Damaged Identification In Framed Structure Using Natural Frequencies In ETABS

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Abstract- *Structural damage identification is an important part of structural health monitoring because damage in beams, columns, joints and lateral-load-resisting members reduces stiffness and changes the dynamic behaviour of framed structures. In reinforced concrete high-rise buildings, damage may occur due to cracking, corrosion, overloading, seismic action, material deterioration or loss of member stiffness. Such damage may not always be visible during routine inspection, but it can be identified through changes in modal parameters such as natural time period and natural frequency. The present study deals with damage identification in a framed structure using natural frequencies obtained from ETABS analysis. A G+15 reinforced concrete high-rise building with moment-resisting frame and shear wall system was modelled in ETABS. The plan dimension of the structure is 40 m × 20 m, with a ground storey height of 4.0 m, typical storey height of 3.0 m and total height of 49 m. M25 concrete and Fe500 steel were used for modelling. The structure was analysed for three conditions: undamaged model, 25% damaged model and 50% damaged model. Damage was simulated by reducing selected property modifiers of beams and columns while keeping mass and weight modifiers constant. Modal analysis was performed to obtain the first twelve mode shapes, natural time periods and frequencies, while response spectrum analysis was used to evaluate displacement, storey drift and base shear under EQX loading. The results show that the fundamental time period increased from 2.1299 s in the undamaged model to 2.4381 s and 2.9458 s in the 25% and 50% damaged models respectively. Correspondingly, the natural frequency reduced from 0.4695 Hz to 0.4102 Hz and 0.3395 Hz. This confirms that reduction in stiffness increases flexibility and reduces natural frequency. Therefore, natural frequency variation can be effectively used as a simple and practical indicator for identifying damage in framed structures.*

Keywords: Structural health monitoring; damage identification; ETABS; natural frequency; modal analysis; stiffness reduction; framed structure; storey displacement; base shear.

I. INTRODUCTION

Modern reinforced concrete framed buildings are expected to perform safely under gravity loads, wind loads, earthquake forces and long-term environmental exposure. A framed structure transfers loads through beams, columns, slabs, joints, shear walls and foundations, and the performance of the entire system depends on the continuity of this load path. During the service life of a building, damage may develop due to concrete cracking, corrosion of reinforcement, excessive loading, poor workmanship, seismic vibration, foundation settlement or deterioration of structural materials. In many cases, the early stage of damage is not clearly visible from the outside because the structure may still appear serviceable. However, even local damage can reduce the effective stiffness of structural members and influence the global behaviour of the frame. This makes damage identification an important requirement for structural safety assessment. Structural health monitoring provides a systematic approach for observing and evaluating the condition of a structure using measurable response parameters. These parameters may be static, such as displacement, strain and crack width, or dynamic, such as acceleration, mode shape, natural frequency and damping. Among these, dynamic parameters are especially useful because they represent the overall behaviour of the structure. Natural frequency is one of the simplest and most practical parameters for identifying damage because it can be obtained from ETABS modal analysis as well as from field vibration measurements. The basic principle is that natural frequency depends on stiffness and mass. If structural damage causes stiffness loss while the mass remains almost unchanged, the time period increases and the natural frequency decreases. Therefore, comparison of modal frequencies between undamaged and damaged conditions can indicate the presence and severity of stiffness degradation. In the present study, the reinforced concrete frame is analysed in ETABS under undamaged, 25% damaged and 50% damaged states. Damage is introduced by reducing property modifiers of selected beams and columns. This modelling approach represents stiffness loss due to cracking, crushing or member deterioration without reducing the seismic mass of the building. The study therefore provides a practical and transparent method for identifying damage-sensitive behaviour in framed structures using natural frequency variation. Your file also explains that natural frequency is governed by the stiffness-to-mass relationship and that multiple modes should be studied because higher modes may capture local stiffness changes better than only the first mode.

The use of ETABS for this study is suitable because ETABS is widely used for modelling, modal analysis and seismic analysis of building frames. It allows easy definition of storey data, grid system, material properties, frame sections, shear walls, diaphragms, load patterns, mass source and response spectrum load cases. In this work, a G+15 reinforced concrete high-rise building is considered with moment-resisting frame and shear walls. The plan size is 40 m × 20 m, the ground storey height is 4.0 m, the typical storey height is 3.0 m, and the total height is 49 m. M25 concrete and Fe500 reinforcement steel are used. Seismic loading is considered as per IS 1893:2016 for Zone III and medium soil condition, while gravity loads are taken as per IS 875 Part 1 and Part 2. The output parameters include natural time period, natural frequency, storey displacement, storey drift and base shear. The structure is first analysed in the undamaged state to obtain the baseline dynamic response. Then damage is simulated by reducing stiffness/property modifiers by 25% and 50%. For beam damage, flexural and torsional modifiers are reduced, while axial and shear modifiers are retained. For column damage, axial area, shear area, torsion and moment of inertia modifiers are reduced. In all cases, mass and weight modifiers are kept equal to 1.00, which ensures that the observed variation in natural frequency is due to stiffness reduction and not due to change in structural weight. This is important because the theoretical relationship between frequency and damage becomes clearer when mass remains constant. The results show a consistent modal trend: as damage severity increases, the time period increases and natural frequency decreases. The fundamental time period increased from 2.1299 s in the undamaged model to 2.4381 s for 25% damage and 2.9458 s for 50% damage, while the corresponding natural frequency reduced from 0.4695 Hz to 0.4102 Hz and 0.3395 Hz. This confirms that natural frequency is a sensitive indicator of stiffness degradation in framed structures. The study is useful because it demonstrates that ETABS can be used not only for conventional structural analysis and design but also as a diagnostic platform for preliminary structural health monitoring.

II. LITERATURE REVIEW

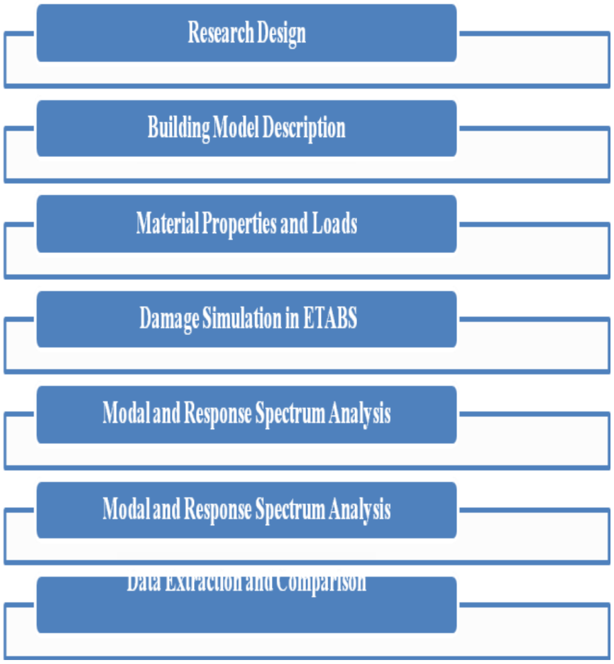
Salawu (1997) reviewed the use of natural frequency changes for structural damage detection and concluded that frequency reduction is a useful global indicator of stiffness loss, although it has limited ability to locate small local damage. Doebling, Farrar, Prime and Shevitz (1996) presented a major review of vibration-based damage identification and classified methods based on frequency, mode shape, modal flexibility and modal strain energy. Doebling, Farrar and Prime (1998) further explained that modal parameters can be used to detect and characterize damage, but accurate baseline data are required. Pandey, Biswas and Samman (1991) used changes in curvature mode shapes and showed that mode-shape curvature provides better spatial sensitivity than frequency alone. Rytter (1993) proposed four levels of damage identification: detection, localization, severity estimation and remaining life assessment. These studies provide the basic foundation for the present work because they show that vibration characteristics change when structural stiffness is reduced.

Carden and Fanning (2004) reviewed vibration-based condition monitoring and discussed the practical difficulties of modal testing, environmental variation and result interpretation. Kim, Ryu, Cho and Stubbs (2003) compared frequency-based and mode-shape-based approaches and observed that frequency measurements are simpler, while mode-shape methods are better for locating local damage. Farrar and Worden (2007) introduced structural health monitoring as a statistical pattern recognition problem, showing that damage diagnosis can be improved by combining physical indicators with data-based decisions. Yan, Cheng, Wu and Yam (2007) reviewed developments in vibration-based structural damage detection and highlighted sensitivity to environmental and operational effects. Fan and Qiao (2011) compared frequency, mode shape, curvature and combined methods and found that damage quantification remains a major challenge. These studies support the present ETABS-based study because natural frequency is selected as a simple and practical first-level damage indicator.

Friswell and Mottershead (1995) explained finite element model updating in structural dynamics and showed that stiffness and mass parameters can be adjusted to match measured modal response. Zhao and Zhang (2012) used modal data changes to identify structural damage coefficients, confirming that modal parameters are sensitive to stiffness reduction. Yu, Kim, Park and Lee (2014) studied earthquake-induced damage in a five-storey frame using finite element model updating and showed that member-end stiffness loss affects natural frequencies and frequency response functions. Alkayem, Cao, Zhang, Bayat and Su (2018) reviewed finite element model updating with evolutionary algorithms and emphasized that frequency, mode shape, FRF and modal strain energy can be used as objective functions. Avci, Abdeljaber, Kiranyaz, Hussein, Gabbouj and Inman (2020/2021) reviewed traditional and machine-learning-based vibration damage detection methods. These studies justify the present approach because the ETABS model uses controlled stiffness reduction and modal frequency comparison to identify damage.

III. METHODOLOGY

The present study adopts a numerical analytical methodology to identify damage in a reinforced concrete framed structure using changes in natural frequencies obtained from ETABS modal analysis. The basic principle of the work is that structural damage reduces stiffness, and when the mass of the structure remains nearly constant, reduction in stiffness causes an increase in natural time period and a decrease in natural frequency. Therefore, comparison of modal properties of undamaged and damaged models provides a practical basis for identifying stiffness degradation in the structure.



3.1 Methodology Flowchart

3.1 Research Design

The research is carried out as a comparative analytical study. A reinforced concrete high-rise building is first modelled in ETABS in its undamaged condition and analysed to obtain baseline modal properties. After this, damaged models are prepared by reducing selected stiffness/property modifiers. Three structural conditions are considered: undamaged model, 25% damaged model and 50% damaged model. The undamaged model acts as the reference case, while the damaged models are compared with it to evaluate the effect of damage on time period, natural frequency, storey displacement, storey drift and base shear.

3.2 Building Model Description

A G+15 reinforced concrete high-rise building is selected for the study. The structural system consists of a moment-resisting frame with shear walls. The plan dimension of the building is 40 m × 20 m. The ground storey height is 4.0 m, while the typical storey height is 3.0 m, giving a total structural height of 49 m. The building is modelled in ETABS using beam, column, slab and shear wall elements. The base of the structure is assumed fixed. Rigid diaphragm action is assigned at each floor level so that lateral loads and floor mass are properly distributed to the vertical resisting elements.

3.3 Material Properties and Loads

The concrete grade adopted for the structure is M25, and the reinforcement steel grade is Fe500. Dead load is considered as per IS 875 Part 1, live load is considered as per IS 875 Part 2, and seismic load is considered as per IS 1893:2016. The structure is located in Seismic Zone III with medium soil condition. The mass source is kept the same for all models so that the comparison between undamaged and damaged states depends mainly on stiffness reduction and not on mass variation.

3.4 Damage Simulation in ETABS

Damage is simulated by reducing ETABS property modifiers of selected structural members. In the undamaged model, the stiffness modifier value is taken as 1.00. In the 25% damaged model, stiffness-related modifiers are reduced to 0.75. In the 50% damaged model, stiffness-related modifiers are reduced to 0.50. For beams, flexural and torsional stiffness modifiers are reduced, while axial and shear modifiers are generally kept unchanged. For columns, axial area, shear area, torsional constant and moment of inertia modifiers are reduced according to the damage level. The weight and mass modifiers are kept as 1.00 in all cases to ensure that damage is represented only as stiffness degradation.

3.5 Modal and Response Spectrum Analysis

After completing the modelling and assigning loads, modal analysis is performed to extract the first twelve mode shapes, natural time periods and natural frequencies. The first few modes are carefully checked because they represent the global dynamic behaviour of the structure. Response spectrum analysis is also performed to evaluate seismic response parameters such as storey displacement, storey drift and base shear. The same procedure is repeated for the undamaged, 25% damaged and 50% damaged models.

3.6 Data Extraction and Comparison

The modal results are extracted from ETABS in tabular form. For each mode, time period and natural frequency are recorded. The results of the damaged models are compared with the undamaged model. The percentage change in frequency is calculated using the following expression:

Frequency Reduction (%) = $[(f_0 - fd) / f_0] \times 100$

where **f_0** is the natural frequency of the undamaged model and **fd** is the natural frequency of the damaged model.

The stiffness-loss-based damage index may also be calculated as:

Damage Index (%) = $[1 - (fd / f_0)^2] \times 100$

This equation is based on the relationship between frequency and stiffness. A higher damage index indicates greater stiffness loss.

IV. RESULTS AND DISCUSSION

The ETABS results show a clear variation in modal properties with increasing damage severity. In the undamaged model, the fundamental time period is 2.1299 s and the natural frequency is 0.4695 Hz. In the 25% damaged model, the fundamental time period increases to 2.4381 s and the frequency reduces to 0.4102 Hz. In the 50% damaged model, the fundamental time period further increases to 2.9458 s and the frequency reduces to 0.3395 Hz. The increase in first-mode time period is 14.47% for the 25% damaged state and 38.30% for the 50% damaged state. This confirms that stiffness reduction increases the flexibility of the structure and shifts the structure towards longer-period vibration.

For the first twelve modes, the same trend is observed. All damaged-state periods are higher than the corresponding undamaged periods. For example, Mode 2 period increases from 1.6768 s to 1.9173 s in the 25% damaged model and 2.3125 s in the 50% damaged model. Mode 3 period increases from 1.3975 s to 1.5892 s and 1.8995 s respectively. Similarly, the higher modes also show period increase and frequency reduction. This proves that the effect of damage is not limited to the fundamental mode but is visible throughout the modal response.

The principal response comparison also includes roof displacement, maximum storey drift and base shear. The roof displacement values obtained from the available screenshots are 28.448 mm for the undamaged model, 23.813 mm for the 25% damaged model and 28.448 mm for the 50% damaged model. The maximum storey drift values are 0.000753, 0.000632 and 0.000753 respectively. The maximum drift is mainly concentrated in the lower-to-middle storey region. The base shear magnitudes are 1385.80 kN, 1656.30 kN and 1385.80 kN for undamaged, 25% damaged and 50% damaged states respectively. Since these story-response values are based on screenshot extraction, they should be interpreted carefully; however, the modal results show a very consistent stiffness-loss trend.

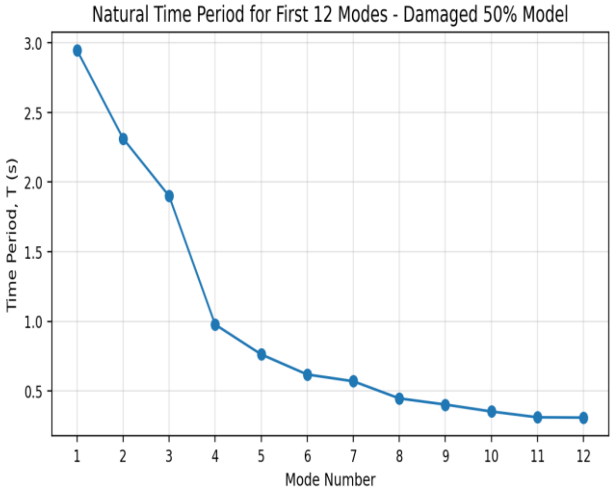


Figure 4.1. Natural time period variation for first twelve modes of the damaged 50% model.

The graph shows that the **50% damaged model has the highest natural time period in Mode 1**, indicating maximum flexibility and significant stiffness reduction. The time period gradually decreases from Mode 1 to Mode 12, showing that higher modes vibrate faster. The sharp reduction after Mode 3 indicates dominant global lateral modes, while later modes represent local dynamic behaviour.

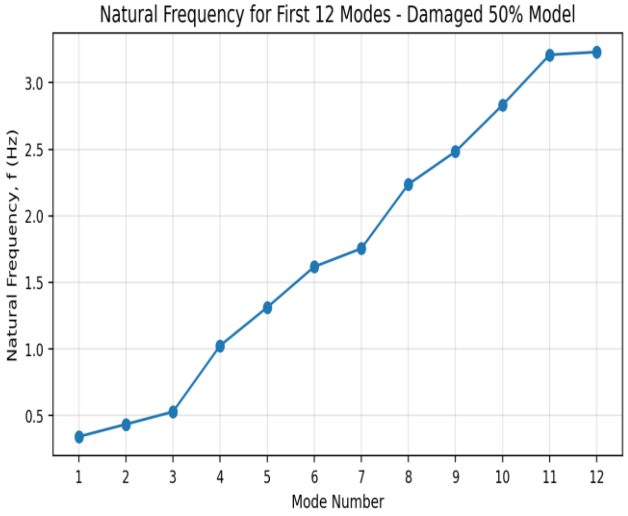


Figure 4.2. Natural frequency variation for first twelve modes of the damaged 50% model.

The graph shows that the natural frequency of the 50% damaged model increases from Mode 1 to Mode 12. The lowest frequency occurs in Mode 1, indicating the most flexible global vibration mode due to stiffness loss. Higher modes show progressively higher frequencies, representing faster and more localized structural vibration behaviour.

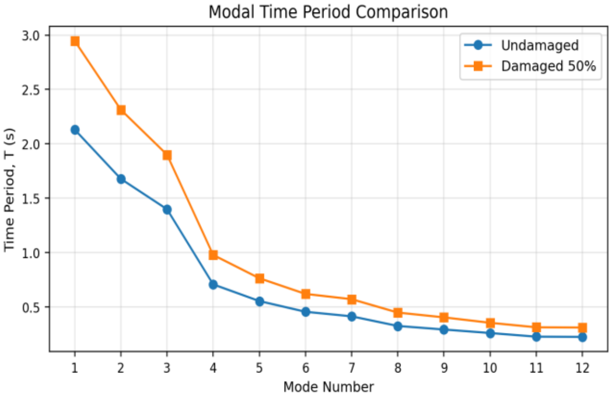
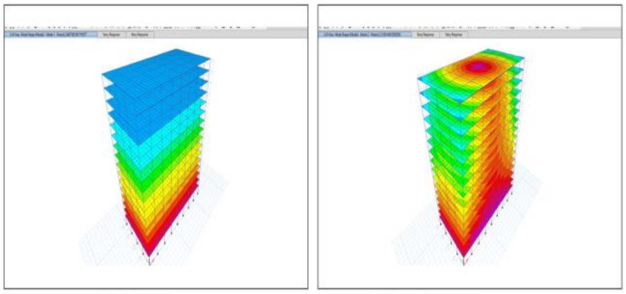
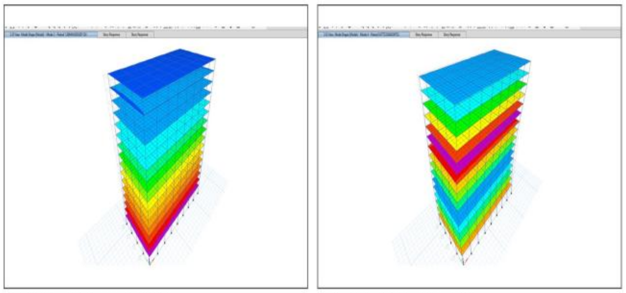


Figure 4.3. Comparison of modal time periods for undamaged and damaged 50% models.

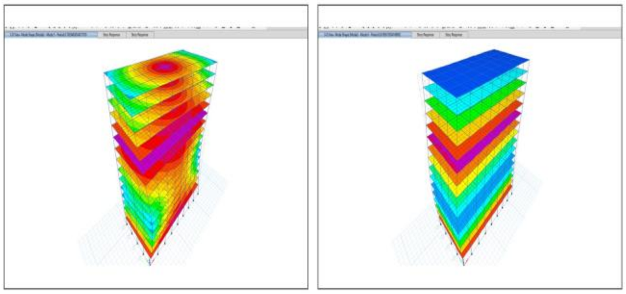
Figure 4.3 compares the modal time periods of undamaged and 50% damaged models. The damaged model shows higher time periods for all twelve modes, indicating reduced stiffness and increased flexibility. The difference is maximum in the first three modes, which represent global structural behaviour. This confirms that 50% damage significantly affects the dynamic response of the frame.



Mode 1: T = 2.9458 s, f = 0.3395 Hz Mode 2: T = 2.3125 s, f = 0.4324 Hz



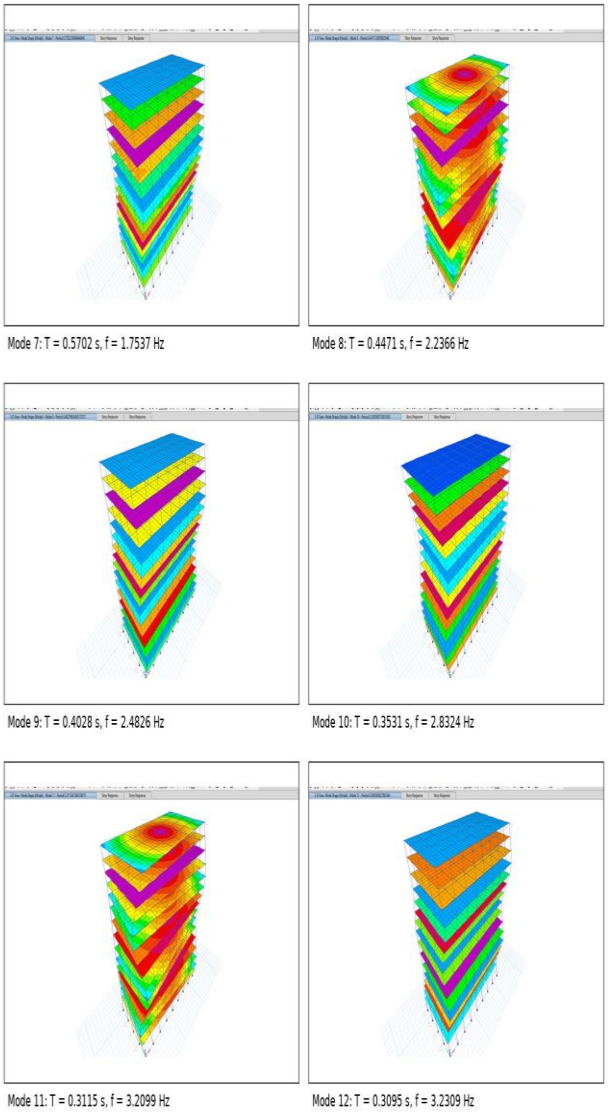
Mode 3: T = 1.8995 s, f = 0.5265 Hz Mode 4: T = 0.9772 s, f = 1.0233 Hz



Mode 5: T = 0.7629 s, f = 1.3107 Hz Mode 6: T = 0.6186 s, f = 1.6167 Hz

Figure 4.4. ETABS mode shape patterns for Modes 1 to 6 in the damaged 50% model.

The mode shape patterns of the 50% damaged model show significant lateral flexibility due to stiffness reduction. Mode 1 and Mode 3 mainly represent global translational movement, while Mode 2 and Mode 5 show torsional behaviour with twisting at upper floors. Higher modes show more localized deformation. The increasing frequency from Mode 1 to Mode 6 indicates faster vibration in higher modes, while the larger time period in lower modes confirms reduced structural stiffness due to 50% damage.



Mode 7: T = 0.5702 s, f = 1.7537 Hz

Mode 8: T = 0.4471 s, f = 2.2366 Hz

Mode 9: T = 0.4028 s, f = 2.4826 Hz

Mode 10: T = 0.3531 s, f = 2.8324 Hz

Mode 11: T = 0.3115 s, f = 3.2099 Hz

Mode 12: T = 0.3095 s, f = 3.2309 Hz

Figure 4.5 . ETABS mode shape patterns for Modes 7 to 12 in the damaged 50% model

The mode shape patterns for Modes 7 to 12 of the 50% damaged model show higher-mode vibration behaviour with shorter time periods and higher natural frequencies. These modes mainly represent localized lateral and torsional deformation patterns rather than overall global sway. The frequencies increase from 1.7537 Hz in Mode 7 to 3.2309 Hz in Mode 12, indicating faster vibration response in higher modes. The irregular deformation patterns confirm that stiffness reduction due to 50% damage affects the dynamic behaviour of the structure across multiple modes.

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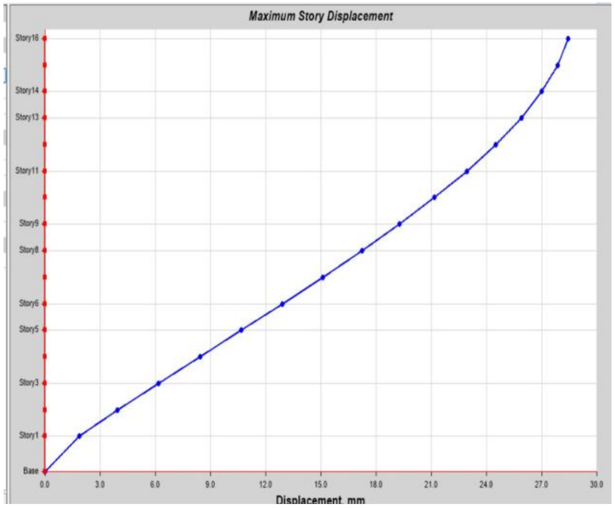

Figure 4.6. ETABS screenshot of maximum story displacement under EQX.

The maximum storey displacement under EQX gradually increases from the base to the top storey. The base displacement is zero due to fixed support condition, while the maximum displacement occurs at Storey 16, approximately 28–29 mm. The smooth increasing curve indicates regular lateral deformation without sudden soft-storey behaviour, showing that the structure responds mainly in global sway under earthquake loading.

V. CONCLUSION

The present study concludes that natural frequency is an effective, practical and reliable parameter for identifying stiffness degradation in reinforced concrete framed structures. The ETABS-based analysis clearly shows that structural damage causes a change in modal behaviour. As the percentage of damage increases, the stiffness of the structure decreases, resulting in higher natural time period and lower natural frequency. The undamaged model was used as the reference condition, while the 25% and 50% damaged models were compared with it to study the effect of stiffness reduction. The fundamental time period increased from 2.1299 s in the undamaged model to 2.4381 s in the 25% damaged model and 2.9458 s in the 50% damaged model. Similarly, the fundamental frequency reduced from 0.4695 Hz to 0.4102 Hz and 0.3395 Hz respectively. This trend confirms the basic dynamic relationship that frequency is directly related to stiffness and inversely affected by flexibility. The comparison of the first twelve modes also shows that the damaged 50% model has higher time periods in all modes than the undamaged model, indicating significant stiffness loss throughout the structure. The mode shape patterns further show global sway, torsional movement and localized higher-mode behaviour due to damage. The maximum storey displacement under EQX gradually increased from the base to the top storey, with maximum displacement occurring near the roof level, which indicates regular lateral deformation of the structure. Storey drift and base shear results also support the response comparison between undamaged and damaged conditions. Overall, the study proves that ETABS property modifiers can be successfully used to simulate damage without changing the mass of the structure. Hence, the proposed method is simple, economical and suitable for preliminary structural health monitoring. It can help engineers compare structural performance, detect stiffness reduction and identify damage severity in high-rise framed buildings.

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