Infilled Frames with Opening Strengthened by Lintel Beam

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Summary - Theoretical and experimental studies on infilled frames with window or door opening subjected to lateral load, have been carried out and the results are reported in this paper. The infilled frames have been analysed by Finite Element Method using SAP IV Package Programme. It is found that the lintel over the window opening behaves as a tension-compression member in both the cases of full contact and separation taking place at the interface of infill and frame; whereas the lintel over door opening behaves as a tension-compression member when full contact exists and as a compression member when separation is allowed.

1. INTRODUCTION

Studies carried out on infilled frames with openings (window or door) are meagre. With the little information available, it is well known that the presence of opening in the infill reduces the lateral stiffness of infilled frames considerably [1,2]. As openings cannot be totally avoided in the buildings, they may however be strengthened by providing stiffeners around them to improve the behaviour of infilled frames. The simplest stiffener normally provided over an opening is the traditional 'lintel'. For vertical loads, the lintel is being designed as a flexural member but its behaviour under lateral loads is not fully understood.

The present study is carried out on an infilled frame comprising of 20 cm x 20 cm reinforced concrete frame infilled with brick masonry 270 cm x 270 cm x 20 cm (Fig.1). Central door opening with sides one-third the width of infill and a central door opening of width one-third that of infill but height two-thirds the height of the infill are considered. For the study here, a reinforced concrete lintel of 20 cm x 10 cm cross-section is provided over the opening. Four different rigidities of lintel are considered to study the effect of rigidity of lintel on the behaviour of infilled frames.

2. METHOD OF ANALYSIS

An iterative finite element method of analysis is adopted for the theoretical study [3]. Typical finite element discretisation of infilled frames with opening is shown in Fig.2. The infill continuum is discretized as a rectangular four noded plane stress elements having two-degrees of freedom at each node. Frame members and the lintel are considered as beam elements with three degrees of freedom at each node. The interface between the bounding frame and the infill panel is represented by short-link elements similar to beam elements having axial and bending rigidities.

Both the cases of perfect contact and separation taking place at the interface of frame and infill are considered in the analysis. However, it is assumed that there is always perfect bond between the lintel and the infill panel and also moment of inertia and area of cross-section of the lintel are assumed to be concentrated along the inner edge of the opening.

Separation, slip and loss of friction at the interface of frame and infill are considered in the analysis by the iterative finite element method explained elsewhere [3]. For the iterative analysis, the Package Computer Programme SAP IV is utilised on IBM 370/155 computer.

3. EFFECT OF LINTEL ON THE STRESS DISTRIBUTION IN INFILL PANEL

Table 1 gives the stress distribution at salient points (A,B, .D,E of Fig.2) in the infill panel. For comparison the corresponding values of stresses in solid infill panel are also given. It is seen that, even though the stresses at infill corners (A,B) are considerably high (particularly when separation takes place) in the case of infills with opening (window or door) when compared to those of solid infills, introduction of lintel over the opening does not affect the stress levels appreciably. Similar behaviour is also observed at the corners of the opening at sill level (C,F) in the case of window opening.

At lintel level, in the cases of both window and door opening, when perfect bond exists at the interface of frame and infill, lintel does not have any effect on the stress distribution at the corners of the opening (D and E). But when separation takes place, lintel considerably reduces the stress concentration at the corners (D,E) of the opening, particularly in the case of door opening.

4. EFFECT OF LINTEL ON THE LATERAL STIFFNESS

Variation of lateral stiffness of infilled frames with opening (with and without lintel) and without opening (solid infill) is also given in Table 1. Window and door openings considered in the analysis reduce the lateral stiffness considerably when compared to that of solid infilled frames and more so when separation takes place at the interface of frame and infill. It is seen from Table 1 that the lateral stiffness of infilled frames with window opening strengthened by lintel is not very much different from that of infilled frames with unstiffened opening. But in the case of door opening an increase in lateral stiffness of the order of 1 % and 8.5 % is observed for full contact and separation respectively. Thus it may be concluded that the effect of lintel on lateral stiffness of infilled frames with openings is negligible.

5. STRUCTURAL BEHAVIOUR OF LINTEL

Stress distribution in the lintels over the window and door openings is presented in Fig.3 and 4 for both the cases of perfect bond and separation at the interface of frame and infill.

5.1 Lintel over Window Opening

Variation of stresses in the lintel over window opening is shown in Fig.3. It is seen that the axial stress varies along the length of the lintel, being tensile on the windward side and changing to compressive on the leeward side; the compressive stress intensity being relatively higher compared

to tensile stress. Total stress along the top fibre of lintel is mostly compressive except over a small length on the windward side. The stress at the bottom fibre is also compressive over a greater length.

When separation takes place at the interface of frame and infill, the intensities of stresses increase considerably and the compressive stresses, in particular, along the bottom fibre being quite higher than those when full contact exists. From the stress distribution in the lintel it can be said that the lintel over the window opening in an infill panel behaves as a 'tension-compression' member.

5.2 Lintel over Door Opening

The behaviour of lintel over door opening in an infill panel is shown in Fig.4. It is observed that when perfect bond exists at the interface of bounding frame and infill, the total stress varies from tension on the windward side to compression on the leeward side of the lintel as in the case of the lintel over the window opening. But, it is interesting to note that when separation takes place, the lintel over the door opening is subjected only to compressive stresses over its entire length with a high intensity near the leeward corner of the opening. Hence the behaviour of the lintel over the door opening can be summarised as a 'tension-compression' member when perfect bond exists and as a 'compression' member when separation takes place.

6. EFFECT OF RIGIDITY OF LINTEL ON LATERAL STIFFNESS

It was seen earlier that lintel (Flexural rigidity $EI = 349.98 \times 10^6$ kg-cm^2) does not have any influence on the lateral stiffness of infilled frames with opening. To study whether variation of rigidity of lintel has any effect on the lateral stiffness, four different rigidities of 43.7×10^6, 349.89×10^6, 1181.25×10^6 and 2799.99×10^6 kg-cm^2 were considered. These rigidities correspond to lintel depths of 5, 10, 15 and 20 cm respectively, keeping the breadth constant equal to 20 cm and modulus of elasticity $E = 210000.0$ kg/cm^2.

The variation of lateral stiffness of infilled frames with opening with lintels of different rigidities for a particular value of relative stiffness $\lambda h = 7.04$ is given in Fig.5. Initially, there is found to be an increase in lateral stiffness by about 1 % for window opening and 2 % for door opening, but it is almost constant for other higher rigidities. Hence, the variation in lateral rigidity of lintel does not have any appreciable effect on the lateral stiffness of infilled frames.

7. EXPERIMENTAL INVESTIGATION

Results of theoretical study have been verified by experiments on seven half-scale models; four with window opening and three with door opening [4]. Salient results are presented in Table 2. The agreement between theoretical and experimental values are fairly good except where the theoretical values are of negligible order especially in the case of bending moment.

8. CONCLUSIONS

Based on the theoretical and limited experimental study made, following conclusions can be drawn:

1. Lintel over the opening in an infill panel does not have any influence on the lateral stiffness of infilled frames.
2. Lintel reduces the stress concentration at the corners of the opening.
3. Lintel over the window opening behaves as a tension-compression member both when perfect bond exists as well as when separation takes place at the interface of bounding frame and infill.
4. Lintel over the door opening behaves as a tension-compression member when perfect bond exists at the interface of bounding frame and infill, but as a compression member when separation takes place.
5. Variation of rigidity of lintel does not have any effect on the lateral stiffness of infilled frames with opening.

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TABLE 1

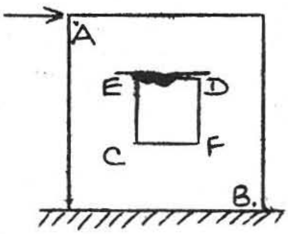
S.No.	Type of Infilled Frame	Type of Contact	Point	Maximum Stress N/mm^2	Lateral Stiffness N/mm
1	2	3	4	5	6
1	Solid Infilled Frame	C	A	-0.295	25.09×10^4
			B	-0.225	
			D	-0.083	
			E	0.093	
2		S	A	-1.676	14.95×10^4
			B	-1.681	
			D	-0.138	
			E	0.050	
3	Infilled Frame with Window Opening (without lintel)	C	A	-0.309	18.03×10^4
			B	-0.255	
			D	-0.491	
			E	-0.393	
4		S	A	-0.309	6.62×10^4
			B	-1.701	
			D	-0.730	
			E	0.441	
5	Door Opening (without lintel)	C	A	-0.270	14.41×10^4
			B	-0.348	
			D	-0.560	
			E	0.491	
6		S	A	-2.166	2.37×10^6
			B	..	
			D	-2.822	
			E	-0.696	
7	Window Opening (with lintel)	C	A	-0.315	18.08×10^4
			B	-0.253	
			D	-0.314	
			E	0.250	
8		S	A	-1.691	6.71×10^4
			B	-1.706	
			D	-0.463	
			E	·0.275	

continued....

Table 1 (continued)

S.No.	Type of Infilled Frame	Type of Contact	Point	Maximum Stress N/mm^2	Lateral Stiffness N/mm
1	2	3	4	5	6
9	Door Opening (with lintel)	C	A B D E	-0.290 -0.354 -0.373 -0.323	14.80×10^4
10		S	A B D E	-1.789 .. -1.368 -0.511	2.70×10^4

C = Contact and S = separation.



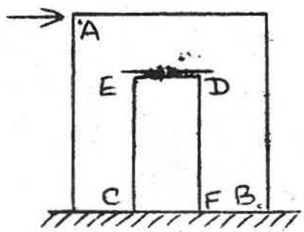
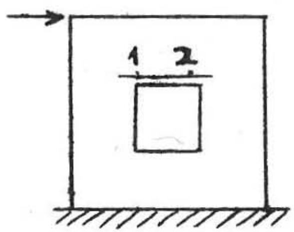
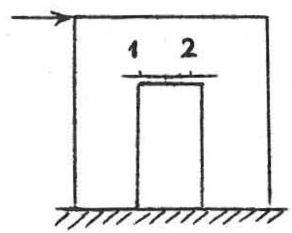


TABLE 2

S.No.	Type of Opening	Full contact or separation	Theory or Expt.	Load	Axial Forces at point, KN		Bending Moment at Point KN-m	
				KN	1	2	1	2
1	Window	Full contact	Theory	9.81	0.751	-2.334	0.009	0.004
			Expt.	9.81	3.349	-3.349	0	0
2	Window	Separation	Theory	19.61	0.290	-8.522	0.003	0.004
			Expt.	19.61	3.349	-10.047	0	0
3	Door	Full Contact	Theory	9.81	0.590	-3.094	0.011	0.006
			Expt.	9.81	3.432	-3.432	0	0
4	Door	Separation	Theory	9.81	-6.151	-13.749	0.010	0.020
			Expt.	9.81	-7.257	-18.142	0	0





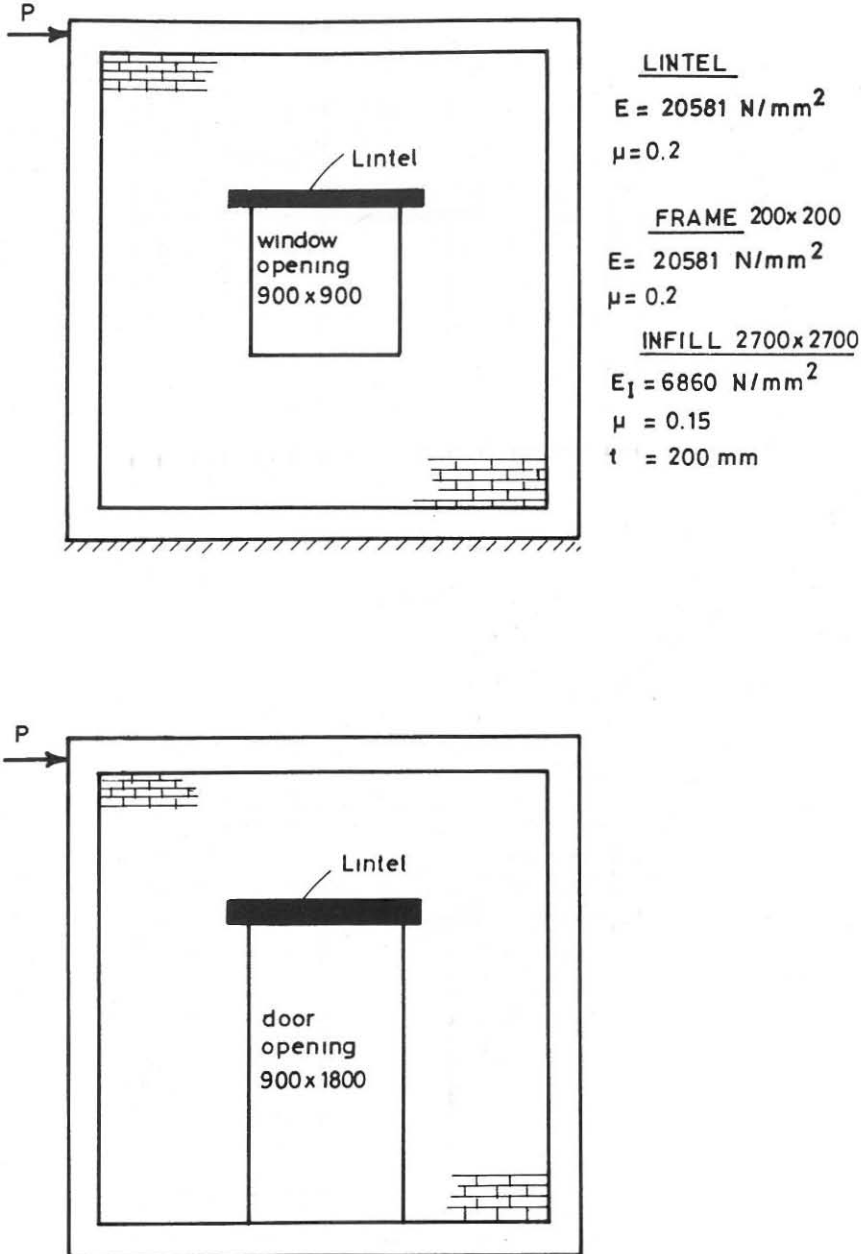


FIG. 1. INFILLED FRAME WITH WINDOW AND DOOR OPENINGS.

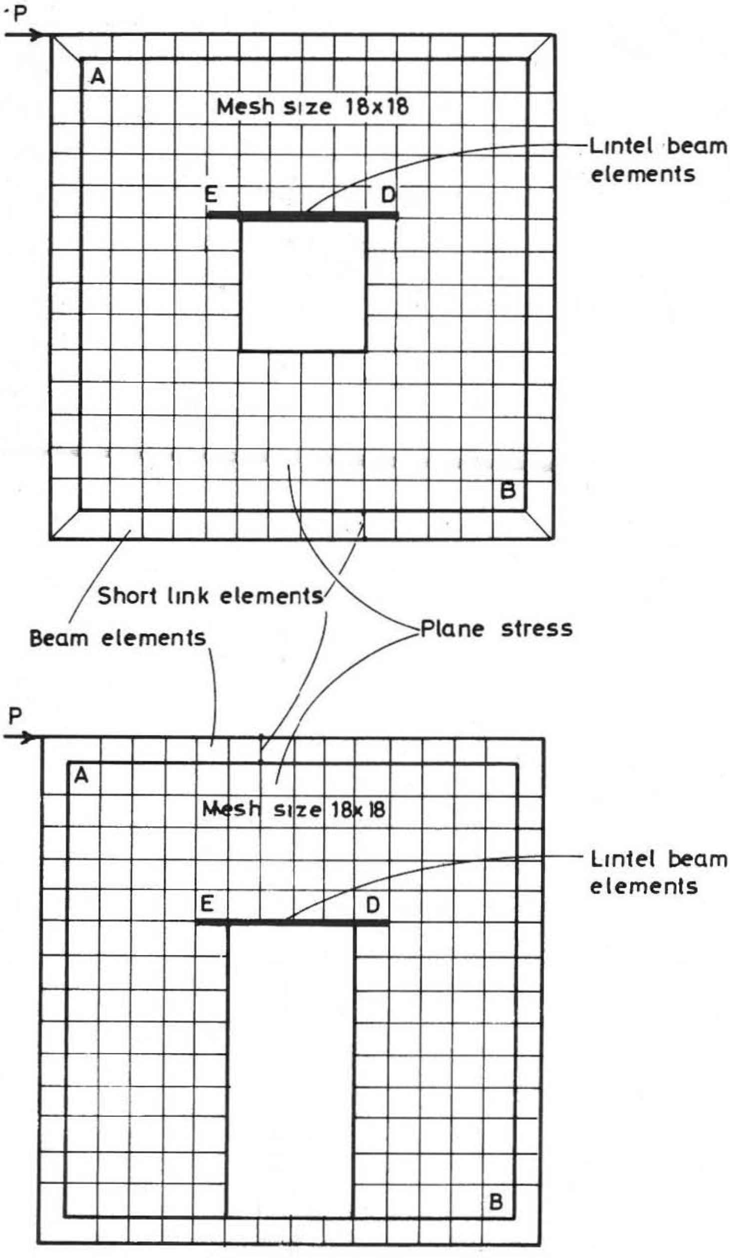


FIG. 2. FINITE ELEMENT DISCRETIZATION.

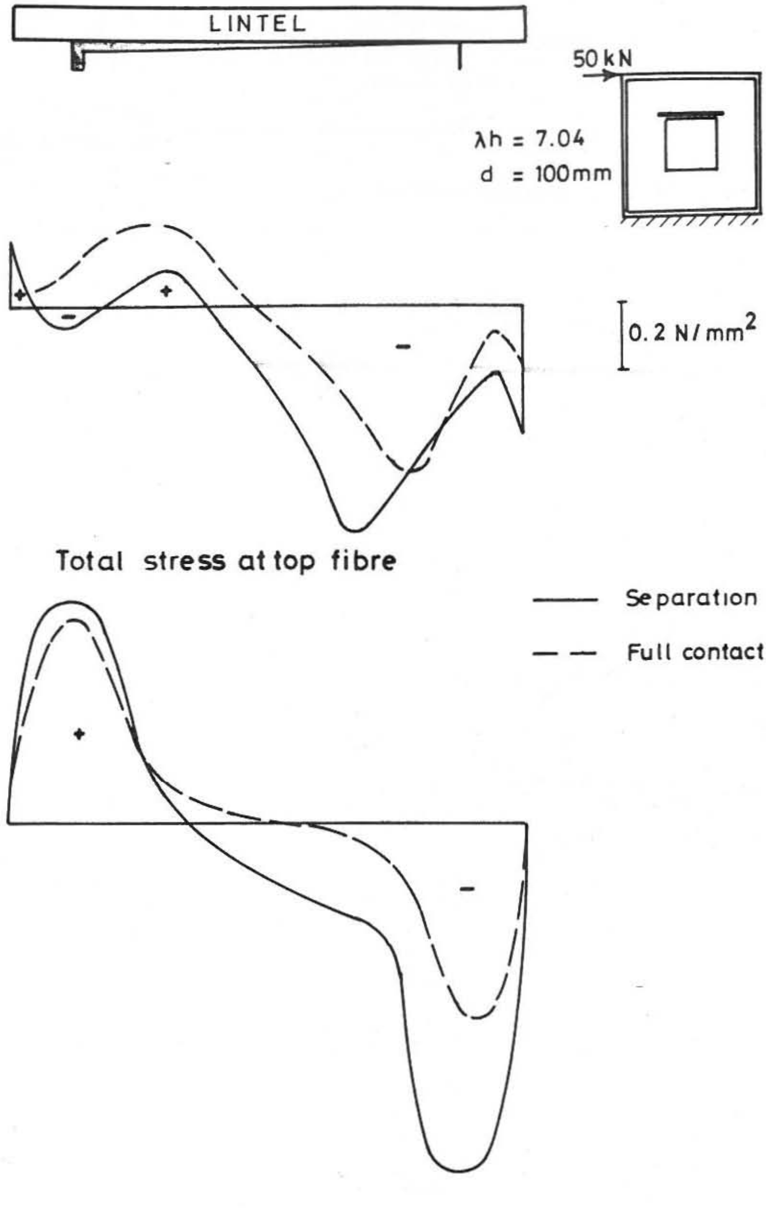


FIG. 3. VARIATION OF STRESSES IN THE LINTEL OVER WINDOW OPENING (WS1)

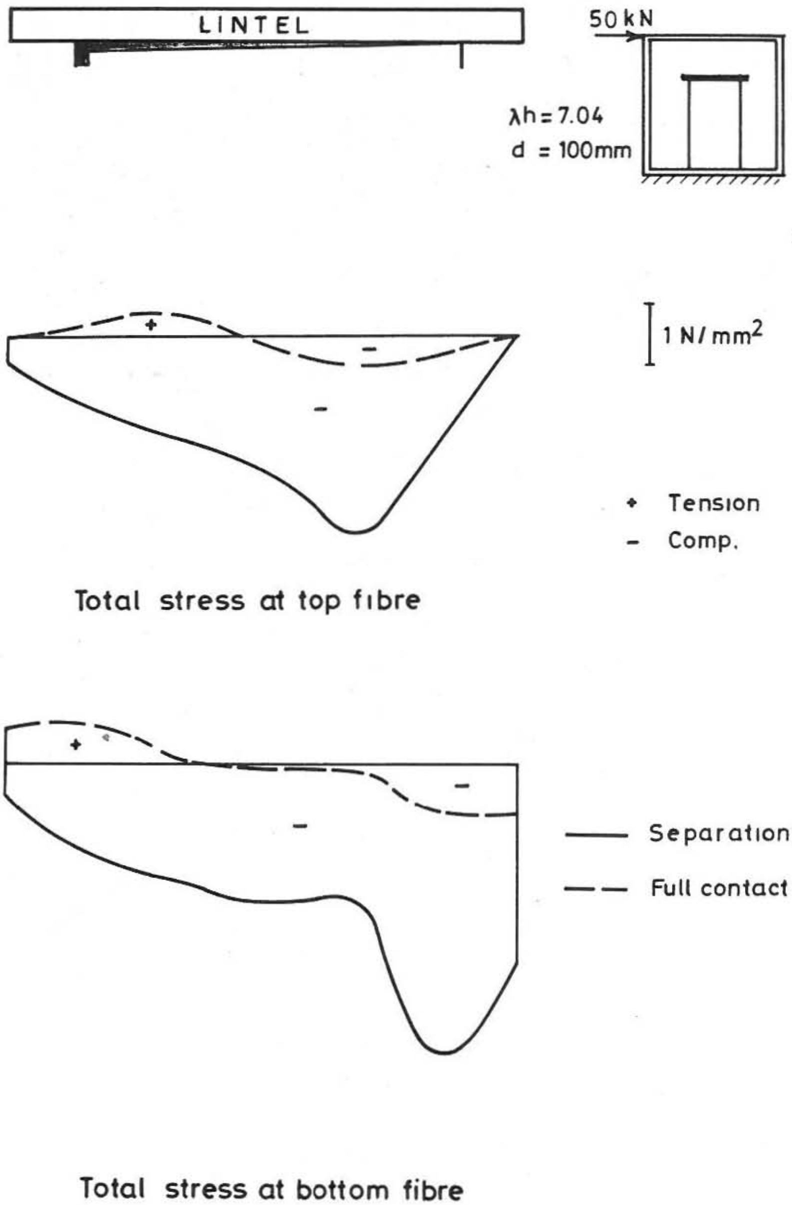
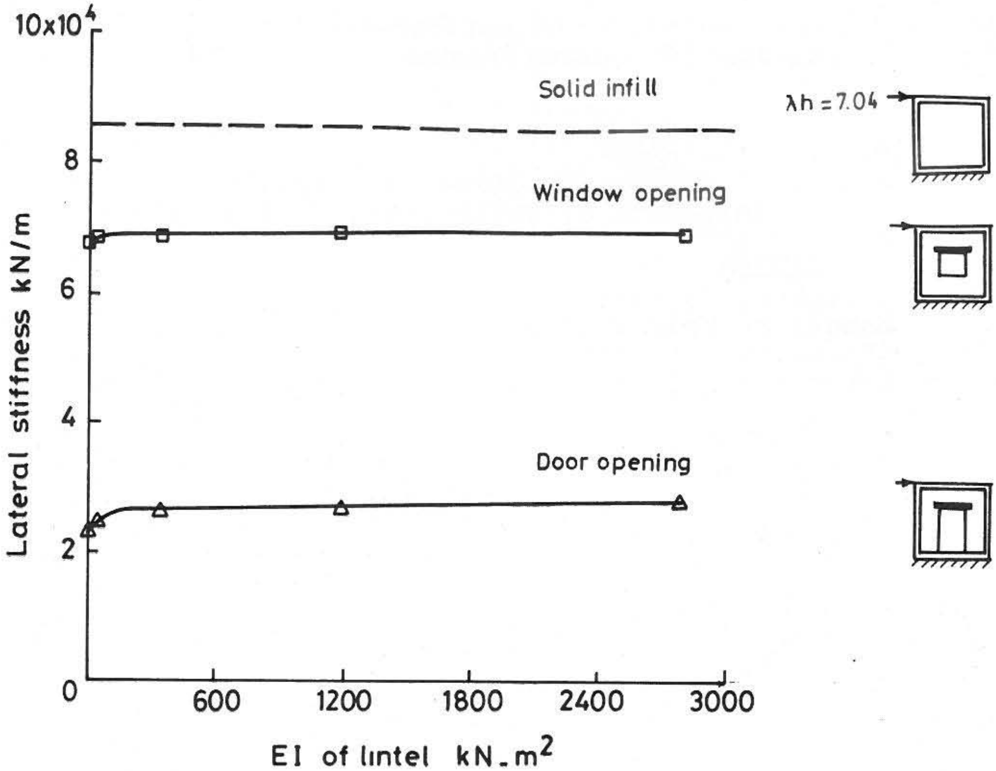


FIG. 4. VARIATION OF STRESSES IN THE LINTEL (DS1) OVER DOOR OPENING.



EI 1 = 43.74 kN.m^2

EI 2 = 349.98 kN.m^2

EI 3 = 1181.25 kN.m^2

EI 4 = 2799.99 kN.m^2

FIG.5. VARIATION OF LATERAL STIFFNESS WITH THE RIGIDITY OF LINTEL (SEPARATION)