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SITE-SPECIFIC ANALYSES OF FRAMED BUILDINGS LOCATED AT DEEPER ALLUVIAL BASIN THROUGH 1D AND 2D GROUND RESPONSE ANALYSES

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ABSTRACT

In the present study, 2D linear ground response analyses of typical alluvial strata located at Ahmedabad has been carried out for M_w 7.6 scenario earthquake and the comparison has been made with 1D equivalent linear ground response analyses results. The spectral amplifications from the present study are compared with field measured site amplifications reported for similar site. Using the surface ground motions from 2D and 1D ground response analyses, linear time history analyses are carried out for typical 15 and 6 storey reinforced concrete framed buildings and the base shears are compared with design base shear as per Indian Seismic code.

Keywords: 2D ground response analyses; 1D ground response analyses; deeper alluvial basin; Bhuj earthquake; artificial ground motion; site-specific.

1. INTRODUCTION

The Bhuj earthquake with magnitude 7.6 of January 26, 2001 that struck the Kutchh area of Gujarat state in India was one of the most severe natural disasters to affect India in the last two decades. The city of Ahmedabad in Gujarat state suffered severe damages which left a trail of death and devastation in Ahmedabad which lies on the banks of the Sabarmati River, in Gujarat. The earthquake caused a heavy toll of about 20,000 dead, injuring more than 60,000, leaving 200,000 people homeless, and loss of more than Rs. 10,000 crores despite being in zone III and at a distance of 250km from the epicentre [1]. It has been reported in literature that amplification of long period waves by Sabarmati river basin could have been the reason for damage of more number of high rise buildings in Ahmedabad during Bhuj earthquake [1,2]. Though several attempts are made towards microzonation of Ahmedabad city after Bhuj earthquake, no or limited studies take into account of effect of basin and the entire depth of soil stratum above hard rock [3-6].

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Building codes are highly simplified tools and do not adequately represent the local soil conditions. The seismic codes of practice viz., IBC 2003 [7], UBC 1997 [8] have incorporated the effect of local soil conditions in terms of spectral amplification factors for site classes A to F, based on the average shear wave velocity of the top 30 m of soil stratum [7]. Though it is stated in IBC that site specific analysis needs to be carried out for class F type of soil, it has been demonstrated in literature [9-12] that, it is required to carry out site-specific analysis which includes generation of strong ground motion at bedrock level and its propagation through soil layers taking into account the entire depth of soil stratum above bedrock to arrive at the design ground motions and response spectra at the ground surface for medium soil sites as well, which are not classified as site class F.

Further, it may be noted that amplification factors specified in international codes are based on field recorded data for lower acceleration levels and are obtained from one dimensional wave propagation analyses for higher acceleration levels [13]. Most of the ground response analyses studies are one dimensional (1D) and do not explicitly account for two dimensional (2D) basin edge effects. Raptakis et al., [14] have demonstrated the need for 2D analysis since site effects accounting for 2D geometry play an important role in the manifestation of complex phenomena, which cause additional amplification and duration than the 1D response. The ratio of 2D to 1D response spectra, has been proposed by Raptakis et al., [14] in order to account for the additional amplification due to complex geology as current seismic norms are based on simple 1D soil profiles with *V*s values defined only for the upper 30 m and neglecting the effect of deeper soil deposits. According to Bielak et al., [15] 1D response tends to exhibit lower peaks and duration than 2D response. However, Bielak et al., [15], have also stated that for some sites, due to the destructive interference of different types of waves, 2D analyses may lead to smaller response than that of 1D analysis. Narayan and Richharia [16] have stated that in a river basin, maximum damage may occur either at the centre of the basin or somewhere else in the basin depending on the angle and direction of incidence of the body waves. Bakir et al., [17] have shown that the surface waves are generated at the basin edges and body waves may be trapped in the alluvium, as a result the ground motion is greatly amplified and prolonged over a certain distance from the edge.

Hence in the present study, both 2D and 1D ground response analyses are carried out including the entire depth of soil stratum above hard rock (1500 m/sec) for Sabarmati river basin located at Ahmedabad by choosing 2001 Bhuj earthquake as the site-specific scenario earthquake. The variations in average peak ground acceleration (PGA), spectral amplification and response spectra are studied for eight sites. The spectral amplifications from the present study are also compared with H/V amplifications reported in literature for similar site and seen that 1D analyses underestimates the response for all the sites. The comparison of response spectra from 2D and 1D ground response analyses with response spectra of recorded ground motion of Bhuj 2001 earthquake shows the necessity of carrying out 2D ground response analyses.

Acceleration and displacement responses of typical fifteen and six storey framed buildings from linear time history analyses for the ground motions obtained through 2D and 1D ground response analyses are compared. Further, base shears obtained from linear time history analyses for ground motions from 2D and 1D ground response analyses are compared with the design base shear calculated as per response spectrum method of Indian seismic code IS 1893(Part1)-

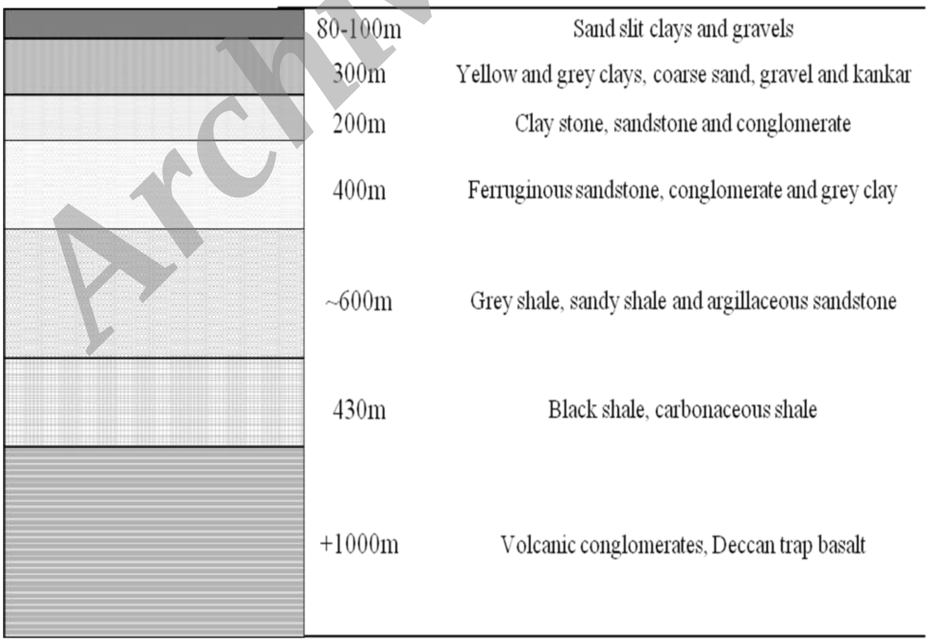
2002 [18]. The details of the studies carried out are described in the following sections.

2. SABARMATI BASIN

Ahmedabad city is situated on the western bank of a non-perennial Sabarmati River and is oriented parallel to the river cutting through the alluvial plains of the Cambay graben which are filled up with the surface deposits of the recent sediments [4]. Geomorphologically, Ahmedabad is located on the Sabarmati alluvial belt and from the soil exploration data, it is observed that the soil is loose up to 3 m depth and from 3 m to 15 m depths it exhibits relatively medium dense condition. The soil found in the area is silty sand whose density varies slightly from shallow to deeper deposits [2]. It is reported that sedimentary rocks ranging in age from Jurassic to Eocene age cover Ahmedabad region. These sediments have seemed to be having a zone of Deccan trap volcanic sandwiched between Jurassic rocks of the northern part and Eocene sedimentary in the south towards the coast. Limestone, shale and sandstones are reported to be the most common rocks found in Ahmedabad region.

In the absence of complete details regarding the alluvial stratum, the maximum data available from the literature [3,4,6] related to soil layer thickness, geometry and shear wave velocity of each soil layer of the basin are adopted for carrying out 2D and 1D analyses. For two dimensional analyses, basin width of 36km, consisting of a maximum soil depth of 1km and overall depth of 2.8km including rock layer at the centre of the basin has been chosen. The whole basin is divided into 8 sites of various soil depths and typical soil profile details of Sabarmati river basin considered for the present study is given in Table 1.

Table 1: Typical soil profile details of Sabarmati River Basin adopted (Brahma 2011)



80-100m	Sand slit clays and gravels
300m	Yellow and grey clays, coarse sand, gravel and kankar
200m	Clay stone, sandstone and conglomerate
400m	Ferruginous sandstone, conglomerate and grey clay
~600m	Grey shale, sandy shale and argillaceous sandstone
430m	Black shale, carbonaceous shale
+1000m	Volcanic conglomerates, Deccan trap basalt

2.1 Typical Sabarmati basin model

Hypothetical model of Sabarmati basin in the present study has been assumed based on the information from the report on Geologic cross-section of Cambay Basin near Ahmedabad by Japanese society of civil engineering [19]. The depth of soil is varied along its length i.e. all along 36km, the depth of soil is taken as 100m, 400m, 800m, 1000m, 800m, 500m, 600m and 80m at 4km interval along the length. Below the soil layers, 3 layers of rock have been modelled with thickness 300m, 500m and 1000m respectively. The typical model of 2D basin, depths of sites and soil properties adopted are given in Fig. 1, Table 2 and Table 3 respectively.

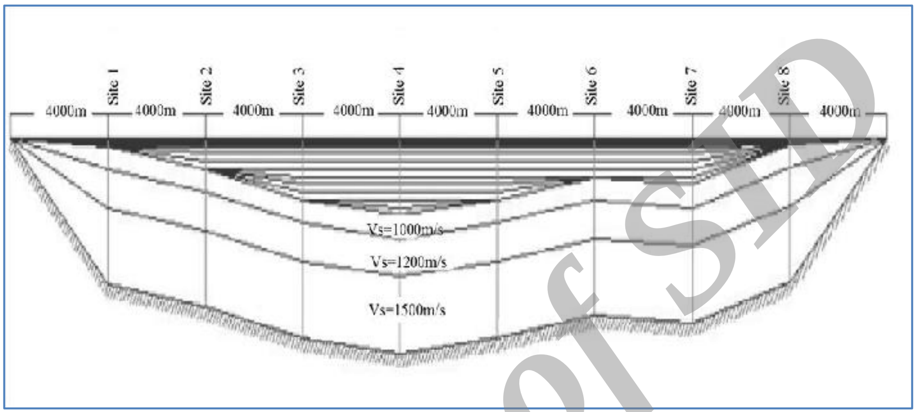


Figure 1. Typical model of Sabarmati basin considered for the present study

Table 2: Depths of sites considered for analyses

Designation	Total thickness of soil layers(m)	Thickness of rock layers (m)
Site 1	100	1800
Site 2	400	1800
Site 3	800	1800
Site 4	1000	1800
Site 5	800	1800
Site 6	500	1800
Site 7	600	1800
Site 8	80	1800

Table 3: Shear wave velocity and density of soil profile

Depth of soil (m)	V_s (m/s)	Density (kN/m^3)
0-10	230	16
10-20	260	17
20-30	330	18
30-40	360	19
40-50	390	19
50-60	410	19
60-70	450	19

70-80	470	19
80-90	510	19
90-100	540	19
100-1000	560	21
1000-1300	1000	21
1300-1800	1200	21
1800-2800	1500	23

3. GENERATION OF GROUND MOTION

Singh et al. [20] used two finite-source stochastic models to generate ground motions for Bhuj 2001 earthquake and they predicted peak acceleration (a_{max}) and peak velocity (v_{max}) for ‘hard rock’ site condition for different places as a function of epicentral distance and compared with field observations. It was noted that for Ahmedabad city which is located at 250 km away from epicentre, the amplification of the alluvial site is reported to be in the order of 4.62. In the present study artificial ground motions are generated for M_w 7.6 scenario earthquake with seismological parameters adopted from Singh et al., [20] for Bhuj earthquake as given in Table 4 using Extended fault SIMulation (EXSIM) [21] model. Fifteen simulations of ground motion are generated for hard rock site conditions in the present study and one typical simulation at bedrock level is shown in Fig. 2. The response spectra of the fifteen simulations of artificial ground motions at rock level with PGA value reported in literature [20] for hard rock site for 2001 Bhuj earthquake are shown in Fig. 3.

Table 4: Seismological parameters for the simulation of Bhuj 2001 earthquake

Fault Strike	66^0	Sub fault width (km)	8.25
Fault dip	64^0	hypocenter at sub fault	3 4
Fault depth to upper edge (km)	10	Magnitude	7.6
Fault Length (km)	44	FFT points	4096
Fault Width (km)	33	dt (sec)	0.02
Latitude of source	23.41^0	Shear wave velocity of rock near the source(β) (km/s)	3.6
Longitude of source	70.18^0	Density(ρ), g/cm^3	2.85
Latitude of site	23.04^0	pulsing Percentage	25
Longitude of site	72.57^0	stress drop (bars)	200
No. of sub faults along strike	5	f_{max} (Hz)	35
No. of sub faults along dip	4	Q_0	$508.00f^{0.48}$
sub fault length (km)	8.8		

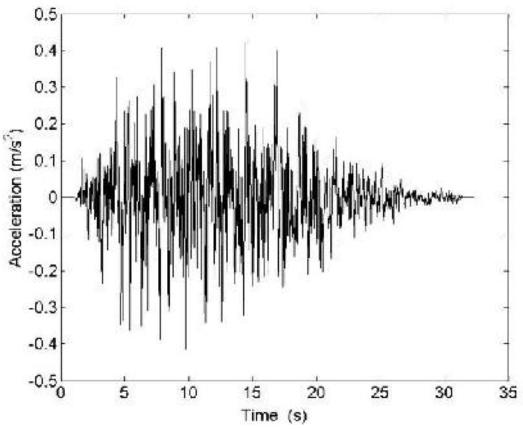


Fig.2 One typical simulation at bedrock level for Bhuj earthquake

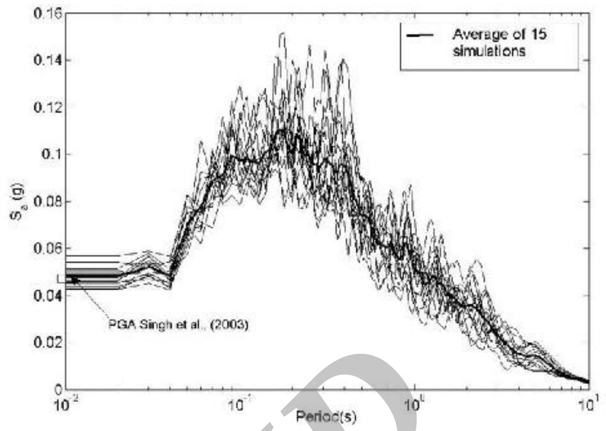


Fig.3 Response spectra of 15 simulations of Bhuj 2001 earthquake at bedrock level with PGA value reported in literature [25] for hard rock site

4. ONE DIMENSIONAL GROUND RESPONSE ANALYSES

Equivalent linear one dimensional wave propagation analysis program SHAKE2000 [22] is being widely used for 1D ground response [23, 24]. However for modelling deeper deposits, DEEPSOIL [25] computer program is preferred for 1D equivalent linear wave propagation analysis and the same has been used in the present study. Dynamic characteristics viz., modulus reduction ratio and damping ratio are adopted from Vucetic and Dobry [26].

1D analyses is carried out for 8 different sites whose soil depths and designations are as mentioned in Table 2. Ground motions generated in the present study are for rock outcrop conditions and the simulated ground motions are applied at the bedrock below the depth of soil stratum and are propagated vertically through the soil layers. Time history and response spectra at surface level are obtained for the 15 earthquake simulations at 8 sites and the responses are studied. The variation of average PGA for fifteen simulations along the depth of soil stratum for the eight sites considered is shown in Fig. 4. As it is observed from Fig. 4, the amplification is more for shallow deposits viz., site 1(100m), site 8(80 m) compared to deeper deposits and the order of amplification is higher near the surface. It may be noted that, PGA observed at surface for site 8 is 0.087g which is in closer agreement with the peak acceleration of 0.1 g which was recorded at the passport office building at Ahmedabad during the Bhuj earthquake. Comparison of surface level average response spectra of fifteen simulations from 1D ground response analyses with the response spectra of recorded ground motion at passport office building for Bhuj earthquake of the eight sites is shown in Fig. 5. Time histories obtained at the surface level are further used to study the responses of fifteen and six storey framed buildings as described later sections in this paper.

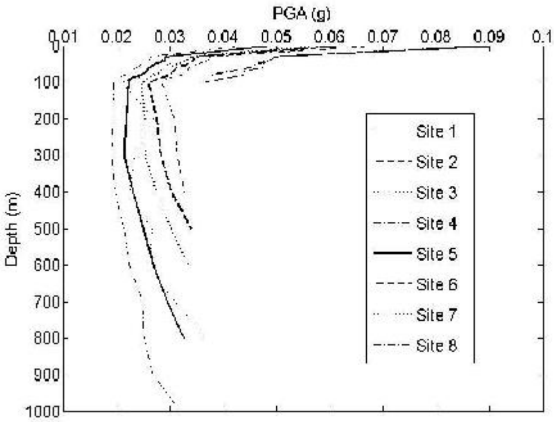


Figure 4. Average PGA variation along depth for the eight sites from 1D analyses

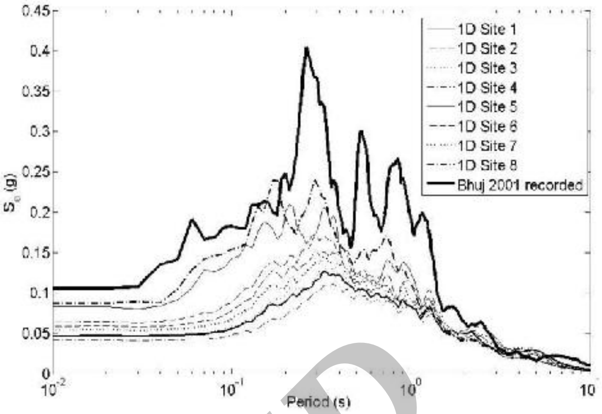


Figure 5. Comparison of surface level average response spectra of fifteen simulations from 1D ground response analyses with the response spectra of recorded ground motion at passport office building for Bhuj earthquake

5. TWO DIMENSIONAL GROUND RESPONSE ANALYSES

Though one dimensional analyses is widely adopted for layered deposits, two dimensional analyses has been recommended in literature [16, 27] for deeper alluvial basins. Hence, two dimensional linear ground response analyses is carried out in the present study using SAP2000 [28] computer program. As it is reported in literature [27, 29] linear finite element two dimensional analyses is carried out in the present study. In the two dimensional model considered for analyses (Fig. 1) rock layers of thickness 300m, 500m and 1000m with different shear wave velocities simulating the field conditions (Table 1) are also included in addition to the soil layers considered for 1D analyses and the ground motion is applied at the base. Solid elements having unit thickness are adopted in the present study as reported by Savage and Safak [30]. Young's modulus obtained from shear wave velocity, Poisson's ratio and the density of soil and rock layers are the main inputs defining the material behaviour for 2D analyses. Acceleration time histories and response spectra are obtained at surface level for the 15 earthquake simulations at 8 different site locations of the basin. Time period of the basin is found to be 4 seconds in two dimensional linear ground response analyses. Comparison of surface level average response spectra of fifteen simulations from 2D ground response analyses with the response spectra of recorded ground motion at passport office building for Bhuj for the 8 sites are as shown in Fig. 6. Form Fig. 6 it is seen that higher amplification is observed for sites 3, 4 and 5 with soil depths of 800m, 1000m and 800m which are at the centre of the basin and lower amplification is observed for the sites 1 and 8 with soil depth of 80m and 100m which are near the basin edge. Time history analyses of the buildings are carried out with the surface time histories obtained from 2D analyses for the eight sites as explained in the later sections of this paper.

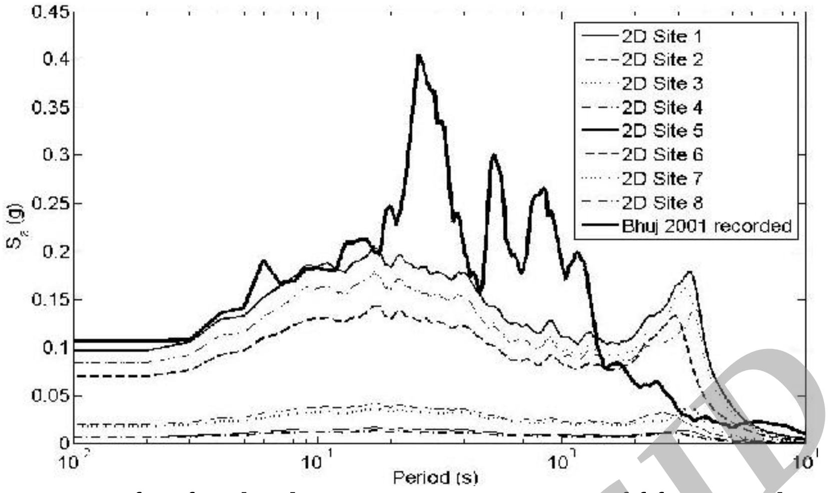


Figure 6. Comparison of surface level average response spectra of fifteen simulations from 2D ground response analyses with the response spectra of recorded ground motion at passport office building for Bhuj earthquake

6. COMPARISON OF 2D AND 1D RESPONSES OF THE SITES

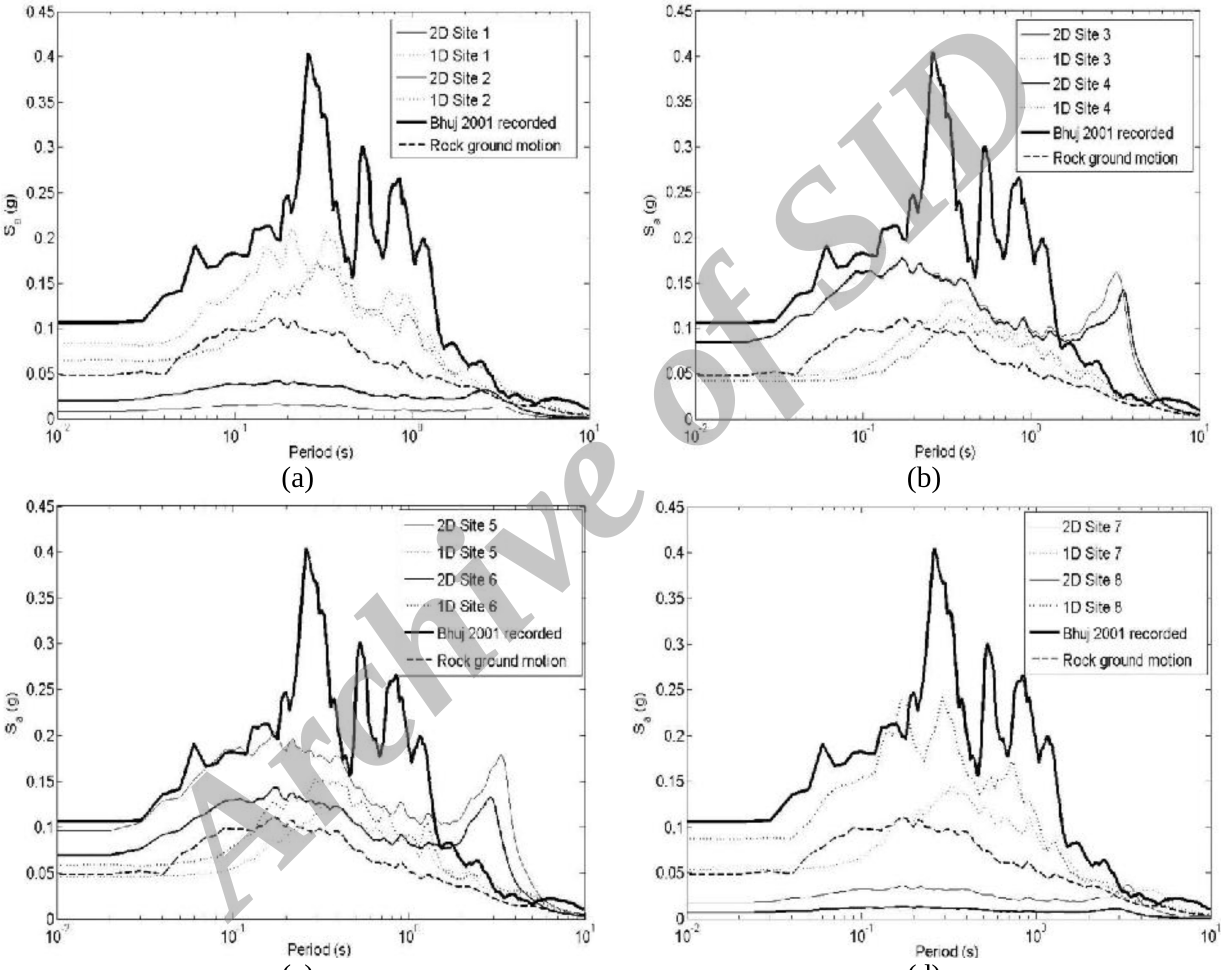
Average PGA of fifteen simulations at surface level from 2D and 1D ground response analyses and the ratio of PGA from 2D and 1D ground response analyses are given in Table 5. It is seen that as mentioned earlier, for sites 1, 2, 7 and 8 which are of relatively lesser depth and also nearer to edge, PGA from 1D analyses are more. However, for deeper deposits near the middle of the basin PGA from 2D analyses are more. PGA obtained from 2D ground response analyses is found to be twice as that of 1D ground response analyses for the deeper soil depths i.e. for site 4 and site 5.

Table 5: Average PGA of fifteen simulations at surface level from 2D and 1D ground response analyses

Site	PGA (g)		Ratio 2D/1D
	2D	1D	
1	0.0077	0.0827	0.0927
2	0.0197	0.0639	0.3080
3	0.0839	0.0473	1.7735
4	0.0840	0.0417	2.0165
5	0.0962	0.0467	2.0595
6	0.0695	0.0585	1.1890
7	0.0176	0.0536	0.3274
8	0.0062	0.0870	0.0713

The response spectra obtained from 2D and 1D ground response analyses are compared in Fig. 7. From Figs. 7(a) and (d) for sites 1, 2, 7 and 8 considerable amplifications from 1D analyses and de-amplification from 2D analyses are observed. On the other hand, from Fig.

7(b) and (c), for sites 3, 4, 5 and 6 more amplification has been observed from 2D ground response analyses compared to 1D analyses. Spectral accelerations of response spectra obtained from Bhuj 2001 recorded ground motion are more than that of spectral accelerations from both 2D and 1D, and indicates the contribution of more than one mode. This observation emphasises the necessity of carrying 2D ground response analyses considering the depth of soil strata till the hard rock level. It is seen from results that, not only the depth of soil stratum, and also the model for ground response analyses has a significant role to play in amplification of soil sites.



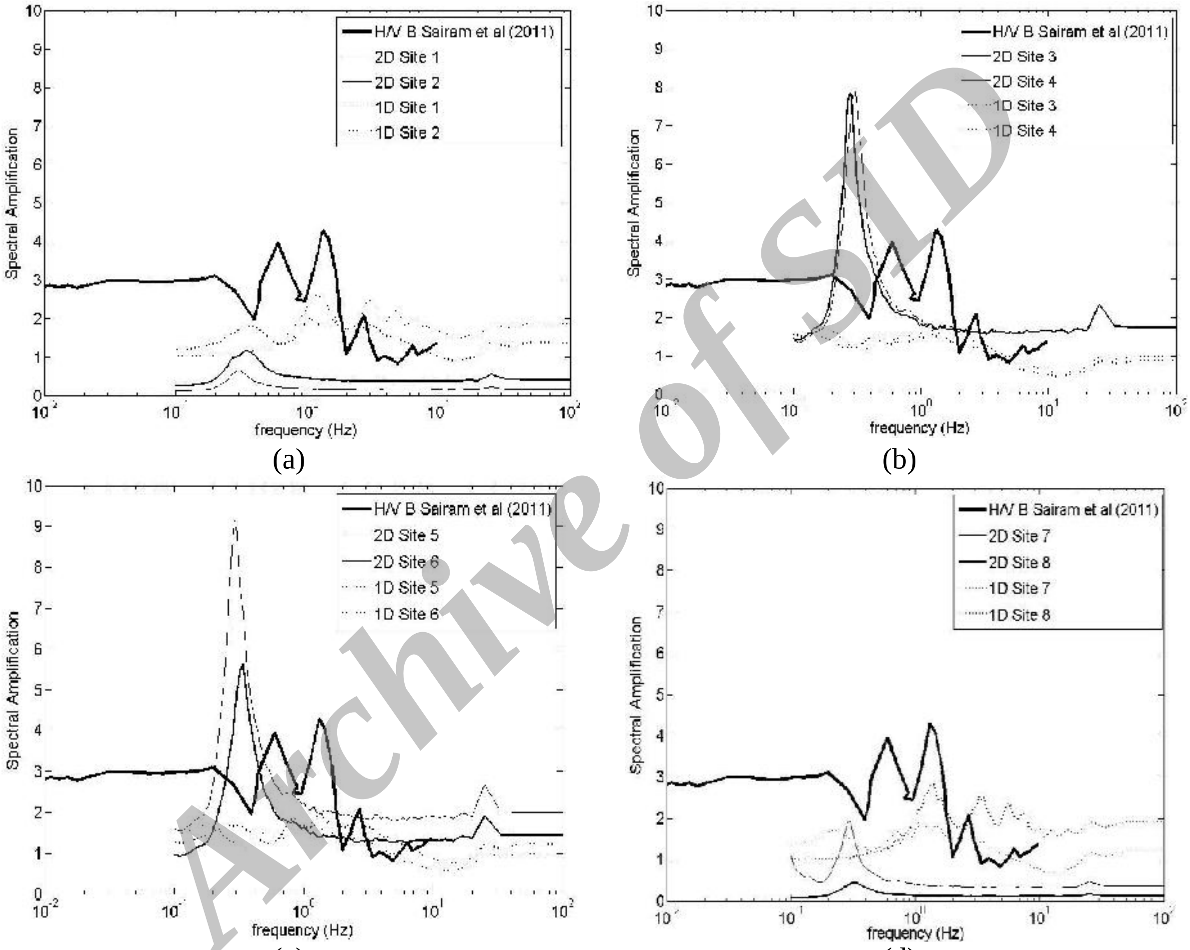
(a) (b)

(c) (d)

Figure 7. Surface level average response spectra of fifteen simulations from 2D and 1D, rock level ground motion and response spectra of recorded Bhuj earthquake. (a) site 1, site 2 (b) site 3, site 4 (c) site 5, site 6 (d) site 7, site 8

6.1 Amplification ratio with field observed H/V

Spectral amplification obtained from 2D and 1D ground response analyses are compared with field observed site amplification represented as the maximum spectral ratio (H/V) reported in literature [4] for a typical site at Sabarmati river basin as shown in Fig. 8. From the comparison it is seen that spectral amplification from 1D analyses is less than H/V reported for all the sites. This shows that 1D analyses alone may not be adequate to represent the amplification expected in deeper river basins similar to Sabarmati basin considered in the present study. Further it is noted from Fig.8 that, the spectral amplification from 2D analyses are more for sites 3,4,5 and 6 and less for sites 1, 2, 7 and 8 than H/V reported from literature. This indicates the necessity to critically examine the applicability of H/V measurements for the estimation of spectral amplification for deeper deposits.



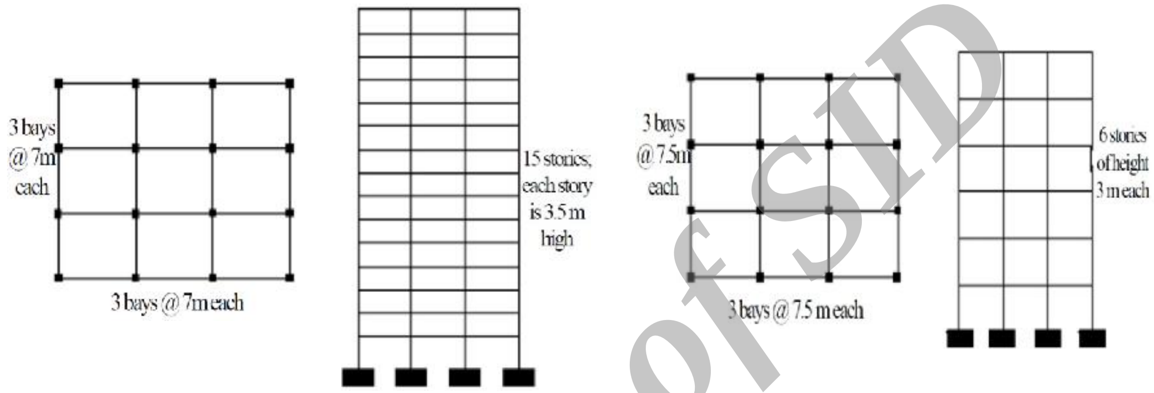
(a) (b)

(c) (d)

Figure 8. Comparison of the spectral ratios, H/V of 2D and 1D with the field measured spectral ratio (a) site 1, site 2 (b) site 3, site 4 (c) site 5, site 6 (d) site 7, site 8

7. RESPONSE OF FRAMED BUILDINGS

As the maximum surface level PGA of 8 sites is 0.096g from 2D ground response analyses and 0.086g from 1D ground response analyses, linear elastic analyses is found to be adequate for the framed buildings considered in the present study. Linear time history analyses of typical fifteen storey and six storey framed buildings (Fig. 9) assumed to be situated at 8 different sites are carried out using SAP2000 computer program with the fifteen time histories obtained at surface level from 2D and 1D ground response analyses. Structural details of beams and columns of 15 storey (designated as B1) and 6 storey framed building (designated as B2) are given in Table 6. From the free vibration analyses fundamental time periods of B1 and B2 are obtained as 2.6 s and 1.2 s respectively. Comparison of displacement responses and acceleration responses for ground motions from 2D ground response analyses are made with that of ground motions from 1D ground response analyses for one typical time history for both B1 and B2 as described below.



(a) (b) (c) (d)

Figure 9. Plan and elevation of buildings B1 and B2 (a) Plan of B1 (b) Elevation of B1 (c) Plan of B2 (d) Elevation of B2

Table 6: Structural details of B1 and B2

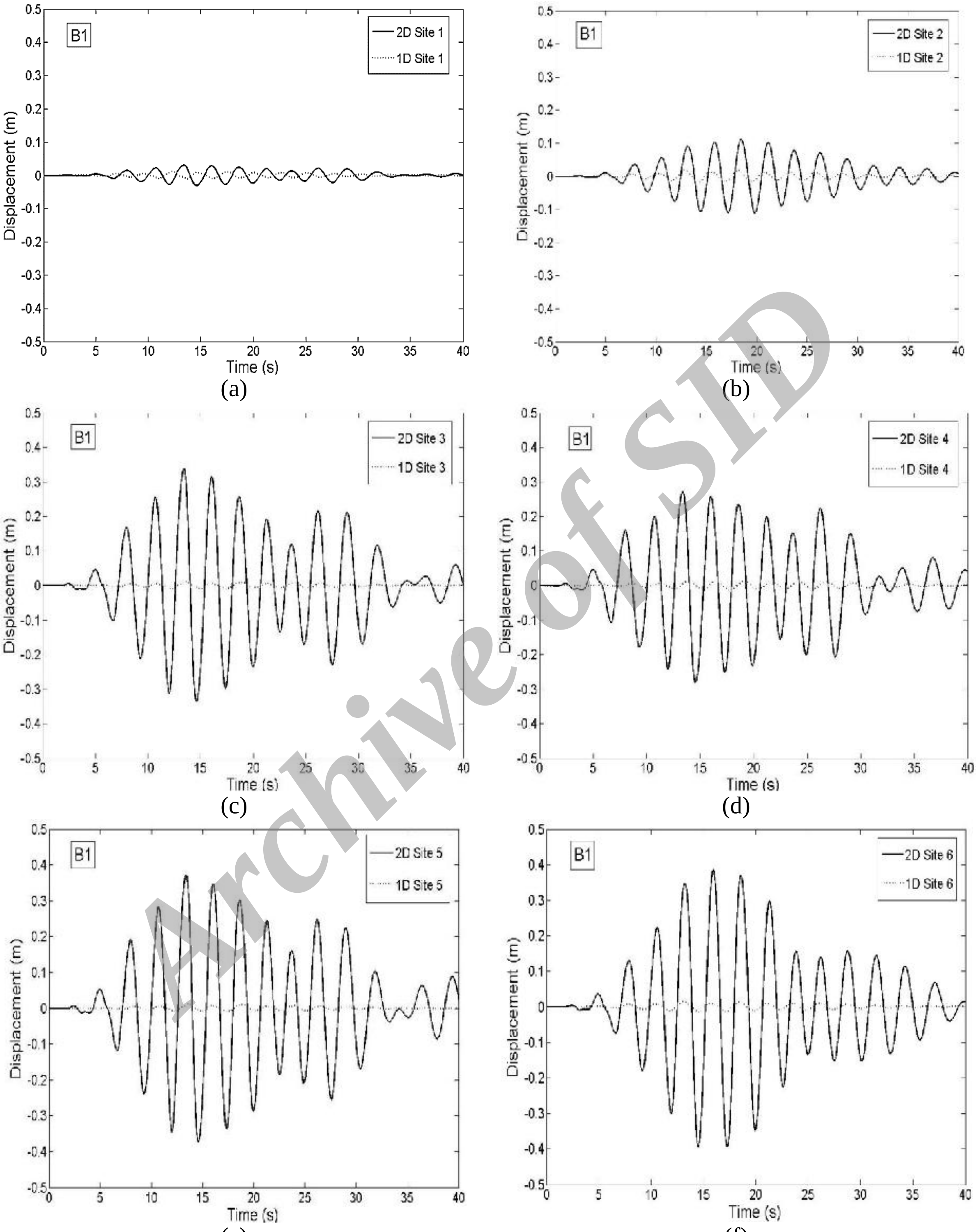
Building	Mass of all the floors except top floor (kN-s^2/m)	Mass of the top floor (kN-s^2/m)	Storey	Moments of inertia of columns 10^{-4} (m^4)		Moments of inertia of beams 10^{-4} (m^4)	Area of columns (m^2)
				I_{XX}	I_{YY}		
B1	500	300	1 to 5	108.00	108.00	200.00	0.36
			6 to 10	52.08	52.08	200.00	0.25
			11 to 15	26.67	41.67	200.00	0.20
B2	496	538	1 to 6	26.67	41.67	200.00	0.20

7.1 Response of B1

Time periods of B1 corresponding to the first five modes are given in Table 7. The comparison of roof displacement responses of B1 assumed to be situated on the 8 sites for one typical ground motions obtained from 2D and 1D ground response analyses is shown in Fig. 10.

Table 7: Time periods of B1 corresponding to first five modes

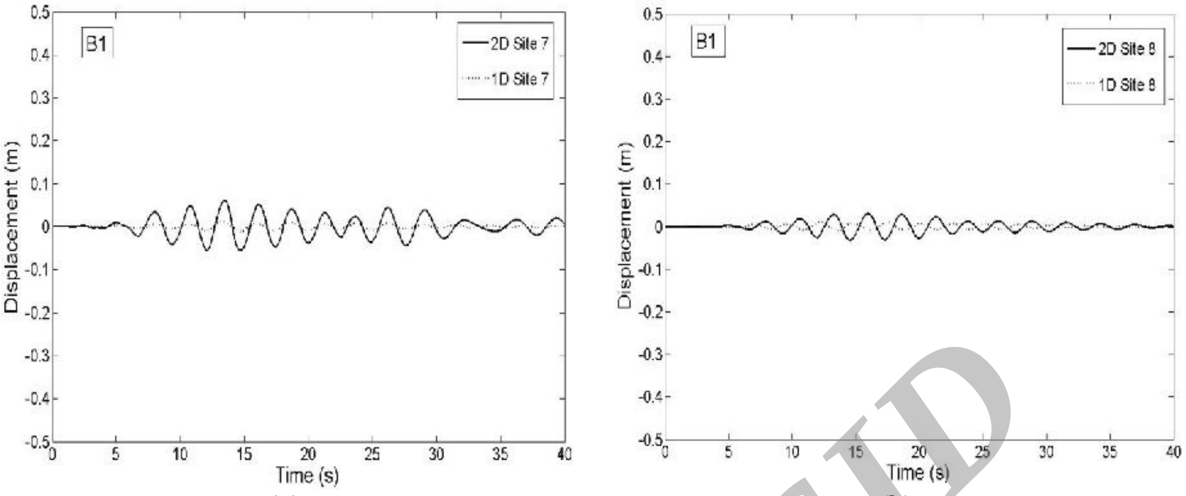
Mode	1	2	3	4	5
Time period (s)	2.6	0.98	0.86	0.75	0.64


B1
2D Site 1
1D Site 1
2D Site 2
1D Site 2
2D Site 3
1D Site 3
2D Site 4
1D Site 4
2D Site 5
1D Site 5
2D Site 6
1D Site 6
Displacement (m)
Time (s)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
5
10
15
20
25
30
35
40

(a) (b)

(c) (d)

(e) (f)



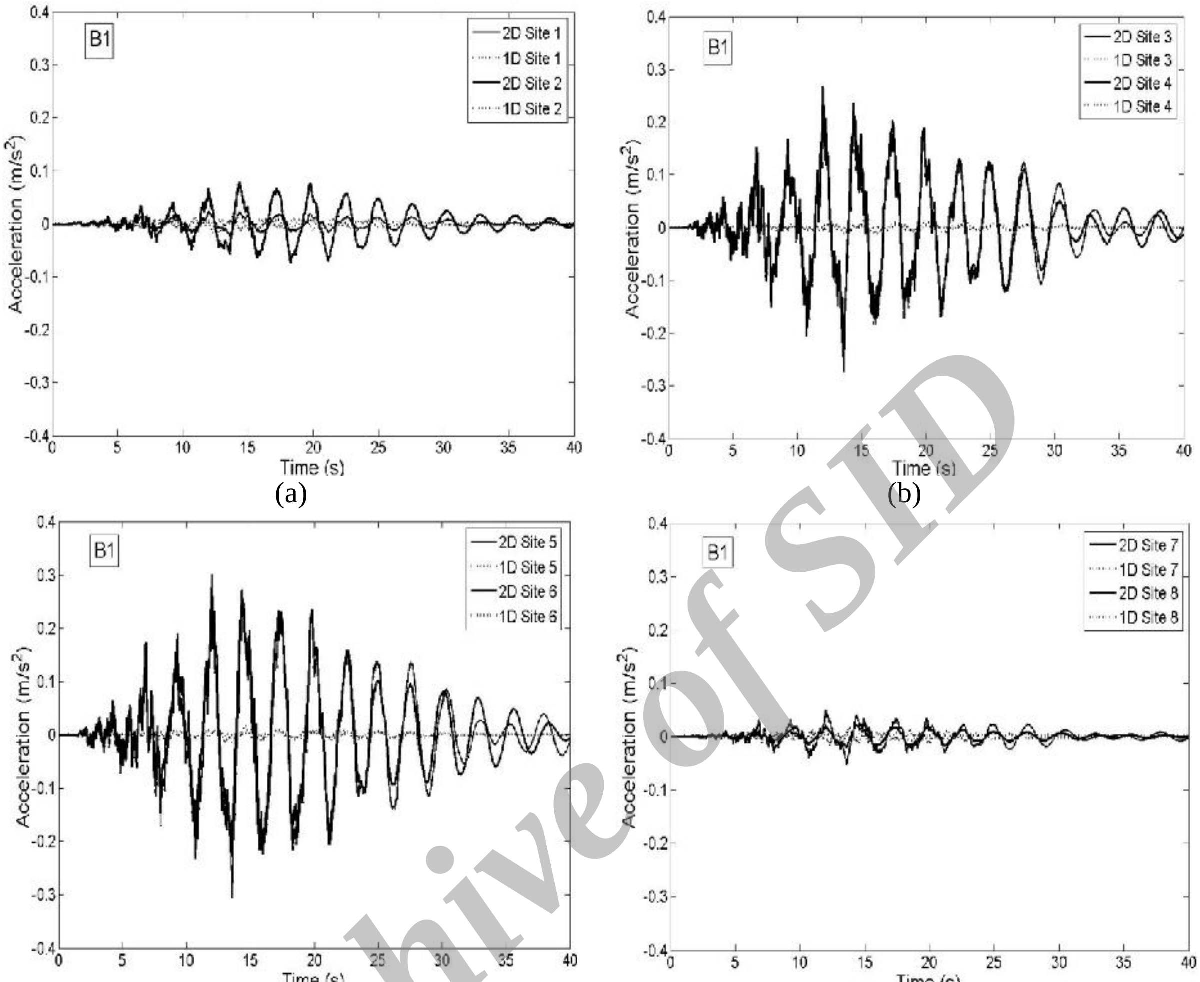
(g) (h)

Figure 10. Roof displacement responses of B1 for one typical ground motion from 2D and 1D ground response analyses. (a) site 1 (b) site 2 (c) site 3 (d) site 4 (e) site 5 (f) site 6 (g) site 7 (h) site 8

It is observed that the displacement responses of B1 are higher for all the sites with the ground motions obtained through 2D analyses compared to displacement response for ground motions from 1D analyses, even though, the PGA of surface level ground motions from 1D analyses is more for sites 1,2,7 and 8. Percentage differences in average peak roof displacement of B1 for fifteen linear time history analyses using surface ground motions from 2D and 1D ground response analysis for B1 is given in Table 8. Maximum percentage difference in average peak displacement of fifteen simulations between 2D and 1D ground response analyses is observed to be 98% for site 3 which has a depth of soil stratum of 800m. Maximum displacement of 0.4117m is observed at this site. Typical roof acceleration responses for B1 for one simulation of ground motion from 2D and 1D ground response analyses are compared in Fig. 11. From the comparison it is seen that, acceleration response obtained at the roof for B1 using time history obtained from 2D ground response analyses is higher than that obtained from 1D ground response analyses for all the eight sites considered.

Table 8: Average peak roof displacement of B1 for fifteen ground motions from 2D and 1D ground response analyses

Site	Average peak displacement of 15 simulations (m)		Percentage difference w.r.t 2D
	2D	1D	
1	0.0259	0.0098	62.2709
2	0.0726	0.0190	73.8537
3	0.4117	0.0082	98.0172
4	0.2437	0.0151	93.8199
5	0.3250	0.0126	96.1312
6	0.2828	0.0107	96.2196
7	0.0563	0.0202	64.0781
8	0.0232	0.0155	33.1103



(a) (b)

(c) (d)

Figure 11. Roof acceleration responses of B1 for one typical ground motion from 2D and 1D ground response analyses.(a) site1, site2 (b) site3, site4 (c) site5, site6 (d) sites7, site8

7.1.1 Comparison of design base shear with base shears obtained for ground motions from 2D and 1D ground response analyses for B1

Design base shear for B1 has been calculated according to Indian seismic code [18] provision by response spectrum method and is found to be 2714.45kN. As B1 is an important structure designed as ordinary moment resisting frame located in zone III, an importance factor of 1.5 (I=1.5) and response reduction factor of 3 (R=3) is adopted. Base shear obtained from IS 1893(part1)-2002 is compared with the base shears from linear time history analyses with ground motions obtained through 2D and 1D ground response analysis for B1 and the ratio of design base shear obtained from time history analyses with 2D and 1D ground response analysis are given in Table 9. It is observed that maximum base shear is obtained for site 5 with ground motions from 2D ground response analyses and is around 4 times than that of the design base shear as per IS 1893(part1)-2002 [18]. Base shears obtained from time history analysis with 1D ground response analysis are found to be lesser than the design base shear estimated.

Table 9: Comparison of Base shear for B1

Site	Base Shear (kN)		IS 1893(part1) -2002 (kN)	Ratio	
	2D	1D		2D	1D
1	927.91	352.27	2714.45	0.3418	0.1298
2	2538.33	462.64	2714.45	0.9351	0.1704
3	10635.93	315.41	2714.45	3.9183	0.1162
4	8853.26	359.02	2714.45	3.2615	0.1323
5	11779.67	315.40	2714.45	4.3396	0.1162
6	9862.06	393.28	2714.45	3.6332	0.1449
7	2081.13	352.84	2714.45	0.7667	0.1300
8	819.56	332.00	2714.45	0.3019	0.1223

7.2 Response of B2

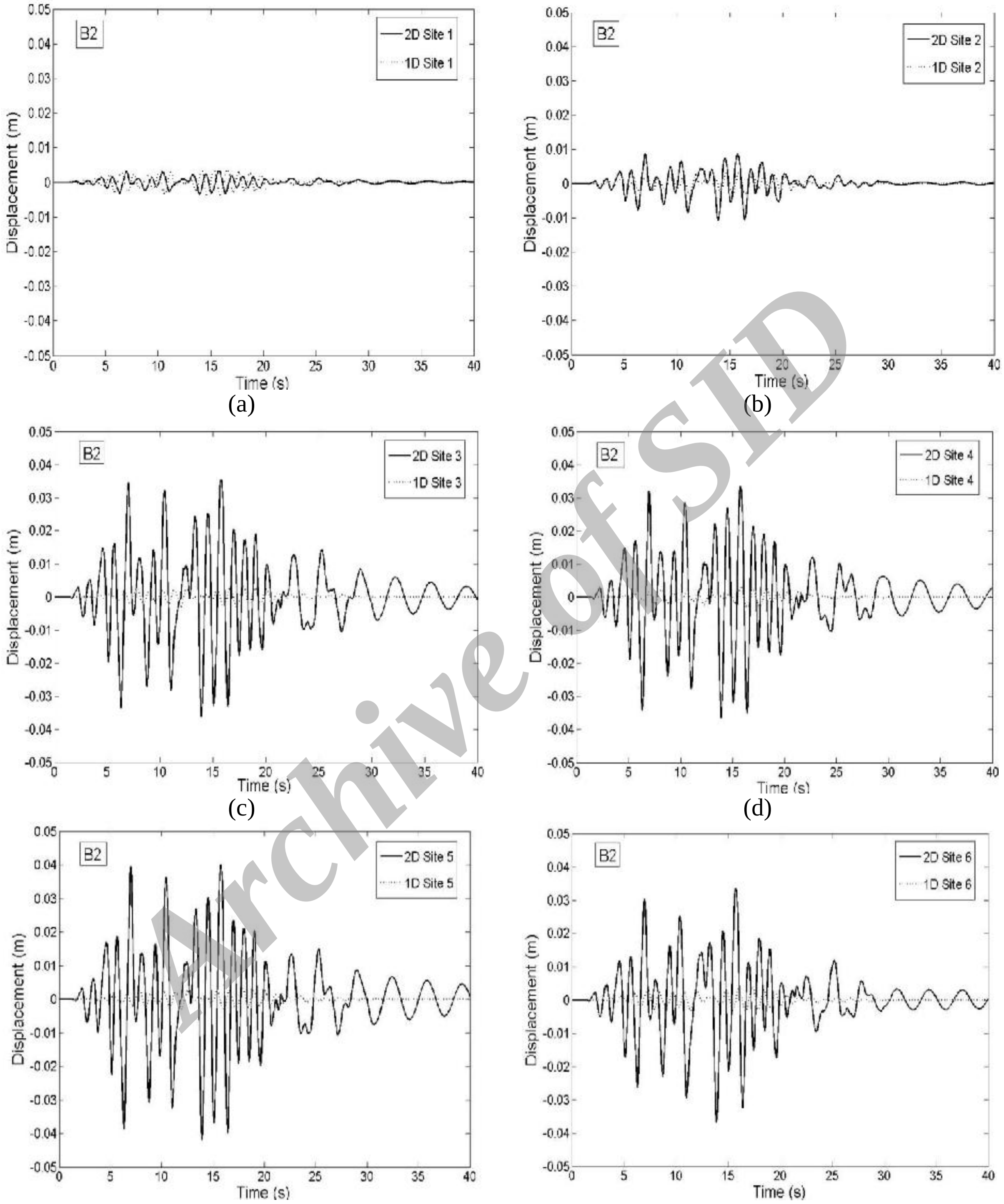
Similarly, displacement responses, acceleration responses and base shear are studied for B2. It is observed that similar to B1 the displacement responses are higher for ground motions from 2D ground response analysis compared to displacement responses for ground motions from 1D ground response analysis for B2 and a maximum displacement is observed for site 5. The comparison of displacement responses of B2 for ground motions from 2D and 1D ground response analyses are shown in Fig 12. Time periods of B2 corresponding to the first five modes are given in Table 10. Percentage differences in average peak roof displacement of B2 due to 2D and 1D analyses based ground motions are given in Table 11.

Table 10: Time periods of B2 corresponding to first five modes

Mode	1	2	3	4	5
Time period (s)	1.2	0.64	0.59	0.39	0.33

Table 11 Percentage difference in average peak roof displacement of B2 for 2D and 1D analysis based ground motions

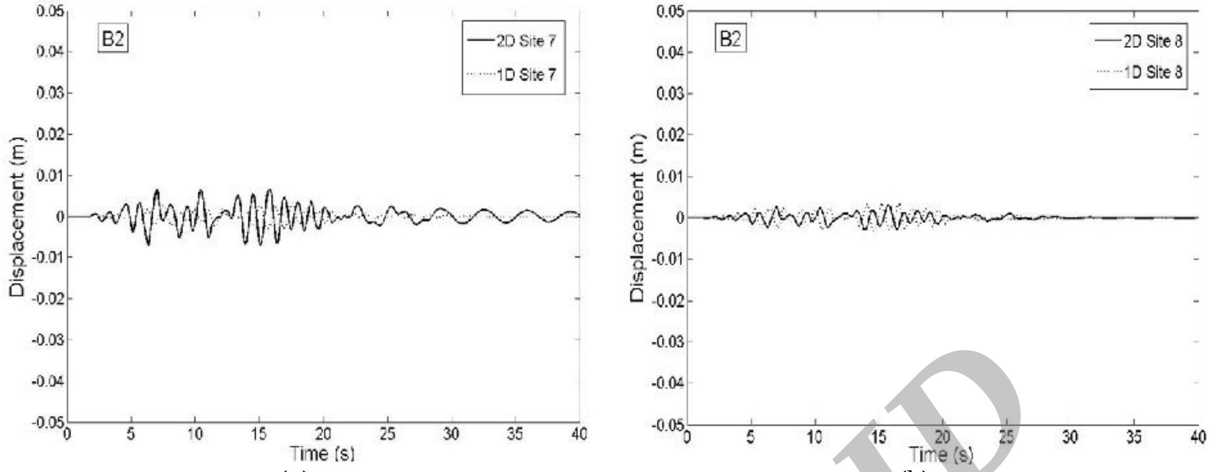
Site	Average peak displacement of 15 simulation (m)		Percentage difference
	2D	1D	
1	0.0036	0.0034	3.5814
2	0.0086	0.0030	64.8972
3	0.0370	0.0029	92.0997
4	0.0350	0.0027	92.4231
5	0.0432	0.0030	93.0387
6	0.0321	0.0034	89.4547
7	0.0078	0.0030	61.3133
8	0.0030	0.0028	3.8557


B2
2D Site 1
1D Site 1
2D Site 2
1D Site 2
2D Site 3
1D Site 3
2D Site 4
1D Site 4
2D Site 5
1D Site 5
2D Site 6
1D Site 6
Displacement (m)
Time (s)
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
0
5
10
15
20
25
30
35
40

(a) (b)

(c) (d)

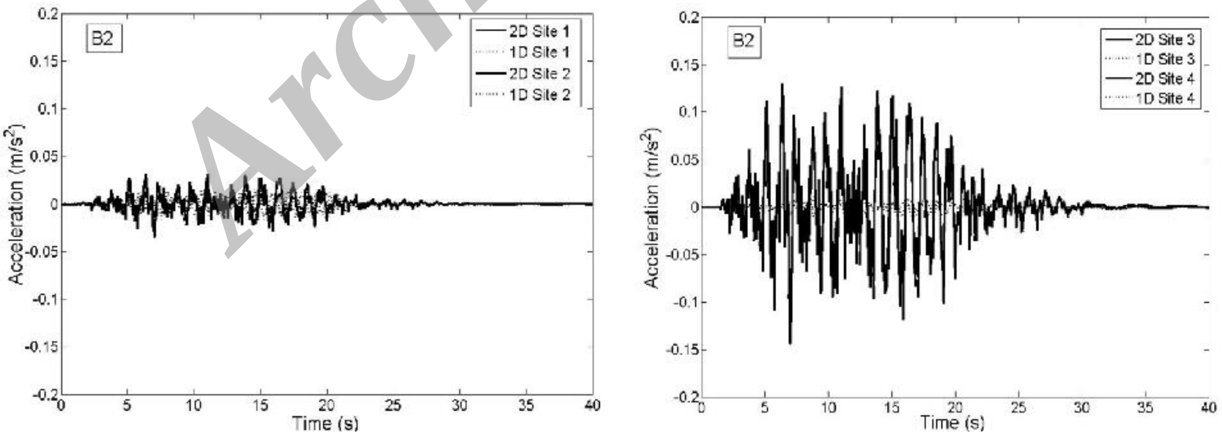
(e) (f)



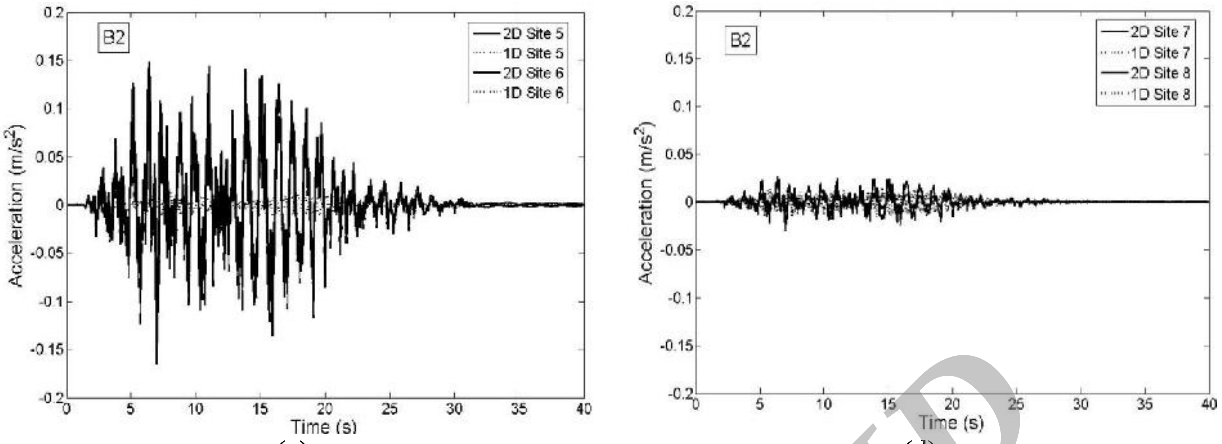
(g) (h)

Figure12. Roof displacement responses of B2 for one typical ground motion from 2D and 1D ground response analyses. (a) site 1 (b) site 2 (c) site 3 (d) site 4 (e) site 5 (f) site 6 (g) site 7 (h) site 8

It can be seen that higher percentage difference of around 93% is observed for the sites 3 and 5 which has a soil depth of 800m. The comparison of acceleration responses of B2 for 2D and 1D based ground motions are shown in Fig. 13. It is seen that, for all the sites, the acceleration response of B2 for ground motions from 2D analysis are found to be higher than that of ground motions from 1D ground response analysis. Though from Table 5 it may be noted that, PGA obtained at sites 1 and 8 from 1D ground response analyses are more than PGA obtained from 2D ground response analyses, average peak displacements of B2 for ground motions from 2D and 1D ground response analyses are found to be more or less equal.



(a) (b)



(c) (d)

Figure 13. Roof acceleration responses of B2 for one typical ground motion from 2D and 1D ground response analyses. (a) site1, site2 (b) site3, site4 (c) site5, site6 (d) site7, site8

7.2.1 Comparison of design base shear with base shears obtained for ground motions from 2D and 1D ground response analyses for B2

Design base shear has been calculated according to IS 1893(Part1)-2002 [18] for B2 from response spectrum method and is found to be 2646 kN and is compared with the base shear obtained from 2D and 1D linear time history analyses. Similar to B1, B2 is also an important structure designed as ordinary moment resisting frame located in zone III, hence an importance factor of 1.5 (I=1.5) and response reduction factor of 3 (R=3) is adopted. From the ratio of base shears obtained from 2D and 1D ground response analysis based ground motions to the design base shear as given in Table 12, it is seen that maximum base shear is obtained for site 5 for 2D based ground motions. It may be noted that 2D ground response analyses based base shear is 1.5 times that of design base shear and base shear obtained from 1D analyses is lesser than the design base shear.

Table 12: Comparison of Base shear for B2

Site	Base Shear (kN)		IS 1893(Part1)-2002 (kN)	Ratio	
	2D	1D		2D	1D
1	320.99	329.57	2646	0.1213	0.1246
2	828.84	286.77	2646	0.3132	0.1084
3	3518.40	274.98	2646	1.3297	0.1039
4	3450.53	245.85	2646	1.3040	0.0929
5	3958.66	274.98	2646	1.4961	0.1039
6	2950.66	309.94	2646	1.1151	0.1171
7	730.82	273.02	2646	0.2762	0.1032
8	261.12	284.78	2646	0.0987	0.1076

8. RESULTS AND DISCUSSIONS

In the present study peak ground accelerations, spectral amplifications and response spectra from 2D ground response analyses are compared with 1D ground response analyses for Sabarmathi river basin for the simulated scenario earthquake of M_w 7.6 with seismological parameters of Bhuj 2001 earthquake and considerable differences are observed. For the sites with greater depth of soil strata higher PGA values are observed compared to the lesser depth of soil strata in 2D analyses, whereas, in 1D analyses, sites with lesser depth of soil strata showed higher PGA than the sites with greater soil depth. Further it is observed that PGA values obtained from 2D ground response analyses at sites 4 and 5 are twice as that of PGA values obtained from 1D ground response analyses, which indicates the necessity for carrying out the 2D ground response analyses considering depth of soil strata till the bedrock. PGA observed at surface for site 5 in 2D analysis is 0.096 g which is in closer agreement with the peak acceleration of 0.1 g which was recorded at the passport office building at Ahmedabad during the Bhuj earthquake.

Spectral amplification obtained from 2D and 1D analysis is compared with the field measured typical amplification (H/V) reported by Sairam et al., [4] for the alluvial basin considered in the present study. From the comparison it is observed that the spectral amplification from 2D analyses are more for sites 3,4,5 and 6 with greater soil depths and lesser for sites 1, 2, 7 and 8 with lesser soil depths than H/V reported from literature. However, amplification from 1D analyses is lesser than H/V reported for all the sites considered. This shows that 1D ground response analyses alone may not be adequate and 2D ground response analyses considering the entire depth of soil strata and soft rock strata upto bedrock level is necessary to estimate the amplification that is expected to occur in deeper alluvial basins similar to Sabarmati basin considered in the present study.

The comparison of response spectra from 2D and 1D analyses for 8 sites shows that not only the depth of soil strata but also the model for ground response analysis has a profound influence on the amplification of soil sites. As it has been reported in literature [15], for deeper sites 2D analyses based results are more than 1D analyses and for shallow sites 2D analyses based results are less than 1D analyses. Response spectra for recorded ground motions for Bhuj 2001 earthquake is compared with the response spectra obtained from 2D and 1D ground response analyses and it is found that spectral ordinates of recorded ground motions of Bhuj 2001 earthquake are higher than that obtained from 2D and 1D ground response analyses.

Time history analyses of B1 and B2 showed huge difference in displacement response for 2D analyses based ground motion compared to 1D analyses based ground motions. Buildings situated on greater soil depths showed around 96 % difference in displacement response between 2D and 1D analysis for both B1 and B2. Acceleration responses for ground motions from 2D analyses are more than the responses for ground motions from 1D analysis for both B1 and B2 for all the sites.

Base shears obtained for ground motions from 2D and 1D ground response analyses for B1 and B2 showed that base shear obtained from 2D analysis is higher than the design base shear calculated from IS 1893(Part1)-2002 [18] and hence amplification based on 1D analysis proves to be inadequate. Displacement responses show considerable percentage difference in average peak displacement for both B1 and B2 and hence shows the necessity for carrying out 2D ground response analyses including entire soil and soft rock strata up to the bedrock to estimate the response of building during future earthquakes.

9. CONCLUSIONS

The importance of carrying out two dimensional ground response analyses for deeper alluvial basin taking into account the depth of soil and soft rock strata till the bed rock level has been emphasized in the present study. From the comparison of 2D and 1D ground response analyses, it is seen that the PGA and S_a from 2D analyses are more than the PGA and S_a from 1D analyses for deeper deposits at the middle of the basin and lesser than PGA and S_a from 1D analyses for shallow sites near the edge of the basin. This observation is in line with the observations reported in literature. Though PGA obtained from 1D ground response analyses for sites near the edge of the basin are higher than 2D ground response analysis; the building responses are higher for the ground motions from 2D ground response analyses than 1D ground response analyses. This observation has indicated that, ground motions from 2D analyses are rich in energy content to cause damage to buildings than it is considered as per the existing code of practice of accounting for amplification factors obtained through 1D ground response analysis. The spectral amplifications from the present study are also compared with H/V amplifications reported in literature for similar site and seen that 1D analyses underestimates the response for all the sites.

The comparison of acceleration and displacement response of typical fifteen and six storey framed buildings from linear time history analyses for the ground motions obtained through 2D and 1D ground response analyses has revealed that the acceleration and displacement response of both the buildings are more for the ground motions obtained from 2D analyses for all the sites. Further, base shears obtained from linear time history analysis for ground motions from 2D and 1D ground response analyses are compared with the design base shear calculated as per response spectrum method of IS 1893(Part1)-2002. Base shear obtained from 2D analysis of B1 and B2 were 4.3 times and 1.5 times higher than the design base shear calculated as per Indian seismic code for buildings located at deeper soil sites which shows the necessity of 2D ground response analyses considering the entire soil and rock geometry till the bedrock level with site-specific ground motion.

With the limited studies carried out, it is seen that 1D ground response analyses alone may not be adequate for simulating the response of deeper alluvial basin for site specific earthquake and there is a need to carry out 2D ground response analyses also for realistic site-specific analyses. Present study demonstrates that the geotechnical, geological strata and geometry of basin upto hard rock has a significant influence on surface level ground motions and the response of the buildings and considering only the soil amplification factors as per average shear wave velocity of top 30m soil depth or the modification of spectra based on the soil type alone may not be adequate for deeper basins similar to the Sabarmathi basin considered in present study.

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