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SEISMIC CAPACITY ASSESSMENT FOR STREET-FRONT REINFORCED-BRICK BUILDINGS IN TAIWAN

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SUMMARY

In this paper, the structural system of existing reinforced brick street buildings in Taiwan was investigated and classified into 72 types. The seismic assessment method proposed by Sheu et al[1] was employed to check the collapse PGA for each type of existing street buildings. But 49 types of them could not satisfy 0.33g that is required by Taiwan Building Code. The actual strengthening countermeasures adopted by the owners at disaster area of the Chi-Chi Earthquake were also investigated. However, they did not show much help. An economical and feasible strengthening scheme is proposed in this paper for the existing street buildings if their collapse peak ground accelerations are less than 0.30g.

Key Words: existing street building. Reinforced brick building, seismic resistance, shear building, collapse PGA, strengthening

INTRODUCTION

Reinforced brick buildings in Taiwan were constructed unique and different than any other region. This paper was to investigate the structure type of street-front reinforced brick buildings including of the thickness of the brick-walls, the ratio of height over width, the height of the story, the numbers of the span and the corresponding span-length in major and minor directions and so on. Then, the static pushover theoretical method [1] was employed in this study. It could be used to diagnosis the seismic capacity for reinforced brick buildings including the outputs of PGA in different loading stage, the corresponding base shears, component stresses and floor deflections. Finally, the suggestion for well and poor layout of reinforced brick buildings will be proposed.

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This theoretical method was assumed the shear buildings mode that was weak-column and strong-beam mode. It was applicable to the low-rise reinforced brick buildings with periods under 0.7 second, especially suitable for standard school buildings, street-front buildings in Taiwan. The lateral load applies at each floor and distributes in anti-triangle form regulated by the seismic design code of Taiwan. The lateral load increases proportionally until any floor collapses. Lateral load is superposed with respect to displacement. During the process of load increment the stiffness of each single vertical componet was changed gradually.

THE TYPE OF THE STREET-FRONT REINFORCED-BRICK BUILDINGS

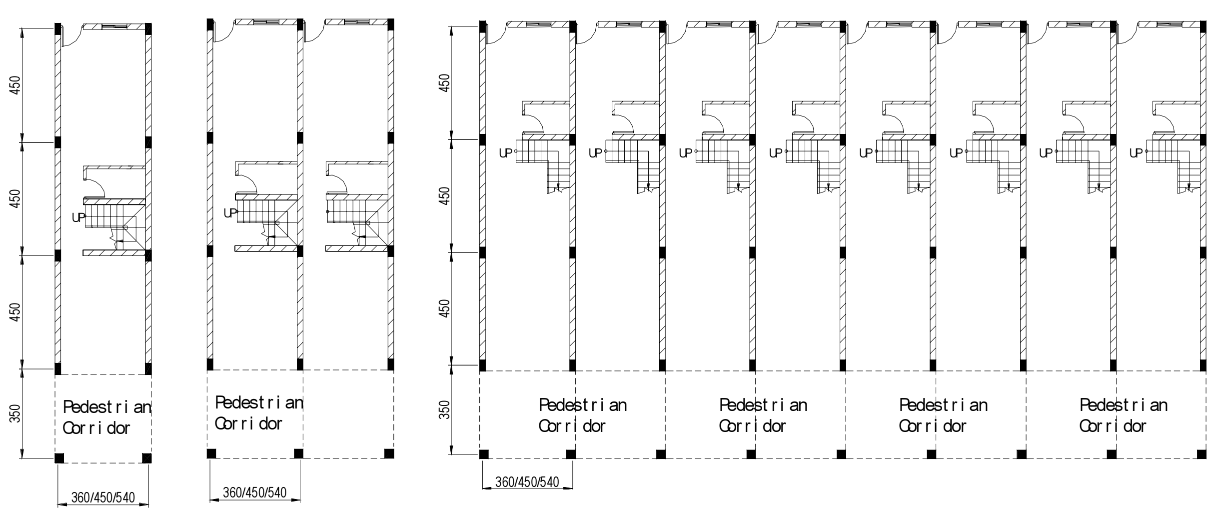
Almost all the existing street buildings in Taiwan are mixed use. That is commercial on ground story and residential for above stories. In general it is 2 to 3 story high in rural area and 3 to 4 story high in metropolitan area. The span of each unit along direction of pedestrian corridor is 3.6 to 5.4 meters, the number of the span that the perpendicular direction to the direction of the pedestrian corridor is 3 to 4. Most of the structural system for the existing street buildings in Taiwan is so called reinforced-brick structure. That means the brick walls with 23cm thickness are constructed first and then concrete of RC columns are poured. Finally the RC slab and RC beams are constructed. Once the concrete in RC beam and column shrinks, the brick wall would be confined very well.

After field investigation in the disaster area of the Chi-Chi Earthquake, 1999 and in the city of Tainan, city of Kaoshiung, city of Chia-I, the structural system of the existing reinforced brick street buildings may be classified into 72 different types. The parameters for classification are: number of story, number of unit connected together to be one building, number of brick wall in corridor direction in each unit and span of each unit in corridor direction. The parameters for different type of street building are listed in Table 1.

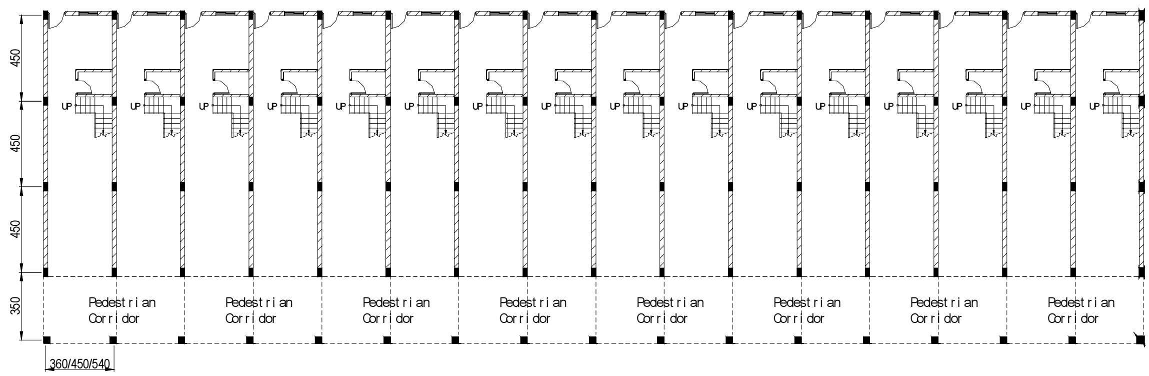
Some typical plans of ground story are shown in Fig.1. The number of story might be 2 or 3; the number of brick shear wall parallel to corridor direction might be 0 or 1 or 2 in one unit; the span of each unit in corridor direction might be 3.6m or 4.5m or 5.4m.

Table 1 Parameter for Different Type of Street Building

Nb. of Story	Span of each Unit (meters)	Nb. of Unit Connected Together	Nb. of Brick Wall in Corridor Direction
2, 3	3.6, 4.5, 5.4	1, 2, 8, 16	0, 1, 2



(a) one unit (b) 2 units (c) 8 units



(d) 16 units

Fig.1 Some Typical Plans of Ground Story of Existing Street Building in Taiwan

From the report of BRI, Taiwan [2], 45% of the total numbers of seriously damaged buildings were street building. The structural system of damaged street building is shown as Fig.1. After Chi-Chi Earthquake, 1999, the design PGA increased by Taiwan Building Code. So retrofit for street building is necessary. However, the owners in disaster area retrofitted their own buildings by steel jacketing or RC jacketing for the exterior corridor columns. The assessment shows such retrofit does not help much to increase the earthquake resistance because the owners of these buildings retrofitted one column for one unit. It is not enough.

An economical and feasible strengthening scheme is proposed in this paper for different type of existing street building with parameters listed in Table 1. The assessment method for collapse PGA of the building is employed from Sheu et al [1].

THEORECTICAL METHOD-- THE PUSH OVER THEORETICAL METHOD

The push over method [3,4] was used to calculate the seismic capacity of the street-front reinforced-brick buildings in Taiwan. The method adopted the deterministic and static pushover method to calculate the collapse peak ground acceleration of buildings by assuming the shear building mode that is weak-column and strong-beam mode. It is applicable to the low-rise RC or reinforced-brick buildings with periods under 0.7second, especially suitable for street-front buildings in Taiwan. The lateral load applies at each floor and distributes in anti-triangle from regulated by the seismic design Code of Taiwan. The lateral load increased proportionally until any floor collapse. During the process of load increment, the stiffness of each individual vertical component is changed gradually. The story shear-displacement curve could be calculated by summing the lateral force-deflection curve of each individual vertical component. And by using equations suggested by ATC-40, the corresponding capacity spectrum, period , damping ratio and PGA could also be obtained. This method could provide not only the collapse of PGA of a building but also the damage condition of each individual vertical component at any specific ground acceleration.

ASSESSMENT OF COLLAPSE PGA FOR EXISTING STREET BUILDINGS IN TAIWAN

From field observation of the damaged low-rise reinforced brick street buildings and from shaking table test of small scale RC building structures [3], it is believed that shear-building model for RC column and semi shear-building model for brick wall and RC wall are reasonable for seismic assessment of low-rise buildings. The details of the assessment method were presented at Manila Workshop [4] and Tokyo Workshop [1]. The same assessment method is used again in this paper to calculate the collapse PGA for each type of the street buildings listed in Table 1. The assessed results are listed in Table 2 without parentheses. Fig.2 shows some examples of the evaluated seismic performance curves. Fig

Table 2 Collapse PGAs for Different Type of Street Building (g)

shear wall \ unit connected \ span (meters) \ nb. of story		2-Story High			3-Story High		
		3.6	4.5	5.4	3.6	4.5	5.4
0 Brick Wall in X-Direc.	1 Unit	0.19(**0.42**)	0.18(**0.46**)	0.17(**0.51**)	0.15(**0.33**)	0.14(**0.36**)	0.14(**0.40**)
	2 Units	0.19(**0.47**)	0.18(**0.51**)	0.17(**0.57**)	0.15(**0.37**)	0.14(**0.40**)	0.13(**0.45**)
	8 Units	0.19(**0.52**)	0.17(**0.57**)	0.16(**0.64**)	0.15(**0.41**)	0.14(**0.45**)	0.13(**0.52**)
	16 Units	0.19(**0.53**)	0.17(**0.58**)	0.16(**0.65**)	0.15(**0.41**)	0.14(**0.45**)	0.13(**0.43**)
1 Brick Wall in X-Direc.	1 Unit	0.29(**0.49**)	0.29(**0.55**)	0.29(**0.61**)	0.22(**0.38**)	0.22(**0.42**)	0.22(**0.48**)
	2 Units	0.30	0.31	0.31	0.23(**0.43**)	0.24(**0.48**)	0.24(**0.55**)
	8 Units	0.32	0.33	0.34	0.25(**0.49**)	0.26(**0.55**)	0.26(**0.44**)
	16 Units	0.33	0.34	0.34	0.26(**0.50**)	0.26(**0.56**)	0.27(**0.40**)
2 Brick Walls in X-Direc.	1 Unit	0.36	0.36	0.38	0.28(**>0.33**)	0.29(**>0.33**)	0.30
	2 Units	0.41	0.41	0.43	0.31	0.33	0.34
	8 Units	0.46	0.47	0.50	0.36	0.37	0.38
	16 Units	0.47	0.49	0.50	0.37	0.38	0.39

From the collapse PGA listed in Table 2, without parenthesis, is it seen that 47 out of 72 types of street building (65.3%) do not satisfy the 0.33g required by current Taiwan Building Code. Retrofit is strongly recommended for those street buildings with collapse PGA less than 0.30g.

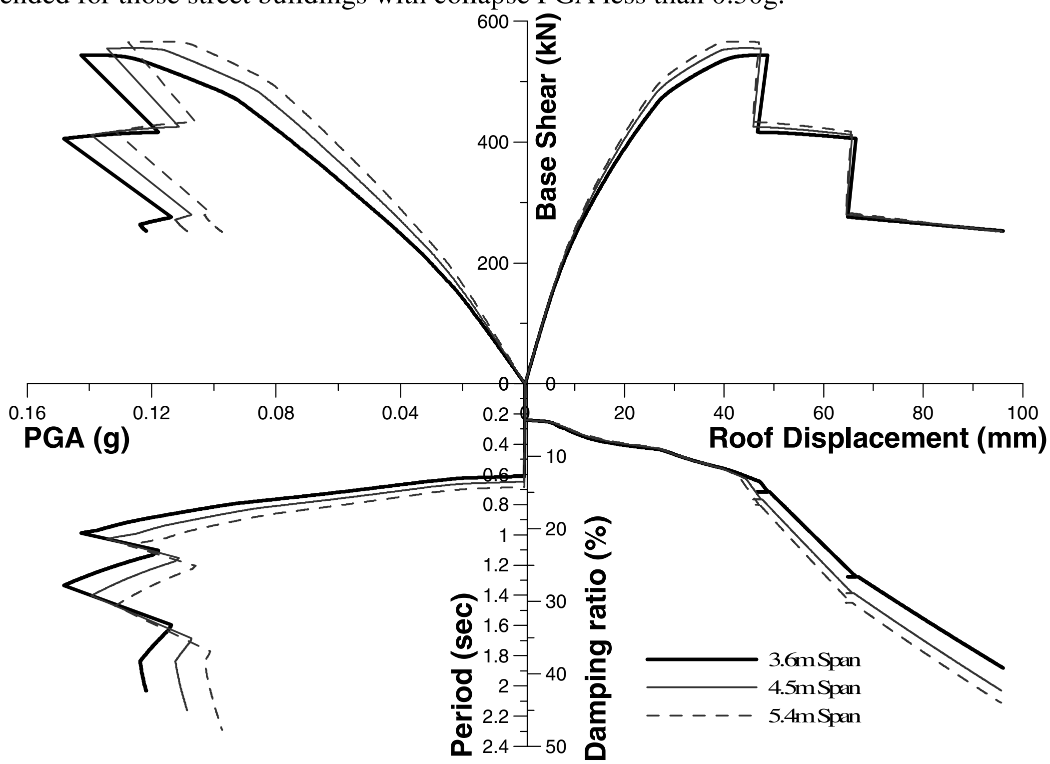


Fig.2a Seismic Performance Curve For 3-Story, 2-Unit Connected, Zero Brick Wall Street Buildings Before Retrofit Before Retrofit

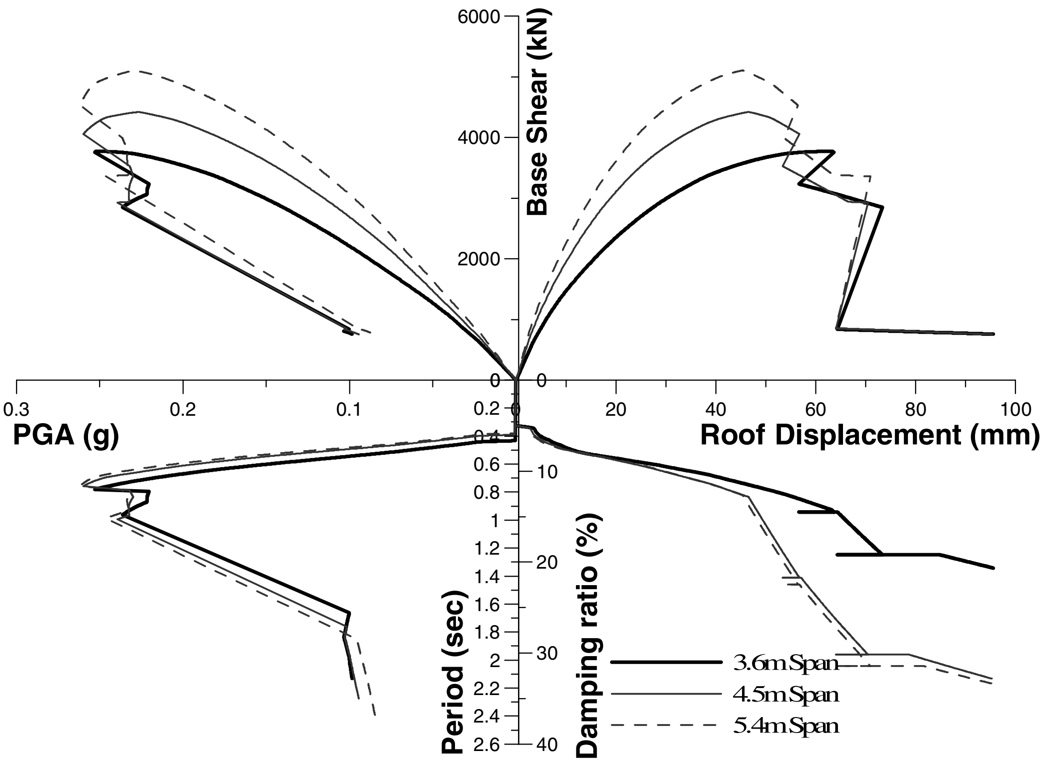


Fig.2b Seismic Performance Curve For 3-Story, 8-Unit Connected, One Brick Wall Street Buildings Before Retrofit

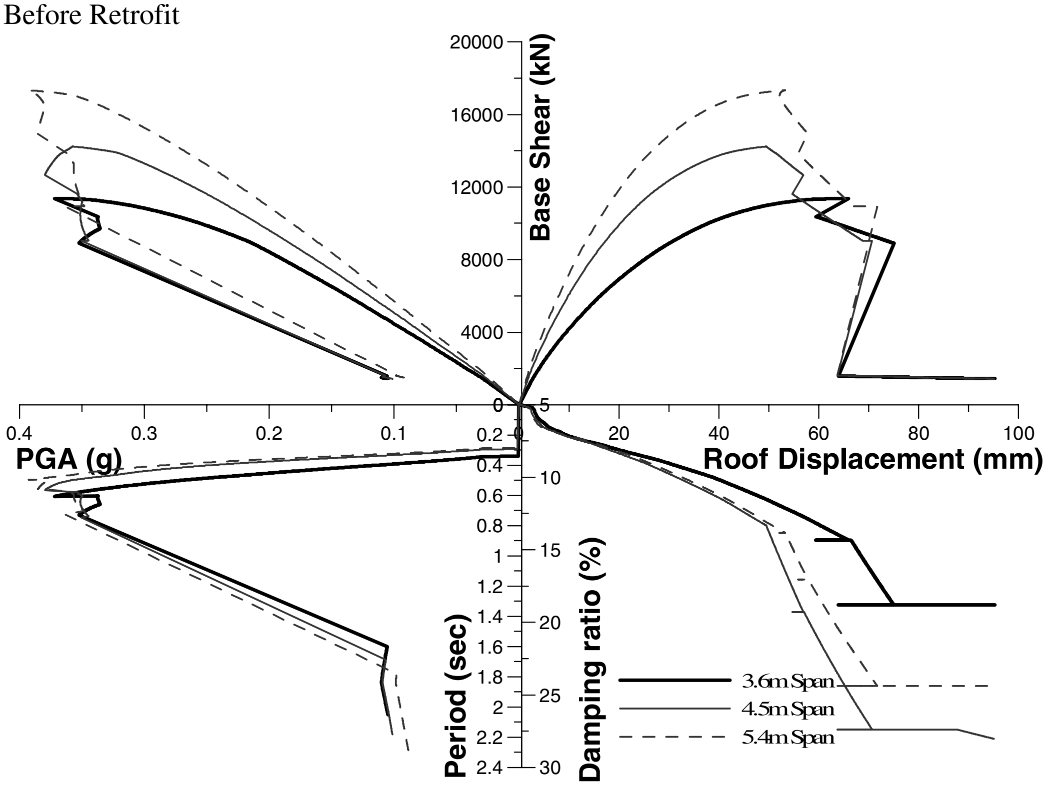
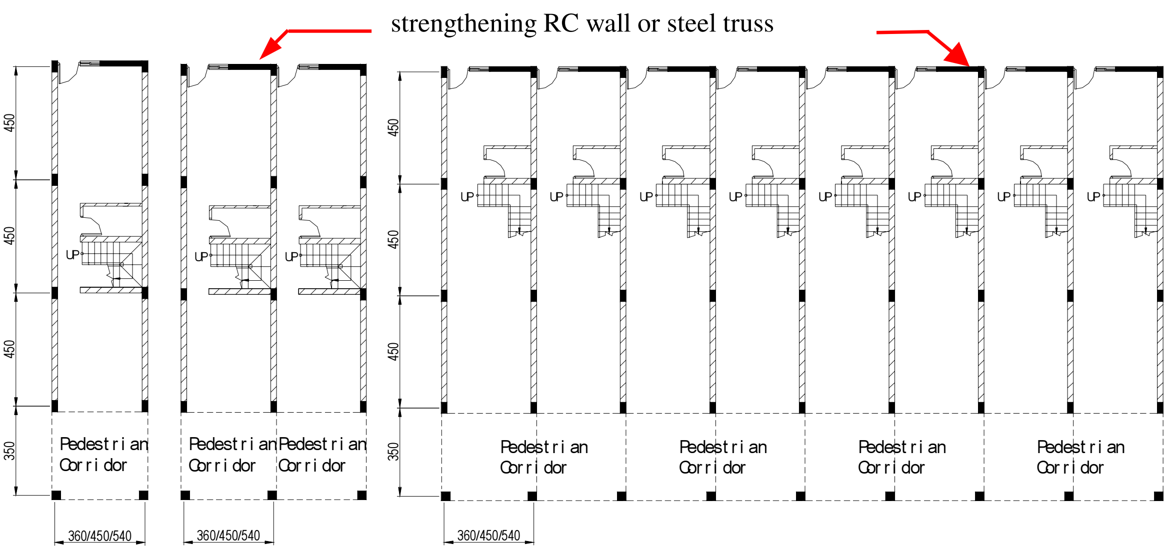


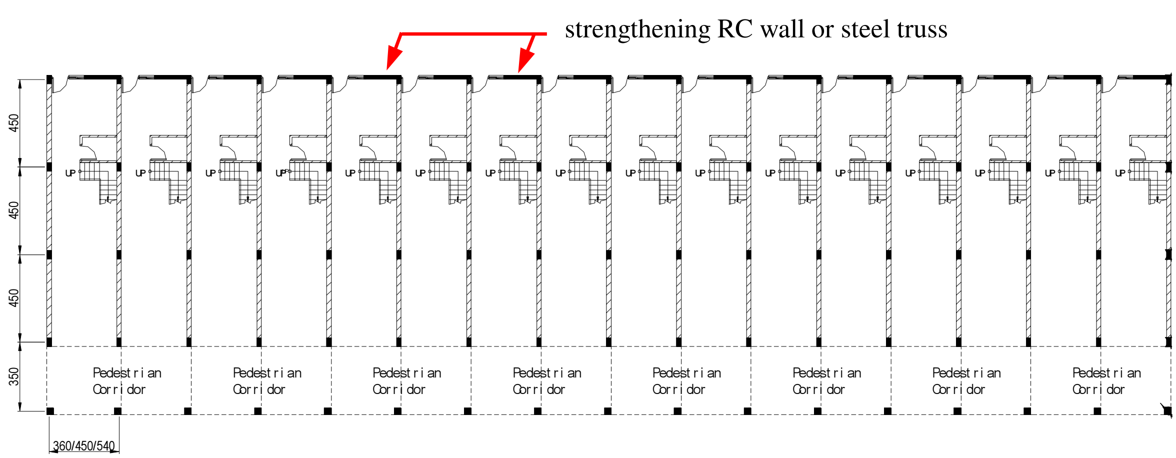
Fig.2c Seismic Performance Curve For 3-Story, 16-Unit Connected, Two Brick Walls Street Buildings Before Retrofit

RECOMMENDED STRENGTHING SCHEME FOR STREET BUILDINGS IN TAIWAN

After the Ch-Chi Earthquake, 1999, if the street buildings in disaster area did not collapse, the owners would prefer to do steel jacketing or RC jacketing for the exterior front columns along pedestrian corridor. Because the number of column retrofitted was limited, so the jacketing did not help much to increase the earthquake resistance. However, if at rear exterior wall in the X-direction (along direction of corridor), one RC shear wall with 25cm thickness and #4 rebars with 12cm spacings in two directions on both faces and 20MPa concrete is casted, the collapse PGA in X-direction (along direction of corridor) would increase very much to satisfy the minimum design PGA, 0.33g, required by the current Taiwan Building Code. The width of RC shear wall for each unit is taken as half span of the unit in corridor direction. The location of strengthening RC shear wall or steel truss is shown in Fig.3. Using the same assessment method, the collapse PGA for each type of street building after strengthening with RC shear wall, is listed in the parentheses of Table 2. The performance curves of Fig.2 change to the curves shown in Fig.4 after retrofit. It is seen that every collapse PGA is larger than 0.33g, which is the Code requirement. Fig.5 shows the comparison of the collapse PGA before and after retrofitted.



(a) one unit (b) 2 units (c) 8 units



(d) 16 units

Fig.3 Location of Strengthening RC Wall or Steel Truss

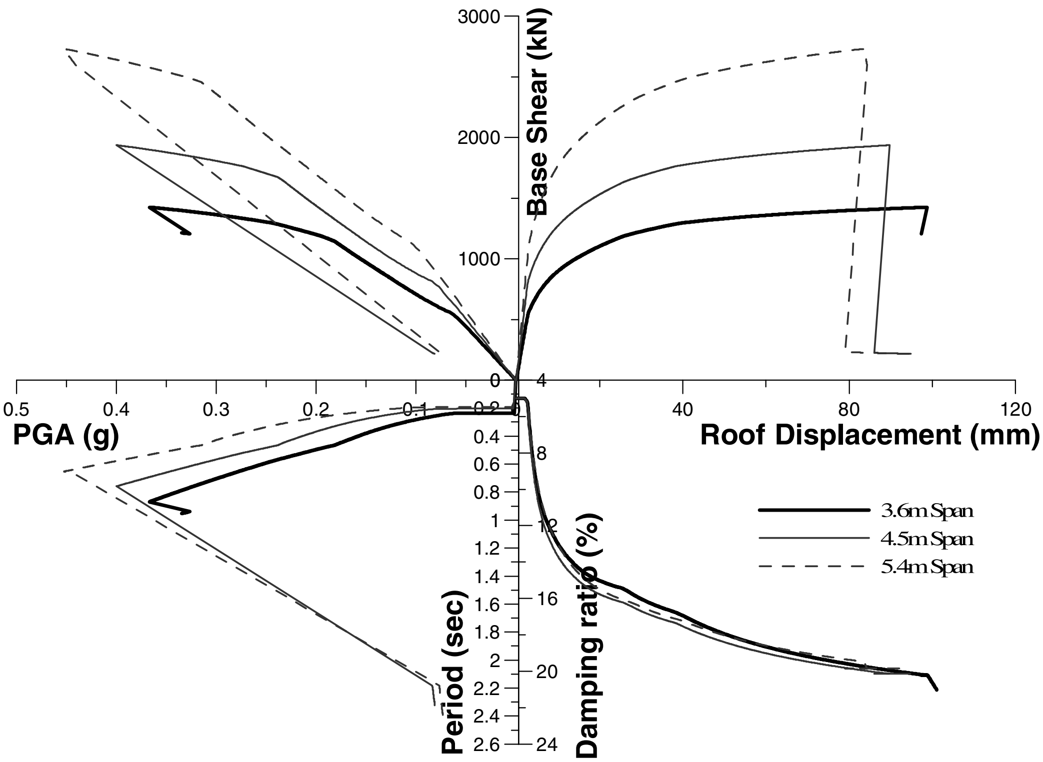


Fig.4a Seismic Performance Curve For 3-Story, 2-Unit connected, Zero Brick Wall Buildings After Retrofit

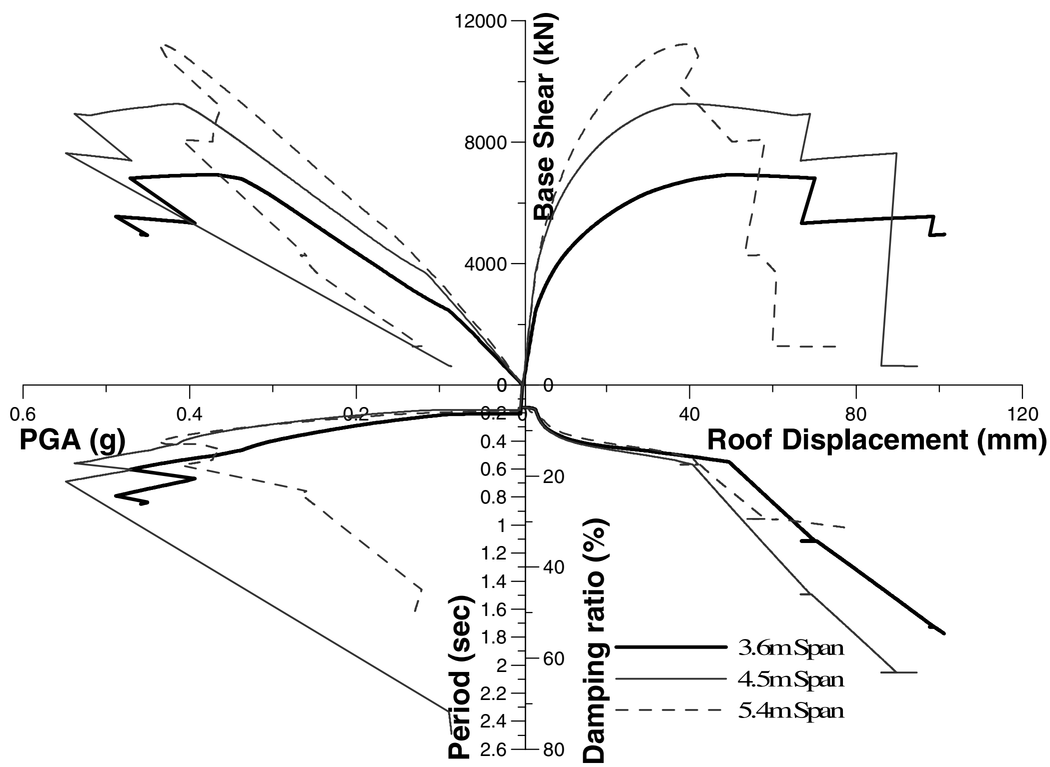


Fig.4b Seismic Performance Curve For 3-Story, 8-Unit connected, One Brick Wall Buildings After Retrofit

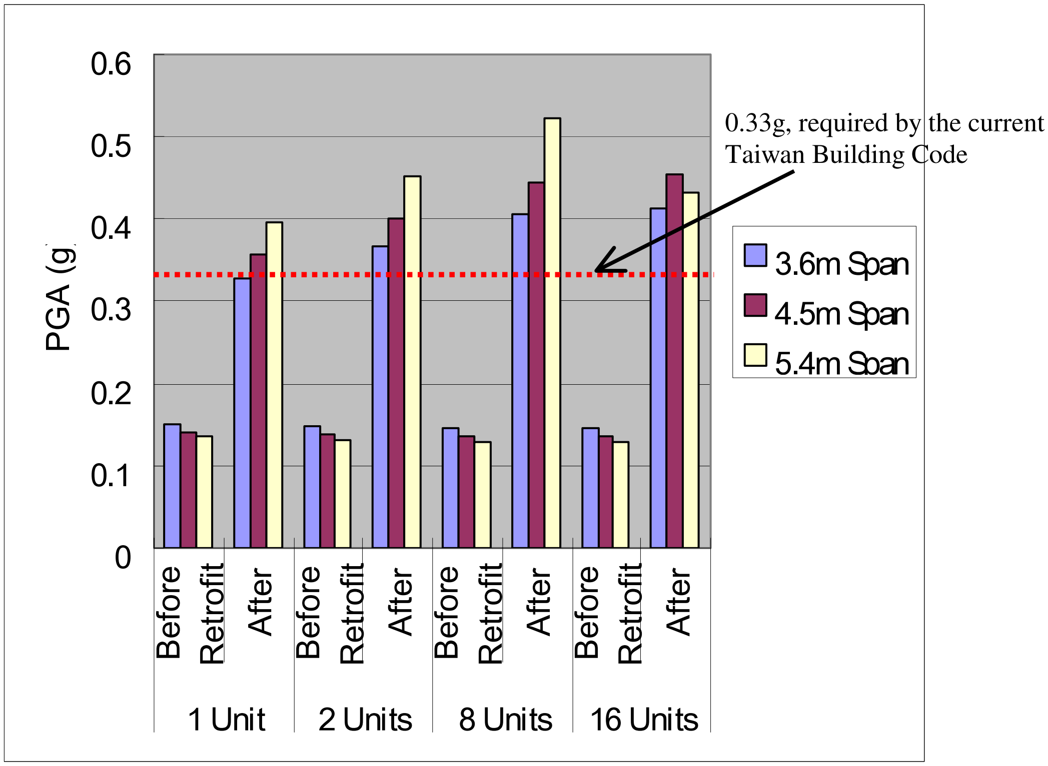


Fig.5a The Collapse PGA For 3-Story, Zero Brick Wall Buildings Before And After Retrofit

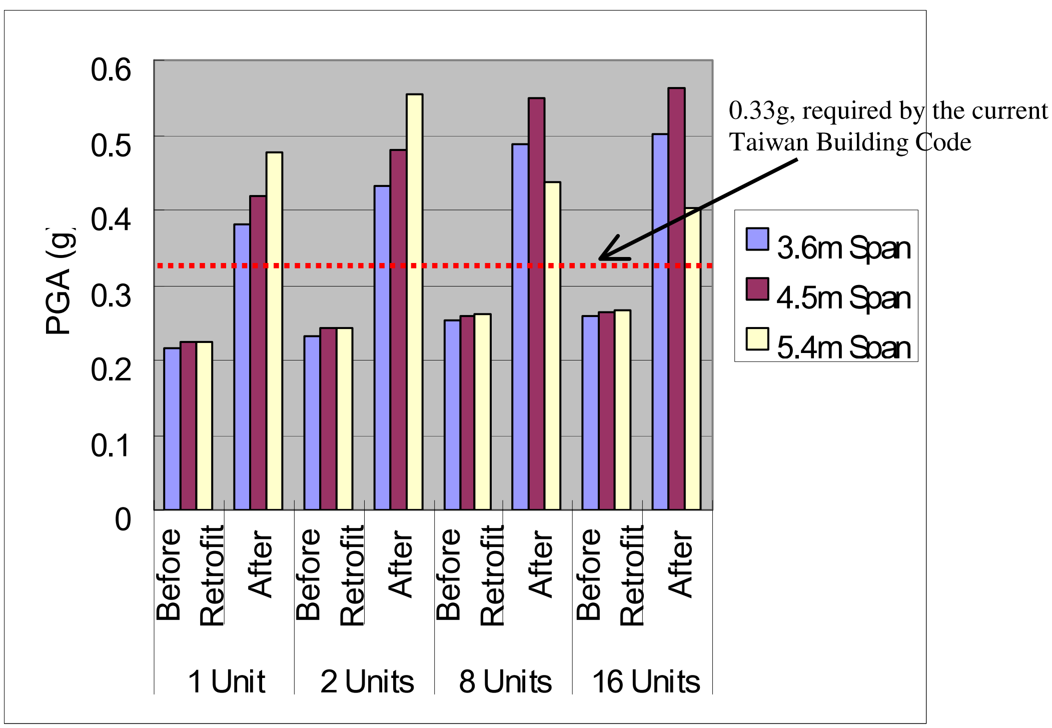


Fig.5b The Collapse PGA For 3-Story, One Brick Wall Buildings Before And After Retrofit

CONCLUSIONS

1). After field investigation, the existing street buildings in Taiwan might be classified into 72 types as shown in Table 1.
2). 65.3% of the existing street buildings in Taiwan need retrofit to upgrade the collapse PGA to be larger than 0.33g.
3). An economical and feasible retrofit scheme for existing street buildings in Taiwan is to add a RC shear wall or a steel brace at rear exterior wall in the direction parallel to the pedestrian corridor for each unit.

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REFERENCES

1.M.S Sheu, Y.H Tu, H.Y. Kuo and Y. P. Liu, 〝Seismic Evaluation and Its Verification of Street Buildings in Taiwan〞, Workshop on Development of Disaster Mitigation Technologies for the EqTAP project, Tokyo Green Palace, Kojimachi, Feb. 20~21, 2003.
2.Bulding Research Institute, GIS Research Center of Fong-Cha University, 〝Statistics and Analysis of Building Damage for the Chi-Chi Earthquake 1999〞, Published by the Building Research Institute, Ministry of Interior, Oct. 2001.
3.Y.H. TU, M.S. Sheu and S.Y. Hsu, 〝Shaking Table Test of One Third Scale RC School Buildings〞, Report of National Center for Research of Earthquake Engineering, Taipei, Taiwan, April, 2002.
4.M.S Sheu and H.Y Kuo, 〝Fast EQK Resistance Assessment for School Buildings in Taiwan〞, WG-I Report, Earthquake-Resisting Technologies for Building Structures, 3rd EqTAP Workshop, Manila, Philippines, Nov. 28~30, 2000.