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Effect of Higher Modes on the Design of Structures that Resist Earthquakes

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Abstract: Seismic waves carry the earthquake's kinetic energy to the structure, where it is then transferred into vibrational motion through the foundations. The reaction acceleration for extremely short time period (high frequency) structures will be close to the maximum acceleration felt by the ground. Long-lasting buildings can take use of the system's adaptability; the mass won't budge no matter how much the earth shifts underneath it, and the relative deformation will be just as large. Examine the impact of higher modes on earthquake-proof building design in this research.

Keywords: Earthquakes, Seismic Waves, Seismic Waves, Resist, Structures.

1. Introduction

Seismic waves, which are the consequence of an earthquake's release of stored energy, travel through the ground and cause buildings to sway back and forth. The building puts up a fight, which creates inertia, damping, and spring forces throughout the structure. The magnitude of an earthquake's impact on a structure is determined by many factors in addition to the peak value of ground acceleration itself. [1-2]

These include the building's size and form, the layout of its structural parts, and the existence of mass and stiffness abnormalities. The spectral acceleration of a high-frequency (short time period) structure will be close to the maximum acceleration felt by the earth below. Extreme or fundamental rigidity characterizes a short period system. Since its mass follows the ground's motion, the system's deformation will be minimal. [3-4]

Long-lasting structures may take advantage of the system's adaptability, since the mass will stay there despite the underlying earth shifting. By treating buildings as if they were massless springs with stiffness in the lateral direction, we may analyze their vibration behavior. The concentrated masses are lumped at roof/floor levels.[5-7]

Direct integration of a equation of motion is thought to accurately predict how a structure will react to a given earthquake time history, hence it is widely used in seismic analysis and design. Instead of using direct integration, which requires having the actual time recording at every site, the response spectrum approach is utilized because of the computing limitations involved with analyzing large real-world structural models. A reaction spectrum is used to determine the seismic input required for building design. [8-9]

The frequency content of ground motion and the structure's dynamic qualities are both taken care of by the response spectrum approach. It has become the de facto industry standard and

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is so extensively used. It is based on the modal idea of judging responses. A structural model's total amount of modes is equivalent to its total number of free parameters, or degrees of freedom. As real-world structures might have several degrees of freedom, it would be difficult to compute all of their modes. In the case of simple regular structures, the overall response may be evaluated with good accuracy using just a few low-frequency modes. This causes a cutting off of the higher modes. Fundamental mode of vibration is the primary basis for seismic evaluation and design approach in most building codes.[10]

2. Material and Methods

- **Residual Mode Method Modified**

The two DOF system shown is taken into account in order to assess the residual mode's approximation of the periodic portion of the response. we can see the modal characteristics.

Table 1:Two degrees of freedom modal characteristics

Modal Properties			
Mode Number	**Mass participation %**	**Damping ratio %**	**Natural Frequency (Hz)**
1	30.24	5	2.05
2	69.76	5	0.97

The structure is evaluated using spectra of the ground's reaction to an earthquake. With 5% dampening, the stiff frequency is 31.0 Hz, whereas the key frequency f1 is just 1.47 Hz. The structure is studied in the first mode, while the second is shortened. Lower than the stiff frequency and near to the fundamental frequency f1, the 2nd stage has a frequency of 2.05 Hz. This shows that the vast majority of the reaction is periodic, albeit with a dulling effect.

Despite having a frequency of 2.05Hz, which is substantially lower than the stiff frequency but near to a critical frequency f1, this sample illustrates that the residual mode properly calculates the responses. It is shown that the second mode shape and the residual mode shape are identical.

Table2:The 2 DOF spring force error

Analysis	**SpringForce**	
	1 Element	**2 Element**
ModalAnalysis	$3.05\text{x}10^5$	$1.79\ \text{x}10^5$
First Mode alone	$2.45\text{x}10^5$(-19.67)	$1.69\text{x}10^5$(-5.13)
FirstMode+ResidualMode	$3.05\text{x}10^5$(0.00)	$1.79\ \text{x}10^5$(0.00)

Take, for example, the 5 DOF system shown. The damping ratio of the system is 5%, and the system's natural frequencies are 0.39 Hz, 1.14 Hz, 1.80 Hz, 2.32 Hz, 2.64 Hz, with modal mass participation values of 88%, 8.7%, 2.4%, 0.75 %, and 0.15%. Almost 90% of the total

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mass is participating in the first mode of the modal distribution. El Centro (1940) ground motion response spectra are used to assess the building. The study makes use of a custom MATLAB programme.

The residual mode technique is used to provide a correction to the shortened upper modes. Equation is written to determine the modal expansion of Ub for the truncated modes. Simplifying the equation by ignoring the factor ug leads to

Table3:The 2 DOF spring force error

Analysis	SpringForce	
	1 Element	2 Element
Modal Analysi	$3.05x10^5$	$1.79\ x10^5$
First Mode alone	$2.45x10^5$(-19.67)	$1.69x10^5$(-5.13)
FirstMode+ResidualMode	$3.05x10^5$(0.00)	$1.79\ x10^5$(0.00)

Take a 5 DOF setup and apply the scaling factor ug to get the following equation. The damping ratio of the system is 5%, and the system's resonant frequency are 0.39 Hz, 1.14 Hz, 1.80 Hz, 2.32 Hz, 2.64 Hz, with modal mass participation values of 88%, 8.7%, 2.4%, 0.75 %, and 0.15%. Almost 90% of the total mass is participating in the first mode of the modal distribution. El Centro (1940) ground motion response spectra are used to assess the building. The study makes use of a custom MATLAB programme. Comparison of storey shear calculated with just the first mode with storey shear calculated with all.

The mode shape is different from what we seen before. Modal response is a function of the mode increasingly visible, mode shape, or spectral displacement, as shown in Equation (1.5). The residual mode takes into consideration the mode participation factor of the shortened upper modes. In accordance with the residual mode, the proportion of potential voters is 12 percent. From lowest to highest, the masses at each mass point related to the residual mode are 25749.14kg, 12652.8kg, 1771.97kg, -6011.85kg, and -10068.10kg, respectively. The residual response closely resembles the damped periodic component by using the stiff portion of the shortened modal response. Response is also affected by a third factor: the mode shape. As a result, we may recast the residual mode shape as the second mode shape & derive the relevant response using Eq. The data is shown in Table, where it can be seen that the largest mistake is brought down to 13.38% in the top storey, while the error in other levels is minimal. The table shows that the error caused by the first mode alone is 33.06%, and that the error caused by the first mode plus the residual mode is 30.64%. The suggested solution is straightforward and can cut the worst case error by as much as 13.38%. Some explanations

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include the initial mode's interaction with the modified residual mode as a modal response.

Table 4: Shear force error for 5 degrees of freedom system

Analysis	**Storey Shear(N)**				
	1 Storey	**2 Storey**	**3 Storey**	**4 Storey**	**5 Storey**
ModalAnalysis	$3.15\text{x}10^5$	$2.73\ \text{x}10^5$	$2.35\text{x}10^5$	$1.89\ \text{x}10^5$	$1.24\ \text{x}10^5$
First Mode	$2.92\text{x}10^5$ (-7.3)	$2.68\ \text{x}10^5$ (-1.8)	$2.23\text{x}10^5$ (-1.83)	$1.59\ \text{x}10^5$ (-15.8)	$0.83\ \text{x}10^5$ (-33.06)
Residual Mode Method	$3.29\text{x}10^5$(4.44)	2.77 $\text{x}10^5$(1.46)	$2.30\text{x}10^5$(-2.12)	1.65 $\text{x}10^5$(-12.69)	0.86 $\text{x}10^5$(-30.64)
ProposedMethod	$3.01\text{x}10^5$(-4.44)	2.69 $\text{x}10^5$(-1.46)	$2.29\text{x}10^5$(-2.55)	1.83 $\text{x}10^5$(-3.17)	1.07 $\text{x}10^5$(-13.38)

It is suggested to use a residual mode to determine the contribution of higher modes beyond the basic mode, and an equation is constructed to do so.

$$\mathbf{U}_i = \Gamma_r \phi_2 S_{Dr}$$

Where The second mode form and mode are denoted by 2, where r is the modal participation factor of the residual mode. The residual's related spectral displacement is denoted by SDr. The structure's reaction may be determined without taking into account all of the modes by focusing on the first mode or the modified residual mode provided by Equation. The suggested technique significantly streamlines the seismic analysis of buildings with substantial contributions from higher modes. Here, we provide six numerical examples to test the reliability of the derived equation.

- **NumericalExample1(Regular)**

Five degrees of freedom (DOF) are derived from the structure using modal harmonics below the stiff frequency. Each floor is a standard 3 metres in height. This structure complies with all current construction codes. The mass participation percentages, relative frequencies, and modal damping of the system are all tabulated in Table. The frequencies were chosen such that the structural response's third through fifth modes would be emphasised to their full potential. Modal mass involvement is close to 90% if just the first mode is considered, which completely meets the codal criterion for the number of modes.

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Table 5: Five degrees of freedom modal characteristics

ModalProperties				
ModeNumber	**NaturalFrequency(Hz)**	**Dampingratio %**	**Massparticipation %**	**SpectralAcceleration m/s^2**
1	0.50	5	87.95	1.74
2	1.46	5	8.71	6.39
3	2.30	5	2.42	6.52
4	2.95	5	0.75	6.37
5	3.37	5	0.15	6.91

Expansion of Ub in modal terms is provided by,

$$\mathbf{U}_b = \sum_{i=1}^{n} \phi_i \Gamma_i$$

- **NumericalExample2(MassIrregularity)**

Modal frequencies lower than the stiff frequency are shown for a mass-irregular 6-DOF structural system. Natural frequencies, modal damping, or mass participation percent are shown in the table for the different modes of the system. If just the initial mode of transportation is taken into account, than the modal masses participation is very near to 90%, and the legal criteria are satisfied.

Table 6: Six degrees of freedom modal characteristics

Storey	**Modal Properties**		
	Mass participation%	**Damping ratio %**	**Natural Frequency(Hz)**
1	1.33	5	2.39
2	5.26	5	1.15
3	0.24	5	3.06
4	89.95	5	0.34
5	3.87	5	1.55
6	0.05	5	2.74

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Table displays the results of calculating the modal expansion of for each mode. From This, we can deduce that nodes 4, 5, and 6 have higher modal mass involvement for mode 1 than nodes 1, 2, and 3. The percentage of mass operating in mode 1 is 90% overall, however it is lower than 90% at nodes 1-6 and more than 100% at nodes 4-6.El Centro (1940) ground motion response spectra are used to assess the building. Tabulated below is the amount by which storey shear calculations based on the 90% modal mass are off. As can be shown in Table, the inaccuracy in calculating storey shear for all modes in storeys 6 and 5 is 37.8% & 50.7%. As the magnitude of shear force relies on the relative displacement between the storeys, Ub increases with storey height and the response shear force decreases for first mode as storey height increases.

Table 7:Ub modal growth for a 6 degrees of freedom system

Node	1 Mode	6 Mode	2 Mode	4 Mode	3 Mode	5 Mode	U_b
1	0.833	0.072	0.256	-0.214	0.060	-0.004	1
2	0.294	0.065	0.198	0.216	0.240	0.009	1
3	1.155	0.010	-0.199	0.052	0.027	-0.055	1
4	0.575	-0.094	0.300	-0.021	0.269	-0.007	1
5	1.205	-0.004	-0.389	-0.047	0.232	0.031	1
6	1.055	-0.011	0.087	0.042	-0.201	0.010	1
M_i^*%	89.95	0.24	5.26	1.33	3.87	0.05	

Table 8: Shear force error for 6 degrees of freedom system

Analysis	StoreyShear(N)					
	1 Storey	2 Storey	3 Storey	4 Storey	5 Storey	6Storey
Modal Analysis	$4.04\text{x}10^5$	$3.62\text{x}10^5$	$3.36\text{x}10^5$	$3.11\text{x}10^5$	$2.01\text{x}10^5$	$1.29\text{x}10^5$
FirstMode	$3.71\text{x}10^5$ (-8.47)	$3.55\text{x}10^5$ (-1.90)	$3.25\text{x}10^5$ (-3.32)	$2.80\text{x}10^5$ (-9.94)	$1.25\text{x}10^5$ (-37.8)	$0.63\text{x}10^5$ (-50.70)
Proposed Method	$3.86\text{x}10^5$(-4.63)	3.59 $\text{x}10^5$(-0.61)	$3.25\text{x}10^5$(-3.18)	2.92 $\text{x}10^5$(-5.98)	1.93 $\text{x}10^5$(-3.90)	$1.16\text{x}10^5$(-10.07)

The truncated modes are used with the suggested approach. The residual mode has a frequency of 1.56 Hz, which is much lower than the stiff frequency. In order to determine the second residual mode's response, we use the following equation. Table shows that the improved residual mode technique only produces a maximum error of 10.07 percent in storey 6 when calculating storey shear with regard to all modes. This demonstrates that the initial mode and a modified mode shape residual mode are all that are needed for response computation.

- **Numerical Example3 (Stiffness Irregularity)**

Illustration of a six degree-of-freedom structural system whose stiffness is not uniform and whose modal frequencies are less than the stiff frequency. The building's ground level is spongy and its stiffness is inconsistent. Natural frequencies, modal damping, or mass participation in each mode of the system are all tabulated in Table.

Table 9:Six degrees of freedom modal characteristics

ModalProperties			
ModeNumber	**Mass participation%**	**Dampingratio %**	**NaturalFrequency(Hz)**
1	0.76	5	1.79
2	90.73	5	0.37
3	0.12	5	2.88
4	7.21	5	1.09
5	0.41	5	2.40
6	0.03	5	3.19

Modal mass growth is seen in Table. Modal mass involvement is 90% if just the first mode is examined, hence the statutory requirements are met. El Centro (1940) ground shaking response spectra are used to assess the building. Table shows that for stories 5 and 6, the error in calculating storey shear when accounting for the 90% modal mass with regard to all the modes is 23.35% and 33.04%, respectively.

Table 10:Ub modal growth for a 6 degrees of freedom system

Node	**1 Mode**	**6 Mode**	**2 Mode**	**4 Mode**	**3 Mode**	**5 Mode**	**U_b**
1	0.42	0.01	0.29	0.08	0.12	0.03	1
2	1.05	-0.02	0.05	0.05	-0.11	0.03	1

3	0.67	-0.02	0.36	-0.04	0.05	-0.05	1
4	1.23	-0.01	-0.34	-0.06	0.09	0.02	1
5	0.88	0.02	0.26	-0.07	-0.07	0.02	1
6	1.18	0.01	-0.18	0.07	-0.02	-0.05	1
M_i^*%	90.73	0.03	7.21	0.41	0.76	0.12	

Table11: Shear force error for 6 degrees of freedom system

Analysis	**Storey Shear(N)**					
	1 Storey	**2 Storey**	**3 Storey**	**4 Storey**	**5 Storey**	**6 Storey**
Modal Analysis	$3.61x10^5$	$3.18x10^5$	$2.80x10^5$	$2.44x10^5$	$1.97x10^5$	$1.15x10^5$
Firstmodealone	$3.41x10^5$ (-5.54)	$3.14x10^5$ (-1.25)	$2.72x10^5$ (2-.85)	$2.17x10^5$ (-11.06)	$1.51x10^5$ (-23.35)	$0.77x10^5$ (-33.04)
ProposedMethod	$3.52x10^5$ (-2.49)	$3.16x10^5$ (-0.63)	$2.75x10^5$ (-1.78)	$2.35x10^5$ (-3.68)	$1.81x10^5$ (-0.08)	$1.01x10^5$ (-12.17)

The truncated modes are used with the suggested approach. The stiff frequency is a lot higher than the residual mode frequency of 1.36 Hz. It is therefore possible to determine the second residual mode's reaction.The response of the structure may be determined without taking into account all of the modes by focusing on the first mode and the modified residual mode provided by Equation. The suggested technique significantly streamlines the seismic analysis of buildings with substantial contributions from higher modes. Here, we provide six numerical examples to test the reliability of the derived equation.

- **Numerical Example 4 (Mass and Stiffness Irregularity)**

Five degrees of freedom (DOF) models of structures with semi-rigid bases and flexible towers are investigated using the suggested approach. The Table displays the natural frequencies, modal damping, and mass participation percentages of all system modes.

The fifth mode accounts for the vast majority of this data set. The first mode only contributes around 40.55 percent of the total mass. For this study, we just care about the first mode and ignore the higher ones. Using spectral analysis of ground motion to induce earthquakes.

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Accuracy is determined by comparing the response to the mean of all possible outcomes. The table demonstrates the errors introduced when computing storey shear with only the first mode. The table shows that the storey shear estimate is off by 32.77% for all modes on the ground level. A residual mode approach is used to compensate for "missing mass" in the shortened higher modes. This residual mode vector has a frequency of 31.01 Hz. The frequency of the residual mode is quite similar to the frequency of the stiff mode. The residual mode tends to have a stiff behaviour. When the mode is sufficiently stiff, the effects of damping & inertial forces are disregarded. Taking the 90% modal mass into account in relation to all the modes results in a response of 23.35 & 33.04 percent of the floor shear for levels 5 and 6, respectively.

Shows a structural system with five degrees of freedom and modal frequencies below the stiff frequency (Chopra, 2007). Each floor is a standard 3 metres in height. This structure complies with all current construction codes. The system's inherent frequencies, modal damping, or mass participation percent are shown in Table. The frequencies were chosen such that the structural response's second though fifth modes would be emphasised to their full potential. Modal mass participation is close to 90% if just the first mode is considered, which completely meets the codal criterion for the number of modes.

$$\mathbf{U}_i = \Gamma_r \phi_r S_{Dr}$$

Table 12: Five degrees of freedom modal characteristics

Modal Properties			
Model Number	**Mass Participation%**	**Damping Ratio %**	**Natural Frequency(Hz)**
1	40.55	5	5.71
2	6.21	5	16.44
3	4.52	5	25.21
4	8.00	5	30.94
5	40.71	5	33.23

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Table13:Shear force error for 5 degrees of freedom system

Analysis	StoreyShear(N)				
	1 Storey	**2 Storey**	**3 Storey**	**4 Storey**	**5 Storey**
Modal Analysis	8.97×10^5	5.97×10^5	5.03×10^5	3.65×10^5	1.92×10^5
First mode alone	6.03×10^5(-32.77)	5.84×10^5(-2.17)	5.11×10^5(1.59)	3.78×10^5(3.56)	2.01×10^5(4.68)
First Three modes	6.52×10^5(-27.31)	6.12×10^5(2.51)	5.02×10^5(-0.19)	3.58×10^5(-18.91)	1.93×10^5(-0.52)
Proposed Method	9.02×10^5(0.55)	6.00×10^5(0.51)	5.04×10^5(0.19)	3.6×10^5 (-1.37)	1.91×10^5(-0.52)

The findings are compared to the maximum modal answers found using all-mode modal analysis. Table shows the relative inaccuracy between each technique of calculating storey shear and a modal analysis including all modes. According to Table , the suggested technique yields a response calculation error of less than 4%.

- **Pushover Analysis**

NumericalExample5

Depicts the characteristics of the 2 DOF system under consideration. In Table , we can see the modal characteristics. The first mode has an effective modal mass of 900 kg, or 90% of the total mass.

Table 14:Two degrees of freedom modal characteristics

ModalProperties			
ModeNumber	**Mass participation%**	**NaturalFrequency(Hz)**	**Dampingratio %**
1	9.99	50.37	5
2	90.01	5.32	5

El Centro 1940 earthquake non-linear static pushover analysis with 5% damped response spectra yields spring forces in components 1, 2, and 3. Both and Ry are assumed to be 3, with set at 0.03. The bilinear hysteretic relationship is used as an idealisation of the lateral-force displacement relation. Using Equation 1.18, we can determine the yield deformation.

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Maximum force associated with inelastic system's maximum deformation Um is The yield deformation of members 1 and 3 are assumed to be the same. Using Equation, we can determine the time period that is appropriate for the inelastic system (1.25). The inelastic response is computed using the response spectrum of the El Centro, 1940, earthquake and the empirical formulae provided by Equation . Modal response combination rules are used to combine the storey shear for higher modes (determined by the elastic response spectrum approach) with the storey shear for the first mode (determined by the pushover analysis).

The suggested modified residual mode approach is used to truncate the second mode. The frequency of the second mode and the residual mode are same. Using Table 4.16, we can see that the suggested technique yields results that are on par with those obtained using any of the structure's modes.

Table15:Two-degrees-of-freedom spring force

Analysis	**SpringForce(N)**		
	1 Element	**2 Element**	**3 Element**
Withallthe modes	2229.99	355.74	11.25
With90% modalmass	2230.21 0.00	48.48 86.37	11.19 0.53
Proposedmethod	2229.99 0.00	355.74 0.00	11.25 0.00

Numerical Example 6

In this case, we take into account the 5 degrees-of-freedom structure from of the numerical example. The first mode is analyzed using a non-linear static pushover analysis since it is assumed that higher modes are elastic. We choose Ry = 5 and = 0.03 to simplify the expression. Depicts the relationship between base shear and roof displacement for the first mode. Using Equation, we can determine the time period that is appropriate for the inelastic system . The inelastic response is computed using the response spectrum of the El Centro, 1940, earthquake and the empirical formulae provided by Equation. The storey shear may be determined using the storey drift. Maximum force associated with inelastic system's maximum deformation Um is Modal response combination rules are used to combine the storey shear for higher modes with the storey shear for the first mode. Table summarizes the results of measuring the shear between floors. Error in the answer is determined by comparing it to the average response across all modalities.

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Table16: Shear force error for 5 degrees of freedom system

Analysis	Storey Shear(N)				
	1 Storey	2 Storey	3 Storey	4 Storey	5 Storey
ModalAnalysis	$2.63x10^5$	$2.21x10^5$	$2.1x10^5$	$1.92x10^5$	$1.31x10^5$
Modes	$2.23x10^5$(-15.29)	$2.15x10^5$(-2.71)	$1.93x10^5$(-8.09)	$1.38x10^5$(-28.12)	$0.71x10^5$(-45.80)
Proposed Method	$2.58x10^5$(-1.90)	$2.18x10^5$(-1.2)	$2.08x10^5$(-1.43)	$2.01x10^5$(4.68)	1.32 $x10^5$(0.76)

The suggested approach is applied to the truncated higher modes, which are all the modes above the first mode. The stiff frequency is a lot higher than the residual mode's 1.8 Hz. In order to determine the second residual mode's response, we use the following equation. Table shows that the residual mode approach to calculating storey shear results in errors of less than 5% for all modes. It demonstrates that the suggested initial mode and a residual mode with a changed mode shape are enough for response computation. The suggested strategy is shown to account for the influence of higher modes.

3. Results

- **Response Spectrum Method**

Using the provided numerical examples, the newly created approach is shown to successfully include contributions from higher modes beyond the first mode. Mass exhibiting first-mode participation in numerical instances. Section 1's numerical example is a regular structure with such a uniform distribution of mass and stiffness, so the response may be estimated using just the first mode of vibration, as required by standard building regulations. The first mode's comparable mass participation is 87.95% here, with values ranging from 0.35 times mass in node 1 to 1.25 times mass at node 5. Although the first mode contributes 89.95% of the total mass at node 1, its relative importance increases to 1.2 times the mass as the building rises to node 6. This is shown numerically in section. If the modes are cut short, the structure will have "missing mass," as seen by the expansion of 1. Errors in calculating the answer are evaluated relative to the response determined by using all possible modes. There is a maximum 33.33%, 50.7%, and 33.04% mistake in the upper storey's shear calculation. In order to analyse buildings with vertical irregularity, the suggested technique utilises the first mode and a modified residual mode to account for the contributions of truncated upper modes. Large floor accelerations that are not anticipated in the design cause many building collapses during earthquakes. For the design of both structural and nonstructural components placed at different floor levels, a precise calculation of storey shear or lateral force distribution is crucial.

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As can be seen from the aforementioned numerical examples, the 90% mass participation criterion for the number of modes evaluated may not provide accurate responses in all of the structural elements of an irregular structure. All the modes up to frequency must be considered for an accurate assessment of response in all the structural components, and "missing mass" correction utilizing residual mode beyond stiff frequency must be used. The newly established approach for seismic analysis of the buildings is straightforward and may be used to the seismic analysis of non-standard building types.

- **Pushover Analysis**

Pushover analysis of structures is made possible with the help of the newly created approach, as shown by the provided numerical examples. The nonlinear pushover analysis of buildings is adapted from the guidelines provided by building codes of practise for the response spectrum technique of seismic analysis. Numerical examples show that proper responses in all structural parts of a structure are not guaranteed when considering modes contributing in 90% seismic mass for seismic analysis of structures. When there are a lot of moving parts in a system, it's easy to forget how many people are responsible for each action. The fifth floor is where the biggest mistake is made (by 45.8%). According to standard building rules, the building in question is regular in appearance; nevertheless, using just the first mode of analysis yields an error of 45.8%, whereas the suggested technique yields an error of less than 5%. Response contributions from higher modes may be more conservative if elastic behaviour in higher modes is taken into account. To determine the contribution of higher modes, the elastic response of the first mode may be used in conjunction with the suggested modified residual mode technique.

4. Conclusion

Ub's modal expansion shows that the streamlined method based on the first method for regular structures or 90% seismic mass involvement in the various modes considered for irregular structures, as required by the building codes of practise, may not always result in the order to take into account of responses throughout all structural members. The investigated cases show that the current criteria under-estimate shear at the top and bottom floors of the building. The suggested novel technique incorporates the contributions of reduced higher modes into the response calculation through a modified residual mode applied to the first mode. The examined cases demonstrate that the computed response is quite close when using the suggested technique.

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