Indian Journal of Science and Technology, *Vol 9(36), DOI: 10.17485/ijst/2016/v9i36/99993, September 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Approximation of Floor Amplification Factors for Seismic Protection of Non-Structural Elements

M. A. Azeem* and Hashim Mohiuddin

Department of Civil Engineering, Deccan College of Engineering and Technology, Hyderabad - 500001, Telangana, India; abdulazeem@outlook.com, hashimmohiuddin60@gmail.com

Abstract

Objectives: Countries with proficient seismic evaluation techniques have efficiently managed to minimize the losses due to failure of the structure, thereby protecting the lives and non-structural systems. In India, there is no provision for seismic protection of non-structural elements. The contents of the buildings, attachments/accessories attached on various floors of the buildings, services and utilities in the buildings fall under the category of non-structural elements. **Methods/ Statistical Analysis:** By using non-linear time history analysis on seven building models exposed to fifteen earthquake records, accelerations at each floor, for the case study models was found. The amplification factors, computed using the accelerations, were compared with IITK-GSDMA guidelines. Findings: From the results of time history analyses, it was concluded that the floor amplification factor suggested by IITK-GSDMA needs revision. **Application/Improvements:** The proposed formulae for the amplification factors can be used in lieu of the IITK-GSDMA formulae in order to achieve more representative results.

Keywords: Floor Amplification Factors, Non-Structural Elements, Non-Linear Time History, Seismic Design, Towers

1. Introduction

Due to rapid evolution of India, both in terms of lifestyle and infrastructure, there has been a tremendous advancement in different technologies used and utilized in those infrastructural systems. These buildings play host to various components or accessories, which are an integral part of the structure. These components are either placed directly on the floor of the building or are fixed to the structural components of the buildings. The book stacks in libraries, the cupboards, the various machinery in a hospital building, various commercial buildings, rooftop water tanks, hoardings, the chandeliers, false ceilings etc. come under the category of non-structural elements. With the advent of an earthquake, the safety of the people also depends on the resistance of these non-structural elements to earthquake accelerations.

The non-structural elements can be both rigid and flexible. These components possess different damping properties, particularly lower than that of RC buildings. When the frequencies of the non-structural elements and the host building match, resonance occurs which further amplify the response of the non-structural element. For stiff buildings with short periods, medium range period buildings the acceleration distribution assumed by the code is acceptable but for the buildings with long periods and high-rise buildings the acceleration response is conservative[1]. The sharp increase in the acceleration profile for top floors in case of tall buildings, is attributed to whiplash effect from higher modes of vibration[2]. The whiplash effect is especially large for irregular buildings. Due to the variable characteristics of different non-structural elements, dynamic analysis of the combined structure is required for accurate modeling of the seismic amplification effects.

Since the dynamic analysis methods can be tedious and time consuming, and the static procedures adopted by the codes underestimate the amplification effects, an attempt has been made in this regard to assess the codal provisions and propose alternate amplification factors.

2. Review on IITK-GSDMA

The current code for seismic design IS 1893:2002 doesn't have any provisions explicitly related to non-structural elements. The Clause 7.12.2 states that the

** Author for correspondence*

connection between the component and the building be designed for five times the horizontal design acceleration coefficient, multiplied by the weight of the component[3]. The provisions of IS 1893:2002 for seismic design of non-structural elements are highly inadequate[4]. In IITK-GSDMA, Introduction to Earthquake protection of Non-structural Elements in Buildings, the equation for amplification of floor accelerations along the height of the structure is given by (1+x/h) where h is the height of the building from the base and x is the height of the non-structural component from the base[5]. It gives a maximum acceleration amplification of 2; when x equals h. The above expression is on the assumption that there is a linear relationship between the peak ground acceleration and peak floor acceleration along the height of the building.

3. Methodology

3.1 Building Models

In order to access the accelerations in the building models, five building models of different heights were analyzed in ETABS 2015 using Non-linear time history analysis. The building models considered were representative of the buildings generally constructed in India. The geometric details of the buildings are as shown in Table 1. All the buildings are of RC moment resisting frame type. The models were generated in ETABS assuming rigid diaphragms. Although the analysis has been performed for both sway modes, the results shown in this paper are corresponding to the sway in X-direction. It is assumed that in building models, the 1st mode of vibration is dominant[6-8]. The Table 2 lists the first three time periods of the building models.

Table 2. Time periods of building models

Building	Mode 1(Sway)	Mode 2(Sway)	Mode 3(Torsion)
B1	0.425	0.354	0.33
B2	0.579	0.459	0.443
B3	0.863	0.636	0.626
B4	1.157	0.944	0.928
B5	1.884	1.639	1.637

3.2 Earthquake Records used

The generated models are subjected to fifteen accelerograms. The records were classified based on peak ground acceleration to peak ground velocity (a/v) ratio with 7 records with high a/v ratio and 8 records with low a/v ratio. Earthquake records with high a/v ratios are usually of short duration with seismic energy in the high frequency range; earthquakes with high a/v ratios correlated to ground motions close in vicinity to a small or moderate earthquake. Conversely, earthquakes with low a/v ratios usually have long duration with energy in the low frequency range; earthquakes with low a/v ratios correlate with ground motions distant from large earthquakes[9]. To measure the effect of frequency content on acceleration amplification different sets of records were used to investigate the frequency of the ground motion on the buildings. The earthquake records used are listed in Table 3 and Table 4.

Table 1. Properties of the building models considered

Property / Building	Height	Plan Dimensions	Size of Beams	Size of Columns	Thickness of slab
B1	6m	10.6m x 18.6m	230mm x 300mm	230mm x 300mm	125mm
B2	9m	12.6m x 16.6m		230mm x 375mm	
B3	15m	16.6m x 23.6m		230mm x 450mm	
B4	21m	26.6m x 28.85m		300mm x 600mm	
B5	30m	32.6m x 46.6m		375mm x 675mm	

Table 3. Low a/v ratio records

Earthquake and location	Date	Station	Component	PGA (g)	PGV (m/sec)	a/v ratio
Gorkha Earthquake, Nepal	25-Apr-15	Kantipath	90	0.158	1.049	0.15
Gorkha Earthquake, Nepal	25-Apr-15	Kantipath	360	0.188	0.961	0.196
Gorkha Earthquake, Nepal	25-Apr-15	Kantipath	UP	0.175	0.31	0.564
Bhuj Earthquake, Gujarat	26-Jan-01	Ahmedabad	N78E	0.977	1.306	0.748
Chamoli Earthquake, UP	28-Mar-99	Gopeshwar	N70W	1.826	2.548	0.716
NE – India Earthquake, Indo – Bangladesh Border Region	6-Feb-88	Baigao	UP	0.087	0.114	0.762
NE – India Earthquake, Indo – Bangladesh Border Region	6-Feb-88	Katakhal	UP	0.081	0.107	0.757

Table 4. High a/v ratio records

Earthquake and location	Date	Station	Component	PGA (g)	PGV (m/sec)	a/v ratio
Bhuj Earthquake, Gujarat	26-Jan-01	Ahmedabad	UP	0.749	0.424	1.767
Xizang-India Border Earthquake	26-Mar-96	Ukhimath	N15E	0.375	0.147	2.547
Chamba Earthquake, HP	24-Mar-95	Chamba	N00E	1.35	0.724	1.86
Uttarkashi Earthquake, Uttarakhand	20-Oct-91	Bhatwari	N85E	2.563	1.839	1.394
NE – India Earthquake, Indo – Burma Border Region	6-Aug-88	Bokajan	N34E	1.48	0.994	1.488
NE – India Earthquake, Indo – Bangladesh Border Region	6-Feb-88	Dauki	S72E	0.265	0.17	1.559
NE – India Earthquake, Shillong	10-Sep-86	Ummulong	N87E	1.103	0.235	4.696
H.P Earthquake, H.P	26-Apr-86	Dharmsala	N76W	1.771	0.678	2.611

4. Results and Discussions

The floor amplification factor, the ratio of peak floor acceleration to peak ground acceleration, is calculated using the results from the time history analysis of the building models. The floor acceleration increases along the height of the building in most low-rise regular buildings, whose responses are primarily governed by their fundamental mode of vibration. In high rise buildings with significant contribution of higher modes of oscillations, the floor acceleration can be smaller and need not vary linearly along the height. The Figures 1 to 5 illustrate the floor amplification factors at different floors and the acceleration amplification factors given by IITK-GSDMA, at normalized height. The results are computed as the mean of the low a/v records and high a/v records for the 15 accelerograms considered.

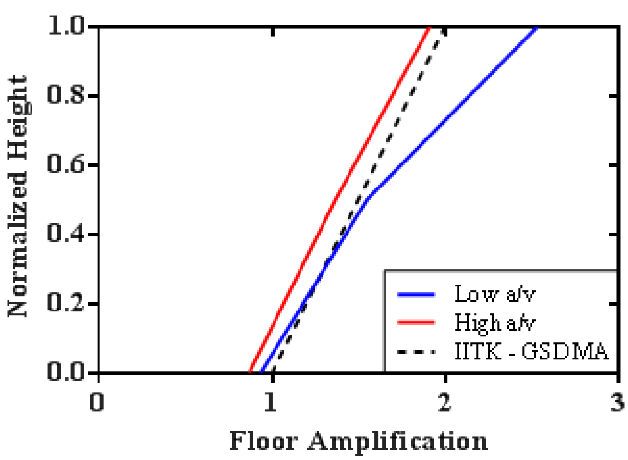

Figure 1. Floor amplification profile for building B1.

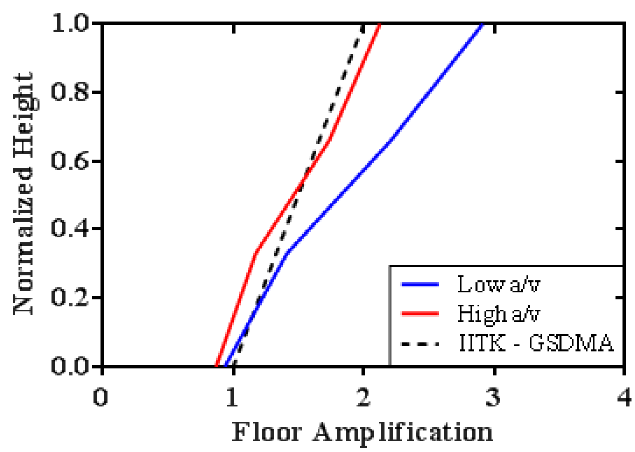

Figure 2. Floor amplification profile for building B2.

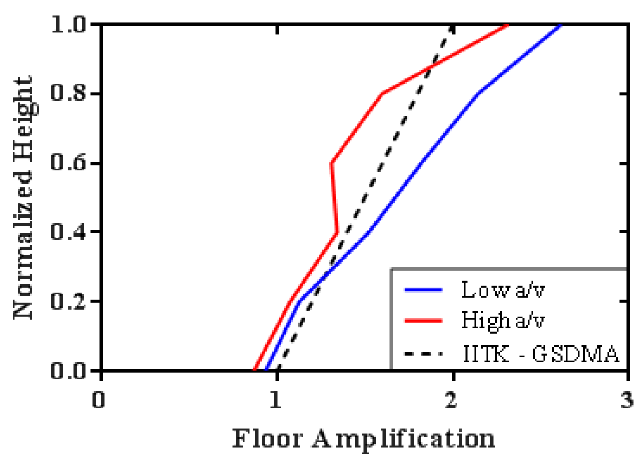

Figure 3. Floor amplification profile for building B3.

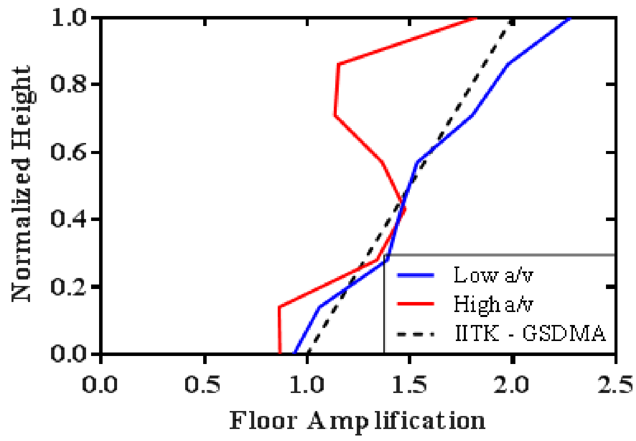

Figure 4. Floor amplification profile for building B4.

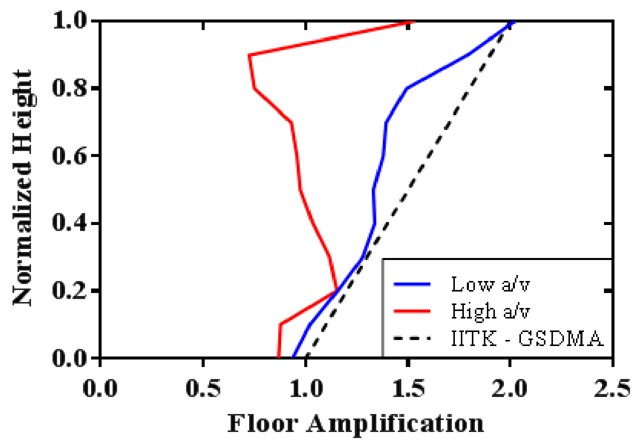

Figure 5. Floor amplification profile for building B5.

Although the codal provisions are conservative for all the models studied, it can be seen that for the buildings with short periods (Figures 1 and 2) the acceleration amplification is increasing linearly with height, indicating that the building oscillates in its first mode of oscillation. For the building models with medium and long periods (Figures 3, 4 and 5) it can be seen that there is a decrease in acceleration in the intermediate floors, it can be attributed to the higher frequency modes of the structure. This decrease in amplification response in the intermediate floors than those above and below it further enhances as the building height increases, where the building oscillates in its second mode. Inelastic response of the building can also contribute to this effect. Therefore, for the flexible components attached to high-rise buildings, it is suggested that a detailed dynamic analysis be performed. However, the proposed amplification factor will give an upper bound in estimating the floor amplification in buildings.

From conclusions drawn from the results, it is recommended that the floor amplification factor of $\left(1+\frac{2x}{h}\right)$ be used for the design in lieu of the codal provisions. The proposed floor amplification profile along with the amplification profiles of the case study buildings are also represented in Figure 6.

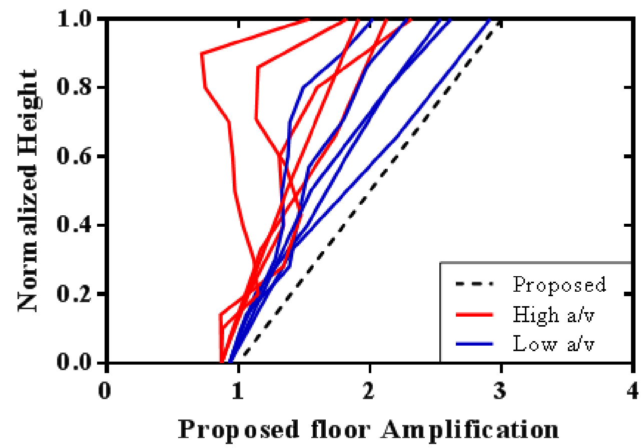

Figure 6. Proposed floor amplification profile.

5. References

1. Fathali S, Lizundia B. Evaluation of current seismic design equations for nonstructural components in tall buildings using strong motion records. Struct Design Tall Spec Build. 2011; 20(1):30–46.
2. Singh M, Moreschi L, Suarez L, Matheu E. Seismic Design Forces. I: Rigid Nonstructural Components. J Struct Eng. American Society of Civil Engineers. 2006 Oct; 132(10):1524–32.
3. IS 1893 (Part-1): 2002. Criteria for Earthquake Resistant Design of Structures, Part 1– General Provisions and Buildings. New Delhi: Bureau of Indian Standards; 2002. p. 1–42.
4. Goutam M, Sudhir KJ. Design of non-structural elements for buildings: A review of codal provisions. The Indian Concrete Journal. 2005 Oct; 79(8):22–8.
5. Murty CVR. Earthquake protection of non-structural elements in buildings, IITK-GSDMA Gujarat State Disaster Management Authority. Gujarat: Govt of Gujarat; 2013. p. 1–176.
6. Penzin J, Chopra AK. Earthquake response of appendage on a multi-story building. Proceedings of the 3rd World Conference on Earthquake Engineering; Wellington, New Zealand. 1965; 2(2):476–90.

7. Banihashemi MR, Mirzagoltabar A, Tavakoli H. Development seismic design of steel moment frames and the evaluation by energy spectrum method. Indian Journal of Science and Technology. 2014 Jan; 7(10):1699–711.
8. Chopra A. Dynamics of structures: Theory and Applications to Earthquake Engineering. NJ: Prentice Hall Inc; 2001.
9. Clough RW, Penzien J. Dynamics of structures. New York: McGraw Hill; 1993.
10. Tso WK, Zhu TJ, Heidebrecht AC. Engineering implication of ground motion A/V ratio. Soil Dynamics and Earthquake Engineering. 1992; 11(3):133–44.