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SEISMIC RESILIENCE AND SAFETY OF STEP-BACK AND SET-BACK RC FRAME BUILDINGS ON SLOPING GROUND: A COMPARATIVE STUDY OF VULNERABILITY

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ABSTRACT :
Buildings are erected on sloping hills greatly; they have irregular shape, mass and stiffness, thus prone to earthquake. This paper aims at investigating the performance of RC buildings situated on hilly ground with concern to step-back (SB) and step-back setback (SB-SB) building patterns. The investigation focuses on the deficiencies of structures constructed on hill sides particularly under earthquake loads, and possible approaches towards enhancing their performance under those loads. Analytical modeling was carried out in the ETABS 2018 software for 24 G+5 RC framed building models subjected to different slope angles and seismic zones. Key parameters such as inter-story drift ratio, peak floor acceleration, peak roof displacement, and torsional responses were analyzed. Furthermore, the performance comparison of various positions of the shear walls for the building under consideration was also evaluated for understanding the extent of improvement in structural stiffness and displacement control.
It such findings from post-earthquake reconnaissance from events such as the Sikkim (2011) and Nepal (2015) earthquakes highlighted damages on RC buildings on slopes, there is now a clear need to undertake more focused studies on these structures. Hillside building arrangements include step back building configuration, suspending building configuration, step back setback building configuration and suspending setback building configuration. It is these that manifest seismic behavior different from that characteristic of building and structures in level ground mainly due to the side and irregular spatial distribution of mass and stiffness. The study uses AutoCAD in designing structures and mechanics of earth slopes in analysing stabilities of terrain. Furthermore, the configurations static and dynamic designs (response spectrum) for an X force and force in Y direction were assessed regarding seismic actions.
The findings underscore the critical role of shear walls in mitigating seismic vulnerabilities. Bare-frame structures exhibited significant displacements and drift, while the inclusion of shear walls notably improved seismic performance. The analysis further revealed that step-back setback configurations are better suited for hilly terrains due to their relatively balanced structural responses. The study contributes to the understanding of hillside building behavior under seismic loads and provides practical recommendations to enhance their safety and resilience, reducing potential loss of life and property during earthquakes.
Keywords: Step back building, Setback building,inter-story drift ratio, peak floor acceleration, peak roof displacement, and torsional responses.

INTRODUCTION :
Earthquake induced damages to structures are unavoidable. But it can be reduced by observance of seismic design provisions [2]. The structures are generally constructed on level ground but because of scarcity of level grounds the development activities are started on sloping grounds. Multi-storeyed R.C. framed buildings are decent popular in hilly areas as a result of increase in land cost and under sunless circumstances due to inadequacy of land in urban areas. Thus, many of them are constructed on hilly slopes. Set back & Step Back-Set back buildings are quite common on hilly slopes [3].Thus, the risk factor of those irregular structures increases abruptly as even the base of those structures becomes inclined at slope. This deadly combination of geometrical irregularity, mass irregularity, stiffness irregularity and torsional response makes the structures too much weak to survive during earthquake. Hence, it is important to study the responses of such buildings to make such buildings

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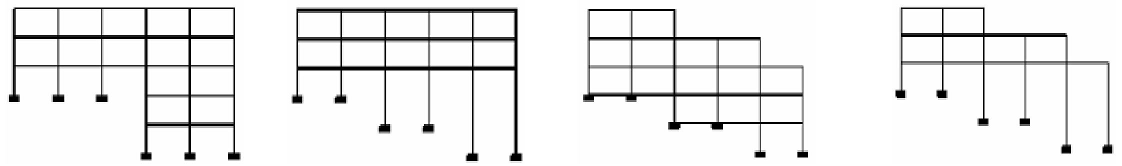
earthquake-resistant and prevent their collapse to save the loss of life and property [1]. It was found that open ground storey buildings were highly vulnerable to shear generated during strong earthquakes and those were relatively flexible in the ground storey. The effect of vertical irregularities on multi-storeyed buildings under dynamic load using linear static analysis and observed torsional response due to vertical irregularity. The seismic response of three different configurations of buildings situated on sloping ground and found that step back set back buildings were more suitable on sloping ground and also investigated the deficiency of soft storeyed structure in both linear static and linear dynamic method. It was then recommended that the use of shear walls in the soft storey to mitigate its failure by increasing its stiffness and controlling its dis placement and drift excellently [22-24].Step back (SB) and split-foundation (SF) are examples of reinforced concrete (RC) building configurations commonly found in hilly areas. These configurations have their foundations at two or more levels to match the natural ground slope. Sikkim (2011) and Nepal (2015) earthquakes were few such events when practitioners realized that even after using the reinforced concrete, buildings constructed over slopes faced severe damages [14-16].The hillside building structures are usually divided into four categories, i.e., step back building (Fig.1a), suspending building (Fig.1b), step back-set back building (Fig.1c), suspending-set back building (Fig.1d), depending on the mode of connection between foundation and soil and the mode of setback [11].The performance of RC buildings with unplanned infill walls was reported to be very poor, as the infills faced acute cracking at the corners or collapsed. After a few such post-earthquake reconnaissance observations, several studies were performed to ascertain the behaviour of these building configurations. It was then established that their seismic behaviour is quite different from the regular buildings on flat land owing to their irregular distribution of mass and stiffness. [15-18].



(a) Step back building (b) Suspending building (c) Step back-set back building (d) Suspending-set back building

Fig.1 Type of hillside building structures

The effect of infill in buildings on flat land has been explored widely, and it has been found that the infill increases the strength and stiffness of a framed building. However, the allocation of unplanned infill affects the torsional behaviour and the responses such as inter-story drift ratio (IDR), base shear, story shear, etc., of the buildings [19-21].

LITERATURE:

Auto CAD

All type of drawing is generally created in the AutoCAD software. This software gives the plan, elevation with different layers and colours for the easy understanding of drawing and good presentation for the users. Due to the AutoCAD the job for the engineer is make easy due to its working and better understanding and also easy to change the plan make faster because of layers and it provide too many options for working.

Numerical modelling of hilly buildings

Modelling of two hilly building configurations commonly discussed by various researchers were (i) step back (SB) and (ii) split-foundation (SF) which are considered. Step back and Split-foundation buildings were considered to be fixed initially additionally the number of floors below the uppermost foundation level is also considered. For each configuration, three different story ratios, i.e., (i) 0.5, (ii) 1.0, and (iii) 2.0, are to be considered. Here, the story ratio is the ratio of the number of stories above the uppermost foundation level (UFL) to the number of stories below this level. It can be

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noted here that the lowermost floor in the step back buildings is generally not accessible due to the natural slope or the presence of curtain walls. Therefore, the responses corresponding to the lowermost foundation level (LFL) are recorded at the corresponding node of the level above. A generic building plan is adopted for all the configurations. The buildings have bays of length 3.2 m each in the longitudinal direction and in the transverse direction with the external bay length and internal bay is numerically modelled [7].

Configuration of Building in Hilly Terrain

The Slope of the terrain is also to be considered using Mechanics of Earth Slope using If the equilibrium of the sliding wedge is to be maintained, the disturbing moment (W x d) must be opposed by the shearing resistance of the soil along the arc of failure. The failure surface is assumed as a part of a circle.

$$W \times d = S \times La \times r$$

Where, W = weight of soil of wedge BDCB of unit thickness BC = failure arc with r as the radius and O as the centre of rotation La = length of failure arc BC S = shear resistance, d = distance of line of action of W from the vertical line passing through the centre of rotation [5].

METHODOLOGY:

The proper modelling of the behaviour of materials, elements, connection and structure is very important. Therefore, it is important to select an appropriate and simple model to match the purpose of the analysis. So, the analysis is to be carried out by both Static & Dynamic (Response Spectrum) Analysis.The seismic force was applied in X- direction and Y-direction independently. Results have been obtained from Static and Dynamic (Response Spectrum) Analysis for different angle of slopes (23, 27, 31 degree) and plane ground in different seismic Zones (Zone III and Zone IV) using ETABS 2018 software [5].

The study analyses a total of twenty-four 3D analytical models of G+5 RC framed buildings using ETABS. The models will represent both step-back and step-back setback configurations at different slope angles (23, 27, 31 degree). The configurations will be analyzed both without shear walls (bare frame only) and with shear walls placed at corner spans and mid-spans to assess their impact on seismic behavior [3].

The analysis mainly focuses on effect and assessment of RC building with shear wall and without shear wall and its effect on inter-story drift ratio, dynamic characteristics of the building, peak floor acceleration, peak roof displacement, story shear and additionally assessment of Seismic performance, inter-story drift ratio, peak roof displacement, peak floor acceleration [7].

The analysis of seismic performance of different SF structures in across-slope direction focuses on the torsional effect of the typical SF structure in across-slope direction. The weakest part of the SF structure and destruction of that part under earthquake action additionally the effect of rigidity eccentricity of the structure essentially on the torsional effect of the SF structure based on the parametric and theoretical analysis. Identifies the demands difference in ductility between the upper ground columns and the lower part and effect on the rigidity eccentric of the SF structure in across-slope direction. In addition, the measures beneficial to the seismic performance of SF structures in both along-slope and across-slope directions are also summarized [6].

CONCLUSION:

This research observes the inherent risks of RC buildings constructed on slopes and further explains the structural behavior under seismic loads. Geometry, mass, and stiffness of the structures, due to inherent irregularity associated with hillside, exert tremendous influence on their seismic behavior; and thus are generally more vulnerable to destruction as opposed to those on flat terrains. Step-back and step-back setback building configurations were compared when bare frame construction or with shear walls integrated in the structure, at different slope angles and seismic zones. This research

incorporates a scientific modeling platform including ETABS 2018 to analyze and enhance the seismic performance of hillside building through structural planning in AutoCAD.
Including the shear walls was confirmed as the key parameter in increasing the stiffness of these structures as well as reducing displacement and drifts. The analysis shows stand back step back setback configuration to be superior to lateral stand back in terms of seismic load performance provided further complemented with the use of shear walls. Furthermore, the presence of torsional effects and the level of ductility requirements were revealed as two more essential parameters defining the split-foundation buildings' structural behavior. The research specifically focuses on the gap in the provisions of design requirements for structures on the hillside with responses to both along-slope and across-slope seismic forces.
Specific recommendations are as follows: - Location of shear walls at corner spans and mid-spans Balanced configuration such as the step back setback buildings, Coordination of terrain slopes at design stage. It should be noted that when these measures are applied and focus is made on the solutions for construction at slopes, then the use of RC buildings can be notably improved with reference to the reducing of risks that are connected with earthquakes. To engineers, architects, and policymakers, this study provides constructive reference towards designing and building safer and sustainable muscular structures on the hills with a reputation of progressing safer hilly urbanization.

REFERENCES :

[1]. Ghosh R, Debbarma R. Performance evaluation of setback buildings with open ground storey on plain and sloping ground under earthquake loadings and mitigation of failure. International Journal of Advanced Structural Engineering. 2017 Jun; 9:97-110.
[2]. Kaveh A, Zakian P. Optimal seismic design of reinforced concrete shear wall-frame structures. KSCE Journal of Civil Engineering. 2014 Nov; 18:2181-90.
[3]. Prajapati A, Parikh KB. PARAMETRIC STUDY ON STEP BACK & STEP BACK-SET BACK BUILDING ON SLOPING GROUND. Annals of the Faculty of Engineering Hunedoara-International Journal of Engineering. 2021 Feb 1(1)
[4]. Yang Y, Chen A, Yang T. Progressive collapse of the base-isolated frame structures supported by stepped foundation in mountainous city. Applied Sciences. 2022 Feb 18;12(4):2151
[5]. Chandak Narayan R, Onkar V, Achal A. Seismic Analysis Of Reinforced Concrete Buildings In Hilly Topography. Webology (ISSN: 1735-188X). 2021;18(06).
[6]. Xu G, Zhang R, Li A. Seismic performance and improvements of split-foundation buildings in across-slope direction. Advances in Structural Engineering. 2020 Mar;23(4):749-63.
[7]. Aggarwal Y, Saha SK. Seismic performance assessment of reinforced concrete hilly buildings with open story. InStructures 2021 Dec 1 (Vol. 34, pp. 224-238). Elsevier.
[8]. Subhash C, Sailesh A. Seismic performance of step back, step back set back and set back buildings in sloping ground base. Строительнаямеханикаинженерныхконструкций и сооружений. 2021;17(5):538-47.
[9]. Dangol A, Motra GB. Seismic Response of Buildings Resting on Hill Slope. InProc. 10th IOE Grad. Conf 2021 (Vol. 10, pp. 115-122).
[10]. Singh R, Sekhawat RS, Gupta T. Seismic Response of RCC Buildings on Hill Slopes with Step Back and Step Back-Set Back Configuration. Journal of Scientific Research and Reports. 2024 Feb 19;30(3):259-74.
[11]. Liu L, Wu C, Li Y, Zheng N, Xie Q. Seismic response of stepped building supported by stepped foundation on hillside. InProceedings of 16th world conference on earthquake engineering, Chile 2017.
[12]. Surana M, Singh Y, Lang DH. Seismic fragility analysis of hill-buildings in Indian Himalayas. InSECED Conference: Earthquake Risk and Engineering towards a Resilient World 2015 Jul.

[13]. Xiao Y, Li H, Chen J, Zhou T, Lumantarna E. Simplified Method for Analysis of Tall Buildings in an Earthquake. American Journal of Civil Engineering and Architecture. 2019 Nov 5;7(5):190-201.
[14]. Narayanan AV, Goswami R, Murty CV. Performance of RC buildings along hill slopes of Himalayas during 2011 Sikkim earthquake. EERI Newsletter, EERI Special Earthquake Report. 2012 Sep:1-4.
[15]. Sharma ML, Maheshwari BK, Singh Y, Sinvhal A. Damage pattern during Sikkim, India earthquake of September 18, 2011. In Proceedings of the 15th world conference on earthquake engineering, Lisbon, Portugal 2012 Sep 24 (Vol. 28).
[16]. Varum H, Dumaru R, Furtado A, Barbosa AR, Gautam D, Rodrigues H. Seismic performance of buildings in Nepal after the Gorkha earthquake. InImpacts and insights of the Gorkha earthquake 2018 Jan 1 (pp. 47-63). Elsevier.
[17]. Kumar S, Paul DK. A simplified method for elastic seismic analysis of hill buildings. Journal of earthquake engineering. 1998 Apr;2(02):241-66.
[18]. TatobaPatil R, Raghunandan M. Seismic performance assessment of buildings located on hillside slope.
[19]. Fardis MN, Panagiotakos TB. Seismic design and response of bare and masonry-infilled reinforced concrete buildings part II: infilled structures. Journal of Earthquake Engineering. 1997 Jul;1(03):475-503.
[20]. Das D, Murty CV. Brick Masonry infills in seismic design of RC framed buildings: Part 1- Cost implications. Indian Concrete Journal. 2004 Jul;78(7):39-44.
[21]. Aggarwal Y, Saha SK. Seismic Loss Estimation due to Damage of Structural Components for Buildings in Hilly Region. In17th World Conference on Earthquake Engineering 2020.
[22]. Murthy CV. Open Ground Storey RC Frame Buildings with 230 mm Columns unsafe during Earthquakes. InPublished in the National Seminar on Seismic detailing of RCC structures proceedings 2006 (pp. 1-30).
[23]. Khadiranaikar RB, Masali A. Seismic performance of buildings resting on sloping ground− A review. IOSR J MechCivEng (IOSR-JMCE). 2014;11(3):12-9.
[24]. Prashant D, Kori JG. Seismic response of one way slope RC frame building with soft storey. International Journal of Emerging Trends in Engineering and Development. 2013;3(5):311-20.