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Static Linear and Nonlinear Analysis of R.C Building on Sloping Ground with Varying Hill Slopes

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ABSTRACT: *Earthquake field investigations repeatedly confirm that irregular structures suffer more damage than their regular counterparts. This is recognized in seismic design codes, and restrictions on abrupt changes in mass and stiffness are imposed. Irregularities in dimensions affect the distribution of stiffness, and in turn affect capacity, while mass irregularities tend to influence the imposed demand. Elevation irregularities have been observed to cause story failures due to non-uniform distribution of demand-to-supply ratios along the height. Plan irregularities, on the other hand, cause non-uniform demand-to-capacity ratios amongst the columns. In this paper the structure chosen for study is a 4, 5 storied commercial complex building. The building is located in seismic zone IV on a rock soil site. Three dimensional mathematical models for the same are generated in ETABS software. The structural elements, M40 grade of concrete, floor diaphragms are assumed to be rigid. Seismic loads were considered acting in the horizontal direction along either of the two principal directions and the ground slope choosen in between 0° and 25° and building that which produce less torsion effect for setback - stepback with irregular configuration in horizontal and vertical direction is modeled and analyzed.*

KEYWORDS: *Setback-Stepback, Static linear analysis, Static Nonlinear Analysis ,Base shear, Target displacement, Hinge Status*

I. INTRODUCTION

In many parts of India it is a common practice to construct buildings on hill slopes, if there is a natural hill sloping terrain. The building on a sloping terrain undergo severe torsion under earthquake excitation due to considerable variation in the height of ground floor columns .Buildings constructed on hill slopes are highly unsymmetrical in nature. The scarcity of plain ground in hilly areas compels construction activity on sloping ground resulting in various important buildings such as reinforced concrete framed hospitals,colleges,hotels and offices resting on hilly slopes. Since the behavior of building during earthquake depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings, both of which vary in case of hilly building with irregularity and asymmetry due to stepback –setback configuration .Such constructions in seismically prone areas makes them exposed to great shears and torsion as compared to conventional buildings.

Hence, while adopting practice of multistorey buildings in these hilly and seismically active areas, utmost care should be taken for making these buildings earthquake resistant.

Every structure is subjected to elastic and inelastic behavior .Since inelastic behavior is intended in most of structures subjected to infrequent earthquake loading , the use of nonlinear analysis is essential to capture behavior of structures under seismic effects .Due to simplicity, the structural engineering profession has been using the nonlinear static procedure (or)Pushover analysis, described in FEMA-356 and ATC-40 .It is widely accepted that ,when pushover analysis is used carefully, it provides useful information that cannot be obtained by linear static or dynamic analysis procedures. In the implementation of pushover analysis, modeling is one of the important steps. The model must consider nonlinear behavior of structure/ elements .Such a model requires the determination of the nonlinear properties of each component in the structure that are quantified by strength and deformation capacities.

II. OBJECTIVES

The objective of this work is to study the linear, nonlinear behavior and performance of building frame on sloping ground depends on various hill slopes and number of stories. The objective of study is as follows:

1. To study the variation of base shear, displacement, drifts with respect to variation in various hill slopes
2. To study the target displacement, performance i.e. plastic hinges formation in various hilly slopes. And finding the angle that subjected to less torsion and which is safe in increasing the height of building.

III. LITEARTURE REVIEW

Mr.Satish Kumar and Mr.D.K.Paul have presented the methodology of analysis for irregular buildings with rigid floor system where center of mass and center of stiffness of each floor lie on different vertical axes .A.K.Jain evaluated the eccentricity distribution for floor eccentricity and storey eccentricity for different types of lateral load distribution along the height of the building. Mr.B.G.Birajdar and Mr. S.S.Nalawade presented the results obtained from seismic analysis performed on three different configuration.viz. Stepback building, Setback building, Stepback-Setback building. 3-D analysis including torsional effect has been carried out by using response spectrum method. It has been found that combination of stepback –setback building was less affected by torsion as compared to stepback building. Hence they observed that Stepback-Setback buildings are found to be more suitable on sloping ground.

IV. ANALYSIS METHODS

Static analysis methods are broadly classified as linear static and nonlinear static analysis .In linear static analysis will produce the effect of the higher modes of vibration and the actual distribution of forces in the elastic range i.e, which the response of building is assumed as linear elastic manner .This analysis is carried out as per IS1893-2002(Part-1) Nonlinear static analysis is an improvement over linear static and linear dynamic analysis in the sense that it allows the inelastic behavior of the structure .The nonlinear analysis of a structure is an iterative procedure .It depends on the final displacement ,as the effective damping depends on the hysteric energy loss due to inelastic deformations h in turn depends on the final displacement .This makes the analysis procedure iterative. Difficulty in the solution is faced near the ultimate load, as the stiffness matrix at this point becomes negative definite due to instability of the structure becoming a mechanism. Software available to perform nonlinear static analysis as ETABS,(Extended Three Dimensional Building System) and Structural Analysis Program finite element program that works with complex geometry and monitor deformations at all hinges to determine ultimate deformation. It has built-in defaults for ACI 318 material properties and ATC-40and FEMA 273 hinge properties. Also it has capability for inputting any material or hinge property. ETABS 9.7 deals with the buildings only. The analysis in ETABS 9.7 involves the following four step.1) Modeling,,2) Static analysis, 3)Designing, 4)Pushover analysis Steps used in performing.

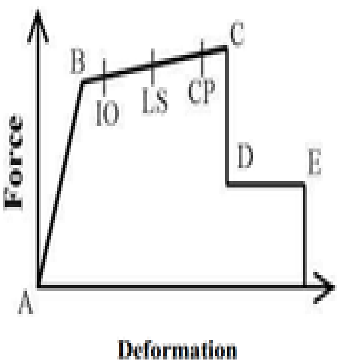


Fig A. Graph shows the curve Force Vs. Deformation

1. Point A corresponds to unloaded condition.
2. Point B represents yielding of the element.
3. The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strength degradation begins.
4. The drop from C to D represents the initial failure of the element and resistance to lateral loads beyond point C is usually unreliable.
5. The residual resistance from D to E allows the frame elements to sustain gravity loads. Beyond point E, the maximum deformation capacity, gravity load can no longer be sustained.

PLASTIC HINGE MECHANISM : In deciding the manner in which a beam may fail it is desirable to understand the concept of how plastic hinges form where the beam is fully plastic. At the plastic hinge an infinitely large rotation can occur under a constant moment equal to the plastic moment of the section. Plastic hinge is defined as a yielded zone due to bending in a structural member at which an infinite rotation can take place at a constant plastic moment Mpof the section. The number of hinges necessary for failure does not vary for a particular structure subject to a given loading condition, although a part of a structure may fail independently by the formation of a smaller number of hinges. The member or structure behaves in the manner of a hinged mechanism and in doing so adjacent hinges rotate in opposite directions. Theoretically, the plastic hinges are assumed to form at points at which plastic rotations occur. Thus the length of a plastic hinge is considered as zero. The values of moment, at the adjacent section of the yield zone are more than the yield moment up to a certain length ΔL, of the structural member. This length ΔL is known as the hinged length. The hinged length depends upon the type of loading and the geometry of the cross-section of the structural member. The region of hinged length is known as region of yieldorplasticity.

Mechanism : When a system of loads is applied to an elastic body, it will deform and will show a resistance against deformation. Such a body is known as a structure. On the other hand if no resistance is set up against deformation in the body, then it is known as a mechanism.

Plastic moment condition: The bending moment at any section of the structure should not be more than the fully plastic moment of the section.

V. DESCRIPTION OF STRUCTURES.

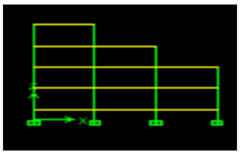
The structure choosen is of type setback –stepback which is 4 storied, 5-storied with different hill slopes varying from 0 to 25 degress.. The presence of abrupt reduction of the lateral dimension of the building at specific levels of the elevation. This building category is known as 'setback and stepback building'. The structure chosen material in which is subjected to less torsion effect.

Detailed data of buildings

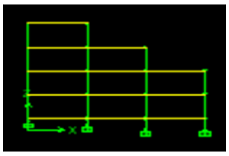
General details of building				
No of Storey				4 Storey,5Storey
Storey Height				Floor to Floor Height=3.5mts
				Plinth Height=1.75mts
Building frame system				OMRF
The concrete floors are modeled as				Rigid
Building use				Commercial Building
Foundation type				Stepped
Seismic Zone				IV
Soil Type				ROCK
Material Properties				
Grade of concrete				M40
Grade of steel				$415N/mm^2$
Youngs Modulus of M40 concrete,E				$5000\sqrt{fck}$
Density of concrete				$25KN/m^3$
Poison's ratio (of concrete)				0.2
Density of Brick masonary				$19KN/m^3$
Structural members				
Thick ness of Slab				0.12mts
All beam Size				For 4 storied=0.23*0.45mts
				For 5 storied=0.30*0.45mts
All Column Size				For 4 storied=0.23*0.50mts
				For 5 storied=0.30*0.50mts
Thickness of wall				Full brick wall=0.230mts
				Half brick wall=0.115mts
Assumed Dead load intensities				
Floorfinishes				$1.5KN/m^3$
Live load				$3KN/m^3$
Earthquake LL on slab as per Clause 7.3.1 and 7.3.2 of IS 1893(part-1)-2002				
Roof				$0 KN/m^2$
Floor				$0.25 \times 3.0 = 0.75kN/m^2$
EARTHQUAKE PARAMETERS				
Time period T				$0.09h/\sqrt{d}$
Importance factor				1
Sa/g				1/T,2.50
Response Reduction Factor				3
LOAD CASES FOR PUSHOVER ANALYSIS				
Pushover cases	Names	Loads	Controlled by	
1	Gravity	DL+0.25LL	Forces	

2	PUSH X	EQX	Displacements	
3	PUSHY	EQ	Displacements	

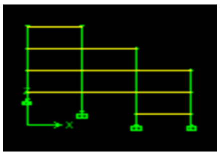
SKETCHES



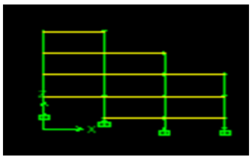
4-BAY 0^0



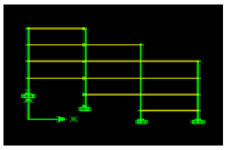
4-BAY 5^0



4-BAY 10^0



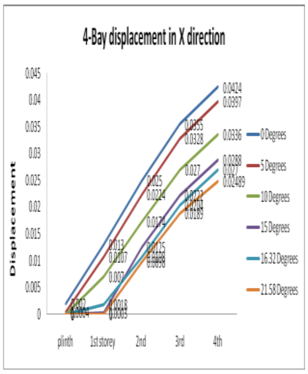
4-BAY 16.32^0

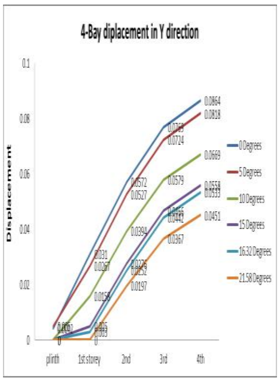


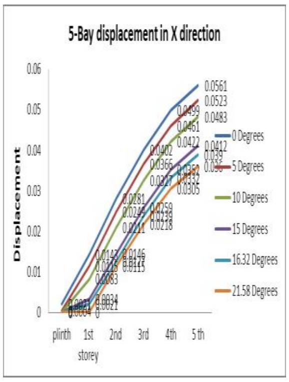
4-BAY21.58^0

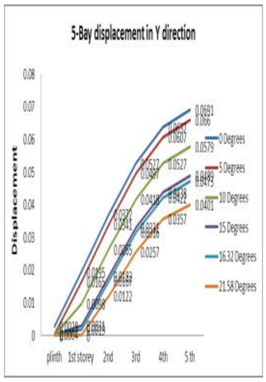
FIGURES AND TABLES FROM STATIC LINEAR ANALYSIS

DISPLACEMENTS

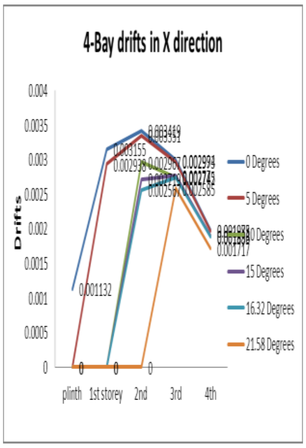


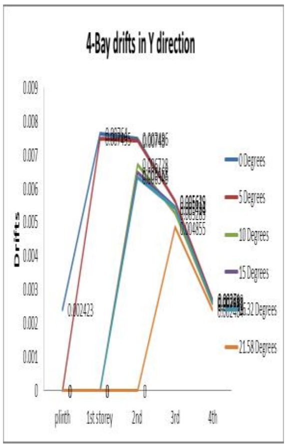


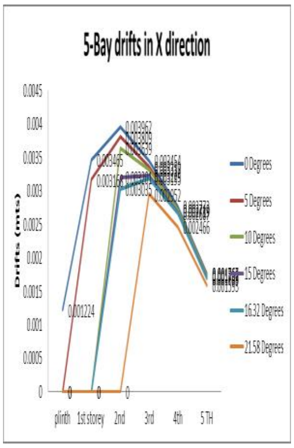


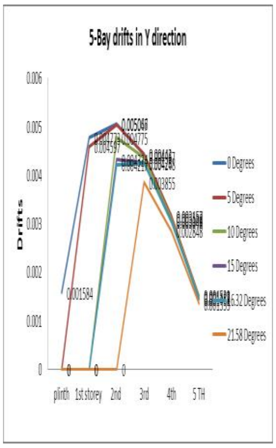


DRIFTS

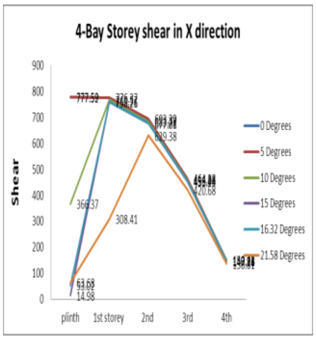


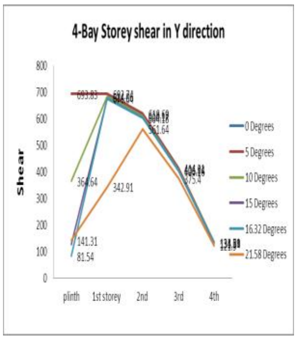


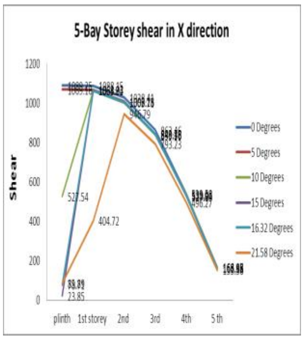


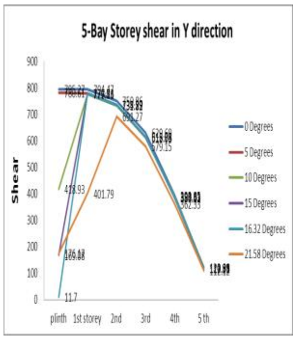


STOREY SHEARS

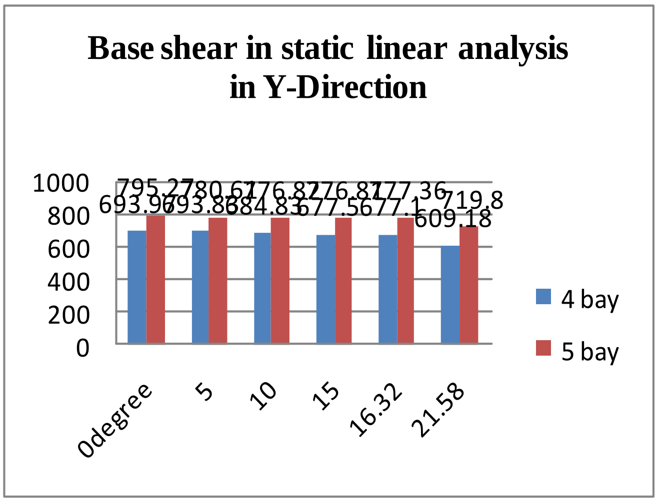


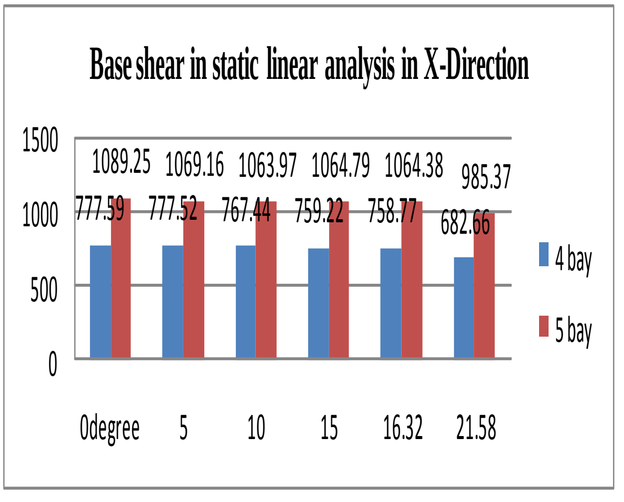






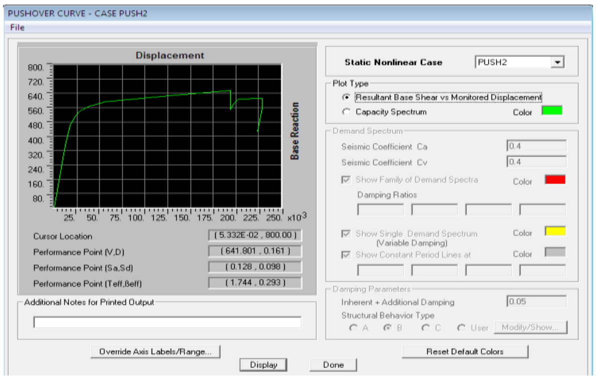
BASE SHEAR

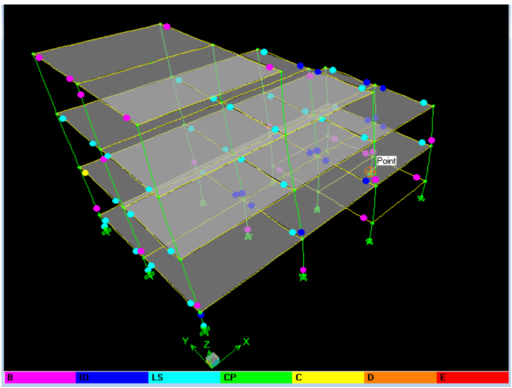

Base shear in static linear analysis in Y-Direction
1000
800
600
400
200
0
795.27
693.96
719.8
609.18
4 bay
5 bay
Odegree
5
10
15
16.32
21.58


Base shear in static linear analysis in X-Direction
1500
1000
500
0
1089.25
1069.16
1063.97
1064.79
1064.38
985.37
777.59
777.52
767.44
759.22
758.77
682.66
4 bay
5 bay
Odegree
5
10
15
16.32
21.58

TABLES FROM NONLINEAR STATIC ANALYSIS

X-DIRECTION **Y-DIRECTION**





HINGE PERFORMANCE OF STRUCTURE **m PUSHOVER CURVE IN X- DIRECTION**

V. CONCLUSION

[1] The performance of reinforced concrete frames was investigated using the pushover analysis

[2] From this analysis the observations are as the angle of slope increases base shear increases and displacement decreases.

[3] The base shear acts more in longitudinal direction than in transverse direction.

[4] It is observed that left columns, which are on the higher side of the sloping ground and are short, are most affected. Special attention is required while designing short columns.

[5] As the slope increases no of hinges will decreases.

[6] From this we observed that for 15, 16.32 degrees are safe upto 5- bay .But as the bay increases more no of hinges are to be formed and subjected to collapse region.

[7] In static linear analysis we observed that as the angle of slope increases storey shear decreases and base shear decreases

MODELS	TARGET DISPLACEMENT(mm)	BASESHEAR (KN)	PERFORMANCE LEVEL	NO OF HINGES
4-Bay 0^0	128	546.409	LS-CP	382
5^0	126	546.5862	LS-CP	382
10^0	119	569.034	C-D	356
15^0	105	603.184	LS-CP	330
16.32^0	96	612.650	LS-CP	330
21.58^0	101	596.305	C-D	304
MODELS	**TARGET DISPLACEMENT(mm)**	**BASESHEAR(KN)**	**PERFORMANCE LEVEL**	**NO OF HINGES**
5-Bay 0^0	141	646.88	LS-CP	474
5^0	137	646.8	LS-CP	474
10^0	133	657.660	A-B	448
15^0	123	698.460	LS-CP	422
16.32^0	114	703.851	LS-CP	422
21.58^0	121	702.473	D-E	396

[8] As the angle of slope increases displacement and drifts decreases.

[9] For the buildings studied, it is found that the plastic hinges are less in case of buildings resting on sloping ground as the slope increases. Most of these elements are in the range of LS-CP and some of the elements lie in the range of C-D which indicates failure of elements lies in the range of collapse point increases the seismic vulnerability of the structure and such elements which are in LS-CP state requires retrofitting

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