# 7 4 September 2010 Earthquake Horizontal Components

In this earthquake the strongest shaking is seen in the North-South direction.

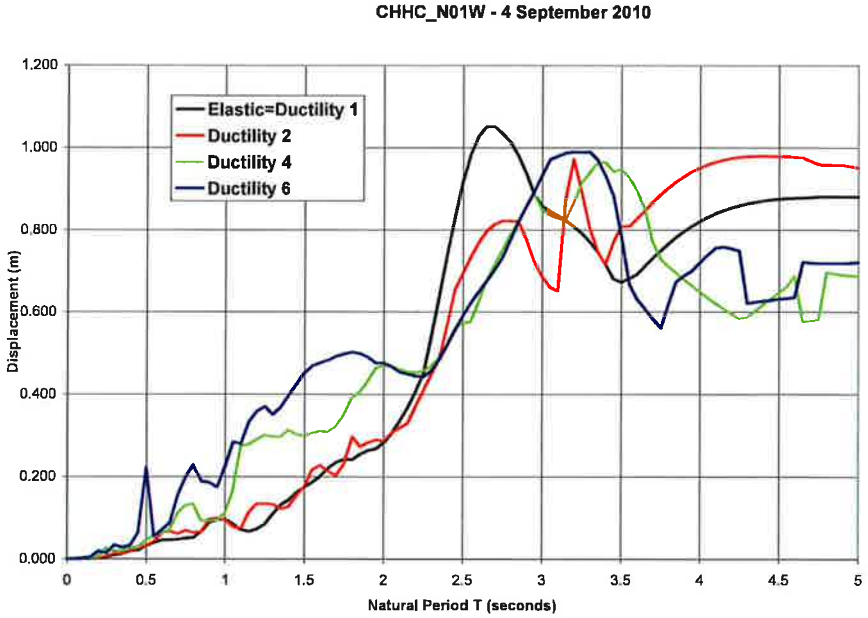


**Figure 12. Displacement Response Spectra**
**Christchurch Hospital, 4 September 2010- North 01° West Component**

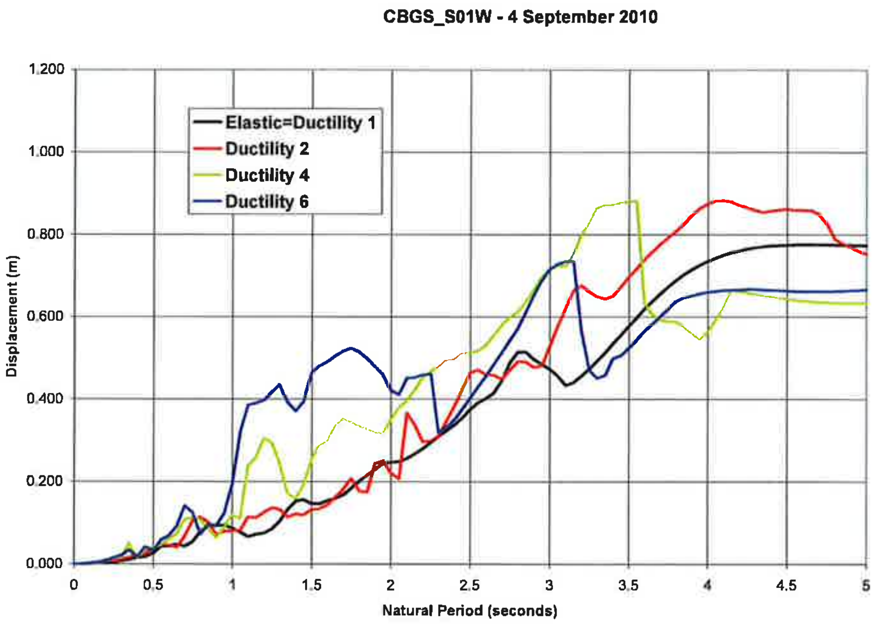


**Figure 13. Displacement Response Spectra**
**Christchurch Botanic Gardens. 4 September 2010- South 01° West Component**

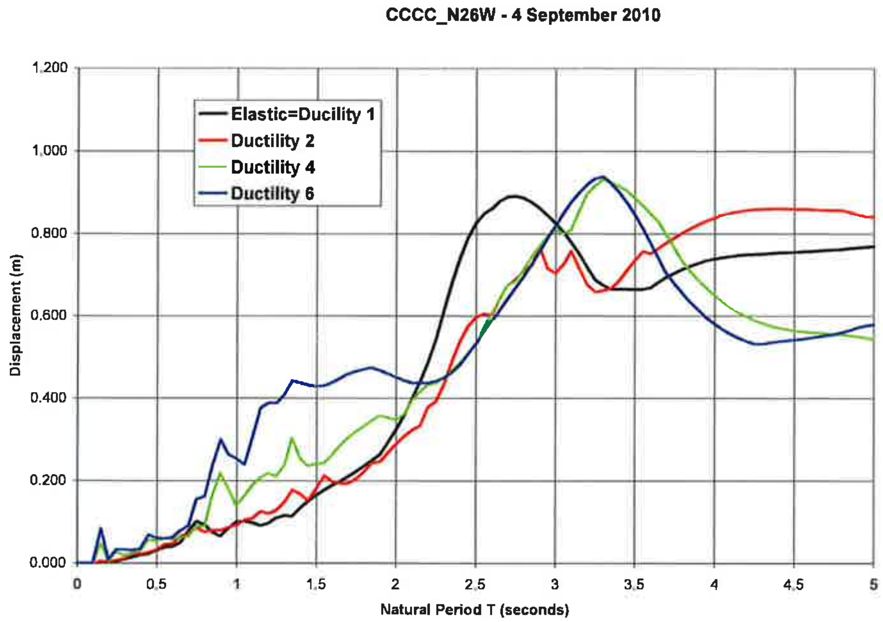


**Figure 14. Displacement Response Spectra**
**Christchurch Cathedral College. 4 September 2010- North 26° West Component**

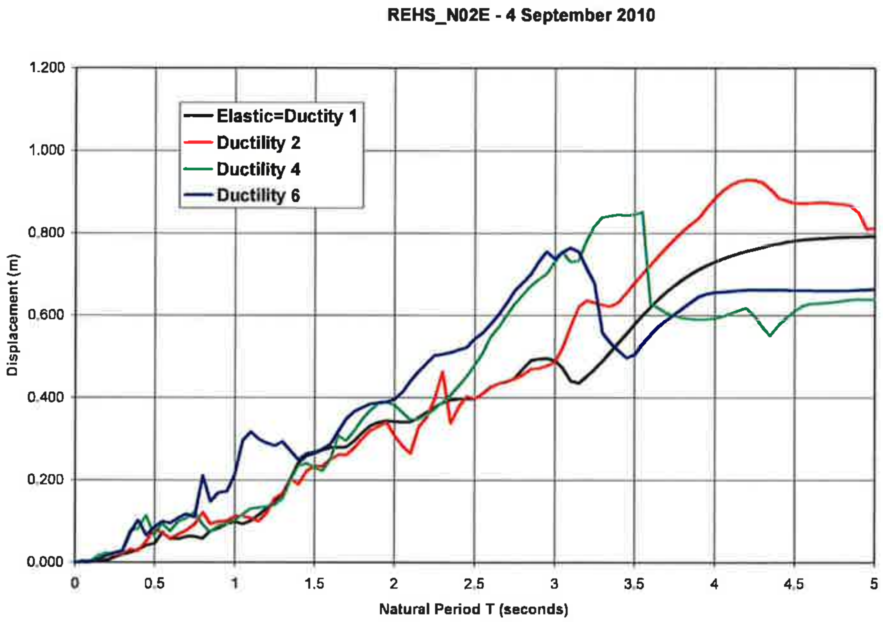


**Figure 15. Displacement Response Spectra**
**Resthaven. 4 September 2010- North 02° East Component**

It can be seen that none of these spectra fit the equal displacement concept. The inelastic displacements are greater than the elastic displacements for nearly all natural periods of free-vibration with only reductions for large ductility displacements for natural periods greater than about 3.5 seconds.

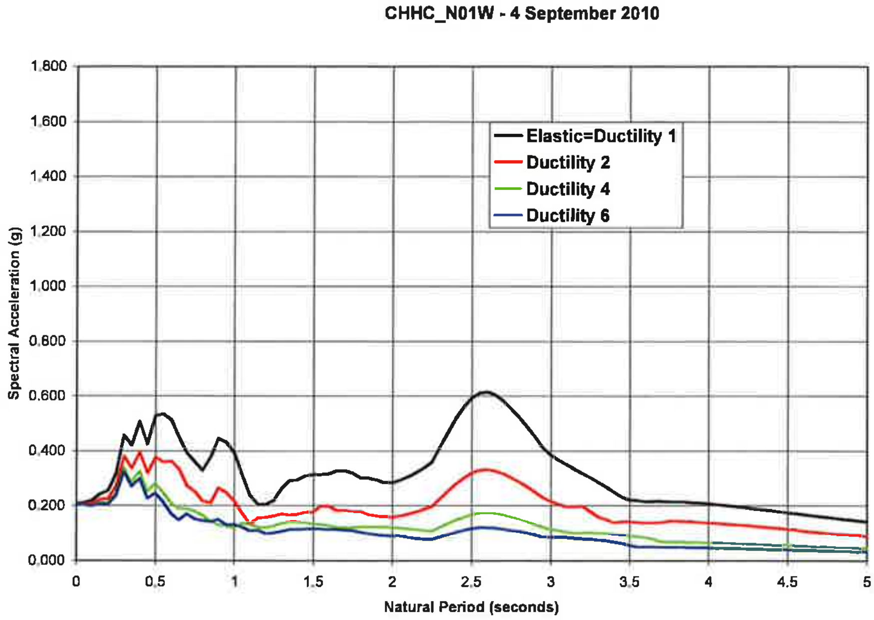


**Figure 15. Acceleration Response Spectra**
**Christchurch Hospital 4 September 2010- North 01° West Component.**

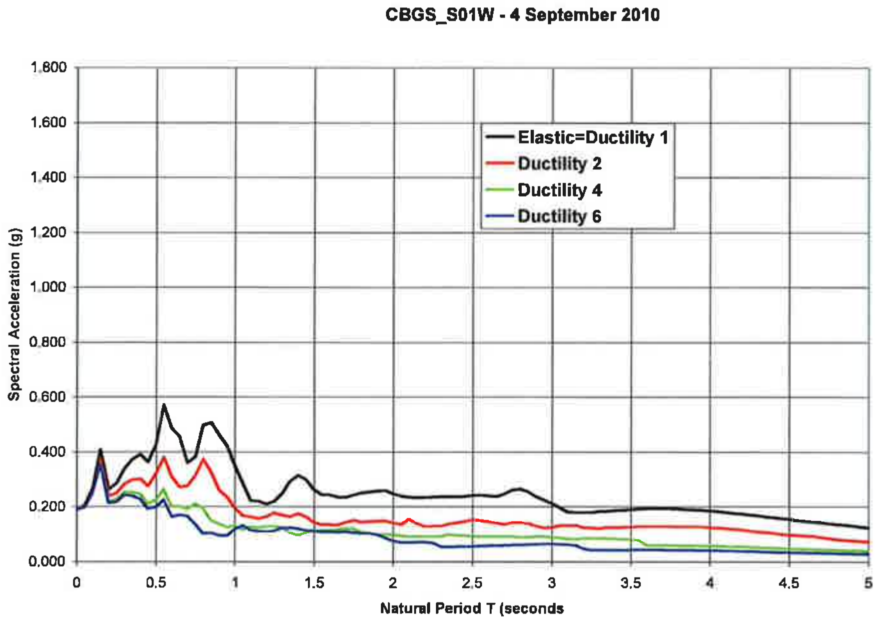


**Figure 16. Acceleration Response Spectra**
**Christchurch Botanic Gardens. 4 September 2010- South 01° West Component**

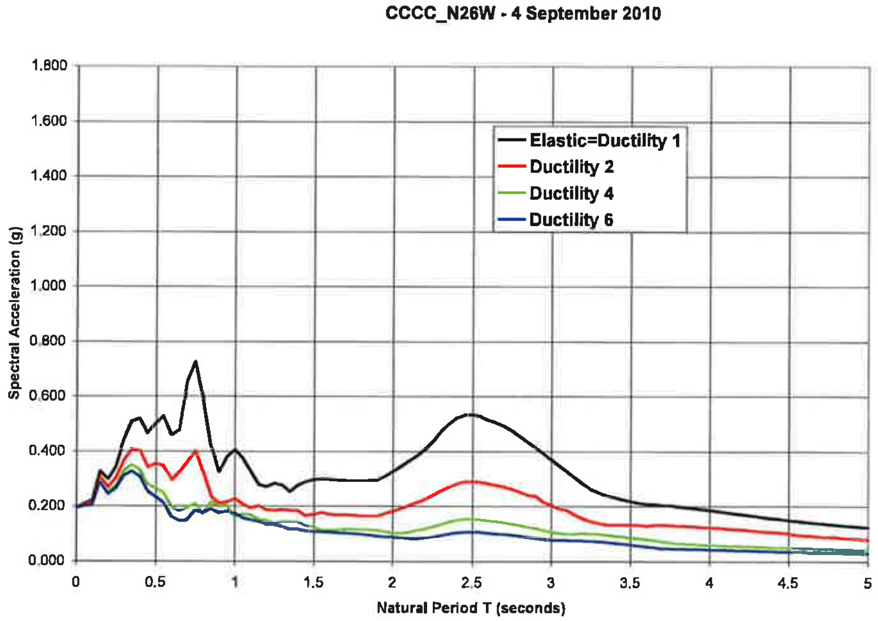


**Figure 18. Acceleration Response Spectra**
**Christchurch Cathedral College. 4 September 2010- North 26° West Component**

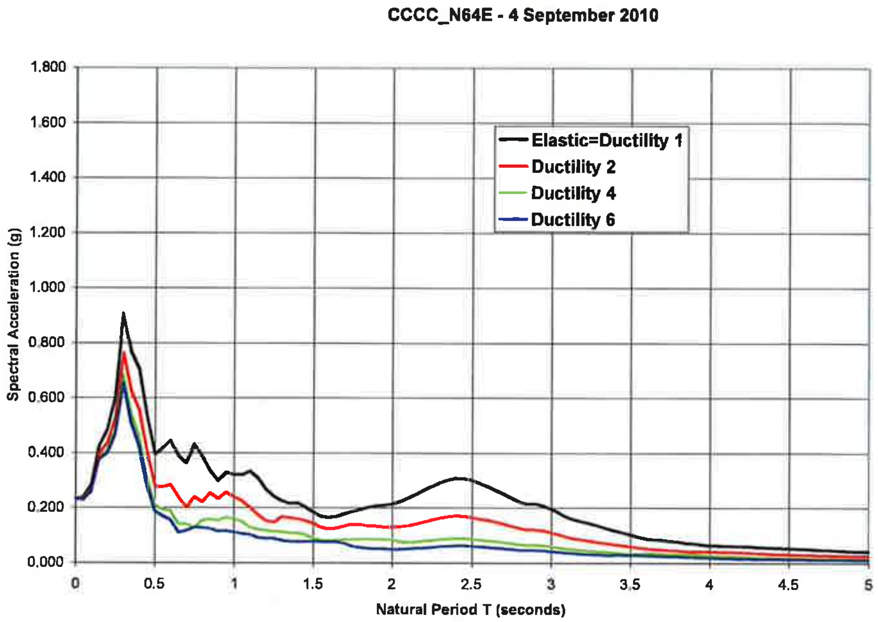


**Figure 19. Acceleration Response Spectra**
**Christchurch Cathedral College. 4 September 2010- North 64° East Component**

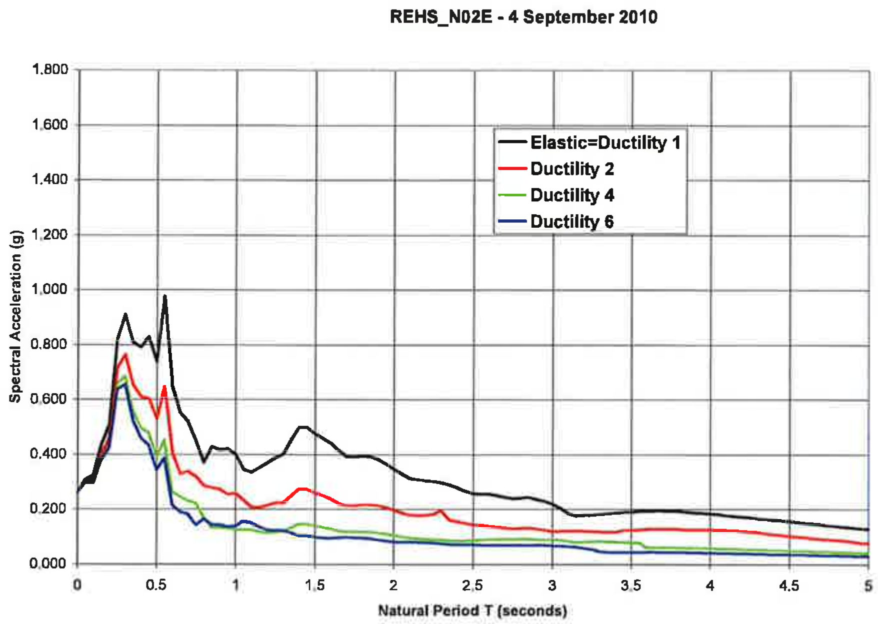


**Figure 20. Acceleration Response Spectra**
**Resthaven. 4 September 2010- North 02° East Component**

The acceleration records, in general, show large accelerations for the longer natural periods of free-vibration. This is probably the effects of attenuation with distance for the higher frequencies (short periods) and also the amplification of the responses in the longer natural periods caused by the great depth of gravels and other soft material underlying the city. Two spectra for Christchurch Cathedral College are shown. One clearly shows the amplification of the long period response whilst in a direction at right angles the motion is predominantly in the higher frequencies (shorter periods).

It must be noted that the yield forces as a function of the elastic forces (accelerations) are not reduced by dividing by the ductility factor as expected from the equal displacement concept but by numbers equal to, or greater, than the ductility factor. The ratio is sometimes greater than twice the ductility factor.

# 8 22 February 2011 Earthquake Horizontal Components

This earthquake indicated greatest shaking in the East-West direction.

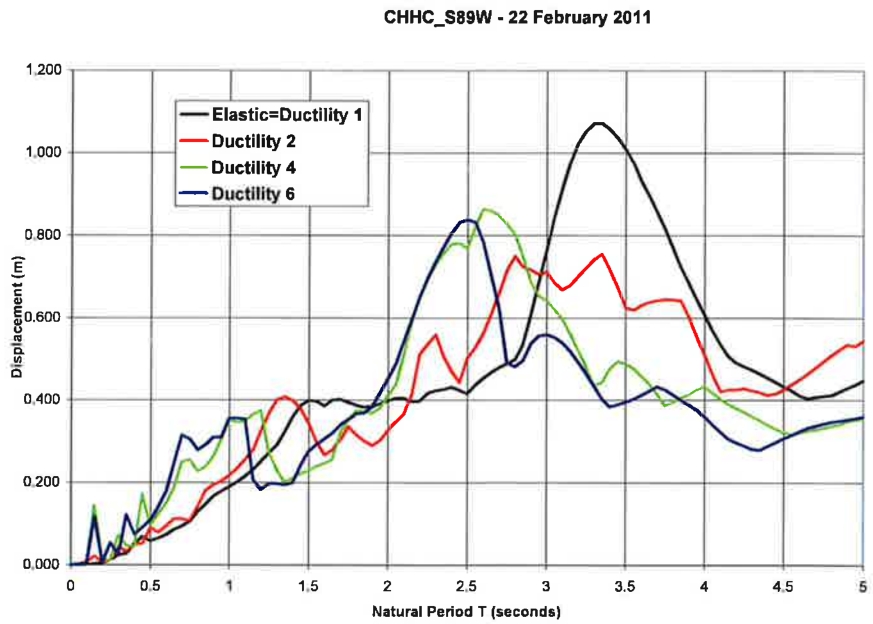


**Figure 21. Displacement Response Spectra**
**Christchurch Hospital 22 February 2011- South 89° West Component**

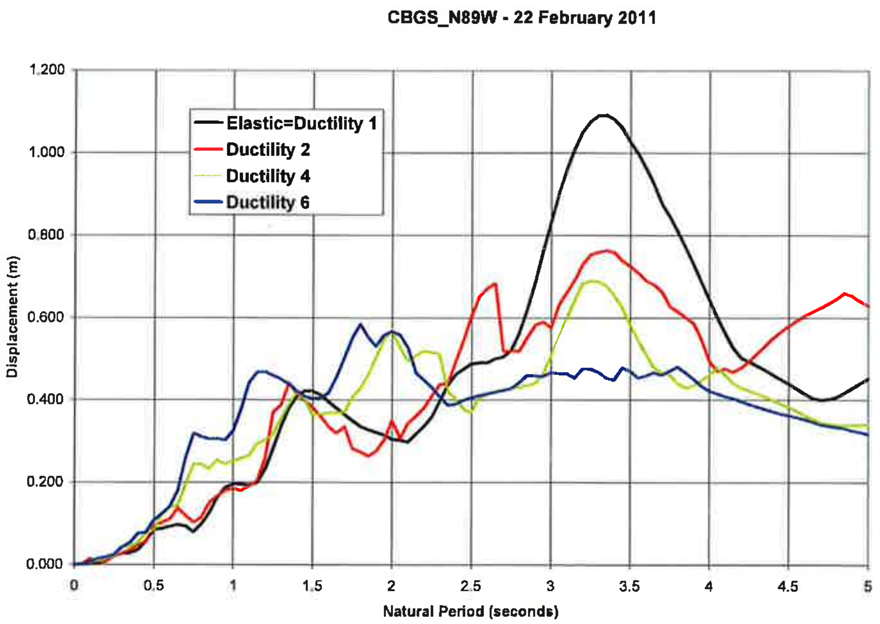


**Figure 22. Displacement Response Spectra**
**Christchurch Botanic Gardens. 22 February 2011- North 89° West Component**

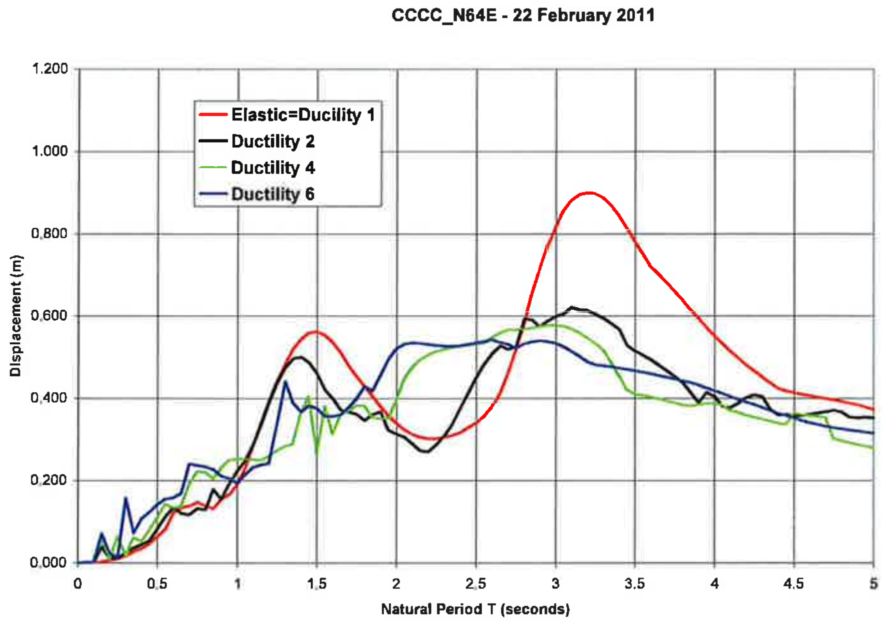


**Figure 23. Displacement Response Spectra**
**Christchurch Cathedral College. 22 February 2011- North 64° East Component**

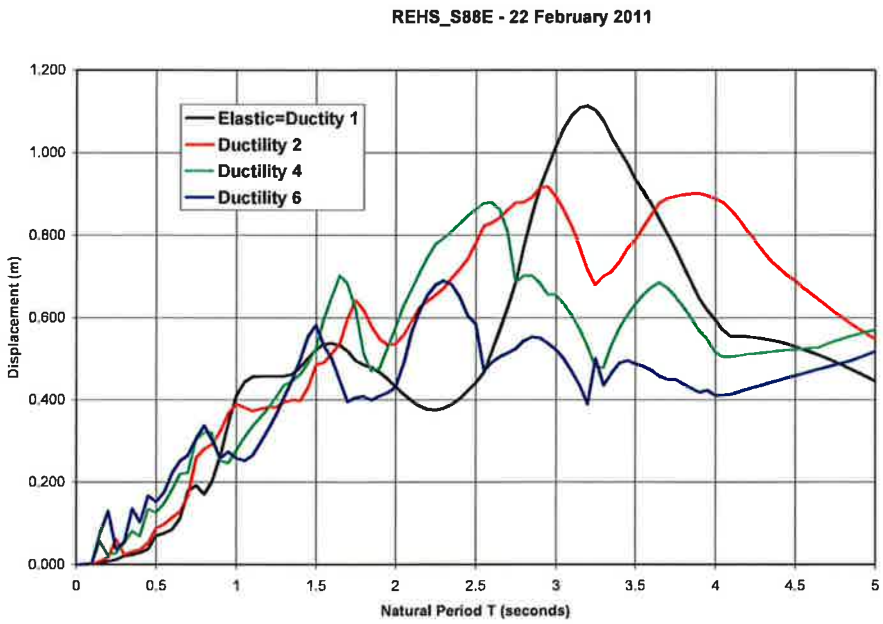


**Figure 24. Displacement Response Spectra**
**Resthaven. 22 February 2011- South 88° East Component**

It can be seen that none of these spectra fit the equal displacement concept. The inelastic displacements are greater than the elastic displacements for nearly all natural periods less than 3 seconds and for greater periods the inelastic spectra of often less than the elastic spectra. The Christchurch Cathedral College spectra show very large displacements for ductility 2 at the longer natural periods.

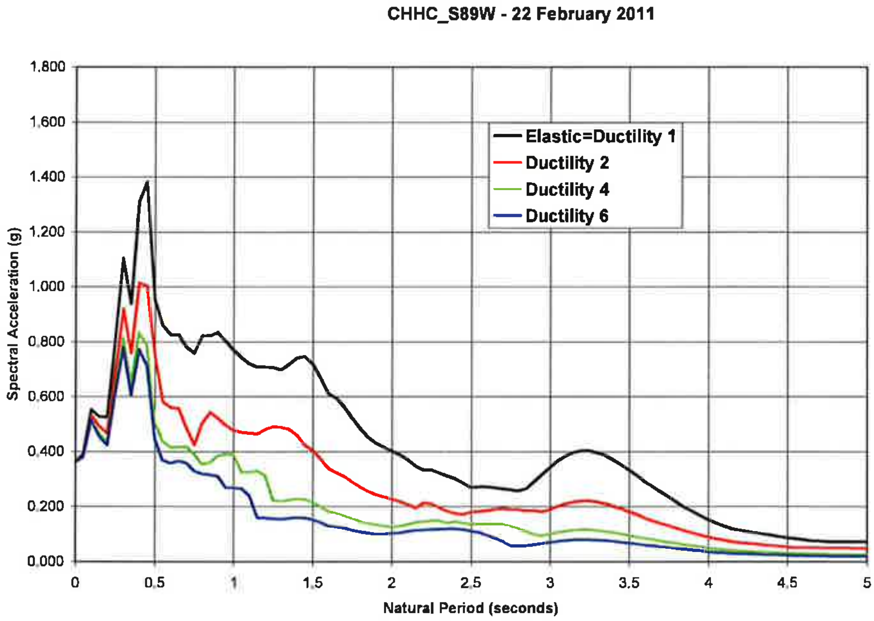


**Figure 25. Acceleration Response Spectra**
**Christchurch Hospital 22 February 2011- South 89° West Component**

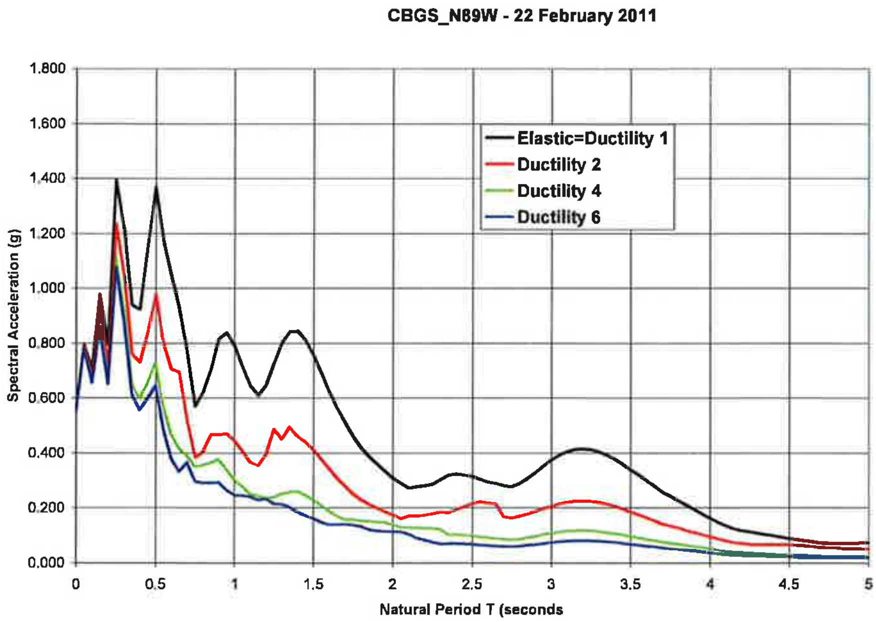


**Figure 26. Acceleration Response Spectra**
**Christchurch Botanic Gardens. 22 February 2011- North 89° West Component**

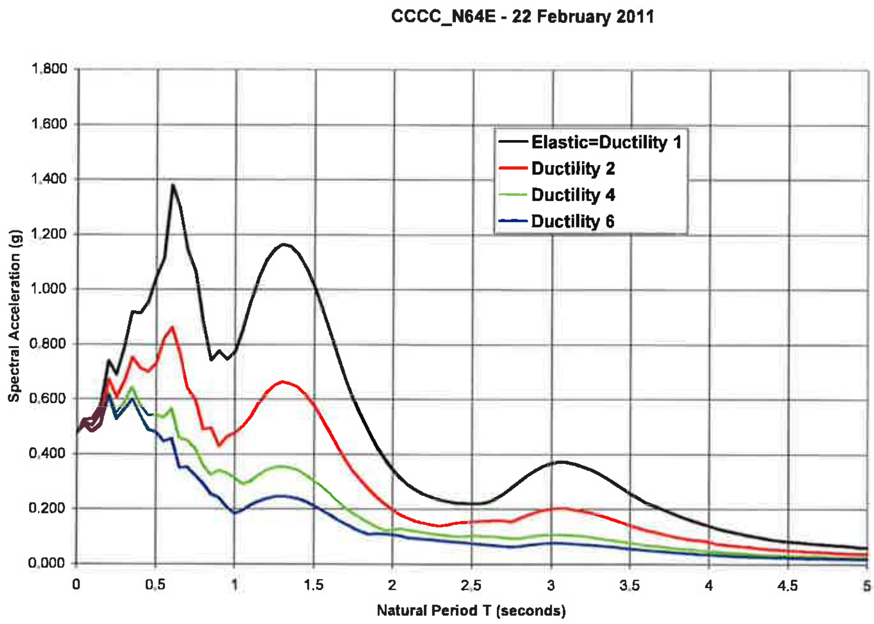


**Figure 27. Acceleration Response Spectra**
**Christchurch Cathedral College. 22 February 2011- North 64° East Component**

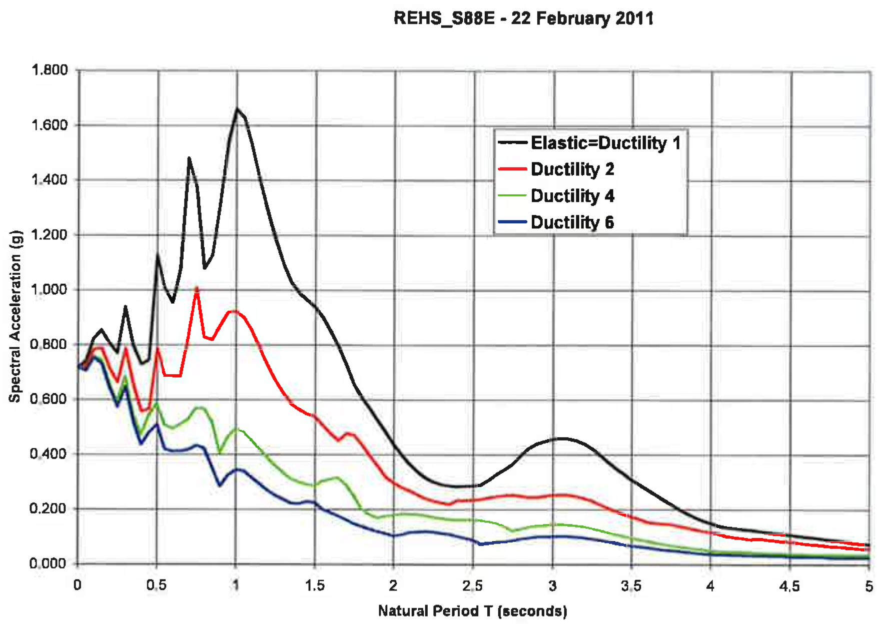


**Figure 28. Acceleration Response Spectra**
**Resthaven. 22 February 2011- South 88° East Component**

The acceleration records, in general, show large accelerations for short natural periods of free-vibration. This is probably the effects of the very close earthquake epicentre with near-fault effects, but at about a 3 second period the effects of the soft deep underlying soils is also evident. Again study of the force reduction factors shows that the yield forces, as a function of the elastic forces (accelerations), are not reduced by dividing by the ductility factor as expected from the equal displacement concept, but by numbers greater than the ductility factor, the ration often being up to twice the ductility factor.

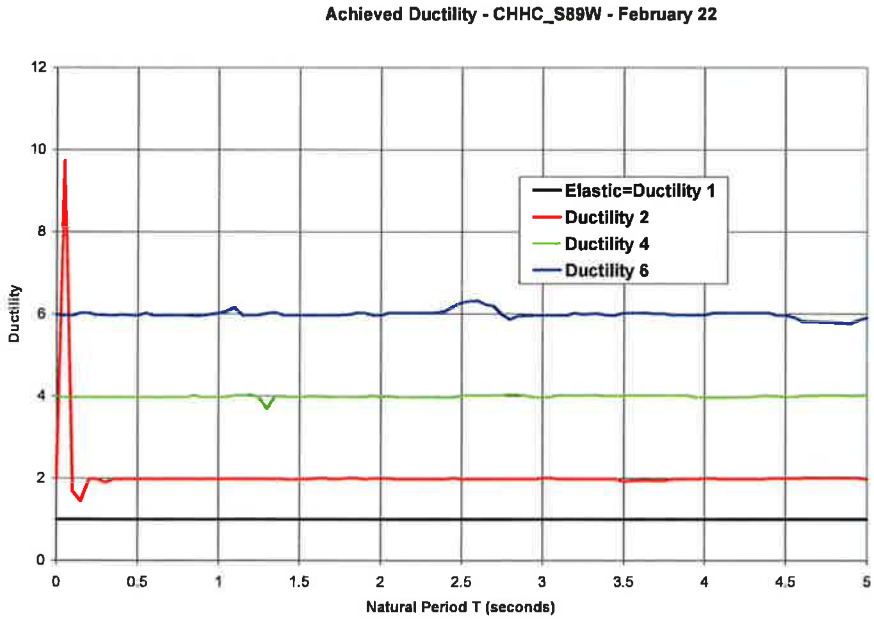


**Figure 29. Achieved versus Target Ductility Christchurch Hospital 22 February 2011- South 89° West Component**

Figure 29 show good convergence for most target ductility values except for the first natural period (0.05 seconds) for ductility 2. Most spectra show better convergence over the whole range of the natural periods.

# 9 13 June 2011 Earthquake Horizontal Components

The records indicate that the predominant shaking in this earthquake is in the North-South direction.

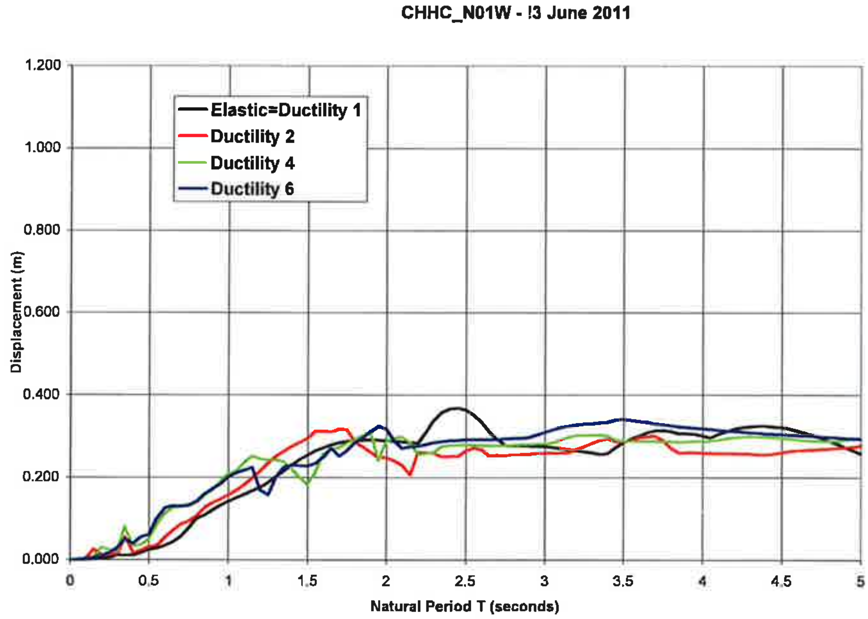


**Figure 30. Displacement Response Spectra**
**Christchurch Hospital, 13 June 2011- North 01° West Component**

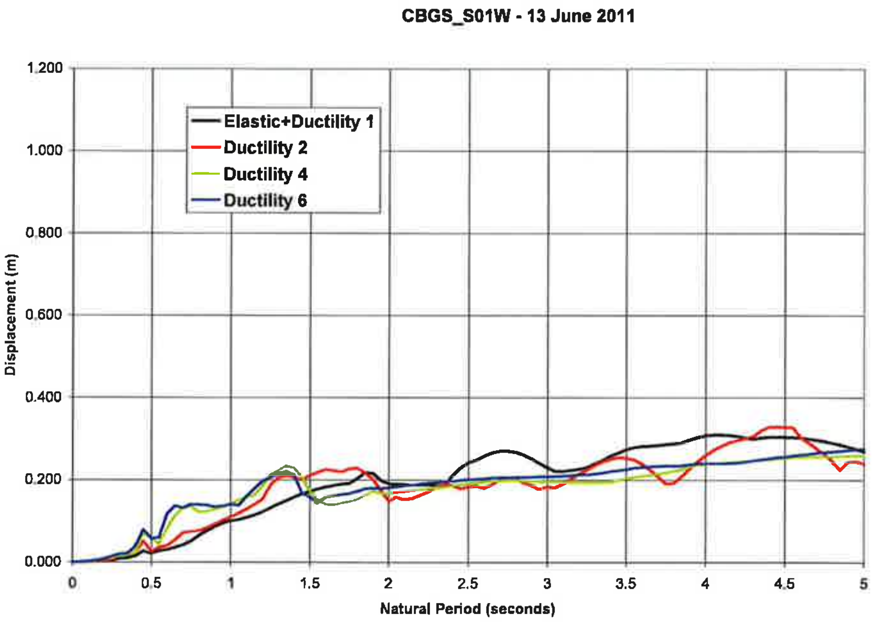


**Figure 31. Displacement Response Spectra**
**Christchurch Botanic Gardens. 13 June 2011- South 01° West Component**

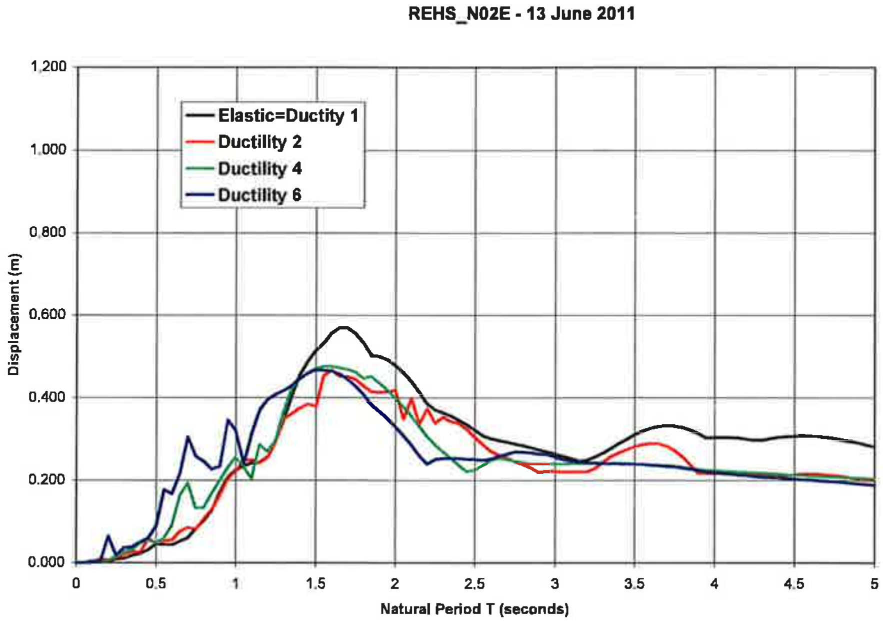


**Figure 32. Displacement Response Spectra**
**Resthaven. 13 June 2011- North 02° East Component**

These spectra appear to show a better fit to the equal displacement concept than do the other earthquakes. However, the inelastic displacements are greater than the elastic displacements for nearly all natural periods less than 2 seconds.

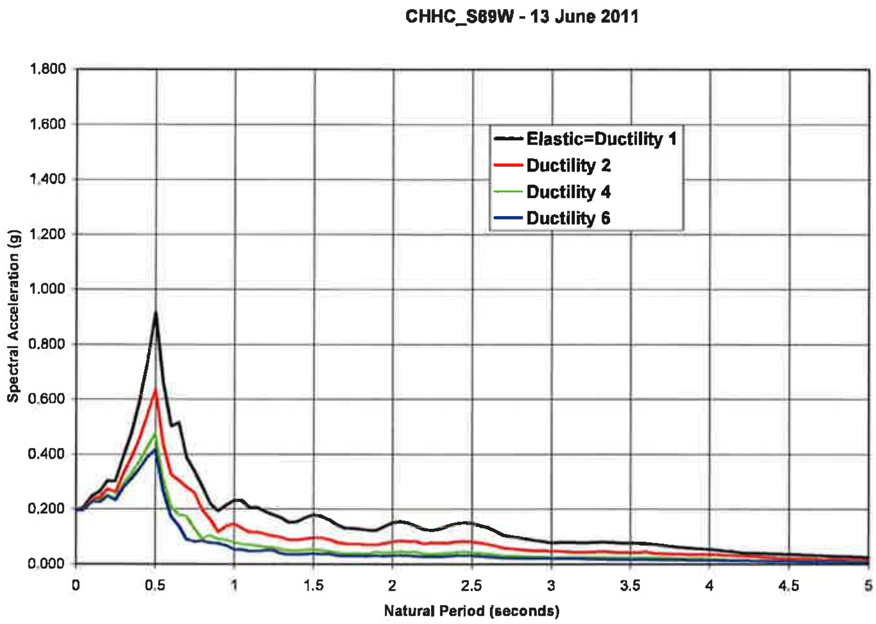


**Figure 33. Acceleration Response Spectra**
**Christchurch Hospital, 13 June 2011- South 89° West Component**

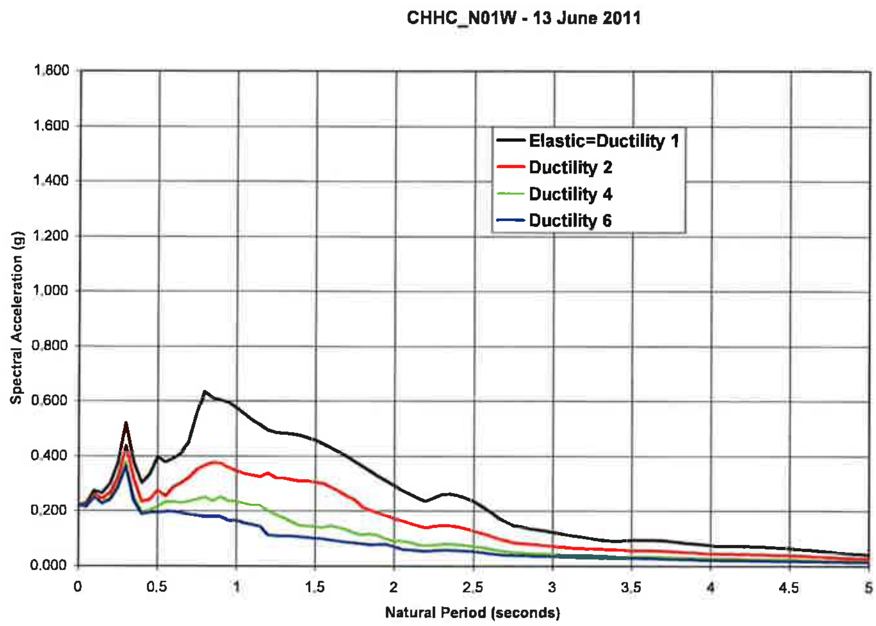


**Figure 34. Acceleration Response Spectra**
**Christchurch Hospital 13 June 2011- North 01° West Component.**

Figure 33 shows a dominant response at the short natural periods whereas the North-South component has marked increase in response at natural periods greater than 0,5 seconds.

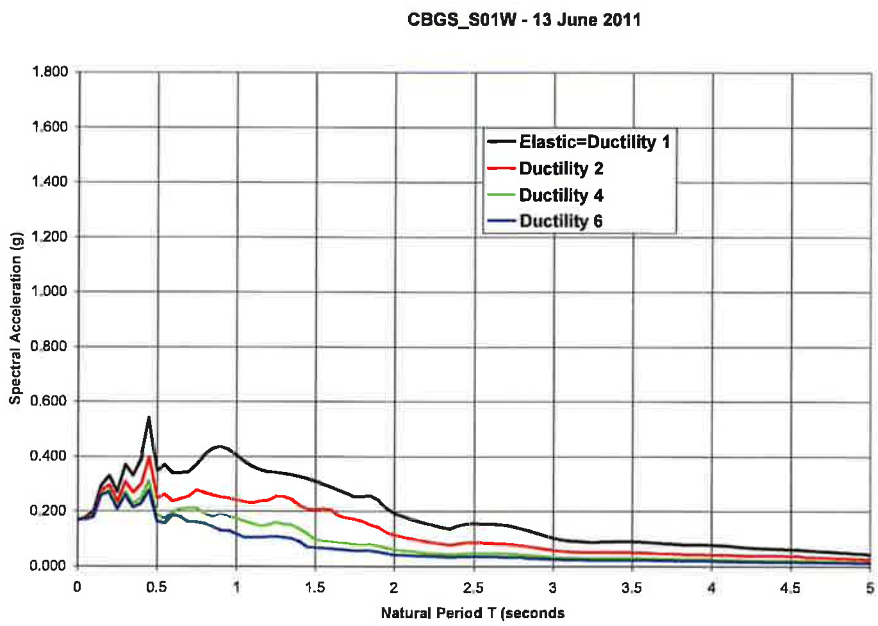


**Figure 35 Acceleration Response Spectra**
**Christchurch Botanic Gardens. 13 June 2011- South 01° West Component**

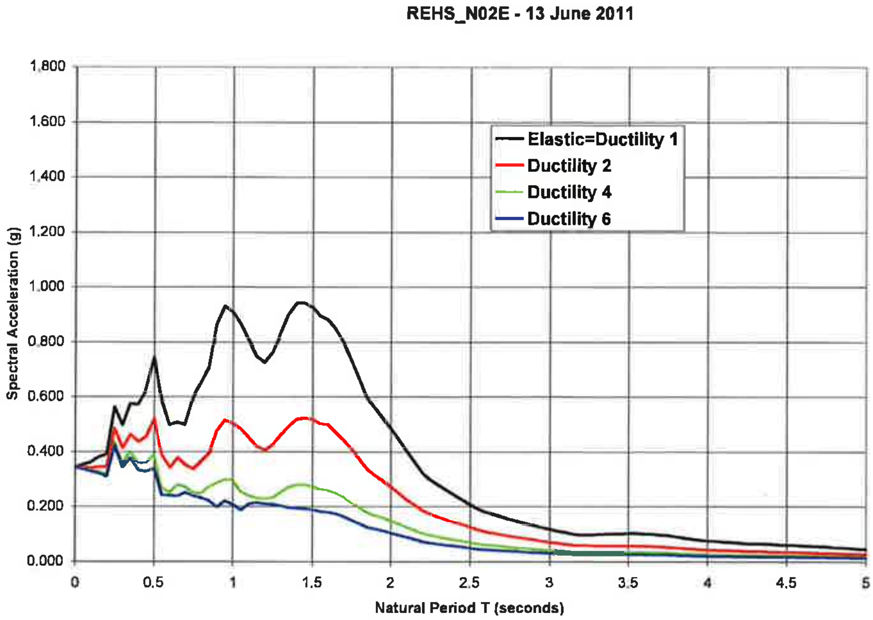


**Figure 36. Acceleration Response Spectra**
**Resthaven. 13 June 2011- North 02° East Component**

All of the these acceleration spectra show large accelerations in the 1 second to 2 second natural period range, showing the amplification due to the soft underlying soils. The epicentre was a little further away than for the February earthquake and the orientation of the predominant motion does not appear to be directed towards the city centre as was evident in the February earthquake. The effects of the deep soft underlying soils can be seen in the spectra. As was observed for the earlier earthquakes a study of the force reduction factors shows that the yield forces as a function of the elastic forces (accelerations) are not reduced by dividing by the ductility factor as expected from the equal displacement concept.

It must be noted that although the differences are not so noticeable in the spectra for this earthquake the differences are masked by the fact that when compared with the September and February earthquakes the displacements are much smaller and the plots for all earthquakes are drawn using the same scales.

# 10 22 February 2011 Earthquake Vertical Components

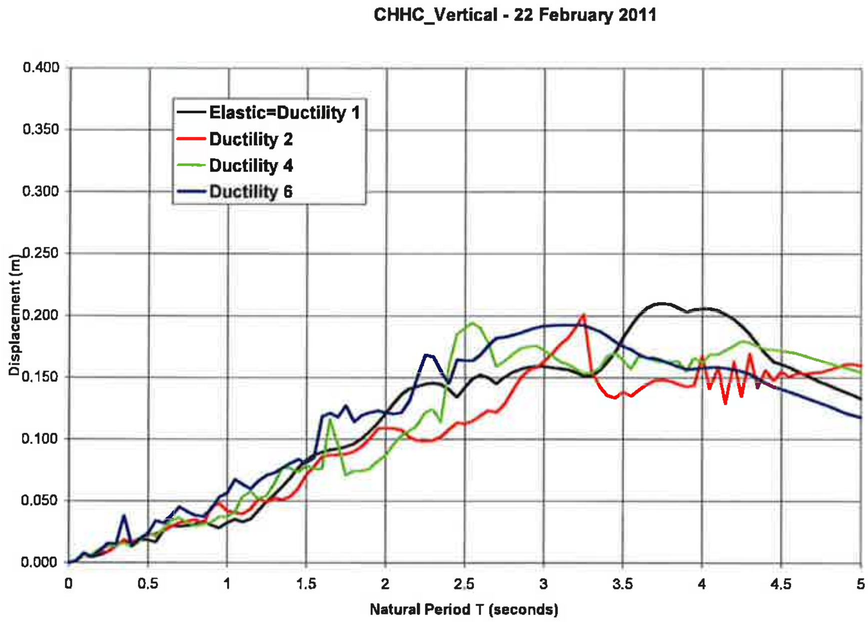


**Figure 37. Displacement Response Spectra**
**Christchurch Hospital 22 February 2011- Vertical Component**

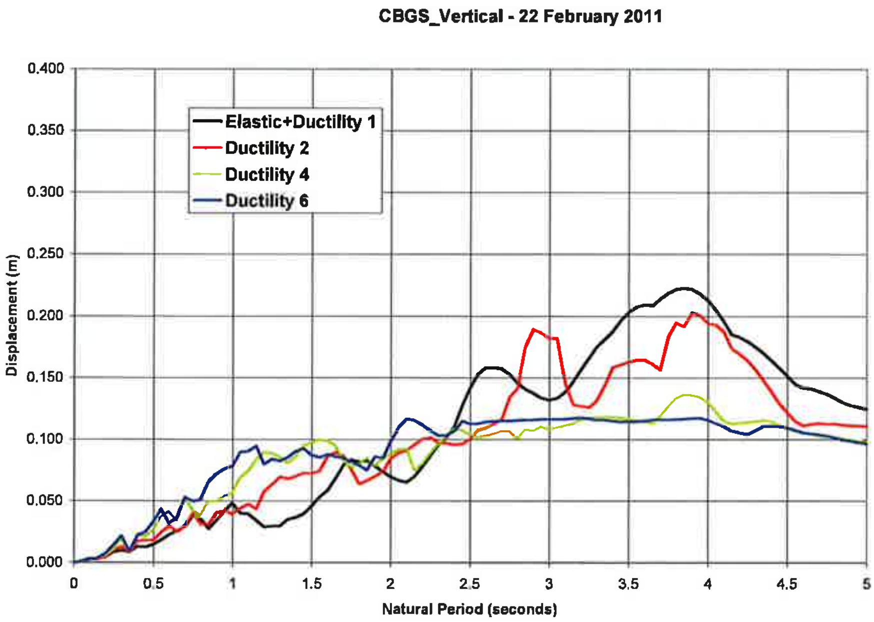


**Figure 38. Displacement Response Spectra**
**Christchurch Botanic Gardens. 22 February 2011- Vertical Component**

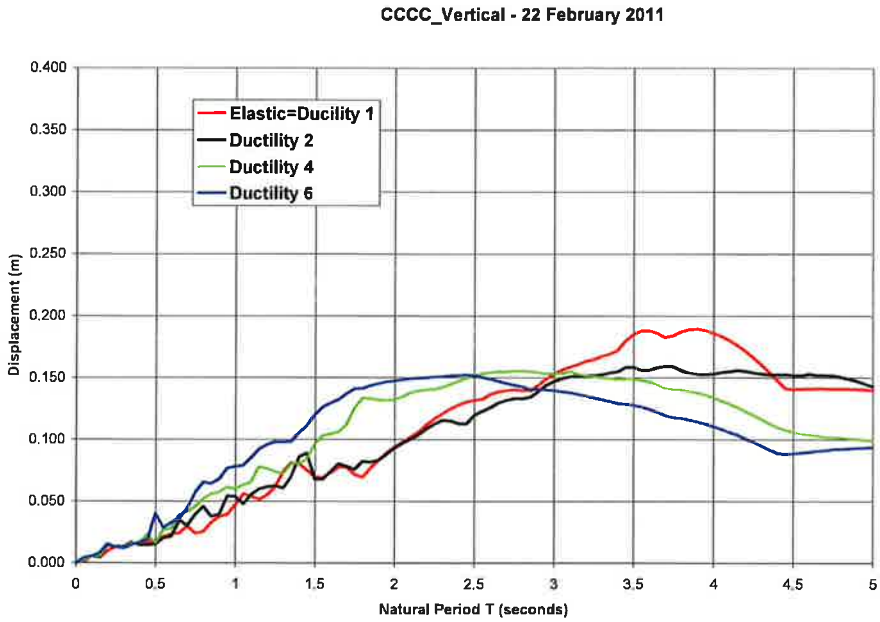


**Figure 39. Displacement Response Spectra**
**Christchurch Cathedral College. 22 February 2011- Vertical Component**

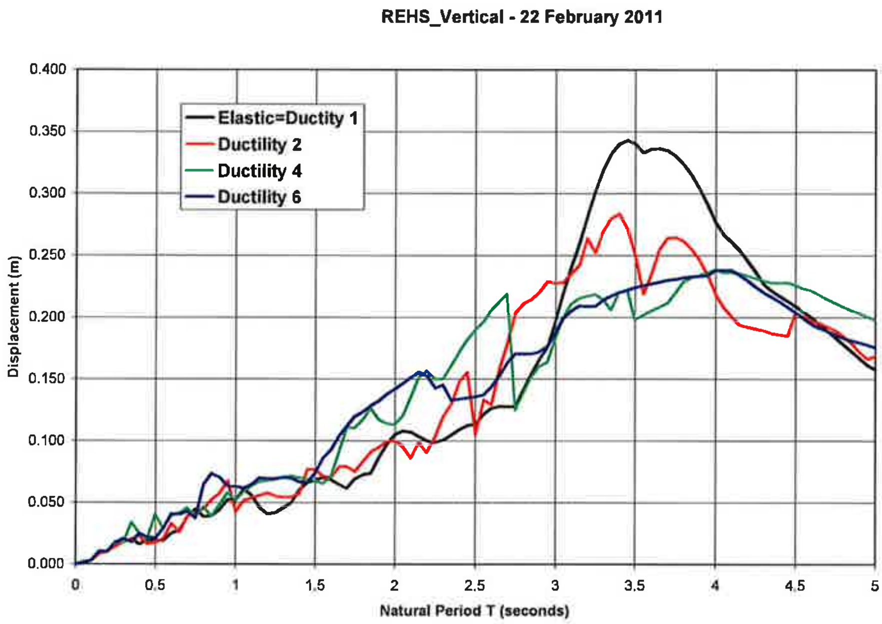


**Figure 40. Displacement Response Spectra**
**Resthaven. 22 February 2011- Vertical Component**

These spectra, apart from that at Christchurch Cathedral College spectra, show a marked peak at a natural period of about 3 seconds. This again probably is an effect of the soft soils underlying the city. In general the inelastic displacements are greater than the elastic displacements for natural periods less than 3 seconds.

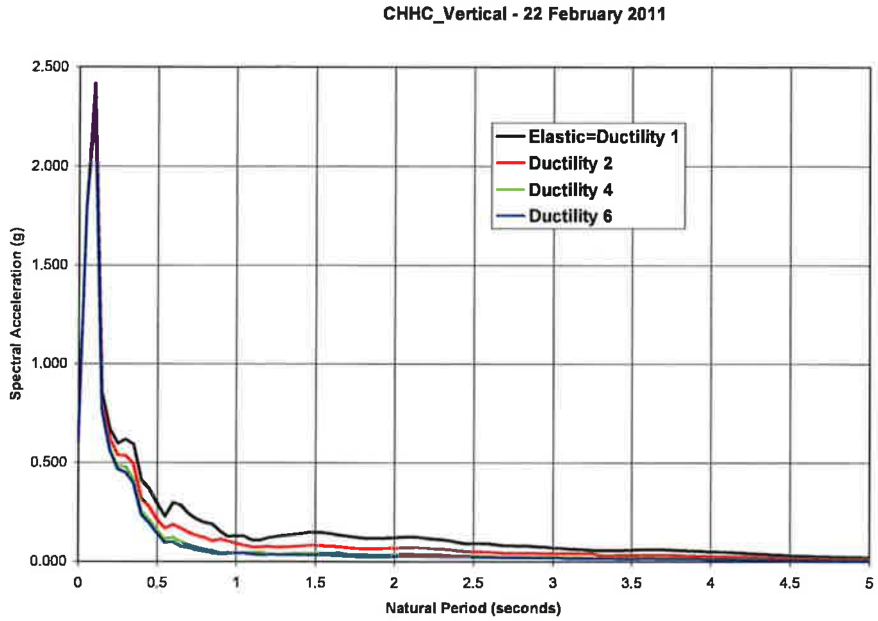


**Figure 41. Acceleration Response Spectra**
**Christchurch Hospital 22 February 2011- Vertical Component**

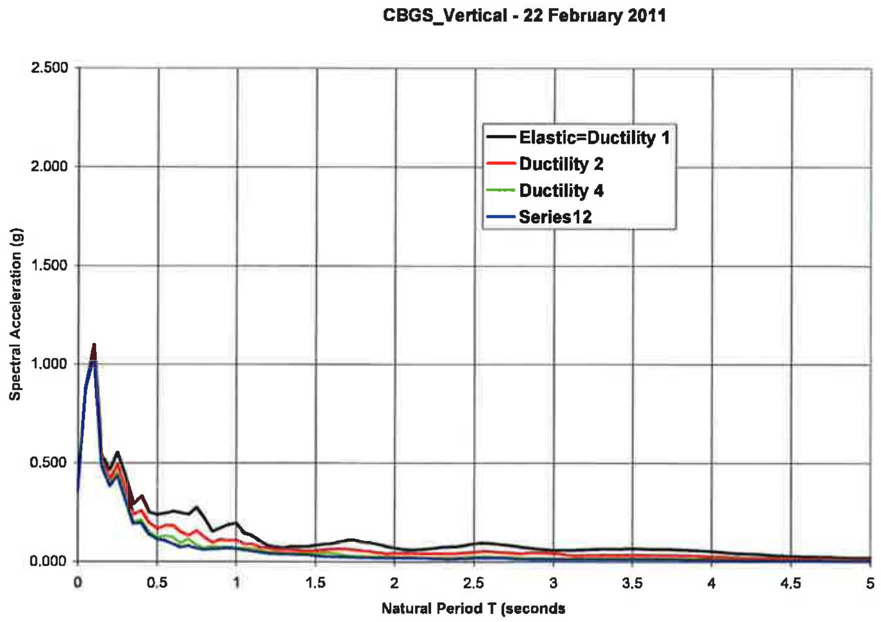


**Figure 42. Acceleration Response Spectra**
**Christchurch Botanic Gardens. 22 February 2011- Vertical Component**

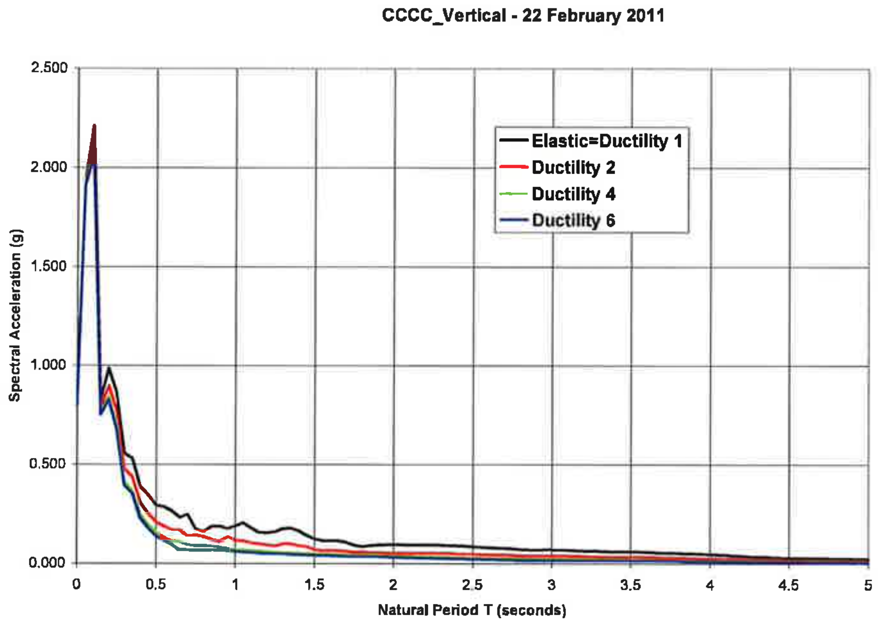


**Figure 43. Acceleration Response Spectra**
**Christchurch Cathedral College. 22 February 2011- Vertical Component**

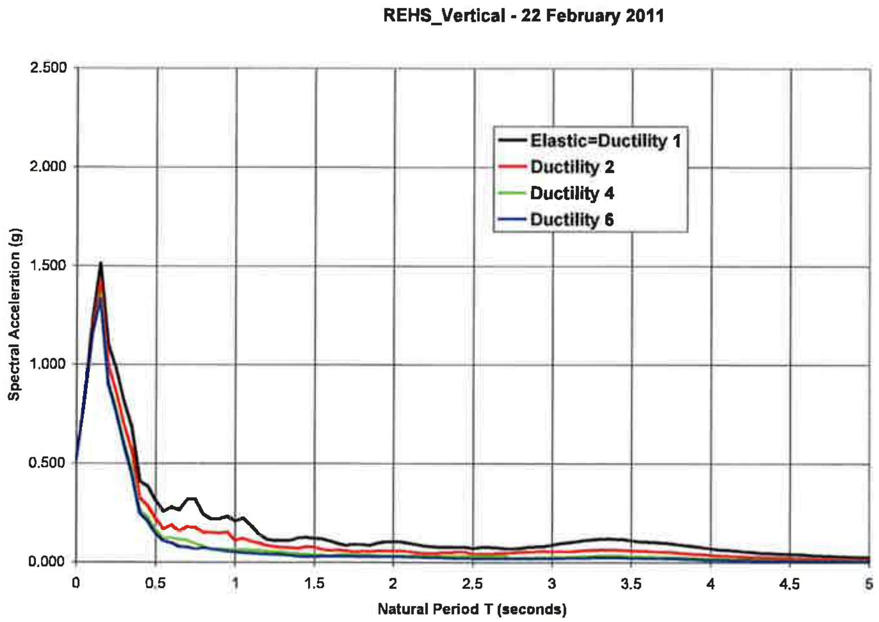


**Figure 44. Acceleration Response Spectra**
**Resthaven. 22 February 2011- Vertical Component**

These acceleration spectra show the predominance of the high frequency content of the vertical acceleration records. This is a feature seen in almost all earthquake acceleration records.

## 11. Relationship between the Observed Response Spectra and the Design Response Spectra (NZS1170.5:2004)

Figures 45 to 56 present the averaged spectra of the records listed with each figure plotted together with the design response spectra given in NZS1170.5.

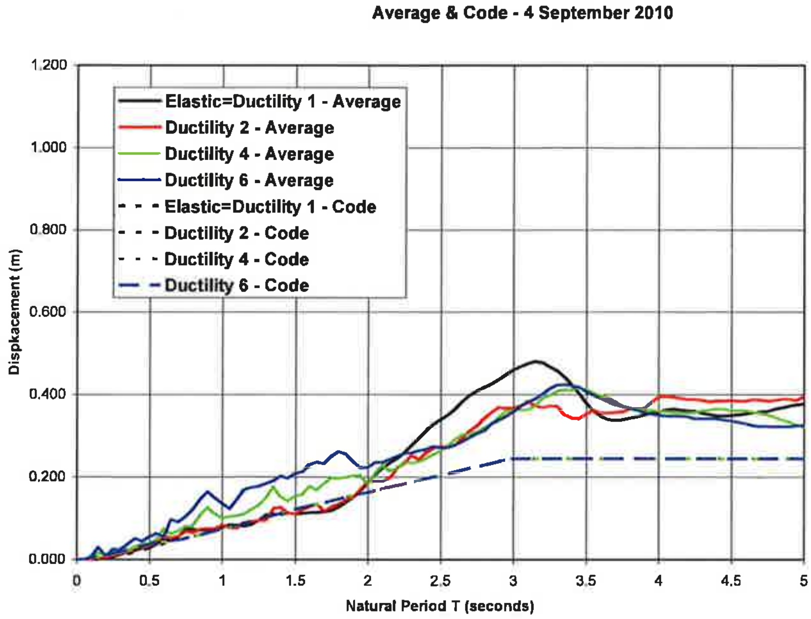


**Figure 45. Average Displacement Response Spectra vs NZS1170.5**
**Christchurch 4 September 2010**
CHHC_S89W, CBGS_N89W, CCCC_N64E, REHS_N88W

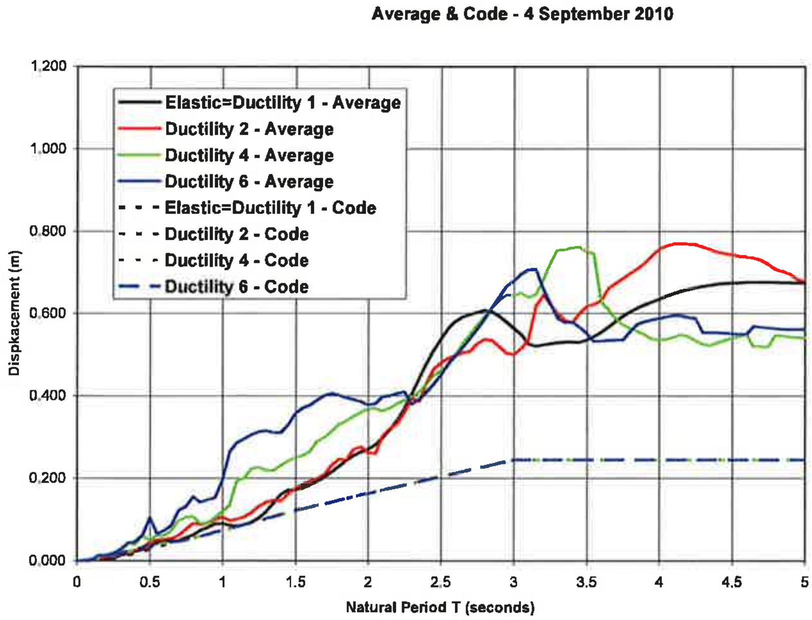


**Figure 46. Average Displacement Response Spectra vs NZS1170.5**
**Christchurch 4 September 2010**

CHHC_N01W, CBGS_S01W, CCCC_N26W, REHS_N02E

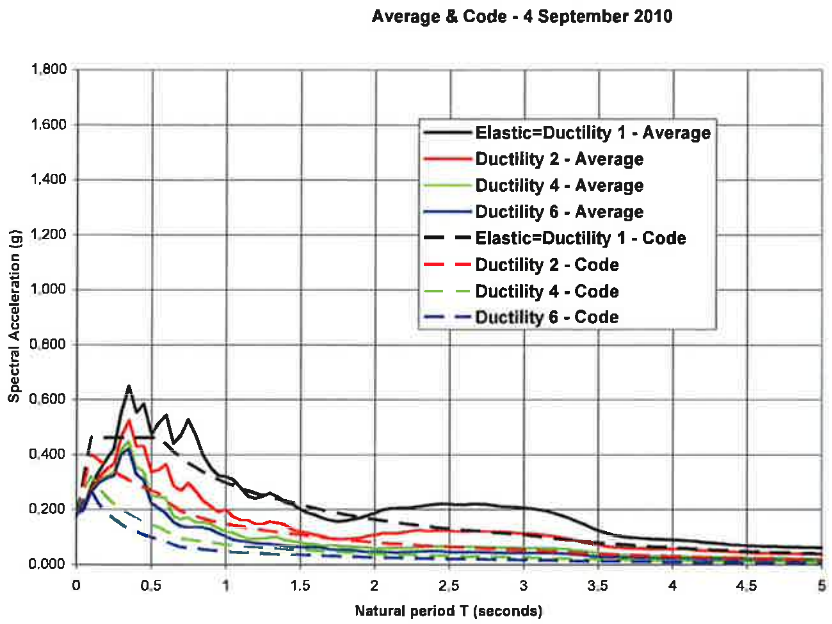


**Figure 47. Average Acceleration Response Spectra vs NZS1170.5**
**Christchurch 4 September 2010**
CHHC_S89W, CBGS_N89W, CCCC_N64E, REHS_N88W

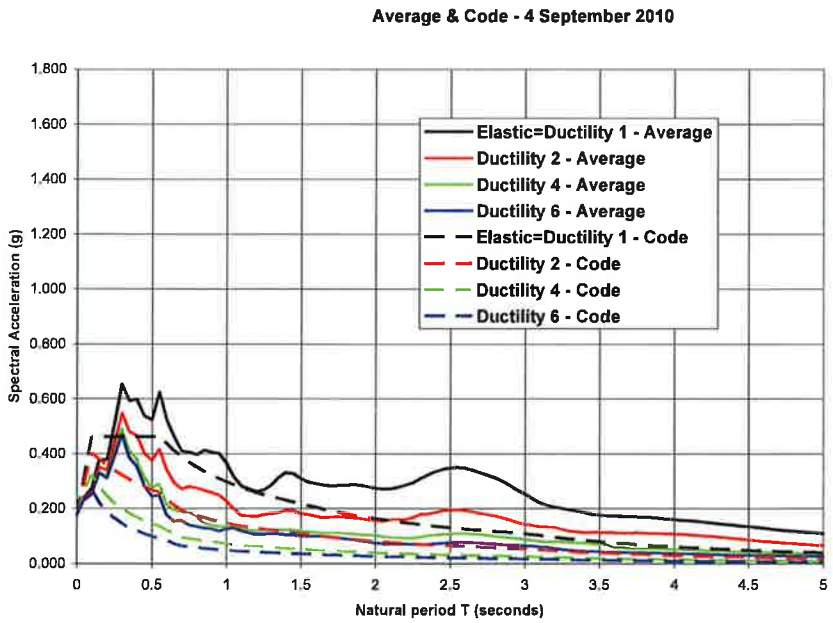


**Figure 48. Average Acceleration Response Spectra vs NZS1170.5**
**Christchurch 4 September 2010**
CHHC_N01W, CBGS_S01W, CCCC_N26W, REHS_N02E

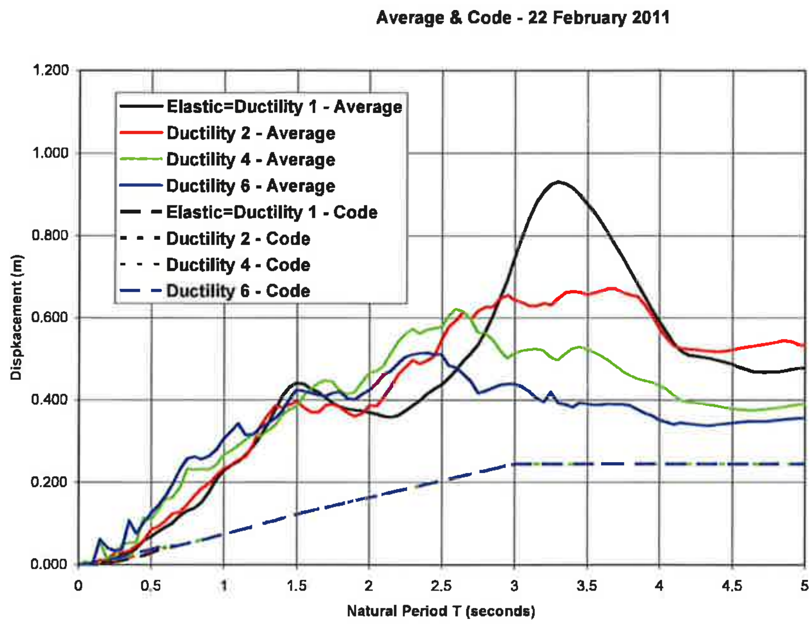


**Figure 49. Average Displacement Response Spectra vs NZS1170.5**
**Christchurch 22 February 2011**
CHHC_S89W, CBGS_N89W, CCCC_N64E, REHS_N88W

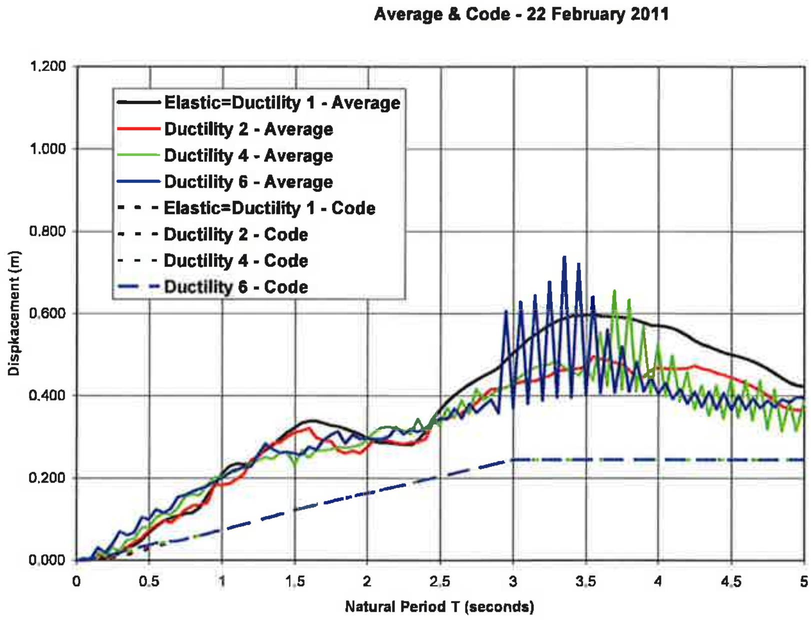


**Figure 50. Average Displacement Response Spectra vs NZS1170.5**
**Christchurch 22 February 2011**
CHHC_N01W, CBGS_S01W, CCCC_N26W, REHS_N02E

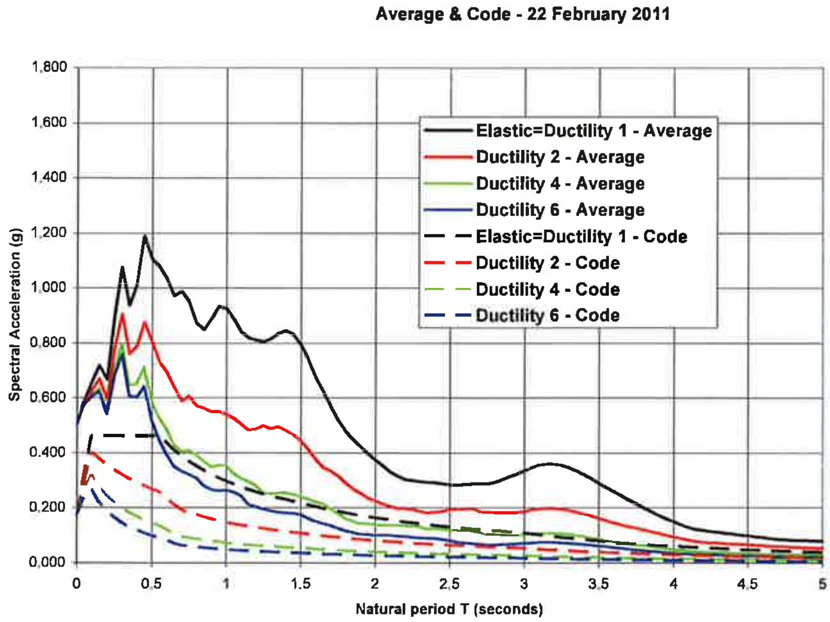


**Figure 51. Average Acceleration Response Spectra vs NZS1170.5**
**Christchurch 22 February 2011**
CHHC_S89W, CBGS_N89W, CCCC_N64E, REHS_N88W

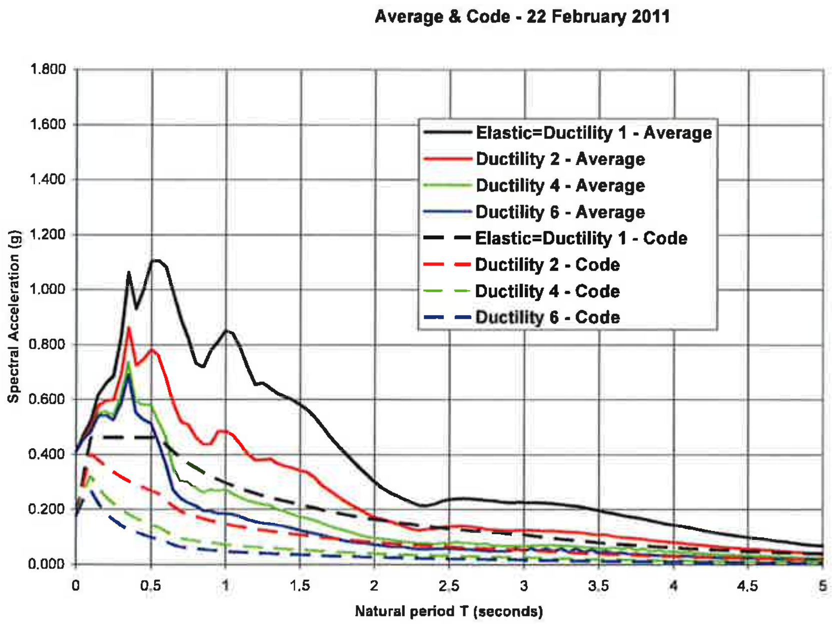


**Figure 52. Average Acceleration Response Spectra vs NZS1170.5**
**Christchurch 22 February 2011**
CHHC_N01W, CBGS_S01W, CCCC_N26W, REHS_N02E

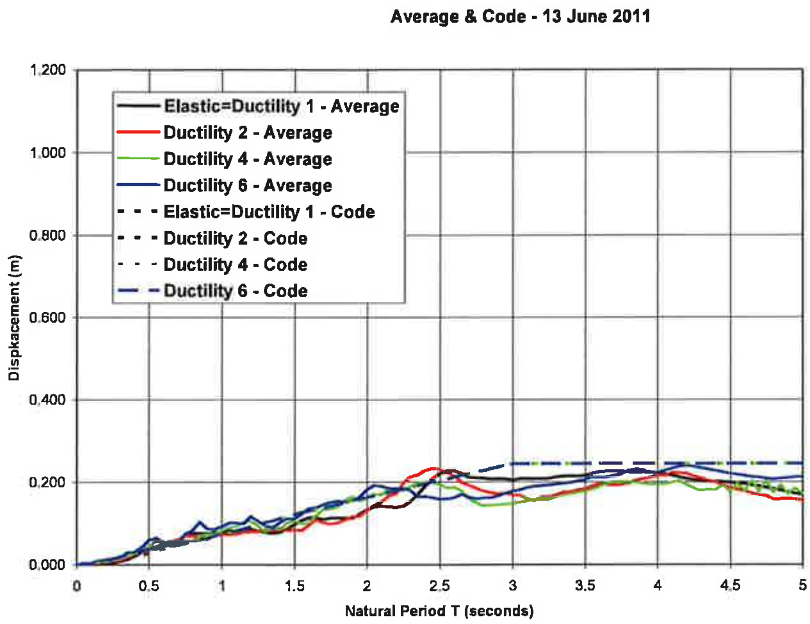


**Figure 53. Average Displacement Response Spectra vs NZS1170.5 Christchurch 13 June 2011**
CHHC_S89W, CBGS_N89W, REHS_N88W

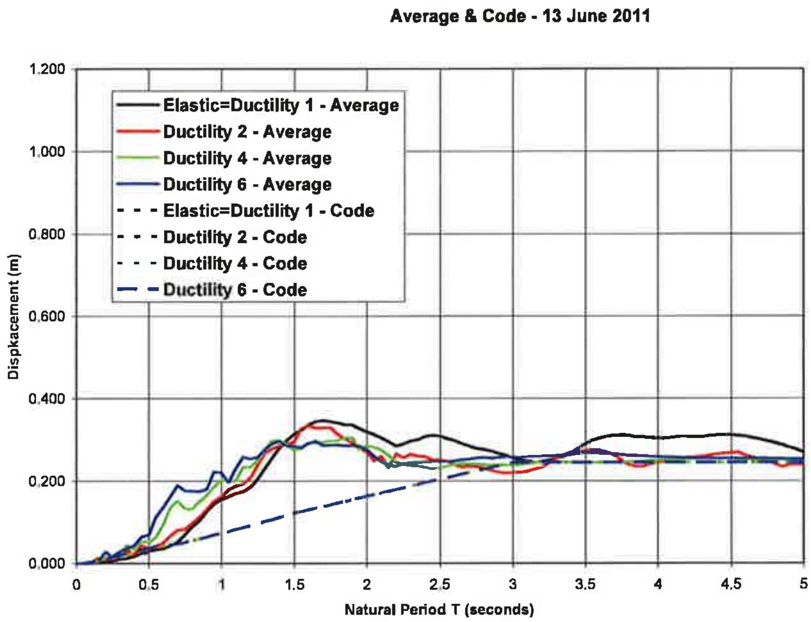


**Figure 54 Average Displacement Response Spectra vs NZS1170.5 Christchurch 13 June 2011**
CHHC_N01W, CBGS_S01W, REHS_N02E

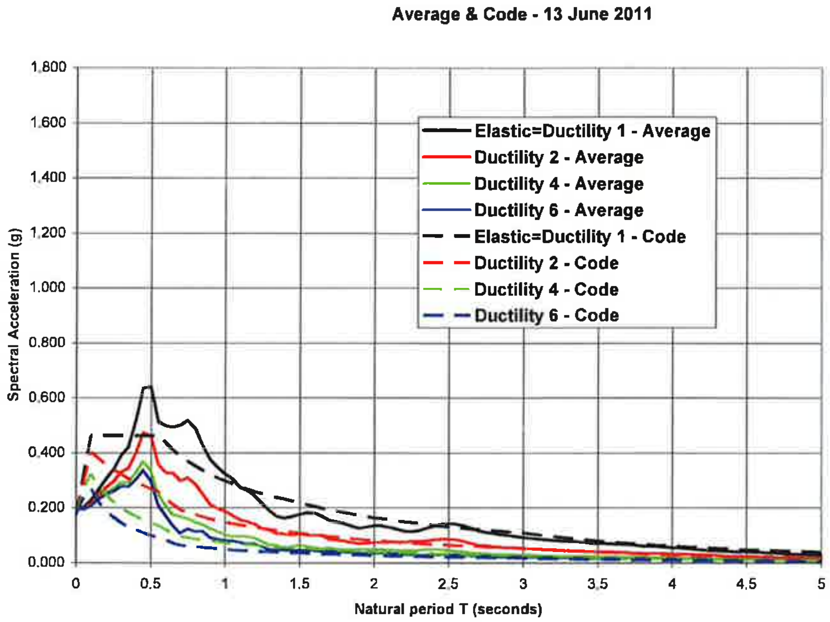


**Figure 55. Average Acceleration Response Spectra vs NZS1170.5**
**Christchurch 13 June 2011**
CHHC_S89W, CBGS_N89W, REHS_N88W

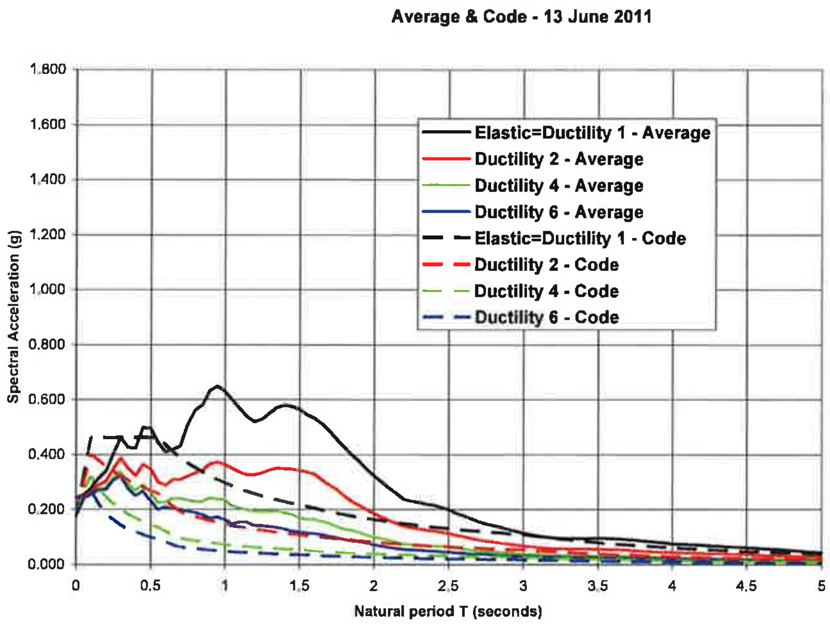


**Figure 56. Average Acceleration Response Spectra vs NZS1170.5**
**Christchurch 13 June 2011**
CHHC_N01W, CBGS_S01W, REHS_N02E

From the plots it can be observed that the shaking the Christchurch CBD in the September earthquake and the June earthquake was predominantly in the North-South direction while the shaking in the February earthquake had a predominant shaking in the East-West direction.

In the September earthquake the acceleration spectra were above the design values for nearly all natural periods and of the order of twice the elastic design spectra in the longer 2.5 second period range. The displacement spectra also show very large displacements with the displacements being of the order of two to three times the design displacements for almost all natural periods of free-vibration.

In the February earthquake the accelerations are up to three times the elastic design acceleration which accounts for the very large amount of damage. If one considers that the 2250 years return **R** factor is 1.8 then this represents a very rare event. The only questions is whether the 475 year risk for the Christchurch region was correct or was this between a once in 2500 year and a once in 10,000 year event. The displacement spectra also show very large displacements with the displacements again being of the order of two to three times the design displacements for almost all natural periods of free-vibration. It can also be observed that equal displacement does not fit the displacement spectra very well.

In the June earthquake the acceleration spectra show values up to twice the design values in the 0.7 to 2.0 second period range, and these are not as large as for the February earthquake the epicenter was a little further away. However, the effects on buildings already severely compromised by the February earthquake were very damaging. In the North-South direction the displacements were up to twice the design values in the 0.5 to 2.5 second period range and close to the design values for other natural periods. The deviation from equal displacement does not seem to be so marked in this earthquake spectra but this is masked because the smaller values were plotted using the same scales as for the September and February earthquakes.

In both the September and February earthquakes the inelastic displacements were greater than the elastic displacements to natural periods of the order of 2.5 seconds rather than the 0.7 seconds used by the current design standard. At longer natural periods the variation was more unpredictable with large ductility values in some cases showing greater displacements than those for linearly elastic buildings whilst in other cases showing significantly smaller displacements. If the February earthquake is considered a near-fault event for Christchurch then this may account for some of the very strong variations. Another effect that may lead to poor comparisons with behaviour in other earthquakes could be the effects of the underlying deep soft foundation material and subsequent liquefaction.

## Vertical Components in the February earthquake.

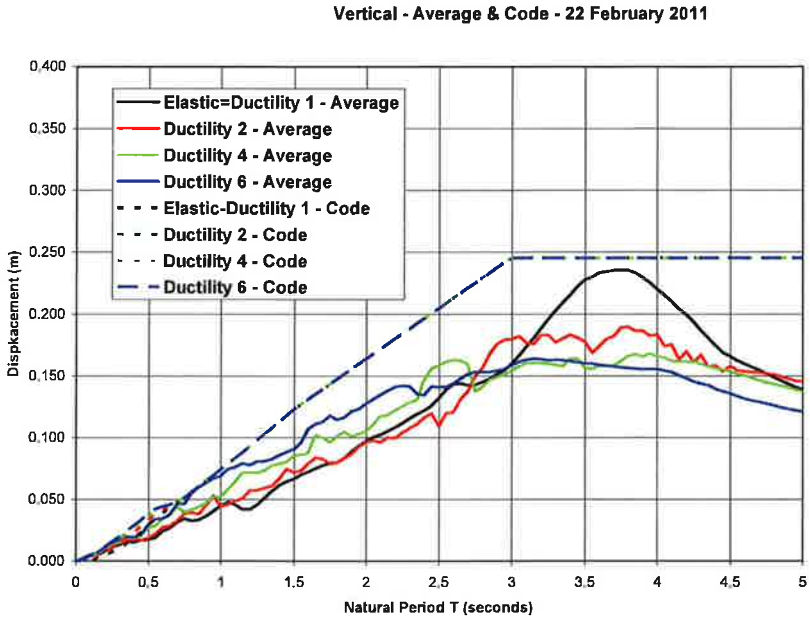


**Figure 58. Average Vertical Displacement Response Spectra vs NZS1170.5 Christchurch 22 February 2011**

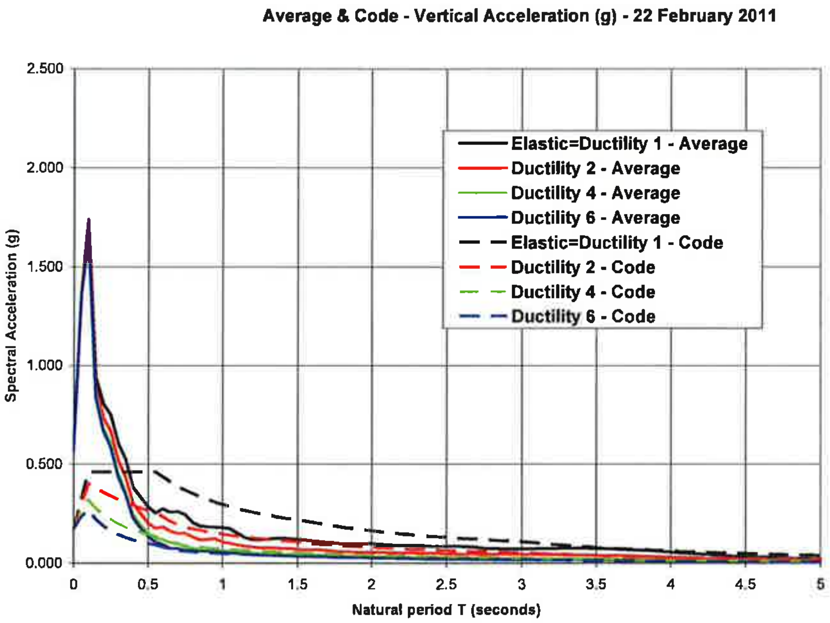


**Figure 59. Average Vertical Acceleration Response Spectra vs NZS1170.5 Christchurch 22 February 2011**

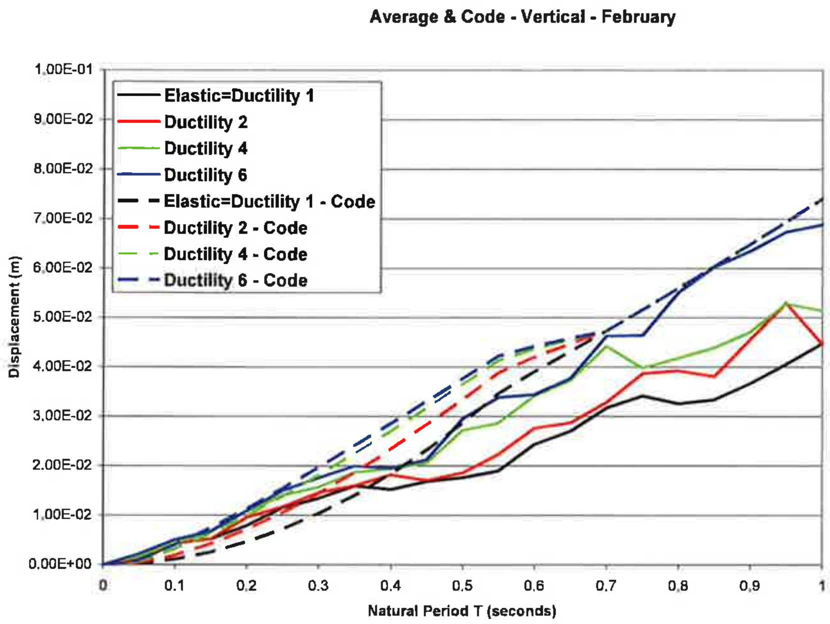


**Figure 60. Average Vertical Displacement Response Spectra vs NZS1170.5 Christchurch 22 February 2011 – 0.0 to 1.0 Seconds**

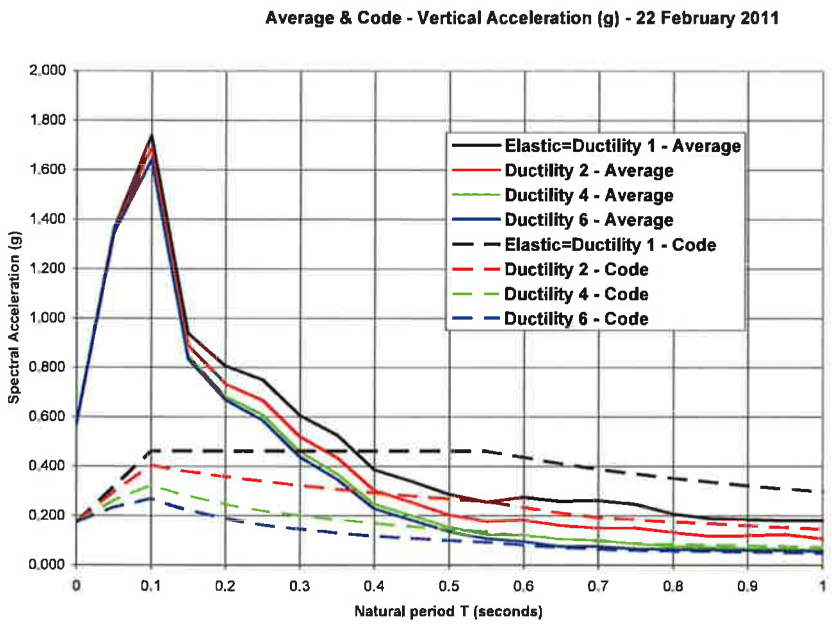


**Figure 61. Average Vertical Acceleration Response Spectra vs NZS1170.5 Christchurch 22 February 2011 – 0.0 to 1.0 Seconds**

In general the displacements are less than the design values obtained from the design standard NZS1170.5. However, the accelerations observed are much greater than the design values in the 0.0 to 0.4 second natural period range. The natural period of free-vibration for most building in the vertical direction will be very short, when compared with their natural periods of free-vibration in the horizontal directions and these high accelerations may be of major concern, in particular the effects on the flexural strengths of reinforced concrete column and wall members.

The vertical acceleration spectra for the February earthquake do not support the usual notion that they are of the order of two-thirds of the horizontal acceleration spectra. The recorded accelerations near the epicenter of the February were exceptionally large, possible the largest ever recorded. The accelerations in the CBD were also very large and whether this is to change design spectra or not will be resolved when it is decided that the Christchurch earthquakes were similar to other earthquakes or a very rare event to be treated differently. It must be noted that the very high accelerations really only apply for very low natural periods of free-vibration.