Understanding the Characteristics of Christchurch Earthquake (2011) by Observing SDOF Systems

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SUMMARY:
A series of earthquakes has hit Canterbury, New Zealand, causing loss of lives and collapse of several buildings as well as a wide spread damage. Darfield Earthquake of 2010 and Christchurch Earthquakes of February 2011 and June 2011, caused liquefaction and structural damage throughout the city. The very dense network of accelerometers has shown that the characteristics of the recorded motion could vary significantly despite the fact that they have been recorded in very close distance. This certainly has an effect on the building stock, meaning that the same building would suffer different varieties of damage depending on where exactly it was built in the city. The alteration of the recorded motions is mostly due to the liquefaction observed as well as the soil performances in the area.

This paper focuses on investigating the response of a group of single-degree-of-freedom systems, representing short and long period structures, when subjected to different recorded accelerations. Comparisons are made on SDOF systems, which are assumed to represent the existing buildings in Christchurch, in terms of energy dissipation, ductility demand and residual displacements. Other issues such as the dominant response direction of the systems as well as the effects of experiencing the earthquake close to the epicentre are also examined.

Keywords: Christchurch Earthquake, SDOF systems, strong motion characteristics

1. INTRODUCTION

The city of Christchurch and around is densely instrumented allowing engineers to investigate the variation of the ground motion and its effects in detail. The paper initiated from an idea to apply the recorded strong motions from the February 2011 Christchurch Earthquake to some representative single-degree-of-freedom (SDOF) systems to observe the variation in demand on identical systems.

The SDOF representation is done by using a hysteretic model that is implemented in OpenSees (2012) as shown in **Figure 1**. The model allows to define a tri-linear representation of the force-deformation relationship of the element/system, an asymmetric behaviour in opposite loading directions, a damage indicator to represent stiffness or strength degradations, a pinching parameter, and alteration of the unloading stiffness. Damage parameter, unloading stiffness parameter, pinching and asymmetry in opposite directions are supressed in this study in order to simplify the problem and to obtain the first set of outputs in the simplest manner to allow easier comparisons. These properties can be activated in further research if the effect of the recorded motions needs to be checked over more structural parameters.

2. ANALYSES AND OBSERVATIONS

13 recorders, which are placed around the Central Business District of Christchurch, have been used in this study. The seismicity and fault system in Christchurch is given in **Figure 2** whilst the locations of the 13 records are given in **Figure 3**.

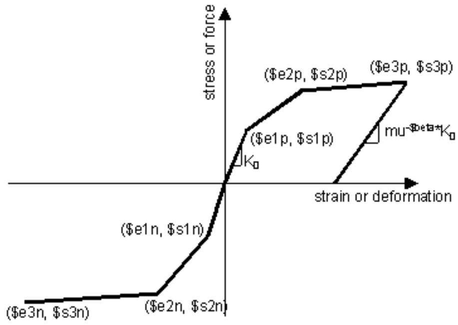

Figure 1. Hysteretic model used in SDOF representation (OpenSees, 2012)

Nonlinear time history analyses were conducted on 4 different SDOF systems for the 13 records. The SDOF systems are symmetric in opposite directions, representing short and long period structures with 0.3sec and 1.2sec fundamental periods, respectively.

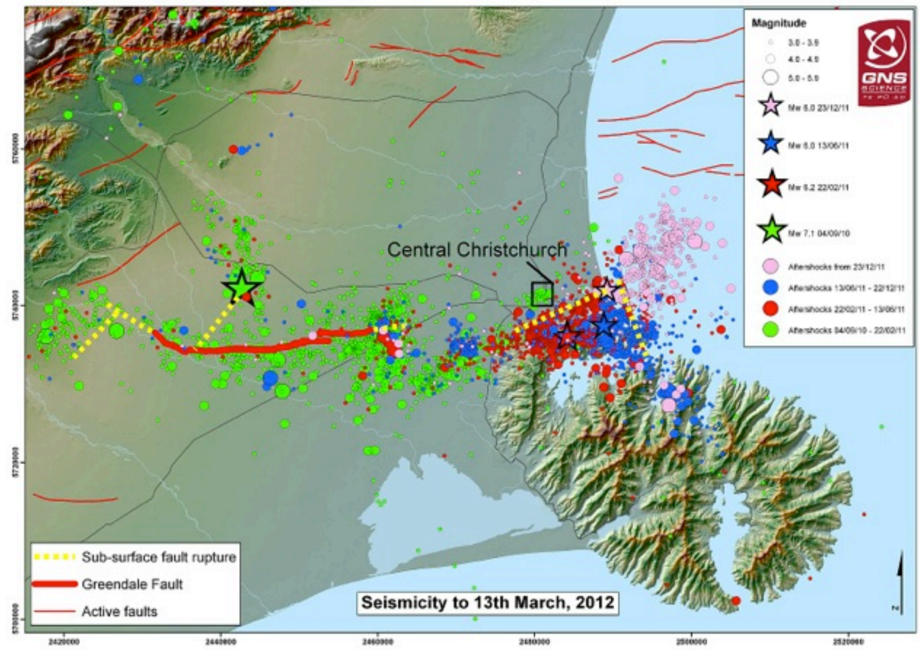

Figure 2. Seismicity of Christchurch since September 2010 Darfield Earthquake (GNS, New Zealand)

The range of structures to represent the characteristic building in Christchurch area is taken from a recent study by Moghaddasi et al. (2011). The collapse drift is assumed as 2%, the overall building ductility was chosen as 5, and other values are set default as described in Moghaddasi et al (2011).

The recorders in Christchurch were not placed in fault-parallel or fault-perpendicular directions, thus a description of a dominant direction is needed. Smyrou et al. (2011) investigated the direction of the highest PGA in each of these recorders. A new set of records has been trigonometrically obtained by using these dominant directions, and the time-history plots of these new records are given in **Figure 4**. According to the most up-to-date maps from EQC (available at http://eqc.eaglegis.co.nz /PublicViewer/), recorders CBGS, CCCC and CHHC were placed on soil that severely liquefied during the February 2011 Earthquake. The locations of the recorders PRPC, REHS, and SHLC, on the other hand, experiences moderate level of liquefaction. Liquefaction was not observed around the rest of the recorders, which are CMHS, HPSC, HVSC, LPCC, PPHS, RHSC and SMTC.

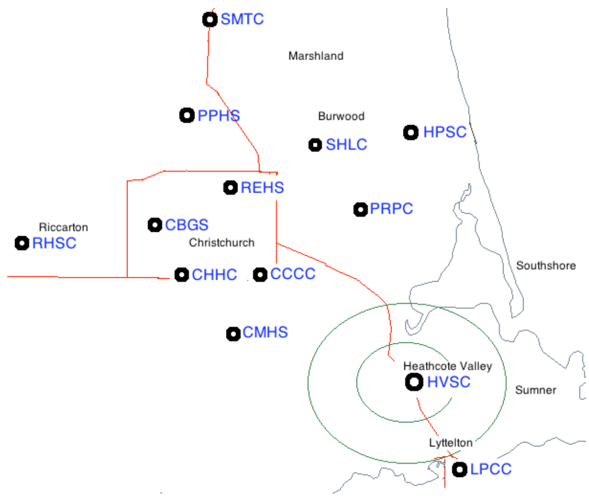

Figure 3. Locations of the 13 recorders used in this study

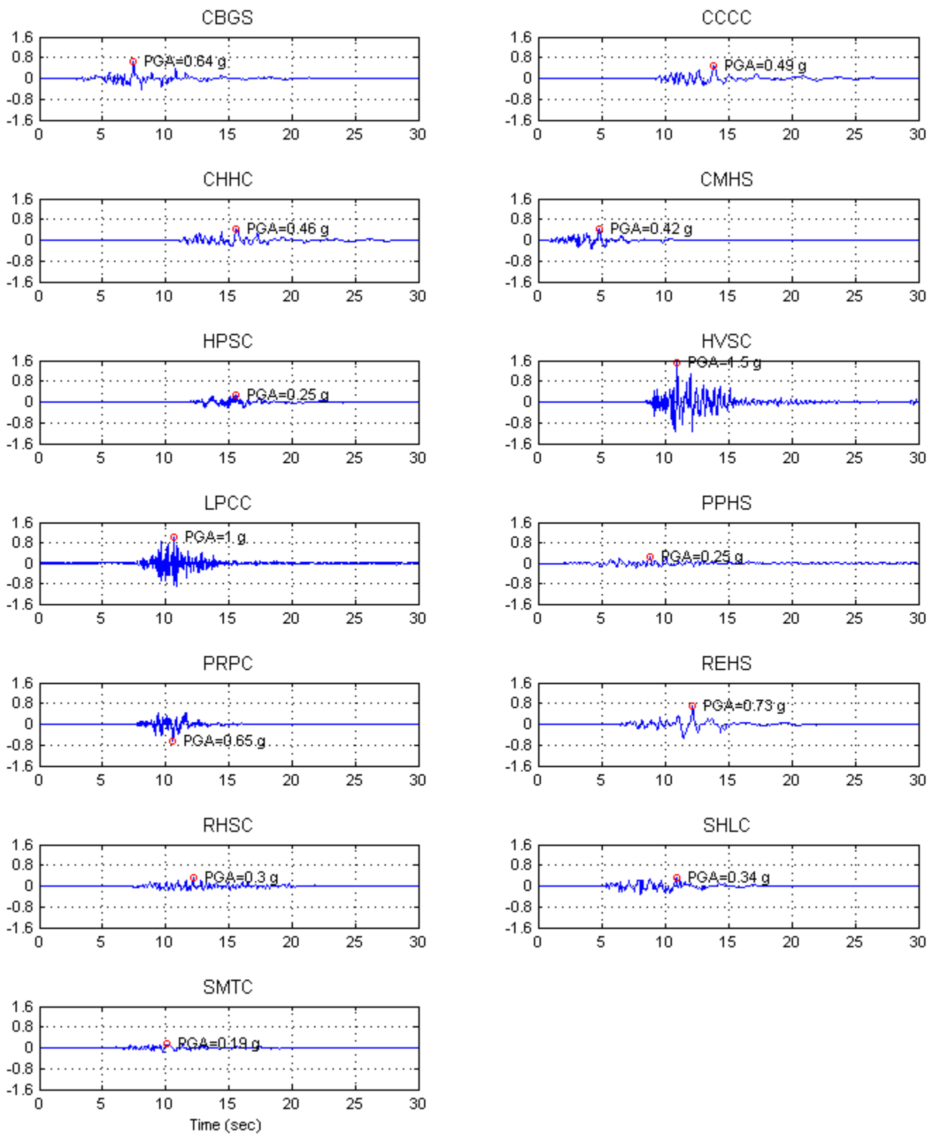

Figure 4. Time-history plots of the new records rotated to the direction of the highest PGA

1.1. Asymmetric response of the symmetric systems

One of the characteristics of the Christchurch records is the asymmetry in PGA in opposite directions. Some records also exhibited residual ground displacements in a certain direction repeating in some records in CBD. These are findings that may suggest some soil movement, something that was quite common in Christchurch.

Symmetric SDOF systems (i.e. equal capacities in opposite directions) have been created in order to investigate the asymmetry of the records and degree of its effects on the SDOF systems. **Figure 5** to **Figure 7** present the force-displacement plots of the SDOF systems modelled. In a window of 4 figures in **Figure 5** to **Figure 7**, above figures are short-period structures (0.3sec fundamental period) and below figures are long-period (1.2sec) structures. There is also distinction between the structures with positive and negative post-yield stiffness ratios, on the left and on the right, respectively.

These figures show that the selected records created an intensively asymmetric response leading to accumulation of the deformations in one side. This accumulation of deformations occurred in long-period SDOF systems for the records CCCC, CHHC, REHS and SHLC, while the asymmetric response is more obvious in the short period structures for the CBGS record.

In brief, a tendency of significantly asymmetric behaviour in records with observed liquefaction and with long period structures can be observed in general. A further investigation is required to better understand the causes of the asymmetric response. These findings also suggest that the frequency content of some records makes the record more demanding in long periods, possibly due to liquefaction.

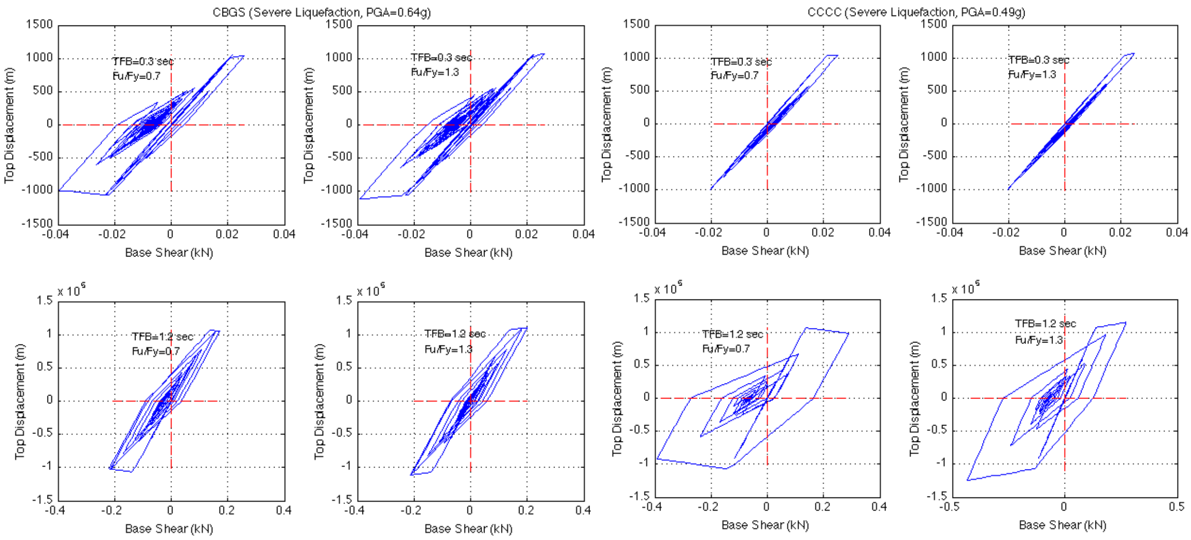

Figure 5. SDOF cyclic responses for CBGS (left) and CCCC (right) recorders

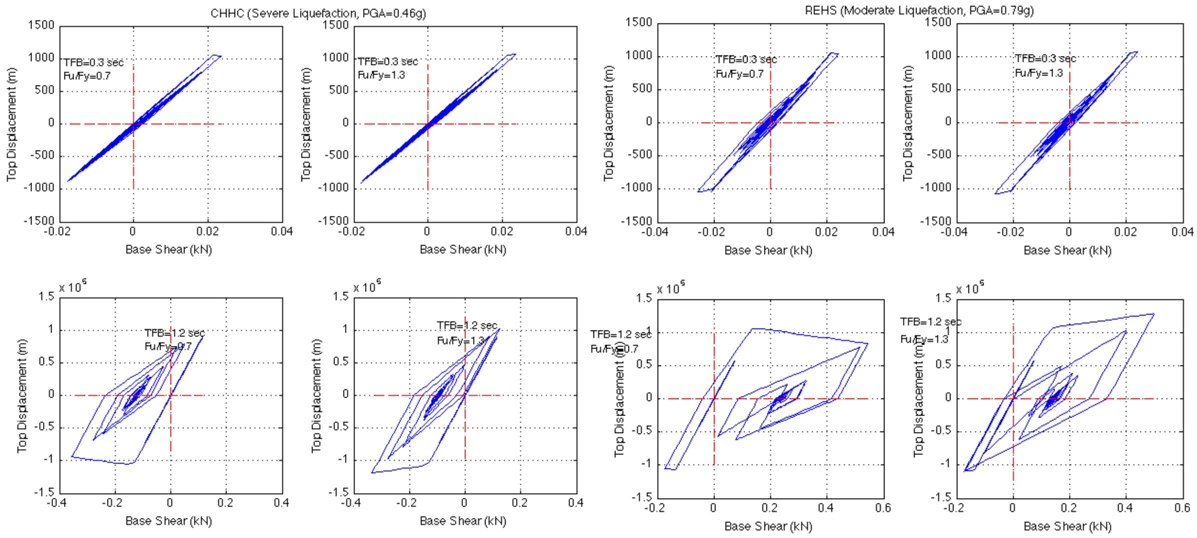

Figure 6. SDOF cyclic responses for CHHC (left) and REHS (right) recorders

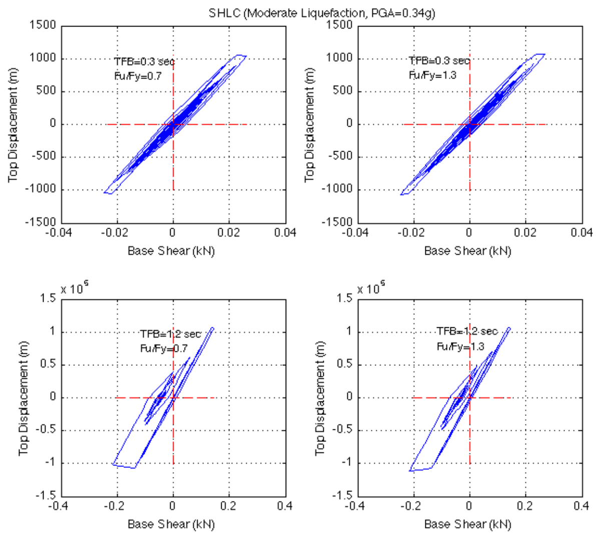

Figure 7. SDOF cyclic response for SHLC recorder

The direction of the accumulation of the deformations is also examined. It was found that all of the 5 strong motion records given above cause a deformation pattern that constantly accumulates the deformations towards east. This tendency could be related to the liquefaction phenomena, lateral spreading, or to near-field effects. Investigation of the same parameters by using Darfield'10 and June'11 earthquakes could provide some insights into this issue.

1.2. Dissipative characteristics of the SDOF systems

The displacement demand each record created on the examined SDOF systems is an indication how destructive a record could be for the structures in the building stock of Christchurch. The destructiveness of a given strong motion is often correlated with its PGA value, but there are several other parameters that affect how demanding a record could be on a particular system and PGA parameter can be particularly misleading.

An effort is made in this study to correlate the response of the long-period SDOF structures and their energy dissipation (i.e. the area below the force-displacement cycles) with the PGA and the liquefaction level observed. **Figure 8** shows that, for the long-period SDOF systems used in this study, some high-PGA strong motion records create less intense cycles and thus impose less energy dissipation to the structure than some lower-PGA records. The main difference is the observation of liquefaction. It seems in **Figure 8** that the records registered on liquefied soils push the same SDOF structure with many more cycles and demand much more energy dissipation from the structure as compared to higher-PGA records with no observed liquefaction. Smyrou et al (2011) came to a similar conclusion by examining the ductility demands on short and long period structures on liquefied and non-liquefied soils in Christchurch after the February 2011 Earthquake.

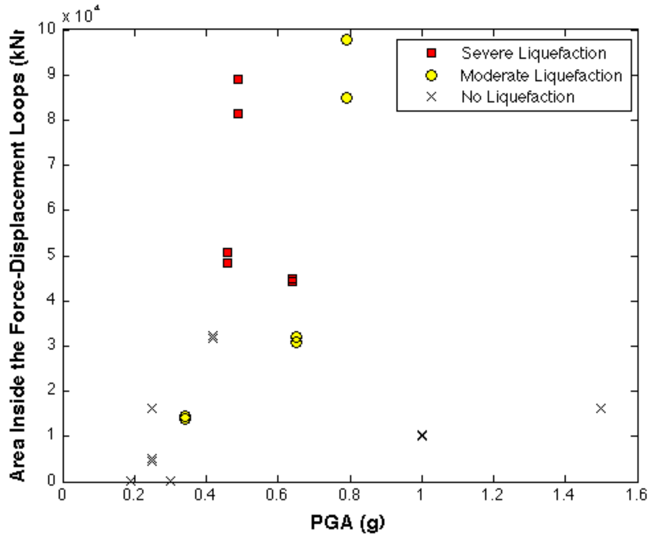

Figure 8. Comparison of the energy dissipation (i.e. area below the force-displacement cycles) of different long-period SDOF systems and the PGA of the records they are subjected to

1.3. Response of the short-period SDOF systems on the epicentre

It is known by theory that the short-period waves are quite effective close to the epicenter of the earthquakes but they are quickly damped and cannot travel long distances. The epicenter of the Christchurch Earthquake of February 2011, Heathcote Valley, experienced a PGA up to 1.5g in the strongest direction, a very high acceleration value for any type of structure. The damage on the structures as well as on the close-by old masonry railway tunnel, however, was rather limited.

The force-displacement plots of the nonlinear time-history analyses conducted on short and long period SDOF systems by using the Heathcote Valley record are given in **Figure 9**. It is evident in these plots that the short-period SDOF structure easily reaches its displacement capacity and the structure collapses rather easily. The ultimate displacement is around 30% more if the SDOF structure has negative post-yield stiffness ratio, which represents the strength degradation in structures. This finding suggests that the HVSC record was particularly destructive for short-period structures but it seems that, since this finding is not evident in the other records recorded close-by, the destructiveness of the HVSC record on short-period structures diminished quickly and could not onset on other locations.

3. CONCLUSIONS

Christchurch Earthquake of February 2011 caused extensive damage in the area, especially around the Central Business District (CBD) of the city. Densely placed strong motion recorders allow engineers to investigate more precisely the effects of the shakings on existing structures.

This paper focuses on the response of SDOF systems specifically chosen to represent short and long-period structures as well as the degrading and non-degrading systems. The identical systems were subjected to 13 different acceleration records recorded in and around the CBD of Christchurch. Findings reported in this paper, despite their preliminary nature, provide some valuable information about what kind of seismic demand the existing structures were subjected to.

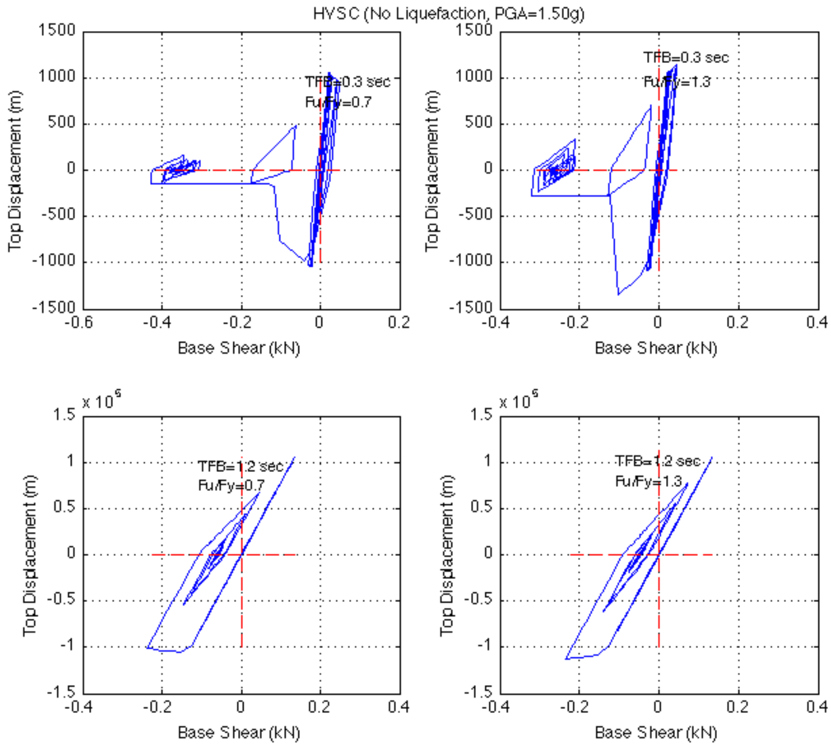

Figure 9. Force-displacement plots for the SDOF systems subjected to the HVSC record registered at the epicenter

The first finding is the asymmetric response of the symmetric SDOF systems. Asymmetry in response becomes more evident in long-period structures and in cases liquefaction was observed around the recorder. Another finding regarding the asymmetry is that the accumulation of deformations is consistently towards East for the Christchurch February'11 even examined, something that may be explained by soil movements or by near-field effects. This is a finding that requires further research. It is also required to conduct a wavelet analysis on the records to disaggregate the frequency content of the record in time-domain so that the long-period waves caused by liquefaction can be captured.

It is also observed that records with lower-PGA causes very high energy dissipation demand on long-period SDOF systems, and again these are the records where liquefaction is observed. Records with liquefaction triggers many more cycles in the SDOF system pushing thus the structure to higher ductility demands and this behaviour possibly causes more damage on real structures. Another conclusion from this exercise is that PGA may be a very misleading parameter to understand the destructiveness of a given earthquake record.

The HVSC recorder was placed on epicentre and recorded very high PGA values up to 1.5g in the strongest direction. SDOF analyses by using the HVSC record suggests that the short-period structures would easily reach collapse while the long-period SDOF structure yields but survives under this very high PGA value. This fining indicates that the short-period waves are quite effective on the epicentre but they quickly diminish as one moves to other close-by recorders.

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