IV-11. Dynamic Behavior of Brick Structural Elements Infilled to Strengthen R.C. Structures

Nina Avramidou Maio

ABSTRACT

The present paper reports the experimental investigations of the dynamic response of R.C. portal frames with or without hollow brick infill walls, also taking into account the geometry and location of the existing apertures in the brick walls. Life size models were damaged by sinusoidally varying horizontal loads by means of a jack or—for some of them—by a shaking machine purposely constructed.

With the aim of reducing the frame/infill hammering the masonry of some specimens was bound by no-shrinkage concrete. A renovation technique is finally proposed for brick infill walls damaged by loads below collapse values.

The strength obtained in the repair specimens was of the same order as the original specimens.

Dans cette mémoire on expose les résultats espérimentaux des essais dynamiques sur des ossatures en béton armé raidies avec des tamponnements en maçonnerie. On examine aussie la géometrie et la disposition des ouvertures dans les tamponnements. Les échantillons à l'échelle 1/1, ont été soumis a des essaies destructifs avec directions de chargement horizontales de loi sinusoidale au moyen de martinets et au moyen d'un "vibrodina" à dessein. Au fin d'amoindrir le martelage entre l'ossature et le tamponnement certaines planches en maçonnerie ont été bâties avec des mortiers antiretrait. De plus on suggère et experimente une technique de restauration des tamponnements endommagès soumis à des charges inferieurs à ceux de rupture. La résistances des échantillons restaurés avec cette tecnique a été du même ordre de grandeur que celle des échantillons originaires.

In folgendem Bericht werden die Vesuchsergebnisse dargelegt, die mittels dynamischer Prüfung mit Rahmentragstrukturen in Eisenbeton die mit versteiften Ausfachtungen erreicht wurden. Weiterhin wurden die Geometrie und die Auschaltstellung, die in diesem Mauerwerk vorhanden sind, untersucht. Die Modelle in natürlichem Masstab wurden Zerstörungsprüfungen unterzogen indem horizontale sinusförmige Beschickungen mittels Winden vorgenommen wurden—oder bei einigen von ihnen mittels einer besonders für sie kostruierte Vibrationseinrichtungen. Um da, Einschlagen (Hämmern) der Rahmenausschaftung zu resuzieren wurden einige Füllwände in Mauerwerk mit einem besonderen nichtschrumpfenden Zement vorgenommen.

Zum Schluss wurde eine Restaurierungstechnik für die beschädigten Ausfachtungen geprüft und versucht, mit Belastungen deren Werte unterhalb derjenigen des Zusammnbruchs liegen, vorgeschlagen und ausprobiert. Der Widerstand, der von den mittels einer solchen Technik restaurierten Mustern geleistet wurden, hat sich als der gleiche wie der ursprüngliche erwiesen.

Nella presente relazione si espongono i risultati sperimentali ottenuti con prove dinamiche su strutture intelaiate in cemento armato irrigidire con tamponamenti in muratura di mattoni, prendendo inoltre in esame la geometria e posizione di aperture esistenti nei tamponamenti stessi.

I modelli in scala al vero, sono stati sottoposti a prove distruttive imponendo carichi orizzontali di legge sinusoidali per mezzo di martinetti—oppure per alcuni di essi—per mezzo di una vibrodina costruita appositamente.

Allo scopo di ridurre il martellamento telaio-tamponamento, alcuni dei pannelli in muratura sono stati murati con speciali malte antiritiro.

Infine, viene proposta e sperimentata una tecnica di restauro per i tamponamenti danneggiati sottoposti a carichi inferiori a quelli corrispodenti al collasso. La resistenza offerta dai campioni restaurati con tale tecnica è risultata dello stesso ordine di grandezza di quelli originari.

INTRODUCTION

The dynamic behavior of brick structural elements and the interaction with R.C. portal frames is of a major importance in the design of buildings subjected to wind and seismic action.

Although many structural codes do not consider the interaction wall panel/framework, the strength and ductility of the latter are conditioned by the presence of infilling. In many of the buildings of this type damaged by recent earthquakes it is in fact observed that infill—when it has not disintegrated—also has a load-bearing function. Photos 1 and 2 show the typical behavior observed.

In these buildings the hammering in the frame/infill caused the nodes to become disjointed and cracking in various sections of the columns. These considerations confirm the interest of this line of research, whose purpose is to contribute to the understanding of the interaction of structural elements such as frame/infill and the improvement of the technology of their related joints.

Loading Program and Testing Technique

Three different types of specimens have been considered, as shown in Fig. 1. For each one of them one frame without infill wall was also tested as a comparison.

The infill of the specimen marked "A" consisted in two wall panels, made of hollow brick units, 12 cm thick and bonded in mortar. The compressive strength of the frame concrete resulted 400 Kgf/cm^2 and the modulus of elasticity 400.000 Kgf/cm^2.

The steel reinforcement had a yield stress of 2.960 Kgf/cm^2. The infill of the specimen marked "B" consisted in a hollow tile wall (with six cells) laid on edge, and bonded in mortar. The mechanical properties of the frames and their steel reinforcement were about at the same order as the specimen marked A. Specimens A and B were frames of a building in demolition opportunely predisposed for the tests.

The infill of the specimen marked C was a solid brick header wall panel, bonded in mortar. Compression strength of the brick wall resulted 240 Kgf/cm^2 at testing time.

The last two specimens, type C (marked T_D and T_E), were bonded with no-shrinkage concrete. The compressive strength of the latter brick wall was 360 Kgf/cm^2 at testing time. The compressive strength of the frames of this third group resulted 320 Kgf/cm^2 for specimens T_A, T_B, T_C and 220 Kgf/cm^2 for T_D, T_E.

The loading program was as follows:

Specimen A (three tests)

Repetitive loadings were applied to the top beam of each frame by means of a jack. The load was increased until the incremental collapse load was reached, Fig. 2 (referred to the specimen with blend infill).

Specimen B (two tests)

Periodic forced vibration was induced in the structures by means of a "shaking machine" purposely constructed and fixed to the middle of the span of the top beam, Fig. 3. In order to theoretically determine the natural frequencies, the modulus of elasticity of concrete was measured previously. The stiffness of the frame with panel wall was calculated as the sum of the stiffness of the frame without a panel and that of the shear wall. Table 1 shows the theoretical f1 frequencies and the $\overline{f}_1$ frequencies measured on the frames during free vibrations by accelerometers.

Specimen C (six tests)

A sinusoidally varying horizontal displacement (Fig. 4) was imposed to the top beam of each frame by means of a double-effect jack activated by a closed-loop hydraulic system. The amplitude of the displacement was kept constant for a certain number of cycles (usually 50) then increased. The frequency was comprised between 1 Hz (for smaller displacements) and 0.2 Hz. The force in the jack was continuously recorded. The test was discontinued when severe structural damage occurred, except in the case of one cracked panel wall which was repaired. The repairing of the detachment of the wall from the frame and the initial cracking of the wall was carried out by employment of no-shrinkage concrete. It was then retested under the same preceding loading history.

TEST RESULTS

Photos 3, 4, 5 show typical crack patterns of test specimens subjected to incremental and alternate stresses. On the table 2 the peak force values and corresponding displacements are reported.

Fig. 5 compares the force-displacement amplitude curves of the frame tested under incremental load (type A specimen).

Fig. 6 presents the horizontal average amplitude of displacement $\overline{q}$ obtained theoretically and experimentally for type B specimens, without and with panel respectively.

Fig. 7 shows the peak force in the first and last cycles versus the displacement amplitude of some type C specimens. It should be observed that the downward curve of the diagram (Fig. 7) has no particular experimental interest as it depends on the disintegration of the infill wall which occurs in a purely arbitrary manner.

Fig. 8 compares the force-displacement amplitude curves of the five type C specimens. The peak forces recorded (F) during the tests occurred at the moment the first diagonal lesion of the infill appeared. The diagonal lesion of the infill then spread across the columns. Before the peak values of F were reached cracking of the whole columns took place, more accentuated in the nodes.

The rotations in the bottom and top sections of the frame columns were measured. For type A specimen with panel wall, limit rotation values were observed because the cracking of the columns occurred in sections above the points measured. This was due to the presence of the infill, which moved the maximum values of the bending moment upwards.

CONCLUSIONS

On the grounds of the eleven tests reported here, the following general trends were observed.

In the dynamic tests, in both frames, with and without panel walls, the experimental average amplitudes of displacements were generally less than those computed analytically. It was also found that the maximum experimental displacements of the frames were in good agreement with the amplitudes computed with the analytic method. During the vibrations it was observed that after about 200 loading cycles the brick panel wall detached from the framework and fell without forming cracks. The detachment of the wall from the frame and the initial cracking of the wall repaired and retested practically give the same dynamic response.

It is held that the infill wall could contribute more efficiently to the resistance of the whole structure if the technology of the bonding element of the masonry–R.C. structure were improved. The bonding element can in fact partly lose its efficiency owing to mortar shrinkage or badly carried out masonry work thus causing the early detachment of the masonry interface from the R.C. frame. Owing to the oscillation of the structure in its plane, this detachment can become several millimeters wide and can thus assume a considerable importance in the dynamic response of the building.

During the first oscillation movements, when the displacements of the framework are still small, the size of the detachments varies without any contact between the skeleton structure and the infill. In this stage the structure appears to be relatively flexible. As the displacements increase, the gaps caused by the detachments close and the frame is therefore placed in contact with the masonry infill wall. Subsequently, as the displacements reverse, the gaps of the detachments open again and the structure regains its initial flexibility.

This opening and closing of the detachment, mainly caused by mortar shrinkage, can occur various times during the lifetime of a building, with a varying sequence.

The masonry intervenes only after the R.C. frame has undergone a certain degree of strain, and this has also been observed during the static tests. This means that if the structure is subjected to dynamic actions, a mutual hammering takes place, with evident damage of the two elements, the frame and the infilling.

This deduction was reached after carrying out dynamic tests on other similar frameworks in the same building.

As regards the dynamic calculation of the structure, this fact involves a non-linear response, even in the case in which the various parts of the structure are all assumed to have an elastic linear behavior. It is therefore held that the framework/wall infill bonding element should consist in a material which is capable of expanding and which therefore could counterbalance the shrinkage of the masonry, efficiently blocking it within the R.C. framework.

The ratio between maximum strength values for frames with and without fenestrated infill wall tested under incremental load resulted 1.74. The latter ratio between frames with and without blind infill wall always tested under incremental load resulted 2.76.

The mean values of the ratio between maximum strength values for frames with and without blind infill wall tested under alternated load resulted 2.95.

The specimens bounded by no-shrinkage concrete have been almost completely reduced hammering frame/infill.

ACKNOWLEDGEMENTS

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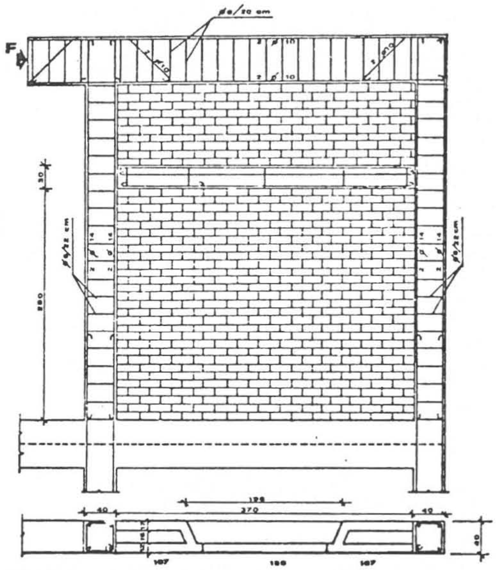
TABLE 1

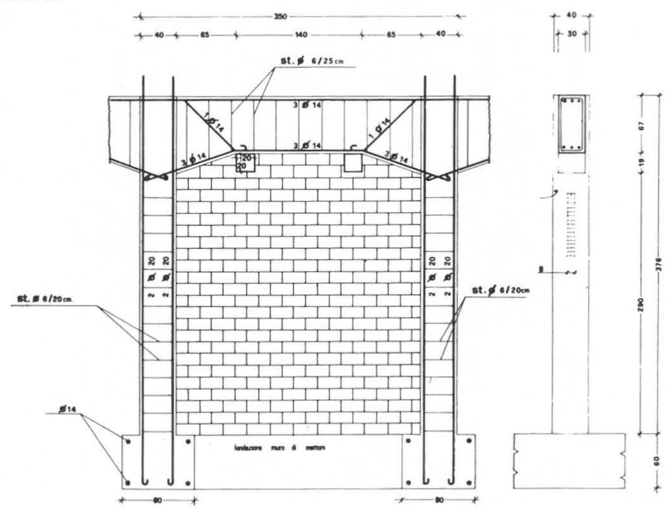
	f1 (Hz)	$\bar{f}_1$ (Hz)
Frame with infill wall	13.59	14.00
Frame without infill wall	8.53	7.95

TABLE 2—Peak Force Values and Corresponding Displacements

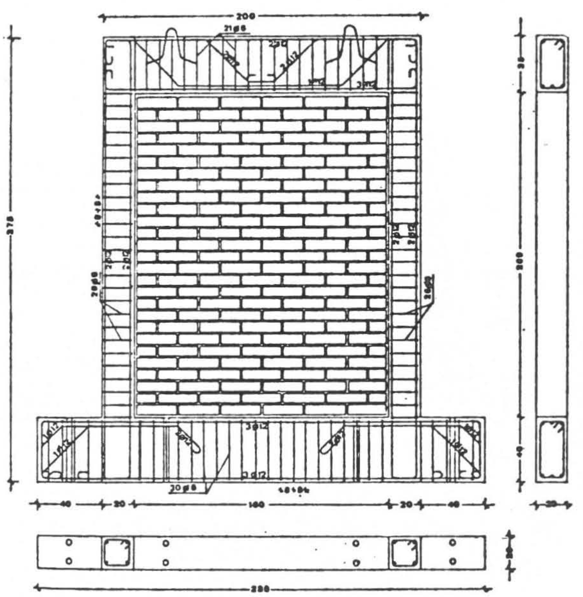
Type of Specimen	Max. Strength (ton)	Corresponding Displacement (cm)
Blind infill wall	12.7	1.65
Finestrated infill wall	8.0	2.95
Without infill wall	4.6	4.70



Specimen A



Specimen B



Specimen C

Figure 1. Geometry and steel reinforcement of the specimens tested.

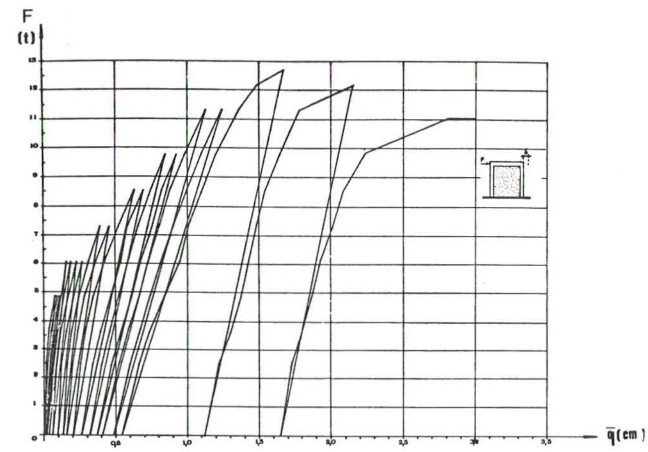


Figure 2. Loading history for specimen marked A.

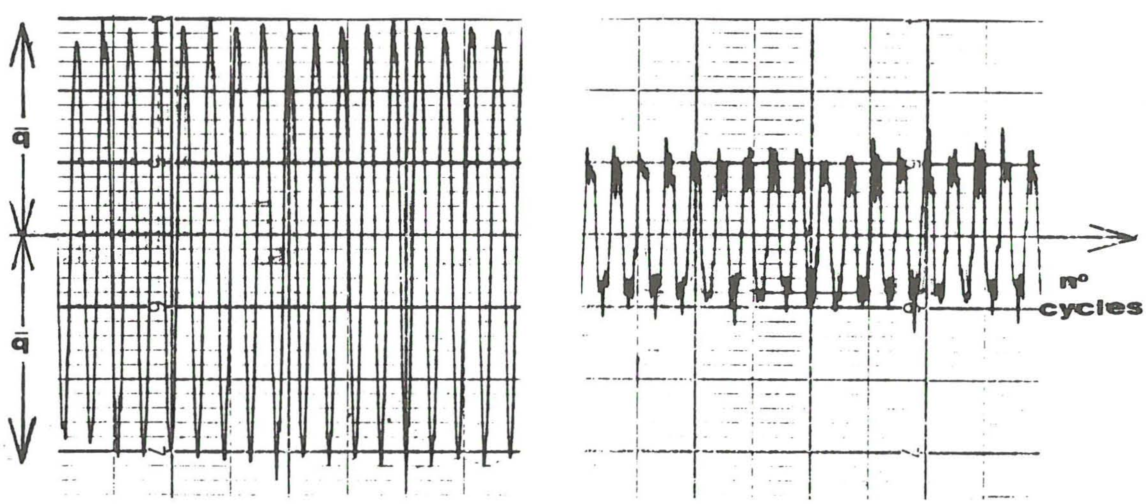


Figure 3. Displacement amplitude $\bar{q}$ versus time for frames without and with infill, respectively, refered to 2,22 Hz frequency.

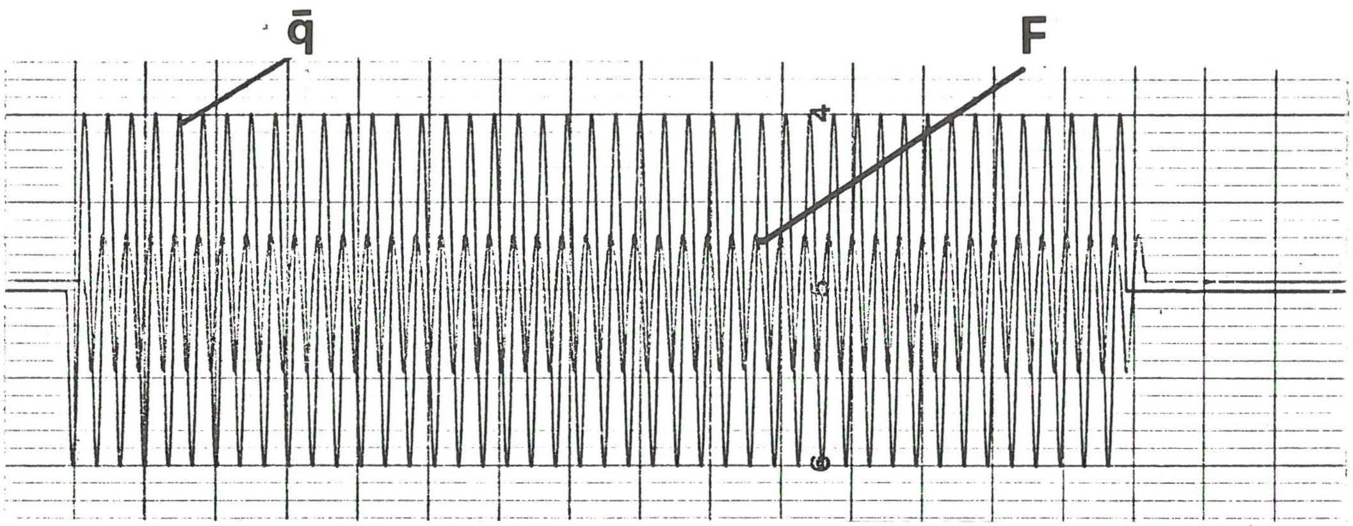


Figure 4. Typical sinusoidally varying horizontal displacement and load referred to specimen C.

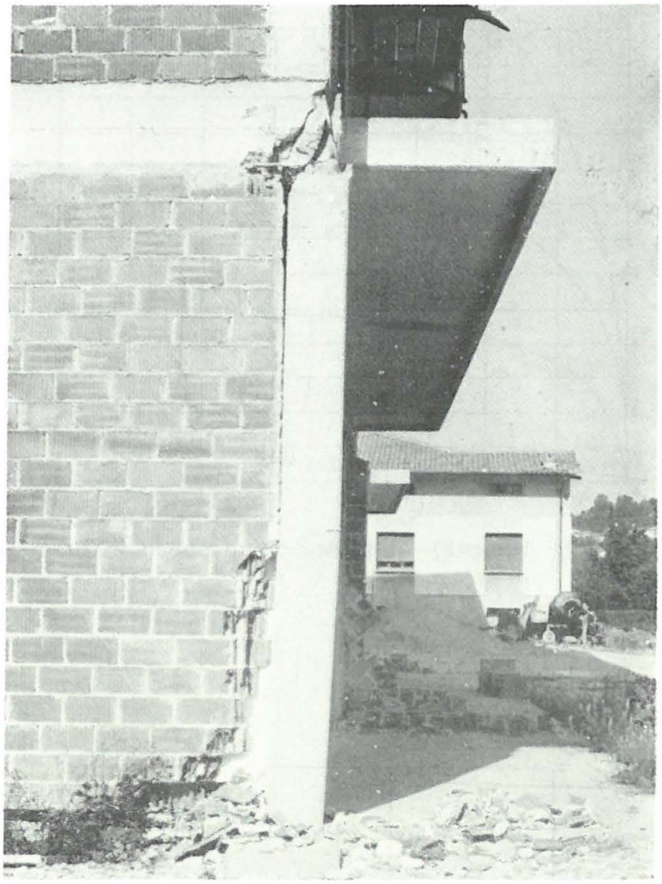


Photo 1

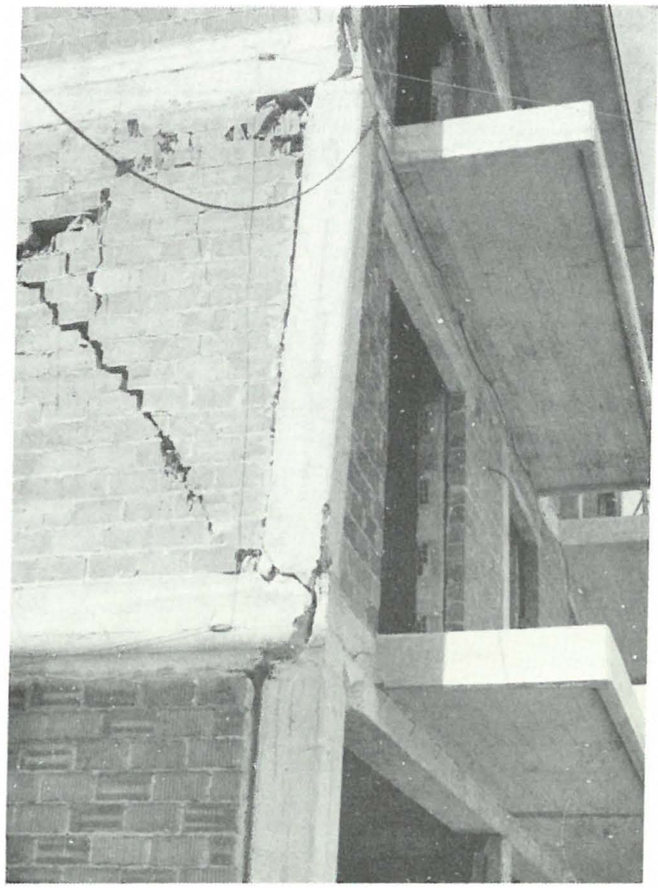


Photo 2

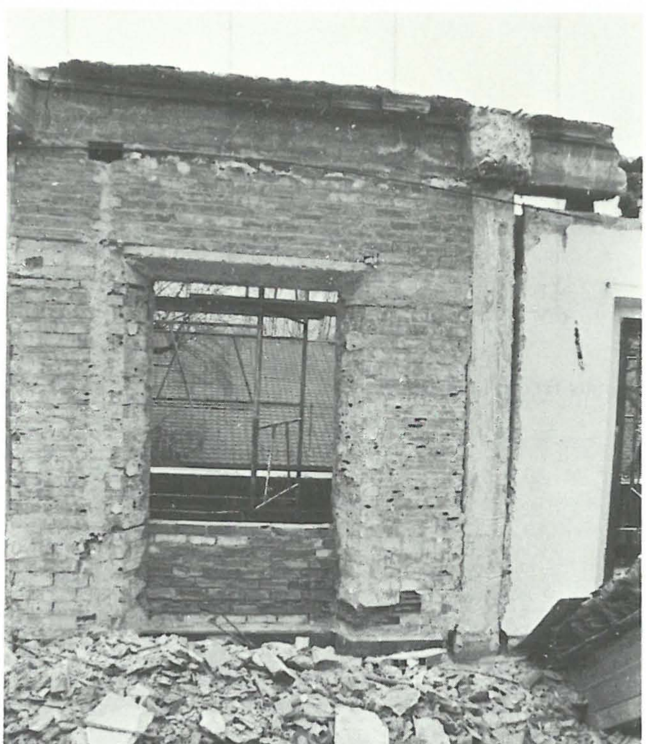


Photo 3

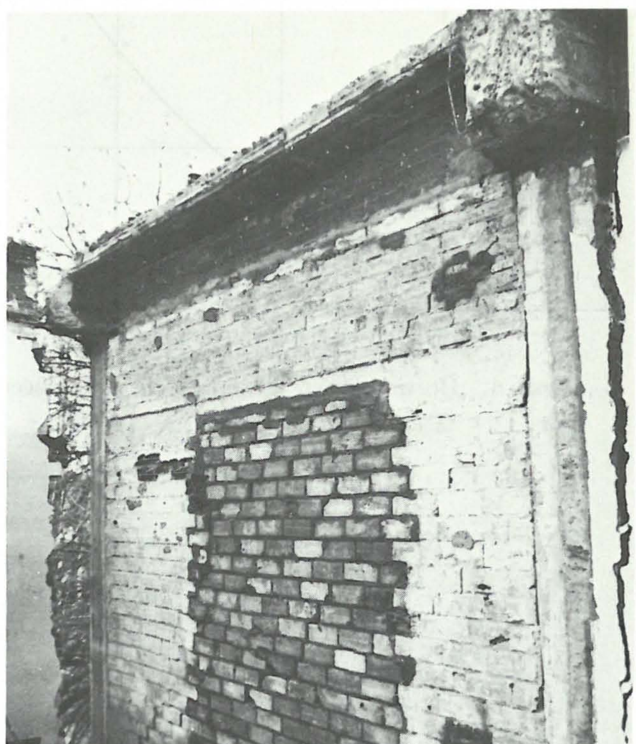


Photo 4

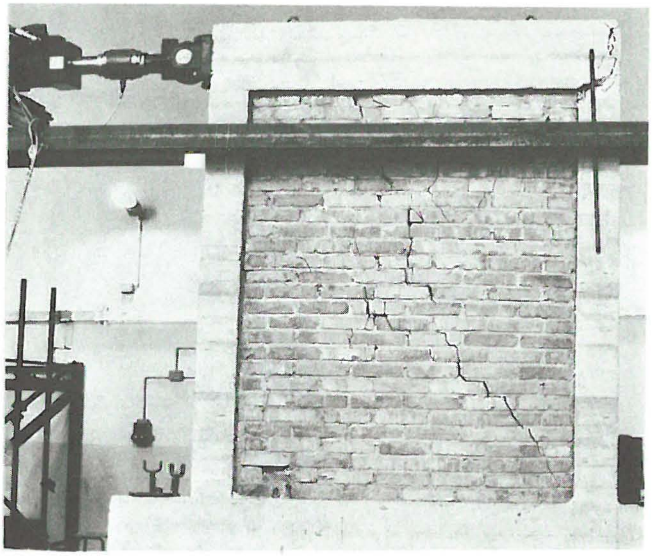


Photo 5

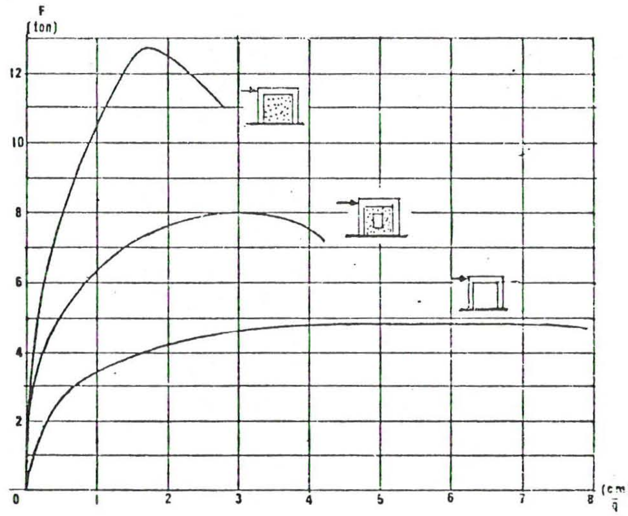


Figure 5. Force (F)—displacement ($\bar{q}$) amplitude curves of specimens.

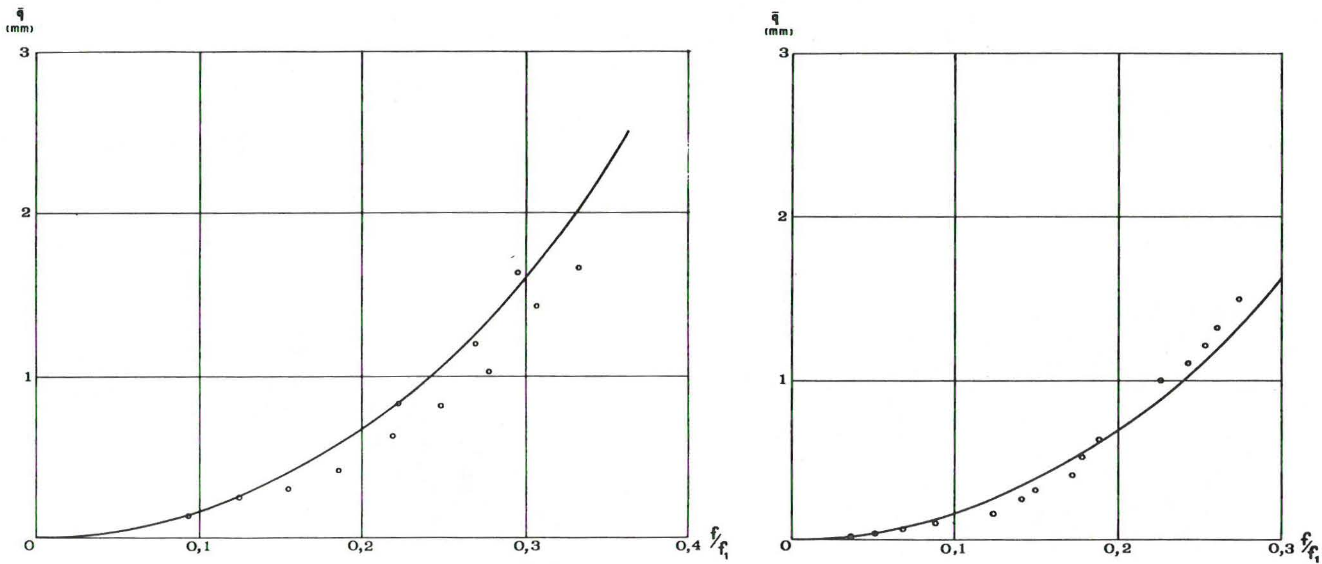


Figure 6. Horizontal average amplitude of displacement $\bar{q}$ versus frequencies ratio f/f_1 without and with infill respectively.

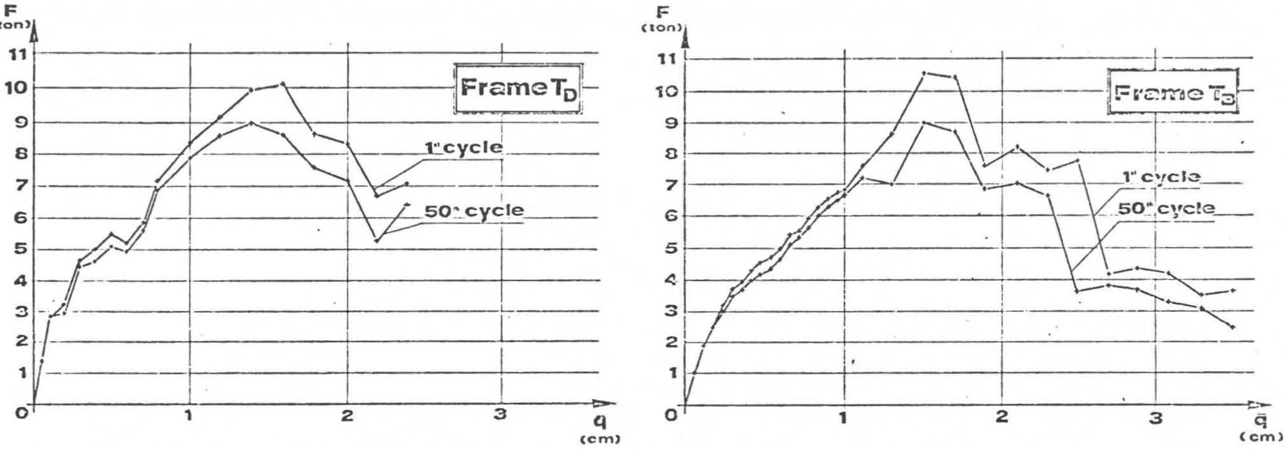


Figure 7. Peak force in the first and last cycles versus the displacement amplitude.

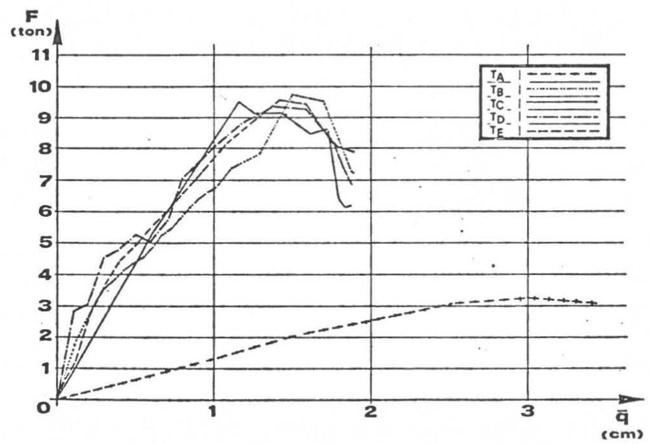


Figure 8. Comparison of force—displacement amplitude curves between specimen without infill (T_A) and with infill wall (T_B, T_C, T_D, T_E).