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Effect of Vertical Ground Motion on Reinforced Concrete Structures

Narayana Murthy. T[1], Prof. Patil. G. R[2]
[1](*M.E. (Structure) Student, Department of Civil Engineering Rajarshi Shahu College of Engineering, Tathawade, Pune, Maharashtra-India)*
[2]*(Assistant Professor Department of Civil Engineering Rajarshi Shahu College of Engineering, Tathawade, Pune, Maharashtra-India)*

Abstract: *The characteristics of the horizontal components of earthquake ground excitation have been studied extensively in the last few decades with both the earthquake engineering and engineering seismology research focusing primarily on these components to mitigate seismic risk. In contrast, the vertical component of earthquake ground motion has been virtually ignored in earthquake engineering and engineering seismology. However, with the considerable increase in near-source strong motion recordings and field evidence from recent earthquakes, awareness of the importance of vertical ground motion has gradually increased. For example Papazoglou and Elnashai (1996) amongst a few others drew attention to the significance of vertical ground motion and its damaging effects on structures. In this project the characteristics of vertical ground motion are introduced including critical factors to be considered in seismic assessment. The current state of practice as expressed by seismic design codes pertaining to vertical motion is discussed. Based on Modeling analysis was carried out using ETAB, with various Zones of earthquake, it is observed that cantilever projections are deforming due to vertical ground acceleration, also results show that deflections are more for balcony projections without beams, it is evident that high intensity earthquakes produces large deflections compared to low intensity earthquakes. So it is clear that vertical ground motion need to be taken account while designing of reinforced concrete structures.*

Keywords: *G+20 High Rise Building, Acceleration, Storey Drift, Displacement, V/H Ratio, Balcony projections, ETAB.*

I. Introduction

1.1 General

Civil engineering structures are generally subjected to three-dimensional earthquake ground motion. In the past several decades, horizontal earthquake excitation has been studied extensively and considered in the design process whereas the vertical component of earthquake excitation has generally been neglected in design, and rarely studied from the hazard viewpoint. However, recent studies, supported with increasing numbers of near-field records, indicate that the ratio of peak vertical-to-horizontal ground acceleration can exceed the usually adopted two thirds. Furthermore, field observations from recent earthquakes have confirmed the possible destructive effect of vertical ground motion. Therefore, the significance of vertical ground motion has gradually become of concern in the structural earthquake engineering community. Vertical motion has also been attracting increasing interest from the engineering seismology community. This report presents an investigation of the effect of vertical ground motion on RC structures studied through analytical approach. The analytical study investigated the effect of vertical ground motion on buildings considering various geometric configurations.

1.2 Objective and Scope of Work

The main purpose of this study is to investigate the effect of vertical ground motion on structures such as Reinforced Concrete buildings using analytical methods. To achieve this goal, the following tasks were identified and completed:

- Analytical Investigation
- Evaluate the seismic performance of Reinforced Concrete buildings with emphasis on the effect of vertical ground motion.
- Assess the effect of various peak vertical-to-horizontal acceleration (V/H) ratios Reinforced Concrete buildings.
- Study the effect of time intervals between the vertical and horizontal peak acceleration on Reinforced Concrete Buildings
- Investigating acceleration and Drift at Cantilever Projections considering various zones of Earthquake

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1.2.1 Characteristics of Vertical Ground Motion

Frequency Content

The vertical component of earthquake ground motion is associated with the arrival of vertically propagating P-waves, while the horizontal component is more of a manifestation of S-waves. The wavelength of P-waves is shorter than that of S-waves, which means that the vertical component of ground motion has much higher frequency content than the horizontal component. Figure 4.0 illustrates the horizontal and vertical components of ground motion from the Sylmar converter station, Northridge earthquake (1994). The figure shows Fourier amplitude spectra, response spectra, and Arias intensity, which represents the energy content of ground motion. This figure confirms that higher frequency content is usually observed in vertical ground motion components, compared with horizontal motion.

Ratio of Peak Accelerations (V/H)

The significance of the vertical component of ground motion is often characterized by the vertical-to-horizontal peak ground acceleration (V/H) ratio. Many codes suggest scaling of a single spectral shape, originally derived for the horizontal component using an average V/H ratio of 2/3. This procedure was originally proposed by Newmark et al. (1973). As a result, all components of motion have the same frequency content in almost all design codes. The frequency content, however, is demonstrably different, as discussed above. Also, the 2/3 rule for V/H is unconservative in the near-field and overconservative at large epicentral distances.

II. Methods of Design

Earthquakes produces horizontal and vertical forces due effect of inertia. Earthquake motions consist of series of accelerations and decelerations. The magnitude of resulting forces is much higher than designed forces. There are several simplified procedures are developed to understand the behavior of structure under cyclic loads, these can be classified as static and dynamic; and linear and non linear procedures. Out these the simplest procedure is known as Equivalent Static Load Method. Another known method is Linear Dynamic Method using Response Spectrum, which is termed as Mode Superposition Method.

The Code gives expected frequency content of the ground motion in the form of Response Spectra.

2.1 Equivalent Static Load Method

In this method the inertia forces are determined as static force with the use of empirical formulas. To adequately represent the dynamic behavior of the structures, the method is highly recommended for regular structures with uniform distribution of mass and stiffness as well as uniform shape and statistical system. However, it can be applied to irregular ones with some limitations. The design base shear can be calculated as:

$$Q_{i=}V_B \frac{W_i\ h_i^2}{\sum_{i=1}^{n} W_i\ \ h_i^2}$$

Where

Q_i = Design lateral force at Floor i

W_i= Seismic weight of Floor i

h_i = Height of floor Measured from Base

N = No. of storeys in the building

The Total Earthquake force acting on a building, express as base shear Vb, expressed as below

$V_b = A_h W$

Where

$$A_h = \frac{Z\ I\ S_a}{2\ R\ g}$$

Where

Z = Zone Factor

I= Importance Factor

R=Response Reduction Factor

g = acceleration due to gravity

Sa/g = Average response acceleration coefficient.

The approximate fundamental natural period of vibration (Ta), in seconds, of all buildings, including moment-resisting frame buildings with brick infill panels, is estimated by the empirical expression

$$T_a = \frac{0.09h}{\sqrt{d}}$$

2.2 Response Spectrum Method

This Method is based on dynamic analysis of the structure. First a free vibration i.e, solution of eigen value problem is performed to determine the time periods and Mode Shapes of the structure in different Mode Shapes

Response spectrum analysis is used for analyzing the performance of structures under earthquake motions. The method assumes a single degree of freedom system to be excited by a ground motion in order to obtain the response spectrum curves for peak displacement, peak velocity or peak acceleration. Thus once the natural period of the structure is known then the response spectrum curves helps in estimating the peak responses of such structure. These estimated values are considered as the basis for calculating the earthquake forces to be resisted through earthquake resistant design stages.

Design Lateral Force at Each Floor in Each Mode:

$$Q_{ik} = A_k \, \emptyset_{ik} \, P_k \, W_i$$

Where,

A_k = Design horizontal acceleration spectrum value

$\emptyset_{ik}$ = Mode shape coefficient at floor i in mode k

W_i = Seismic weight of floor i.

P_k = Modal participation factor

Modal Participation Factor P_k :

$$P_k = \frac{\sum_{i=1}^{n} W_i \quad \emptyset_{ik}}{\sum_{i=1}^{n} W_i \quad (\emptyset_{ik})^2}$$

Story Shear Force in Each Mode:

Acting in story i in mode k is given by

$$V_{ki} = \sum_{j=i+1}^{n} Q_{ik}$$

Story shear force due to all modes considered-The peak story shear force (□□) in story i due to all modes considered is obtained by combining those due to the individual modes by various methods such as SRSS (Square root of sum of squares), CQC (Complete quadratic combination) or absolute sum method (ABC) etc.

III. Analysis and Modeling.

3.1.1 Brief

Analysed Modal : Ground + 20 floors, Framed structure having span 5mX5m, with Floor to Floor height -3M

The modal is analyzed for various Zones of Earth Quakes taking in to consideration of balcony projections.

The towers are analyzed as OMRF (Ordinary Moment Resisting Frames).

ETABS is used as analysis software. The towers are modeled in 3D. Shell elements are used to model shear walls. Frame elements are used to model columns and beams. Membrane elements are used to model slab supported on shear walls and beams (Core area). Shell elements used except as shear walls are meshed and membrane elements used are Auto meshed. The mesh is generated using auto mesh facility in ETABS. The mesh size is 0.5m x 0.5m.

3.1.2 Gravitational force analysis

Vertical forces are primarily carried by the walls/columns. Live load, Superimposed dead load are applied on slabs as pressures. Weight of masonry / facade is applied as uniformly distributed load.

3.1.3 Wind analysis

The wind loads as per IS: 875 are applied in orthogonal directions.

3.1.4 Seismic analysis

The wings are analyzed by ESM & Response spectrum

3.1.5 Deflection, Sway and Drift

Beam and Slab deflections are kept under permissible limits as per IS: 456 2000. The general guidelines indicate span/250 as the allowable deflection. For long term deflection, allowed value is span /350 and these limits are accounted while doing the analysis and designed. According to IS: 1893 part 1-2002, the drift limit is 0.004 times the storey height and will be achieved. The lateral sway at the top should not exceed H/500 where H is the total height of the building. The codal requirements are taken care.

3.1.6 Design Methodology:

All structural elements shall be designed according to the Limit State Method as specified in IS: 456 - 2000 for reinforced concrete elements and IS: 800 – 1984 for structural steel elements

3.2 Load combinations:

3.2.1 Foundation analysis

1	Dead Load	DL
2	Dead Load + Imposed Load	DL+LL
3	Dead Load + Wind Load	DL+/-WL
4	Dead Load + Earthquake Load	DL+/- EL
5	Dead load + Imposed load + Wind load	DL+0.8LL+/-0.8WL
6	Dead load + Imposed load + Earthquake load	DL+0.8LL+/-0.8EL

3.2.3 **Super Structure Analysis**

S. No.	**Combination**	**Label**	**Details**
1	Un-Factored Dead Load	Total Dead	DL + Super DL
2	Un-Factored Gravity Load	Total Gravity	Total DL + LL
3	Factored Dead Load	DCON1	1.5 Total DL
4	Factored Gravity Load	DCON2	1.5 Total GL
5	Gravity + Wind	DCON3	1.2 Total GL + 1.2 Wind X
6	Gravity + Wind	DCON4	1.2Total GL - 1.2 Wind X
7	Gravity + Wind	DCON5	1.2 Total GL + 1.2 Wind Y
8	Gravity + Wind	DCON6	1.2Total GL - 1.2 Wind Y
9	Dead + Wind	DCON7	1.5 Total DL + 1.5 Wind X
10	Dead + Wind	DCON8	1.5 Total DL - 1.5 Wind X
11	Dead + Wind	DCON9	1.5 Total DL + 1.5 Wind Y
12	Dead + Wind	DCON10	1.5 Total DL- 1.5 Wind Y
13	Dead + Wind	DCON11	0.9 Total DL + 1.5 Wind X
14	Dead + Wind	DCON12	0.9 Total DL - 1.5 Wind X
15	Dead + Wind	DCON13	0.9 Total DL + 1.5 Wind Y
16	DL + Wind Load	DCON14	0.9 Total DL - 1.5 Wind Y
17	GL+ EQ Load	DCON15	1.2 Total GL + 1.2 EQX
18	GL + Earthquake Load	DCON16	1.2 Total GL - 1.2 EQX
19	GL + Earthquake Load	DCON17	1.2 Total GL + 1.2 EQY
20	GL + Earthquake Load	DCON18	1.2 Total GL - 1.2 EQY
21	DL + Earthquake Load	DCON19	1.5 Total DL + 1.5 EQX

22	DL + Earthquake Load	DCON20	1.5 Total DL - 1.5 EQX
23	DL + Earthquake Load	DCON21	1.5 Total DL + 1.5 EQY
24	DL + Earthquake Load	DCON22	1.5 Total DL - 1.5 EQY
25	DL + Earthquake Load	DCON23	0.9 Total DL + 1.5 EQX
26	DL + Earthquake Load	DCON24	0.9 Total DL - 1.5 EQX
27	DL + Earthquake Load	DCON25	0.9 Total DL + 1.5 EQY
28	DL + Earthquake Load	DCON26	0.9 Total DL - 1.5 EQY
29	GL + Response Spectrum	DCON27	1.2 Total GL + 1.2 RSX
30	GL + Response Spectrum	DCON28	1.2 Total GL + 1.2 RSY
31	GL + Response Spectrum	DCON29	1.2 Total GL + 1.2 RSZ
32	DL + Response Spectrum	DCON30	1.5 Total DL + 1.5 RSX
33	DL + Response Spectrum	DCON31	1.5 Total DL - 1.5 RSY
34	DL + Response Spectrum	DCON32	1.5 Total DL + 1.5 RSZ
35	DL + Response Spectrum	DCON33	0.9 Total DL + 1.5 RSX
36	DL + Response Spectrum	DCON34	0.9 Total DL - 1.5 RSY
37	DL + Response Spectrum	DCON35	0.9 Total DL + 1.5 RSZ

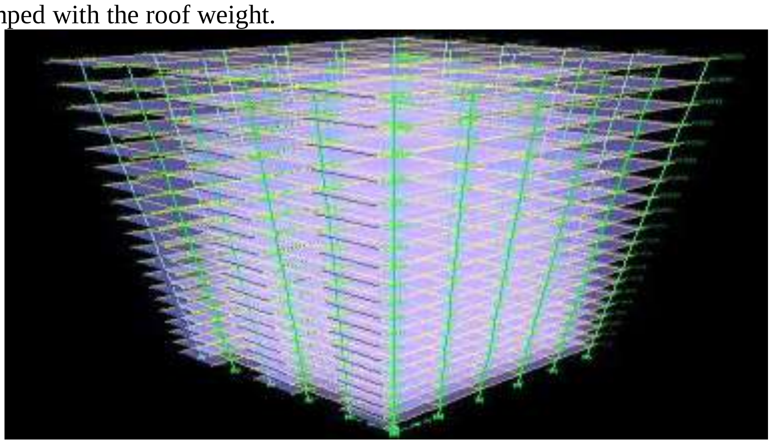
IV. Response Spectra Analysis Using ETAB

Once given input data, the model is unlocked and response spectra analysis is performed to check the performance of the structure.

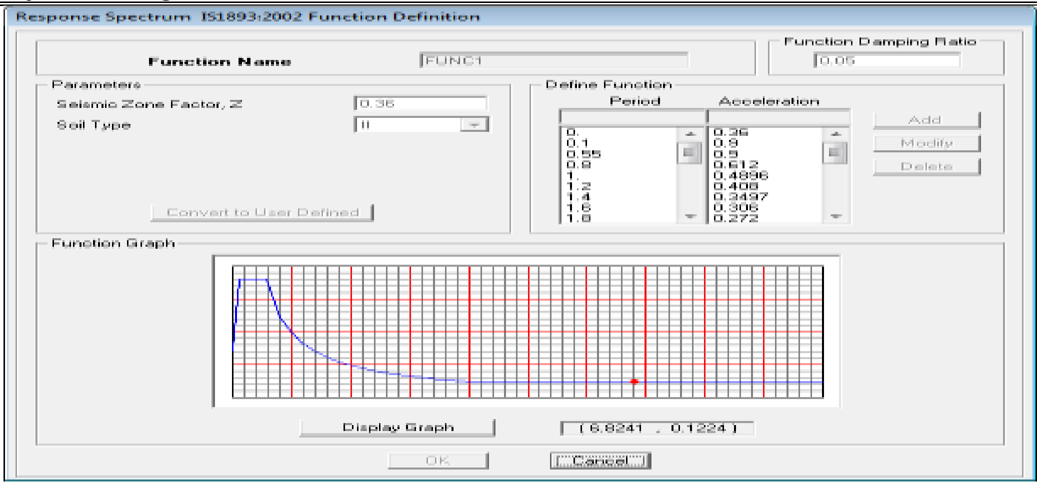
Create Frame by drawing grid lines in X and Y direction as per plan and column positions from grid option. Specify number of stories and story height from edit story data option. Define properties of various materials like steel and concrete, and then define frame elements such as Beam, Column etc.

The design acceleration spectrum for vertical motions, when required, may be taken as two-thirds of the horizontal acceleration spectrum

As per Seismic Code 1893(PartI):2002, Clause No.7.12.2.2 Horizontal Projections like cornices and balconies shall be designed and checked for stability. In the analysis of the building, the weight of these projecting elements will be lumped with the roof weight.

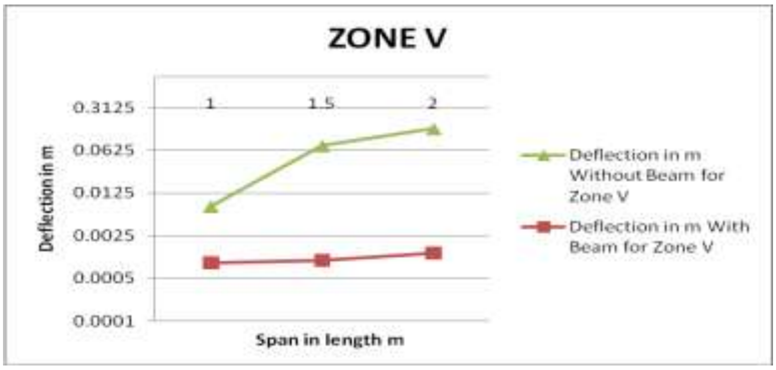


Define Response Spectra Functions in X, Y, Z Directions based on seismic Zones
FUNC1, FUNC2, FUNC3
Example for FUNC1 Shown Below

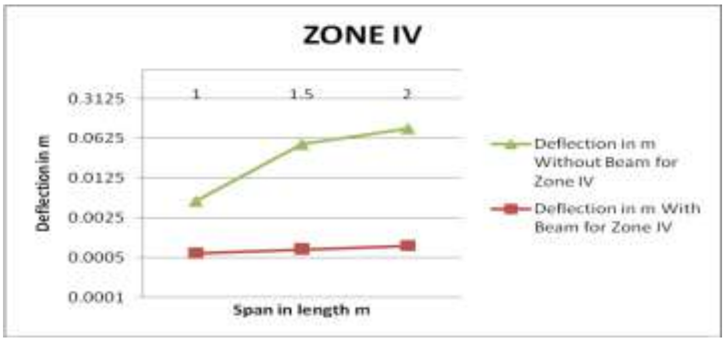


V. Results

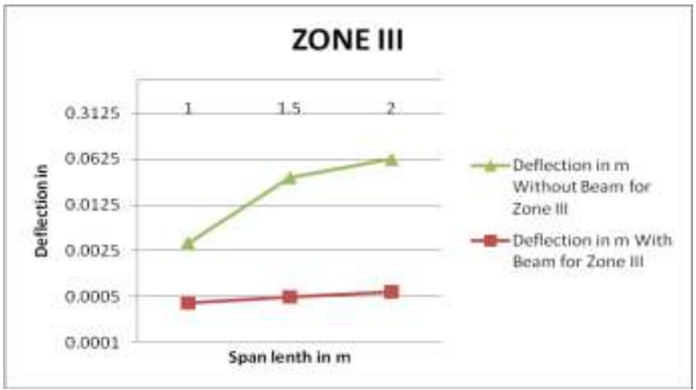
ZONE V



ZONE IV



ZONE III



VI. Conclusion

The effect of vertical ground motion on Reinforced Concrete structures is investigated through analytical approach. Taking into account the observations from this investigation, it is concluded that Reinforced Concrete structures subjected to combined horizontal and vertical components of earthquakes are more vulnerable than those subjected to horizontal ground motion only.

It is evident that from analytical study for various Zones of earthquake, horizontal projections for RC buildings such as balconies are subjected to vertical deformations by considering the vertical acceleration due to ground motion.

Moreover, vertical ground motion significantly increased the axial force level and variation in columns. The increase in the axial force results in corresponding reduction in shear capacity within the vertical members and increases the potential for shear failure. Hence, neglecting vertical ground motion in the design procedure could lead to serious underestimation of demand, and thus jeopardize overall structural safety. Therefore, in the vicinity of active faults, including the vertical ground motion is important for the reliable seismic assessment of structures.

Based on Modeling analysis was carried out using ETAB, with various Zones of earthquake, it is observed that cantilever projections are deforming due to vertical ground acceleration, also results show that deflections are more for balcony projections without beams, it is evident that high intensity earthquakes produces large deflections compared to low intensity earthquakes. So it is clear that vertical ground motion need to be taken account while designing of reinforced concrete structures.

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