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Pushover Analysis of a Reinforced Cement Concrete (RCC) Structure Incorporating Fibre-Reinforced Polymers to Address Vertical Irregularities

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Abstract: ***India has had four of the world's most destructive earthquakes in the past ten years, and our country is often rocked by earthquakes of low to moderate intensity. Since many buildings were severely damaged or collapsed, it has sparked debate whether framed constructions are sufficiently sturdy to withstand significant vibrations. As a result, the strength or ability of existing reinforced concrete structures to withstand seismic loads can be evaluated. The performance level of earthquake-prone buildings is evaluated using a performance-based design. One seismic technique for assessing a building's performance level is push-over analysis. It is possible to determine whether damage occurs at the member or structure level using pushover analysis. The study employs pushover analysis by Applied Technology Council (ATC) – 4), a seismic assessment technique, to evaluate the ability of 20-story buildings in seismic Zone III (with hard soil characteristics) to resist earthquake-induced forces. The primary objective was to assess the performance of structures reinforced with different fiber-reinforced polymer (FRP) materials, including aramid, glass, and carbon fibers, known for their high flexibility and strength in seismically active regions. To determine the best fiber-reinforced polymer configuration, the study considers the following parameters: pushover curve, target displacement, story shear, time period, maximum story displacement, and story drift based on pushover analysis independently. Through the pushover analysis method, the research discovers that FRP wrapping can significantly improve the seismic performance of reinforced concrete buildings. The findings aim to improve building design practices by recommending fiber-reinforced polymer configurations for better earthquake resistance, ensuring that future constructions are better equipped to handle seismic activity.***

Keywords: Target Displacement, Lateral Displacement, Carbon Fiber Reinforced Polymer (CFRP), Glass Fiber Reinforced Polymer (GFRP), and Aramid Fiber Reinforced Polymer (AFRP)

I. INTRODUCTION

The shaking of the earth's surface that occurs after a sudden release of energy in the crust is known as an earthquake. The earthquake puts RCC constructions at risk of collapsing.

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As a result, there are numerous fatalities, injuries, and financial losses. Buildings and high-rise structures are typically impacted by lateral motions brought on by earthquakes, which eventually compromise the structure's stability and trigger sideways collapse. Many conventional construction techniques are not very resistant to lateral stresses because structures are often built to withstand gravity loads. It has been demonstrated that strengthening these structures is a more practical and affordable short-term shelter option than replacing them. Therefore, a pushover analysis has been carried out to examine how well RCC-framed buildings will fare in future, unforeseen earthquakes.

Developing straightforward yet precise techniques to estimate seismic demand on structures while taking into account their inelastic behavior is the main challenge in performance-based engineering. Pushover analyses are unavoidably used in place of intricate, nonlinear time-history methods that are too complicated for general professional use. The process entails applying loads until the structure's weak point is identified, after which the model is updated to account for the structural changes brought about by the weak point. The structure is "pushed" once more in the second iteration until the second weak link is found. Until the entire structure reaches its yielding point, this process keeps going.

II. LITERATURE

A brief review of previous studies on the Pushover analysis of RCC Structure is presented. This literature review focuses to find out the behavior of the symmetrical and asymmetrical RCC structure with infilled with a single layer and double layer etc under earthquake [5]. Literature is helpful in understanding of previous studies carried out on particular topic [6].

Yurizka and Rosyidah (2020): - This research was conducted to determine the performance of the setback building with a soft first story due to the earthquake based on the results of the pushover analysis curve. 10 floor irregular structure with 1st floor as soft story which consists of 2 structural models with setback ratio of 0.3 and 0.6 of type 1 and type 2 building respectively. The results of the analysis of this study indicate that the maximum shear force based on capacity curves in type 1 is 50260.55 kN and type 2 buildings is 53560.49 kN. Buildings with smaller setback area ratios, i.e., type 2 buildings have displacement of 515.68 mm in the X direction and 558.105 mm in the Y direction. Story drift 0.0186 m in the X and 0.0043 in the Y direction. Performance of type 1 and type 2 building structures that refer to ATC-40 and FEMA 356 is at the Damage Control level [1].

Shinde et al. (2016): - The present study represents the seismic response of the vertical irregular building frame as compared to the regular building frame. There are various types of vertical irregularities. The building frame considered for this study that are irregular in elevation. Performed static nonlinear analysis on G+7 RCC building frame with and without vertical irregularity design and analysis software ETABSv9.5.0 as per the Indian Standard 456:2000 and 1893:2002. Structure having height of story as 3m, bay width is 4.5m along x-direction and 3m along Y-direction. The results of the analysis of this study indicate that the maximum shear force based on capacity curves in Model 1 is 2000.698 kN and Model 2 buildings is 827.97 kN. Models 1 have displacement of 0.187 m and Model 2 have displacement of 0.115 m. Story drift 0.001878 m and 0.003011 in the Model 1- and Model 2 respectively. The building frame with vertical irregularity having less performance point value as compared to the building frame without vertical irregularity [2].

Selim et al. (2015): - The present study is of a layer made of Engineered Cementitious Composite (ECC) has recently been used to modify the behaviour of many structural components [7]. Eleven frame models were examined in this study: the bare frame (BF0), the infilled frame (IF-0), the infilled frame with a single layer of ECC (IF-1), and the infilled frame with double layers of ECC (IF-2) [8]. The first four frames were chosen as single degree of freedom (SDOF) models. The other seven frames, however, were MDOF (multi-degree of freedom) models. Following building has been modelled in SeismoStruct [9]. After pushover analysis results were that Peak load is increased by around 1.7 times when an infilled frame is used instead of a bare frame. Infilled frames with the ECC layer are stiffer than other infilled frame constructions. Peak load is increased by 1.178 times over (IF) when only one ECC layer is used and by 1.20 times over (IF when two ECC layers are used [3].

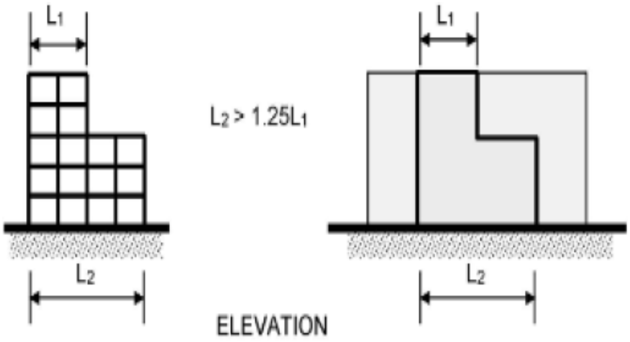
III. DESCRIPTION

A. Vertical Geometric Irregularity

Vertical geometric irregularity shall be considered to exist when the vertical dimension of the lateral force-resisting system in any story is more than 125 percent of the story below.

- For Model 1, Model 2, Model 3 and Model 4 in X-direction,
  1.25 x L1 = 1.25 x 25.51= 31.88
  L2 = 43.51
  L2 > 1.25L1
- For Model 1, Model 2, Model 3 and Model 4 in Y-direction,
  1.25 x L1 = 1.25 x 12.8 = 16
  L2 = 19.54
  L2 > 1.25L1

In the present study, we have considered Vertical Geometric Irregularity in Model 1, Model 2, Model 3, and Model 4 as per IS 1893:2016 Table 6.



[Fig.1: Vertical Geometric Irregularity as per IS 1893:2016 (Table 6)]

B. Pushover Analysis

Seismic analysis, a branch of structural analysis, aims to understand how structures respond to earthquakes. It's a crucial process, especially in seismically active regions. By ensuring that buildings are earthquake-resistant, seismic activity can reduce financial damage and save lives.

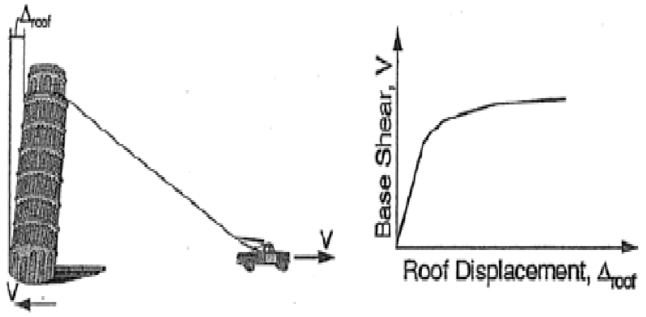
Non-linear Static Seismic analysis can be done by pushover method.

Pushover analysis is a series of incremental analyses carried out to build up a capacity curve for the building. Fig. 2. illustrates pushover analysis. This procedure needs the execution of a nonlinear static analysis of structure that allows monitoring of progressive yielding of the structure component. The building is subjected to a lateral load. The load magnitude increases until the building reaches the target displacement. This target displacement is used to represent the top displacement when the building is subjected to design-level seismic criteria.

Pushover analysis produces a pushover curve or capacity curve that presents a relationship between base shear (V) and roof displacement (Δ). The Pushover curve depends on the deformation and strength capacities of the structure and describes how the structure acts beyond the elastic limit.

Structural response to ground motion during an earthquake cannot be accurately predicted due to the complexity of the structural properties and ground motion parameters. In pushover analysis, a series of lateral displacements is used as a design condition. The displacement is an estimate of the maximum expected response of the structure during seismic activity. Once pushover analysis is defined, the performance level can be determined using demand displacement. The performance verifies that the structure is adequate to the acceptable limits of performance level.

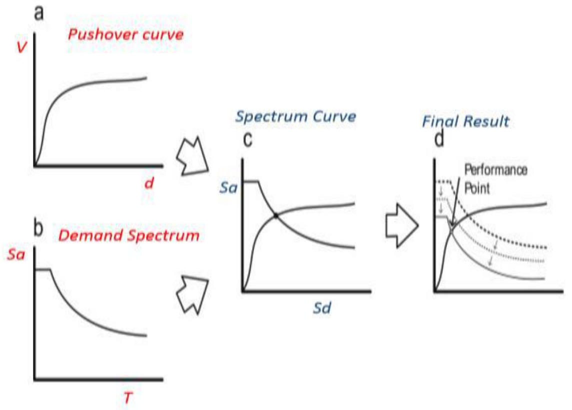
Recently, there are some codes such as Applied Technology Council (ATC)-40, Federal Emergency Management Agency (FEMA) 356 and Federal Emergency Management Agency (FEMA) 440 adopted standards and guidance provisions regarding the assessment of existing structures. Some programs are also developed for pushover analysis such as ETABS and Staad.Pro.



[Fig.2: Illustration of Pushover Analysis (ATC 40)]

C. Capacity Spectrum Method

Building performance level can be determined by target displacement using the capacity spectrum method (ATC 40). Using the capacity spectrum method, we get a graphical comparison between the seismic demand and structure capacity. The response spectrum curve represents the seismic demand and the pushover curve represents the vertical resisting capacity of the structure. The capacity spectrum method, which is given in Figure 3, is started by producing a force-displacement curve that considers inelastic conditions. The obtained result is then plotted together in Acceleration Displacement Response Spectrum (ADRS) format. Demand is also converted into ADRS format so that the capacity curve and demand curve are in the same format.



[Fig.3: Capacity Spectrum Method]

In the Capacity spectrum method, we get performance points by superimposing the demand spectrum on the capacity curve into spectral coordinates or Acceleration Displacement Response Spectrum (ADRS) format. The capacity spectrum method has been built in the ETABS program.

Table 1: Performance Levels of Buildings as per Applied Technology Council (ATC) - 40

Operational	Very light damage, no permanent drift, structure retains original strength and stiffness, and all systems are normal.
Immediate Occupancy	Light damage, no permanent drift, the structure retains original strength and stiffness, elevator can be restarted, Fire protection operable.
Life Safety	Moderate damage, some permanent drift, some residual strength and stiffness left in all stories, damage to partition, and building may be beyond economical repair.
Collapse Prevention	With severe damage, large displacement, and little residual stiffness and strength but loading bearing column and wall function, the building is near collapse.

D. Fiber Reinforced Polymer

A composite material composed of a polymer matrix reinforced by fibers is known as Fiber-Reinforced Polymer (FRP). Carbon, glass, and aramid are the most commonly utilized fibers. These FRPs' ultimate strength and elastic modulus are higher than those of any other material, which eventually improves the structure's ductility without significantly adding to the dead weight of the current structure.

E. Application of Fiber Reinforced Polymer

Fiber-reinforced polymer (FRP)'s exceptional properties make it an ideal choice for structural strengthening structures. Here are some of the key advantages and applications of FRP in the construction industry.

- Fiber-reinforced polymer (FRP) sheets can be used to wrap columns in buildings and bridges to improve their confinement and axial load-carrying capability.
- To improve strength, FRP is very successful at enhancing the flexural capacity of structural elements like beams and slabs on both the bottom and sides.
- To increase the load-bearing capacity of concrete, steel, or timber structures, FRP can be externally attached to them. Buildings, bridges, and other infrastructure that may have deteriorated over time are typically reinforced using this technique.
- In concrete constructions, FRP can be used to fix cracks and stop them from spreading. It aids in preserving the damaged components' structural integrity and longevity.
- FRP is a great material for constructions exposed to adverse environmental conditions, like those seen in industrial or maritime settings, because it is naturally resistant to corrosion.

IV. DESCRIPTION OF BUILDING

The following parameters are being used for the modeling and analysis of irregular RCC structures.

Table 2: Configuration of Models

Model Number	Type of Configuration
Model 1	RCC without FRP
Model 2	RCC with AFRP
Model 3	RCC with GFRP
Model 4	RCC with CFRP

Table 3: Input Data for Modeling

Height of Building	61.5 M
Slab thickness	150 mm
Beam size	230 X 600 mm
	230 X 325 mm
	230 X 450 mm
Shear Wall	300 mm
Floor-to-floor height	2.9 m

Table 4: Material Properties of Structure

Grade of Concrete	M30
Grade of Steel	Fe500
Density of Reinforced Concrete	25 kN/m^3
Density of lightweight blockwork	10 kN/m^3
Density of water	10 kN/m^3

Table 5: Seismic Data for Structure

Seismic Parameter (As Per IS 1893 Part -1 2016)	
Seismic Zone (Z) (From Table 3)	III
Zone Factor	0.16
Importance Factor (From Table 8)	1.2
Soil category	I
Response reduction factor (R) (From Table 9)	4

Table 6: Loading on Structure

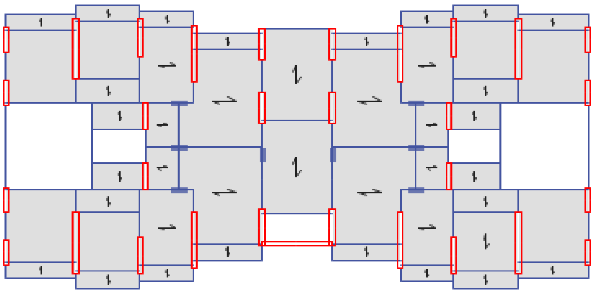
Loading (As Per IS: 875: Part 2: 2018)	
Live load	Floor = 2 kN/m^2. Terrace Floor = 3 kN/m^2.
Floor finish load	Floor = 1.5 kN/m^2. Terrace floor = 3 kN/m^2.
Wall load	0.23*3*10 = 6.9 kN.

Table 7: Wind Data for Structure

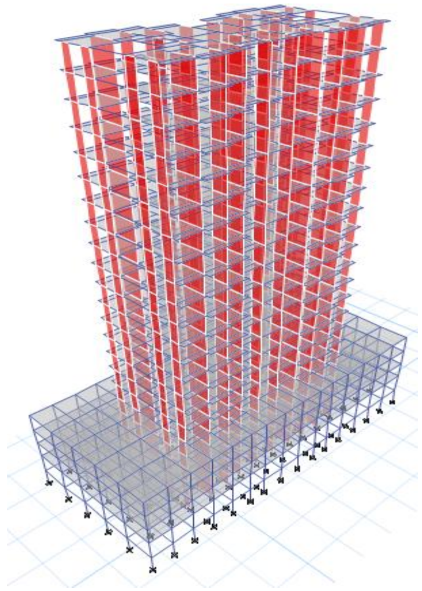
Loading (As Per IS: 875: Part 3: 2018)	
Wind speed	44 m/s
Terrain category	3

Table 8: Physical and Mechanical Properties of Different FRPs from Gudonis et al. (2013) [4]

Properties	CFRP	GFRP	AFRP
Elastic Modulus (Gpa)	250	72.4	62
Fabric Weight (kg/m3)	1700	2500	1440
Ultimate Strength (Mpa)	3700	3450	2760
Poisson ratio	0.2	0.22	0.35
Coefficient of thermal expansion 10–6/°C	1.2	5	2



[Fig.4: Plan of Vertical Irregularity Models]



[Fig.5: 3D Frame Structure of Vertical Irregularity Models]

V. VALIDATION

The pushover analysis is validated with examples taken from the National Program on Technology Enhanced Learning (NPTEL) and Dhiraj D. Ahiwale, Rushikesh R. Khartode, and Kaustubh V. (2020).

In this validation, we have taken a story RCC frame of height 3.5 m and a bay width of 4 m which is situated in seismic zone IV having hard rock strata with a mass of 1500 kg on each floor.

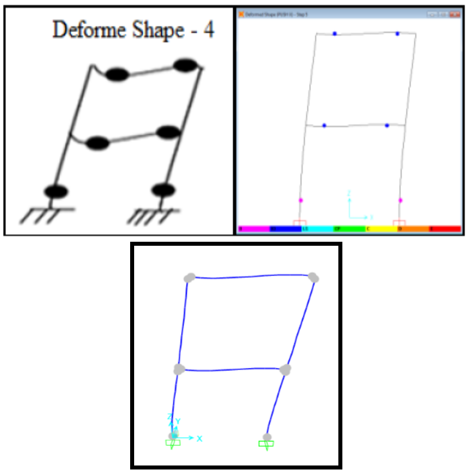
The details of the solved example are given below.

A pushover analysis for a two-storied RCC frame having the properties is done as follows:

- RCC frame with single bay and two storied
- Floor-to-floor height is 3.5 m and bay width is 4 m
- Reinforcement – Fe 415 and Concrete – M20
- Column Size – 400 mm x 230 mm
- Beam Size – 300 mm x 230 mm
- Response Spectra- IS: 1893 (Part 1)-2002
- Soil strata- Hard Rock
- Zone – IV
- Importance Factor- 1
- Lumped Mass – 1500 kg on each floor
- Modal Combination – Square root of the sum of squares (SRSS)
- Directional Combination - Square root of the sum of squares (SRSS)
- Load Combination- 1.5 (DL+EL) as per IS: 1893-2002

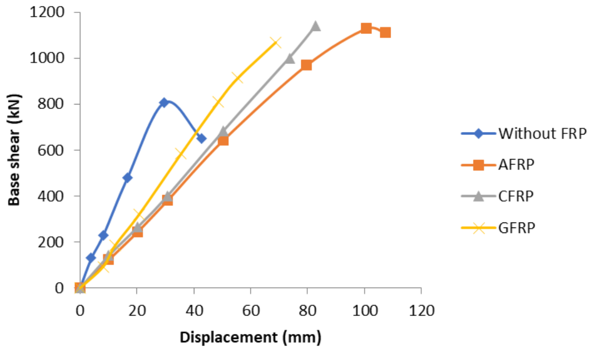
Table 9: Show the Comparison of Performance Parameters as per NPTEL, Ahiwale et al. (2020) and Present

Parameters	Standard Problem	Ahiwale et al. (2020)	Present Study
Performance point- V (kN), D (m)	41.063, 0.019	46.249, 0.013	40.85, 0.017
Performance point (Sa, Sd)	0.700, 0.015	0.811, 0.011	1.278, 0.013
Performance point (Teff, Beff)	0.297, 0.137	0.231, 0.089	0.202, 0.126

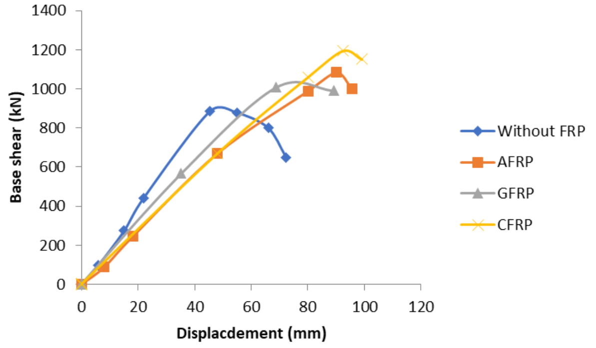


[Fig.6: Shows the Deformed Shape of the Frame as per Model Analysis per NPTEL, Dhiraj D. Ahiwale, Rushikesh R. Khartode and Kaustubh V. Raut Ahiwale (2020) and Present Study]

VI. RESULTS AND DISCUSSION



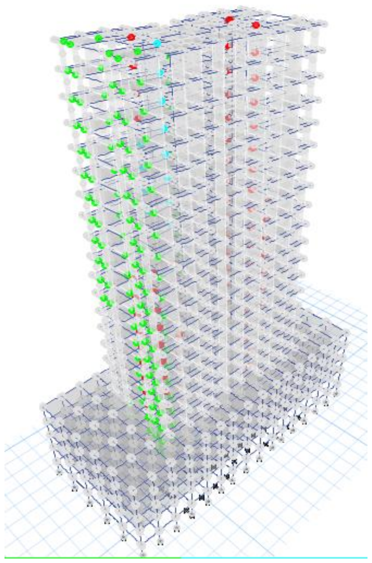
[Fig.7: Comparison of Pushover Curve of Models with Vertical Irregularity in X Direction]



[Fig.8: Comparison of Pushover Curve of Models with Vertical Irregularity in Y Direction]

Table 10: Comparison of Total Hinges of Models with Vertical Irregularity

Model No	Description	A-IO	IO-LS	LS-CP	>CP	Total
Model 1	Without FRP	6734	218	38	186	7176
Model 2	With AFRP	7005	171	0	0	7176
Model 3	With GFRP	7007	169	0	0	7176
Model 4	With CFRP	7072	104	0	0	7176

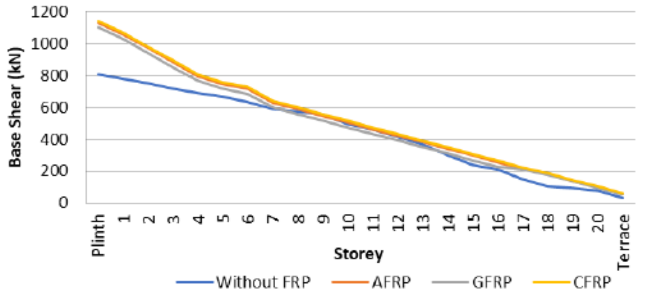


[Fig.9: Hinges Observed in Model 1 (without FRP)]

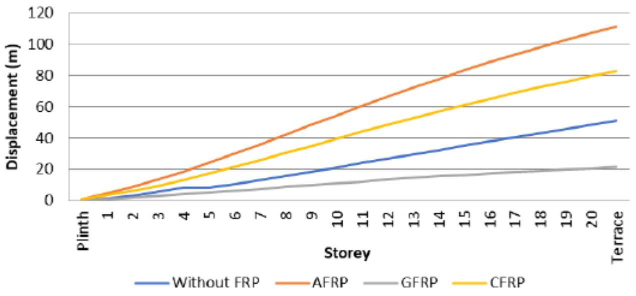
Table 11. Comparison of Target Displacement of Models with Vertical Irregularity

Model No	Description	Target Displacement (mm)
Model 1	Without FRP	45.49
Model 2	With AFRP	90.00
Model 3	With GFRP	68.68
Model 4	With CFRP	92.38

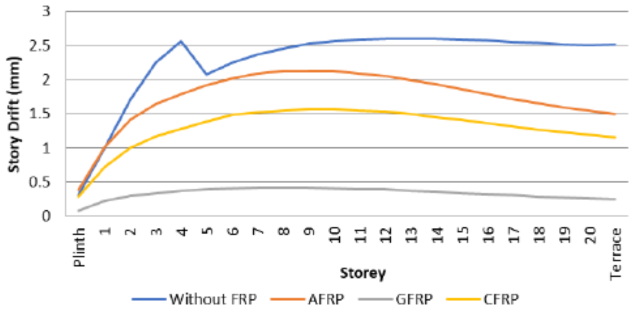
- Model 1 which is with vertical irregularity without FRP shows the nonlinear inelastic transition from 29.694 mm in the X direction and 45.49 mm in the Y direction, lower than all other models.
- Model 4 which has vertical irregularity with CFRP is showing more target displacement and fewer hinges than all other models.



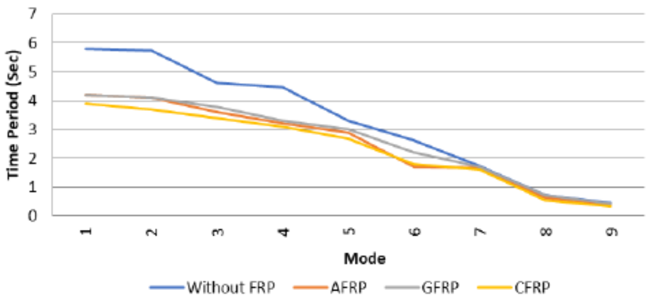
[Fig.10: Comparison of Base Shear]



[Fig.11: Comparison of Displacement]



[Fig.12: Comparison of Story Drift]



[Fig.13: Comparison of Time Period]

VII. CONCLUSION

- Model 4 which is an RCC structure with CFRP is showing more target displacement and fewer hinges among all the models having vertical irregularity.
- Model 4 which is an RCC structure with CFRP is showing more storey shear among all the models having vertical irregularity.
- Model 4 which is an RCC structure with carbon fiber reinforced polymer (CFRP) shows 236.53% less story displacement and 195.77% less story drift wrt to model 1 which is without FRP having vertical irregularity.
- Model 4 which is with CFRP has a minimum time period of 3.9 sec among all other models which has vertical irregularity.
- Models with CFRP are showing better results in vertical irregularity.
- The performance level of models without FRP is at collapse prevention level and all models with FRP are at immediate occupancy level.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it has been conducted without any external sway.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

REFERENCES

1. Hanan Yurizka and Anis Rosyidah, "The Performance of Irregular Building Structures using Pushover Analysis" Journal of Engineering Design and Technology, vol: 20, Issue: 2, July. Doi: https://doi.org/10.31940/logic.v20i2.1456
2. D. N. Shinde and Patil Sadhana, "Pushover Analysis to Study Seismic Performances of Vertical Irregular Structure" by, International Journal of Research in Engineering and Technology (IJRET), vol: 05, Issue: 06, Jun 2016. Doi: https://doi.org/10.15623/ijret.2016.0506062
3. Mohamed Selim, Mohamed Metwaly and Eman Elshamy, "Effect of Unreinforced Masonry Infill Walls with and Without ECC Layer on the Performance of RC Framed Structure" Asian Journal of Civil Engineering, Issue:08, May 2023. Doi: https://doi.org/10.1007/s42107-023-00706-1
4. Eugenijus Gudonis, Aleksandr K. Arnautov, Edgaras Timinskas, Viktor Gribniak, Gintaris Kaklauskas, Vytautas Tamulėnas, "FRP Reinforcement for Concrete Structures: State-of-the-art review of Application and Design" Taylor and Francis Group, 4, May 2013. Doi: https://doi.org/10.3846/2029882X.2014.889274
5. Ramesh, G. (2022). Damage Assessment of Reinforced Concrete Structures: A Review. In Indian Journal of Design Engineering (Vol. 2, Issue 1, pp. 1–7). Doi: https://doi.org/10.54105/ijde.B8004.021322
6. S, S., selvarani, G., & Kumar M, R. (2019). Behaviour of Micro Reinforced Concrete with Hooked End Steel Fibres subjected to Impact Loads. In International Journal of Recent Technology and Engineering (IJRTE) (Vol. 8, Issue 3, pp. 3453–3461). Doi: https://doi.org/10.35940/ijrte.C5076.098319
7. Southararajan, D. V., Sivasankar, D. S., Dinakaran, Mr. S., Modak, Mr. N., & Gopalakrishnan, D. R. (2019). Performance in Binary Characteristics of Sisal Fibre Reinforced Concrete. In International Journal of Innovative Technology and Exploring Engineering (Vol. 9, Issue 1, pp. 44–47). Doi: https://doi.org/10.35940/ijitee.A3909.119119
8. Ibrahim, W., & Zamrawi, A. (2021). Fire Behavior of RC Flat Slabs Containing Recycled Ceramic Aggregate. In International Journal of Advanced Engineering and Nano Technology (Vol. 4, Issue 2, pp. 1–5). Doi: https://doi.org/10.35940/ijaent.B0425.024220
9. H., Prof. A. R. B., & Babu, Dr. D. L. V. (2019). Fresh, Strength and Durability Characteristics of Binary and Ternary Blended Self Compacting Concrete. In International Journal of Engineering and Advanced Technology (Vol. 9, Issue 2, pp. 3987–3991). Doi: https://doi.org/10.35940/ijeat.B4540.129219

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Prof. Roshni John, B. Tech (Civil Engg.) M.E(Structural Engg.) is working as an Associate Professor in the Department of Civil Engineering at Saraswati College of Engineering, Navi Mumbai. Dedicated and passionate faculty with a proven record of fostering academic excellence and personal development in students. I strive to create an inspiring and supportive learning environment. My teaching philosophy revolves around nurturing curiosity, creativity, and critical thinking. My expertise is in structural engineering with research publications in the field of dynamic analysis of multistoried buildings, structural dynamics, earthquake engineering, concrete technology, and design of concrete structures.
