

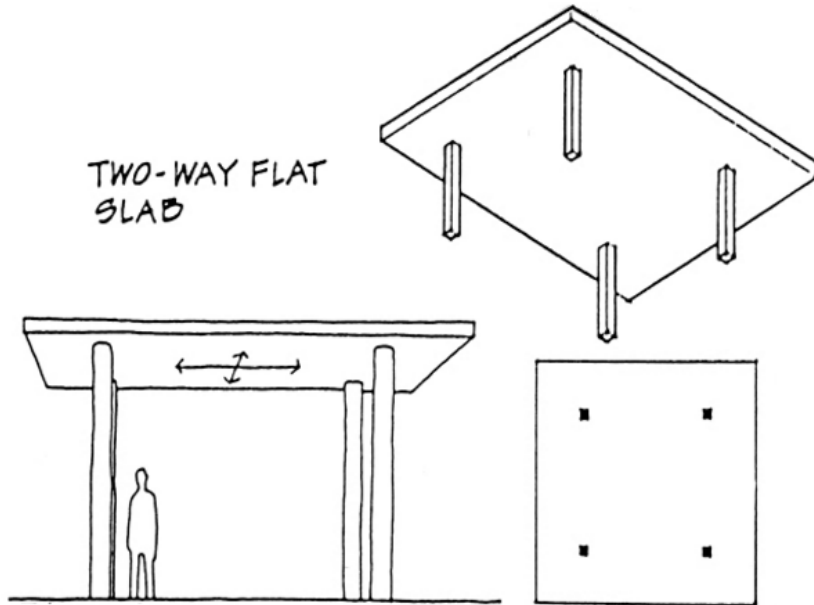


# Seismic Behavior of R/C flat slabs with opening

**Massimo Lapi**

University of Florence  
Prof. Maurizio Orlando  
Prof. Antonio Ramos  
Prof. Paolo Spinelli

Department of Civil Engineering  
Caparica, March 7, 2018

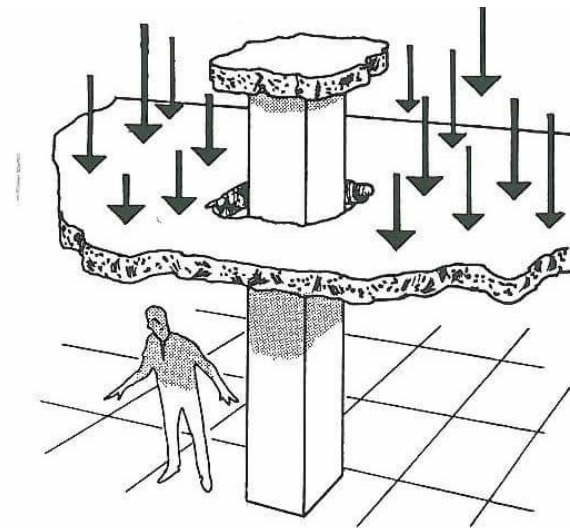


### R/C flat slab

- Two-way slab without beams or girders
- Shorter construction time
- Minimal structural depth
- Weak point: punching failure

## Punching of R/C flat-slabs

- Concentration of stresses near the loaded area
- Truncated cone failure shape
- Very brittle and usually accompanied by limited warning signs
- Progressive collapse



# Punching – Gravity loading

## Codes:

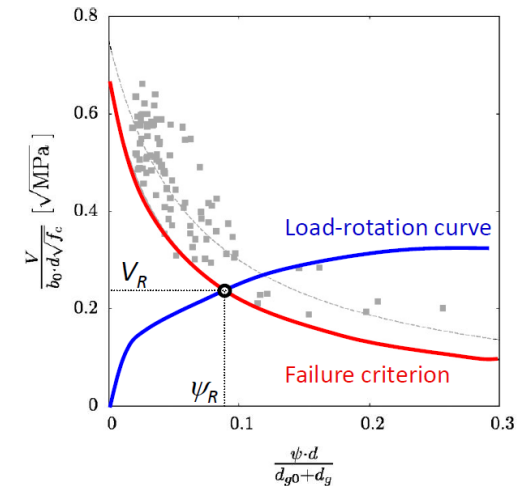
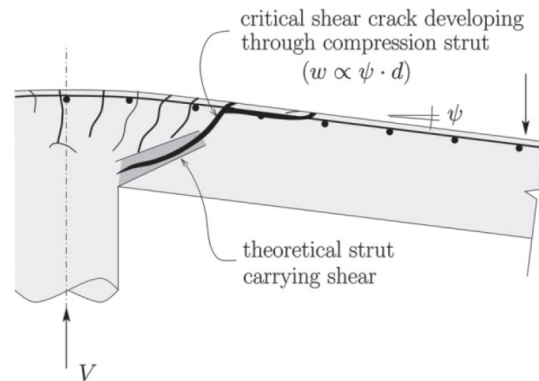
ACI 318-16

EC2 2004

Model Code 2010

SIA 262-13

NBR 6118-14



## Models:

Kinnunen and Nylander (1960)

Shehata and Regan (1989)

Broms (2005)

Critical Shear Crack Theory (CSCT)  
(2008)

Punching capacity is found at the intersection of the failure criterion and the load-rotation curve

# Punching – Combined gravity and horizontal loading

## Codes:

**ACI 421.R-10** Guide to Seismic Design of Punching Shear Reinforcement in Flat Plates

**ASCE – SEI 41-13** Seismic Evaluation and Retrofit of Existing Buildings

## Models:

the research is still ongoing !!



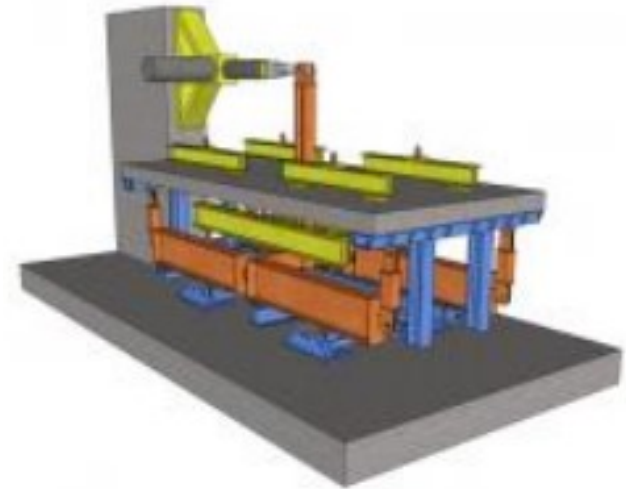
## Bullock's Department Store in Northridge:

January 17, 1994, Punching failure due to an earthquake of 6.8 Mw.

# Research Goals

## Experimental research:

Structural laboratory of Lisbon University, 6 specimens with opening close to the column, subjected to both gravity and lateral loading.



## Analytical research:

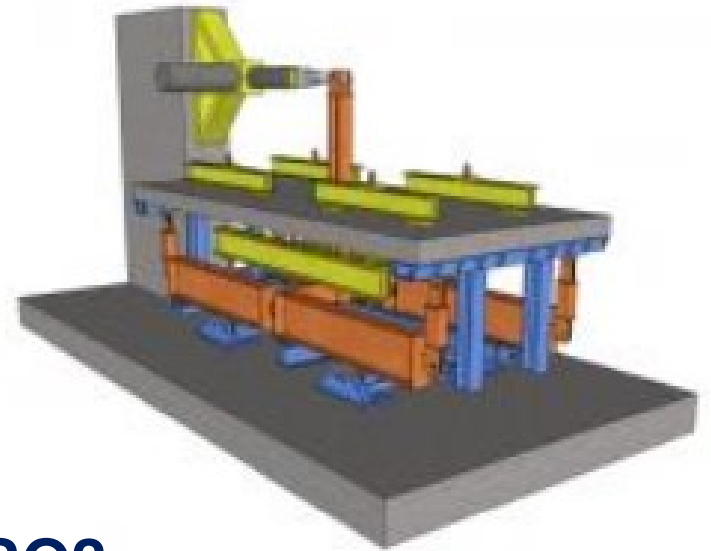
(Try) To develop an analytical model for slabs with opening starting from the CSCT.



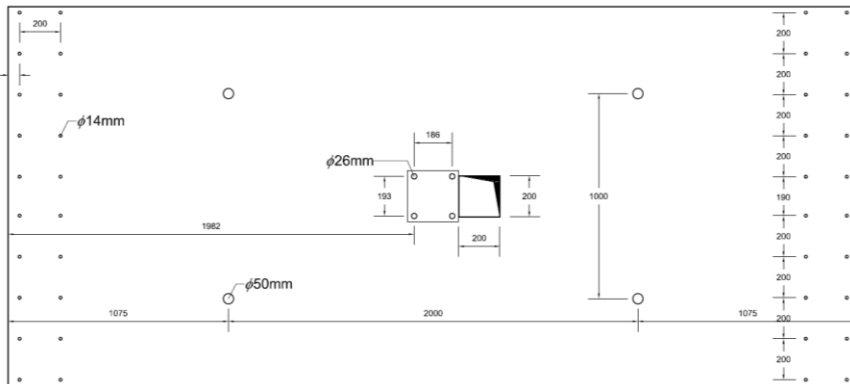


# Experimental research

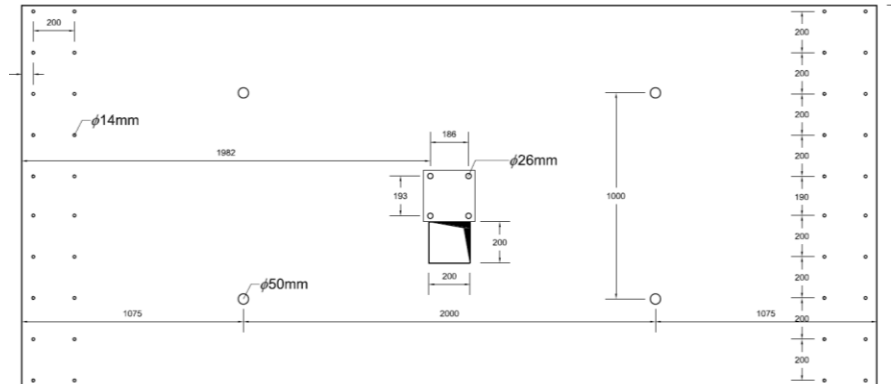
- Two patterns of opening (200 x 200 mm), with and without shear reinforcement (stirrups);



## SO1



## SO2



**Thank you for the attention!**

# Seismic Behaviour of R/C flat slab with opening



UNIVERSITÀ  
DEGLI STUDI  
FIRENZE

**DICEA**  
DIPARTIMENTO  
DI INGEGNERIA CIVILE  
E AMBIENTALE

PhD Student:  
Massimo Lapi



FACULDADE DE  
CIÊNCIAS E TECNOLOGIA  
UNIVERSIDADE NOVA DE LISBOA