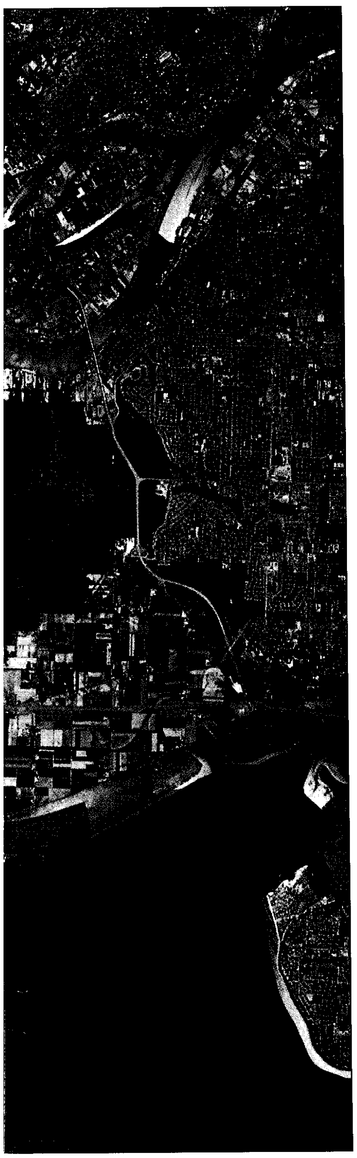
elta Geology:
: Hazard Assessment



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The Fraser River delta (Fig 1), located just south of Vancouver, British Columbia, is the largest delta in western Canada. It formed about 10,000 years ago since deglaciation of the area and is composed primarily of thick sequences of loose, water-saturated sediments deposited on Pleistocene (glacial and interglacial) sediments overlying bedrock. Because the delta is highly urbanized and industrialized and lies within the most seismically active region in Canada, concern about the impact of a major earthquake has heightened interest in the evaluation of potential ground surface response in the region during such an event. The ground surface response to seismic shaking of thick or soft sediments, such as those found in the delta, includes soil liquefaction and amplification of bedrock motions transmitted into overlying sediments.

Recent advances in the geological and geophysical understanding of the Fraser delta are helping to refine assessments of potential earthquake hazards. As more is understood about the impact of recent major earthquakes on other population centres built on similar foundation materials, members of the local geotechnical community have further addressed earthquake hazard concerns by upgrading design for the delta. Such reviews have underscored the importance of considering the magnitude and location of the design earthquake, as well as the reliability of the selected seismic response model, in the seismic design of foundations and in disaster preparedness. The reliability of a seismic response model depends, in part, on the design earthquake selected and the accuracy of information on subsurface geology.

Recent geoscience studies have significantly enhanced current understanding of the subsurface geology of the Fraser delta and have precipitated a rethinking of its effects on the seismic design of structures in the region.

Geoscience Studies of the Delta

Accepted practice recommends that seismic design of engineered structures in the delta consider the effect of a Richter magnitude 7 earthquake with a peak acceleration on firm ground of 0.21g and an estimated shaking time of about 20 seconds. However, the delta lies within the Cascadia subduction zone, which is considered susceptible to earthquakes of M8 or greater with a much longer duration of shaking. This hazard is not yet reflected in the National Building Code of Canada but will be by the year 2000.

The 1985 earthquake that damaged Mexico City was caused by an offshore subduction event similar to those possible at the Cascadia subduction zone. This spurred the Geological Survey of Canada (GSC) to intensify its ongoing investigations of the delta's architecture, in cooperation with other public and private

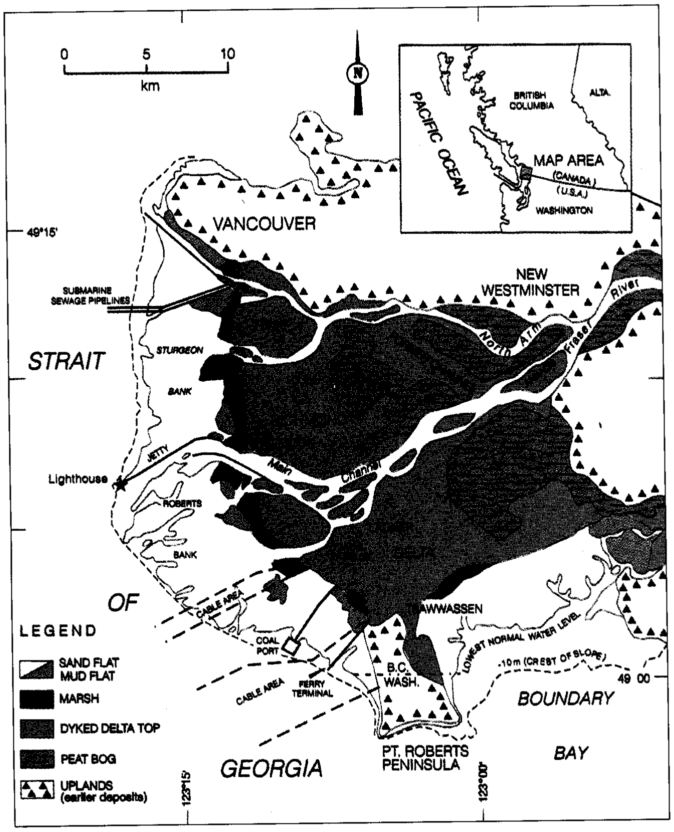

Fig 1: **Location and setting of the Fraser River delta.**

organizations. Initial surveys, which involved high resolution seismic profiling of the subsurface coupled with coring, were followed in later years with:

- regional surface and downhole shear wave velocity measurements, which can be used to identify potentially liquefiable zones and contribute to modeling of ground motion amplification. Shear waves, which are seismic waves that travel through the earth's interior, are propagated by a shearing motion that involves particle oscillation perpendicular to the direction of propagation. They travel at lower velocities in less dense materials such as unconsolidated sediments;
- seismic cone penetrometry, which can help discriminate subsurface sediment deposits according to their relative density, strength, and both shear and compressional wave velocities;
- downhole geophysical logging to further discriminate sediments by measuring their magnetic susceptibility, conductivity and natural gamma radiation;
- deeper coring to permit more reliable, site specific ground motion amplification studies;
- stratigraphic analysis to further define the geometry of deposits; and
- mapping of depth to bedrock using industry seismic reflection data to both refine amplification studies and detect its potential for focusing or dispersing of earthquake energy.

Revised Concepts of Subsurface Geology

The geoscience work described above suggests that the delta has a far more complex geological structure than previously assumed. Newly revised concepts about the geology of the delta and their implications follow:

The bedrock surface beneath the delta has substantial relief and the depth to bedrock varies considerably.

It was formerly assumed that the bedrock surface beneath the delta was relatively flat and no deeper than 300 m. However, new information shows that no bedrock was encountered in two 300 m deep boreholes about 4 km apart that were recently drilled in the City of Richmond (Fig 2). A new map of the bedrock surface beneath the delta indicates that, for three-quarters of the delta that has been so mapped, relief is high and depth to bedrock averages about 500 m, and exceeds 1,000 m in some areas (Fig 3).

The uneven configuration of the bedrock surface indicates that it could produce two- and three-dimensional effects such as trapping, focusing and diffusion of seismic energy, which can be influenced by the propagation direction of the earthquake energy.

Pleistocene sedimentary deposits beneath the delta are highly variable in both composition and thickness.

It was formerly thought that Pleistocene sediments beneath the delta consisted of over 100 m of glacial till (generally, an unsorted mixture of clay, silt, sand, gravel and boulders deposited by and underneath a glacier) with consistent physical properties and that the top of these deposits lay between 40 and 200 m below the land surface. Their variability in both composition and thickness has been dramatically documented in the two 300 m boreholes in Richmond mentioned above. Pleistocene deposits in one site are 281 m thick and consist entirely of sand and mud (silt and clay) except for a capping layer of gravel, less than a metre thick, at 19 m depth. In contrast, in the second hole, these deposits are mainly dense till lying below 236 m depth (Fig 4). Even there, the till sequences are interlayered with clay from which were recorded shear wave velocities about 200 m/s slower than those displayed by the tills (whose shear wave velocities exceeded 700 m/s), suggesting that the density of the clay is considerably lower. In addition, in almost 1,000 m of core examined by the GSC, sediments, including till, consisting of gravel, mud and sand but not necessarily cemented or having uniform density, constituted less than 20% of the total Pleistocene section.

These findings show that Pleistocene sediments beneath the delta are heterogeneous and that their density and shear wave velocity may be overestimated in prevailing geotechnical seismic response models. They could, therefore, affect ground motion amplification in a manner that may not have been previously recognized.

Implications for Earthquake Response Modeling

Geotechnical site models based on the new geological and geophysical data from deep borehole locations in the Fraser delta, coupled with preliminary one-dimensional ground motion amplification analysis, suggest that significantly longer-period ground shaking (ie, periods greater than 3.5 seconds) is likely for the Fraser delta than had previously been predicted in published geotechnical models of the delta. This long-period amplification potential has significant implications for the response of large structures during an earthquake. However, it is generally accepted that the one-dimensional response analysis cannot capture the effects of buried topography on the propagation of seismic waves. Subsurface topographic relief, both on the bedrock and Pleistocene surface, creates surface waves that generally have longer periods and durations than upward propagating shear waves.

In addition, the upland areas surrounding the delta (Vancouver to the north, Surrey to the east and Point Roberts peninsula to the south) are likely boundaries for the conversion of seismic body (interior) waves to surface waves that could, in turn, propagate through the delta. This phenomenon has been observed where surface waves are generated at the edge of alluvial basins and propagate in them (eg, in the Los Angeles basin during the Northridge earthquake of 1994). These topography-related effects will enhance motions at the surface. These effects have generally been ignored, but in the last five years emphasis on their consideration in seismic design has increased. Major studies of these effects are underway in the Los Angeles basin.

Direction of Future Geological Research

Concern about the impact of a major earthquake in the Fraser delta region is reflected in frequent media coverage of the topic, increased readiness of emergency services to cope with such an event and the stockpiling of survival supplies in local schools. It has justified the seismic retrofitting of bridges, public buildings and dams and has prompted the selection of sites on the delta, specifically the George Massey Tunnel and a BC Hydro power substation, for the field program of the Canadian Liquefaction Experiment (reported on during the 48th Canadian Geotechnical Conference held in Vancouver in late September 1995).

The new information about the geophysical characteristics of the Fraser delta has significantly refined the broad geological framework of the delta and has placed the assessment of the region's seismic ground response and potential earthquake hazards on a more solid footing. The studies also have identified important unresolved geological issues that could bear on the seismic design of foundations; for example, the geometry and composition of the Pleistocene sequence beneath the delta, the deep geological profile beneath the western part of the City of Richmond and Vancouver International Airport, and the possible presence of buried faults. There is also no direct measurement of the seismic vulnerability of the Fraser delta from strong motion recordings.

Further research in the form of a joint GSC/City of Richmond drilling program, slated for early 1996, will help define the nature of the deposits to 300 m under downtown Richmond and will help refine future modeling of ground motion in the region.

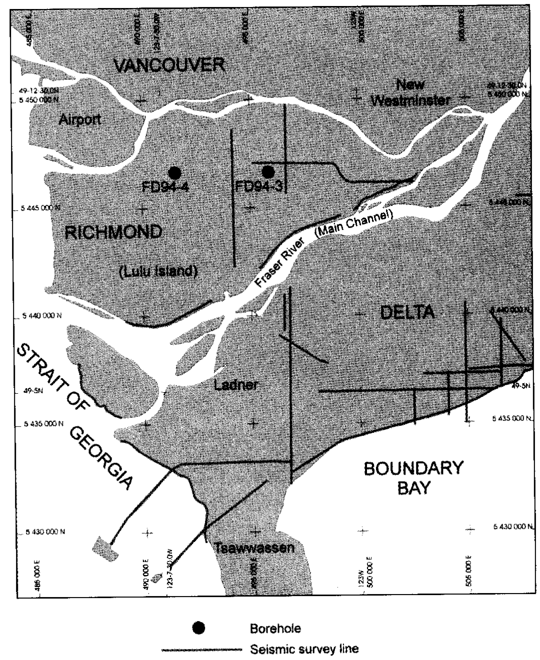

Fig 2: **Borehole sites in the City of Richmond and location of industry seismic reflection survey lines.**

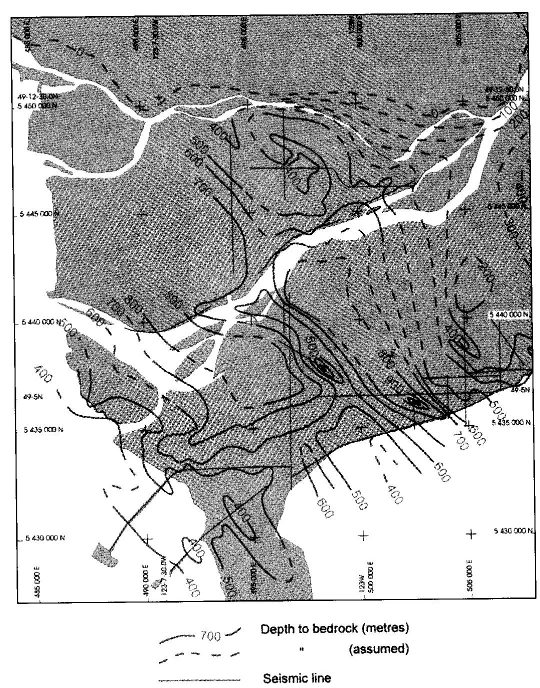

Fig 3: **Interpreted depth to bedrock beneath the Fraser delta based on industry seismic reflection data. (Britton et al, 1995)**

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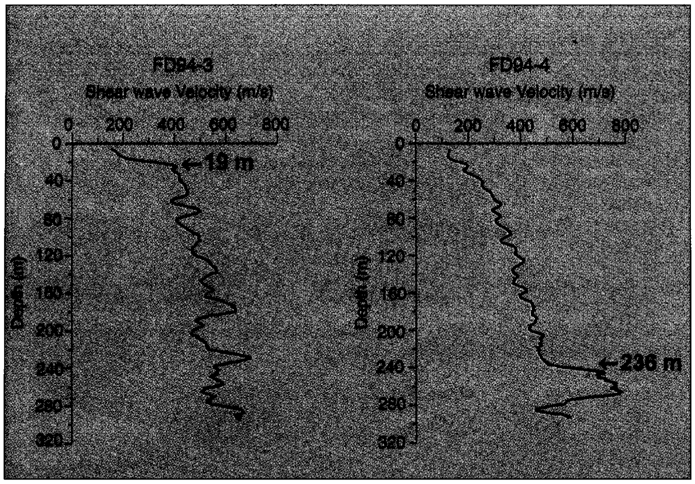
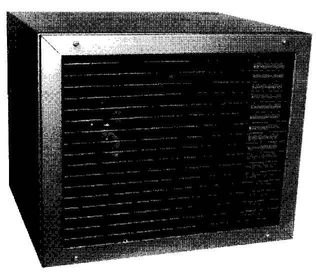


Fig 4: **Shear wave velocities recorded in boreholes (see Fig 2). Note the variation in depth to Pleistocene deposits (marked by arrows). (Dallimore et al, 1995)**



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Dr John Luternauer PGeo, a research scientist with the Geological Survey of Canada in Vancouver, received his PhD in marine geology from the University of British Columbia in 1972. He joined the GSC in 1974 after publishing his post-doctoral studies of the sedimentary processes and sedimentary budget of the Fraser River delta front. His research has focused on the assessment of geological hazards in urban, coastal and offshore regions of western Canada.

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Dr Jim Hunter, a research scientist with the Geological Survey of Canada in Ottawa, received his PhD in geophysics from the University of Western Ontario in 1971. His research interests are high resolution seismic reflection technique development as well as the measurement of shear wave velocities in unconsolidated overburden and their relationship to geotechnical properties. He has been a member of the GSC Fraser delta research team for over 10 years.

Dr Liam Finn PEng is a professor of civil engineering at the University of British Columbia with research and consulting interests in geotechnical earthquake engineering. He is a member of the Canadian National Committee on Earthquake Engineering and a Director of the Canadian Association of Earthquake Engineering.

(Geological Survey of Canada Contribution No 31695)