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Experimental and analytical studies of infill walls in reinforced concrete structures

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ABSTRACT: In order to define the dynamic behaviour of infill walls, as individual elements and within the structure, for different levels of seismic intensity, experimental and analytical studies on four three-storey single-span frame models with infill of masonry, syporex, gypsum, and eltozol have been carried out. Also, a three-storey frame model without infill was tested, in order to define the characteristics of the main structural system and to enable a comparative analysis. Applying an adequate computer software the experimental and analytical results have been processed and analysed. The most important, out of them, are presented in this paper.

1. INTRODUCTION

The infill applied in reinforced concrete frame structural systems represents an important element influencing the behaviour and the stability of a structure under seismic effect, particularly in case of flexible structural systems, such as reinforced concrete frame structures with a moderate number of storeys or high-rise buildings. Although considered as a non-structural element, the infill plays an important role in sustaining part of the seismic forces, the increase in rigidity, during the initial loading phase, and it defines to a considerable extent the vulnerability level, both from technical and economic aspect.

The modern philosophy of earthquake resistant design of structures means application of structures capable of seismic energy absorption and dissipation, which, at the same time satisfy the stability and vulnerability criteria. From the viewpoint of strength and deformability state of the structures, this approach can be illustrated in the following way:

- Under the effect of moderate and small intensity earthquakes, the structure behaves in elastic range, i.e., under the boundary of plastic deformations.
- In the case of strong earthquakes,, the main structural system behaves under the conditions of controllable nonlinear deformations, when no failure of the structural system occurs. This condition corresponds to relatively high storey drifts, which, usually, cannot be sustained by the infilling, that is manifested by its damage.

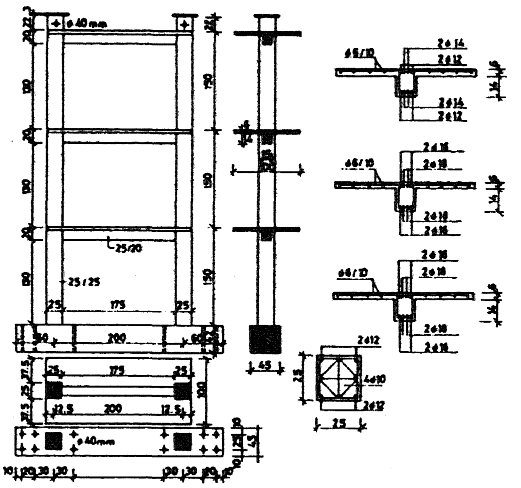
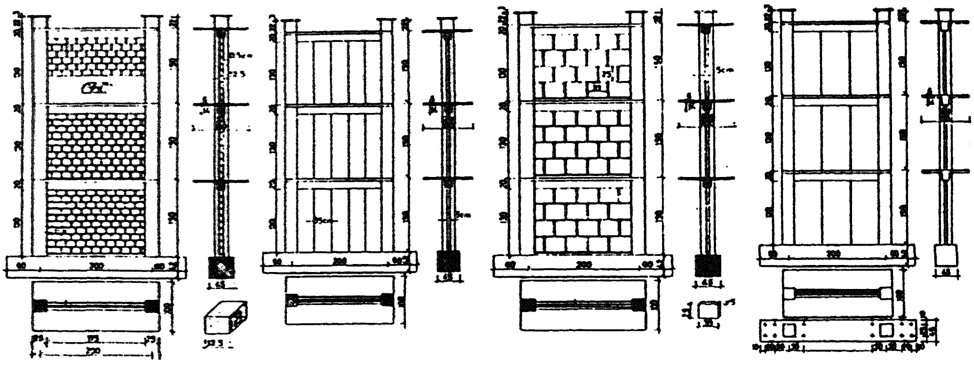


Figure 1. Reinforced-concrete frame model (Model 1).

The design practice to neglect the infill during the formulation of mathematical models and the analysis of the structural resistance, points to the inadequate treatment of the infilling both in elastic and nonlinear range of structural behaviour. The infilling modifies, significantly, the dynamic characteristics of structures, from the calculated ones, when the structure is considered taking into account only the main load carrying system. In the case of maximum intensity ground motions, when nonlinear behaviour is expressed through energy absorption and dissipation, the infill can be of crucial importance, since it causes modification of the behaviour of the main structural system through energy accumulation at some of the floors, change in


M2 – Infilled Massonry

M3 – Infilled Syporex

M5 – Infilled Eltozol

M4 – Infilled Gypsum

Figure 2. Frame infilled models.

damping, etc. On the other hand, the interaction between the infill and the frames may disturb the local stability of the individual structural elements, changing the basic geometry, by forming short elements, susceptible to failure as brittle intersections of shear forces or failure of joints.

All this, imposes the need for investigation of the infill, which is being applied, with the main purpose to provide a more realistic definition of the behaviour and the effect of the infill during the earthquake action. Within the scope of the complex investigation program on the behaviour of the infill, experimental and analytical studies have been performed on three-floor frame models with masonry infill and various industrial prefabricated materials, which have been used in practice.

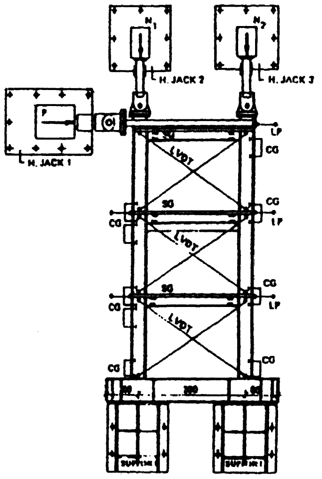


Figure 3. Position of models during testing, arrangement of equipment and instrumentation

2. PROGRAM OF EXPERIMENTAL INVESTIGATIONS

The program for experimental investigation of the infill stability of reinforced concrete structural systems includes, also, definition of the mechanical characteristics of the materials used for the infill and the structure, as a prerequisite for determination of the strength and deformability characteristics, required for understanding of the physical patterns of behaviour and formulation of the mathematical models.

A typical building has been selected out of the residential buildings designed and planned for wide construction. Analytical study of the behaviour of the structure with and without infill has been carried out, and on the basis of the obtained results selection of the most characteristic fragments of the building (floors, frames, infill) has been performed. For the selected fragments, models in a realistic scale 1:2 have been designed (Model 1, Fig. 1) corresponding to the prototype building.

For the construction of the models, masonry, syporex, gypsum and eltozol have been used as construction materials, which cover entirely all the materials applied for this purpose. The characteristics of the basic material have been determined for each of these types of materials, as well as the characteristics of the masonry fragments, through studying and definition of the modulus of elasticity and the shear modulus and for the combined effects through compressive shear tests.

Design and construction of three-storey single-span frame models, without infill (Model 1) and with masonry infill (Model 2), syporex (Model 3), gypsum (Model 4) and eltozol (Model 5) has been carried out, as presented in Fig. 2. For comparative analysis, a frame model without infill has been constructed in order to define the characteristics of the basic system (Model 1).

The model (element) set-up during the

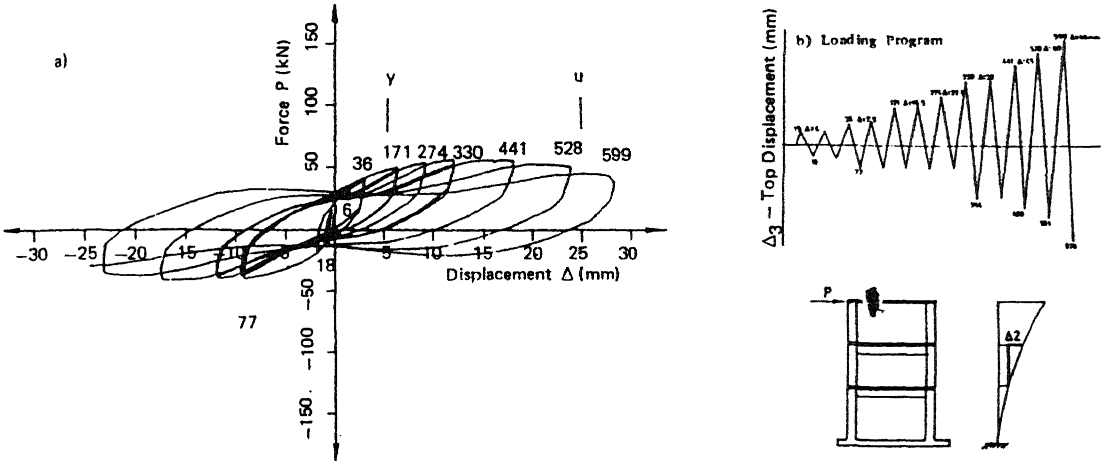


Figure 4. P-Δ relationship for the frame without infill (M1).

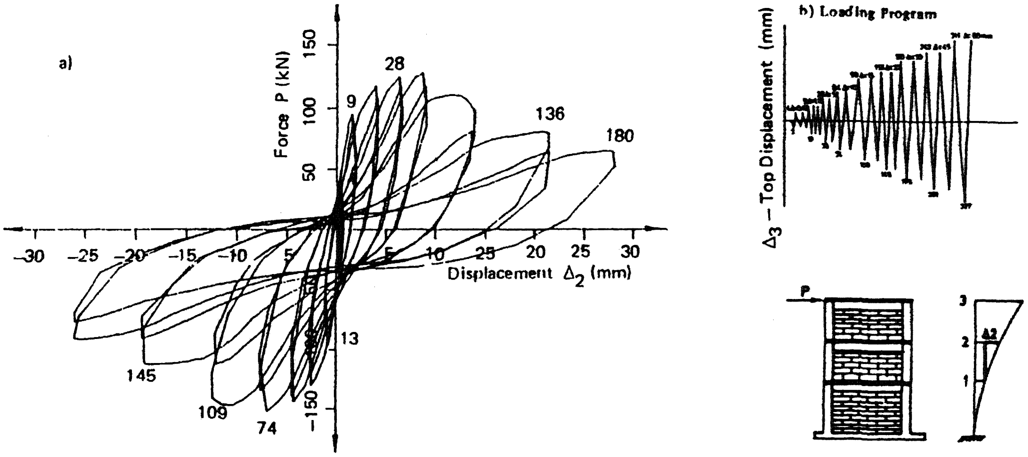


Figure 5. P-Δ relationship for the frame with infilled masonry (M2)

testing is shown in Fig. 3. The testing is carried out by simulation of gravity loads (jacks 2 and 3) and simulation of the earthquake effect through a variable cyclic horizontal force, with gradual increase of the amplitude following a loading programme, until reaching the level of the programmed deformations (jack 1). Applying external instrumentation with modern equipment (LVDT, LP) and internal instrumentation with clip gages and strain gages, the change in the state of the model is controlled, through 42 input channels, by whose adequate processing and combination, the absolute and the relative storey drifts, the change in the strains and the stresses are obtained for each characteristic cross section. The tests have been performed applying an automatic data control and acquisition computer system at the Dynamic Testing Laboratory of the Institute of Earthquake Engineering and Engineering Seismology in Skopje.

3. RESULTS FROM EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS

For interpretation of the test results, the most characteristic parameter for the integral behaviour are the hysteretic loops, i.e., the relationship between the shear forces and the relative storey drifts during the whole loading time.

In Fig. 4a it is presented the hysteretic loop for relationship between force and the relative displacement of the second floor of the frame model without infill (Model 1), obtained by the attached loading program

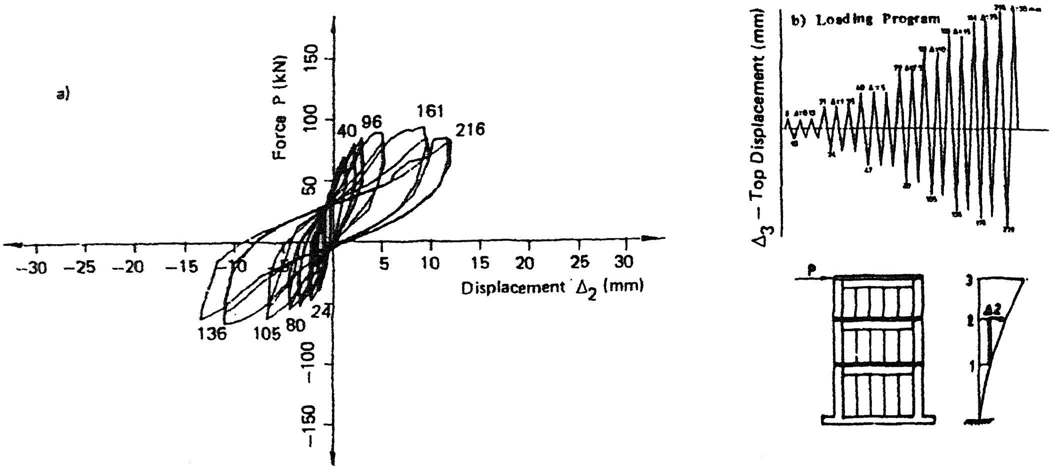


Figure 6. P-Δ relationship for the frame with infilled syporex (M3).

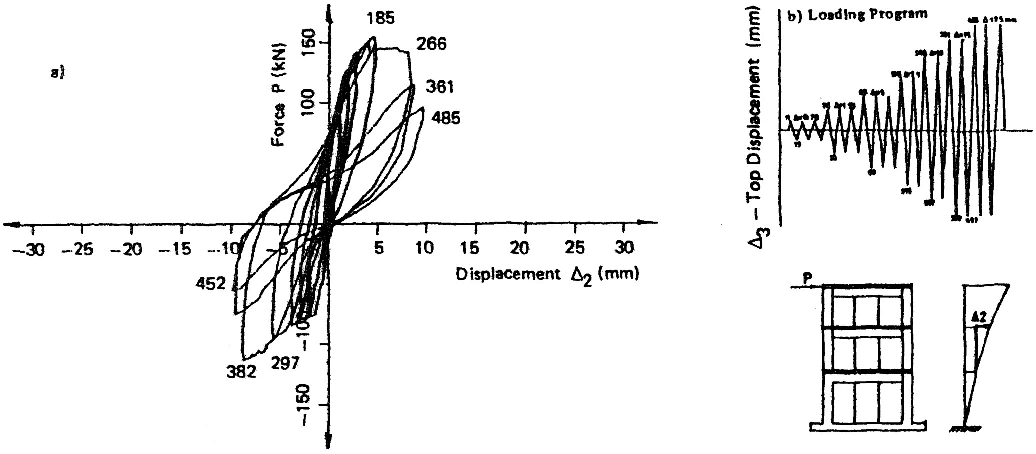


Figure 7. P-Δ relationship for the frame with infilled gypsum (M4).

(Fig. 4b). By analyzing this relationship, it is possible to determine the deformation level at yield point "Y" (Δ^y=5 mm, P^y=42 kN) as well as the bearing capacity and the deformability, *i.e.*, point "*U*" (Δ^u = 25 mm, P^u = 50 kN) for this model. From this, it is also possible to determine the expected ductility level for the plain frame model of μ = 5.

The hysteretic relationship for the frame model with masonry infill (Model 2) and the corresponding loading program are shown in Fig. 5 (a and b). As it is obvious, the stiffness and strength of the element in the initial phase of the hysteretic curve is considerably higher, compared to the frame model without infill, however the stiffness and strength deterioration after the occurrence of large cracks in the elements (Δ > 12 mm) is considerable, after which the masonry ceases to work. The remaining cycles of the hysteresis loop results from the effect of the plain reinforced concrete skeleton.

Figures 6 and 7 show the hysteresis loop for the frame models with syporex infill (Model 3) and gypsum (Model 4), respectively. These models, with the applied loading programme, are not planned to reach the failure state, since being repaired frame models with infill, they will be the topic of other investigations. These investigations prove also the conclusion for higher stiffness and strength, particularly in the case of gypsum infill, and the occurrence of higher deformations after reaching the relative storey drift of 5 mm, accompanied by abrupt stiffness and strength degradation of the element. The failure mechanism of the infill is brittle and

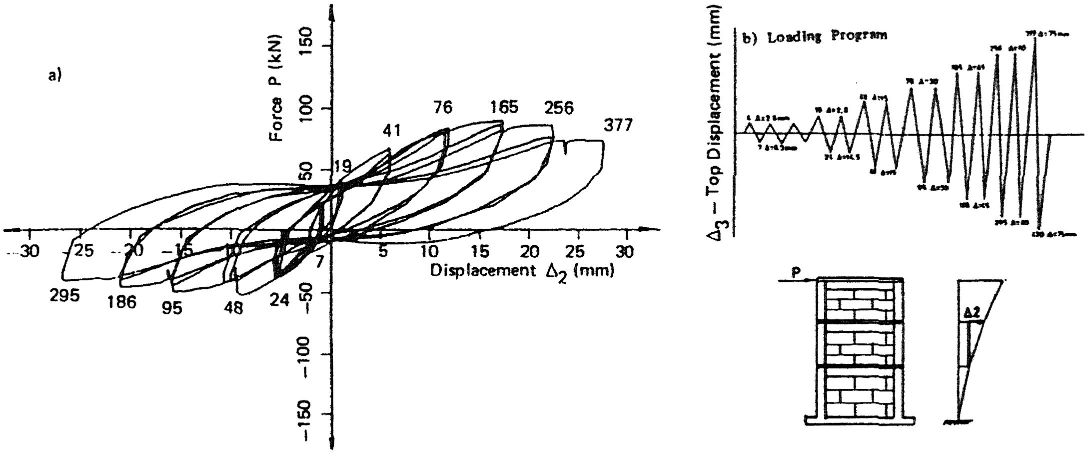


Figure 8. P-Δ relationship for the frame with infilled eltozol (M5).

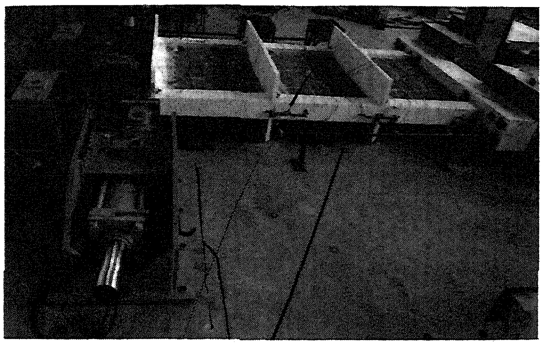


Figure 9a. Photo of model during testing

Figure 9b. Detail of damage

explosive, with an immediate occurrence of collapse.

The hysteretic relationship for frame Model 5 with eltozol infill (Figs 8a and 8b), obtained by the considered loading programme, is characterized by the fact that the eltozol infill does not play an important role in the behaviour of the element, i.e., a relatively slight increase in the initial stiffness is reached, which, on the other hand, does not cause an abrupt stiffness deterioration, since the eltozol infill does not cease to work. The infill follows the frame deformations, and failure and extensive damage develop at a displacement ductility of $\mu = 3 - 5$.

The analysis of the test results, for each model separately, shows considerable differences in the size scale of the maximum force and deformation which can develop in the element. These results from the specific character of each material used for the infill, i.e., their stiffness and strength characteristics, energy dissipation potential and the capability for ductile behaviour. The failure pattern (mechanism) of the element is one of the parameters which are of interest for definition of the dynamic behaviour of infill walls. Fig.9 illustrates also the position of M5 during testing with a close view of a characteristic cracks, showing infill failure.

4. COMPARATIVE ANALYSIS OF OBTAINED RESULTS

The comparison of the results obtained by testing the frame models with and without infill are the basis for performing a comparative analysis, aimed, mainly, at distinguishing the effect of the infill from that of the frame structure, i.e., estimation of the infill influence upon the dynamic behaviour of the main structural system.

Fig. 10 shows the determination of the characteristic points of the P-Δ diagram for each of the individual types of infill. The values of the envelopes of the hysteretic loops for the frame models with infill (denoted as R/C frame + infilled ....), for each corresponding displacement are

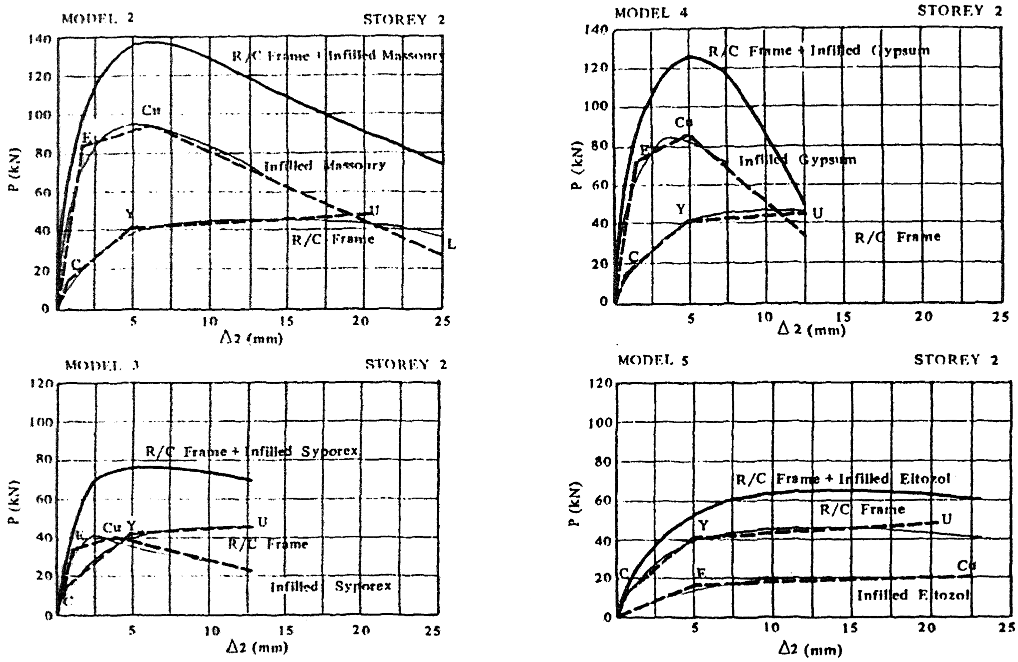


Figure 10. Envelopes of hysteretic loops and identification of characteristic phases.

Table 1. Characteristic points on the P-Δ diagram for different infill types

	Point E				Point Cu		
Type of infill	Δe mm	Pe kN	Ko kN/mm	Δe/h ‰	Δu mm	Pu kN	Δu/h ‰
masonry	1.8	84	48	1.1	6.2	96	4.0
syporex	1.1	35	32	0.7	3.8	42	2.5
gypsum	1.5	73	48	1.0	4.5	85	3.0
eltozol	5.0	15	3	3.0	20.	22	13.

decreased by the values of the envelope of the hysteretic loop for the frame model without infill (denoted as R/C frame). In this way, the curve denoted as "Infilled..." is obtained, illustrating the behaviour of only the infill. According to these curves, and for the needs of performing nonlinear dynamic analysis for actual earthquake time histories, for each infill type, mathematical models are formulated by defining the elasticity boundaries, i.e., the occurrence of the initial crack - point E and the ultimate point Cu, when due to the development of large cracks, failure of the infill occurs. These characteristic points of the diagram, for each infill type, the initial stiffness as well as the level of the reached deformations related to the floor height are demonstrated in the following table.

As obvious from the values presented in the table, depending on its characteristics, the infill can considerably increase the initial stiffness and strength of the structure (as much as 100% in the case of masonry and gypsum infill). On the other hand, the infill prevents development of side displacements, since even for story drifts of about 1‰ of the floor height the first cracks develop in it, which is rapidly followed by large cracks and even failure (at storey drifts of about 4‰).

5. CONCLUSIONS

Based on the presented analytical and experimental results, the following conclusions can be drawn:

- The infilling plays an important role in the modification of the structural response in elastic, and particularly post elastic range depending on the type of infilling, by limiting the lateral displacements.
- It can be pointed out that, in the initial stage, the stiffness of infill structures is higher than that of the structural system, but this relation gradually changes in favour of the reinforced concrete skeleton, due to the abrupt degrading of the infill.
- The infill effect modifies the stiffness and, generally, the dynamic characteristics of the structure, its energy absorption capacity and failure mechanism.

- In the design and the analysis of the stability of infill frame structures, the infill should be given an adequate consideration, regarding the stability as well as the modelling of the dynamic response of the structure in both linear and nonlinear range by introducing criteria regarding the allowable storey displacements of the whole structure, the frames and the infill.

REFERENCES

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