SEISMIC ANALYSIS OF MASONRY INFILLED RC FRAME RESTING ON SLOPING GROUND

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ABSTRACT

In this study finite element analysis of multistorey infilled frame building resting on sloping ground subjected to the seismic force is analyzed considering infill wall. In the present study, the performance of the building resting on slope has been studied for different slopes of 0°, 15°,20°, 25° and 30°. The building resting on slopes are analyzed for presence of with and without masonry infill wall at different sloping ground condition. Analyzing the performance of the building for slope and presence of masonry infill wall, it has been found that, building with infill wall gives better performance compared to bare frame. In the present study it has been noticed that the frame without infill at ground floor shows drastic increase in the deformation, base shear and member forces compared to infill frame with infill at ground floor. With increase in slope of ground the infill frame with short column compared to infill frame with long column at ground floor shows the decrease in the deformation and increase in the base shear and member forces.

1. INTRODUCTION

The growing global and Indian population's demand extensive housing, but the prevalence of hilly terrain in regions like northern, northeastern, western, and eastern India presents obstacles. Building on sloping ground results in irregular structures like hospitals, colleges, hotels, and offices, which face increased seismic risks due to their irregular shapes and varying stiffness. In addition, differing column heights within a single storey increase susceptibility to damage, especially on the uphill side.

Masonry infills are commonly used to fill the spaces between the vertical and horizontal elements of a building frame, with the assumption that they do not contribute to load resistance. Consequently, their significance in structural analysis is often overlooked due to the lack of simple and realistic analytical models. However, infill walls significantly enhance the strength and rigidity of structures, providing more strength and stability compared to bare frames.[2] Ignoring infills has led to failures in many multi-storeyed buildings, exemplified by the Bhuj earthquake of 2001, where infilled frames altered the building's behavior and introduced new failure mechanisms.

Under lateral loads, masonry infills affect the lateral deformations of RC frames by causing separation along one diagonal while forming a compression strut along the other.[3] This results in increased lateral stiffness for the building. The load transfer mechanism shifts from frame action to predominant truss action, altering the forces experienced by frame columns to include increased axial forces but reduced bending moments and shear forces. Unfortunately, there are no definitive guidelines for designing infills to enhance seismic response.[7] Typically, infills are either disregarded in design or mandated to be isolated from the frame. In order to fulfill the purpose of infill on the frame resting on hills with slopes having different column heights subjected to seismic

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force depend on seismic zones, this paper presents the effects of presence of infill in the frames resting on sloping ground with different seismic zones.

Figure 1- Building constructed on sloping ground

2. OBJECTIVE

The seismic analysis of multi-storey masonry infilled RC frame building resting on sloping ground of different sloping angles by FEM using Etabs software. The Multistored masonry infill RC frames resting on sloping ground is analyzed by studying the deformation, base shear and member forces.

3. MODELLING

In the present study RC framed with masonry infill of 1 bay 4 storey has been analyzed by the FEM using ETABS.v20.0.0. The structural specification and material properties of the building considered in the study are tabulated in Table 1 and Table 2. The frame is analyzed for different slope of the grounds like 0°, 15°, 20º, 25º and 30°. The responses were compared in terms of displacement, base shear and member forces.

Columns and beams are considered as frame element. While defining the type of wall and slab section in ETABS, there are three options available based on its behavior, namely shell type, membrane type and plate type behavior. Shell type behavior means, both in-plane membrane stiffness and out of plane plate bending stiffness's can be provided for the section. Membrane type behavior mean, only in-plane membrane stiffness is provided for the section. Plate type behavior means that only out-of-plane bending stiffness is provided for the section. In the present analysis, slabs is considered as membrane type behavior to provide in plane stiffness. In the present study, masonry infill walls behaves as simple diagonal struts, since the focus is mainly on the global behavior of the infilled frame structure.

Link element is adopted as interface element connecting the infill walls to the surrounding RC frames. Link element are represented by this element chosen from element library this element can be used to modal trusses, sagging cables, links etc. The 3 D spar element is a uniaxial tension and compression element with three degree of freedom at each node, translational in the nodal x, y and z direction. It takes two real constant i.e. area and initial strain and material properties like young's module, density, poisson's ratio. The solution output association with the nodal displacement included in all overall nodal solution. The link properties are given as same as the beam element, the link element with negligible density is considered in this study.

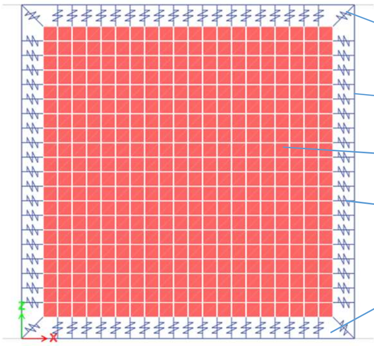


Figure 2-Details of infilled frame used in Etabs

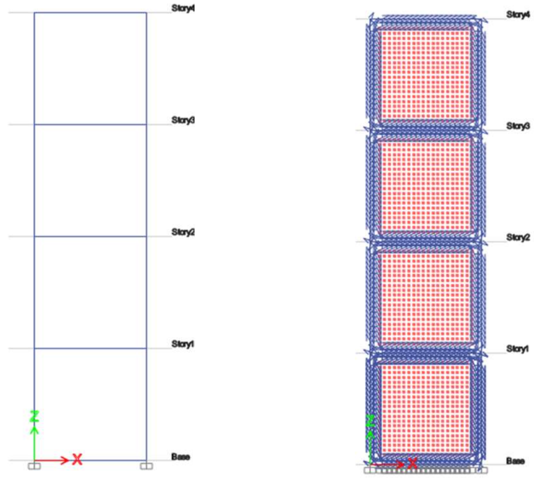
Table 1-Structural specification

Sl. No.	Particulars	Specification
1	Number of storey	4
2	Storey height	3.1m
3	Soil type	Medium
4	Column size	400mm x 400mm
5	Beam size	400mm x 400mm
6	Slab thickness	120mm
7	Infill wall thickness	200mm

Table 2-Material properties

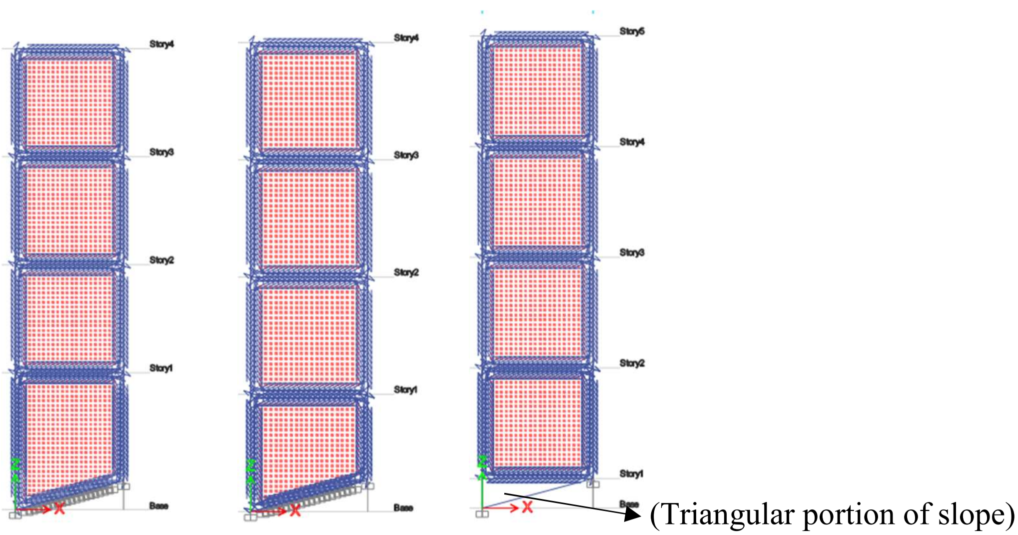
Materials	Concrete	Steel	Masonry infill
Modulus of Elasticity N/mm^2	25000	2×10^5	7000
Poisons ratio	0.2	0.3	0.15
Density KN/m^3	25	78.6	19.2

4. MODELS CONSIDERED IN THE ANALYSIS



BARE FRAME (0BF) INFILL FRAME (0IF)

Figure 3-Bare frame and Infill frame resting on plain ground



IFa IFb IFc

Figure 4- Infill frames resting on a typical sloping ground

1. 0BF-Bare Frame resting on plain ground
2. 0IF-Infill Frame resting on plain ground

Table 3- Designation and description of models of infill frames resting on sloped ground

Infill Frame	Description	Frames resting on sloping ground			
		15^o	20^o	25^o	30^o
IFa	Infill Frame resting on sloping ground keeping the height of column of the frame on upward (Right) side of the slope constant	15IFa	20IFa	25IFa	30IFa
IFb	Infill Frame resting on sloping ground keeping the height of column of the frame on downward (Left) side of the slope constant	15IFb	20IFb	25IFb	30IFb
IFc	Infill Frame resting on sloping ground with soft Storey (triangular portion) at ground floor	15IFc	20IFc	25IFc	30IFc

5. RESULTS AND DISCUSSION

Using the iterative FEM procedure indicated earlier, a typical masonry infill frame resting on plain ground and different sloping ground is analyzed using ETABS software considering all the properties tabulated above. The results of bare frame without infill, infill frame resting on plain ground and resting on different sloping ground are analyzed and compared. The behavior of the frames are discussed in terms of deformation, base shear and member forces.

a) Deformation

Deformation is a natural response of materials to external forces, and it is an important consideration in structural design and analysis. Excessive deformation beyond certain limits can lead to structural failure or compromise the integrity of a building or its components.

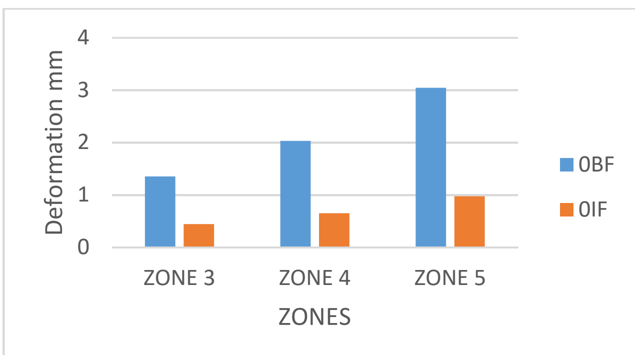
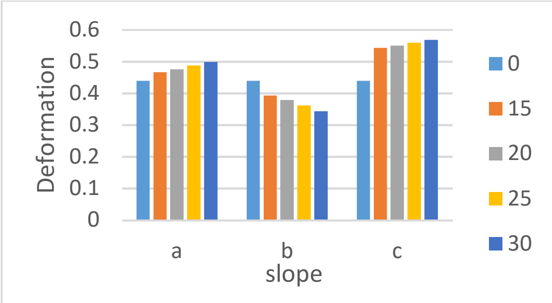
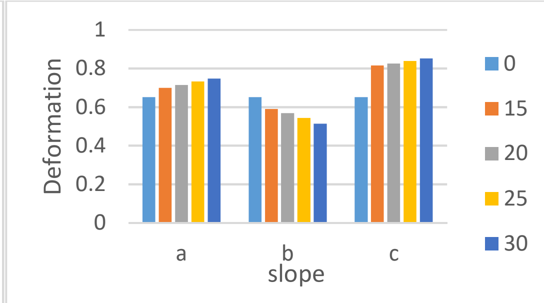


Figure 5-Comparison of deformation of bare frame and infill frame

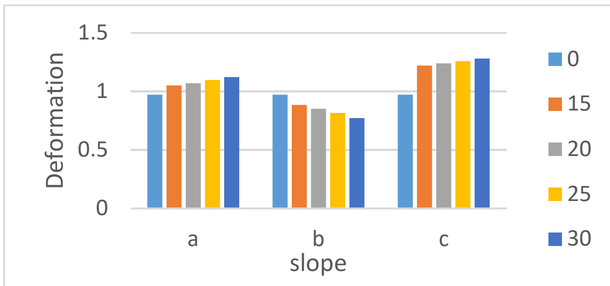
Referring to Figure 5, lateral deformation of bare frame is very high compared to infill frame. The lateral deformation of infilled frame (0IF) compared to bare frame (0BF) reduces drastically from 1.35mm to 0.439mm (67%) for the zone 3, similarly for zone 4 & zone 5, the deformation reduces from 2.03mm to 0.65mm (67%) and 3.04mm to 0.97mm (68%) respectively.



a. ZONE 3



b. ZONE 4



c. ZONE 5

Figure 6-Comparison of deformation of infill frames of a, b and c resting on different slope of the ground for different seismic zones.

From Figure 6, the deformation with increase in slope of ground increases in the infill frame IFa and IFc, whereas in the infill frame IFb decreases. This may be due to the difference in height of a column on the downward side of the slope and upward side of the slope. In infill frame IFa the height of column on the upward side of the slope is kept constant whereas the height of the column on the download side of the slope is kept constant in the frame IFb the area of infill frame and height of the column in the first storey is less in the frame IFb compared to IFa. This factor decreases the deformation in IFb with increasing in slope of ground.

In infill frame IFc both the columns on downward and upward side of the infill frame is kept constant by providing beam at the first story level creating a soft story in the triangular portion of the slope. The presence of soft story in the triangular portion of the slope below the first story increases the deformation drastically compared to infill frame IFa and IFb as infill frame IFa and IFb has infill in the triangular portion of the slope making first story as a whole infill frame without creating a soft story.

When compared to infill frame resting on plain ground the infill IFa increases marginally with increasing in slope of a ground for 15^o, 20^o, 25^o and 30^o compared to plane ground the deformation increases by 6% to 13% but for IFb decreases marginally with increasing in slope of a ground by 10% to 21%. But the infill frame IFc increases drastically with increasing slope of a ground for 15^o, 20^o, 25^o and 30^o compared to plain ground the deformation increases by 23% to 29%. The increase in deformation in IFc compare to IFa and IFb at 15^o, 20^o, 25^o and 30^o slope is higher by 16% to 14% for IFa and 38% to 65% for IFb respectively. In infill frame IFc with increase in slope the deformation increases similar to IFa, The variation in deformation in IFa, IFb and IFc with increase in slope is similar in all seismic zones 3, 4 and 5 but magnitude of deformation increases by an average of 48% to 50% with increasing in zones.

b) Base shear

Base shear is the maximum lateral force expected to be formed at the base of the structure due to seismic vibration. The base shear is a dynamic force that represents the lateral load that the structure must resist.

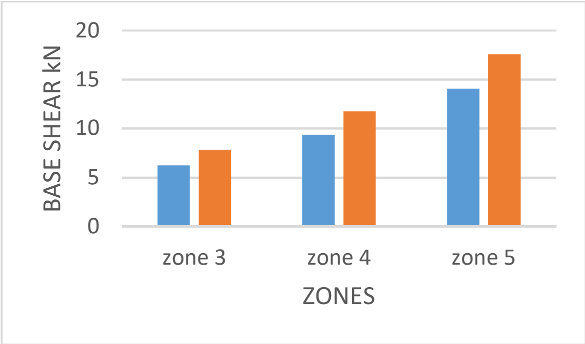
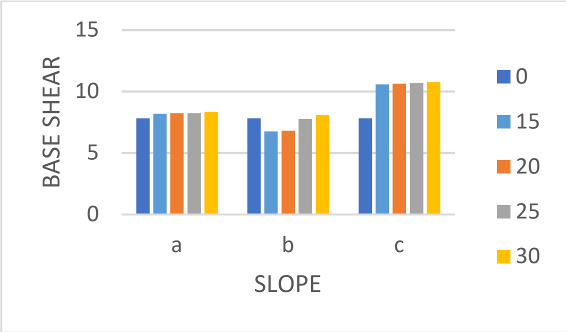
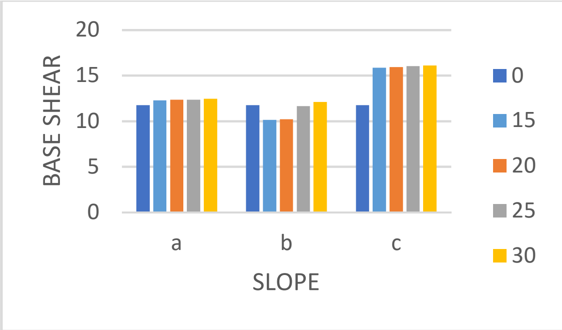


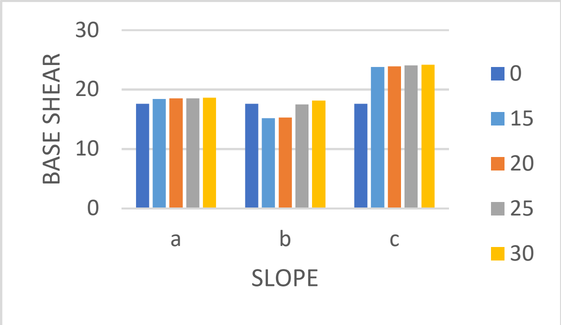
Figure 7-Comparison of base shear of bare frame and infill frame

Referring to Figure 7, base shear of bare frame is less compared to infill frame. The base shear of infilled frame (0IF) compared to bare frame (0BF) increases from 6.24kN to 7.82kN (25%) for the zone 3 similarly for zone 4 & zone 5 the base shear increases from 9.36kN to 11.73kN (25%) and 14.04kN to 17.59kN (25%) respectively.





a. ZONE 3 b. ZONE 4



c. ZONE 5

Figure 8-Comparison of base shear of infill frames of a, b and c resting on different slope of the ground for different seismic zones

From Figure 8 The base shear in infill frame IFa, IFb and IFc increases with increase of slope of a ground from 15º to 30º. When compared to infill frame resting on plain ground the infill frame IFa increases marginally with increasing slope of a ground from 15º, 20º, 25º and 30º compared to plain ground the base shear increases by 4% to 6%.

The infill frame IFb with increase in slope the base share of infill frame IFb resting on 15º, 20º and 25º slope compared to frame resting on plain ground is less by 13% to 0.77% but for 30º slope increases by 3%. But infill frame IFc with increase in slope of ground there is gradual increasing in base shear but when compared to frame resting on plain ground the base shear increases drastically, for 15º, 20º, 25º and 30º, the increase in base shear compared to frame resting on plain ground is higher by 35% to 37.3%.

The presence of soft story in the IFc compared to IFa and IFb there is considerable in a base shear this may be due to the effects of presence of soft story in the IFc between infill frame IFa and IFb the base share is less in the IFb compared to IFa.

The base shear in the infill frame IFb compared to IFa resting on 15º, 20º, 25º and 30º slope is less by 17% to 3%. The Base shear in IFb is less compared to IFa, this may be due to the lesser infill area and reduced column height on the upward side of the slope. With the increase in zone 3 to 4 and 4 to 5 the base shear of IFa, IFb and IFc increases by 49.9% to 50% for every increasing in slope.

c) Axial force in column

An axial force is any force that directly acts on the centre axis of an object. These forces are typically stretching force or compression force, depending on direction. In addition, when the force load is even across the form's geometric centre, it is concentric, and when it is uneven, it is eccentric. The column is a structural member of a building and it is designed to take Axial Compression force. The axial force in the column are maximum at the first storey level the comparison of axial force in the column of IFa, IFb and IFc discussed considering in the maximum force at the first storey.

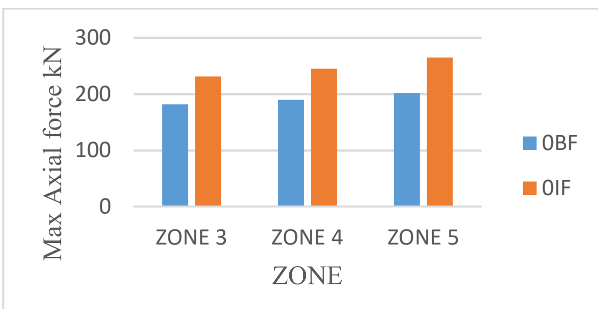
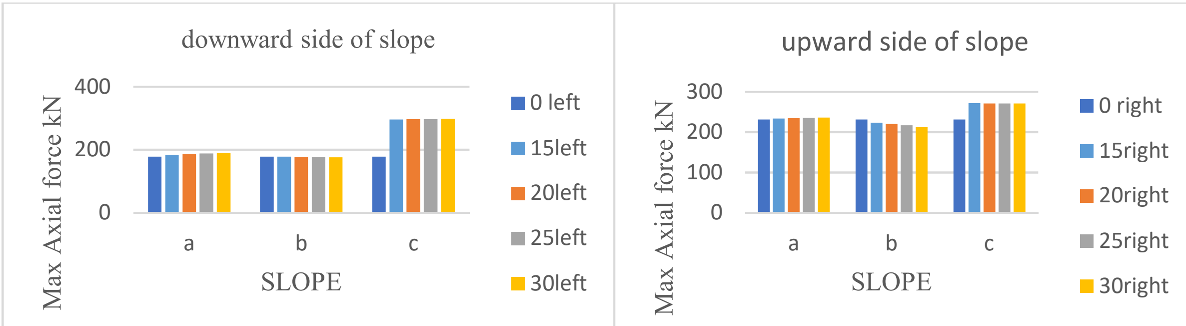
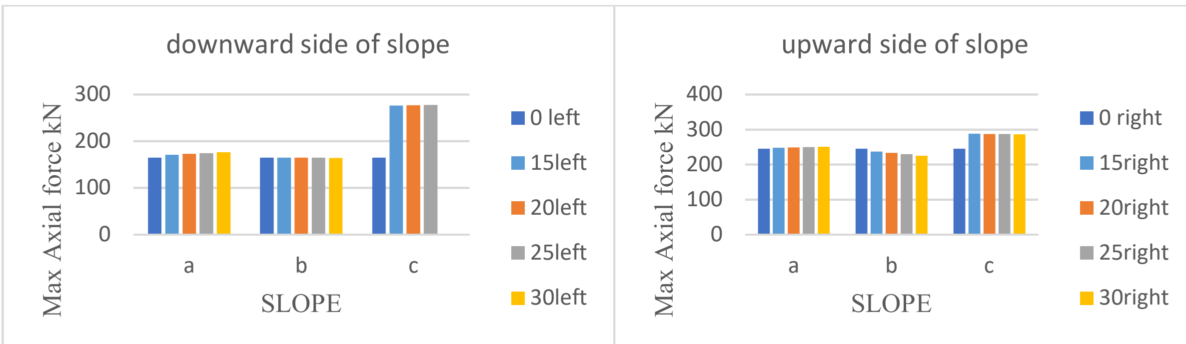


Figure 9-Comparison of max AF in column of bare frame and infill frame

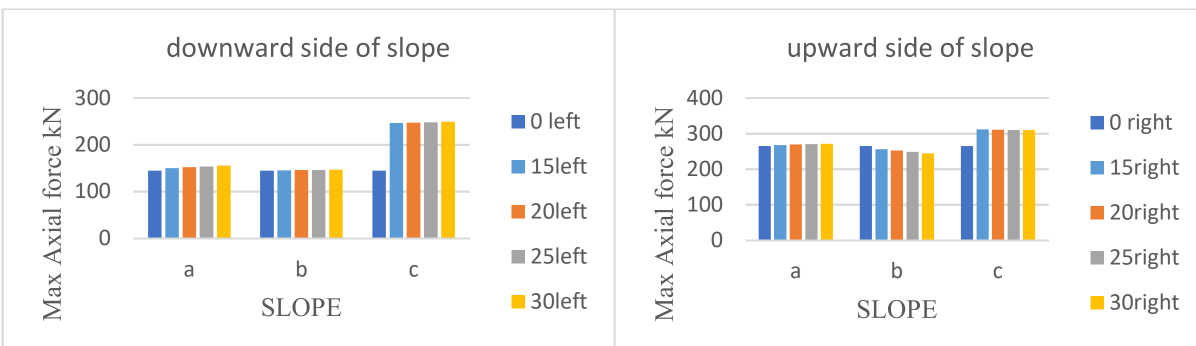
Referring to Figure 9, Max axial force of bare frame is lesser compared to infill frame. The Max axial force of column of bare frame (0BF) compared to infilled frame (0IF) increases from 181.88kN to 231.28kN (27%) for the zone 3 similarly for zone 4 & zone 5 it increases from 189.75kN to 244.59kN (29%) and 201.55kN to 264.55kN (31%) respectively.



a. ZONE 3



b. ZONE 4



c. ZONE 5

Figure 10- Comparison of Max AF in columns of infill frames of a, b and c resting on different slope of the ground for different seismic zones

From Figure 10, It is observed that the axial force in the column on the upward side of slope is drastically higher compared to the column on the downward side of the slope in all IFa, IFb and IFc. For typical case of IFa the axial force in column on downward side compared to column on upward side of 15º, 20º, 25º and 30º slope of ground axial force is higher by 27% to 24%. Similar observation are observed in infill frame IFb and IFc.

Axial force in the columns on the downward or upward side between the IFa and IFb there is not much difference in axial force, however actual force in infill frame IFb is less compared to IFa. The axial force in IFb compared to IFa resting on 15º, 20º, 25º and 30º slope decreases by 3.7% to 7.5% for downward side of slope and 0.04% to 0.1% for upward side of slope.

The axial force in IFc compared to IFa and IFb resting on 15º, 20º, 25º and 30º slope is drastically higher when compared to column on upward side of slope. This shows that the affect of soft story is more on the column on the downward side of the slope compared to frame with infill.

With increase in slope of ground there is a marginally increase in the axial force in both the column of downward and upward side of slope of the infill frame IFa, IFb and IFc but axial force in column on upward side of slope of IFb shows the decrease in axial force in column but it is marginal.

As zone changes the Max axial force in the downward side of slope (left) column of infill frame of models a, b, c and d decreases with increasing zones at average of 6.5% to 12%.

As zone changes the Max axial force in the upward side of slope (right) column of infill frame of models a, b, c and d increases with increasing zones at average of 5.8% to 8.3%.

d) Bending moment in beam

A bending moment is the reaction induced in a structural element when an external force or moment is applied to the element, causing the element to bend. The most common or simplest structural element subjected to bending moments is the beam.

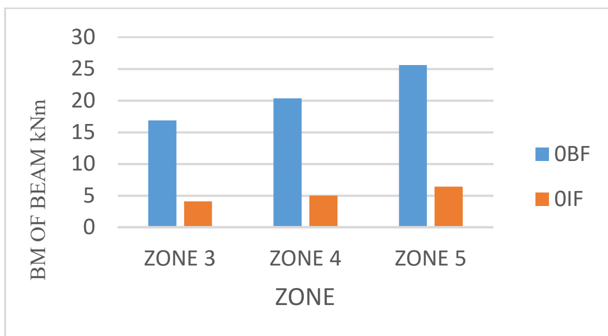
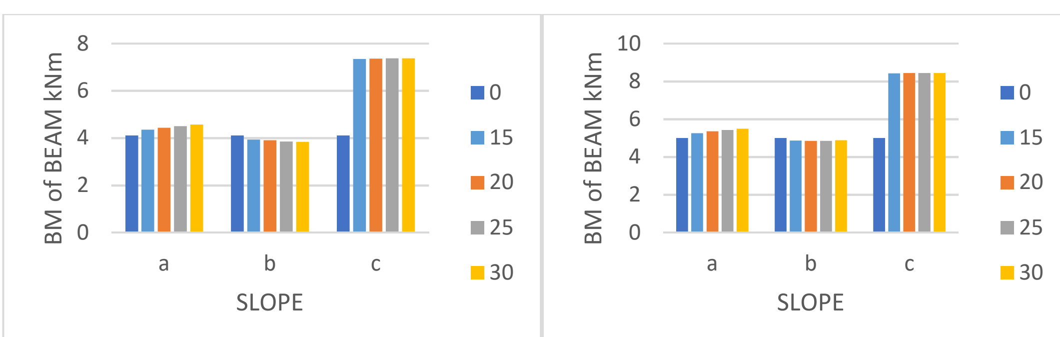
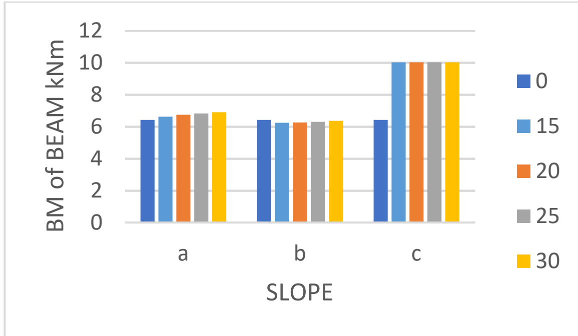


Figure 11-Comparison of bending moment in beam of bare frame and infill frame

Referring to Figure 11, bending moment of beam of bare frame is very high compared to infill frame. The bending moment of beam of infilled frame (0IF) compared to bare frame (0BF) reduces drastically from 16.87 kN-m to 4.105 kN-m (75%) for the zone 3, similarly for zone 4 & zone 5, the bending moment of beam reduces from 20.36 kN-m to 4.995 kN-m (75%) and 25.61 kN-m to 6.33 kN-m (75%) respectively.



a. ZONE 3 b. ZONE 4



c. ZONE 5

Figure 12- Comparison of BM in beam of infill frames of a, b and c resting on different slope of the ground for different seismic zones

From Figure 12 the bending moment in beam with increase in slope of ground increases in the infill frame IFa and IFc, whereas in the infill frame IFb decreases for zone 3 and increases for zone 4 and zone 5. This may be due to the difference in height of a column on the downward side of the slope and upward side of the slope. In infill frame IFa the height of column on the upward side of the slope is kept constant whereas the height of the column on the download side of the slope is kept constant in the frame IFb the area of infill frame and height of the column (upward side of a slope) in the first storey is less than in the frame IFb compared to IFa.

In infill frame IFc both the columns on downward and upward side of the infill frame is kept constant by providing beam at the first story level creating a soft story in the triangular portion of the slope. The presence of soft story in the triangular portion of the slope below the first story increases the bending moment in beam drastically compared to infill frame IFa and IFb as infill frame IFa and IFb has infill in the triangular portion of the slope making first story as a whole infill frame without creating a soft story.

When compared to infill frame resting on plain ground the infill IFa increases marginally with increasing in slope of a ground for 15^o, 20^o, 25^o and 30^o compared to plain ground the bending moment in beam increases by 6% to 11.3% but for IFb decreases marginally with increasing in slope of a ground by 4% to 6.5%. But the infill frame IFc increases drastically with increasing slope of a ground for 15^o, 20^o, 25^o and 30^o compared to plain ground the bending moment in beam increases by 79% to 79.5%. The increase in bending moment in beam in IFc compare to IFa and IFb at 15^o, 20^o, 25^o and 30^o slope is higher by 68.9% to 61.2% for IFa and 86.5% to 91.9% for IFb respectively. In infill frame IFc with increase in slope the bending moment in beam increases similar to IFa,

With the increase in zone 3 to 4 and 4 to 5 the bending moment in beam of IFa, IFb and IFc increases by 21% to 26%, 26% to 30% and 14% to 19% respectively for every increasing in slope.

6. CONCLUSION

- In infill frame IFa the height of column on the upward side of the slope is kept constant whereas the height of the column on the download side of the slope is kept constant in the frame IFb. Due to this the area of infill frame and height of the column in the first storey is less in the frame IFb compared to IFa so in infill frame IFb has less deformation, base shear and member forces compared to IFa.

- In infill frame IFc both the columns on downward and upward side of the infill frame is kept constant by providing beam at the first story level creating a soft story in the triangular portion of the slope. The presence of soft story in the triangular portion of the slope below the first story increases the deformation, base shear and member forces drastically compared to infill frame IFa and IFb
- With increasing slope of ground for 15^o, 20^o, 25^o and 30^o the base shear and member forces in infill frame IFa and IFc increases, whereas in the IFb the deformation decreases but base shear and member forces increase.
- Similar behaviour as explained above is observed in models IFa, IFb and IFc and in all zones however the magnitude of forces increases by an average 50% with increase in zone from zone 3 to zone 4 and zone 4 to zone 5.
- Hence from the study we can conclude that the presence of soft storey affects the performance of infill frame drastically, and between IFa and IFb, in IFb the presence of less area in the infill frame in the bottom storey compare to higher storey performs better than IFa.

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