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INPLANE DISTORTION OF UNREINFORCED MASONRY PANELS INFILLING RC FRAMES

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ABSTRACT

Since excessive and uncontrolled lateral displacements can create severe structural damage in high-rise buildings, lateral drifts have been codified in various building codes. The present study investigates the inplane distortion of reinforced concrete (RC) frames infilled with unreinforced brick masonry panels subjected to inplane lateral loading. Tests were conducted on one-third scale RC infilled frames in order to examine the effect of the height-to-length ratio, H/L, and the beam-to-column moment of inertia ratio, I_b/I_c, on inplane distortion of the composite system. Ultimate distortions are compared to common values of interstorey drifts specified by various codes including UBC-85, BOCA-87 and NBCC-90. In addition to analyzing experimental results with respect to distortion at the occurrence of the first crack and ultimate strength, the study presents formulations which can be used to predict the load sustained by an open RC frame due to lateral loading.

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INTRODUCTION

Masonry panels infilling reinforced concrete or steel frames are vulnerable to inplane distortions caused either by lateral displacements in buildings under wind or seismic action or by vertical movement of supports due to differential settlement of foundations. In recent earthquakes, most extensive damage had derived from cracking of masonry partitions or infills whose flexibility had given rise to lateral displacements exceeding those tolerable by masonry. Codes specify allowable interstorey drifts in order to provide structures which are sufficiently stiff and ductile to avoid excessive structural damage. Since these limitations are mainly related to damageability of masonry panels (Meli, 1982) quantitative information in this regard is needed in order to assess the code requirements with respect to the actual performance of RC infilled frames. Little information has been reported on distortion of various configurations of masonry infilled frames to date. This paper presents the results of an experimental study designed to assess the distortion of infilled frames subjected to inplane lateral loads.

EXPERIMENTAL PROGRAM

In order to investigate the general behaviour of RC frames infilled with masonry panels, an extensive experimental program was initiated and is currently in progress. This program is aimed at assessing the effects of various parameters including the aspect ratio, *H/L*, the ratio of beam-to-column moment of inertia, I_b/I_c, and the presence of an opening on various aspects of the behaviour of infilled RC frames. In the present paper, findings related to inplane distortions with respect to cracking of infills and ultimate state of the composite structural system is reported. Experiments have been arranged in factorial design of 2 x 2 x 3 with three replicates as shown in Table 1. In order to accommodate existing testing facilities, tests were conducted on one-third scale specimens. In total, 36 specimens were cast and stored in a laboratory environment for testing.

Table 1. Parameters under investigation

Aspect Ratio *H/L*	Moment of Inertia ratio $I_r = I_b/I_c$	Opening Size*
R	1	B
S	5	W
		P

* R: Specimen with H/L= 0.5 S: Specimen with H/L=1
B: Open frame W: Infill with door opening P: Infilled Frame

Ten days after casting the RC frames, an experienced mason installed masonry panel infills. On the day of testing, specimens were moved from the curing area to the testing room and set in a universal testing machine with a capacity of 900 kN. Special care was taken during handling and, in order to reduce stress concentration during testing, masonite pads were inserted between the machine head and the specimen. The specimen configuration consisted of one-storey, one-bay RC infilled frames constructed according to the experimental design outlined above. The reinforced concrete frames were built according to CAN-3 A-23-3 M84 and ACI 318-83 as applicable. Rebars were #10M and #15M while stirrups were made of galvanized 9WG steel wire of 3.9mm diameter. Concrete was modelled by microconcrete whose mix proportion was obtained after a series of trial mixes.

TEST SETUP AND INSTRUMENTATION

In order to simulate the behaviour of infilled frames subjected to inplane forces, specimens were compressed along one diagonal from corner to corner. This procedure has been successfully used by numerous investigators including Polyakov 1956, Simms 1967, Smith 1966 and Esteva 1966. The load was increased in monotonic fashion up to failure while a series of parameters including the change in specimen diagonal lengths were monitored by providing linear strain convertors (LSC) along two diagonal directions as shown in Fig. 1. At each load increment, readings were recorded by a data acquisition system. Progressive cracking was traced at each load increment and reported on a chart. Specimens were loaded until they underwent substantial damage due to corner crushing, complete failure of the masonry panel, or distortion.

TEST RESULTS AND DISCUSSION

Interstorey Drift Index

To ensure safety and comfort in the use of buildings subjected to lateral loads, present codes prescribe allowable lateral displacements which are applicable to part or all of a structure. These allowable limits (interstorey drift indices) are mostly given in terms of the ratio of relative lateral displacement of a particular level to associated storey height representing inplane lateral distortion of the composite system.

The maximum interstorey drift index required by UBC-85 and BOCA-87 is 0.005 for seismic action while the National Building Code of Canada (NBCC-1990) limits it at 0.002 for wind and gravity loads. In addition, both NEHRP-85 and NBCC-90 specify 0.01 as the upper interstorey drift limit for earthquake post-disaster buildings whereas they allow different values for all other buildings namely 0.015 and 0.02 respectively.

Test Results

Tests were performed on thirty-six specimens with a series of measurements taken along the diagonals of respective test units. Subsequently, from these experimental data, inplane distortions, γ_{cr}, at the occurrence of the first crack in the masonry panel and γ_{ult}, at the ultimate strength of the infilled frame were derived. The distortion, γ, is the change in the right angle at the loaded corner between a column and a beam. The average distortion from each specimen group is summarized in Table 2.

Discussion

Inspection of the load vs distortion diagrams of various open frames revealed that the inplane distortion of open frames can be used to estimate the load resisted by an open frame in an infilled frame configuration.

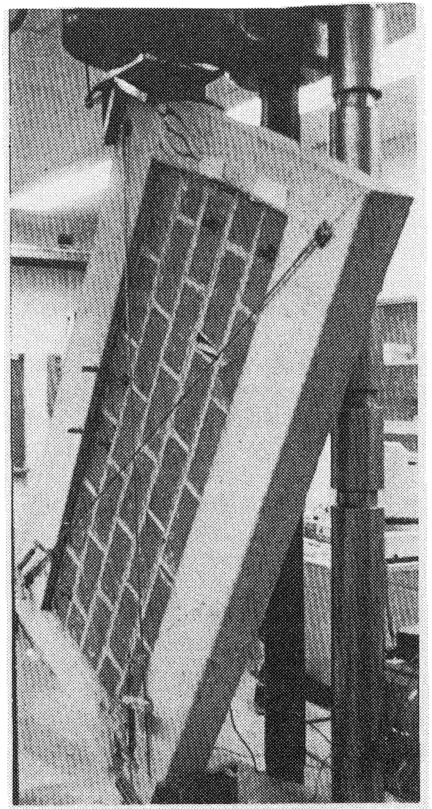

Fig. 1. Test setup and Instrumentation.

Table 2. Summary of Results

Specimens*	Distortion (x 10^{-3} rad)	
	γ_{cr}	γ_{ult}
S1B	-	10.4
S1W	2.2	9.4
S1P	0.9	11.5
S5B	-	14.3
S5W	3.7	12.8
S5P	0.7	14.6
R1B	-	23.5
R1W	1.4	52.8
R1P	1.3	23.6
R5B	-	12.4
R5W	1.8	67.4
R5P	1.1	45.1

*Specimens are designated according to Table 1.
1 and 5 refer to moment of inertia ratios, I_b/I_c.

Regression analyses performed on racking load vs distortion data obtained from different open frame specimens suggested that the best curve fit is a forth degree polynomial. In a normalized form, the relationship yields an expression of the form:

$$\frac{N}{N_{ult}} = a_o + a_1 \frac{\gamma}{\gamma_{ult}} + a_2 \left[\frac{\gamma}{\gamma_{ult}}\right]^2 + a_3 \left[\frac{\gamma}{\gamma_{ult}}\right]^3 + a_4 \left[\frac{\gamma}{\gamma_{ult}}\right]^4 \qquad [1]$$

where N is the racking force, N_{ult} is the ultimate strength of an open frame, γ_{ult} is the inplane angular distortion at N_{ult}, and γ is the actual distortion at racking force N.

The coefficients applicable to different types of open frames are given in Table 3. Each value, a_i, was determined from results obtained from three similar specimens.

Results indicate that the first crack in a rectangular infill panel occurs at a constant distortion of approximately *0.0014 rad* for specimens with an aspect ratio of 0.5 (rectangular) while it is consistently greater than *0.002 rad* for square specimens (H/L=1) with panels provided with a doorway.

Table 3: Polynomial coefficients

Test units*	a_o	a_1	a_2	a_3	a_4	N_{ult} kN	γ_{ult} 10^{-3} rad
S1B	-0.04134	1.6575	-0.70012	0.03379	0.01785	12.78	10.37
S5B	0.014455	2.4419	-2.19	0.82659	-0.11852	20.15	14.33
R1B	0.003575	2.0418	-1.315	0.27389	-0.01054	21.33	23.55
R5B	0.026814	2.0852	-1.483	0.38059	-0.03313	26.70	12.37

*The designation of the test units refers to Table 1.

The value is less than *0.001 rad* for square specimens with solid infill. A further analysis reveals that none of the investigated parameters had a significant effect on the distortion at the occurrence of the first crack. Similar observations have been reported by Meli 1982. The maximum observed value of γ_{cr} was *0.0037 rad.* For square specimens, the first crack of specimens provided with an opening occurred at a distortion ranging from 20 to 25 percent of the ultimate distortion of a related open frame while it dropped markedly in a range of 5 to 8 percent for test units with solid infills. Although rectangular frames with solid infills had their first crack within almost the same range as square specimens (6 to 9%), γ_{cr} for those provided with a doorway occurred within a lower range of 6 to 15 percent. In addition, it was noticed that, after the occurrence of the first crack, the stiffness of a composite system deteriorates up to the ultimate capacity of the test unit followed by a strength degradation accompanied by an extensive inplane distortion.

Among the parameters investigated in this study, only the aspect ratio, H/L, and the presence of openings in infilled frames significantly affect the ultimate distortion, γ_{ult}. This effect is more pronounced for rectangular frames with door openings than for square units. The ultimate distortion of rectangular test units attained more than twofold that of corresponding open frame.

While the ultimate distortion of square specimens (H/L=1), increases slightly with inertia ratio I_b/I_c, experimental data show that γ_{ult} steps up for rectangular test units (H/L=0.5). The greatest increase is recorded for those specimens with door openings.

Among square specimens with the same inertia ratio, I_b/I_c, the ultimate distortion did not change noticeably with respect to that of an open frame in the same category. However, for rectangular frames with panels provided with door openings, γ_{ult} was more than twice that of an open frame of the same type. In addition, for rectangular frames with continuous panels, it was one to four times that of a corresponding open frame.

Regarding the wind action, the interstorey drift index allowed by NBCC-90 was found to be in good agreement with respect to the occurrence of the first crack in the infill panel. For seismic action, UBC-85 and BOCA-87 are more restrictive than NEHRP-85 and NBCC-90 which allow realistic values of relative lateral displacements of structures. Figures 2 to 5 illustrate typical experimental curves plotted in the (N, γ) plane for different specimens groups. Each plot includes three curves which relate to RC frames infilled with either a continuous masonry panel (*Infilled Frame*) or a panel provided with a door opening (*Door Opening*) along with a curve which shows the response of an open frame (*Open Frame*). For comparison to experimental values of γ_{cr} and γ_{ult}, requirements prescribed by UBC-85, BOCA-87, NEHRP-85 and NBCC-90 are indicated by vertical lines.

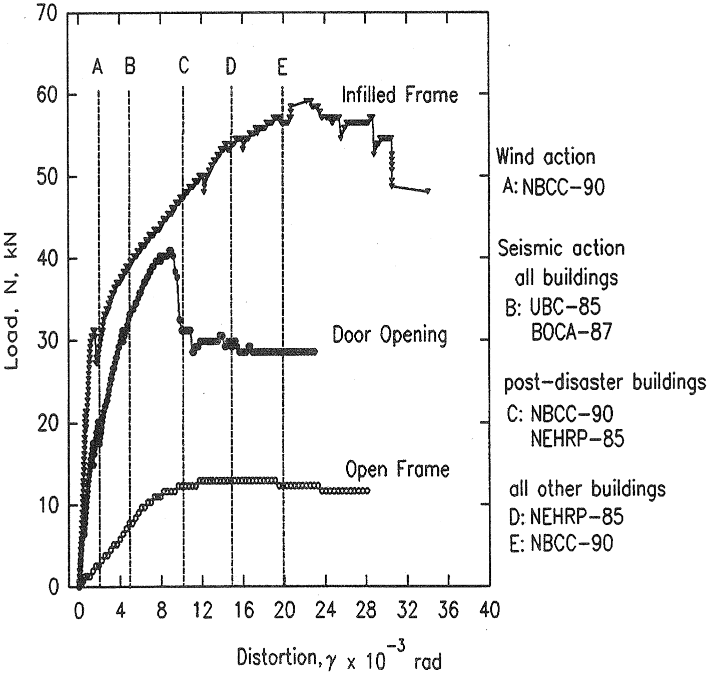

Fig. 2. Horizontal Load vs Shear Distortion for S1 Specimens

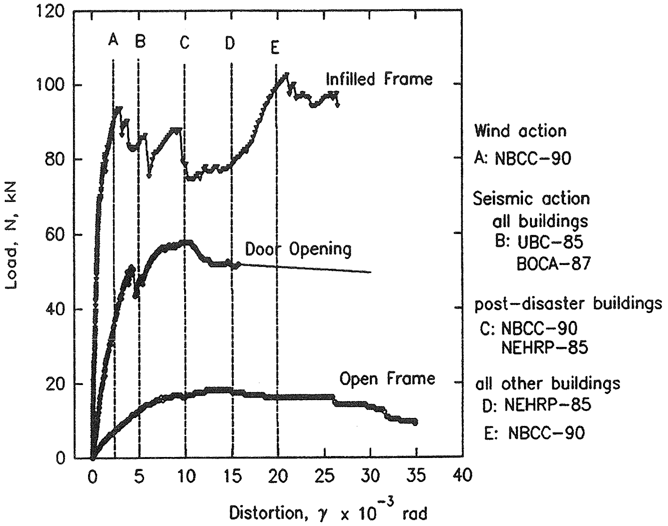

Fig. 3. Horizontal Load vs Shear Distortion for S5 Specimens

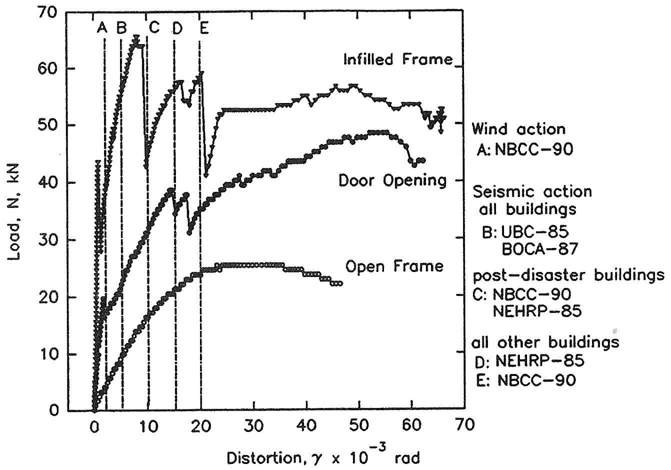

Fig. 4. Horizontal Load vs Shear Distortion for R1 Specimens

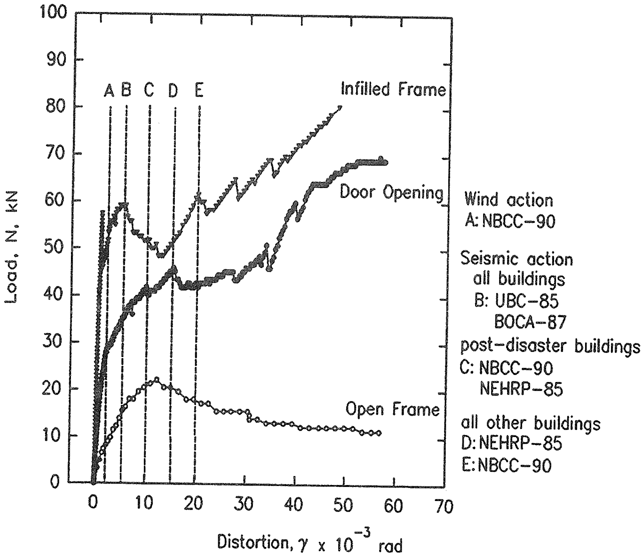

Fig. 5. Horizontal Load vs Shear Distortion for R5 Specimens

Actual results show that ultimate distortions, γ_{ult}, of square infilled frames fall within a range of 0.01 to 0.015. To mobilize all their strength, rectangular infilled frames (H/L=0.5) undergo extensive distortion which may reach more than three times the ultimate distortion of similar bare frames. The presence of a door opening in these units increases γ_{ult} significantly leading to an interstorey drift index of 0.07 which is greater than provisions allowed by existing building codes.

CONCLUSIONS

An analysis of the test results indicates that, among investigated parameters only the aspect ratio and the presence of a doorway opening significantly affect the ultimate distortion of RC infilled frames. In general, rectangular specimens with a door opening underwent greater ultimate distortion compared to square test units. The distortion at the first crack was not markedly affected by the studied parameters. A formulation which relates the racking force to inplane distortion for various types of open frame has been proposed. While for γ_{cr}, the actual experimental data show that the limitation required by NBCC-90 is likely, values specified by UBC-85 and BOCA-87 are conservative with respect to provisions related to seismic action. In addition, for seismic requirements, NEHRP-85 and NBCC-90 specifications are in good agreement with performances of square infilled RC frames while they are conservative regarding rectangular infilled frames. Excluding post-disaster buildings, building codes should allow greater interstorey drift indices for rectangular infilled frame configurations with H/L=0.5.

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