AN EFFECTIVE STRUCTURAL SYSTEM AGAINST EARTHQUAKES - INFILLED FRAMES

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SUMMARY

A structural system against earthquakes as represented by various forms of infilled frames has emerged with practical and economical significance in the prevention of total collapse of buildings. Theoretical study in relation with various types of infilled frames is reviewed and the applicability of the methods of analysis is explained in the light of the behaviour of the various types of infilled frames. Experimental investigation is reported on the static and dynamic characteristics of models showing that they can be used as an effective structural system against the damaging lateral loading produced during earthquakes.

INTRODUCTION

Earthquakes and strong winds have caused in many parts of the world tremendous amount of damage to property and great loss of human lives. So far, no solution has been found to prevent these natural disasters. However, efforts to develop structures resistant to earthquakes and strong winds have yield some promising results. One area of development is in infilled frame, a structure combining the frame and the infill together, which has shown improved characteristics in comparison with the frame or the infill alone.

GENERAL STATIC BEHAVIOUR OF INFILLED FRAMES

Experimental and theoretical investigations [1-7] have been carried out with the realization that by infilling the frame with suitable materials the structure under lateral load has more strength and rigidity. Formulation of design rules has been attempted [8] for specific type of infills. When the infills are not definitely attached to the frame, e.g., the brick-work inside a frame, separation along parts of the interface occurs when the structure is subjected to moderate lateral load. The separation is more obvious when openings in the infills are present. With the increase of loading, cracks in the infills appear along the compression diagonals but they usually are not extensive and are few in number. When connectors are provided along the interface between the frame and the infills, the structure behaves differently from those without connectors in that separation along the interface does not occur and cracks in the infills are generally very extensive and numerous when the structure is subjected to increasing lateral load.

Theoretical Analyses

The fact that infilled frame is stronger and stiffer than the bare frame is mainly due to the interaction developed at the interface of the infill and the frame. The nature of the interaction varies according to the conditions at the interface. Basically, the following theoretical analyses have been put forward.

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1. Stress function method [6]: The infilled frame is treated as a plane problem based on the theory of elasticity. A general stress function in the form of Fourier Series is used to present the stresses in the infill and at the interface.
2. Equivalent diagonal strut method [1,2,7]: Due to the fact that the infill is separated from the surrounding frame except at the compression corner portions when the infilled frame is laterally loaded and no connectors are provided, the infill is acting as a diagonal strut (Fig.1). The properties of the equivalent diagonal strut depend upon the relative stiffnesses of the frame and the infill [2]. When there is opening in the infill, the equivalent diagonal strut can be evaluated by energy method [7].
3. Equivalent frame method [5,7]: When connectors are provided so that the infill is attached definitely to the frame at the interface, the section of the frame and the infill is regarded as composite section and the infilled frame is transformed to an equivalent frame (Fig.2), which can be analysed by conventional methods.
4. Finite element method [3]: The infill and the frame are treated as finite elements and bar elements respectively. At the interface the infill elements and the frame elements are given the same nodes which may have different displacements when the slip and separation occur.

Experimental Investigation

Models of four storey steel frames with micro-concrete infills were constructed for experimental investigation to examine the behaviour of infilled frames under uniformly distributed lateral load. The models were divided into two groups: group A (Fig.3) consisted of infills with width/height ratio of 2/1, and group C (Fig.4) with width/height ratio of 3/1. Each group was divided into two series: series S consisted of infilled frames with connectors between the frame and the infills, and series O without connectors. There were four specimens in each series, one with solid infills and three with a row of central door openings of varying sizes.

GENERAL DYNAMIC BEHAVIOUR OF INFILLED FRAMES

Very little work has been done in the study of infilled frames subject to dynamic load [9-12], although it is precisely the area in which infilled frames as a structural system may offer economical and practical solution for buildings subject to earthquakes and strong winds. The most important feature of infilled frames subject to dynamic loading is the damping characteristics. There are four possible sources of damping in a vibrating infilled frame: (i) internal material damping, (ii) friction between the infill and the frame, (iii) friction due to cracks in the infill, and (iv) damping due to the infill rocking inside the frame in the case when there is no provision of connectors, and where there is provision of connectors the damping is due to the friction between the connectors and the infill. The presence of the infill not only improves the strength capacity of the frame, but also improves the energy dissipation capacity. When using infills which can resist tension stresses and are connected to the frame, numerous cracks develop making the strucutre more flexible, and increasing the damping and energy dissipation.

Theoretical Analyses

The natural frequencies and mode shapes of a vibrating infilled frames can be obtained by finite element method [9], while the equivalent strut concept replacing each infill by a pair of diagonal struts [10] has been used to predict the initial stiffness and strength together with the degradation of the stiffness and strength when the cyclic loading is increased beyond the linear state of the infill materials.

Experimental Investigation

Similar models as those in the previous static experiments were constructed. A point load was applied horizontally at the top by a pulsator jack and the deflections were measured (Figs. 5 & 6).

DISCUSSION

The connectors transform the unstable characteristics of the interaction along the interface into one with definite characteristics, due to which a more reliable structure is obtained and a better analytical prediction can be made (Table 1). By examining the effect of connectors in terms of strength and stiffness (Table 2), the results of the static tests show that the ultimate strengths of the infilled frames increased considerably, but did not increase as high as their stiffnesses. However, the results of the dynamic tests show that the ultimate strengths increased even more. The models with connectors showed much greater strengths than those without connectors due largely to their ability to generate more cracks without premature collapse as a consequense of better composite action between the frames and the infills.

CONCLUSION

From the evidence obtained in connection with infilled frames subject to static and dynamic lateral loading, it can be stated that the superior characteristics of the infilled frames, especially those with shear connectors, render this form of structures suitable for reducing the catastrophies that could bring to buildings during earthquakes and strong winds. Several theories for the analyses of various types of infilled frames are available. With the modern computing facilities, it should be possible to carry out either the dynamic analysis or the static analysis. Properly designed infilled frames for buildings would drastically reduce the probability of total collapse. The use of infills which can resist tension as well as compression and can be connected to the bounding frame should be recommended.

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Table 1. Differences in Analytical and Experimental Ultimate Loads

Model	Diagonal Strut Method	Model	Equivalent Frame Method
A01	27%	AS1	14%
A02	43	AS2	11
A03	46	AS3	21
A04	46	AS4	11
C01	16	CS1	14
C02	34	CS2	10
C03	32	CS3	9
C04	30	CS4	1

Table 2. Increases in strength and stiffness of infilled frames due to the presence of connectors

With/without connectors	Strength ratio		Stiffness ratio	
	Static	Dynamic	Static	Dynamic
AS1/A01	1.37	1.78	1.97	1.04
AS2/A02	1.87	2.62	4.76	3.02
AS3/A03	1.46	-	4.07	-
AS4/A04	1.46	1.91	3.50	4.09
CS1/C01	1.70	3.79	1.70	1.96
CS2/C02	2.41	2.90	7.63	3.01
CS3/C03	1.95	-	7.43	-
CS4/C04	1.70	2.30	7.14	3.34

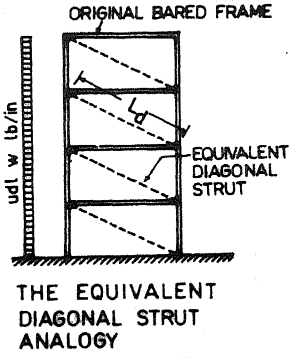


Figure 1

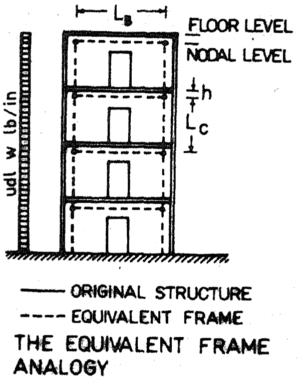


Figure 2

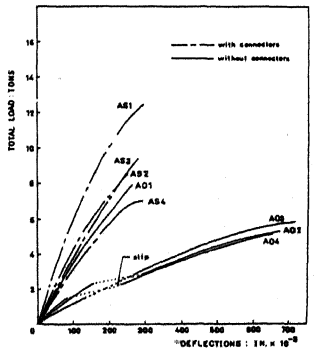
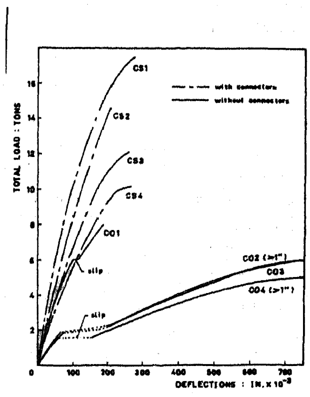


Figure 3



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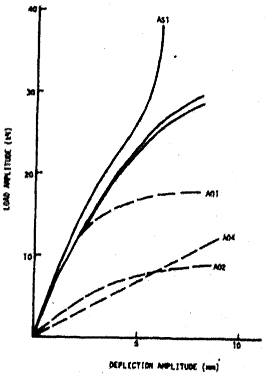

Figure 5

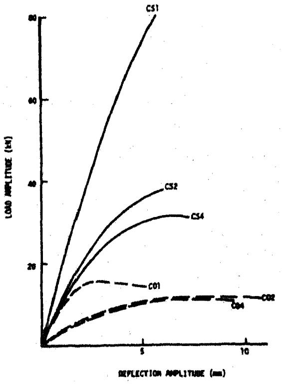

Figure 6