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PSEUDO-DYNAMIC TEST OF CFST BRIDGE PIER UNDER DIFFERENT GROUND EXCITATIONS

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ABSTRACT

The dynamic testing of large-scale structures continues to play a significant role in earthquake engineering research. The pseudo-dynamic test (PDT) is an experimental technique for simulating the earthquake response of structures and structural components in time domain. A Concrete Filled Steel Tube (CFST) built-up pier is a modified form of CFST laced column in which CFST members are connected with RC web in longitudinal direction and with steel tube in transverse direction. For this study, a CFST built-up pier is tested under seven different earthquake time histories having scaled PGA of 0.05g. From the experiment acceleration, velocity, displacement and load time histories are observed. The pier experienced maximum acceleration due to Imperial Valley earthquake and minimum due to Wenchuan earthquake. For the Imperial Valley earthquake the acceleration is magnified by 17 times while for the Wenchuan earthquake the acceleration is magnified by 10 times. The frequency of the pier is found to be 1.41 Hz. The result shows that this type of pier has excellent static and earthquake resistant properties.

KEYWORDS

CFST-Builtup Pier, Pseudo-Dynamic, Time History, Seismic Performance, Bridge Pier

INTRODUCTION

The dynamic testing of large-scale structures continues to play a significant role in earthquake engineering research. Although the shaking table test is recognized as the most direct means for earthquake simulation, the pseudo dynamic test has been an effective and widely accepted practice since the initial studies by Takanashi et al. [1] and Mahin and Shing [2]. In a pseudo-dynamic test, the reaction forces of the tested structure or its components are directly measured and feed backed on-line for earthquake response analysis via numerical integration. A pseudo-dynamic test, requiring a quasi-static loading actuator, allows for the testing of larger scale structures than those permitted by a shaking table test.

Bridges are the important parts of highway structures which must be in function before and after earthquake [3]. Pier is the major component which resists lateral load during earthquake. Concrete Filled Steel Tube (CFST)-built-up piers have been widely used in earthquake-prone regions because of their excellent structural performance and properties such as high ductility, high strength, and large energy absorption capacity [4–8]. A CFST-built-up pier is a column in which CFST members are connected with RC web in lateral direction and with steel tube in longitudinal directions [9-10].

Pseudo-dynamic tests were conducted on blind bolted composite frames to CFST columns by Wang et al [11]. The result shows that CFST composite frames possess plumper hysteretic loops, and thus exhibit an excellent energy dissipation capacity. Chen et al. [12] conducted Pseudo-Dynamic experiment on CFST structure. The result shows that CFST structure is an outstanding structural style with excellent anti-seismic behaviour. Tsai and Hsaio [13] conducted full scale Pseudo-dynamic test of concrete-filled tube (CFT)/buckling-restrained braced frame (BRBF). They concluded that this type of frame structures dissipate energy during earthquakes. The dynamic tests on this type of columns are very rare. To know the seismic performance of this type of column the test is carried out.

Yadav et al. [14] had carried out quasi-static test on CFST-RC column which showed that this type of column has excellent seismic resistant properties. Using the same test setup and the similar specimen, this test was extended to the dynamic loading, since dynamic testing represents closer representation of real seismic behaviour.

For the slender columns, stiffness is an important parameter for geometrical stability. RC-web increases the stiffness of the built-up columns and also increases the lateral load carrying capacity. CFST-built-up piers were used in Ganhaizi Bridge due to their excellent static and earthquake resistant properties. Ganhaizi Bridge is located between Ya-an and Xi-chang (Ya-Xi) expressway in Sichuan Province of China where the seismicity level is very high. The total length of the bridge is 1811 meters and it has 36 spans with the longest span of 62.5 meters and highest pier is of 107 meters. The superstructure is composed of CFST truss girders and prestressed concrete deck slabs.

For this study different input ground motions are taken as main parameter. The performance of this type of bridge pier under different seismic excitations is investigated.

EXPERIMENTAL PROGRAM

Test Specimen

The height of the piers in Ganhaizi Bridge ranges from 20 m to 107 m. The bottom CFST chords are CFST with a diameter of 813 mm. Based on the case of Ganhaizi Bridge, and the test condition in laboratory of Fuzhou University, 1:8 scale ratio for a 20 m pier was selected for the test. The study of this Ganghaizi Bridge pier is divided into three parts: First, the pier without RC-Web [16], Second, pier with full RC-Web and third, the pier with partial RC-Web. For this the pier with full RC- Web is considered. In this study, a CFST-built-up pier specimen was constructed and tested in lab consisting four CFST limbs. The total height of the specimens is 3400 mm including 400 mm depth of concrete foundation and 500 mm thickness of pier cap for loading. The centre-to-centre (c/c) distance between two CFST limbs is 500 mm along the loading direction which is connected by RC web of uniform thickness. The c/c distance of two CFST limbs is 700 mm in the transverse direction which were connected by 48 mm diameter steel tube of 2mm thickness at the spacing of 625 mm. The thickness of RC web is 50 mm, reinforced with 5 numbers of Ø6 mm rebar are in longitudinal direction in each side and stirrups of Ø6 mm bar spaced at 50mm. Q345 grade of steel is used for the steel tube and the rebar while C50 grade of concrete is used for both infill in the steel tube and RC-web. For the foundation and the column cap, C30 grade of concrete was used. The details of specimens are shown in Figure 1.

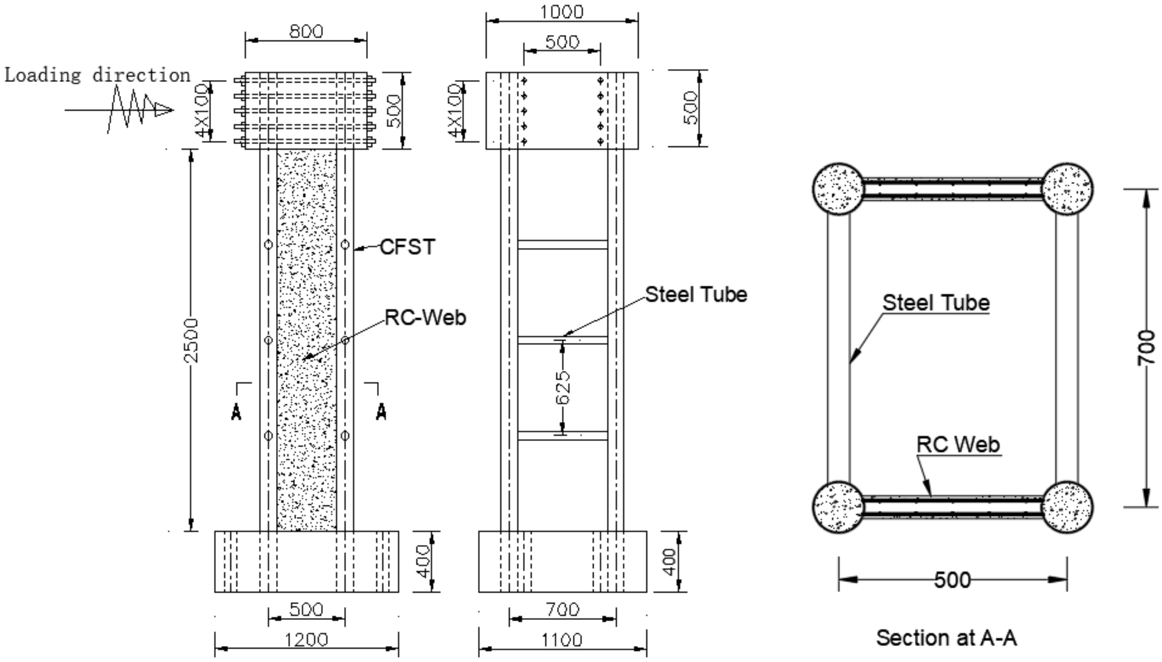

Fig. 1 - Details of CFST-RC Pier

Test Setup

Figure 2 and Figure 3 show the general arrangement of test setup and panoramic view in laboratory. The base of the CFST-RC column was bolted to the strong floor to avoid its tilting due to the horizontal thrust, and the free end was connected with actuator. A 1000 KN actuator was rigidly bolted on a reaction wall to apply pseudo dynamic loading to the free end of the pier. To simulate the superstructure load, a hydraulic jack was used to apply a constant axial compressive force at the top of the column. In most cases, dead load of superstructure on the piers ranges from 10 to 20 percent of the piers capacity [15]. For this study, the ratio of the applied axial load (N) to the calculated axial compressive capacity (N_0) was taken as 0.15.

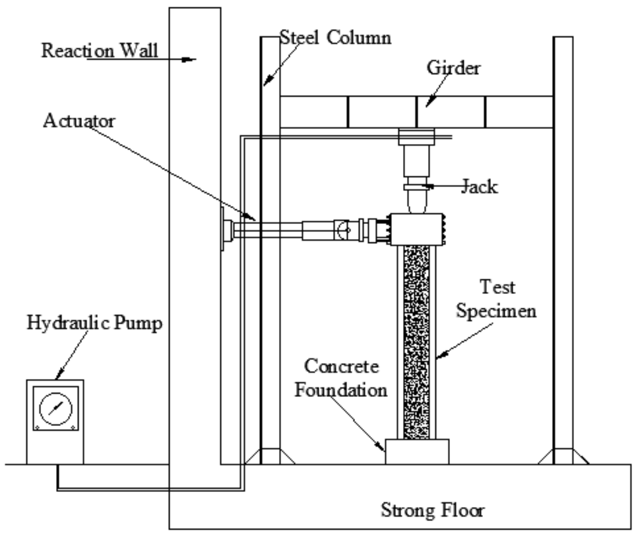

Fig. 2 - General Arrangement

Fig. 3 - Panoramic View

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Seismic Input Motions

Considering the dynamic characteristics of pier seven set of real ground motion records were chosen for this test. Ganhaizi Bridge is situated in Sichuan Province of China, Wenchuan earthquake (also known as Sichuan Earthquake) is selected because it occurred in Sichuan province in 2008. The other input motions are selected from the earthquakes occurred in different countries namely USA, Taiwan (Republic of China), India, Nepal and Japan. This set of records is selected in order to cause important elastic responses and consider 0.05g of PGA magnitudes of all these seven ground motions. Table 1 summarizes the main features of these records and Figure 4 shows scaled acceleration time history of selected earthquakes. The scaled pseudo-acceleration response spectra for all seven waves, corresponding to 0.05g, are shown in Figure 5, considering 5% of damping ratio.

Tab. 1 - Details of Input ground Motions

S.N.	Earthquake	Year	Mw	PGA (g)	Input PGA (g)
1.	Elcentro	1940	6.9	0.3487	0.05
2.	Chi-Chi	1999	7.7	0.3610	0.05
3.	Imperial Valley	1979	6.4	0.3049	0.05
4.	Chamoli	1999	6.8	0.4590	0.05
5.	Gorkha	2015	7.8	0.1549	0.05
6.	Kobe	1995	6.9	0.8280	0.05
7.	Wenchuan	2008	7.9	0.6456	0.05

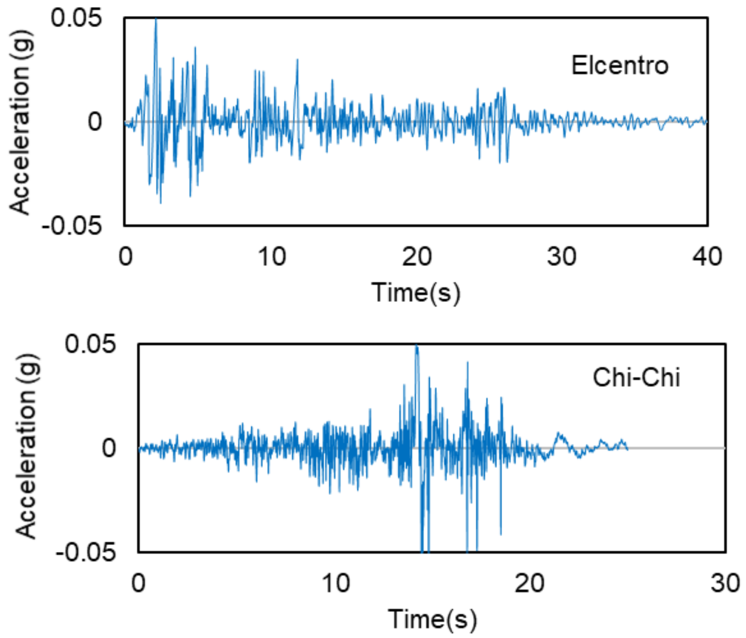

Fig. 4 - Input Seismic Ground Motions

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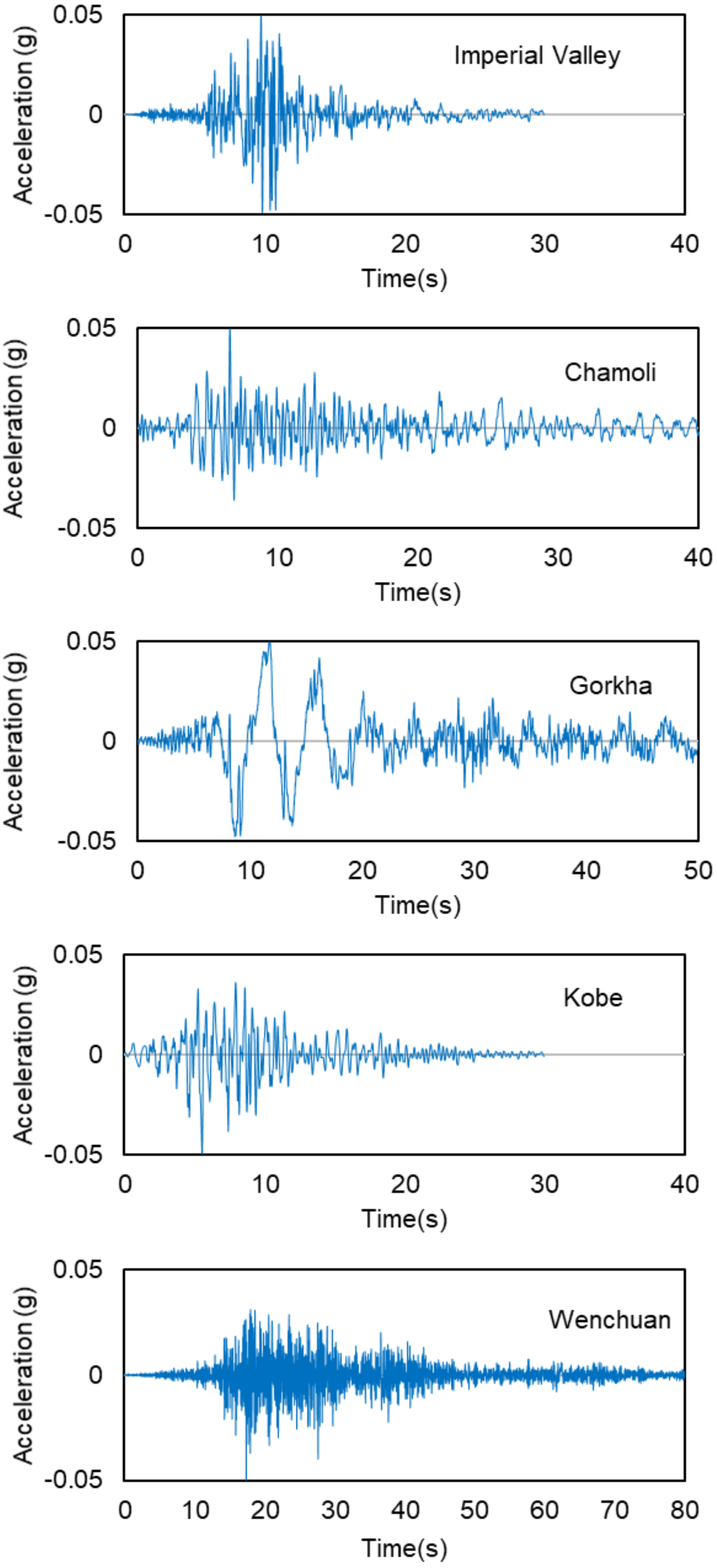

Fig. 4 - Input Seismic Ground Motions

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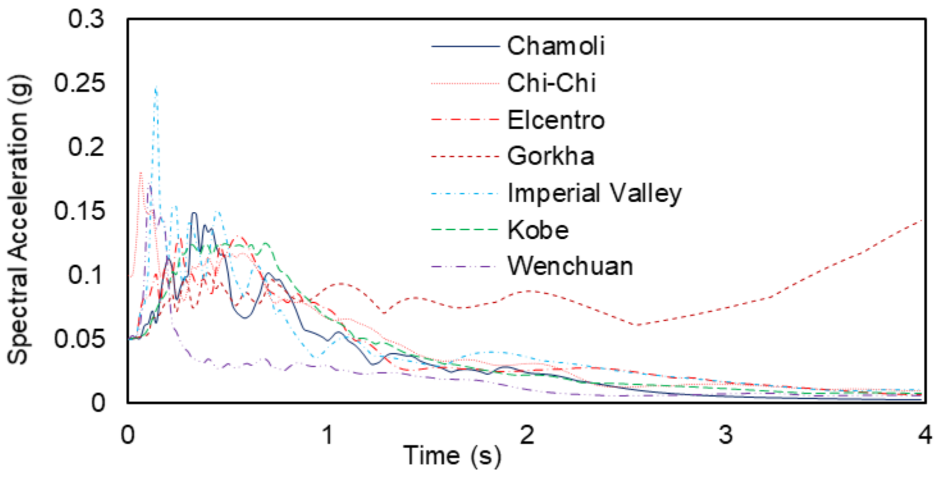

Fig. 5 - Scaled Pseudo-Acceleration Response Spectra (5% Damping)

RESULTS AND DISCUSSIONS

Acceleration Time Histories

Figure 6 shows the acceleration time histories of the tested pier. From the test results the value of peak acceleration has similar relationship with PGA. Input PGA of all seven ground motions is constant as 0.05 m/s^2 but the observed accelerations are different. For Elcentro, Chi-Chi, Imperial Valley, Chamoli, Gorkha, Kobe and Wenchuan earthquake time histories the observed absolute maximum PGA on the top of pier are 768 mm/s^2, 622 mm/s^2, 836 mm/s^2, 589 mm/s^2, 476 mm/s^2, 715 mm/s^2 and 494 mm/s^2 respectively. For the constant PGA of all the selected input motions, the pier experience larger acceleration due to Imperial Valley earthquake while minimum due to Wenchuan earthquake. The dynamic magnification factor is defined as the ratio between the maximum acceleration and PGA. For the Imperial Valley earthquake the acceleration is magnified by 17 times while for the Wenchuan earthquake the acceleration is magnified by 10 times.

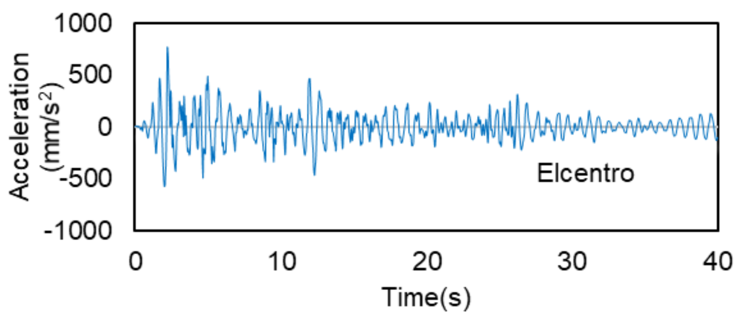

Fig. 6 - Acceleration Time Histories

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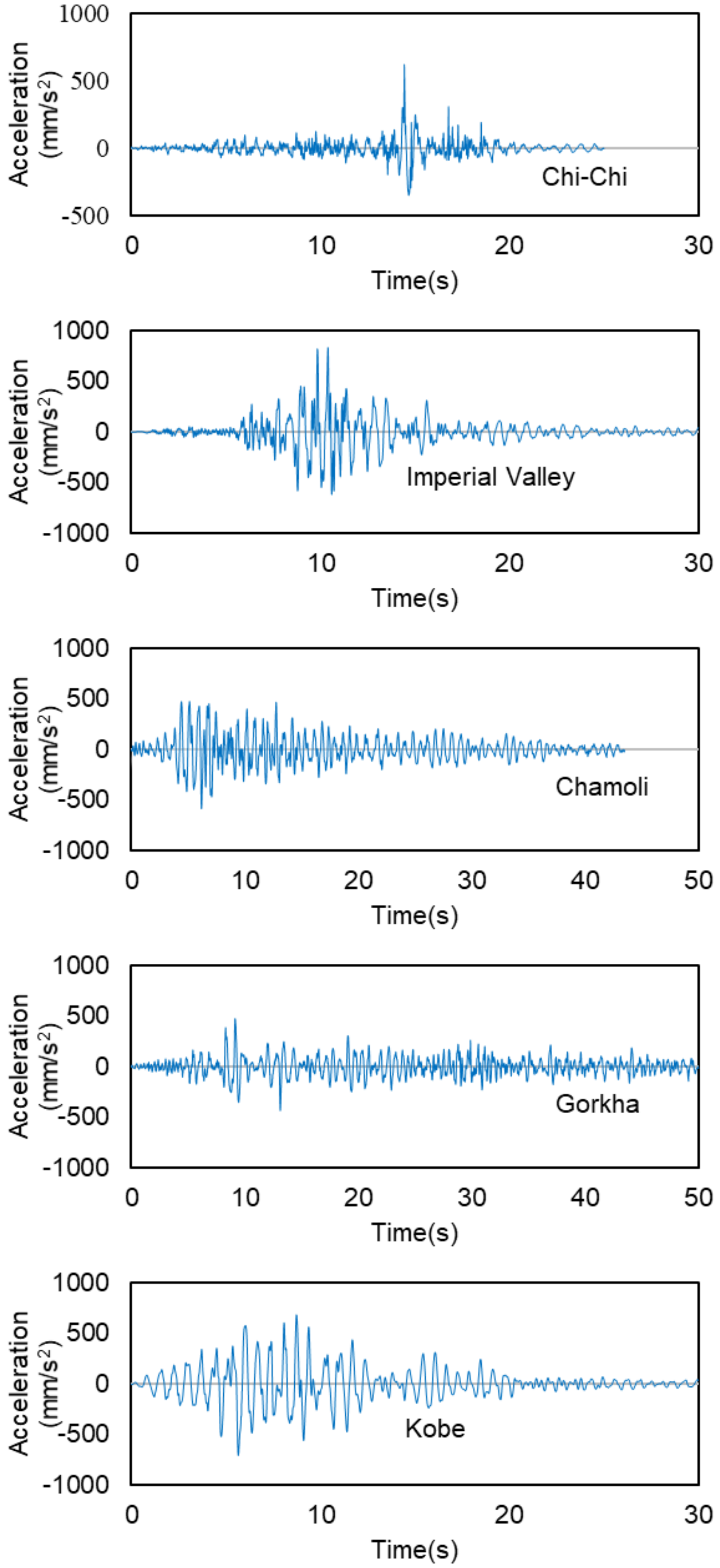

Fig. 6 - Acceleration Time Histories

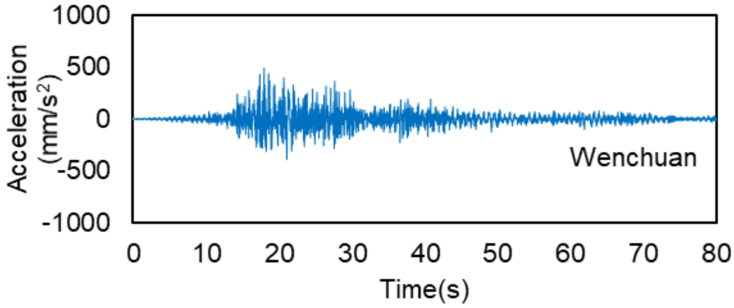

Fig. 6 - Acceleration Time Histories

Velocity Time Histories

Figure 7 shows the velocity time histories of the tested pier. From the test results it can be seen that the value of peak velocity has similar relationship with PGA. Input PGA of all seven ground motions is constant as 0.05 m/s2 but the observed velocities are different. For Elcentro, Chi-Chi, Imperial Valley, Chamoli, Gorkha, Kobe and Wenchuan earthquake time histories the observed absolute maximum velocities on the top of pier are 78 mm/s, 41 mm/s, 58 mm/s, 61 mm/s, 43 mm/s, 73 mm/s and 27 mm/s respectively. Due to the Elcentro Earthquake the pier experiences more velocity than others.

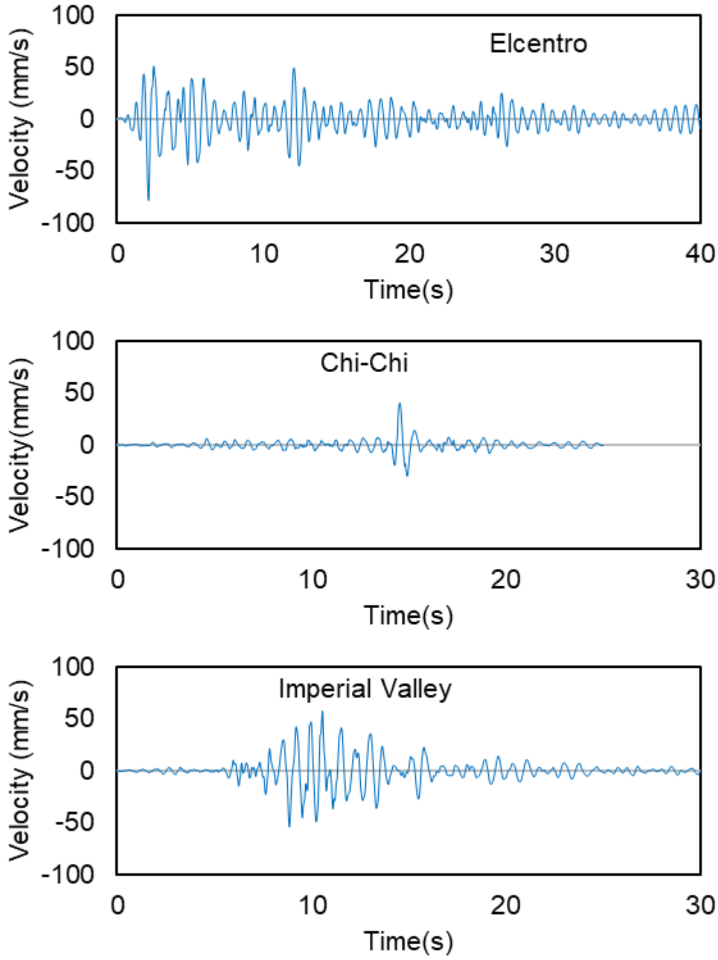

Fig. 7 - Velocity Time Histories

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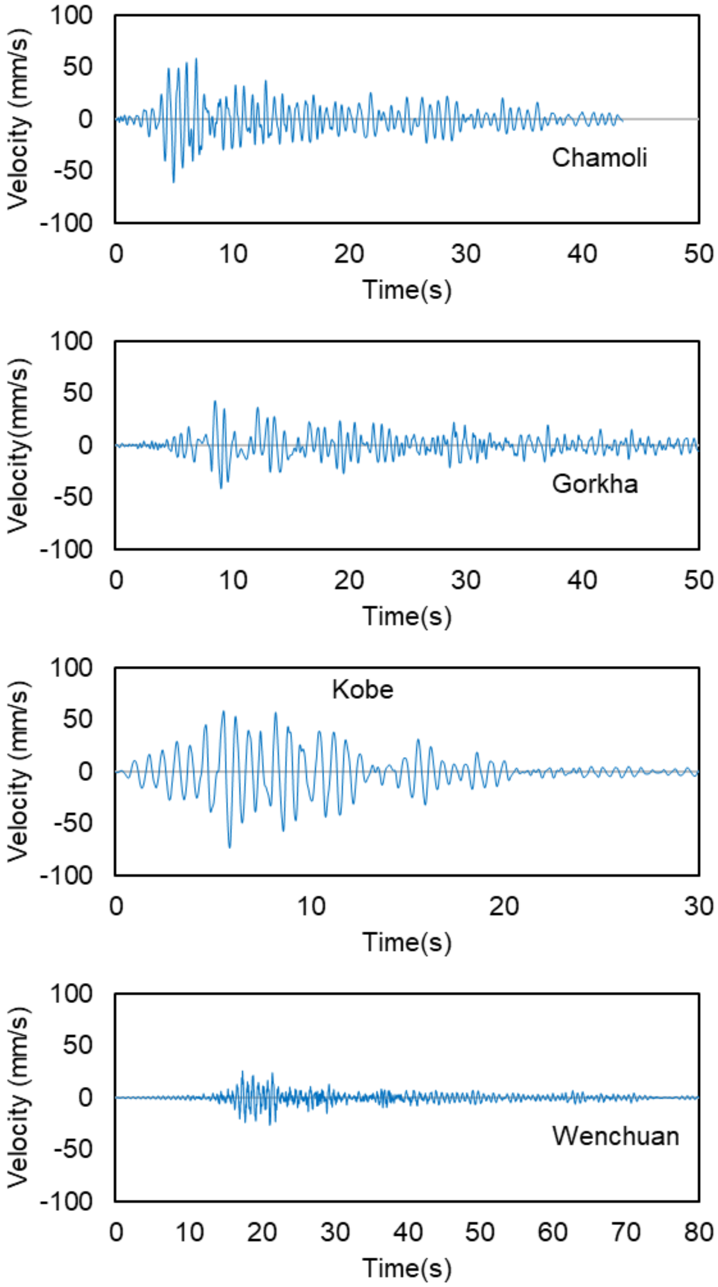

Fig. 7 - Velocity Time Histories

Displacement Time Histories

Figure 8 shows the displacement time histories of the tested pier. From the test results it can be observed that the value of peak displacement has similar relationship with PGA. Input PGA of all seven ground motions is constant as 0.05 m/s^2 but the observed displacements are different. For Elcentro, Chi-Chi, Imperial Valley, Chamoli, Gorkha, Kobe and Wenchuan earthquake time histories the observed absolute maximum displacements on the top of pier are 8.7 mm, 4.8 mm, 6.1 mm, 6.8 mm, 11 mm, 9.6 mm and 3.1 mm respectively. Due to the Gorkha Earthquake the pier experiences more displacement than others.

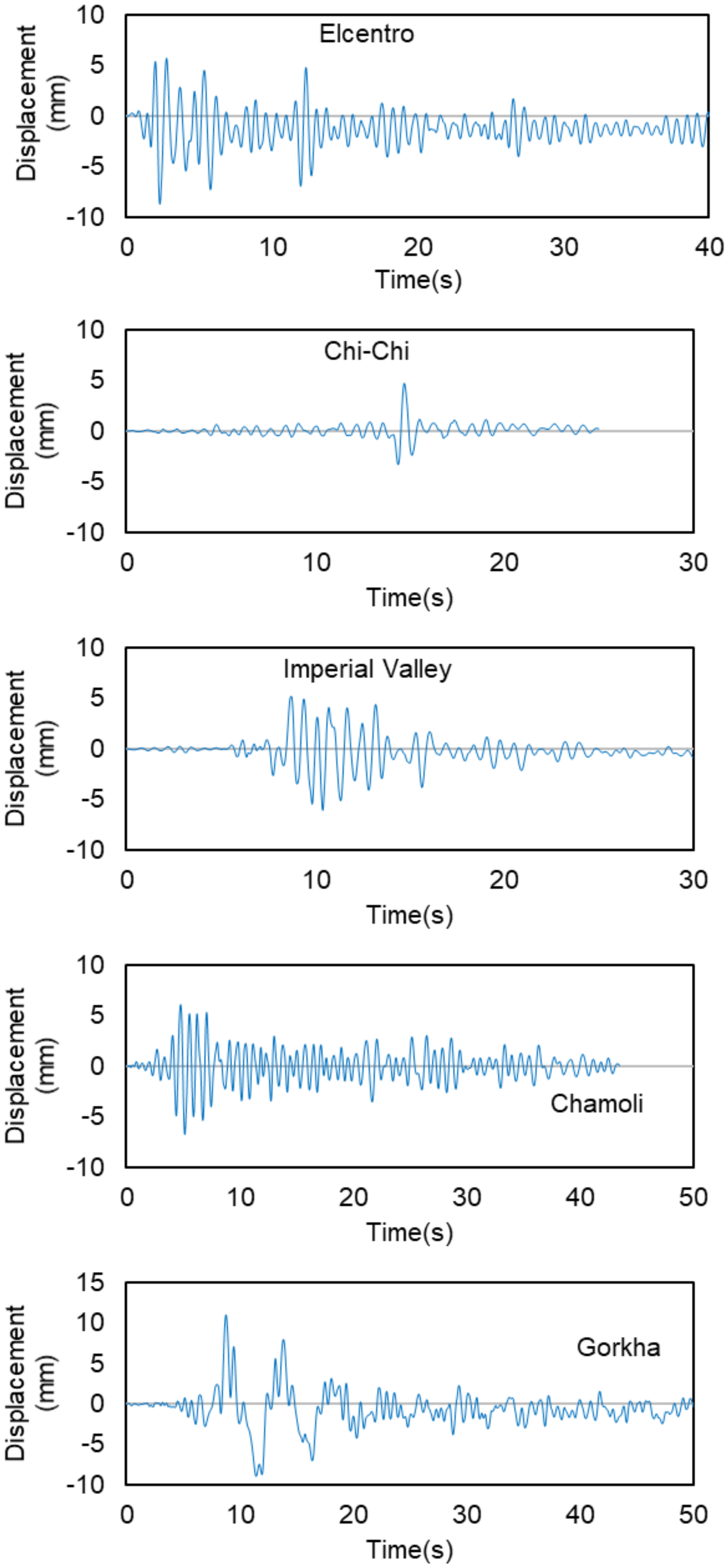

Fig. 8 - Displacement Time Histories

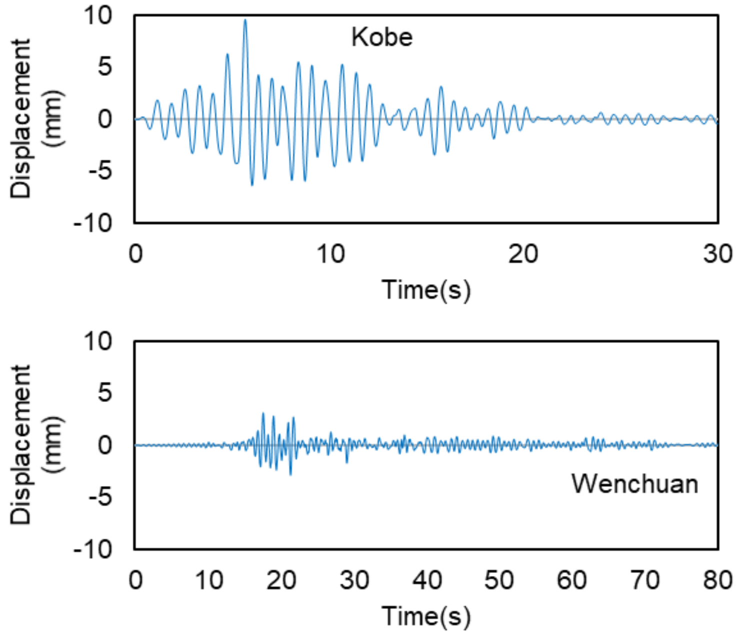

Fig. 8 - Displacement Time Histories

Force Time Histories

Figure 9 shows the force time histories of the tested pier. From the test results it can be observed that the value of peak force has similar relationship with PGA. Input PGA of all seven ground motions is constant as 0.05 m/s^2 but the observed forces are different. For Elcentro, Chi-Chi, Imperial Valley, Chamoli, Gorkha, Kobe and Wenchuan earthquake time histories the observed absolute maximum lateral forces on the top of pier are 1370 kN, 931 kN, 1160 kN, 1356 kN, 2010kN, 1726 kN, and 678 kN respectively. Due to the Gorkha Earthquake the pier experiences more lateral forces than others.

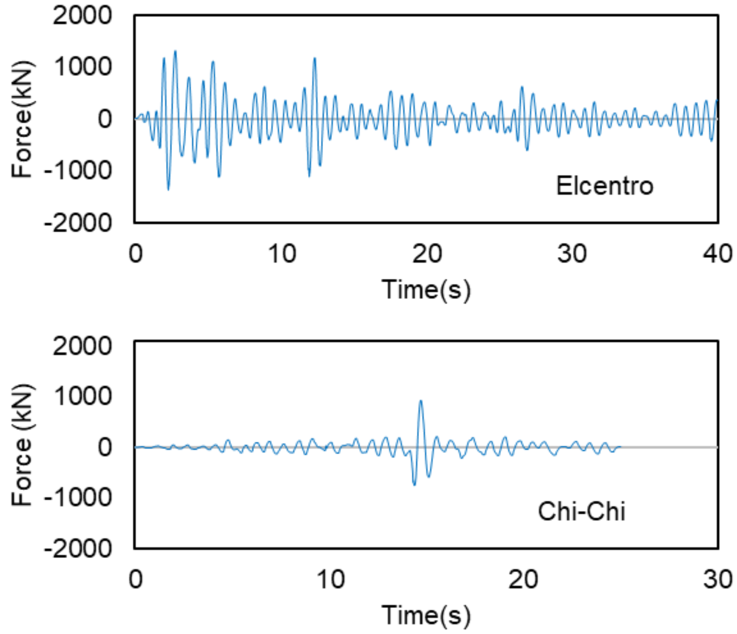

Fig. 9 - Force Time Histories

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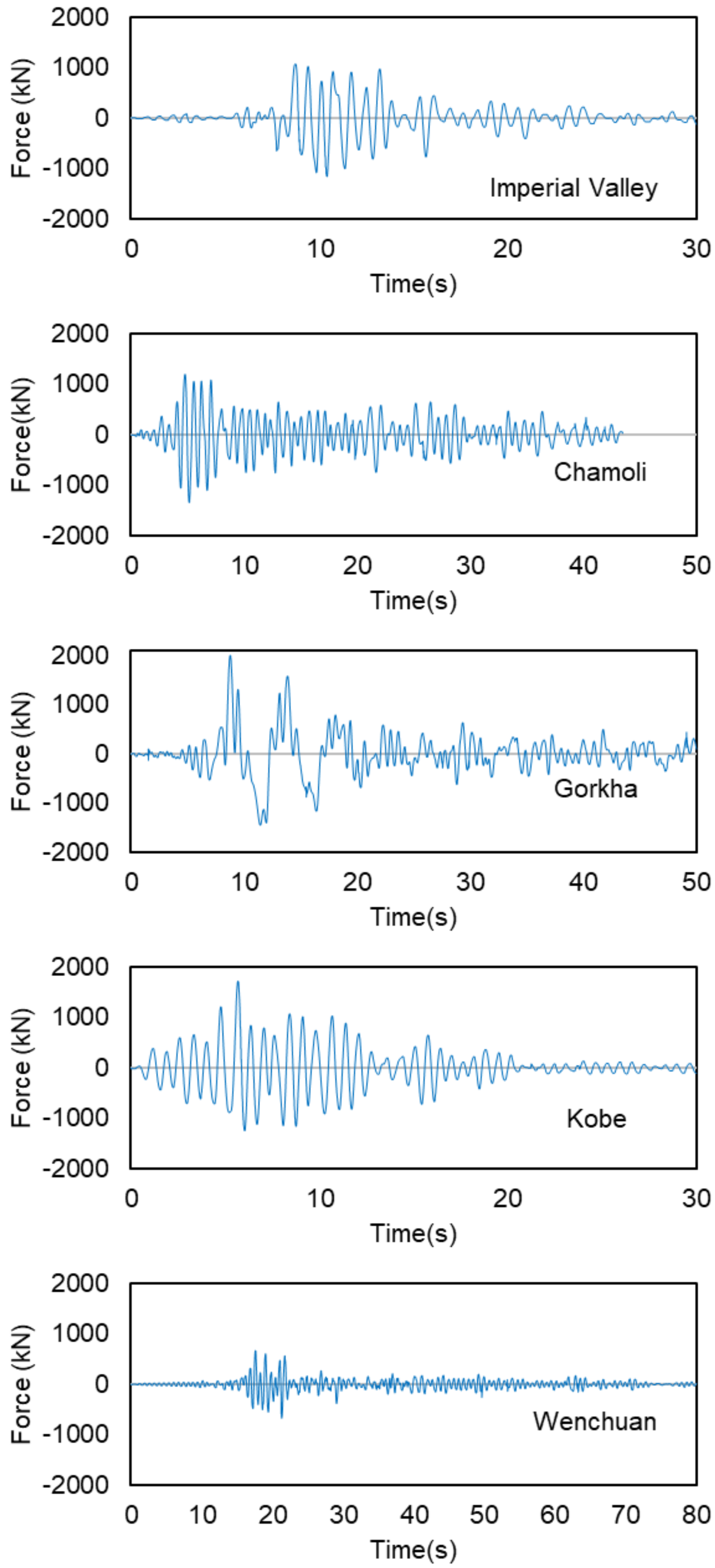

Fig. 9 - Force Time Histories

Hysteretic Curves

Hysteretic curves of CFST-RC Piers subjected to seismic loadings provide an important information for evaluation of their seismic behaviour, including the ductility, energy-dissipation capacity and degradation of stiffness. The Force-displacement hysteretic curves for specimen under seismic lexcitations are shown in Figure 10. It can be observed that the curves are almost perfectly elastic, which indicates the specimens have excellent energy dissipation and hysteretic behaviour.

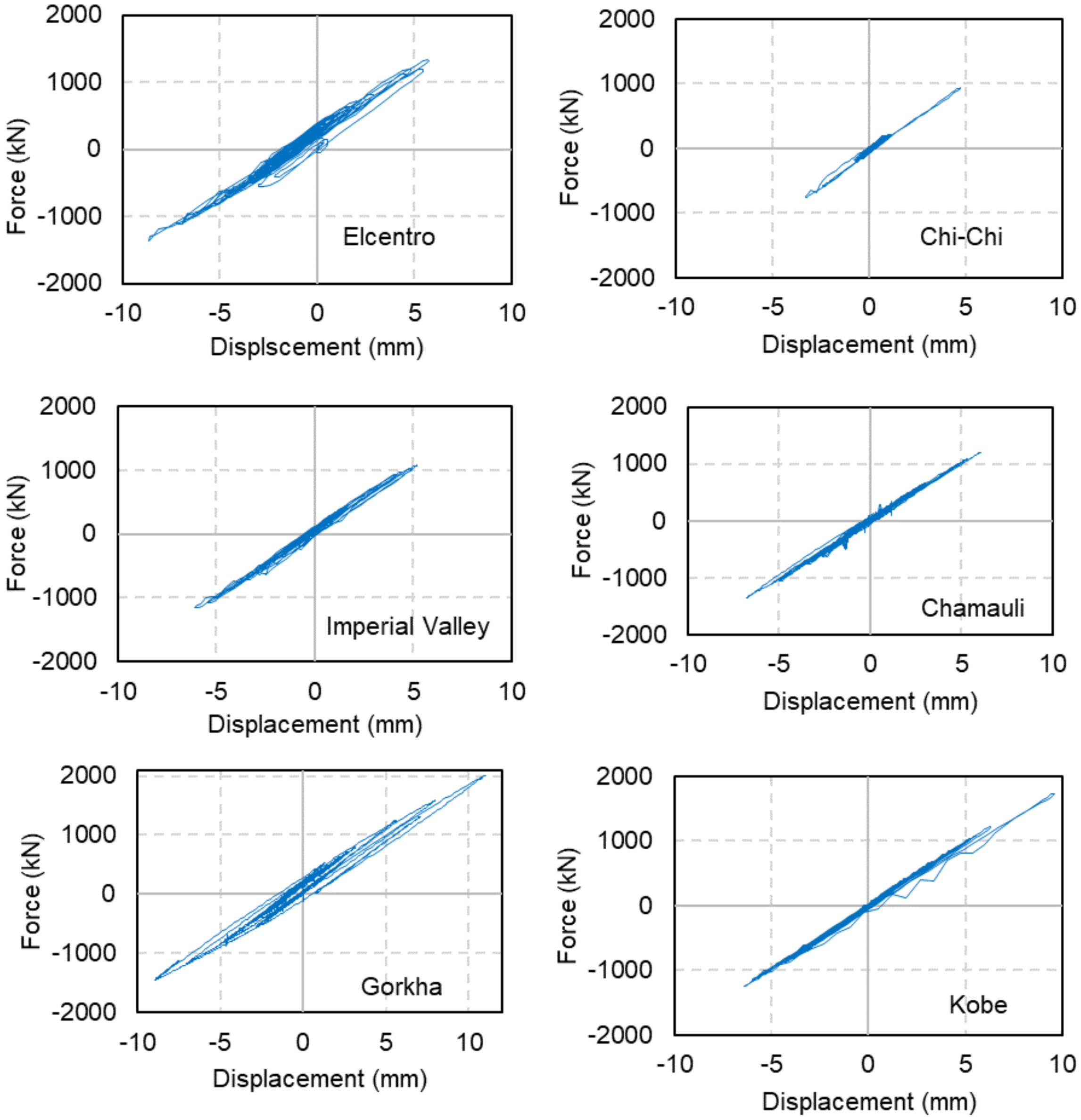

Fig. 10 - Force Displacement Hysteretic Curves

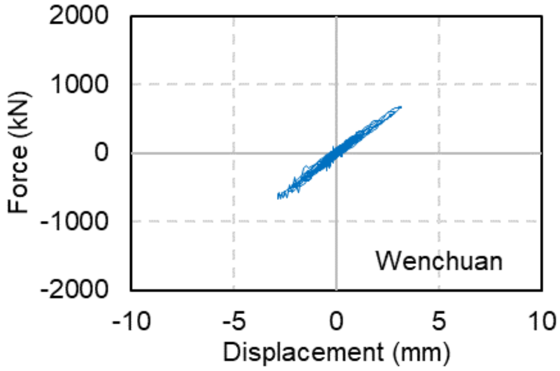

Fig. 10 - Force Displacement Hysteretic Curves

Fundamental Frequency

Fourier spectrum of all the seven observed acceleration was plotted as shown in Figure 11. From the plot it is observed that the peak Fourier amplitude of accelerations were at 1.46 Hz, 1.42 Hz, 1.37 Hz, 1.43 Hz, 1.40 Hz, 1.37 Hz and 1.43 Hz due to Chamoli, Gorkha and Wenchuan earthquake input motions respectively. Frequency of the pier is found to be 1.41 Hz and the time period as 0.71 seconds.

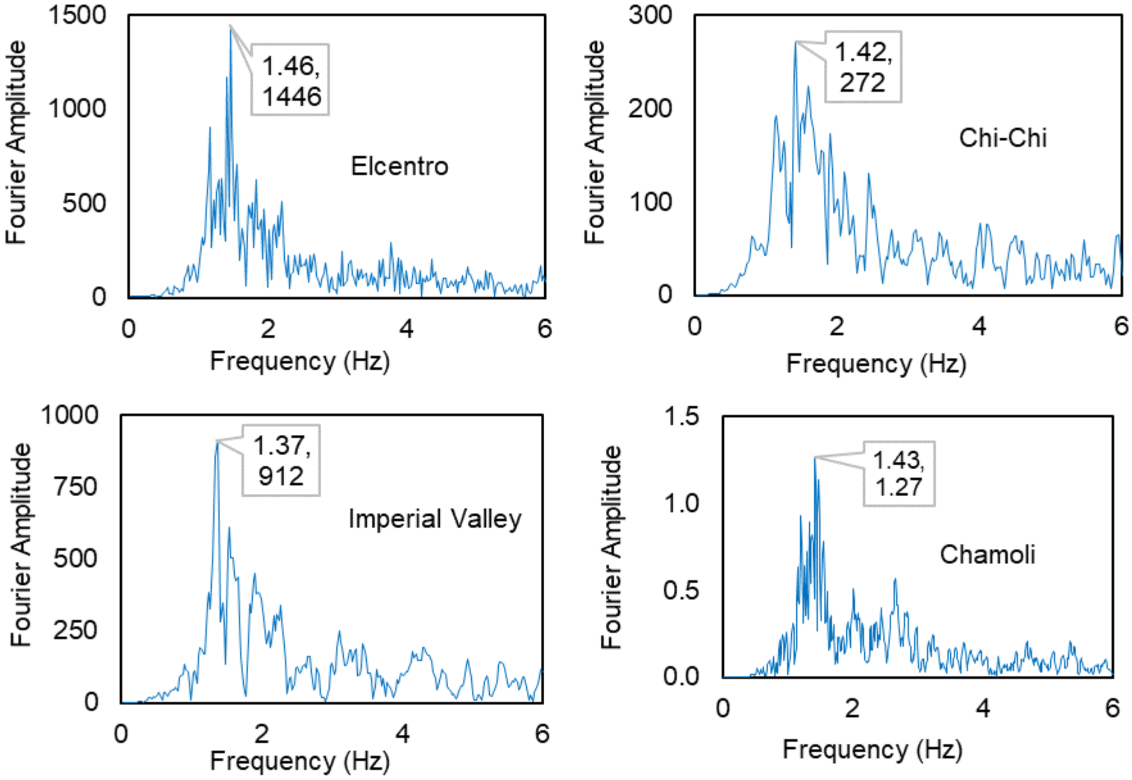

Fig. 11 - Input Seismic Ground Motions

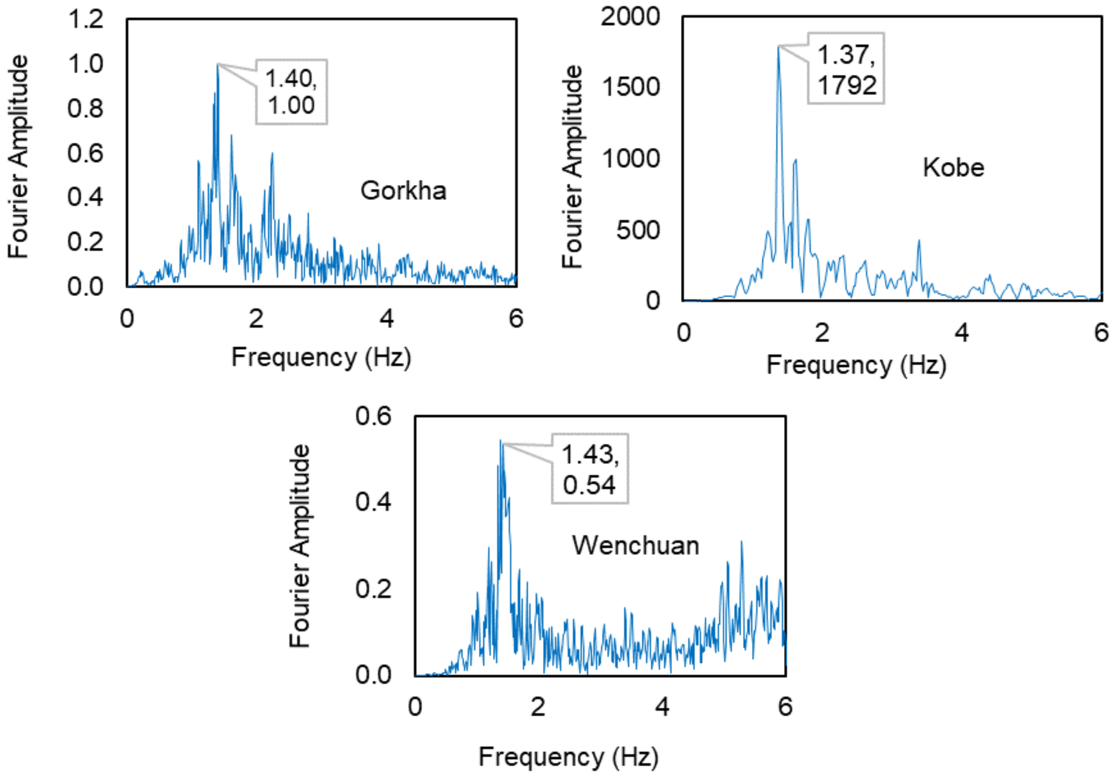

Fig. 11 - Input Seismic Ground Motions

CONCLUSION

From the pseudo-dynamic test of the CFST- built-up pier the following conclusions are withdrawn:

(a) The pier experience larger acceleration due to Imperial Valley earthquake while minimum due to Wenchuan earthquake. For the Imperial Valley earthquake the acceleration is magnified by 17 times while for the Wenchuan earthquake the acceleration is magnified by 10 times.

(b) The maximum absolute velocity is excited due to Chamoli ground motions and minimum due to Wenchuan ground motion while the input PGA was constant in all cases.

(c) The displacement and the lateral force at the top of the pier is maximum due to Gorkha ground motion while they were minimum due to Wenchuan ground motion having the constant input PGA in all cases.

(d) From the experiments, the frequency of the pier is calculated as 1.41 Hz.

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