REPORT
SOIL HAZARD MAP OF THE LOWER MAINLAND OF BRITISH COLUMBIA 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 the Lower Mainland of British Columbia, from West Vancouver to Chilliwack, 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 the Lower Mainland

The Lower Mainland of British Columbia is located in the northern part of the Fraser Lowland, which is bounded to the north by the Coast Mountains, to the southeast by the Cascade Mountains and to the west by the Strait of Georgia (Armstrong, 1981, 1984; Clague, 1994). Bedrock is widely exposed in the mountain ranges adjoining the Fraser Lowland and isolated mountains within the lowland. Bedrock has locally been eroded to depths below 800 metres below sea level in parts of the Fraser River delta (Britton et al., 1995), and locally to 450 metres below sea level to the east in the Fraser River valley. Bedrock is overlain by a thick succession of Pleistocene sediments deposited during several glacial and interglacial periods. Till deposited during the last glaciation forms the uppermost part of this succession, which has been overridden and compacted by glacial ice. These deposits occur at or near the surface in much of the cities of Vancouver and Burnaby. The till-capped succession is overlain by a sequence that formed during the closing phases of the last glaciation and includes glaciomarine clays, glaciofluvial sands and gravels, and some till. These deposits, which locally exceed 80 metres in thickness in the Fraser Lowland between Surrey and Abbotsford, have not been overridden and compacted by glacial ice, except in some of their more easterly occurrences. The youngest deposits in the region are modern alluvial, deltaic and bog deposits. The thickness of these deposits varies from a few metres in upland bogs, to tens of metres in the Capilano and Seymour deltas and in the floodplain of the Fraser River, and to a maximum of 300 metres in the Fraser River delta.

Geological Mapping

This map is based mainly on the Geological Survey of Canada 1:50,000 surficial geological maps (Armstrong, 1980a, b; Armstrong and Hicock, 1980a, b), which are now available in digital format (Dunn and Ricketts, 1994). These maps reflect primarily surface geological conditions and were prepared to support a variety of engineering and environmental applications. Locally, the Geological Survey of Canada mapping has been modified here on the basis of borehole data and recent subsurface geological investigations conducted by the author, particularly in Langley, Richmond and parts of Surrey. In the City of Chilliwack, this map is based on the British Columbia Geological Survey preliminary earthquake hazard map of the Chilliwack area (Levson et al., 1995), which was prepared for an earthquake hazard mapping project and was based on a large body of borehole data as well as surficial geological data.

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 maps (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)

Assigning the NEHRP site classes to the geological map units requires the integration of both geotechnical borehole and shear-wave velocity data. A large volume of geotechnical borehole data is potentially available throughout the Lower Mainland, although they are physically located in the files of numerous agencies. The data obtained for the preparation of this map is limited to that obtainable from a few readily accessible sources with large volumes of regionally distributed data. These sources include the British Columbia Ministry of Highways, B.C. Hydro, the Surrey and Vancouver School Boards, the Greater Vancouver Regional District, the Richmond-Airport-Vancouver Rapid Transit Project, a borehole database compiled by the author for a current earthquake hazard investigation for the City of Richmond, and a borehole database compiled for a groundwater modelling investigation of the Township of Langley (Golder Associates, 2004). These borehole data were used to determine the vertical profiles (i.e. stratigraphic successions) present within the geological map units. However, the volume of borehole data is generally insufficient to significantly revise geological boundaries on the Geological Survey of Canada mapping. Shear-wave velocity data available for this map are unevenly distributed in the Lower Mainland, with significant concentrations available in the Fraser River delta and adjoining parts of Vancouver and North Delta (Hunter et al., 1998) and in Chilliwack (Levson et al., 1995). Elsewhere, shear-wave velocity data are scattered throughout the Lower Mainland, and are located at some major bridge and research sites (e.g. Sully, 1991). The shear-wave velocity data were used to update a shear-wave velocity model of the principal Quaternary units of southwest British Columbia (Monahan and Levson, 2001). This model permits the estimation of the V_{s30} at sites where shear-wave data are not available, but where the stratigraphy is known. However, there are many parts of the map that are poorly characterized by geotechnical and shear-wave velocity data, so that the site classes in these areas have been estimated by comparison with areas with similar geological materials and similar geological histories.

This map also identifies an area of potentially high amplification around the margins of the Fraser River delta. A brief description of each Site Class and the high amplification zone follows.

Sites Classes A & B

Site Classes A and B have been combined on this map. Both site classes pertain to rock, and the Site Class A & B designation has been assigned to areas where bedrock is shown to be at or near the surface on the source maps. Such areas are widespread in the Coast Mountains to the north and in the Cascade Mountains the to the southeast of the Fraser Lowland, and in several isolated mountains along the northern margin and eastern part of the lowland.

Site Class C

Site Class C has been assigned to areas where tills and other deposits overridden by glacial ice occur within approximately 5 metres of the surface. The only till areas excluded are the thinnest tills associated with a late glacial advance during the closing phases of the last glaciation in the eastern part of the Fraser River valley (Map unit Sg, Armstrong, 1980a). Areas assigned to Site Class C are widespread in the upland areas of Vancouver, Burnaby, Coquitlam, Surrey, Whiterock, and North Delta, and on the southern slopes of the Coast Mountains. Shear-wave data to confirm this assignment are available in Vancouver and in North Delta (e.g. Hunter et al., 1998), and similar results have been obtained from similar deposits in Greater Victoria (Monahan et al., 2000; Monahan and Levson, 2001).

Site Class D

Site Class D has been assigned to a number of different settings, most of which are dominated by sediments that have not been overridden by glacial ice. These include: areas where late glacial glaciomarine clays are more than 5 metres and less than 20 metres thick adjoining upland areas assigned to Site Class C; areas of thick late glacial sand and gravel outwash and deltaic deposits, such as in Abbotsford and in the Brookswood area of Langley; the modern sand and gravel deltas of the Capilano, Lynn, and Seymour Rivers; large alluvial fan deposits, such as the Chilliwack fan; and Fraser River alluvium in the eastern part of the Fraser Lowland dominated by medium to coarse sand and gravel. Also assigned to Site Class D are glaciomarine clays of the closing phases of the last glaciation that have been demonstrably overridden by glacial ice in the eastern parts of Langley and the western part of Abbotsford. Areas of sand and gravel outwash in the Capilano, Lynn, and Seymour River valleys in North and West Vancouver (Armstrong, 1981, 1984) that have been assigned to Site Class D on the basis of limited geotechnical data available for this study, may include areas that would be assigned to Site Class C when more data become available. Shear-wave data to confirm these assignments are available in the modern sand and gravel deltas, Abbotsford, Chilliwack and Mission in the eastern part of the Fraser Lowland, and in late glacial deltaic deposits in the Greater Victoria area similar to those in the Lower Mainland (Levson et al., 1995; Monahan and Levson, 2001).

Site Class D-E

This designation was assigned to areas where Site Classes D and E cannot be readily differentiated with the data available for this study. These areas occur primarily in Langley and adjoining municipalities, where glaciomarine clays deposited at the closing phases of the last glaciation are interbedded with glaciofluvial sands and gravels, and where these clays have been partially eroded, exposing slightly overconsolidated sediments at the surface.

Site Class E

Areas assigned to Site Class E include sediments deposited in several different environments. These include: late glacial glaciomarine clays more than 20 metres thick, which are widespread in the valleys of the Nicomekl and Serpentine Rivers in Langley and Surrey; deposits of the modern Fraser River delta, and those of the floodplain in the western part of the Fraser River valley; Fraser River alluvium dominated by thick deposits of silt and clay in the eastern part of the Fraser River valley; and lacustrine deposits in the Sumas Valley. Shear-wave velocity data are available in all these environments to confirm these assignments (Sully, 1991; Levson et al., 1995; Hunter et al., 1998; Monahan and Levson 2001). Many of these areas have peat mapped at the surface. However, upland areas with peat mapped at the surface have also been assigned to this site class, because upland peat deposits may be locally underlain by more than 3 metres of soft fine-grained sediment meeting the criteria for soft clay in Table 1.

High Amplification Zone

A zone of potentially high amplification is shown here around the margins of the Fraser River delta. Several phenomena, some of which are earthquake-specific, can combine to cause particularly high amplification around the margins of sedimentary basins, including the trapping of surface waves and resonance (e.g. Somerville et al., 2004). Consistent with this, the strongest ground motions recorded in the delta during several recent earthquakes commonly occurred at the delta margin, albeit at low levels of ground shaking (Cassidy and Rogers, 2004). Although the modelling to fully define a zone of potentially high amplification is beyond the scope of this project, it is *approximated* on this map by the area in which resonance due to the thickness of deltaic deposits would occur at a period of one second or less. This period corresponds to thicknesses of 50 metres or less. The area forms a narrow band around the delta margin, and follows a buried Pleistocene ridge tending southeast across central Richmond. The high amplification zone includes areas that would otherwise be assigned to both Sites Classes D and E. Although high amplification and resonance may occur around other basins in the Lower Mainland, a high amplification zone is only mapped around the Fraser delta, because high amplification is a complex process, and it has only been observed in this setting.

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.

This map is based on limited subsurface geological and geotechnical information. In most of the map area, the distribution of borehole data was insufficient to define the geological boundaries. Consequently these boundaries are for the most part based on the surface distribution of geological material, not their subsurface distribution. The geological boundaries shown here are in most cases taken from previous geological mapping. The Geological Survey of Canada mapping (Armstrong, 1980a, b; and Armstrong and Hicock, 1980a, b) was initially conducted at a scale of 1:50,000, but these maps have been digitized from paper copies, resulting in a further loss of accuracy. 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. The principal area of fill thus shown is in False Creek in Vancouver. 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, except in the potential high amplification zone in the Fraser delta, 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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