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Behavior of Brick Infilled Reinforced Concrete Frames Under Reversed Cyclic Loading

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ABSTRACT: Structural frames are often filled with masonry walls serving as partitions or as cladding. Although infills usually are not considered in the structural design, their influence on the behavior of the frame is considerable. Up until the infills cracks, the contribution of the infill to both lateral stiffness and strength is very significant. The infill also changes the dynamic characteristics of the frame. The change in lateral stiffness, strength and natural period of the frame structure due to the presence of infills change the behavior of the building under seismic action.

The object of this study was to investigate the behavior of such infilled frames under seismic loads. For this purpose, six two story, one bay brick infilled frames were tested under reversed cyclic loading simulating seismic action. Furtheremore, six infill panels were tested to determine the infill characteristics. Effects of plaster and concrete quality on infilled frames behavior were the main parameters investigated. The behavior of the infilled frames was compared with the behavior of bare frames. Analytical works was done to understand the stiffness, strength and behavior of these types of frames.

As a result of these studies, conclusions were drawn related to the behavior of these types of infilled reinforced concrete frames.

Keywords : Behavior, reinforced concrete frame, hollow clay tile infill, cyclic loading

ÖZET: Bina çerçevelerinin dolgularında, dış kaplama veya bölme duvarı olarak tuğla oldukça yaygın olarak kullanılmaktadır. Çerçevelerin hesabında, mevcut olan dolgu duvarlar genelde dikkate alınmaz. Halbuki dolgu duvarların varlığı, davranışı önemli ölçüde değiştirmektedir. Çatlama konumuna kadar dolgunun, yanal rijitlik ve dinamik özellikler üzerindeki etkisi çok büyüktür. Dolgulu çerçevelerin rijitliği, dayanımı ve dinamik özellikleri çıplak çerçeveye göre oldukça değişik olduğundan, dolgulu çerçevelerin deprem yükleri altındaki davranışı, oldukça farklıdır.

Bu çalışmanın amacı, tuğla dolgulu çerçevelerin deprem yükü altındaki davranışlarını araştırmaktır. Bu amaçla altı adet tek açıklıklı ve iki katlı dolgulu çerçeve, deprem yükünü temsil eden tersinir tekrarlanan yükler altında denenmiştir. Buna ilaveten, altı adet dolgu paneli, duvar özelliklerinin belirlenmesi için denenmiştir. Sıva ve beton kalitesi, tuğla dolgulu betonarme çerçevelerin davranışının irdelemesindeki esas değişkenlerdir. Bu çerçevelerin davranışı dolgusuz çerçevelerin davranışı ile karşılaştırılmıştır. Rijitlik, Dayanım ve davranışın yorumlanması ve öğrenilmesi için analitik çalışmalar yapılmıştır.

Bu çalışmaların ışığı altında bu gibi dolgulu betonarme çerçevelerin davranışı hakkında değerlendirmeler yapılmıştır.

Introduction

Statement of the Problem

Structural frames are often filled with masonry walls serving as partitions or as cladding. In the structural design process, such filler walls are considered to be inert “nonstructural” elements. The structure is assumed to carry the transverse loads by the frame elements resisting primarily in flexure.

It is apparent from geometrical considerations that a reasonably tight fitted wall having finite stiffness will impede deformations compatible with frame action. The frame with filler wall is considerably stronger and stiffer than the frame alone. Ignoring the interaction between the frame and the filler wall is tantamount to wasting a very important structural contribution. Also the critical regions in the frame-wall composite may not be the same as those in the frame alone. And the designer may have a risk on brittle links of the frame-wall composite. There is a general agreement among researchers that infilled frames have greater strength as compared to frames without infills. The presence of the infill will also increase the lateral stiffness considerably. Due to the change in stiffness and the mass, the dynamic characteristics will also change.

Understanding the behavior of infilled frames and having a satisfactory method of analysis will help us to have more realistic and economical solutions. Earthquakes in Erzincan, Dinar, Izmit and Bolu showed that, infills had an important effect on the resistance and stiffness of buildings.

The behavior of the infilled frame under seismic loading is very complex and complicated. Since the behavior is nonlinear and closely related to the link between the frame and the infill, it is very difficult to predict it by analytical methods unless the analytical models are supported and revised by using the experimental data.

Due to the complex behavior of such composite structures, experimental research is of great importance to determine the strength, stiffness and dynamic characteristics at each stage of loading.

Test Specimens

There is considerable experimental data related to the behavior of brick infilled reinforced concrete frames. However, the following criticism can be made for the previous related tests:

- Test specimens have been carefully designed and manufactured in laboratories. Therefore they do not represent the real structures with inherent weaknesses related to design and construction.
- In general, very small scaled models have been used in most of the tests.
- In most of the tests loading was monotonic. In majority of the tests, single-story specimens have been employed. Such specimens do not represent the boundary conditions realistically.
- In previous tests, hollow clay tile has not been used as infill.
- Effect of plaster has not been fully investigated.

It is therefore not appropriate to generalize the results of these tests to predict the behavior of real structures. The main objective of this research was to investigate the behavior and strength of reinforced concrete frames infilled with hollow clay tiles commonly used in Turkey. For this purpose, six 1/3 scale, one-bay, two story reinforced concrete infilled frames were tested at the Structural Mechanics Laboratory of METU, under reversed cyclic loading simulating the seismic effect. This test procedure was developed by Altın for his Ph.D. thesis in the Structural Mechanics Laboratory of METU. A typical test specimen is showns in Figure-1.

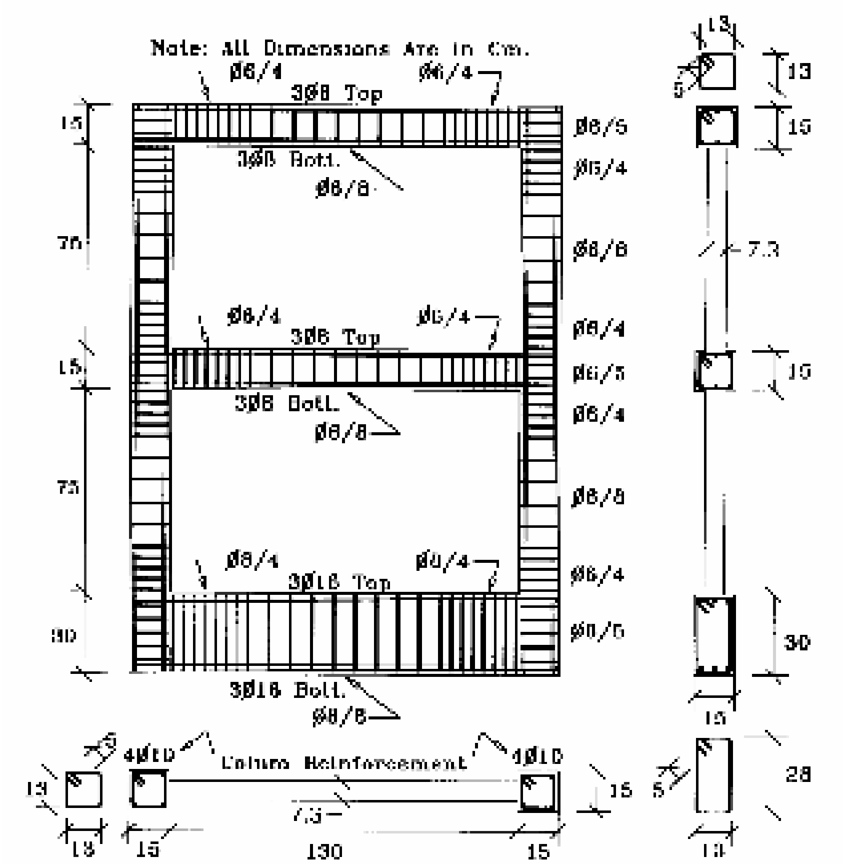


Figure-1. Dimensions and Reinforcement of the Test Frames.
(Bars sizes are given in mm, dimensions are in cm.)

In manufacturing the test specimens, it was intended to make the workmanship for brick laying compatible with the one on the site. Therefore a brick layer from the site was brought to do this job. A couple of bare frames were also tested to serve as reference specimens. In all tests, axial load was applied to the columns. The lateral load was applied at the second story level. In these tests, stiffness and strength degradation, ductility and drift index at different stages were investigated. Analytical studies were made to predict the behavior. The effect of plastering both sides of the infill was also studied. Walls made of hollow clay tile were tested to have an idea about the behavior and other composite properties of infill panels. These panels, either square or rectangular, have been tested by loading in the diagonal direction. This loading was applied by steel caps mounted at the corners. The deformations in two diagonal directions were read by dial gauges which were located away from corners to avoid errors related to the local deformations.

ANALYTICAL STUDIES

There are several analytical methods to predict the behavior, strength and stiffness of infilled frames. Some of these methods are empirical or semi-empirical, and some are more rational and use sophisticated mathematical models for geometry and materials. These analytical methods can be grouped into two categories; (a) Macroscopic approach, which try to predict the overall behavior and (b) Microscopic approach, modelling mechanical properties of the materials to predict the behavior.

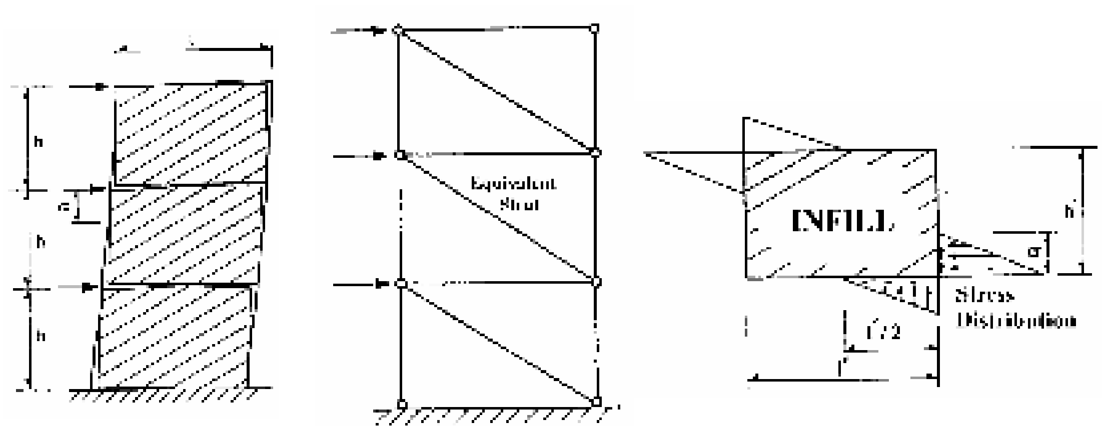
Macroscopic models try to generate the force-deformation characteristics of the infill. They usually idealize the panel by an equivalent beam or strut. Although these methods require less computational effort, they are usually valid only for the tests for which the derivations are made. Changes in the topology of the panel due to crack opening and closing, and change in material properties in macro structure cannot be taken into account in simplified model implementation. This is one of the main disadvantages of macroscopic approaches.

Microscopic methods employ principals of mechanics of solids to model the frame and the infill behavior. Large computational efforts are required to obtain meaningful results. The finite element method is widely used for this purpose. Some of the finite element methods are based on theory of elasticity and some are more complicated and can take plasticity and strain hardening into the accounts. New methods have also been developed to model the nonlinear behavior at connections. However such methods have some difficulties as given below.

- Cyclic load behavior cannot be taken into account, since the material models for such cases do not yield realistic results.
- Boundary conditions and connections can not be modeled properly.
- Friction between the frame and the infill cannot be modeled with reasonable accuracy.
- Elements are assumed to be isotropic, whereas they can be non-isotropic.

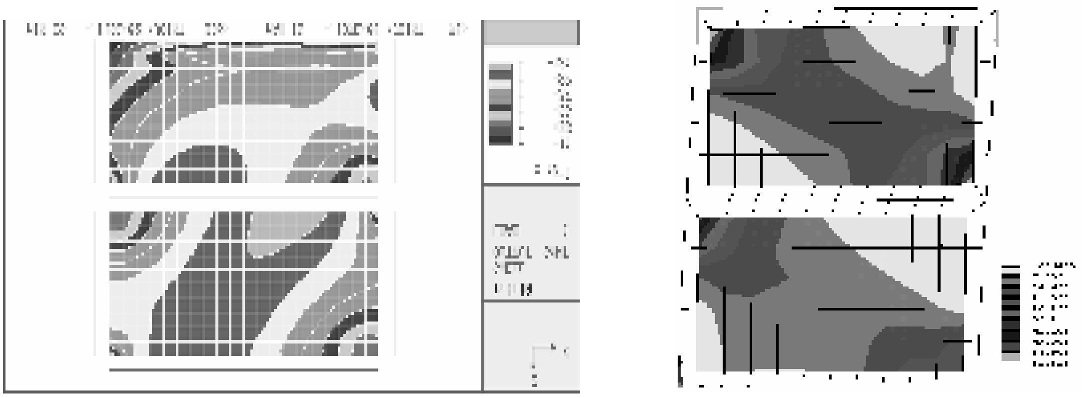
The microscopic models have these disadvantages, but they have the advantage of modelling the real structure and using three dimensional modelling. The new structural concepts are based on these types of methods, so the microscopic methods improved by experimental findings will be used more extensively in the future.

In this paper three analytical methods are used and the evaluation of test results are made using these methods. These methods are; (a) Smith and Carter equivalent strut method, (b) Common linear finite element method, and (c) Sophisticated nonlinear finite element method. These three methods are shown in Figure 2.



Infilled Frame   Equivalent Frame   Assumed Stress Distribution

(a) Smith and Carter equivalent strut method



(b) Linear Finite Element   (c) Nonlinear Finite Element

Figure-2. Analytical Methods

Test Results

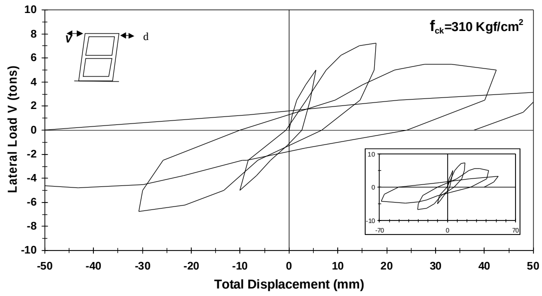
Hysteretic lateral load-second story displacement curves obtained from test specimens are shown in Figure-3. It should be noted that specimens 3(a) and 3(b) were bare frames with no infills.

Test results are summarized in Table-1. In this table, existance of the infill and plaster are indicated. In the table maximum lateral force V (shear) at opposite cycles are given together with the displacement of the second story with respect to the base. Drift relation and initial stifnesses are also given in the table.

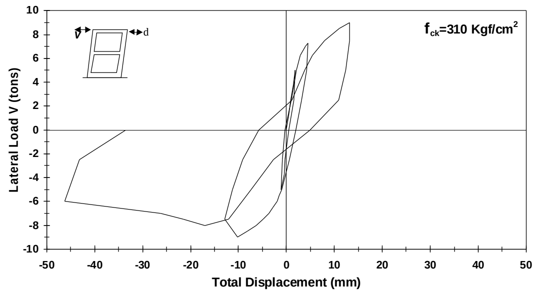
In Table-2, results of the panel tests are given (no frame, just the clay tile panels).

In Figure-4 photos taken after the failure of some of the test panels are shown. In Figure-5 photos showing the failure pattern of infilled frames are given, one plastered and the other one unplastered.

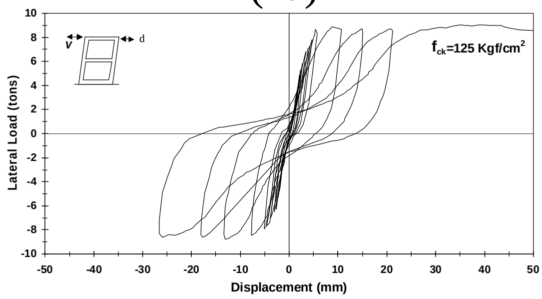
Figure-6 shows the failure of the infill in a building. The photo was taken in Erzincan, after the 1992 earthquake.



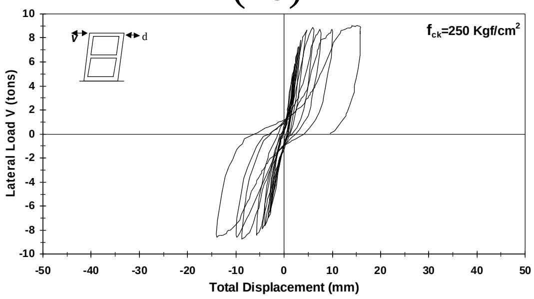
(1a)



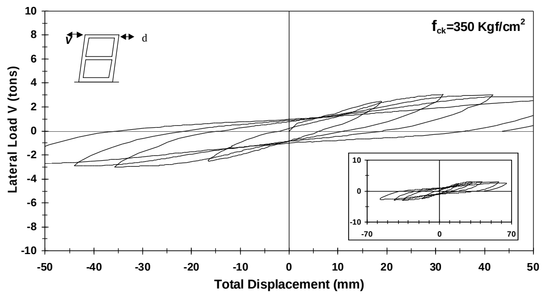
(1b)



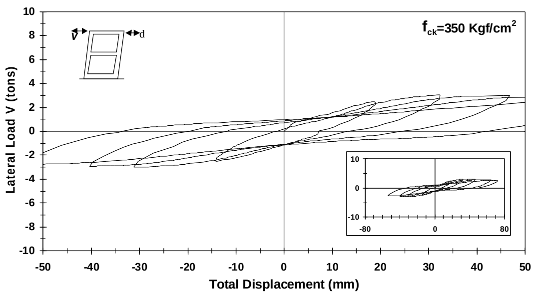
(2a)



(2b)



(3a)



(3b)

Figure-3. Lateral Load – Displacement Curves (2.floor)

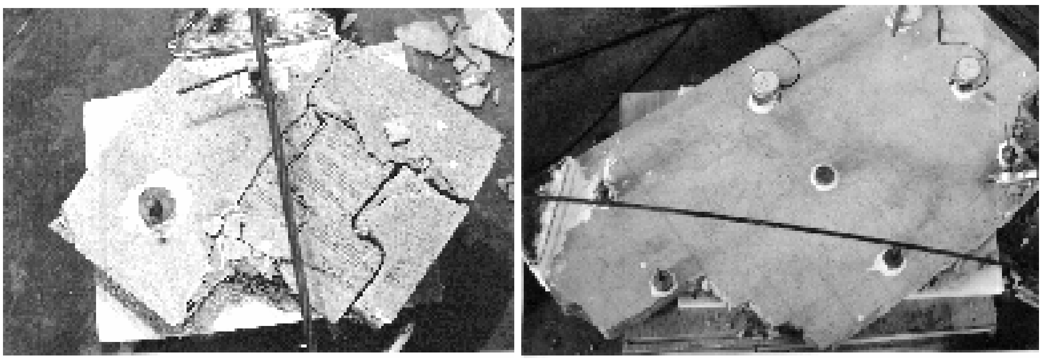


Figure-4. Failure of Test Panels

Table-1. Characteristics of Test Specimens and Summary of Test Results

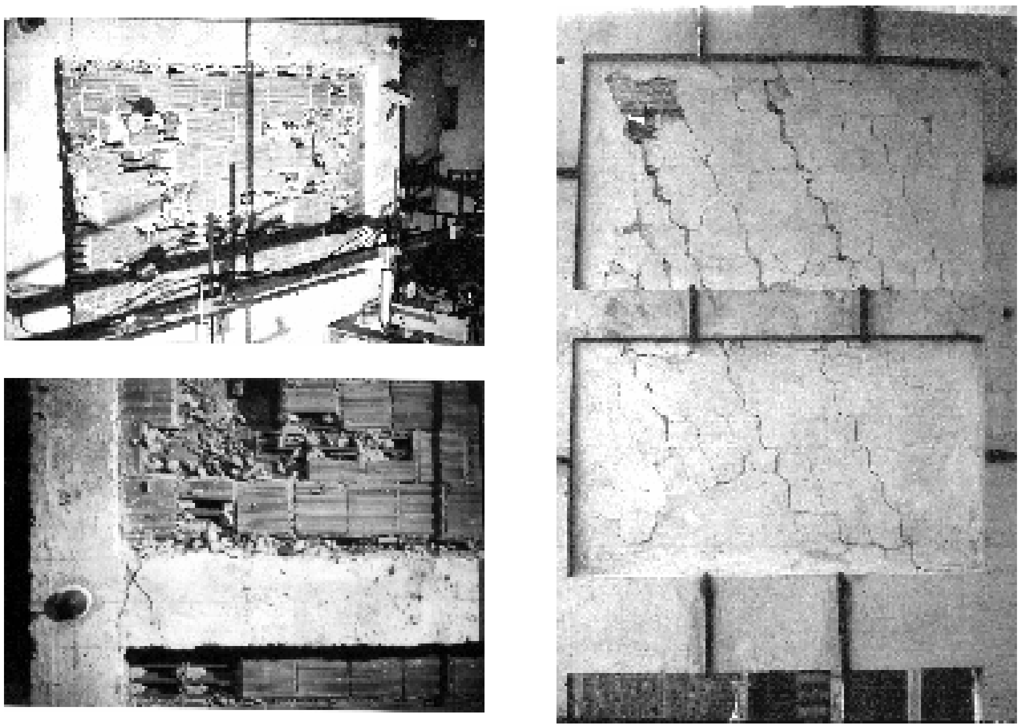
Spec. No	f_{ck} [kgf/cm^2] Frame	Infill	Plaster	Max. .Load V (+) [tons]	Max. .Load V (-) [tons]	Yield V (*) [tons]	Top Disp. at the Max. Load [mm]	Drift Index at Max.Load x10^3 1. Story (**)	Initial Stiffness [tons/cm]
1a	310	Yes	No	7.3	6.8	7.3	18.9	5.01	15.44
1b	310	Yes	Yes	9.0	8.0	9.0	10.2	5.22	27.93
2a	125	Yes	Yes	8.9	8.9	8.9	13.1	6.45	23.1
2b(***)	250	Yes	Yes	8.9	8.9	8.9	8.8	1.99	26.5
3a	350	No	-	3.1	3.0	3.1	31.5	12.27	3.91
3b	350	No	-	3.1	3.0	3.1	32.4	11.4	4.09

(*) The point at which displacement took place without significant load increase.
(**) First story displacement divided by the story height. (x10-3)
(***) Specimen 2b did not reach its max. load. Given data is for the case which coupled test specimen reach its max. load (2a).

Table-2. Summary of Test Results – Panel Tests

Spec. No	Properties	Dimension [cm x cm]	Failure Load [tons]	Compression Strain at Failure[x10-3]	Tension Strain at Failure[x10-3]
1	Plastered	40 x 40	4.45	2.33	4.55
2	Plastered	40 x 40	4.66	2.18	3.64
3	Plastered	75 x75	8.09	-	-
4	Plastered	75 x 130	8.90	-	-
5	Non Plastered	40 x 40	3.15	3.83	2.92
6	Plastered (*)	40 x 40	3.41	1.81	0.80

(*) Cut from the infill of a test specimen after the test. The infill was not cracked.



(a) Nonplastered Infilled Frame (b) Plastered Infilled Frame

Figure 5. Failure Pattern of Infilled Frames.

Conclusions

Hollow clay tile infill increases both strength and stiffness significantly. The strength increase as compared to the bare frame is about 240% for specimens with unplastered infills and 300% for the plastered ones.

Plastering both sides of the infill improves the behavior of the infilled frame considerably. Comparing plastered and unplastered specimens, the strength increase due to the plaster is about 25% and increase in initial stiffness is about 50 to 80%.

Plaster also delays the diagonal cracking of the infill. Plastered infill, cracks at about 20% higher load as compared to the unplastered specimen.

Plaster also improved the ductility significantly. The specimen in which, the infill was not plastered, could not hold the load once the maximum was reached. There was considerable strength decay beyond this point and deformation capacity was limited.

The plastered specimens behaved differently. The maximum load could be carried under increasing deformations. This behavior was not as brittle as those of infilled frames with solid brick infills. As can be seen from the envelope V-δ curves, the behavior of specimens with plastered hollow clay tile infills was quite ductile. This is probably due to the fact that hollow clay tiles do not crush suddenly as solid bricks, but fail at stages by crushing of layers.

The strut method proposed by Smith and Carter can be used to predict the stiffness of frames infilled with hollow clay tiles. Howerver it should be noted that he stiffness is underestimated by this method (about 40%). Smith and Carter method can also be used to predict the strength. However it was found out that the strengths calculated overestimated the actual strength by about 30-50%.

Figure 6. Failure of the infill in a building (Erzincan Earthguake).

Linear and nonlinear finite element methods can confidently be used to predict the strength and stiffness of infilled frames if a proper modulus of elasticity can be assigned for the infill. Tests made by the author showed that this is not easy, especially when hollow clay tile is used as the infill material. The variations in mortar properties make a correct prediction of modulus of elasticity almost impossible. The nonlinear finite element method seems to be very promising for frame analysis, since the presence of the infill can be included.

Recommendations

The behavior of frames infilled with hollow clay tiles should be further investigated. The authors makes the following recommendations for the future research.

In the frames tested, the aspect ratio of the frame was fixed. The influence of aspect ratio should be investigated by tests.

In all test specimens, columns were stronger than beams. Further tests should be made with frames having columns weaker than beams. This will force the hinging in columns and will change the failure mechanism.

In the test reported, frame members were reinforced and detailed properly in accordance with the codes. Frames with poor reinforcement detailing, simulating the common buildings in Turkey should be investigated.

Since scaled clay tiles were used, the scale effect should be investigating by using full size tiles.

Effect of partial infilling and infills with openings should be investigated.

Effect of plaster should be investigated in more details. Tests should be made using different strength and thickness of plasters.

Hollow clay tiles are brittle. Investigations should be made to find ways and means of improving the behavior. Plastic network could be used on the plaster for this purpose.

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