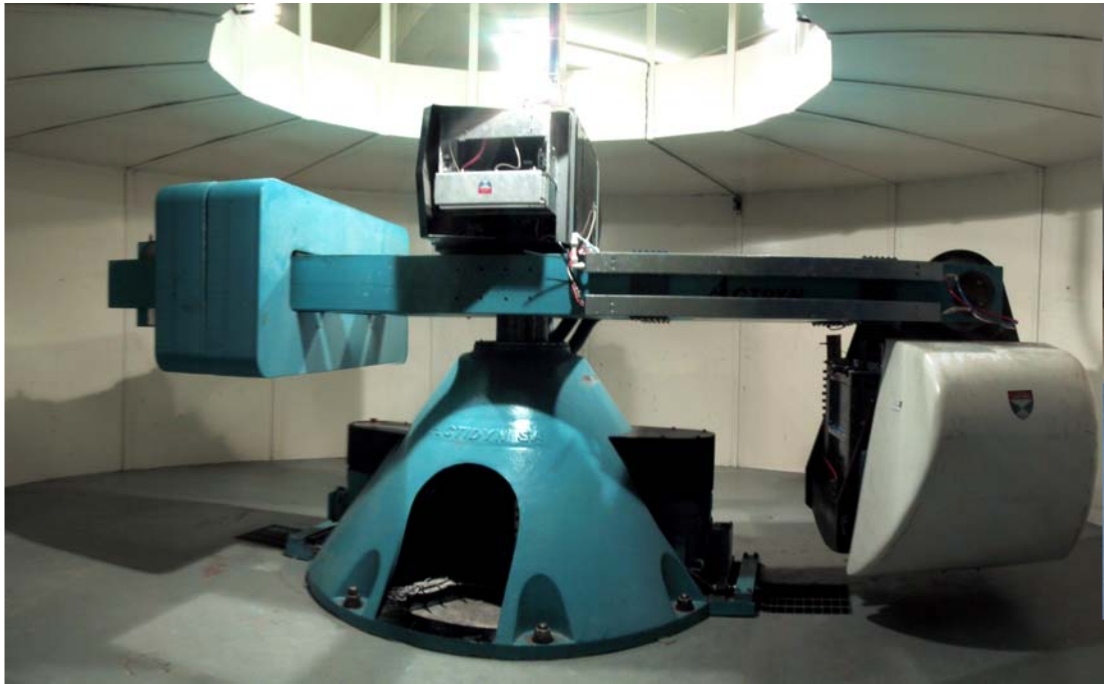
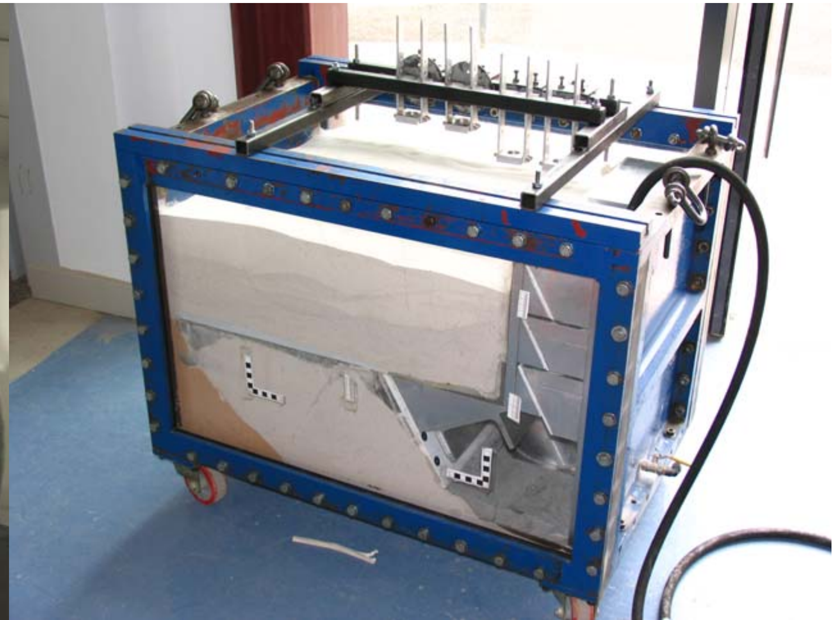
Controlled normal/reverse faults (60º dip) in medium dense sand

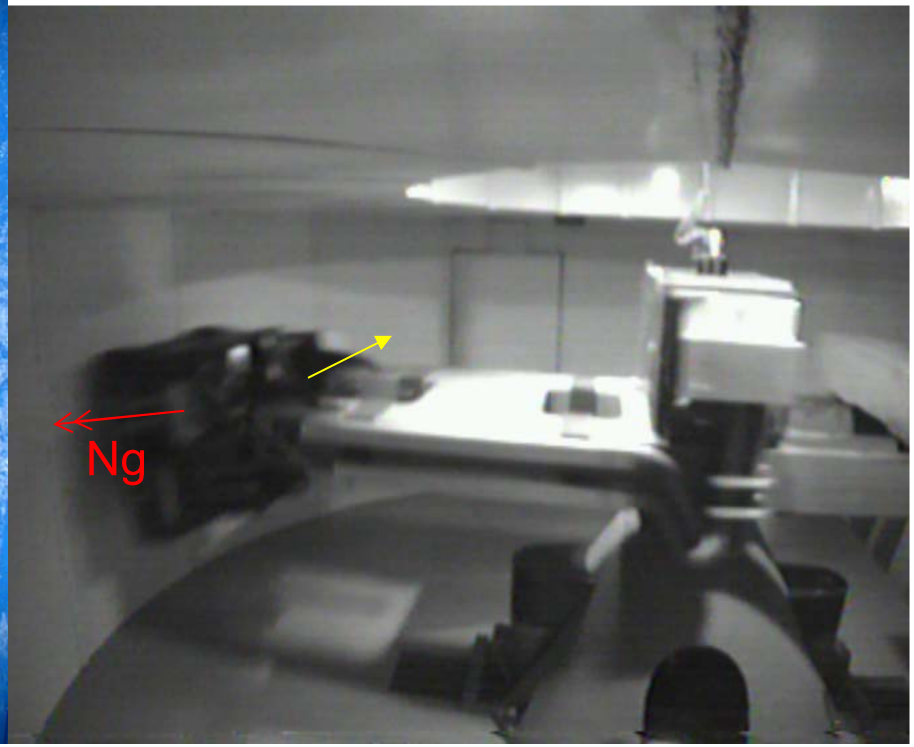


Medium dense Fontainebleau sand.
(d_{50} = 0.2 mm; C_u = 1.3) Dr ≈ 60 %

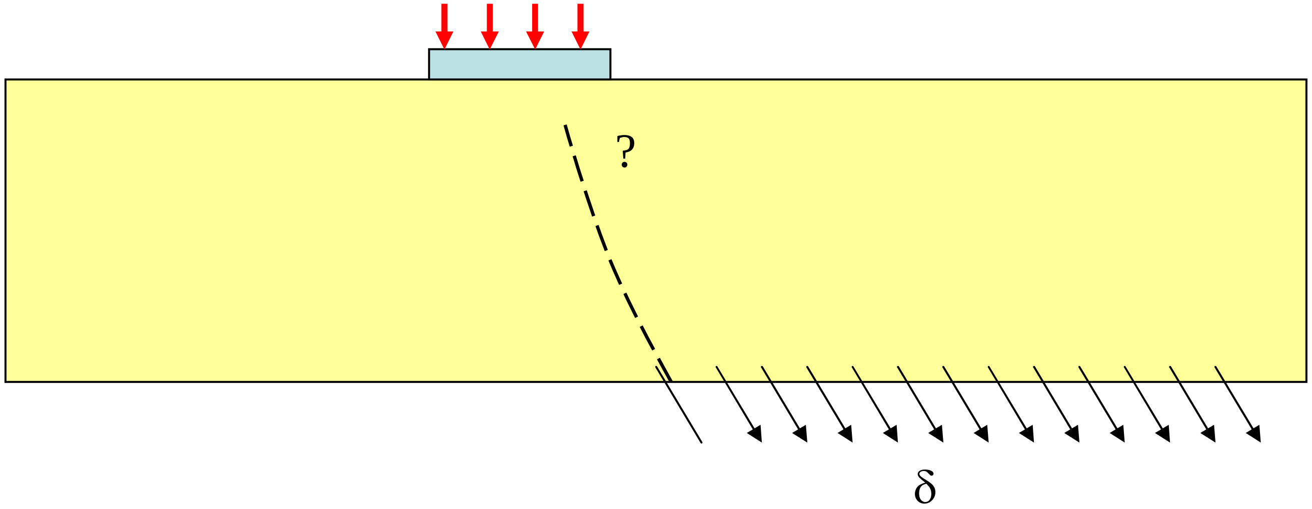
Oil in/out raises/lowers block
→ fault displacement

- Accelerated to 115 g in centrifuge to produce same σ' as for 25 m soil depth.
- Allows well controlled and instrumented tests


Ng

2. Questions



• In which direction does the fault plane propagate through the soil in the free-field condition?

• How much fault offset, δ, causes fault rupture emergence?

• What happens when a footing is present?

• Dans quelle direction fait la propagation en état de champ libre?

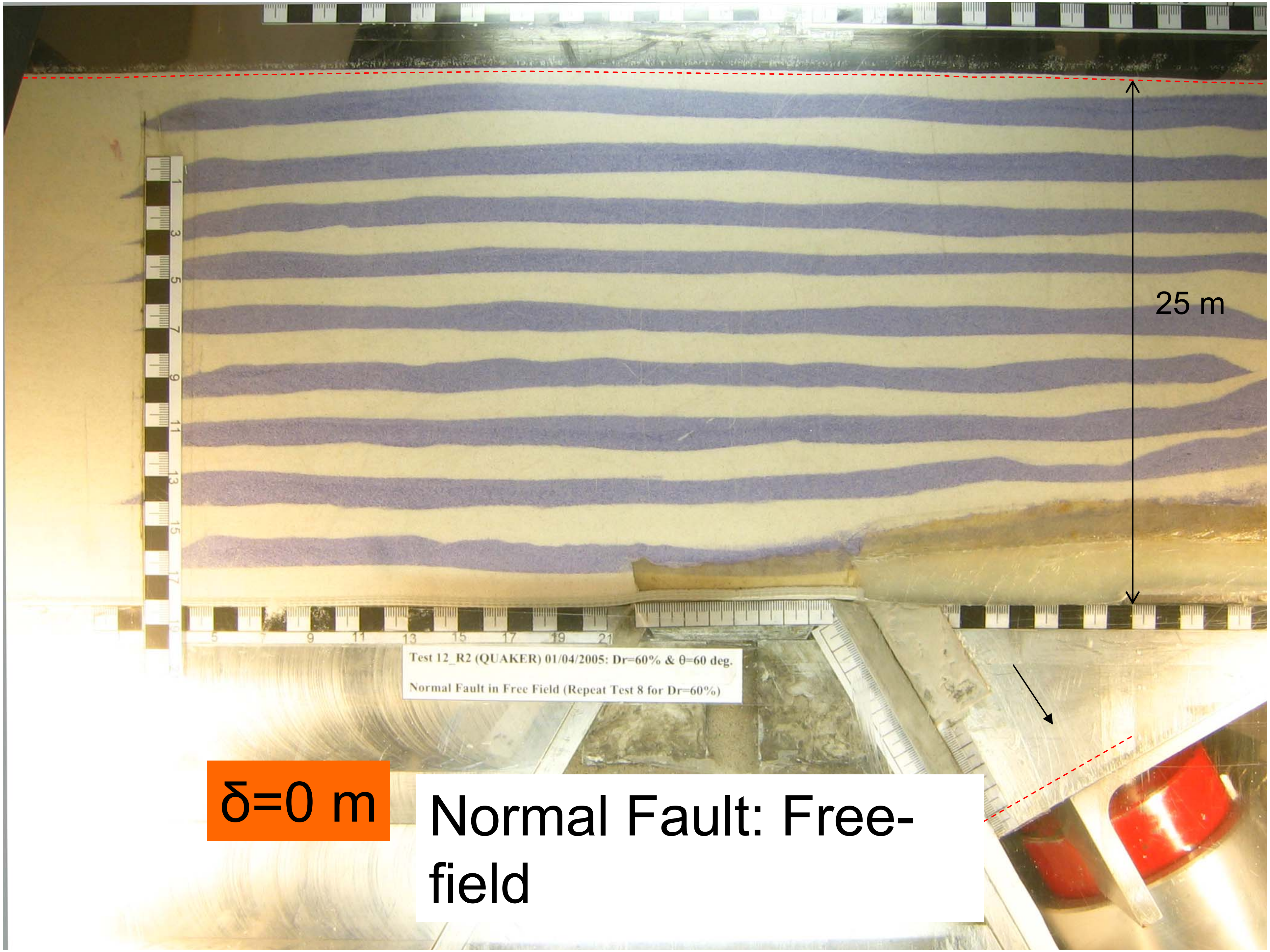
• Combien de déplacement, δ, cause le rupture de faille pour émerger sur la surface de sol ?

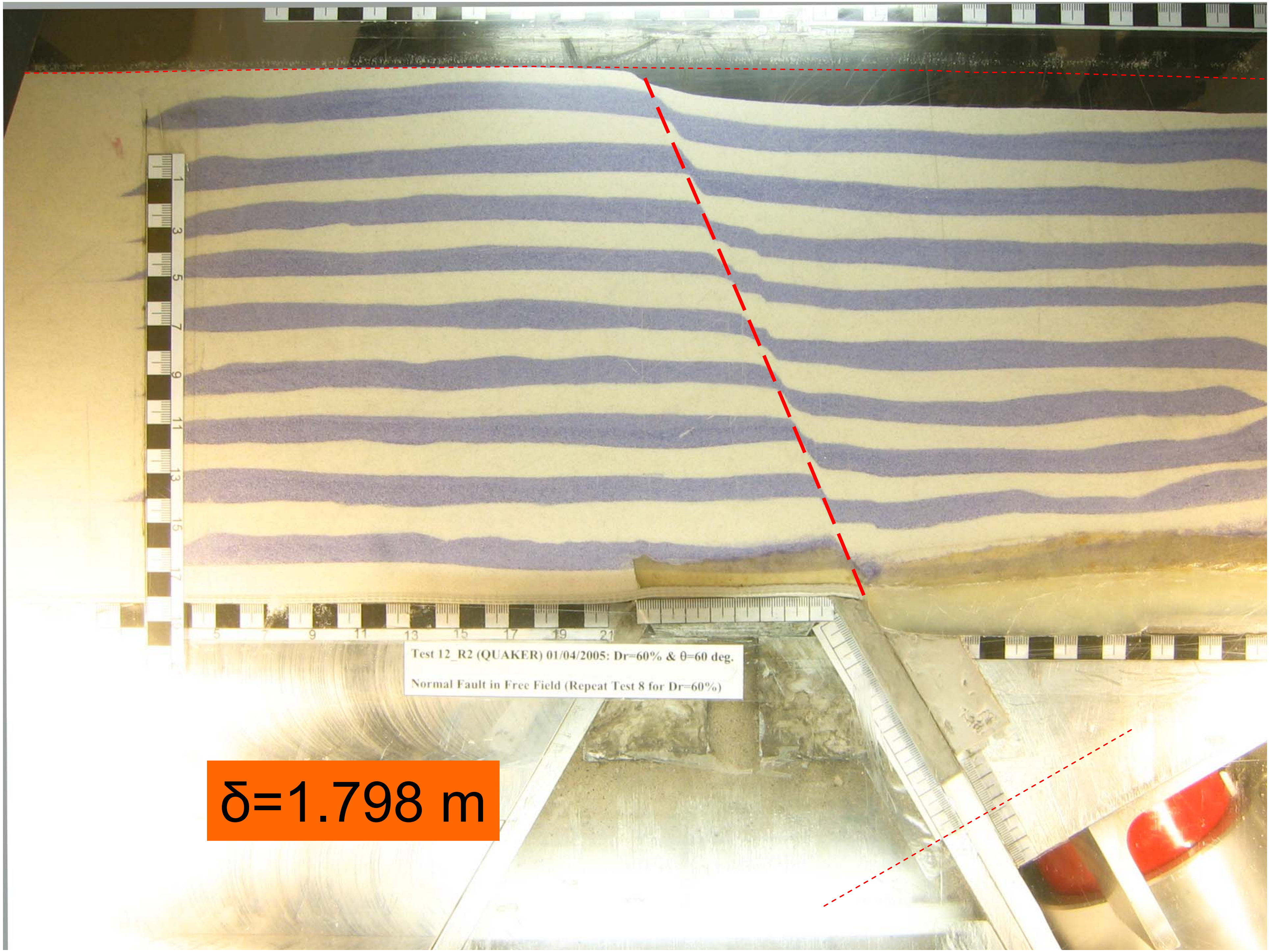
• Que se produit avec une fondation?

3. Results: Free-field

Free-field normal fault

Profondeur de sol, H = 25 m;
Sable de Fontainebleau. Densité relative, Dr = 60 %;

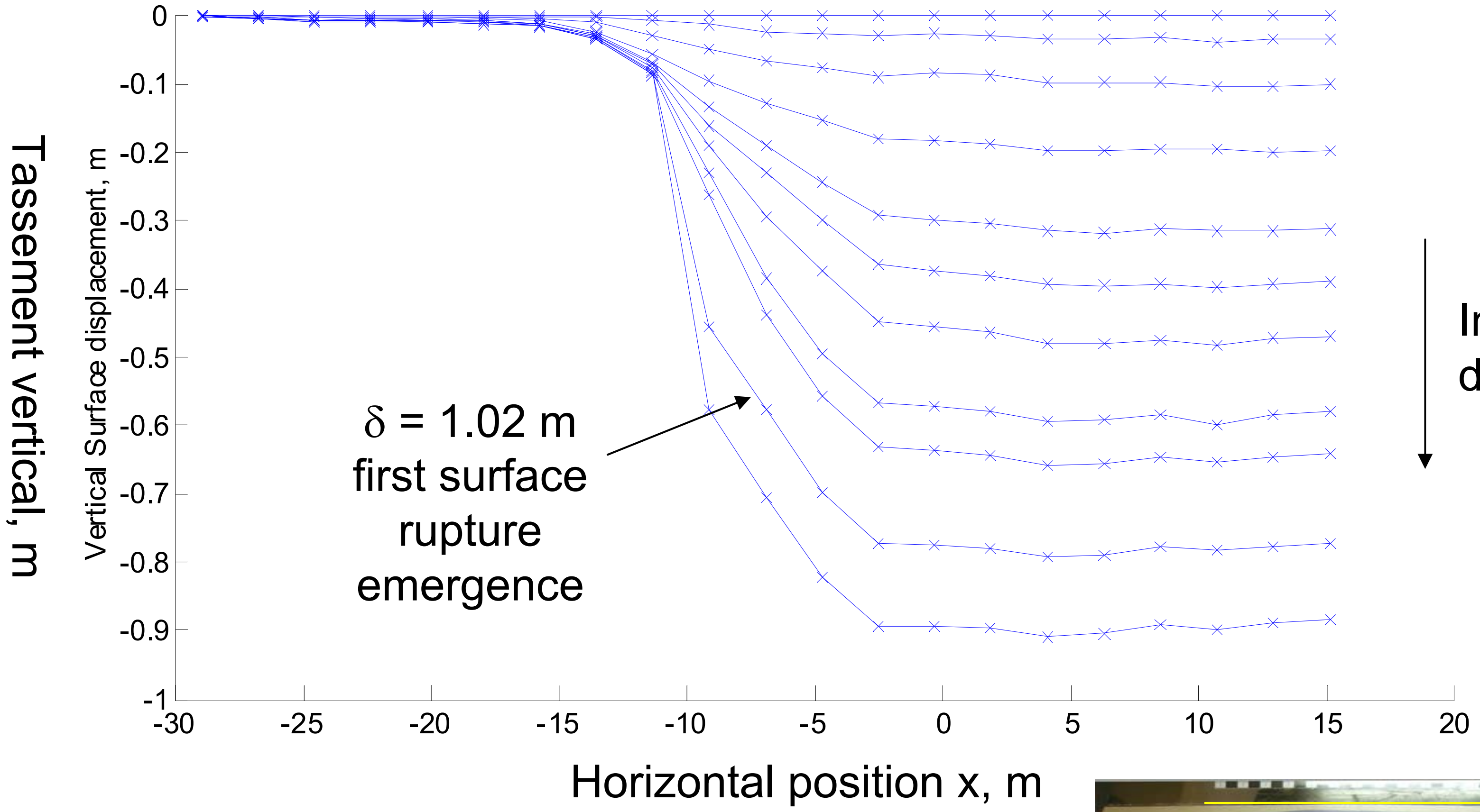

25 m
Test 12_R2 (QUAKER) 01/04/2005: Dr=60% & θ=60 deg.
Normal Fault in Free Field (Repeat Test 8 for Dr=60%)
δ=0 m
Normal Fault: Free-field

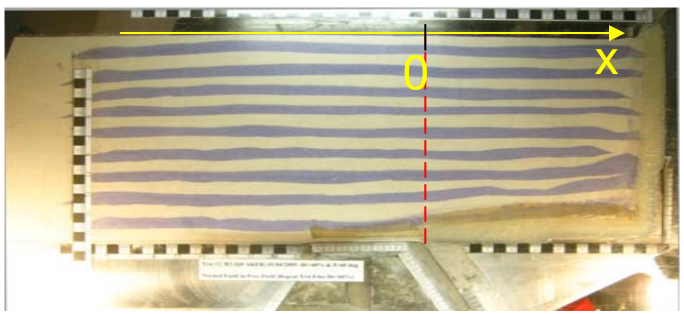


Test 12_R2 (QUAKER) 01/04/2005: Dr=60% & θ=60 deg.
Normal Fault in Free Field (Repeat Test 8 for Dr=60%)
δ=1.798 m

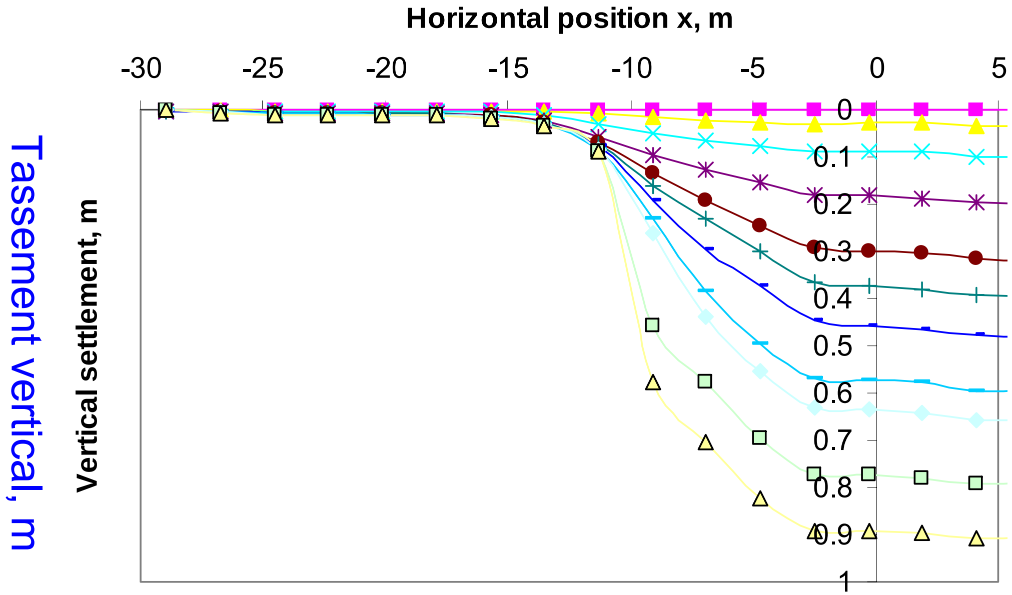
Surface settlement profile

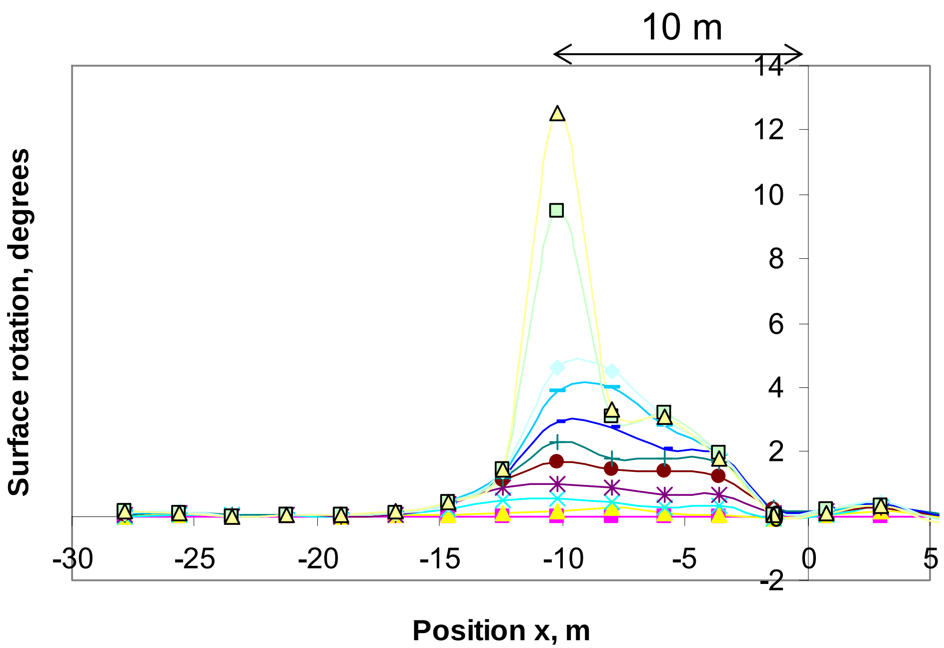
Profil de Tassement



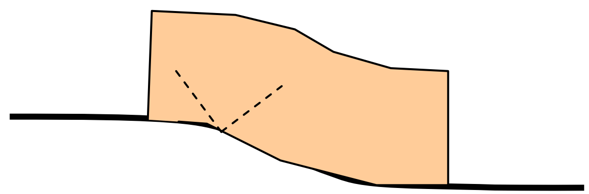


Interaction with buildings/avec bâtiments??





• Problems for foundations/buildings even at small fault movements?



1:150 (0.4°): Structural damage of general buildings expected (Bjerrum, 1963)

4. Results: Fault-footing interaction

Heavy, rigid foundation

Fondation lourde et rigide

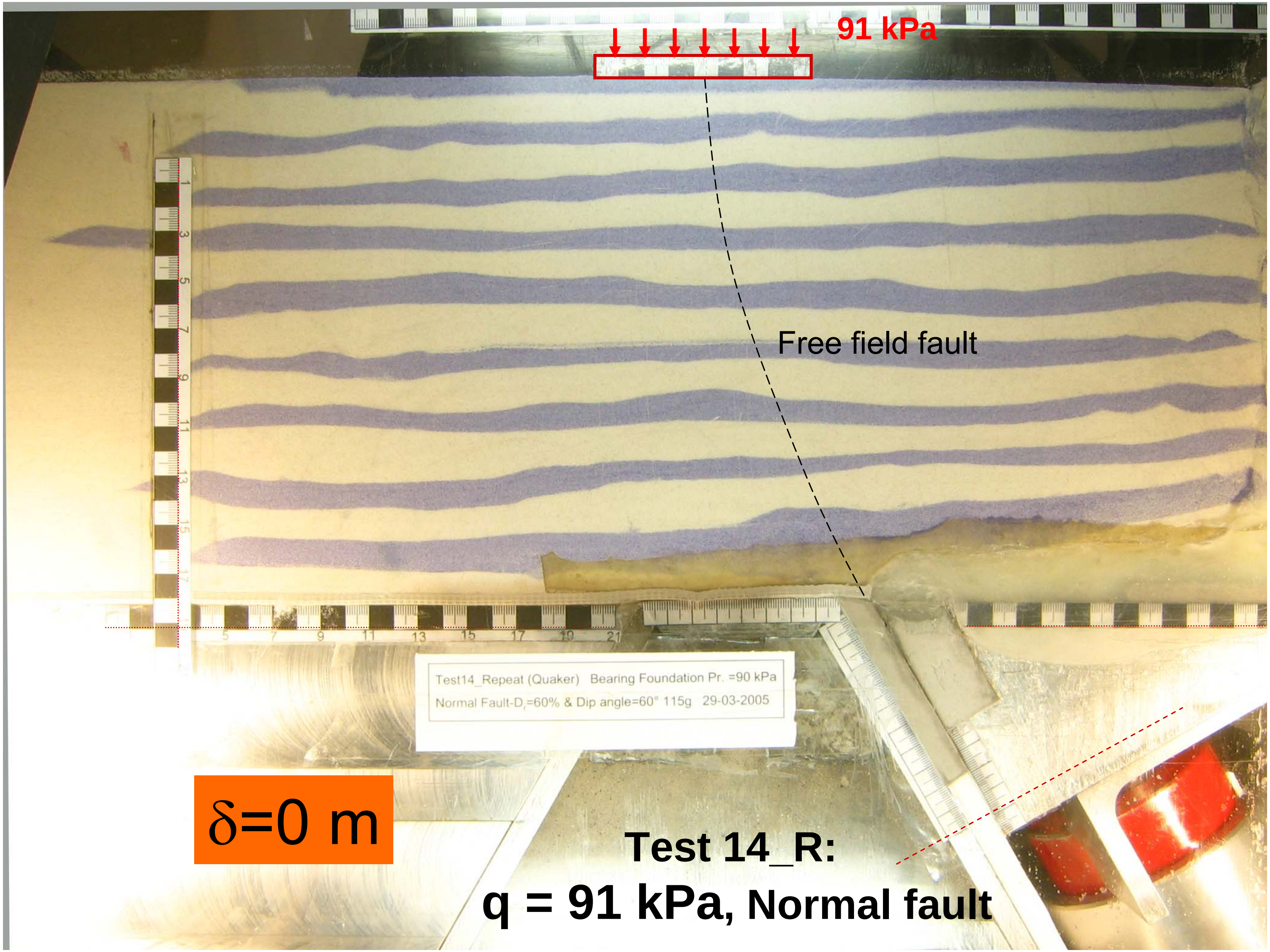
B = 10 m; q = 91 kPa

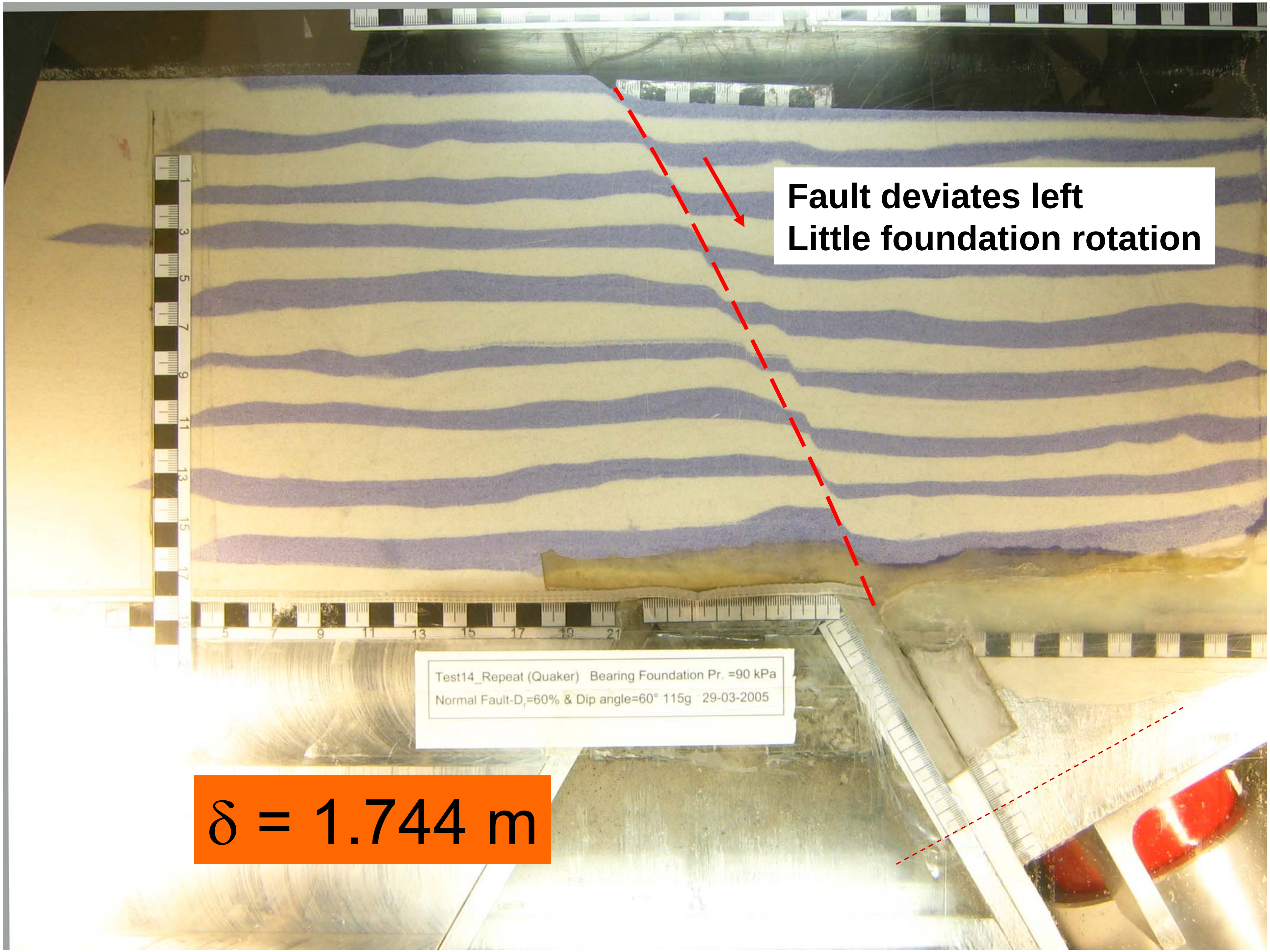
Sol:

H = 25 m; Sable de Fontainebleau; D_r = 60%

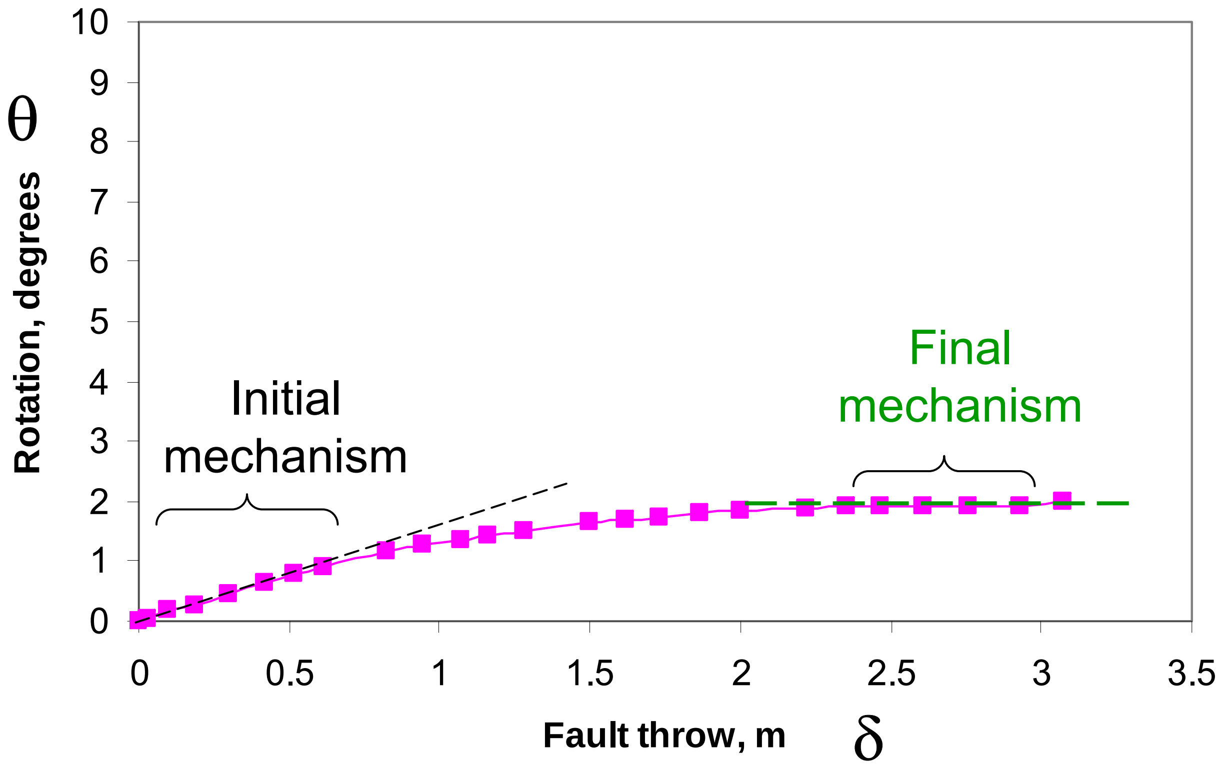
Foundation placed in the worst position?

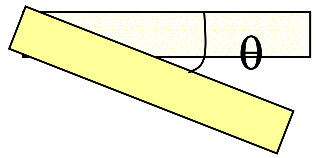
Fondation placée dans la plus mauvaise position?


91 kPa
Free field fault
Test14_Repeat (Quaker) Bearing Foundation Pr. =90 kPa
Normal Fault-D$_r$=60% & Dip angle=60° 115g 29-03-2005
δ=0 m
Test 14_R:
q = 91 kPa, Normal fault


Fault deviates left
Little foundation rotation
Test14_Repeat (Quaker) Bearing Foundation Pr. =90 kPa
Normal Fault-D$_r$=60% & Dip angle=60° 115g 29-03-2005
δ = 1.744 m

Foundation rotation





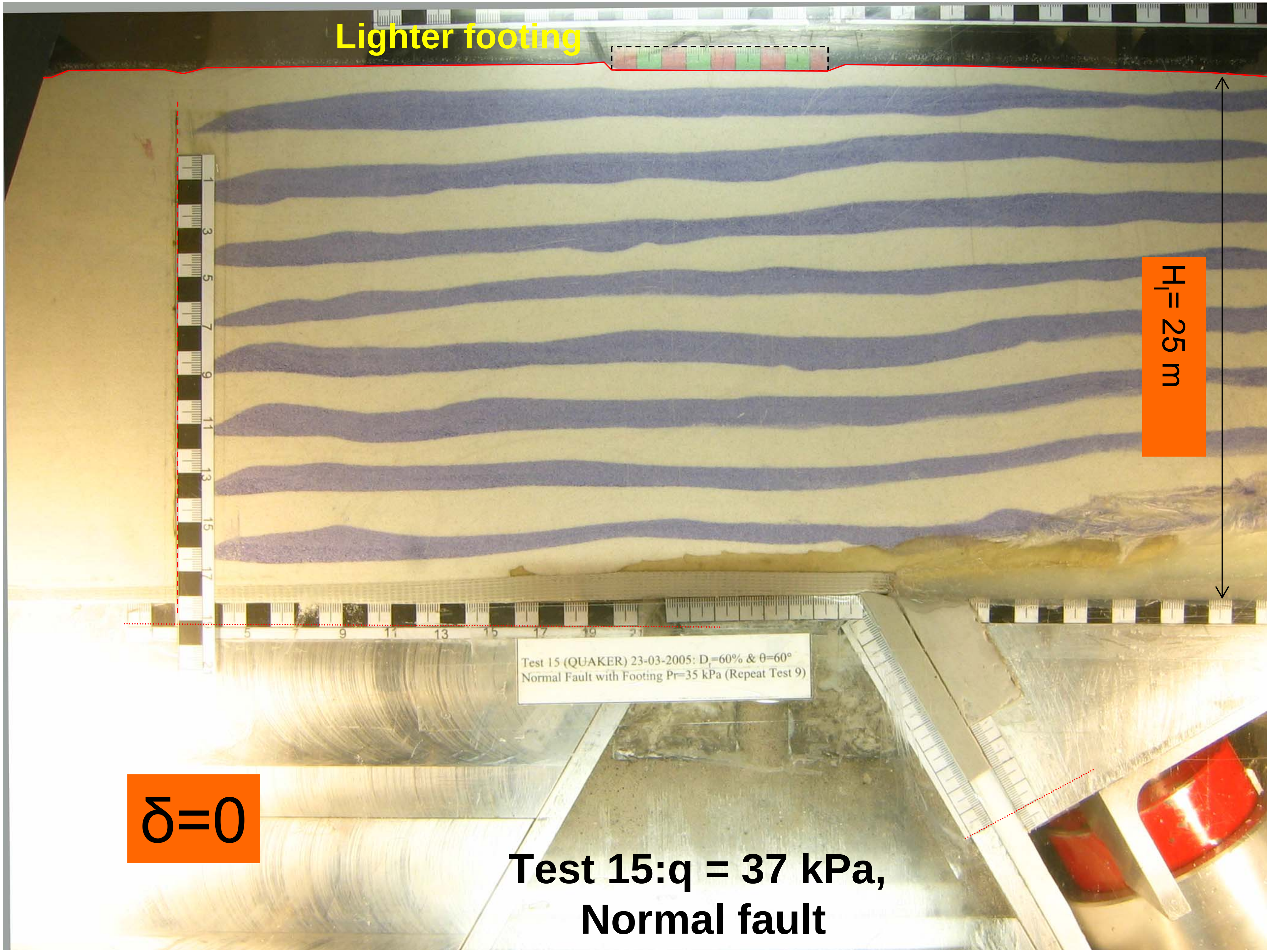
- Some foundation rotation at start of fault movement
- Rotation ceases once final mechanism is formed
- The structure may be OK

Lighter foundation

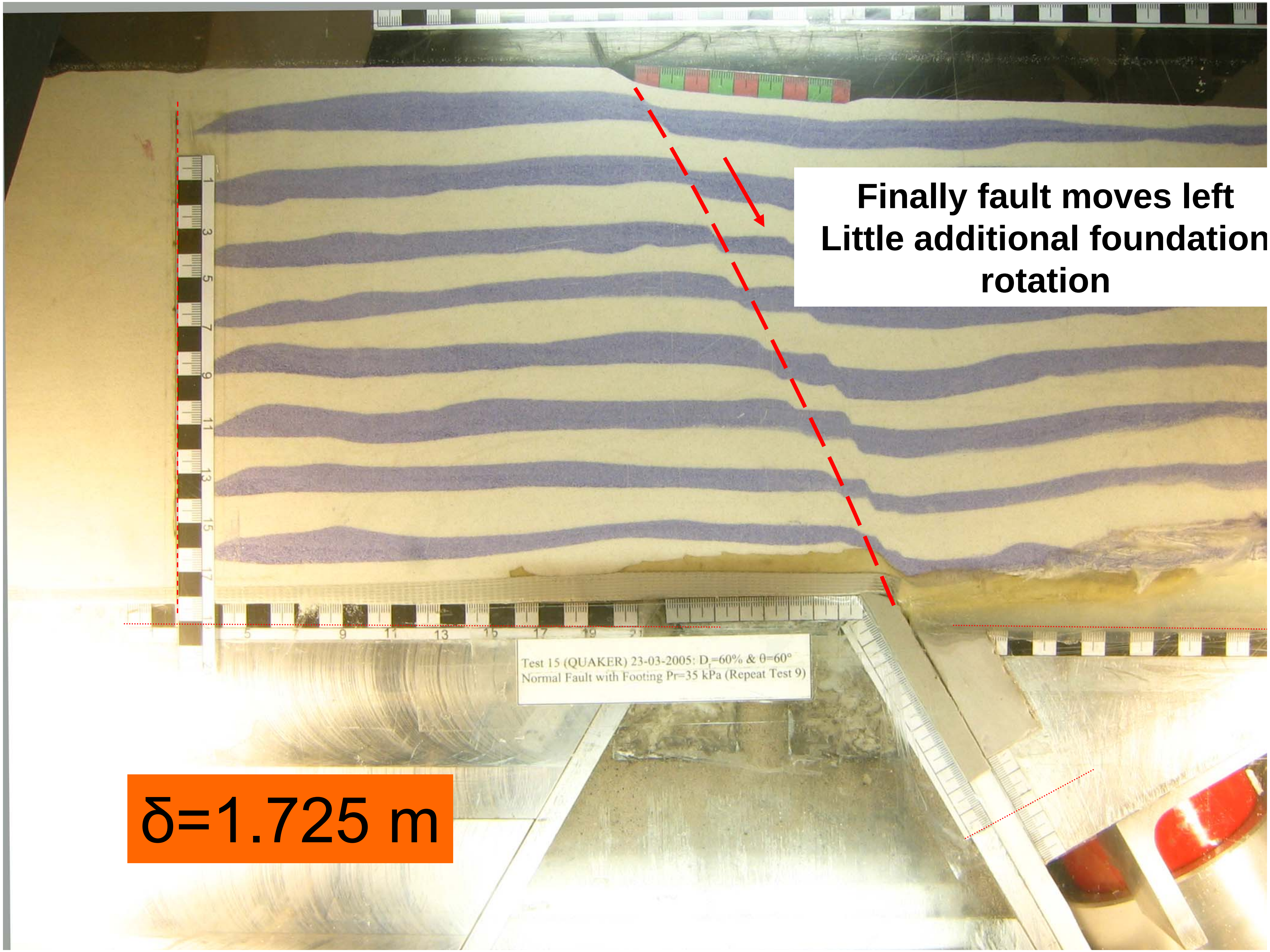
Fondation légère

H = 25 m; Fontainebleau sand, D_r = 60%

B = 10 m; **q = 37 kPa**



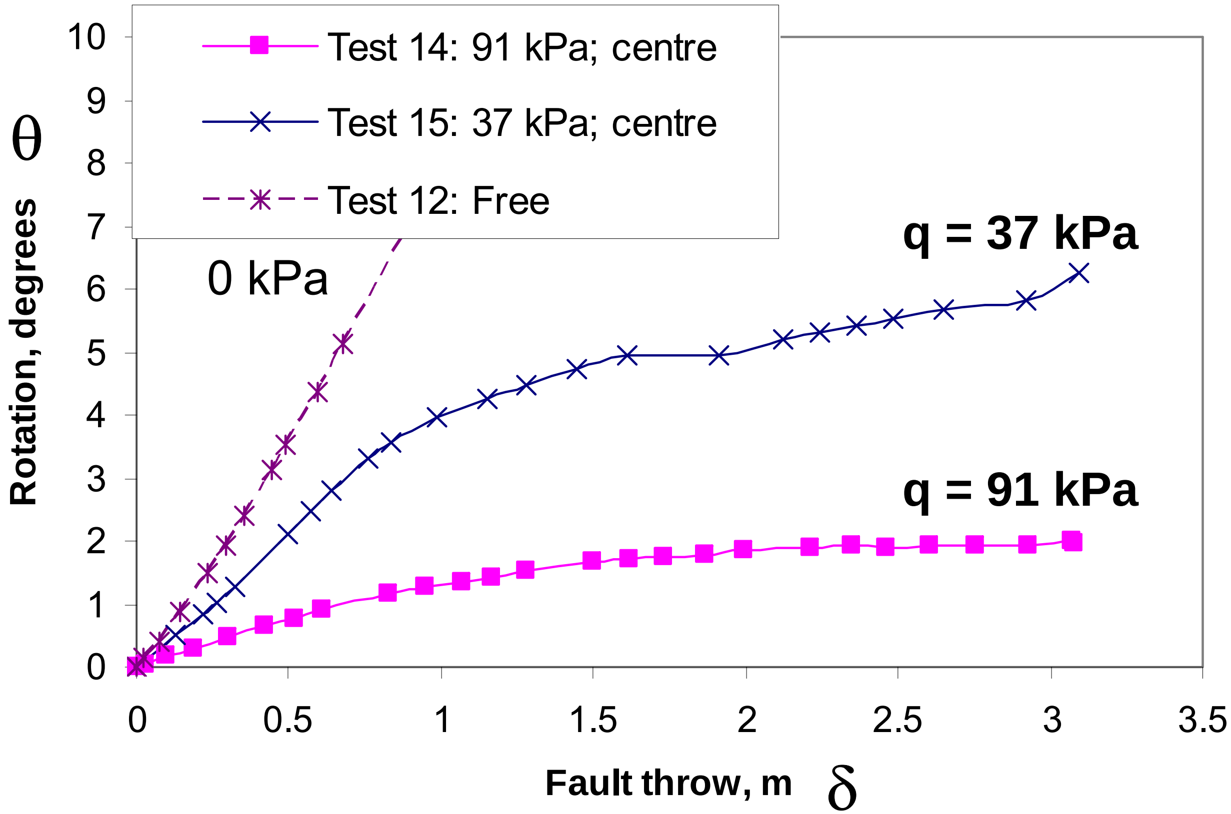
Lighter footing
H_l= 25 m
Test 15 (QUAKER) 23-03-2005: D_r=60% & θ=60°
Normal Fault with Footing Pr=35 kPa (Repeat Test 9)
δ=0
Test 15:q = 37 kPa,
Normal fault



Finally fault moves left
Little additional foundation rotation

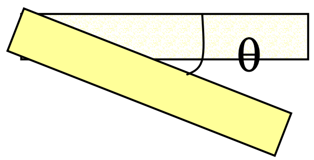
δ=1.725 m

Foundation rotation



- More rotation with lighter footing

- Rotation θ is affected by q

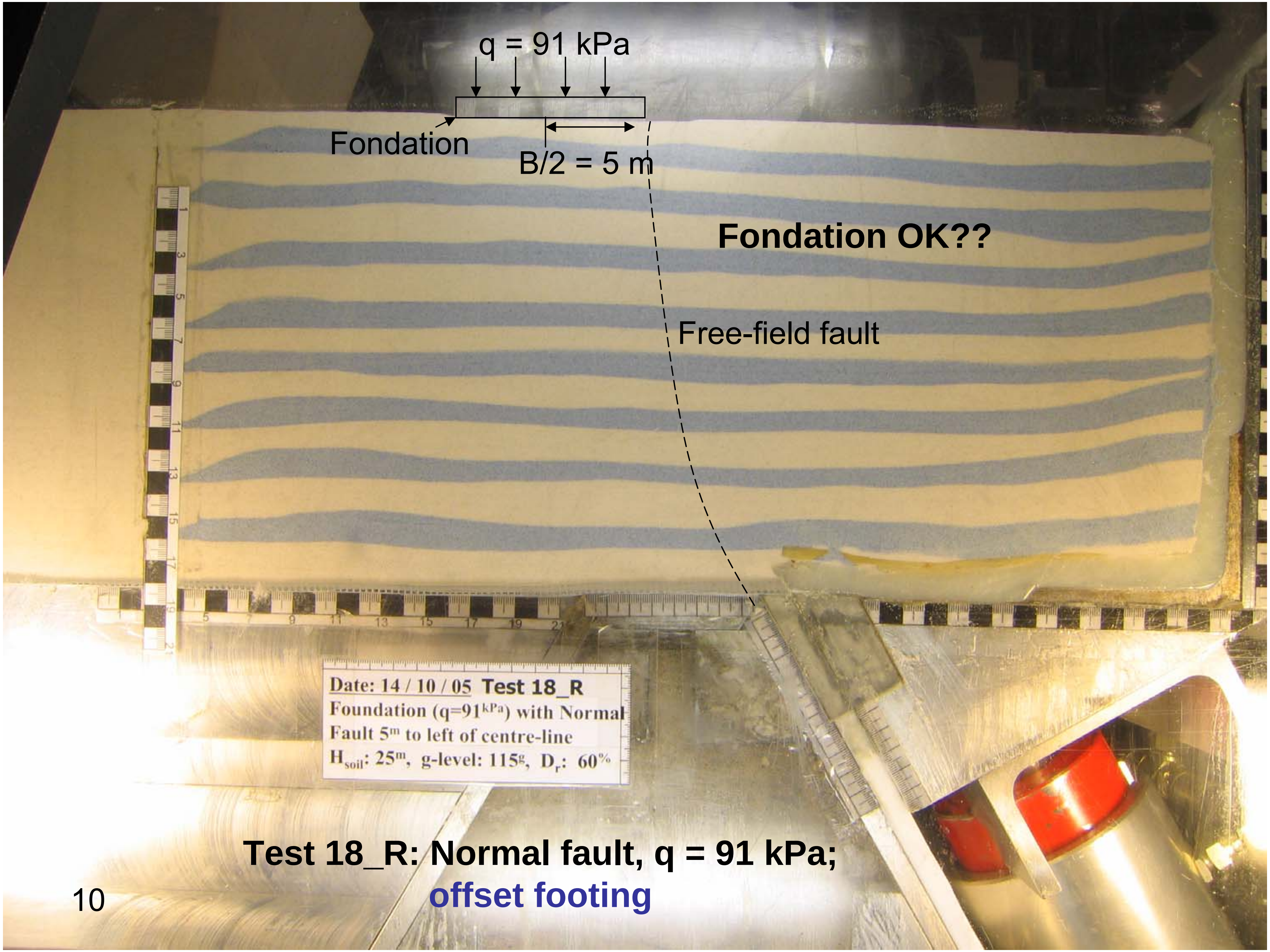


- Significant rotation for lighter footing (despite identical final mechanism)

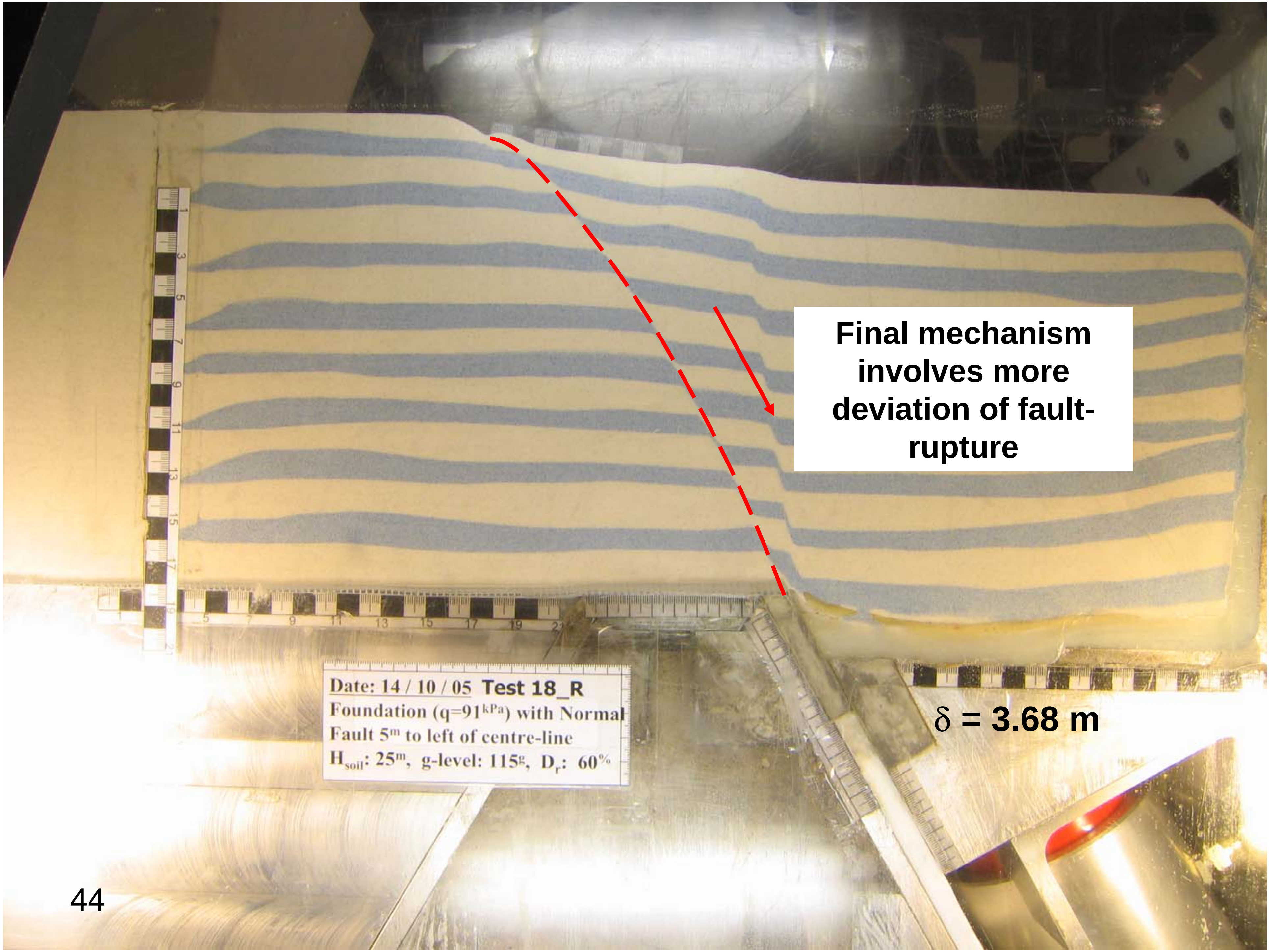
Heavy foundation further away from fault

Fondation lourde et plus loin de la faille

Test 18_R: Normal fault, q = 91 kPa; offset by 5 m

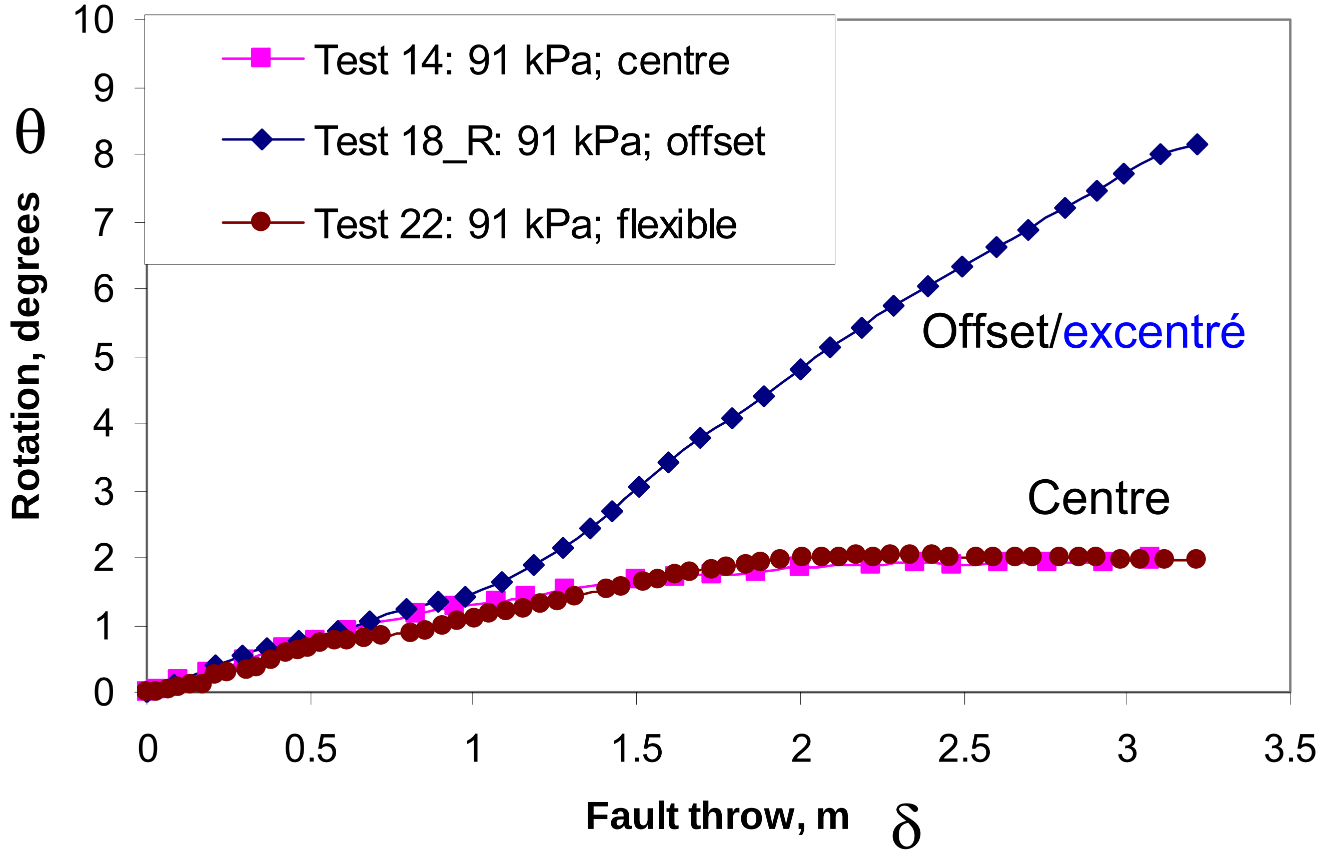


Test 18_R: Normal fault, q = 91 kPa; offset footing



Final mechanism involves more deviation of fault-rupture
δ = 3.68 m
Date: 14 / 10 / 05 Test 18_R
Foundation (q=91 kPa) with Normal
Fault 5m to left of centre-line
H soil: 25m, g-level: 115g, Dr: 60%

Rotation



• plus grande rotation!

5. Initial observations

• There are subtle soil-structure interaction effects

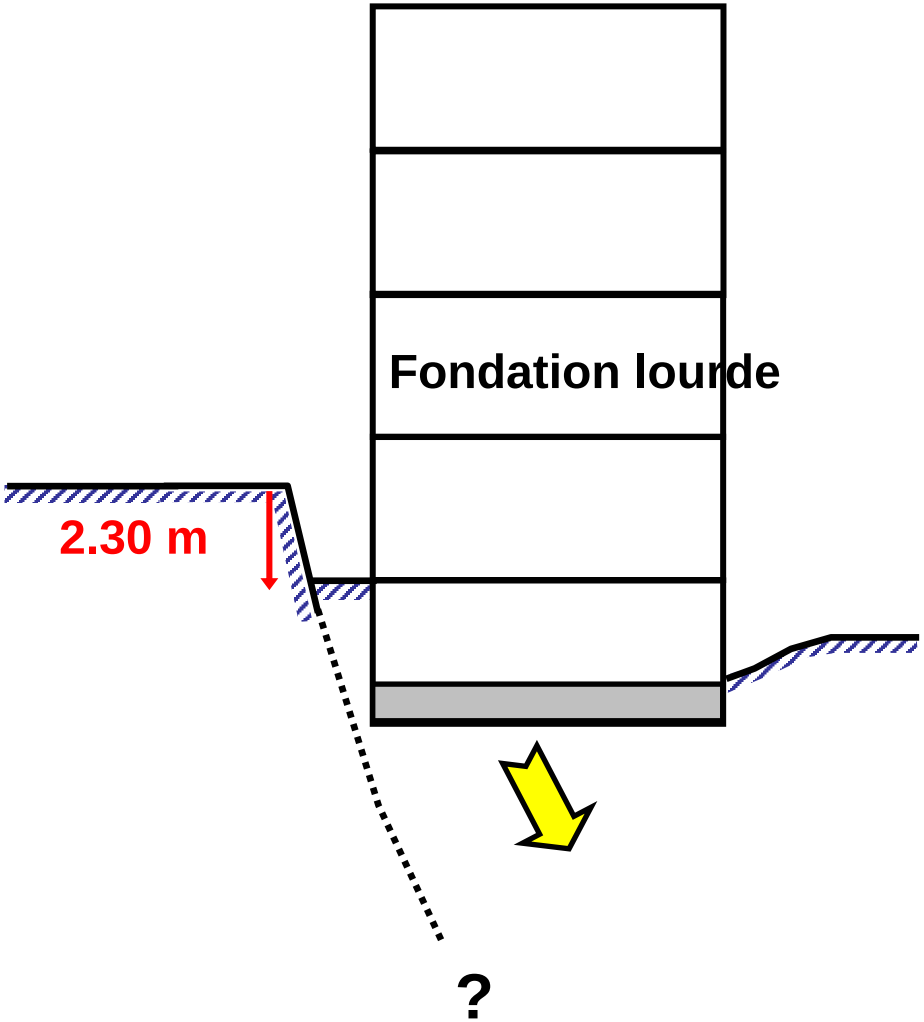
• Interaction depends on: Foundation position x, load q, breadth B, fault mode (normal/reverse and dip angle), foundation rigidity/strength?

• Fault deviation due to footings depends on a combination of:

(i) the changed stress field in the soil due to q;
(ii) the additional work dissipated moving the foundation
(iii) the kinematic restraint of the footing.

• Even if the fault deviates away from the footing there may be significant foundation displacements associated with pre-failure mechanisms

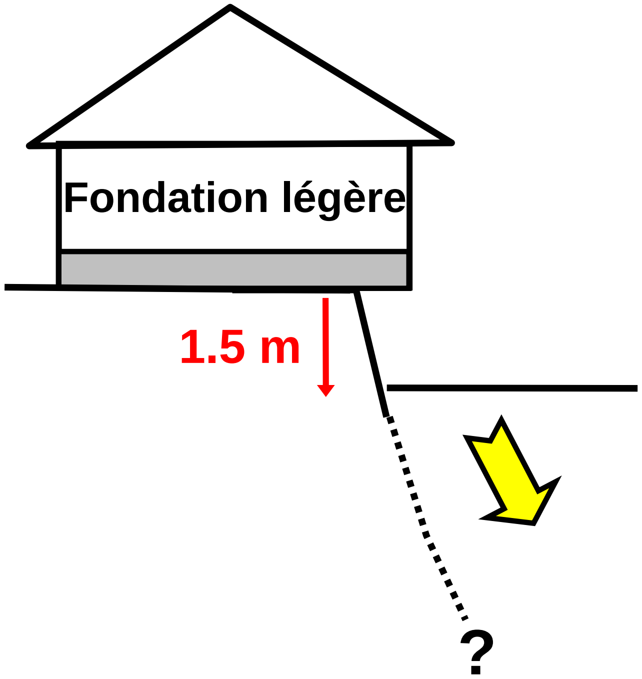
The results may explain this behaviour in Golcuck:
– possible fault deviation



Photos/mapping from George Gazetas

Building 1 : 4 storeys + Basement – No Damage

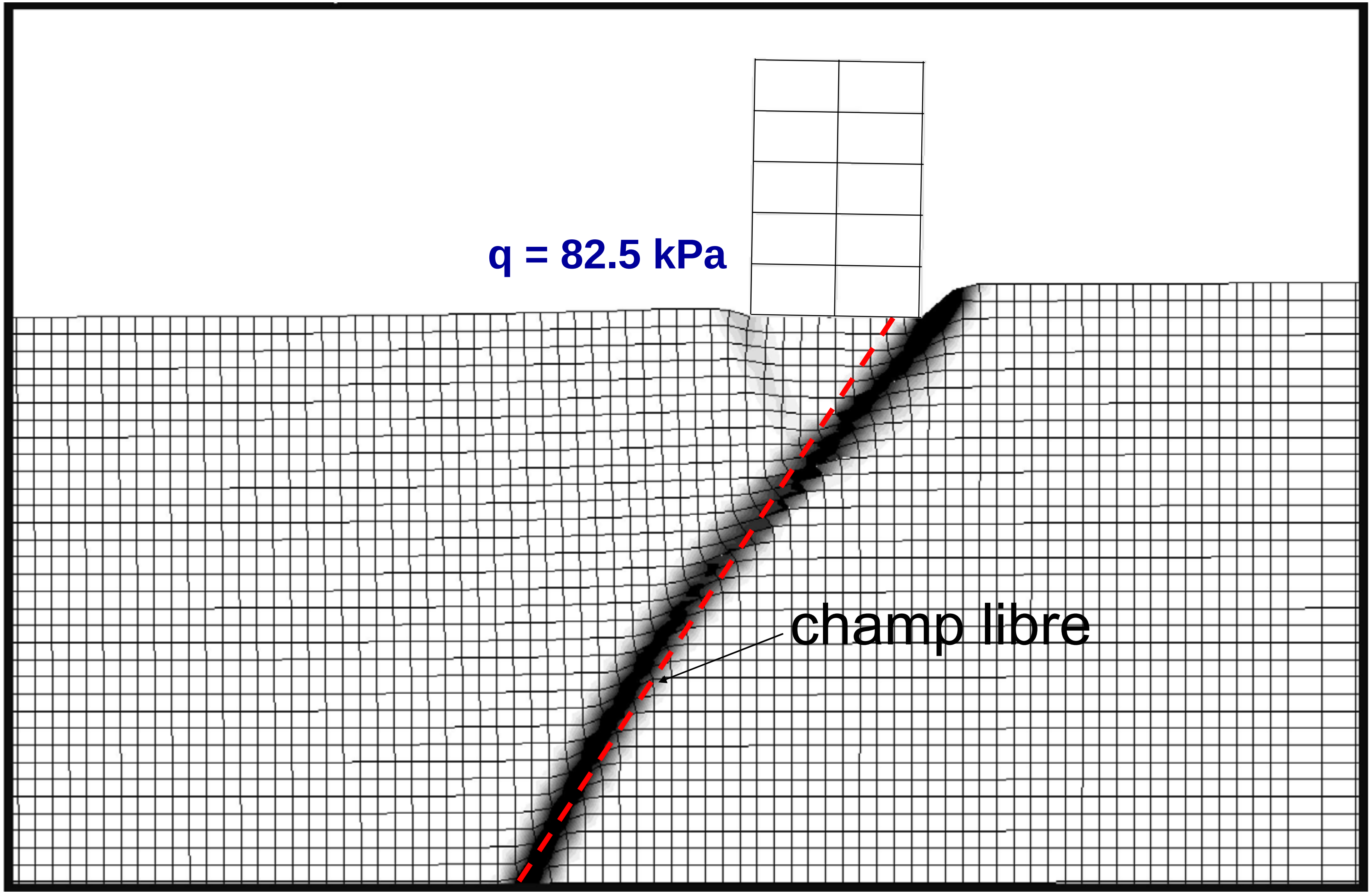
The results may explain this behaviour in Golcuck:
– No fault deviation



Photo/mapping from George Gazetas

Building 2 : 1 storey – partial collapse

Méthode des éléments finis



→ National Technical University of Athens, Greece
et Studio Geotechnico Italiano, Milan

5. Conclusions

• Fault-footing interaction is a subtle soil-structure interaction problem

• Centrifuge modelling is a good tool for investigating this

• Further work is being done using finite element analysis and analytical methods to understand the problem and find critical conditions

• The findings will lead to design recommendations to be reported and disseminated next year

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