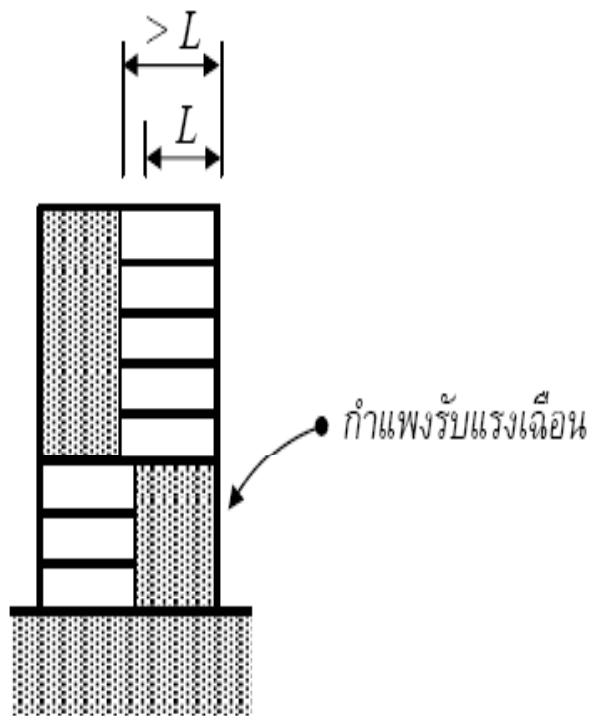
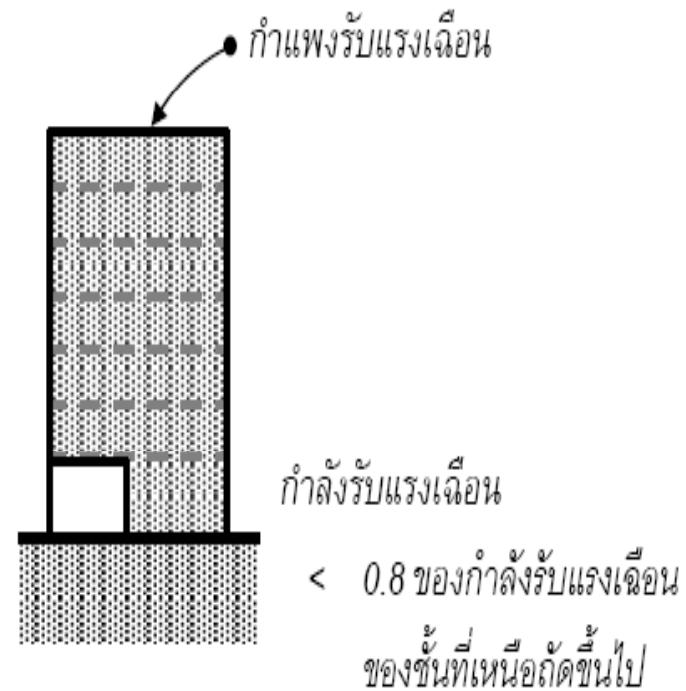


Avoid irregular and  
discontinuous systems

# ตัวอย่างความไม่ต่อเนื่องของโครงสร้างในแนวดิ่ง (จาก มยพ.1301-50 กรมโยธาธิการและผังเมือง)



ความไม่ต่อเนื่องในระนาบ



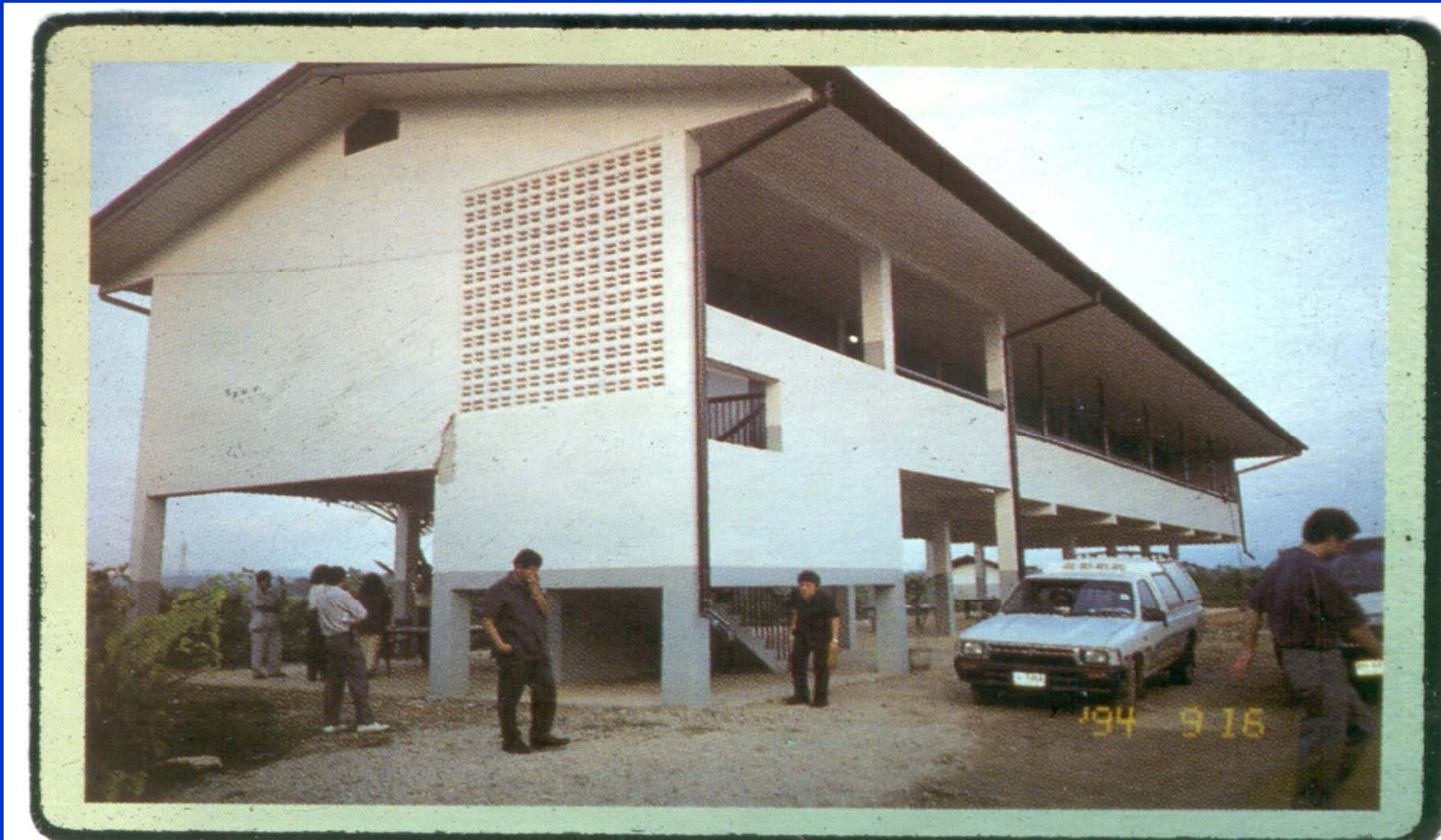
ความไม่ต่อเนื่องของกำลัง



**Olive View Hospital building in ML 6.4 San Fernando earthquake. Poor performance of **SOFT-STORY** system**

- **Olive View Hospital building after the San Fernando earthquake. The building was close to the center of energy release of the ML 6.4 quake. It was above the plane of the thrust fault and received very strong ground shaking having an estimated peak ground acceleration of  $\pm 0.50 g$ . The building, which was essentially a heavy box on slender columns, was not designed to withstand such strong shaking. ( G.W. HOUSNER, P.C. JENNINGS, " Earthquake Design Criteria " , 1982 )**





**Damage to a newly built school building in Phan Earthquake, 1994.**

**Note soft-story and torsional irregular system**

# Strong column-weak beam system





# Anchorage

- Anchor ( tie ) elements
  - ◆ pile - pile cap - footing
  - ◆ beam - column
  - ◆ slab - beam
  - ◆ etc.



Wenchuan eqk

Hollow core slabs not anchored to supporting beam - Pingwu County (0.1g/0.8g )

Courtesy Prof. Y. Wang



A closer view showing the collapsed span and the arch pier. **Failure caused by loss of support.**

# Bracing

- Provide adequate lateral resistance

by means of diagonal bracing ( in timber  
& steel buildings ) or shear walls

# Bennett Federal Building Salt Lake City



Courtesy: GSBS Architects



Prof. Kelly's lecture

# Connections

# JUYUAN



Sichuan eqk M8.0, 12/05/08

# Connection

- weakest link ( usually )
- failure often results from poor connection
- connection must transfer forces ( shear, moment, torsion, etc.) and must be designed
- good detailing ( for workability ) is essential



## Failure due to Inadequate Anchorage



คานกับตอม่อยึดกันไม่แข็งแรงพอ และตอม่อเล็กไป (ไม่ได้ล้วงเหล็กคานเข้าไปในตอม่อให้ลึกพอ)

# Ductility

- good quality materials  
confinement of concrete by adequate &  
properly anchored  
ties / stirrups  
( 135° or 90° hooks with hook clip )
- avoid brittle failure modes-shear,  
bond or instability

- Provide appropriate confinement reinforcement with proper detailing

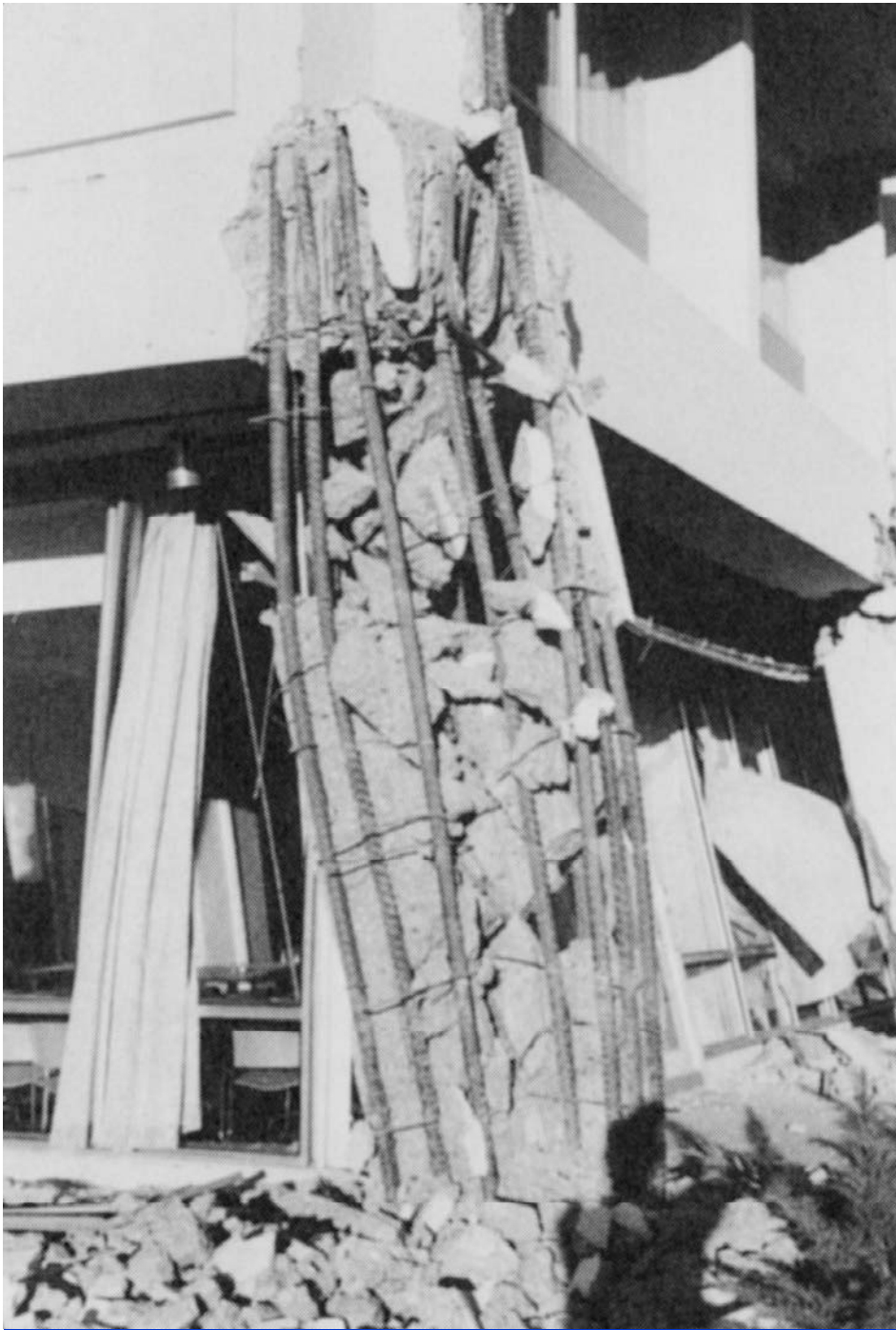
Confinement of  
concrete for

Ductility



### **Ductile vs. Non-ductile Concrete Construction**

*Time and Location of Slide: 1971, San Fernando, CA* Ductile reinforcing of concrete is a necessity. Note the obvious differences of capability of concrete columns to take load after earthquake damage. The spirally rein-forced column (ductile reinforcing) has an obvious capacity to carry much more load than the tied corner column (non-ductile reinforcing).





**Shear failure of large  
bridge piers in Kobe  
Earthquake, 1995**

# เสา

สำคัญ

เหนียว

เหล็กปลอกดี

ขาของยาวพอ



ระยะห่างของเหล็กปลอก (แสดงด้วยลูกศรในรูป) ห่างมากเกินไป



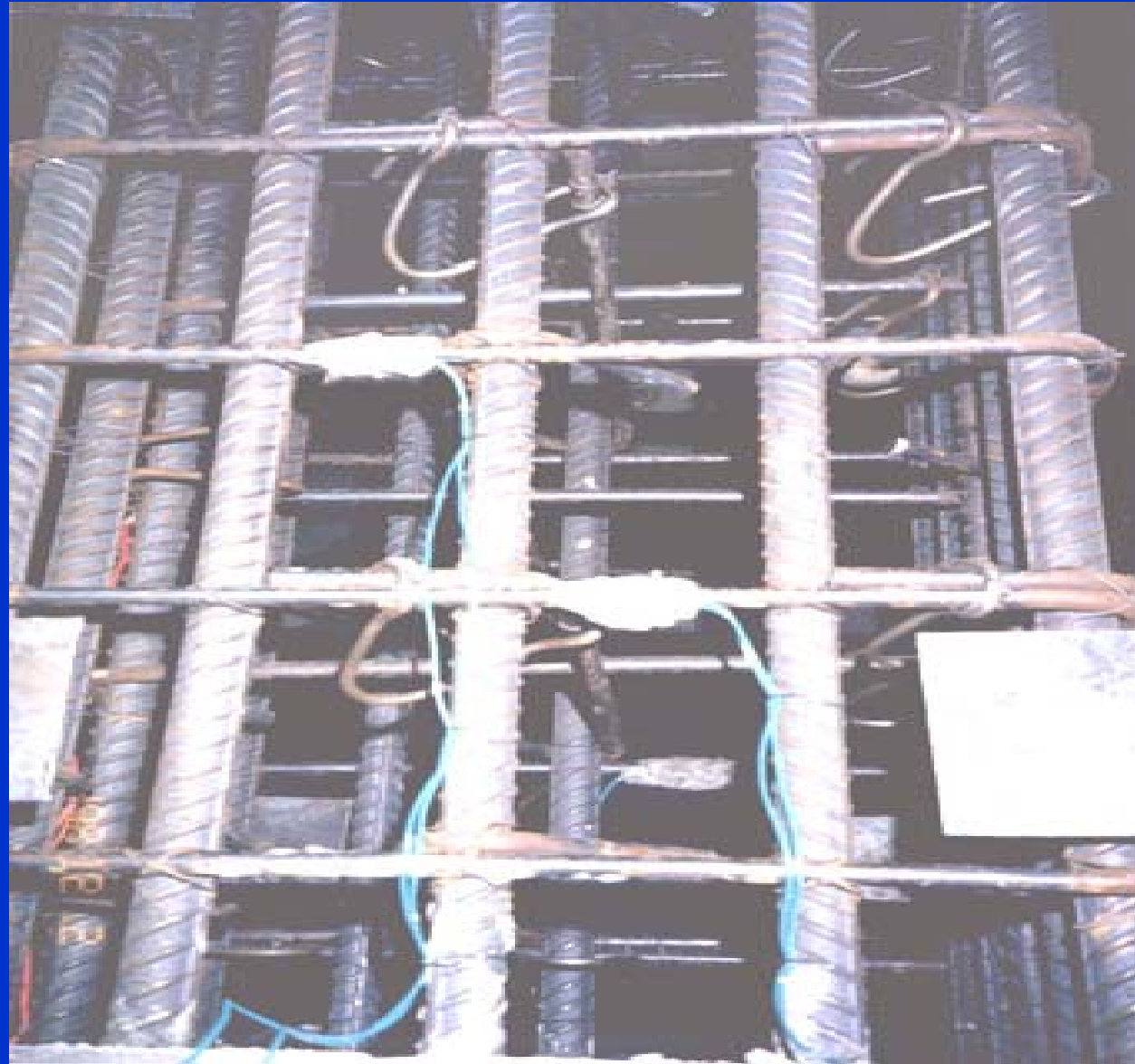
d

# เหล็กปลอก

ขาของอ ควรมีความยาวที่เพียงพอ



**ENHANCEMENT OF  
STRUCTURAL  
PERFORMANCE FOR  
MODERATE SEISMIC RISK  
REGIONS**



# Improvement of 90-deg hook by HOOK-CLIP

**HOOK-CLIP** - Patented (but released now)

Reference:

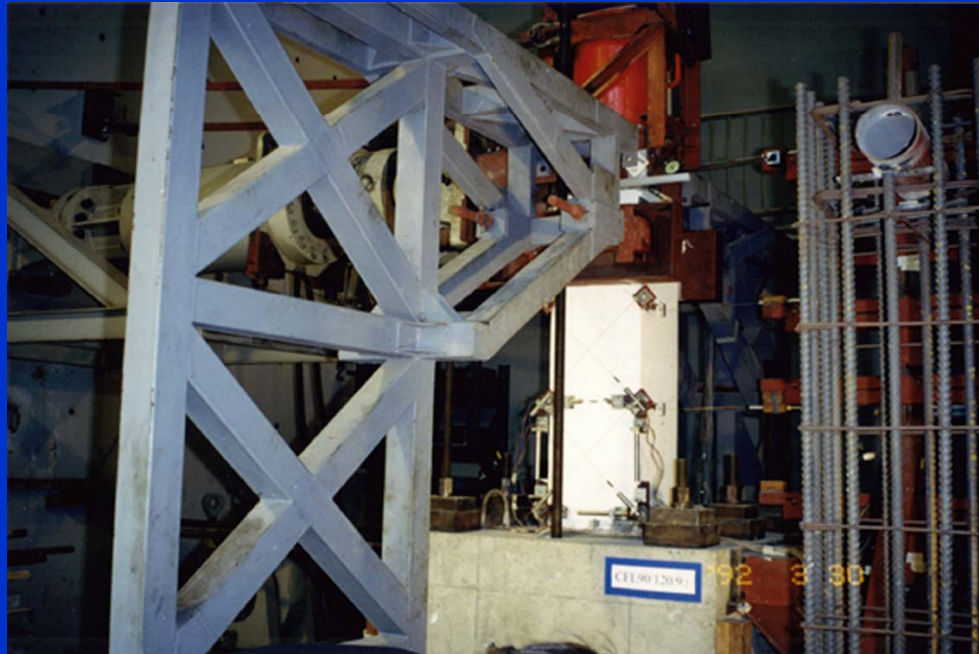
Lukkunaprasit, et al (2003), “Ductility enhancement of moderately confined concrete ties columns with hook-clips”, *ACI structural journal*, 100 (4), pp.

422-429

# Cyclic Behavior of RC Members

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## Columns





**Other considerations**

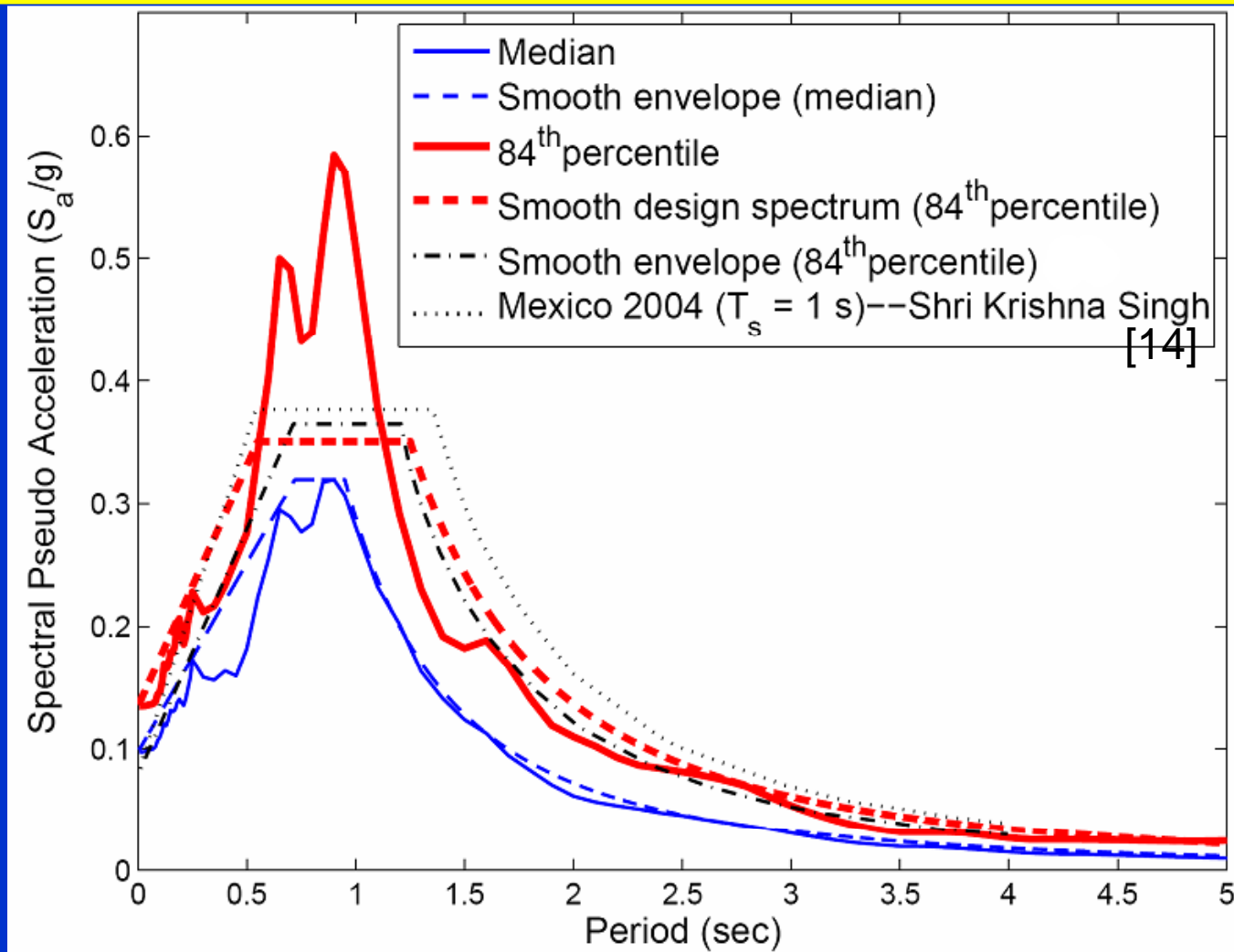
# Issues on Design Spectra

# What seismic loading to design?

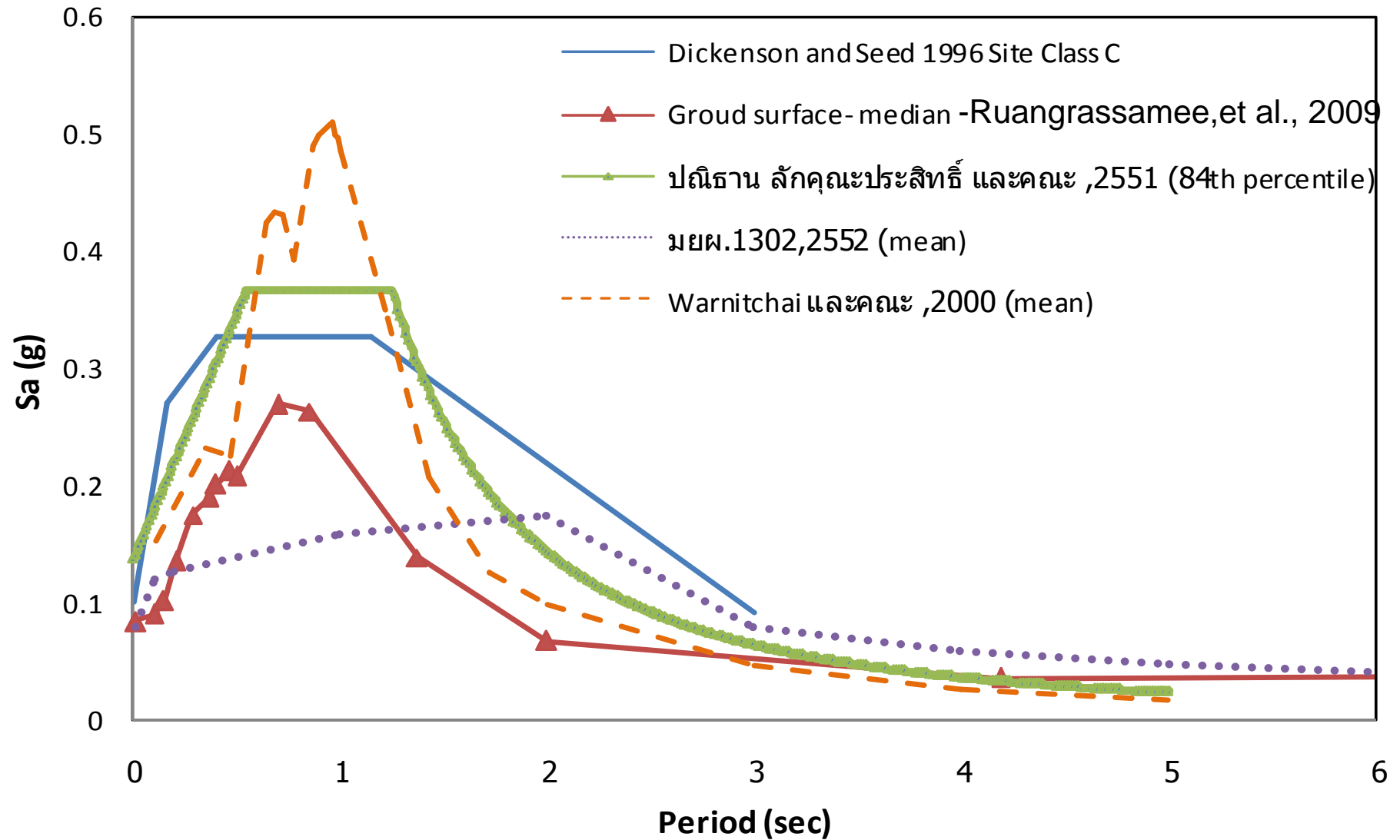
- Different researchers have proposed different spectra, some differ significantly
- Difficulties stem from
  - Uncertainties in seismic sources (e.g. any faults closer than the ones identified so far)
  - lack of data on ground motions on rock site under sizable earthquakes



## Elastic response spectra for Bangkok soil site (PRA=0.03g)

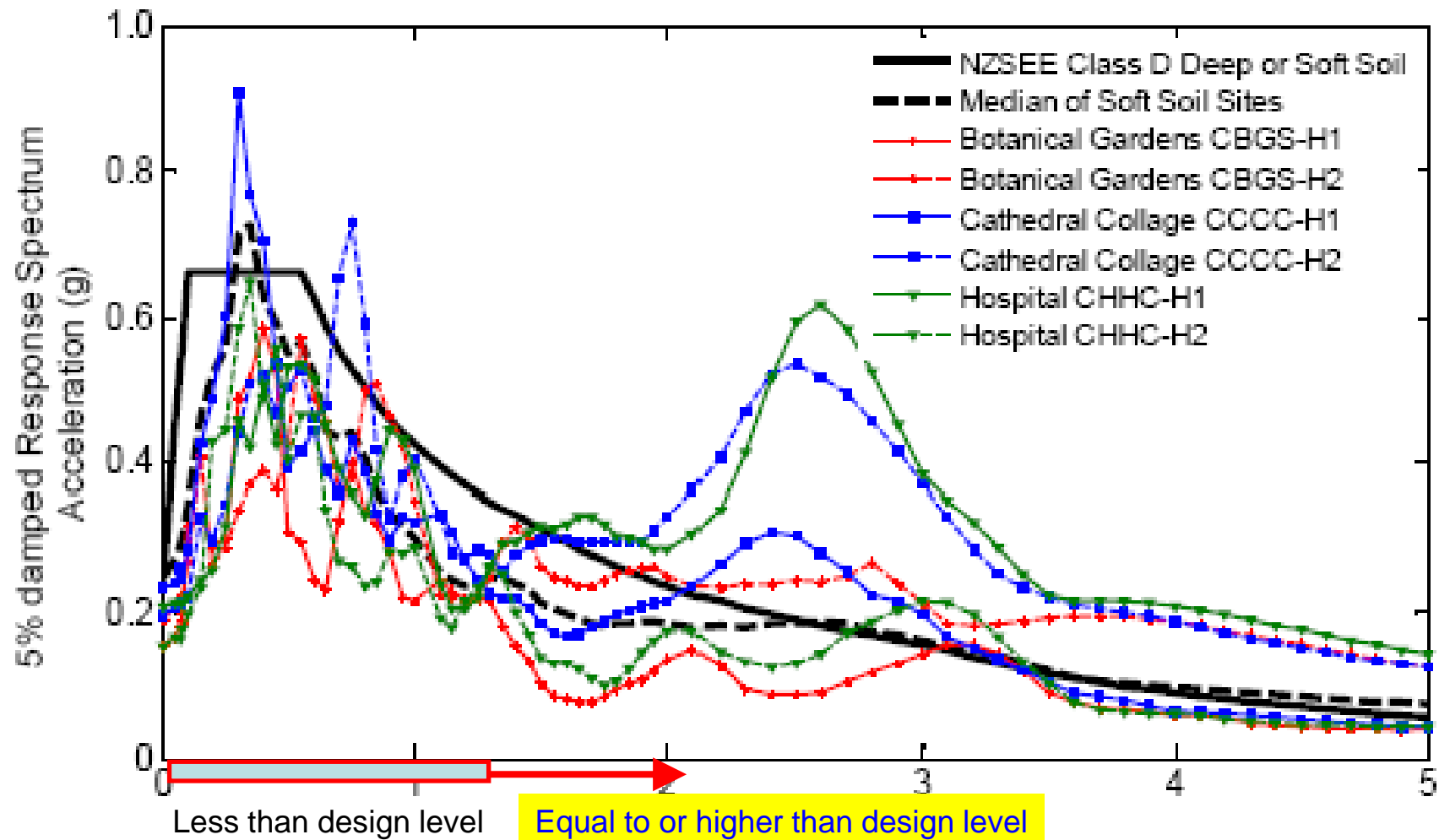


Lukkunaprasit, et al. 2008, 13NCEE



Elastic response spectra for Bangkok soil site (PRA=0.03g, 5% damping ratio)

# Comparison with Design Demand, New Zealand earthquake, 2010



(Dhakal, 2010, 3ACEE)

**Importance of exits/  
stairways in  
evacuation in case  
of emergency**

Collapsed stair shaft in middle of a school building of masonry structure in Mianzhu City ( 0.1g/0.3g )



Wenchuan eqk  
Courtesy Prof. Wang

**Sub-standard design  
and/or construction  
kills people !!**



Sampoong  
department  
store  
collapse,  
1995 - 501  
deaths

# SAMPOONG DEPT STORE COLLAPSE – Korea 1995

- > 500 killed
- 5 story r.c. flat slab bldg
- Column drop panel sizes, reduced, e.g. from 800mm column to 600mm
- Collapse after 6 years of service!
- CEO's of the dept store, engineers, government officials involved in corruption jailed !



# Wenchuan earthquake

M8.0, 12/05/08

- Schools
  - Wide spread damage, even newly built schools
  - Thousands of school children and teachers killed !
- Schools need to have higher performance level to serve as shelters in the event of disaster



Wenchuan earthquake  
M8.0, 12/05/08



**Yuan Wentin**(袁文婷), 26, first grade teacher. When the earthquake struck, she rushed to carry her stunned students from classroom on the 3<sup>rd</sup> floor to the ground. She managed to pull out most of her students, but the building collapsed when she was trying to pull out the last few. At the last moment of her life, she was trying to use her body to shield the students from falling concrete.

Many teachers did the same thing. They are 谭千秋、张米亚、苟晓超、吴忠洪、杜正香.....

**So, it is of utmost  
importance that  
engineers adhere  
to “Professional  
ethics”**