MODELLING AND SEISMIC ANALYSIS OF MASONRY INFILLED R.C.C FRAMES

(MAJOR PROJECT REPORT)

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CIVIL ENGINEERING
(Structural Engineering)

Submitted by

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CERTIFICATE

This is to certify that this report entitled **"MODELLING AND SEISMIC ANALYSIS OF MASONRY INFILLED R.C.C FRAMES"** is report of the Major Project-II done by me. This is a bona fide record of my own work carried by me under the guidance and supervision of Mr.Alok Verma, Associate Professor, in partial fulfilment of the requirement for the award of the Degree of Master of Technology in Civil Engineering (Structural Engineering) by the Delhi Technological University, Delhi.

The matter embodied in this project has not been submitted for the award of any other degree anywhere else.

Date:

Akshit Khurana
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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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AKSHIT KHURANA

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ABSTRACT

In a building construction, the frame is constructed first, and then in later stages of construction, these frames are infilled by, either concrete blocks or masonry infilled bricks, or sometimes with finished stone. These masonry infilled walls provides protection from environment outside.

However, in general practice the main purpose of masonry infilled walls is to fill the gap in between the building frame's horizontal and vertical resisting elements, where it is pre-assumed that masonry infilled walls do not resist any lateral or axial loads. Hence, while designing a structure there presence is neglected, i.e. we design the structure as a bare frame only. But the main fact is that, these masonry infilled walls, to a large extent affects structural strength and stiffness properties, and on the other hand, they are very brittle in nature. Some publications like [5] contain methods for masonry infilled walls stiffness calculations and model them as equivalent diagonal pin-jointed struts. In some other references provisions have been made to consider effects of openings also. Openings in masonry infilled walls are the unescapable part, opening may be provided for windows, or doors or for some other architectural purposes. But in the presence of openings, the strength and stiffness parameters of structures which got increased earlier, start decreasing and this decrease is also dependent on the location and size of opening areas in masonry infilled walls. The aim of this study is the modelling of masonry infilled walls, using two methods, one as equivalent diagonal pin-jointed strut and another as four noded quadrilateral element, using ETABS software. This study also deals with the effects of opening in masonry infilled walls in respect to their size and locations, on the stiffness parameters of structure modelled with masonry infilled walls.

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CHAPTER 1

INTRODUCTION

The masonry walls, in Steel and R.C structures are extensively used as interior partitions and also as an exterior walls to form part of building envelope. They are often intend to be non-load bearing, and not considered in the design to resist any axial or lateral load. In general architect's requirement governs the height and width of such walls, mainly influenced from point of view of optimal utilization of space and economy.

The masonry infilled walls if wished to play role in counter attacking the vertical and lateral loading, then they should be tied to columns and floor system from underside and constructed in such manner that transfer of loads takes place by the relative displacement of the successive floors. For the transfer of loads frictional or mechanical anchorages may also be used along the top side. The masonry infilled walls which are built tight to columns, do not show their contribution in resisting vertical loading, but resist lateral loading, depending on the availability of movement joint at wall top.

The possibility for interaction of masonry infilled walls with the structural frame is ignored in order to have simplicity in the design, as the analysis of composite behavior, considering the effect of masonry infilled walls and column-beam together, demands the modelling of masonry infilled walls in right manner and hence increasing the quantum of work.

While, by ignoring the stiffening effect of masonry infilled walls can result into an inefficient and uneconomical design, where both stiffness and strength requirement of frame are under measured. By ignoring the contribution of masonry infilled walls not always leads to a conservative design. These walls to a great extent effects the lateral loads distribution to various building parts and provides stiffness to a flexible frame, which may cause masonry infilled walls to attract higher loads, leading to overstressing of frames and cracking of the masonry walls. Therefore the aim of the design should be such that both masonry infilled walls and frame didn't get overstressed. On the contrary, by ignoring the interaction between supporting beams and masonry infilled walls may lead to inefficient design of beam and cracking of walls.

1.1 Infill walls

In a multi-storey building infilled walls are enclosed in between surrounding frames of beams and columns and in case of single –storey building, are built between the columns. In former case, interaction between them and frame under in-plane loading is governed by infilled walls being securely constructed inside the surrounding Steel/R.C frame. To ensure a tight-fit with the frame, a great care is needed in construction and also there is necessity to ensure that there is facility of moisture and temperature movement, so that there is no overstressing of frame or walls. Movement joints are provided to avoid structural distress as shrinkage value of frame and moisture and thermal expansion value of masonry infilled walls may not be the same. Presence of such joints may also effects the load transfer mechanism.

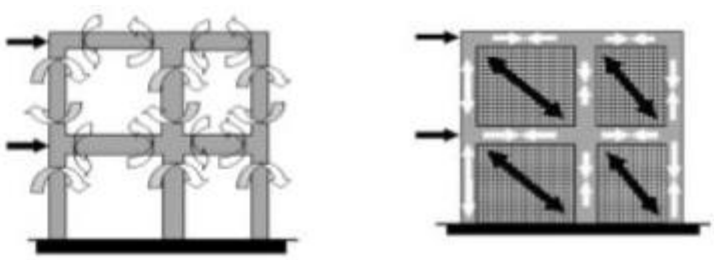

Fig.1.1: Frame Action and Truss Action

1.2 Behaviour of Masonry Infilled Walls

To develop the analysis and design methods, many experimental and analytical researches has been done in past years for individual masonry infilled frames. Finite element analysis may not be fully valid for this due to the uncertainties involved in describing the practical boundary conditions. Thus for such problems an approximate analysis is totally accepted, where behaviour of the structure is dependent on highly variable parameters. Keeping this thing in mind, it is essential to avoid shear-slip failure, so that knee-brace action doesn't occur and thus controlling lateral-load carrying capacity.

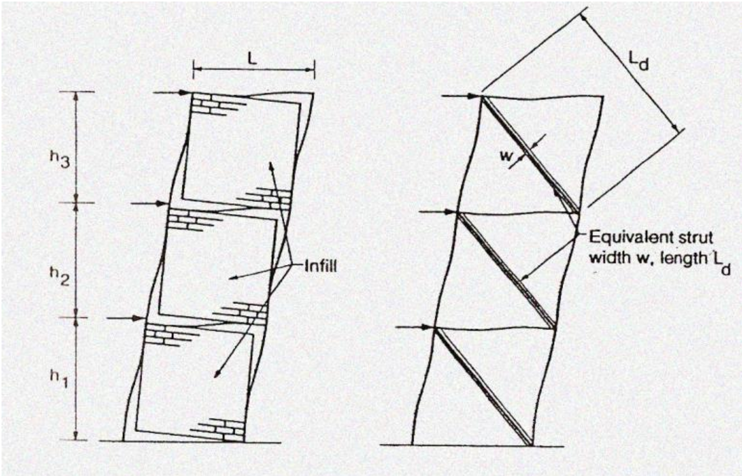

Fig.1.2: Equivalent Diagonal Strut Method

There are various approximate methods proposed by various researchers, the highly developed and the simplest was the idea of equivalent struts, firstly put forwarded by Holmes[1], and then with due course of time re-developed by other researchers as mention in Chapter 3. According to this method, the modelling is done as braced frame, where the masonry infilled walls provide web elements, as shown in figure below. As suggested by Hendry[4] the geometric properties of these equivalent diagonal strut are dependent on lengths of contact between columns and masonry infilled walls and between beam and masonry infilled walls. A typical range of this length of contact lies between one-fourth to one-tenth of the panel length.

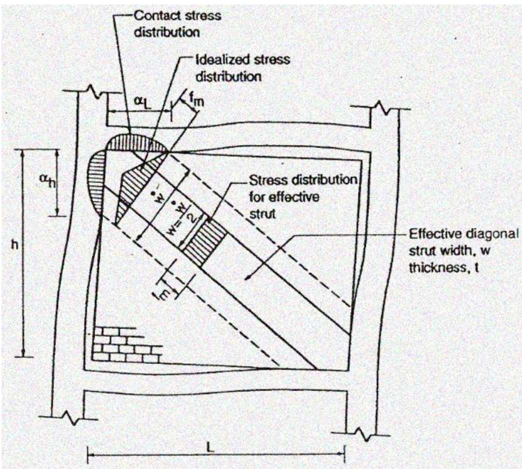

Fig.1.3: Modelling of Masonry Infilled Walls

1.3 Failure Modes of Masonry Infilled Walls

There are mainly three potential modes of failure of masonry infilled walls which arises as a consequence of frame and there interaction. All three modes are clearly shown in the figure below. The first in this case is shear mode of failure, moving down through the masonry joints, and triggered by horizontal shear stresses in bed joints. The second one is the diagonal cracking of the masonry infilled wall, over the masonry wall lines, parallel to principal diagonal, and caused due to the tensile stresses perpendicular to the principal diagonal. The third mode of failure my occur due to masonry infilled wall corner, at one of diagonal strut end, may get crushed due to the presence of highly compressive stresses present at the corner.

For the frame, column at the windward direction and the column at the leeward direction are in tension and compression only. The frame members also witnessed the transverse shear and minor value of bending, reason being the masonry infilled walls, bearing on frame, not as a force which is concentrated at corners exactly but over the minor lengths of columns and beams next to compression corner. As a result, frame connection and its member can fail under shear or axial force, and particularly the column at windward side at base can fail in tension.

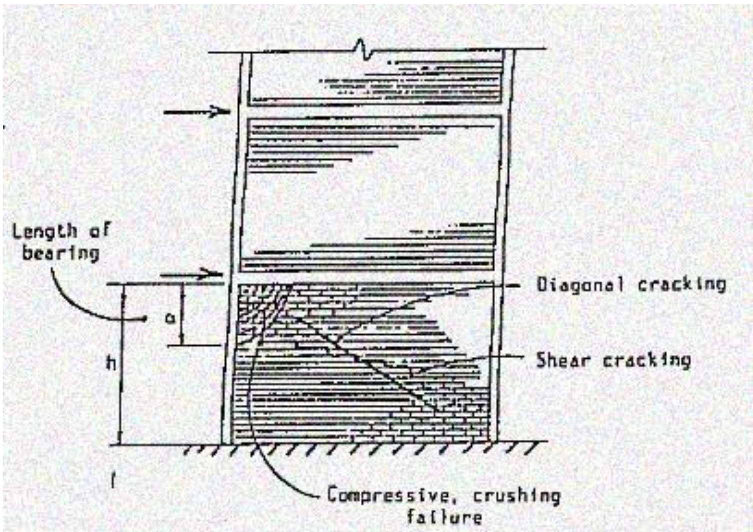

Fig.1.4: Modes of failure of Masonry Infilled Walls

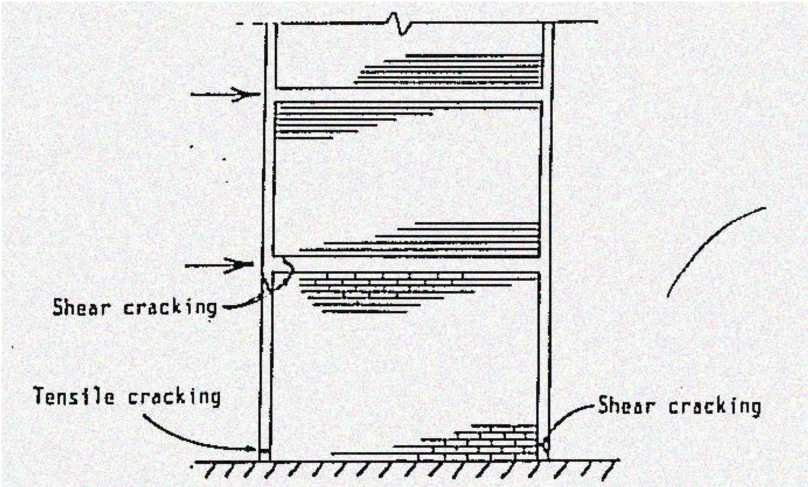

Fig.1.5: Modes of Failure of Frame

1.4 Infilled Walls With Openings

Masonry infilled walls may have opening areas of varying sizes and at different locations. The effects of these opening areas, outside the equivalent diagonal strut and openings provided for conduits, cables within the equivalent diagonal strut, may be minor. But in order to assess the opening effects, it should be kept in mind that in case of load reversals, the other diagonal becomes the strut.

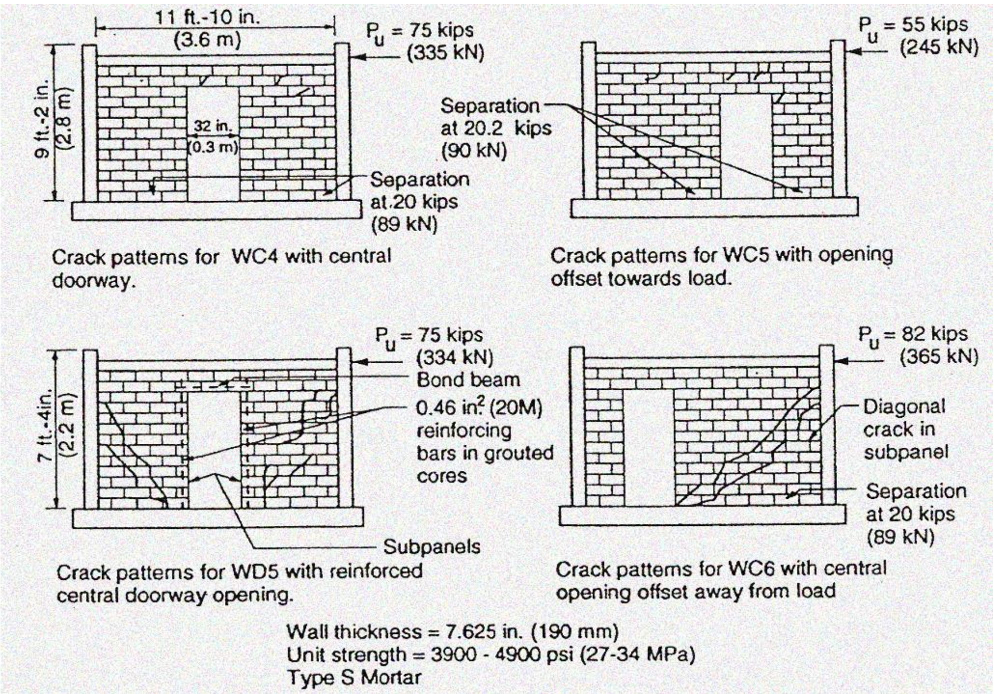

Fig.1.6: Infilled frames with openings

Many studies has been done to know the presence of openings in masonry infilled walls and the core result obtained from each study indicates that the opening areas to a great extent reduces the load carrying capacity and stiffness. This may further cause premature shear failure on either direction of the openings. In many cases it was found that the failure initiates due to the separation created between walls and the frame.

There are multiples of parameters effecting the behavior of masonry infilled walls opening, which may include position, sizes and shape of openings. Thus simple analytical methods doesn't accomplish the task. Finite element analysis might be quite helpful to understand the stresses in the panel owing to the composite action in case of lateral loadings.

1.5 Seismic Design Consideration

Masonry infilled walls are recognized as the one of the major reason for the bad performance of R.C frames when subjected to high magnitude seismic loading. Due to this there is no as such any restriction on infilling the frames, but the main reason for their poor performance is that, as traditional design practice these masonry infilled walls are treated as pure non-structural element and their effects are ignored in structural behavior.

It has been seen that there is great increment in structure's stiffness and reduction in fundamental modal time period, thus resulting in attraction of greater seismic forces when there is no separation between the frame and masonry infilled wall panel. When there is provision for separation between frame and panel top, in that case also stiffness is still provided by the masonry infilled walls to the supporting beams and plastic hinges are forced to get migrated from beams to columns and which falsify the strong-column and weak-beam concept. By providing separation of masonry infilled walls with columns, and marking adequately connection and gaps details, so that during an earthquake no hammering effect between infilled walls and frame should occur.

It is very much important to consider the influence of stiffening of frame on lateral loads distribution to the other frame components. The influence on the location of torsional rigidity center and the resultant torsional effect due to the lateral loads should be incorporated. There is a lot need to pay attention by the designers to the effects in case of concentrated loads from equivalent diagonal pin-jointed strut acting on column-beam joints. There must be provided a sufficient shear reinforcement in the columns and beams near joints and as well as in joints in R.C frame building to resist such loads.

At any elevation, failure of masonry infilled walls in shear, due to the presence of opening areas, reduces the inter-storey stiffness and is the cause for open-storey and there by the ductility demand of columns increases. This may results into asymmetry in application of load, increment in torsional forces and further there may be changes in shear forces distribution between the elements resisting lateral loads. Therefore, a great care should be taken while making choices in deciding the masonry infilled wall plans and positions of opening areas, so that above non-desirable behavior could be minimized.

Under the load reversals in seismic prone areas, the equivalent diagonal pin-jointed strut and contact area effectiveness is under question unless there is anchorage between masonry infilled walls and the frame. In order to ensure the composite action under load reversals and high inter-storey drifts, anchoring can be seen as an effective way. To improve properties of masonry infilled walls like stiffness, deformability and strength, vertical and horizontal reinforcement can be used. Due to the complex behavior of masonry infilled wall frames subjected to seismic loading, to determine the structure ductility available, it is highly recommended to adopt elastic analysis, unless and until an all-inclusive rational analysis is done.

CHAPTER 2

OBJECTIVE, SCOPE OF THE STUDY AND METHODOLOGY

2.1 Objective

While making force resistance and stiffness calculation for a structure, the masonry infilled walls contribution is not taken into consideration. Only their load is taken into account, while making loading calculations. The basic objective of this study is to cognize what modifications takes place in analysis if the stiffness contribution of masonry infilled walls is taken into account or if kept overlooked.

While this study also deals with the modelling of masonry infilled walls as equivalent diagonal pin-jointed strut method and modelling them as four noded quadrilateral element and then comparing the output result of analysis for both the cases.

The another objective of this study is to see what are the effects of presence of opening areas and their locations in masonry infilled walls, for both the cases, i.e. when modelled as equivalent pin-jointed strut and when done as, four noded quadrilateral element, with different percentages of opening areas and thus comparison has been made.

2.2 Scope of the Study

The scope of the study is as follows:

a) This study is done on a R.C.C frame building, which is taken regular in plan.

b) In this study the effects of soil-structure interaction is not taken in account.

c) The column base are taken as fixed in support.

d) Out of plane action of masonry infilled walls is ignored.

e) Masonry infilled walls are symmetric in arrangement.

f) Building torsional response is not considered.

g) The slabs are are assumed to be rigid diaphragms.

h) No types of irregularities are considered in study.

i) Building has no basement, and soft storeys.

j) Only analysis, not designing of frame elements or masonry infilled walls is the part of the study.

2.3 Methodology

The following methodology is adopted in order to carry out the study:

(i) Review of the previous studies and literatures and study various Indian Standard Codes available, related to the project.

(ii) Selection of a building plan for carrying out study.

(iii) Creating models using ETABS 2013 software for modelling bare frame, and masonry infilled wall frames, with different opening areas conditions.

(iv) Applying the dead, live and seismic load as per respective Indian Standard Codes.

(v) Analysis of models created and carrying out comparative study on the basis of results obtained.

(vi) Observation of results.

(vii) Conclusion made from the above study.

2.3.1 Organization of the Thesis

Chapter 1, an introductory chapter, dealing with the basic overview of Masonry Infilled Wall Frames, their behavior, failure patterns of masonry infilled walls, effects opening areas sizes and locations, seismic design consideration of masonry infilled walls.

Chapter 2, deals with objective, scope of the study, and methodology adopted to carry out the study

Chapter 3, contains the various literatures surveyed/studied to develop the understanding required to carry out the project.

Chapter 4, includes the modelling part of structure, as bare frame and masonry infilled wall frame, with varying opening area conditions. It also mentions the various building parameters adopted in the study, different loads applied to structure for carrying out analysis, the modelling of masonry infilled walls by two methods and also the equations adopted to consider the effect of opening area location and sizes.

Chapter 5, deals with results obtained from carrying out the analysis. And finally,

Chapter 6, discusses the conclusion made from the results.

CHAPTER 3

LITERATURE REVIEW

3.1 General

This chapter deals with the various literature surveys carried out for the completion of the project. The details of various past studies is mentioned in this chapter and their conclusions are discussed.

3.2 Seismic Behaviour Of Masonry Infilled Walls In Rigid Frames

Under the effect of lateral loading, the rigid frame and the masonry infilled walls stays intact at the beginning. As there is increase in the lateral loading, the masonry infilled walls get separate from the adjoining frame at the unloaded corner, i.e. the tension corner. At the loading corners (compression corners) the masonry infilled walls remains still intact with the frame. The term used to define this length of intact between frame and masonry infilled walls is called as Length of Contact. Transfer of load can be imagined to occur via an imaginary diagonal, which is supposed to act like a compression strut. Thus masonry infilled walls can be modelled as equivalent diagonal pin-jointed strut connecting the two compressive corners diagonally. These diagonal strut have inherited stiffness property that they get active only when they are subjected to compression. Thus in case of frame subjected to lateral loading only of the diagonal strut will be active at once. This theory was first suggested by Holmes[1].

The frames in which masonry infilled walls are modelled as equivalent diagonal pin-jointed strut are referred to as Macro Models. With the subsequent research on the modelling of masonry infilled walls, various authors have put forward different formulas for calculating the equivalent width of the diagonal pin-jointed strut by conducting various experiments, which is the governing property effecting the strength and stiffness of these diagonal pin-jointed strut and this equivalent width is dependent on the relative stiffness of the infilled-frame. Holmes[1] recommended the effective width of diagonal pin-jointed strut to be the 1/3rd of infilled panel diagonal length.

Liauw and Kwan[2] conducted studies both, methodically and experimentally taking into the account the non-linearity of the structure and also of the material. Paulay and Preistley[3] remarked that the higher value to strut width will lead to stiffer structure, and thus to a greater seismic response. Hendry[4] recommends the effective width of equivalent diagonal pin-jointed strut depends on the Length of Contact. Federal Emergency Management Agency (FEMA-273/306)[5] also recommends the effective width of diagonal compression strut as shown in table below.

Table.3.1: Effective Width of Equivalent Diagonal Pin-jointed Strut by different Formulas

<table>
<tr><th>Author</th><th colspan="2">Formulae for Equivalent Diagonal Compression Strut</th></tr>
<tr><td>Holmes</td><td>$W = 0.333d_m$</td><td rowspan="5">d_m= Length of diagonal

h_m=Height of masonry

t=Thickness of masonry

E_m=Elastic modulus of elasticity of masonry

E_c=Elastic modulus of concrete

I_c=Moment of Inertia of columns

I_b=Moment of Inertia beams

θ=Angle made by the strut with the horizontal</td></tr>
<tr><td>Liauw and Kwan</td><td>$$W = \frac{0.95h_m \cos\theta}{\sqrt{\lambda h_m}}$$
where,
$$\lambda = \sqrt[4]{\frac{E_m t \sin 2\theta}{4E_c I_c h_m}}$$</td></tr>
<tr><td>Paulay and Preistley</td><td>$W = 0.25d_m$</td></tr>
<tr><td>Hendry</td><td>$$W = 0.5\,[\alpha_h^2 + \alpha_l^2]^{1/2}$$
where,
$$\alpha_h = \frac{\pi}{2}\sqrt[4]{\frac{E_c I_c h_m}{2E_m t \sin 2\theta}}$$
$$\alpha_l = \pi\sqrt[4]{\frac{E_c I_b l_m}{2E_m t \sin 2\theta}}$$</td></tr>
<tr><td>FEMA-273/306</td><td>$$W = 0.175(\lambda H)^{-0.4} d_m$$
where,
$$\lambda = \sqrt[4]{\frac{E_m t \sin 2\theta}{4E_c I_c h_m}}$$</td></tr>
</table>

Mohammed Khaja Moinuddin, Professor Vishwanath. B. Patil[6] studied the effects and modelling techniques of masonry infilled walls, with six different models of R.C.C framed building, with two different techniques of modelling masonry infilled walls, first as Four Noded Quadrilateral Shell Element with in-plane stiffness and secondly as Equivalent diagonal in-jointed strut and one with shear wall, subjected to lateral loading. An effort was made to develop relation between strength-stiffness parameters and linear trend line was drawn to normalize parameters using MS Excel. From there conclusions drawn it was clear that fundamental modal time period gets reduced significantly when stiffness of masonry infilled walls and shear wall is taken into account. Further it was noticed that the models with the soft storey have high values of storey drift at levels of soft storey, leading to harmful sway mechanism, thus it is necessary to provide shear wall to avoid such condition. Opening in masonry infilled walls can easily modelled using equivalent diagonal pin-jointed strut method of modelling masonry infilled walls. From the analysis of non-dimensional parameter, it was seen that the for fully masonry infilled wall frame and the frame with shear walls, the value of R^2 i.e. is ratios of Strength and Stiffness are approximately equals to 1, which leads to conclusion that they have adequate stiffness and strength against earthquake loading.

Haroon Rasheed Tamboli and Umesh.N.Karadi[7] performed studies using software ETABS on seismic analysis using Equivalent Lateral Force Method for different R.C.C framed building models, which includes bare frame and frames modelled with masonry infilled walls and open ground storey frames i.e. frames having no masonry infilled walls in first storey. The masonry infilled walls were modelled using equivalent diagonal pin-jointed strut approach as proposed earlier by different researchers. Presence of masonry infilled walls to a large extent effected the seismic behaviour of the building by providing stiffness and strength to the structure. It was seen that in case of open ground storey frame, the storey drift was extremely large as compared to upper storey, which may probably lead to the collapse of structure.

Md Irfanullah, Vishwanath. B. Patil[8] investigated the performance of R.C.C framed structures with different arrangements of masonry infilled walls, like bare frame, rigid frame with masonry infilled walls, open ground storey, soft basement and masonry infilled in swastika pattern in ground/first floor, subjected to seismic loading. The results presented in the study showed that the providing masonry infilled walls improves seismic strength of the structure. The analysis were done using the software ETABS. The paper concluded that the use of masonry infilled wall below the plinth level shrinks the time period and masonry infilled walls proves to be a good solution to reduce story drift at basement level. There is also reduction in the time period due to the presence of masonry infilled walls modelled in ground storey. Paper marked that the rather keeping the ground storey open/soft, it is advisable to provide masonry infilled walls in some directions, so that parking space does not get troubled. By considering the effect of masonry infilled walls displacement and drift parameters of frame building can be controlled.

S.Niruba, K.V.Boobalakrishnan, K.M.Gopalakrishnan[9] conducted the pushover analysis in order to study the influence of masonry infilled walls failure mechanism. Partial factors of safety was assigned to mechanical parameters of masonry walls, to identify their effect on overall response on the structure. Considering masonry infilled walls as structural element also increases the ductility, flexural strength and stiffness of the structure. Researcher have shown that incrementing the opening in masonry infilled wall percentages leads to increase in inter-storey drift.

J.Dorji and D.P Thambiratnam[10] worked on the seismic response of masonry infilled walls framed structure. They are mostly used in the buildings, especially the one, which are located in the seismically prone regions. Current codes doesn’t have the satisfactory guidelines for the modelling, analysis and designing of masonry infilled walls framed structures. Finite Element and Time History analysis was carried out with different earthquake records and the significance of the masonry infilled walls strength, area openings and soft storey mechanism were examined. Results were presented in terms of terms of tip deflection, inter-storey drift, and element stresses, and fundamental modal time period, which were very advantageous in the seismic analysis and design of masonry infilled walls framed structure.

Praveen Rathod, S.S.Dyavanal[11] attempted to study the nature of performance based seismic susceptibility of 2-Dimensional R.C.C multi-storeyed building models, with changing percentages of central area openings of unreinforced masonry infilled walls from the range of 10 to 35%. The infilled walls were modelled as equivalent diagonal pin-jointed strut. The study was conducted on the G+3 and G+6 stories buildings. The method adopted for study was Equivalent Lateral Force Method and Response Spectrum Analysis using SAP 2000 software. Non-linear static pushover analysis was done using user defined hinges properties as per the provisions of FEMA-440. The results were compared on the grounds of fundamental modal time period, hinges status at performance point between various models and lateral displacements. Is was observed that the in mostly models flexural plastic hinges were formed at first storey level due to the presence of the open ground storey. The plastic hinges were formed mainly in the columns and beams. The lateral displacement being the function of the opening area percentages, increases with increase in opening area percentages. Flexural hinges were found to be under the level of life safety and collapse prevention range.

Rahul P. Rathi, Dr. P.S. Pajgade[12] studied the effects of masonry infilled walls with openings. Few available publications like ATC-40 and FEMA-273/306 have the provisions for the modelling of masonry infilled walls as equivalent diagonal pin-jointed strut, however methods to take into the account the opening areas in masonry infilled walls is not discussed. In this study an effort was made to know the performance of R.C.C rigid frame with masonry infilled walls and with different central and corner openings. The results clearly showed that the masonry infilled walls influence the fames behaviour under seismic excitation to a great extent and on the same side lateral stiffness decreases with the increase in opening areas percentages. In case of central openings in masonry infilled walls deflection is very high in contrast to the corned openings. The percentage to steel, bending moment and shear force in columns of bare frame, i.e. without taking into the account the effect of masonry infilled walls, is very high in contrast to frames in which effect to masonry infilled walls was taken into consideration.

C.Suresh Babu, E.Arunakanthi[13] attempted to perform the linear-static, linear dynamic(Response Spectrum Method), and non-linear static analysis(Pushover) to study the effects of rigid bare frame, and masonry infilled walls, at different locations during an earthquake. The analysis was done using a very powerful tool ETABS which took into the account the significant parameters which effects the mass, stiffness, strength and deformability. While performing analysis, deflection at each storey was compared. For the determination of performance level, demand and capacity of considered models, pushover analysis was executed. From the conclusions marked in the journal, it was sated that, for the prediction on R.C.C rigid frames ultimate state and for their seismic evolution, it is necessary to take into the account the effect of masonry infilled walls. The capacity and demand curve are intersecting each other, which is a good indication considering the building performance level and this is happening in case of masonry infilled walls frame structure only. At different displacement levels, the formation of plastic hinges took place for building mechanism. It started from beam ends and column bases of lower storeys and then excites to the upper levels and continues to upper storeys with yielding of intermediate interior columns. The results of capacity, plastic hinges and demand reflects the real performance of the structure.

Panagiotis G. Asteris, Ioannis P. Giannopoulos, and Christis Z. Chrysostomou[14] suggested the analytical equation to take into the account the opening area percentages by introducing the reduction factor, which is defined as the ratio of the effective width of equivalent diagonal pin-jointed strut with opening area percentage to that of a solid masonry infilled wall. The proposed equation was verified by comparing results with the work done by past researchers. In this study, to obtain the reduced effective width of equivalent diagonal pin-jointed strut, so as to incorporate the opening areas in masonry infilled walls, a reduction factor was introduced, which is used as a factor, multiplied with well-known equations to calculate effective width of equivalent diagonal pin-jointed strut. In order to idealize the non-linear properties of masonry infilled walls with opening areas, the same reduction factor can be utilized in multi-strut models.

Naveed. A. G & Dr. Chandradhara. G.P[15] inspected the effect of opening area percentages and positions in masonry infilled walls, based on results available from finite element analysis (Asteris[16]), proposed analytical equations to obtain the effective width reduction factor, in respect to the location and opening area sizes in masonry infilled walls. A comparative study has been carried out with different locations and varying opening area percentages of masonry infilled walls panel for a simple case of two-bay and four storey frame, using Response Spectrum Method, which includes the modelling of masonry infilled walls as equivalent diagonal pin-jointed strut, using ETABS Software. To validate the procedure, a simple frame was analysed and experimental results were compared. The study showed that the introduction of the masonry infilled wall panels in bare frame reduces the fundamental modal time period and also leads to stiffer structure. As the opening area percentages increases, there is reduction in the lateral stiffness of masonry infilled frame. There is increment in the roof displacement with increase in the opening area percentages and in case of openings on compression diagonal, it is highly vulnerable.

Mohammad H. Jinya, V. R. Patel[17] modelled G+9 R.C.C frame building on ETABS Software and performed analysis using Time History Method and Seismic Coefficient Method as per IS 1893:2002 to study the effects of masonry infilled walls on story displacement, storey drift, base shear and axial, with and without open/soft storey with different opening area percentages. The effective width of equivalent diagonal pin-jointed strut is found using FEMA approach method. The comparison between the results of bare frame, masonry infilled wall frame and open/soft storey frame were made and discussed in the study. From the conclusions made, it was clear that the equivalent diagonal pin-jointed strut will change the performance of R.C.C frame under seismic actions. There is increase in the axial forces in the column, and decrement in the storey drift and storey displacement. In the ground level atleast periphery walls should be provide to avoid soft storey mechanism. By increasing the opening area percentages, there is decrement in lateral stiffness of the frame.

C V R Murty And Sudhir K Jain[18] presented a paper in which some experimental results on cyclic tests on R.C.C frame with masonry infilled walls were shown. It was realized that masonry infilled walls contributes to a high level on the lateral stiffness, overall ductility, strength and energy dissipation capacity. It is also possible to improve the out-of plane response of the masonry infilled walls with suitable provisions of providing reinforcement in the masonry walls, i.e. anchoring them well into the columns of frame. There is also a demand for the development of robust seismic design procedure for masonry infilled walls R.C.C frame structure, being much common type of building structure especially in developing countries.

D. Guney, and E. Aydin[19] showed the involvement of masonry infilled walls in seismic response of a building. Using Finite Element Method, masonry infilled walls with different configurations were modelled and analysed. There was a risk of soft storey mechanism in the models. For the analysis of structure, a non-linear force-displacement behaviour was adopted. For Time History method of analysis, EL Centro N-S component was used. From the conclusions marked in the paper, it was seen that the existence of masonry infilled walls leads to the less amount of shear forces on columns of the frame. But in case of masonry infilled wall frame with an open/soft storey, the shear forces in columns is much higher as compared to columns of bare frame. As the modulus of elasticity of masonry infilled wall frame and stiffness of the frame are directly proportional, the material quality of masonry infilled walls directly influences the seismic response.

Santiago Pujol, Amadeo Benavent-Climent, Mario E Rodriguez, and J. Paul Smith-Pardo[20] In order to test the hypothesis that masonry infilled walls helps in reduction of vulnerability of R.C structures, a properly scaled three-storey structure with flat-plate system was strengthened with masonry infilled wall bricks and tested for displacement reversals. The test results were compared with results of test without masonry infilled walls of same system. In the initial level, at slab-column junction, the structure witnessed a punching shear and with the addition of masonry infilled walls, it helped in the prevention of slab collapse and provided stiffness and strength to the structure. The repaired structure had a drift capacity of 1.5% in order to match the experimental results, a numerical model of the structure being tested was calibrated. The results concluded that the R.C structure, with the help of masonry infilled walls was strengthened and repaired. There was increment in the strength by 100% and in stiffness by 500% as compared to the original structure. The strengthened/repaired structure is able to sustain the drift reversals with amplitudes upto 1.5% height of the structure and that too without excessive reduction in stiffness.

CHAPTER 4

PROGRAMME OF STUDY

4.1 Introduction

This chapter includes the details of the computational model for carrying out analysis. For calculation of dead, live and seismic loading, the Indian Standard Codes namely IS:875(Part1), IS:875(Part2) and IS 1893:2002 are used respectively. Some reference is also taken from IS 456:2000 for few points. All the data for execution of study is also mentioned in this chapter. The modelling is done using a very well-known powerful software tool, extensively used for carrying out analysis and design of R.C.C structures, ETABS 2013.

4.2 Building Configurations and Material Properties Details

The building having G+8 storeys is assumed which is regular in plan, with 5 bays in each direction. Total length of building in x and y direction is 25m and total building height is 27m. Further it is R.C.C building which is specified as Special Moment Resisting Frame (SMRF). Various other details related to building and materials used is mentioned in the Table.4.1 below.

Table.4.1: Building Property and Material Details

S.no.	Design parameter	Value
1	Floor Height (c/c)	3.0 m
2	Size of Beam	230x450 m
3	Size of Column	230x600 m
4	Unit Weight of Concrete	25 kN/m^3
5	Unit Weight of Masonry Infilled Walls	20 kN/m^3
6	Characteristic Strength of Concrete (f_{ck})	25 MPa
7	Characteristic Strength of Masonry Infilled Walls	3.5 MPa
8	Modulus of Elasticity of Concrete (E_c)	$5000\sqrt{f_{ck}}$
9	Modulus of Elasticity of Masonry Infilled Walls (E_m)	5500 MPa
10	Poison’s Ratio for Concrete	0.20
11	Poison’s Ratio for Masonry Infilled Walls	0.15
12	Slab Thickness	150 mm
13	Masonry Infilled Walls Thickness	230 mm
14	Angle made by Strut with the Horizontal (θ)	30.0942°

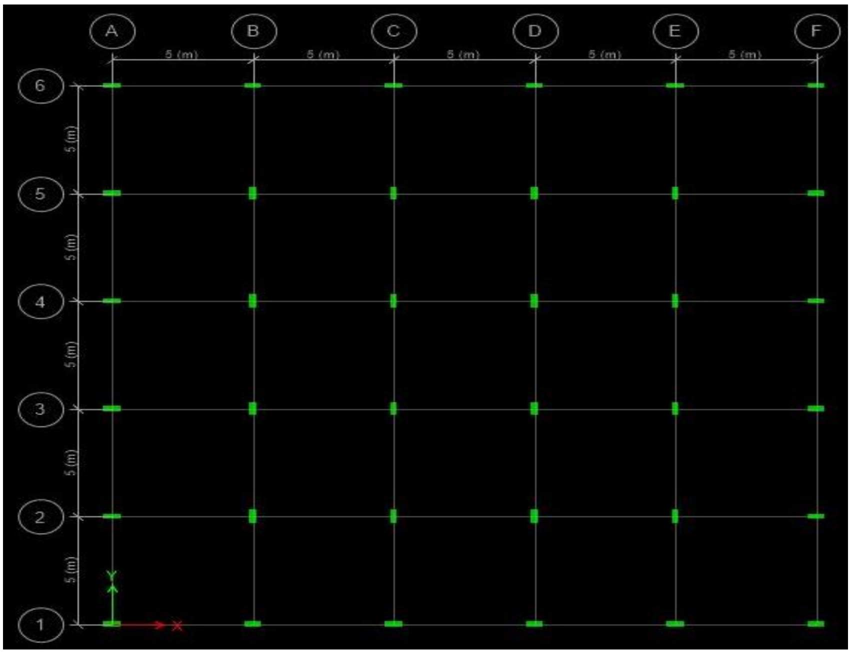

Fig.4.1: Plan of the Building

The designed seismic data for assumed SMRF building is shown in Table.4.2

Table.4.2: Seismic Design Data

S.no.	Design Parameter	Value
1	Seismic Zone	V
2	Zone Factor	0.36
3	Response Reduction Factor (R)	5
4	Importance Factor (I)	1.0
5	Soil Type	Medium Soil (Type II)
6	Damping Ratio	5%
7	Frame Type	Special Moment Resisting Frame

The dead and the live load applied to the structure are as follows:

(a) Dead Load :

(i) Dead load of Beams and Columns: As per unit weight of material and dimensions.

(ii) Dead Load on slabs (Flooring Load) : 1 kN/m²

(iii) Dead Load on Periphery Beams (Exterior Wall Load,230mm thick) : 12.742 kN/m

(iv) Dead Load on Interior Beams (Interior Wall load,115 mm thick) : 6.742 kN/m

(v) Dead on Periphery Beams of Roof (Parapet Wall load,1m high) : 4.6 kN/m

(b) Live Load:

(i) Live Load on Floor Slabs (except roof) : 3 kN/m²

(ii) Live Load on Roof Floor Slab : 1.5 kN/m²

As per IS 1893:2002, clause 7.3.1, the percentage of live load considered for seismic load calculation is 25%.

4.3 Modelling of Frame Members and Masonry Infilled Walls

While the frame horizontal elements are modelled as beams and vertical elements as column, and slab is modelled as rigid diaphragm. For modelling of masonry infilled wall in the frame, two different methods are adopted.

(a) As Four Noded Quadrilateral Element

In this method adopted for modelling of masonry infilled walls, these are modelled as four noded quadrilateral element with in-plane stiffness, by defining it as membrane element, with a uniform thickness of 0.230 m.

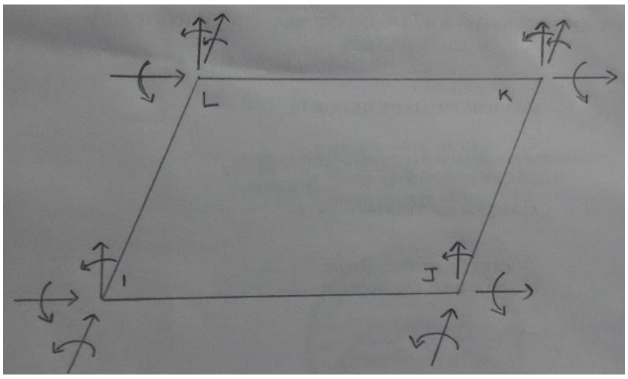

Fig.4.2: Four Noded Quadrilateral Element

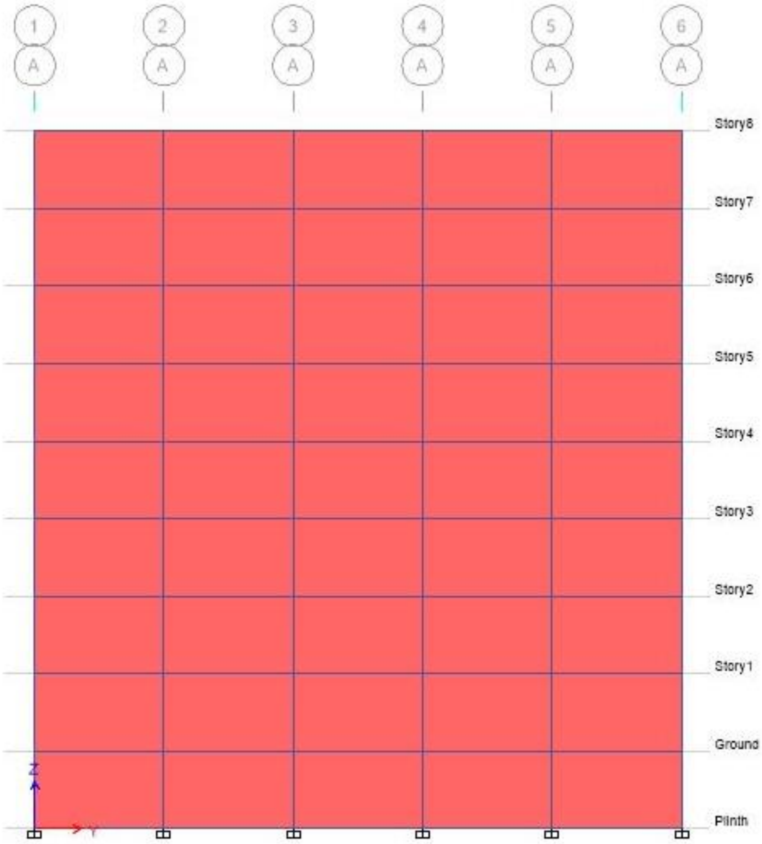

Fig.4.3: Infilled Frame Model

(b) As Equivalent Diagonal Pin-Jointed Strut

In this method the masonry infilled walls are modelled as equivalent diagonal pin-jointed strut having an effective width as proposed by different researchers. Here in this study the method given in FEMA 273/306[5] has been used to find out the effective width of equivalent diagonal pin-jointed strut. The proposed formula is:

$$W = 0.175(\lambda H)^{-0.4} d_m$$

where,

$$\lambda = \sqrt[4]{\frac{E_m t \sin 2\theta}{4E_c I_c h_m}}$$

Where, E_m is modulus of elasticity of masonry infilled walls, t is thickness of masonry infilled walls, E_c is modulus of elasticity of concrete, I_c is moment of inertia of columns,

h_m is height of masonry infill, θ is the angle made by strut with the horizontal, H is the height of the floor (c/c) and d_m is the length of diagonal pin-jointed strut.

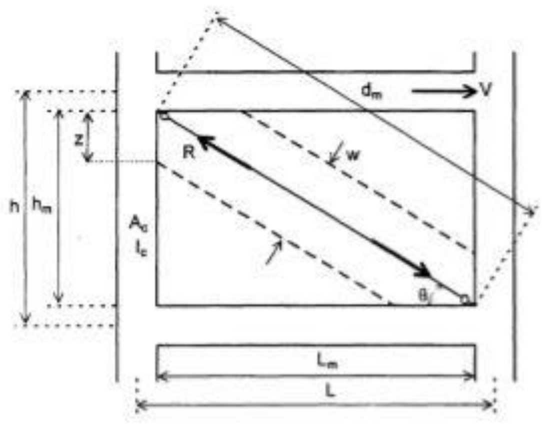

Fig.4.4: Equivalent Diagonal Pin-Jointed Strut

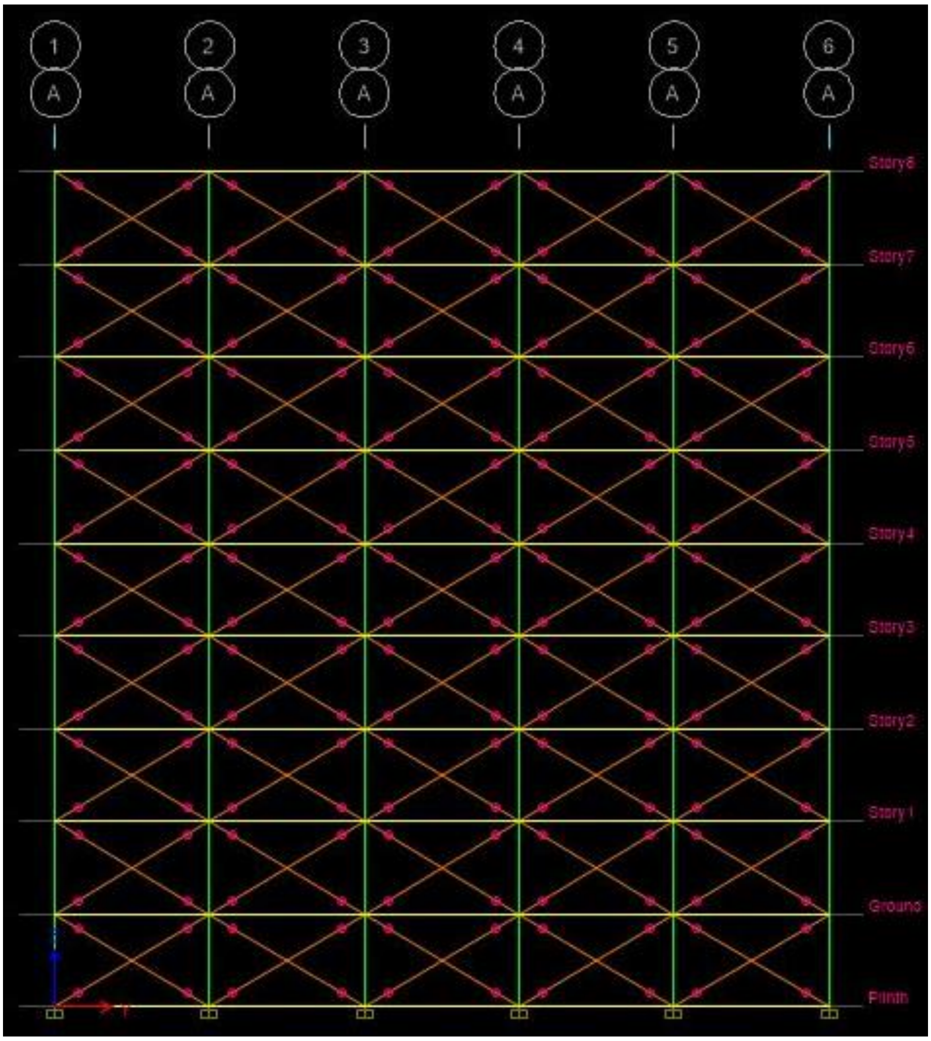

Fig.4.5: Strut Frame Model

4.3.1 Modelling of Openings in Masonry Infilled Walls

Openings in masonry infilled walls can occur at any location, i.e. it may have central openings, or openings in the left or in the right. In order to incorporate openings areas in masonry infilled walls in the model created in ETABS, different ideology were adopted for both, the above mentioned ways to model masonry infilled walls. Both the cases are discussed below. The openings considered for comparison in both the cases are 10%, 15%, 20% and 25% at three different locations i.e. bottom left, central, and up right.

(a) Openings in Masonry Infilled Walls modelled as Equivalent Diagonal Pin-jointed Strut

For modelling of opening areas, in case of diagonal struts, which may occur on any side of diagonal, some equations are used to calculate the stiffness reduction factor, which when multiplied by the actual effective width, gives the reduced width of equivalent diagonal pin-jointed strut. There equations were proposed by Asteris[16], in order to consider the effects of opening areas and there location, in masonry infilled walls.

Width of strut for openings = Stiffness Reduction Factor (k) x W (width without opening)

(i) For the Openings, on the compressed diagonal, i.e. Central Openings :

$$k = 0.12 + 0.88e^{-x/15.75}$$

(ii) For the Openings, Down the diagonal Left

$$k = 0.14 + 0.88e^{-x/41.6}$$

(iii) For the Openings, Up the diagonal Right

$$k = 1 - 0.085e^{-(x-31)^2/245}$$

Where, Opening Area Percentage (x) = $\frac{Area\ of\ Opening}{Area\ of\ Infilled\ Wall}$

The different percentages of opening areas i.e. 10%, 15%, 20%, 25% for each location are taken, to know effects of opening areas size and location and thus to make a comparison between them. The graphs below shows the variation of stiffness reduction factor with increase in opening area percentages for each location considered.

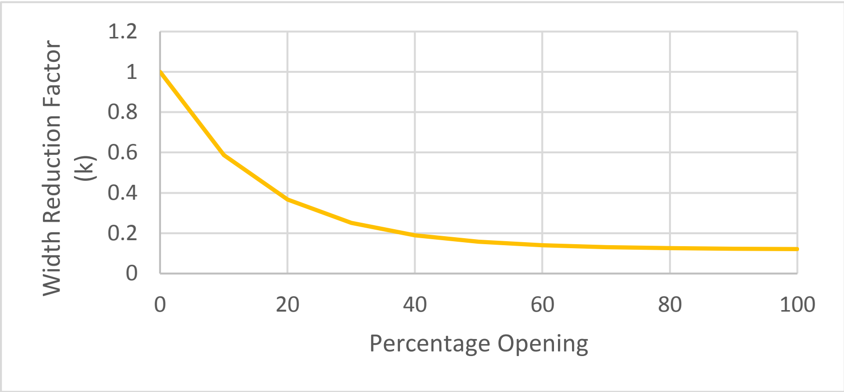

Fig.4.6: Width Reduction Factor for Central Openings

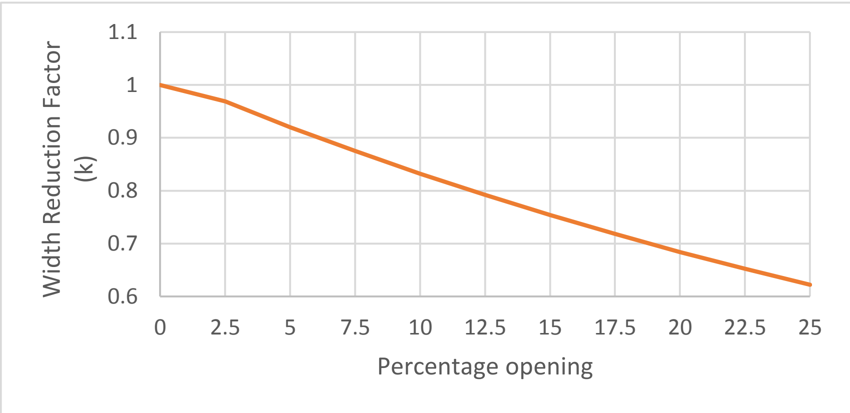

Fig.4.7: Width Reduction Factor for Openings Down the Diagonal Left

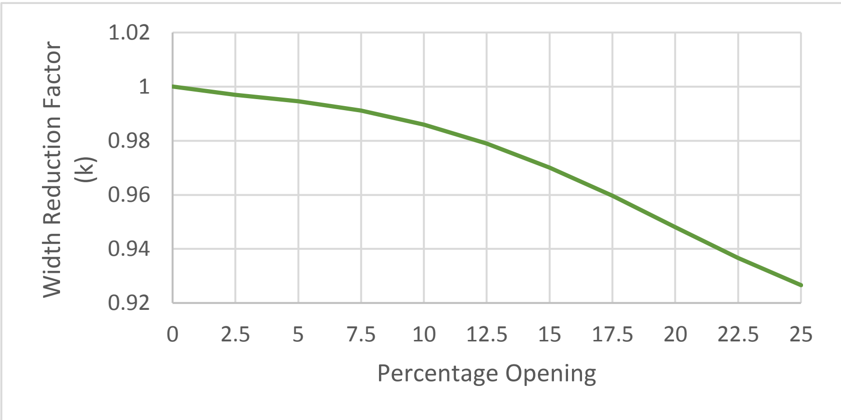

Fig.4.8: Width Reduction Factor for Openings Up the Diagonal Right

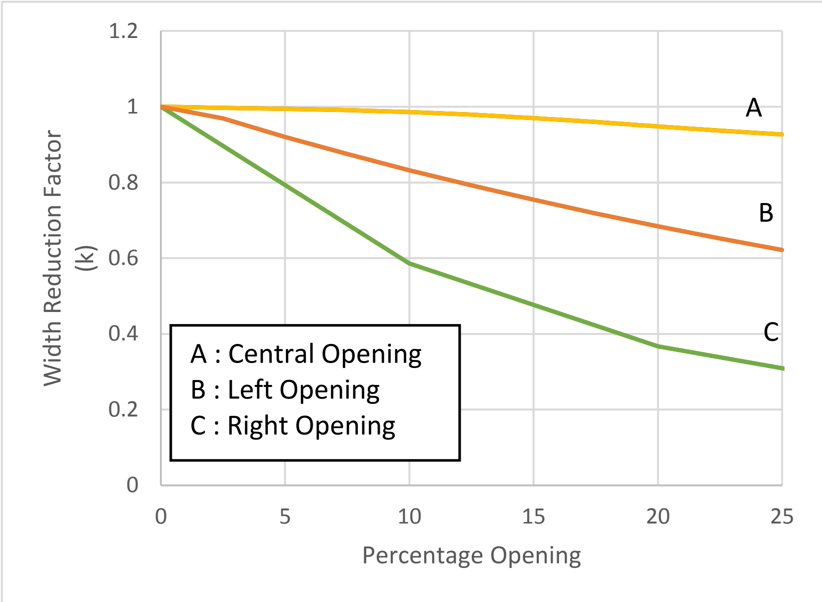

Fig.4.9: Combined Graph for Width Reduction Factor for Openings At Centre, Left Corner Down, and Right Corner Up

(b) Opening in Masonry Infilled Walls modelled as Four Noded Quadrilateral Element

For modelling opening area in this case simple tools of ETABS are used to create openings at different location. It can be simply illustrated as, Select elevation view in which you want to create openings, and then go to Draw option → Draw Floor/Wall Objects → Draw Wall Openings and then enter the size of opening area and for location click on the wall on which opening has to be created. The variation of the opening area percentage i.e. 10%, 15%, 20%, 25% remains the same and the locations also i.e. central openings, openings in left corner down and openings in right corner up.

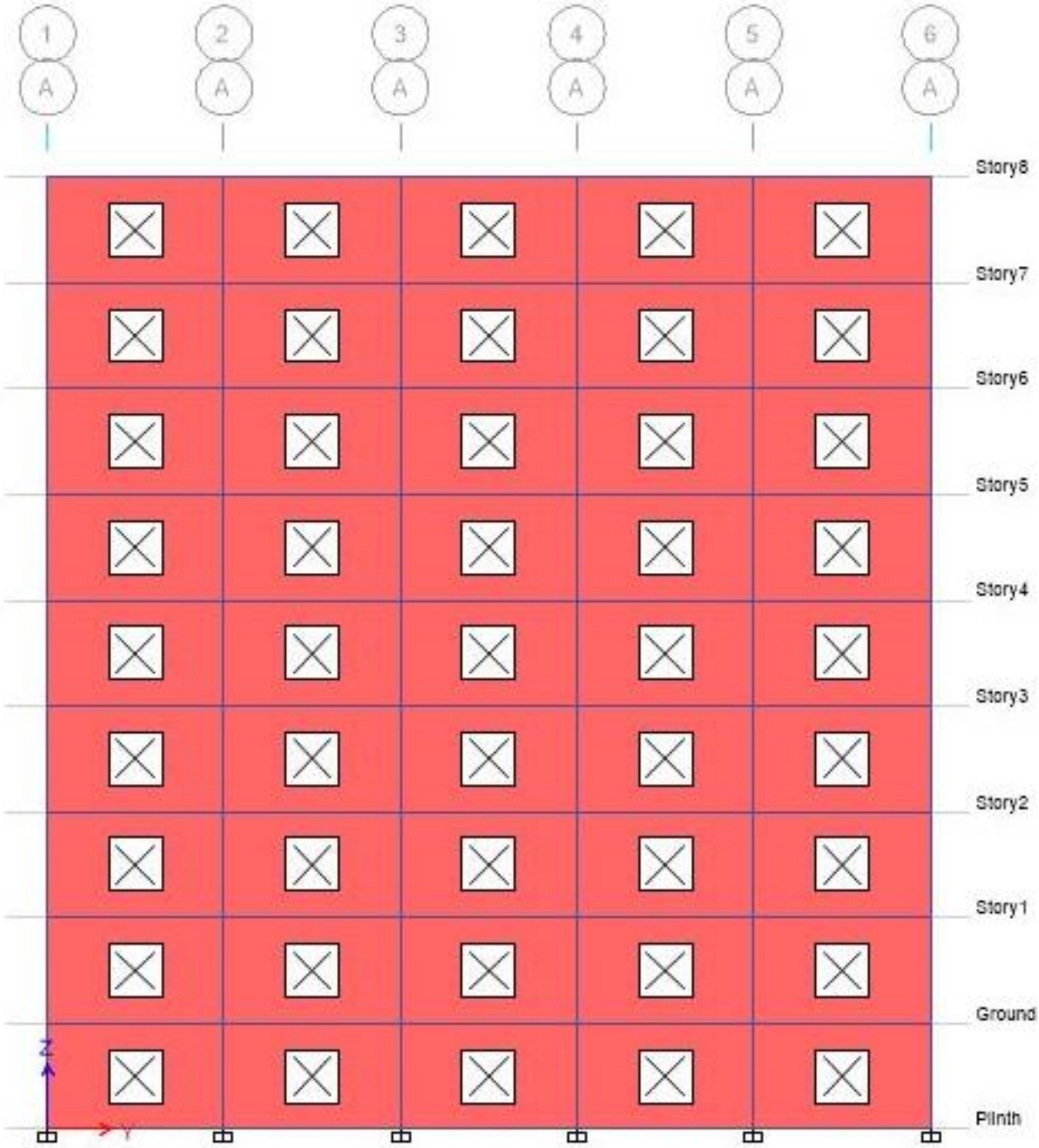

Fig.4.10: Infilled Frame Model with Central Opening

In all 27 models were prepared, details of which are described in Table.4.3 below.

Table.4.3: Model Details

Model No.	**Model Description**	**Model ID**
1	Bare Frame, without masonry infilled walls modelled	BF
2	Strut Frame, using FEMA method, with 0% opening area	SF0%
3	Strut Frame, using FEMA method, with 10% central openings	SF10%CO
4	Strut Frame, using FEMA method, with 15% central openings	SF15%CO
5	Strut Frame, using FEMA method, with 20% central openings	SF20%CO
6	Strut Frame, using FEMA method, with 25% central openings	SF25%CO
7	Strut Frame, using FEMA method, with 10% left openings	SF10%LO
8	Strut Frame, using FEMA method, with 15% left openings	SF15%LO
9	Strut Frame, using FEMA method, with 20% left openings	SF20%LO
10	Strut Frame, using FEMA method, with 25% left openings	SF25%LO
11	Strut Frame, using FEMA method, with 10% right openings	SF210%RO
12	Strut Frame, using FEMA method, with 15% right openings	SF15%RO
13	Strut Frame, using FEMA method, with 20% right openings	SF20%RO
14	Strut Frame, using FEMA method, with 25% right openings	SF25%RO
15	Infilled Frame, using quad element, with 0% opening area	IF0%
16	Infilled Frame, using quad element, 10% central openings	IF10%CO
17	Infilled Frame, using quad element, 15% central openings	IF15%CO
18	Infilled Frame, using quad element, 20% central openings	IF20%CO
19	Infilled Frame, using quad element, 25% central openings	IF25%CO
20	Infilled Frame, using quad element, 10% left openings	IF10%LO
21	Infilled Frame, using quad element, 15% left openings	IF15%LO
22	Infilled Frame, using quad element, 20% left openings	IF20%LO
23	Infilled Frame, using quad element, 25% left openings	IF25%LO
24	Infilled Frame, using quad element, 10% right openings	IF10%RO
25	Infilled Frame, using quad element, 15% right openings	IF15%RO
26	Infilled Frame, using quad element, 20% right openings	IF20%RO
27	Infilled Frame, using quad element, 25% right openings	IF25%RO

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

This chapter includes the results obtained from the analysis of models described in last chapters and these results obtained are compared on the grounds of fundamental modal time period of vibration, modal participation factors, base shear, storey drifts in both the directions i.e. for earthquake in x-direction (EQX) and earthquake in y-direction (EQY) and then trend line for different opening conditions is compared for storey drift and maximum storey displacements both in EQX and EQY direction.

5.2 Comparison on Fundamental Modal Time Period

When the building is modelled as bare frame only, the fundamental modal time period came out to be 1.994 sec, while when the effects of masonry infilled walls was taken into consideration, the time period gets reduced drastically to 0.773 sec, when they are modelled as diagonal strut and further reduced when, modelled as shell element, to 0.502 sec. This clearly indicates that the masonry infilled walls exhibits a great stiffness which is inherited to structure. Further in case of presence of openings areas, this stiffness reduces considerably with increment in the opening sizes and this reduction in stiffness is also effected by the location of opening areas. All these are discussed in tables and graphs below.

1) Comparison of fundamental modal time between bare frame, strut frame and infilled frame.

Table.5.1: Fundamental Modal Time Period for bare frame, strut frame and infilled frame

S.no.	Model ID	Fundamental Model Time Period (in sec)
1	BF	1.994
2	SF0%	0.773
3	IF0%	0.502

2) Comparison of fundamental modal time period between bare frame and strut frame with varying percentage of central opening areas.

Table.5.2: Fundamental Modal Time Period for various central opening areas

S.no.	Model ID	Fundamental Model Time Period (in sec)
1	BF	1.994
2	SF0%	0.773
3	SF10%CO	0.933
4	SF15%CO	1.015
5	SF20%CO	1.094
6	SF25%CO	1.169

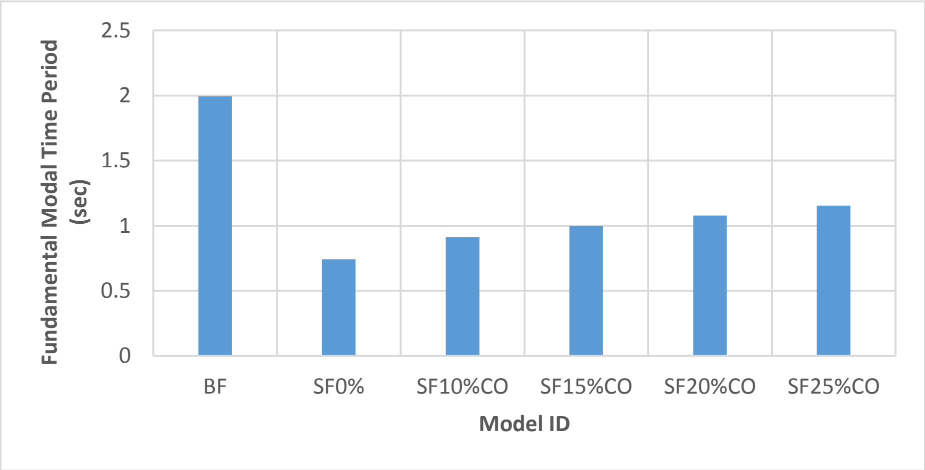

Fig.5.1: Fundamental Modal Time Period for various central opening areas

3) Comparison of fundamental modal time period between bare frame and strut frame with varying percentage of opening areas down the diagonal left.

Table.5.3: Fundamental Modal Time Period for various opening areas down the diagonal left

S.no.	Model ID	Fundamental Model Time Period (in sec)
1	BF	1.994
2	SF0%	0.773
3	SF10%LO	0.825
4	SF15%LO	0.854
5	SF20%LO	0.883
6	SF25%LO	0.914

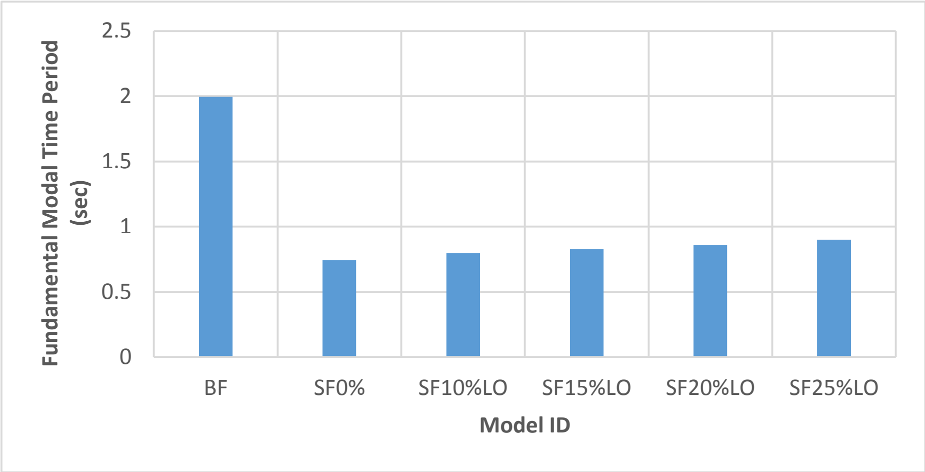

Fig.5.2: Fundamental Modal Time Period for various Opening areas down the diagonal Left

4) Comparison of fundamental modal time period between bare frame and strut frame with varying percentage of opening areas up the diagonal right.

Table.5.4: Fundamental Modal Time Period for various opening areas up the diagonal right

S.no.	Model ID	Fundamental Model Time Period (in sec)
1	BF	1.994
2	SF0%	0.773
3	SF10%RO	0.777
4	SF15%RO	0.781
5	SF20%RO	0.788
6	SF25%RO	0.794

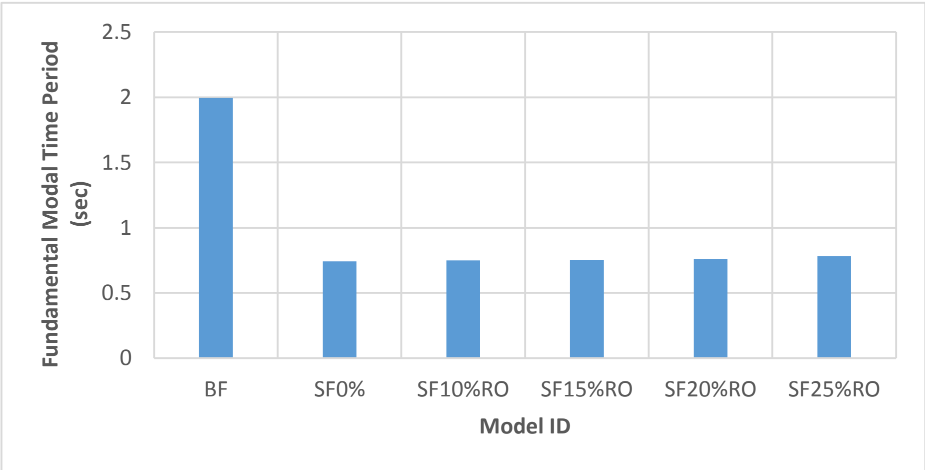

Fig.5.3: Fundamental Modal Time Period for various Opening areas up the diagonal Right

5) Comparison of fundamental modal time period between bare frame and infilled frame with varying percentage of central opening areas.

Table.5.5: Fundamental Modal Time Period for various central opening areas

S.no.	Model ID	Fundamental Model Time Period (in sec)
1	BF	1.994
2	IF0%	0.502
3	IF10%CO	0.546
4	IF15%CO	0.579
5	IF20%CO	0.619
6	IF25%CO	0.667

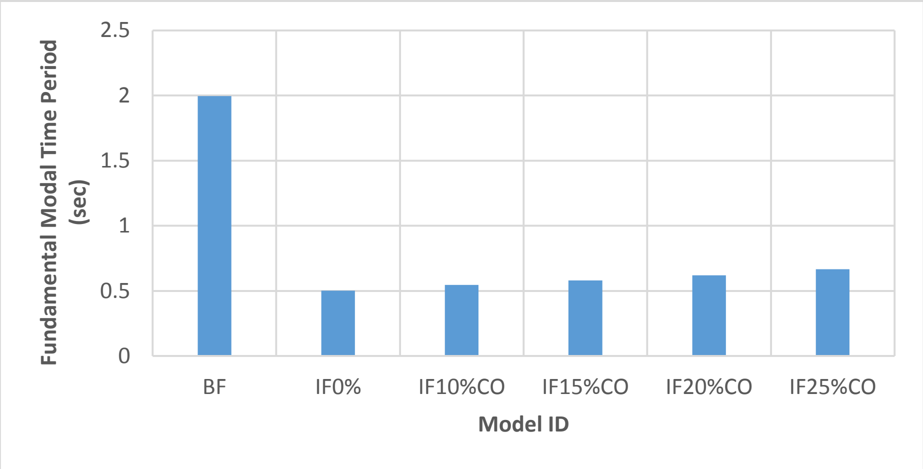

Fig.5.4: Fundamental Modal Time Period for various Central Opening areas

6) Comparison of fundamental modal time period between bare frame and infilled frame with varying percentage of opening areas down the left corner.

Table.5.6: Fundamental Modal Time Period for various opening areas down the left corner

S.no.	Model ID	Fundamental Model Time Period (in sec)
1	BF	1.994
2	IF0%	0.502
3	IF10%LO	0.527
4	IF15%LO	0.549
5	IF20%LO	0.580
6	IF25%LO	0.598

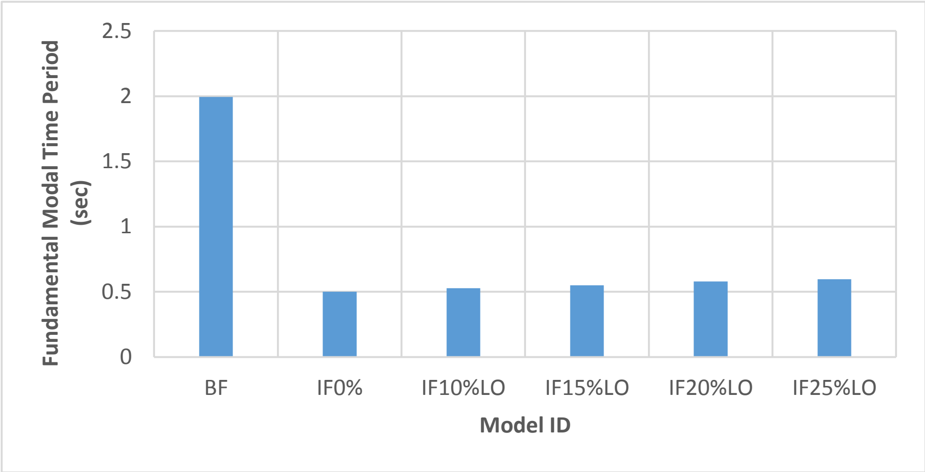

Fig.5.5: Fundamental Modal Time Period for various Opening areas down the Left Corner

7) Comparison of fundamental modal time period between bare frame and infilled frame with varying percentage of opening areas up the right corner.

Table.5.7: Fundamental Modal Time Period for various opening areas up the right corner

S.no.	Model ID	Fundamental Model Time Period (in sec)
1	BF	1.994
2	IF0%	0.502
3	IF10%RO	0.524
4	IF15%RO	0.541
5	IF20%RO	0.568
6	IF25%RO	0.587

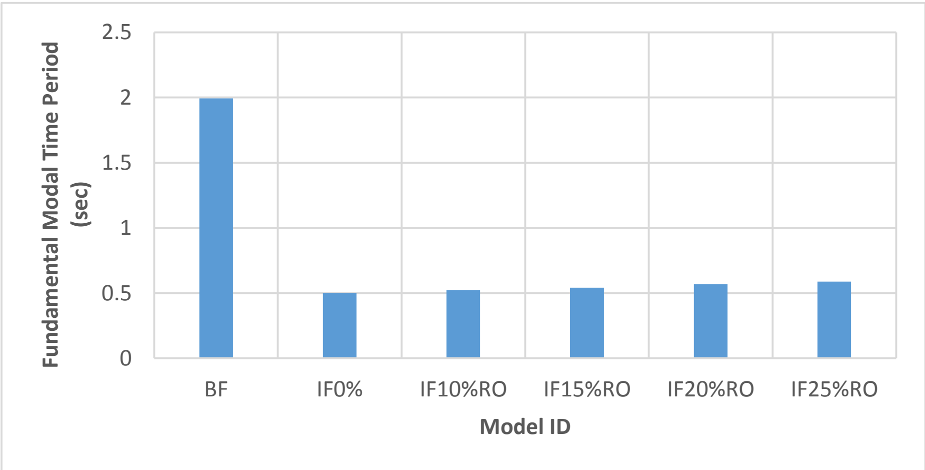

Fig.5.6: Fundamental Modal Time Period for various Opening areas up the Right Corner

5.3 Modal Mass Participation Factor

Here the modal mass participation factor of different modes obtained from analysis are discussed.

1) Modal mass participation factor for bare frame model (BF).

Table.5.8: Modal mass participation factor for model bare frame

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	1.994	80.71	0	0	80.71	0
Modal	2	1.991	0	81.4	0	80.71	81.4
Modal	3	0.979	0	0	0	80.71	81.4
Modal	4	0.674	9.96	0	0	90.67	81.4
Modal	5	0.656	0	9.78	0	90.67	91.19
Modal	6	0.617	0	0	0	90.67	91.19
Modal	7	0.38	3.88	0	0	94.55	91.19
Modal	8	0.375	0	3.76	0	94.55	94.95
Modal	9	0.352	0	0	0	94.55	94.95

2) Modal mass participation factor for strut frame model with 0% openings (SF0%).

Table.5.9: Modal mass participation factor for strut frame model with 0% openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.773	81.88	0	0	81.88	0
Modal	2	0.768	0	82.13	0	81.88	82.13
Modal	3	0.484	0	0	0	81.88	82.13
Modal	4	0.261	10.28	0	0	92.16	82.13
Modal	5	0.26	0	10.13	0	92.16	92.26
Modal	6	0.22	0	0	0	92.16	92.26
Modal	7	0.219	0.25	0	0	92.41	92.26
Modal	8	0.219	0	0.25	0	92.41	92.51
Modal	9	0.218	0	0.07	0	92.41	92.59

3) Modal mass participation factor for strut frame model with 10% central openings (SF10%CO).

Table.5.10: Modal mass participation factor for strut frame model with 10% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.933	82.24	0	0	82.24	0
Modal	2	0.924	0	82.57	0	82.24	82.57
Modal	3	0.603	0	0	0	82.24	82.57
Modal	4	0.309	10.7	0	0	92.94	82.57
Modal	5	0.307	0	10.58	0	92.94	93.15
Modal	6	0.203	0	0	0	92.94	93.15
Modal	7	0.182	3.26	0	0	96.2	93.15
Modal	8	0.181	0	3.22	0	96.2	96.37
Modal	9	0.152	0	0.22	0	96.2	96.59

4) Modal mass participation factor for strut frame model with 15% central openings (SF15%CO).

Table.5.11: Modal mass participation factor for strut frame model with 15% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	1.015	82.3	0	0	82.3	0
Modal	2	1.004	0	82.66	0	82.3	82.66
Modal	3	0.667	0	0	0	82.3	82.66
Modal	4	0.336	10.51	0	0	92.81	82.66
Modal	5	0.334	0	10.37	0	92.81	93.04
Modal	6	0.225	0	0	0	92.81	93.04
Modal	7	0.203	2.32	0	0	95.12	93.04
Modal	8	0.203	0	2.25	0	95.12	95.28
Modal	9	0.192	0	0.08	0	95.12	95.36

5) Modal mass participation factor for strut frame model with 20% central openings (SF20%CO).

Table.5.12: Modal mass participation factor for strut frame model with 20% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	1.094	82.3	0	0	82.3	0
Modal	2	1.081	0	82.7	0	82.3	82.7
Modal	3	0.73	0	0	0	82.3	82.7
Modal	4	0.362	10.34	0	0	92.65	82.7
Modal	5	0.359	0	10.2	0	92.65	92.9
Modal	6	0.251	0	0	0	92.65	92.9
Modal	7	0.241	0.44	0	0	93.08	92.9
Modal	8	0.241	0	0.42	0	93.08	93.32
Modal	9	0.239	0	0.04	0	93.08	93.36

6) Modal mass participation factor for strut frame model with 25% central openings (SF25%CO).

Table.5.13 Modal mass participation factor for strut frame model with 25% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	1.169	82.27	0	0	82.27	0
Modal	2	1.153	0	82.7	0	82.27	82.7
Modal	3	0.792	0	0	0	82.27	82.7
Modal	4	0.387	10.17	0	0	92.44	82.7
Modal	5	0.384	0	10.01	0	92.44	92.71
Modal	6	0.296	0	0	0	92.44	92.71
Modal	7	0.294	0.14	0	0	92.58	92.71
Modal	8	0.294	0	0.13	0	92.58	92.84
Modal	9	0.293	0	0.03	0	92.58	92.87

7) Modal mass participation factor for strut frame model with 10% left openings (SF10%LO).

Table.5.14: Modal mass participation factor for strut frame model with 10% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.825	82.05	0	0	82.05	0
Modal	2	0.818	0	82.32	0	82.05	82.32
Modal	3	0.521	0	0	0	82.05	82.32
Modal	4	0.273	11.03	0	0	93.07	82.32
Modal	5	0.271	0	10.92	0	93.07	93.24
Modal	6	0.175	0	0	0	93.07	93.24
Modal	7	0.159	3.37	0	0	96.45	93.24
Modal	8	0.159	0	3.34	0	96.45	96.58
Modal	9	0.117	0	1.32	0	96.45	97.9

8) Modal mass participation factor for strut frame model with 15% left openings (SF15%LO).

Table.5.15: Modal mass participation factor for strut frame model with 15% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.854	82.11	0	0	82.11	0
Modal	2	0.847	0	82.4	0	82.11	82.4
Modal	3	0.543	0	0	0	82.11	82.4
Modal	4	0.282	10.93	0	0	93.04	82.4
Modal	5	0.281	0	10.82	0	93.04	93.22
Modal	6	0.183	0	0	0	93.04	93.22
Modal	7	0.165	3.36	0	0	96.4	93.22
Modal	8	0.165	0	3.33	0	96.4	96.55
Modal	9	0.124	0	0.98	0	96.4	97.53

9) Modal mass participation factor for strut frame model with 20% left openings (SF20%LO).

Table.5.16: Modal mass participation factor for strut frame model with 20% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.883	82.17	0	0	82.17	0
Modal	2	0.876	0	82.47	0	82.17	82.47
Modal	3	0.565	0	0	0	82.17	82.47
Modal	4	0.292	10.84	0	0	93.01	82.47
Modal	5	0.29	0	10.72	0	93.01	93.2
Modal	6	0.19	0	0	0	93.01	93.2
Modal	7	0.171	3.34	0	0	96.35	93.2
Modal	8	0.171	0	3.3	0	96.35	96.5
Modal	9	0.133	0	0.57	0	96.35	97.07

10) Modal mass participation factor for strut frame model with 25% left openings (SF25%LO).

Table.5.17: Modal mass participation factor for strut frame model with 25% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.914	82.22	0	0	82.22	0
Modal	2	0.906	0	82.54	0	82.22	82.54
Modal	3	0.588	0	0	0	82.22	82.54
Modal	4	0.302	10.75	0	0	92.97	82.54
Modal	5	0.3	0	10.63	0	92.97	93.17
Modal	6	0.198	0	0	0	92.97	93.17
Modal	7	0.178	3.3	0	0	96.27	93.17
Modal	8	0.177	0	3.26	0	96.27	96.43
Modal	9	0.144	0	0.3	0	96.27	96.74

11) Modal mass participation factor for s strut frame model with 10% right openings (SF10%RO).

Table.5.18: Modal mass participation factor for strut frame model with 10% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.777	81.9	0	0	81.9	0
Modal	2	0.771	0	82.15	0	81.9	82.15
Modal	3	0.486	0	0	0	81.9	82.15
Modal	4	0.256	11.21	0	0	93.11	82.15
Modal	5	0.255	0	11.11	0	93.11	93.26
Modal	6	0.163	0	0	0	93.11	93.26
Modal	7	0.149	3.39	0	0	96.51	93.26
Modal	8	0.149	0	3.37	0	96.51	96.63
Modal	9	0.108	0	1.51	0	96.51	98.14

12) Modal mass participation factor for strut frame model with 15% right openings (SF15%RO).

Table.5.19: Modal mass participation factor for strut frame model with 15% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.781	81.91	0	0	81.91	0
Modal	2	0.775	0	82.17	0	81.91	82.17
Modal	3	0.489	0	0	0	81.91	82.17
Modal	4	0.258	11.19	0	0	93.11	82.17
Modal	5	0.256	0	11.09	0	93.11	93.26
Modal	6	0.165	0	0	0	93.11	93.26
Modal	7	0.15	3.39	0	0	96.5	93.26
Modal	8	0.15	0	3.36	0	96.5	96.62
Modal	9	0.109	0	1.5	0	96.5	98.12

13) Modal mass participation factor for strut frame model with 20% right openings (SF20%RO).

Table.5.20: Modal mass participation factor for strut frame model with 20% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.788	81.94	0	0	81.94	0
Modal	2	0.782	0	82.19	0	81.94	82.19
Modal	3	0.494	0	0	0	81.94	82.19
Modal	4	0.26	11.17	0	0	93.1	82.19
Modal	5	0.259	0	11.07	0	93.1	93.26
Modal	6	0.166	0	0	0	93.1	93.26
Modal	7	0.151	3.39	0	0	96.49	93.26
Modal	8	0.151	0	3.36	0	96.49	96.62
Modal	9	0.11	0	1.49	0	96.49	98.11

14) Modal mass participation factor for strut frame model with 25% right openings (SF25%RO).

Table.5.21: Modal mass participation factor for strut frame model with 25% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.794	81.96	0	0	81.96	0
Modal	2	0.788	0	82.22	0	81.96	82.22
Modal	3	0.499	0	0	0	81.96	82.22
Modal	4	0.262	11.14	0	0	93.1	82.22
Modal	5	0.261	0	11.04	0	93.1	93.26
Modal	6	0.168	0	0	0	93.1	93.26
Modal	7	0.153	3.39	0	0	96.49	93.26
Modal	8	0.152	0	3.36	0	96.49	96.61
Modal	9	0.111	0	1.47	0	96.49	98.08

15) Modal mass participation factor for infilled frame model with 0% openings (IF0%).

Table.5.22: Modal mass participation factor for infilled frame model with 0% openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.502	81.34	0	0	81.34	0
Modal	2	0.498	0	81.42	0	81.34	81.42
Modal	3	0.391	0	0	0	81.34	81.42
Modal	4	0.234	12.15	0	0	93.49	81.42
Modal	5	0.128	0	12.1	0	93.49	93.52
Modal	6	0.079	0	0	0	93.49	93.52
Modal	7	0.073	3.45	0	0	96.94	93.52
Modal	8	0.073	0	3.44	0	96.94	96.96
Modal	9	0.053	0	1.54	0	96.94	98.5

16) Modal mass participation factor for infilled frame model with 10% central openings (IF10%CO).

Table.5.23: Modal mass participation factor for infilled frame model with 10% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.546	81.53	0	0	81.53	0
Modal	2	0.54	0	81.66	0	81.53	81.66
Modal	3	0.435	0	0	0	81.53	81.66
Modal	4	0.261	11.89	0	0	93.42	81.66
Modal	5	0.243	0	11.82	0	93.42	93.48
Modal	6	0.142	0	0	0	93.42	93.48
Modal	7	0.088	3.47	0	0	96.89	93.48
Modal	8	0.082	0	3.44	0	96.89	96.92
Modal	9	0.059	0	1.56	0	96.89	98.48

17) Modal mass participation factor for infilled frame model with 15% central openings (IF15%CO).

Table.5.24: Modal mass participation factor for infilled frame model with 15% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.579	81.51	0	0	81.51	0
Modal	2	0.577	0	81.66	0	81.51	81.66
Modal	3	0.469	0	0	0	81.51	81.66
Modal	4	0.284	0	11.63	0	81.51	93.29
Modal	5	0.279	11.69	0	0	93.2	93.29
Modal	6	0.195	0	0	0	93.2	93.29
Modal	7	0.089	0	3.48	0	93.2	96.77
Modal	8	0.088	3.51	0	0	96.71	96.77
Modal	9	0.064	0	1.61	0	96.71	98.38

18) Modal mass participation factor for infilled frame model with 20% central openings (IF20%CO).

Table.5.25: Modal mass participation factor for infilled frame model with 20% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.619	81.36	0	0	81.36	0
Modal	2	0.616	0	81.5	0	81.36	81.5
Modal	3	0.509	0	0	0	81.36	81.5
Modal	4	0.311	11.66	0	0	93.02	81.5
Modal	5	0.31	0	11.58	0	93.02	93.08
Modal	6	0.198	0	0	0	93.02	93.08
Modal	7	0.096	4.05	0	0	97.07	93.08
Modal	8	0.095	0	3.95	0	97.07	97.03
Modal	9	0.08	0	0	0	97.07	97.03

19) Modal mass participation factor for infilled frame model with 25% central openings (IF25%CO).

Table.5.26: Modal mass participation factor for infilled frame model with 25% central openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.667	81.18	0	0	81.18	0
Modal	2	0.664	0	81.32	0	81.18	81.32
Modal	3	0.559	0	0	0	81.18	81.32
Modal	4	0.345	11.33	0	0	92.5	81.32
Modal	5	0.342	0	11.28	0	92.5	92.6
Modal	6	0.226	0	0	0	92.5	92.6
Modal	7	0.104	3.66	0	0	96.17	92.6
Modal	8	0.103	0	3.64	0	96.17	96.24
Modal	9	0.074	0	1.79	0	96.17	98.03

20) Modal mass participation factor for infilled frame model with 10% left openings (IF10%LO).

Table.5.27: Modal mass participation factor for infilled frame model with 10% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.527	81.37	0	0	81.37	0
Modal	2	0.525	0	81.56	0	81.37	81.56
Modal	3	0.414	0	0	0	81.37	81.56
Modal	4	0.245	12.12	0	0	93.49	81.56
Modal	5	0.243	0	11.98	0	93.49	93.54
Modal	6	0.134	0	0	0	93.49	93.54
Modal	7	0.078	3.46	0	0	96.95	93.54
Modal	8	0.077	0	3.43	0	96.95	96.97
Modal	9	0.056	0	1.54	0	96.95	98.51

21) Modal mass participation factor for infilled frame model with 15% left openings (IF15%LO).

Table.5.28: Modal mass participation factor for infilled frame model with 15% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.549	81.23	0	0	81.23	0
Modal	2	0.545	0	81.42	0	81.23	81.42
Modal	3	0.432	0	0	0	81.23	81.42
Modal	4	0.26	11.99	0	0	93.22	81.42
Modal	5	0.258	0	11.85	0	93.22	93.27
Modal	6	0.141	0	0	0	93.22	93.27
Modal	7	0.082	3.51	0	0	96.73	93.27
Modal	8	0.081	0	3.48	0	96.73	96.75
Modal	9	0.059	0	1.59	0	96.73	98.34

22) Modal mass participation factor for infilled frame model with 20% left openings (IF20%LO).

Table.5.29: Modal mass participation factor for infilled frame model with 20% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.58	80.94	0	0	80.94	0
Modal	2	0.571	0	81.13	0	80.94	81.13
Modal	3	0.459	0	0	0	80.94	81.13
Modal	4	0.279	11.86	0	0	92.8	81.13
Modal	5	0.277	0	11.71	0	92.8	92.84
Modal	6	0.163	0	0	0	92.8	92.84
Modal	7	0.087	3.57	0	0	96.37	92.84
Modal	8	0.086	0	3.55	0	96.37	96.39
Modal	9	0.063	0	1.65	0	96.37	98.04

23) Modal mass participation factor for infilled frame model with 25% left openings (IF25%LO).

Table.5.30: Modal mass participation factor for infilled frame model with 25% left openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.598	80.54	0	0	80.54	0
Modal	2	0.591	0	80.74	0	80.54	80.74
Modal	3	0.492	0	0	0	80.54	80.74
Modal	4	0.302	11.71	0	0	92.25	80.74
Modal	5	0.298	0	11.56	0	92.25	92.3
Modal	6	0.189	0	0	0	92.25	92.3
Modal	7	0.093	3.64	0	0	95.89	92.3
Modal	8	0.092	0	3.63	0	95.89	95.93
Modal	9	0.073	0	1.73	0	95.89	97.66

24) Modal mass participation factor for infilled frame model with 10% right openings (IF10%RO).

Table.5.31: Modal mass participation factor for infilled frame model with 10% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.524	86.12	0	0	86.12	0
Modal	2	0.519	0	86.38	0	86.12	86.38
Modal	3	0.41	0	0	0	86.12	86.38
Modal	4	0.239	10.64	0	0	96.76	86.38
Modal	5	0.238	0	10.46	0	96.76	96.84
Modal	6	0.127	0	0	0	96.76	96.84
Modal	7	0.076	1.92	0	0	98.68	96.84
Modal	8	0.075	0	1.88	0	98.68	98.72
Modal	9	0.052	0	0.55	0	98.68	99.27

25) Modal mass participation factor for infilled frame model with 15% right openings (IF15%RO).

Table.5.32: Modal mass participation factor for infilled frame model with 15% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.541	81.88	0	0	81.88	0
Modal	2	0.54	0	82.06	0	81.88	82.06
Modal	3	0.426	0	0	0	81.88	82.06
Modal	4	0.241	6.14	0	0	88.02	82.06
Modal	5	0.24	0	6.14	0	88.02	88.2
Modal	6	0.138	0	0	0	88.02	88.2
Modal	7	0.081	2.28	0	0	90.3	88.2
Modal	8	0.08	0	2.18	0	90.3	90.38
Modal	9	0.057	0	0.76	0	90.3	91.14

26) Modal mass participation factor for infilled frame model with 20% right openings (IF20%RO).

Table.5.33: Modal mass participation factor for infilled frame model with 20% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.568	85.44	0	0	85.44	0
Modal	2	0.562	0	85.7	0	85.44	85.7
Modal	3	0.438	0	0	0	85.44	85.7
Modal	4	0.266	8.27	0	0	93.71	85.7
Modal	5	0.265	0	8.62	0	93.71	94.32
Modal	6	0.159	0	0	0	93.71	94.32
Modal	7	0.084	2.29	0	0	96	94.32
Modal	8	0.082	0	2.32	0	96	96.64
Modal	9	0.061	0	0	0	96	96.64

27) Modal mass participation factor for infilled frame model with 25% right openings (IF25%RO).

Table.5.34: Modal mass participation factor for infilled frame model with 25% right openings

Case	Mode	Period (sec)	UX	UY	UZ	Sum UX	Sum UY
Modal	1	0.587	84.82	0	0	84.82	0
Modal	2	0.585	0	85.05	0	84.82	85.05
Modal	3	0.464	0	0	0	84.82	85.05
Modal	4	0.291	9.85	0	0	94.67	85.05
Modal	5	0.289	0	9.68	0	94.67	94.73
Modal	6	0.173	0	0	0	94.67	94.73
Modal	7	0.091	2.42	0	0	97.09	94.73
Modal	8	0.09	0	2.414	0	97.09	97.144
Modal	9	0.072	0	0	0	97.09	97.144

5.4 Comparison on Base Shear

The presence of masonry infilled walls, stiffens the structures. Thus it attracts more forces and there is increase in base shear. This base shear reduces with the presence of openings. The effect of base shear with varying opening area percentages and their locations is discussed below.

1) Comparison of base shear between bare frame, strut frame and infilled frame.

Table.5.35: Base Shear for bare frame, strut frame and infilled frame

S.no.	Model ID	Base Shear (kN)	
		EQX Direction	EQY Direction
1	BF	3370.070	3370.070
2	SF0%	5969.800	5969.800
3	IF0%	6556.840	6556.840

2) Comparison of base shear between bare frame and strut frame with varying percentage of central opening areas.

Table5.36: Base Shear for various central opening areas

S.no.	Model ID	Base Shear (kN)	
		EQX Direction	EQY Direction
1	BF	3370.070	3370.070
2	SF0%	5969.800	5969.800
3	SF10%CO	5776.100	5776.100
4	SF15%CO	5716.184	5716.184
5	SF20%CO	5673.259	5673.259
6	SF25%CO	5641.336	5641.336

Fig.5.7: Base Shear for various central opening areas for EQX and EQY direction

3) Comparison of base shear between bare frame and strut frame and with varying percentage of opening areas down the diagonal left.

Table.5.37: Base Shear for various opening areas down the diagonal left

S.no.	Model ID	Base Shear (kN)	
		EQX Direction	EQY Direction
1	BF	3370.070	3370.070
2	SF0%	5969.800	5969.800
3	SF10%LO	5891.007	5891.007
4	SF15%LO	5854.072	5854.072
5	SF20%LO	5822.063	5822.063
6	SF25%LO	5792.515	5792.515

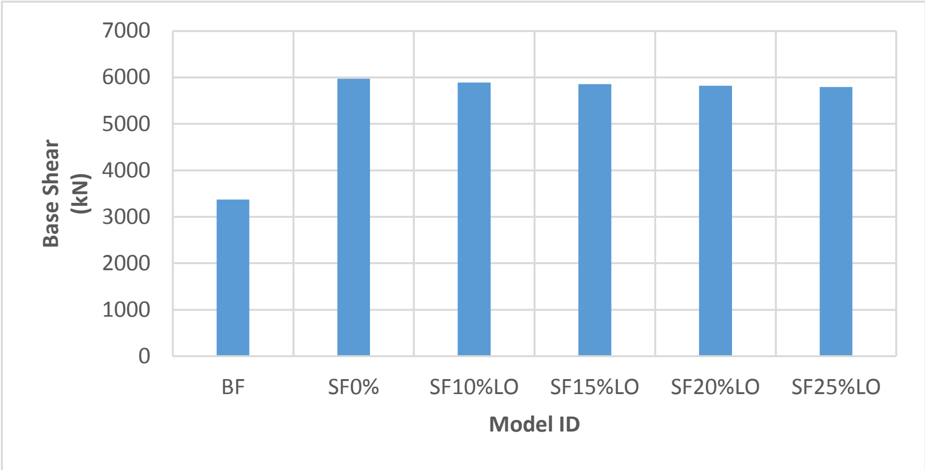

Fig.5.8: Base Shear for various Opening areas down the diagonal Left in EQX and EQY direction

4) Comparison of base shear between bare frame and strut frame and with varying percentage of opening areas up the diagonal right.

Table.5.38: Base Shear for various opening areas up the diagonal right

S.no.	Model ID	Base Shear (kN)	
		EQX Direction	EQY Direction
1	BF	3370.070	3370.070
2	SF0%	5969.800	5969.800
3	SF10%RO	5963.234	5963.234
4	SF15%RO	5955.847	5955.847
5	SF20%RO	5945.177	5945.177
6	SF25%RO	5935.328	5935.328

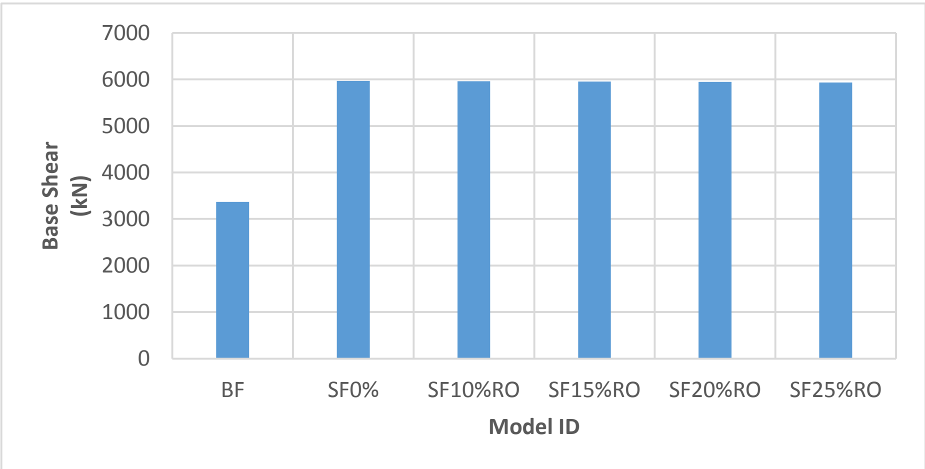

Fig.5.9: Base Shear for various Opening areas up the diagonal Right in EQX and EQY direction

5) Comparison of base shear between bare frame and infilled frame with varying percentage of central opening areas.

Table.5.39: Base Shear for various central opening areas

S.no.	Model ID	Base Shear (kN)	
		EQX Direction	EQY Direction
1	BF	3370.070	3370.070
2	IF0%	6556.840	6556.840
3	IF10%CO	6450.540	6450.540
4	IF15%CO	6397.490	6397.490
5	IF20%CO	6346.780	6346.780
6	IF25%CO	6294.410	6294.410

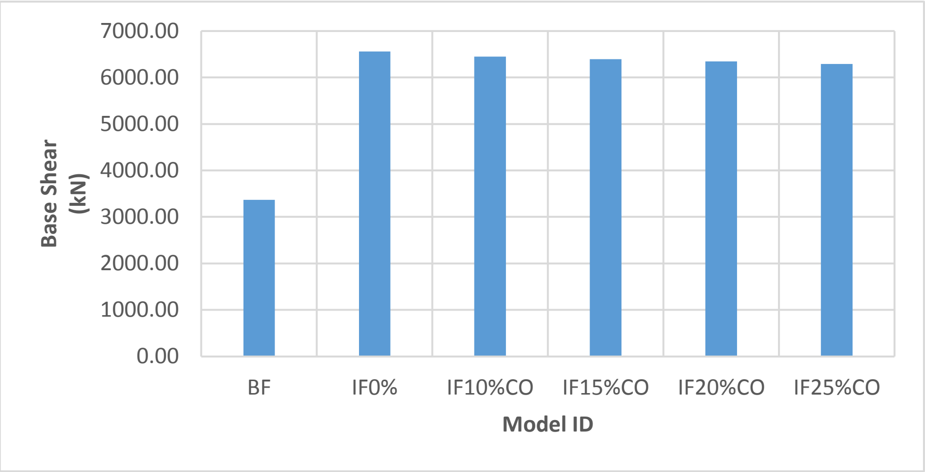

Fig.5.10: Base Shear for various Central Opening areas in EQX and EQY direction

6) Comparison of base shear between bare frame and infilled frame with varying percentage of opening areas down the left corner.

Table.5.40: Base Shear for various opening areas down the left corner

S.no.	Model ID	Base Shear (kN)	
		EQX Direction	EQY Direction
1	BF	3370.070	3370.070
2	IF0%	6556.840	6556.840
3	IF10%LO	6455.880	6455.880
4	IF15%LO	6403.440	6403.440
5	IF20%LO	6352.120	6352.120
6	IF25%LO	6300.080	6300.080

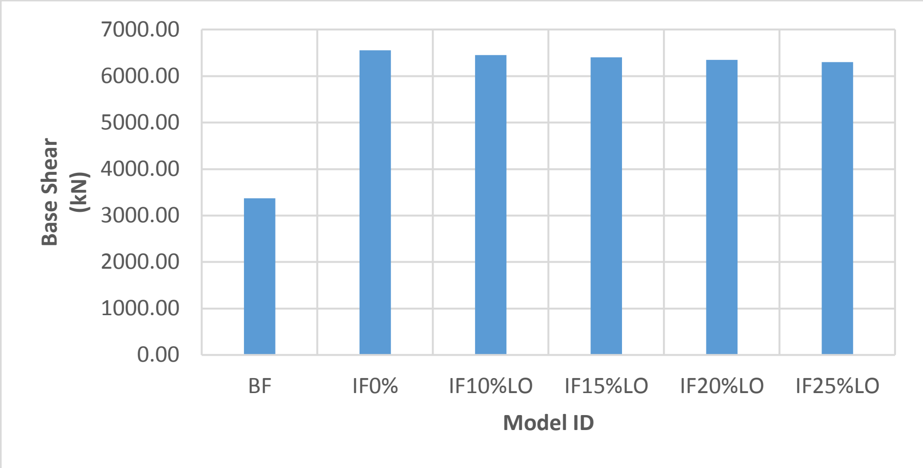

Fig.5.11: Base Shear for various Opening areas down the Left Corner in EQX and EQY direction

7) Comparison of base shear between bare frame and infilled frame with varying percentage of opening areas up the right corner.

Table.5.41: Base Shear for various opening areas up the right corner

S.no.	Model ID	Base Shear (kN)	
		EQX Direction	EQY Direction
1	BF	3370.070	3370.070
2	IF0%	6556.840	6556.840
3	IF10%RO	6550.280	6550.280
4	IF15%RO	6540.890	6540.890
5	IF20%RO	6531.220	6531.220
6	IF25%RO	6519.370	6519.370

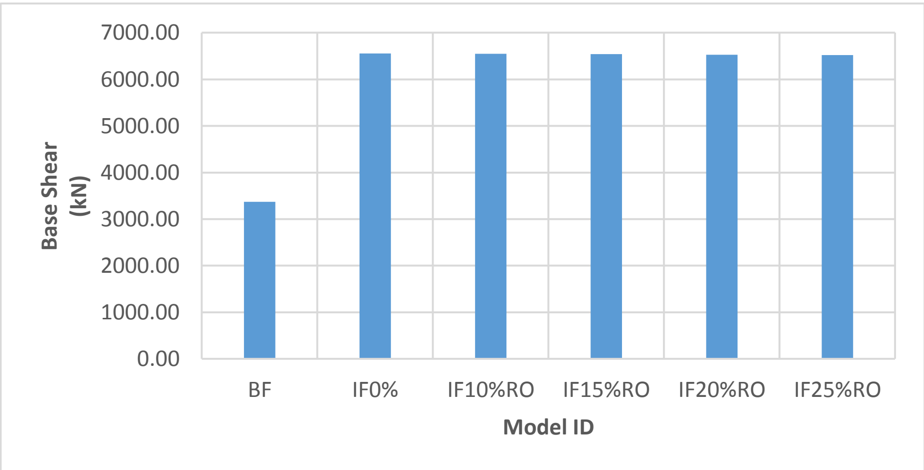

Fig.5.12: Base Shear for various Opening areas up the Right Corner in EQX and EQY direction

5.5 Comparison on Storey Drift in EQX and EQY Direction

Taking into the account the effects of masonry infilled walls in the frame, the story drift in x and y direction are reduced, when modelled as both, i.e. as equivalent diagonal pin-jointed strut and as quad element, but the reduction is seen more in the second case. The storey drift starts again increasing as soon as the opening areas begins to occur, and with increment in area of openings, this pattern continues to follow, but still storey drift as compared to bare frame are less, even at 25% central openings in masonry infilled walls. All these are discussed in tables and graphs below.

1) Comparison of storey drift between bare frame, strut frame and infilled frame.

Table.5.42: Storey drift for bare frame, strut frame and infilled frame

Storey no. / Model ID	**Storey Drift-EQX (mm)**			**Storey Drift-EQY (mm)**		
	BF	SF0%	IF0%	BF	SF0%	IF0%
8	1.604	0.637	0.416	1.342	0.588	0.414
7	2.772	1.026	0.863	2.444	0.985	0.860
6	3.777	1.384	1.162	3.430	1.301	1.200
5	4.585	1.576	1.413	4.176	1.526	1.413
4	5.149	1.724	1.561	4.696	1.673	1.565
3	5.491	1.801	1.638	5.020	1.752	1.640
2	5.595	1.818	1.655	5.151	1.773	1.666
1	5.227	1.809	1.638	4.915	1.767	1.638
Ground	3.040	1.406	1.235	3.041	1.426	1.236

2) Comparison of storey drift between bare frame and strut frame with varying percentage of central opening areas.

Table.5.43: Storey drift for various central opening areas in EQX direction

Storey no./Model ID	Storey Drift-EQY (mm)					
	BF	SF0%	SF10%CO	SF15%CO	SF20%CO	SF25%CO
8	1.604	0.637	0.851	0.968	1.083	1.196
7	2.772	1.026	1.417	1.631	1.837	2.039
6	3.777	1.384	1.902	2.205	2.449	2.786
5	4.585	1.576	2.250	2.620	2.980	3.332
4	5.149	1.724	2.479	2.896	3.302	3.700
3	5.491	1.801	2.608	3.055	3.491	3.918
2	5.595	1.818	2.655	3.118	3.570	4.012
1	5.227	1.809	2.645	3.100	3.537	3.960
Ground	3.040	1.406	1.994	2.217	2.470	2.707

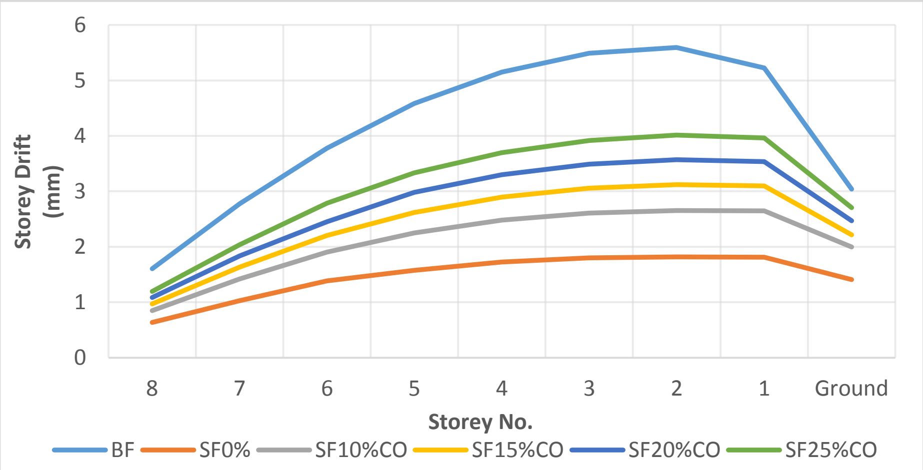

Fig.5.13: Storey Drift for various Central Openings in EQX direction

Table.5.44: Storey drift for various central opening areas in EQY direction

Storey no./Model ID	Storey Drift-EQY (mm)					
	BF	SF0%	SF10%CO	SF15%CO	SF20%CO	SF25%CO
8	1.342	0.588	0.768	0.865	0.960	1.052
7	2.444	0.985	1.346	1.540	1.727	1.908
6	3.430	1.301	1.819	2.099	2.369	2.561
5	4.176	1.526	2.159	2.503	2.835	3.158
4	4.696	1.673	2.386	2.774	3.150	3.516
3	5.020	1.752	2.516	2.934	3.339	3.773
2	5.151	1.773	2.567	3.010	3.424	3.834
1	4.915	1.767	2.543	3.003	3.418	3.818
Ground	3.041	1.426	1.975	2.254	2.511	2.750

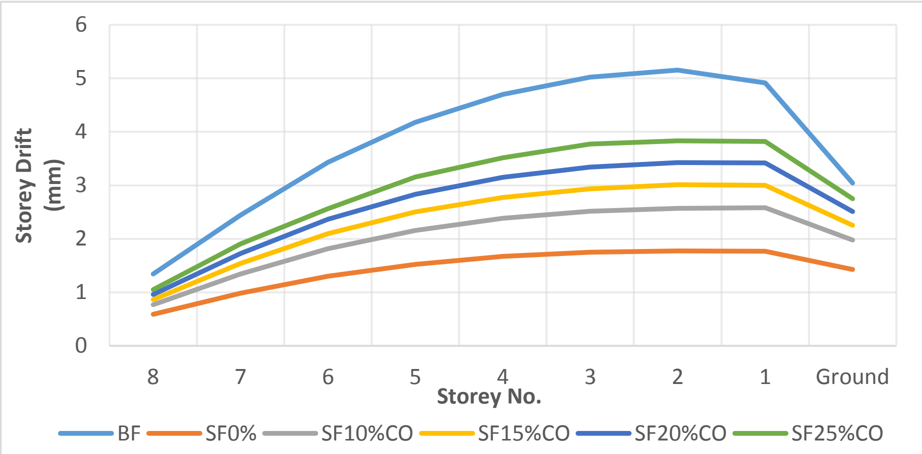

Fig.5.14: Storey drift for various Central Opening areas in EQY direction

3) Comparison of storey drift between bare frame and strut frame with varying percentage of opening areas down the diagonal left.

Table.5.45: Storey drift for various opening areas down the diagonal left in EQX direction

Storey no./Model ID	**Storey Drift-EQX (mm)**					
	BF	SF0%	SF10%LO	SF15%LO	SF20%LO	SF25%LO
8	1.604	0.637	0.705	0.744	0.783	0.825
7	2.772	1.026	1.149	1.221	1.293	1.370
6	3.777	1.384	1.523	1.624	1.726	1.835
5	4.585	1.576	1.788	1.911	2.036	2.168
4	5.149	1.724	1.961	2.099	2.238	2.387
3	5.491	1.801	2.054	2.202	2.351	2.510
2	5.595	1.818	2.080	2.233	2.388	2.552
1	5.227	1.809	2.072	2.226	2.280	2.544
Ground	3.040	1.406	1.581	1.681	1.779	1.882

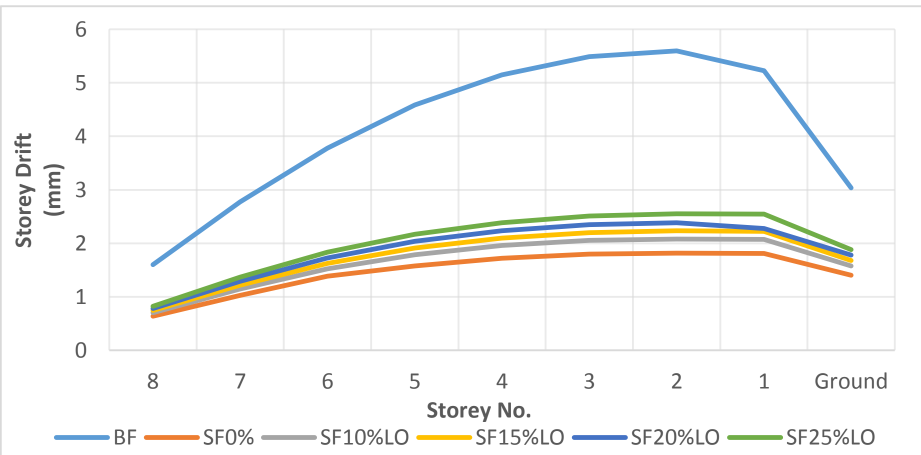

Fig.5.15: Storey drift for various Opening areas down the diagonal Left in EQX direction

Table.5.46: Storey drift for various opening areas down the diagonal left in EQY direction

Storey no./Model ID	Storey Drift-EQY (mm)					
	BF	SF0%	SF10%LO	SF15%LO	SF20%LO	SF25%LO
8	1.342	0.588	0.645	0.678	0.771	0.815
7	2.444	0.985	1.099	1.166	1.232	1.303
6	3.430	1.301	1.465	1.560	1.655	1.756
5	4.176	1.526	1.726	1.842	1.959	2.082
4	4.696	1.673	1.897	2.028	2.160	2.329
3	5.020	1.752	1.992	2.132	2.273	2.423
2	5.151	1.773	2.022	2.168	2.315	2.470
1	4.915	1.767	2.020	2.068	2.215	2.372
Ground	3.041	1.426	1.605	1.707	1.807	1.912

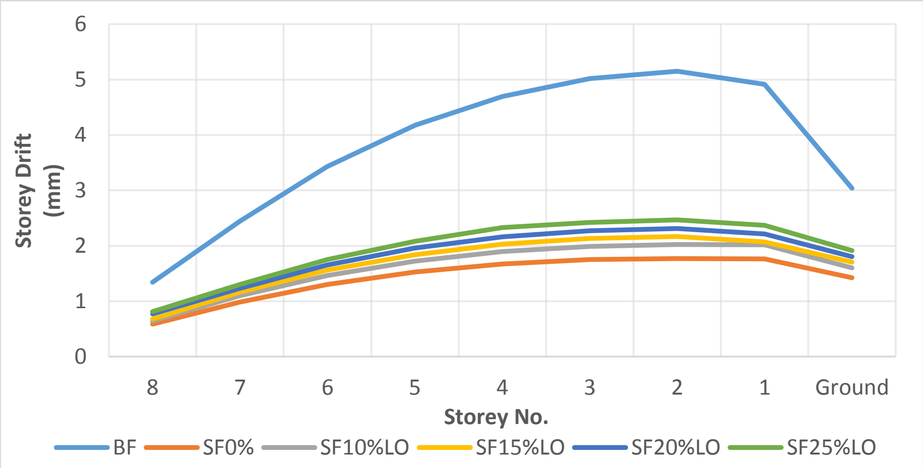

Fig.5.16: Storey drift for various Opening areas down the diagonal Left in EQY direction

4) Comparison of storey drift between bare frame and strut frame with varying percentage of opening areas up the diagonal right.

Table.5.47: Storey drift for various opening areas up the diagonal right in EQX direction

Storey no./Model ID	Storey Drift-EQX (mm)					
	BF	SF0%	SF10%RO	SF15%RO	SF20%RO	SF25%RO
8	1.604	0.637	0.642	0.648	0.656	0.664
7	2.772	1.026	1.035	1.045	1.061	1.075
6	3.777	1.361	1.376	1.384	1.397	1.418
5	4.585	1.576	1.592	1.610	1.636	1.661
4	5.149	1.724	1.741	1.761	1.791	1.819
3	5.491	1.801	1.820	1.841	1.872	1.903
2	5.595	1.818	1.837	1.859	1.892	1.923
1	5.227	1.809	1.828	1.850	1.883	1.915
Ground	3.040	1.406	1.419	1.434	1.456	1.478

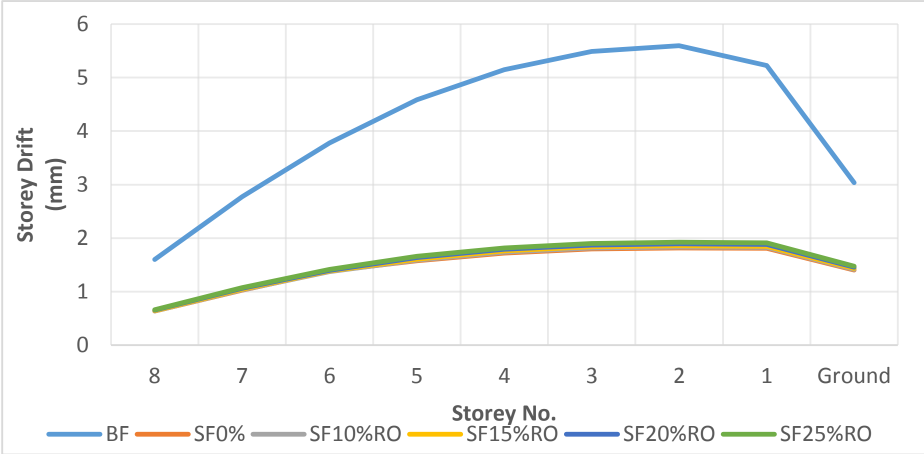

Fig.517: Storey drift for various Opening areas up the diagonal Right in EQX direction

Table.5.48: Storey drift for various opening areas up the diagonal right in EQY direction

Storey no./Model ID	Storey Drift-EQY (mm)					
	BF	SF0%	SF10%RO	SF15%RO	SF20%RO	SF25%RO
8	1.342	0.588	0.592	0.597	0.604	0.611
7	2.444	0.985	0.993	1.003	1.017	1.031
6	3.430	1.301	1.313	1.327	1.374	1.376
5	4.176	1.526	1.541	1.558	1.583	1.607
4	4.696	1.673	1.689	1.708	1.736	1.763
3	5.020	1.752	1.769	1.789	1.820	1.848
2	5.151	1.773	1.791	1.812	1.843	1.873
1	4.915	1.767	1.785	1.806	1.838	1.869
Ground	3.041	1.426	1.439	1.454	1.477	1.499

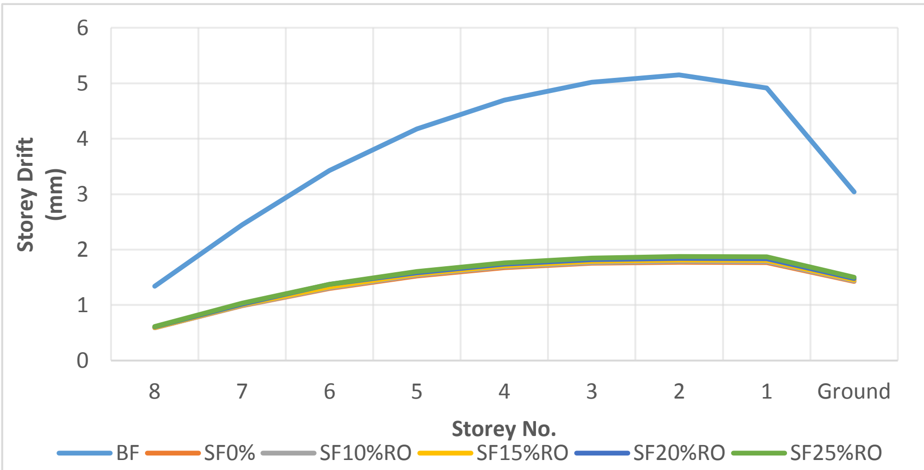

Fig.5.18: Storey drift for various Opening areas up the diagonal Right in EQY direction

5) Comparison of storey drift between bare frame and infilled frame with varying percentage of central opening areas.

Table.5.49: Storey drift for various central opening areas in EQX direction

Storey no./Model ID	Storey Drift-EQX (mm)					
	BF	IF0%	IF10%CO	IF15%CO	IF20%CO	IF25%CO
8	1.604	0.416	0.539	0.687	0.795	0.986
7	2.772	0.863	1.020	1.224	1.433	1.641
6	3.777	1.162	1.538	1.727	1.902	2.167
5	4.585	1.413	1.923	2.201	2.310	2.523
4	5.149	1.561	2.225	2.486	2.705	2.843
3	5.491	1.638	2.408	2.649	2.990	3.127
2	5.595	1.655	2.465	2.698	3.108	3.210
1	5.227	1.638	2.428	2.636	3.101	3.204
Ground	3.040	1.235	1.576	1.704	1.98	2.078

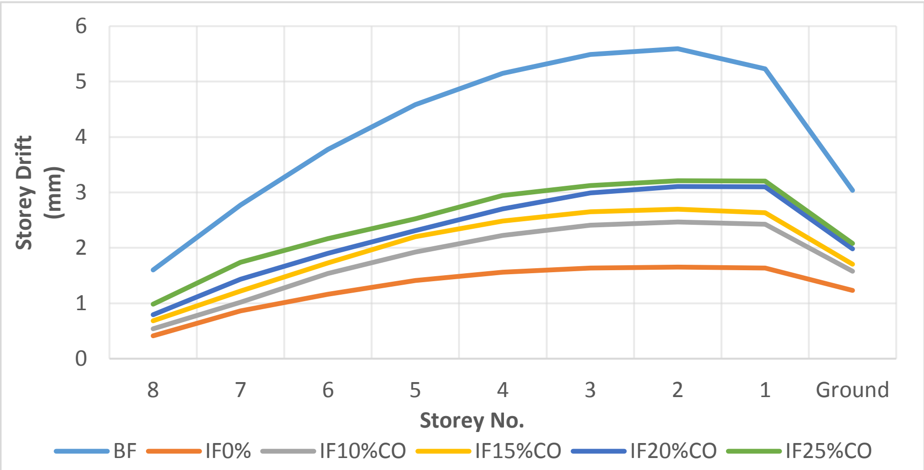

Fig.5.19: Storey drift for various Central Opening areas in EQX direction

Table.5.50: Storey drift for various central opening areas in EQY direction

Storey no./Model ID	Storey Drift-EQY (mm)					
	BF	IF0%	IF10%CO	IF15%CO	IF20%CO	IF25%CO
8	1.342	0.414	0.536	0.684	0.791	0.984
7	2.444	0.86	1.010	1.223	1.430	1.643
6	3.430	1.200	1.536	1.776	1.902	2.167
5	4.176	1.413	1.923	2.201	2.314	2.523
4	4.696	1.565	2.226	2.487	2.653	2.847
3	5.020	1.640	2.409	2.649	2.991	3.156
2	5.151	1.666	2.466	2.698	3.109	3.210
1	4.915	1.638	2.407	2.654	2.889	3.109
Ground	3.041	1.236	1.577	1.707	1.990	2.080

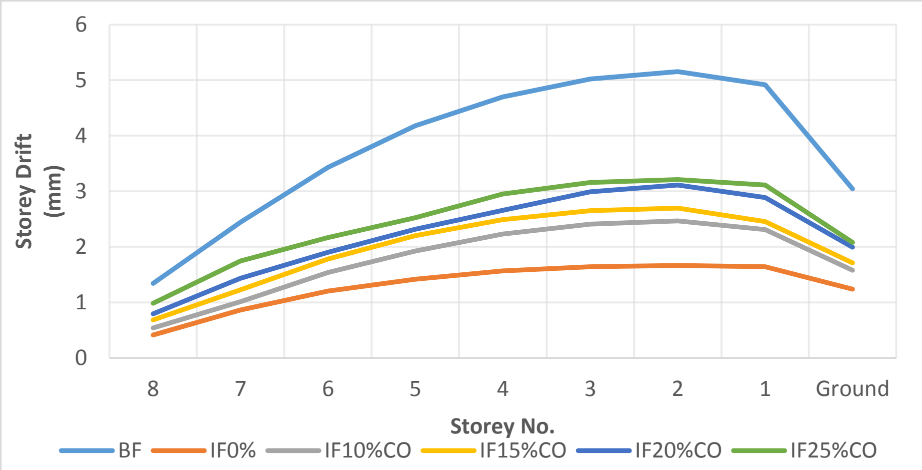

Fig.5.20: Storey drift for various Central Opening areas in EQY direction

6) Comparison of storey drift between bare frame and infilled frame with varying percentage of opening areas down the left corner.

Table.5.51: Storey drift for various opening areas down the left corner in EQX direction

Storey no./Model ID	**Storey Drift-EQX (mm)**					
	BF	IF0%	IF10%LO	IF15%LO	IF20%LO	IF25%LO
8	1.604	0.416	0.490	0.525	0.566	0.609
7	2.772	0.863	0.990	1.065	1.108	1.164
6	3.777	1.162	1.291	1.478	1.495	1.604
5	4.585	1.413	1.635	1.758	1.883	2.010
4	5.149	1.561	1.798	1.940	2.080	2.228
3	5.491	1.638	1.888	2.037	2.184	2.343
2	5.595	1.655	1.925	2.076	2.232	2.393
1	5.227	1.638	1.901	2.059	2.114	2.372
Ground	3.040	1.235	1.410	1.523	1.621	1.725

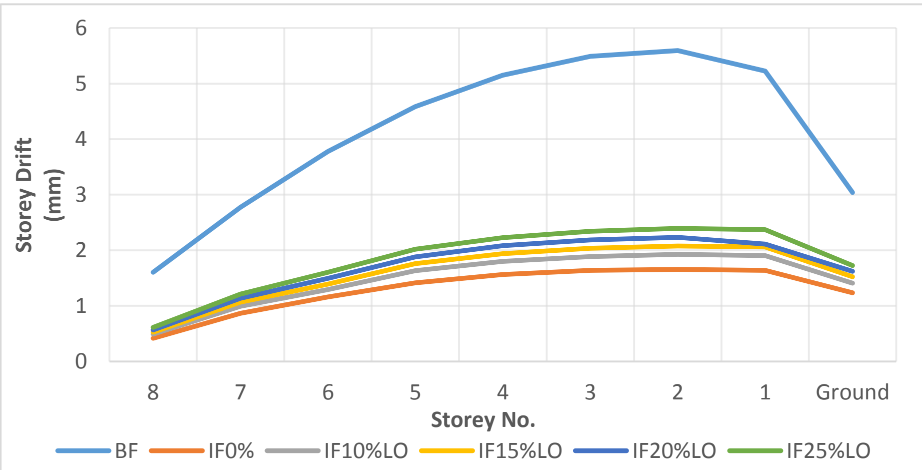

Fig.5.21: Storey drift for various Opening areas down the Left corner in EQX direction

Table.5.52: Storey drift for various opening areas down the left corner in EQY direction

Storey no./Model ID	Storey Drift-EQY (mm)					
	BF	IF0%	IF10%LO	IF15%LO	IF20%LO	IF25%LO
8	1.342	0.414	0.492	0.523	0.568	0.611
7	2.444	0.86	0.958	1.066	1.104	1.106
6	3.430	1.200	1.288	1.465	1.500	1.601
5	4.176	1.413	1.639	1.752	1.885	1.982
4	4.696	1.565	1.798	1.970	2.100	2.230
3	5.020	1.640	1.884	2.039	2.189	2.341
2	5.151	1.666	1.919	2.076	2.235	2.395
1	4.915	1.638	1.903	2.058	2.117	2.368
Ground	3.041	1.236	1.414	1.52	1.625	1.728

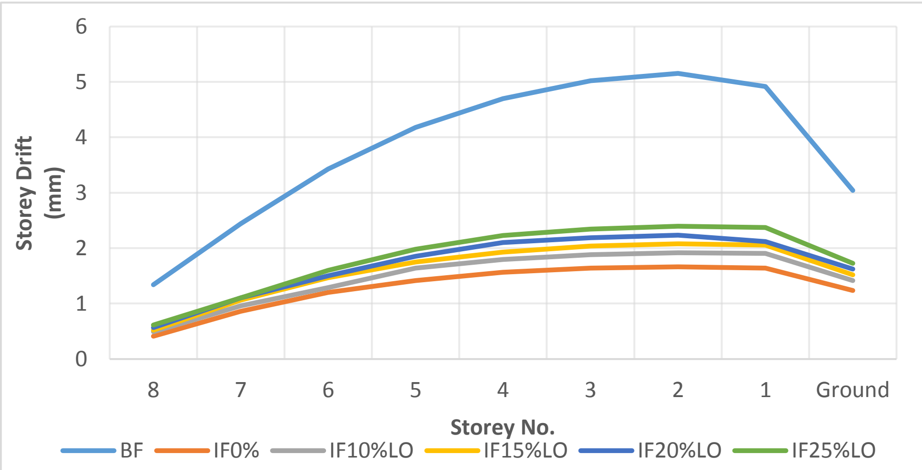

Fig.5.22: Storey drift for various Opening areas down the Left corner in EQY direction

7) Comparison of storey drift between bare frame and infilled frame with varying percentage of opening areas up the right corner.

Table.5.53: Storey drift for various opening areas up the right corner inEQX direction

Storey no./Model ID	Storey Drift-EQX (mm)					
	BF	IF0%	IF10%RO	IF15%RO	IF20%RO	IF25%RO
8	1.604	0.416	0.421	0.427	0.435	0.443
7	2.772	0.863	0.872	0.882	0.898	0.912
6	3.777	1.162	1.177	1.185	1.198	1.219
5	4.585	1.413	1.429	1.447	1.473	1.498
4	5.149	1.561	1.578	1.598	1.628	1.656
3	5.491	1.638	1.657	1.678	1.709	1.740
2	5.595	1.655	1.674	1.696	1.729	1.760
1	5.227	1.638	1.657	1.679	1.712	1.744
Ground	3.040	1.235	1.248	1.263	1.285	1.307

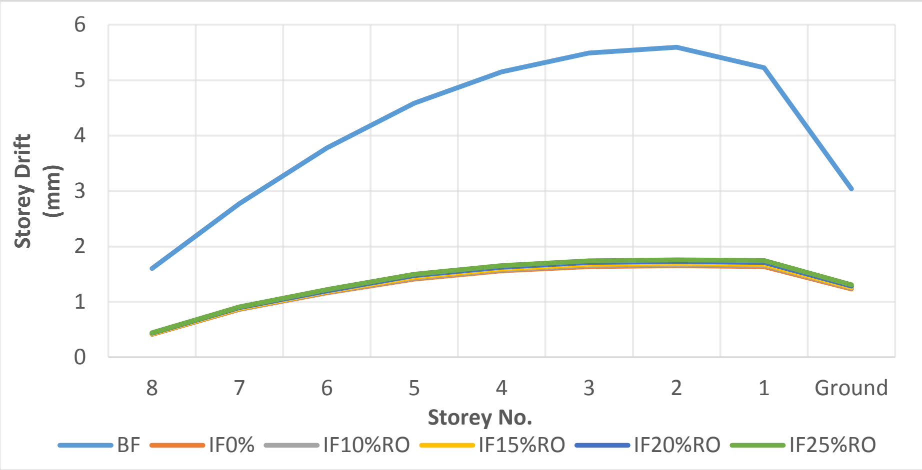

Fig.5.23: Storey drift for various Opening areas up the Right corner in EQX direction

Table.5.54: Storey drift for various opening areas up the right corner inEQY direction

Storey no./Model ID	**Storey Drift-EQY (mm)**					
	BF	IF0%	IF10%RO	IF15%RO	IF20%RO	IF25%RO
8	1.342	0.414	0.420	0.425	0.437	0.445
7	2.444	0.860	0.873	0.885	0.897	0.915
6	3.430	1.200	1.175	1.183	1.198	1.218
5	4.176	1.413	1.430	1.449	1.475	1.495
4	4.696	1.565	1.579	1.598	1.630	1.659
3	5.020	1.640	1.657	1.679	1.711	1.742
2	5.151	1.666	1.674	1.695	1.729	1.765
1	4.915	1.638	1.655	1.678	1.715	1.744
Ground	3.041	1.236	1.249	1.265	1.289	1.309

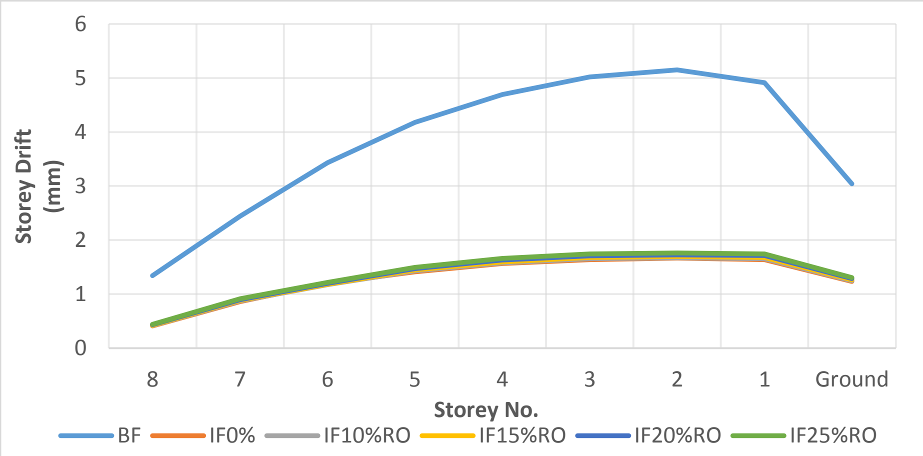

Fig.5.24: Storey drift for various Opening areas up the Right corner in EQY direction

5.5.1 Comparison on Trend Line For Various Opening Conditions For Storey Drift

a) For Earthquake in x-direction, i.e. EQX direction

1) Storey drift for strut frame model (SF0%) and infilled frame model (IF0%) with 0% openings.

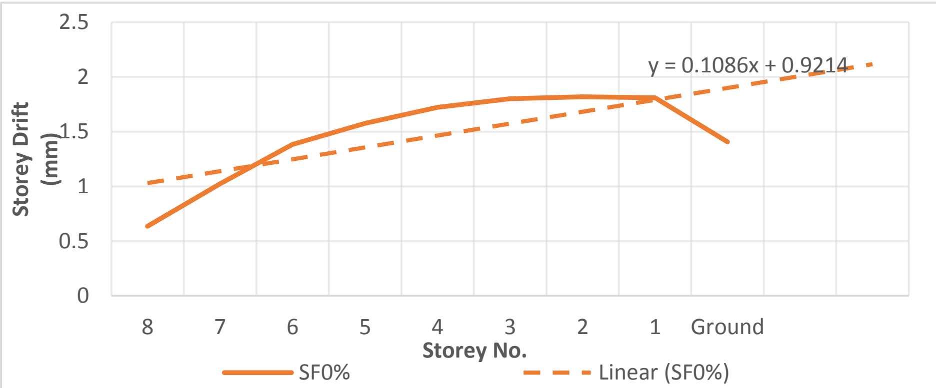

Fig.5.25: Trend line for Storey Drift for Strut Frame model with 0% openings

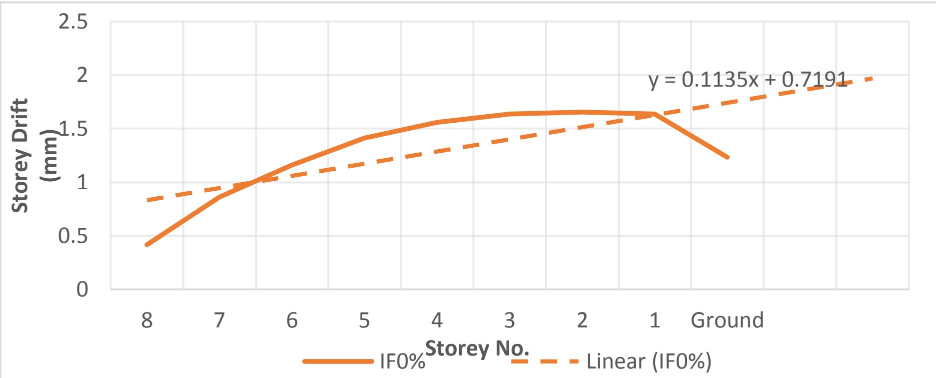

Fig.5.26: Trend line for Storey Drift for Infilled Frame model with 0% openings

2) Storey drift for strut frame model (SF10%CO) and infilled frame model (IF10%CO) with 10% central openings.

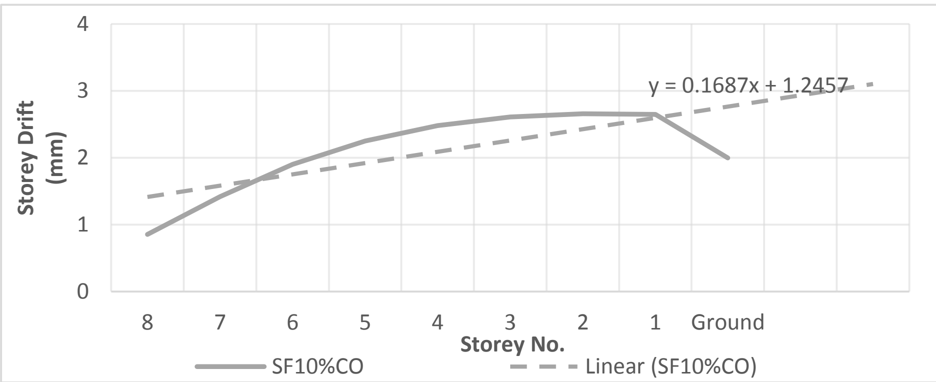

Fig.5.27: Trend line for Storey Drift for Strut Frame model with 10% central openings

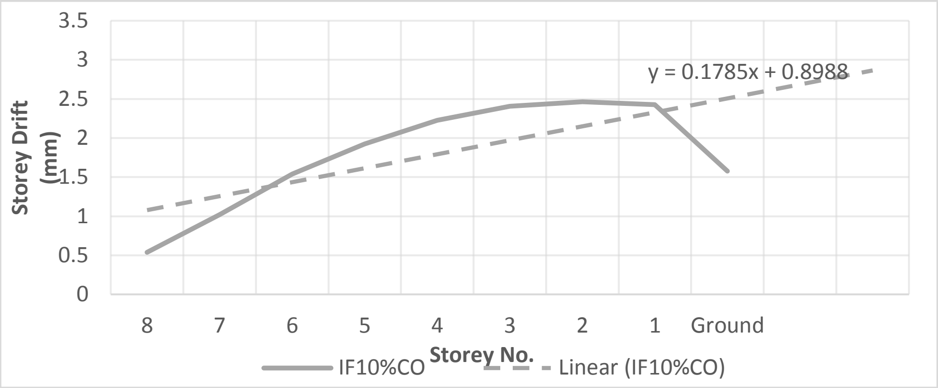

Fig.5.28: Trend line for Storey Drift for Infilled Frame model with 10% central openings

3) Storey drift for strut frame model (SF15%CO) and infilled frame model (IF15%CO) with 15% central openings.

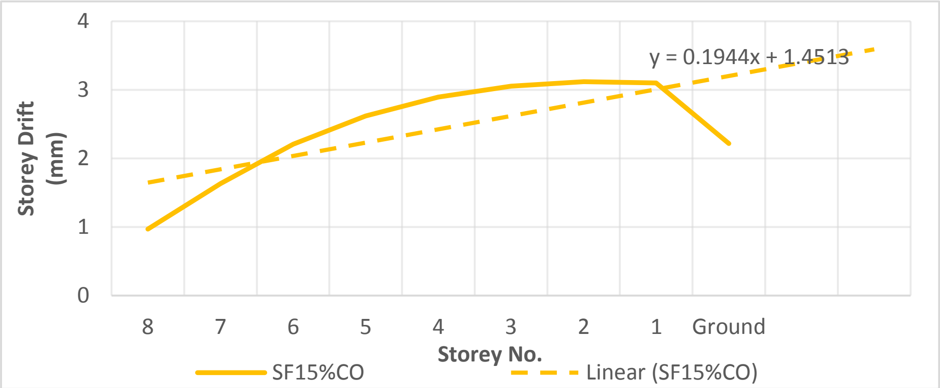

Fig.5.29: Trend line for Storey Drift for Strut Frame model with 15% central openings

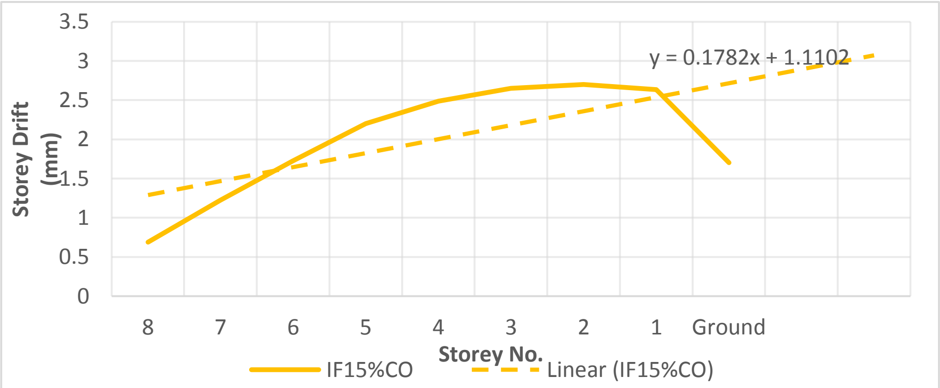

Fig.5.30: Trend line for Storey Drift for Infilled Frame model with 15% central openings

4) Storey drift for strut frame model (SF20%CO) and infilled frame model (IF20%CO) with 20% central openings.

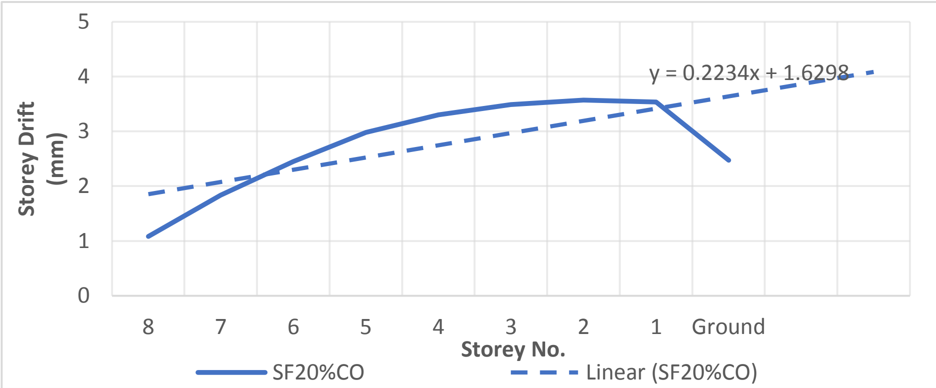

Fig.5.31: Trend line for Storey Drift for Strut Frame model with 20% central openings

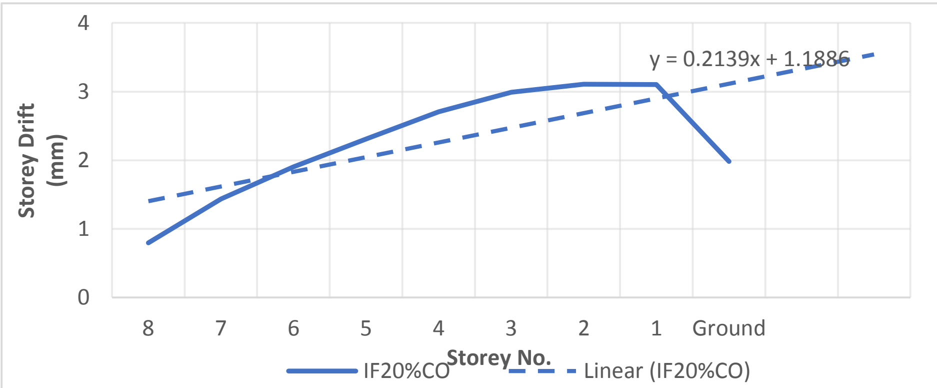

Fig.5.32: Trend line for Storey Drift for Infilled Frame model with 20% central openings

5) Storey drift for strut frame model (SF25%CO) and infilled frame model (IF25%CO) with 25% central openings.

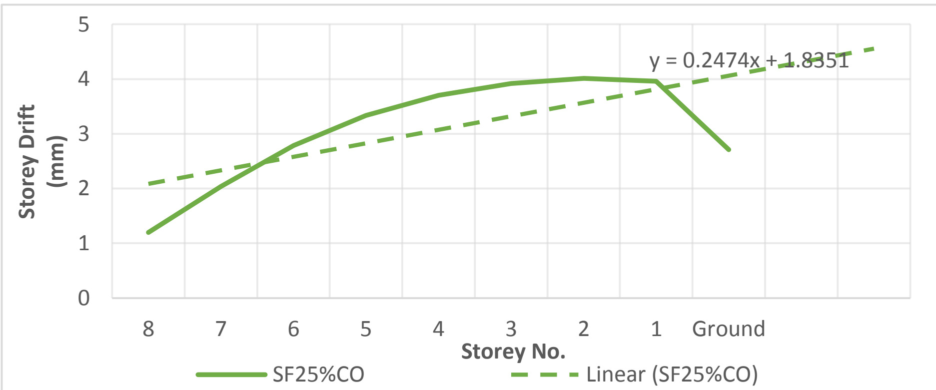

Fig.5.33: Trend line for Storey Drift for Strut Frame model with 25% central openings

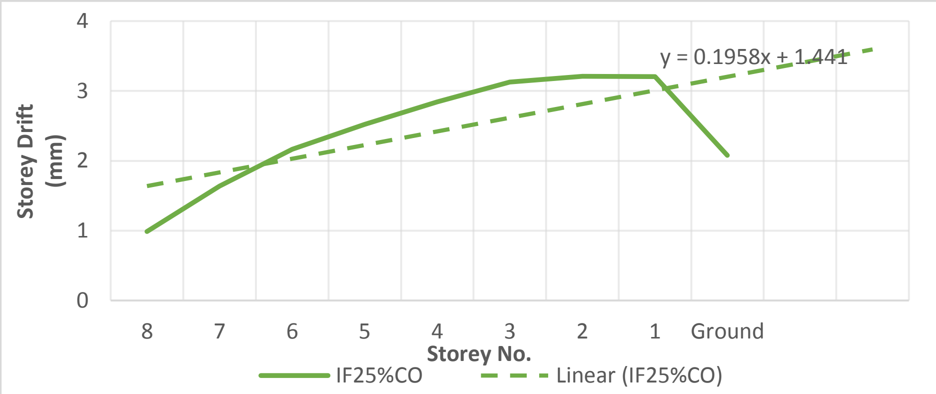

Fig.5.34: Trend line for Storey Drift for Infilled Frame model with 25% central openings

6) Storey drift for strut frame model (SF10%LO) and infilled frame model (IF10%LO) with 10% left openings.

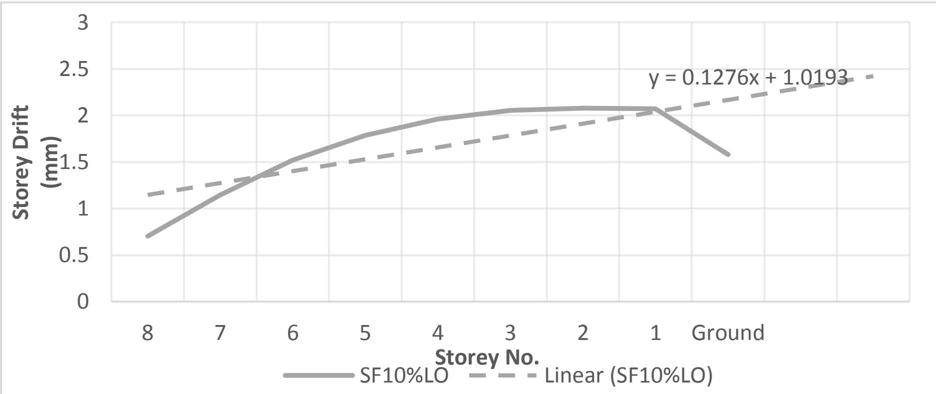

Fig.5.35: Trend line for Storey Drift for Strut Frame model with 10% left openings

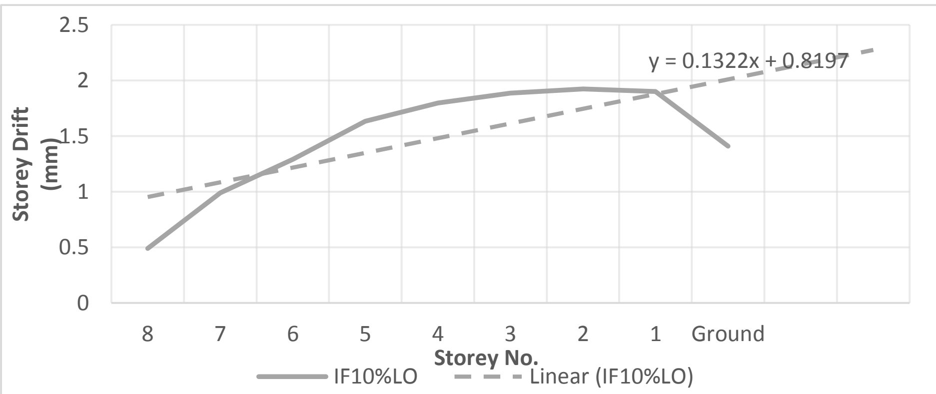

Fig.5.36: Trend line for Storey Drift for Infilled Frame model with 10% left openings

7) Storey drift for strut frame model (SF15%LO) and infilled frame model (IF15%LO) with 15% left openings.

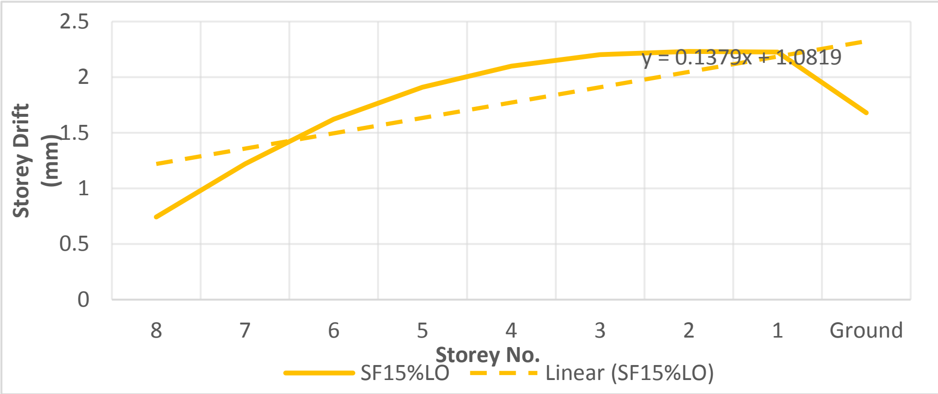

Fig.5.37: Trend line for Storey Drift for Strut Frame model with 15% left openings

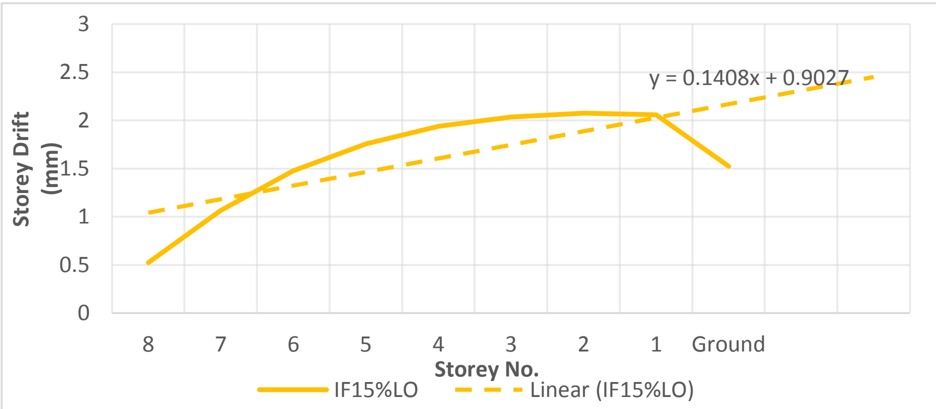

Fig.5.38: Trend line for Storey Drift for Infilled Frame model with 15% left openings

8) Storey drift for strut frame model (SF20%LO) and infilled frame model (IF20%LO) with 20% left openings.

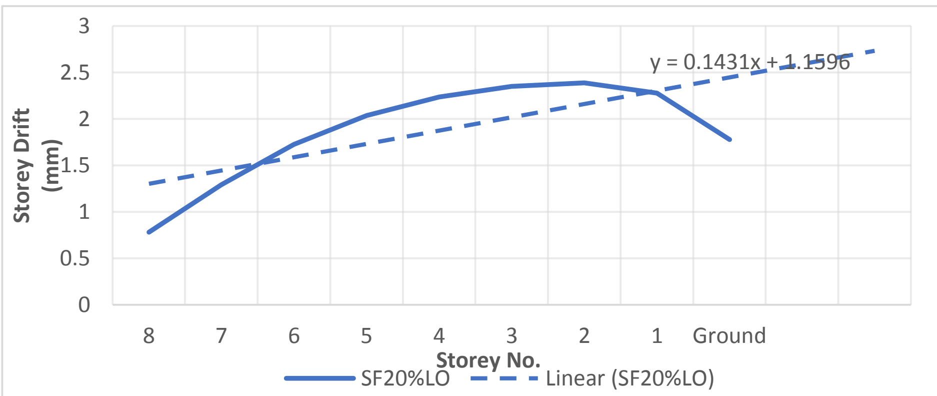

Fig.5.39: Trend line for Storey Drift for Strut Frame model with 20% left openings

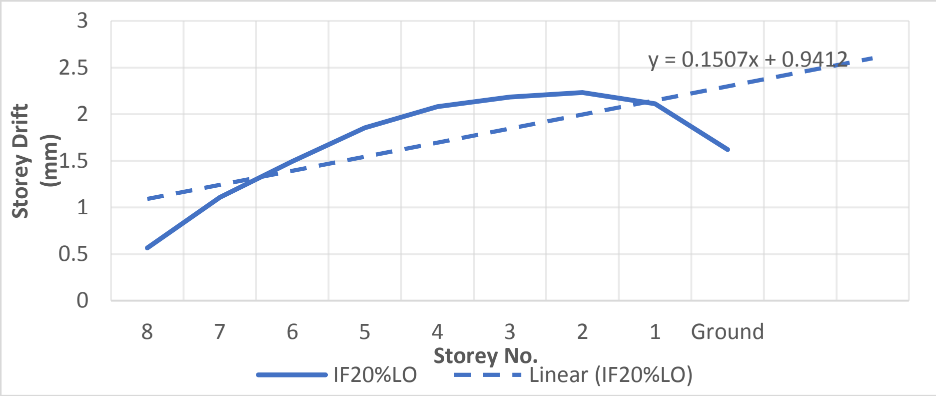

Fig.5.40: Trend line for Storey Drift for Infilled Frame model with 20% left openings

9) Storey drift for strut frame model (SF25%LO) and infilled frame model (IF25%LO) with 25% left openings.

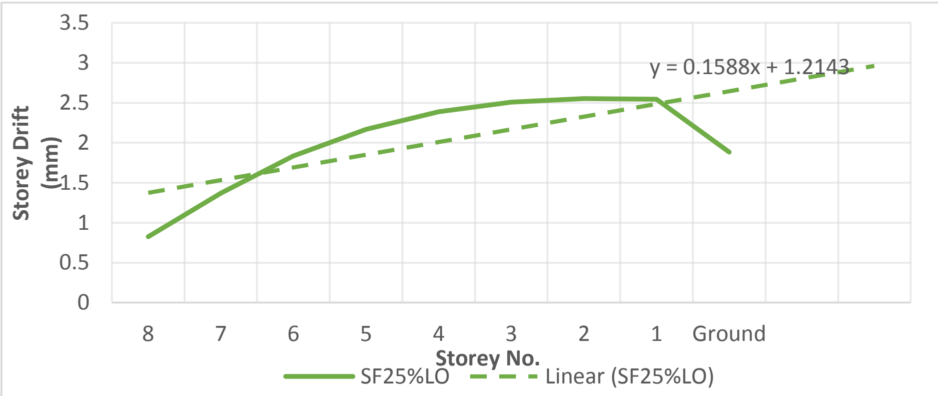

Fig.5.41: Trend line for Storey Drift for Strut Frame model with 25% left openings

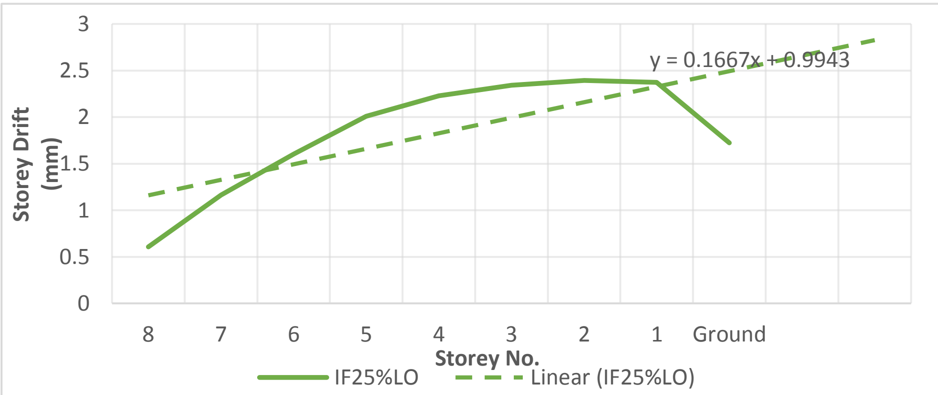

Fig.5.42: Trend line for Storey Drift for Infilled Frame model with 25% left openings

10) Storey drift for strut frame model (SF10%RO) and infilled frame model (IF10%RO) with 10% right openings.

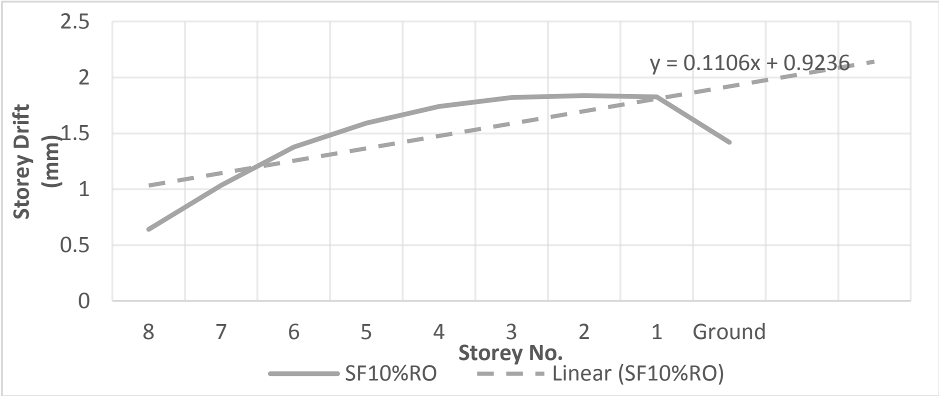

Fig.5.43: Trend line for Storey Drift for Strut Frame model with 10% right openings

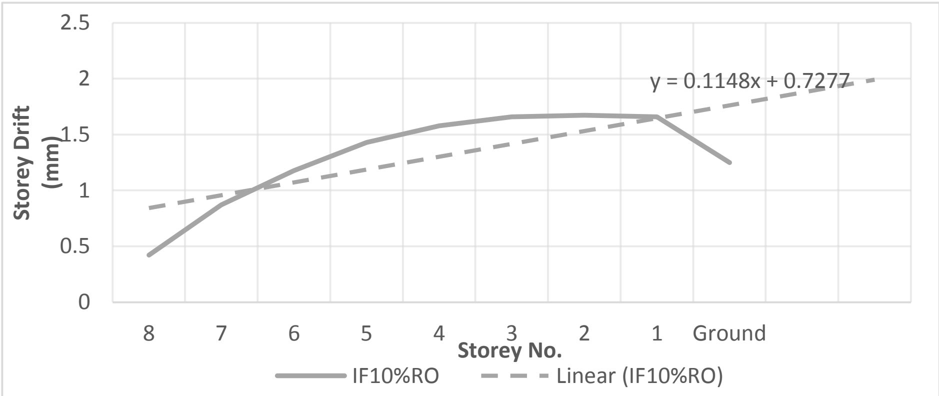

Fig.5.44: Trend line for Storey Drift for Infilled Frame model with 10% right openings

11) Storey drift for strut frame model (SF15%RO) and infilled frame model (IF15%RO) with 15% right openings.

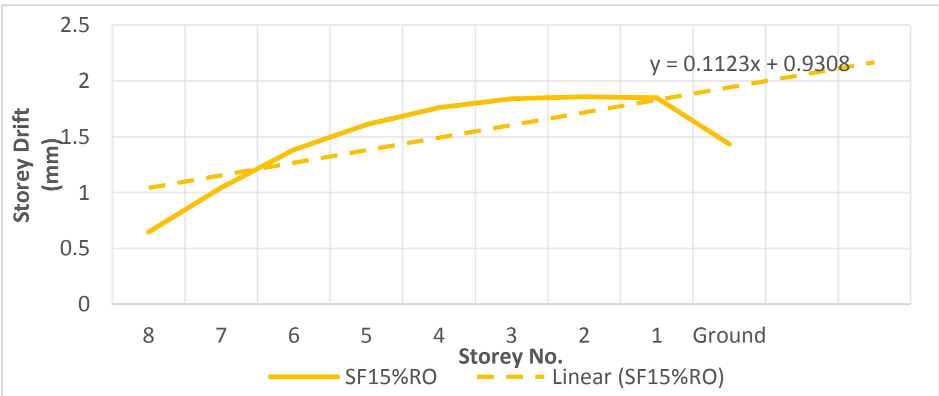

Fig.5.45: Trend line for Storey Drift for Strut Frame model with 15% right openings

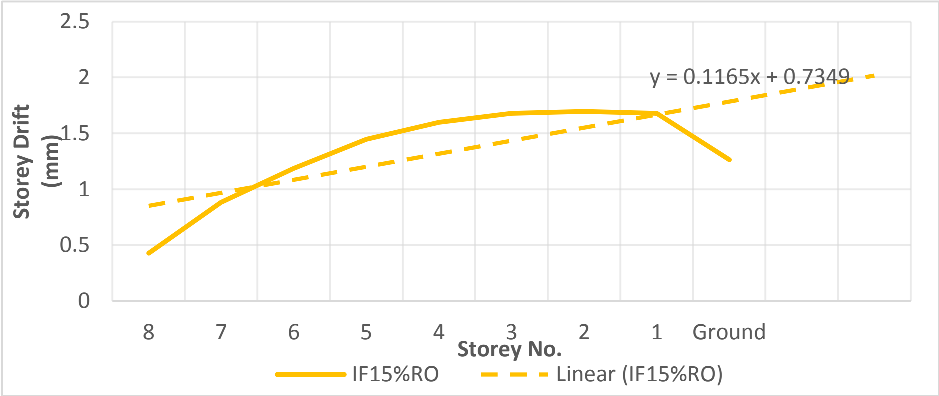

Fig.5.46: Trend line for Storey Drift for Infilled Frame model with 15% right openings

12) Storey drift for strut frame model (SF20%RO) and infilled frame model (IF20%RO) with 20% right openings.

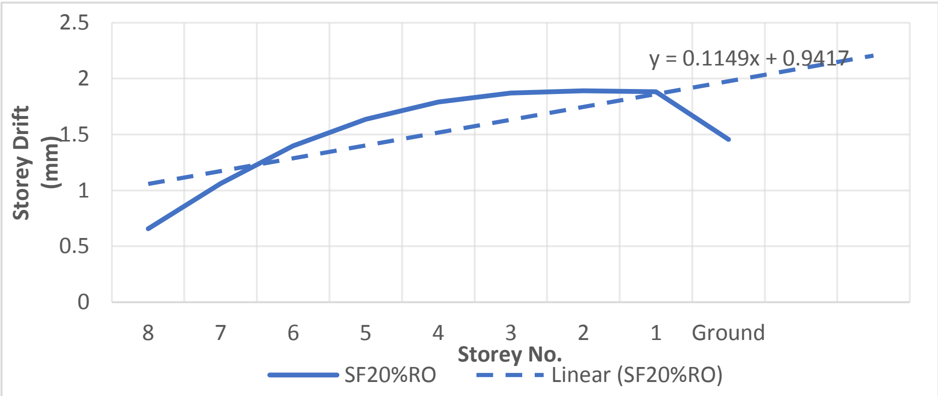

Fig.5.47: Trend line for Storey Drift for Strut Frame model with 20% right openings

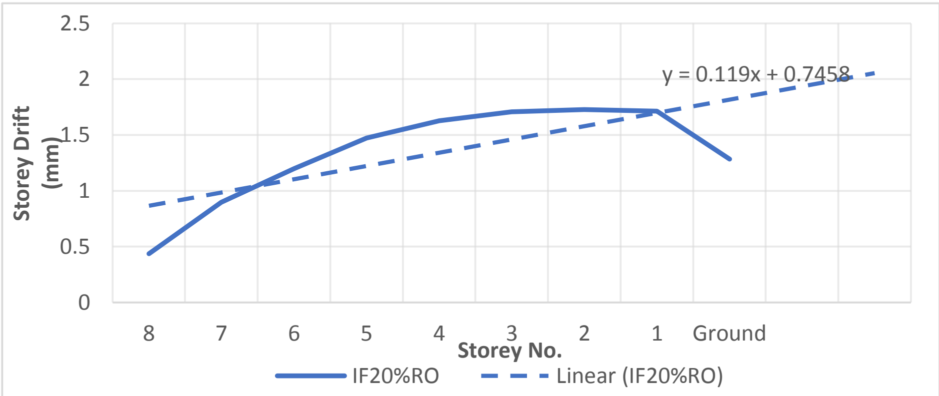

Fig.5.48: Trend line for Storey Drift for Infilled Frame model with 20% right openings

13) Storey drift for strut frame model (SF25%RO) and infilled frame model (IF25%RO) with 25% right openings.

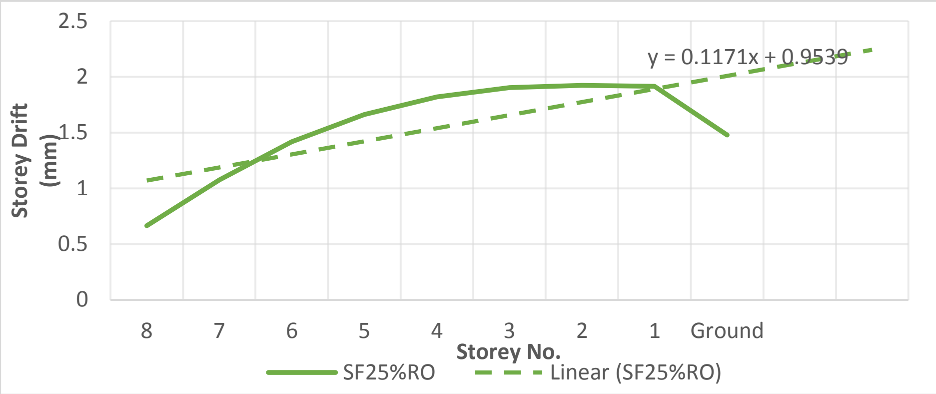

Fig.5.49: Trend line for Storey Drift for Strut Frame model with 25% right openings

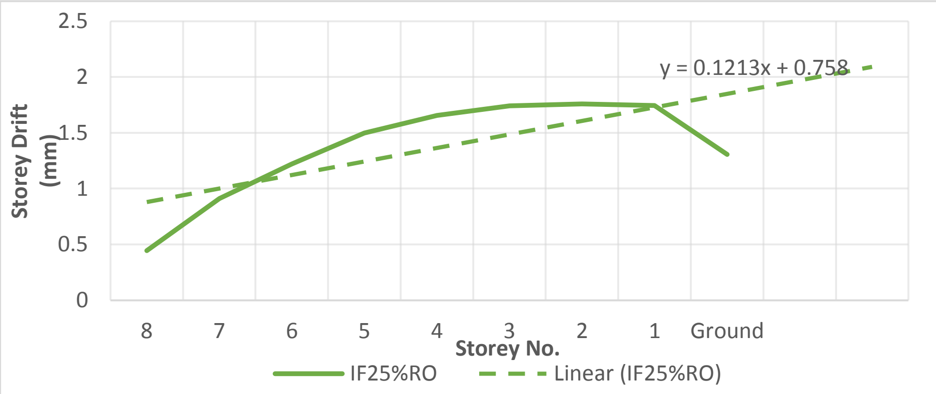

Fig.5.50: Trend line for Storey Drift for Infilled Frame model with 25% right openings

b) For Earthquake in y-direction, i.e. EQY direction

1) Storey drift for strut frame model (SF0%) and infilled frame model (IF0%) with 0% openings.

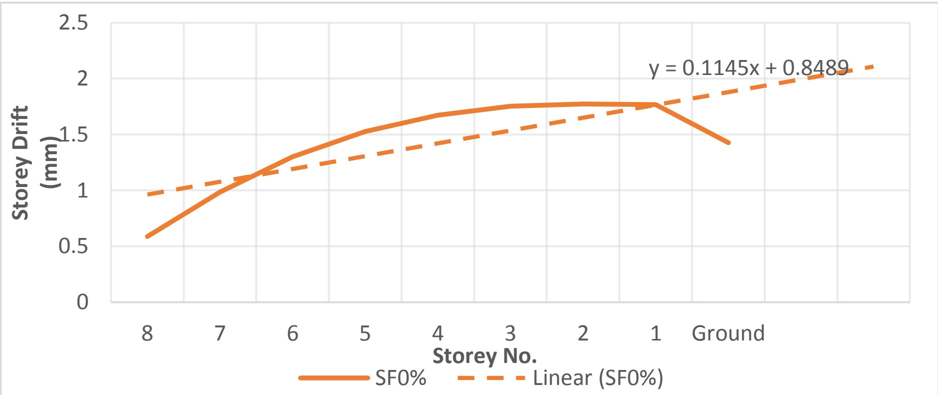

Fig.5.51: Trend line for Storey Drift for Strut Frame model with 0% openings

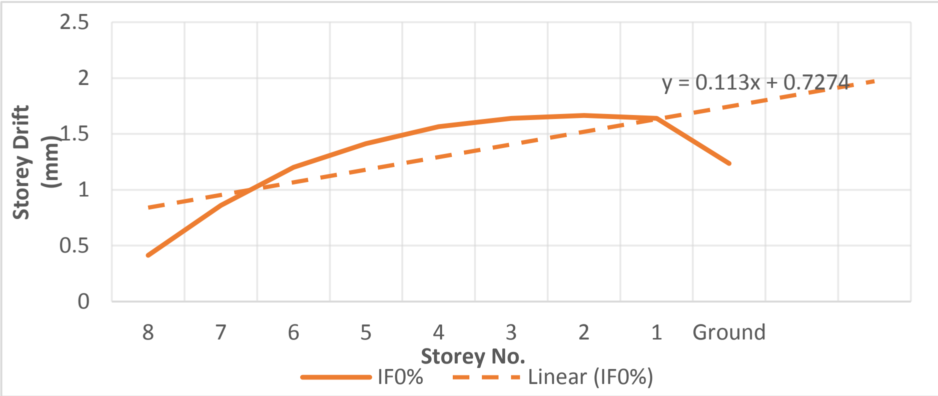

Fig.5.52: Trend line for Storey Drift for Infilled Frame model with 0% openings

2) Storey drift for strut frame model (SF10%CO) and infilled frame model (IF10%CO) with 10% central openings.

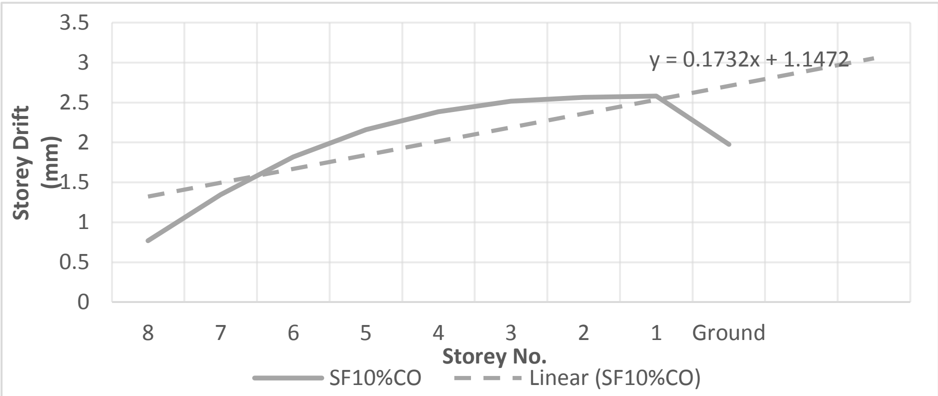

Fig.5.53: Trend line for Storey Drift for Strut Frame model with 10% central openings

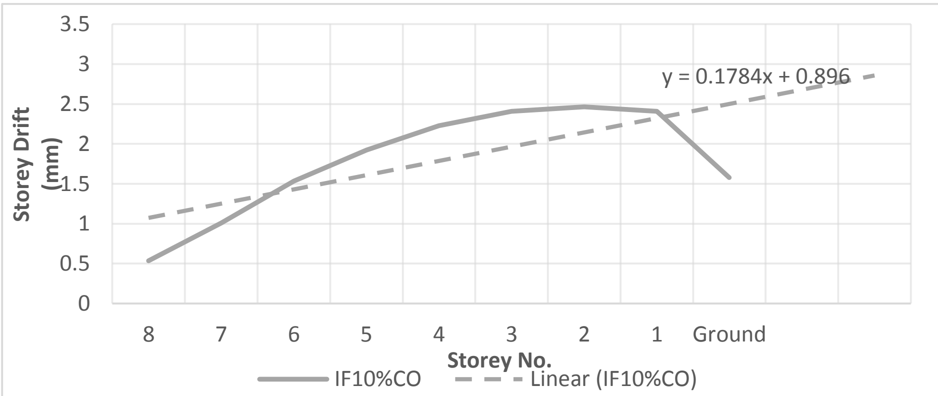

Fig.5.54: Trend line for Storey Drift for Infilled Frame model with 10% central openings

3) Storey drift for strut frame model (SF15%CO) and infilled frame model (IF15%CO) with 15% central openings.

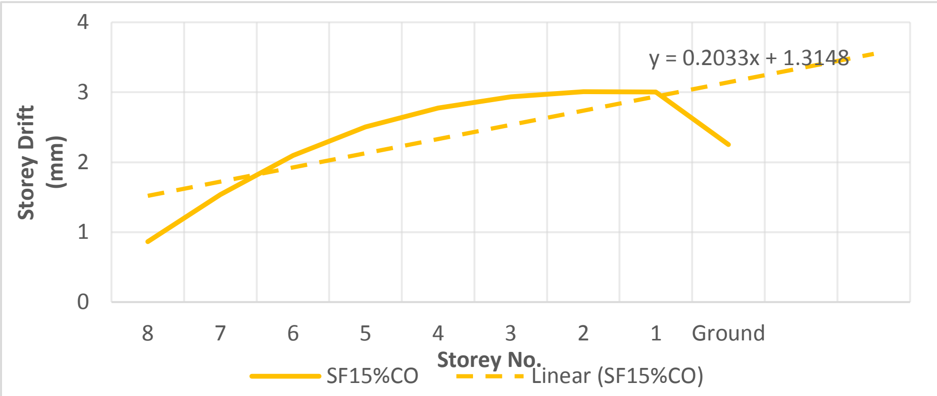

Fig.5.55: Trend line for Storey Drift for Strut Frame model with 15% central openings

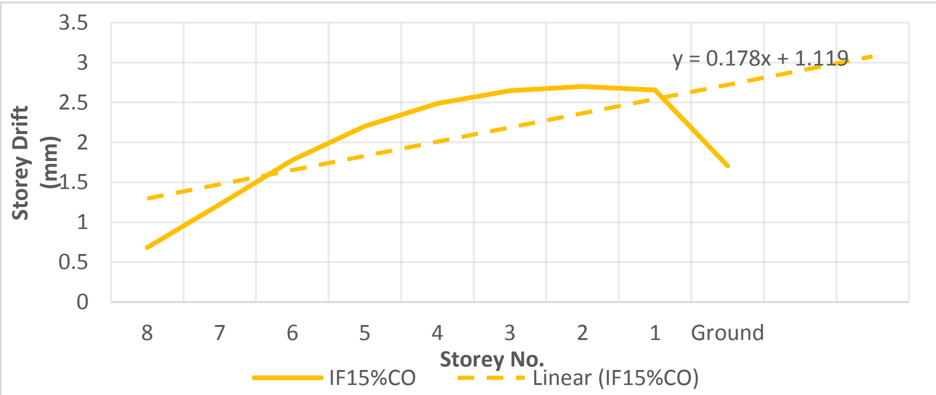

Fig.5.56: Trend line for Storey Drift for Infilled Frame model with 15% central openings

4) Storey drift for strut frame model (SF20%CO) and infilled frame model (IF20%CO) with 20% central openings.

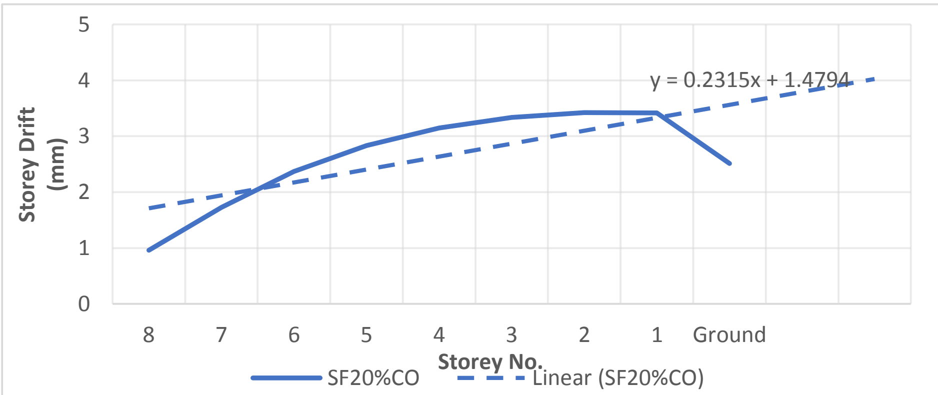

Fig.5.57: Trend line for Storey Drift for Strut Frame model with 20% central openings

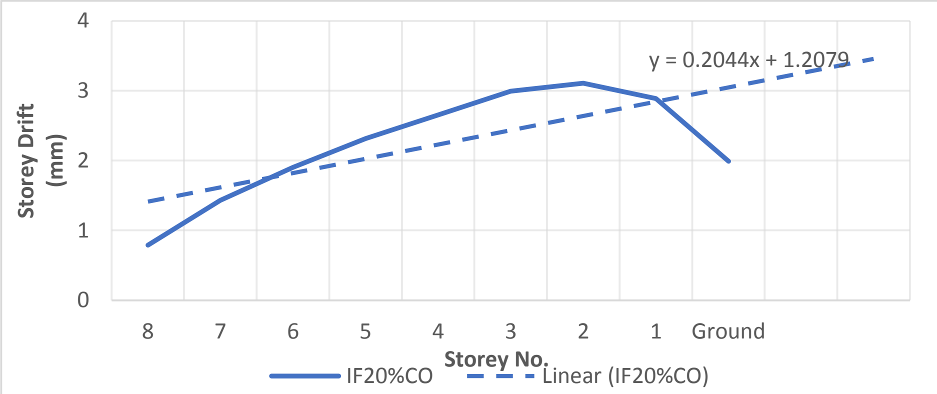

Fig.5.58: Trend line for Storey Drift for Infilled Frame model with 20% central openings

5) Storey drift for strut frame model (SF25%CO) and infilled frame model (IF25%CO) with 25% central openings.

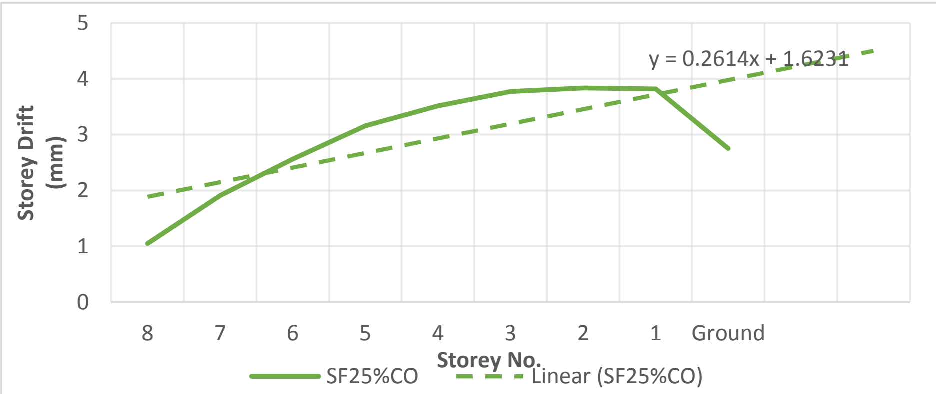

Fig.5.59: Trend line for Storey Drift for Strut Frame model with 25% central openings

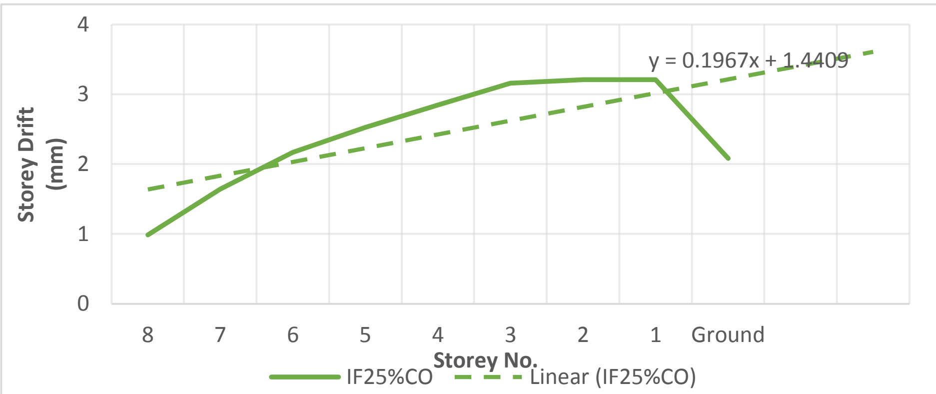

Fig.5.60: Trend line for Storey Drift for Infilled Frame model with 25% central openings

6) Storey drift for strut frame model (SF10%LO) and infilled frame model (IF10%LO) with 10% left openings.

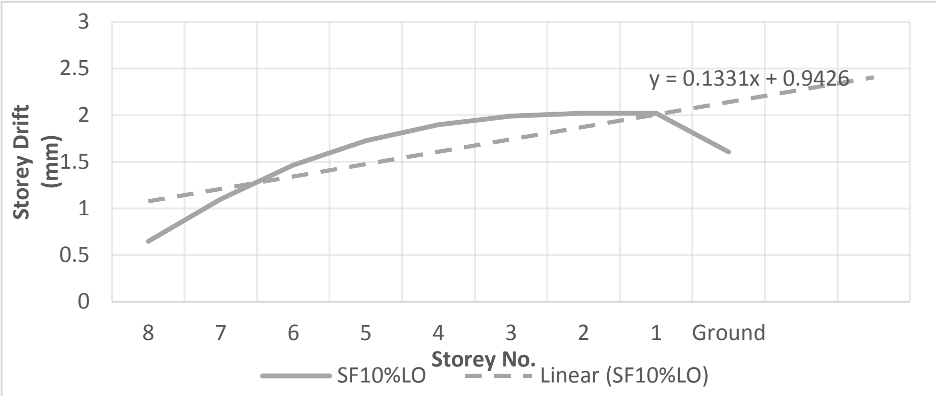

Fig.5.61: Trend line for Storey Drift for Strut Frame model with 10% left openings

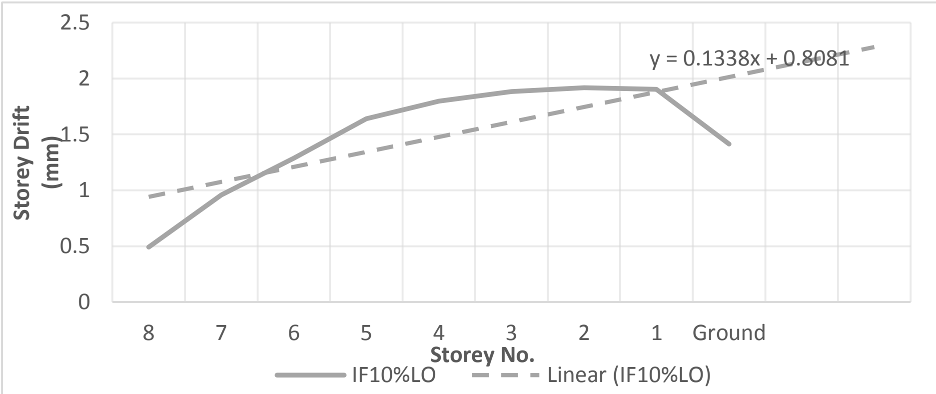

Fig.5.62: Trend line for Storey Drift for Infilled Frame model with 10% left openings

7) Storey drift for strut frame model (SF15%LO) and infilled frame model (IF15%LO) with 15% left openings.

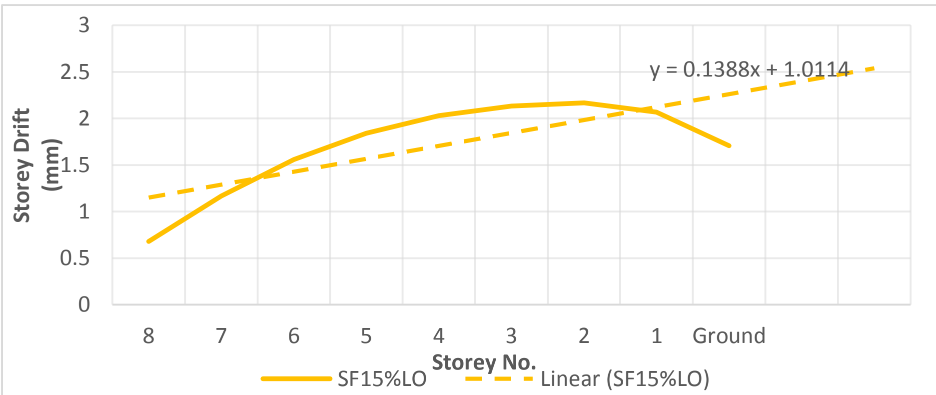

Fig.5.63: Trend line for Storey Drift for Strut Frame model with 15% left openings

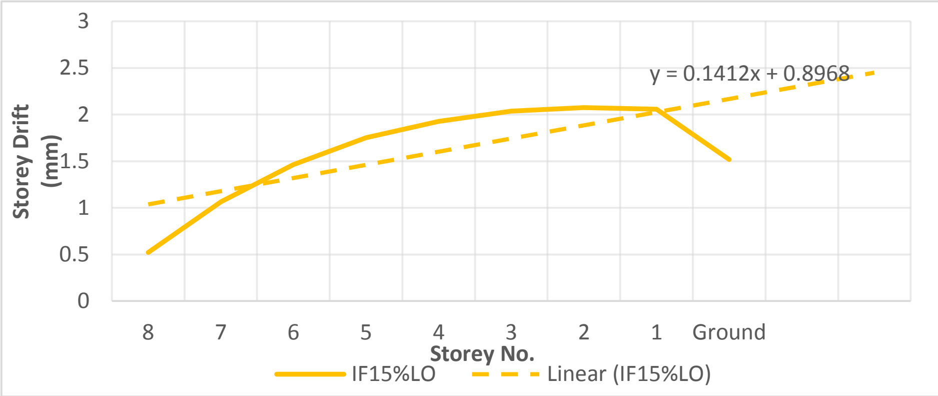

Fig.5.64: Trend line for Storey Drift for Infilled Frame model with 15% left openings

8) Storey drift for strut frame model (SF20%LO) and infilled frame model (IF20%LO) with 20% left openings.

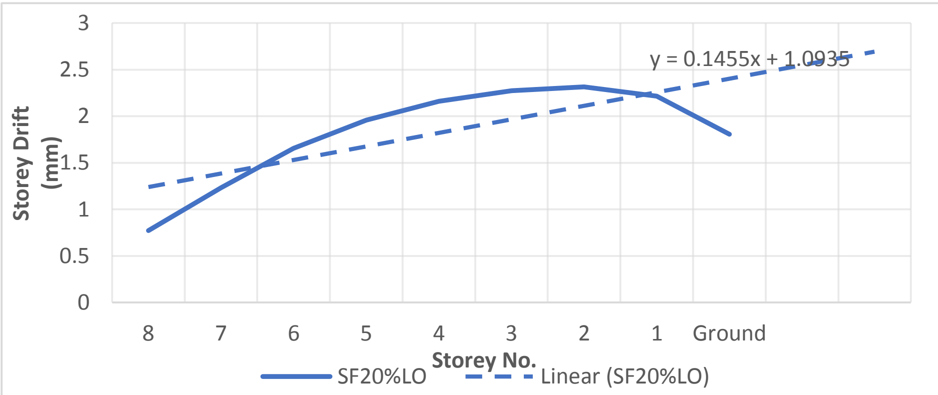

Fig.5.65: Trend line for Storey Drift for Strut Frame model with 20% left openings

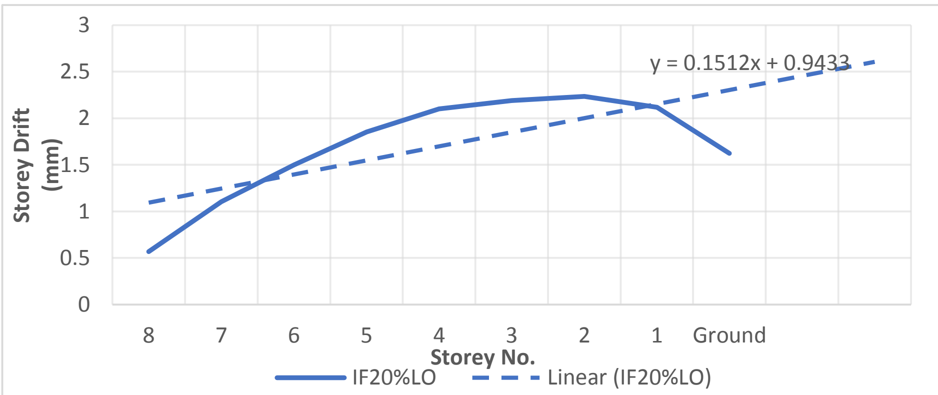

Fig.5.66: Trend line for Storey Drift for Infilled Frame model with 20% left openings

9) Storey drift for strut frame model (SF25%LO) and infilled frame model (IF25%LO) with 25% left openings.

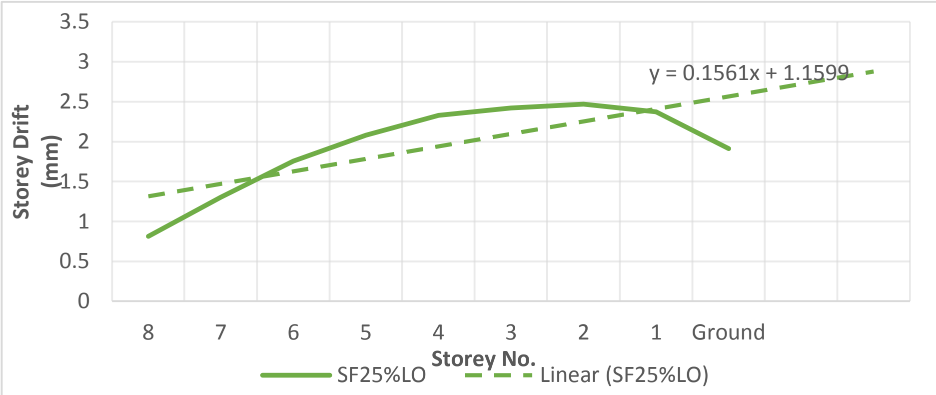

Fig.5.67: Trend line for Storey Drift for Strut Frame model with 25% left openings

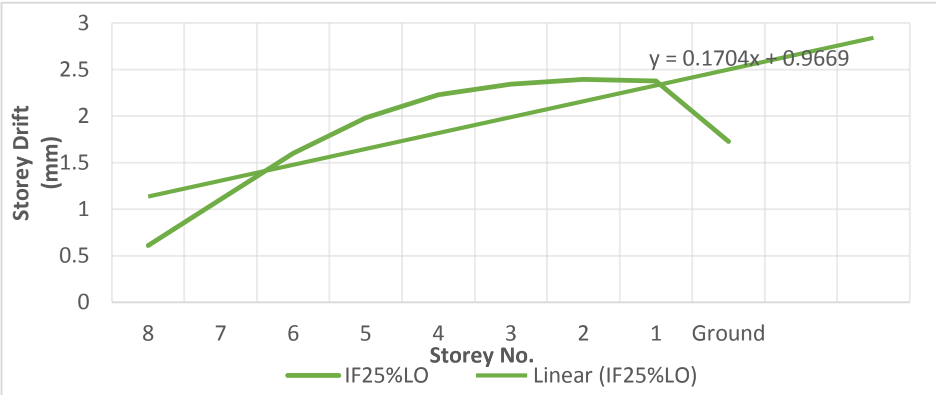

Fig.5.68: Trend line for Storey Drift for Infilled Frame model with 25% left openings

10) Storey drift for strut frame model (SF10%RO) and infilled frame model (IF10%RO) with 10% right openings.

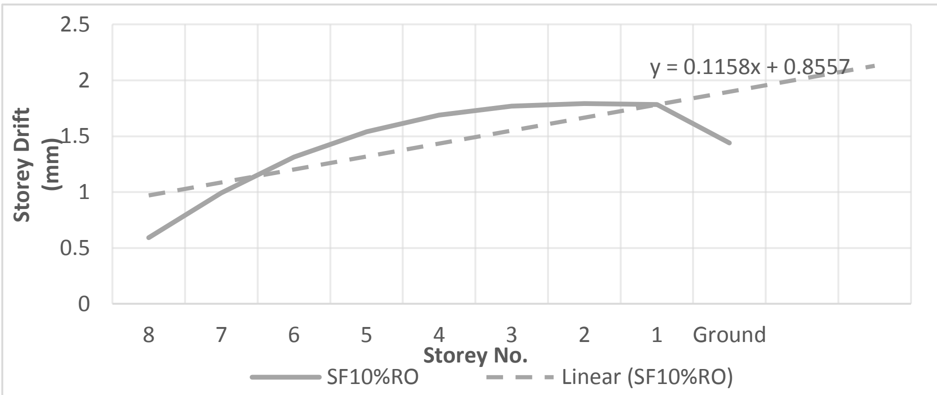

Fig.5.69: Trend line for Storey Drift for Strut Frame model with 10% right openings

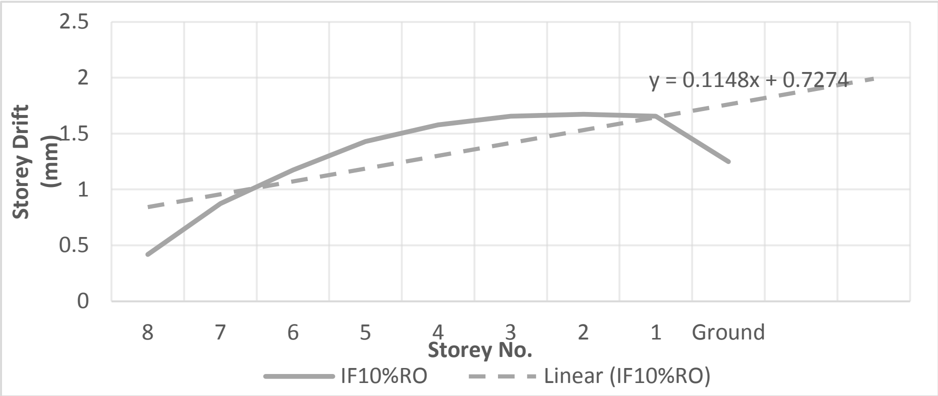

Fig.5.70: Trend line for Storey Drift for Infilled Frame model with 10% right openings

11) Storey drift for strut frame model (SF15%RO) and infilled frame model (IF15%RO) with 15% right openings.

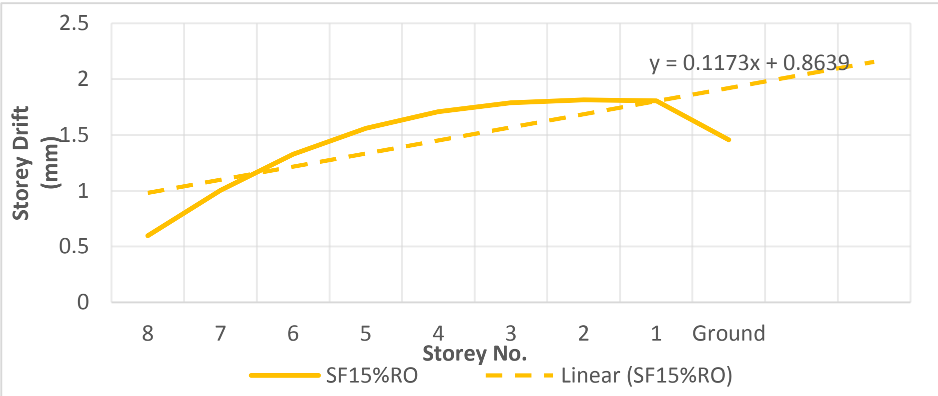

Fig.5.71: Trend line for Storey Drift for Strut Frame model with 15% right openings

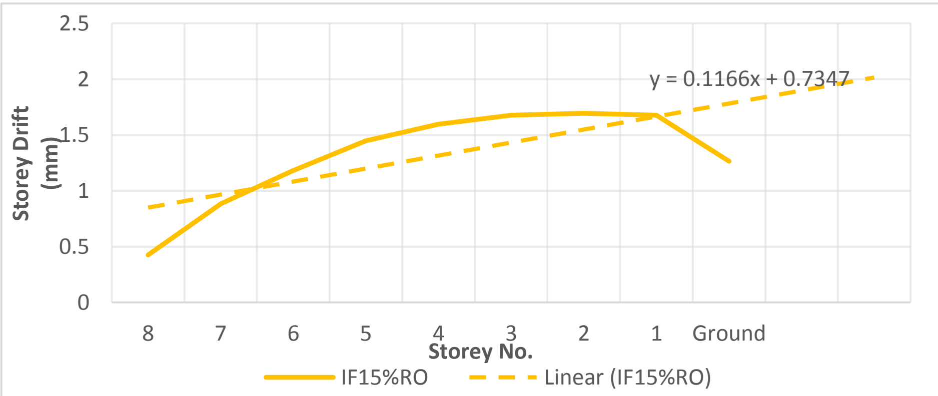

Fig.5.72: Trend line for Storey Drift for Infilled Frame model with 15% right openings

12) Storey drift for strut frame model (SF20%RO) and infilled frame model (IF20%RO) with 20% right openings.

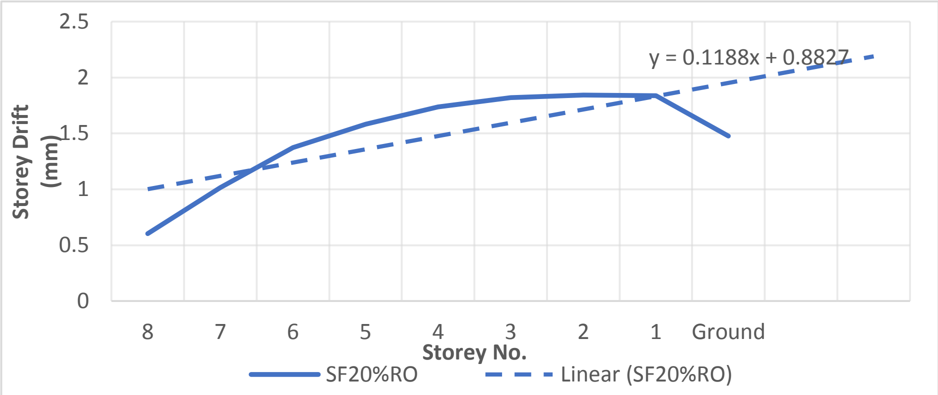

Fig.5.73: Trend line for Storey Drift for Strut Frame model with 20% right openings

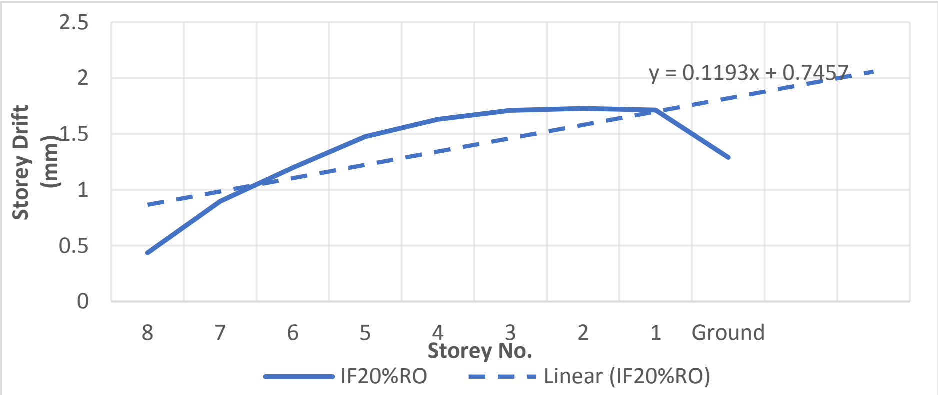

Fig.5.74: Trend line for Storey Drift for Infilled Frame model with 20% right openings

13) Storey drift for strut frame model (SF25%RO) and infilled frame model (IF25%RO) with 25% right openings.

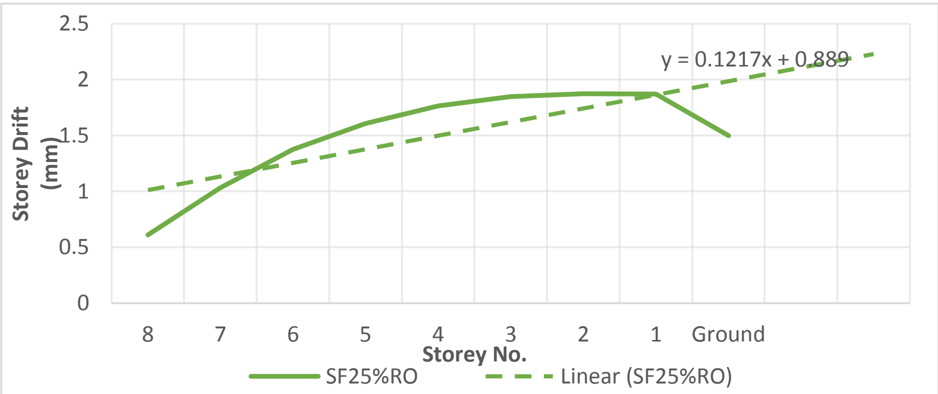

Fig.5.75: Trend line for Storey Drift for Strut Frame model with 25% right openings

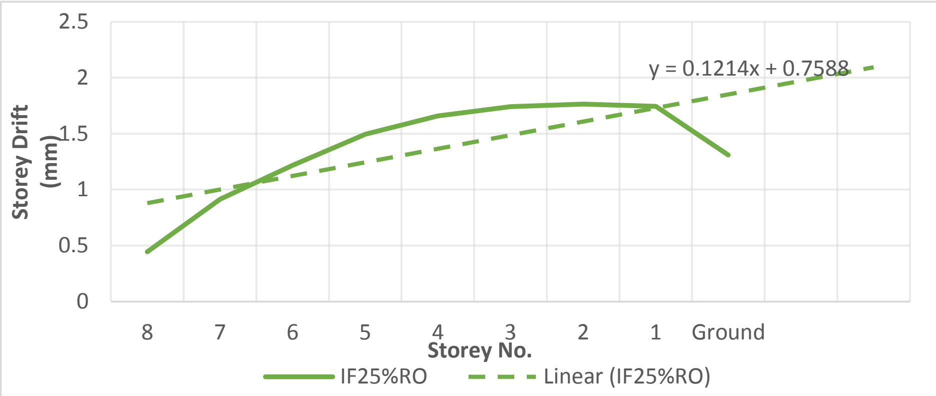

Fig.5.76: Trend line for Storey Drift for Infilled Frame model with 25% right openings

5.6 Comparison on Maximum Storey Displacement in EQX and EQY Direction

Taking into the account the effects of masonry infilled walls in the frame, the maximum story displacement in x and y direction are reduced, when modelled as both, i.e. as equivalent diagonal pin-jointed strut and as quad element, but the reduction is seen more in the second case. The maximum storey displacement increases as soon as the opening begins to occur, and with increment in area of openings, this pattern continues to follow. All these are discussed in tables and graphs below.

1) Comparison of maximum storey displacement between bare frame, strut frame and infilled frame.

Table.5.55: Maximum storey displacement for bare frame, strut frame and infilled frame

Storey no. / Model ID	**Max Storey Displacement-EQX (mm)**			**Max. Storey Displacement-EQY (mm)**		
	BF	SF0%	IF0%	BF	SF0%	IF0%
8	111.570	39.438	25.529	102.644	38.369	25.530
7	106.758	37.526	24.250	98.618	36.605	24.354
6	98.591	34.450	22.199	91.287	33.651	22.385
5	87.261	30.405	19.502	80.998	29.748	19.783
4	73.505	25.676	16.350	68.470	25.169	16.730
3	58.058	20.505	12.902	54.382	20.150	13.384
2	41.586	15.101	9.300	39.322	14.896	9.881
1	24.802	9.646	5.663	23.869	9.577	6.335
Ground	9.121	4.219	2.045	9.123	4.278	2.183
Plinth	0	0	0	0	0	0

2) Comparison of maximum storey displacement between bare frame and strut frame with varying percentage of central opening areas.

Table.5.56: Maximum storey displacement for various central opening areas in EQX direction

Storey no./Model ID	Max. Storey Displacement-EQX (mm)					
	BF	SF0%	SF10%CO	SF15%CO	SF20%CO	SF25%CO
8	111.570	39.438	56.254	65.429	74.306	82.949
7	106.758	37.526	53.702	62.524	71.058	79.362
6	98.591	34.45	49.450	57.632	65.546	73.245
5	87.261	30.405	43.743	51.017	58.049	64.887
4	73.505	25.676	36.995	43.158	49.111	54.892
3	58.058	20.505	29.557	34.471	39.205	43.793
2	41.586	15.101	21.732	25.305	28.732	32.038
1	24.802	9.646	13.767	15.951	18.022	20.001
Ground	9.121	4.219	5.832	6.652	7.411	8.121
Plinth	0	0	0	0	0	0

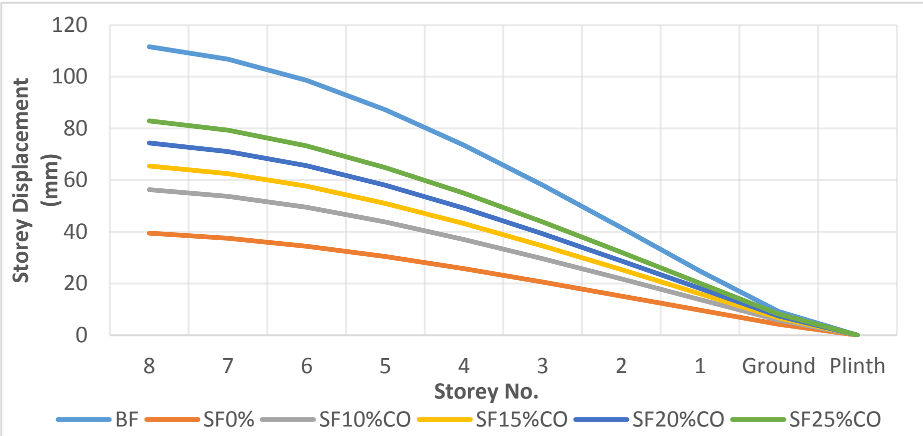

Fig.5.77: Maximum storey displacement for various Central Opening areas in EQX direction

Table.5.57: Maximum storey displacement for various central opening areas in EQY direction

Storey no./Model ID	Max. Storey Displacement-EQY (mm)					
	BF	SF0%	SF10%CO	SF15%CO	SF20%CO	SF25%CO
8	102.644	38.369	54.314	62.922	71.201	79.203
7	98.618	36.605	52.010	60.327	68.322	76.047
6	91.287	33.651	47.972	55.706	63.14	70.322
5	80.998	29.748	42.516	49.410	56.034	62.430
4	68.470	25.169	36.039	41.901	47.528	52.995
3	54.382	20.150	28.882	33.578	38.076	42.407
2	39.322	14.896	21.335	24.777	28.061	31.209
1	23.869	9.577	13.633	15.769	17.788	19.706
Ground	9.123	4.278	5.926	6.762	7.533	8.251
Plinth	0	0	0	0	0	0

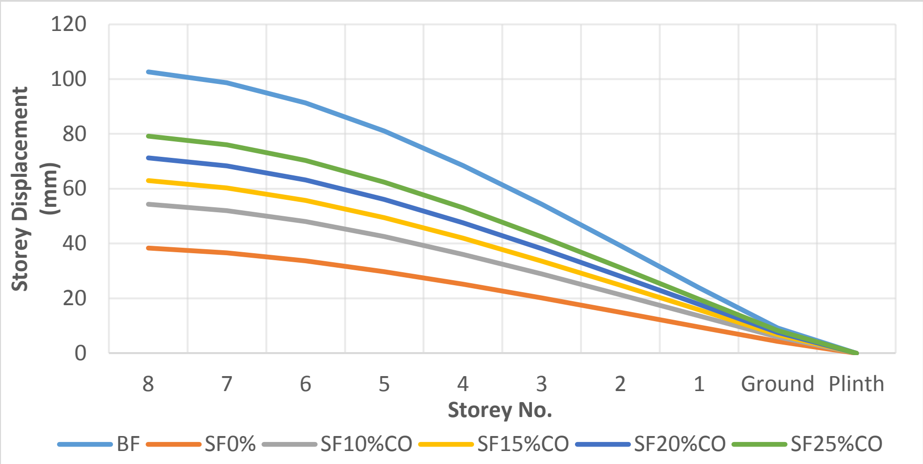

Fig.5.78: Maximum storey displacement for various Central Opening areas in EQY direction

3) Comparison of maximum storey displacement between bare frame and strut frame with varying percentage of opening areas down the diagonal left.

Table.5.58: Maximum storey displacement for various percentage of opening areas down the diagonal left in EQX direction

Storey no./Model ID	**Max. Storey Displacement-EQX (mm)**					
	BF	SF0%	SF10%LO	SF15%LO	SF20%LO	SF25%LO
8	111.57	39.438	44.371	47.827	50.924	54.213
7	106.758	37.526	42.623	45.596	48.575	51.738
6	98.591	34.45	39.175	41.932	44.694	47.628
5	87.261	30.405	34.608	37.059	39.516	42.124
4	73.505	25.676	29.244	31.324	33.409	35.622
3	58.058	20.505	23.363	25.027	26.694	28.461
2	41.586	15.101	17.201	18.421	19.641	20.932
1	24.802	9.646	10.961	11.721	12.478	13.275
Ground	9.121	4.219	4.744	5.043	5.338	5.645
Plinth	0	0	0	0	0	0

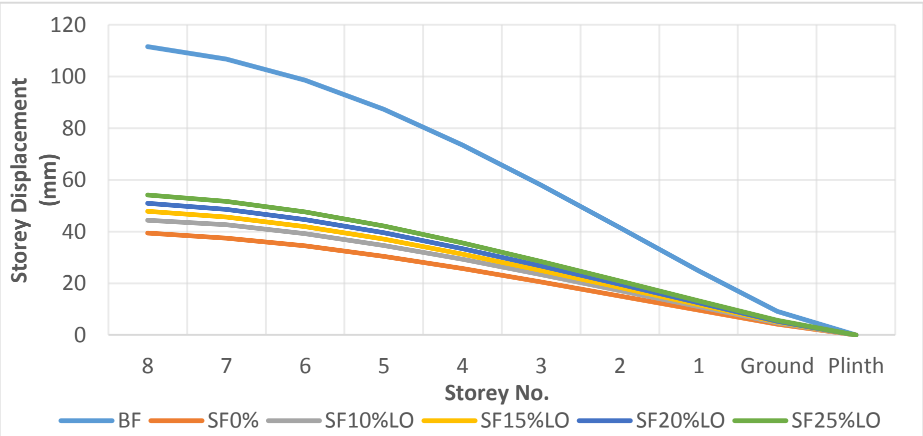

Fig5.79: Maximum storey displacement for various percentage of Opening areas down the diagonal Left in EQX direction

Table.5.59: Maximum storey displacement for various percentage of opening areas down the diagonal left in EQY direction

Storey no./Model ID	Max. Storey Displacement-EQY (mm)					
	BF	SF0%	SF10%LO	SF15%LO	SF20%LO	SF25%LO
8	102.644	38.369	43.416	46.349	49.283	52.389
7	98.618	36.605	41.481	44.315	47.149	50.151
6	91.287	33.651	38.183	40.817	43.452	46.243
5	80.998	29.748	33.788	36.137	38.486	40.975
4	68.470	25.169	28.610	30.610	32.610	34.728
3	54.382	20.15	22.918	24.525	26.131	27.83
2	39.322	14.896	16.942	18.128	19.311	20.562
1	23.869	9.577	10.875	11.623	12.367	13.150
Ground	9.123	4.278	4.815	5.12	5.421	5.735
Plinth	0	0	0	0	0	0

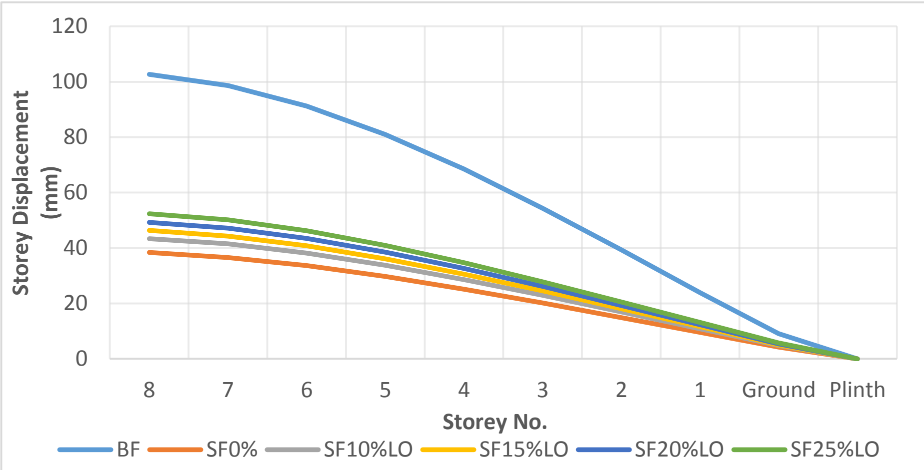

Fig.5.80: Maximum storey displacement for various percentage of Opening areas down the diagonal Left in EQY direction

4) Comparison of maximum storey displacement between bare frame and strut frame with varying percentage of opening areas up the diagonal right.

Table.5.60: Maximum storey displacement for various opening areas up the diagonal right in EQX direction

Storey no./Model ID	Max. Storey Displacement-EQX (mm)					
	BF	SF0%	SF10%RO	SF15%RO	SF20%RO	SF25%RO
8	111.57	39.438	39.825	40.271	40.936	41.572
7	106.758	37.526	37.899	38.328	38.967	39.579
6	98.591	34.45	34.795	35.192	35.785	36.352
5	87.261	30.405	30.712	31.066	31.593	32.097
4	73.505	25.676	25.937	26.237	26.685	27.113
3	58.058	20.505	20.714	20.954	21.313	21.656
2	41.586	15.101	15.255	15.432	15.696	15.948
1	24.802	9.646	9.743	9.854	10.02	10.178
Ground	9.121	4.219	4.258	4.303	4.369	4.433
Plinth	0	0	0	0	0	0

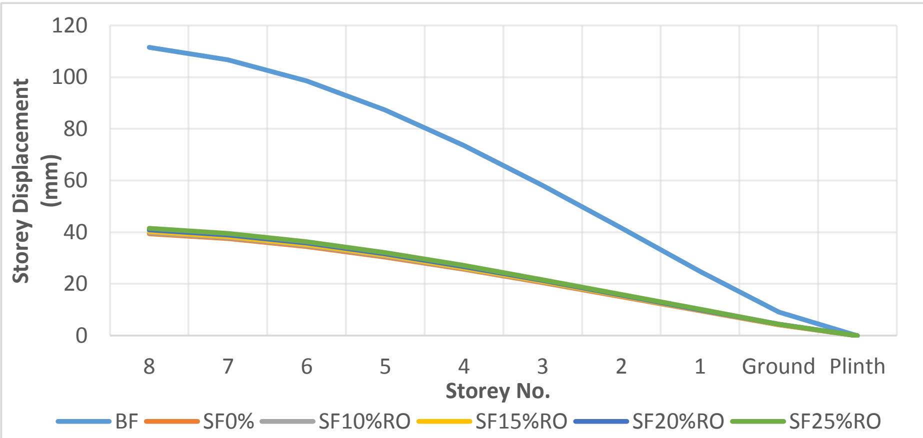

Fig.5.81: Maximum storey displacement for various Opening areas up the diagonal Right in EQX direction

Table.5.61: Maximum storey displacement for various opening areas up the diagonal right in EQY direction

Storey no./Model ID	Max. Storey Displacement-EQY (mm)					
	BF	SF0%	SF10%RO	SF15%RO	SF20%RO	SF25%RO
8	102.644	38.369	38.738	39.163	39.797	40.404
7	98.618	36.605	36.962	37.373	37.985	38.571
6	91.287	33.651	33.983	34.364	34.933	35.478
5	80.998	29.748	30.044	30.384	30.892	31.377
4	68.470	25.169	25.421	25.711	26.143	26.556
3	54.382	20.150	20.353	20.586	20.934	21.266
2	39.322	14.896	15.045	15.218	15.475	15.721
1	23.869	9.577	9.672	9.782	9.946	10.102
Ground	9.123	4.278	4.317	4.363	4.431	4.496
Plinth	0	0	0	0	0	0

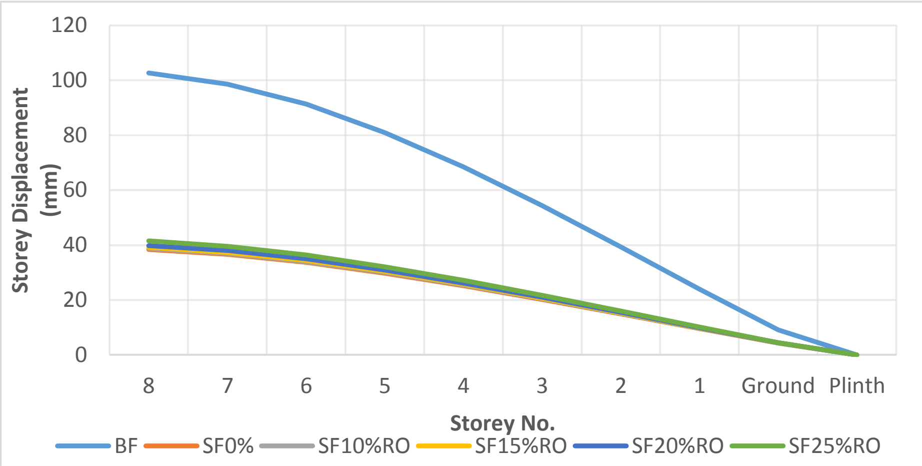

Fig.5.82: Maximum storey displacement for various Opening areas up the diagonal Right in EQY direction

5) Comparison of maximum storey displacement between bare frame and infilled frame with varying percentage of central opening areas.

Table.5.62: Maximum storey displacement for various central opening areas in EQX direction

Storey no./Model ID	Max. Storey Displacement-EQX (mm)					
	BF	IF0%	IF10%CO	IF15%CO	IF20%CO	IF25%CO
8	111.57	25.529	33.937	38.525	42.963	47.285
7	106.758	24.250	32.338	36.749	41.016	45.168
6	98.591	22.199	29.699	33.790	37.747	41.597
5	87.261	19.502	26.171	29.808	33.324	36.743
4	73.505	16.350	22.009	25.091	28.067	30.958
3	58.058	12.902	17.428	19.885	22.252	24.546
2	41.586	9.300	12.615	14.402	16.115	17.768
1	24.802	5.663	7.724	8.816	9.851	10.841
Ground	9.121	2.045	2.852	3.262	3.641	3.996
Plinth	0	0	0	0	0	0

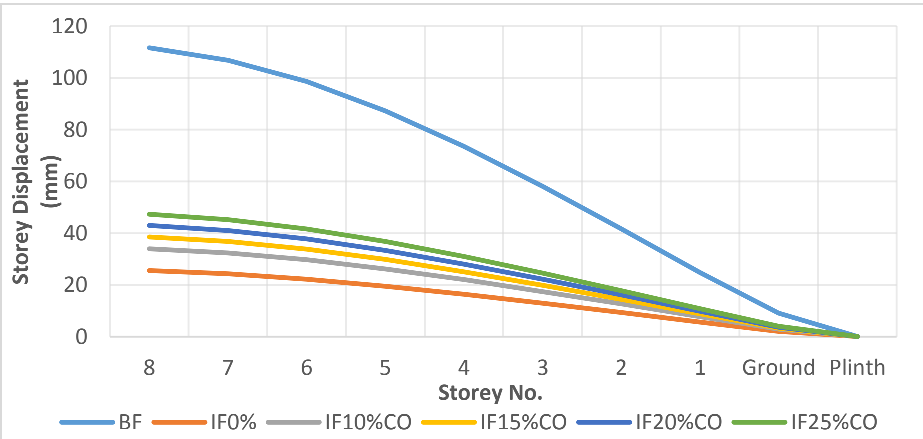

Fig.5.83: Maximum storey displacement for various Central Opening areas in EQX direction

Table.5.63: Maximum storey displacement for various central opening areas in EQY direction

Storey no./Model ID	Max. Storey Displacement-EQY (mm)					
	BF	IF0%	IF10%CO	IF15%CO	IF20%CO	IF25%CO
8	102.644	25.530	33.503	37.807	41.946	45.947
7	98.618	24.354	32.057	36.215	40.213	44.075
6	91.287	22.385	29.545	33.412	37.129	40.720
5	80.998	19.783	26.167	29.614	32.926	36.124
4	68.470	16.730	22.165	25.096	27.910	30.643
3	54.382	13.384	17.750	20.098	22.347	24.513
2	39.322	9.881	13.101	14.822	16.464	18.038
1	23.869	6.335	8.363	9.431	10.441	11.400
Ground	9.123	2.183	3.007	3.425	3.811	4.170
Plinth	0	0	0	0	0	0

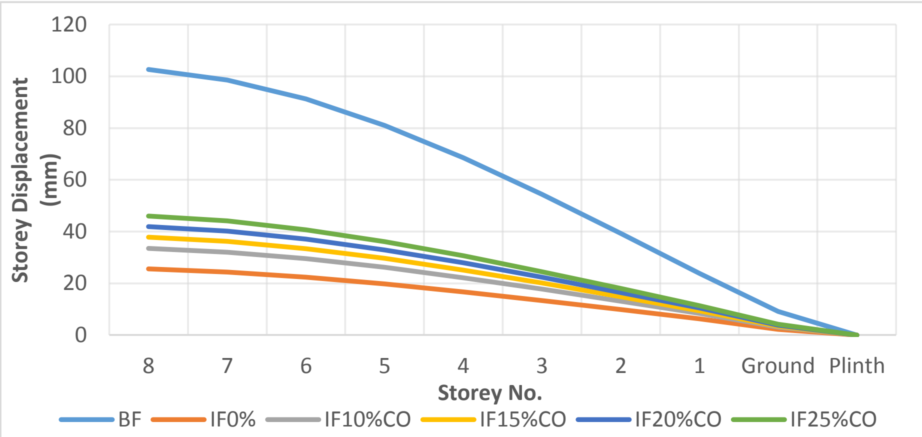

Fig.5.84: Maximum storey displacement for various Central Opening areas in EQY direction

6) Comparison of maximum storey displacement between bare frame and infilled frame with varying percentage of opening areas down the left corner.

Table.5.64: Maximum storey displacement for various opening areas down the left corner in EQX direction

Storey no./Model ID	Max. Storey Displacement-EQX (mm)					
	BF	IF0%	IF10%LO	IF15%LO	IF20%LO	IF25%LO
8	111.57	25.529	27.996	29.724	31.272	32.917
7	106.758	24.250	26.799	28.285	29.775	31.356
6	98.591	22.199	24.562	25.940	27.321	28.788
5	87.261	19.502	21.604	22.829	24.058	25.362
4	73.505	16.350	18.134	19.174	20.216	21.323
3	58.058	12.902	14.331	15.163	15.997	16.880
2	41.586	9.300	10.350	10.960	11.570	12.215
1	24.802	5.663	6.321	6.701	7.079	7.478
Ground	9.121	2.045	2.308	2.457	2.605	2.758
Plinth	0	0	0	0	0	0

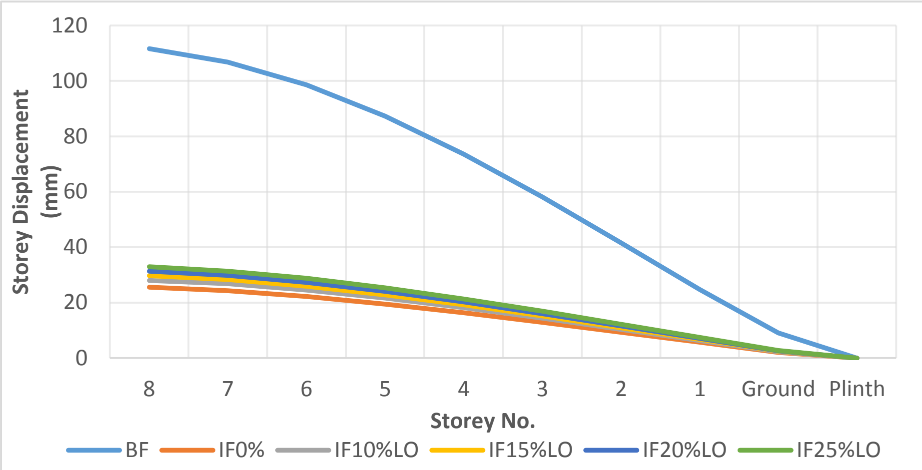

Fig.5.85: Maximum storey displacement for various Opening areas down the Left corner in EQX direction

Table.5.65: Maximum storey displacement for opening areas down the left corner in EQY direction

Storey no./Model ID	Max. Storey Displacement-EQY (mm)					
	BF	IF0%	IF10%LO	IF15%LO	IF20%LO	IF25%LO
8	102.644	25.530	28.054	29.520	30.987	32.540
7	98.618	24.354	26.792	28.209	29.626	31.127
6	91.287	22.385	24.651	25.968	27.285	28.681
5	80.998	19.783	21.803	22.977	24.152	25.396
4	68.470	16.730	18.451	19.451	20.451	21.510
3	54.382	13.384	14.768	15.572	16.375	17.224
2	39.322	9.881	10.904	11.497	12.089	12.714
1	23.869	6.335	6.984	7.358	7.730	8.122
Ground	9.123	2.183	2.452	2.604	2.755	2.912
Plinth	0	0	0	0	0	0

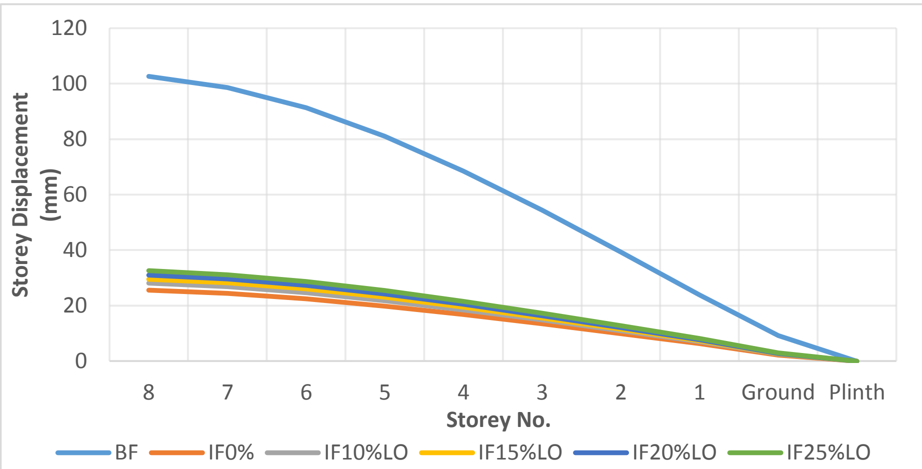

Fig.5.86: Maximum storey displacement for various Opening areas down the Left corner in EQY direction

7) Comparison of maximum storey displacement between bare frame and infilled frame with varying percentage of opening areas up the right corner.

Table.5.66: Maximum storey displacement for various opening areas up the right corner in EQX direction

Storey no./Model ID	Max. Storey Displacement-EQX (mm)					
	BF	IF0%	IF10%RO	IF15%RO	IF20%RO	IF25%RO
8	111.57	25.529	25.723	25.946	26.278	26.596
7	106.758	24.250	24.437	24.651	24.971	25.277
6	98.591	22.199	22.372	22.570	22.867	23.150
5	87.261	19.502	19.656	19.833	20.096	20.348
4	73.505	16.350	16.480	16.630	16.854	17.068
3	58.058	12.902	13.007	13.127	13.306	13.478
2	41.586	9.300	9.377	9.465	9.597	9.723
1	24.802	5.663	5.712	5.767	5.850	5.929
Ground	9.121	2.045	2.065	2.087	2.120	2.152
Plinth	0	0	0	0	0	0

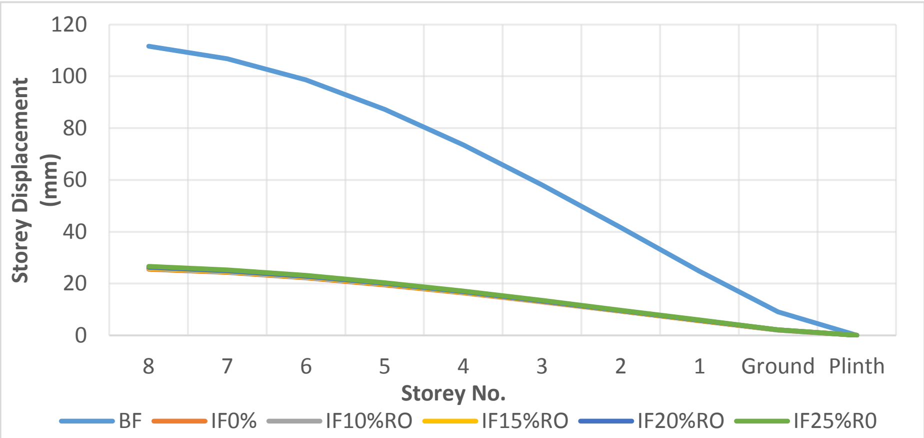

Fig.5.87: Maximum storey displacement for various Opening areas up the Right corner in EQX direction

Table.5.67: Maximum storey displacement for opening areas up the right corner in EQY direction

Storey no./Model ID	Max. Storey Displacement-EQY (mm)					
	BF	IF0%	IF10%RO	IF15%RO	IF20%RO	IF25%RO
8	102.644	25.530	25.715	25.927	26.244	27.132
7	98.618	24.354	24.533	24.738	25.044	25.841
6	91.287	22.385	22.551	22.741	23.026	23.735
5	80.998	19.783	19.931	20.101	20.355	20.957
4	68.470	16.730	16.856	17.001	17.217	17.702
3	54.382	13.384	13.486	13.602	13.776	14.137
2	39.322	9.881	9.956	10.042	10.171	10.407
1	23.869	6.335	6.383	6.438	6.520	6.636
Ground	9.123	2.183	2.203	2.226	2.260	2.261
Plinth	0	0	0	0	0	0

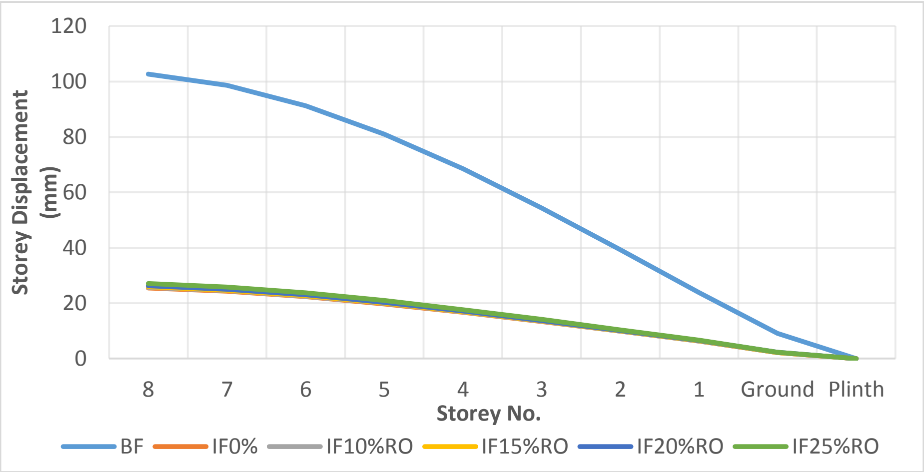

Fig.5.88: Maximum storey displacement for various Opening areas up the Right corner in EQY direction

CHAPTER 6

CONCLUSIONS

6.1 Conclusions:

Following are the conclusions of this study:

1) It may be concluded that results may be different if masonry infilled walls are considered in a frame. This is because of increased stiffness of the frame due to incorporation of infilled walls. The difference can be appreciated in terms of reduced storey drift, increased base shear and changes in time period.
2) In the case of strut frame with solid masonry infilled walls, the fundamental modal time period gets reduced by 61.24% as compared to that of bare frame. In the case of infilled frame this value is 74.82%.
3) The modal mass participation ratio is found to be equal in the both translational x and y-direction. It may indicate this effect due to regularity of the structure considered in this study.
4) As compared to bare frame, the base shear increases by 77.14% in the case of strut frames and 94.56% in the case of infilled frames. It indicates that structural components of the frame, would be subjected to different amount of forces in all the three different types of frames. When the infilled walls fails as a non-structural component, all the frames may be supposed to vibrate like a bare frame. In that condition margin of safety for structural components in different frames would be different.
5) As compared to bare frame and solid masonry infilled frames, the top storey drifts in the case of strut frame are 60.3% and 56.18% less in EQX and EQY direction respectively. In the case of infilled frame these value are 74.06% and 69.15% in EQX and EQY direction respectively.

6) In case of strut frame, maximum top storey displacements are 64.65% and 62.62% less in EQX and EQY direction respectively, as compared to bare frame. In case of infilled frame these value are 77.12% and 75.13% less in EQX and EQY direction respectively.
7) In case of openings, the stiffness parameters gets reduced as compared to solid masonry infilled walls, and this reduction continues with increase in opening area sizes.
8) Base shear tends to decrease as the opening area increases as compared to solid masonry infilled frame. Concentration of openings at a particular level may be given due importance while distributing base shear along the height of building.
9) If 25% central opening is provided in solid masonry infilled walls then the fundamental modal time period, top storey drift and displacement increases by 51.23%, 87.75%, and 110.33% respectively, in the case of strut frame. For the infilled frames these values are 32.87%, 137.02%, and 85.22% respectively.
10) If 25% left opening is provided in solid masonry infilled walls then the fundamental modal time period, top storey drift and displacement increases by 18.24%, 29.51%, and 37.46% respectively, in the case of strut frame. For the infilled frames these values are 19.12%, 46.39%, and 28.94% respectively.
11) If 25% right opening is provided in solid masonry infilled walls then the fundamental modal time period, top storey drift and displacement increases by 2.72%, 4.24%, and 5.41% respectively, in the case of strut frame. For the infilled frames these values are 16.93%, 6.49%, and 4.18% respectively.
12) When the openings are provided at central location the reduction in stiffness (as compared to solid masonry infilled walls) is more than when the openings are provided at left corner down and right corner up locations.
13) It is easier to model openings when masonry infilled walls are taken as equivalent diagonal pin-jointed strut as compared to quadrilateral element.

14) Modelling of masonry infilled walls as quadrilateral element shows higher value of stiffness as compared to equivalent diagonal pin-jointed struts.

6.2 Future Scope of the Study

Future scope of the study may consist of following aspects:

1) To consider the behaviour of masonry infilled walls in different types of R.C frames such as special moment resisting frame (SMRF) and ordinary moment resisting frame and making comparison between them.
2) To consider various effects of different seismic zone.
3) To consider various other ways of modelling masonry infilled walls and their comparison.
4) To consider various aspects linked with constructional techniques and modelling of masonry infilled walls.
5) To consider various aspects linked with infills of other material, which may provide better seismic behaviour and their modelling.
6) To consider undertaking efforts for developing user friendly aids for analysis, design and construction of R.C frames for different seismic zones under varying conditions.

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