Analysis of Fundamental Natural Period of Irregular Rcc Framed Structure

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ABSTRACT:- **The determination of the fundamental natural period of vibration is essential to design a structure against earthquake loading. Current design codes in India such as IS 1893(Part 1):2002 or IS 875 (Part III):1987 provide formulas for the approximate period of earthquake-resistant building systems, which are dependent only on the height of the structure or number of stories. Such a formulation is overly conservative and unable to account for structures with geometric irregularities. This study investigates the fundamental periods of different types of reinforced concrete earthquake resistant building structures having structurally irregular frames (both vertical and horizontal). A total of 66 MRF structures for set-back, 168 MRF structures for mass irregularity, 90 MRF structures for soft-storey irregularity, 72 MRF structures for re-entrant corner irregularity and 160 MRF structures for torsional irregularity due to heavy mass are analyzed with STAAD.Pro-V8i.**

The fundamental periods based on vibration theory for each example were compared with current code equations. Through statistical comparison, it was found that a multi-variable power model which is able to account for irregularities resulted in a better fit to the Rayleigh data than equations which were dependent on height only. The proposed equations were validated through a comparison of available measured period data. These proposed equations will allow design engineers to quickly and accurately estimate the fundamental period of moment resisting frame structures by taking into account these types of irregularities.

KEY WORDS: - **Seismic analysis, Fundamental Natural period analysis, setbacks, Mass irregularity, Vertical irregularity, Time Period.**

INTRODUCTION:- As part of structural design, members in buildings are selected and detailed such that the expected demands, such as forces or displacements, on a structure are less than the capacity of the structure to resist those forces and displacements. However, to obtain these forces or displacements, structural analysis is required considering the loading applied to the building from its weight, its use, and other factors such as wind, or shaking of the ground in the case of earthquake.

The sophistication of the structural analysis affects both the detail of the analysis results and the design fee. Simple methods (e.g., Equivalent Static method) may provide a reasonable representation of the likely seismic behavior to enable rapid assessment of the expected building performance. More complex methods, such as inelastic dynamic time history analysis provide more information about the response, but take more time and computational cost to perform properlyEngineers need conceptually simple methods for the following reasons:

1. To design full structures

2. To enable a rapid check of likely building performance

3. To preliminary size members before some more sophisticated studies are undertaken.

AIM & SCOPE:- The determination of the fundamental period of vibration of structures is essential to design and assessment against earthquake loading. A reasonably accurate estimation of the fundamental period in such irregular structures is necessary in both response-spectrum and static earthquake analysis of structures. An accurate estimation would allow for an improved estimation of the global seismic demands on an irregular structure.

As such, the goal of this research is to investigate the accuracy of existing code-based equations for estimation of the fundamental period of irregular building structures and provide suggestion More specifically, the objectives of this research are:

1. To perform numerical experiments for the parametric study of the fundamental period of different types of RCC framed structures considering different number of stories, number of bays, configuration, and types of irregularity. Two types of irregular structures are examined in this study: a) structures with vertical irregularity and structures with horizontal irregularity. Each structure is analyzed using STAAD.Pro V8i,an analysis and design software.

2. To compare the fundamental periods of each structure obtained from a) Rayleigh method b) IS Code equations, and c) STAAD.Pro generated fundamental period based on a normal mode analysis.

LITERATURE REVIEW:- Seismic analysis is a major tool in earthquake engineering which is used to understand the response of building due to seismic excitations in a simpler manner. In the past the buildings were designed just for gravity loads and seismic analysis is a recent development. It is a part of structural analysis and a part of structural design where earthquake is prevalent.

Mayuri D. Bhagwat et.al [1] In this work dynamic analysis of G+12 multistoried practiced RCC building considering for Koyna and Bhuj earthquake is carried out by time history analysis and response spectrum analysis and seismic responses of such building are comparatively studied and modeled with the help of ETABS software. Two time histories (i.e. Koyna and Bhuj) have been used to develop different acceptable criteria (base shear, storey displacement, storey drifts).

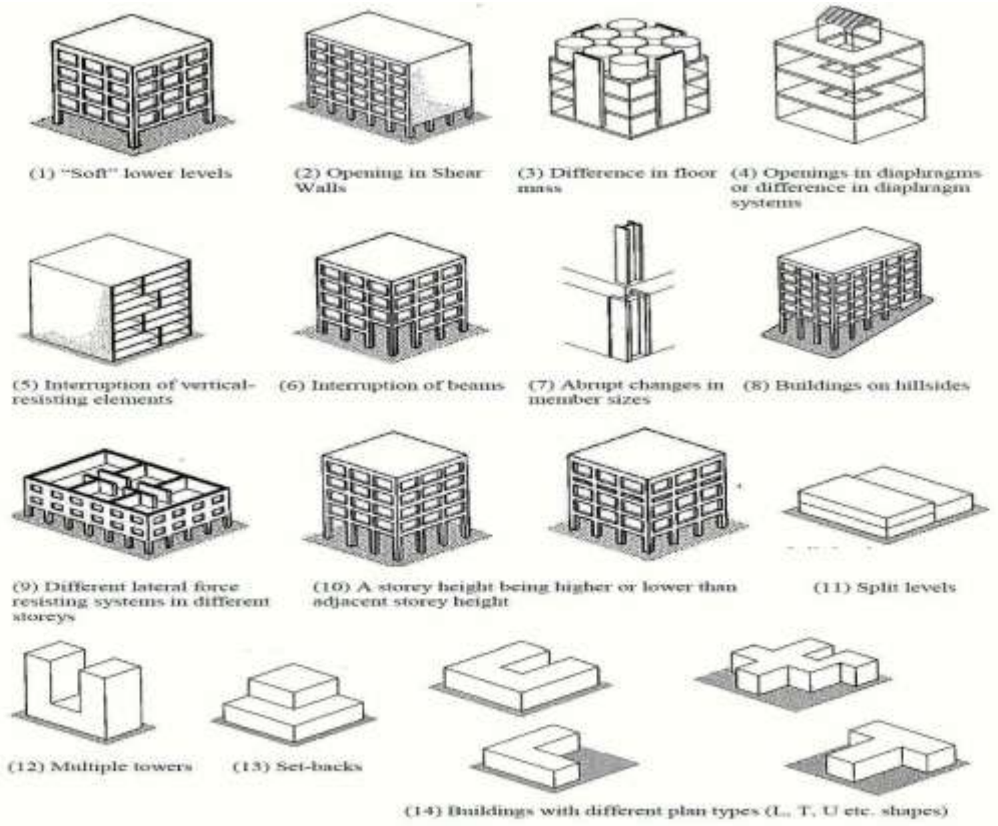
Himanshu Bansal et al [2] in this study the storey shear force was found to be maximum for the first storey and it decreased to a minimum in the top storey in all cases. It was found that mass irregular building frames experience larger base shear than similar regular building frames. The stiffness irregular building experienced lesser shear and has larger inter storey drifts.

Mohit Sharma et al [3] In this study a G+30 storied regular building. The static and dynamic analysis has done on computer with the help of STAAD-Pro software using the parameters for the design as per the IS-1893-2002-Part-1 for the zones-2 and 3.

P.P. Chandurkar et al [4] in this study shear walls, is considered as major earthquake resisting member. Structural wall gives an effective bracing system and offer good potential for lateral load resistance. So it is important to determine the seismic response of the wall or shear wall. In this study main focus is to determine the location for the shear wall in multi storey building.

Prof. S.S. Patil et al [5] This study gives seismic analysis of high rise building using program in STAAD Pro. with considering different conditions of the lateral stiffness system. Analysis is carried out by response spectrum method. This analysis gives the effect of higher modes of vibration and actual distribution of force in elastic range in good way. These result include base shear, Storey drift and storey deflection are presented.

METHODOLOGY:- f the structure not properly constructed with required quality they may cause large destruction of structures due to earthquakes.
1) Extensive literature survey by referring books, technical papers, carried out to understand basic concept of topic.
2) Selection of type of structures.
3) Modeling of the selected structures
4) analysis of me selected structure.
5) Interpretation of result and conclusion.



(1) "Soft" lower levels

(2) Opening in Shear Walls

(3) Difference in floor mass

(4) Openings in diaphragms or difference in diaphragm systems

(5) Interruption of vertical-resisting elements

(6) Interruption of beams

(7) Abrupt changes in member sizes

(8) Buildings on hillsides

(9) Different lateral force resisting systems in different storeys

(10) A storey height being higher or lower than adjacent storey height

(11) Split levels

(12) Multiple towers

(13) Set-backs

(14) Buildings with different plan types (L, T, U etc. shapes)

Figure 1: Examples of some common irregularities in structures

Type of irregularities in strucutre

STRUCTURAL MODELLING:-

VERTICAL IRREGULARITIES:

A structure could be irregular because architectural design requirements call for non-uniformity of some sort. This is designed/planned use (DPU) irregularity. Common examples of this type are; a residential building having a car park at the basement and a corresponding less stiff first storey , an academic institution having a heavy library on one floor level, or a structure designed to have setbacks to meet boundary offset requirements. What is important is not whether or not a structure contains irregularities, but the ability of the designer to estimate the likely demands on structures with the irregularity present at the time of earthquake shaking.

a) Stiffness Irregularity — Soft Storey: A softstorey is one in which the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average lateral stiffness of the three storeys above.

b) Stiffness Irregularity — Extreme Soft Storey: A extreme soft storey is one in which the lateral stiffness is less than 60% of that in the storey above or less than 70% of the average lateral stiffness of the three storeys above.

1. Mass Irregularity: Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200% of that of its adjacent storeys. This need not be considered in case of roofs.

2. Vertical Geometric Irregularity: Vertical geometric irregularity shall be considered To exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150% of that in its adjacent storey.

3. In-Plane Discontinuity in Vertical Elements Resisting Lateral Force: An in- plane offset of the lateral force resisting elements greater than the length of those elements.

4. Discontinuity in Capacity — Weak Storey: A weakstorey is one in which the storey lateral strength is less than 80% of that in the storey above, The storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.

PLAN IRREGULARITIES:-

Torsion Irregularity: To be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure.

Re-entrant Corners: Plan configurations of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15% of its plan dimension in the given direction.

Diaphragm Discontinuity: Diaphragms with abrupt discontinuities or variations in stiffness, including those having cut-out or open areas greater than 50% of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50% from one storey to the next.

Out-of-Plane Offsets: Discontinuities in a lateral force resistance path, such as out-of-plane offsets of vertical elements.

Non-parallel Systems: The vertical elements resisting the lateral force are not parallel to or symmetric about the major orthogonal axes or the lateral force resisting elements.

FUNDAMENTAL NATURAL PERIOD :- When the ground shakes, the base of building moves with the ground, and the building swings back-and-forth. If the building were rigid, then every point in it would move by the same amount as the ground. But, most buildings are flexible, and different parts move back-and-forth by different amounts.

The timetaken (in seconds) for each complete cycle of oscillation (i.e., one complete back-and-forth motion) is the same and is called Fundamental Natural Period (T) of the building Value of T depends on the building flexibility and mass; more the flexibility, the longer is the T, and more the mass, the longer is the T. In general, taller buildings are more flexible and have larger mass, and therefore have a longer T. On the contrary, low- to medium-rise buildings generally have shorter T. Fundamental natural period T is an inherent property of a building. Any alterations made to the building will change its T.

The ground shaking during an earthquake contains a mixture of many sinusoida l waves of different frequencies, ranging from short to long periods. The time taken by the wave to complete one cycle of motion is called period of the earthquake wave. In general, earthquake shaking of the ground has waves whose periods vary inthe range 0.03-33sec.Even within this range,some earthquake waves are stronger than the others. Intensity of earthquake waves at a particular building location depends on a number of factors, including the magnitude of the earthquake, the epicentral distance, and the type of ground that the earthquake waves travelled through before reaching the location of interest.

In a typical city, there are buildings of many different sizes and shapes. One way of categorizing them is by their fundamental natural period T. The Ground motion under these buildings varies across the city. If the ground is shaken back-and-forth by earthquake waves that have short periods, then short period buildings will have larger response. Similarly, if the earthquake ground motion has long period waves, then long period buildings will have larger response. Thus, depending on the value of T of the buildings and on the characteristics of earthquake ground motion, some buildings will be shaken more than the others. Flexible buildings undergo larger relative horizontal displacements, which may result in damage to various nonstructural building components and the contents. For example, some items in buildings, like glass windows.

CODAL PROVISIONS FOR FUNDAMENTAL PERIOD OF STRUCTURES:- Seismic design codes specify empirical formulas to estimate the fundamental period which are based on data from instrumented buildings subjected to ambient vibrations or small to moderate earthquakes. The approximate fundamental natural period of vibration (Ta), in seconds, of a moment-resisting frame building without brick infill panels may be estimated by IS-1893 (Part 1): 2002, Clause 7.6.1, for concrete structures is in the form.

$$Ta = 0.075 H^{0.75} \qquad (1)$$

Where, H = Height of building, in m.This excludes the basement storeys, where basement walls are connected with the ground floor deck or fitted between the building columns. But it includes the basement storeys, when they are not so connected Up until 2002, the fundamental period estimated by ASCE 7-02 code for all structures was in the same form where the parameter 0.075 was chosen specifically by structure type. Equation 1 is still in use in the building codes of many countries, including Eurocode 8 , which limits its use to buildings less than 40m (131 feet). Also present in certain design. Codes for many years, the fundamental period of braced steel frames and concrete shear walls is estimated as:

$$Ta = 0.05 H / \sqrt{D} \qquad (2)$$

Parameter D corresponds to the dimension of the braced frame in a direction parallel to the applied force, called the depth of the structure in this paper. In Equation, H and D are in feet. This equation was first introduced in California building codes for reinforced concrete shear wall structures, and was more recently present in the 1995 NBC of Canada . A very similar type of equation found in IS-1893 (Part 1): 2002, Clause 7.6.2. The approximate fundamental natural period of vibration (T a), in seconds, of all other buildings, including moment-resisting frame buildings with brick infill panels, may be estimated by the empirical expression:

$$Ta = 0.09 H/\sqrt{D} \qquad (3)$$

Where, H = Height of building, in m as defined in 7.6.l. & D = Base dimension of the building at the plinth level, in m,along the considered direction of the lateral force.

According to another Indian Standard Code, IS-875(Part 3):1987 and a previous version, IS-1893:1984 the fundamental time period (T) may either be established by experimental observations on similar buildings or calculated by any rational method of analysis. In the absence of such data, T may be determined as follows for multi-storeyed buildings – for moment resisting frames without bracing or shear walls for resisting the lateral loads.

$$Ta = 0.1\,n \qquad (4)$$

Where, n = number of storeys including basement storeys. ASCE 7-10 defines two equations for the approximate fundamental period in seconds.One of them is Equation. It has been present in the code since the1970s. ASCE 7-10 limits it use for buildings of 12 stories or fewer,with Story height so fat least 10feet.

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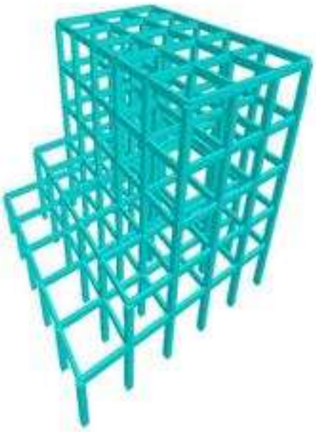
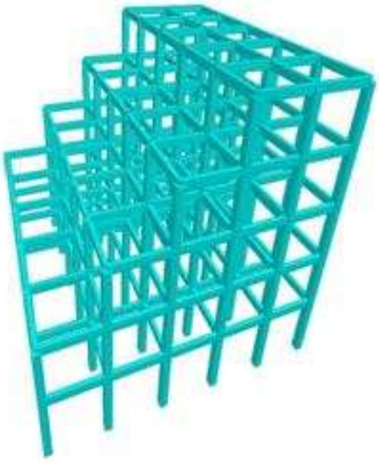
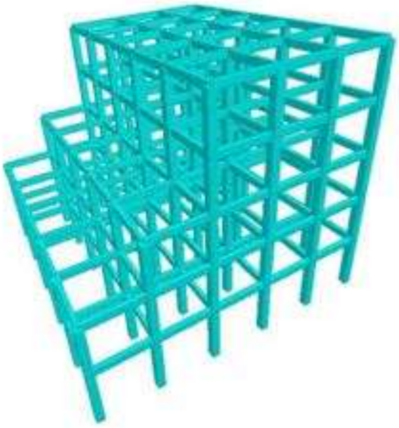
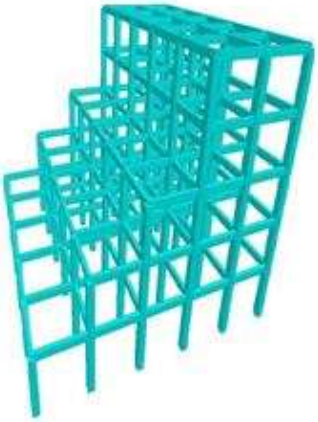
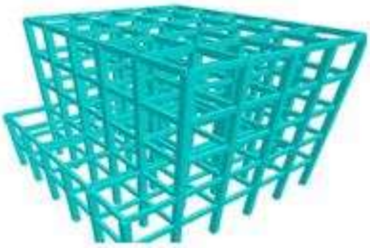
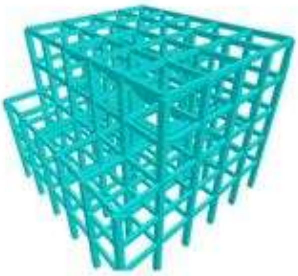
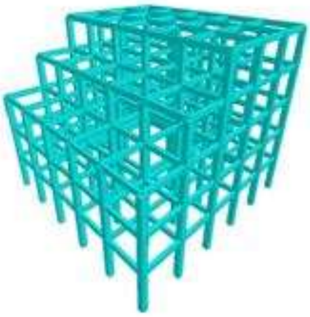
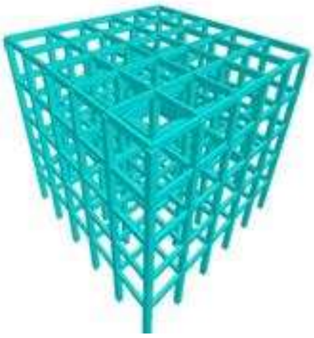
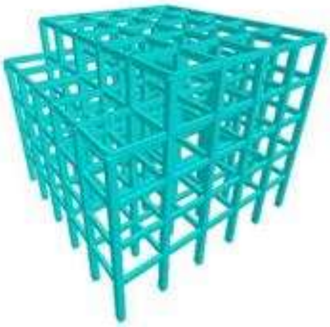
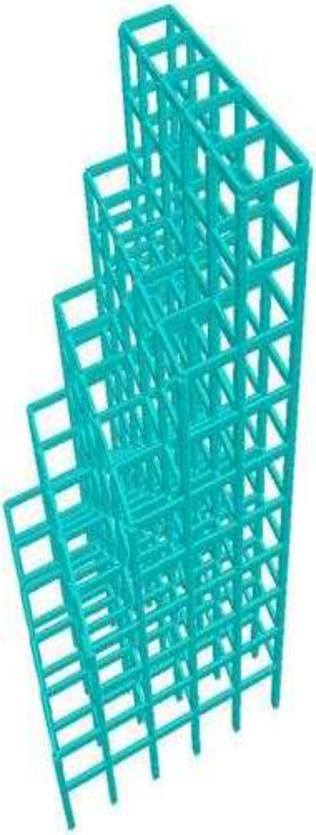
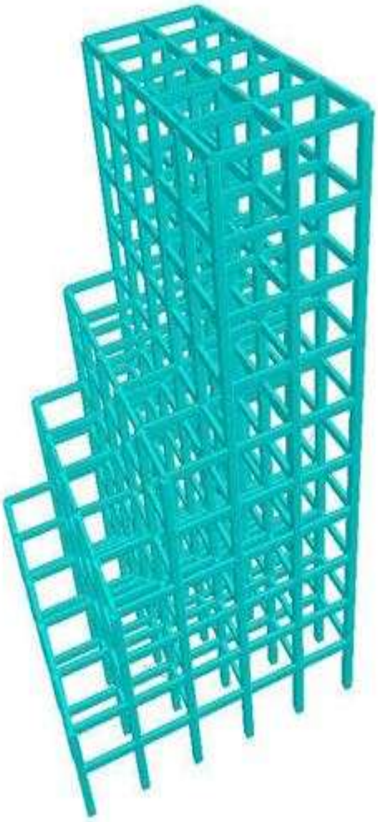
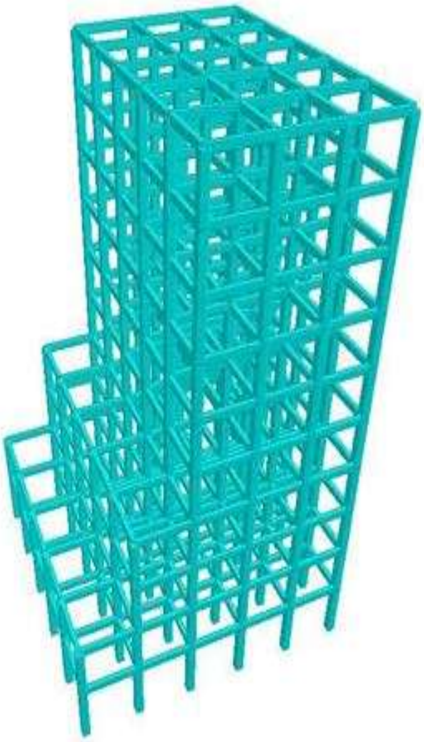
VERTICAL IRREGULARITY – SETBACK:-

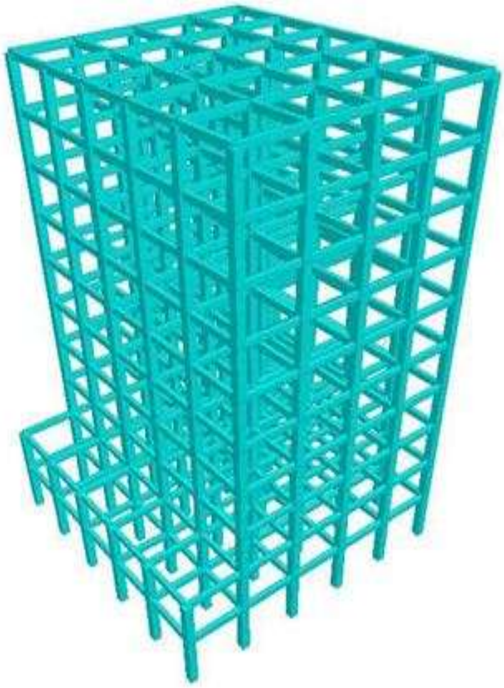
The estimation of the fundamental period of a building structure is essential for determination of the design base shear and lateral design forces. A number of studies have been performed on the fundamental period of building structures.As more buildings are instrumented and recorded seismic response data have become available, a number of recent studies have compared results obtained from empirical code equations for the fundamental period with actual measured data of structures during seismic events.

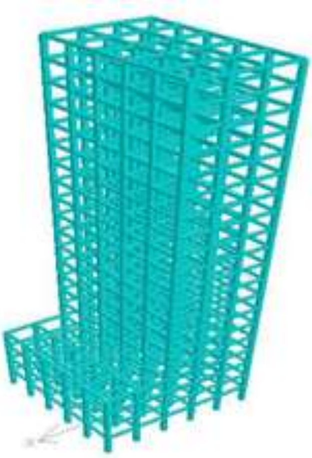










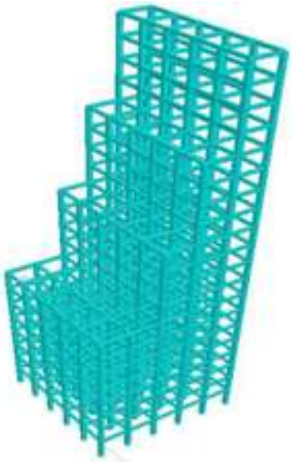


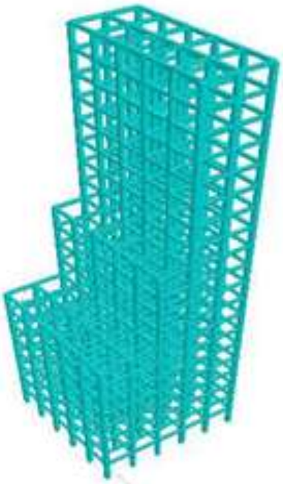


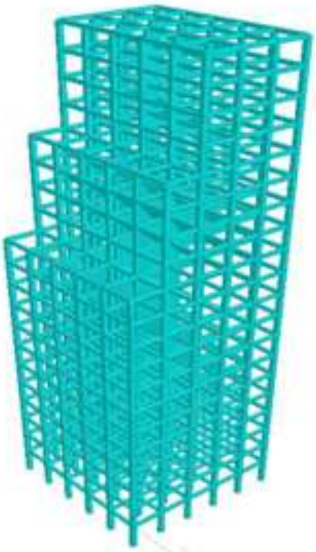


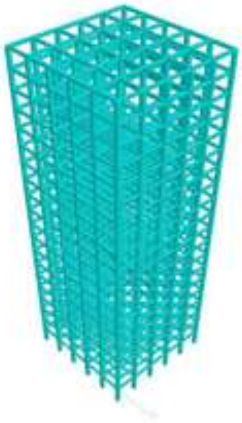












	Building Desiognation	H	H_{av}/H	D_{av}/D	Eq. 1	Eq.4	$T_{reyleigh}$	Tstadd
5 bay Bay 5 storey	V-05-05	17.5	1	1	0.6417	0.5	0.1258	0.03641
	V-04-05	17.5	0.96	0.96	0.6417	0.5	0.1222	0.03632
	V-03-05	17.5	.0.92	.0.92	0.6417	0.5	0.1215	0.03629
	V-03-05-2-04	17.5	0.88	0.88	0.6417	0.5	0.1173	0.03610
	V-02-05	17.5	0.88	0.88	0.6417	0.5	0.1212	0.03624
	V-02-05-2-03	17.5	0.8	0.8	0.6417	0.5	0.1185	0.03604
	V-02-05-2-03-3-04	17.5	0.76	0.76	0.6417	0.5	0.1130	0.03567
	V-01-05	17.5	0.84	0.84	0.6417	0.5	0.1215	0.03626
	V-01-05-2-02	17.5	0.72	0.72	0.6417	0.5	0.1229	0.03600
	V-01-05-2-02-3-03	17.5	0.64	0.64	0.6417	0.5	0.1175	0.03552
	V-01-05-2-02-3-03-4-04	17.5	0.6	0.6	0.6417	0.5	0.1099	0.03473
5 Bay 10 storey	V-08-10	35	0.96	0.96	1.0792	1	0.1876	0.06405
	V-06-10	35	0.92	.0.92	1.0792	1	0.1931	0.08370
	V-06-10-2-08	35	0.88	0.88	1.0792	1	0.1884	0.12093
	V-04-10	35	0.88	0.88	1.0792	1	0.1964	0.08402
	V-04-10-2-06	35	0.8	0.8	1.0792	1	0.1894	0.06775
	V-04-10-2-06-3-08	35	0.76	0.76	1.0792	1	0.1805	0.06697
	V-04-10	35	0.84	0.84	1.0792	1	0.1999	0.06833
	V-08-10-2-04	35	0.72	0.72	1.0792	1	0.1980	0.06773
	V-08-10-2-04-3-06	35	0.64	0.64	1.0792	1	0.1909	0.06678
	V-08-10-2-04-03-06-4-08	35	0.6	0.6	1.0792	1	0.1776	0.06540
5 Bay 20 storey	V-20-20	70	1	1	1.815	2	0.0264	0.13329
	V-16-20	70	0.96	0.96	1.815	2	0.2795	0.13098
	V-12-20	70	0.92	.0.92	1.815	2	0.2823	0.07986
	V-12-20-2-16	70	0.88	0.88	1.815	2	0.2777	0.13103
	V-08-20	70	0.88	0.88	1.815	2	0.3018	0.13117
	V-08-20-2-12	70	0.8	0.8	1.815	2	0.2966	0.12939
	V-08-20-2-12-3-16	70	0.76	0.76	1.815	2	0.2771	0.12670
	V-04-20	70	0.84	0.84	1.815	2	0.3191	0.13141
	V-04-20-2-08	70	0.72	0.72	1.815	2	0.3342	0.12949
	V-04-20-2-08-3-12	70	0.64	0.64	1.815	2	0.3394	0.12630

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ANALYSIS OF RESULTS:-

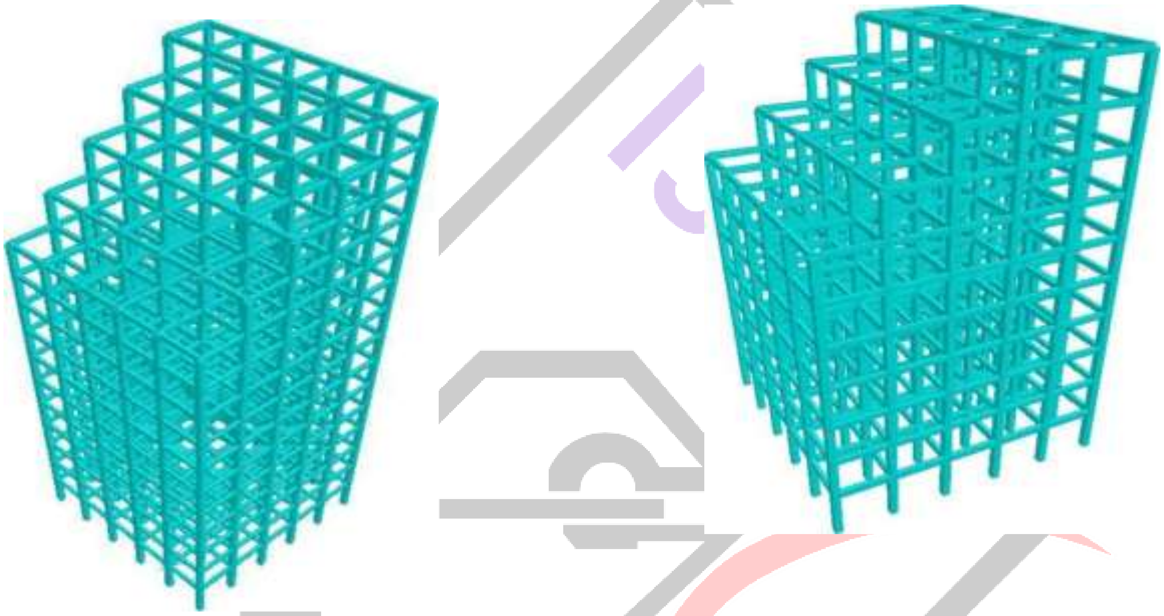
The Equation 4 yields the most conservative estimate of the fundamental period for all 5 and 10 storey MRFs, followed by Equation 1. The general trend observed is that structures without irregularities tend to have a longer period compared with those with irregularities.

VERTICALIRREGULARITY – MASS IRREGULARITY:-

All MRF structures are modeled with either 20 stories, 15 stories, or 10 stories (N) and 5 or 10 bays (Nb) . All structures have a uniform storey height of 3.5m. The bays have a uniform spacing of 4m. A total of 114 MRF structures are evaluated considering three different types of mass ratio as 1.25, 1.5 and 2.

Each structure has a designation beginning with M representing Mass Irregularity. Following is a numerical designation indicating the Mass Ratio. For example, M-1.50-4-5-10 represents a 10 storey moment resisting frame with a vertical irregularity. It has 5 bays and 1.50 times more mass at 4th floor. For each structure, the criterion for irregularity is checked to ensure that an irregularity is present as defined by the code as described in Table 5 or in Fig. 4 of IS:1893 (Part 1)-2002, and none falls under the classification of extreme irregularity.

The deflection, lateral force, and weight per storey used in the Rayleigh Equation 6come directly from the structural models developed inSTAAD.Pro. The period calculated from STAAD.Pro comes directly from the mode of vibration which has the largest modal participation mass ratio in the direction under consideration.



MASS IRREGULARITY

	Model Name	H	D	H_m/H	M_r	T_{STAAD}	$T_{Rayldigh}$
5 Bay 15 storey	**M-1.25-1-5-15**	**52.5**	**20**	**0.0667**	**1.25**	**0.09730**	**0.220685**
	M-1.25-3-5-15	**52.5**	**20**	**0.20**	**1.25**	**0.09736**	**0.219781**
	M-1.25-5-5-15	**52.5**	**20**	**0.3333**	**1.25**	**0.09748**	**0.219815**
	M-1.25-7-5-15	**52.5**	**20**	**0.4667**	**1.25**	**0.09762**	**0.220361**
	M-1.25-9-5-15	**52.5**	**20**	**0.60**	**1.25**	**0.09777**	**0.221687**
	M-1.25-11-5-15	**52.5**	**20**	**0.7333**	**1.25**	**0.09790**	**0.223511**

	M-1.25-13-5-15	**52.5**	**20**	**0.8667**	**1.25**	**0.09798**	**0.224279**
	M-1.25-15-5-15	**52.5**	**20**	**1**	**1.25**	**0.09784**	**0.224278**
5 Bay 15 storey	**M-1.5-1-5-15**	**52.5**	**20**	**0.0667**	**1.25**	**0.09731**	**0.219319**
	M-1.5-3-5-15	**52.5**	**20**	**0.2**	**1.25**	**0.09744**	**0.217871**
	M-1.5-5-5-15	**52.5**	**20**	**0.3333**	**1.25**	**0.09767**	**0.21787**
	M-1.5-7-5-15	**52.5**	**20**	**0.4667**	**1.25**	**0.09796**	**0.218717**
	M-1.5-9-5-15	**52.5**	**20**	**0.6**	**1.25**	**0.09825**	**0.220877**
	M-1.5-11-5-15	**52.5**	**20**	**0.7333**	**1.25**	**0.09851**	**0.223884**
	M-1.5-13-5-15	**52.5**	**20**	**0.8667**	**1.25**	**0.09868**	**0.22507**
	M-1.5-15-5-15	**52.5**	**20**	**1**	**1.25**	**0.09840**	**0.224937**
5 Bay 15 storey	**M-2-1-5-15**	**52.5**	**20**	**0.0667**	**1.25**	**0.09734**	**0.220042**
	M-2-3-5-15	**52.5**	**20**	**0.2**	**1.25**	**0.09763**	**0.218141**
	M-2-5-5-15	**52.5**	**20**	**0.3333**	**1.25**	**0.09815**	**0.217874**
	M-2-7-5-15	**52.5**	**20**	**0.4667**	**1.25**	**0.09880**	**0.218803**
	M-2-9-5-15	**52.5**	**20**	**0.6**	**1.25**	**0.09946**	**0.22168**
	M-2-11-5-15	**52.5**	**20**	**0.7333**	**1.25**	**0.10003**	**0.225946**
	M-2-13-5-15	**52.5**	**20**	**0.8667**	**1.25**	**0.10040**	**0.227334**
	M-2-15-5-15	**52.5**	**20**	**1**	**1.25**	**0.09976**	**0.226541**

IJSDR

	Model Name	H	D	H_m/H	M_r	T_{STAAD}	$T_{Rayleigh}$
10 Bay 10 Storey	M-1.25-1-10-10	35	40	0.1	1.25	0.09600	0.182265
	M-1.25-2-10-10	35	40	0.2	1.25	0.09599	0.181452
	M-1.25-3-10-10	35	40	0.3	1.25	0.09596	0.181215
	M-1.25-4-10-10	35	40	0.4	1.25	0.09593	0.181213
	M-1.25-5-10-10	35	40	0.5	1.25	0.09588	0.181394
	M-1.25-6-10-10	35	40	0.6	1.25	0.09584	0.18178
	M-1.25-7-10-10	35	40	0.7	1.25	0.09138	0.182811
	M-1.25-8-10-10	35	40	0.8	1.25	0.09130	0.184316
	M-1.25-9-10-10	35	40	0.9	1.25	0.09246	0.185733
	M-1.25-10-10-10	35	40	1	1.25	0.09433	0.186563
10 Bay 10 Storey	M-1.5-1-10-10	35	40	0.1	1.5	0.09599	0.180975
	M-1.5-2-10-10	35	40	0.2	1.5	0.9596	0.179651
	M-1.5-3-10-10	35	40	0.3	1.5	0.09591	0.179192
	M-1.5-4-10-10	35	40	0.4	1.5	0.09585	0.179102
	M-1.5-5-10-10	35	40	0.5	1.5	0.09574	0.179356
	M-1.5-6-10-10	35	40	0.6	1.5	0.09567	0.179971
	M-1.5-7-10-10	35	40	0.7	1.5	0.08781	0.181684
	M-1.5-8-10-10	35	40	0.8	1.5	0.06232	0.184502
	M-1.5-9-10-10	35	40	0.9	1.5	0.08963	0.1865
	M-1.5-10-10-10	35	40	1	1.5	0.09291	0.187883
10 Bay 10 Storey	M-2-1-10-10	35	40	0.1	2	0.09599	0.182148
	M-2-2-10-10	35	40	0.2	2	0.09596	0.180254
	M-2-3-10-10	35	40	0.3	2	0.09591	0.179195
	M-2-4-10-10	35	40	0.4	2	0.09583	0.178506
	M-2-5-10-10	35	40	0.5	2	0.09572	0.178313
	M-2-6-10-10	35	40	0.6	2	0.09564	0.178881
	M-2-7-10-10	35	40	0.7	2	0.08801	0.181321
	M-2-8-10-10	35	40	0.8	2	0.08815	0.185067

	M-2-9-10-10	**35**	**40**	**0.9**	**2**	**0.08998**	**0.188722**
	M-2-10-10-10	**35**	**40**	**1**	**2**	**0.09302**	**0.191022**

	Model Name	**H**	**D**	**H_m/H**	**M_r**	**T_{STAAD}**	**$T_{Rayleigh}$**
5 Bay 20Storey	**M-1.25-2-5-20**	**70**	**20**	**0.1**	**1.25**	**0.13107**	**0.278336**
	M-1.25-4-5-20	**70**	**20**	**0.2**	**1.25**	**0.13113**	**0.278156**
	M-1.25-6-5-20	**70**	**20**	**0.3**	**1.25**	**0.13121**	**0.278129**
	M-1.25-8-5-20	**70**	**20**	**0.4**	**1.25**	**0.13132**	**0.278266**
	M-1.25-10-5-20	**70**	**20**	**0.5**	**1.25**	**0.13144**	**0.278701**
	M-1.25-12-5-20	**70**	**20**	**0.6**	**1.25**	**0.13155**	**0.279455**
	M-1.25-14-5-20	**70**	**20**	**0.7**	**1.25**	**0.13165**	**0.280416**
	M-1.25-16-5-20	**70**	**20**	**0.8**	**1.25**	**0.13174**	**0.281589**
	M-1.25-18-5-20	**70**	**20**	**0.9**	**1.25**	**0.13179**	**0.282338**
	M-1.25-20-5-20	**70**	**20**	**1**	**1.25**	**0.13171**	**0.282261**
5 Bay 20 Storey	**M-1.5-2-5-20**	**70**	**20**	**0.1**	**1.5**	**0.13110**	**0.27695**
	M-1.5-4-5-20	**70**	**20**	**0.2**	**1.5**	**0.13121**	**0.276634**
	M-1.5-6-5-20	**70**	**20**	**0.3**	**1.5**	**0.13138**	**0.276545**
	M-1.5-8-5-20	**70**	**20**	**0.4**	**1.5**	**0.13159**	**0.276723**
	M-1.5-10-5-20	**70**	**20**	**0.5**	**1.5**	**0.13182**	**0.277403**
	M-1.5-12-5-20	**70**	**20**	**0.6**	**1.5**	**0.13205**	**0.278629**
	M-1.5-14-5-20	**70**	**20**	**0.7**	**1.5**	**0.13226**	**0.280231**
	M-1.5-16-5-20	**70**	**20**	**0.8**	**1.5**	**0.13242**	**0.282211**
	M-1.5-18-5-20	**70**	**20**	**0.9**	**1.5**	**0.13252**	**0.282211**
	M-1.5-20-5-20	**70**	**20**	**1**	**1.5**	**0.13236**	**0.283452**
5 Bay 20 Storey	**M-2-2-5-20**	**70**	**20**	**0.1**	**2**	**0.13115**	**0.277594**
	M-2-4-5-20	**70**	**20**	**0.2**	**2**	**0.13140**	**0.277065**
	M-2-6-5-20	**70**	**20**	**0.3**	**2**	**0.13178**	**0.276755**
	M-2-8-5-20	**70**	**20**	**0.4**	**2**	**0.13225**	**0.276801**

IJSDR

	M-2-10-5-20	70	20	0.5	2	0.13276	0.277582
	M-2-12-5-20	70	20	0.6	2	0.13327	0.279232
	M-2-14-5-20	70	20	0.7	2	0.13373	0.281585
	M-2-16-5-20	70	20	0.8	2	0.13410	0.284615
	M-2-18-5-20	70	20	0.9	2	0.13433	0.286398
	M-2-20-5-20	70	20	1	2	0.13397	0.285474

	Model Name	H	D	Hm/H	Mr	TSTAAD	TRayeigh
5 Bay 10 Storey	M-1.25-1-5-10	35	20	0.1	1.25	0.06724	0.178074
	M-1.25-2-5-10	35	20	0.2	1.25	0.06730	0.177177
	M-1.25-3-5-10	35	20	0.3	1.25	0.06737	0.177048
	M-1.25-4-5-10	35	20	0.4	1.25	0.06747	0.17723
	M-1.25-5-5-10	35	20	0.5	1.25	0.06758	0.177773
	M-1.25-6-5-10	35	20	0.6	1.25	0.06769	0.178755
	M-1.25-7-5-10	35	20	0.7	1.25	0.06778	0.179985
	M-1.25-8-5-10	35	20	0.8	1.25	0.06786	0.181076
	M-1.25-9-5-10	35	20	0.9	1.25	0.06792	0.182021
	M-1.25-10-5-10	35	20	1	1.25	0.06791	0.18249
5 Bay 10 Storey	M-1.5-1-5-10	35	20	0.1	1.5	0.06727	0.176398
	M-1.5-2-5-10	35	20	0.2	1.5	0.06737	0.174964
	M-1.5-3-5-10	35	20	0.3	1.5	0.06753	0.174712
	M-1.5-4-5-10	35	20	0.4	1.5	0.06773	0.174969
	M-1.5-5-5-10	35	20	0.5	1.5	0.06794	0.175835
	M-1.5-6-5-10	35	20	0.6	1.5	0.06815	0.177436
	M-1.5-7-5-10	35	20	0.7	1.5	0.06835	0.179485
	M-1.5-8-5-10	35	20	0.8	1.5	0.06851	0.181225
	M-1.5-9-5-10	35	20	0.9	1.5	0.06862	0.182714
	M-1.5-10-5-10	35	20	1	1.5	0.06860	0.183431

5 Bay 10 Storey	**M-2-1-5-10**	**35**	**20**	**0.1**	**2**	**0.06732**	**0.177106**
	M-2-2-5-10	**35**	**20**	**0.2**	**2**	**0.06757**	**0.175247**
	M-2-3-5-10	**35**	**20**	**0.3**	**2**	**0.06794**	**0.17473**
	M-2-4-5-10	**35**	**20**	**0.4**	**2**	**0.06839**	**0.174865**
	M-2-5-5-10	**35**	**20**	**0.5**	**2**	**0.06889**	**0.175878**
	M-2-6-5-10	**35**	**20**	**0.6**	**2**	**0.06937**	**0.177975**
	M-2-7-5-10	**35**	**20**	**0.7**	**2**	**0.069811**	**0.180819**
	M-2-8-5-10	**35**	**20**	**0.8**	**2**	**0.07017**	**0.183077**
	M-2-9-5-10	**35**	**20**	**0.9**	**2**	**0.07040**	**0.184973**
	M-2-10-5-10	**35**	**20**	**1**	**2**	**0.07032**	**0.185778**

Analysis of Results:-

From Equation 1, we can easily calculate that the fundamental time period for heights 35m, 52.5m and 70m is respectively 1.0792s, 1.4628s and 1.815s. And from Equation 4, we can calculate that the fundamental time period for 10,15 and 20 storey is respectively 1s, 1.5s and 2s. Whereas, from the data obtained, it is clearly seen that Equation1 yields the most conservative estimate of the fundamental period for all example MRFs having more than 35m height.

It can also be seen from Figures that for a fixed number of storey and Mass ratio, time period decreases with increase in bay number i.e.width. For a fixed Mass ratio and width, time period increases with increase in no of storey i.e. height. For a fixed height and width, time period increases with increase in Mass ratio. And finally, for a fixed height,width and mass ratio, time period increases as the height ratio (H m /H) increases.

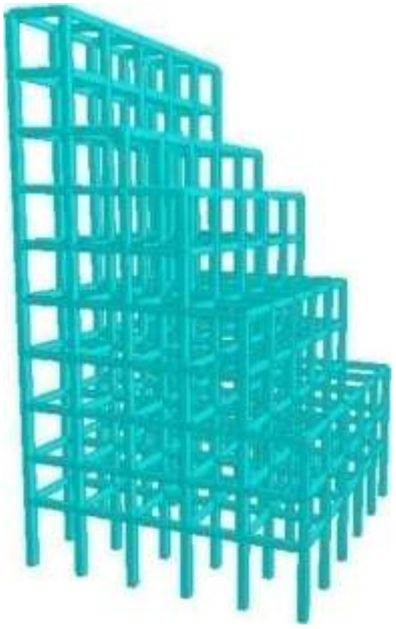
VERTICAL IRREGULARITY –SOFT STOREY:-

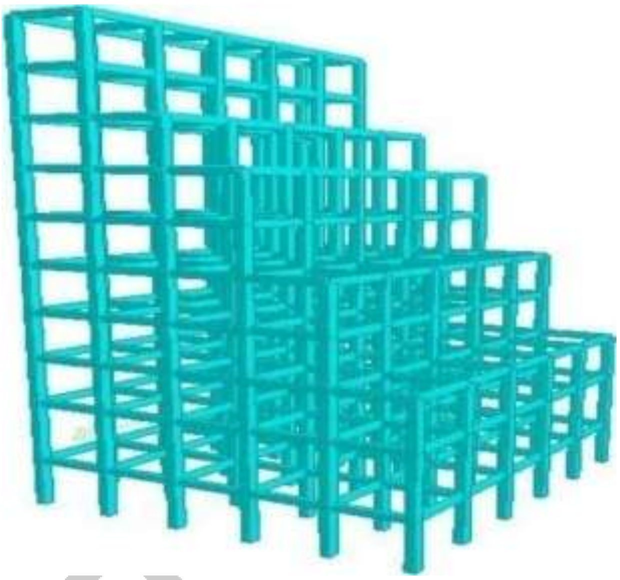
All MRF structures are modeled with either 20 stories, or 10 stories (N) and 5 or 10 bays (N). All structures have a uniform storey height of 3.5m. The bays have a uniform spacing of 4m. A total of 90 MRF structures are evaluated considering three different types of column lengths as 4.5m, 5mand 5.5m making column-length ratios as 0.778, 0.7 and 0.6364 respectively.

Each structure has a designation beginning with SS representing Soft-Storey Irregularity. Following is a numerical designation indicating the Column-length Ratio. For example, SS-0.7-4-5-10 represents a 10storey moment resisting frame with a vertical irregularity. It has 5 bays and (0.7) time more column-length at 4th floor.

For each structure, the criterion for irregularity is checked to ensure that an Irregularity is present as defined by the code as described in Table 5 or in Figure 4 of IS:1893 (Part 1)-2002, and none falls under the classification of extreme irregularity.

The deflection, lateral force, and weight per storey used in the Rayleigh Equation 6 come directly from the structural models developed in STAAD.Pro. The period calculated from STAAD.Pro comes directly from the mode of vibration which has the largest modal participation mass ratio in the direction under consideration.





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SOFT STOREY

	Model Name	H	D	Hs/H	L/Ls	TSTAAD	Trayleigh
20 Storey, 4.5m Col	SS-0.7778-1-10-20	71	40	0.0317	0.7778	0.13535	0.115744
	SS-0.7778-3-10-20	71	40	0.1303	0.7778	0.13531	0.116824
	SS-0.7778-5-10-20	71	40	0.2289	0.7778	0.13525	0.11685
	SS-0.7778-7-10-20	71	40	0.3275	0.7778	0.13511	0.116892
	SS-0.7778-9-10-20	71	40	0.4261	0.7778	0.13497	0.11666
	SS-0.7778-11-10-20	71	40	0.5246	0.7778	0.13483	0.11597
	SS-0.7778-13-10-20	71	40	0.6232	0.7778	0.13469	0.114806
	SS-0.7778-15-10-20	71	40	0.7218	0.7778	0.13456	0.113564
	SS-0.7778-17-10-20	71	40	0.8204	0.7778	0.13447	0.113196
	SS-0.7778-19-10-20	71	40	0.919	0.7778	0.13440	0.113194
20 Storey, 5.0m Col	SS-0.7-1-10-20	71.5	40	0.035	0.7	0.13796	0.117007
	SS-0.7-3-10-20	71.5	40	0.1329	0.7	0.13623	0.11869

	SS-0.7-5-10-20	71.5	40	0.2308	0.7	0.13610	0.118728
	SS-0.7-7-10-20	71.5	40	0.3287	0.7	0.13593	0.118775
	SS-0.7-9-10-20	71.5	40	0.4622	0.7	0.13572	0.118402
	SS-0.7-11-10-20	71.5	40	0.5245	0.7	0.13551	0.11732
	SS-0.7-13-10-20	71.5	40	0.6224	0.7	0.13530	0.115477
	SS-0.7-15-10-20	71.5	40	0.7203	0.7	0.13511	0.113482
	SS-0.7-17-10-20	71.5	40	0.8182	0.7	0.13497	0.1129
	SS-0.7-19-10-20	71.5	40	0.9161	0.7	0.13486	0.112897
20 Storey, 5.5m Col	SS-0.6364-1-10-20	72	40	0.0382	0.6364	0.13975	0.113887
	SS-0.6364-3-10-20	72	40	0.1354	0.6364	0.13966	0.11618
	SS-0.6364-5-10-20	72	40	0.2326	0.6364	0.13947	0.111672
	SS-0.6364-7-10-20	72	40	0.3299	0.6364	0.13835	0.111663
	SS-0.6364-9-10-20	72	40	0.4271	0.6364	0.13805	0.110884
	SS-0.6364-11-10-20	72	40	0.5243	0.6364	0.13777	0.108917
	SS-0.6364-13-10-20	72	40	0.6215	0.6364	0.13749	0.105891
	SS-0.6364-15-10-20	72	40	0.7188	0.6364	0.13724	0.10358
	SS-0.6364-17-10-20	72	40	0.816	0.6364	0.13704	0.11257
	SS-0.6364-19-10-20	72	40	0.9132	0.6364	0.13691	0.112565

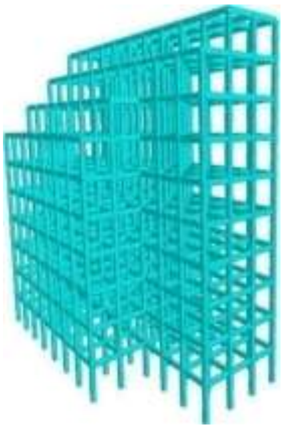
ANALYSIS OF RESULTS:-

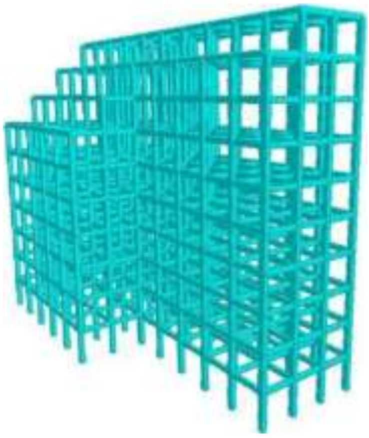
From Equation 1, we can easily calculate that the fundamental time period for heights 35m and 70m is respectively 1.0792s and 1.815s. And from Equation 4, we can calculate that the fundamental time period for 10 and 20 storeys is respectively 1s and 2s. Whereas, from the data obtained, it is clearly seen that the Equation 1 yields the most conservative estimate of the fundamental period for all example MRF whenever the height is more than 35m. It can also be seen from Figures that for a fixed number of Storey and Column-length ratio,time period decreases with increase in bay number i.e. width For a fixed Column-length ratio and width, time period increases with increase in no. of storey i.e height. For a fixed height and width, time period increases with increase in Column-length ratio. And finally, for a fixed height, width and Column-length ratio, time period increases as the height ratio (H_S/H) increases at first, and then it started to decrease gradually.

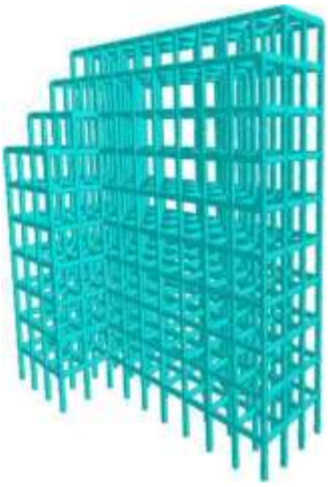
HORIZONTAL IRREGULARITY – RE-ENTRANTCORNER:-

All MRF structures are modeled with either 15 stories, 10 stories, or 5 stories (N) and 10 or 12 bays (Nb). All structures have a uniform storey height of 3.5m. The bays have a uniform spacing of 4m. A total of 33 MRF structures are evaluated.Each structure has a designation beginning with R representing Re-Entrant Corner Irregularity. Following is a numerical designation. Forexample, R-X4-Z7-5-10 Represents a 5storey 10 bay moment resisting frame with a vertical irregularity. And the notation X4-Z7 represents that it is externally void in plan by 4 bays in X-direction and by 7 bays in Z- direction.

For each structure, the criterion for irregularity is checked to ensure that an Irregularity is present as defined by the code as described in Table 5 or in Figure 4 of IS:1893 (Part1)-2002, and none falls under the classification of extreme irregularity. The deflection, lateral force, and weight per storey used in the Rayleigh Equation 6 come directly from the structural models developed in STAAD.Pro. The period calculated from STAAD.Pro comes directly from the mode of vibration which has the largest modal participation mass ratio in the direction under consideration.







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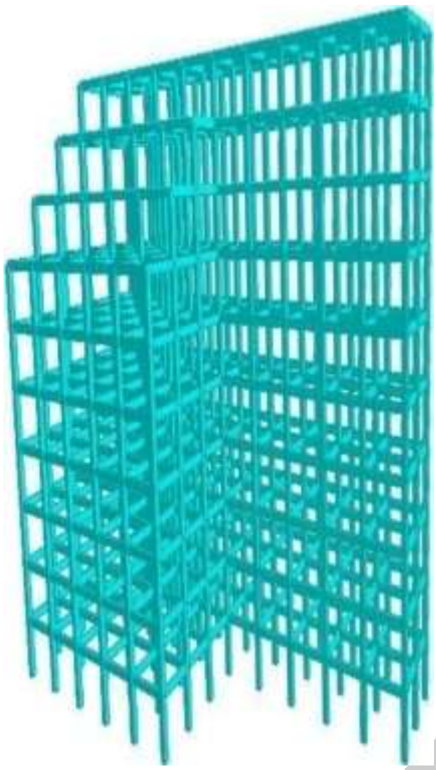
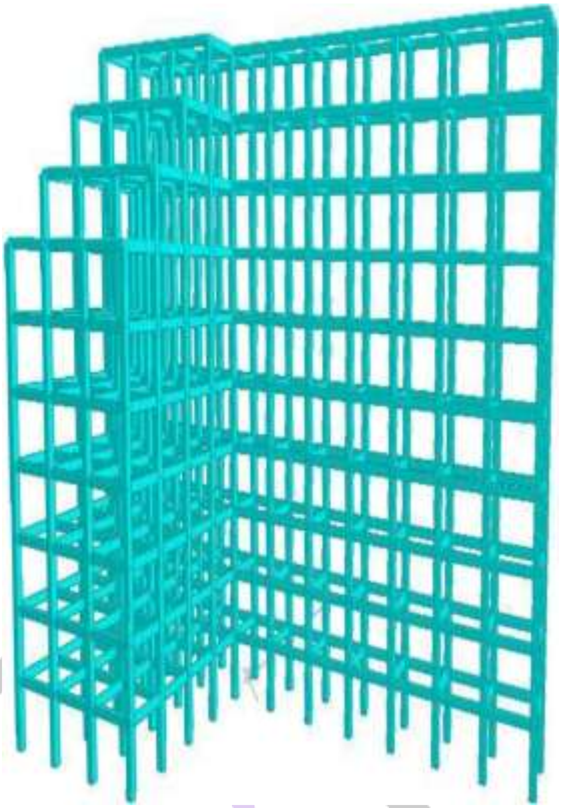
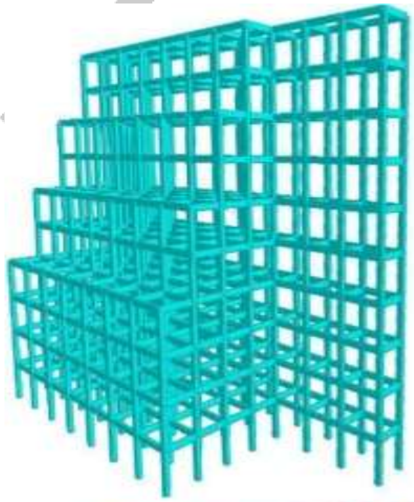






	MODEL NAME	H	Eq. 1	Eq.4	TSTAAD	TRayleigh
10 Bay 5 storey	R-X2-Z3-5-10	17.5	0.642	0.5	0.03588	0.037509
	R-X2-Z5-5-10	17.5	0.642	0.5	0.03587	0.037413
	R-X2-Z7-5-10	17.5	0.642	0.5	0.03585	0.03734
	R-X4-Z3-5-10	17.5	0.642	0.5	0.03586	0.037353
	R-X4-Z5-5-10	17.5	0.642	0.5	0.03581	0.037121
	R-X4-Z7-5-10	17.5	0.642	0.5	0.03577	0.03691
	R-X6-Z3-5-10	17.5	0.642	0.5	0.03583	0.037205
	R-X6-Z5-5-10	17.5	0.642	0.5	0.03573	0.036788
	R-X6-Z7-5-10	17.5	0.642	0.5	0.03559	0.03631
10 Bay 10 storey	R-X2-Z3-10-10	35	1.0792	1	0.7286	0.089097
	R-X2-Z5-10-10	35	1.0792	1	0.7283	0.08887
	R-X2-Z7-10-10	35	1.0792	1	0.7183	0.089714
	R-X4-Z3-10-10	35	1.0792	1	0.07220	0.089758
	R-X4-Z5-10-10	35	1.0792	1	0.07208	0.089301
	R-X4-Z7-10-10	35	1.0792	1	0.07114	0.088871
	R-X5-Z3-10-10	35	1.0792	1	0.06981	0.089601
	R-X5-Z5-10-10	35	1.0792	1	0.06916	0.088977
	R-X5-Z7-10-10	35	1.0792	1	0.06902	0.088351
	R-X6-Z3-10-10	35	1.0792	1	0.0623	0.089435
	R-X6-Z5-10-10	35	1.0792	1	0.06872	0.088614
	R-X6-Z7-10-10	35	1.0792	1	0.06833	0.087711
10 Bay 15 storey	R-X2-Z3-15-10	52.5	1.4628	1.5	0.10226	0.127314
	R-X2-Z5-15-10	52.5	1.4628	1.5	0.10217	0.127122
	R-X2-Z7-15-10	52.5	1.4628	1.5	0.10210	0.126955
	R-X4-Z3-15-10	52.5	1.4628	1.5	0.10212	0.126994
	R-X4-Z5-15-10	52.5	1.4628	1.5	0.10189	0.126545
	R-X4-Z7-15-10	52.5	1.4628	1.5	0.10168	0.126122
	R-X5-Z3-15-10	52.5	1.4628	1.5	0.10205	0.126823
	R-X5-Z5-15-10	52.5	1.4628	1.5	0.10172	0.126214

IJSDR

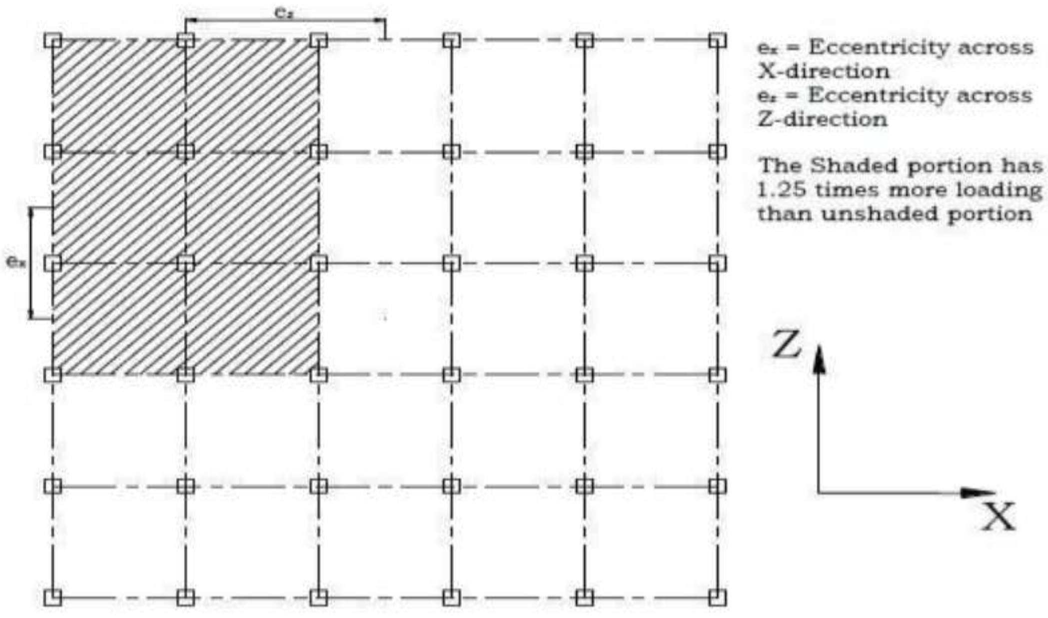
	R-X5-Z7-15-10	**52.5**	**1.4628**	**1.5**	**0.10138**	**0.141624**
	R-X6-Z3-15-10	**52.5**	**1.4628**	**1.5**	**0.10197**	**0.126645**
	R-X6-Z5-15-10	**52.5**	**1.4628**	**1.5**	**0.10154**	**0.125853**
	R-X6-Z7-15-10	**52.5**	**1.4628**	**1.5**	**0.10099**	**0.125031**

ANALYSIS OF RESULTS:-

From IS Code Equation 1, we can easily calculate that the fundamental time period for heights 17.5m, 35m and 52.5m is respectively 0.642s, 1.0792s and 1.4628s. And from IS Code Equation 4, we can calculate that the fundamental time period for 5, 10 and 15 storey is respectively 0.5s, 1s and 1.5s. Whereas, from the data obtained, it is clearly seen that Equation 4 yields the most conservative estimate of the fundamental period for all example MRF when the building height is less than 35m.

HORIZONTAL IRREGULARITY-TORSIONAL IRREGULARITY DUE TO HEAVY MASS:-

All MRF structures are modeled with either 20 stories or 10 stories (N) and 5 or 10 bays . All structures have a uniform story height of 3.5m. The bays have a uniform spacing of 4m. A total of 160 MRF structures are evaluated.
Each structure has a designation beginning with T representing Torsional Irregularity due to Heavy Mass. Following is a numerical designation. For example, T-l.25-X2-Z3-5-10 represents a 5 story 10 bay moment resisting frame with a vertical irregularity. And the notation X4-Z7 represents that it is having 1.25 more Loads in plan by 2 bays in X-direction and by 3 bays in Z- direction. The corresponding plan is shown below.



e_x = Eccentricity across X-direction
e_z = Eccentricity across Z-direction

The Shaded portion has 1.25 times more loading than unshaded portion

Plan view of T-1.25-X2-Z3-5-10

MODEL NAME	H	D	Ma/M	2eX/X	2eZ/Z	TSTAAD	TRAYLEIGH
T-1.25-X1-Z1-5-10	35	20	1.25	0.4	0.4	0.0.3862	0.10889
T-1.25-X1-Z2-5-10	35	20	1.25	0.3	0.4	0.3895	0.10889
T-1.25-X1-Z3-5-10	35	20	1.25	0.2	0.4	0.03891	0.10889
T-1.25-X1-Z4-5-10	35	20	1.25	0.1	0.4	0.03884	0.10889
T-1.25-X1-Z5-5-10	35	20	1.25	0	0.4	0.03872	0.10889
T-1.25-X2-Z1-5-10	35	20	1.25	0.4	0.3	0.03859	0.10889
T-1.25-X2-Z2-5-10	35	20	1.25	0.3	0.3	0.03925	0.10889
T-1.25-X2-Z3-5-10	35	20	1.25	0.2	0.3	0.04038	0.10889
T-1.25-X2-Z4-5-10	35	20	1.25	0.1	0.3	0.04082	0.10889
T-1.25-X2-Z5-5-10	35	20	1.25	0	0.3	0.04103	0.10889
T-1.25-X3-Z1-5-10	35	20	1.25	0.4	0.2	0.03891	0.10889
T-1.25-X3-Z2-5-10	35	20	1.25	0.3	0.2	0.04038	0.10889
T-1.25-X3-Z3-5-10	35	20	1.25	0.2	0.2	0.04159	0.10889
T-1.25-X3-Z4-5-10	35	20	1.25	0.1	0.2	0.04206	0.10889
T-1.25-X3-Z5-5-10	35	20	1.25	0	0.2	0.04228	0.10889
T-1.25-X4-Z1-5-10	35	20	1.25	0.4	0.1	0.03884	0.10889

IJSDR

T-1.25-X4-Z2-5-10	**35**	**20**	**1.25**	**0.3**	**0.1**	**0.04082**	**0.10889**
T-1.25-X4-Z3-5-10	**35**	**20**	**1.25**	**0.2**	**0.1**	**0.04206**	**0.10889**
T-1.25-X4-Z4-5-10	**35**	**20**	**1.25**	**0.1**	**0.1**	**0.04254**	**0.10889**
T-1.25-X1-Z5-5-10	**35**	**20**	**1.25**	**0**	**0.1**	**0.04277**	**0.10889**

ANALYSIS OF RESULTS:-

From Equation 1, we can easily calculate that the fundamental time period for heights 35 m is respectively 0.10889 and from Equation 4,we can calculate that the fundamental time period for 10 storeys is respectively 1s and 2s. Whereas, from the data obtained, it is clearly seen that Equation 4 yields the most conservative estimate of the fundamental period for all example MRF, when the building height is less than 35m.

SUMMARY AND CONCLUSIONS:-

A study has been conducted on the fundamental period of irregular concrete structures. A total of 273 MRFs (31 MRF structures for Setback, 114 MRF structures for Mass Irregularity, 75 MRF structures for Soft Storey, 33 MRF structures for Re-entrant Corner and 20 MRF structures for Torsional Irregularity Due to Heavy Mass) were analysed and their fundamental periods were determined by several different methods. Based on these analyses, empirical equations based on a multi-variable power model are suggested to improve the accuracy of the fundamental period approximation and account for the effect of irregularities on the period.

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