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EXPERIMENTAL TEST AND ANALYTICAL PREDICTION OF ENVELOPES FOR BRICK WALLS WITH OPENINGS AND BOUNDARY R.C. FRAMES

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ABSTRACT

Most popular buildings in Taiwan, if constructed before 1970, are RC frames infilled with brick shear walls. In order to assess the aseismic capacities for such existing buildings, the fundamental behaviours of brick shear walls confined by RC frames are necessarily to be known. 16 full scale specimens, with different openings, are tested under static horizontal reversed cyclic loadings. Numerical model by using equivalent truss are proposed for brick shear walls. The predicted nonlinear P-Δ curves, for brick walls with openings and boundary RC frames, are compared to the experimental curves with reasonable accuracy.

KEYWORDS

brick shear wall; reversed cyclic load; P-Δ curve; truss model; opening; boundary frame.

INTRODUCTION

The typical size of brick blocks in Taiwan is either 4.4cm×9.8cm×20.5cm or 5cm×11cm×23cm. The layout patterns of brick blocks are pretty the same as those in America or Europe except that there are no reinforcing bars passing through brick layers. Infilled brick walls are used very frequently in Taiwan for low-rise RC buildings, if they are constructed before 1970. So if vulnerability of existing RC buildings is to be assessed, the behaviours of brick shear walls will become very important to provide the necessary informations for assessment. However few tests were investigated for aseismic behaviours for such infilled brick shear walls.

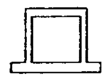
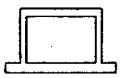
The purpose of this paper is to study the aseismic behaviours of infilled brick shear walls through full scale specimens test. After test, an equivalent truss model are proposed to calculate the ultimate horizontal loads and ultimate horizontal deflections for brick shear walls. P-Δ curves of brick shear walls are proposed and superposed to P-Δ curves of pure RC frames to get total P-Δ curves for RC frame with infilled brick wall.

EXPERIMENTAL STUDY

16 full scale specimens are tested in this paper. Table 1 shows the parameters of specimens. Cross-section of column is 35cm×30cm with 8-D22 rebars. Cross-sections for top beam is 35cm×40cm with 4-D22 on both sides. f_y of rebars is $374MPa$. Thickness of brick wall is 20.5cm.

Horizontal relative deflections are measured between top of brick wall and bottom of brick wall. Static horizontal cyclic loadings are applied to one side of top beam by accurators and loading rods. The ultimate loads of FBW5 and FBW6 are almost 2.5 times those of OF1 and OF3. This shows that brick shear wall is very effective for horizontal load resistance. The details of experimental results are discussed in (Lin, 1995).

Table 1 Specimen Parameters

Specimen No.	Appearance	Total Size(cm)	Wall Size	Opening Size(cm)	Loading Cycles	fc'(MPa)	Ulti Load (kn)
OF1 OF2		320*300	-------	230*240	One Multiple	26.7	220
OF3 OF4		320*400	-------	230*340	One Multiple	29.5	218
FBW1 MFBW1		320*400	2-230*120*20.5	230*100	One Multiple	22.4	459
FBW2 MFBW2		320*400	230*240*20.5	230*100	One Multiple	30.3	361
FBW3 MFBW3		320*400	170*340*20.5	60*340	One Multiple	23.8	394
FBW4 MFBW4		320*300	110*240*20.5	120*240	One Multiple	21.9	277
FBW5 MFBW5		320*300	230*240*20.5	------	One Multiple	27.9	619
FBW6 MFBW6		320*400	230*340*20.5	------	One Multiple	25.5	522

EQUIVALENT TRUSS MODEL

Fig.1 shows the idea of analysis. In which, brick shear wall surrounded by RC frame is considered to link two sub-structures : one is open RC frame, the other is brick shear wall plus interaction. The nonlinear load-deflection curve of open frame is easily obtained if anchorage bond-slip effect at beam-column joints and at bottom of columns is involved in the analysis (Chen, 1979). P-Δ curve of brick wall, which takes care the interaction effect between open frame and brick shear wall, is obtained by substracting analytical P-Δ curve of open RC frame from experimental P-Δ curve of the specimen. Once P-Δ curve of brick shear wall is obtained, the equivalent truss model is possible to derive from that P-Δ curve.

Consider a brick shear wall, $b \times h \times t$, subjects to vertical load Q and horizontal load P as shown in Fig. 2(a) and (b). The vertical deformation due to Q is :

$$\Delta_v = \frac{Qh}{Etb} \tag{1}$$

Let G=0.4E, the horizontal deflection due to P is :

$$\Delta_h = \frac{4Ph^3}{Etb^3}\left(1+\frac{15}{16}\cot^2\theta\right) \tag{2}$$

Now consider an equivalent truss as shown in Fig. 2(c). The cross-sectional area of vertical member is A_c; The cross-sectional area of diagonal brace is A_d; the cross-sectional area of horizontal member approaches infinitive. Let modulus of elasticity of every truss member, E, is the same as that of the plate in Fig. 2(a). The vertical joint displacement of Fig. 2(c) is:

$$\Delta_v = \frac{Qh}{2E}\left(\frac{1}{A_c + A_d \sin^3\theta}\right) \tag{3}$$

The horizontal joint displacement of Fig. 2(d) is :

$$\Delta_h = \frac{Ph}{2E}\left(\frac{\tan^2\theta}{A_c} + \frac{1}{A_d \sin\theta\cos^2\theta}\right) \tag{4}$$

Let Equ.(1) equal to Equ.(3) and Equ.(2) equal to Equ.(4), we get two simultaneous equations. From which we can solve the cross-sectional areas of equivalent truss members:

$$A_c = \frac{bt}{4}\left[1 + \sqrt{\frac{15}{15+16\tan^2\theta}}\right] \tag{5}$$

$$A_d = \frac{bt}{4\sin^3\theta}\left[1 - \sqrt{\frac{15}{15+16\tan^2\theta}}\right] \tag{6}$$

In general, $A_c >> A_d$. If A_c of Fig. 2(c) and (d) is considered to be infinitive. The horizontal deformation of Fig. 2(f) becomes:

$$\Delta_h = \frac{Ph}{2EA_d}\cdot\frac{1}{\sin\theta\cos^2\theta} \tag{7}$$

Let Equ.(7) equal to Equ.(2), we get

$$A_d = \frac{2dt\cot\theta}{15+\sin^2\theta} \tag{8}$$

A_d of Equ.(6) is very close to A_d of Equ.(8) for different θ. The equivalent compressive diagonal brace is picked up to be the target member for judgment of cracking stage or ultimate stage.

From brick piers tested by (Tseng, 1994) and the P-Δ curves of brick wall in Fig. 1 of this paper, the empirical compressive cracking and ultimate strengths of equivalent diagonal brace are :

$$f_c = \alpha_{cr}C_{cr}\left(0.87f_b^{'} + 0.13f_m^{'}\right) \tag{9}$$

$$f_u = \alpha_u C_u\left(0.87f_b^{'} + 0.13f_m^{'}\right) \tag{10}$$

where $f_b^{'}$ and $f_m^{'}$ are compressive strengths of brick block and mortar. Let θ be the diagonal brace angle of Fig. 2, then

$$C_{cr} = 0.268 - 5.45 10^{-4}\theta + \theta(90-\theta)(6.06\times10^{-6} - 3.1\times10^{-6}\theta + 3.3\times10^{-8}\theta^2) \quad (11)$$

$$C_u = 0.431 - 1.66 10^{-3}\theta + \theta(90-\theta)(1.84\times10^{-5} - 4.93\times10^{-6}\theta + 5.02\times10^{-8}\theta^2) \quad (12)$$

For brick shear walls with 3 sides confined by boundary RC frame :

$$\alpha_{cr} = 0.556\tan\theta - 0.0408 \quad (13)$$

$$\alpha_u = 0.596\tan\theta - 0.0999 \quad (14)$$

If 4 sides of wall confined by boundary RC frame :

$$\alpha_{cr} = 1.37\tan\theta - 0.473 \quad (15)$$

$$\alpha_u = 1.93\tan\theta - 0.803 \quad (16)$$

From brick piers tested by (Tseng, 1994) and P-Δ curve of brick walls in Fig. 1, the empirical compressive secant modulus of elasticity at cracking stage and ultimate stage for equivalent diagonal brace are :

$$E_c = \beta_{cr} e_c \sqrt{f_b' f_m'} \quad (17)$$

$$E_u = \beta_u e_u \sqrt{f_b' f_m'} \quad (18)$$

And

$$e_c = 93.78 - 0.408\theta + \theta(90-\theta)(4.53\times10^{-3} - 5.99\times10^{-4}\theta + 5.53\times10^{-6}\theta^2) \quad (19)$$

$$e_u = 74.43 - 0.383\theta + \theta(90-\theta)(4.26\times10^{-3} - 6.24\times10^{-4}\theta + 5.88\times10^{-6}\theta^2) \quad (20)$$

For brick shear walls with 3 sides confined by boundary RC frame :

$$\beta_{cr} = 0.608\tan\theta + 0.062 \quad (21)$$

$$\beta_u = 0.25\tan\theta + 0.184 \quad (22)$$

If 4 sides of brick wall confined by boundary RC frame :

$$\beta_{cr} = 0.16\tan\theta + 0.824 \quad (23)$$

$$\beta_u = 0.138\tan\theta + 0.873 \quad (24)$$

Since the substructure of brick wall plus interaction in Fig. 1 is substituted by the equivalent truss of Fig. 2(d), so the brick shear wall surrounded by RC frame is idealized to link an open RC frame and an equivalent brick truss. Nonlinear P-Δ curve of open RC frame is analyzed by the technique of (Chen, 1979). Nonlinear P-Δ curve of equivalent brick truss is analyzed according to the stress of diagonal compressive brace. That is to say, the stresses of brick columns and tensile brace of Fig. 2(d) are ignored. The modulus of elasticity of every truss member is changing to be the same as that of diagonal compressive brace. And the cracking stage or ultimate stage of the equivalent brick truss is judged according to the stress level of compressive brace.

COMPARISONS BETWEEN EXPERIMENTAL AND ANALYTICAL P-Δ curves

Specimens OF1 to OF4 of this paper are used to make sure P-Δ curve of pure frame is well predicted. For example, the solid curve of Fig. 3 is from test for specimen OF3; the longer broken curve is predicted by using effective moment of inertia of ACI Code; the shorter broken curve is predicted by using effective moment of inertia of ACI Code and considering the anchorage bond slip effect at member ends. This shorter broken curve is used for prediction of the P-Δ curve for pure frames. Fig. 4 is the comparison for confined brick shear wall without opening. Fig. 5 is the comparison for confined brick shear wall with opening. From the comparisons between experimental and analytical P-Δ curves, it is clear that the equivalent truss model for brick walls proposed by this paper predicts very well the envelope for RC frames with infilled brick walls with or without opening.

CONCLUSIONS

1. The ultimate horizontal load of ductile moment resisting frame, if infilled with brick wall without openings, may be increased from 220 Kn to 619 Kn. This shows brick walls are good for resisting earthquake loads for low-rise buildings. It could be used for strengthening element for low-rise RC buildings.
2. The equivalent truss model proposed by this paper, predicts very well the P-Δ curves for RC frame infilled with brick walls with or without opening.

REFERENCES

Chen,Y.K. (1979). Nonlinear Load-Deflection Curves of Open RC Frame by Considering Anchorage Bond-Slip Effect.,Master Thesis, Dept. of Architecture, National Cheng-Kung Univ., Tainan, Taiwan

Lin,C.W. (1995). Experimental Test of Brick Shear Walls Confined by Boundary RC Frame., Master Thesis, Dept. of Architecture, National Cheng-Kung Univ., Tainan, Taiwan

Tseng,K.H. (1994). Experimental Test of Brick Piers and Pure Brick Shear Walls., Master Thesis, Dept. of Architecture, National Cheng-Kung Univ., Tainan, Taiwan

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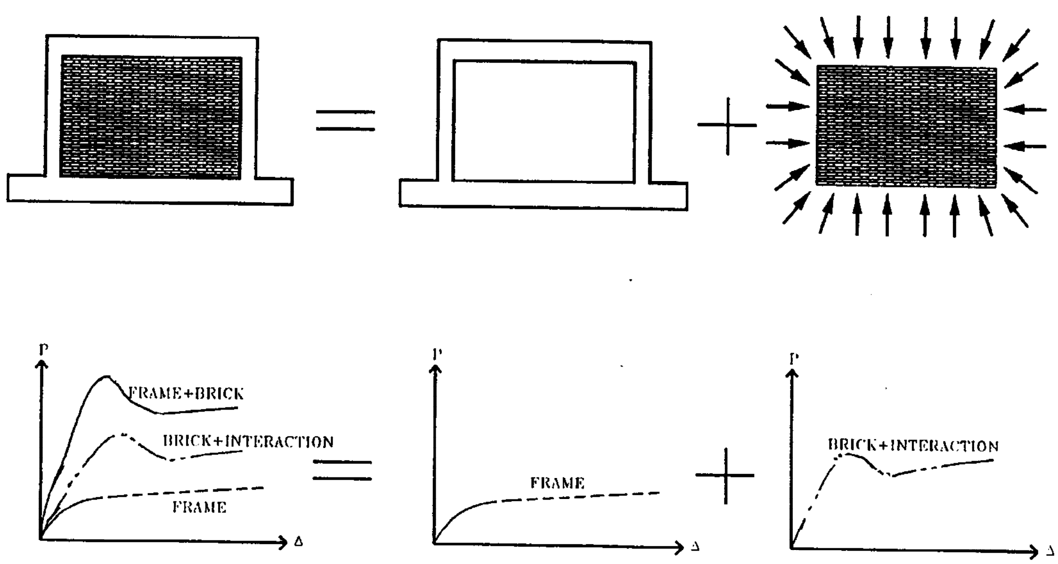

Fig. 1. Specimen Parameters

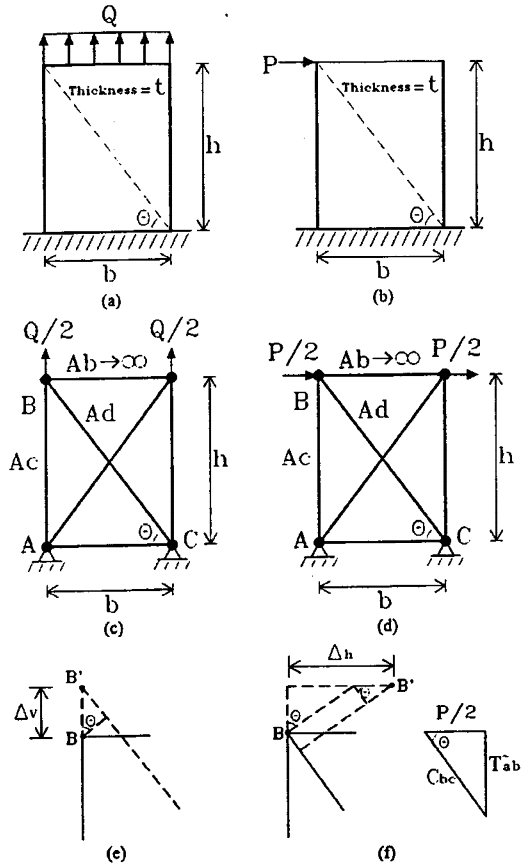

Fig. 2. Idea of Linked Structures

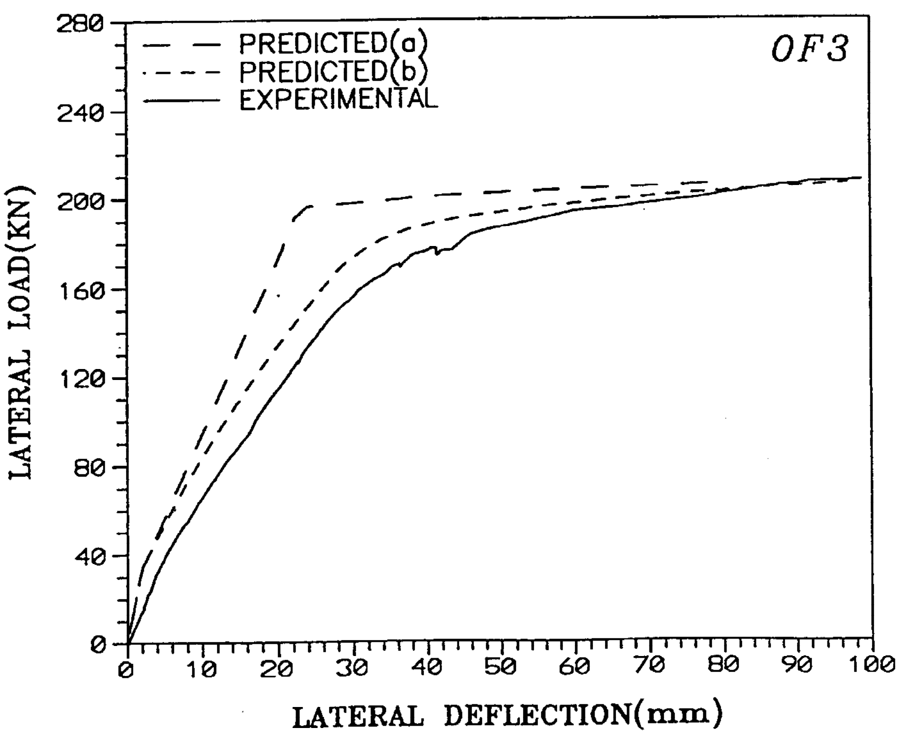

Fig. 3. P-Δ Curve of Open RC Frame

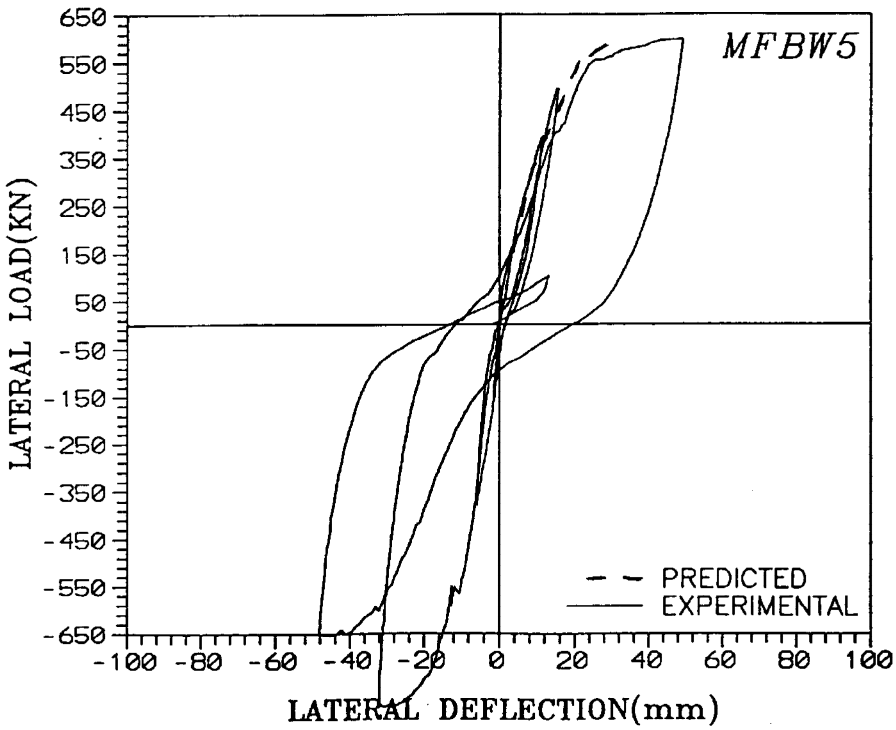

Fig. 4. P-Δ Curve of Confined Brick Shear Wall Without Opening

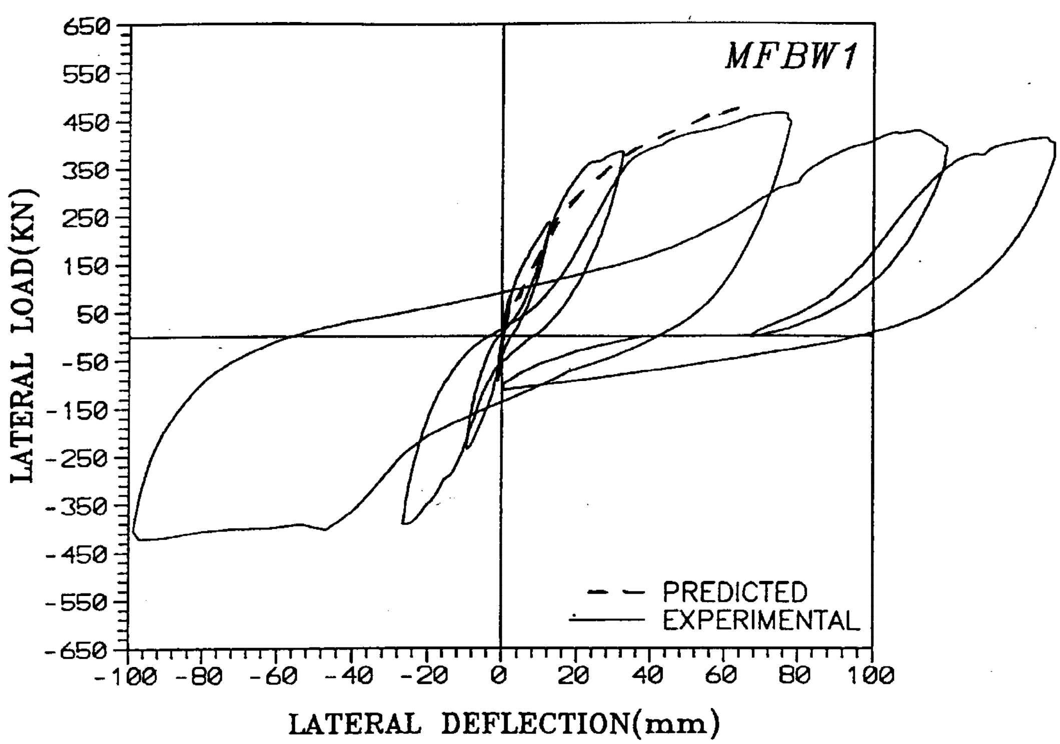

Fig. 5. P-Δ Curve of Confined Brick Shear Wall With Opening