10th Canadian Masonry Symposium, Banff, Alberta, June 8 – 12, 2005

EXPERIMENTAL STUDY OF STRESS DISTRIBUTIONS IN BRICK WALLS UNDER AN OVERHANGING BEAM

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ABSTRACT

Based on previous research, an experimental method was developed to determine stress distributions in the longitudinal and transverse brick walls under an overhanging beam. 12 brick wall panels were tested under an overhanging beam in different conditions. Experimental results of the stress distributions in the longitudinal and transverse brick walls were obtained. The influence of the length of longitudinal wall and the height of ring beam on the load carried by the longitudinal wall was investigated. Finite element analysis was conducted. The technology of artificial neuron network was used for the analysis. A computer model was developed to investigate the various influences on the load carried by the longitudinal wall. The experimental and numerical results indicate that contributions of the longitudinal wall to share the load applied to the transverse wall should be taken into account in our design work. In design, the appropriate measure should be used to strengthen the connection of the longitudinal-transverse walls, otherwise, the connection might easily be broken, which will result in losing the contributions of the longitudinal wall to bear the load.

KEYWORDS: Overhanging Beam, Brick Wall, Stress Distribution, Finite Element Analysis.

INTRODUCTION

The stress distributions where the longitudinal brick wall meets the transverse wall under an overhanging beam in multiple-story brick masonry buildings is complicated. There exist stress concentrations and localization. The longitudinal brick wall shares to some extent the load applied to the transverse brick wall because of the interaction of the floor, ring beam, and longitudinal and transverse brick walls. However, in the current Chinese design code for multiple-story masonry buildings it is assumed that the entire load is carried by the transverse wall. The contributions of the longitudinal wall to carry the load are not taken into account. However, there exists a compatibility of deformation between the walls. The longitudinal wall does make contributions in real masonry buildings. In order to consider such contributions, reduce the construction cost and increase the effective areas to use, 12 brick walls under the overhanging beam were tested, the stress distributions in these walls were studied. The experimental results provide a basis for modification of the current Chinese Standard of Masonry Design.

TEST ARRANGEMENTS

Experiments on Standard Masonry Specimens

79 standard masonry specimens were tested to get the properties of masonry. 35 of them were tested for determination of Modulus of Elasticity and Poisson's ratio of masonry, the rest of them were tested for the compressive strength of masonry. At least 3 specimens were tested to get the Modulus of Elasticity and Poisson's ratio of masonry at the same time as when the brick wall panels were tested. The specimens were cured for 28 days. Dimensions of the standard specimens are: 240 mm (Width) x 370 mm (Length) x 720 mm (Height). The mortar specimens were tested to obtain the compressive strength as well [1]

From these tests, the stress-strain curve of masonry was obtained. The parabolic regression technology was used for the curve fitting. The curve was utilized for calculation of stresses in the brick wall panel.

Test Arrangements for Brick Wall Panels

The test was based on the Chinese Standard Test of Concrete Structures [2] and the Standard Test of Masonry Properties [3]. The testing arrangement is shown in Figure 1. The strain gauges were placed on the brick wall, as shown in Figure 1. The vertical load P1 was applied to the brick wall in five increments until the stress in the transverse wall reached 1.25MPa, then the vertical load P1 was maintained, and the vertical load P was applied to the overhanging beam in increments until the overhanging beam failed. The strains in the brick walls were measured during each increment of load P.

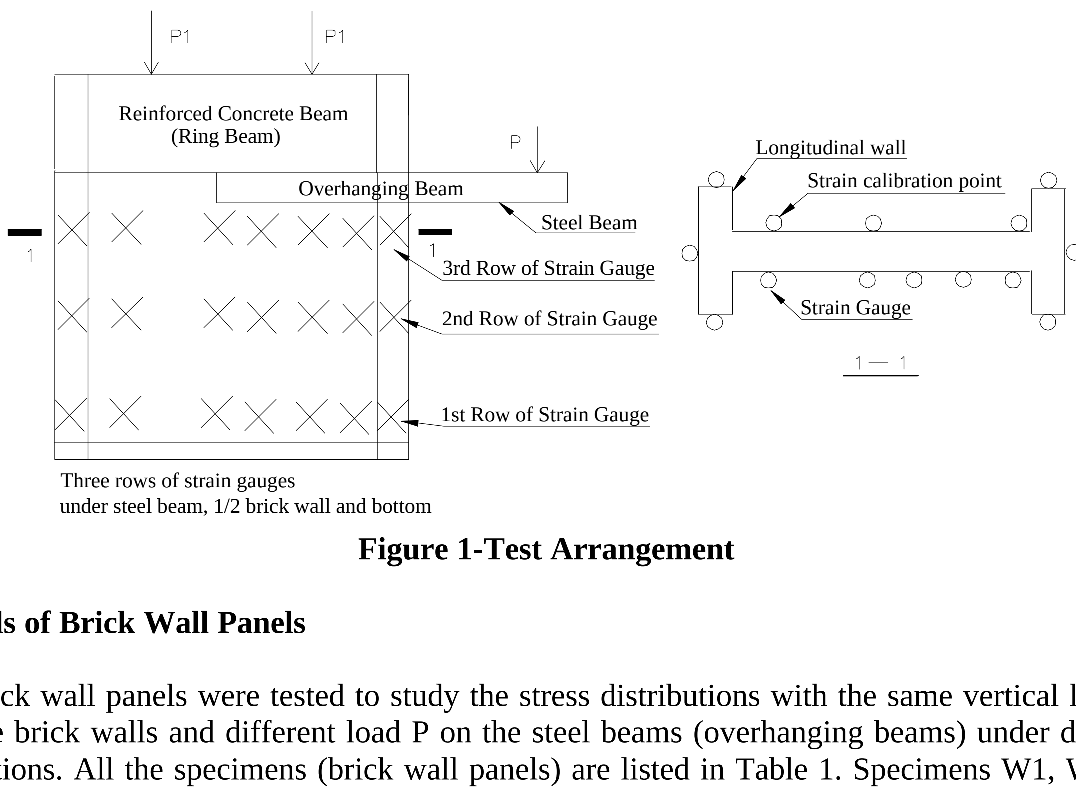

Figure 1-Test Arrangement

Details of Brick Wall Panels

12 brick wall panels were tested to study the stress distributions with the same vertical load P1 on the brick walls and different load P on the steel beams (overhanging beams) under different conditions. All the specimens (brick wall panels) are listed in Table 1. Specimens W1, W2 and W3 are full-sized specimens. Dimensions of these specimens are 240 mm (width) x 3000 mm (Length) x 2670 mm (Height). The concrete beam (ring beam) on the panels is a rectangular

shaped beam which is 370 mm high. Vertical cracks were observed in these three panels during testing which were mainly located near the intersection of the longitudinal and transverse walls. The vertical cracks extended to the bottom of the panels. Those vertical cracks can be observed in some existing buildings. A few horizontal cracks were also observed in the longitudinal wall. The pattern of stress distributions in the longitudinal and transverse walls was not clear. The experimental results were scattered which was not expected. Therefore, an improvement to the test was made. The size and cross-section of the specimen were changed. Nine specimens with half thickness were subsequently tested.

Table 1 - Details of Brick Wall Panels

Specimen	Thickness of Wall (mm)	Length of Transverse Wall (mm)	Length of Longitudinal Wall (mm)	Height of Concrete Beam (mm)	Type of Brick
W1	240	3000	3000	0	SB
W2	240	3000	3000	0	SB
W3	240	3000	3000	0	SB
BW4	115	2000	240	0	SB
BW5	115	2000	740	0	SB
BW6	115	2000	1500	0	SB
BW7	115	2000	740	240	SB
BW8	115	2000	740	60	SB
BW9	115	2000	740	120	SB
HW10	115	2000	1200	0	PSB
HW11	115	2000	740	0	PSB
HW12	115	2000	480	0	PSB

Note: SB stands for shale brick; PSB stands for perforated shale brick. Specimen BW9 was a little damaged during curing.

For the 9 (BM4, BM5, BM6, BM7, BM, BM9, HW10, HW11, HW12) half thickness brick wall panels that were tested, the vertical loads P1 was again applied to the transverse wall by increments until the stress reached 1.25 MPa, then P1 was maintained, and the vertical load P was applied to the overhanging beam (steel beam) in increments. The strains were measured during each increment of loading. When a load of 60 kN on the overhanging beam (steel beam) was reached, significant plastic deformation occurred in the overhanging beam, and testing was stopped.

EXPERIMENTAL RESULTS AND DISCUSSION

Loads Carried by Transverse and Longitudinal Walls

The load distributions in the walls were calculated. The procedure of the calculation is as follows [4]: the Modulus of Elasticity and the relationship of stress and strain were obtained from the previous standard test of masonry. This information was used to calculate the stresses from the strains recorded during the experiments. Then the loads in the longitudinal and transverse walls were calculated during each step of loading. Therefore, the patterns of load distributions were obtained. The ratio of load carried by the longitudinal wall to the total vertical load applied to the transverse wall was obtained. These ratios are listed in Tables 2-4. Due to the space limitations, only the results of specimens BW4~BW6 are listed in Tables 5-7, and test results of specimens BW4 and BW7 are shown in Figures 2 and 3. Note in all tables: column A is the load applied to the transverse wall (load applied to the overhanging beam), column B is the ratio of total load carried by longitudinal wall to the total vertical load applied to the transverse wall, column C is the load carried by the part of the longitudinal wall under the overhanging beam and column D is the load carried by the rest of the longitudinal wall.

Table 2 - Load Carried by the Longitudinal Wall (1st Row of Strain Gauges)

Specimens	A	B	C	D
BW4	287.5(30)	0.126	0.103	0.023
BW5	287.5(30)	0.227	0.128	0.099
BW6	287.5(30)	0.425	0.344	0.081
BW7	287.5(30)	0.274	0.222	0.052
BW8	287.5(30)	0.487	0.314	0.172
BW9	287.5(30)	0.207	0.157	0.050
HW10	287.5(30)	0.313	0.187	0.126
HW11	287.5(30)	0.300	0.227	0.073
HW12	287.5(30)	0.244	0.162	0.082

Table 3 - Load Carried by the Longitudinal Wall (2nd Row of Strain Gauges)

Specimens	A	B	C	D
BW4	287.5(30)	0.0987	0.074	0.024
BW5	287.5(30)	0.378	0.127	0.251
BW6	287.5(30)	0.509	0.315	0.194
BW7	287.5(30)	0.333	0.240	0.094
BW8	287.5(30)	0.495	0.171	0.324
BW9	287.5(30)	0.264	0.177	0.087
HW10	287.5(30)	0.411	0.265	0.146
HW11	287.5(30)	0.287	0.217	0.070
HW12	287.5(30)	0.327	0.111	0.216

Table 4 - Load Carried by the Longitudinal Wall (3rd Row of Strain Gauge)

Specimens	A	B	C	D
BW4	287.5(30)	0.099	0.064	0.035
BW5	287.5(30)	0.375	0.169	0.206
BW6	287.5(30)	0.514	0.196	0.318
BW7	287.5(30)	0.383	0.215	0.168
BW8	287.5(30)	0.561	0.321	0.240
BW9	287.5(30)	0.313	0.193	0.120
HW10	287.5(30)	0.464	0.391	0.073
HW11	287.5(30)	0.388	0.209	0.179
HW12	287.5(30)	0.428	0.304	0.124

Table 5 - Load Carried by the Longitudinal Wall (Specimen BW4)

A	B	C	D
57.5(0)	0.1078	0.038	0.070
115(0)	0.1058	0.040	0.067
172.5(0)	0.099	0.037	0.062
230(0)	0.092	0.035	0.057
287.5(0)	0.091	0.034	0.057
287.5(10)	0.090	0.039	0.051
287.5(20)	0.1208	0.082	0.039
287.5(30)	0.1259	0.1026	0.023

Table 6 - Load Carried by the Longitudinal Wall (Specimen BW5)

A	B	C	D
57.5(0)	0.1791	0.085	0.094
115(0)	0.1793	0.085	0.095
172.5(0)	0.1721	0.081	0.091
230(0)	0.1947	0.093	0.1017
287.5(0)	0.1927	0.088	0.1047
287.5(5)	0.2016	0.088	0.1137
287.5(10)	0.2086	0.098	0.1107
287.5(15)	0.2195	0.1061	0.1134
287.5(20)	0.2291	0.1195	0.1096
287.5(25)	0.2318	0.1288	0.1031
287.5(30)	0.2273	0.1285	0.099
287.5(35)	0.2138	0.1181	0.096

Table 7 - Load Carried by the Longitudinal Wall (Specimen BW6)

A	B	C	D
287.5(10)	0.406	0.297	0.1100
287.5(20)	0.421	0.324	0.0097
287.5(30)	0.425	0.344	0.0082
287.5(40)	0.417	0.345	0.0072
287.5(50)	0.418	0.352	0.0066

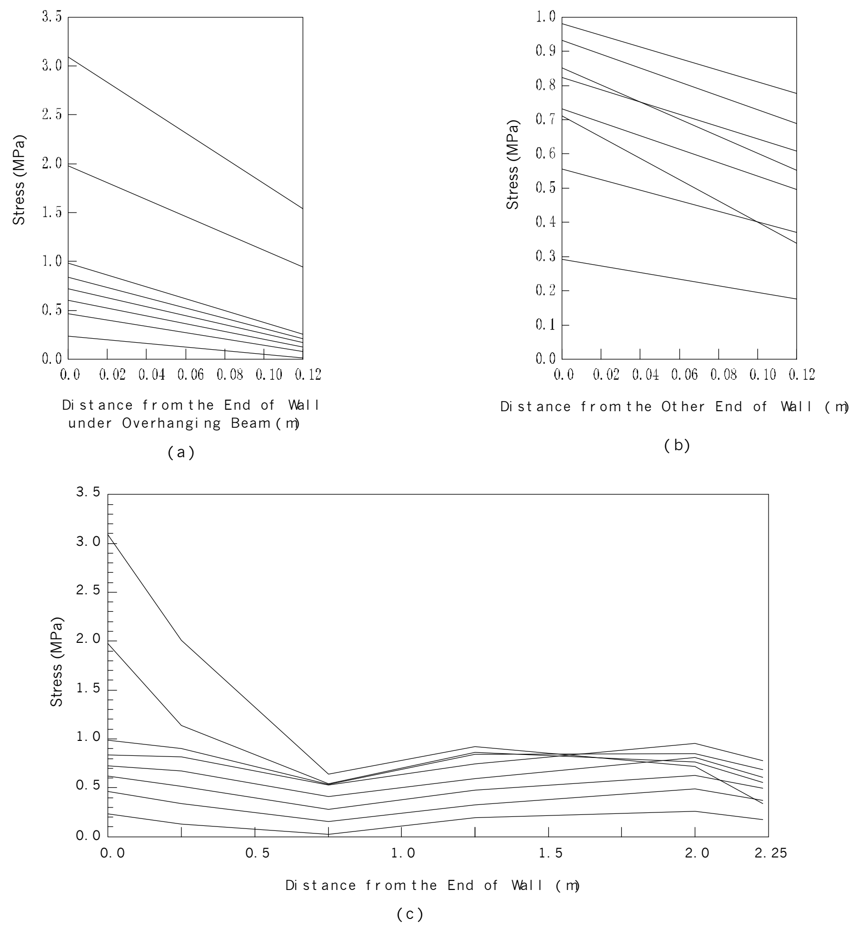

Figure 2 - Stress Distributions on the Longitudinal Wall (Specimen BW 4)
(a) Stress Distributions in the Longitudinal Wall (Overhanging Beam Side)
(b) Stress Distributions in the Longitudinal Wall (Side away from Overhanging Beam)
(c) Stress Distributions in the Transverse Wall

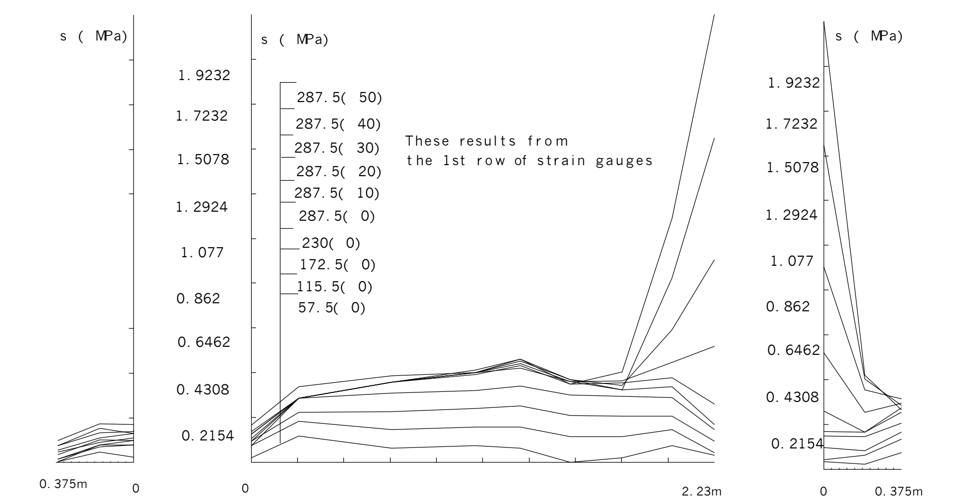

Figure 3 - Stresses in Specimen BW 7

Finite Element Analysis

The analysis model is shown in Figure 4. ANSYS was used for the FE analysis. The stress distributions in the brick wall panels under different conditions were analysed. Material properties were: C20 reinforced concrete beam, Mu10 shale brick and M5 mortar [1, 2]. The height of the reinforced concrete beam was varied: 240mm, 400mm and 600mm. There are four types of the cross sections of the brick wall panels: 1 (without the longitudinal wall and the reinforced beam), L, T and I shape. The length of the longitudinal wall was also varied for the different cross sections of the brick wall panels, for example, there are three different lengths for the longitudinal wall: 480mm, 740mm and 1500mm. The loading was also varied, a vertical load of 1.5 MPa was applied to the concrete beam, while the vertical load applied to overhanging beam was 0, 20 kN and 30 kN.

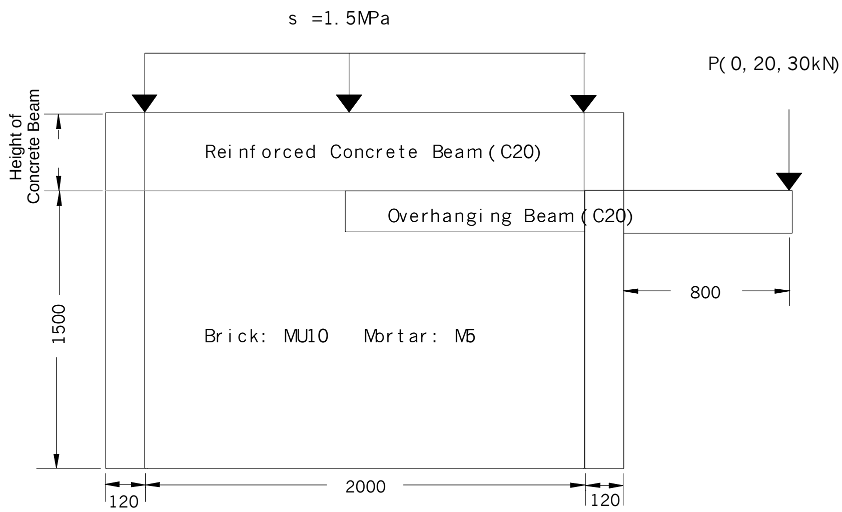

Figure 4 - Model of Finite Element Analysis

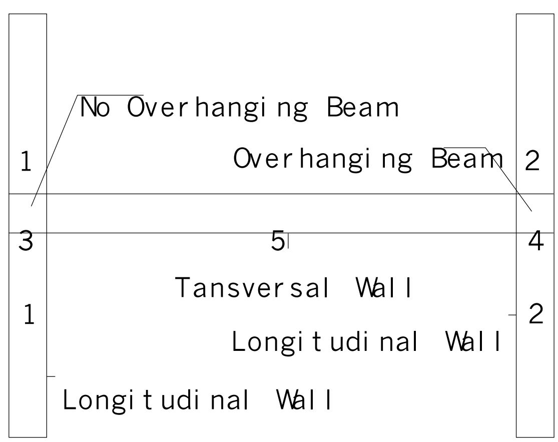

Figure 5 - Different Areas for Finite Element Analysis

For the brick wall panel with I-shape cross section, the cross section was divided into five different areas for finite element analysis as shown in Figure 5, i.e., Area 1 without the overhanging beam, Area 2 with the overhanging beam, Area 3 and 4 are intersection of the longitudinal and transverse walls, Area 5 is the transverse wall. Elements of Solids45 were used in the finite element analysis. The size of the element is 40mm x 40mm x 40mm. The analysis was conducted for the above three types of loadings [1, 5]. The details of specimens for the finite element analysis are listed in Tables 8-10. The results are shown in Figures 6 and 7.

Table 8 - Details for I-Shape Specimens

Specimen	Height of Concrete Beam (mm)	Length of Long. Wall (mm)	Specimen	Height of Concrete Beam (mm)	Length of Long. Wall (mm)
IW1	600	740	IW6	240	480
IW2	400	740	IW7	600	1500
IW3	240	740	IW8	400	1500
IW4	600	480	IW9	240	1500
IW5	400	480			

Table 9 - Details for L-Shape Specimens

Specimen	Height of Concrete Beam (mm)	Length of Long. Wall (mm)	Specimen	Height of Concrete Beam (mm)	Length of Long. Wall (mm)
LW1	600	420	LW6	240	300
LW2	400	420	LW7	600	810
LW3	240	420	LW8	400	810
LW4	600	300	LW9	240	810
LW5	400	300			

Table 10 - Details for T-Shape Specimens

Specimen	Height of Concrete Beam (mm)	Length of Long. Wall (mm)	Specimen	Height of Concrete Beam (mm)	Length of Long. Wall (mm)
TW1	600	740	TW6	240	480
TW2	400	740	TW7	600	1500
TW3	240	740	TW8	400	1500
TW4	600	480	TW9	240	1500
TW5	400	480			

Suggestions for Ratio of Load Carried by the Longitudinal Wall to Load Applied to the Transverse Wall

The finite element analysis was conducted for the 9 specimens, then BP artificial neuron net work was used for the curve fitting, as shown in Figure 7.

For the purpose of practical use in design work, the use of an α and β relationship is suggested in Table 11 when the height of the concrete beam is greater than 240mm. Here, α is defined as the ratio of the length of the longitudinal wall to the length of the transverse wall, and β is defined as the ratio of the load carried by longitudinal wall to the load applied to the transverse wall without the load on the overhanging beam. When α is greater than 1, β is taken as 0.212.

Table 11 - Suggestion for Use of α-β Relationship

α	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
β	0.000	0.023	0.050	0.092	0.108	0.135	0.157	0.176	0.190	0.202	0.212

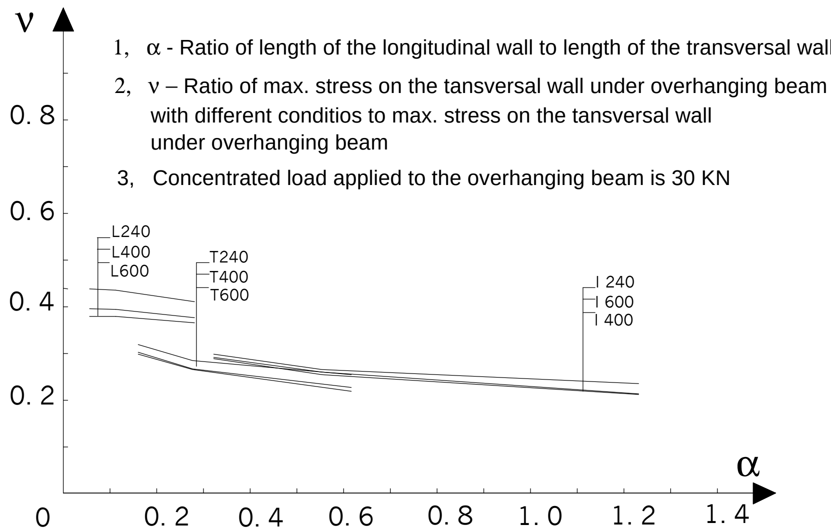

Figure 6 - α–ν Curve

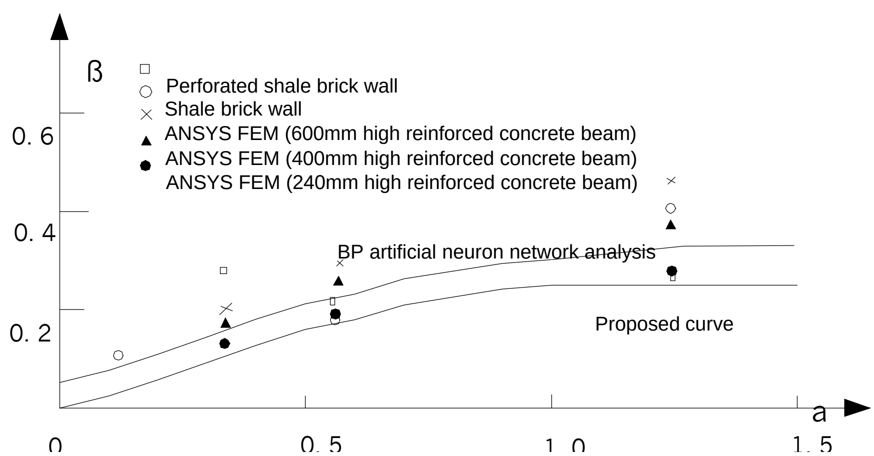

Figure 7 - α–β Curve

CONCLUSIONS

The following conclusions can be reached from the above tests, finite element analyses and curve fitting.

1. Because of the presence of the longitudinal wall and the reinforced concrete beam, the longitudinal wall carries a certain amount of load when the transverse wall is loaded. The ratio of the load carried by the longitudinal wall to the load applied to the transverse wall increases with the length of the longitudinal wall, the stiffness of the floor, and the height of the overhanging beam. However, there exists a critical value. When the critical value is reached, the ratio does not increase with the length of the longitudinal wall.

2. When a constant vertical load is applied to the transverse wall, the load carried by the longitudinal wall under the overhanging beam increases with the load applied to the overhanging beam. The load carried by the longitudinal wall away from the overhanging beam decreases. The total load carried by the longitudinal walls increases slightly. Meanwhile, a stress concentration occurs at the intersection of the longitudinal and transverse walls, that is, there is a localization of compression. It is suggested that the strength at the intersection should be checked in design work. When the stiffness of the overhanging beam is not large enough, significant deformation happens in the overhanging beam and the structure collapses.

3, The presence of the longitudinal wall reduces the stress concentration under the overhanging beam, and increasing length of the longitudinal wall reduces the stress concentration as well.

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