Journal of Advances and Scholarly Researches in Allied Education
Vol. 21, Issue No. 5, July-2024, ISSN 2230-7540

Evaluate the Dynamic response of Buildings to Seismic Forces, Considering the Interaction between human Occupants and Structural vibrations

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Abstract - Damage to buildings and other structures may occur when dynamic loads, caused by earthquake vibrations, drive the ground and everything related to it to shake in a complicated way. Civil engineers are always thinking of new methods to deal with this inevitable problem. Humans put stress on a variety of buildings, including floors, footbridges, stadiums, and more. Modern material and manufacturing technology, together with human desire for aesthetics, have made it possible to build long span structures like bridges, stadiums, floors, etc. that are sleek, lightweight, and slim. To dampen a structure's dynamic reaction, engineers use devices called (TMDs), which consist of a mass and a spring, are tuned mass dampers. When it comes to managing the structural reactions to wind and harmonic excitations, Tuned Mass Damper (TMD) is the way to go. Specifically, the shear beam and 1D lumped-mass beams are the models under consideration. The main purpose of this piece is to demonstrate how methods that use records of ambient vibration may enhance and supplement seismic risk assessments of preexisting structures. To compare the structure's reaction with and without TMD, or tuned mass damper, is mounted on the building's exterior. Using a model calculated from outside vibrations and recorded within the structure, we were able to effectively compare the building's motion to a fake ground motion. It was also determined the inter-storey drift and the stiffness of each floor.

Keywords: Dynamic Response, Building, Seismic Force, Human, Structural Vibration

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INTRODUCTION

Many buildings are purpose-built to accommodate enormous crowds of people, including arenas, dance floors, conference rooms, and footbridges. Thanks to technological advancements in materials and production as well as human preferences for aesthetics, modern long-span buildings may be sleek, lightweight, and very slim. Modern constructions are more susceptible to vibrations caused by humans because of this trend towards greater flexibility. So, problems with vibration serviceability have emerged, whereby buildings may be stimulated by subjecting people to unpleasant or unsettling vibration levels. One example is the sensitivity of newly constructed buildings to vibrations caused by humans. Appropriate structural design must contend with two distinct challenges: the dynamic load caused by the occupants' movements and the alteration of the dynamic properties of the structure's modes due to the crowd's presence. The so-called "human-structure interaction" encompasses all of these factors. Most people agree that leaping is the worst kind of human-induced dynamic stress on a building. The current tendency in structural design is to build slimmer buildings, which means that the stands are more flexible and the structures' natural frequencies are lower, getting closer to the range of induced loads that is common. Vibrations in the stands, which may be harmful to spectator comfort and structural integrity, can result from combining these two factors. The notorious swaying of the London Millennium Footbridge across the Thames River in central London brought this issue to much more public and professional attention, though there have been other instances of pedestrians causing excessive vibration on footbridges before. More than 150 news shows and 1,000 newspaper stories covered the millennium bridge issue globally.

Earthquakes are natural disasters that may happen at any point in a building's lifespan and can cause significant damage. Seismic waves generate a cascade of vibrations as they propagate through the Earth. The ground and everything linked to it vibrate in a complicated way due to these motions, which are converted into dynamic loads or inertial forces. Buildings and other things are damaged by these inertial forces. Traditional seismicity-free zones are those where the goal of structural member design is to provide elastic resistance to both static (gravitational) and dynamic (wind) stresses. Yet, in situations where seismic excitation needed to be considered, this kind of design may result in solutions that were economically undesirable and energy inefficient. Additionally, larger masses and, by extension, stronger seismic forces, are the results of this tactic. It is important to simulate earthquake loads with precision in order to evaluate the actual behaviour of structures, keeping in mind that damage is inevitable but should be controlled. Attached to a structure, Dampers, springs, and masses work together in a Tuned Mass Damper (TMD) to reduce the dynamic response of a structure. There will be a phase difference between the structural motion and the damper's resonance frequency. when activated, in order to dampen vibrations at a certain structural frequency. The inertia force of the damper acts on the structure to disperse energy. It is common practice to use the passive control method for Base Isolation (BI). A building may get a flexible basis by being installed on rubber or another material with a low lateral stiffness. With respect to of an earthquake, the structure will remain intact because to the flexible base's ability to dampen the ground's high-frequency vibrations.

LITERATURE REVIEW

Madani, Budiono & Behnamfar, Farhad & Tajmir Riahi, Hossein. (2015) Buildings that are too close together and don't have enough space to move freely collapse during powerful earthquakes. Not only does this kind of hammering compound the situation, but soil contact between nearby structures may also cause vibration energy to be exchanged between them. This research looks at how those two things affect the inelastic response of some steel buildings. There was a wide range of clear distances up to the value specified by seismic rules, and the number of storeys ranged from three to twelve. Within Opensees, we simulate the hammering aspect. For two kinds of soft soils, the surrounding structures' interactions via the soil are represented by a coupled model of dashpots and springs. In order to evaluate the impact force, relative story displacements, story shears, and plastic hinge rotations in various scenarios, the maximum responses averaged across seven consistent earthquakes are used. This leads us to talk about the interplay between structures, soil, and hammering all at once.

Kawan, Chandra & Rayamajhi, Satish & Karanjit, Sudip. (2023) The hilly nation of Nepal is located on the most seismically active continent. Due to the scarcity of flat land in metropolitan areas, most buildings are built on slopes. A building's reaction on sloped ground differs from that on flat ground because of the height difference between the columns. Construction projects often fail to adequately account for soil impacts, making it impossible to predict how structures would fare in the case of seismic activity. The most practical technique to analyse the reaction of structures on hill slopes is to vary the slope ground under various soil conditions while considering soil structure interaction (SSI). This research aims to investigate the effects of slope angle change on buildings that rest on slope ground, taking into account both permanent and flexible bases (SSI). We have constructed numerical models and conducted dynamic analyses for seismic excitations, testing different slope angles with and without SSI to evaluate dynamic characteristics such time period, displacements, inter-storey drifts, and floor accelerations. Soil structure interaction consideration amplifies dynamic factors, and torsional response is at its peak with slope, according to the research. Research may also help provide light on how RC structures behave on sloped land, which might lead to safer building practices overall.

Wang, Huai-feng & Ru-lin Zhang (2021) An investigation involving big buildings and the interactions between structures, earth, and other structures is out using numerical methods. With the latest updates to ANSYS, frequency domain calculations are now possible, allowing for the inclusion of hysteretic damping in soil and structural models. Two publications that follow provide the results of this investigation. The first section, which is this article, presents the changes in the following variables: interstory drift angle, story shear force, foundation sway, velocity, acceleration, displacement, and axial and shearing pile forces. The orientation of the building's plan, the direction of a thrilling wave's shaking, and the excitement frequency of a harmonic or seismic wave are the main aspects that influence. When the stimulation frequency is between 1 and 5 Hz, the interaction is most prominent under harmonic waves. The superstructure is most vulnerable to earthquakes when the lateral axis of the building is parallel to the ground and the shaking from the waves is in a direction perpendicular to the building's configuration.

Abdul Khaliq, et al (2024) Severe earthquakes have rocked several parts of the world, including Turkey, Syria, and Morocco, throughout the last few months, and the aftermath is being felt today. As a result, The realm of seismic activity began to capture the interest of everyone from engineers and scientists to ordinary citizens. When making plans for this area, it is important to focus on soil-structure interaction (SSI) and structure-soil-structure interaction (SSSI). This link between a building's foundation, soil, and structure is known as SSI, while the connection between neighbouring buildings and soil is known as SSSI. In the past, these factors were disregarded in the numerical and analytical methodologies used to assess the buildings' seismic reaction (i.e., the influence of soil was not considered), which resulted in catastrophic expenses, such as property and life loss. This article aims to provide a comprehensive and useful understanding of some important factors that have not been considered in previous research. These factors can be used in seismic engineering and analysis to define the SSSI behavior of adjacent buildings in order to lessen the likelihood of earthquakes, particularly powerful ones. So as to accomplish this objective, a battery of seismic tests will be conducted using a shaking table system, with the influence of soil media taken into account. Two adjacent steel buildings set on sand will have their dynamic reactions studied in these experiments, along with the influence of orientation and distance between the buildings. There are two kinds of orientations that were considered for this: one that runs parallel to the earthquake wave's direction and another that runs perpendicular to it. There will be three distance tests—close, medium, and far—in every direction. Two new three-story This study makes use of small-scale multi-degrees-of-freedom steel models.. There is a statistically significant relationship between the directional variety of nearby buildings and their SSSI behaviour, according to the test findings. At long range, an direction orthogonal to the seismic wave's propagation had the most influence on dynamic reactions, but at medium range, a parallel orientation had the most impact.

Xie, Weiping & Hua, Yumeng. (2024) Academic and engineering communities have begun to place a greater emphasis on the vibration comfort of building structures as a result of rising social and economic standards and individual living standards. This includes vibrations caused by vehicles near buildings, humans in constructions with long spans, wind in skyscrapers, and vibrations generated by machines. As a separate field from conventional safety-based structural analysis, comfort-based structural analysis has not yet developed its own theoretical framework or set of standards. Major load categories and their implications, structural analysis based on comfort, assessment methodologies, and vibration-mitigation solutions are all part of the latest research on structural vibration comfort that this article discusses. By outlining the limitations of the current literature, we may propose new avenues of inquiry.

RESEARCH METHODOLOGY

Tuned Mass Damper

The seismic behavior of the building can only be studied by attaching the TMD with three different mass ratios to the model. Mentioned before. Table 1 provides some information on adjusted mass dampers.

Table 1: Details of the TMD

Content	9% mass of primary structure	6% mass of primary structure	3% mass of primary structure
Mass of the damper	86906 kg	57937kg	28968kg
Damping ratio	0.16	0.13	0.1
Effective stiffness in x-direction	7.5*10^7 kN/m	7.5*10^7 kN/m	7.5*10^7 kN/m
Effective stiffness in y,z directions	4262kN/m	2841kN/m	1420kN/m
Effective damping in the x-direction	25834kN-sec/m	18457kN-sec/m	9322kN-sec/m
Effective damping in y,z directions	641kN-sec/m	113kN-sec/m	40kN-sec/m

Method

Using varying mass ratios (3%, 6%, and 9%), this study presents the results of a examination of G+9 structures with and without thermal mass damping (TMD). Buildings containing and without TMD are compared in terms of displacement, acceleration, and frequency in this article.

Initial test: AV (Ambient Vibrations)

With regard to the Brincker criteria, which requires 1000 periods, Figure 1 shows the results of the first experiment, which recorded background vibrations for fifteen minutes using a 200 Hz sampling rate. The scanners were arranged in a way that allowed them to span the whole building. In order to get a single point for every level , two sets of recordings were carried out (Fig. 1). The wandering sensors were removed and replaced with the top-floor (8th and 9th floor) sensors, which were retained as references due to their larger amplitudes. Figure 2 and Table 2 show the results of using the FDD approach to extract the two initial bending modes over all planes, including horizontal and vertical. The 2.73 Hz and 7.71 Hz transverse mode and the 2.28 Hz and 8.69 Hz longitudinal mode are distinct modes. Also, the modal forms are anonymous, but the third-bending mode's frequency in both directions is may be, even with a low energy level. It is possible that this is also the case with the second transverse mode, which displays an unusual modal form.

The shear beam model's theoretically-assumed sequence 1, 3, and 5 was fit by the ratio of harmonic to fundamental frequencies running down its length. Equivalent ratios in the opposite direction are 1, 3.8, and 6.8. Selecting the model that best fits the building is made easier by this ratio, which is a feature of the model. According to Table 2, our structure exhibits more transverse bending than longitudinal bending. Figure 2 shows the initial transverse modal shape, which is similar to a cantilever beam, and the experimental results corroborate this. Even though we knew the shear beam model only worked for the longitudinal direction, we nonetheless used it for both construction orientations. Given that stiffness is directly related to square of frequency, the initial frequencies indicate that the longitudinal direction is forty percent stiffer than the transverse one. Additional modes that could be associated with torsional behaviour are revealed using the FDD approach. Section 2. This sort of torsional motion is definitely caused by the uneven positioning of the shear walls and beams; many recording stations on the same floor might prove this.

Table 2. Modal frequencies retrieved from AV using the FDD method

Mode	Frequency (Hz)	fk /f1
Transverse 1	2.28	1
Longitudinal 1	2.73	1
Torsion 1	4.74	
Torsion 2	5.64	
Transverse 2	8.69	3.8
Longitudinal 3	12-13	4.5
Transverse 3	15.5	6.8

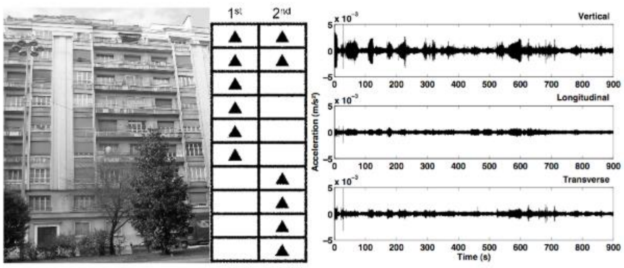

Figure 1. Pictured on the left is the building under investigation; in the middle is the strategy for the first and subsequent sets of AV experiments data; and on the right is the acceleration throughout time that was inferred from the AV velocities obtained on the eighth level.

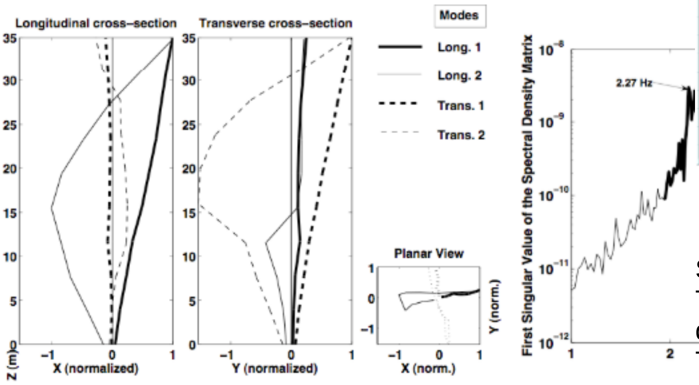

Figure 2. Matrixes representing power spectral density computed from audiovisual recordings (on the left) and corresponding modal shapes (on the right) obtained by means of the FDD method (bending modes only) are used to choose the building frequencies. A MAC value higher than 80% is shown by the bold bell for each mode that has been recognised.

DATA ANALYSIS

Using a Tuned Mass Damper to control building vibrations caused by seismic forces

This research compares the effects of using and not using the TMD in a three-dimensional, ten-story SAP 2000 model. In both instances, we subject the same model to a linear dynamic analysis by manipulating the mass ratios.

Displacement

When a structural member is pushed or pulled out of its original location by an outside force, this is called displacement. In order to ensure the structure's safety, it is recommended to minimise the displacement induced by the force by inserting TMD. Both the floor with and without TMD diaphragm displacements are reported in table 3 and figure 3.

Table 3: Floor diaphragm displacement with and without transverse mechanical damping

diaphragm	displacement without TMD (mm)	Displacement with TMD(mm)		
		3% mass ratio	6% mass ratio	9% mass ratio
1	3.2	1.2	0.8	0.6
2	7.5	2.9	1.9	1.5
3	11.6	4.5	3.0	2.4
4	15.5	6.1	4.1	3.3
5	19	7.6	5.2	4.2
6	22	9.0	6.2	5
7	24	10.3	7.1	5.8
8	26	11.4	8.0	6.6
9	28	12.4	8.8	7.3
10	28	13.1	9.5	7.9

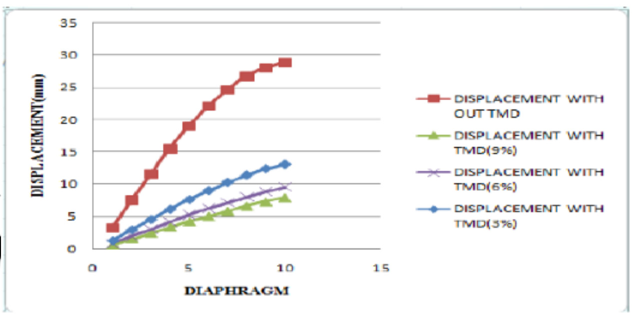

Figure 3: Diaphragm versus Displacement

See how each level of the building with and without TMD compares in terms of displacement at the diaphragm in Fig. 3. Clearly, in the first mode without TMD, the maximum displacement at the 10th structural diaphragm is 28 mm. Reduced displacement to 13.1 m, 9.5 mm, and 7.9 mm delivered to TMD in three different mass ratios—3%, 6%, and 9%—at the structure's tenth diaphragm in first mode.

Frequency

When a structure vibrates in response to an external stimulus, Frequency is the time it takes for an oscillation to complete one cycle.. The structure's pliability or rigidity may be assessed by measuring its frequency. The structure is prone to damage if the oscillations are excessive. Structures with and without TMD are described in table 4 and figure 4, respectively.

Table 4: Patterns of models including and lacking TMD

Mode Number	Frequency without TMD (rad/sec)	Frequency with TMD(rad/sec)		
		3% mass ratio	6% mass ratio	9% mass ratio
1	6.6	1.84	1.50	1.30
2	7.3	2.19	1.99	1.84
3	7.4	2.54	2.53	2.52
4	20.07	6.27	5.94	5.79
5	22.2	6.82	6.45	6.15
6	22.5	7.72	7.63	6.35
7	37.7	10.86	7.69	7.66
8	43.0	12.14	11.61	11.30
9	53.9	13.22	12.76	12.43
10	70.35	18.43	17.3	16.24

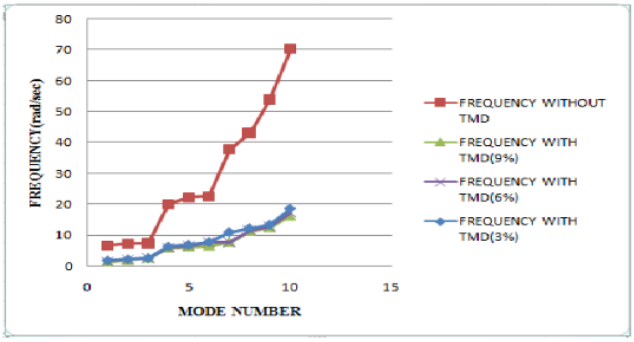

Figure 4: Mode number as a function of frequency

For a look at how structure frequency changes with and without TMD, see Figure 4. In first mode, the frequency of the structure is 6.6 rad/sec, even without a tuned mass damper. The structure's frequency dropped to 1.84 followed by TMD at varied rates of 1.5 rad/sec, 1.3 rad/sec, and 1.4 rad/sec mass ratios (3%, 6%, and 9%).

Structures' dynamic characteristics derived from observations of ambient vibration

To ensure the accuracy of the previously described technique, we first tested AV modal modelling to see how well it could forecast the building's motion when vibrated due to the bridge destruction. With the experimental modal parameters obtained from the surrounding vibrations and the experimental mode shapes supplied, the building's motion and behavior during earthquakes may be simulated using Eq. 10. Under no circumstances was any mode other than the first two bending modes used in either direction. The effective damping ratio was determined for every mode with the exception of the first longitudinal mode as 4% using the random decrement approach. For this mode, the value is 2%.

Figure 5 shows the calculated and recorded displacements obtained from the building's peak. The data and models are well-aligned, as we can see. Although the model does not include the building's complicated behaviour, the simulation nonetheless captures the amplitude levels, length, frequency, and phase of the building's motion. Another way to calculate the inter-story drift is to take the difference between the displacements recorded at successive levels over time. At most This is how Figure 6 was generated using the bridge destruction recordings and the modal model. The same values have been compared by averaging the model in non-recorded tales. While the model accurately portrays the maximum drift magnitude, its under-estimates the longitudinal drift at higher floors, particularly the fourth. The Duhamel integral is solving these N separate problems analytically with respect to yj(0)=0 and y'j(0)=0, which is articulated as:

$$\forall j \in [1,N] \;\; y_j(t) = \frac{-p_j}{\omega'} \int_0^t U_s''(\tau) e^{-\xi_j \omega_j (t-\tau)} \sin(\omega'(t-\tau)) d\tau$$

With

$$\omega_j'^2 = \omega_j^2 (1 - \xi_j^2).$$

Without making any assumptions about the structural design, we can calculate the system's elastic behavior during mild earthquakes, with the modal parameters determined from ambient vibrations and the assumption of a constant mass per floor of 1000 kg/m² and knowing the geometry of the recording array.

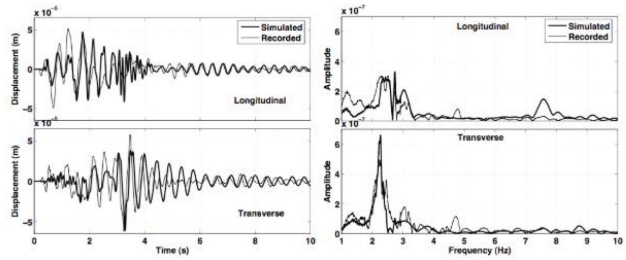

Figure 5. Time series at ground level, and spectra at eaves level, contrasting the building's reaction via models and observations after the bridge removal.

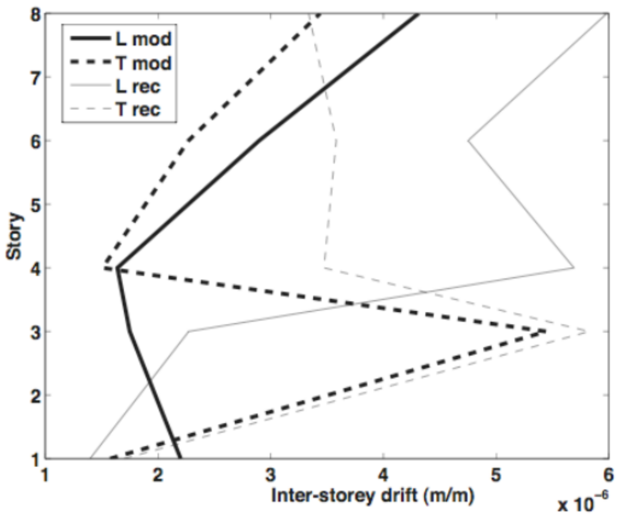

Figure 6. At each possible story during the bridge's disassembly, we recorded and then recreated the drift envelope. The transverse motion is shown by the dotted line, while the longitudinal motion is shown by the solid line.

transverse motion. For models, use thick lines, while for recordings, use thin ones.

A vertical seismic motion peaking at about 11 Hz was produced by the deck's immediate collapse (source time length of approximately 5 ms) (Fig. 7). The building's ground level measured a horizontal peak ground acceleration (PGA) of 0.025 m/s2 (Refer to Table 5). That figure surpasses the PGA recorded by the French Accelerometric Network (http://www-rap.obs.ujf-grenoble.fr) in the Grenoble basin during the most recent Alps earthquakes. But with that out of the way, the Grenoble's design acceleration values as used in the code region (1.5 m/s^2) are sixty times higher. At the very top of the building, the highest horizontal acceleration was 0.061 m/s^2. Despite the need for white noise as a fundamental assumption, the FDD approach was used to ascertain the structural modes for these explosion recordings. Consistent with what Ventura shown, the following findings demonstrate that the modal parameter determination is unaffected by ignoring the white noise assumption. Fig. 8 shows that the only modes that can be detected are the first modes of bending in all directions and the initial modes of supposed torsion. The transverse mode's modal shape reveals a non-insignificant twisting component, which was absent in the AV recordings. Because of this, we may understand why the two trials showed such a weak association (Fig. 8). There is a frequency discrepancy of less than 1% between the two recordings for the initial bending and torsion modes, as shown in Table 6. Due to the limited number of points that could be captured at once, the MAC values reveal a striking degree of agreement between the two experiments' mode forms (Table 6). In order to account for the bridge destruction, linear interpolation was used at many places along the modal curve.

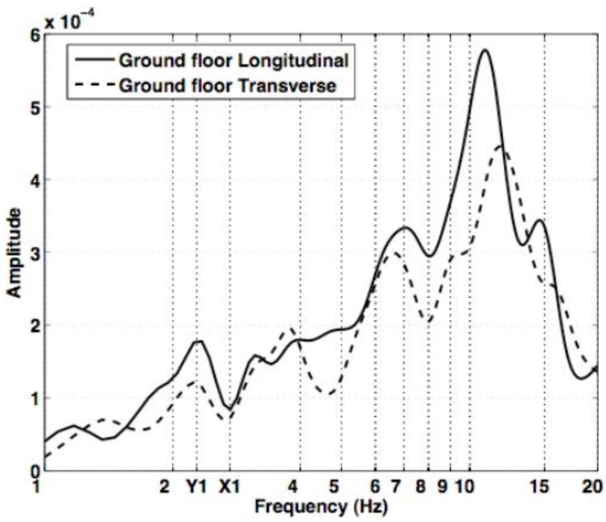

Figure 7. Spectra of the Fourier transform of the ground-floor recordings of the bridge being demolished. The function is used to smoothen the spectra. The structure's modal frequencies, as determined by environmental vibrations, are denoted as X1 and Y1, respectively.

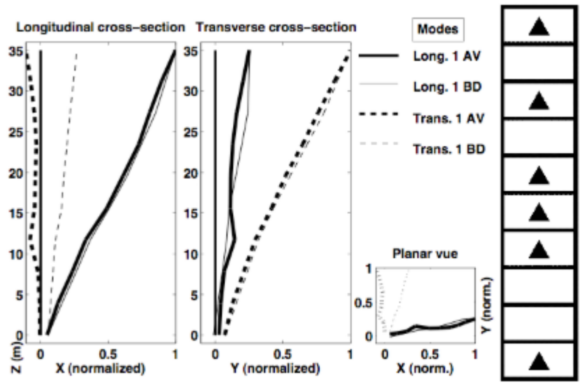

Figure 8. Side by side, we can see the experimental plan for the BD and the first modal forms retrieved from the AV and BD. The narratives that were not quantified are extrapolated in a linear fashion.

Table 5. Speeds reached at their peak during the bridge dismantling (m/s^2)

Direction	Ground Floor	Top floor
Longitudinal	0.025	0.051
Transverse	0.019	0.062
Vertical	0.046	0.094

Table 6. Analysing the Ambient Vibration (AV) and Bridge Demolition (BD) studies for frequency and modal shape (MAC value)

Mode	AV	BD	Comparison	
	f (Hz)	f (Hz)	Freq. Var.	MAC value
Transverse 1	2.28	2.27	-0.4%	85%
Longitudinal 1	2.73	2.75	0.7%	99%
Torsion 1	4.74	4.77	0.6%	97%
Transverse 2	8.69	8.46	-2.6%	20%

In order to augment seismic risk assessment examinations of preexisting structures, we proved the practicality of a suite of simple methods by capturing ambient vibrations. The first stage in evaluating a building's behaviour after an earthquake is to break its motion down into its most basic modes, which are bending and torsion.

CONCLUSION

We analyzed a 10-story building with and without TMD using linear dynamic analysis and compared the results using sap2000. Superior to other methods, TMD controls seismic displacement and frequency. The earthquake's seismic waves cause the structure to tremble and oscillate in every direction. There are a lot of different approaches to reducing structural vibrations, but the most popular and successful one is the Tuned Mass Damper. Using sap2000, we contrasted G+9 3D models exposed to TMD with those that were not. This tuned mass damper (TMD) is placed on top of the structure to compare its reactivity with and without it. Even when faced with white noise, the findings demonstrate that the FDD is still capable of extracting valuable information like as frequency, modal shapes, and damping. This building's stiffness may be estimated from the recorded frequency values, which can then be compared to the transverse to longitudinal stiffness ratio. We used a simple lumped-mass model that depends on the shear beam stiffness matrix to predict the stiffness at each story since this is not enough for vulnerability assessment.

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