Earthquake Hazard Investigations in the Pacific Northwest

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Investigations

The objective of this research is to investigate earthquake hazards in the Pacific Northwest including problems related to possible large subduction earthquakes. Improvement in our understanding of earthquake hazards is based on better understanding of the regional structure and tectonics. Current investigations by our research group focus on the configuration of the subducting Juan de Fuca plate, differences in characteristics of seismicity between the overlying North American and the subducting Juan de Fuca plates, and kinematic modeling of deformation of the Juan de Fuca slab.

Deep three-dimensional velocity structure of the Cascadia Subduction zone

Using an approximation to non-linear inversion, we estimated the velocity structure of the upper mantle portion of the Cascadia subduction zone using a data set of about 10,000 relative arrival times of teleseismic *P* waves recorded from 1980 to 1990 on WRSN (Washington Regional Seismic Network) short-period vertical stations in Washington and Northern Oregon. To approximate non-linear inversion, linear travel-time inversions (conjugate gradient method) were performed alternately with three-dimensional ray tracing.

The most prominent and robust characteristic of the models obtained is a steeply eastward dipping fast, planar feature which is inferred to be the thermal and compositional anomaly associated with the subducting Juan de Fuca oceanic plate. The high velocity zone is located at a depth of approximately 100 km beneath the Cascade volcanos, similar to subduction zones elsewhere. At shallow depths (i.e. 60-80 km) the velocity anomaly is consistent with projections from models of slab structure from 40-60 km depth.

At 48° N latitude, the high velocity zone extends to depths of 400 km or more. However, south of 46°, the velocity anomaly disappears at a depth of ~ 150 km. Considering the tectonic history of the region and other geophysical observations such as seismicity, this observation is consistent with a deep slab which has separated completely from the shallow slab in the south, and descended into the mantle. The three-dimensional velocity structure is used to model other geophysical observations, such as the regional gravity field and *P*-wave amplitude variations due to geometrical ray spreading.

Kinematic Modeling:

We are working on the theoretical formulation and implementation of a finite element scheme to invert for both the geometry of a thin sheet (the slab) and the flow field within it which minimizes the global dissipation power associated with its membrane deformation rate. The sheet is assumed to be a fluid with a Newtonian or a power-law rheology, and an effective viscosity at least a few orders of magnitude higher than that of the surrounding mantle. The boundary conditions used for Cascadia subduction are that (1) seaward of the trench, the sheet is a spherical shell rotating at the Juan de Fuca/North America relative plate rates, and (2) the slab dips 20° into the mantle along two cross sections under northernmost California and under northernmost Vancouver Island. The geometry and flow field are otherwise free to vary except that the flow must not cross the slab.

The important aspect of the fixed part of the geometry is the concave oceanward bend in the trench axis which occurs at the latitude of the Olympic Mountains and Puget Sound. The combination of the bend in the trench and the downward dipping slab produce the problem, like that of a table cloth hanging over the corner of a table, that there is too much slab material for the available space. The trench geometry forces along-arc compression of the slab, or geometric arching/buckling, or a combination of the two. We have investigated two possibilities: For the first we fix the geometry so that the slab dips at 20° along all cross sections and invert for the flow field only. In the second, we allow the geometry to vary using the boundary conditions described above. Root-mean-squared effective strain rate of the flow field calculated in the second experiment is reduced by a factor of ten relative to the first experiment, and the geometry after inversion displays a pronounced arch whose axis is normal to the trench and dips at about 10° under Puget Sound. The arch is flanked by parallel troughs. This minimum strain-rate geometry is similar to the slab geometry estimated by hypocenter distributions and receiver function analyses.

It is well known that a sheet of corrugated metal is difficult to bend along an axis normal to the corrugations. This is because of strong resistance to membrane strains. Similarly, once the arch has formed in the shallow portions of the slab (above 50 km depth), it is difficult to bend the arch from its 10° dip to its 50° dip at a depth of 150km and below. Our seismic tomography results provide compelling evidence that the slab below a depth of 150 km dips steeply. Bending the arch provides a possible explanation for the observed pronounced concentration of intra-plate seismicity beneath the Puget Sound basin relative to regions to the north or south. We are investigating this hypothesis.

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