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In-Plane Behavior of Masonry Infilled Reinforced Concrete Frames with Wooden Choh-kat Openings

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Abstract- ***Determination of the behavior of infilled framed structures with openings has been a matter of study lately. However, analysis of infilled structures have of yet ignored the vital effect of opening frameworks, which in Kashmir valley is a wooden assembly called 'Choh-kats'. This study focuses on study of the behavior of the infilled frames with wooden 'Choh-kats' under in-plane lateral loads and is based on determination of initial lateral stiffness of infilled frame with wooden choh-kat under control parameters of opening location, opening area, opening aspect ratio and model of choh-kat framework. The finite elements are used to illustrate the behavior, and linear stiffness of the frames is determined at 10% lateral strength of a fully infilled frame. This work illustrates that the in-plane lateral stiffness of the frame increases with the addition of choh-kat and also gives a better understanding of illustrating infill with choh-kat openings as multiple compressive struts.***

Keywords-Brick infills,finite element method, lateral stiffness, wooden choh-kat.

I. INTRODUCTION

Brick masonry reinforced or un-reinforced is generally used as an infill material dating back to 18th century when steel frames were used. Modern framed structures are assembly of columns and beams constructed in reinforced concrete or steel. The bare frames have no infill while the infilled frames are generally filled in masonry. Bare frames would behave as framed systems that generate moments and axial forces. This is particularly the case under an action of in-plane lateral forces [1]. Under an action of in-plane lateral forces, infilled frames behave monotonically with the framed system up to the stage the infill shows corner separation at 2% lateral in-plane drift [2]. At this stage the system shows maximum stiffness, this tends to decrease with further increase in loads due to infill tensile crack initiation.It is at this moment that the infill behaves as an axialdiagonal compressive strut [3]. For in-plane lateral loads, a simple mathematical infill representation is a diagonal compressive strut pin-jointed at junctions [4]. Equivalent width of this strut is taken as 1/3 of its diagonal length [1], 1/8 of diagonal length [5], 1/10 of diagonal length [6], ¼ of diagonal length [7]. Infill is also modeled as three parallel struts with width of diagonal strut 1/8 of diagonal length and two off-diagonal struts as 1/16 of diagonal length [8]. Polyakov suggested that the strut displacement occurs at corners and stresses are transmitted in compression zone of frame-infill interface. Thereby, contact length which depends on the stiffness of frame and infill is determined by various methods [9].

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Studies on infilled frames have suggested that the presence of an infill leads to increase in the in-plane stiffness up to 500%, increase in strength by 70% and in increase in energy dissipation capacity by 100%, besides changing the seismic behavior of the system [10].

Opening in an infill is a perforation produced due to presence of a door, a window or a ventilator. The purpose of opening is to allow light as well asventilation. Under gravity loads, the behavior of infill is as piers and spandrels around openings. An infill with an opening under an action of in-plane lateral loads does not behave as an axial compressive strut but as multiple struts. With this, lesser chances of corner separation is induced, possibility of which decreases further with increase in opening area and deviation of aspect ratio about unity. Thereby, maximum in-plane lateral stiffness decreases expectedly with increase in the area of an opening [11]. There is an absence of knowledge of contact length parameters. The perforated infill is difficult to model. For this purpose, the effective width of a diagonal strut for infilled frame without opening may be reduced by a reduction factor to simulate the presence of openings of various aspect ratios in the infilled frame [12-14]. Multi-strut models are also suggested to simulate the local effect due to presence of an opening [15]. Mesh modeling of a perforated infill suggests the mesh to be broken at the junction of the opening and the infill.

However, all works prior have not incorporated the main component of the opening about which a shutter of a door or a window is hinged. This is the opening frame and this frame in sub-tropical and temperate regions of the world is made in wood. In *valley of Kashmir*, where traditional construction was either dhajji-dwari or taq, *choh-kat frame* constructed in wood was an essential component. This choh-kat frame has found its presence in modern infilled construction as well. In many contemporary constructions, the wooden choh-kat has been replaced by Aluminium or steel frames. It is observed that these wooden choh-kats are partially embedded in infill masonry by means of steel hold fasts or flats. Choh-kat is a monolithic construction with masonry infill apart from frame-infill construction which is not so. The behavior of masonry infill will change from the system without choh-kat. With consideration of choh-kat in a masonry infill, the possibility of infill corner separation and of axial diagonal compressive forces transmitted through infill seem to increase, which is however, not the area of this study.

II. OBJECTIVES

This study focuses on determining the *initial lateral stiffness* of infilled reinforced concrete frame with wooden choh-kat. The initial lateral stiffness is the stiffness at the load when infill and frame behave monolithically.

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This is at a load of 10-15% of the ultimate strength of the frame [16]. Initial lateral stiffness in this study is taken at 10% of ultimate strength of the frame [17]. The study is done in SAP 2000 (Structural Analysis Program). Initial lateral stiffness gives the maximum expected stiffness and this variable illustrates the change in in-plane behavior of choh-kat opening masonry infill reinforced concrete frame.

III.METHODOLOGY

[A] System Parameters

To illustrate the behavior of choh-kat framed masonry infill reinforced concrete frame, a basic model with geometrical properties given for 1-Bay 1-Story is given in figure (1). The frame elements have system properties which are given in table (I). Choh-kat is a wooden frame. For small size openings, the choh-kat frame has a general model as given in figure (2a) and for larger openings, the model configurations change with size of opening with change in number of intermediate wooden stiffeners. The general choh-kat model properties for larger openings are as given in figure (2b, 2c). For more than one bay and one story, the basic geometric model is repeated.

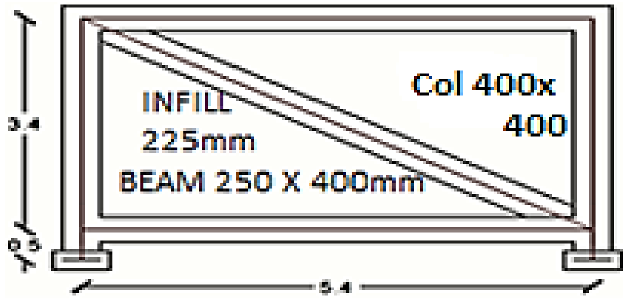

Fig.1.a.Basic Infill Frame (IF) Model-Strut Model (IFs-1B1S) Dimensions in ‘m’

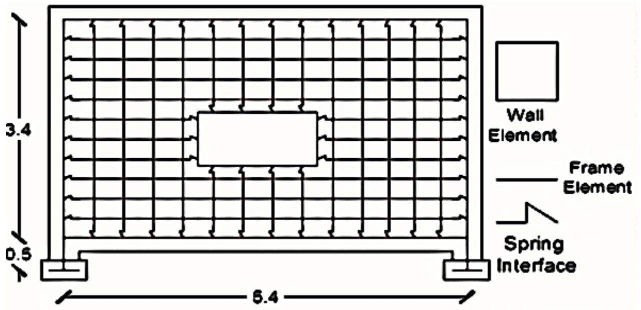

Fig.1.b.Basic Infill frame mesh model with an opening (IF_m O-1B1S); ‘O’ is opening; Dim. In ‘m’

Table- I System Properties

Element	Property			
	Concrete/Mortar Mix	Longitudinal Steel Reinforcement	Confinement bars	Stiffness Modifier (ATC-40 1996)
Beam 5.4m length 250x400 (1S) 200x300 (2S)	M25, E = 25000000 KN/m^2, ц = 0.2	Fe415 8mmØ 2#bottom, 2#top	Fe415 4mmØ1 50mm c/c	0.5EI
Column 3.4m length 400x400(1S) 300x300(2S)	M25, E = 25000000 KN/m^2, ц = 0.2	Fe415 8mmØ2# bottom, 2# top	Fe 415 4mm 150mm c/c	0.7EI
Infill Masonry 225mmThick	1:4.5, E= 2750000 KN/m^2, ц= 0.18	-	-	-

Wooden Choh-kat 2.25inx5in each member	Deodar/*Cedrus Deodara G.Don.f.*; Specific Gravity= 0.29; E_R = 5500 E_T =2434.426 E_L =30054.64; G_{LR} =6311.47 G_{LT} =5620.22 G_{RT} =450.82$ц_{lr}$=0.337, $ц_{lt}$=0.34 ,$ц_{rt}$0.458 *ц= Poisson’s ratio;E=Mod.of Elasticity*

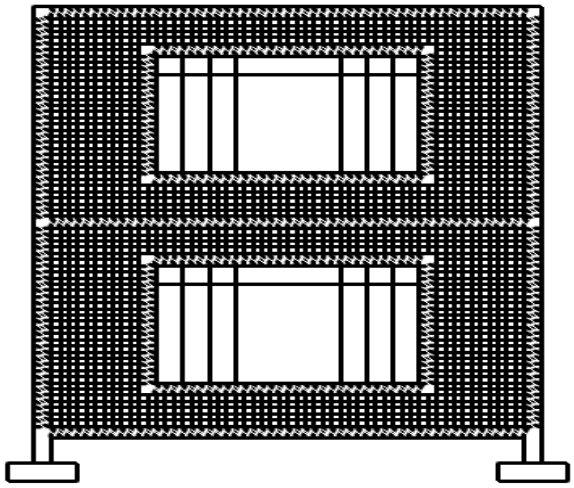

Fig.2.a. Choh-kat Opening Infilled Frame (IFm-CHs-1B2S)

Fig.2.b. Bare Choh-kat (CHb)

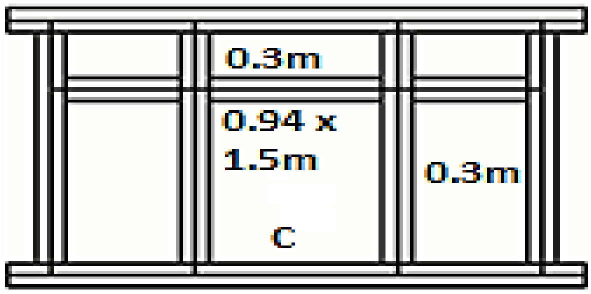

Fig.2.c. Standard Choh-kat (CHs)

Generally, infilled frames are macro-modeled and micro-modeled [18]. Macro-modeling is simpler, where an infill shell or plate mesh models, rectangular/square in shape are analyzed as finite elements with two translational degrees of freedom at each node [16, 19]. The line elements with two nodes [16] or rectangular elements with four nodes [20]depict the beam-column frame.Mortar interface is modeled as linear spring link element capable of transferring compressive and bond forces but incapable of taking any tension [15] or as linear interface element which is 6-Noded [21]. A spring element is a frictional shear element resisting slip. Stiffness of linear spring element is taken as $A_{mor}E_{mor}/t_m$where, $A_{mor}$is the effective area of mortar, $t_m$is the thickness of mortar, and $E_{mor}$is the modulus of elasticity of mortar E_{mor}=550f_m; f_m= Masonry Prism strength in ‘MPa’[22].

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Masonry infill strut has a central dissipative zone; that is at 0.5l over a dissipation length of 0.75l; forming the plastic hinge [22]. The plastic hinge in mesh modeled infill is complex to depict, and is located at ‘Guass points’ as lumped hinge [21]. For RCC beams and columns, the plastic hinges are assumed to form at a distance equal to one-half of the average plastic hinge length l_p (from the member ends). $l_p$is obtained from $l_p = 0.08L + 0.022d_bf_y$ (m); L = Length of member in m; d_b = diameter of longitudinal steel in m; f_y = yield strength of longitudinal steel in MPa[7]. Otherwise, l_p = 0.15L; Plastic hinges for RCC frames generally are formed corresponding to P-M and V-Δ [19]. Rigidity of RCC frame joints varies from rigid to semi-flexible to flexible and in modeling is featured by joint off-set [16]. Flexural rigidity at cracking of all components is illustrated by stiffness modifiers. For RCC beams, these are 0.5EI, for RCC columns 0.7EI [16].

As openings in infill have different aspect ratio and sizes, modeling of infills with openings as compressive struts has not been a viable option given absence of knowledge of contact length parameters. Openings are modeled as cuts in the infill mesh [16].The bottom beam is considered to be tied down. Column with fixed base and semi-flexible beam-column joints with rigidity factor of 0.8 is considered [16]. Its end-offset is taken equal to quarter of column depth along beam from center of column and equal to quarter of beam depth along column from center of beam. Choh-kat size depends on size of opening. Bare choh-kat model has no interlinking element. Standard choh-kat model has a fixed central panel of 0.93m x 1.5m. Choh-kat in this study, as is usually a case, would define size of opening with all top and side panels being 0.3m in size and multiplying thereon for more panels. The flexural rigidity of choh-kat is varied from stiffness modifier of 0 to 1 considering being same for whole of choh-kat frame at a given time. The choh-kat joint is considered to be semi-flexible with offset equal to quarter of choh-kat depth and joint rigidity factor varied from 0.4 to 0.8.

[B] Control parameters

Four primary control parameters are adopted: 1. Opening location (Ol), 2. Opening area (Oa)- which is width * height of opening, 3. Opening aspect ratio(Oas)- which is width/height of opening, 4. Choh-kat model (CH). At one time, three of these parameters are kept constant. Two complimentary control parameters are: 1. Frame stories (S), 2. Frame bays (B).

[C] Procedure

The basic model of fully infilled frame modeled as a compressive strut is assigned with plasticity and subjected to in-plane static lateral loads. The compressive strut has equivalent width as ¼ of its diagonal length [23]. Live load of 3 KN/m^2 and DL of slab is also taken into account. A Push-over analysis which is a monotonically increasing load or displacement keeping the displacement or force respectively constant is performed. The lateral strength which is the ultimate strength of frame at which it collapses is obtained. Subsequently, the infill is modeled as a mesh shell or plate. 10% lateral load of this lateral strength is used in further analysis in determining the initial lateral stiffness of the frames by considering RCC frame modeled as line element with 2 nodes each with two degrees of freedom and infill is modeled as a rectangular mesh element with 4 nodes each with 2 degrees of freedom at each node. Mortar interface is modeled as 2-noded linear spring element capable of resisting compression but not tension. Contact length theory based on contact length parameters is used which describes that a series of linear analysis are performed on mesh models until all spring elements are in compression [16].

IV. RESULTS

[A] Change in Opening Location

With change in location of an opening and thereby, of a wooden choh-kat, the initial stiffness varies asdescribed in figure (3).This figure explains the amount of initial lateral stiffness for an opening (of area about 30% of wall area and aspect about 1.6) with respect to initial lateral stiffness of solid infill wall; at the same time showing the shift in location of opening over the infill wall. For shift in loaded corner, the stiffness pattern would shift. It is thereby, seen that choh-kat increases the initial lateral stiffness by 5-15% for openings located at center, otherwise also depending on the area and aspect of the choh-kat opening. However, with the addition of a choh-kat, for openings located at corners, the stiffness increases by up to 0-55% as seen in figure (3a), figure (3b) and figure (3c).

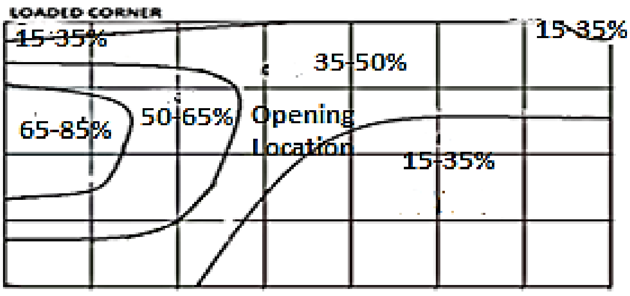


Fig.3.a.Initial lateral stiffness patterns for change in location of opening w.r.t. initial lateral stiffness of solid infill wall

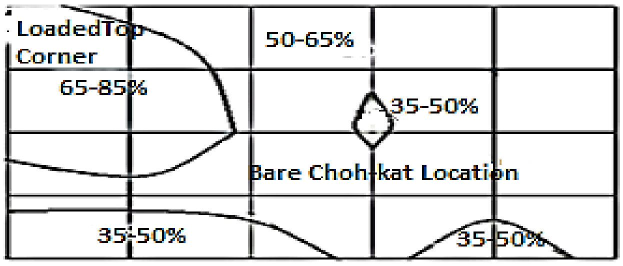


Fig.3.b.Initial lateral stiffness patterns for change in location of bare choh-kat opening w.r.t. initial lateral stiffness of solid infill wall

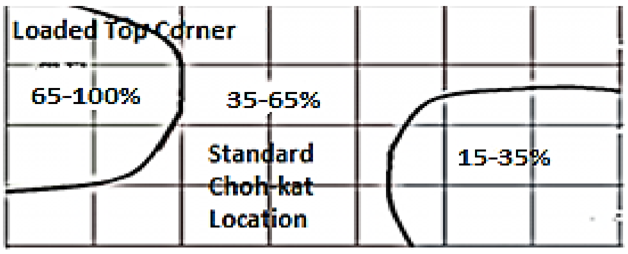


Fig.3.c.Initial lateral stiffness patterns for change in location of bare choh-kat opening w.r.t. initial lateral stiffness of solid infill wall

[B] Change in Opening Area

In this study, the choh-kat is added to an opening of aspect ratio of 1.6 and centrally located, while the opening area along with the choh-kat model and number of bays and stories are changed. The initial lateral stiffness is compared for an opening with standard choh-kat with respect to an opening without choh-kat; then plotted against change in opening area (expressed in terms of area of opening with respect to area of an infill) as in figure (4). The number of bays is varied as in figure (4a) and number of stories is varied as in figure (4b).

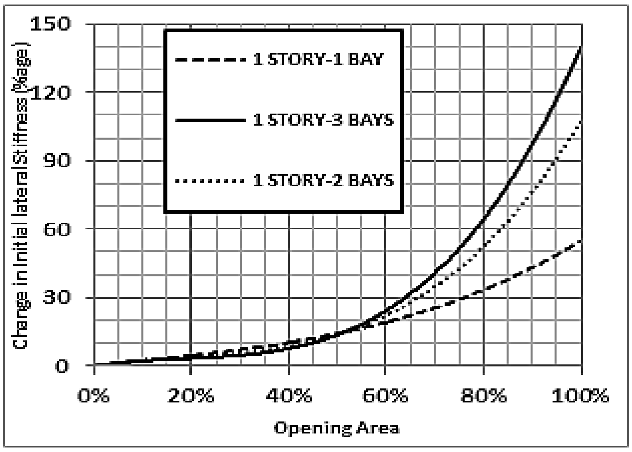


Fig.4.a. Variation in stiffness (%) of infilled frame with standard choh-kat over infilled frame without choh-kat for change in opening area (Bays)

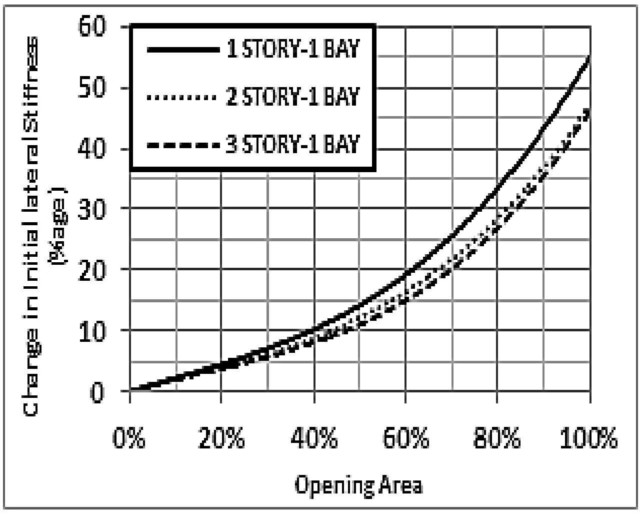


Fig.4.b. Variation in stiffness (%) of infilled frame with standard choh-kat over infilled frame without choh-kat for change in opening area (Story)

It is observed that for an opening area of up to 40%, only 10-15% increase in the initial lateral stiffness occurs on adding a choh-kat. Besides, up to 40% opening area, initial lateral stiffness shifts by just 5% for change in either in the number of bays and the number of stories. For 100% opening area, the initial lateral stiffness increases by 40% to 150% depending on number of bays and stories.For 100% opening area, the initial lateral stiffness value changes by 100% for 1st bay addition, 25% for 2nd bay additionand 12% for 3rdbay addition and then varies little for further addition in bays.With the increase in the number of stories, the initial lateral stiffness decreases appreciably for addition of 1st story by 20%, for 2nd story addition by 5% and then decreases negligibly with further addition of stories.

[C] Change in Opening Aspect-Ratio

The aspect ratio of an opening is varied keeping area of an opening fixed at 30%. The change in initial lateral stiffness of aninfilled framewith the change in opening aspect ratio is illustrated in figure (5) which is compared with theinitial lateral stiffness of a solid infill. However, it depends on infill aspect as well which is 1.2 in this case.

The initial lateral stiffness of a choh-kat opening is usually more than that of the non-choh-kat opening. The initial lateral stiffness is maximum for an opening aspect of 1.5-2 and the addition of a choh-kat to an opening increases it further by 25% between opening aspect of 2-2.5; for a fixed opening area of 30%. However, it tends to decrease for aspect ratios greater than 4. Change in number of bays and stories; for a particular aspect of an opening has no appreciable effect on initial lateral stiffness of the infill.

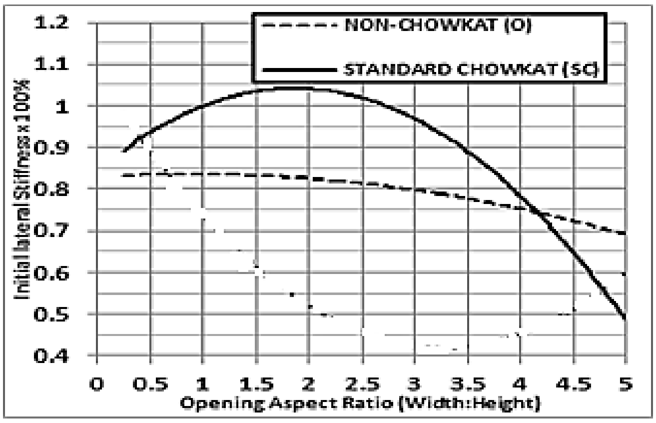
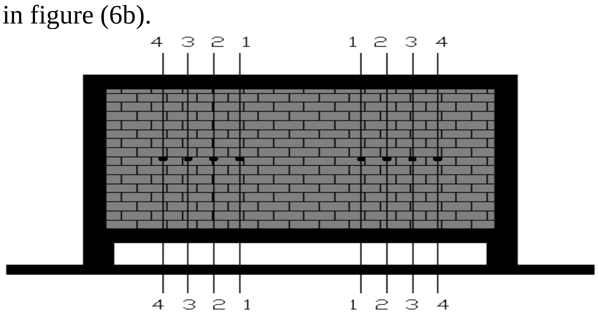


Fig.5.Stiffness variation (w.r.t. stiffness for solid infill) with change in opening aspect ratio for non-choh-kat and choh-kat opening (1 Bay-1 Story)

[D] Change in location of two openings in a single bay

Two openings 1500mm x 1500mm are used for investigating the effect of two openings in a single bay and their choh-kats on the initial lateral stiffness. This is compared in figure (6) where initial lateral stiffness of openings at ends is maximum and other values are compared with it. There is a 30-50% increase in the initial lateral stiffness for openings at ends than the same two openings at the centre; and a still further increase in initial lateral stiffness by 5-15% with addition of a choh-kat for such openings; the maximum being for choh-kat openings at the centre of an infill frame as in figure (6a). For two openings at bottom and top in a single bay, the initial lateral stiffness increases by 25% than for the openings at the centre of infill as in figure (6b).



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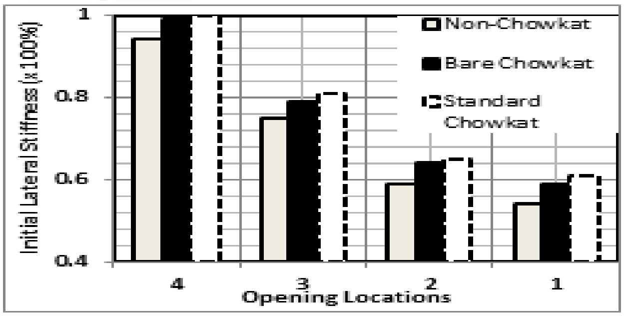

Fig.6.a. Initial lateral stiffness for infill with two openings compared to maximum stiffnessfor change in horizontal openings location

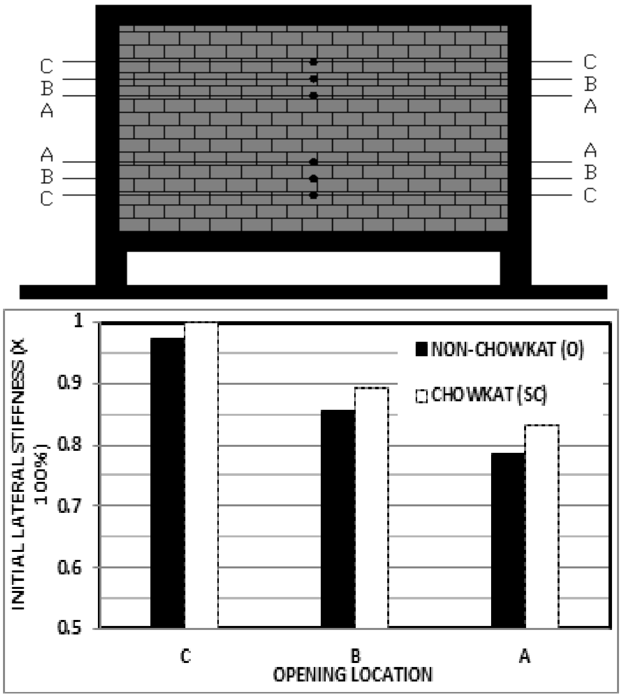

Fig.6.b. Initial lateral stiffness for infill with two openings compared to maximum stiffness for change in vertical openings location

V. CONCLUSION

Initial lateral stiffness is an important property of the infilled frame. The cracking of the infill leads to decrease in stiffness of the infill and thereby, of the frame. Choh-kat leads to vital contribution in increasing initial lateral stiffness and thereby, delaying crack initiation of an infill. This has been studied here and seen that the initial lateral stiffness is maximum for solid infills and tends to decrease with an opening in an infill. However, openings with and without choh-kats that are at center of the infill have maximum initial lateral stiffness.

The general area of an opening is 40% of the infill area while as its aspect ratio varies. With the addition of infill, the initial lateral stiffness increases by about 780% over a bare frame. However, an opening reduces the initial lateral stiffness by 25-75% for an opening area of 40% with respect to the initial lateral stiffness of a solid infill. The addition of a wooden choh-kat increases the initial lateral stiffness by 12-15% for central openings of area 40% compared to initial lateral stiffness of same infill opening without choh-kat.

With increase in the number of bays, the initial lateral stiffness increases, while as it decreases with increase in the number of stories for a given opening area; and for an optimum aspect ratio of 1.6. However, there is no appreciable effect on initial lateral stiffness for opening area of up to 40% with change in the number of bays and stories.

Opening aspect ratio of 2.0 for infill aspect ratio of 1.2 has maximum initial lateral stiffness and tends to decrease for an opening aspect ratio of 4.0. Choh-kat addition at opening aspect ratio of 2.5 for infill aspect ratio of 1.2 increases initial lateral stiffness the most. This pattern is believed to be on account of absence of compressive struts for large aspect ratios.At opening aspect ratio of 0.5, the increase in initial lateral stiffness with addition of choh-kat,is 10%, 16% at opening aspect ratio of 1, and 21% at opening aspect ratio of 2; though depending on infill aspect ratio.

For two openings in a single bay panel, the initial lateral stiffness tends to decrease with decrease in distance of two openings by 40% for horizontally located openings while by about 20% for vertically located openings. However, maximum increase in initial lateral stiffness with addition of Choh-kat is seen for closer openings. Choh-kat openings that are >25% (of bay width) apart and non-choh-kat openings that are 30% of (of bay width) apart have greater initial lateral stiffness than a single opening of comparable area.

VI. FUTURE SCOPE

Study on opening area, aspect ratio and opening location along with changing number of bays and stories needs to be resolved for choh-kat and non-choh-kat openings into mathematicalequations.

Study on steel, Aluminium and other choh-kats isto be carried further.

Lintel (wooden, steel, reinforced concrete) and its behavior in infills in-plane and out-of-plane loads needs to be studied along with choh-kat.

The development of piers and spandrels in infill with openings is resolved from studying initial lateral stiffness of infill with choh-kat where infill masonry is more confined, acting as a true compressive strut. Multi-strut models can be developed for infills with choh-kat openings.

The same study needs to be done in un-reinforced and reinforced masonry construction.

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