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Sesmic Performance And Retrofit For Yuvaraja's College: The Case Study

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Abstract: More than 80% of the buildings in India are composed of masonry, 20% of which are significant historical structures. As one of the 90% of historical structures in Mysore, Yuvaraja's College, which is made of masonry and only meant to withstand static stresses, had its performance evaluated. Due to their very complicated behaviour under seismic loads, which is characterised by a combination of enormous shear pressures, diagonal tension, and high bond stresses in the columns, all of which are brittle modes of failure, beam column joints of masonry structures require special consideration. The behaviour of the masonry construction during seismic conditions is known. Sap 2000 has been used to analyse the study on the masonry structure of Yuvaraja's College, which is located in seismic Zone II and has G+ 1 storeys. Pushover analysis contains some approximations and simplifications; therefore, some fluctuation is always anticipated in the pushover analysis' seismic demand estimate. To get around some of the drawbacks of conventional pushover processes, certain enhanced pushover procedures have been put out in literature. With the aid of SAP 2000. This study highlights the main causes of the inadequate seismic performance of stone masonry buildings and offers solutions for improving seismic performance for existing structures. By putting the suggestions provided here into effect, the risk to occupants of no designed stone masonry buildings and their property can, in our opinion, be significantly reduced in the case of a future earthquake. This study will be useful to building specialists who want to understand more about this type of construction, whether for post-earthquake reconstruction or seismic mitigation.

1. Introduction:

Seismology is the study of elastic wave generation, propagation, and recording within the Earth, particularly focusing on natural phenomena such as earthquakes. Earthquakes are abrupt movements or tremors occurring within or beneath the Earth's surface. Roughly 90% of earthquakes result from tectonic activities, mainly associated with movements along geological faults. The remaining 10% can be attributed to factors like volcanic activity, subterranean cavity collapses, or human-made causes.

Pushover analysis, along with assessments of building performance using approaches like the Capacity Spectrum Approach or Displacement Coefficient Method, has gained popularity for this purpose. To achieve uniformity in seismic retrofitting approaches, it is crucial to address key considerations for their incorporation into Indian building codes. This entails a thorough understanding of the principles underlying documents like ATC-40 (ATC, 1996) and FEMA-356 (FEMA, 2000), followed by necessary adaptations to suit Indian conditions. Initiating and concluding discussions on this matter promptly is imperative to achieve desired outcomes.

Pre-disaster preparedness strategies often entail repairing and retrofitting reinforced concrete structures to ensure their satisfactory performance during seismic events. These actions can lead to improvements in structural stiffness, strength, and resistance to deformation. While performance factors have been proposed to quantify the effectiveness of these measures, their applicability may vary depending on specific cases. Large-scale experimental programs conducted at SERC have revealed that if structural weaknesses exist in the original design, achieving desired performance levels through retrofitting may not be feasible. In such instances, the evaluation of performance factors might be contingent on the deformation state considered, potentially lacking uniformity. Addressing these complexities is essential to adequately evaluate the suitability of repair measures.

Concrete has been the dominant construction material for the 20th century and is likely to remain so unless a revolutionary material emerges. While concrete technology has seen substantial progress, with concrete strengths increasing from 15-20 MPa to 40-70 MPa over the past five decades, there is a shift from strength-based designs to performance-based designs. Strength is just one criterion in these designs, as there is a heightened focus on predicting the lifespan of structures and scheduling maintenance. Finite element software has become extensively utilized in design offices for analyzing and designing concrete structures. It is essential to assess the current status of analysis and design methods, ensuring that they provide realistic estimates of load effects and deformations. These methods rely on lateral load-deformation variations obtained through nonlinear static analysis under gravity loading and idealized lateral loading induced by seismic forces. This analytical process is commonly referred to as pushover analysis.

Technical measures to enhance the performance structure

1. Strengthening: Performance of the structure did not satisfy the existing requirements at the time of design/construction.
2. Upgrading: Structure does not meet the new requirements introduced after the building construction such as new code provisions.

2. Literature Review

Codal provisions for performance-based analysis:

1. **The FEMA-273 (1997)** Document offers guidance for the seismic rehabilitation of buildings that are acceptable and technically sound. The Seismic Rehabilitation of Buildings Guidelines are meant to be a ready resource for design experts, a guide for building regulatory officials, and a base for the future creation and application of building code provisions and standards. This document details the various seismic performance levels for both structural and non-structural building components. Additionally, it provides several analysis techniques for building seismic restoration.

2.**The FEMA-349 (2000)** performance-based design and evaluation system will be able to be adopted by building stakeholders, including owners, financial institutions, engineers, architects, contractors, researchers, the general public, and governing bodies, with the help of the action plan. The plan acknowledges that stakeholder groups have a strong need for more dependable, quantifiable, and useful ways to control building damage. It also acknowledges that different groups do not share a common idea of how these objectives might be met. In order to accomplish these objectives, this Plan explains how performance-based seismic design principles might be created and applied. By involving all of the parties in the creation of these rules, future building design will become more dependable and efficient.

3.T**he FEMA-356 (2000)** standard is intended to serve as a nationally applicable tool for design professionals, code officials, and building owners undertaking the seismic rehabilitation of existing buildings. The procedures contained in this standard are specifically applicable to the rehabilitation of existing buildings and are, in general, more appropriate for that purpose than are new building codes. Advancement of present-generation performance-based seismic design procedures is widely recognized in the earthquake engineering community as an essential next step in the nation's drive to develop resilient, loss-resistant communities.

4. FEMA 445 (2006) program plan offers a step-by-step, task-oriented program that will develop next-generation performance-based seismic design procedures and guidelines for structural and non-structural components in new and existing buildings. This program plan isa refinement and extension of two earlier FEMA plans: FEMA 273 Performance-Based Seismic Design of Buildings – an Action Plan, which was prepared by the Earthquake Engineering Research Centre, University of California at Berkeley in 1997, and FEMA 349Action Plan for Performance Based Seismic Design, which was prepared by the Earthquake Engineering Research Institute in 2000. The state of practice for performance-based assessment, performance-based design of new buildings, and performance-based upgrades of existing buildings will all be significantly advanced under this Program Plan.

5. ATC-40 (1996) document provides a comprehensive, technically sound recommended methodology for the seismic evaluation and retrofit design of existing concrete buildings. Although it is not intended for the design of new buildings, the analytical procedures are Applicable. The document applies to the overall structural system and its elements and components. The methodology used here is performance based: the evaluation and retrofit design criteria are expressed as performance objectives, which defines desired levels of seismic performance when the building is subjected to specified levels of seismic ground motion. Acceptable performance is measured by the level of structural and/or non-structural damage expected from the earthquake shaking. Damage is expressed in terms of post yield, inelastic deformation limits for various structural components and elements found in concrete buildings. The analytical procedure incorporated in the methodology accounts for post elastic deformations of the structure by using simplified nonlinear static analysis methods.

Pushover Analysis: Sudhir and Navin (2000) studied the historical developments and current status of earthquake engineering in India. Detailed information about the earthquake engineering in India, Indian earthquake problem cannot be overemphasised. More than about 60% of the land area is considered prone to shaking of intensity VII and above (MMI scale). In fact, the entire Himalayan belt is considered prone to great earthquakes of magnitude exceeding 8.0, and in a short span of about 50 years, four such earthquakes have occurred: 1897 Assam (M8.7), 1905 Kangra (M8.6), 1934 Bihar-Nepal (M8.4), and 1950 Assam-Tibet (M8.7).Earthquake engineering developments started rather early in India

Maung (2005) presented a study on the building which was not considered the seismic effects, and is reviewed with subjected to moderate seismic forces to know the performanceof the building. In this study, twelve-storey reinforced concrete building (ordinary moment-Seismic Performance of Yuvaraja’s College and its Retrofitresisting frame) was considered to investigate the effects of moderate earthquake but Substructure analysis was not considered.

Enrico (2005) By creating a PC-based software tool for performing nonlinear pushover analysis of reinforced concrete buildings, researchers explored and presented the Nonlinear Pushover Analysis of Reinforced Concrete Structures. The software integrates two libraries with FEAP, a finite element programme already in use that was created at the University of California, Berkeley. The two libraries are a) a library of uniaxial material laws, and b) a library of frame elements, which comprises beam, beam-column, and shear wall elements.

Retrofit techniques of masonry wallsMander et al. (1993) retrofitted the masonry infill surrounded by a steel frame by applying a thick ferro cement overlay with two layers of wire mesh. The retrofit boosted the masonry's strength in the filled steel frame by around 60%, but a broad diagonal crack that developed in the ferro cement overlay caused the retrofitted frame to quickly lose its resistance to cyclic stresses.

A review of the effectiveness of a few cutting-edge retrofit methods for masonry structures has been made. In conclusion, FRP laminates are successful in significantly increasing the strength of masonry infill. However, the governing mechanism of failure may be the debonding of FRP as a result of inadequate masonry surface preparation before application. Almost no research has been done.

3. Methodology:

Finite Element Software: Computers and Structures Inc.'s sophisticated SAP-2000 programme can significantly improve an engineer's ability to analyse and design structures. There are several choices and characteristics that contribute to such power. The ease of usage is the other important factor. The fundamental method of utilising the programme is quite simple. Using the point, line, and area object tool, the user creates gridlines, specifies material and structural attributes, and positions structural objects in relation to the gridlines. Buildings Made of Stone Masonry Around the World

Problem:

SEISMIC PERFORMANCE ON YUVARAJA COLLEGE OFMYSORE:

ABOUT YUVARAJA COLLEGE

Fig 1: Yuvaraja's College of Mysore in the year 1928

One of the first institutions established in the state of Karnataka is Yuvaraja's College. His Highness Sri Krishnaraja Wodeyar generously approved the construction of the Intermediate College in the year 1927. The building's foundation stone was set on 8 August 1927, by the vice chancellor at the time, the illustrious thinker and scholar Rajatantra Pravina Sir Brajendranath Seal. A prominent group, including Sir Mirza Ismail, the former Deewan of Mysore, Pandit Motilal Nehru, the revered father of our first Prime Minister Pandit Jawaharlal Nehru, and Mahamokhopadhyaya Sidhanthi Shivashankara Shastry, were present when the foundation stone was set.

Fig 2: Yuvaraja College of Mysore in the year 2015

The construction of main block was completed in the year 1928 shown in fig 1. As the building is old it was constructed by using thick stone masonry walls (thickness around 500mm) built in sandstone and lime mortar. This building has timber roofs with rafters. Floor and roof structures in this stone masonry building utilize a variety of construction materials and systems shown in fig 38. The choice is often governed by the regional availability and cost of materials, and local artisan skills and experience. Floor and roof systems include masonry vaults, timber joists with steel (I-section of 400mm×600 mm) beam and slabs.

Influence of Earthquake on Yuvaraja College: "Geologically, Mysore plateau is on a stable landmass and forms part of Indian shield. Though it was believed that no earthquakes take place in the shield, it has been proved in recent studies that earthquakes do not occur but the magnitude is not more than 3.5 on the Richter scale." The mild tremors in Mysore the ranges of 3 to 3.5 on Richter scale could at most cause vibration of doors, minor cracks in buildings constructed on loose foundation and so on. But, it would not be powerful enough to cause the widespread damage that is associated with earthquakes of higher magnitude. As Yuvaraja College in Mysore is a historical building, our study has shown that Yuvaraja College which is present in the "SHIELD REGION" that is zone 2. If earthquake occurs in Mysore region, it is proven that the college building will collapse completely.

Buildings of this type range from cultural and historical landmarks, often built by highly skilled stonemasons. Stone masonry buildings are vulnerable to the effects of even moderate earthquakes. The excessive thickness of stone walls, often compounded by heavy floors and roof, account for the heavy weight of this building, thus resulting in significant inertia forces being developed during an earthquake. As a building material, stone usually has a significant strength when subjected to compression, and it is stronger than most other conventional masonry units (bricks and concrete blocks). However, when round, unshaped stones and low strength mortar are used and artisan skills are at a low level, the resulting structures are extremely vulnerable. These unsafe practices are the result of economic constraints and lack of proper training for artisans. This Stone masonry building will show poor performance in earthquakes, which lead to significant human and economic losses.

Seismic analysis on Yuvaraja College using Sap-2000:

A performance based procedure developed for seismic rehabilitation of already constructed buildings. Analysis procedures for such kind of detailed evaluation include linear and nonlinear methods of static or dynamic analysis. These procedures include ATC 40, FEMA 356 & many other procedures. FEMA 356 is the recommended design procedure for evaluation of existing buildings. Acceptance criteria for these kind of detailed procedures for different performance levels depend on strength, stiffness and ductility properties of elements. If linear analysis procedure is adopted, the analysis should implicitly and/or explicitly recognize nonlinear behaviour. Force levels which are used for analysis in the provisions for seismic evaluation of already constructed existing buildings shall be multiplied by 0.75 when used in Evaluation phase as these methods are intended for design. In the reduction factor is taken into account in various factors including material strength. The use of reduction factor is verified by following points.

1. The reduction factor lowers the earthquake shaking from a level that was conservatively used in design to one that is believed to be more accurate for assessing existing buildings.

2. The element's or component's actual strength will be higher than what is employed in the technique.

3. Since an existing structure's remaining usable life is obviously shorter than that of a newly constructed building, it is not necessary for it to be as safe as a newly created building.

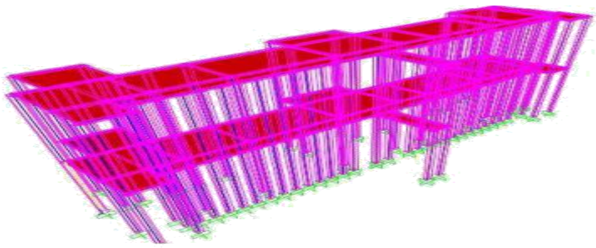


Fig 4: Sap Model of Yuvaraja College main blocks

Fig 5: Front view of Yuvaraja College of Mysore for which Seismic evaluation is performed

Section Properties Table:

MEMBER	DIMENSION
BEAM(I section-Steel of Fe-250)	0.4 m×0.6 m
COLUMN(M20-Concrete)	0.5 m×0.7 m
SLAB	0.15 m
WALL	0.5 m
HEIGHT OF THE FLOOR	5.5 m
LIVE LOAD	5 kN/m^2
UNIFORM DISTRIBUTED LOAD	55 kN/m^2

4. Methods Of Analysis:

In evaluation of seismic performance of a building, a structural analysis of the considered mathematical model is required to determine the demands for force and displacements in various elements/components of the building. Several analysis procedures including both linear and nonlinear, are used to determine the seismic performance of the building shown in figure 4:

Selection Of Detailed Procedures:

Analysis of the Structure is carried out using nonlinear static analysis of the methods. Linear procedures are considered to be adequate when the expected nonlinearity level is low. This is measured by finding the ratio of component demand to capacity (DCRs) (< 2.0).The procedures which recognize the nonlinear behaviour of the structural components in earthquake are considered to give the most accurate results. Nonlinear analysis procedures should be selected for complex and/or irregular buildings and for case where performance level is high. For the Buildings with any of the following characteristics should not be evaluated by linear analysis methods shown in fig 5.

The fundamental Time period of the structure, $T \geq 3.5$

1. Ratio of the building horizontal dimension at any story height exceeds 1.4 times of the horizontal dimension with an adjacent story.
2. The building having irregularity in its torsional stiffness.
3. The structure has a vertical mass or stiffness irregularity.
4. The lateral force resisting system is non-orthogonal.

According to the study if earthquake occurs, this will be the failures that occurs in the

Building of Yuvaraja College:

1. Lack of structural integrity.
2. Roof collapse.
3. Out-of-plane wall collapse.
4. In-plane shear cracking.
5. Poor quality of construction.
6. Foundation problems.

5. Results and Discussion's:

1. Displacement V/S Base

ZONE 2 SOIL1

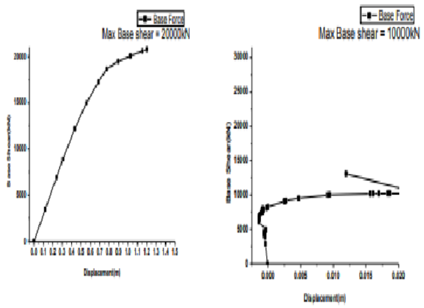


Fig 7: X-YDIRECTION

ZONE 2 SOIL 2

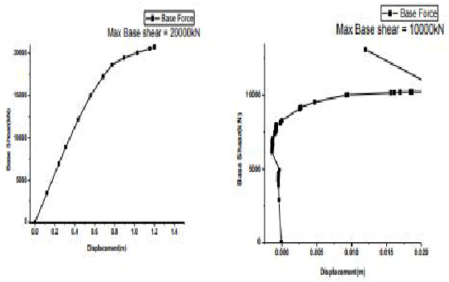


Fig 8: X-YDIRECTION

ZONE 2 SOIL3

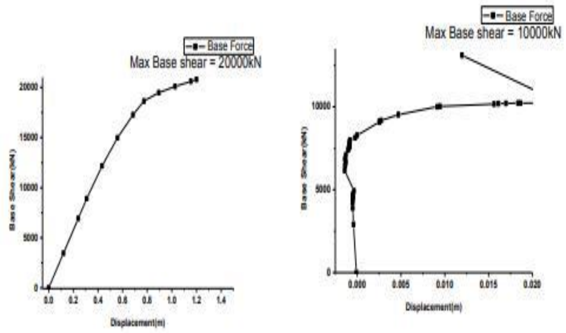


Figure: 9 X-YDIRECTION

ZONE 3 SOILS 1

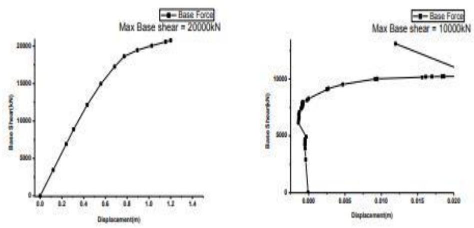
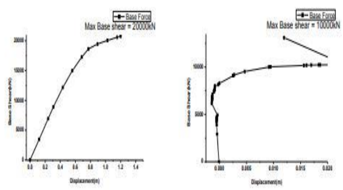


Figure: 10 X-YDIRECTION

ZONE 3 SOILS 2



ZONE 3 SOIL

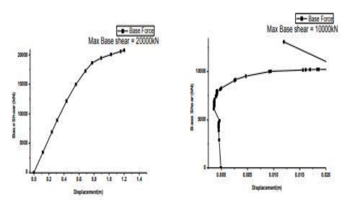
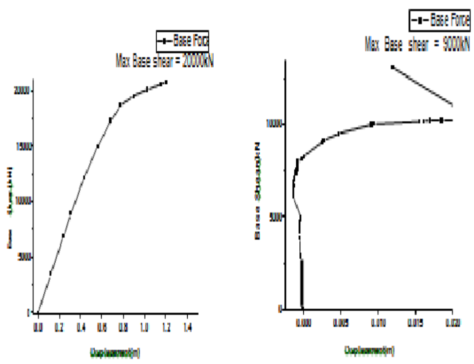


Figure: 11 X-YDIRECTION

ZONE 4 SOILS 1

Figures: 12 X-YDIRECTION

ZONE 4 SOILS 2



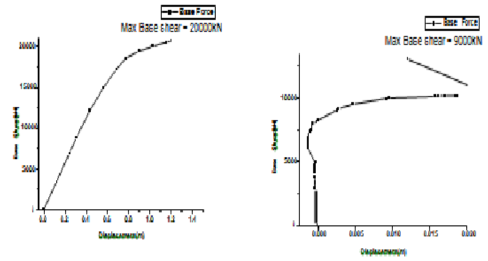


Figure: 13 X-YDIRECTION

ZONE 4 SOILS 3

Figures: 14 X-YDIRECTION

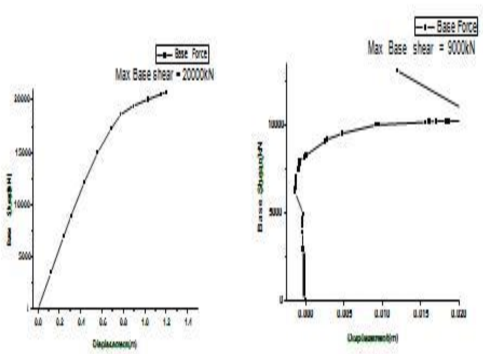
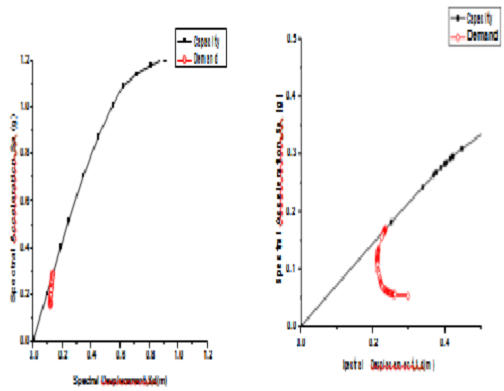


Figure: 15 X-YDIRECTION

CAPACITY V/S DEMAND:

ZONE 2 SOIL 1

ZONE 2 SOIL 2



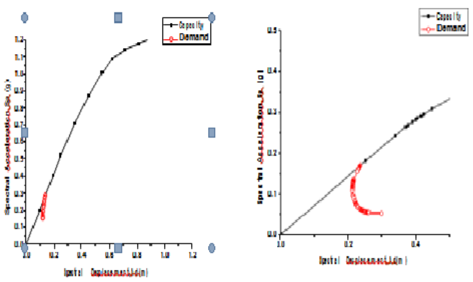


Figure: 16 X-YDIRECTION

Figures: 17 X-YDIRECTION

ZONE 2 SOIL 3

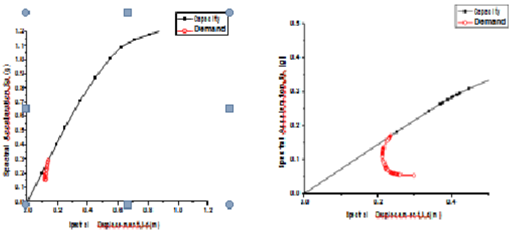
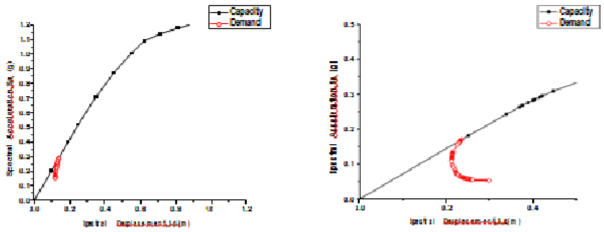


Figure: 18 X-Y DIRECTION

ZONE 3 SOIL 1



Figures: 19 X-Y DIRECTION

ZONE 3 SOIL 2

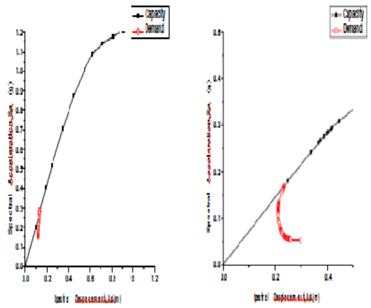
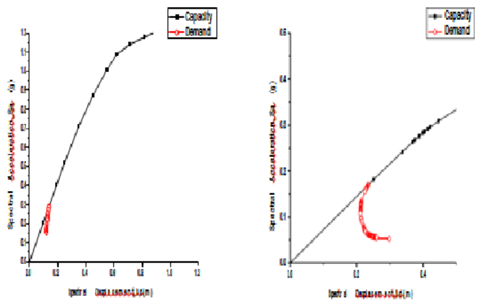


Figure: 20 X-Y DIRECTION

ZONE 3 SOIL 3



Figures: 21 X-Y DIRECTION

ZONE 4 SOIL 1

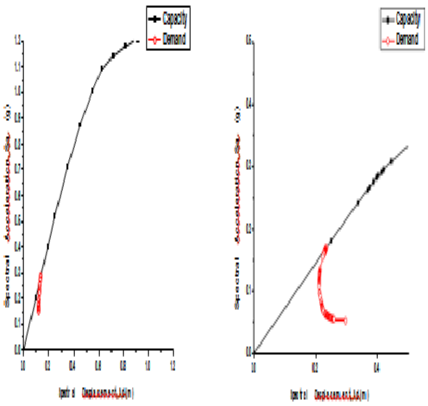
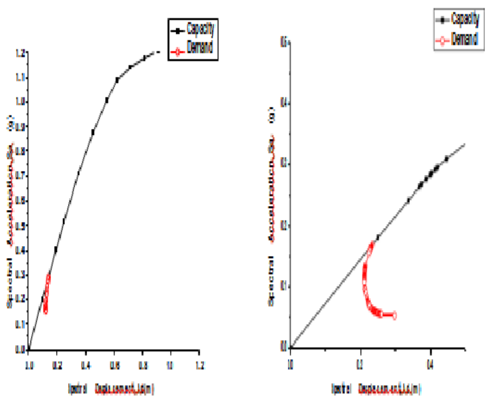


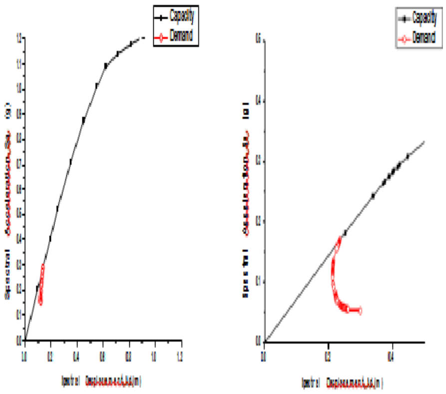
Figure: 22 X-Y DIRECTION

ZONE 4 SOIL 2



Figures: 23 X-Y DIRECTION

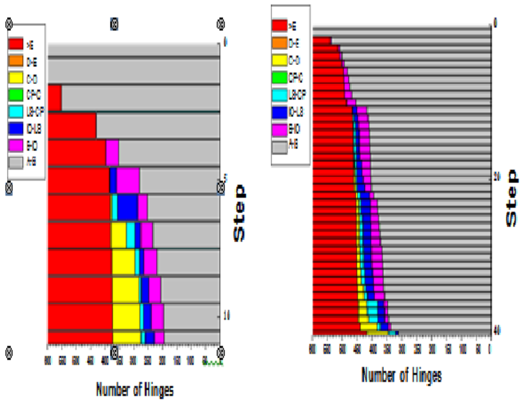
ZONE 4 SOIL 3



Figures: 24 X-Y DIRECTION

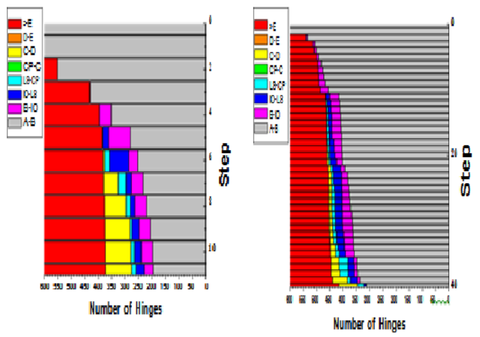
NUMBER OF HINGES V/S STEPS

ZONE 2 SOIL 1



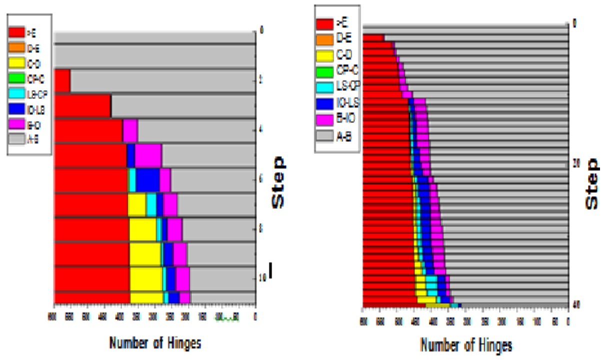
Figures 26:X-Y Directions

ZONE 2 SOIL 3



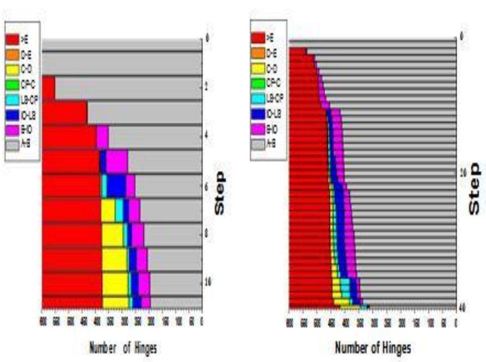
Figures 27:X-Y Directions

ZONE 2 SOIL 2



Figures 28:X-Y Directions

ZONE 3 SOIL 1



Figures 29:X-Y Directions

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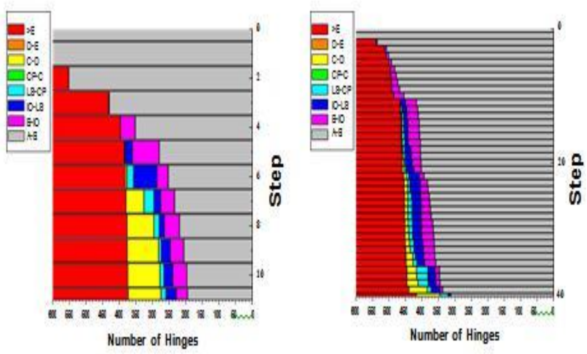

Figures 30:X-Y Directions

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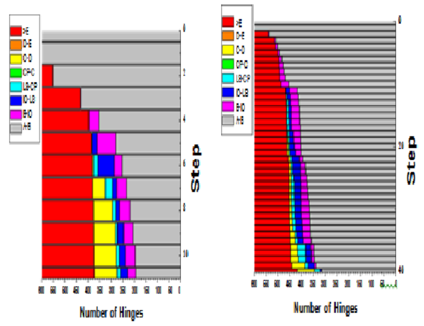
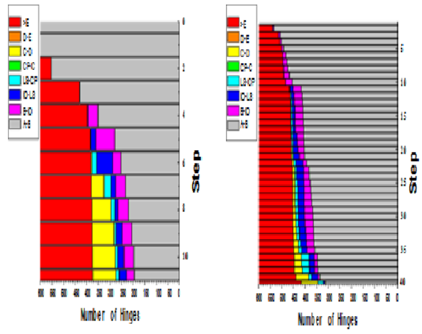


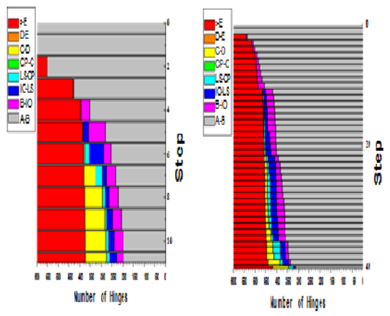
Figures 31:X-Y Directions

ZONE 4 SOIL1



Figures 32:X-Y Direction

ZONE 4 SOIL 2



Figures 33:X-Y Directions

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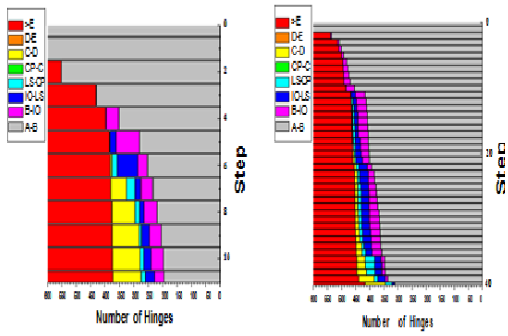

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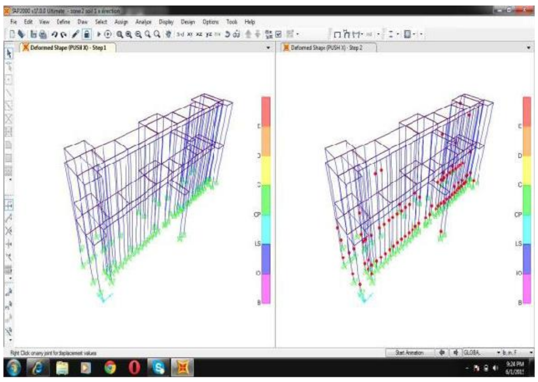

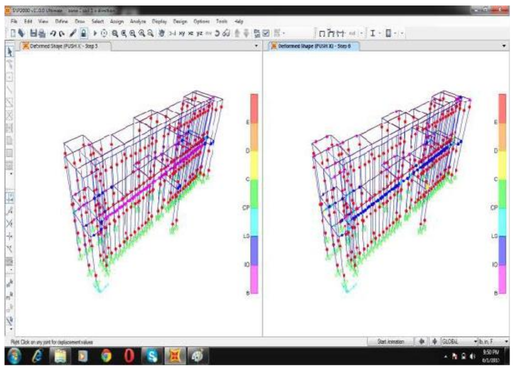

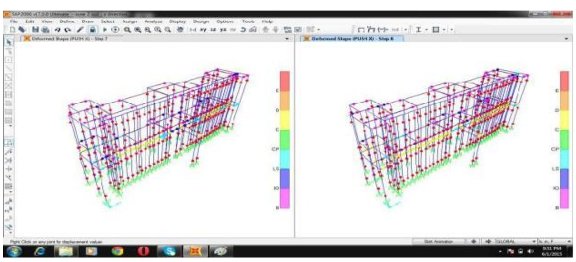

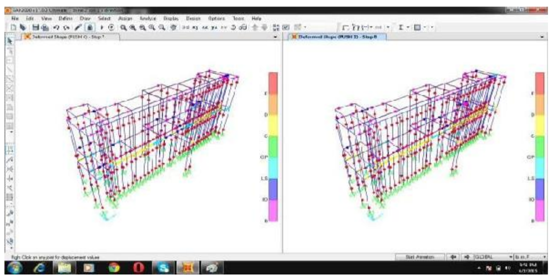

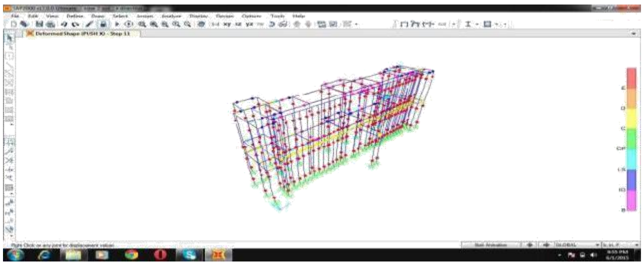

6. Conclusion:

It highlights the poor seismic performance of stone masonry buildings, especially in earthquake-prone regions. It emphasizes the importance of using performance-based analysis and retrofitting to mitigate seismic risks. The conclusion effectively ties together the various aspects of the study.

1. Observing the pushover curves in figures 07to 23, it is evident that the base shear capacity in the Y direction is significantly lower compared to the X direction. This discrepancy is primarily due to the structural shape, where the stiffness is much higher along the Y direction, resulting in the structure performing better in one direction.
2. Along the X direction, the structure exhibits minimal deflection, approximately 0.02 meters, mainly due to its masonry construction.
3. Figures 26to 32 illustrate the Capacity vs. Demand curves, indicating a concerning overlap between them. This overlap suggests premature failure, with the demand exceeding the structure's limited capacity. Consequently, the structure is prone to failure without significant deformation.
4. Analysing figures 32 to 40, it becomes apparent that there is a higher number of nonlinear hinges along the Y direction compared to the X direction. This prevalence of various types of failure hinges along the Y direction highlights the structure's vulnerability in that orientation.
5. In figures 40to 45, the deformation and formation of failure hinges are depicted. Notably, the initial steps show the formation of failure hinges in the columns, primarily attributed to the masonry construction. To align with earthquake design principles, it is imperative to implement the "Strong Column and Weak Beam" concept. Retrofitting the masonry columns with steel columns and establishing connections with existing steel beams within the structure is essential to enhance its overall capacity. Failing to do so may result in immediate structural failure without any significant response.

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