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Examining Infill Frame Openings with Damping under Lateral and Seismic Loads

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ABSTRACT

Nonstructural members such as Infill walls are considered typically in the design of Reinforced concrete buildings with multiple stories. As these walls do not bear the load of the structure, there are not considered as structural walls. In general designs, infill walls and their effects are not considered. However in reality, Just like composite members, masonry infill walls affects the structural strength positively. They also enhance the structure's stiffness along with its ductility capacity. However, if there are irregular infill walls, the effect of the infill could become hazardous during lateral application of the loads. Presently available analytical techniques that primarily focus on strength forecasting were typically inappropriate for a comprehensive examination of infill panels in a 3D space. The goal of the present research is to assess how infill frames respond to seismic application of the loads. We are going to use a computer model of Equivalent Diagonal Strut as an element replaced in diagonal position in place of the frame infill. First, the analysis of bare frame along with infill frame will be done through a computer taking into considerations the behavioral properties under deformations. Diagonal load deformation response will now be termed as DLDR.

Keywords: Infill walls, Infill Panels, Damping, Openings, Seismic load, lateral load

INTRODUCTION

General

Infill Frames (IF) are called so because of the combined response of the brick wall with the Moment Resisting Steel or RCC Frame. If the bond between them is durable enough, the stiffness is also increased. If the impact of brick wall is not considered than the response of combined member becomes difficult to determine. If openings are present in the walls, then the response pattern changes significantly. There are two types of Infilled frames. They are classified on the basis of the bond between the infill wall and the surrounding frame.

Non-integral IF: In these types of frames neither any tie nor any shear connector is present.

Integral IF: In these types of frames a special bond orshear connector is present.

Advantages of Infill Frames

- Infill wall enhances the effectiveness, strength and load bearing capacity of thebuilding.
- Infill wall enhances the stiffness of the building, therefore deflection is reduced.
- The shear and moment resisting capacity is altered.
- Because of enhanced stiffness, the dimensions of the members can be reduced now.
- Sway coefficient is diminished resulting in reduction in structure's stability index and thereby member of reduced effective length can be selected [1].
- Structure's damping properties also gets affected.

Use of Infill Frames

During the experimentation process, I observed that the response of the composite frame is changed because of Infills. The Infills enhances the lateral load carrying capacity and diminishes the lateral deflection, if designed accordingly. When the stiffness of the frame is less, the lateral load bearing capacity is badly affected. This in turn forces the design to have bigger dimensions. The composite response of both the frame element and the infill panel element offers better resilience against lateral applied loads. The durability and stability of the frame element against lateral forces are enhanced by the inclusion of infill element, which also significantly minimize deflection. Infills function like structural components since they operate diagonally within the frames [2].

Scope of the study

In this research work I have used a technique which mixes the active system of stiffness parameter with the active system of damping parameter, thereby creating a partly active control system of stiffness and damping parameter (ASSDP) [3] under seismic loads. The research moves forward on the principle that with an increases in the value of damping parameters, the capacity to dissipate energy and its effect is also increased. This is helpful as it diminishes the maximum reaction / excitation. The examination of significant works on masonry infilled composite reinforced concrete frames is included in this study. The paper examines how infill panels contribute to the exterior frames' stiffness and its strength. A review of several analytical techniques used to examine both strength - stiffness of these composite infill frames was also performed. The aim of this thesis is to arm the engineers with an analytical approach that will enable them to forecast the appropriate response of a multiple story building with composite infill frames. Due of its convenience, this method is very much similar to the one developed by Stafford and Smith in 1967 [4].

LITERATURE REVIEW

"Holmes (1961, 1963)" [5] Following a similar strategy by Polyakov, he developed a semi-empirical technique to forecast frame strength and demonstrated that the infill functions as a diagonal shape brace. A model of scale 1/6, composed of steel along with masonry - concrete infill walls was used. He suggested that the width - length ratio of the diagonal strut to be equal to 1/3 . He made the assumption that the failure point of the infill will reach at the pre-established average strain taken along the diagonal strut in compression, in order to determine the specimens' maximum capacity. The total strength of the diagonal strut and that of the frame can then be used for establishing the strengthof the IF.

"Stafford Smith (1969)" [6] Experiments were done on frame models of steel scaled to 1/8th of actual size infilled with mortar, with the application of diagonal or opposite loads. The results showed that there are 2 possible cases of failure - compression infill diagonal failure and tension infill diagonal failure. Experiments showed a relationship between the contact infill length and infill's capacity to resist load. The analysis rested on a beam in elastic supports. He also proposed a new parameter defined as Relative factory of stiffness which is given below. This factor depends upon the contact length of frame elementand infill element.

Lfi / Hi = (π / 2) * RSh

Where, Lfi = Contact length between the bonding frame and infill
Hi = Infill height

RSh = Relative stiffness parameter.

"Mainstone (1971)" [7] experimented extensively to study behavior of solid IF. By employing various kinds of multiple frames, he provided the infill with the complete spectrum of limiting factors in his study, to study the impact of neighbor frames on IF. Additionally, his method relied on the diagonal infill strut for assessing the strength, rigidity and complete stiffness of IF. Refer to Figure 1.

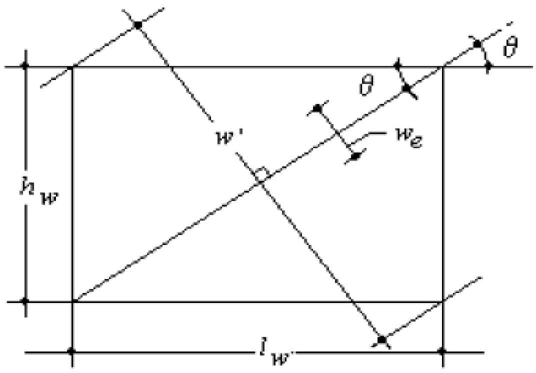

Figure – 1 : Mainstone's model

Conclusions indicate that there is a possible solution to alter the infill by placement of more struts contingent upon how well the infill is suited for the frame. An equation was developed showing the correlation between the parameters Kh, w' and we :

We / W' = Am Kh-Bm

Kh = (Hi4 * Ew * tw * Sin 2 Ө) / (Ef * If * hw)

The parameters Am represents loading stage and the parameter Bm represents Infill material. Table representing Am and Bm is displayed in Table – 1.

Table – 1 : Mainstone's Constants

Loading Stage		Before first crack		At first crack		At ultimate stage	
Infilledmaterial	h	Am	Bm	Am	Bm	Am	Bm
Brickwork	< 5	0.175	0.400	0.170	0.400	0.560	0.875
Concrete	<5	0.115	0.400	0.225	0.400	0.870	0.875
Brickwork	> 5	0.160	0.300	0.150	0.300	0.520	0.800
Concrete	>5	0.110	0.300	0.220	0.300	0.780	0.800

"Lee and Woo (2000)" [8] of FEMA did an in-depth study of the the seismic response on a mason infilled panel within a reinforced concrete frame of ratio 1/5 to the original, inspired from southkorea's standard. 2 Bays and 3 floor. A number of seismic simulations were run with detailed analysis and the data was compared with unaffected models. He reached on the conclusion that addition of infill eventually enhances the overall stiffness and rigidity of the building by participating in the bearing and resisting characteristics of the building. Infill's shear failure happens due to sliding at the respective bed joints. The experimental results indicate that the Infills enhance the resisting capacity of the building during an earthquake. The strengthening capacity is also increased. Although there is no change in the deformation resisting ability of the structure.

METHODOLOGY

Types of Approaches

All the techniques and design approach can be grouped into 3 different types:

I category: Proposed first by Polyakov in 1956 [9] and then modified by Stafford Smith in 1969 and later enhanced by Mainstone in 1971. This method revolves around Equivalent technique of DiagonalStrut, commonly known as EDS.

II category: This method is centered on the analysis of various types of failures. Through that the ultimate load bearing capacity is calculated. This method findsits genesis in the theory of plasticity.

III category: This method revolves around the examination of the different types of responses by the Infill. This method is centered on the numerical method techniques such as Finite different technique or the much used finite element technique.

IV category: Seismic evaluation method as proposed by Mehrabi and Shing.

Diagonal Strut Method

The equivalent technique of the diagonal strut method was first formulated by Polyakov in the year 1960. Several modification happened thereafter. Some of the scientists include Holmes in 1961, Stafford smith in the year 1962, Cater in the year 1966, Mainstone in the year 1971, Liauw lee in the year 1977. The diagonal technique was given priority by all the above based on their research, and the conclusions of the response of Infill frame under lateral application of loads. From all of the aforementioned hypotheses, it was apparent that a number of parameters, including the panel's special aspect ratio, the link between IF, the proportions of the mason, the mortar's durability, and others, alter the stiffness, rigidity and respective strength of the IF. The members remain within the elastic range till the failure occurs. The cracks generates all-round the perimeter of the frame and at the diagnal compressional at the foremost. The biggest issue in this technique is the identification of diagnal strut's measurements. Thickness of strut = thickness of infill. Width of strut vary because of column's relative factor of stiffness with the infill. Experimental results do not match the theory part as the technique is difficult and many parameters are involved.

Plasticity Method

"Liauw (1972)" [10] A new principle of the restructuring of the stress in a structure of multiple floors during failure. The restructuring takes into consideration both the cracking stage and the breaking of system at the point of failure.

Another parameter taken into consideration is the shear resisting capacity of the IP to IF contact point. Four modes of failure suggested were -

- Composite failure - weak infill
- Rotational failure – average infill
- Diagonal failure – weak frame
- Corner cracking failure – strong infill

It was also found that during collapse the composite response not only encompasses the crushing but also the bending and cracks in the wall.

Numerical Method

"Saneinejad and Hobbs (1985)" [11] discovered a technique to calculate the strength capacity, rigidity, stiffness property and ultimate load of IF. Including for analyzing and designing IF made of steel /Brickwork / Conc. subjected to forces along the plane, in all elastic / plastic / ductile conditions of infill and frames. Cons of the infill including its impact on surrounding was also studied. This whole process was then scaled up and implemented to the study of buildings with multiple floors convertingthem as a braced equivalent struts.

Seismic Evaluation Method

"Mehrabi and Shing (1996)" [12] They undertook analytical research about the seismic response of 2 types of prototypes with ACI regulations subjected to masonry IP. The study was conducted under both the reasonable and strong seismic intensities. The detriment of vertical stresses and the frame's aspect absolute ratio were also chosen for the research. The results shows that the IP has deterministic value in the response of IF. Capacity of disipate energy, load resisting capacity, strength of frames and panels were the parameters considered and conclusion showed that stronger are better than weak. For prototypes of stronger infill combined with weaker frames, types of failure was brittle and shear, with greater efficiency to disipate energy comparatively to the weaker panel + frames. Therefore, it was proven that the efficiency can be increased by the use of stronger IP. Refer to Figure 2.

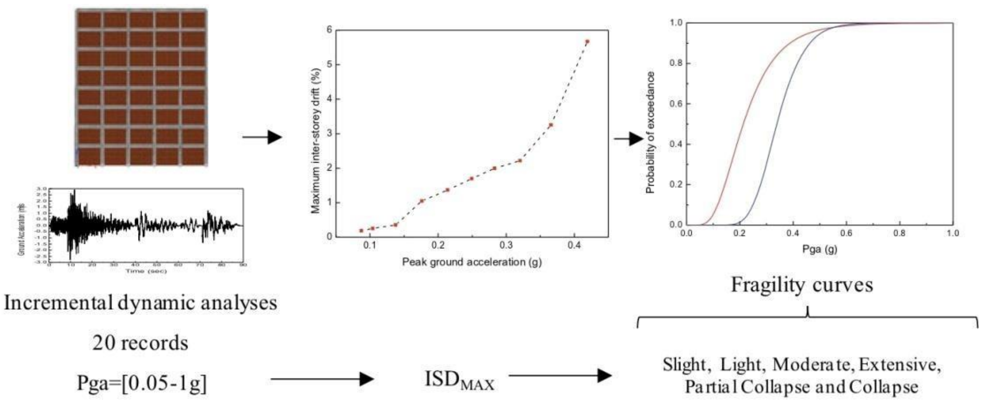

Figure – 2 : Methodology of Seismic Evaluation Method

ANALYSIS AND MODELLING

A triple layered frame made of steel is used for the analysis process to determine the active system of stiffness / damping parameters and the processing algorithm using Etabs software [13]. Refer to Figure 3 and Figure 4. The seismic intensities applied to the frame were very intense. The analysis technique for calculating displacements and the generated stress depends heavily on a static velocity spectrum of response from 1 second to 3 second.

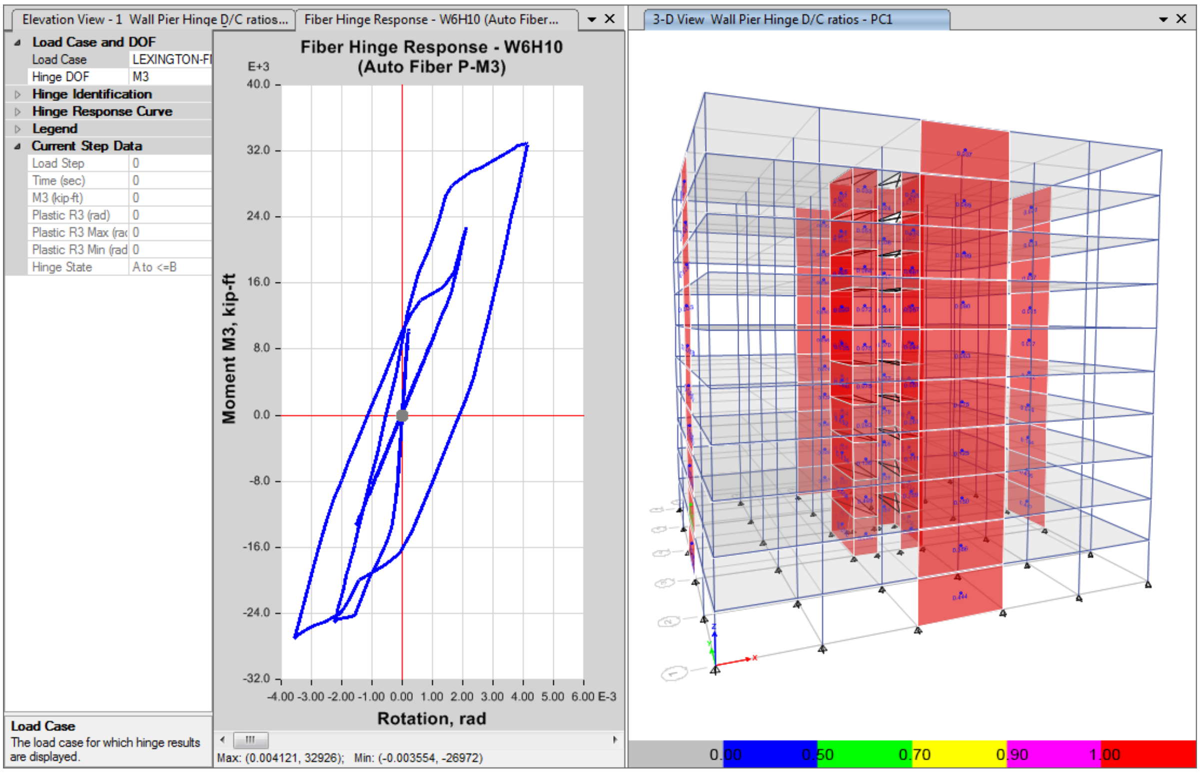

Figure – 3 : Fibre Hinge Response of the Infill Panel

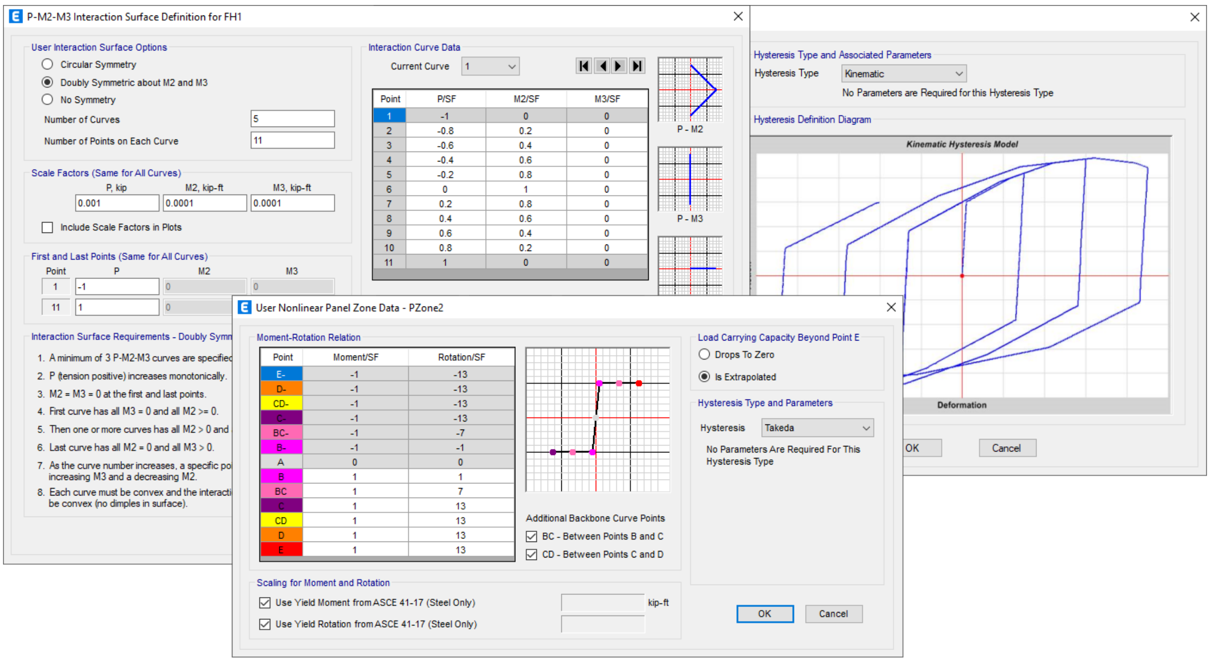

Figure – 4 : Interaction between Infill Panel and the Surrounding Frame

Spectrum velocity = g * Sd1 / 2 π

where Sd1 means design acceleration because of damping. The spectrum Sd of displacement at T = Td can be calculated from the following formula.

Sd = (g * Sd1 * Td) / 4 π2

The spectrum under consideration is then altered with the help of introducing a new damping reducing parameter Dd.

Table – 2 : Different parameters for material to be used in concrete and masonry in frame.

Parameter	Description	Concrete inFrame	Concrete in masonry hollow units	Concrete in masonry solidunits
E	Modulus of elasticity	3.55 E+6 (psi)	2.0 E+6 (psi)	2.0 E+6 (psi)
ν	Poisson's ratio	0.16	0.16	0.16
ft	Tensile strength	390 (psi)	240 (psi)	230 (psi)
GfI	First mode fracture energy	0.09 (psi-in)	0.09 (psi-in)	0.09 (psi-in)
β	Shear retention factor	NA	NA	NA
f'c	Compressive strength	3,900 (psi)	2,400 (psi)	2,300 (psi)
Gfc	Fracture energy in compression	22 (psi-in)	22 (psi-in)	22 (psi-in)
Tension Curve	Shape of tensile stress/strain curve	Exponential	Exponential	Exponential
Compression Curve	Shape of compressive stress/strain curve	Parabolic	Parabolic	Parabolic

Table – 3 : Different parameters for material to be used in ETABS interface model.

Parameter Set	Width (in.)	Knn (psi)	Kss (psi)	ft (psi)	co (psi)	tgφi	tgφr	f'c (psi)
Target valuesfor bed joints	1.25	280,000	350,000	40	40	0.9	0.75	1500
Actual values used for bed joints	12.5	28,000	35,000	4	4	0.9	0.75	150
Target valuesfor head joint	1.25	215,300	269,200	10	10	0.8	0.7	1500
Actual values used for head joint	12.5	21,530	26,920	1	1	0.8	0.7	150
Target valuesFor frame/ wall joints	1.4	215,300	269,200	20	20	0.8	0.7	1500
Actual values used for frame/wall joints	14	21,530	26,920	2	2	0.8	0.7	150

The spectrum is then modified by a damping reduction factor DR, which will correspond to the effectivedisplacement within the infill.

The design displacement DD therefore would be calculated from the starting point of crack as

$$DD = (g / 4 \pi 2) * ((SD1 * TD) / BD)$$

The effective ration for damping will be calculated from ξ

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ξ = (1 / 2 п) * (Area in hysteresis loop of the frame
/ (KDMax * D2D))

KDMax = Maximum effective stiffness at DD.

The twin particles m1, m2 on the frame are similar and both have 1 DOF. Refer to Table 2 and Table 3. In case the particle m1 collides with the right side of the frame at t = 0, then the response will be recorded at $\Omega t = \alpha 0$. Similarly particle m2 will collides with the left side of the frame at $\Omega t = \pi$. And again the twin will collide at $\Omega t = \pi + \alpha 0$. The periodic motion of the corresponding plane phase is shown through Figure 3.38. It is analyzed through the data collected that there are 2 x 2 response cycles which are heavily involved in steady static behavior of the structure because of seismic variations.

RESULTS AND DISCUSSIONS

Displacement Analysis

From the above analysis of eigen values, for each prototype the natural frequency was determined. From the recordings of the experiments it was found that the 1st mode of natural vibration is along longitudinal axis (X) and the 2nd mode of natural vibration is along transverse axis (Y) and the 3rd mode is purely torsional. All the natural frequency mode discussed above are presented in tabulated form. The calculation of the natural frequency of the structure was done without considering the damping in the infill walls through analytical studies. Refer to Table 4.

Table – 4 : Results of Natural frequencies of the damping modes.

Model	1st damping mode (Hz)	2nd damping mode (Hz)	3rd damping mode (Hz)
Analytical configuration of structural model	0.88	1.06	1.39
BF	0.89	1.07	1.46
IP	1.94	2.03	5.73
IP-OOP	1.99	2.08	5.76

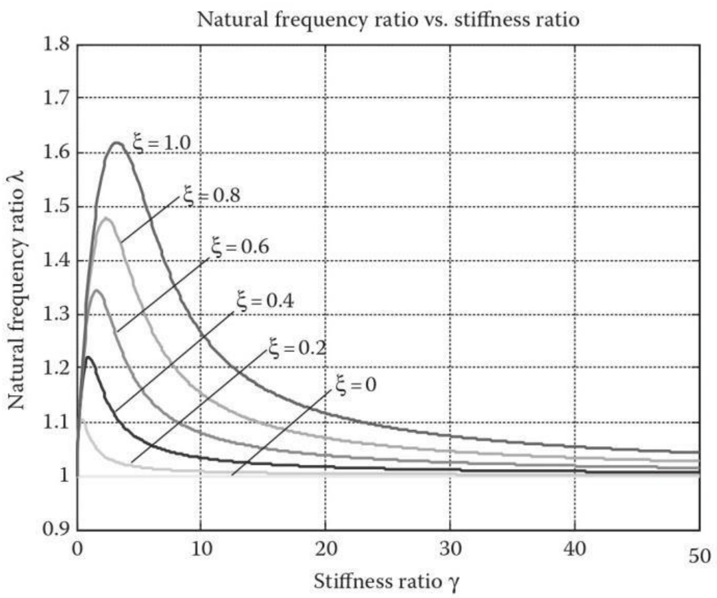

Figure – 5 : λ vs. γ

Results shows that the addition of IP into the structure not only enhanced the natural frequency of the structure but also increased its stability. 2 x natural frequencies in case of 1st and 2nd mode. 4 x natural frequency in case of 3rd mode. These frequencies as noted in the results are also near about the those frequencies which were predicted theoretically. Based on the results obtained, it can be said that if the stiffness value of the damper = 0, then the equivalent value of natural frequency of IF is similar to that of non - frame structure. Results are plotted in below charts. Refer to Figure 5 and Figure 6.

1. Natural frequency and Stiffness
2. Equivalent damping and Stiffness

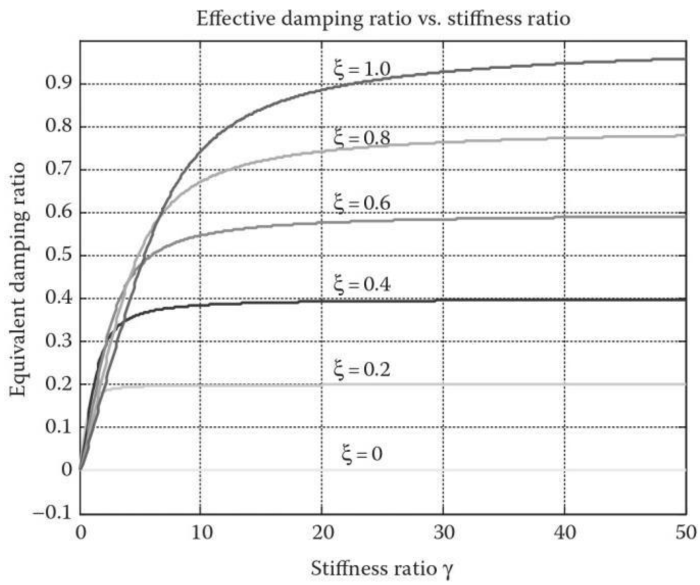

Figure – 6 : Equivalent damping vs Stiffness

CONCLUSION

In this study of the response of Infill panel frame under seismic load and lateral application of loads, the focus was made on their IP and opening behaviour along with the interaction with the structure and finding out possible ways to enhance the performance. The analysis produced fresh results and correlations that provide credence to the opening of the infill panels seismic response. The results exhibit a low degree of dispersion, which can be attributed to various factors including variations in the grade of the material, craftsmanship, and varying loading methodologies. The following are the main conclusions of the research :

- It is recommended that the structure should have enough damping to dial down the effect of the seismic vibration in the IP.
- An increase in the value of damping will result in decrease in vibrations and stress induced in the IP.
- If the structure possesses sufficient damping then the opening present in the IP enhances its stability and reduces the slenderness of the panel.
- With the increases in the aspect ratio of the opening and panel, the strength of the damped IP decreases.
- With the variations in the aspect ratio of the opening and the panel, the type of failure and crack pattern also varies.
- The strength of a damped IP with an opening, increases with increases in compressive strength along with flexural strength.

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