REPORT
SOIL HAZARD MAP OF GREATER VICTORIA FOR ASSESSING THE EARTHQUAKE HAZARD DUE TO LATERAL GROUND SHAKING

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Southwest British Columbia is located in the most seismically active region of Canada. However, the strength of ground shaking during an earthquake varies considerably due to local geological conditions, and is generally greater at sites located on deposits of soft soil than at sites located on bedrock. For example, during the 1989 Loma Prieta Earthquake, ground shaking in San Francisco was commonly two to three times stronger on soft soil sites than on bedrock sites nearby (Clough, et al., 1994).

The objective this map is to delineate the different soil types in Greater Victoria for use in determining the earthquake hazard due to lateral ground shaking. **The map is intended to be used for planning purposes, such as land use planning, emergency response planning, and prioritization of seismic retrofit candidates. It is not intended to replace site-specific investigations where these are normally required. Furthermore, other earthquake hazards, such as liquefaction, landslides and tsunamis have not been considered in the preparation of this map.** ***Appropriate use of this map requires careful reading and understanding of the following text.***

Geological Summary of Greater Victoria

Quaternary sediments in the Victoria area overlie a highly irregular bedrock surface. The depth to bedrock can vary from zero to as much as 30 metres within the space of a city block. The oldest sediments include the till of the Late Wisconsinan Glaciation and earlier glacial and non-glacial deposits. These deposits are all overconsolidated. They are up to 60 m thick in drumlinoid ridges on the Saanich Peninsula, but elsewhere they are generally discontinuous and a few metres thick.

The Wisconsinan till is overlain by the Capilano sediments, which were deposited at the close of the Fraser Glaciation and consist here of the Victoria clay and the Colwood sand and gravel. The Victoria clay is a glaciomarine clayey silt that ranges in thickness from zero over bedrock knolls to 30 metres in depressions on the till or bedrock surface. The lower part consists of soft to firm grey clay, and is normally overlain by up to 6 metres of stiff brown clay. The brown clay is at the surface in most of the Victoria area. However, in low-lying areas the Victoria clay commonly consists entirely of grey clay, and is overlain by Holocene organic silts and peat. The upper part of the grey clay is slightly overconsolidated where overlain by the brown clay, but normally consolidated where overlain by Holocene organic soils. The Colwood sand and gravel consists of glaciofluvial outwash and deltaic deposits up to 30 metres thick located in the Colwood area. The surface of the delta and outwash plain is between 60 and 90 metres elevation.

Holocene sediments in the area are restricted to organic soils, and locally sands deposited in beaches, deltas, alluvial fans and river channels and beach sands.

More details of the Quaternary geology are can be found in papers and reports by Crawford and Sutherland (1971), Nasmith and Buck (1998), Monahan and Levson (1997, 2000), and Monahan et al. (1998, 2000).

Geological Mapping

This map is based mainly on published earthquake hazard mapping conducted by British Columbia Geological Survey (Monahan et al., 2000). Locally, some minor changes have been made to the geological boundaries on the basis of more recent investigations by the author.

Definition of Soil Types

The soil types are defined here primarily by assigning NEHRP site classes to the various geological map units shown on the source map (Building Seismic Safety Council, 1994). These site classes, which are being incorporated into the current national building code, are defined fundamentally on the basis of the average shear-wave velocity in the upper 30 metres (V_{30}). However, other criteria can be used where shear-wave velocity data are lacking (Table 1). In general, the intensity of ground shaking increases from site class A to E.

Table 1. NEHRP Site Classes (Building Seismic Safety Council, 1994)

Site Class	General Description	Definition (V_{s30}=average shear-wave velocity in upper 30 m, m/sec; N_{30}=average N in the upper 30 m)
A	Hard rock	V_{s30}>1500
B	Rock	760<V_{s30}<1500
C	Very dense soil and soft rock	360<V_{s30}<760; or N_{30} >50; or >3 m of soil over bedrock, where V_{s30}>760 m/sec
D	Stiff soils	180<V_{s30}<360; 15<N_{30}<50
E	Soft soils, or soil profile with >3 m soft silt and clay	V_{s30}< 180; or N_{30}<15; or >3 m silt and clay with plasticity index >20, moisture content >40%, and undrained shear strength <25 kPa)

Site classes were assigned to the geological map units on the basis of a shear-wave velocity model of the Quaternary deposits of the Victoria area that was initially developed for the original earthquake hazard mapping project and was updated with more recent shear-wave velocity data (see Monahan and Levson, 1997, 2001; Monahan et al., 2000). This model permits the estimation of the V_{s30} at sites where shear-wave data are not available, but where the stratigraphy is known.

Sites Classes A & B

Site Classes A and B both pertain to bedrock and have been combined on this map. The Site Class A & B designation has been assigned to areas of nearly continuous outcrop.

Site Class C

Site Class C has been assigned on this map to areas where till occurs at surface, or where till or bedrock have a soil cover up to 5 metres thick. In the areas assigned to this site class where soil overlies bedrock, bedrock outcrops occur commonly. Consequently, such areas shown here as Site Class C would include smaller areas of Site Class A or B. This is particularly true in the northern and western parts of the map, where areas of continuous outcrop and thin soil cover were not differentiated on the source map.

Site Class D

Site Class D has been assigned to deposits of the Colwood sand and gravel and to areas where more than 5 metres of Victoria clay overlies either bedrock or till. In many of the areas assigned to this site class where the Victoria clay is present, estimates of V_{s30} based on the shear-wave velocity model span the boundary between Site Classes C and D, varying with the thickness of the clay units and till. Consequently, such areas shown here as Site Class D would include areas of Site Class C. Because of the extreme irregularity of the bedrock surface, areas of Site Class C and D can occur together within a single building lot. Areas of upland peat have also been assigned to this site class rather than Site Class E. Unlike in the Lower Mainland, upland peat deposits in the Victoria area do not appear to be overlie thick accumulations of soft clay, which would lead to an assignment of Site Class E.

Site Class D-E

This designation has been assigned to areas where Site Classes D and E cannot be readily differentiated at this time. Generally, this site class has been assigned to areas where the grey clay of the Victoria clay is thicker than 3 metres and is capped by the brown clay. On the basis of the shear-wave velocity model, Site Class D could be anticipated where the total thickness of the Victoria clay is less than 20 metres, and Site Class E where the Victoria clay is thicker than 20 meters. However, Site Class E is also defined on the basis of more than 3 metres of soft clay, and a comparison of field vane data obtained in the Victoria clay indicates that the Victoria clay locally includes more than 3 metres of soft clay where it is thicker than 15 metres. The general increase of the thickness of soft clay as the total thickness increases is to be expected, because the Victoria clay thickens into topographic lows, where the water table would have remained higher. However, this criterion should be used with caution, because local topography is the direct control of the preservation of soft clay in the upper part of the Victoria clay rather than total clay thickness. Site Class D-E has also been assigned to areas of thick clay fill.

Site Class E

Site Class E has been assigned to areas where the Victoria clay is overlain by peat and consists entirely of grey clay. Not only does the total thickness of Victoria clay commonly exceed 20 metres in such areas, so that they should be assigned to Site Class E on the basis of the shear-wave velocity model, but the amount of soft clay commonly exceeds 3 metres.

Limitations of this map

This map is intended for regional planning purposes only, such as prioritizing seismic retrofits and land use and emergency response planning, and should not replace site-specific evaluations where normally required.

The map on which this map is based was based on the interpretation of borehole records, which are unevenly distributed throughout the area (Monahan et al., 2000). In areas where borehole data are scarce, subsurface conditions had to be *inferred* from topographic and geomorphic evidence. Furthermore geological boundaries are generally gradational and geological materials are variable, so that deposits of a particular deposit may locally have unusual properties. For these reasons, geological boundaries are *approximate*, areas assigned to one site class may enclose smaller occurrences of other site classes, and the mapping is subject to revision as more borehole data become available. **Consequently, the hazard *at a specific site* could be either higher or lower than that indicated by these maps.**

This map does not address man-made alterations to ground conditions, whether the changes lower or increase the hazard at a site. Furthermore, the map does not consider the effect of fill on the shear-wave velocity profile, except in those areas where fill is identified on the source map. However, other areas of fill occur present, and new areas of fill will be developed in the future.

The stability of dams under earthquake shaking, and hazards due to the failures of dams or other man-made structures have not been addressed.

This map shows the distribution of soil classes, which largely reflect the variation in the ground-shaking hazard in an earthquake. However, a low hazard indicated on the map does not mean freedom from earthquake hazards, because all areas could be subjected to significant ground shaking during an earthquake. Furthermore, the map does not address the variation in the ground-shaking hazard due to topography, or due to resonance or subsurface structure.

The map does not address other earthquake hazards, such as liquefaction, landslides, tsunamis, land subsidence and ground rupture.

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