CHAPTER 3

SEISMIC ACCELERATION AMPLIFICATION FACTOR MODEL FOR NON-STRUCTURAL COMPONENTS IN RC FRAME STRUCTURES

In this chapter, the peak horizontal floor acceleration of non-structural components for low to moderate hazard level has been obtained. For this 2,4,6,8 and 10 stories moment-resisting RC frame models with low to moderate hazard level (0.01g-0.31g) have been considered. For the analysis 32 ground motion data in the range of 0.01g to 0.1g, 29 ground motion data in the range of 0.1g to 0.2g and 31 data in the range of 0.2g to 0.31g are considered using linear time history method. Based on analysis results, mathematical models are proposed to determine the absolute acceleration amplification factor.

3.1 BUILDING MODELS

This chapter deals with five RC moment-resisting frame models having a base to first storey height is 4m and above floor height is 3.4m respectively (Fig. 3.1). The sizes of the beams and columns are given in Table 3.1. Fundamental natural period of the structures lies within the range of 0.5 sec to 1.3 sec., as obtained from linear time history analysis with the damping ratio 5%.

Table 3.1 Size of beams and columns

Beam	Size in mm
B1	300x400
B2	300x450
B3	450x500
B4	450x600
B5	450x650

B6	450x675
Column	Size in mm
C_0	300X400
C1	300x450
C2	450x500
C3	525x550
C4	550x600
C5	600x700
C6	650x850

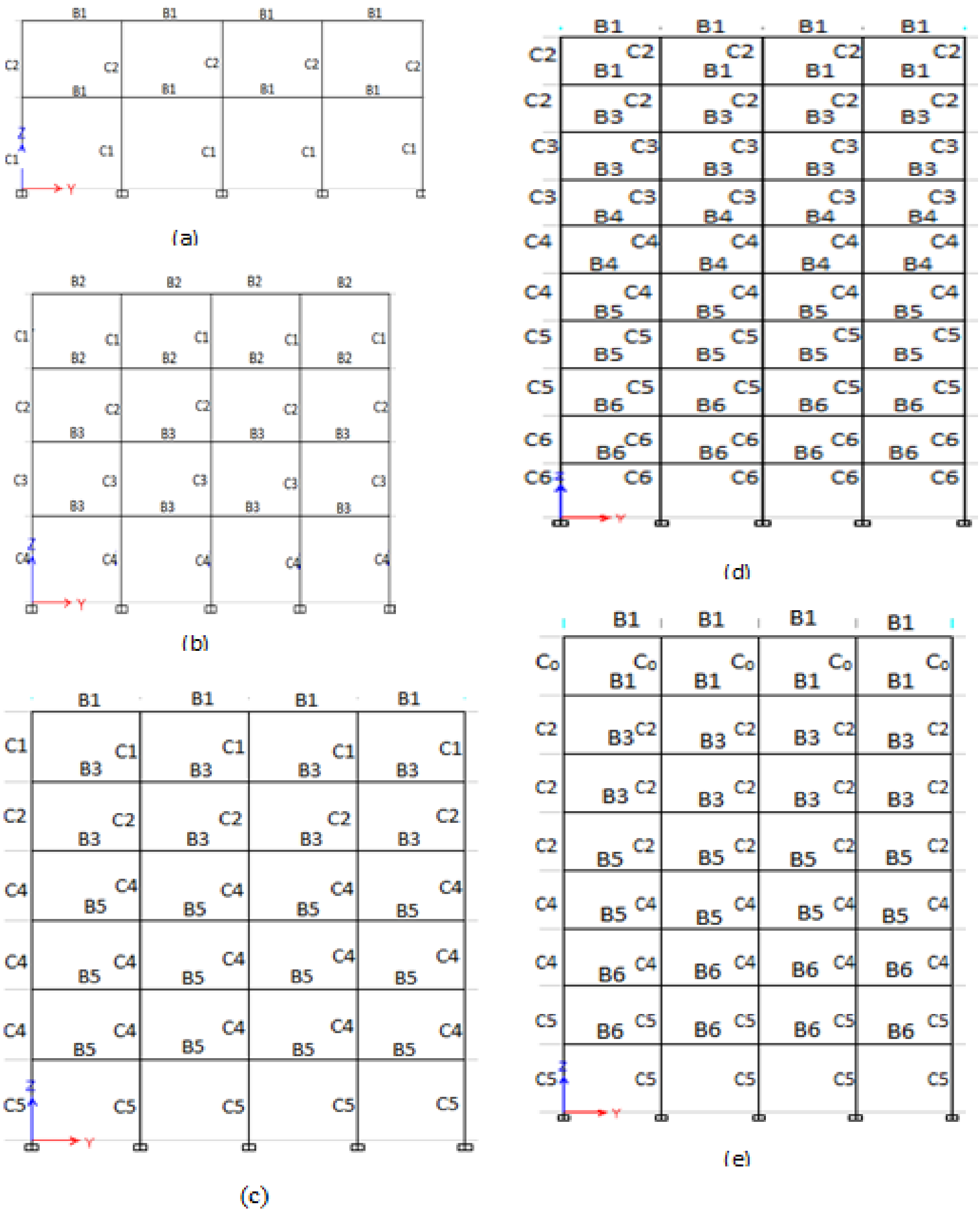


Figure 3.1 Moment resisting frame models (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories

3.2 CONSIDERED GROUND MOTIONS

In this study, 31-time history recorded data between 0.01g to 0.1g, 29 data between 0.1g to 0.2g and 31 data between 0.2g to 0.31g are considered. These ground motion data are obtained from the website of Strong ground motion site [140]. The list of the different recorded time history data is given in Table 3.2, 3.3, and 3.4 respectively.

Table 3.2 Time History Data for Peak Ground Acceleration between 0.01g to 0.1g

Earthquake Station	**PGA (g)**	**T_t (sec)**	**T_p (sec)**
Chamoli (NW Himalaya)	0.028	9.04	7.3
Uttarkashi	0.021	21.32	1.62
Uttarkashi	0.017	21.34	3.2
North East INDIA	0.057	12.18	2.36
North East INDIA	0.058	12.18	4.86
North East INDIA	0.03	11.72	0.26
North East INDIA	0.022	11.72	2.28
North East INDIA	0.021	12.60	1.06
Chamoli (NW Himalaya)	0.022	14.98	1.24
Uttarkashi	0.093	31.74	6.06
Uttarkashi	0.081	31.74	5.48
Chamoli (NW Himalaya)	0.052	24.96	4.38
North East INDIA	0.039	9.52	1.06
Chamoli (NW Himalaya)	0.081	28.58	1.50
Chamoli (NW Himalaya)	0.1	28.58	1.36
North East INDIA	0.093	27.42	9.26
North East INDIA	0.077	27.42	9.78

Chamoli (NW Himalaya)	0.037	10.64	1.92
Chamoli (NW Himalaya)	0.024	10.66	2.42
North East INDIA	0.044	12.94	0.44
North East INDIA	0.031	12.94	1.08
North East INDIA	0.078	16.56	2.02
North East INDIA	0.086	16.58	1.82
North East INDIA	0.045	18.84	5.36
North East INDIA	0.043	18.88	4.14
North East INDIA	0.022	16.50	3.12
Chamoli (NW Himalaya)	0.071	25.04	5.62
North East INDIA	0.084	27.36	7.68
North East INDIA	0.009	10.38	1.38
Uttarkashi	0.033	13.32	11.80
Uttarkashi	0.042	15.94	0.22

Table 3.3 Time History Data for Peak Ground Acceleration between 0.1g to 0.2g

Earthquake Station	**PGA (g)**	**T_t (sec)**	**T_p (sec)**
Chi-chi	0.135	150	40.89
Chi-chi	0.142	146	45.58
Chi-chi	0.113	144	49.57

Chi-chi	0.150	150	48.52
Chi-chi	0.193	150	34
Chi-chi	0.124	150	34.77
Chi-chi	0.162	150	55.02
Bhuj	0.106	133.53	46.94
Camarillo	0.124	65	10.52
Elizabath Lake	0.114	60.01	10.87
Northridge	0.183	60.01	15.34
Northridge	0.106	60	11.38
Costa Rica	0.105	72	11.84
Mammoth Lake	0.121	44.66	10.14
Mammoth Lake	0.196	65	10.70
Mammoth Lake	0.163	65	3.14
Coalinga	0.133	60	11.56
Coalinga	0.192	65	6.94
Pomona	0.160	79	28.08
Northridge	0.120	65.02	7.44
Chi-Chi	0.146	120	36.82
Mammoth Lakh	0.155	67.78	2.44
Costa Rica	0.114	80	14.8
Coalinga	0.131	21.40	2.08
Coalinga	0.124	65	6.96
Coalinga	0.164	21.02	4.62
Chi-Chi	0.160	150	38.21
Chi-Chi	0.113	144	49.57

Chi-Chi	0.136	150	49.54

Table 3.4 Time History Data for Peak Ground Acceleration between 0.2g to 0.3g

Earthquake Station	**PGA (g)**	**T_t (sec)**	**T_p (sec)**
Cartago	0.262	80	15.58
Chi-Chi	0.263	68.05	15.39
Baigao	0.221	54.82	23.32
Berlongfer	0.300	119.7	29.58
Batwari	0.247	36.16	5.82
Bokjan	0.224	57.82	26.90
Chi-Chi	0.225	120	38.12
Chi-Chi	0.232	68.05	15.39
Chi-Chi	0.240	68.05	15.22
Chi-Chi	0.242	64	14.28
Chi-Chi	0.227	140.01	35.80
Chi-Chi	0.248	150	37.53
Chi-Chi	0.272	150	30.44
Chi-Chi	0.204	150	30.11
Chi-Chi	0.234	90.20	35.21
Chi-Chi	0.245	74.00	18.48
Chi-Chi	0.218	60	11.95
Chi-Chi	0.259	71	18.01
Diphu	0.282	81.74	21.04

Chi-Chi	0.282	105	12.82
Chi-Chi	0.233	48.01	8.05
Chi-Chi	0.223	124.08	10.12
Chi-Chi	0.254	60.05	10.61
Chi-Chi	0.223	62.00	19.62
Uttarkashi	0.310	23.92	5.9
Lacc-nor	0.221	60	8.92
Whittier	0.292	40	3.02
Chalfant Vally	0.231	40	4.00
Landers	0.273	40	25.98
Northwest China	0.273	60	6.14
Northwest China	0.233	45.02	5.5

In these tables, T_t represents the total Recorded time period and T_p represents the time of the peak acceleration. The ground acceleration to time period is shown in Figure 3.2.

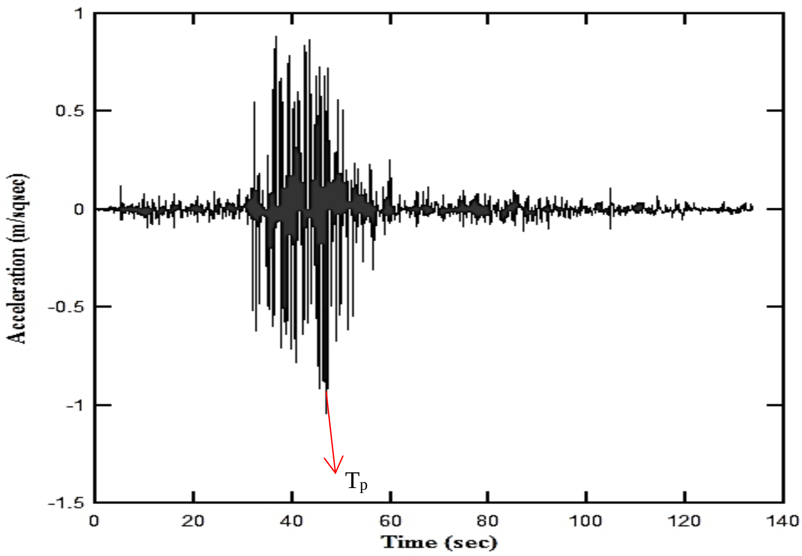
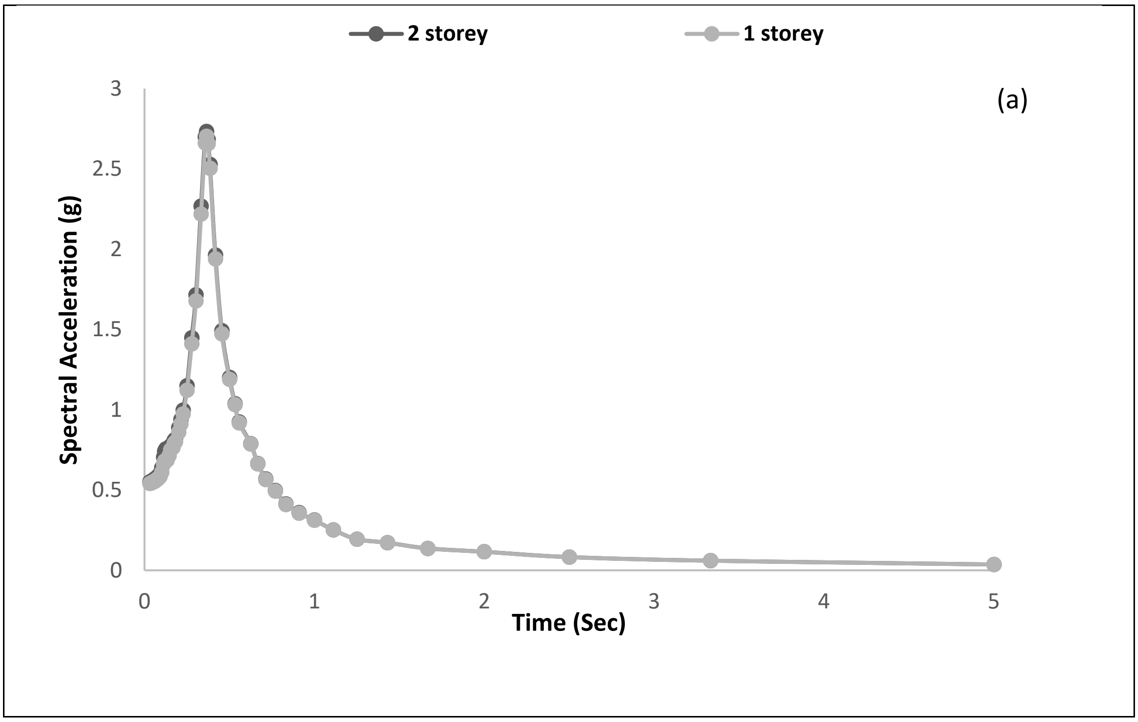
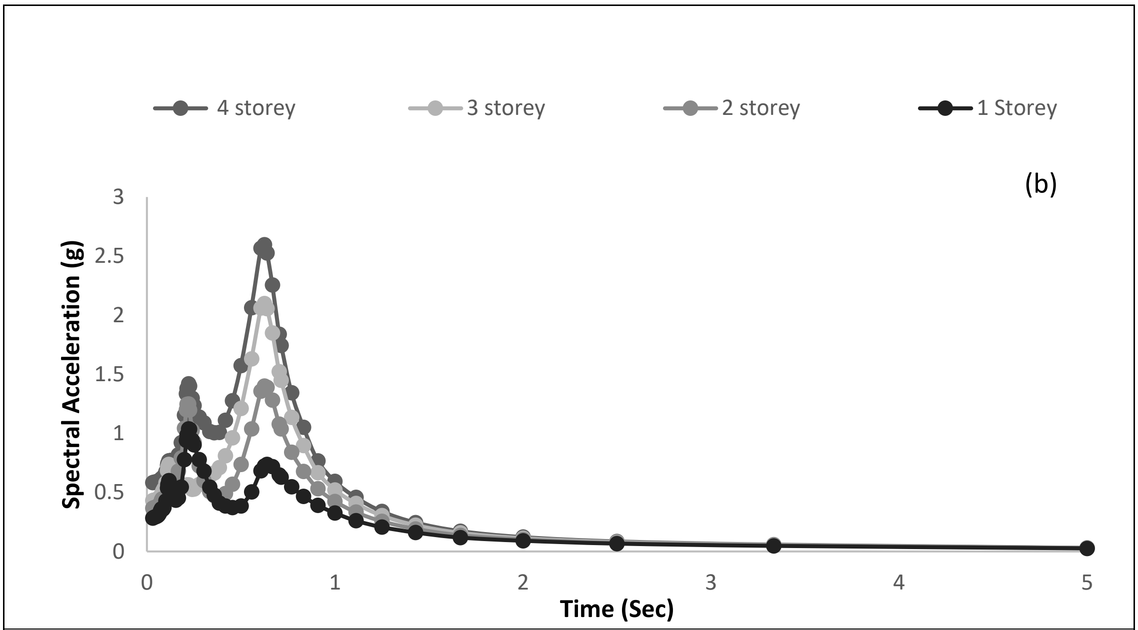


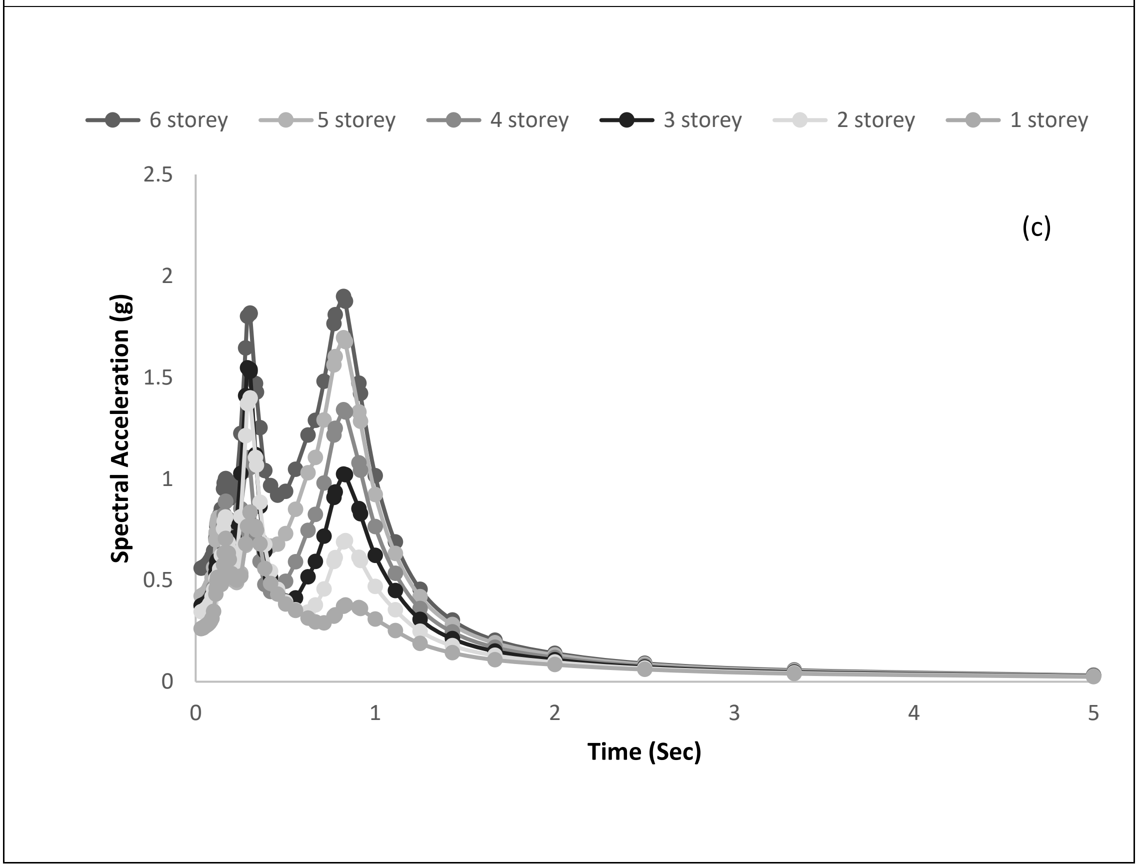
Figure 3.2 T_t and T_p for Time history data of Bhuj Earthquake

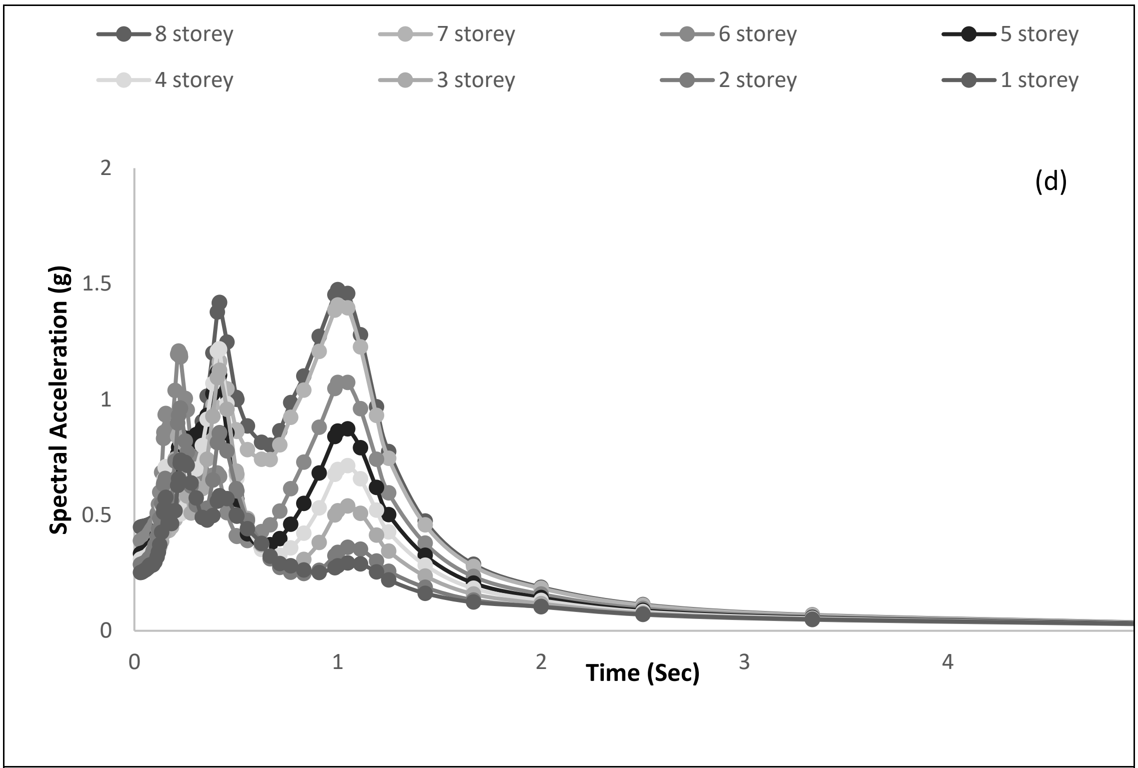
3.3 FLOOR SPECTRAL ACCELERATION

Dynamic analysis is performed for each model, for selected accelerogram to record the horizontal acceleration time histories at a different level. The floor spectral acceleration is obtained by using the ground acceleration with 5% damping. The mean response spectral acceleration for each floor with the ground motion ranging between 0.2g to 0.31g is shown in Figure 3.3. These floor spectra give the acceleration demand on the non-structural component, connected to the floor with a fundamental period T. It observed that as the height of the building increases, the amplification value decreases. For two-storey model, the amplification value is large, but it reduces as building height increases.




4 storey
3 storey
2 storey
1 Storey
(b)
Spectral Acceleration (g)
Time (Sec)


6 storey
5 storey
4 storey
3 storey
2 storey
1 storey
(c)
Spectral Acceleration (g)
Time (Sec)



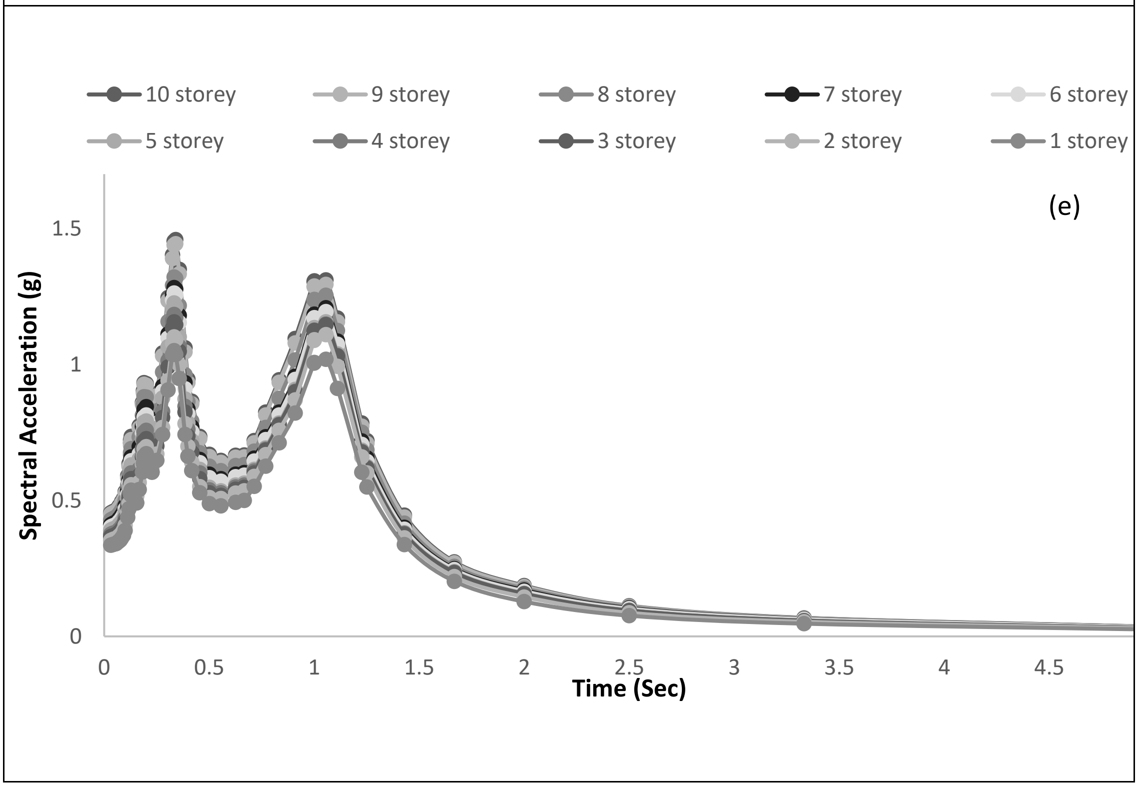
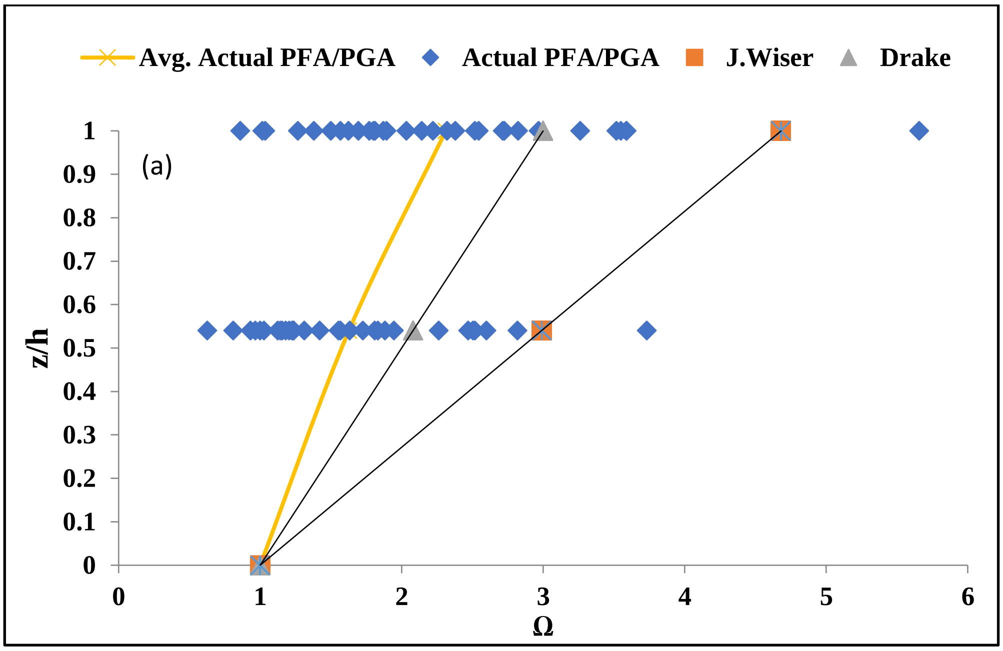


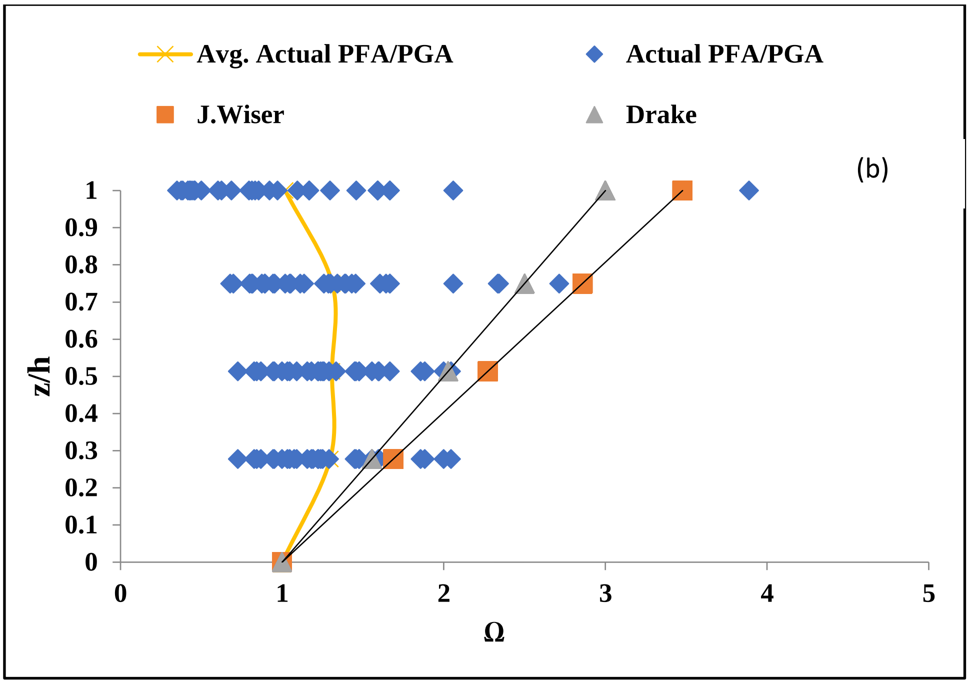
Figure 3.3 Mean floor spectral acceleration in the ground motion range 0.2g to 0.3g (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories.

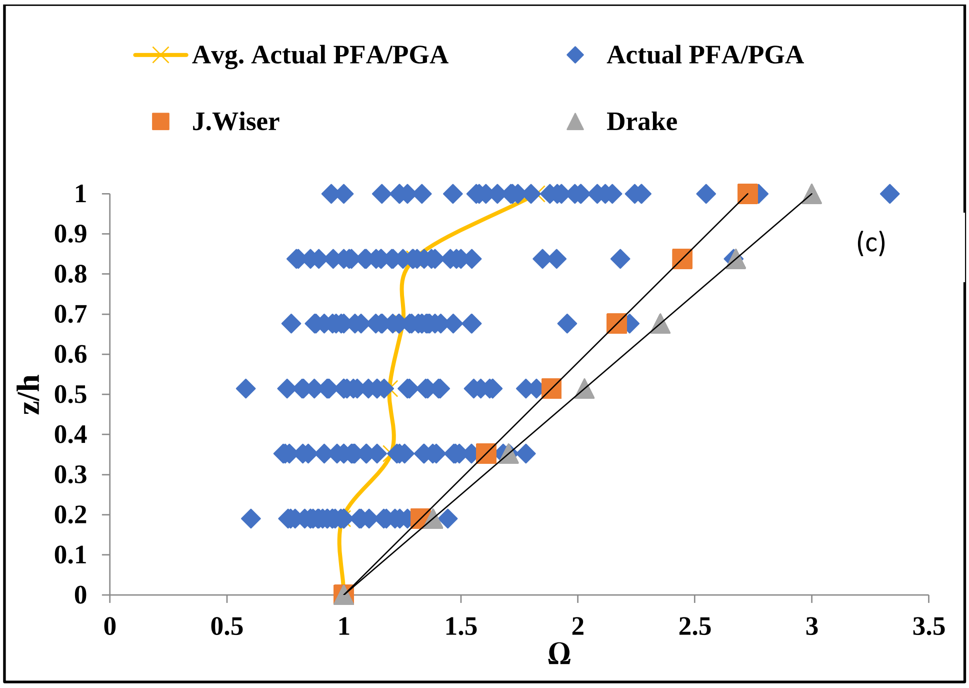
3.4 DYNAMIC ANALYSIS AND COMPARISON OF THE MODELS

The lateral seismic force on the on structural components is described by ASCE/SEI 7-05, depicted in chapter 2. Based on this equation it was observed that the acceleration amplification factor on NSCs is maximum values 3 at the top of the building. However, wiser [86] gives the amplification formula (describe in chapter 2) based on the structural period of the building.

To compare these two models with the actual PFA/PGA model has been found by the linear time history analysis for all the building models using Etabs software [141], considering different ground motion data as given in Table 3.2, 3.3 and 3.4. The results of all the models are shown in Figures 3.4(a) to (e), when the ground acceleration ranges from 0.01g to 0.1g. These figures show the behaviour of the building in terms of peak floor amplification factor (Ω) for normalised height, defined as the ratio between the height of the floor and total height of the structure to the base.




Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
(b)
z/h
Ω
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
(c)
z/h
Ω
1
0.9
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0.7
0.6
0.5
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0.3
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0.1
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0
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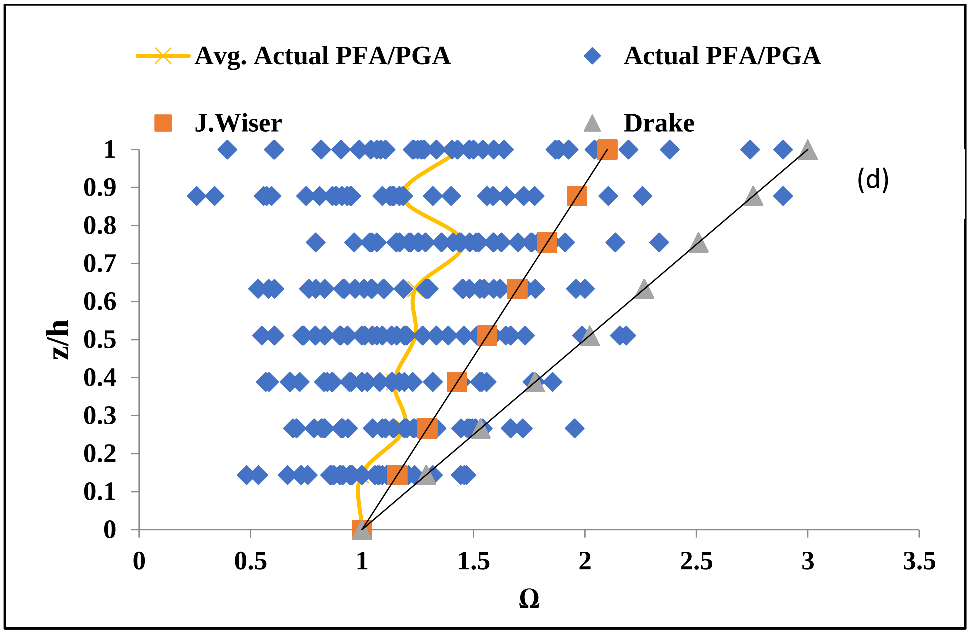
1.5
2
2.5
3
3.5



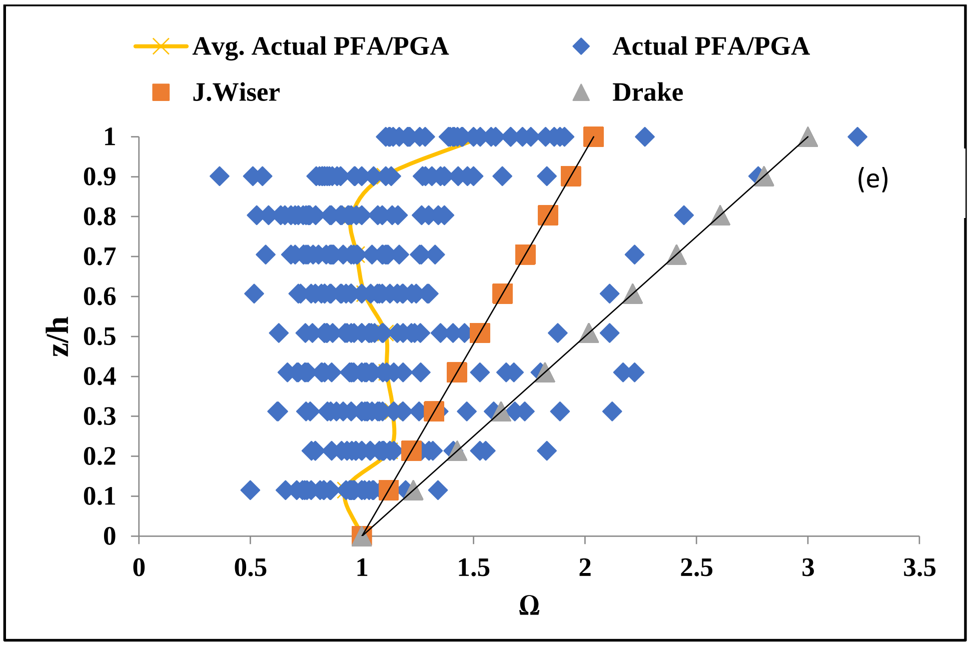
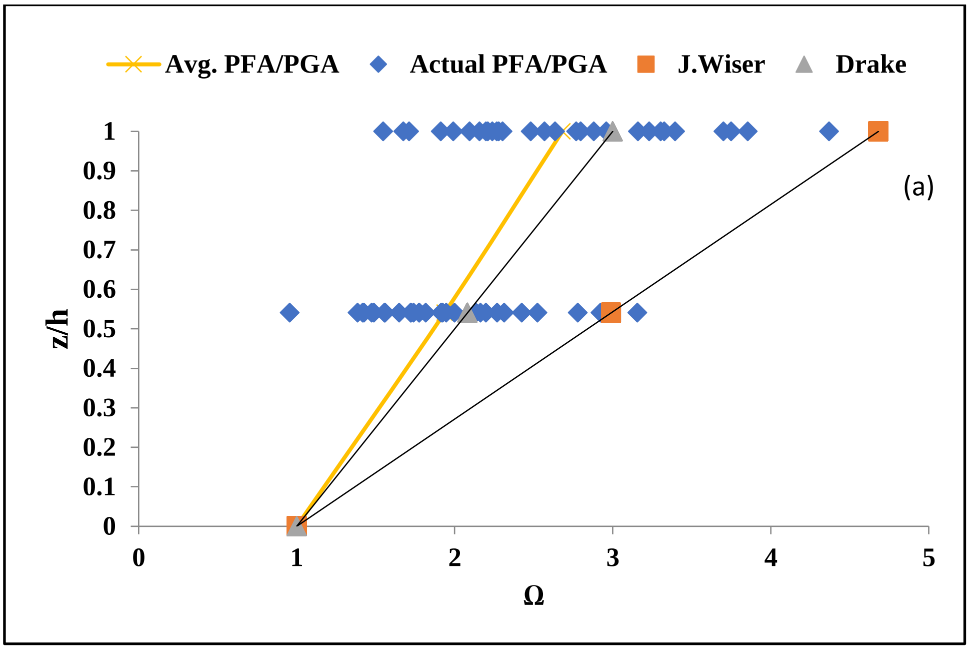
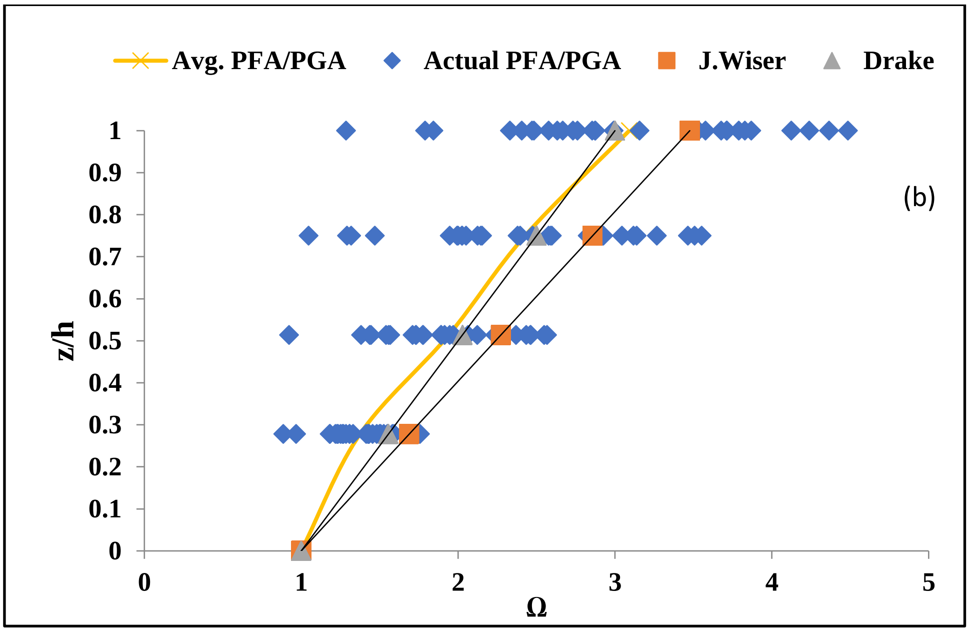


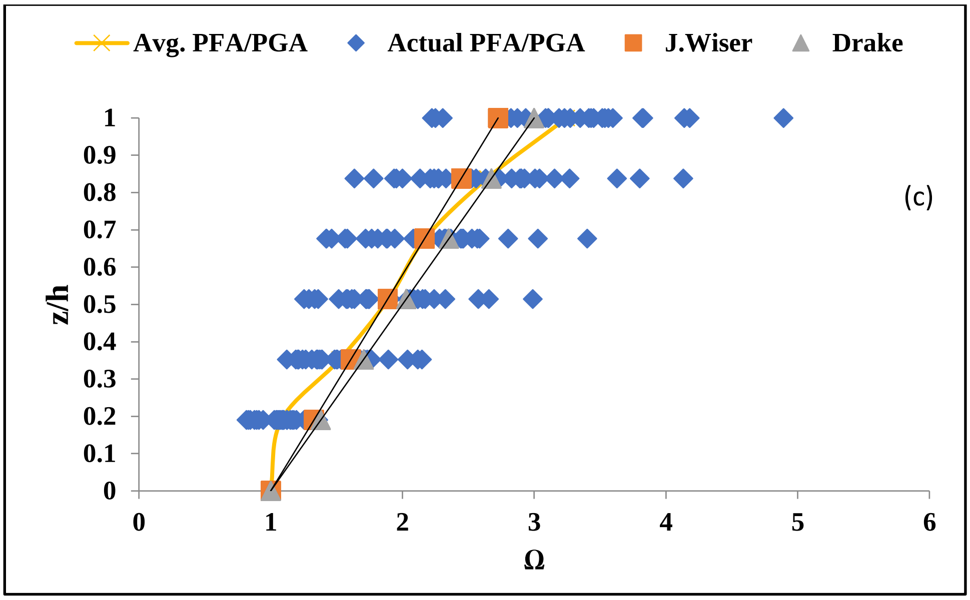
Figure 3.4 Comparison between PFA/PGA with respect to normalize height when ground motion range 0.01g to 0.1g (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories

It is found that when seismic ground motion is in the range of 0.01g to 0.1g, some of the Ω values are outside the equation proposed by the Drake and Wiser [134, 86]. The shapes of the Ω behave as nonlinear (S shape) to normalise height.

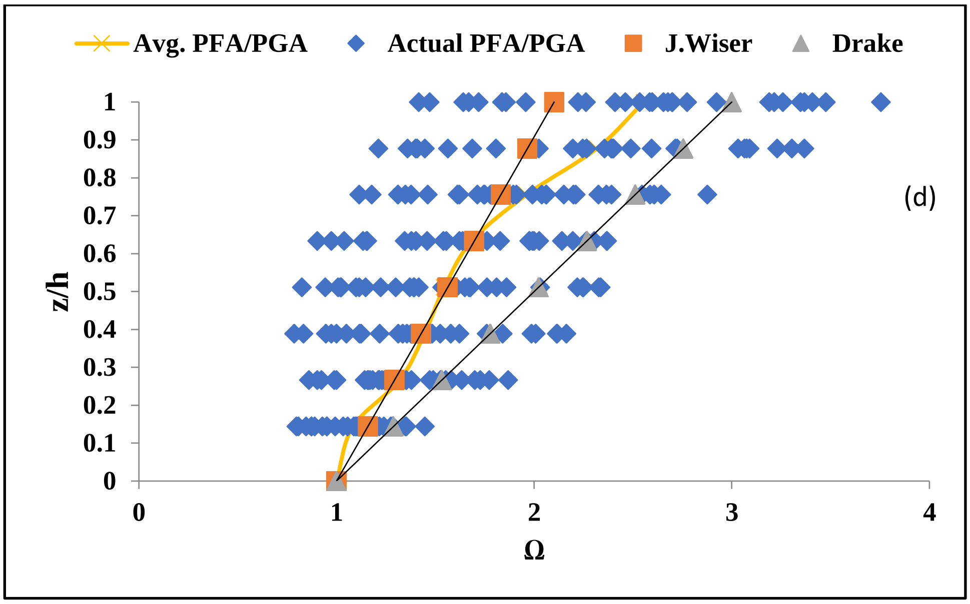
For another case, when the ground motions observed in the range of 0.1g to 0.2g the amplification value is large at the top storey, are represented in Figure 3.5 (a) to (e). The two-storey model, amplification values are high and when the storey height increases and vice versa.







Avg. PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
z/h
0
1
2
3
4
5
6
Ω
(c)



Avg. PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
1
0.9
0.8
0.7
0.6
0.5
0.4
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z/h
0
1
2
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4
Ω
(d)

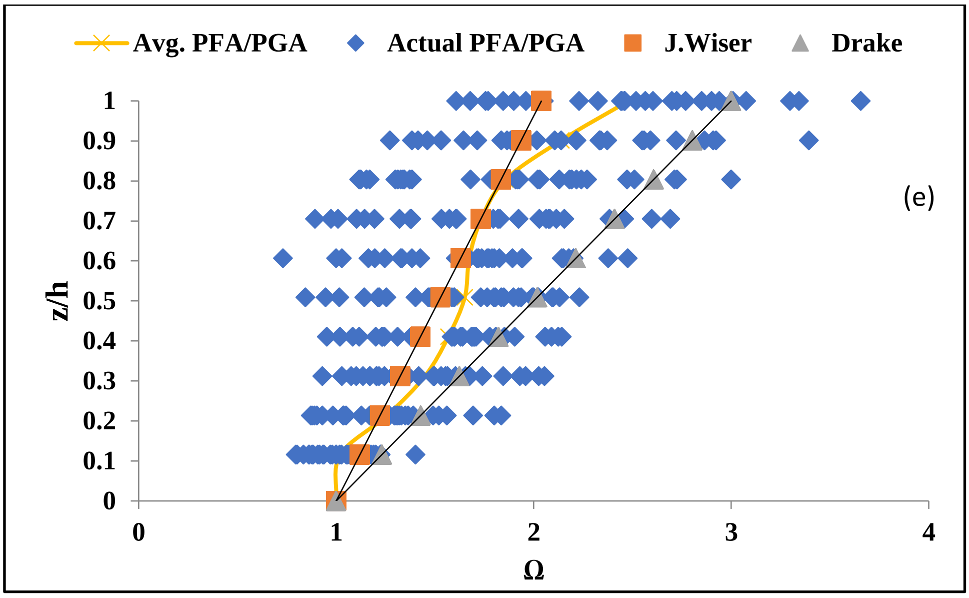
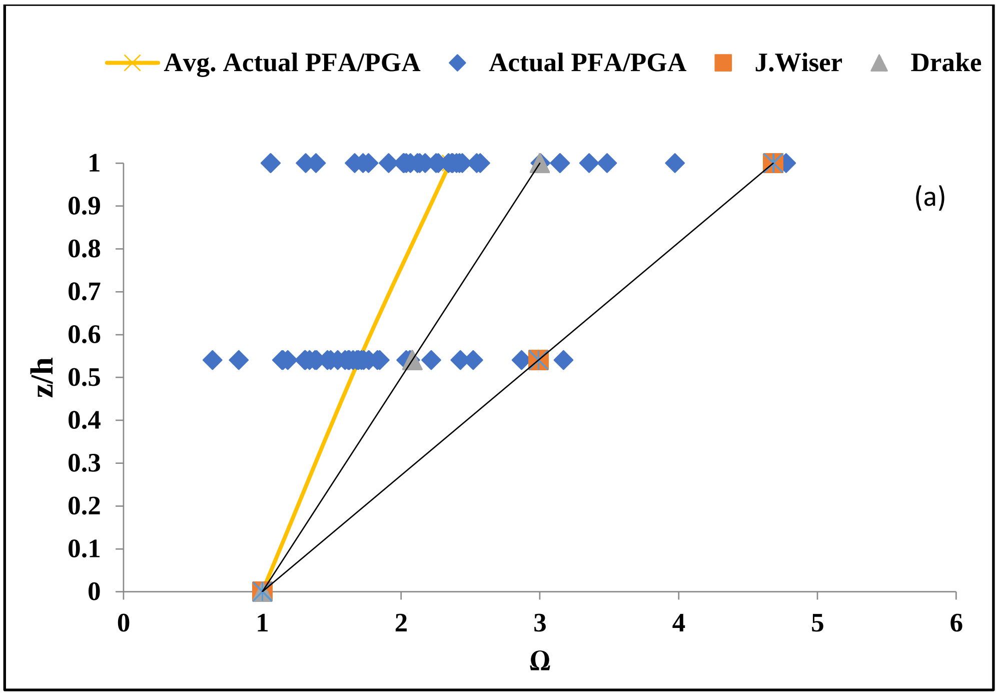


Figure 3.5 Comparisons between PFA/PGA with respect to normalised height when ground motion ranges are 0.1g to 0.2g (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories

In this case, the shapes of the Ω are not linear as defined by the Drake equation, with some of the Ω values lying outside the limits of formulas presented by Drake and J.Wiser.

When the ground motion is in the range of 0.2g to 0.31g, results are shown in Figures 3.6 (a) to (e)


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
(a)
z/h
Ω
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0.1
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0.7
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1
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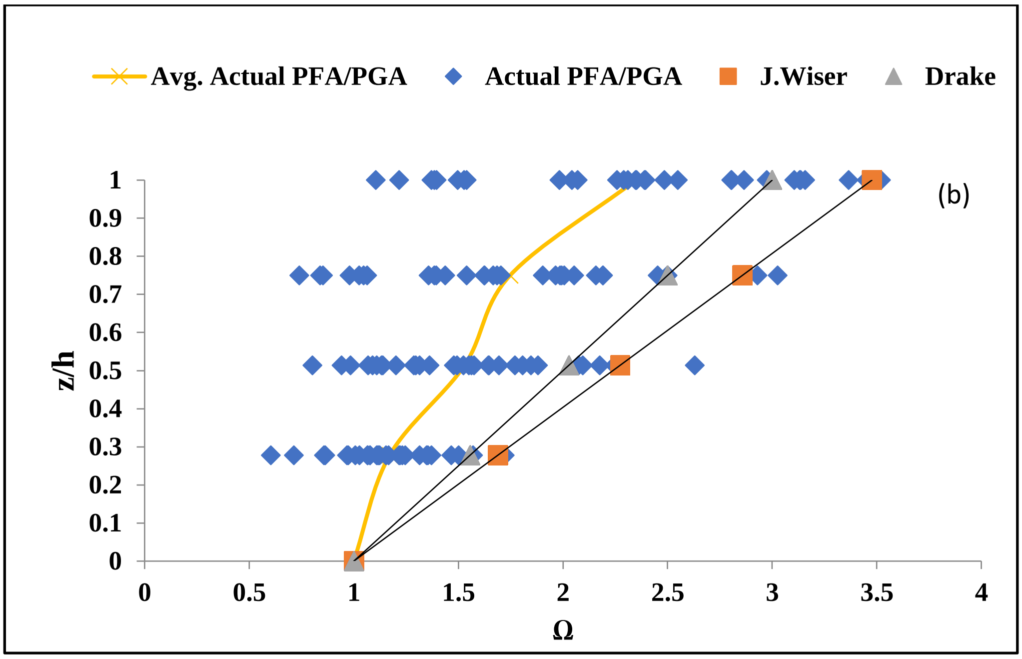
6


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
(b)
z/h
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0.4
0.5
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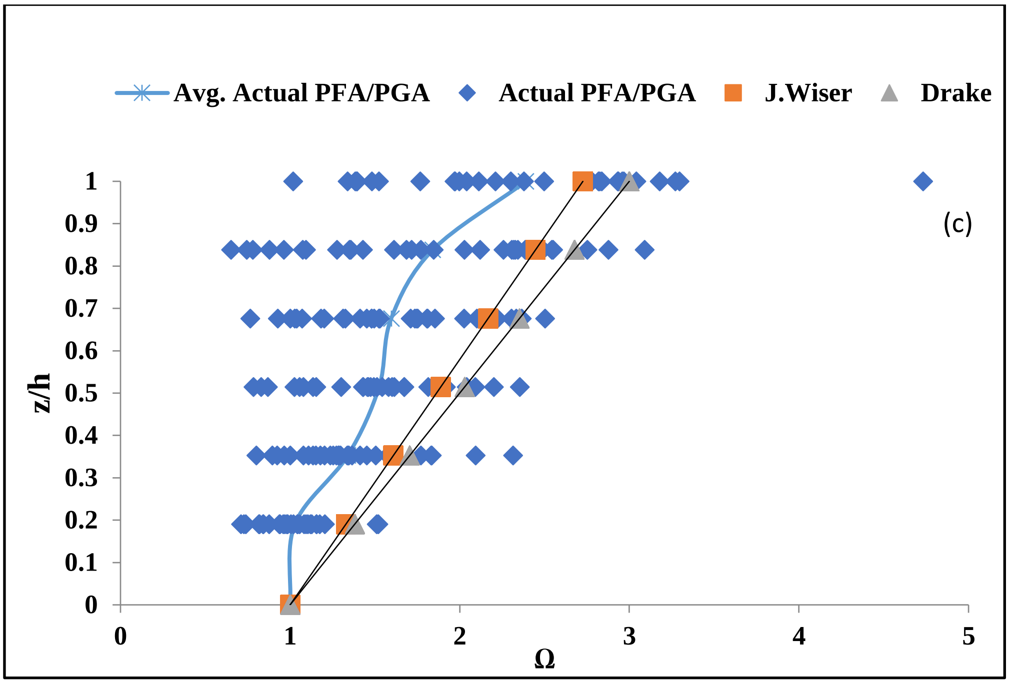
4


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
(c)
z/h
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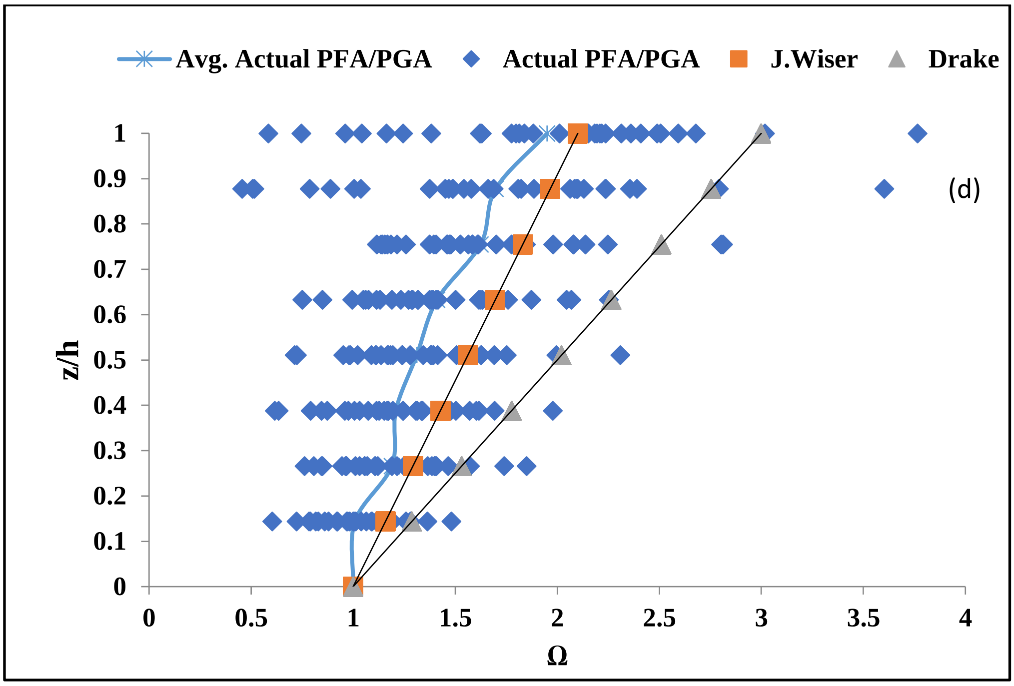
Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
(d)
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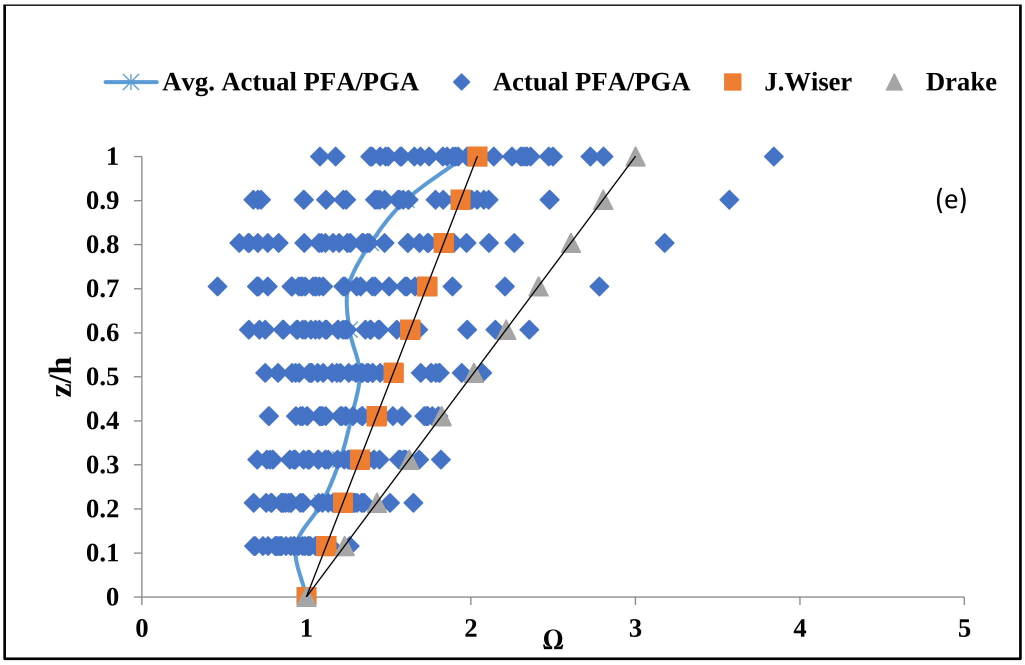


Figure 3.6 Comparisons between PFA/PGA with respect to normalised height when ground motion ranges are 0.2g to 0.31g (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories

The shapes of all acceleration amplification factor are nonlinear except when the natural period of the structure is low (less than 0.6 sec), to the nominal height of the building. The above figures also represented that the formula proposed by the Drake and J. Wiser need some modification so that the actual values (Ω) lies below the required formula for the safe design of the structures.

3.5 PROPOSED MATHEMATICAL MODELS

From Figures 3.4, 3.5, and 3.6, it is observed that the amplification factor to the normalised height formed a nonlinear curve; having the avg. Ω as lower value at lower floor and higher values on the upper floor. These figures also showed that the relative average acceleration distribution depends upon the nature, flexibility, rigidity and the fundamental natural period of the buildings. Drake model [134] proposes that the absolute acceleration amplification factor (Ω) depends upon the normalise height and there is no role of the fundamental natural period. Wiser [86] proposed that it should account the natural period of the structures.

Wiser [86] recommended the maximum structural period as 2.5sec, but from the above figures, it observed that this value gives a lower amplification factor. To overcome this drawback, mathematical models are proposed in this study. In these models, no single maximum structural period is found to satisfy the actual amplification factor. To find the realistic amplification factor, two steps have been followed. Firstly, the ground acceleration has been divided into three ranges viz. 0.01-0.1 g, 0.1-0.2g and 0.2-0.31g. Secondly, T_{max} is divided into three ranges in each acceleration range based on natural period. About 90 simulation studies have been carried out to arrive at the Tmax values. The proposed models based on observed results are given below:

$$\Omega = \frac{PFA}{PGA} = \left(1+\frac{\text{Tmax}-\text{T}}{T}\frac{z}{h}\right) \tag{3.1}$$

When -

1) The ground motion acceleration ranges between 0.01g to 0.1g

Tmax = 2.5 sec for 0.0 <T<0.6 sec

= 3.2 sec for 0.6 <T<1.0 sec

=5.5 sec for 1.0 <T<1.3 sec

2) Ground motion acceleration range between 0.1g to 0.2g

Tmax = 2.5 sec for 0 <T<0.6 sec

= 4.3 sec for 0.6 <T<1 sec

=5.5 sec for 1<T<1.3 sec

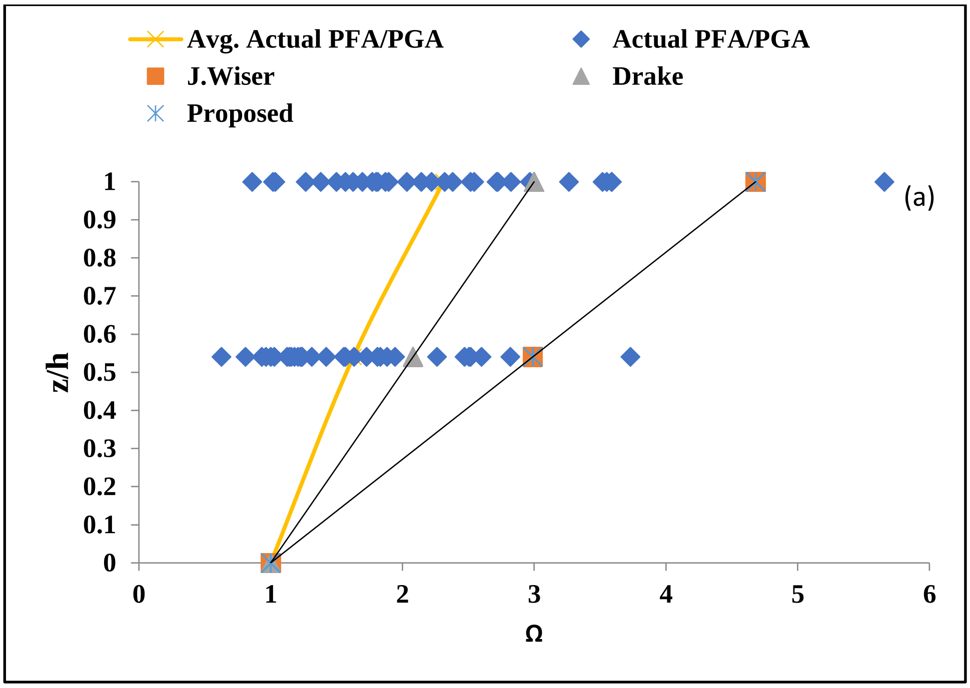
3) Ground motion acceleration range between 0.2g to 0.31g

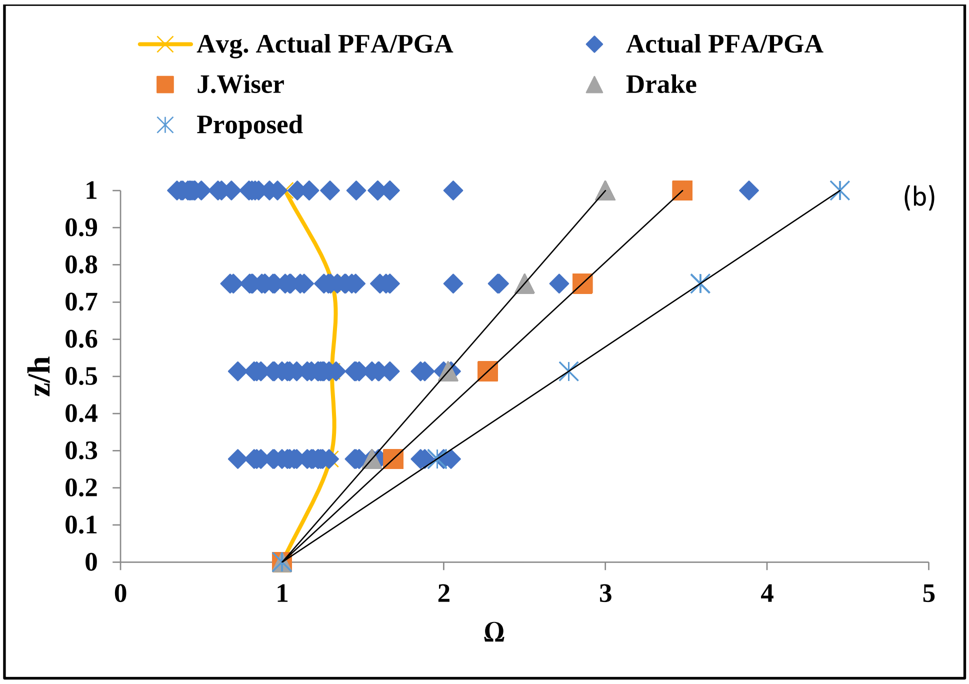
Tmax = 2.5 sec	for	0 <T<0.6 sec
= 4.0 sec	for	0.6 <T<1 sec
=5.0 sec	for	1<T<1.3 sec

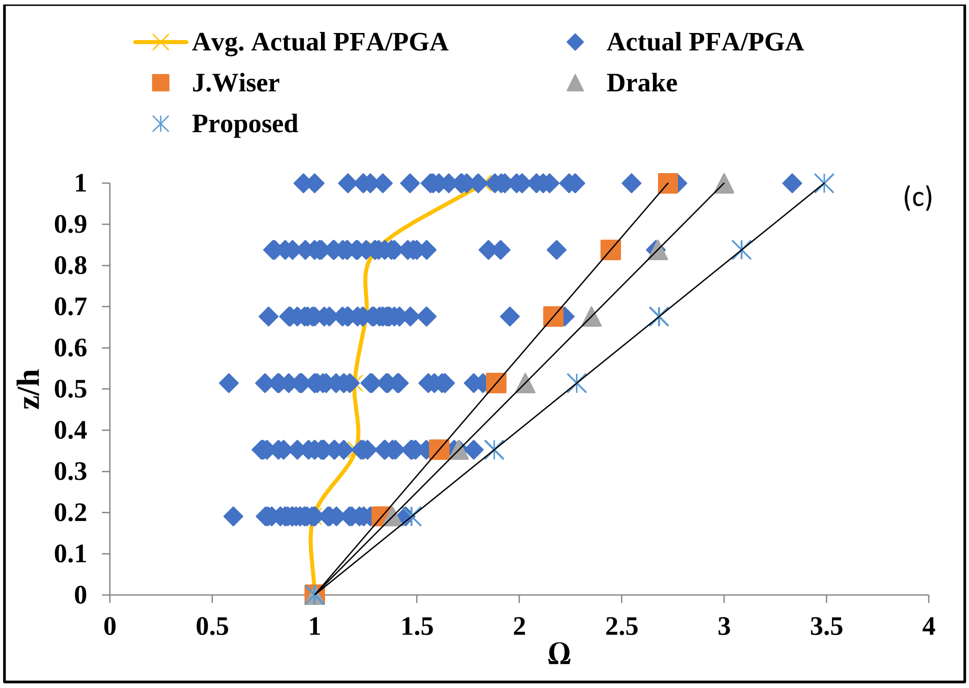
Where Tmax = maximum structural period

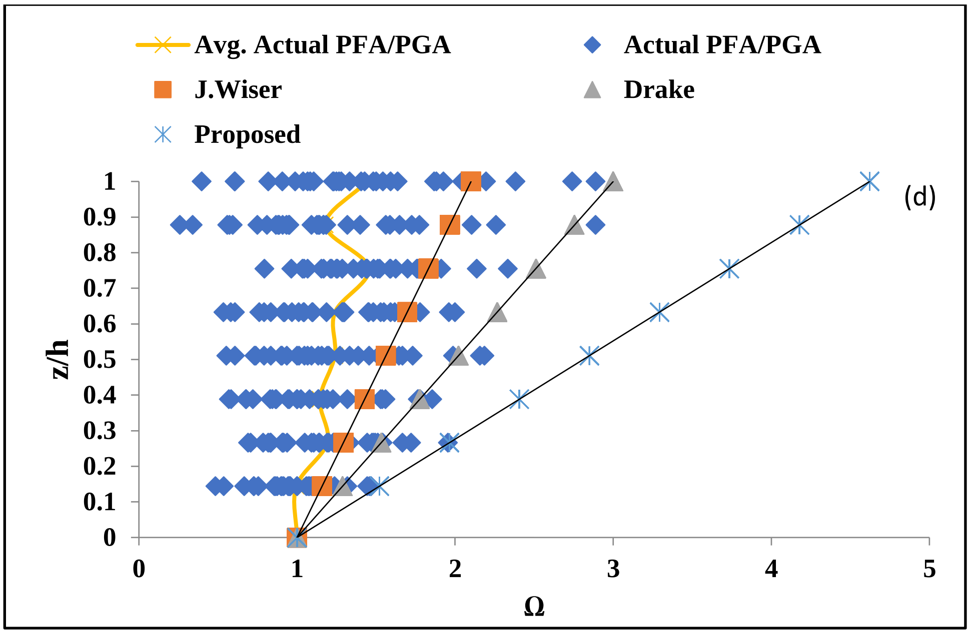
T= Fundamental natural period of the buildings.

The final results after the investigation are represented in Figures 3.7,8, and 3.9 for the ground motion accelerations ranges between 0.01g to 0.1g, 0.1g to 0.2g and 0.2g to 0.31g respectively.




Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(b)
z/h
Ω


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(c)
z/h
Ω



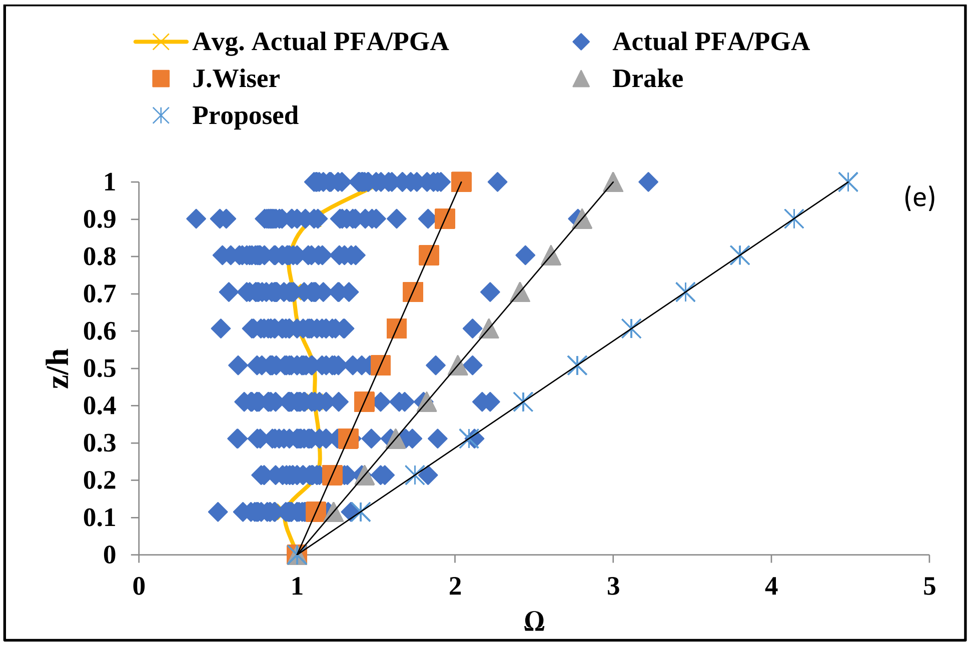
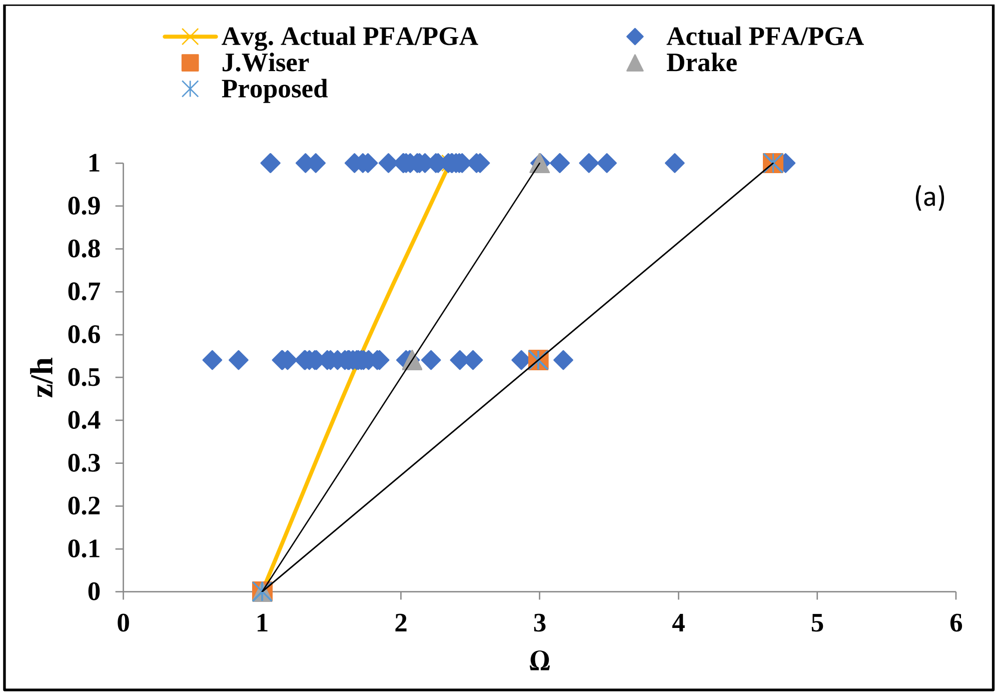
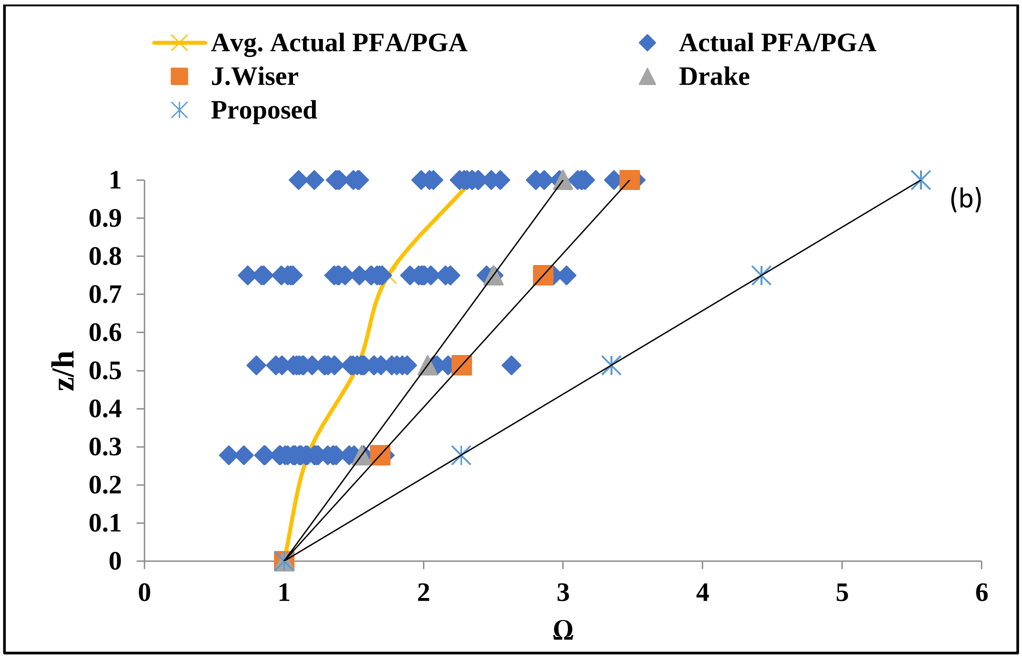
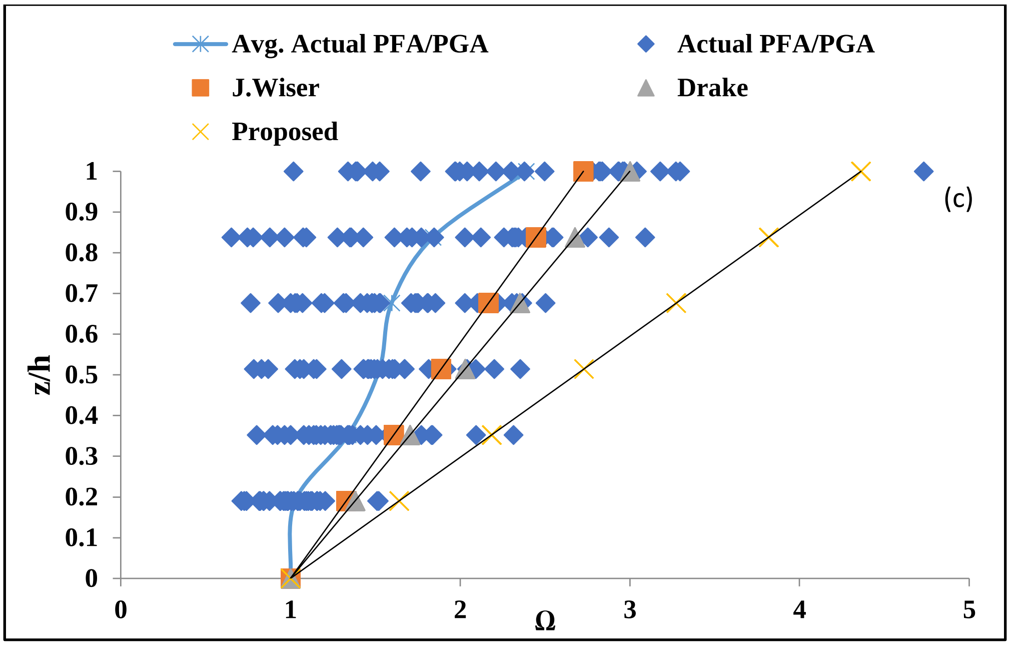
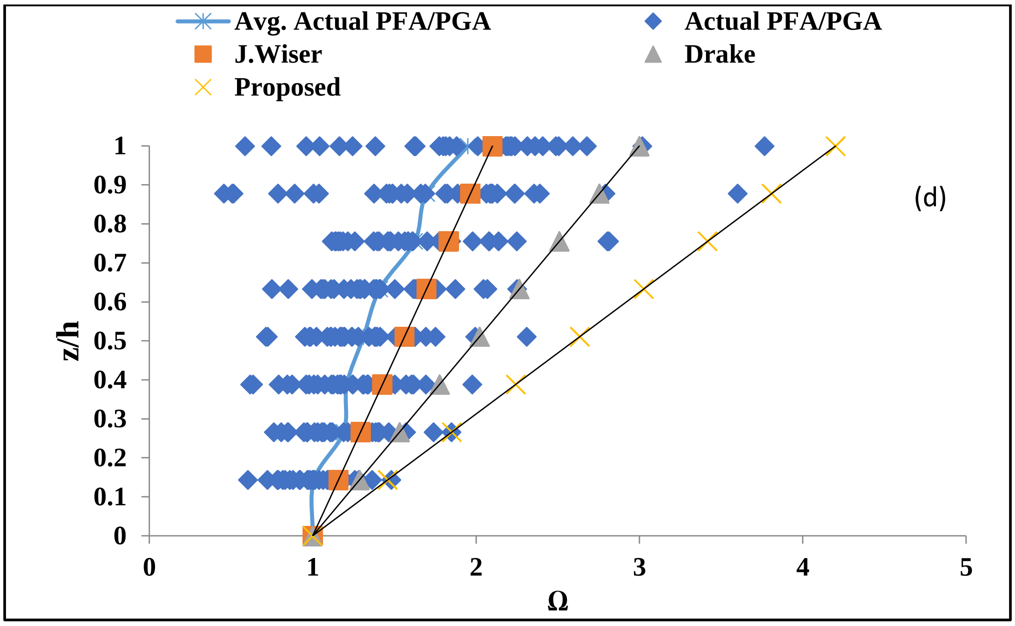


Figure 3.7 Comparison between PFA/PGA with respect to normalize height when ground motion range 0.01g to 0.1g (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(a)
z/h
Ω
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(b)
z/h
Ω
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(c)
z/h
Ω


Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(d)
z/h
Ω

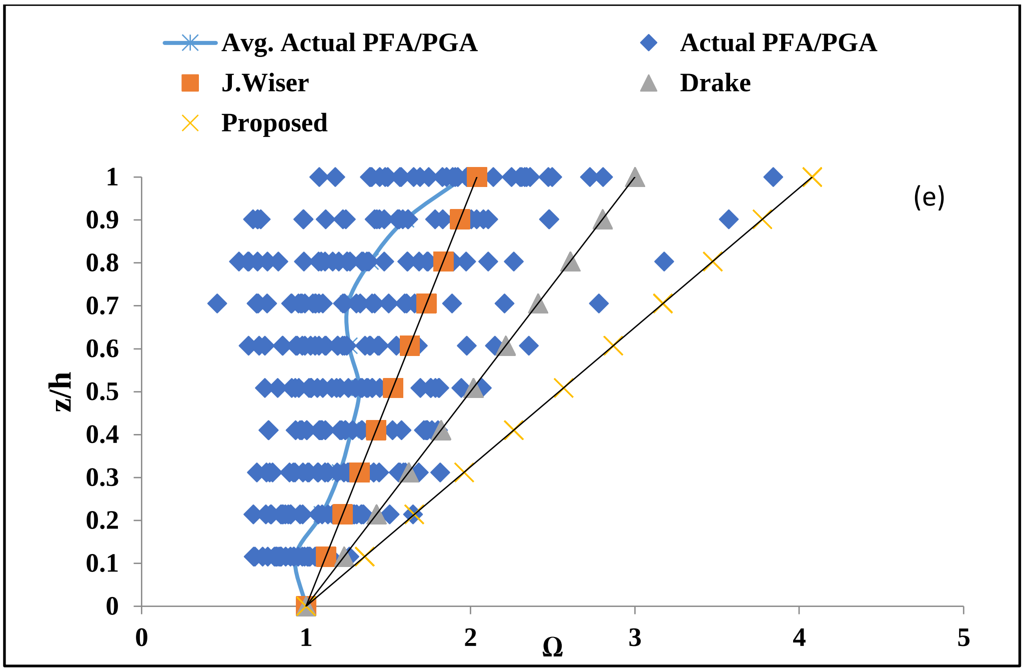
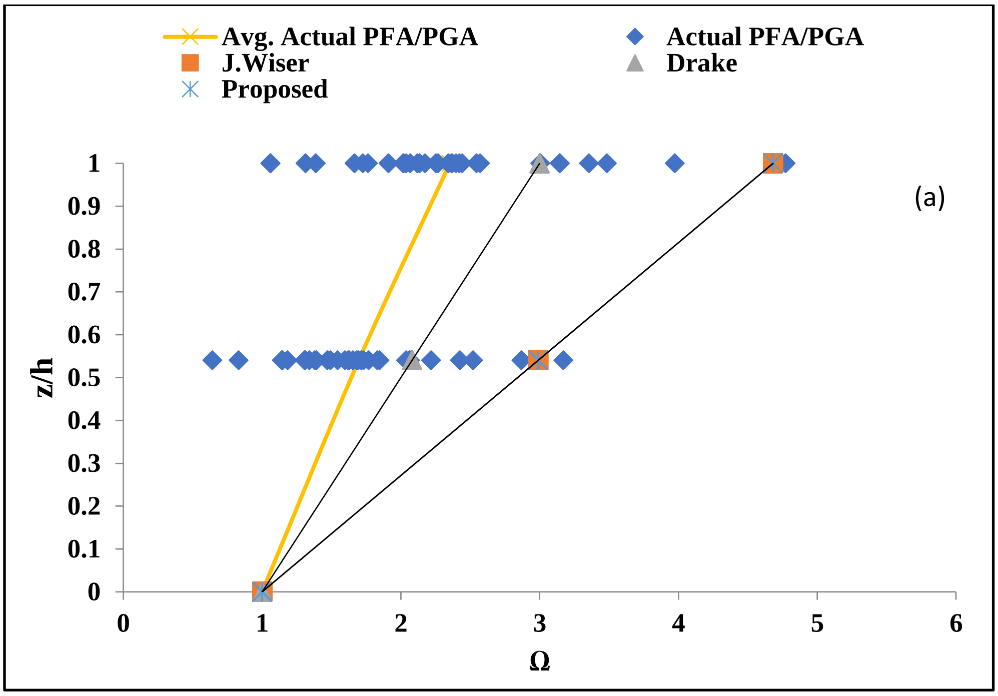
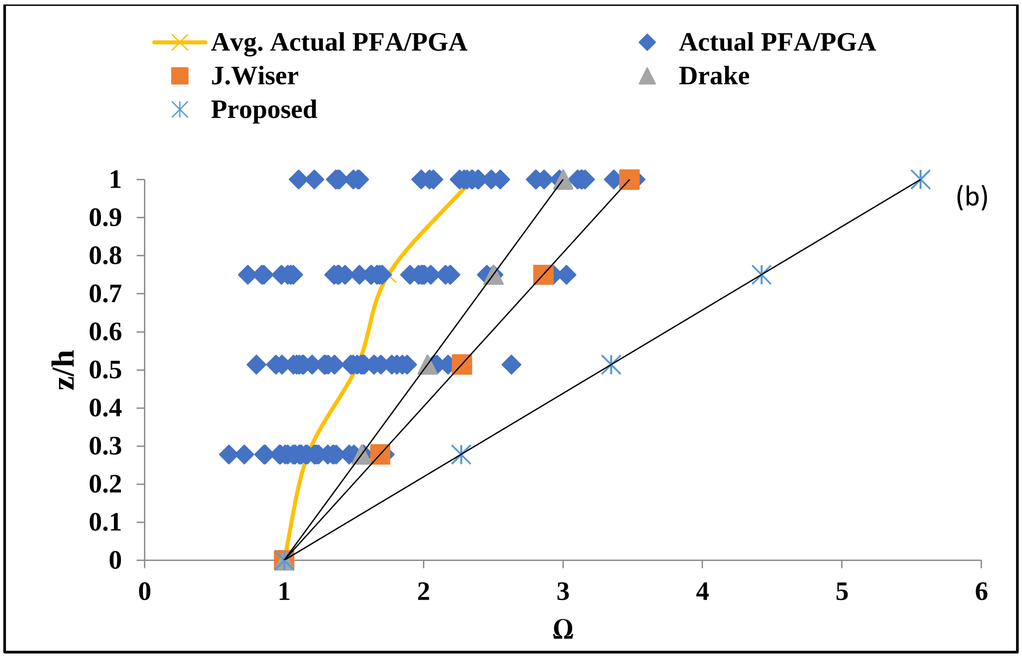
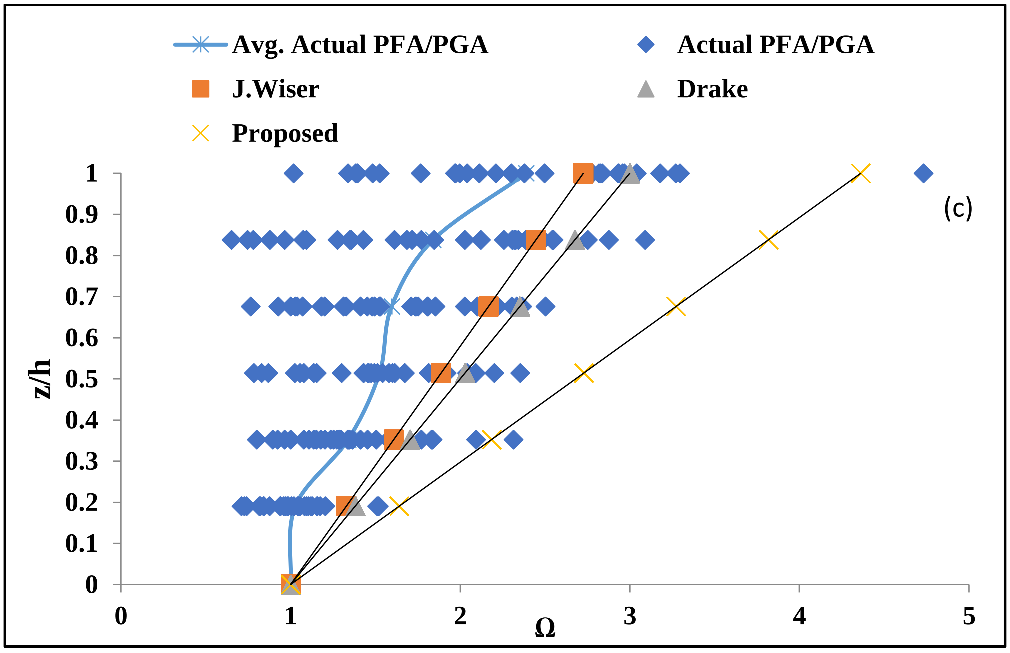


Figure 3.8 Comparisons between PFA/PGA with respect to normalised height when ground motion ranges are 0.2g to 0.31g (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories

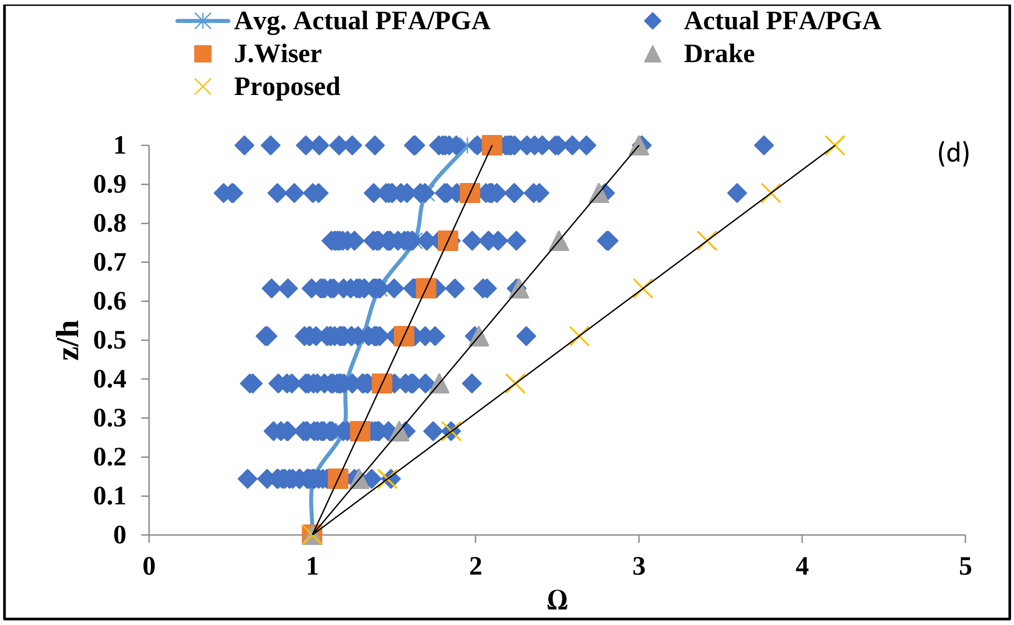




Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(b)
z/h
Ω
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6



Avg. Actual PFA/PGA
Actual PFA/PGA
J.Wiser
Drake
Proposed
(c)
z/h
Ω
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5



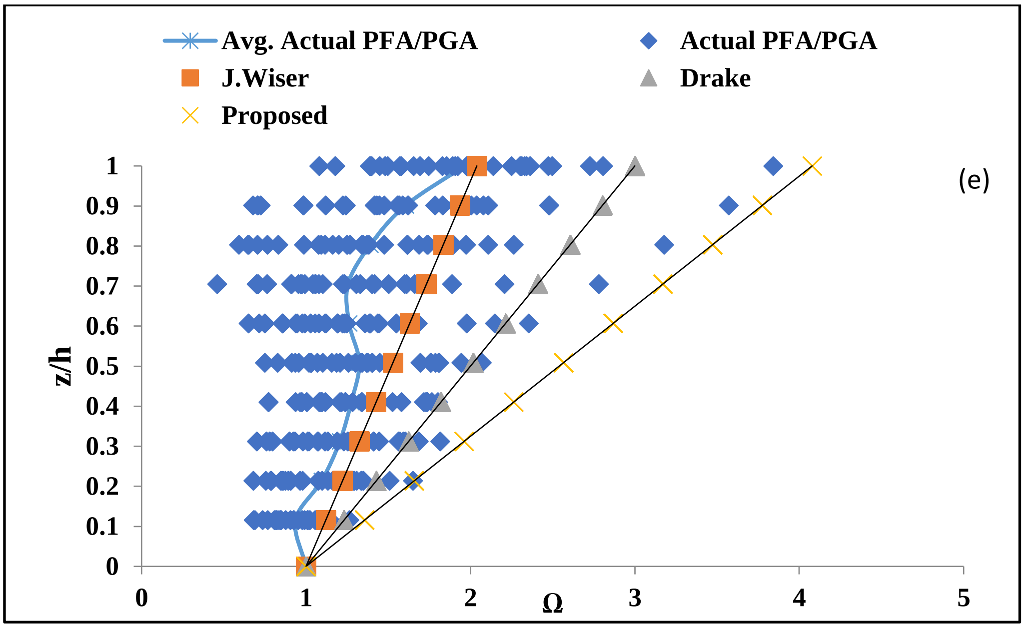


Figure 3.9 Comparisons between PFA/PGA with respect to normalised height when ground motion ranges are 0.2g to 0.31g (a) 2 (b) 4 (c) 6 (d) 8 and (e) 10 stories

Comparison of the proposed model with other modes is given in Table 3.5 and shown in Figure 3.10.

Table 3.5 Number of Ω data exceed the actual Ω data given by different mathematical models

Storey Models	Actual Data Ω	Exceed Ω Data		
		Drake Model	**Wiser Model**	**Proposed Model**
2 Storey	276	43	5	5
4 Storey	455	67	34	1
6 Storey	637	86	132	5
8 Storey	819	64	129	2
10 Storey	1001	60	274	4

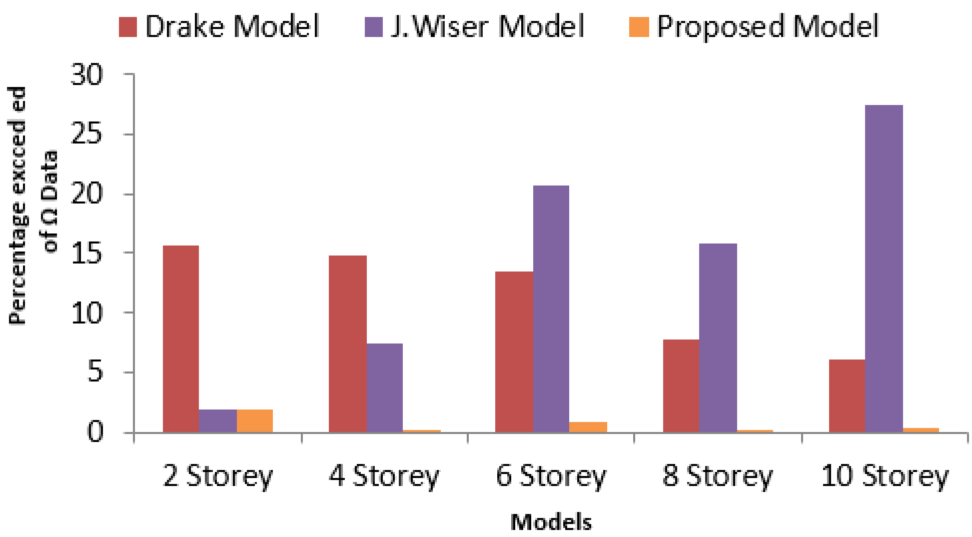


Figure 3.10 Percentage increases of Ω values with respect to actual Ω values

It is observed, when the fundamental period of the building is less (T<0.6 sec), the Wiser model gives better results, and when the natural periods are more, Drake model gives the better result. The floor amplification decreases when the height of the buildings increases. For the more realistic results when the natural period is more than 0.6 sec., the proposed model performs better results.

3.6 CONCLUDING REMARKS

In this Chapter, analyses of different building models have been attempted considering the linear time history method and large numbers of ground motion data in the ranges of 0.01- 0.1g,0.1-0.2g and 0.2 - 0.31g. Mathematical models have been proposed to find the acceleration amplification factor, which is compared with the popular model due to Wiser and Drake. The following conclusions are drawn from the study:

- The Drake model does not consider the natural period of the structure, which plays a major role in an acceleration amplification factor. The proposed model consider the natural period between 0.1 to 1.3 sec.
- The Wiser model considers the fundamental natural period but accounts maximum structural period as 2.5 sec, which is not always true.
- The wiser model gives better results when the natural periods observed in the range of 0 to 0.6 sec.
- The values of structural period are not constant for all types of ground motion. It varies between 2.5 to 5.5 sec. with the range of the ground motion.
- Proposed mathematical models provide a realistic estimation of the acceleration amplification factor for low to moderate hazard levels.