Inelastic Response Spectra for the Christchurch Earthquake Records

Summary by Canterbury Earthquakes Royal Commission Staff

The Commission sought advice from Professor Athol Carr at the University of Canterbury. The Commission has summarised his report.

The report is intended to assist structural engineers in the task of interpreting the observed performance of buildings in the Christchurch earthquakes of 2010 and 2011.

In the seismic design of buildings elastic spectra are used as part of the process of assessing the required strength of a building and the lateral displacement it must sustain to perform satisfactorily in an earthquake. Elastic response spectra show how the peak accelerations, which enable the lateral forces to be calculated and induced displacements change with the period of vibration of simple structures (single degree of freedom). In practice the design elastic spectra given in design codes and Standards for the design ultimate limit state are smoothed curves derived from the analytical analyses of a large number of recorded earthquake ground motions, which have strong motion ground shaking lasting typically 20 seconds or more. Empirical coefficients have been derived from such earthquake ground-motion records, which enables the design strength to be reduced, provided the structure has sufficient capacity to deform inelastically without loss of strength. The ability to deform inelastically is measured by (displacement) ductility, which is equal to the peak lateral displacement sustained in the design level earthquake divided by the lateral displacement of the structure at the point where it ceases to behave as an elastic structure. Thus a structure with a ductility of 4 sustains without the loss of significant strength a peak displacement equal to 4 times the maximum displacement reached when elastic response ceases (the structure yields).

The Christchurch earthquakes of 2010 and 2011 had unusually intense shaking but their duration was very much shorter than that of the typical earthquake records used to develop the empirical seismic design rules. For that reason it was felt the response spectra for the Christchurch earthquakes should be found, as the empirical rules used in design may not be representative of actual behaviour. The report shows this was the case. Using the actual elastic spectra and spectra for different ductility ratios should enable more realistic assessments of the performance of buildings in the Christchurch earthquakes to be obtained.

The report briefly describes the way in which response spectra are used in seismic design and it highlights a number of important factors that can influence the numerical values. These include the effect of the level of damping and the type of hysteretic response assumed for the structure. Both these factors are illustrated by showing the change in spectral values found by using different damping values and a different hysteretic model.

The report gives the acceleration and displacement spectra for the three main Christchurch earthquakes of 2010 and 2011. These spectra are derived using an elastic perfectly-plastic hysteretic model with an equivalent viscous damping of 5 percent. The choice of analytical model and the level of damping are standard assumptions made in deriving response spectra for design codes (standards). For each earthquake response spectra were derived for accelerations and displacements, for:

- Four locations in the central business district;

- Elastic response and for displacement ductility values of 2, 4 and 6;
- In two horizontal directions at right angles at each location; and
- In the vertical direction in each location.

In addition there are a few response spectra illustrating the differences obtained with different damping levels, and with a hysteretic model which is more representative of the behaviour of reinforced concrete structures than that of the elastic perfectly-plastic model.