BEHAVIOUR OF ONE STOREY REINFORCED CONCRETE FRAME INFILLED WITH BRICKWORK UNDER LATERAL LOADS

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SYNOPSIS

A predominantly experimental approach has been adopted for summarising the results of twenty one tests on reinforced concrete frames infilled with brickwork under lateral loads. The test data furnish some new information regarding the influence of the quality of brickwork on the modes of failure, stiffness, strength and share of load between the frame and the infill. Simple expressions for lateral stiffness and strength as well as for share of load between the frame and the infill have been proposed in non-dimensional forms on the basis of the test results.

NOTATIONS

l_i, h_i, t	width, height and thickness of infill
l_c, h_c	width and height of frame on centre lines
θ	slope of the diagonal of infill
r	panel proportion (l_i/h_i)
E_c, E_{bw}	modulus of elasticity of concrete and brickwork respectively
I_{ec}	equivalent moment of inertia of column section
δ_H	lateral deflection at the point of application of lateral load H
f_{tbw}, f_{tb}, f_{tm}	tensile strength of brickwork, brick and mortar respectively
f_{cbw}, f_{cm}	crushing strength of brickwork and mortar respectively
f_{bs}, f_{bt}	bond-shear and bond-tensile strengths of brickwork respectively
$S_e, S_p, S_s, S_m, S_{sm}$	lateral stiffness of infilled frame obtained from test, proposed expression, formulations of Smith and Carter, Mainstone and Smolira respectively
$H_{ue}, H_{up}, H_{us}, H_{um}$	ultimate strength obtained from test, proposed expression, formulations of Smith and Carter and Mainstone respectively (superscripts t and s relate to values in mode 1 and mode 2)
H_{ie}, H_{ip}	lateral load on infill obtained from test and proposed expression respectively

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H_{ce} strength at first crack obtained in the tests

INTRODUCTION

The lateral stiffness against forces due to wind, earthquake or blasts is a primary consideration in the design of tall buildings(10). In recent years, the possibility of utilising the composite stiffness and strength of the structural framework and the infill walls as a means of providing lateral stability in tall buildings, has been receiving considerable attention.

The earlier investigations were carried out by Polyakov(6), Benjamin and William(1), Wood(10) and Sachanski(7). Holmes(3) proposed a simplified analysis based on the concept of equivalent diagonal strut originally postulated by Polyakov. Smith and Carter(8) adopted this concept of replacing the infill by a pin-connected diagonal strut in their formulations developed on the basis of the results of tests on steel frames infilled with mortar. The approach proposed by Mainstone(4) was also based on the same concept. Malhotra(5) carried out an experimental investigation and reported appreciable variations of the results from those obtained through the formulations of Smith and Carter. Smolira(9) proposed a simplifid approach for thec prediction of the lateral stiffness only.

The available literature on this field summarised above reveals that only Benjamin and William, Malhotra, Sachanski and Smolira have reported the results of a limited number of tests on reinforced concrete frames infilled with brickwork. Other investigators carried out tests on steel or steel-encased frames infilled with brickwork. The present investigation has been carried out to study the behaviour of this type of composite structure fully for different qualities of brickwork infill and to examine the results in the light of the predictions obtained with the aid of the formulations of Smith and Carter, Mainstone and Smolira.

DETAILS OF SPECIMENS AND TEST PROCEDURE

The details of tests are given in Table 1. The dimensions were chosen to represent a scale ratio of 1:3. The variables in the tests are as under :

(a) Panel proportion l_i/h_i (Column 2 of Table 1)

(b) Quality of brickwork, i.e. 1:3, 1:4 and 1:6 cement mortar.

The specimens were prepared and tested in the back-to-back arrangement. The load was applied on the central post and the reaction at each support constituted the lateral load on each of the two panels.

GENERAL BEHAVIOUR

The infill had invariably failed in all the tests. The observed modes of failure can be distinguished as :

(i) Mode-1 : Tensile cracking through the bricks and mortar joints.

(ii) Mode-2 : Shear cracking along the mortar joints, i.e. along the interfaces between brick and mortar.

The modes of failure were found to depend on the composition of cement mortar used in the brickwork. All the specimens with brickwork in 1:3 and 1:4 mortar failed in mode-1 and those in 1:6 mortar failed in mode-2. The separation between the frame and the infill did not occur at any stage of loading, indicating thereby that the tension developed at the interfaces was less than the tensile strength due to bond between the brickwork and concrete. The slip, i.e. the relative movement between the frame and the infill was also not observed.

The load-deflection curves obtained from the tests exhibited two distinct zones. The first zone is almost linear for all the specimens. The second region starts with the incidence of first crack. The load falls with increase of deflection to a certain point beyond which the rate of ~~failure~~ deflection increases till failure.

ANALYSIS AND DISCUSSION OF RESULTS

The influence of the properties of brickwork and the panel proportion on the behaviour of the specimens has been incorporated in the dimensionless parameter $\lambda_c l_c$ given by the expression

$$\lambda_c l_c = l_c \sqrt[4]{E_{bw} t \sin 2\theta / (4 E_c I_{ec} h_i)} \quad \ldots \quad \ldots \quad (1)$$

This parameter has been used in the expressions devised for predicting the stiffness, strength and the share of load between the frame and the infill.

(a) Stresses in the infill

The distribution of stresses computed from the strains measured at nine sections on the infill has suggested the following pattern :

The normal and shear stresses are symmetrically distributed ; the compressive and tensile stresses are maximum at the loaded and unloaded corners respectively, the shear stress being maximum at the centre of the infill. The maximum principal tensile stress occurs at the centre of the infill, which is reflected in the locations of the first cracks. The magnitudes of the maximum principal compressive stress occuring at the loaded corners have been found to be smaller than those of the crushing strengths of brickwork. Consequently, the crushing of brickwork did not occur.

(b) Lateral stiffness

The lateral stiffness

$$S_e = \frac{H}{\delta_H} \quad \ldots \quad \ldots \quad (2)$$

has been computed for the specimens from the linear zone of their respective load-deflection curves. It has been found to increase with the panel proportion and the modulus of elasticity of brickwork.

The comparison of the test results with the predictions obtained through other formulations is brought out in Table 2 (Columns 4,5,6 and 7). The order of discrepancies has been appreciable. The expression

$$\frac{S_p}{E_{bw}\, t\, r} = 0.1114 (\lambda_c l_c)^{-0.15} \quad \ldots \quad \ldots \quad (3)$$

has been derived from the plots of the results of the tests. The values obtained through this expression are in close agreement with the test results (Column 8).

(c) Ultimate strength

The modes of failure and the ultimate strengths have been found to depend primarily on the relative values of f_{bs} and f_{tbw}. Mode-2 invariably occurred in the specimens with 1:6 mortar for which f_{bs} was minimum(Column 8 of Table 1).For the specimens in 1:3 and 1:4 mortar, the values of f_{bs} (Column 8) were relatively higher and consequently $f_{tb\omega}$ was critical and failure in mode-1 took place.The ultimate strengths have been found to increase with the panel proportion and modulus of elasticity of brickwork.

The results obtained with the aid of the formulations of Smith and Carter and Mainstone have shown considerable variations in respect of test data.The expressions

$$H^t_{up}/(f_{tb\omega} l_c t) = 0.7018\,(\lambda_c l_c)^{-0.152} \quad \ldots \quad (4)$$

$$H^s_{up}/(f_{bs} l_c t) = 1.1730\,(\lambda_c l_c)^{-0.06} \quad \ldots \quad (5)$$

have been obtained from the plots of the values $H^t_{ue}/(f_{tb\omega} l_c t)$ and $H^s_{ue}/(f_{bs} l_c t)$ .The values obtained through these expressions have been found to be in close agreement with the observed results (Columns 11 and 12 of Table 2).Expressions (4) and (5) may also be used for the prediction of the modes of failure.

(d) Share of load between the frame and the infill

The total load H may be expressed as

$$H = H_f + H_i \quad \ldots \quad (6)$$

in which H_f and H_i are the loads shared by the frame and the infill respectively.The total shear force at the base of the infill(H_{ie}) has been obtained from the stress diagrams.In the domain of elastic behaviour, the expression

$$H_{ip}/H = 0.3266\,(\lambda_c l_c)^{0.36} \quad \ldots \quad (7)$$

closely predicts the value of H_i for the determination of H_f through expression (6).

CONCLUSIONS

The extension of the formulations of Smith and Carter and Mainstone to reinforced concrete frames infilled with brickwork is not a close approximation.Smolira's approach also significantly overestimates the stiffness.The possible reasons of variations have been explained in reference no. 2.

The panel proportion and the qualities of mortar used in the brickwork have got a significant influence on the modes of failure, stiffness and strength.

The proposed expressions have been found to predict the lateral stiffness, lateral strength and the share of load between the frame and the infill with a reasonable degree of accuracy.

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TABLE 1

Details of tests and properties of concrete and brickwork

$t = 76$ mm ; $h_i = 1070$ mm ; $f_{tb} = 11.0$ kg/cm

Section of reinforced concrete frame is 100 mm X 100 mm with 4- 10 mm m.s. rounds

Specimen no	*Mortar (proportion by weight) 1	r 2	E_c kg/cm 3	E_{bw} kg/cm 4	f_{cbw} kg/cm 5	f_{cm} kg/cm 6	f_{tm} kg/cm 7	f_{bs} kg/cm 8
1	1 : 3		247000	450000	45	40	13.0	10.0
1D	1 : 3		237000	43000	37	116	12.0	10.0
2	1 : 4		223000	37000	35	93	9.0	7.5
2D	1: 4	1.000	220000	37000	36	86	8.5	7.0
3	1 : 6		211000	28000	29	41	5.0	2.8
3D	1 : 6		206000	27000	26	35	4.0	3.0
4	1 : 3		237000	43000	39	125	13.0	10.0
5	1 : 4	1.125	222000	36000	35	88	9.5	7.5
6	1 : 6		221000	29000	32	48	6.0	2.9
7	1 : 3		189000	43000	43	120	12.0	9.5
7D	1 : 3		192000	43000	36	115	12.0	10.0
8	1 : 4		193000	35000	33	85	9.0	6.0
8D	1 : 4	1.250	185000	37000	35	90	9.5	7.0
9	1 : 6		203000	27000	29	43	5.0	2.7
9D	1 : 6		200000	28000	32	46	5.0	3.0
10	1 : 3		205000	42000	37	112	12.0	9.0
11	1 : 4	1.375	215000	38000	35	87	8.5	7.0
12	1 : 6		232000	29000	32	47	5.5	2.8
13	1 : 3		190000	43000	38	120	13.0	10.0
14	1 : 4	1.500	198000	37000	35	95	10.0	7.5
15	1 : 6		225000	28000	31	46	5.0	3.0

* D indicates duplicate tests.

TABLE 2

Comparison of results

Specimen no	H_{ue} (t)	$\frac{H_{ce}}{H_{ue}}$	S_c t/cm	S_c/S_s $H = \frac{1}{4} H_u$	S_c/S_s $H = \frac{1}{2} H_u$	$\frac{S_c}{S_m}$	$\frac{S_c}{S_{sm}}$	$\frac{S_c}{S_p}$	$\frac{H_{ue}}{H_{us}}$	$\frac{H_{ue}}{H_{um}}$	$\frac{H^t_{ue}}{H^t_{up}}$	$\frac{H^s_{ue}}{H^s_{up}}$
	1	2	3	4	5	6	7	8	9	10	11	12
1	5.00	0.64	31	0.76	0.88	1.94	0.53	1.03	0.46	0.36	0.93	
1D	5.80	0.60	26	0.65	0.76	1.73	0.45	0.90	0.58	1.07	1.07	
2	4.50	0.60	25	0.74	0.86	1.92	0.50	1.00	0.60	0.82	1.02	
2D	4.00	0.50	25	0.74	0.86	1.92	0.50	1.00	0.56	0.75	0.95	
3	2.73	0.83	20	0.74	0.91	2.00	0.51	1.05	0.93	0.58	-	1.02
3D	2.90	0.52	18	0.69	0.86	1.80	0.47	0.95	1.00	0.67	-	0.92
4	6.50	0.66	31	0.69	0.84	1.94	0.52	0.97	0.62	1.07	1.10	
5	4.20	0.75	26	0.67	0.81	1.85	0.49	0.96	0.48	0.72	0.82	
6	3.12	0.58	21	0.66	0.81	1.91	0.51	0.96	0.93	0.55	-	1.01
7	6.40	0.71	35	0.74	0.87	1.94	0.51	1.03	0.63	1.06	1.00	
7D	6.50	0.69	32	0.68	0.80	1.73	0.46	0.94	0.63	1.07	1.02	
8	4.95	0.67	29	0.72	0.85	1.93	0.51	1.03	0.67	0.82	0.94	
8D	5.70	0.70	31	0.74	0.89	1.94	0.53	1.03	0.66	0.99	1.02	
9	2.93	0.76	23	0.72	0.88	1.92	0.51	1.04	0.85	0.53	-	0.94
9D	3.60	0.83	25	0.76	0.89	2.08	0.54	1.09	0.94	0.60	-	1.03
10	6.15	0.70	35	0.74	0.84	1.95	0.51	1.03	0.59	0.93	0.89	
11	4.50	0.75	32	0.69	0.82	1.88	0.49	0.97	0.46	0.69	0.84	
12	3.40	0.58	25	0.69	0.81	1.92	0.49	0.96	0.36	0.53	-	0.96
13	8.48	0.85	40	0.75	0.89	2.00	0.50	1.00	0.81	1.19	1.15	
14	7.28	0.88	34	0.75	0.89	2.00	0.52	1.00	0.71	1.05	0.93	
15	4.18	0.76	27	0.73	0.90	2.08	0.52	1.00	0.93	0.64	-	1.02