Earthquake Resistant Design of a Typical Multistorey Industrial Building – Impact on Cost Due to Revision of Codes

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Abstract: *Earthquake resistant design of structures is continuously evolving, learning from the behavior of structures during each earthquake. World over the codes of practice are incorporating necessary changes to make the structures behave in a better manner during the earthquakes reducing the loss of life and property. In India, major changes have been incorporated in the codes of practice dealing with earthquake resistant design and detailing of buildings. In this paper cost implications of these changes are studied for a typical multi-story industrial building. Industrial buildings are more vulnerable to earthquakes due to building irregularities and irregular mass concentration of plant and machinery. Seismic analysis and design of a typicalG+7 multistorey building is carried out for seismic zone II and zone V as per the previous code IS 1893 (Part-4)-2005 and as per the latest code IS 1893 (Part-4)-2015. For zone V, ductile design & detailing is required, which is applied as per the previous code IS 13920-1993 and as per the latest code IS 13920-2016. The quantities of concrete and steel required for the superstructure in different zones, as per old and revised codes are compared. Percentage increase in the quantities of concrete, steel reinforcement & cost of building for the different zones using the old and the revised codes are compared with reference to non-seismic (Dead load + Live load) analysis and design. It is found that almost no additional quantity of concrete is required for seismic analysis and design in zone II. Whereas, in zone V, the seismic analysis requires additional quantity of concrete of nearly 1.70% as per the old codes and nearly 4.5% as per the revised codes. The additional quantity of steel required for seismic analysis is found to be nearly 5.75% as per the old codes and nearly 14.50% as per the revised codes in zone II and nearly 46% and 57.25% as per the old and the revised codes, respectively in zone V. The impact on the overall cost of the building remain within 5%. The increase in cost due to seismic analysis as per the old and the revised codes is found to be nearly 0.5% and 1% respectively, for zone II and nearly 3.5% and 4.5% respectively, for zone V.*

Index Terms **- IS 1893 (Part-1)-2015, IS 1893 (Part-1)-2005, IS 13920-1993, IS 13920-2016, Seismic Analysis, Earthquake Resistant Design of Structures, Industrial Buildings, Cost impact of Earthquake Analysis, Old and Revised Codes, Quantity of Concrete and Steel.**

I. INTRODUCTION

Earthquakes are taking place throughout the world posing danger to life and property. With the advancements in the earthquake resistant design of structures now more rational design is possible reducing the risk. Still each earthquake brings some new knowledge to the society needing updating of the design philosophies. The design codes are also accordingly revised from time to time.

Indian standard codes of practice dealing with the earthquake resistant design of buildings have also been updated. In the year 2005 and 2006 many major changes have been incorporated in these codes after a long gap. These changes have a great impact on the earthquake resistant design of buildings. Most of the buildings (including temporary and ancillary buildings) in zones III, IV and V and majority of the multi-story buildings in zone II now falls under the purview of these codes. Earthquake resistant design based on these codes is not only necessary to safeguard against the risk of damages due to earthquake but also it is mandatory. Therefore, every structural designer as well as architect must be aware of these provisions. Present study is based on the Indians standard codes of practice only, though similar results are expected using codes of other countries as revisions in the codes are on more por less similar lines.

When earthquake takes place, the buildings go through dynamic motion. Apart from the gravity loads, the buildings face lateral forces of significant magnitude throughout the time of earthquake shaking due to the dynamic motion. For earthquake resistant design of building, detailed analysis is carried out to know the governing lateral forces on the building. In multi-story buildings these lateral forces produce critical stresses in the components of building and creates undesirable stresses, vibration & causes excessive amount of lateral sway of building.

The ductile behavior of building is the key factor influencing its seismic performance and if the building is well designed and detailed it behave efficiently when earthquakes takes place. A ductile designed building structure gives enough time to vacate the building before its final collapse and minimize the loss of life. Well-designed ductile joints are capable to resists the forces and deformation at the yield point of steel reinforcement.

Limited studies have so far been carried out to know the impact of the revised codes on the earthquake resistant design of buildings and on comparison the design with the earlier codes. The behavior of buildings, especially multi-storeyed buildings which are more susceptible to damage, still to be understood properly under the influence of earthquakes and there is a need of continuous research in this field. Many researchers have studied the behavior of buildings under earthquakes, using Indian standard codes of practice.

Surwase *et al* [1] carried out seismic analysis and comparison of IS-1893(Part-1)2002 & 2016 for G+4 regular & irregular buildings located in zone II & zone IV. They computed the values of base shear, time period, story displacement using E-TABS software and compared the results among different models. They found that lateral forces are higher in IS 1893-2016 based analysis as comparison to IS 1893-2002 based analysis because of change in importance factor value. Gottal *et al* [2] carried out comparative study of static and dynamic analysis of a G+9 multi-story building and showed comparative results of mode shapes, bending moment and nodal displacement for different building components. Significant increase in values were found in dynamic analysis as compared with static analysis. Mahesh & Rao [3] studied the behavior of G+11 multi-story buildings of regular and irregular configurations using E-TABS & STAAD Pro software. Linear static and dynamic analyses were carried out for different zones and responses like base shear, story drift etc. were plotted and it was concluded that the base shear value was more in regular configuration. Balaji & Selvarasan [4] performed analysis of a G+13 residential building under seismic loads using E-TABS. Linear static and dynamic analyses were carried out for type II soil condition. Different responses such as displacement, base shear were plotted. Mindaye & Yajdani [5] carried out the earthquake analysis of a G+10 framed structure for different seismic zones, applying equivalent static and response spectrum methods using E-TABS as per the IS 1893 (Part-1)-2002. This analysis was carried out for seismic zone II & III and various response such as lateral force, displacement, overturning moment, story-drift were plotted in order to compare the result of static & dynamic analysis. Jain and Jain [6] carried out comparative study of old and revised provisions of Indian Seismic codes on earthquake resistant design of general and industrial buildings. They compared the important provisions of the earlier codes and the revised codes in the context of IS 1893. Some very important revised provisions of the IS:13920 pertaining to ductile design and detailing were also included in the study. The study highlighted the changes in approach that are needed to be incorporated in the most basic earthquake resistant design of general and industrial buildings.

From the earlier studies it seems that most of the researcher performed the static & dynamic analysis of multi-story residential buildings of different heights by equivalent static method and response spectrum method. They compared the results such as base shear, story drift, displacement, story moment etc. between two methods, between two zones etcs. Most of the researches were based on the provision of the old code i.e. IS 1893-(Part-1)-2002 and only a few studies were conducted using the latest code IS 1893-(Part-1)-2016 comparing the results with the old code.

The latest code includes several new as well as revised stringent provisions to safeguard against the damages due to earthquake and has made these provisions mandatory. Their impact on the analysis and design of buildings is still not largely known. So, there is a strong need for more research using the latest code to know its impact and implications. Impact of latest code in the design of regular building and irregular building such as industrial building as compared to old code needs to be assessed to understand the revised seismic parameter requirement as well as cost aspects.

In this research study a typical G+7 industrial building is considered for earthquake resistant design as per the provisions of the earlier code IS1893(Part-4)-2005 and the revised code IS 1893(Part-4)-2015. Industrial building is chosen as such buildings are basically irregular in nature and have irregular mass concentration due to placement of plant and machinery which makes them more susceptible to earthquake stresses. Moreover, there are very limited studies on design of earthquake resistant multi-storey industrial buildings. Analysis and design is carried out for two seismic zones i.e. zone II and zone V which are the least and the most severe zones, respectively, in India. IS 1893 (Part 1)-2002 and IS 1893 (Part 1)-2016 for general buildings are also involved as these are also referred in IS 1893 (Part 4). Ductile detailing and design is now mandatory for buildings in zone V so provisions of IS 13920-1993 and IS 13920-2016 are also followed. The analysis and design is carried out using STAAD-Pro Connect Edition software. Quantities of concrete, steel reinforcement, % increase in the quantities of concrete and steel and % increase in cost of building are compared for both the zones using the earlier and the revised codes with respect to non-seismic design to compare the impact of seismic design based on the earlier codes and based on the revised codes.

II. DETAILS OF THE INDUSTRIAL BUILDING

For this research study a typical G+7 multi-story industrial building structure is considered for the analysis and design. The configuration of the building and other parameters considered are shown in the Table 1.

Table 1 Details of the building structure & material properties

S. No.	Description	Details
1.	Base Dimension of building (Centre to Centre)	26.00 m x 20.5 m
2.	No. of Story (level)	7 (4.0 m, 9.0 m, 13.5 m,17.5 m, 21.0 m, 27.0 m, 29.5 m)
3.	Height of Building	29.5 m
4.	Depth of Foundation	1.5 m
5.	Size of columns	C1: 600 x 600, C2: 500 x 500, C3: 300 x 400 (in mm)
6.	Size of Beams	B1: 300 x 500, B2: 300 x 400, B3: 400 x 800 (in mm)
7.	Thickness of Shear Wall (provided around lift well)	150 mm
8.	Grade of Concrete	M 25
9.	Grade of Steel	Fe 415
10.	Occupancy	Less than 200 persons

The typical plan of the Industrial Building is shown in Figure 1. The center to center length of the building in the X-direction is 26 m, which is divided into 5 bays of varying length i.e. 8 m, 3 m, 4.5 m, 4.5 m, and 6 m as shown in the plan. The center to center length of the building in the Y-direction is 20.5 m which is divided into 4 bays of varying length of 5.5 m, 5 m, 5 m, and 5 m. as shown in the plan. Total height of the building is 29.50 m, which is divided into 7 floors having heights above the ground level as 4 m, 9 m, 13.5 m, 17.5 m, 21 m, 27 m, and 29.5 m as shown in the elevation (Figure 2).

The vertical geometry changes from 17.50 m level upwards where the plan area of building reduces as shown in the elevation. The machinery is placed on different floors on one side only. Thus, the building has both plan irregularities as well as vertical irregularities, calling for dynamic analysis as per the requirement of the revised code IS: 1893 (Part 4)-2015 and IS:1893 (Part 1)-2016.

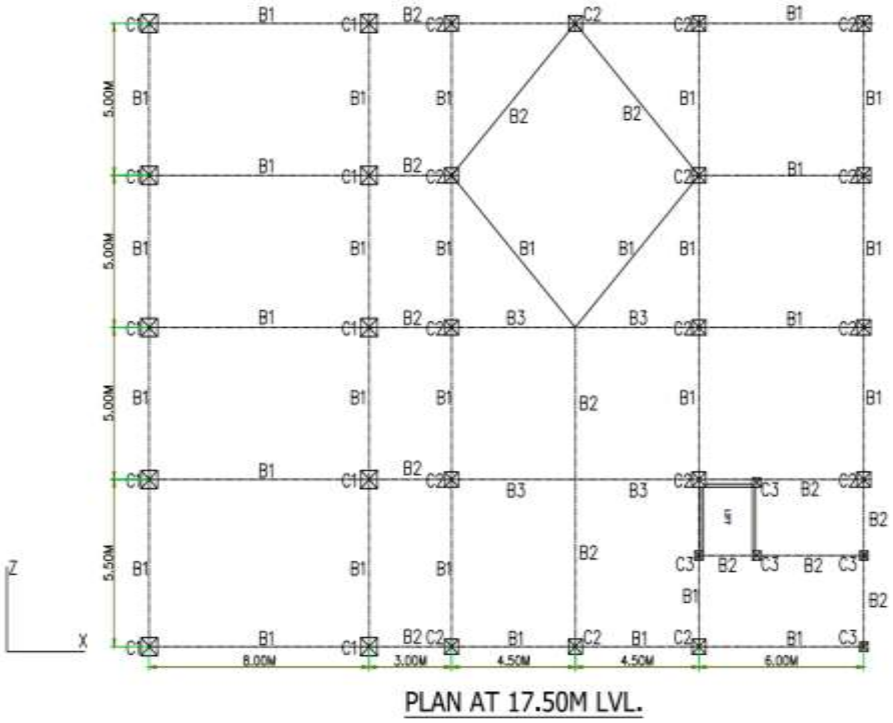

Fig. 1 – Plan View of the Industrial Building

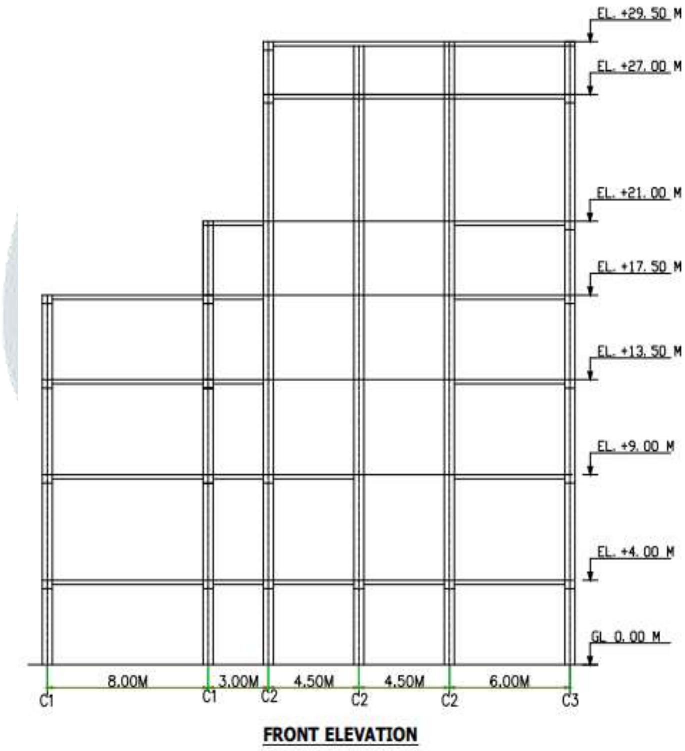

Fig. 2 – Front Elevation View of Industrial Building

III. EARTHQUAKE PARAMETERS

For the analysis & design of the industrial building, various seismic parameters are considered as stipulated in the codes. The same are shown in the Table 2.

Table 2 Seismic parameters for zone II and zone V as per the old and revised IS codes

Seismic Zone	**Parameter**	**Values for the Industrial Building**	
		As per the old code i.e. IS 1893-2005 (Part-IV)	As per the revised code i.e. IS 1893-2015 (Part-IV)
Zone II	Zone Factor (Z)	0.1 (Annexure A)	0.1 (Annexure A: Table 14)
	Importance Factor (I)	1.0 (Table 2 & 5, category 4)	1.0 (Table 3 & 6, category 4)
	Response reduction factor (R)	5.0 (Table 3)	5.0 (Table 4)
	Soil Type	II (Medium Soil) (Table 1)	II (Medium Soil) (Table 1)
	Fundamental Natural Time Period (Ta)	For category 4 building code 2002 Part 1 applicable: For RCC Moment Resistant Frame Building	For category 4 building code 2016 Part 1 applicable: For RCC Moment Resistant Frame Building

		(clause 7.6.1) Ta=0.075*h^0.75	(clause 7.6.2) Ta=0.075*h^0.75
	Average Response Acceleration coefficient (Sa/g), for medium soil	Type II Curve for medium soil, as per Annexure B and clause 8.3.2 of code 2005, Part 4, and as per Fig.2 and clause 6.4.5 of code 2002, Part 1, Sa/g=1.36/T	Type II Curve for medium soil, as per Annexure B, clause 10 and 10.2 and Fig.1 of code (for category 4 building Fig. 2 and clause 6.4.2 of code 2016, Part 1, applicable). For 0.55s<Ta<4s Sa/g=1.36/T
	Whether dynamic analysis required -	simplified analysis to be carried out for category 4 in seismic zone II as per code 2002 Part 1. Therefore, No (Irregular building but height less than 40 m - clause 7.8.1 b of code 2002 Part 1)	simplified analysis to be carried out for category 4 in seismic zone II as per code 2016 Part 1. Therefore, Yes (Irregular building with Height more than 15M. - clause 7.7.1 as per code 2016 Part 1)
	Method of Dynamic Analysis	N.A.	Response spectrum method with closely spaced mode
	No. of modes considered in dynamic analysis, for sum total mode mass to be > 90% of total seismic mass, and whether modes are within frequency of 33 Hz	N.A.	30
	No. of Load combination	73	73
Zone V	Zone Factor (Z)	0.36(Annexure A)	0.36 (Annexure A: Table 14)
	Importance Factor (I)	1.0 (Table 2 & 5, category 4)	1.0 (Table 3 & 6, category 4)
	Response reduction factor (R)	5.0 (Table 3)	5.0 (Table 4)
	Soil Type	II (Medium Soil) (Table 1)	II (Medium Soil) (Table 1)
	Fundamental Natural Time Period (Ta)	For category 4 building code 2002 Part 1 applicable: For RCC Moment Resistant Frame Building (clause 7.6.1) Ta=0.075*h^0.75	For category 4 building code 2016 Part 1 applicable: For RCC Moment Resistant Frame Building (clause 7.6.2) Ta=0.075*h^0.75
	Average Response Acceleration coefficient (Sa/g), for medium soil	Type II Curve for medium soil, as per Annexure B and clause 8.3.2 of code 2005, Part 4, and as per Fig.2 and clause 6.4.5 of code 2002, Part 1, Sa/g=1.36/T	Type II Curve for medium soil, as per Annexure B, clause 10 and 10.2 and Fig.1 of code (for category 4 building Fig. 2 and clause 6.4.2 of code 2016, Part 1, applicable). For 0.55s<Ta<4s Sa/g=1.36/T
	Whether dynamic analysis required -	For Zone V detailed i.e. dynamic analysis is mandatory.	For Zone V detailed i.e. dynamic analysis is mandatory.
	Method of Dynamic Analysis	Response spectrum method with closely spaced mode (CSM)	Response spectrum method with closely spaced mode (CSM)
	No. of modes considered in dynamic analysis, for sum total mode mass to be > 90% of total seismic mass, and whether modes are within frequency of 33 Hz	30	30
	No. of Load combination	73	73

IV. EARTHQUAKE ANALYSIS

The methods of earthquake analysis of building as specified in revised IS 1893 are as mentioned below:

1. Static Analysis
2. Dynamic Analysis

1. Static Analysis –

Static Analysis is known as Equivalent Static Seismic Force Method. This method is used only for regular buildings with height < 15M in seismic Zone II. For all other buildings, dynamic analysis is made mandatory.

In this method, design base shear V_B is calculated for the building. Then, this design base shear value is distributed to the various floor level at the corresponding centre of mass.

Design Seismic Base Shear,

VB = Ah X W

Where,

W= Seismic Weight of the building

Ah = Design Horizontal Seismic Coefficient

Ah = (Z /2) X (I/R) X (Sa/g)

Z= Zone Factor,

I = Importance Factor,

R= Response Reduction Factor,

Sa/g = Design Acceleration coefficient of different soil

The design lateral force at any floor i is calculated using following formula

$Q_i = [\{W_i \times h_i^2\} / \{\sum_{j=1}^{n} W_j h_j{}^2\}] V_B$

Where,

Q_i = Design lateral force at floor *i*

W_j = seismic weight of floor *i*

h_i = height of floor *i* measured from base

n = number of story in building that is number of levels at which masses are located.

2. Dynamic Analysis –

Static analysis is used for simple regular buildings of height up to 15M in zone II only, for all other building structures more than height of 15M and construction in zone III, IV & V required dynamic analysis.

For buildings, linear dynamic analysis should perform to obtain the design seismic force and its distribution at different floor levels and to different structural elements.

Three methods are mentioned in the revised code for dynamic analysis as mentioned below-

I. Response Spectrum Method

II. Modal Time History Method

III. Time History Method

The IS: 1893 recommends methods I and III and these are

I. Response Spectrum Method –

Response spectrum method of dynamic analysis carried out for building using the design acceleration spectrum which are specified in IS 1893.

II. Time History Method –

Time History method of dynamic analysis is based on appropriate ground motion and shall be performed by accepted principles of structure dynamics.

IS: 1893 mentioned detailed procedure for the Response Spectrum Method. Design base shear calculated from dynamic analysis is compared with the base shear calculated using fundamental time (static method) period and compare them, if it is less than the fundamental base shear value, the lateral force is multiplied by the ratio of fundamental base shear to calculated design base shear in order to obtain the design base shear.

Details of performed analysis –

For this research study 5 different earthquake analyses are carried out. Two analyses are carried out for zone II i.e. one each based on the old and the revised code respectively. Two analyses are carried out for zone V, one each based on the old and the revised code, respectively. One non-earthquake (dead load + live load) analysis is also carried out for comparison purpose to see the impact of earthquake resistant design on the cost of the building. All the analyses are carried out on the latest version of STAAD Pro Connect Edition software. The details of the different analyses are as follows.

1. Non earthquake (Dead Load + Live Load) Analysis –

This analysis is performing only for comparison purpose, dead and live load are considered in this analysis without any lateral load. After the analysis and design, the quantities of concrete and steel are worked out for comparison with the seismic analyses.

2. Analysis for Zone II based on the Old Code: Static Analysis as per IS 1893 (Part-4) 2005 –

The building falls in the category 4 building. IS 1893 (Part 4) 2005 stipulates simplified (static) analysis for category 4 building in seismic zone II as per IS 1893(Part-1)2002. Total 73 load combinations are used for this static analysis as per IS 1893 (Part 4) 2005. Various structural members are designed, and quantities of concrete and steel worked out for comparison purpose.

3. Analysis for Zone II based on the Revised Code: Dynamic Analysis as per IS 1893 (Part-4) 2015 –

The building falls in the category 4 building. IS 1893 (Part 4) 2015 stipulates analysis for category 4 building in seismic zone II to be carried out as per IS 1893(Part-1) latest edition i.e 2016, which, in turn, stipulates detailed (dynamic) for all irregular buildings as well as for all buildings having height more 15 m in zone II. Dynamic analysis is carried out using response spectrum method with closely spaced mode. 30 no. of modes are used to get more than 90% participation as required by the code. Total 73 load combinations are used as per IS 1893 (Part 4) 2015.

As per the new provisions introduced in the revised code, reduced moment of inertia of column & beam is applied to implement strong column weak beam concept which leads to a more controlled failure mechanism. Analysis was performed and design carried out. It was found that 2 numbers of 9 m span beams failed at each of the floor numbers 5 and 6, requiring upward revision in their sizes. Based on the final sizes of the designed members, the quantities of concrete and steel were calculated for comparison purpose.

4. Analysis for Zone V based on the Old Code: Dynamic Analysis as per IS 1893 (Part-4) 2005 –

The building falls in the category 4 building. IS 1893 (Part 4) 2005 stipulates analysis for category 4 building as per IS 1893(Part-1)2002, which, in turn stipulates detailed (dynamic) analysis for all irregular buildings in zone V, Having height more than 12 m. Dynamic analysis is carried out using response spectrum method with closely spaced mode. 30 no. of modes are used to get more than 90% participation as required by the code. Total 73 load combinations are used as per IS 1893 (Part 4) 2005. While designing the members, ductile detailing is applied as per IS 13920-1993, which is applicable for buildings in zone V. This resulted in significant increase in quantity of steel reinforcement. While designing the members, beams of span 9 m failed requiring further upward revision in their sizes. Based on the final design, the quantities of concrete and steel were calculated for comparison purpose.

5. Analysis for Zone V based on the Revised Code: Dynamic Analysis as per IS 1893 (Part-4) 2015 –

IS 1893 (Part 4) 2015 stipulates analysis for category 4 building as per IS 1893(Part-1) latest edition i.e. 2016, which, in turn stipulates detailed (dynamic) analysis for all irregular buildings in zone V. Dynamic analysis is carried out using response spectrum method with closely spaced mode. 30 no. of modes are used to get more than 90% participation as required by the code. Total 73 load combinations are used as per IS 1893 (Part 4) 2015. While designing the members, ductile design and detailing is applied as per IS 13920-2016, which is mandatory for buildings in zone III, IV and V as per the revised code. This resulted in highly significant increase in quantity of steel reinforcement.

As per the new provisions introduced in the revised code, reduced moment of inertia of column & beam is applied to implement strong column weak beam concept which leads to a more controlled failure mechanism. Analysis was performed and design carried out. While designing the members, beams of span 9 m failed requiring further upward revision in their sizes. To meet the requirements of ductile design as per the revised code 13920, grade of concrete for 25 numbers of columns at different story levels had to be changed from M25 to M40. Based on the final design, the quantities of concrete and steel were calculated for comparison purpose.

V. RESULTS AND DISCUSSION

As mentioned above, four different earthquake analysis are carried out for two different seismic zones, using the old and the revised codes. A non-earthquake analysis is also carried out for dead load + live load combination, without lateral loads, for comparison purpose. Design is also performed based on the old and the revised codes for the corresponding analyses. As per the final design of various structural members, the Quantity of concrete in cu-m and quantity of steel reinforcement in kg are calculated for the superstructure. Percentage increase in the quantity of concrete and percentage increase in the quantity of steel reinforcement are also worked out with respect to the non-earthquake analysis, for comparison purpose.

Approximate cost of the building is worked out as per Central Public Works Department (CPWD) plinth area rates 2020. Approximate cost of concrete and steel reinforcement is worked out as per CPWD, Delhi Schedule Rate 2018-2019. For the plinth area of 2620 sqm, the approximate cost of the building works out to be Rs.7 crore. Percentage increase in the cost of building for all the four earthquake analyses is worked out with respect to the non-earthquake analysis, for comparison purpose.

Table 3 shows the quantities of concrete required for the structural members of the superstructure in cu-m for different analyses.

Table 3: Quantity of concrete for superstructure in cu-m for different analyses

Quantity of Concrete for Superstructure in cu-m for Different Analyses		
S. No.	Type of Analysis	Quantity of Concrete in cum
1	Non earthquake (DL+LL) Analysis	848
2	2005 Zone II EQ-Static Analysis	848
3	2015 Zone II EQ-Dynamic Analysis	849
4	2005 Zone V EQ- Dynamic Analysis	862
5	2015 Zone V EQ-Dynamic Analysis	886

From Table 3 it is seen that the quantity of concrete in superstructure remains almost unchanged in the earthquake analysis as compared to non-earthquake analysis in zone II, with the old code as well as with the new code. Whereas the quantity is increased in the earthquake analysis in zone V using old code and the quantity is increased further when the new code is used. The increase in quantity of concrete in zone V is mainly due to ductile detailing and design requirements as per IS 13920. Additional increase in the quantity in analysis using the new code in zone V is mainly attributable to revised provisions incorporated in IS:13920-2016 which now includes ductile design in addition to ductile detailing, and introduction of reduced moment of inertia of beams and column in the revised code IS:1893-2016 to enforce strong column weak beam type mechanism.

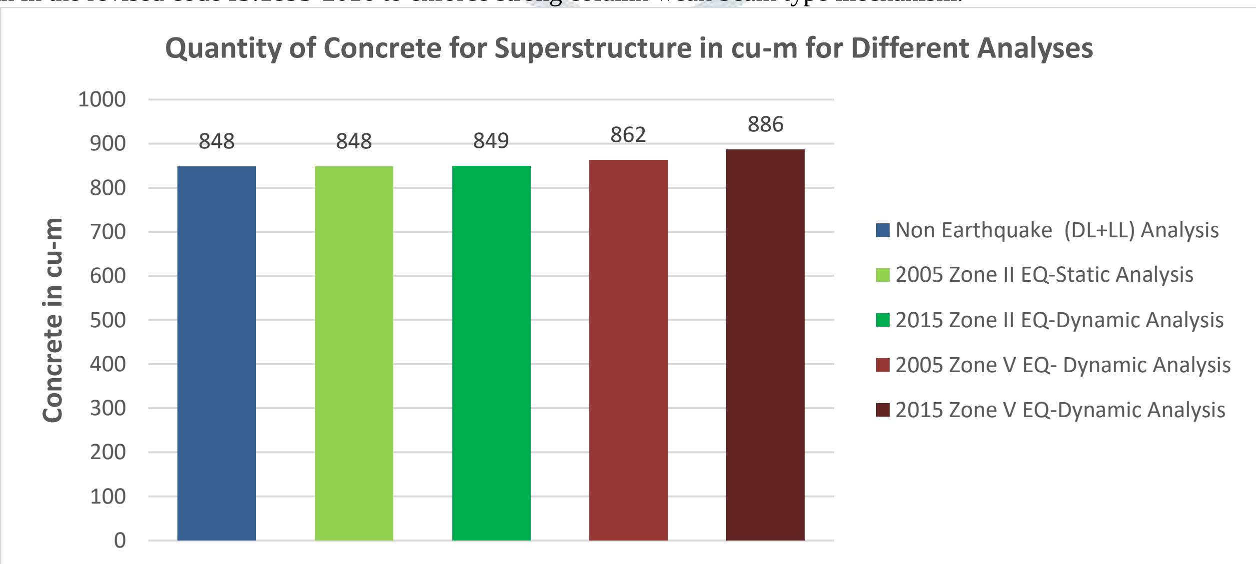

Fig.3: Quantity of Concrete in cu-m

Figure 3 graphically represents the quantities of concrete in cu-m for different analyses, where y-axis represents the values of concrete in cum.

Table 4 shows the quantities of steel reinforcement required for the structural members of the superstructure in kg for different analyses.

Table 4: Quantity of steel reinforcement for superstructure in kg for different analyses

Quantity of Steel Reinforcement for Superstructure in Kg for Different Analyses		
S. No.	Type of Analysis	Quantity of Steel in Kg
1	Non earthquake (DL+LL) Analysis	56563
2	2005 Zone II EQ-Static Analysis	59797
3	2015 Zone II EQ-Dynamic Analysis	64705
4	2005 Zone V EQ- Dynamic Analysis	82539
5	2015 Zone V EQ-Dynamic Analysis	88942

It is found that there is increase in quantity of steel reinforcement required for superstructure members in all the earthquake analyses as compared to the non-earthquake analysis. For zone II, there is slight increase in quantity as per the analysis based on the old code, whereas the analysis based on the revised code requires significant increase in the quantity. For zone V, there is highly significant increase in the quantity as per the analysis based on the old code, whereas the analysis based on the revised code requires still further increase in the quantity. Substantial increase in the quantity of steel in zone V as compared to that in zone II is mainly attributable to the ductile design and detailing requirement as per IS 13920, which becomes applicable for the building in zone V.

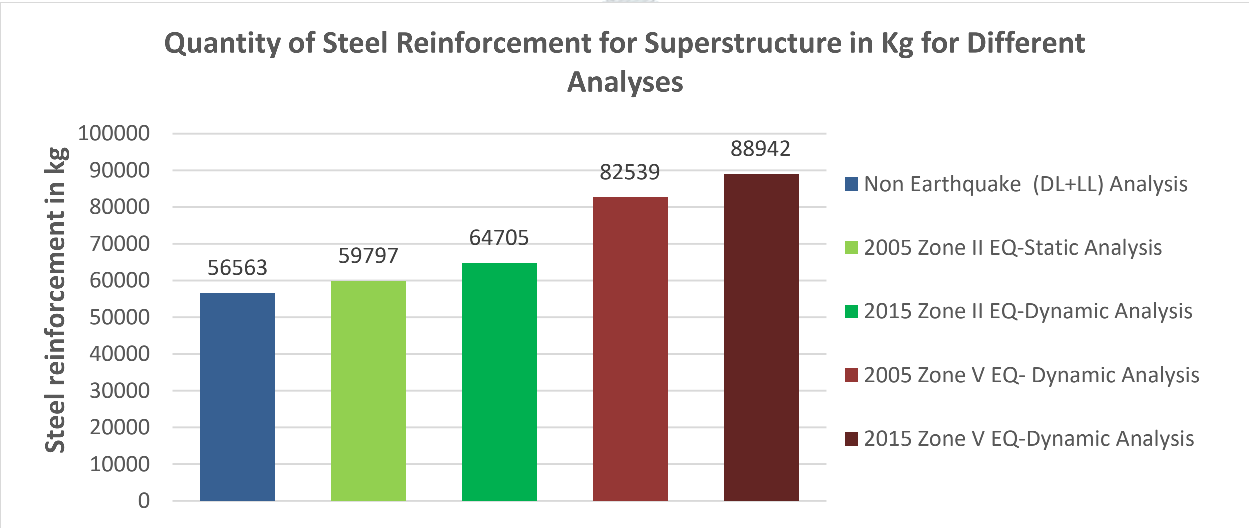

Fig.4: Quantity of Steel Reinforcement in Kg

Figure 4 graphically represents the quantity of steel reinforcement for structural members of the superstructure in Kg for different analyses in which the y-axis represents the values of steel reinforcement in Kg.

Table 5 shows the percentage increase in quantities of concrete in superstructure in different earthquake analyses with respect to the non-earthquake analysis.

Table 5: Percentage increase in the quantity of concrete with respect to the non-earthquake analysis

% Increase in the Quantity of Concrete with respect to the Non-EQ (DL+LL) Analysis		
S. No.	Type of Analysis	% Increase in the Quantity of Concrete
1	2005 Zone II EQ-Static Analysis	0.00
2	2015 Zone II EQ-Dynamic Analysis	0.15
3	2005 Zone V EQ- Dynamic Analysis	1.71
4	2015 Zone V EQ-Dynamic Analysis	4.52

Table 5 shows that there is no increase in quantity of concrete in zone II earthquake analysis, conducted using old code, with respect to non-earthquake analysis. When the same analysis is conducted using the revised code, there is only a marginal increase of 0.15% in the quantity of concrete. In zone V, the earthquake analysis using the old and revised codes results in increase in the quantity of concrete by 1.71% and 4.52%, respectively. The increase in the quantity of concrete in zone V is mainly attributed to ductile detailing and design requirements as per IS 13920. Additional increase in the quantity in analysis using the new code in zone V is mainly attributable to revised provisions incorporated in IS:13920-2016 which now includes ductile design in addition to ductile detailing, and introduction of reduced moment of inertia of beams and column in the revised code IS:1893-2016 to enforce strong column weak beam type mechanism. It is also seen that the implementation of the revised code increases the quantity of concrete of the order of 0.15 % and 2.8% in zones II and V, respectively.

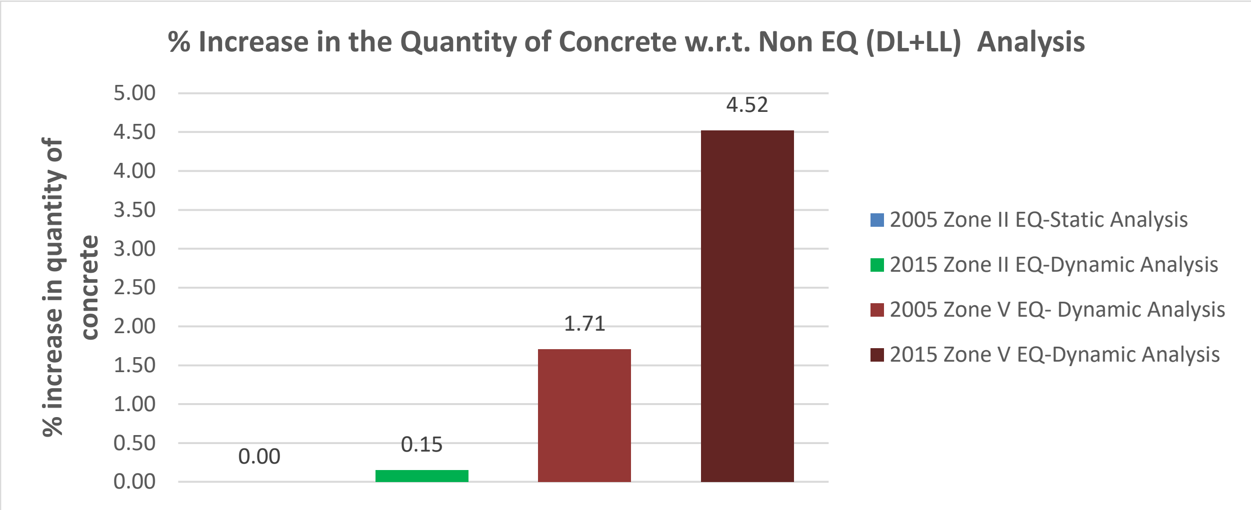

Fig.5: % Increase in Quantity of Concrete with respect to Non-Earthquake Analysis

Figure 5 graphically represents the percentage increase in the quantity of concrete in superstructure for different earthquake analyses with respect to non-earthquake analysis.

Table 6 shows the percentage increase in quantities of steel reinforcement with respect to non-earthquake analysis

Table 6: Percentage increase in the quantity of steel reinforcement in superstructure with respect to the non-earthquake analysis

% Increase in the Quantity of Steel Reinforcement in Superstructure w.r.t. Non-EQ (DL+LL) Analysis		
S. No.	Type of Analysis	% Increase in the Quantity of Steel
1	2005 Zone II EQ-Static Analysis	5.72
2	2015 Zone II EQ-Dynamic Analysis	14.39
3	2005 Zone V EQ- Dynamic Analysis	45.92
4	2015 Zone V EQ-Dynamic Analysis	57.24

Table 6 shows that there is increase in the quantity of steel reinforcement in superstructure in all the earthquake analyses with respect to the non-earthquake analysis. In zone II, the earthquake analysis using the old and revised codes results in increase in the quantity of steel reinforcement by 5.72% and 14.39%, respectively which is a significant increase. In zone V, the earthquake analysis using the old code results in highly significant increase in the quantity of steel reinforcement by 45.92%. Whereas the same analysis for zone V when conducted using the revised code it results in still further increase in the quantity of steel which now stands at 57.24% higher as compared to the non-earthquake analysis. Substantial increase in the quantity of steel in zone V as compared to that in zone II is mainly attributable to the increased zone factor as well as to the ductile design and detailing requirements as per IS 13920, which becomes applicable for the building in zone V. It is also seen that the implementation of the revised code increases the quantity of steel of the order of 8.7 % and 11.3 % in zones II and V, respectively.

Figure 6 shows the percentage increase in the quantity of steel reinforcement in superstructure with respect to non-earthquake analysis

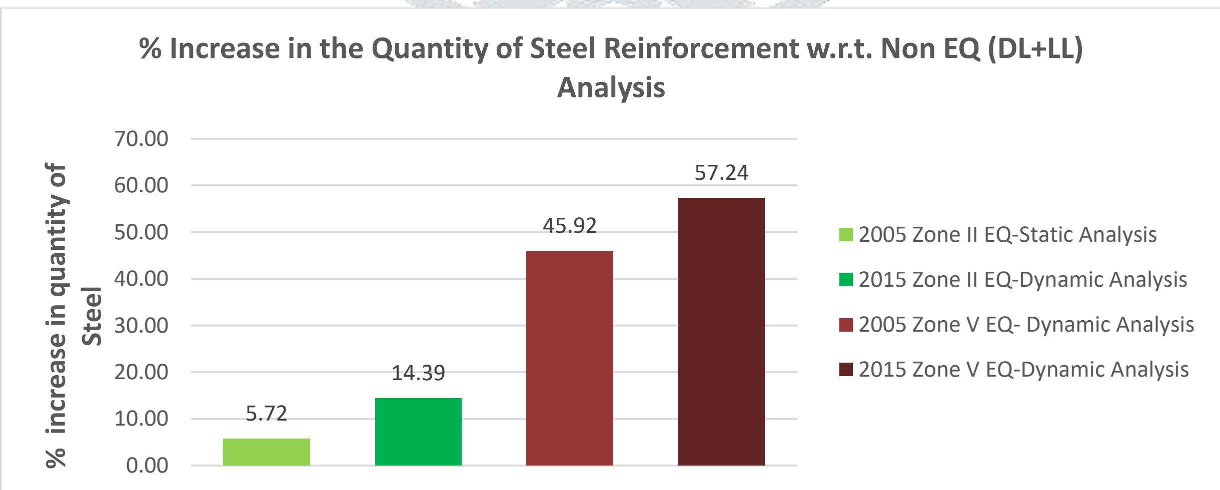

Fig.6 % Increase in Quantity of Steel w.r.t. Non-Earthquake Analysis

Figure 6 graphically represents the percentage increase in the quantity of steel reinforcement in superstructure for the different EQ analyses with respect to the non-earthquake analysis.

Table 7 shows the percentage increase in overall cost of the building for different earthquake analyses with respect to the non-earthquake analysis. The basic cost of the building is worked out first for the non-earthquake analysis. The cost of increased quantities of concrete and steel is added to the same for each different earthquake analysis. The overall cost of the building for different earthquake analyses are then compared with the overall cost of the building for the non-earthquake analysis.

Table 7: Percentage increase in the overall cost of the building for different earthquake analyses with respect to the overall cost of the building for the non-earthquake analysis

% Increase in the Overall Cost of the Building w.r.t. Non-EQ (DL+LL) Analysis		
S. No.	Type of Analysis	% Increase in Cost
1	2005 Zone II EQ-Static Analysis	0.40
2	2015 Zone II EQ-Dynamic Analysis	1.02
3	2005 Zone V EQ- Dynamic Analysis	3.41
4	2015 Zone V EQ-Dynamic Analysis	4.53

From Table 7 it is seen that for zone II, the additional cost of earthquake resistant design of building is only 0.4 % and 1.02 % for analysis based on the old and the revised code, respectively, as compared to the cost of the building for the non-earthquake resistant design of the building. For zone V, the additional cost of earthquake resistant design of building is 3.41 % and 4.53 % for analysis based on the old and the revised code, respectively, as compared to the cost of the building for the non-earthquake resistant design of the building. Thus, the increase in cost for the earthquake resistant design can be said to vary from 1 % to 5 % for a typical industrial building which is not too much when the benefits of the safety to life and property are considered. For a general building it may be still lesser. However, the exact increase may vary from building to building. It is also seen that the implementation of the revised code increases the overall cost of the building of the order of 0.6 % and 1.1 % in zones II and V, respectively.

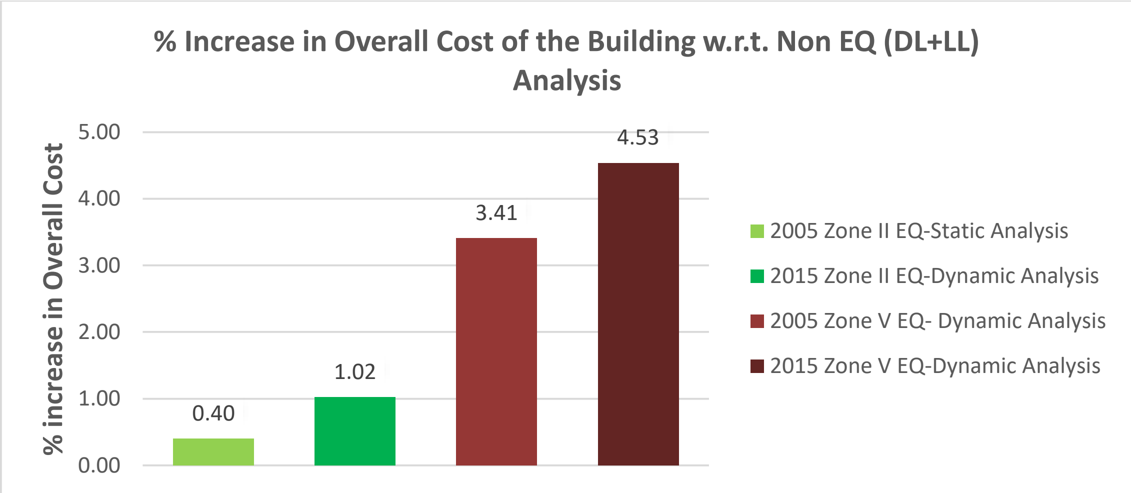

Fig.7 % Increase in the Overall Cost w.r.t. Non-Earthquake Analysis

Figure 7 graphically represents the percentage increase in the overall cost of the building for different earthquake analyses with respect to the overall cost of the building for the non-earthquake analysis.

VI. CONCLUSIONS

Earthquake resistant design of buildings is not only a necessity to safeguard life and property against the risks of damages during the earthquakes but also it is mandatory as per the prevalent codes of practice. The results of this research study on a typical multi-storey industrial building shows that it does not cost too much to implement the earthquake resistant design. The revised Indian Standard codes ensures better safety at a marginally increased cost. The findings of the study are summarized as follows. Here the old codes refer to IS:1893 (Part 4) -2005, IS: 1893 (Part 1)-2002 and IS:13920-1993. The revised codes refer to S:1893 (Part 4) -2015, IS: 1893 (Part 1)-2016 and IS:13920-2016. These findings are for the building considered for study. Increase in cost of superstructure only is considered in this study. Increase in cost of foundation is expected to for a much lesser extent and not considered in this study.

1. It is found that for the building considered in this study, the earthquake resistant design of building does not increase the quantity of concrete at all in zone II when analysed and designed using the old codes, whereas, it increased the quantity of concrete only marginally by 0.15 % when designed using the revised codes. In zone V, the earthquake resistant design of building increased the quantity of concrete by 1.71 % and 4.52 % when analysed and designed using the old codes and the revised codes, respectively. It is also found that the implementation of the revised codes increases the quantity of concrete of the order of 0.15 % and 2.8 % in zones II and V, respectively.

2. The increase in the quantity of concrete in zone V is mainly attributed to ductile detailing and design requirements as per IS 13920. Additional increase in the quantity in analysis using the new code in zone V is mainly attributable to revised provisions incorporated in IS:13920-2016 which now includes ductile design in addition to ductile detailing, and introduction of reduced moment of inertia of beams and column in the revised code IS:1893-2016 to enforce strong column weak beam type mechanism.

3. In zone II, the earthquake resistant design using the old and revised codes results in increase in the quantity of steel reinforcement by 5.72 % and 14.39 %, respectively which is a significant increase. In zone V, the earthquake resistant design using the old codes results in highly significant increase in the quantity of steel reinforcement by 45.92 %. Whereas the same design for zone V carried out using the revised codes results in still further increase in the quantity of steel which now stands at 57.24 % higher as compared to the non-earthquake resistant design.

4. Substantial increase in the quantity of steel in zone V as compared to that in zone II is mainly attributable to the increased zone factor as well as to the ductile design and detailing requirements as per IS 13920, which becomes applicable for the building in zone V. The revised code 13920 of 2016 now includes ductile design in addition to ductile detailing. It is also seen that the implementation of the revised codes increases the quantity of steel of the order of 8.7 % and 11.3 % in zones II and V, respectively.

5. It is found that for zone II, the additional cost of earthquake resistant design of building is only 0.4 % and 1.02 % for analysis based on the old and the revised codes, respectively, as compared to the cost of the building for the non-earthquake resistant design. For zone V, the additional cost of earthquake resistant design of building is 3.41 % and 4.53 % for analysis based on the old and the revised codes, respectively, as compared to the cost of the building for the non-earthquake resistant design. Thus, the increase in cost for the earthquake resistant design is found to vary from nearly 1 % to 5 % for the typical industrial building considered in the study. This additional does not appear too much when the benefits of the safety to invaluable life and property from the earthquake resistant design are taken into account. For a general building the increase in cost may still be lesser. However, the exact increase may vary from building to building. It is also seen that the implementation of the revised codes increases the overall cost of the building of the order of 0.6 % and 1.1 % in zones II and V, respectively, for the building considered for the study. Thus, the revised codes providing additional safety at a marginal increase in the overall cost of the building.

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