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Contribution of Infills to the Response of Multistoreyed Frames

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The paper describes the increase in stiffness due to the infilled wall in a frame for different values of normal and shear stiffness at the interface of the infilled walls and the RCC frame members. The changes in the moments at the critical sections, which are generally beneficial from the design point of view are highlighted. The free vibration characteristics of infilled frame vis-a-vis bare frame are also discussed.

Key Words : Infill, Deflection, Stiffness, Stresses, Vibration

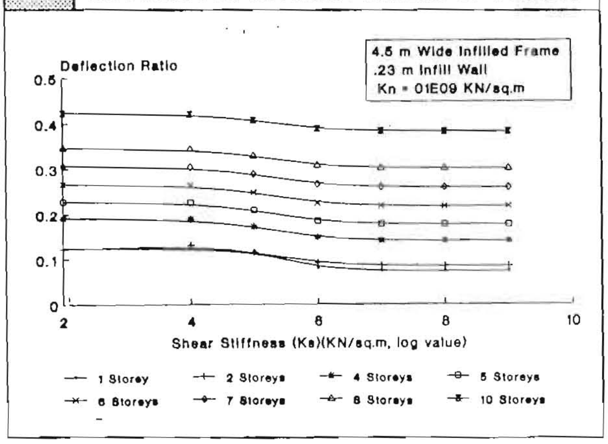
NOTATION

B	:	span of the frame
h	:	height at any point from the foundation
H	:	overall height of the frame
Kn	:	normal stiffness
Ks	:	shear stiffness
X	:	H/B ratio

INTRODUCTION

In normal design practice the contribution of the infill panels towards the strength and stiffness of a multistoreyed building frame is not taken into account. The reasons for not taking the advantage are complications involved in analysis as well as the uncertainty about the integral action between the infill and the frame. The method of construction followed in multistoreyed building frame is to construct the RCC frames first and then lay the brick walls between the RCC members. This introduces the uncertainty about the effectiveness of the bonding at the interface.

FIGURE 1
VARIATION OF DEFLECTION RATIO WITH SHEAR STIFFNESS FOR DIFFERENT NUMBER OF STOREYS



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When a multistoreyed building is subjected to lateral loads, the frame deflects in the direction of the loads. The infilled wall then comes into play to carry a part of the load by providing strut action to the frame. This, in turn reduces the overall deflection of the frame. The stress configuration in the frame also gets changed due to the strut action introduced in the structural system.

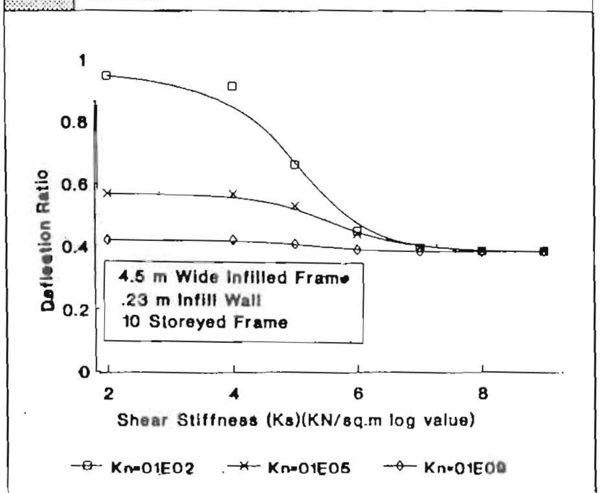
In this paper, a study has been made to assess the increase of stiffness in the overall structural system and to find out the changes that take place in the stress configuration and deformation at the critical sections in the beams and columns. The free vibration characteristics alongwith the mode of vibration are also discussed.

In order to study the effect of uncertainty involved in the monolithicity at the interface, different combinations of normal and shear stiffness values ranging from very low to high have been assumed.

MODELLING OF THE INFILLED FRAME

The infilled frame has been treated as a plane stress problem with interface characteristics at the frame and wall junctions. The RCC frame members as well as the infilled brick walls have been represented by 8-noded isoparametric plane stress

FIGURE 2
VARIATION OF DEFLECTION RATIO WITH SHEAR STIFFNESS FOR DIFFERENT NORMAL STIFFNESS VALUES



elements[1]. The interface characteristics at the junctions of RCC members and brick walls have been discretized by joint elements[2]. The nodal variables for the joint elements have been taken as the relative displacements normal and parallel to the interface. The bending moments at the critical sections of the RCC members have been obtained by numerical integration of the stresses at that section.

The static and free vibration analyses have been carried out by the general FEM package STRSJT developed at this Institute[3].

PARAMETRIC STUDY OF INFILLED FRAMES

To study the influence of interface characteristics between the RCC frame members and the 0.23 m thick brick wall, parametric study was carried out on displacement patterns and bending moment distributions along the RCC members. The building frame taken for the purpose was single bay with storey height of 3.5 m. The parameters considered for the study were :

Number of storeys	1 to 10
Widths of the frame, m	3.5, 4.0, 4.5, 5.0
Shear stiffness at interface (Ks), kN / m^2	1×10^2, 1×10^5, 1×10^9
Normal stiffness (Kn), kN / m^2	1×10^2, 1×10^5, 1×10^9

For the sake of comparison, a frame of the same dimension without the infill (bare frame) was considered. The deflection as well as the moment at the critical sections of this frame were taken as the reference values and those of the infilled frames with different interface stiffness values were expressed as a ratio of the above reference values to make them non-dimensional.

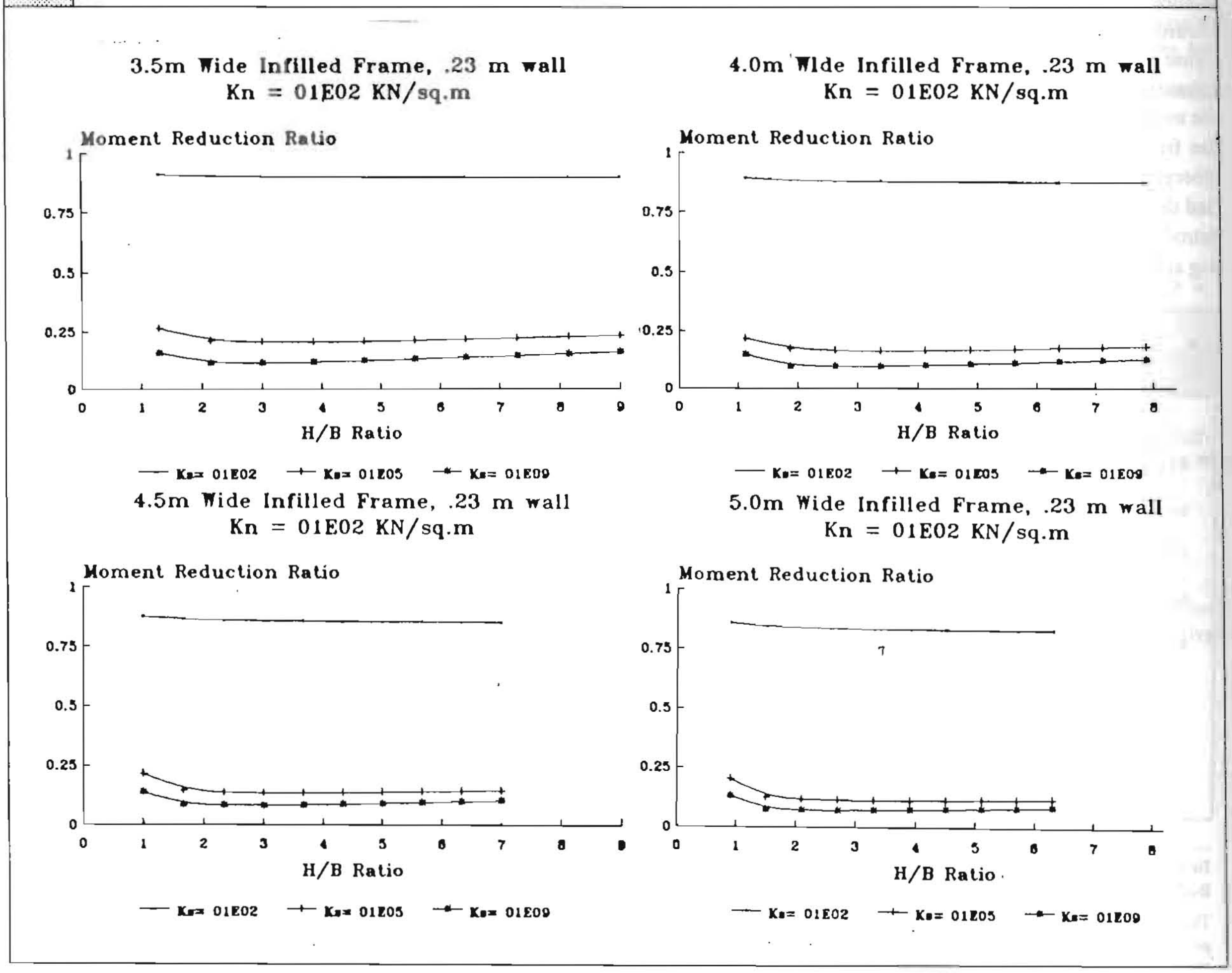
As expected, the infill walls of the frame contributed significantly towards its stiffness and the stress configurations changed considerably vis-a-vis the bare frame.

Since there is overall increase in the stiffness, the dynamic behaviour of such infilled frame is also likely to improve. The fundamental time period of any structural system is related to its stiffness. Reduction in the time period is expected to reduce the amplitude of the structure and in turn the dynamic stresses. The stress history of the structure through the duration of shock is thus likely to be reduced in magnitude. The modal analysis of structure for earthquake load is greatly dependent on the fundamental time period. Parametric study on the variation of time periods for different values of shear and normal stiffnesses has been carried out.

Displacement Characteristics

The deflection ratio of 4.5 m wide single bay infilled frames of

FIGURE 3(a)
COLUMN MOMENT REDUCTION AT FOUNDATION LEVEL



height 1 to 10 storeys vis-a-vis frame without infill are shown in Fig 1.

It may be seen from Fig 1 that for a high value of *Kn* (1×10^9 kN/m^2), the reduction in the deflection of infilled frame due to infill action vis-a-vis a frame without infill wall is quite substantial ranging from 0.1 to 0 45 depending on the number of storeys. The reduction in deflection is more in case of low-rise frames. It may also be noted that for the same value of *Kn* the deflection ratio reduces marginally with increase of shear stiffness.

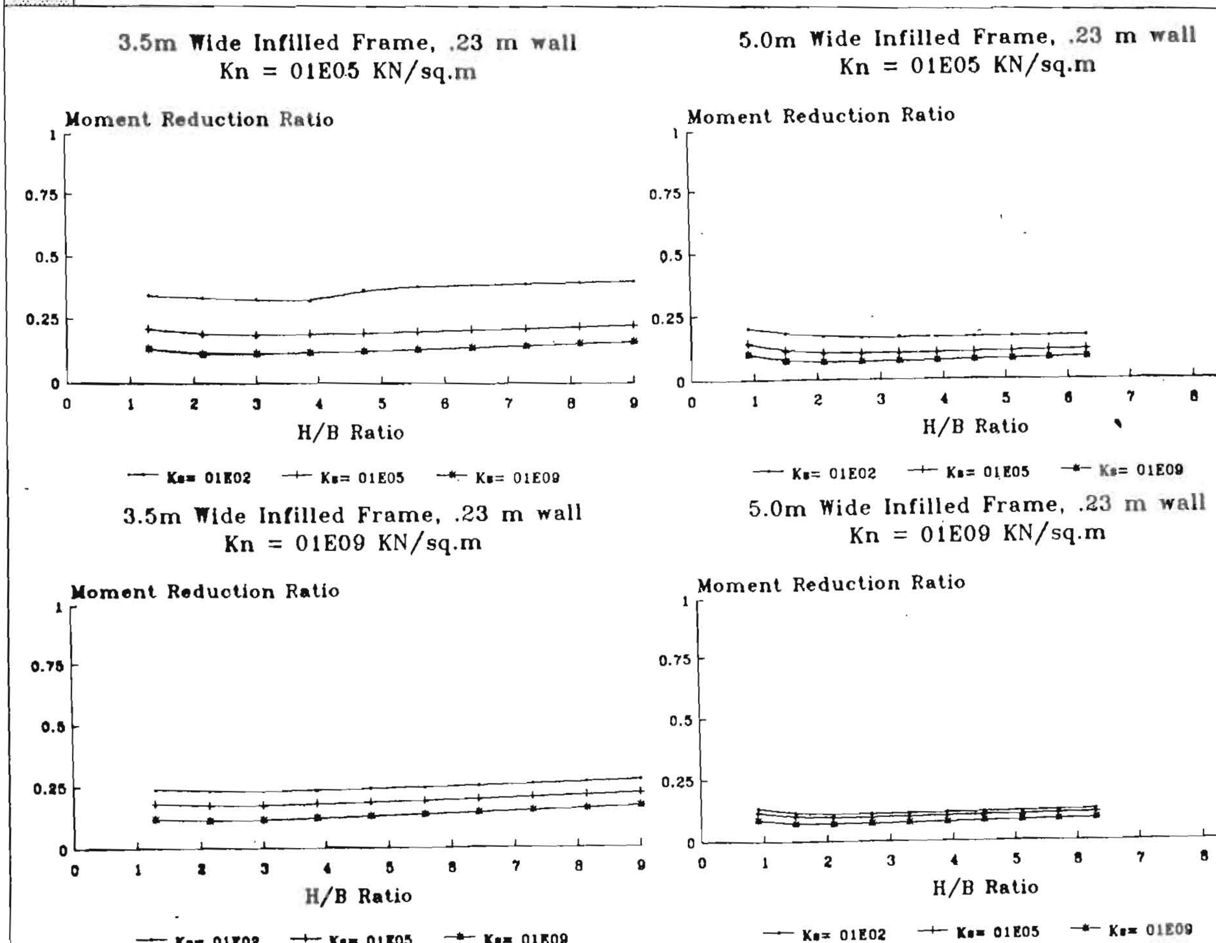
In Fig 2 the variation of the deflection ratio of 10-storeyed infilled frame with three different values of *Kn* has been represented diagramatically. It is observed that for a low value of *Kn* the deflection ratio for 10-storeyed infilled frame vis-a-vis frame without infill reduces substantially with increase of shear stiffness at the interface. As the value of *Kn* increases, the deflection ratio reduces for lower values of shear stiffness. The deflection ratio for very high shear stiffness is almost same for all values of normal stiffness. Figs 1 and 2 combined indicate that the deflection of a 10-storeyed infilled frame reduces considerably with higher values of *Ks* or *Kn* and converges to around 40% of the deflection of a frame without infill. This reduced value is much less as the *H/B* ratio of the building decreases. For single storey building it is as low as 10% to 15%.

Bending Moment Characteristics

It has been observed from this study that the bending moment at the different critical sections in the columns and the beams gets modified to a considerable extent. Fig 3(a) shows the reduction in column moment at foundation level due to infill action for different *H/B* ratios and for different values of *Kn* and *Ks*. It may be noted from Fig 3(a) that the bending moment reduction ratio is almost 1.0 when the values of the two stiffnesses are very low. Very low values of *Ks* and *Kn* physically can be interpreted as lack of integral action between the RCC frame members and the infill panels. When the integral action is almost absent, the infilled frame may be treated as nothing but a frame without infill walls. Hence, the bending moment reduction ratio is very near to 1.0 for very low value of *Ks* and *Kn*. Keeping *Kn* constant, as the value of *Ks* increases the ratio also decreases.

In Fig 3(b) the effect of *Kn* on the moment reduction ratio at foundation level has been demonstrated for two different widths. It may be observed that as *Kn* increases, the ratio further reduces. From Figs 3(a) and 3(b) it may be concluded that in comparison to a frame without infill wall, the column moment at the foundation level of infilled frame decreases as *Ks* and *Kn* values increase. The reduction in moments have been found to be as low as 10% for very high values of *Ks* and *Kn*.

FIGURE 3(b)
COLUMN MOMENT REDUCTION AT FOUNDATION LEVEL



The present construction practice is to construct the infill wall only after the RCC frame has been laid and possibly hardened too. This involves the risk that the integration and interaction between the RCC frame members and infill wall may not be satisfactory. In multistoreyed building, sometimes reinforcing dowel bars, project out from the RCC column members to be embedded in bed joints of the infill wall panels. This sort of dowelling across the interface increases its shear stiffness. If the joints between the infill wall and the concrete RCC framing members be filled up properly with mortar, the stiffness at the joints will develop. The question of *Ks* and *Kn* becoming simultaneously negligible is not very likely, since the same will occur only when there is distinct gap at the interface. That is why the effect of increasing *Ks* and *Kn* has been studied.

Till now, not much information is available for the quantitative values of *Ks* and *Kn* at the interface of RCC members and infill wall in a multistoreyed frame. A test program for assessing the shear stiffness at the interface was undertaken at this Institute. Based on the test results, the values of *Ks* at the interface can be approximately estimated to vary between 0.25×10^6 to 1.0×10^6 kN/m^2 for 0.23 m width of brick infill wall. It is quite difficult to assess experimentally the value of *Kn* at the interface. For an interface tolerably well packed with mortar, the value of *Kn* will be quite high. It may be observed from Figs 3(a) and (b) that the reduction in moment is quite substantial even for *Ks* value of 1×10^5 kN/m^2 and very low value of *Kn*. Same observation is also true when the value of *Kn* is equal to 1×10^5 kN/m^2 and the value of *Ks* very low. From this, it can be inferred that even though the joints between the RCC framing members and the infill walls are not very satisfactory, there will be some reduction in the bending moments, the advantage of which can be taken in design.

The bending moment reduction ratio of the columns at 4th floor level for the infilled frames with widths 3.5 m and 5.0 m has been shown in Fig 4. It may be observed from the diagrams of 3.5 m wide infilled frame that the moment reduction ratio changes sign for the 4-storeyed frame only. This trend has been observed even for 4.0 m wide infilled frame. For 4.5 m and 5.0 m wide infilled frame there is no reversal of sign of the moment reduction ratio. For the column moment at the bottom of 7th floor, similar behaviour has been obtained for 3.5 m and 4.0 m wide 7-storeyed frame. The peculiar behaviour of reversal of sign for comparatively narrow infilled frame may be because the deformation of infilled frame of higher *H/B* value is mainly in shear mode whereas, that with lower *H/B* ratio and higher values of *Ks* and *Kn* is in flexure mode.

FIGURE 4
COLUMN MOMENT REDUCTION AT FOURTH FLOOR LEVEL

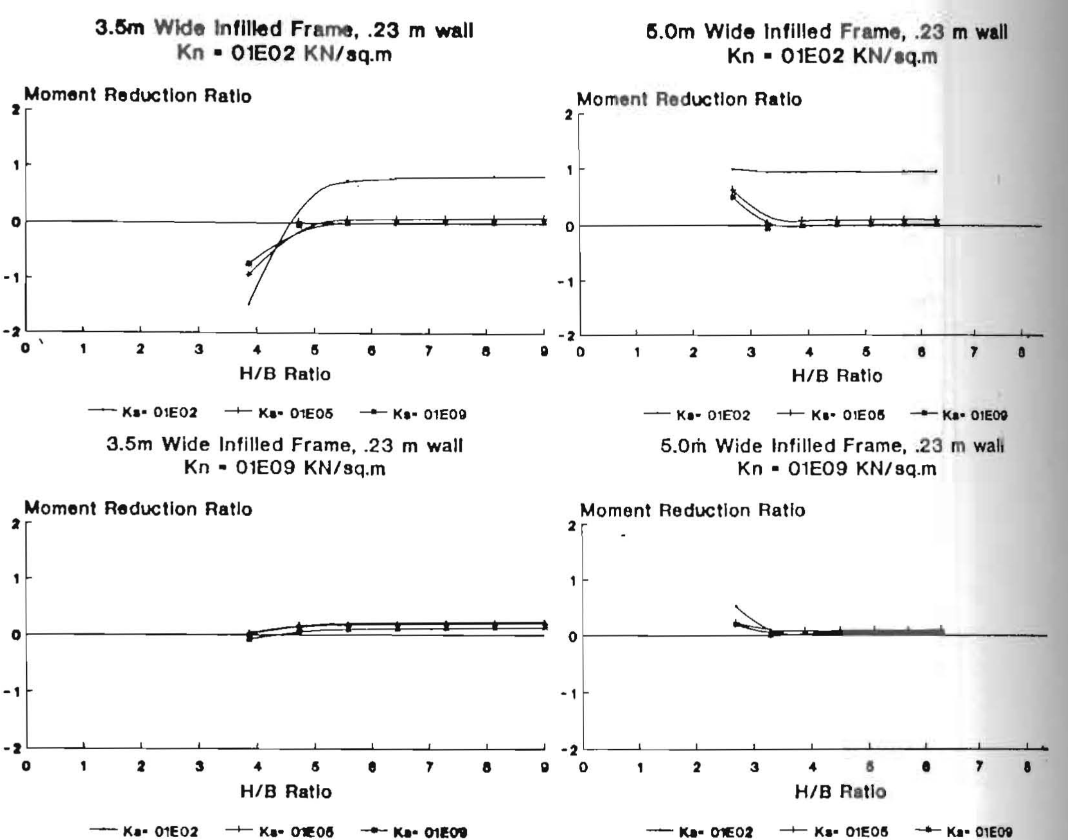
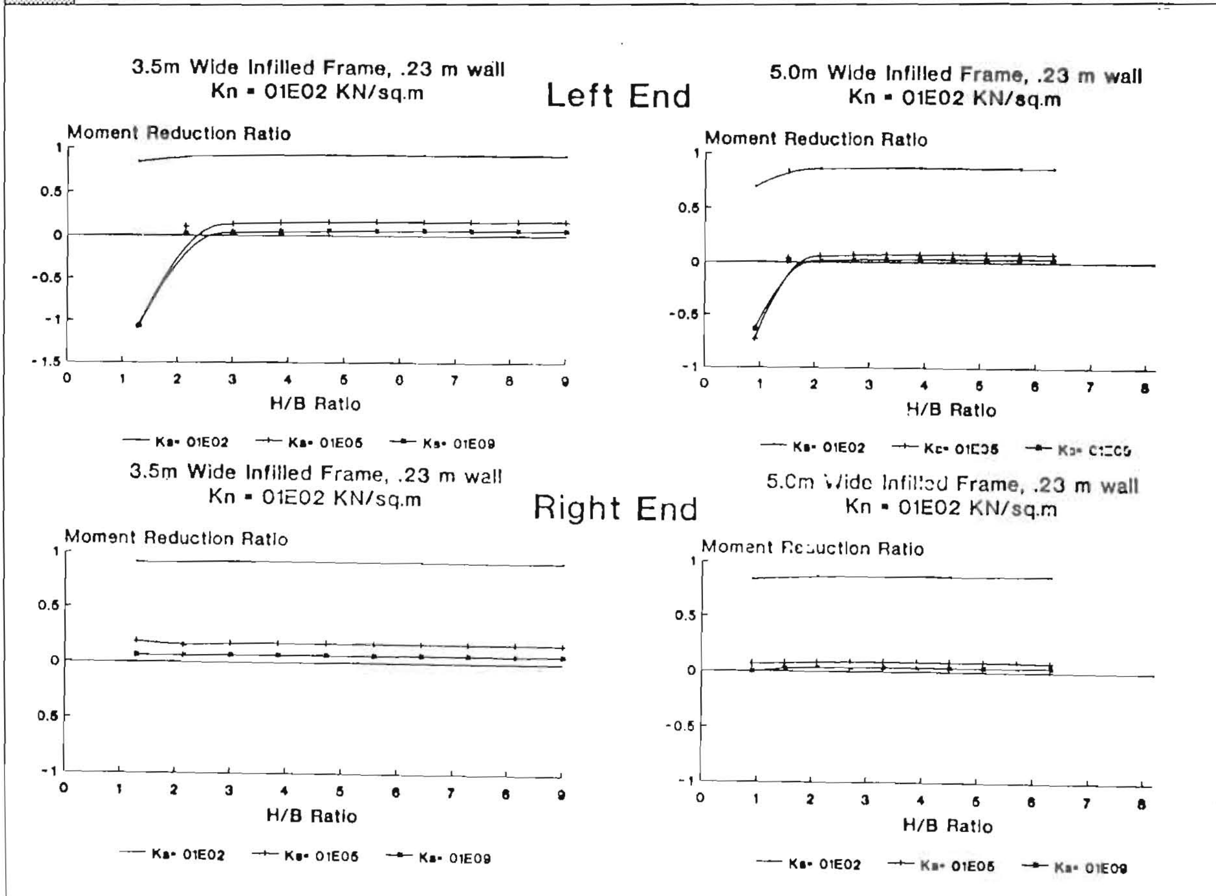


FIGURE 5
MOMENT RATIO AT GROUND FLOOR LEVEL BEAM



The bending moment ratio at the ground floor level beam on the windward (left side) and leeward (right side) ends are shown in Fig 5 for Kn = 100 kN/m^2. On the windward end of the beam there is reversal of bending moment ratio at the ground floor level for high values of Ks and Kn. This tendency is more prominent where the width of the infill frame is smaller. This trend is observed in the beams of all storeys. Fig 6 shows the moment ratio at 4th floor level for very high value of Kn. It may be noted that the general tendency of reversal of moment ratio still persists but the same is greatly reduced. On the leeward side there is no reversal of bending moment ratio. However, the bending moment is greatly reduced with increasing values of Ks and Kn. This phenomenon can be explained from the fact that the interface between the wall and beam applies upward pressure on the beam on the windward side and downward pull at the leeward side. This pressure/pull is more when Kn is higher. It is due to that moment is reduced at the two ends and sometimes reversal on the windward end.

Free Vibration Characteristics

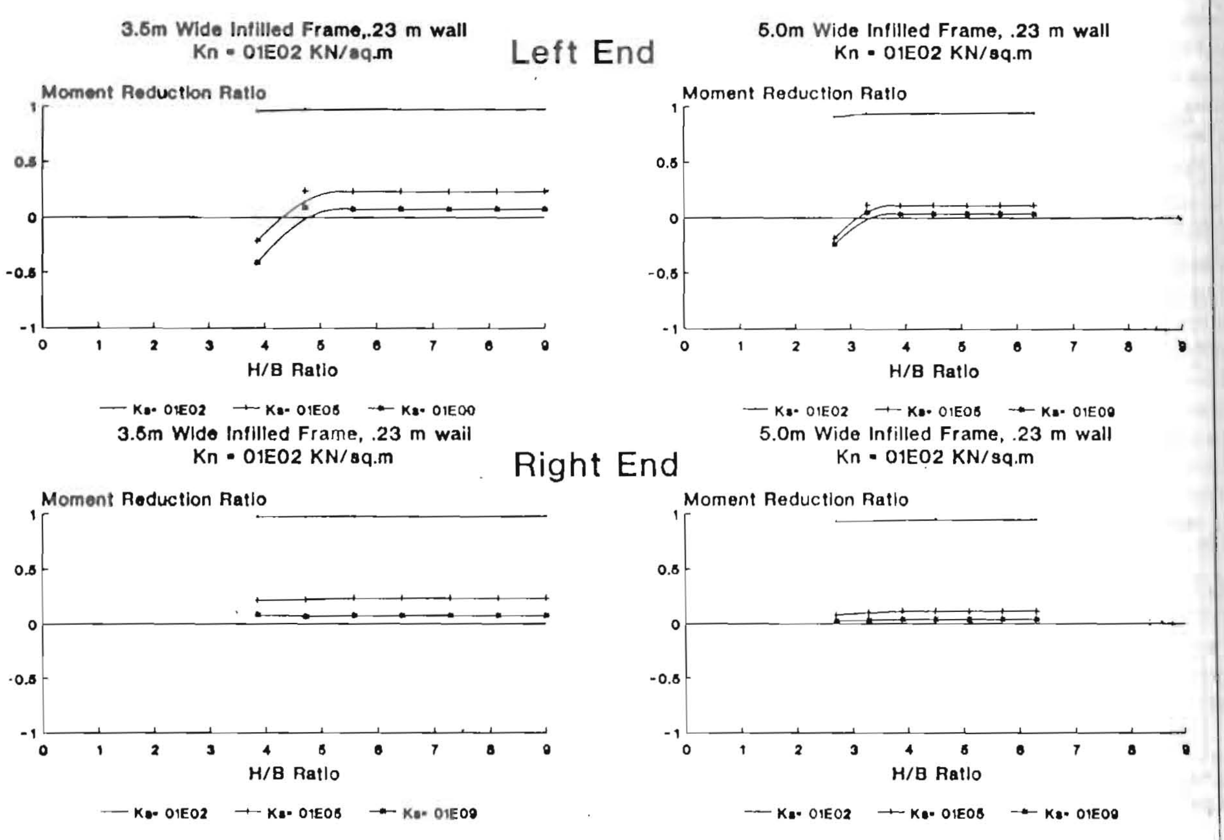
The free vibration characteristics of the infilled frame with different values of shear and normal stiffness have been studied. Fig 7 shows the variation of the fundamental time period for different H/B ratios and three different values of shear stiffness. It may be noted that for the same H/B ratio the time period is more when the shear stiffness is less. This is in confirmity to expectation. For the sake of the brevity of the paper, such variation for other values of Kn are not shown.

The best fit equation for the fundamental time period has been obtained taking into account different values of shear stiffness and the same are shown in Fig 8 for two different values of normal stiffness keeping the normal stiffness at the interface constant. Fig 9 shows similar diagram for two different constant values of shear stiffness considering all values of normal stiffness.

Fig 10 shows the first mode shape for 4-and 10 – storeyed bare frames and infilled frames for two sets of shear and normal stiffness values. Mode shape of the frames are plotted against h/H ratio. It may be noted from the figure that the mode shape diagrams of the bare frames are in shear mode whereas those from the infilled frames are more towards flexure mode. However, on critical examination it may be found that the mode shape of the 10-storeyed infilled frame has more tendency towards shear mode as compared to 4-storeyed infilled frame.

A bare frame being more flexible as compared to an infilled frame of the same dimensions should have higher time period. But from Figs 8 and 9 it may be noticed that for higher values of H/B the fundamental time periods for the infilled frame are more than that of the bare frame. This may be due to the tendency of the tall infilled frames towards shear mode of vibration.

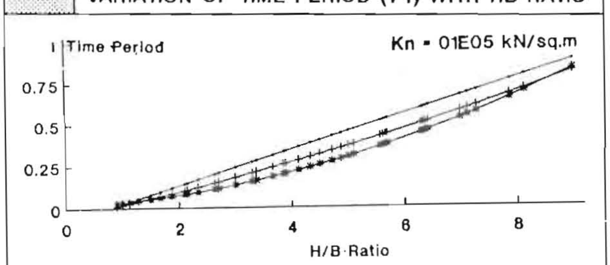
FIGURE 6
MOMENT RATIO AT FOURTH FLOOR LEVEL BEAM



For the same width a taller infilled frame has less distinctive flexure mode of vibration (as discussed earlier with respect to Fig 10). On the other hand flexure mode of vibration is more predominent in low rise infilled frames. An infilled frame with a tendency to vibrate in shear mode is expected to have higher time periods as compared to one vibrating in flexure mode. This may be the possible reason for higher time period of infilled frame with higher H/B ratios.

It may be noted that the fundamental time period of an infilled frame depends upon the stiffness properties of the interface between infill and RCC frame. It may be quite difficult to find out the time period for such infilled frame in absence of proper knowledge about the stiffness properties at the interface. An

FIGURE 7
VARIATION OF TIME PERIOD ($T1$) WITH HB RATIO



attempt has therefore been made to derive a best fit equation for assessing the fundamental time period of infilled frames considering the time periods obtained for various values of shear and normal stiffness (for three values of Ks and Kn) with different H/B ratios. Fig 11 shows the best fit curve vis-a-vis the analytical results. The best fit curve for the fundamental time period is

$$T1 = 0.0366 + 0.0647X + 0.0044X^2 \quad (1)$$

It may be noted that this equation is true only for single span infilled frame and can not be extended to multispan infilled frame. In absence of proper computational facilities and knowledge of the stiffness at the interface, the equation for the fundamental time period can be used within certain accuracy and the same may be used for modal analysis for single span infilled frame under assessed earth quake load.

CONCLUSIONS

1. The moments get considerably reduced at the critical sections of beams and columns of an infilled frame due to the structural action provided by the infill wall. Provided that the joints between the RCC members and infill walls are properly done, the reduction in bending moment may be conservatively taken to be of the order of 50%.

2. The stiffness of the infilled frame also gets increased substantially due to the infill panels.

3. Imperfect joints at the interface of the RCC framing members and the infill walls reduce both the interface stiffness along and across the joint. Provided that the bonding at the interface is fairly good through some projecting dowels from the columns being embedded in the infill walls or through good mortar filling of the joints, the relief in the stresses as well as deformations in the infilled frame are considerable.

4. In absence of adequate computational facilities and proper knowledge about the stiffness at the interface the equation proposed for the fundamental time period of single span infilled frame may be used for design purpose.

5. The study is limited to single span infilled frame only and the conclusions obtained herein may not be valid for infilled frame of multiple span.

6. With the introduction of high speed personal computers and the easy availability of computer code, design of multi-storeyed frames should be done considering the beneficial effect of infill wall. This will reduce the overall cost of the building.

ACKNOWLEDGEMENTS

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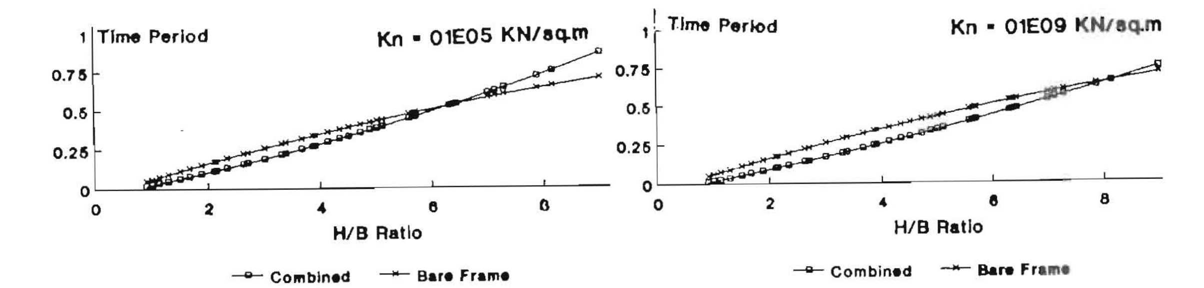
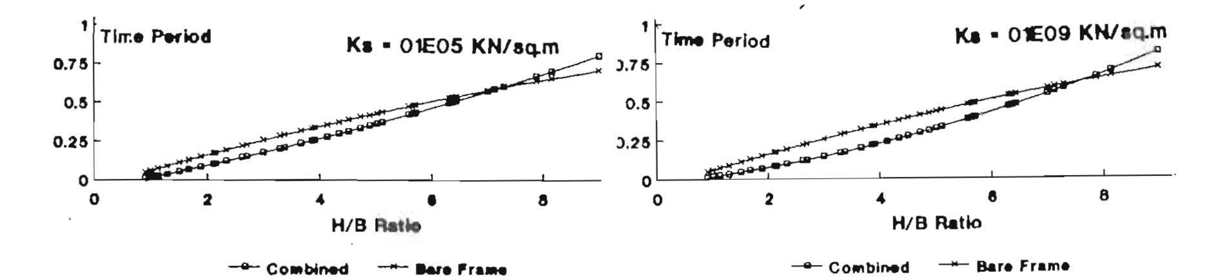
FIGURE 8
VARIATION OF TIME PERIOD ($T1$) WITH H/B RATIO



T1 = -.0434+.0653•X+.0037•X•X
(Considering all values of Ks)

T1 = -.052+.066•X+.0025•X•X
(Considering all values of Ks)

FIGURE 9
VARIATION OF TIME PERIOD ($T1$) WITH H/B RATIO



T1 = -.0577+.0700•X+.0028•X•X
(Considering all values of Kn)

T1 = -.0286+.0407•X+.0058•X•X
(Considering all values of Kn)

FIGURE 10
FIRST MODE SHAPE FOR 4-AND 10-STOREYED FRAME

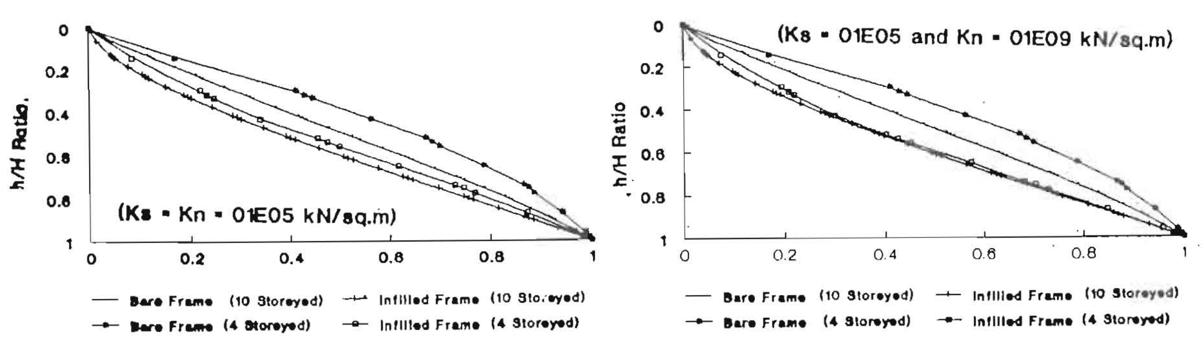
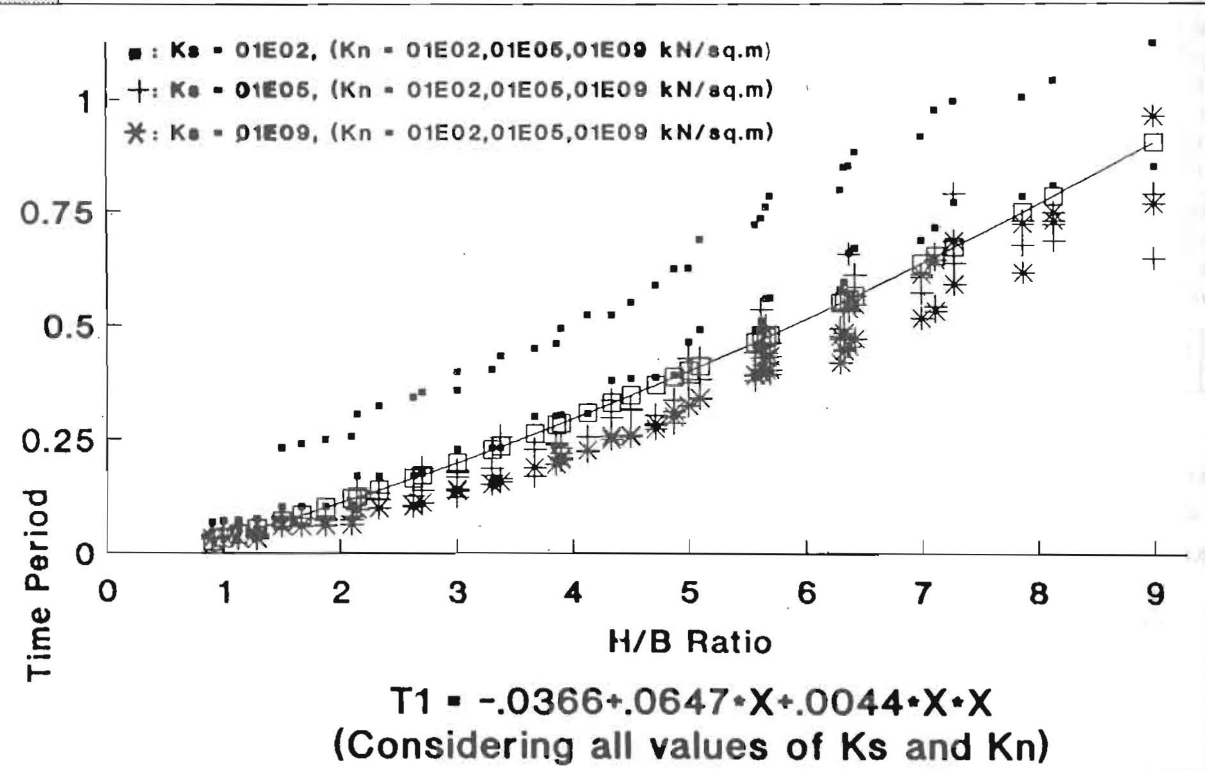


FIGURE 11
BEST FIT CURVE FOR *T*1 FOR SINGLE SPAN INFILLED FRAME



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