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AN EXPERIMENTALLY OBTAINED METHOD FOR EVALUATION OF THE BEHAVIOUR OF MASONRY INFILLED R/C FRAMES

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SUMMARY

On the basis of analysis of the behaviour of masonry infilled R/C frames subjected to cyclic lateral loading a simple method for evaluation of fundamental parameters of lateral resistance and deformability is proposed. Alltogether 28 specimens have been tested. 9 of them repaired after finished tests in original state and then retested in order to study the effect of different repair and strengthening techniques. The effect of different types of unreinforced and reinforced infill on lateral load-carrying capacity and stiffness, ductility, strength and stiffness degradation and deterioration, and energy absorption and disipation capacity has been investigated.

INTRODUCTION

Mixed structural systems constructed of materials which have different mechanical properties should be carefully designed to resist earthquakes. When subjected to earthquake loading, interaction forces develop between different structural systems. If not taken into account in a proper way, those forces can result into an unexpected behaviour of the structure.

R/C frame-work represents a very frequent structural system. In the current design practice, however, the effect of filler-wall on the basic frame system is in most cases neglected. This sometimes causes severe damage or failure of individual structural elements or even the collapse of whole buildings. However, the filler-wall, although constructed as a secondary structural element, has in general beneficial influence on the behaviour of a framed structure. The experiences gained during Mexico City, 1985 earthquake show that in many cases filler-walls have prevented the collapse of high buildings. Therefore, the understanding of interaction mechanism between masonry filler-wall and basic R/C frame structure is of relevant importance.

EXPERIMENTAL INVESTIGATIONS OF MASONRY INFILLED R/C FRAMES

Altogether 28 specimens, divided into four different groups, have been so far tested at the Institute for Testing and Research in Materials and Structures (ZRMK) in Ljubljana :

- group I: 1 bare frame and 3 infilled frames with clay-brick masonry filler-walls, constructed in 1:2 reduced scale;

- group II: 1 bare frame and 8 infilled frames with concrete-block masonry filler-walls, constructed in 1:3 reduced scale;
- group III: 6 infilled frames with concrete-block masonry filler-walls, 2 specimens having window an 2 specimens having door openings;
- group IV: repaired and strengthened specimens of group II.

Different kinds of filler-walls, both unreinforced and horizontally reinforced, some of them connected to the frame, have been compared in the investigations. Two basically different methods of repair have been used in the case of group IV specimens: the epoxy-grouting of filler-wall and the combination of epoxy-grouting and application of reinforced-cement coating on both faces of infill.

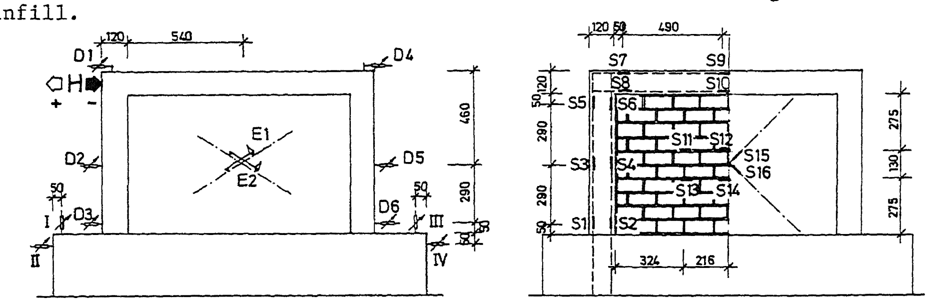


Fig.1: Typical specimens and instrumentation

The behaviour of tested specimens can be explained by analysing lateral load-lateral displacement and lateral load - strain of the frame and infill reinforcement relationship. The characteristic hysteresis diagrams are shown in Fig.2. Average values of lateral resistance and initial stiffness of tested frames ($H_{u,f}$, $K_{e,f}$) and tested infilled frames ($H_{u,if}$, $K_{e,if}$), as obtained from the diagrams and compared to the calculated values, are shown in Table 1.

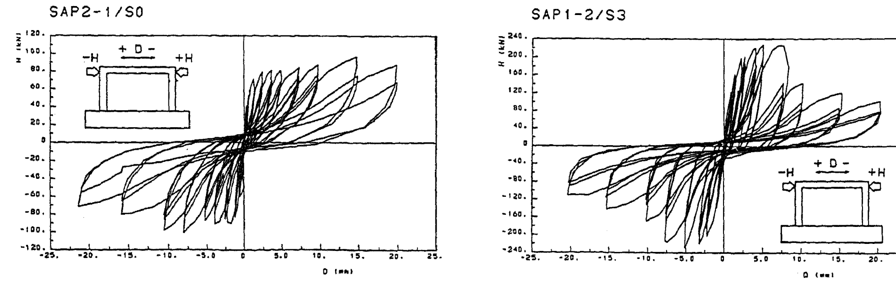


Fig.2: Lateral load - lateral deformation hysteresis loops of epoxy-grouted infilled frame and epoxy-grouted and concrete-coated infilled frame

On the basis of analysis of test results, the main characteristics of behaviour of different types of virgin and repaired infilled frames can be determined. Lateral resistance and stiffness of infilled frames are significantly greater than those of the bare frames. In most cases, lateral resistance of the structure has been attained at approximately 25% of the corresponding lateral deformation of the bare frame. Type of construction of filler-wall does not influence the behaviour of infilled frame to such an extent as is the case of quality of infill material and quality of contact between the frame and the filler-wall, or of the openings in filler-walls. Significant influence of infill reinforcement on the behaviour of specimens has been observed only in case of infilled frames with openings. Significant strength deterioration at repeated load reversals has been observed, especially after the attainment of lateral resistance of the entire structure. During the second cycle of loading, only 75% of lateral resistance obtained in the first cycle of loading has been attained. However, the process of strength deterioration tends to stabilize after the third cycle of loading.

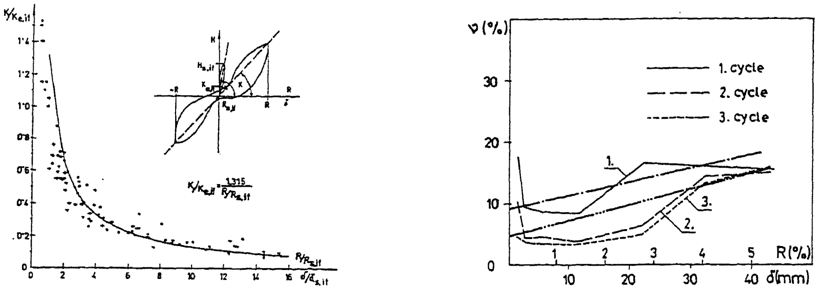


Fig.3: Stiffness degradation and eqivalent viscous damping ratio in dependance on lateral deformations

Change in hysteretic behaviour of the infilled frames has been observed at repeated lateral loading at the same displacement amplitude. It has been found, that energy absorption capacity during the first cycle of loading is 80% greater than energy absorption capacity during the subseqqent cycles of loading. The values of equivalent viscous damping ratio are also decreasing accordingly.

Table 1: The load capacity and initial stiffness

		Group I		Group II		Group III				Group IV	
		F.	I.F.	F.	I.F.	I.F.	I.F.W.	I.F.D.	R.F.	G.I.	C.I.
$H_{u,f}$	T	151	349	41	59	93	75	78	35	92	210
$H_{u,if}$	C	157	369	40	62	92	74	80	34	92	205
(kN)	T/C	0.96	0.95	1.03	0.95	1.01	1.01	0.98	1.03	1.00	1.02
$K_{e,f}$	T	12	354	3.7	84	147	83	96	3.4	206	217
$K_{e,if}$	C	11	361	6.8	85	169	96	103		209	194
(kN/mm)	T/C	1.09	0,98	0,54	0.99	0.87	0.86	0.93		0.98	0.99

F.-frame, I.F.-infilled frame, I.F.W.-infilled frame with window opening, I.F.D.-infilled frame with door opening, R.F.-repaired frame, G.I.-epoxy-grouted infill, C.I.-epoxy-grouted and coated infill, T - test results, C - calculated values

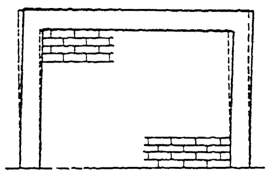
ANALYTICAL APPROACH

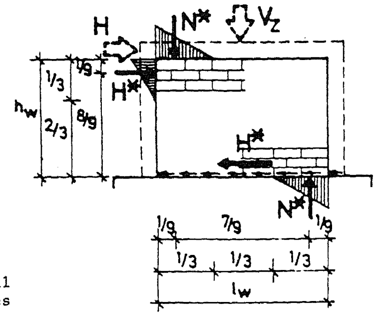
By analysing the behaviour of tested specimens, a simple model for the calculation of fundamental parameters of lateral resistance and deformability (hysteresis envelope) has been proposed. The equations for evaluation of fundamental parameters have been derived by observing the behaviour of tested specimens in the small and large deformations range. The parameters are expressed as function of dimensions of the constituent elements of infilled frame structure, mechanical characteristics of used matherials and experimentally obtained parameters which depend on the interaction forces action between the frame and infill. The values of parameters depend on the quality of contact between the frame and infill and type of infill. C_I is parameter, which depends on position of resultant of interaction forces. C_E denotes the level of contribution of frame to the stiffness of infilled frame structure and may varies from 1 in the case of perfect frame to infill contact to 0 in the case of slipping gap between the contact surfaces of frame and infill. C_R is infill lateral resistance reduction factor. It has different values for different types of infill.

Small deformations range. The lateral resistance of the infilled frame is determined by the lateral resistance of infill ($H_{s,if}$), subjected to combined vertical and lateral loading (Eq.1). Lateral stiffness of the entire structure is modelled with lateral stiffness of a cantilever shear-wall, composed of frame columns and filler-wall. (Eq.2).

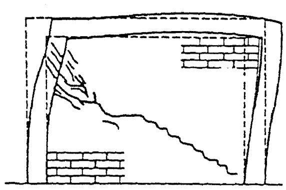
$$H_{s,if} = (A_{if}\ f_{t,if}/\ C_I\ b)\ (1 + (C_1^{\ 2}\ (1 + \sigma_{oz}/\ f_{t,if}) + 1)^{\ 0.5}) \qquad (1)$$

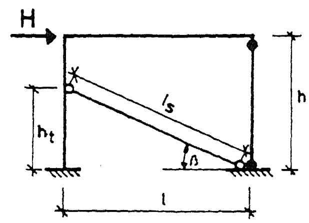
$$K_{e,if} = ((h^3/3\ E_{if}\ I_e) + (\kappa\ h_{if}/G_{if}\ A_e))^{-1} \qquad (2)$$





Behaviour of infilled frame before the separation of infill and assumed distribution of external and interaction forces





Behaviour of infilled frame after the separation of infill and assumed bracing of frame with lower, triangular part of wall

Fig.4: Mechanism of the infilled frame behaviour

The tensile strength ($f_{t,if}$) of coated filler-wall.can be expressed with the tensile strength of masonry infill ($f_{t,w}$) and concrete coating ($f_{t,c}$)(Eq.3), or with the tensile strength of masonry infill and reinforcement of coating ($f_{y,cr}$) (Eq.4). The higher value should be taken into account calculating the lateral resistance of structure.

$$f_{t,if} = (A_w\ f_{t,w} + A_{wc}\ f_{t,c})/\ A_{if}\ , \qquad A_{if} = A_w + A_{wc} \qquad (3)$$

$$f_{t,if} = (A_w\ f_{t,w} + A_{cr}\ f_{y,cr})/\ A_{if}, \qquad A_{if} = A_w + A_{cr} \qquad (4)$$

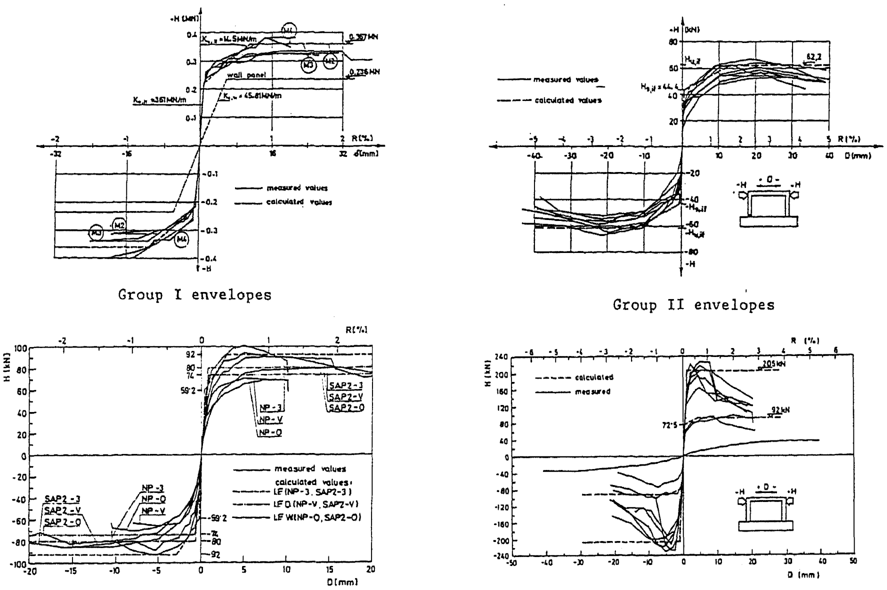
The Eq.1 expresses the lateral resistance of filler-wall as well as lateral resistance of each pier in the case of infilled frames with openings. Constant C_I (Eq.5), which depends on the assumed position of the resultant of interaction forces and on the value of shear stress distribution factor (b) has a different value for windward and leeward pier. In the paper the values of α= 7/8 for windward pier, and α= 7/9 for leeward pier have been assumed for the calculation.

$$C_I = 2\ \alpha\ b\ l_{if}/h_{if} \qquad (5)$$

The value of the effective horizontal cross-sectional area (A_e) and moment of inertia (I_e) of the infilled frame (Eqs.6 and 7) is influenced by the quality of contact between the frame and filler-wall (C_E). In the case of extremely good contact (achieved in the case of specimens of Group I), C_E= 1. In other cases, however, the valuesof C_E can vary between 1 and 0. According to test results, the following values of C_E have been taken into account: specimens withouth openings (Group II and III) C_E= 0,4, specimens with openings C_E= 0.25, specimens with epoxy-grouted filler-wall C_E=0.5, and specimens with epoxy-grouted and coated filler-wall C_E=0. In the last case the avarage stiffness of tested specimens has been equal to the stiffness of coatings itself.

$$A_e = A_{if} + 2\ C_E\ A_{fc}\ (G_f/G_{if}) \tag{6}$$

$$I_e = I_{if} + 2\ C_E\ (E_f/E_{if})\ (I_{fc} + 0.25\ A_{fc}\ l^2) \tag{7}$$



Group I envelopes

Group II envelopes

Group III envelopes

Group IV envelopes

Fig.5: Comparison between the calculated and experimentally obtained hysteresis envelopes

Large deformations range. After the separation of filler-wall, lateral resistance of the system is determined by the lateral resistance of the frame (Eq. 8). Two different failure mechanisms of the frame have been observed: in the first case, plastic hinges developed at the bottom and the top of leeward column (M_y), whereas windward column failed in shear (Q_y) due to short column effect (Eq.9). In the second case, however, plastic hinges developed at the bottom and the top of both frame columns (Eq.10). The lateral resistance of repaired frame is lower than lateral resistance of original frame, what is expressed with reduction factor C_F in Eq.8. The contribution of filler-wall is added, depending on the mechanism of separation of filler-wall. For this purpose lateral resistance of the infill is reduced by experimentally obtained capacity reduction factor C_R.

$$H_{u,if} = C_F\ H_{uf} + C_R\ H_{s,if} \tag{8}$$

$$H_{u,f} = (2\ M_y/h) + Q_y \tag{9}$$

$$H_{u,f} = 4\ M_y/h \tag{10}$$

Lateral stiffness of the structure depends on lateral stiffness of the plastic hinged frame, which may be, according to the mechanism of the separation of the filler-wall, laterally supported by the undamaged part of the infill, which is analytically represented with equivalent diagonal strut (Eqs. 11 and 12).

$$A_s = K_t \, l_{if}/E_{if} \tag{11}$$

$$K_t = ((5 \, h_t^3/12 \, E_{if} \, I_{if}) + (\kappa \, h_t/2 \, G_{if} \, A_{if}))^{-1} \tag{12}$$

In the case of specimens with openings and with coated filler-wall mechanism of bracing of frame by triangular part of infill has not been so obvious as in cases of filler-walls withouth openings and coating. Therefore, it is suggested, that only initial effective stiffness and lateral load capacity are the parameters defining the bilinear diagram. In other cases the triliner diagram is describing the behaviour of infilled frames in linear and nonlinear range.

CONCLUSIONS

Good analytical results can be obtained by means of the proposed model, the correlation between the experimental and analytical values being in the range of 10% . The calcualted hysteresis envelope represents the hysteresis envelope of the first cycles of loading. Therefore, when analysing the behaviour of masonry infilled frame structures subjected to earthquake loading conditions, the phenomena of strength and stiffness degradation and deterioration as well as the deterioration of energy absorption capacity must be properly taken into account.

Infilled frames damaged by severe earthquake can be repaired and strengthened in order to be able to resist future possible earthquake loadings. By means of epoxy-grouting of the infill both lateral stiffness and load-bearing capacity of the structure are moderately improved. In that case, overall behaviour of the repaired structure remains similar to the behaviour of the original structure. By means of epoxy-grouting and reinforced-concrete coating of the infill lateral load bearing capacity and lateral stiffness of the structure improve significantly. However, they deteriorate very severely after the attainment of their maximum value. When repairing and strengthening masonry infilled R/C frames damaged by an earthquake the effects of various techniques for repair and strengthening must be adequately taken into account.

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REFERENCES

1. R.Žarnić, M.Tomaževič: "Study of the Behaviour of Masonry Infilled Reinforced Concrete Frames Subjected to Seismic Loading", 7 - th International Brick-Masonry Conference, Melbourne, 1985, Vol.2, p. 1315-1325;

2. R.Žarnić, M.Tomaževič,T.Velechovsky: "Experimental Study of Methods for Repair and Strengthening of Masonry Infilled R/C Frames", 8 -th European Conference on Earthquake Engineering, Lisbon, 1986, Vol.5, p.11.1/41 -11.1/48.