論文 **SEMI EMPIRICAL SEISMIC DESIGN FORMULA OF COMPOSITE BLOCK MASONRY WALL**

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ABSTRACT: Seismic resisting behaviors are studied experimentally and analytically on composite block masonry walls that consist of block masonry wall confined by surrounding reinforced concrete beam and columns with shear keys. Semi empirical seismic design formulas to predict the cracking, ultimate lateral resistant strength and its corresponding displacements are discussed. Comparing with test results and analytical results using rigid body spring model, these formulas are considered very useful for engineering practices.
KEYWORDS: composite block masonry wall, rigid body spring model, concrete block, semi empirical seismic design formula, cracking strength, ultimate strength

1. INTRODUCTION

In view of the continued use of buildings, constructed in concrete blocks in the most of the countries of world, a simple and economical structure was proposed by Dalian University of Technology, China (hereafter DUT) [1] for introducing seismic resistance features in the block masonry wall, which is named as the composite block masonry wall that consists of block masonry wall confined by the surrounding reinforced concrete beam and columns with shear keys having rectangular shape. In our researches [2][3], the seismic resisting behaviors of composite block masonry walls were studied by performing experiments under the various types of vertical loadings and shear span ratio. To simulate the experimental results, an analytical method was made using rigid body spring model [4][5] for monotonic loadings. The semi empirical seismic design formulas proposed by DUT to predict the cracking, ultimate lateral resistant strength and the corresponding displacements of composite block masonry walls are discussed. The calculated results by these formulas, in term of cracking and ultimate strength, are compared with the observed ones.

2.TEST SPECIMEN

Fig.1 shows the details of the half scale, one and half story, and single span test specimen. Here the actual sized concrete blocks were used.

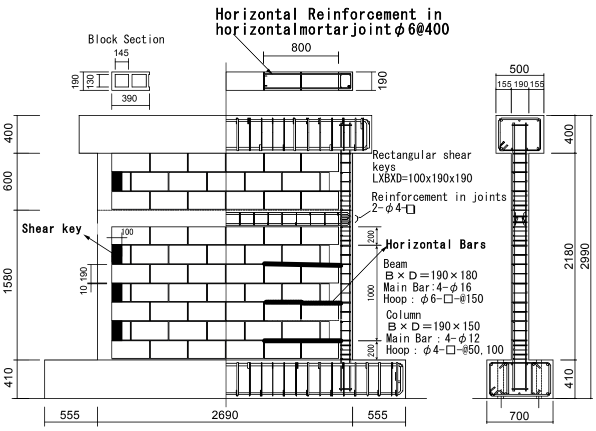

Fig.1 Test specimen

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The joint mortars made of cement, lime and sand in the proportion 1:0.65:6.59 were used to construct block masonry wall. Properties of joint mortar were investigated by the three-layered block test on shear and compression [2]. The vertical reinforcements were not provided in the block masonry wall. But horizontal reinforcements were provided in horizontal mortar joints up to 800mm from the inner side of both columns on the alternate layer of block masonry. The strength of concrete and the yield strength of steel (SR235) were 30.5MPa and 340MPa respectively that were obtained by element tests.

3.LOADING SYSTEM

Fig.2 shows the loading system used for performing the experiments of composite concrete block masonry wall. The constant vertical loads to simulate dead load were applied by three vertical hydraulic jacks. The specimens were subjected to cyclic horizontal load to simulate the earthquake by a horizontal hydraulic jack. The axial stresses applied on three specimens are as follows:

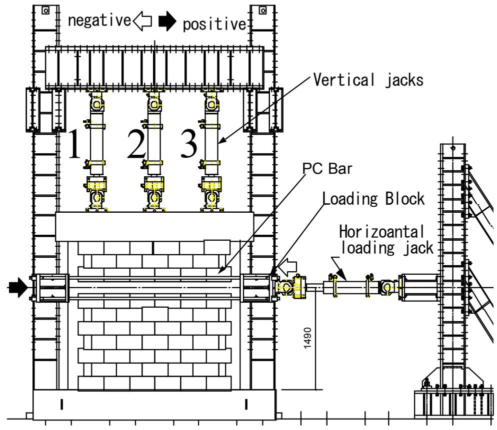

Fig.2 Loading system

1) 0.5MPa in both direction having M/QD=0.55,
2) 0.0MPa in negative direction, 1.0MPa in positive direction having M/QD=0.55
3) 0.5MPa in both directions having M/QD=1.0.

The axial loads developed by the vertical jacks No.1 and No.3 as shown in **Fig.2** were changed in the positive and negative direction to generate the moment.

4.ANALYTICAL METHOD

Rigid body spring model [4] [5] was used to simulate the experimental results considering monotonic load. **Fig.3** shows the model of rigid body spring model that consists of finite number of rigid bodies connected with normal and shear springs on its boundary. This model defines the responses of springs that provide the reaction of rigid bodies instead of the internal behaviors of each rigid body.

The relative displacements of rigid bodies are defined in normal and shear spring given by Eq. 1.

$$\begin{Bmatrix} \delta_n(x,y) \\ \delta_s(x,y) \end{Bmatrix} = [B(x,y)]\{u_1, v_1, \theta_1, u_2, v_2, \theta_2\}^T \text{……………………..(1)}$$

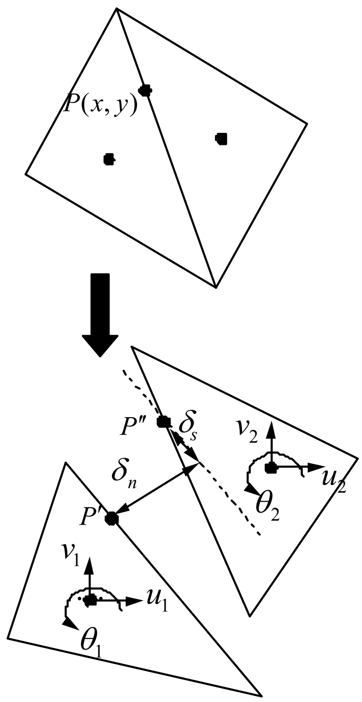

Fig.3 RBS Model

The stresses in the normal and shear springs are defined by Eq. 2

$$\begin{Bmatrix} \sigma_n(x,y) \\ \tau_s(x,y) \end{Bmatrix} = [D] \begin{Bmatrix} \delta_n(x,y) \\ \delta_s(x,y) \end{Bmatrix} \text{ ……………………………………………………..(2)}$$

Where, $$[D]^e = \begin{bmatrix} k_n & 0 \\ 0 & k_s \end{bmatrix}, \quad k_n = \frac{E}{(1-\upsilon^2)(h_1+h_2)}, \quad k_s = \frac{E}{(1+\upsilon)(h_1+h_2)}$$

$[B(x,y)]$ -Geometrical matrix of element boundary, $[D]$ -Constitutive matrix of materials used in specimen, $\delta_n(x,y)$, $\delta_s(x,y)$ -Relative displacement of normal and shear springs respectively. k_n, k_s – Stiffness of normal and shear spring, E- Tangential modulus of elasticity, υ - Poisson's ratio and h_1, h_2 – Perpendicular distance between boundary and geometric center of a rigid body.

The element stiffness of springs in the boundary element are defined by the Eq.3

$$[K] = t\int_s [B]^T [D][B]\, ds \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where, t- Thickness of element, s- Variable length of element boundary.

Fig.4 shows the normal stress and strain relation of concrete and joint mortar. The yield surface is determined considering the normal and shear stress of each boundary element as shown in **Fig. 5**. As a yield condition, the Mohr-Coulomb's yield function (4) was assumed. Non-linear behaviors of mortar joints were the most important for this specimen and their constants were obtained by performing the three-layered blocks test on shear and compression. For nonlinear condition the plastic theory was assumed [2] [3].

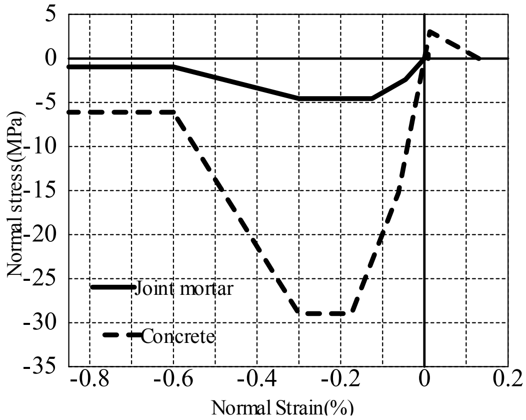

Fig.4 Normal stress strain relation

$$f = \tau_s^2 - \left(c - \sigma_n \tan\phi\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where, c = Cohesion, ϕ = Angle of internal friction

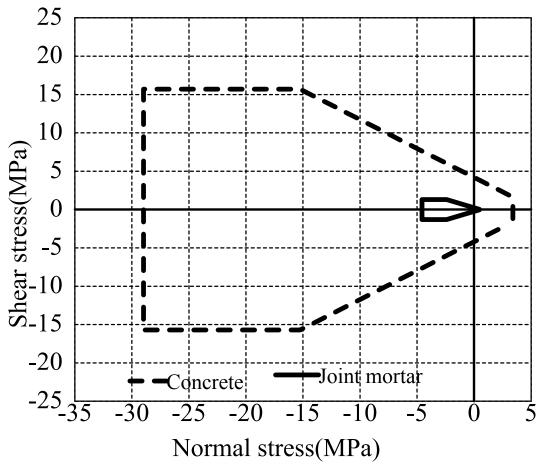

Fig.5 Yield surface model

5. SEMI EMPIRICAL SEISMIC DESIGN FORMULA

Based on the analytical results by finite element method, considering the different parameters and test results of composite concrete block masonry wall with various dimensions and material characteristics, simplified semi-empirical seismic design formulas [1] were proposed by DUT. Semi empirical formulas would be simple and very effective for actual seismic design. Tests and RBS model analysis were done to check the accuracy of semi empirical formulas.

5.1 SIMPLIFIED STRENGTH FORMULA

(1) Cracking lateral resistant strength

The cracking lateral resistant strength of composite block masonry wall is defined by Eq.5

$$V_{cm} = \alpha\left[\gamma f_{VEm} A_m + \sum \eta_i \times 0.07 f_{cm} A_{ci}\right] \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

(2) Ultimate lateral resistant strength

The ultimate lateral resistant strength of composite block masonry wall is defined by Eq.6

$$V_{Um} = \alpha\left[\gamma f_{VEm} A_m + \sum \eta_i \left(0.07 f_{cm} A_{ci} + 0.15 f_{ym} A_{si}\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where, f_{VEm} - The induced strength of concrete block wall calculated by the following formula

$$f_{VEm} = \frac{f_{Vm}}{1.2}\sqrt{1+\frac{\sigma_0}{f_{Vm}}} \qquad (7)$$

f_{Vm} - Average shear strength obtained by three-layered block test (MPa) [2]
σ_0 - Average axial stress on wall to simulate dead load (MPa)
A_m - The net cross-sectional area of concrete block masonry wall (mm^2)
f_{cm} - The average compressive strength of concrete for column (MPa)
A_{ci} - The cross-sectional area of i^{th} reinforced concrete column (mm^2)
f_{ym} - The average yielding strength of reinforcing bars (MPa)
A_{si} - Total cross-sectional area of reinforcement in i^{th} column (mm^2)
α - Bending influence factor, [1], γ - Strength utilizing factor of block masonry; for cracking strength 1.2 and for ultimate strength 1.35 [1]
η_i - Participating factor of concrete column; for cracking strength 0.45 and for ultimate strength 0.65 [1]

(3) Comparisons of the calculated results with tests results and RBSM analysis

Fig.6 shows shear strength and axial stress relation analyzed under different axial stress for the composite block masonry wall specimen with shear span ratio (M/QD) 0.55 corresponding to 1 or 2-story building. RBSM analysis gives good results compared with test ones. The simplified strength formulas proposed by DUT predict well the effect of axial stress on the maximum strength of composite concrete block masonry wall with some margins.

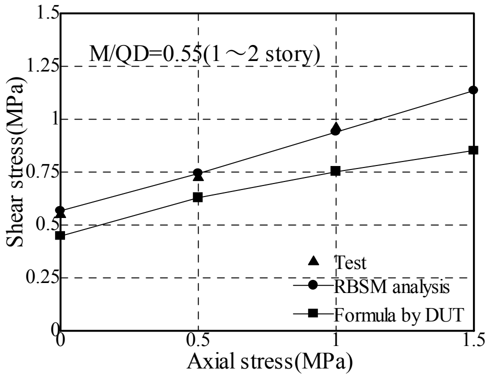

Fig. 6 Shear and axial stress relation

Fig.7 shows shear strength and shear span ratio relations of composite block masonry wall specimen under the applied axial stress 0.5MPa with the different shear span ratios. The lateral resistant strength formulas proposed by DUT gives good results up to shear span ratio 1.0 corresponding to 5 or 6 story building but becomes larger in case of shear span ratio 1.5 corresponding to 8 story building. Thus, for the case of shear span ratio 1.5, the reduction factor for bending is necessary to be studied more experimentally.

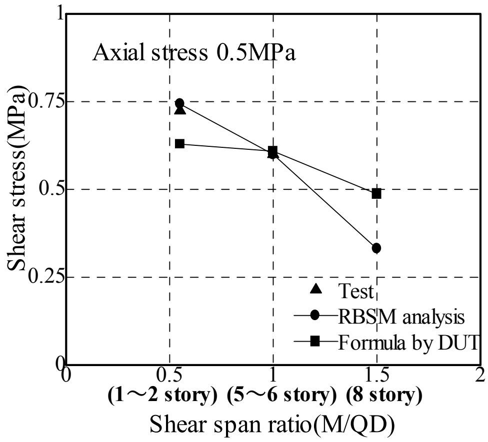

Fig. 7 Shear stress shear span relation

5.2 SIMPLIFIED LATERAL RESISTANT STIFFNESS

The displacements corresponding to the cracking and ultimate lateral resistant strength are calculated by defining the simplified lateral resistant stiffness, which is described below. For considering the effect of openings in the wall, the opening factor is also included in the simplified formulas of stiffness, which were also proposed by DUT. Coefficient values were obtained by referring the results obtained by finite element analyses. Using the height of specimen (H) and cross section of block masonry wall (A_m), the effect of aspect ratio is included, which specifies the characteristic role of bending deformation.

To define the lateral resistant stiffness of composite concrete block masonry wall, the simplified sketch of envelope curve is assumed as shown in **Fig. 8**. The slope of line OA is the elastic stiffness K_0. Some hair cracks could be observed in the masonry block at point A. At the point B where the load is assumed as the cracking strength, obvious cracks could be observed. The stiffness could be changed a little quickly after exceeding point B. The slope of line OB is defined as cracking stiffness K_1. Load at the peak point C is defined as ultimate strength and the slope of line BC is defined as cracked stiffness K_2. The three stiffness of wall were simplified for transversal and longitudinal walls. As we performed the tests and analyses of transversal composite block masonry wall, here the simplified lateral resistant stiffness formulas for transversal wall are described briefly.

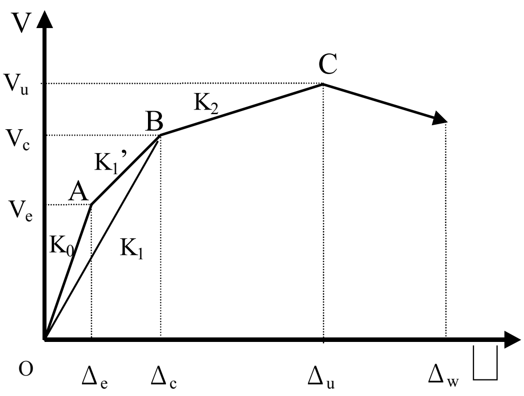

Fig.8 Assumed load displacement curve

(1) Elastic stiffness:

Elastic stiffness of transversal wall is formulated as follow:

$$K_0 = \frac{\sum G_c A_{ci} + G A_m}{1.5 \times 1.2 H}.\psi \quad \text{...(8)}$$

(2) Cracking secant stiffness

Cracking secant stiffness of transversal wall is formulated as follow:

$$K_1 = \frac{0.39 \sum G_c A_{ci} + 0.26 G A_m}{1.2 H}.\psi \quad \text{...(9)}$$

(3) Cracked tangent stiffness

Cracked tangent stiffness of transversal wall is formulated as follow:

$$K_2 = 0.14 K_1 \quad \text{...(10)}$$

Where,

G_c – Shear modulus of concrete of the reinforced concrete members ; $G_c=0.4E_c$

G – Shear modulus of the concrete block masonry wall ; G=0.4E

ψ – The opening factor, which considers the effect of openings

A_{ci} –Cross-sectional area of i^{th} concrete column, A_m – Cross-sectional area of concrete block masonry wall, E_C –Tangential modulus for concrete, E – Tangential modulus for concrete block masonry wall , H – The story height of building

5.3 COMPARISON OF LOAD DISPLACEMENT RELATION

Using the cracking and ultimate lateral strength formula and lateral resistant stiffness, the load displacement relations for different cases of loadings were calculated. **Fig. 9** shows the load displacement relations obtained by tests, RBSM analyses, for the different cases of loadings indicated in the figures, and semi empirical design formulas corresponding to the cracking and ultimate strength.

It is seen that the behaviors of composite concrete block masonry wall, explained by the semi empirical seismic design formulas are close to the observed behaviors.

6. CONCLUSIONS

The results obtained by the semi empirical seismic design formulas proposed by DUT are consistent well with the test and analysis results of specimens up to shear span ratio 1.0. But in case of shear span ratio1.5, the strengths obtained by RBSM were less than the strengths obtained by semi empirical formulas. Thus it should be studied experimentally. The calculated results by semi empirical seismic design formulas, in terms of load displacement relations, agreed well with the observed one. These formulas are effective for seismic design.

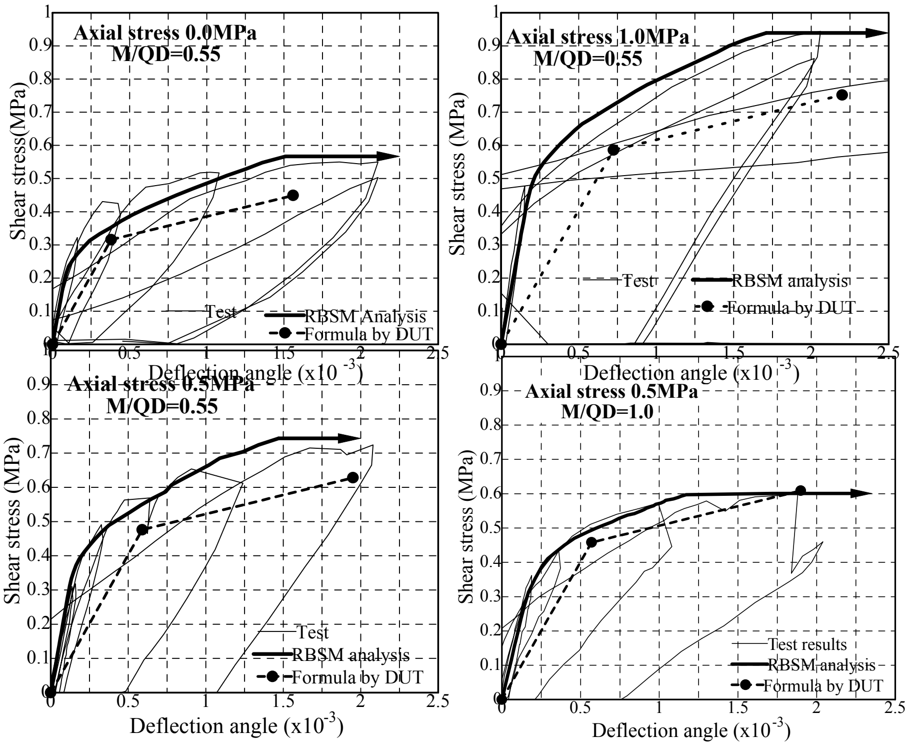

Fig.9 Load displacement relations

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