EVALUATION AND PERFORMANCE OF TAIWAN HOUSING AND SCHOOLS IN THE KAOHSIUNG/MEINONG EARTHQUAKE

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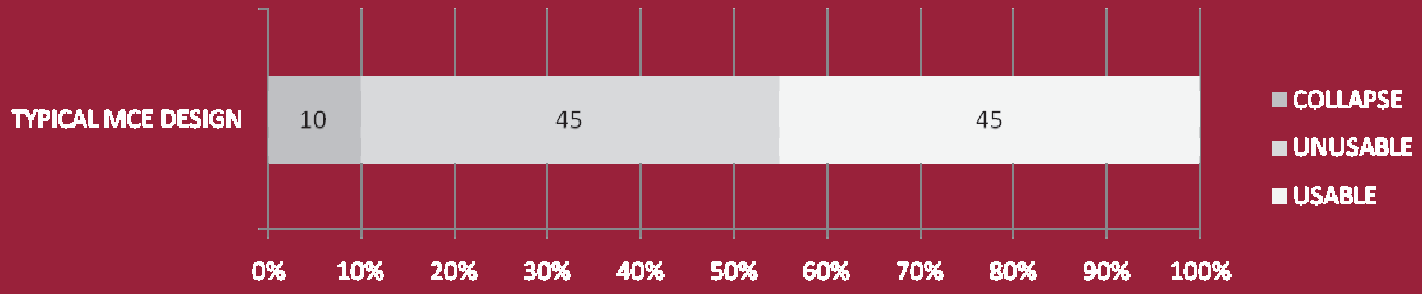
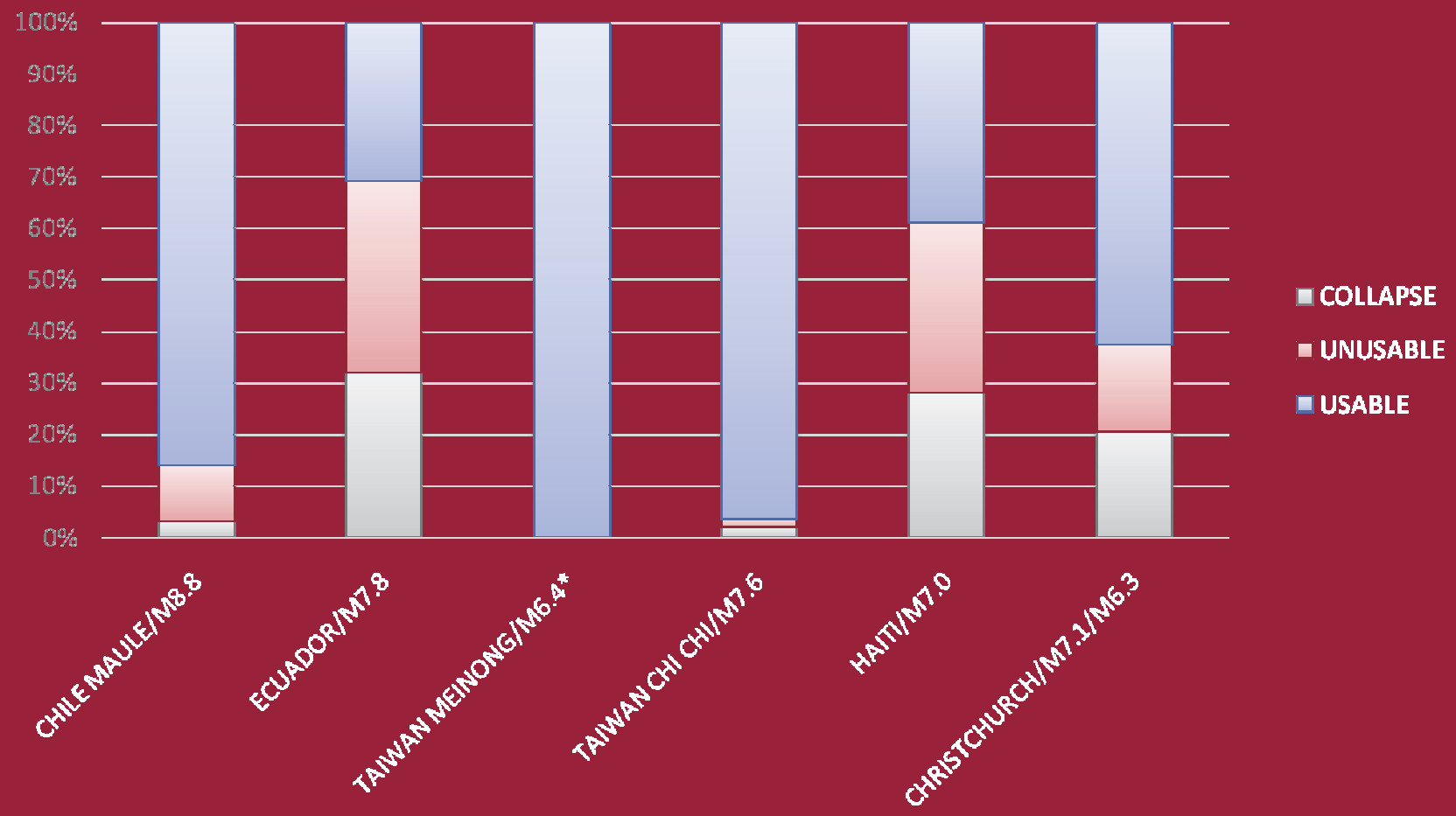
INTRODUCTION

- Resiliency: the ability of a community to recover following a natural disaster
- Resiliency is tied to the extent of losses a community suffers



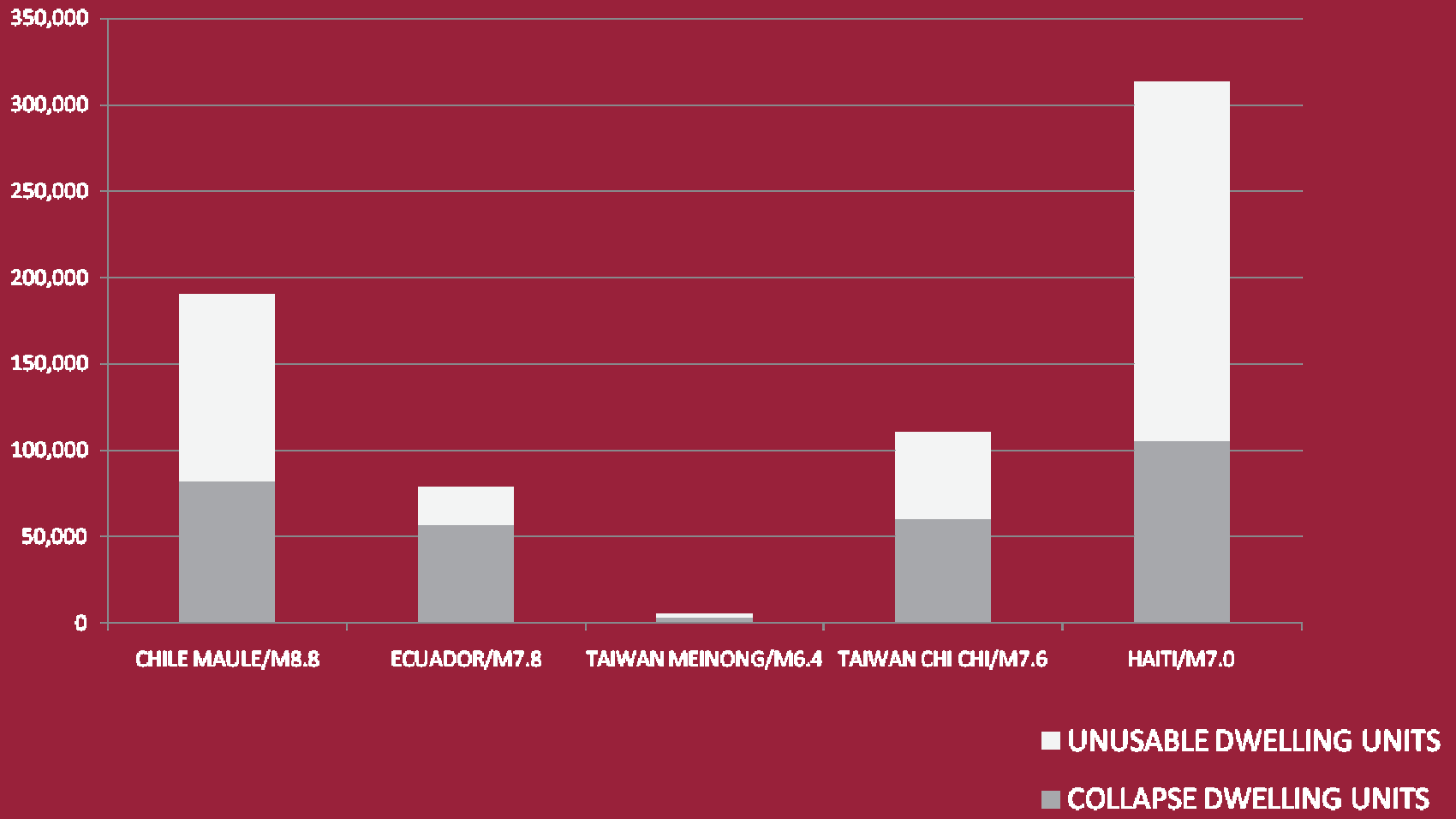
Design code's assigned probability of collapse, major damage rendering a building unusable, and minor damage permitting building usage (ASCE 7-10, ATC 63)

INTRODUCTION



Performance of buildings observed in recent earthquakes

INTRODUCTION



Number of collapsed housing units and unusable housing units

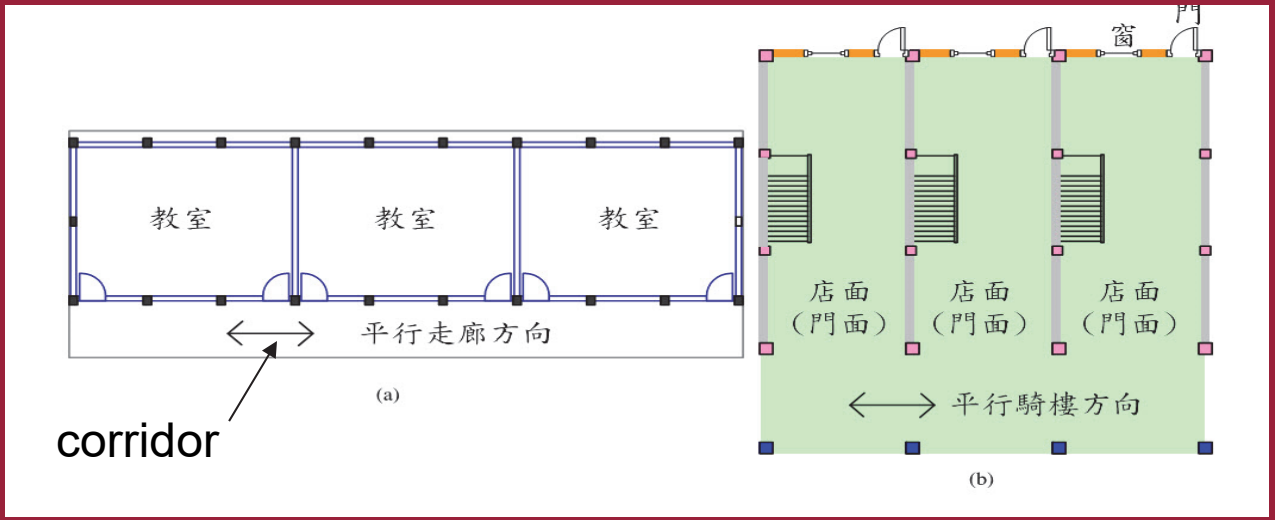
TAIWANESE CONSTRUCTION

5 major types of the buildings in Taiwan:

1. Concrete framed buildings
2. High rise steel office buildings
3. Street houses
4. Individual single-family homes
5. School buildings

TAIWANESE CONSTRUCTION

- Typical street house
  - A row of houses under 5 stories
  - Typically 1st floor commercial and 2nd up residential
  - Lack of lateral stability in the direction parallel to street
- Typical school building
  - Similar to street house: lack of walls in corridor



Typical Floor Plans: *(a) School Building* *(b) Street House*

- **National Center for Research on Earthquake Engineering (NCREE)**

- NCREE assessment programs:
  - NCREE School Evaluation and Retrofit Program
  - NCREE Street House Evaluation Program

NCREE School Evaluation and Retrofit Program

- Following the 1999 Chi-Chi Earthquake an evaluation and retrofit program for school buildings was started.
- Observation of failure of significant number of street houses and schools
- The current evaluation and retrofit procedure:
  1. screening evaluation
  2. detailed evaluation
  3. retrofit design

Screening evaluation:

"capacity to demand" comparison based on the ratio of ground floor column and wall area to building total floor area.

$$I_s = \frac{Capacity}{Demand} = \frac{\sum \tau_c A_c + \sum \tau_w A_w}{a_g \times W \times \sum A_f}$$

τ_w column strength adjustment factor
τ_c wall strength adjustment factor
A_c ground floor column area
A_w ground floor wall area
a_g design ground acceleration
W seismic weight
A_f total building floor area

If Capacity/Demand ratio (Is) exceeds 0.8, the school building would be selected for a more detailed analysis.

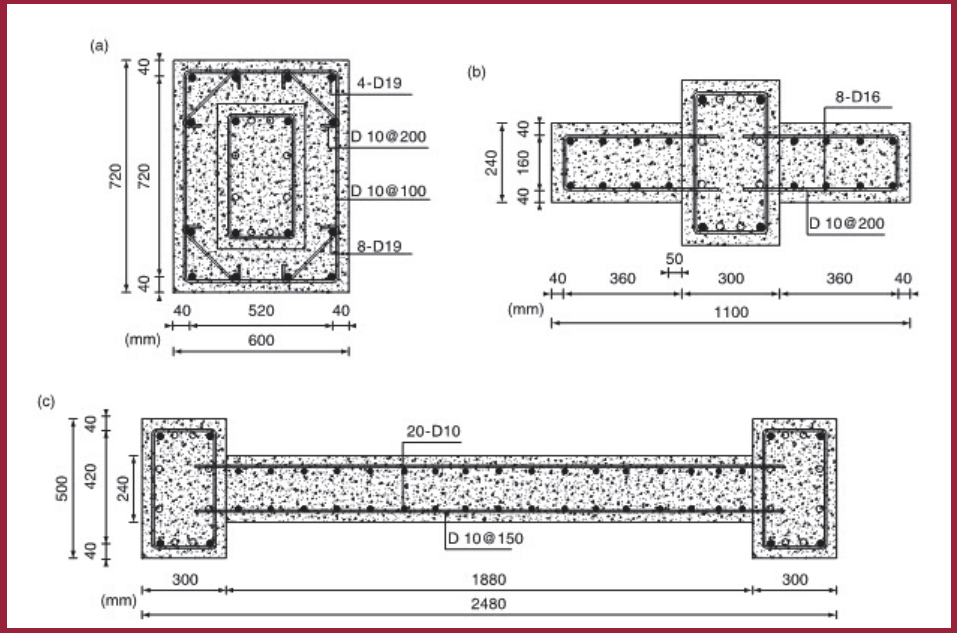
- Detailed analysis procedure (non-linear static pushover analysis) : Taiwan Earthquake Assessment for Structures by Pushover Analysis (TEASPA)

- TEASPA computes the building capacity in terms of peak ground acceleration (Ap) for comparison to the code derived peak ground acceleration

- The TEASPA method is tuned to the specific building stock of low rise, lightly reinforced (< 2% A_g) concrete moment frames typical of the school buildings

NCREE School Evaluation and Retrofit Program

- Analyzed school buildings with insufficient strength are tagged for retrofit.
- Reinforcement methods are suggested for school buildings to meet the required demand under the peak ground acceleration.



Typical Reinforcing Cross Sections: (a) Existing Column Jacketing; (b) Shear Panels Adjacent to Existing Columns; Shear Wall Between Existing Columns (Hsiao et al. 2014)

NCREE School Evaluation and Retrofit Program

Performance of school buildings in Taiwan after the Meinong earthquake (Feb 6, 2016)

→ Program successful

- In the Tainan area (near the event epicenter), none of the 58 retrofitted schools were observed to have structural damage.
- 18 of the 85 (21%) school buildings marked for retrofitting were observed to have severe damage.
- Among the school buildings that passed the screening evaluation, only 1 of the 158 (0.6%) buildings was found to suffer severe damage

NCREE School Evaluation and Retrofit Program

Performance of school buildings in Taiwan after the Meinong earthquake (Feb 6, 2016):

Guiren Middle School Retrofitted with Added Moment Frame (Minor Damage)

Guiren Middle School Retrofitted with Jacketed Column (No Damage)

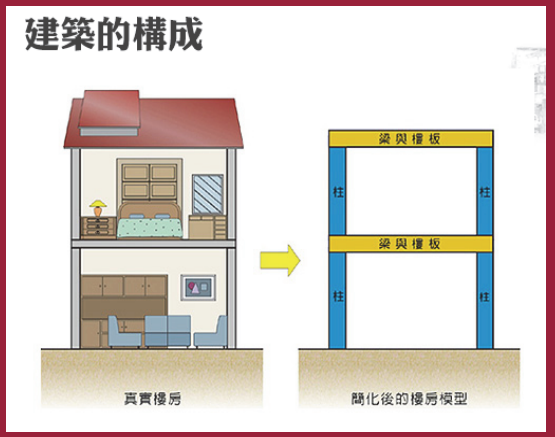
Yujing Junior High School Not Retrofitted (Severely Damage)

NCREE Street House Evaluation Program

- Based on the database of the detailed seismic evaluations of 1,187 school buildings, by using regression analysis
- Validated with an evaluation of 59 street houses damaged in previous earthquakes, including the Chi-Chi earthquake (1999), Jiaxian earthquake (2010), Nantou earthquake (2013) etc
- The program was beta tested using 145 sample street houses throughout the island of Taiwan
  - Using preliminary assessment, 40% need detailed analysis

Simplified preliminary assessment for public

- website program: provides a preliminary analysis to determine if the building has sufficient seismic load capacity.

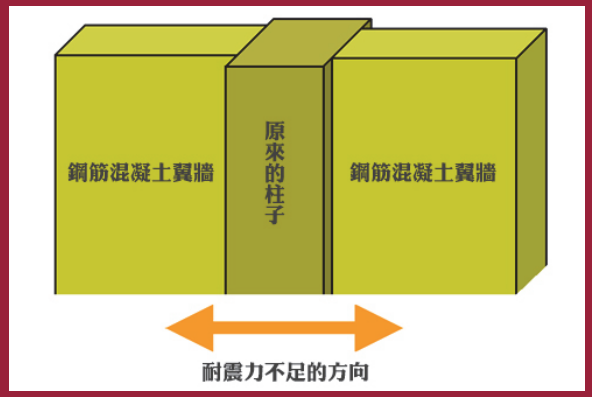


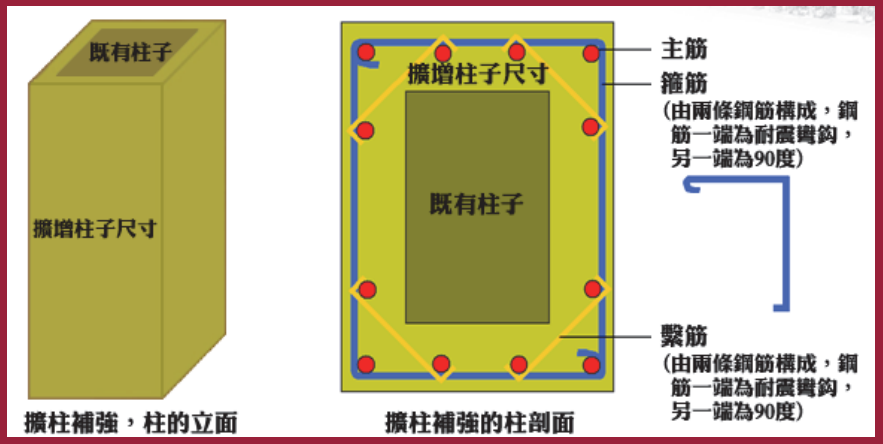
Input information:

- Number of stories
- approximate year built
- building depth and width
- column sizes
- column quantities
- wall length, etc.

Simplified preliminary assessment for public

- The NCREE street house website also introduces a few preliminary reinforcing retrofit suggestions





Case Studies

- Two case study “street house” buildings with observed failures during the Meinong earthquake.

- Analysis data:
  - measured field dimensions
  - typical building material parameters from the school detailed evaluation data base as a supplemental

- Preliminary analysis in accordance with the NCREE “street house” evaluation program

CASE STUDIES

Case Study I: Yujing district “street house”

- 2 Story, multi-family street house in Yujing District with 6 bays parallel to the street.

CASE STUDIES

Case Study II, Guiren Tainan "street house"

- 5 story, multi-family street house in Tainan's Guiren District with 12 bays parallel to the street and 5 transferred columns at the first floor level.

CASE STUDIES

Typical Properties and Case Study Parameters and Results

(1) Column sizes, (2) Column reinforcement ratio, (3) Concrete compression strength (f^1_c), (4) Column tie spacing, (5) Wall thickness, (6) Concrete wall shear strength, (7) Solid brick wall shear strength								
	1	2	3	4	5	6	7	Computed
Typical Parameters School House	8”x16” 20cm x 40cm	1.7-2%	2500 psi 175kgf/cm^2	10”-12” 25-30cm	8” 20cm	4 sides restrained: 300psi (21kgf/cm^2) 3 sides restrained: 170psi (12kgf/cm^2)	4 sides restrained: 55psi (3.9kgf/cm^2) 3 sides restrained: 38psi (2.7kgf/cm^2)	
Typical Parameters Street House	8”x16” 20cm x 40cm	1.94-2.16%	2150psi 150kgf/cm^2	10”-12” 25-30cm	8” 20cm	4 sides restrained: 300psi (21kgf/cm^2) 3 sides restrained: 170psi (12kgf/cm^2)	4 sides restrained: 55psi (3.9kgf/cm^2) 3 sides restrained: 38psi (2.7kgf/cm^2)	
Case Study 1 (Interior shear wall failure observed)	35cm x 35cm and 20cm x 35 cm	ASSUME TYPICAL	ASSUME TYPICAL	20 cm	20 cm	ASSUME TYPICAL	ASSUME TYPICAL	CFR=.00577 Ap= 0.242 At=0.28 E= 0.867 Is=0.82<1
Case Study 2 (Exterior column failure observed)	19” x 20” 48cm x 51cm 12”x12” stirrups 30x30cm	2.2%	ASSUME TYPICAL	#3@9”o.c. (23cm)	10” (25cm)	ASSUME TYPICAL	ASSUME TYPICAL	CFP=0.0016 Ap=0 E=0 Is=0

FUTURE WORK:

This work is being followed up with analysis of the 3D finite element models of the two case study structures, utilizing ground motion data recorded at stations in proximity to the two sites.

CONCLUSIONS

-RESILIENCY NOT ONLY NEEDS TO ADDRESS NEW DESIGN, BUT MUST BRING OLDER BUILDING STOCK UP TO AT LEAST MODERN PERFORMANCE EQUIVALENT

-DEVELOPMENT OF SIMPLE SCREENING TOOLS HELPS EVALUATION OF SIGNIFICANT NUMBER OF BUILDINGS QUICKLY

-SIMPLE METHODS MORE EASILY COMMUNICATE PERFORMANCE TO PUBLIC

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