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Estimating Slab Earthquake Response Spectra from a 3D *Q* Model

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Abstract The problem of estimating response spectra for a heterogeneous lithosphere can be addressed by directly computing attenuation from physical models. In a subduction zone, slab earthquakes will have different attenuation through the mantle wedge than the slab. This article is primarily concerned with very high loss paths through the attenuating mantle underlying the volcanic zone of the North Island, New Zealand, where low *Q* requires modification of the "standard" New Zealand engineering response spectrum model.

A lack of strong-motion data prevents a standard regression analysis for paths from deep slab earthquakes through the highly attenuating mantle zone. Instead, modifications have been derived using a 3D frequency-independent *Q* model that has been developed for the North Island subduction zone from 2–20 Hz local earthquake t^* data. By calibrating the t^* crustal results to the standard New Zealand model, amplitudes can be compared between the standard model and the 3D *Q* model. Additional path-averaged attenuation rate coefficients, *CQ*, for each source and station pair are determined. This results in simple expressions for *CQ* as a function of centroid depth, for modifying the standard model.

This modification reduces the model spectra by a factor of approximately 2–4 for mantle wedge paths below the volcanic region. This reduction is similar to the observed variation in response spectra, at periods below 0.4 sec, for a 160-km-deep M_w 6.0 earthquake. For shallow earthquakes propagating through the shallow volcanic region, the new model gives results that are similar to a volcanic-path attenuation term derived by regression analysis.

Introduction

It is important for engineering prediction of earthquake ground motion to model the heterogeneous transmission of shaking from deep slab earthquakes in New Zealand. The North Island lies above the Hikurangi subduction zone (Fig. 1), which has resulted in volcanism and extension in the Taupo volcanic zone (TVZ). Because of along-strike variation in plate motion and plate-interface properties, the TVZ is limited to the central and northern portions of the North Island, although the subducted slab continues to the northern South Island (Reyners, 1998; Eberhart-Phillips *et al.*, 2002; Upton *et al.*, 2002). Seismograms from mantle paths indicate high attenuation compared to slab paths, yet there are not enough strong-motion data to use a standard regression approach to model the attenuation in the mantle.

The geometry for deep earthquakes is illustrated schematically in Figure 2a. Below 40-km depth, earthquakes tend to occur only in the subducting slab and hence are located directly below the TVZ. The subducting Pacific plate slab has very low attenuation, the crust of the Australian plate has moderate attenuation, and the mantle wedge between the slab and the overlying crust has very high attenuation. Additionally the crust in the TVZ has very high attenuation. Thus deep earthquakes will be more strongly felt at more distant eastern sites with low-loss slab paths, such as Napier, than at closer sites with paths through the mantle wedge. Deep earthquakes have produced triggered strong-motion records at eastern sites, but for engineering applications the response for deep earthquakes at sites including high-loss paths, such as Taupo and Rotorua in the TVZ and other locations to the northwest, must also be estimated.

The effect of high attenuation in the mantle and TVZ can be clearly seen in both felt and instrumental data. An atlas of isoseismal maps for New Zealand (Downes, 1995) contains several deep-earthquake maps for which the major axis of the ellipse that fits the isoseismal pattern is displaced well to the east of the epicenter (Fig. 2b). These maps of felt effects provide insight for earthquakes that lack strong-motion records. Although not formally mapped, the same effect can be seen in records from strong-motion accelerographs. For several deep earthquakes in the general vicinity of the TVZ, the strongest accelerations have been recorded in the vicinity of Napier and Gisborne, whereas instruments at sites above or west of the epicenter have either not been triggered or have returned weaker motions.