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Earthquake Engineering in the low and moderate seismic regions of Southeast Asia and Australia (2008)

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The Sichuan Earthquake: structural engineering perspectives

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16 July 2008, The University of Melbourne

2008 . 5 . 12 14:28
M8 EARTHQUAKE …
Sichuan Province of China ...

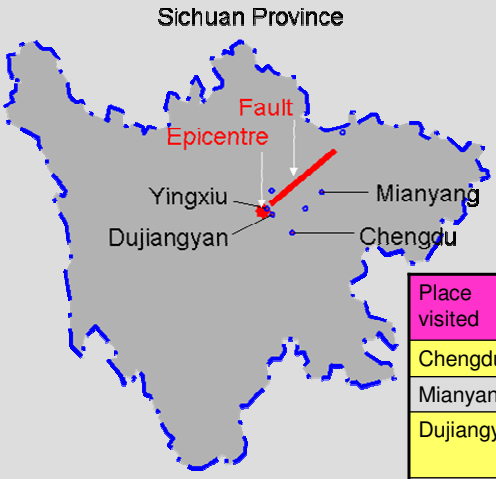
(*as of July 2, 2008*)

69,195 died , 373,606 injured ,

18,389 missing , > 5 million homeless

79,852 rescued

Post-Earthquake Field Study



29 June to 3 July 2008, a post-earthquake field investigation team comprising of the earthquake engineering researchers from The University of Hong Kong, The University of Melbourne and The Swinburne University of Technology visited the earthquake affected areas.

Place visited	Dist. from the fault	Population	MMI
Chengdu	80km	4M (urban)	VI-VII
Mianyang	60km	264k	VII
Dujiangyan	20km	200k (death toll 3k)	VII-IX
Yingxiu	~0km	16k (death toll 10k)	XI

(MMI=Modified Mercalli Intensity)

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Relevance to Australia & HK

Some seismic parameters

Place	MMI		E-W	N-S	Z	Melbourne/ Sydney/ HK
Chengdu	VI-VII	PGA PGD	110gal 225mm	90gal 180mm	55gal 17mm	RP≈500yrs on rock site
Mianyang	VII	PGA PGD	130gal 225mm	145gal 115mm	100gal 5mm	RP≈500yrs on soil site
Dujiangyan	VII-IX	PGA PGD	142gal 700mm	175gal 500mm	120gal -70mm	RP≈2500yrs on soil site
Yingxiu	IX-XI	PGA PGD	170gal 1000mm	205gal 750mm	155gal -220mm	N/A

Source: Chinese Seismic Information Network

Objectives

Objectives of this study

1. To investigate the degree of earthquake damage to buildings in big cities (e.g. Chengdu, Mianyan, Dujiangyan) with hazard levels on a par with Australia and Hong Kong (i.e. with a low-to-moderate seismicity)
2. To learn how to equip ourselves to prepare for next earthquakes
3. To study the failure modes of infill frame structures
4. To study soft-storey failure

Scopes of this presentation

1. To present the degree of earthquake damage to buildings in cities with various hazard levels
2. To illustrate the possible causes of the collapse for precast-slab buildings

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Chengdu City

Chengdu MMI=VI

Damage in Chengdu

Pounding at the movement joint
Damage to plaster

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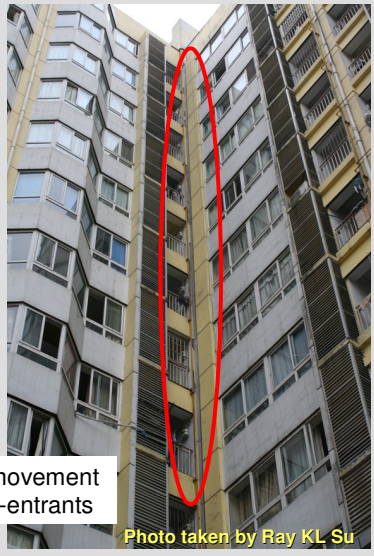
Chengdu MMI=VI

Damage in Chengdu



Damage to movement joints and re-entrants

Chengdu MMI=VI

Damage in Chengdu

Minor damage to glass structures

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Chengdu MMI=VI

Damage in Chengdu

Damage at the interface between RC part and the brick work

Chengdu MMI=VI

Damage in Chengdu

Damage to a movement joint and facade

Photo taken by Ray KL Su

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Chengdu MMI=VI

Damage in Chengdu

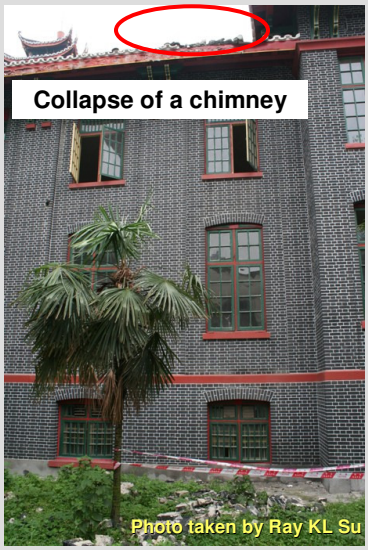
Failure of tiling on the roof, Damage to a window frame

Photo taken by Ray KL Su

Constructed in 1819

Chengdu MMI=VI

Damage in Chengdu



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Chengdu MMI=VI

Damage in Chengdu

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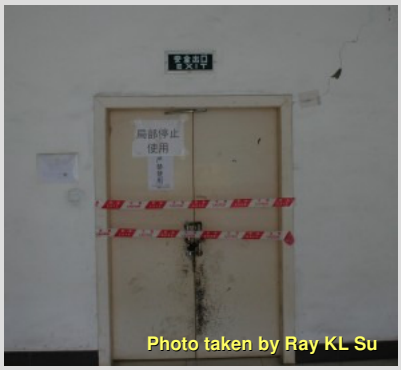
Chengdu MMI=VI

Damage in Chengdu



Chengdu MMI=VI

Damage in Chengdu

Damage to plaster, tiles and brick work

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Chengdu MMI=VI

On the first day of earthquake, 45 people died in Chengdu urban area.

Because many of them jump out from windows and some of them suffer heart attack.

In Australia, collapse of buildings under an earthquake attack is very unlikely. You need not evacuate from windows.

Mianyan City

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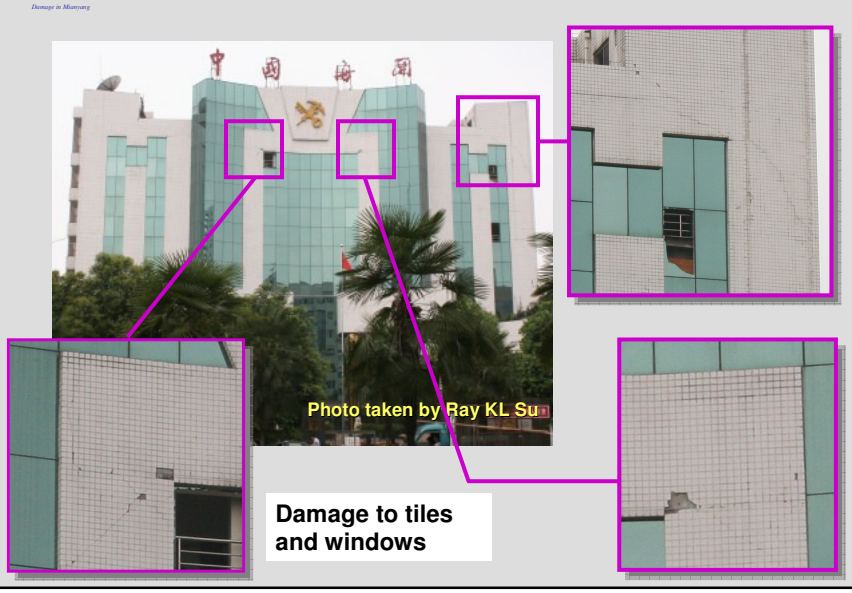
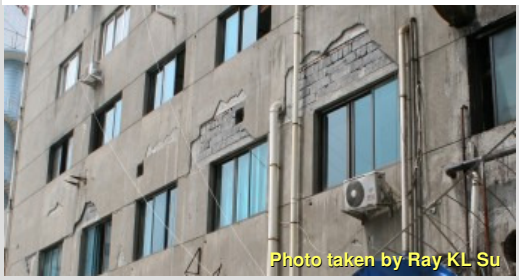
Mianyang MMI=VII



Mianyang MMI=VII

Damage in Mianyang

Quite serious damage to plasters and movement joints



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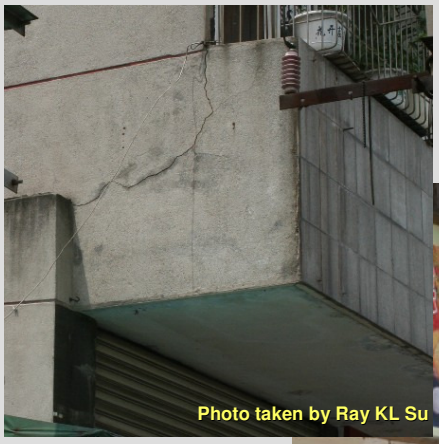
Mianyang MMI=VII

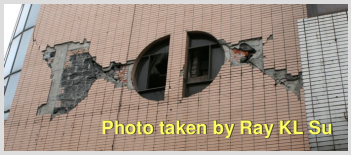
Damage in Mianyang



Cracks above cantilever beams

Mianyang MMI=VII

Damage in Mianyang



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Mianyang MMI=VII

Damage in Mianyang

Mianyang MMI=VII

Damage in Mianyang

Tiles damaged but not glazing

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Mianyang MMI=VII

Damage in Mianyang

An unsafe building

Damage to parapet walls

Mianyang MMI=VII

Partial collapse of a six storey building

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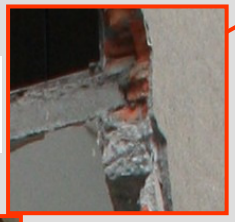
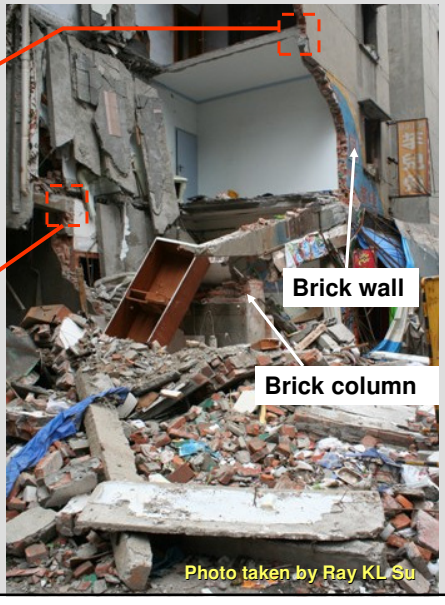
Mianyang MMI=VII

Damage in Mianyang

precast slabs just sit on a brick wall



No ties between beams



The integrity of the building is poor.

Mianyang MMI=VII

Damage in Mianyang

Strengthening of external walls and cantilevers

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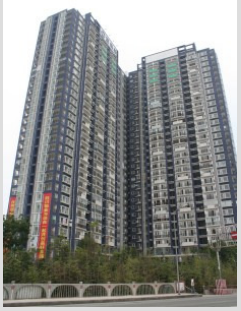
Mianyang MMI=VII

Damage in Mianyang

Many tall buildings survived without notable damage



Dujiangyan

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Dujiangyan MMI=VII-IX

Damage in Dujiangyan

A damaged Hotel

Photo taken by Ray KL Su

Dujiangyan MMI=VII-IX

Damage in Dujiangyan

Dujiangyan MMI=VII-IX

Damage in Dujiangyan

Serious damage to an old timber temple

Dujiangyan MMI=VII-IX

Damage in Dujiangyan

A primary school suffered an extensive damage

Corridor | Classroom | Office

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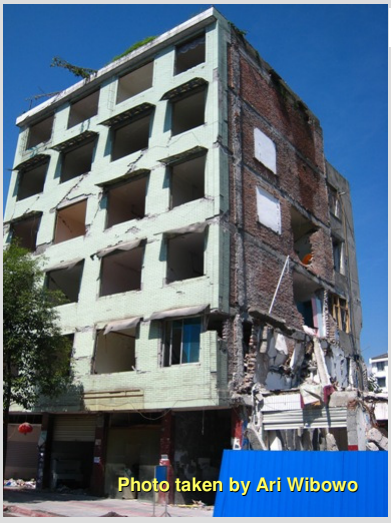
Dujiangyan MMI=VII-IX

Damage in Dujiangyan

Partially collapsed residential buildings



Dujiangyan MMI=VII-IX

Damage in Dujiangyan

Many residential buildings in this area were partially or totally collapsed

Photo taken by Ray KL Su

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Dujiangyan MMI=VII-IX

Damage in Dujiangyan

A partially collapsed 6-storey residential buildings

Front view

View from right

Dujiangyan MMI=VII-IX

Soft storey at the 2nd floor of the building

4% inter-storey drift ratio is too high for unreinforced masonry structures

Dujiangyan MMI=VII-IX

Damage in Dujiangyan

A 6-storey building with soft-storey damage but without collapse

View from Left Front View

Dujiangyan MMI=VII-IX

Damage in Dujiangyan

The inter-storey drift ratio goes up to 8%.

The infill wall at G/L acting as a buttress protecting the whole building

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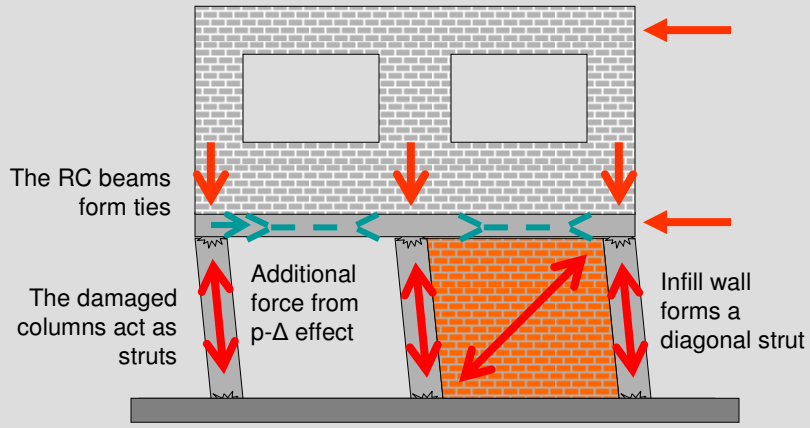
Dujiangyan MMI=VII-IX

Damage in Dujiangyan

A 5-storey building with soft-storey damage without collapse

Dujiangyan MMI=VII-IX

Lateral load transfer mechanism for infill frame



Inter-storey drift ratio of this system can go up to 6 to 8%.

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Dujiangyan MMI=VII-IX

Damage in Dujiangyan

Partial collapse of residential buildings adjacent to stairwells

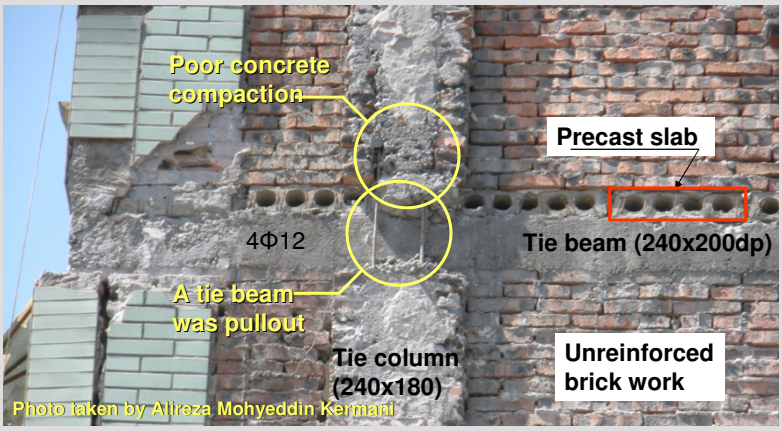
stairwell

stairwell

Dujiangyan MMI=VII-IX

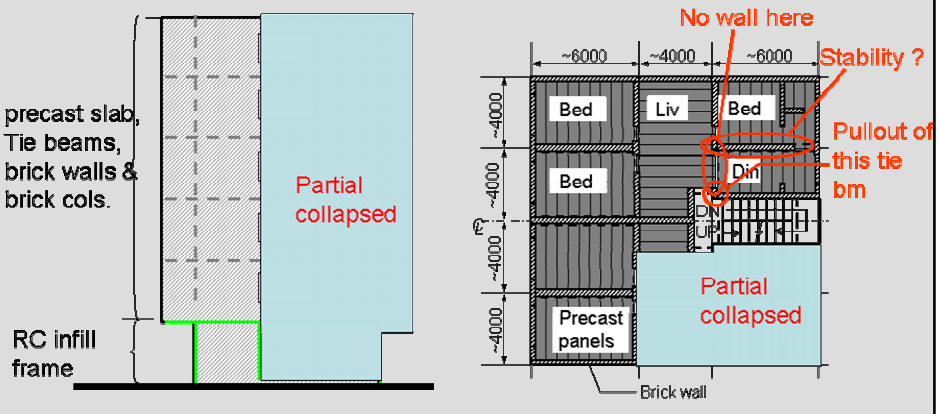
Poor details and workmanship

Precast slab panels directly sit on tie beams



Dujiangyan MMI=VII-IX

Deficiency in the layout plan



Elevation

Plan at Typ. Floor

Dujiangyan MMI=VII-IX

Example of pullout failure of tie beams

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Dujiangyan MMI=VII-IX

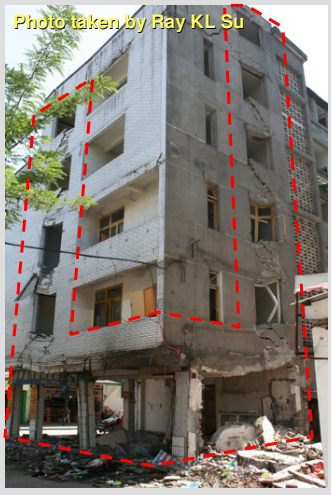
Examples of buckling of external wall & collapse of internal walls

Dujiangyan MMI=VII-IX

Columns failed under seismic bending and then gravity axial load

Dujiangyan MMI=VII-IX

Foundation failure



Settlement of columns

Typical column foundations

Dujiangyan MMI=VII-IX

12 to 16 storey high-rise buildings with repairable damage


Photo taken by Ming Hei Cheng


Photo taken by Ray KL Su

Photo taken by Ray KL Su

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Dujiangyan MMI=VII-IX

Beams failed in shear rather than bending, no formation of plastic hinge


Photo taken by Ari Wibowo

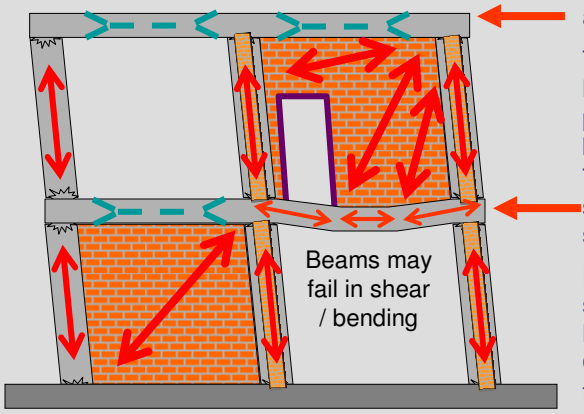

Photo taken by Ming Hei Cheng


Photo taken by Ari Wibowo


Photo taken by Ari Wibowo

Dujiangyan MMI=VII-IX

Functions of infill brick walls



They increase both the strength and stiffness of the building.

They can share the gravity loads with the columns, in particular those have failed in bending.

They can resist the horizontal shear force and prevent soft storey collapse of the building.

However, the RC beams supporting the infill walls should have sufficient strength. Otherwise, shear / bending failures of beams would happen.

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Dujiangyan MMI=VII-IX

Column failed in shear

Dujiangyan MMI=VII-IX

Column failed in bending and axial load

Photo taken by Ari Wibowo

Photo taken by Ray KL Su

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Dujiangyan MMI=VII-IX

Column failed in buckling

Photo taken by Ari Wibowo

Photo taken by Ray KL Su

Dujiangyan MMI=VII-IX

Column failure poor design or workmanship

Insufficient links

Poor compaction, too many coarse aggregates

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Dujiangyan MMI=VII-IX

Column failure poor design or workmanship

lack of bar anchorage

Dujiangyan MMI=VII-IX

Preferred failure mode – Beams failed but not columns

Photo taken by Ari Wibowo

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Dujiangyan MMI=VII-IX

Glass is less fragile as expected

Photo taken by Ari Wibowo

Concluding remarks

- All medium-rise buildings (>10 storeys) passed the earthquake attack.
- Low-rise brick buildings with precast slab failed badly under seismic load.
- A proper tie system (with internal and peripheral ties) and appropriate joint details should be provided for precast structures to improve their overall structural integrity.
- Lateral strength of RC frame are improved remarkably by infill brick walls.
- Many buildings with high strength and stiffness (e.g. with abundant brick walls) could perform satisfactorily under strong earthquake loads.
- The RC beams supporting the infill walls usually failed in shear rather than bending.
- After a lot of damage to columns, significant amount of gravity load was transferred from columns to infill brick walls. (without infill wall, building would experience very large settlement)
- With the infill walls above the RC beams, the RC columns supporting the beams often failed first. (Strong columns weak beams difficult to implement)
- Unreinforced brick structures could partially collapse when the inter-storey drift ratio is higher than 4%.
- In view of the construction practice and the building technology in China, the simple yet effective construction method should be developed for seismic resistance of brick buildings.

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Thank you for your kind attention!