Article

Consideration of Irregularities in Reinforced Concrete Structures

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Abstract

Earthquakes are the most unpredictable and destructive natural phenomena, and it is very hard to save engineering properties from them. In order to avoid structural damage and collapse, the contribution of the lateral load resisting system, the number of stories, and the regularity of the structure must be carefully analyzed and evaluated. Therefore, in this article, all of the irregularities introduced by ASCE/SEI 7-19 were studied using 11 models, one with all of the regular configuration and ten with one irregular configuration, and at the end, all of the maximum storey displacement, maximum storey drifts, diaphragm max over average drifts, and stability index of the ten models were compared with the regular model for a better understanding of the behaviour of the irregularity in a structure. The result marks the conclusion that most of the irregularities had various outcomes compared to the regular model. The most unexpected result was with the mass irregularity model, that the structure behaviour got better with the mass irregularity on the top floor.

Keywords: Irregularities, RC Structures, Stability Index, Diaphragm max over avg drifts, Storey displacements.

Introduction

The failure in the multi-story building due to seismic loading generally occurs with the structure's symmetrical and compact shapes. The purpose of building regularity is to prevent unpredictable stress concentrations that can trigger local collapses and changes in dynamic behaviour. The experience of previous earthquakes, such as Mexico City 1986, confirms these results that irregularities are the primary cause of failure in most structures. [1]

Due to various economic factors, the urban region has experienced very rapid population growth in the last few decades, so there is an urgent need to assess the seismic vulnerability of buildings in Afghanistan's urban areas as an essential component of a comprehensive earthquake disaster risk management policy. Furthermore, this study aims to provide a better understanding of the various types of irregularities discovered by different researchers and their results for each form of irregularity.

2. Literature Review

Several studies have been performed on the seismic behaviour of reinforced concrete and steel structures. Many researchers have also investigated all of the effects of seismic response on a structure with vertical and horizontal irregularities.

A building is defined as torsional irregular if the maximum storey drift, including accidental torsion at one end of the structure, transverse to an axis, is more than four times the average of the storey drifts at the two ends of the structure. [2]

Re-entrant corner irregularity is defined as the existence of both plan projections of the structure beyond a re-entrant corner being greater than the plan dimension of the structure in the given direction. [2]

Diaphragm discontinuity irregularity is defined as existing where there is a diaphragm that has an abrupt discontinuity or variation in stiffness, including one that has a cut-out or opens in an area greater than of the gross enclosed diaphragm area or a change in effective diaphragm stiffness of more than one storey to the next. [2]

An out-of-plane offset irregularity is defined as an existence where there is a discontinuity in a lateral force resistance path, such as an out-of-plane offset of at least one of the vertical elements. [2]

Non-parallel system irregularity is defined as existing where vertical lateral force resisting elements are not parallel to the major orthogonal axis of the seismic force-resisting system. [2]

Stiffness-Soft storey irregularity is defined as existing where there is a storey in which lateral stiffness is less than 70% of that in the storey above or less than 80% of the average stiffness of the three stories above. [4]

Weight (mass) irregularity is defined as existing where the effective mass of any given storey is greater than the effective mass of the adjacent story. A roof that is lighter than the floor below need not be considered. [4]

Vertical geometry irregularity is defined as existing where the horizontal dimensions of the seismic force-resisting in any storey are more than 130% of those in an adjacent storey. [4]

In-plane discontinuity in vertical lateral force/resisting element irregularity is defined to exist where there is an in-plane offset of a vertical seismic/resisting element resulting in overturning demands on supporting structural elements.[4]

Discontinuity in lateral strength-weak storey irregularity is defined as existing where the storey lateral strength is less than 80% of that in the storey above. The storey lateral strength is the total lateral strength of all seismic-resisting elements sharing the storey shear for the direction under consideration. [4] According to the ASCE-SEI 7-16, weak storey irregularity is not allowed in seismic categories D through F. [5]

Purpose of Study

Over the last few decades, earthquakes have damaged a large number of houses, with irregularities being the primary cause of distraction in the majority of these structures. People moved to cities for a variety of reasons, and as the population of cities grows, so does the demand for high-rise buildings; however, as the building gets higher, the risk of damage increases, and the main cause of it is irregularity. The ASCE/SEI 7-16 (ASCE 2016) classification of irregularities divided them into two categories: vertical and horizontal. Therefore, this study is intended to examine all of the irregularities and compare the main results of the storey displacement, maximum storey drifts, diaphragm maximum over average drifts, and stability index parameters with a regular structure.

Highlighting the Problem

Earthquakes are the most unpredictable and destructive natural disasters, and it is very difficult to save engineering properties and people from them. The behaviour of a building during an earthquake is determined by several factors, including stiffness, sufficient lateral resistance, torsional sensitivity, ductility, and a simple and regular configuration. Buildings with regular geometry and evenly distributed mass and stiffness in plan and elevation experience much less harm than irregular structures. Therefore, it's necessary to have every design checked for each irregularity.

Methodology

The method under consideration for this study is based on existing structures. These ten-story structures are each deemed irregular according to ASCE 7-16, and these 11 structures will be linearly studied utilising Finite element methods in CSI-ETABS software. The structure configurations are given below:

- **Model-1:** This is a regular structure with no irregularities; a ten-story with a story height of 3 m. The building parameters are as follow:
  - The dimension of Columns is $500 \times 500\ mm$.
  - The dimension of Beams is $400 \times 500\ mm$.
  - The slab thickness is $150\ mm$.
  - Dead load is calculated at $230\ {kg_f}/{m^2}$ and live load is $200\ {kg_f}/{m^2}$.
  - The Concrete compressive strength is $28.1 Mpa$.
  - Rebar Tensile strength is $420 Mpa$.
  - Seismic site class D.
  - Structure important factor 1.25.
  - The load combinations are:
    - $1.4DL + 1.4LL$
    - $1.2DL + 1.6LL$
    - $1.3DL + 1.3LL + EX$
    - $1.3DL + 1.3LL - EX$
    - $1.3DL + 1.3LL + EPX$
    - $1.3DL + 1.3LL + ENX$
    - $1.3DL + 1.3LL + EY$
    - $1.3DL + 1.3LL - EY$
    - $1.3DL + 1.3LL + EPY$
    - $1.3DL + 1.3LL + ENY$
- **Model-2:** To illustrate torsional irregularity, this model includes two shear walls only in the X-direction of the building.
- **Model-3:** This model has an external corner that is greater than 15% of the other side of the structure, causing the reentrant-corner irregularity.

- **Model-4:** This type features openings from the fourth to the tenth floors of the structure. This leads to a diaphragm discontinuity irregularity.
- **Model-5:** To illustrate out-of-plane offset irregularity, this model features a discontinuity in shear walls defined in the model's x-direction.
- **Model-6:** This model is trapezoidal in shape and will result in non-parallel structure system irregularity.
- **Model-7:** This structure has variable story heights, for instance, the first and second-floor story heights are greater than the above stories. To show the stiffness irregularity.
- **Model-8:** This structure has a lot of mass on the top floor to get the maximum shear response and displacement. For instance, a swimming pool is added to the top story, making it heavier; the structure becomes irregular.
- **Model-9:** From the third level and up, this structure has discontinuous shear walls. Which leads to In-plane-discontinuity irregularity.
- **Model-10:** This model has varying shapes according to height, ranging from the fifth to the tenth floor, and it features vertical geometric irregularity.
- **Model-11:** The first two stories are weak in this type; no slab is introduced in these floors.

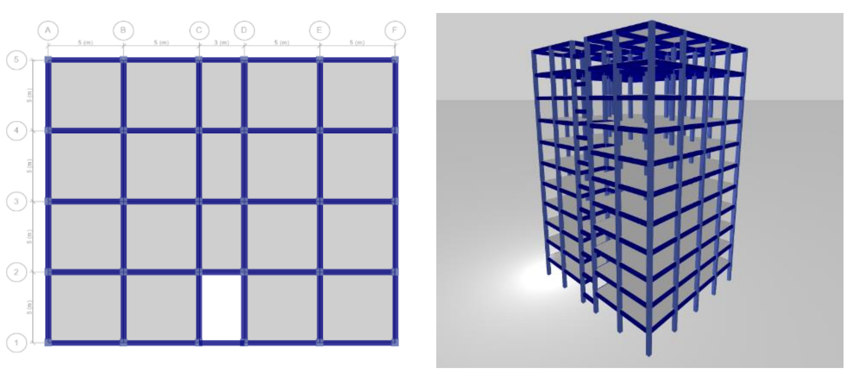

Figure:1 Model-1 Regular Model

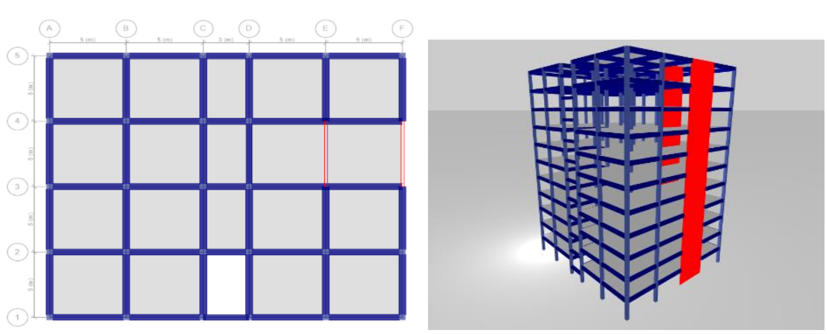

Figure: 2 Model-2 Torsional Irregular Model

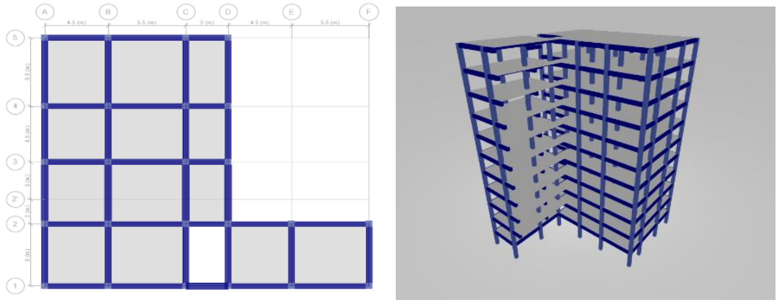

Figure:3 Model-3 Reentrant Corner Irregularity

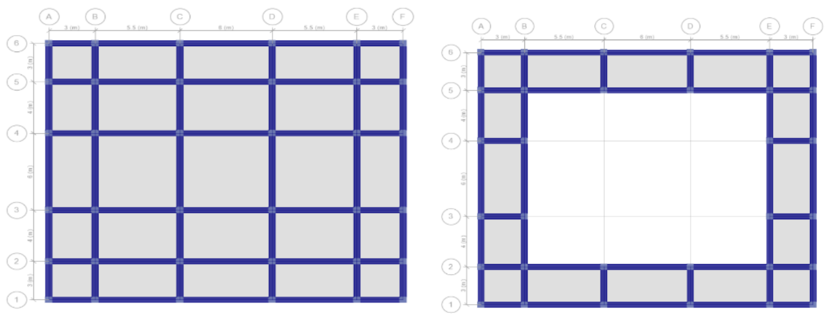

Figure: 4 Model-4 Diaphragm discontinuity irregularity Model

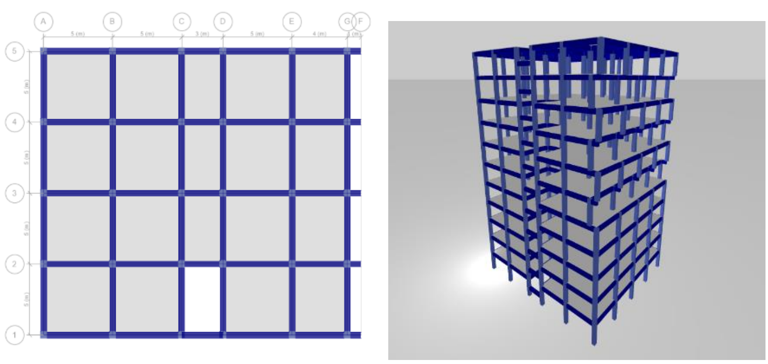

Figure: 5 Model-5 Out-of-Plane offset irregularity Model

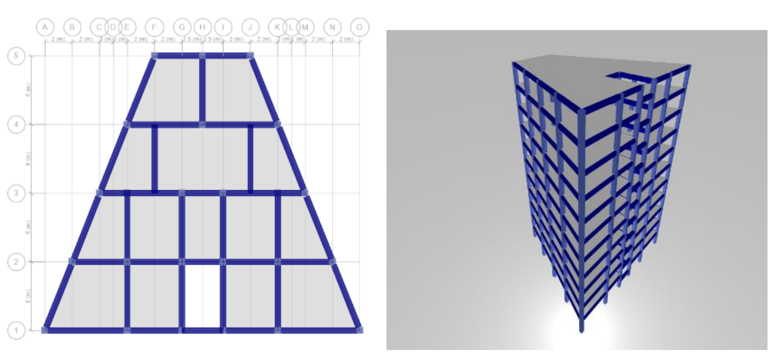

Figure: 6 Model- 6 Non parallel system irregularity Model

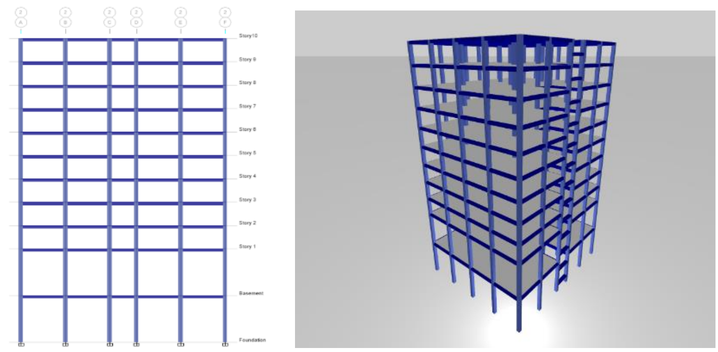

Figure: 7 Model-7 Stiffness irregularity Model

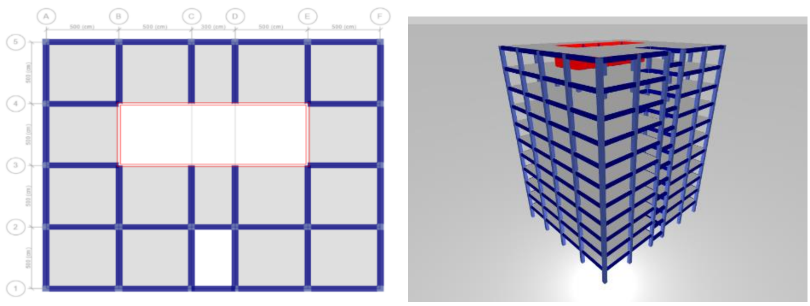

Figure: 8 Model-8 Mass Irregularity Model

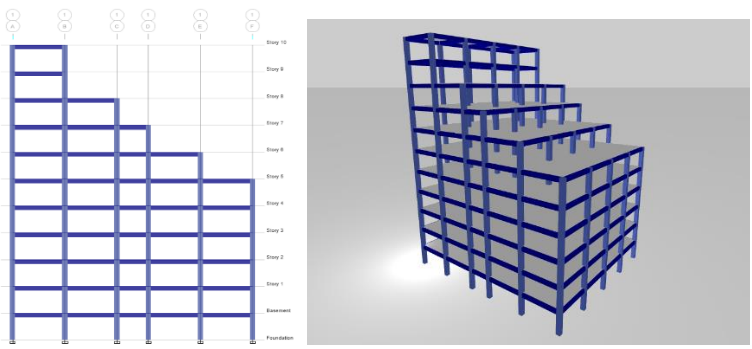

Figure: 9 Model-9 Vertical geometry Irregularity Model

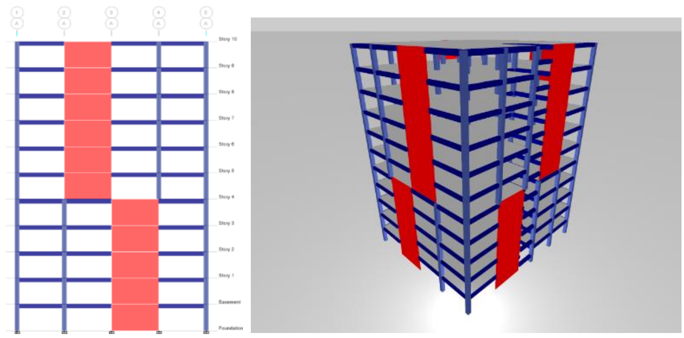

Figure: 10 Model-10 In-Plane-Discontinuity irregularity Model

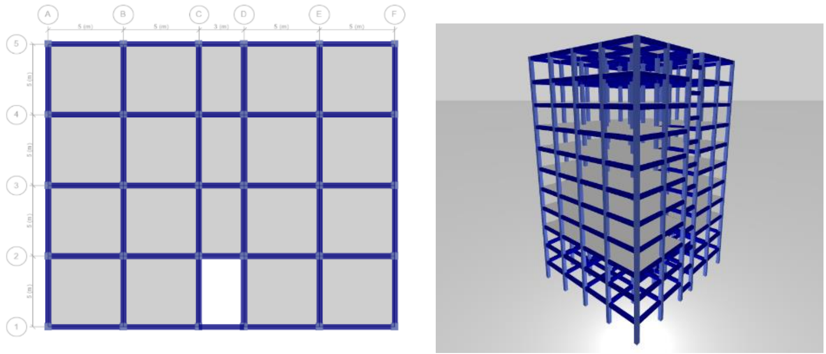

Figure: 11 Model-11 Weak-Story irregularity Model

Data Analysis and Results

It should be known that from all of the four parameters analysed and compared, which are maximum storey displacement, maximum storey drifts, diaphragm max over average drifts, and stability index, the graphical plots are as follows:

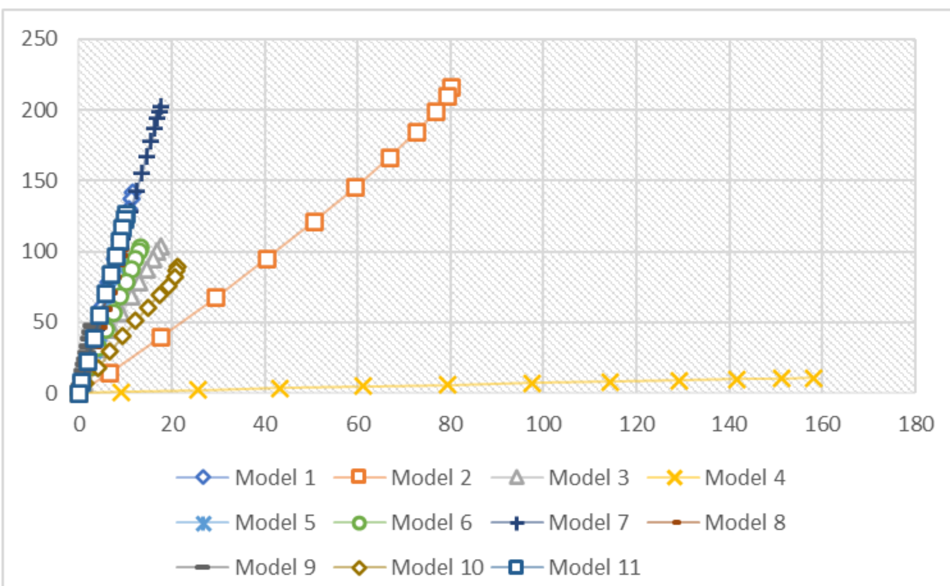

Figure:12 Maximum Story Displacement results

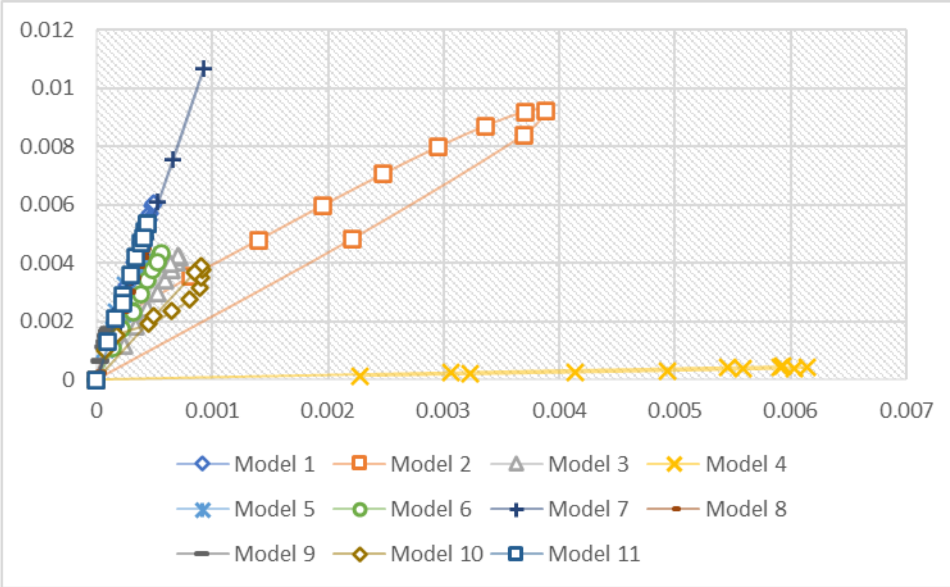

Figure:13 Maximum Story Drifts results

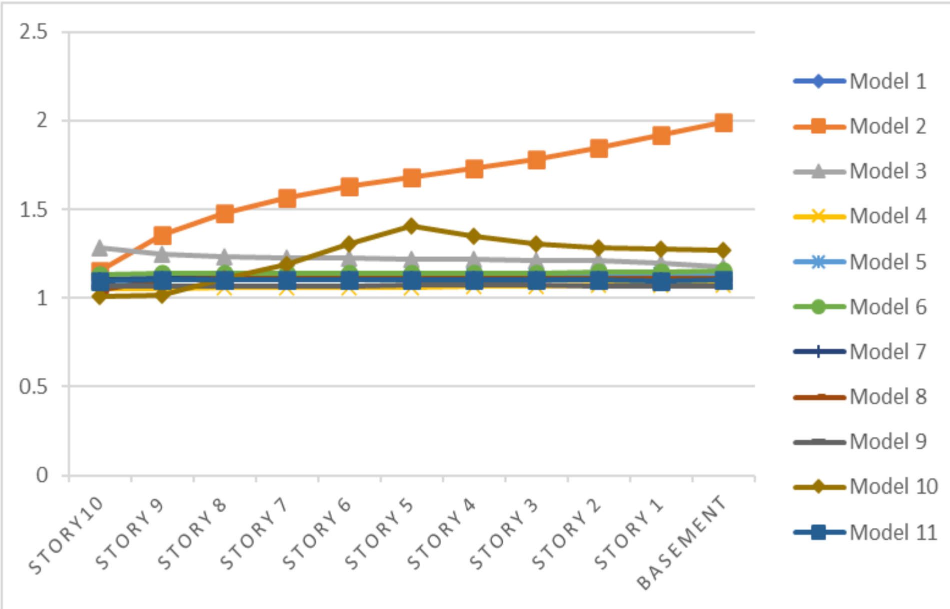

Figure:14 Diaphragm Max over avg drifts

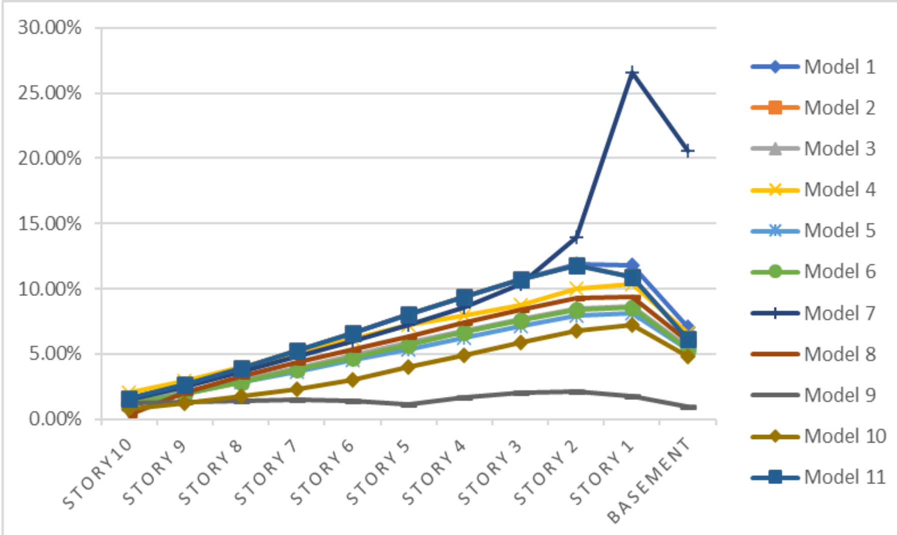

Figure:15 Stability Index results

- In the comparison of models 1 & 2 in allowable storey displacement, the maximum storey drifts are 0.009237 in the torsional irregular model, but the allowable drifts according to ASCE 7-16 are $\frac{0.002}{Cd}$ which is 0.00363. the check of the diaphragm max over avg drifts shows that it is more than 1.2 in model 2 the highest amount is 1.989 and this structure is considered extremely torsional irregular. The stability index is more than 10% in both of the structures.

- In the comparison of models 1 and 3, the storey displacements are within the permitted range, but in the reentrant corner, the storey drifts are greater than the allowable range, necessitating a considerable increase in the stiffness of the overall structure. The diaphragm max over average drifts differs somewhat, with the highest in storey 10 being 1.28. Furthermore, the stability index in the reentrant corner model is less than 10%. This structure is deemed unbraced, and p delta effects do not need to be taken into account.

- In the diaphragm discontinuity model, the maximum storey drifts in storey 2 are 0.00593, while the allowable storey drifts for this structure are 0.00363, and it is considered regular in torsional irregularity since the diaphragm max over average drifts ratio is less than 1.2. If the stability index in either structure is more than 10%, the P-delta effects should be addressed in the study.

- In the comparison of Models 1 and 5, the displacement of the model In-Plane-Offset is within the range, but the maximum storey drifts are within the range from the 5th floor and above, but not from the 5th level below. The first five stories in the diaphragm max over average drifts are considered irregular in torsion, whereas the second five stories, which are irregular in-plane offset but regular in torsional, have a ratio smaller than 1.2. The value of the stability index check indicates that the P-delta effects do not need to be addressed in model 5.

- The displacement of the non-parallel model is within the allowed range in the comparison of models 1 and 6. The maximum storey drifts, likewise, show no discernible difference from the regular structure. The examination of the diaphragm max over average drifts reveals that it does not produce torsional irregularity. It is also safe from torsion. The stability index check indicates that the P-delta effects do not need to be included in the analysis, and the narrative is classified as unbraced.

- In the comparison of models 1 and 7, the displacement is more than in the regular model but still within the range. Other than the preceding stories, the maximum storey drafts for the first two stories are quite high. The torsional irregularity is unaffected by increasing the structure's height. The stability index examination reveals that the stiffness difference might cause the structure to be unstable.

- In the comparison of models 1 and 8, the displacement in the mass irregularity has been improved; it has less displacement than the regular model. The maximum narrative drifts of the Model 8 are noticeably better than those of the regular model. Because of the increased mass, the building is more regular in torsion than a normal model. The stability index indicates that addressing the P-delta effects is not required for analysis if the structure should be done as an unbraced story.

- Models 1 and 9 are compared. Because of the four shear walls on the building's sides, the displacement of the structure reduces drastically in-plane discontinuities and irregularities. The maximum storey drifts are likewise reduced, and the structure is within the permitted range. Since the diaphragm max over average drift ratio is less than 1.2, the structure is considered regular in terms of torsional irregularity. Because the value of the stability index is less than 5%, the stories should be classified as bracing.

- In comparison to models 1 and 10, the vertical geometry irregularity and displacement of the structure are smaller in model 10, implying that the fewer the spans, the less displacement. The outcome of maximum storey drifts is also favourable and within the range. However, it creates a torsional irregularity in the structure since the diaphragm max over the average drifts is more than 1.2. The P-delta impact is negligible in the vertical geometry model, but it is recommended in the regular structure.

- In comparison to models 1 and 11, the soft storey irregularity model's lack of two-floor slabs might cause the structure's displacement to be smaller than that of the regular model. There isn't much of a difference in storey drifts. Both structures have values of less than 1.2 and are considered regular in torsion. The computation of P-delta effects is required.

Conclusion

This research studied the irregularity and considered all of the irregularities mentioned by ASCE-SEI 7-16. The problem was formulated as 11 models, with one model with a regular configuration and 10 models of irregular shapes. After the analysis using the ETABS software, the results were the maximum storey displacement, maximum storey drifts, diaphragm max over average drifts, and stability index. Most of the irregularities had various results compared to the regular model. The most unexpected result was with the mass irregularity model that the structure's behaviours got better with the mass irregularity on the top floor.

References

[1] A. M. Chandler, X.-N. Duan, and A. Rutenberg, "Seismic torsional response: assumptions, controversies, and research progress," *Eur. Earthq. Eng.*, vol. 10, pp. 37–51, 1996.

[2] American Society of Civil Engineers, "12.3.2.1 Horizontal Irregularity," in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, 7th ed., Reston, VA: American Society of Civil Engineers, 2017, p. 96.

[3] G. Özmen, K. Girgin, and Y. Durgun, "Torsional irregularity in multi-story structures," *Int. J. Adv. Struct. Eng.*, vol. 6, no. 4, pp. 121–131, Dec. 2014, doi: 10.1007/s40091-014-0070-5.

[4] American Society of Civil Engineers, "12.3.2.2 Vertical Irregularity," in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, 7th ed., Reston, VA: American Society of Civil Engineers, 2017, p. 96.

[5] American Society of Civil Engineers, "12.3.3.1 Prohibited Horizontal and Vertical Irregularities for Seismic Design Categories D through F," in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, 7th ed., Reston, VA: American Society of Civil Engineers, 2017, p. 97.

[6] G. Özmen, K. Girgin, and Y. Durgun, "Torsional irregularity in multi-story structures," *Int. J. Adv. Struct. Eng.*, vol. 6, no. 4, pp. 121–131, Dec. 2014, doi: 10.1007/s40091-014-0070-5.

[7] Zabihullah, P. Singh, and M. Z. Aryan, "Effect of (Vertical & Horizontal) Geometric Irregularities on the Seismic Response of RC Structures," *Int. J. Emerg. Technol.*, vol. 11(3), pp. 965–974, 2020.

[8] S. Naveen E, N. M. Abraham, and A. K. S D, "Analysis of Irregular Structures under Earthquake Loads," *Procedia Struct. Integr.*, vol. 14, pp. 806–819, 2019, doi: 10.1016/j.prostr.2019.07.059.

[9] American Society of Civil Engineers, "12.3.3.4 Increase in Forces Caused by Irregularities for Seismic Design Categories D through F," in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, 7th ed., Reston, VA: American Society of Civil Engineers, 2017, p. 97.

[10] P Sanketh and B. D. V. C. M. Rao, "Seismic Strengthening of Plan Irregular RC Building with Re-entrant corners using Sear walls," *Int. J. Res. Eng. Technol.*, vol. 05, no. 14, pp. 21–26, Feb. 2016, doi: 10.15623/ijret.2016.0514005.

[11] Reshma K Bagawan and M Q Patel, "Seismic Performance Study of RC Framed building with Diaphragm Discontinuity," *Int. J. Eng. Adv. Technol.*, 2018, doi: 10.13140/RG.2.2.30401.66402.

[12] R. Kadiyala and T. Kota, "Effect of Diaphragm Discontinuity of the Building," *Int. J. Res. Eng. IT Soc. Sci.*, vol. 06, no. 09, pp. 33–40, Sep. 2016.

[13] American Society of Civil Engineers, "12.3.3.3 Elements Supporting Discontinuous Walls or Frames," in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, 7th ed., Reston, VA: American Society of Civil Engineers, 2017, p. 97.

[14] American Society of Civil Engineers, "12.4.3 Seismic Load Effects Including Overstrength," in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, 7th ed., Reston, VA: American Society of Civil Engineers, 2017, p. 99.

[15] M. Santhosh and S. Pradeep, "Seismic Analysis and Design of Multi-Storey Building with Non-Parallel Shear Wall System," *Int. J. Eng. Manag. Res.*, vol. 4, no. 2, pp. 157–160, Apr. 2014.

[16] C. Chintanapakdee and A. K. Chopra, "Seismic response of vertically irregular frames: response history and modal pushover analyses," *J. Struct. Eng.*, vol. 130, no. 8, pp. 1177–1185, 2004, doi: 10.1061/~ASCE!0733-9445~2004!130:8~1177!

[17] C. M. R. Kumar, H. B. Manjunatha, T. M. Channappa, and M. H. Prashanth, "Seismic Performance Evaluation of Irregular RC Buildings with Mass Irregularity," 2011, [Online]. Available: https://www.researchgate.net/profile/Prashanth-M-H/publication/340273749_Seismic_Performance_Evaluation_of_Irregular_RC_Buildings_with_Mass_Irregularity/links/5e85c86ca6fdcca789e96132/Seismic-Performance-Evaluation-of-Irregular-RC-Buildings-with-Mass-Irregularity.pdf.

[18] D. Darshan and H. K. Shruthi, "Study on Mas Irregularity of High-Rise Buildings," *Int Res J Eng TechnolIrjet*, vol. 3, no. 8, pp. 1123–1131, 2016.

[19] D. Rana and J. Raheem, "Seismic Analysis of Regular & Vertical Geometric Irregular RCC Framed Building," *Int. Res. J. Eng. Technol.*, vol. 02, no. 04, p. 6, Jun. 2015.

[20] A. S. Bhosale, R. Davis, and P. Sarkar, "Vertical Irregularity of Buildings: Regularity Index versus Seismic Risk," *ASCE-ASME J. Risk Uncertain. Eng. Syst. Part Civ. Eng.*, vol. 3, no. 3, p. 04017001, Sep. 2017, doi: 10.1061/AJRUA6.0000900.

[21] American Society of Civil Engineers, "12.3.3.1 Prohibited Horizontal and Vertical Irregularities for Seismic Design Categories D through F," in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, 7th ed., Reston, VA: American Society of Civil Engineers, 2017, p. 97.

[22] S. E. Ruiz and R. Diederich, "The Mexico earthquake of September 19, 1985—the seismic performance of buildings with the weak first storey," *Earthq. Spectra*, vol. 5, no. 1, pp. 89–102, 1989.

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