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ANALYSIS OF SEISMIC RESPONSE OF A MULTI-STOREY BUILDING WITH STIFFNESS IRREGULARITY

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ABSTRACT: Earthquakes are perhaps the most unpredictable and devastating of all natural disasters. They not only cause great destruction in terms of human casualties, but also have a tremendous economic impact on the affected area. The concern about seismic hazards has led to an increasing awareness and demand for structures designed to withstand seismic forces. In such a scenario, the onus of making the buildings and structures safe in earthquake-prone areas lies on the designers, architects, and engineers who conceptualize these structures. Factors that should be considered in the designing of an earthquake resistant structure includes an understanding of the physics of earthquakes, the properties and configuration of the structure, study on the behaviour of structures in past earthquakes and also recommendations and codes provided by the relevant authorities. Vibration of the earth's surface is a net consequence of motions, vertical as well as horizontal caused by seismic waves that are generated by energy release at each material point within the three-dimensional volume that ruptures at the fault. These waves arrive at various instants of time, have different amplitudes, and carry different levels of energy. Thus, the motion at any site on the ground is random in nature, its amplitude and direction varying randomly with time. In the present work, the complete assessment of the response parameters of an idealized 15 storey modelled (frame) structure subjected to various combinations of soft storey locations was analyzed using the computer program ETABS and compared with manual calculations. The R.C frame consisted of M25 concrete and Fe 415 grade steel reinforcement, having characteristic properties as per IS 456: 2000.The structure was then modelled in the ETABS and analyzed to determine the seismically induced lateral force distribution and response of the structure in seismic zone 5. In accordance with 1893(Part 1): 2002, the structure is categorized as irregular, therefore linear dynamic analysis was preformed, however, the result from this analysis was compared with that of linear static analysis. The response of the structure including sway, inter-storey drift, stresses and deformation in members, particularly those in the soft storey, were compared by varying the location and combination of the soft storeys.

Key Words: Seismic Response, Irregular structure, stiffness irregularity, soft storey, Response Spectrum Analysis

I. INTRODUCTION

Irregular buildings constitute a large portion of the modern urban infrastructure. The group of people involved in constructing the building facilities, including owner, architect, structural engineer, contractor and local authorities, contribute to the overall planning, selection of the structural system, and to its configuration. This may lead to building structures with irregular distributions in their mass, stiffness and strength along the height of building. When such buildings are located in a high seismic zone, the structural engineer's role becomes more challenging. Therefore, the structural engineer needs to have a thorough understanding of the seismic response of irregular structures. In recent past, several studies have been carried out to evaluate the response of irregular buildings. During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. Irregular structures contribute a large portion of urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example, structures with soft storey were the most notable structures which collapsed. So, the effect of vertically, irregularities in the seismic performance of structures become really important. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the regular buildings.

IS-1893 definition of Irregular Structures:

The irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height of building. When such buildings are constructed in high seismic zones, the analysis and design become more complicated.

There are two types of irregularities.

- Plan Irregularities
- Vertical Irregularity.

Vertical Irregularities are mainly of five types-

i) Stiffness Irregularity — Soft Storey-A soft storey is one in which the lateral stiffness is less than 70 percent of the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.

ii)Mass Irregularity -Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. In case of roofs irregularity needs not be considered.

iii)Vertical Geometric Irregularity- A structure is considered to be Vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.

iv)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.
v) Discontinuity in Capacity — Weak Storey-A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above.
As per IS 1893, Part 1 Linear static analysis of structures can be used for regular structures of limited height as in this process lateral forces are calculated as per code based fundamental time period of the structure. Linear dynamic analysis are an improvement over linear static analysis, as this analysis produces the effect of the higher modes of vibration and the actual distribution of forces in the elastic range in a better way.
Buildings are designed as per Design based earthquake (DBE), but the actual forces acting on the structure is far more than that of DBE. So, in higher seismic zones ductility based design approach is preferred as ductility of the structure narrows the gap. The primary objective in designing an earthquake resistant structure is to ensure that the building has enough ductility to withstand the earthquake forces, which it will be subjected to during an earthquake.

II. NEED FOR PRESENT INVESTIGATION

It has been largely accepted that soft storey (stiffness irregularity) influences the dynamic characteristics and seismic performance of reinforced framed concrete structures. Many studies have been theoretically conducted to predict the response of various structural models subjected to earthquake excitation, however it was evident that many such studies and literatures have ignored the fact that soft storey can practically be located or created at any story level of a reinforced concrete structures, and not only exist at the first storey alone. It is important to note that soft stories may be created at the inception to satisfy the functional requirement of the structure such as, taller storeys that facilitate parking, lobbies and mechanical floors. As the storey level increase changes in column dimensions may be required due to the gradual reduction of gravity loadings, this change in column dimensions alter the lateral stiffness property of the structure creating a soft story at that level. Soft stories may be created as a direct consequence of vibration, that is, the damage induced to walls by either corner crushing or shear failure at a particular storey level, and results for the reduction of the lateral stiffness at some point after initial excitation. The formation is therefore, unpredictable, especially for reinforced concrete buildings where the in-filled walls are non structural. It is therefore, necessary to better understand the effects that the presence of soft stories on a 15 storey structure chosen as a reference for RC structures in developing rural areas, and taking into account the probable occurrence of soft storey at a single level or a combination of levels.

Problem Definition
With urbanization, demand for aesthetics in structures to satisfy their functions, and the increasing unbalance of required space to availability, it is becoming imperative to satisfy these requirements, which in most cases is to provide either open or taller storey in commercial and residential buildings. These provisions reduce the stiffness of the lateral load resisting system and a progressive collapse becomes unavoidable in a severe earthquake of such buildings due to soft storey. In a Soft storey the columns are unable to provide adequate shear resistance during the earthquake, since less resistance or stiffness or inadequate ductility (energy absorption capacity) is there, and the structure cannot satisfactorily resist the induced stresses. This behaviour exhibits higher stresses in the columns and the columns fail as the plastic hinges are developed, if the soft storey is formed as a result of failing infill walls, plastic hinges may not form at predetermined positions. Thus, the vulnerability of soft storey effect has caused structural engineers to rethink the design of a soft storey building in areas of high seismicity. In the present work, the complete assessment of the response parameters of an idealized 15 storey modelled (frame) structure subjected to various combinations of soft storey locations was analyzed using the computer program ETABS and compared with manual calculations. Parametric studies on displacement, inter storey drift, storey shear and storey moments was conducted and a series of response charts plotted using both equivalent static analysis and dynamic analysis as per the Indian Seismic Codes, to investigate the influence of these parameters on the behaviour of buildings with soft storey at varying levels. The outcome of the investigation will help us to idealize the response of RC Structures and to take necessary precautions when designing structures in earthquake prone areas.

III. OBJECTIVE IF THE PRESENT WORK

A. Modelling of the Structure
To idealize the actual structure for analysis:
Determine building configuration (storey height, element dimensions etc..)
B. Propose soft storey location and combination
Construction materials and structural element properties
Establish Loadings and load functions
C. Analysis of Idealized Model
To analyze the idealized structural models subjected to dynamic loadings, using the finite element software ETABS.
To analyze the idealized structural models subjected to dynamic loadings, and conduct manual calculations.
Review of models
To make notable observations and conclusions from the outputs of the analysis, so as to understand in detail the effects of the irregularities on the response of reinforced concrete structures.

IV. METHODOLOGY

To satisfy the objectives and achieving the aim of the study, the following was carried out:
Objective-1: Modelling of Structure
Structure Type and Form: The building was idealized as a 3-Dimensional, Reinforced Concrete Moment resisting framed Structure. The lateral load resisting system was chosen since the framework of a R.C building consist of elements monolithically connected and resist lateral forces primarily by flexure, this is considered as the fundamental structural

system .Since relative displacements (inter storey drifts) are proportional to the shear distribution and shear forces, and on the limitation of drift, this system is recommended for structures up to thirty- storeys. The modeled structure is just fifteen storey tall and based on the recommendations on drift limitations, dual systems consisting of moment resisting frame either braced or with shear walls was not considered in study.

Building Configuration

The fifteen storey reinforced concrete framed structure was kept symmetrical in both orthogonal directions in plan, to avoid tensional response under lateral excitation. Buckling response was also avoided by providing appropriate plan and vertical dimensions that is by providing a height to base ratio (slenderness ratio) of less than four.

Structural elements such as columns, beams and slabs were assumed preliminary dimensions with regards to permissible limits for slenderness and serviceability limit state as recommended by IS 456: 2000.

Since walls, both internal partition and external cladding can alter the storey stiffness as well as the lateral load distribution, they were not considered in the analysis.

Function and Loading

In India, multi storied buildings of similar configurations as assumed for the analysis are found mostly in city areas.

These structures function primarily as either residential or office buildings, however they often provide multiple functions consisting of a combination of occupancy classification.

In this study, the concept of form follows function was implemented and the structure was assumed to function as an office building, subjected to designed loads in accordance with IS: 875-1987 for dead and imposed loads. Seismic loadings and load combinations were considered in accordance with IS: 1893(Part 1): 2002.

Construction Materials and Structural Element Properties:

The R.C frame consisted of M25 concrete and Fe 415 grade steel reinforcement, having characteristic properties as per IS 456: 2000.

Masonry walls, contribute to the loadings on the structure however they were not modeled in to the structure for analysis since their behavior is unpredictable.

Objective 2: Analysis of Idealized Model:

The structure was then modeled in the program ETABS and analyzed to determine the seismically induced lateral force distribution and response of the structure in seismic zone 5. In accordance with 1893(Part 1): 2002, the structure is categorized as irregular, therefore linear dynamic analysis was preformed, however the results of this analysis was compared with that of linear static analysis.

Since we are considering concrete buildings the value of damping was taken as 5 percentage of critical, and building was assumed to be founded on a site having soil of type two (medium soil).

P-Δ effect was taken into consideration in the analysis.

The response of the structure including sway, inter storey drift, stresses and deformation in members particularly those in the soft storey, were compared by varying the location and combination of the soft storeys.

The load combinations were as per 1893(Part 1): 2002 and seismic forces were considered in one direction simultaneously.

Objective 3: Review of models:

Observations and Conclusions after completing the analysis of the 3-D framed models subjected to different combination of soft storey locations, the models were reviewed for any discrepancies that may have occurred.

Results from the analysis were presented as required in a favourable manner so as to be able to make generalized observations about the response of the structure as well as rational conclusions and recommendations for the design of R.C structures with soft storey.

Data:
Loadings:
Dead loads :
Finishes : 1.5 KN/m^2
Reinforced Concrete Elements : 25KN/m^3
Cladding Wall 20 KN/m^3
Live loads: 2 KN/m^2 on all floors and 3KN/m^2 imposed on roof.
Lateral loads : Earthquake load as per IS 1893(Part 1): 2002
Material Properties
Concrete Grade : M 25
Steel Grade : Fe 415
Soil Condition:
Medium
Importance Factor of Structure:
Importance factor =1
Zone factors:
Seismic Zone III : 0.16 g
General Building Configuration
15 Storey R.0 Moment Resisting Framed building to both orthogonal directions in plan.
27.15 m x 28.67 m plan dimensions
48 m total height
7 Bay in each direction of with different length ranging from 4.77 meters to 2.87 meters span
Storey Height 3.2 meter
Assumed Element Dimensions:
Columns: 400mm x 400 mm
415mm x 415mm
375mm x 375mm
350mm x 350mm
Beams: 230mm x 230mm
500mm x 230mm
500mm x 300mm
Floor and Roof Slabs: 125 mm

NOTE: We consider the above data for both regular and irregular structures, in order to achieve the stiffness property and design we have taken few considerable changes at the location where the stiffness is varying.

V. RESULTS AND DISCUSSION

The plan, elevation and stiffness irregularities considered for seismic analysis are shown in the following Figures 3.1 to 3.4.

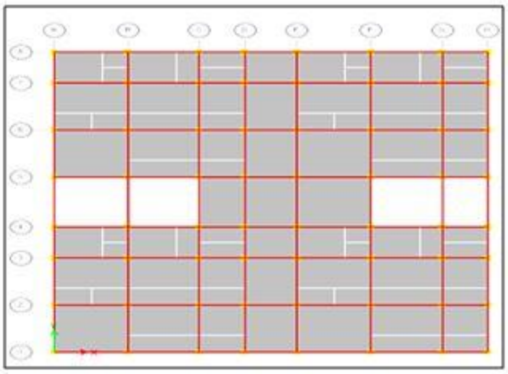

Figure 3.1 Regular structure plan view

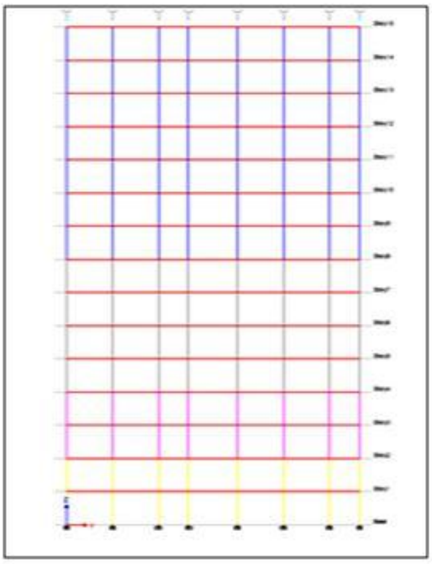

Figure 3.2 Regular structure elevation view

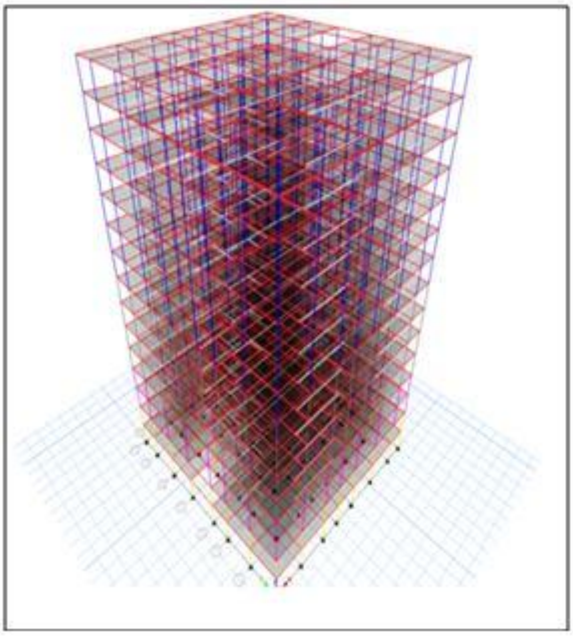

Figure 3.3 Regular structure 3 dimensional view

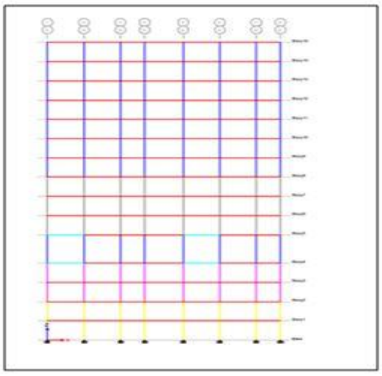

Figure 3.4 Irregular Structure @5th Storey Elevation View

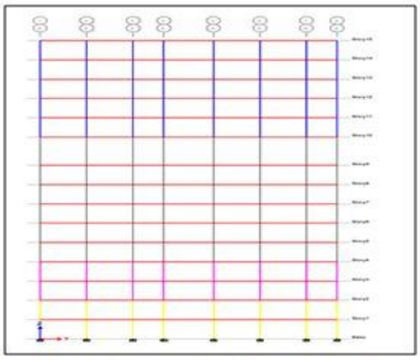

Figure 3.5 Irregular Structure @10th Storey Elevation View

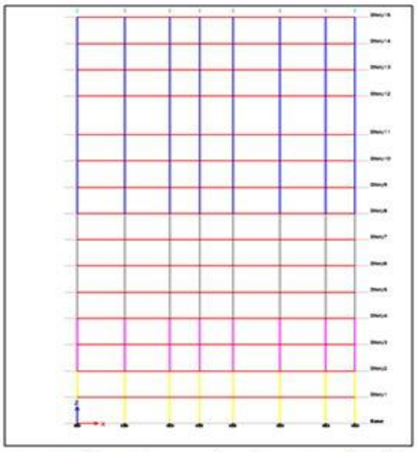

Figure 3.6 Irregular Structure @12th Storey Elevation View

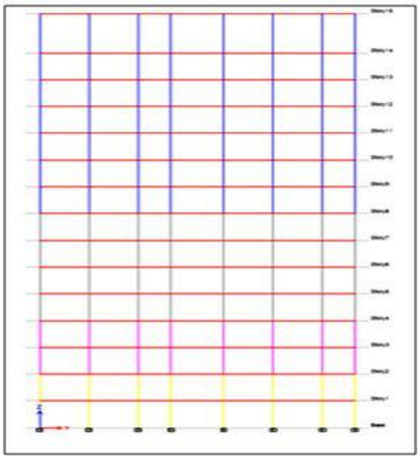

Figure 3.7 Irregular Structure @15th Storey Elevation View

STOREY STIFFNESS

Table.3.1 Stiffness values of Reg & Irrg structure in X dir

STOREY	REG. STRUCTURE	IRREGULAR STR. @5th STOREY	IRREGULAR STR. @10th STOREY	IRREGULAR STR. @12th STOREY	IRREGULAR STR. @15th STOREY
15	244558	251533	240918	229866	126765
14	350423	355724	348042	339555	344440
13	367528	371371	365553	344650	364208
12	371438	373688	368357	152021	369293
11	374260	375135	355564	356956	373318
10	378312	379099	183418	375915	377528
9	382762	384111	418291	382489	381975
8	444999	446711	442417	445140	444345
7	451437	451327	450206	451416	450952
6	457567	437087	456708	457244	457046
5	464390	288763	463736	463840	463971
4	532965	605705	532652	532289	532713
3	547116	657826	547099	546844	546919
2	700739	702299	700694	700922	700323
1	1058559	1060000	1058406	1059152	1057909

Table 3.2Stiffness ratio of Irrg structure wrt to Reg. structure in X dir

STOREY	REG. STRUCTURE	IRREGULAR STR. @5th STOREY	IRREGULAR STR. @10th STOREY	IRREGULAR STR. @12th STOREY	IRREGULAR STR. @15th STOREY
15	1.00	1.03	0.99	0.94	0.52
14	1.00	1.02	0.99	0.97	0.98
13	1.00	1.01	0.99	0.94	0.99
12	1.00	1.01	0.99	0.41	0.99
11	1.00	1.00	0.95	0.95	1.00
10	1.00	1.00	0.48	0.99	1.00
9	1.00	1.00	1.09	1.00	1.00
8	1.00	1.00	0.99	1.00	1.00
7	1.00	1.00	1.00	1.00	1.00
6	1.00	0.96	1.00	1.00	1.00
5	1.00	0.62	1.00	1.00	1.00
4	1.00	1.14	1.00	1.00	1.00
3	1.00	1.20	1.00	1.00	1.00
2	1.00	1.00	1.00	1.00	1.00
1	1.00	1.00	1.00	1.00	1.00

Table 3.3 Time Period &Horizontal Acceleration Manual Calculation.

Structure type	Horizontal accelaration in X Direction (Ah)	Horizontal accelaration in Y Direction (Ah)	Time Period in X Direction in Sec (Tx)	Time Period in Y Direction in Sec (Ty)
Regular	0.0262	0.0269	0.829	0.806
Irregular @ 5	0.0254	0.0261	0.854	0.832
Irregular @ 10	0.0254	0.0261	0.854	0.832
Irregular @ 12	0.0254	0.0261	0.854	0.832
Irregular @ 15	0.0254	0.0261	0.854	0.832

Table 3.4 Modal Participation Ratio Calculated by ETABS for all the Modes

Mode	REG IN %		IRRG @ 5th %		IRRG @ 10th %		IRRG @ 12th %		IRRG @ 15th %	
	Sum UX	Sum UY	Sum UX	Sum UY	Sum UX	Sum UY	Sum UX	Sum UY	Sum UX	Sum UY
1	0%	75%	0%	74%	0%	73%	0%	73%	0%	75%
2	77%	75%	76%	75%	75%	73%	75%	73%	77%	75%
3	77%	77%	76%	76%	75%	75%	75%	75%	77%	77%
4	77%	88%	76%	87%	75%	88%	75%	87%	77%	88%
5	88%	88%	87%	87%	88%	88%	87%	87%	88%	88%
6	88%	88%	87%	87%	88%	88%	87%	87%	88%	88%
7	88%	92%	87%	93%	88%	92%	87%	92%	88%	92%
8	92%	92%	93%	93%	92%	92%	92%	92%	92%	92%
9	92%	93%	93%	93%	92%	92%	92%	92%	92%	92%
10	92%	95%	93%	95%	92%	94%	92%	95%	92%	94%
11	95%	95%	95%	95%	94%	94%	95%	95%	94%	94%
12	95%	95%	95%	95%	94%	94%	95%	95%	94%	94%

Table 3.5 Time Periods for Regular& Irregular structure in both X & Y direction

Mode	REG	IRRG @ 5th	IRRG @ 10th	IRRG @ 12th	IRRG @ 15th
	Period	Period	Period	Period	Period
	sec	sec	sec	sec	sec
1	2.59	2.64	2.68	2.65	2.60
2	2.55	2.61	2.64	2.62	2.56
3	2.40	2.45	2.48	2.46	2.41
4	0.89	0.89	0.95	0.98	0.89
5	0.88	0.88	0.93	0.97	0.88
6	0.83	0.83	0.88	0.91	0.83
7	0.52	0.52	0.52	0.56	0.53
8	0.51	0.51	0.51	0.55	0.52
9	0.49	0.49	0.49	0.52	0.49
10	0.37	0.39	0.40	0.38	0.39
11	0.37	0.38	0.40	0.37	0.38
12	0.35	0.36	0.38	0.35	0.36

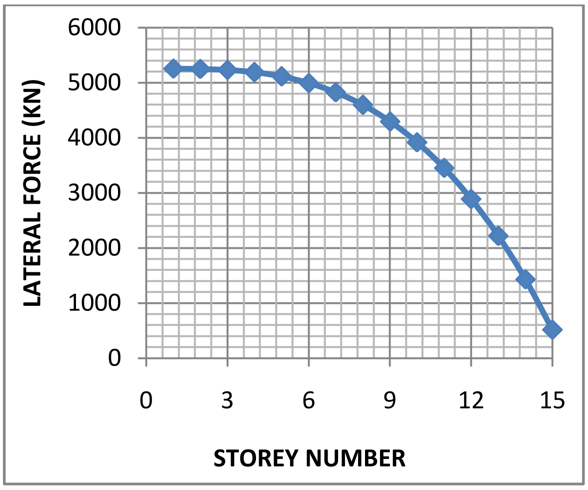

Fig. 3.8 Lateral Force plot: storey number Vs Lateral Force of Regular structure in X Dir

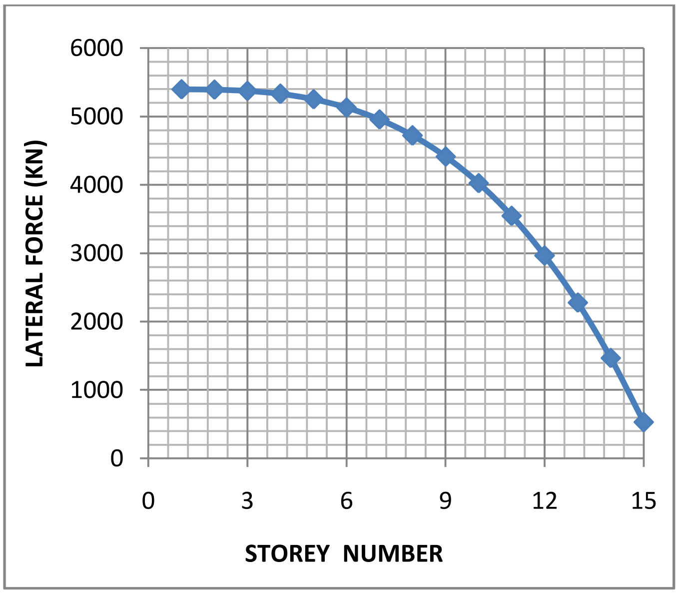

Fig. 3.9 Lateral Force plot: Storey Number Vs Lateral Force of Regular structure.in Y Dir.

Table 3.6 Calculation of Seismic Weight of the Irrg @10th storey in Y Direction.

BASE SHEAR CALCULATION								
S.NO	SLAB	BEAM	COL	WALL	FFAL	ROOFLIVE	LL	SEISMIC LOAD
1	1645	1514	875	4029	700	0	382	9146
2	1645	1514	875	4029	700	0	382	9146
3	1645	1514	691	4029	700	0	382	8963
4	1645	1514	691	4029	700	0	382	8963
5	1645	1514	608	4029	700	0	382	8879
6	1645	1514	608	4029	700	0	382	8879
7	1645	1514	608	4029	700	0	382	8879
8	1645	1514	608	4029	700	0	382	8879
9	1645	1514	608	4029	700	0	382	8879
10	1645	1514	945	4029	700	0	382	9216
11	1645	1514	529	4029	700	0	382	8801
12	1645	1514	529	4029	700	0	382	8801
13	1645	1514	529	4029	700	0	382	8801
14	1645	1514	529	4029	700	0	382	8801
15	1645	1514	265	2548		1050		5972
TOTAL	24682	22716	9496	58952	9803	0	5355	131004

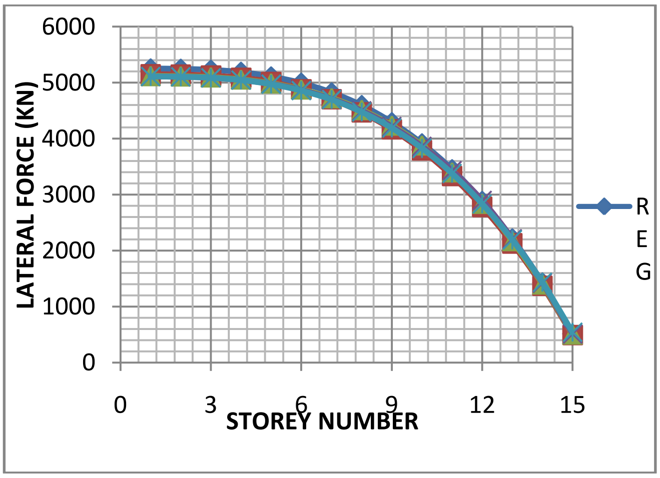

Fig. 3.10 Lateral Force plot storey number Vs Lateral Force of both Reg & Irrg. in X Dir.

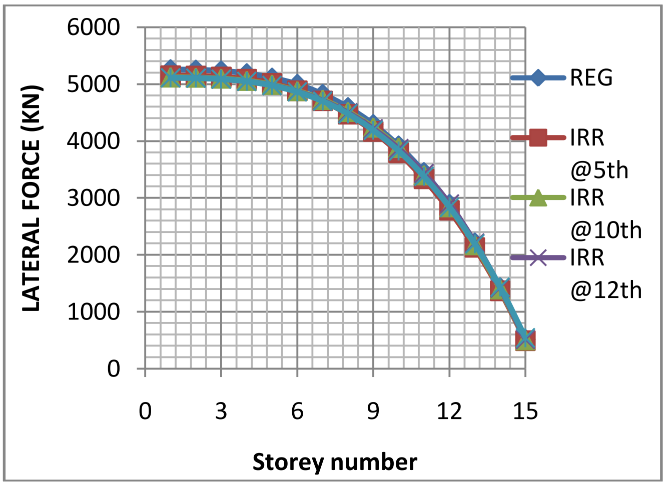

Fig. 3.11 Lateral Force plot storey number Vs Lateral Force of both Reg & Irrg. in Y Dir.

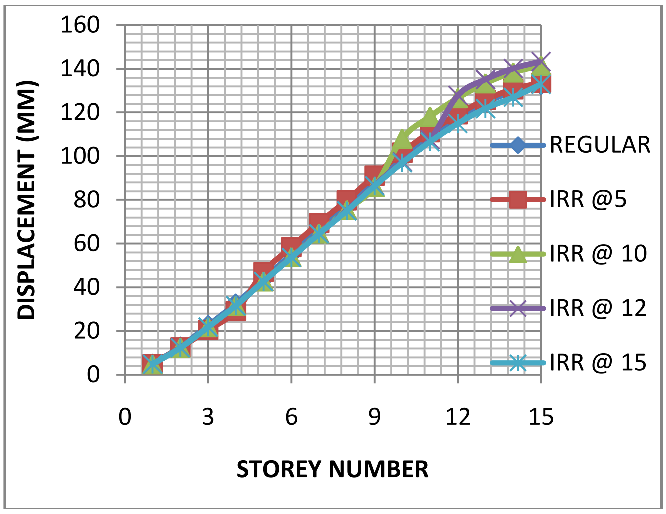

Fig. 3.12 Displacement plot Storey Number Vs Displacement of both Reg & Irreg. in X Dir.

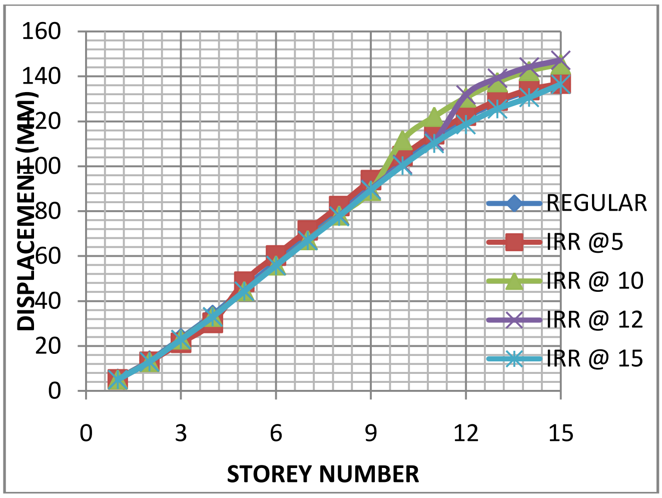

Fig. 3.13 Displacement plot Storey Number Vs Displacement of both Reg & Irreg. in Y Dir.

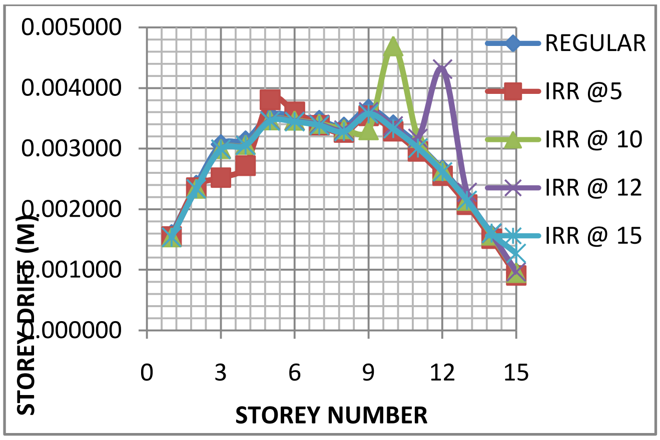

Figure 3.14 Storey Drift Plot: Storey Number Vs Storey Drift of both Reg & Irreg Str. in X Dir

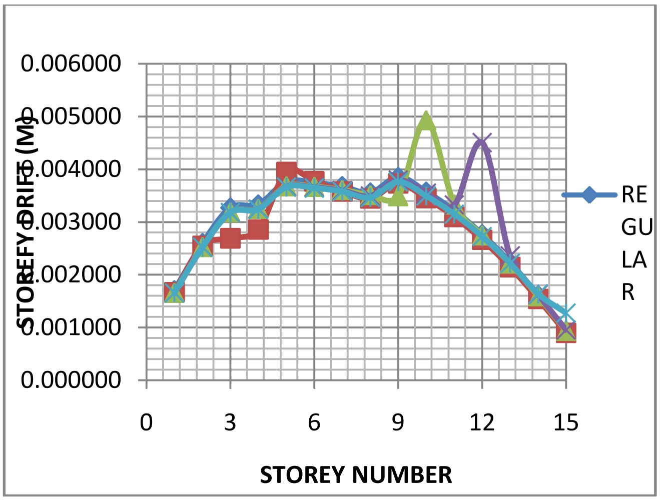

Figure 3.15 Storey Drift Plot: Storey Number Vs Storey Drift of both Reg & Irreg Str. in Y Dir

From the results obtained from ETABS the following points were observed:

- The lateral force is maximum and ground level and reduced with increase in floor number and reached minimum at 15th floor for both regular and irregular structures.
- Displacement is zero at ground level but increases with floor number and reached maximum at 15th floor for both regular and irregular structures.
- Starting at the 1st storey level, the curve gradually increase until maximum inter storey drift is reached, then gradually reduces to the some extent and then increases and at the 15th floor the drift reaches it is minimum value for both regular and irregular structures.

VI. CONCLUSIONS

In the present work, the complete assessment of the response parameters of an idealized 15 storey modelled (frame) structure subjected to various combination of soft storey locations was analyzed using the computer program ETABS and compared with manual calculations. Parametric studies on displacement, inter storey drift, storey shear and storey moments was conducted and a series of response charts plotted using both equivalent static analysis and dynamic analysis as per the Indian Seismic Codes, to investigate the influence of these parameters on the behaviour of buildings with soft storey at varying levels. The load combinations were as per 1893(Part 1): 2002 and seismic forces were considered in one direction simultaneously. The building was considered to be one of multiple functions and was kept symmetrical in both orthogonal directions in plan, to avoid tensional response under lateral excitation. Buckling response was also minimized by providing appropriate plan and vertical dimensions, and the analysis conducted as per IS 1893(Part 1) :2002 provisions, for Linear Static and Dynamic analysis, assuming medium soil condition for seismic zone 5, also the effect of infill was not taken into consideration on the initial response of the structure. Under the assumption that the structure behaves as a sheared building, the resulting stiffness variations obtained by ETABS calculations are obtained in X direction & Y direction respectively. This assumption of structure stiffness is the fundamental criteria for the seismic coefficient and response spectrum analysis and shows that the stiffness changes occur only at the soft storey level. It shows that as the storey level increase, the stiffness decreases having maximum values at the first story and continuously decreasing towards the 15th. We considered the above data for both regular and irregular structures, in order to achieve the stiffness property and design, we have taken few considerable changes at the location where the stiffness is varying. The response of the structure, including sway, inter-storey drift, stresses and deformation in members, particularly those in the soft storey, were compared by varying the location and combination of the soft storeys. The outcome of the investigation will help us to idealize the response of RC Structures and to take necessary precautions when designing structures in earthquake-prone areas.

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