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DYNAMIC CHARACTERISTICS OF SINGLE STOREY INFILLED FRAMES WITH BRICK PANELS

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INTRODUCTION

This paper deals with the experimental determination of natural frequency and, damping in infilled frames subjected to dynamic loads. The damping in infilled frames though of dry friction type is expressed as a co-efficient of equivalent viscous damping which is obtained from free vibration and half cycle load tests. The tests were conducted on relatively large size R.C.C. frames bounding brickwork infill with and witout shear connectors. Load-deflection curves are obtained from static tests which are subsequently used in assessing the lateral stiffness of infilled frames prior to their dynamic analysis. An equivalent dynamic model of an infilled is assumed for computing theoretically the fundamental frequency of the system. The model has an equivalent mass lumped at the girder level. Its lateral-stiffness is determined from the experimentally obtained load-deflection curve and, also from the idealised diagonally braced pin-joined frame. The results of analytical and experimental natural frequencies agree satisfactorily. Damping in infilled frames, with and without shear connectors, as obtained from dynamic tests subjected to oscillations of small amplitude is found to be 6 and 7 percent of critical damping respectively.

INFILLED FRAMES

A number of research papers ([1, 2, 3, 4]) have appeared on the static behaviour of infilled frames but their dynamic behaviour have not been given much attention although most of the lateral loads due to wind, earthquake and blast are dynamic in nature. It has been recommended([5]) that the effect of dynamic loads on infilled frames can be taken into account merely by replacing the value of static modulus of elasticity by the corresponding dynamic values in the formulae derived for static behaviour. The author([6]) has published some work on the dynamic tests conducted on moduls of infilled frames but not much information is available on the dynamic testing of prototype infilled frames with brick infilling. Further realising the influence of initial lack of fit between the infill panel and the bounding frame along the boundary function, the author has previously suggested the use of infilled frames with shear connectors for buildings situated in seismic zone.([7])

Two types of infilled frames as mentioned below were tested.

(a) Infilled frames without shear connectors:

In this type of frames, brick mortar infill panel was bounded by a R.C.C. frame as shown in Fig. 1.

(b) Infilled frames with shear connectors:

This type refers to infilled frames in which the brick mortar infill panel was enclosed by R.C.C. frame provided with shear connectors as shown in Fig. 2. The shear connectors were made of 8 mm dia rods welded to the main reinforcement of R.C.C. frame members and projecting 5" into the seams of brick mortar panel. Each shear connector consisted of four bars lying in the same horizontal plane and equally spaced over a distance of $4\frac{1}{2}$" that is, the width of one brick.

Both type of frames with similar dimensions were cast and tested under identical conditions. The details of dimensions and materials used in prototype testing are as given below:

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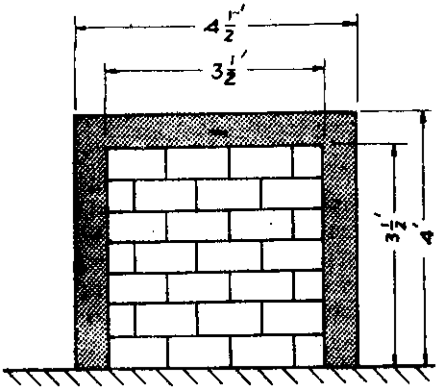

Fig. 1a. Infilled Frame without Shear Connectors.

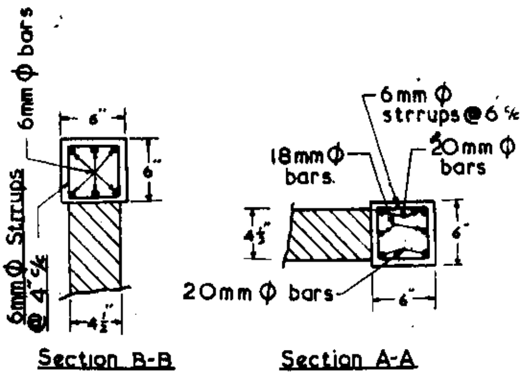

Fig. 1b. Details of Reinforcement in Infilled Frames.

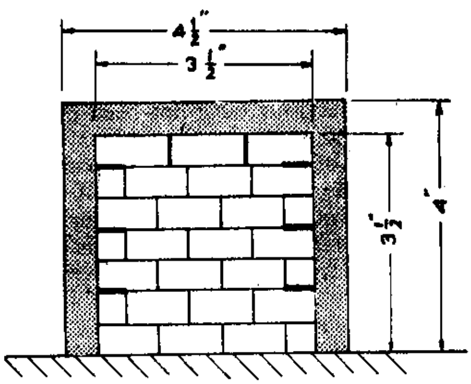

Fig. 2. Infilled Frame with Shear Connectors.

1.	Overall size of the frame	$4\frac{1}{2} \times 4$
2.	Cross-section of the frame members	$6'' \times 6''$
3.	Frame material	R.C.C. with M150 concrete
4.	Size of the infill	$3\frac{1}{2}'' \times 3\frac{1}{2}'' \times 4\frac{1}{2}''$
5.	Infill material	Brick with 1:4 cement mortar

ANALYTICAL SOLUTION

The exact solution of the behaviour of infilled frame involves treating it as an elastic continuum having an infinite degree of freedom system. But this makes the analysis very tedious and time consuming. A rigorous solution has already been presented(8) by using finite element approach in which the continuum was replaced by a number of square finite elements joined together at the node points so as to satisfy the conditions of compatibility at these nodes. For the sake of simplicity, it is desirable if possible to invent an equivalent model which will possess the same vibrational characteristics in terms of stiffness and time period as the actual system. An infilled frame, whose load-deflection curve is known, can be represented by an equivalent single degree of freedom system as shown in Fig. 3. The

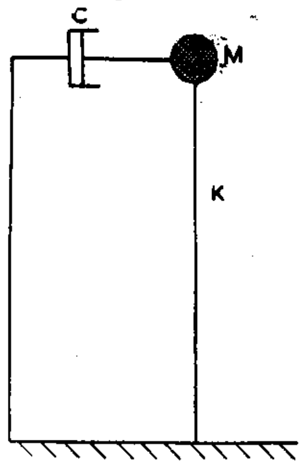

Fig. 3. Equivalent Dynamic of a Single Storey, Single Bay Infilled Frame.

stiffness of this equivalent model can be determined either from the load deflection curve obtained experimentally as shown in Fig.4 or analytically as explained subsequently.

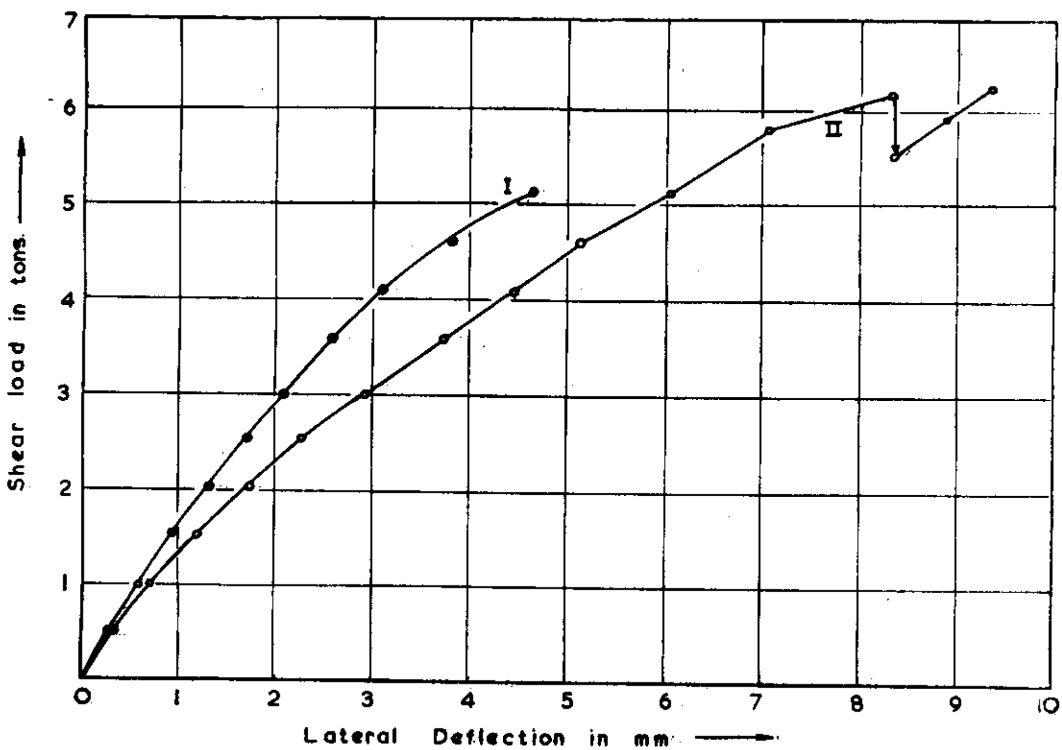

Fig. 4. I—Load Deflection Curve of Infilled Frame with Shear Connectors
II—Load Deflection Curve of Infilled Frame without Shear Connectors

It has been observed that a good estimate of the lateral stiffness of infilled frames without shear connectors can be obtained theoretically by idealising from as a pin jointed structure in which the infill is replaced by an equivalent diagonal strut. Such an idealisation is valid for very small amplitude of oscillations. The stiffness of the equivalent frame work for any particular value of load can be determined by taking the appropriate equivalent width of the strut at that load from the design curves developed by Smith.(9) The total lateral displacement at a particular loading is given by the relationship.

$$\delta H = H \left[\sum_{F} \frac{FUL}{A_1 E} + \frac{H}{2H_c} \sum_{S} \frac{FUL}{E} \frac{(A_1 - A_c)}{A_1 A_c} \right]$$

where

δH = total horizontal displacement under the applied load

H = Lateral load

F = Force in bar due lateral load $H = 1$

Σ = Summation of all bars in frame including diagonal struts

$\underset{S}{\overset{F}{\Sigma}}$ = Summation of all diagonal struts only

U = Force in bars due to unit load only at the point where displacement is required

A_1 = Initial cross-sectional area of members when $R/R_c = 0$.

A_c = Final cross-sectional area of the diagonal member of the frame

E_s = Modulus of elasticity of brick panel, 1.194×104 kg/cm^2

H_c = Horizontal load required to cause crushing in the critical panel of infill determined from the curves of reference.

L = Length of member under consideraiton.

The stiffness of infilled frames with shear connectors can be determined by taking the width of the equivalent diagonal strut equal to d/3 as suggested by Holmes where d is the diagonal length of the infill panel because in this case there is no apparent separation between the frame and the infill along the boundary junction. Table 1 shows the comparison of lateral stiffness of infilled frames obtained experimentally and theortically in the initial straight portion of the load deflection curve as shown in Fig. 4.

TABLE I. LATERAL STIFFNESS TONS/MM

Infilled frame without shear connectors		Infilled frame with shear connectors	
Experimental	Theoretical	Experimental	Theoretical
1.2	1.0	1.5	1.22

The equivalent lumped mass of the system can be estimated in two ways. Firstly, the mass of half of the infilled frame can be imagined to be lumped at its top and the other half at its bottom. This approach give reasonably accurate results for single storey frames. Secondly, the equivalent mass can be determined by using Rayleigh method, assuming the defected shape to be a half cosine curve.

$$m_1\gamma_0^2=\int_0^l \rho_1\, t\, y^2\, dy$$

where

$$y=\frac{y_0}{2}\left(1-\cos\frac{\pi x}{l}\right)$$

and, it represents the deflected curve of the first mode of vibration of the system. The equivalent mass of the system can be computed by adding the individual contributions of the frame and the infill, computed separately.

Table 2 shows the comparison of natural frequencies of infilled frames obtained experimentally and analytically using the concept of simplified dynamic model as discussed above.

TABLE 2. FUNDAMENTAL FREQUENCY

	Experimental c. p. s.	Equivalent dynamic model	
		using exptl. stiffness	using theotl. stiffness
Infilled frame without shear connectors	48	41	39
Infilled frame with shear connectors	50	45	43.1

EXPERIMENTAL INVESTIGATIONS

Two types of tests were conducted. The first of these was the static test and its aim was to find the lateral stiffness of the infilled frames with increasing load. The second test was the dynamic test in which the infilled frame was subjected to free vibrations by imparting an initial velocity to the system.

The bounding R.C.C. frames were designed to have sufficient strength in bending and shear to prevent their failure before the failure of the infill.

Since fairly large size frames were tested, the infill material adopted was the same as used in actual structures, that is, Brickwork. The bricks used were the common bricks used in partition walls of the building. The mortar had a mix of proportion 1:4 of cement and sand by weight with an adequate water cement ratio to give it a good workability. Various tests-regarding the strength of mortar and compressive strength of brick work were conducted as recommended by I.S.I. Code.

The frames were made of R.C.C. of size 6″×6″. The details of reinforcement in the frame are shown in Fig. 1b.

STATIC TESTS

The testing arrangement used for determining lateral stiffness of infilled frames subjected to static horizontal loads is shown in Fig. 5a. It could have as well as been possible to use the same arrangement as used by Benjamin and Williams,[1] if only static tests were required to be done. The loading arrangement adopted by the author had an edge over that of Benjamin because the trinangular frame used to take up reaction from hydraulic jack could easily be moved aside by removing the nuts and bolts which fix it with the ground. In order to provide a rigid base, the prototype frame was fastened to a steel beam of high

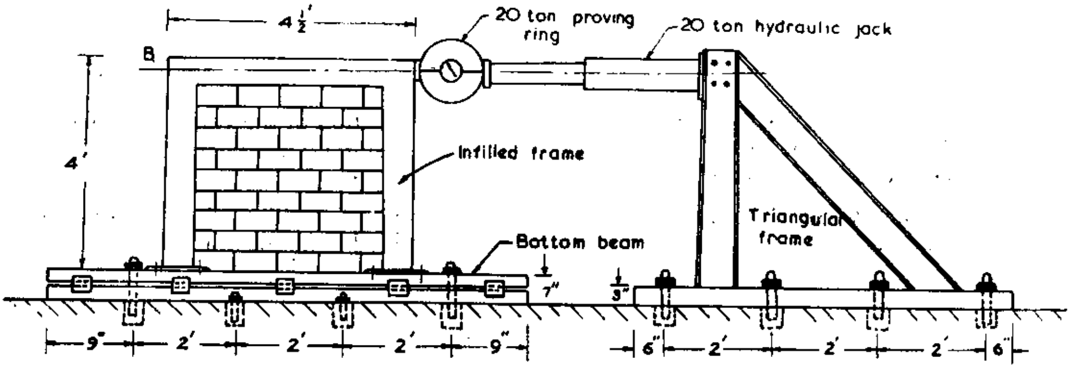

Fig. 5a. Testing Arrangement for Loading Infilled Frames Laterally

rigidity with the help of nuts and bolts. The steel beam was anchored to the ground at four points along its length. The triangular frame made of rolled steel section was designed and fabricated to load the frame laterally. The tilting of the frame due to any possible eccentricity on its either side was prevented by connecting a member normal to the plane or triangular frame as shown in Fig. 5b. Before the static load was applied to infilled frame

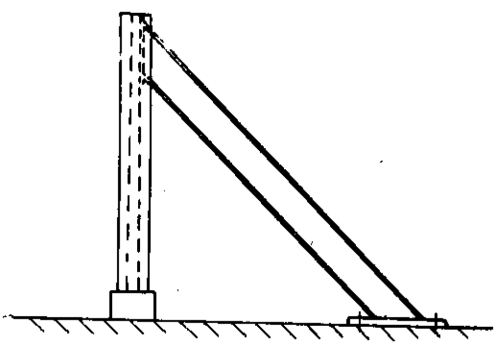

Fig. 5b. Side View of Triangular Frame

it was ensured that the longitudinal axis of the girder of the frame and that of hydraulic jack were perfectly aligned so as to avoid any twisting moment acting on the infilled frame. The lateral load was applied through hydraulic jack fixed to the triangular frame through a 20 ton proving ring. The load was increased gradually at intervals of 0.5 ton till the diagonal crack occured in the infill. The corresponding deflections at the other end of the girder were observed by a dial gauge of least count 0.01 mm.

DYNAMIC TEST

The dynamic behaviour of the infilled frame could be studied experimentally either by conducting forced or free vibration tests. Due to non-availability of adequate apparatus required for forced vibrations, it was not possible to undertake forced vibration tests. It was then decided to conduct free vibration tests. In this type of dynamic test the system can be set to vibrate freely either by giving it an initial displacement or an initial velocity. Due to very high in-plane stiffness of infilled frames it was not easy to give an initial displacement to the system. The system was, therefore set to vibrate freely by imparting to it an initial velocity by means of an impact by a freely falling pendulum mass weighing about 35 kg. as shown in Fig. 6. The energy imparted to the infilled frame was varied by changing the height of the fall. The penedulum mass was held back immediately after the impact so as to enable the frame to vibrate freely. The amplitudes of vibration were picked up by a seismic pick up fixed at the end 'B' of frame, and were recorded with the help of a pen recorder.

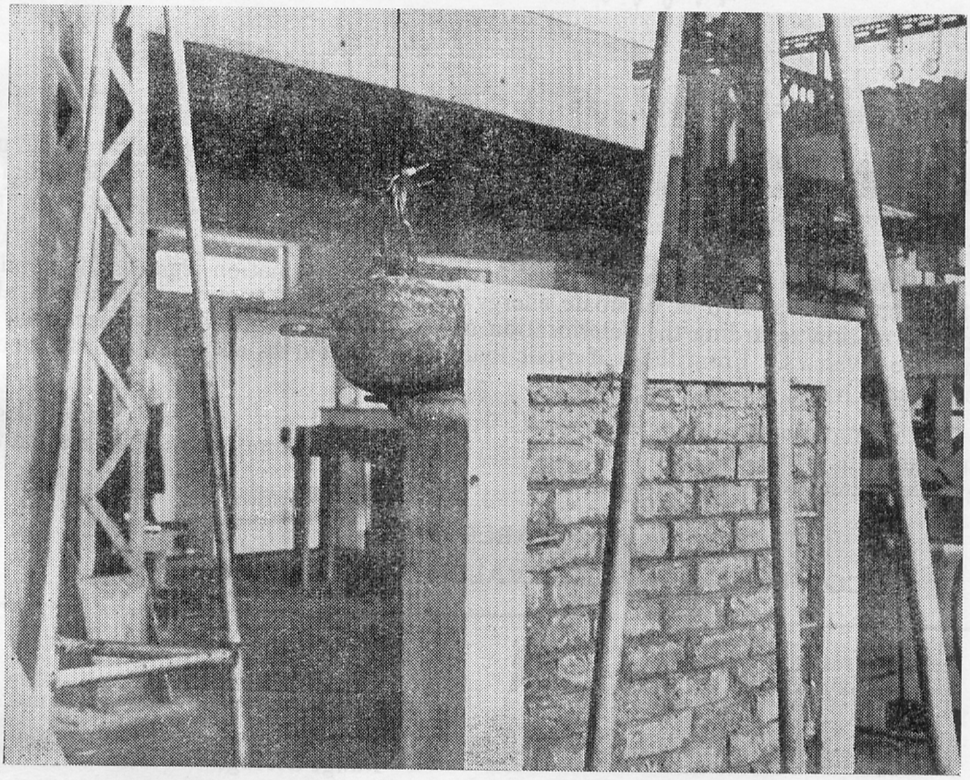

Fig. 6.

The free vibration records are shown in Fig. 7. The natural frequency can be computed from these traces. The experimentally obtained frequencies are given in table 2.

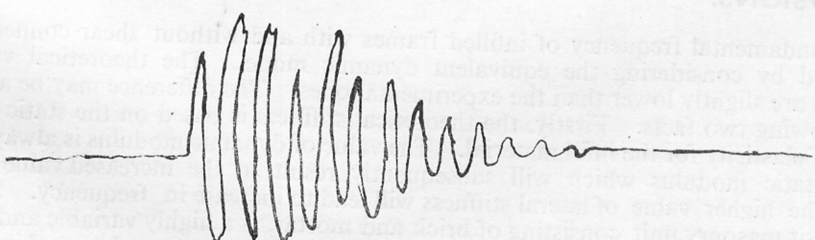

Fig. 7a. Trace without Shear Connectors

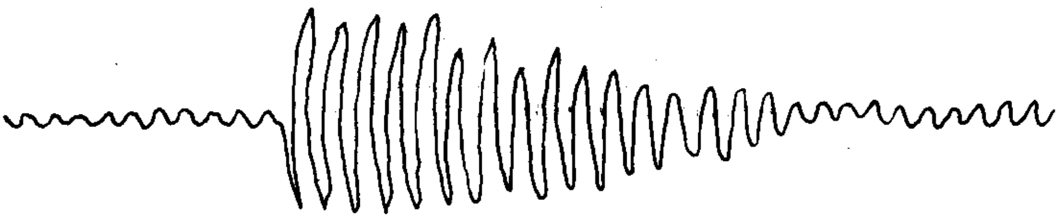

Fig. 7b. Trace with Shear Connectors Paper speed 200 m m/sec

DAMPING IN INFILLED FRAMES:

Damping can only be determined experimentally because of the complicated and undefined sources of energy dissipation present in a composite structure like infilled frames. The coefficient of equivalent viscous damping is evaluated from the record of free vibrations.

Half cyclic load tests were also carried out to obtain information regarding the ability of the structure to absorb or dissipate energy during vibratory motion. Such tests also yield information regarding the deterioration of structures resulting from subjecting it to large force reversals. From the half cyclic load deflection curves also, damping has been determined (6).

Table 3 represents experimental results from cyclic load tests and free vibration tests. Comparing the values of damping obtained by these two methods, it will be seen that the two values agree satisfactorily.

TABLE 3.

COEFFICIENT OF EQUIVALENT VISCOUS DAMPING

Infilled frame without shear connectors	Infilled frame with shear connectors	
	cyclic load test Range average	dynamic test
7.12	5.5-6.5	6.2

CONCLUSIONS:

The fundamental frequency of infilled frames with and without shear connectors can be obtained by considering the equivalent dynamic model. The theoretical values of frequencies are slightly lower than the experimental ones. The difference may be attributed to the following two facts. Firstly, the theoretical stiffness is based on the static value of modulus of elasticity for the infill material. The value of dynamic modulus is always greater than the static modulus which will subsequently result in the increased value of lateral stiffness. The higher value of lateral stiffness will lead to increase in frequency. Secondly, the composit masonry unit consisting of brick and mortar, is a highly variable and complex material. Possible variation in manufacture, construction and craftsmanship can also make a difference between experimental and theoretical values.

Damping in infilled frames, with and without shear connectors is obtained from dynamic tests and is found to be about 6 and 7 percent respectively when subjected to small amplitudes. Damping in frames with shear connectors by half cyclic load tests is found to range from 5.5 to 6.5 percent of the critical damping.

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