6th Canadian Conf. Earthquake Engineering / Toronto / 1991 / 6ème Conf. Canadienne Sismique

Seismic site amplification study for Fraser Delta, British Columbia

Robert C. Lo[I], Alex Sy[I], Paul W. Henderson[I], David Y. Siu[I],
W.D. Liam Finn[II], and Arthur C. Heidebrecht[III]

ABSTRACT

A site amplification study was carried out for the Fraser Delta of British Columbia. The study consisted of three major components: (1) definition of representative soil profiles and selection of dynamic soil properties to simulate typical conditions in the delta, (2) selection of input motions compatible with the local seismo-tectonic setting, including possible megathrust earthquakes offshore, and (3) dynamic response analyses for the selected sites using current state-of-the-practice procedures. The foundation factor computed from these analyses were compared to the provision in the 1990 National Building Code of Canada. The comparison appears to indicate that for typical sites involving deep soil deposits in the Fraser Delta, the current code value of 2 as the foundation factor is generally adequate, except for the period range of about 0.5 to 2 sec depending on: the type of building, the site conditions and the level of spectra considered.

INTRODUCTION

Severe structural damages on deep soil sites during recent major earthquakes around the world highlight the importance of amplification of ground motions at these sites. Notable examples are the 1985 Mexico earthquake, the 1988 Armenian earthquake, and the 1989 Loma Prieta earthquake. A site amplification study was, therefore, carried out to assess the level of protection offered by the seismic provisions of the current National Building Code of Canada (NBCC 1990) to buildings founded on deep soil deposits in the Fraser Delta. The delta is located in the southwest corner of the British Columbia mainland within the Greater Vancouver Regional District, and is in one of the highest seismic areas in Canada.

Ground response studies for sites in the Fraser Delta have been carried out by others (Wallis 1979; Byrne and Anderson 1987; Finn and Nichols 1988). The present study

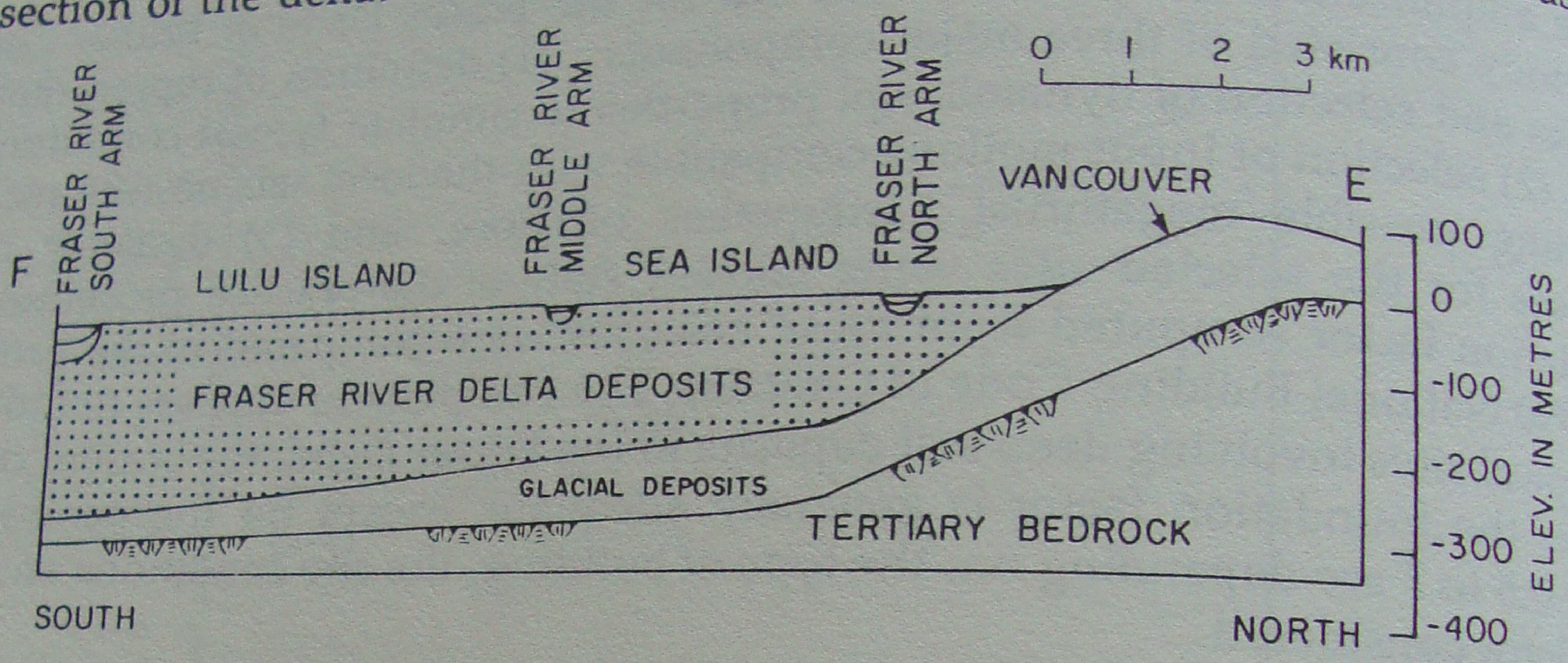
---

[I] Klohn Leonoff Ltd., Richmond, British Columbia
[II] University of British Columbia, Vancouver, British Columbia
[III] McMaster University, Hamilton, Ontario

extends the previous works and includes: (1) site specific field and laboratory dynamic soil data, (2) the latest understanding of the areal seismicity, and (3) dynamic soil and structural analyses to study possible performance of buildings of different types. The study focuses on the site amplification aspect, and does not include ground failure aspects such as liquefaction and lateral spreading, which require special foundation treatments. Possible surface wave phenomena involving two or three dimensional effects are also outside the scope of this study.

FRASER DELTA AND STUDY SITES

The Fraser River has been developing its delta since the retreat of the last glaciation approximately 11,000 years ago. Figure 1 shows the areal extent and a typical north-south section of the delta. The soil deposits can be broadly classified into Fraser



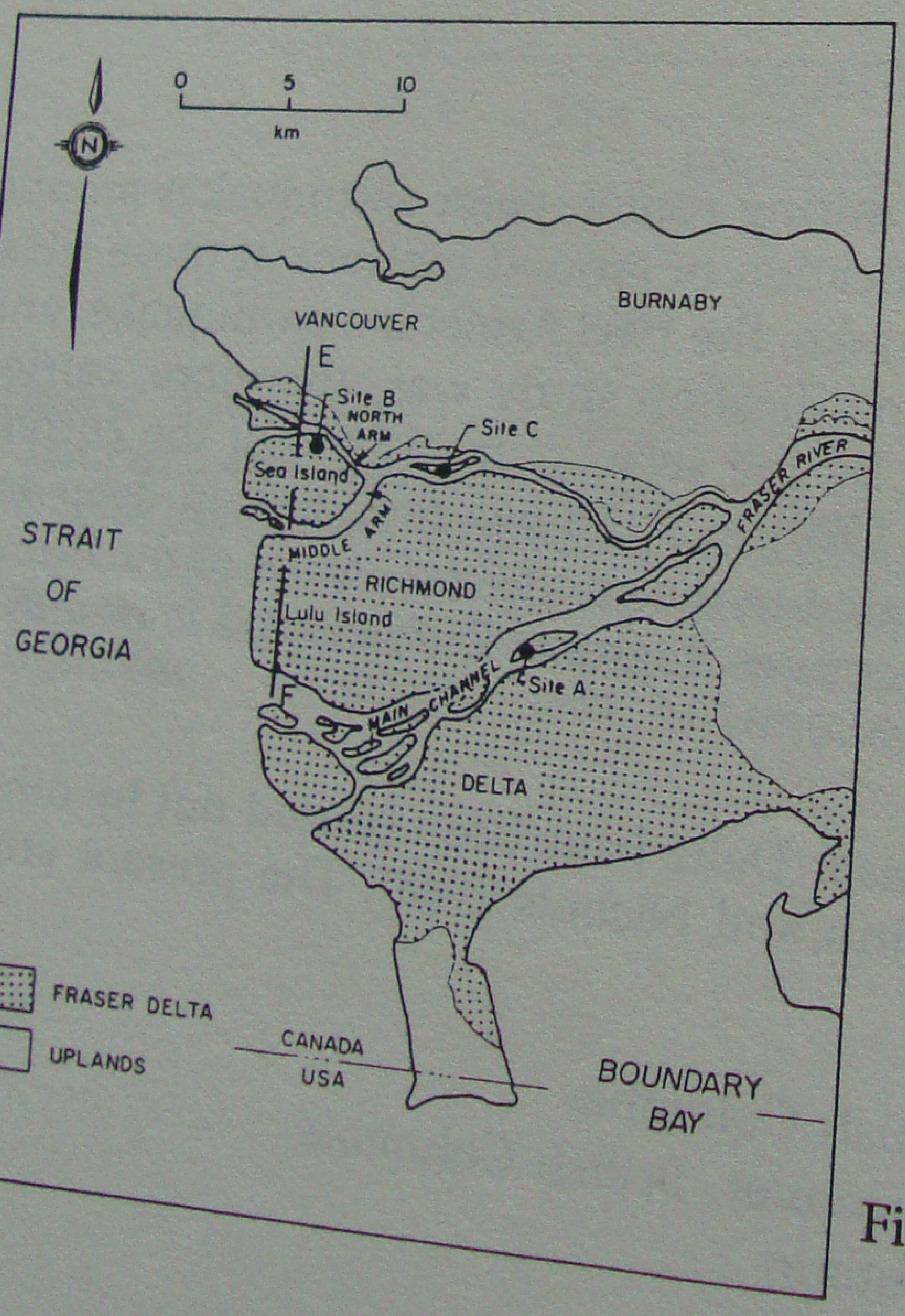


Fig. 1 Areal extent (left) and typical section (above, after Blunden 1975) of Fraser Delta

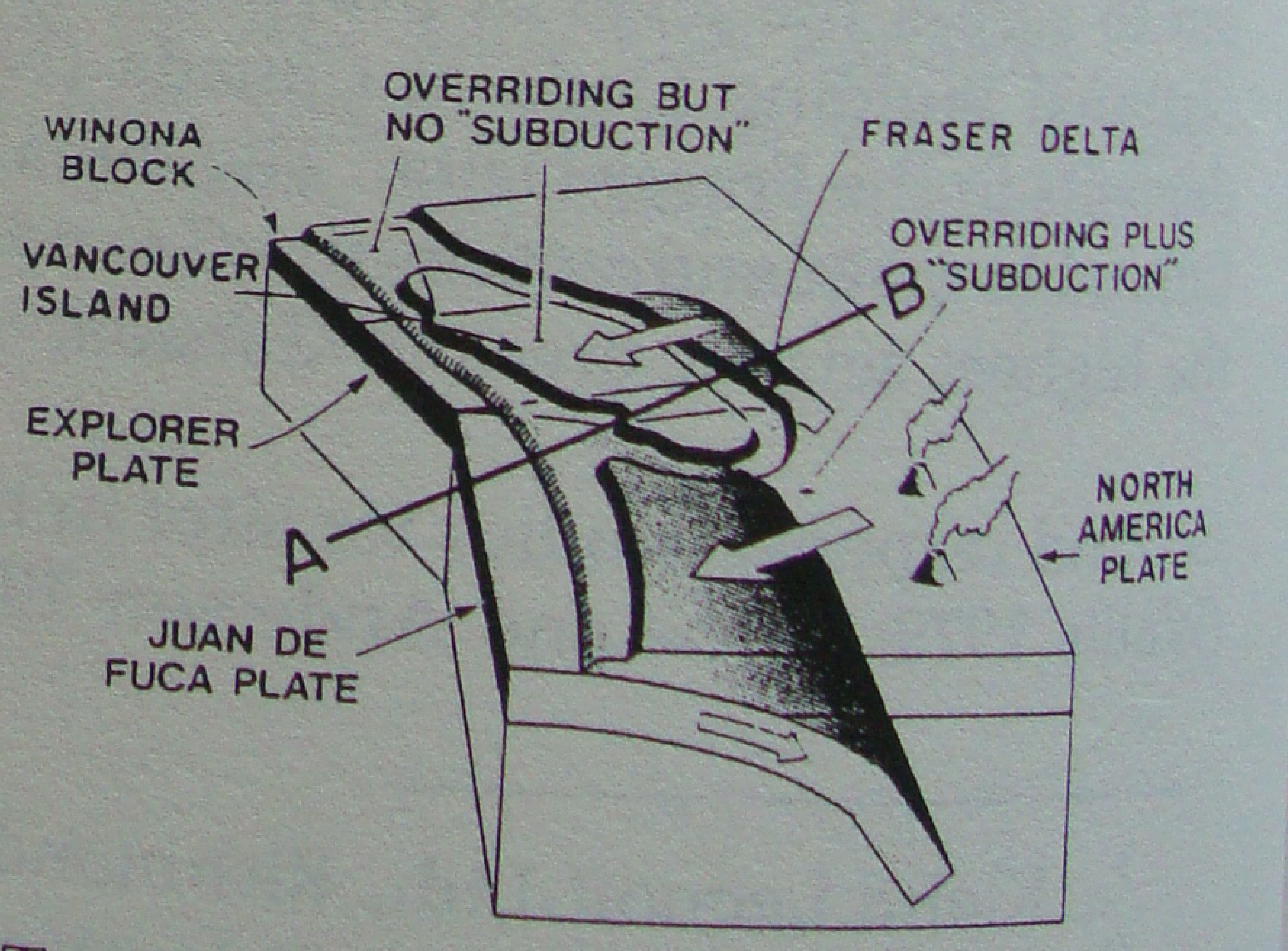


Fig. 3 Tectonic setting of Fraser Delta Area (above, after Rogers 1988)

River sediments of Holocene age and glacial deposits of the Late Wisconsin age or older. The river sediments generally consist of unconsolidated fine-grained marine sediments (silts and clays) overlain by sand-sized marine and tidal flat deposits which are in turn overlain by fine silty overbank deposits. These postglacial deposits are up to about 200 m thick. The underlying glacial deposits consist of ice-loaded tills, glaciomarine and glaciofluvial deposits which overlie Tertiary sedimentary bedrocks. The bedrock surface is estimated to occur at depths of 250 m or deeper under most of the delta (Blunden 1975).

Three representative deep soil sites in the Fraser Delta (Sites A, B and C) were selected for ground response analyses. The selection was based on site locations relative to urban and industrial development as well as available site specific data. The idealised soil and small-strain shear modulus profiles are shown in Fig. 2, based

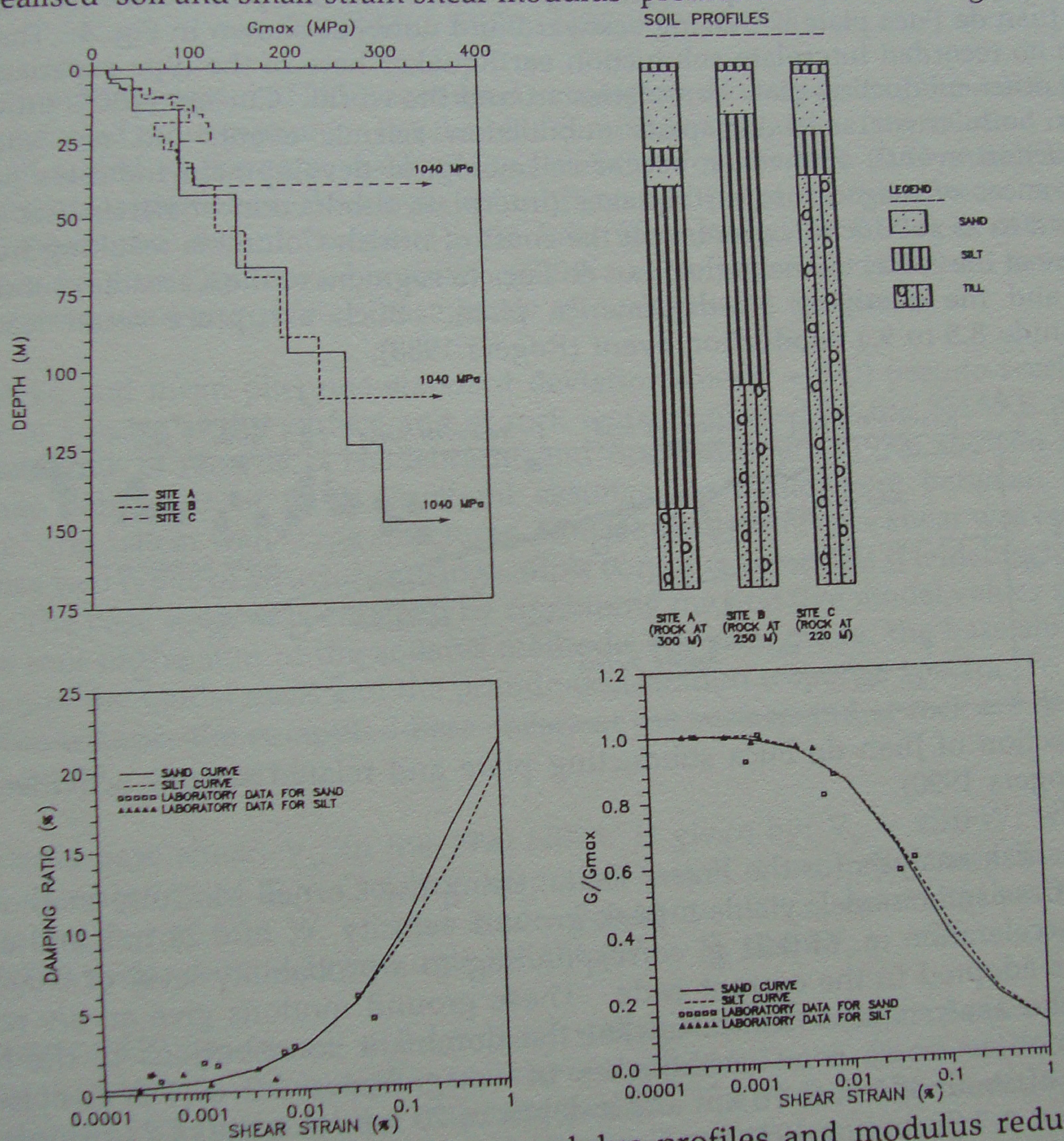


Fig.2 Subsoil and small-strain shear modulus profiles and modulus reduction and damping curves for study sites

on data from deep boreholes, insitu shear wave velocity measurements and other geotechnical and geophysical data. Shear modulus and damping ratio values as functions of shear strain were based on laboratory resonant column test data supplemented by other published data. Figure 2 also shows the modulus reduction and damping curves for sand and silt in the soil profiles. In the small-strain range mobilized in the glacial till, its dynamic properties are represented adequately by the curves indicated for both sand and silt in the figure.

SEISMO-TECTONIC SETTING AND EARTHQUAKE MOTIONS

Most of the seismic activities affecting the Fraser Delta are associated with the interactions among the following tectonic plates: the North America plate, the Juan de Fuca plate, the Explorer plate (see Fig. 3) and the Pacific plate further to the west. The Juan de Fuca plate is moving eastward and down as shown in Fig. 4. There has been no recorded interplate subduction earthquakes here of the type experienced at most other subducting plate boundaries around the world. Current NBCC provisions cover both crustal and intraplate subduction seismic events but not interplate subduction events. However, recent seismological development indicates possible occurrences of megathrust earthquakes (interplate subduction or hereinafter simply referred to as subduction events) off the coast of British Columbia resulting from the rupture at the contact zone of the Juan de Fuca (a segment of the Cascadia) subducting plate and the overlying North America plate. Such a rupture could lead to a magnitude 8.5 to 9.1 subduction event (Rogers 1988).

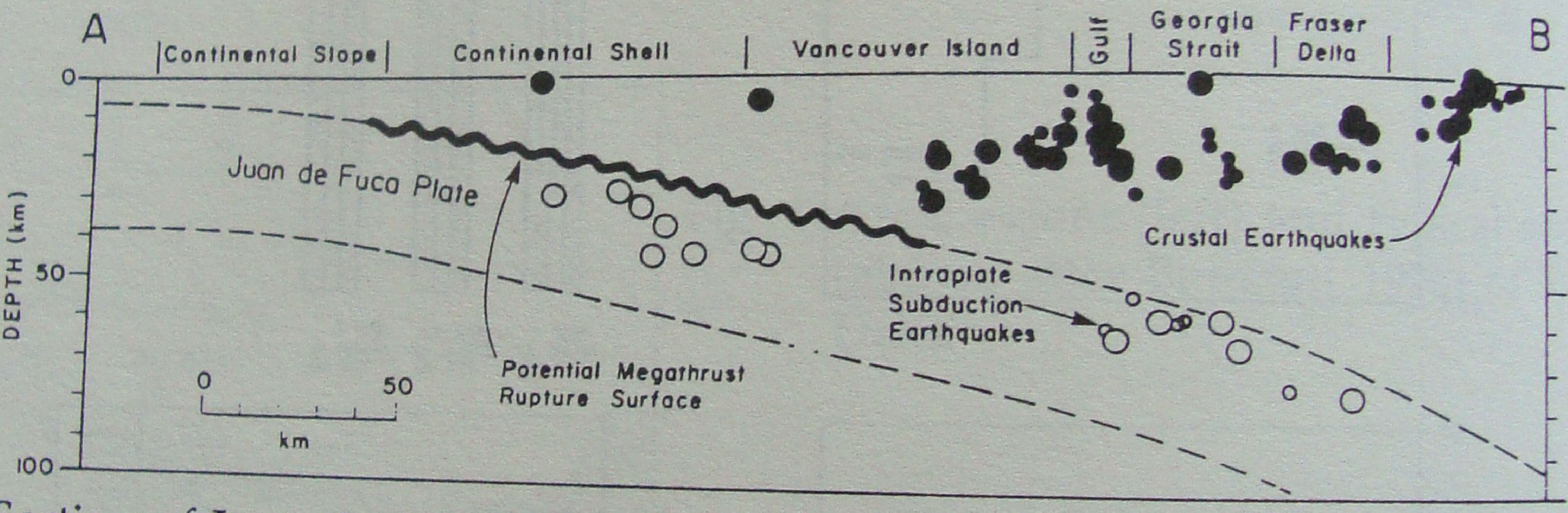


Fig. 4 Section of Juan de Fuca subducting plate and related seismic activities (after Rogers 1990)

A seismic risk analysis for the Fraser Delta, using the Cornell-McGuire method and the NBCC seismic model, yields a peak ground velocity ,v, of 0.21 m/s and a peak ground acceleration ,a, of 0.21 g, corresponding to a probability level of 0.0021 per annum as adopted in the current code. These ground motions give an a/v ratio of unity. The analysis also indicates that the dominant contributions to the NBCC ground motions come from earthquakes of magnitudes 6.3 to 7.3 at epicentral distances of about 30 km to 70 km and a depth of 20 km. A suite of 22 records with $0.8 < a/v < 1.2$ (including 1971 San Fernando, two 1979 Yugoslavia, 1986 Taiwan and 1989 Loma Prieta earthquakes) were selected to meet the above criteria and to minimize undue influence by any specific earthquake. Records satisfying the above magnitude and epicentral distance ranges but with a/v ratios significantly higher and lower than unity were also included in another part of the study (Sy et al. 1991).

Rogers (1990) indicated that the potential subduction thrust earthquake could occur at a focal depth down to about 40 km and as close as 100 km west of the study area. The rupture surface could extend another 150 km further to the west. A search for earthquake records on rock at epicentral distances between 100 km and 250 km from subduction events with a magnitude greater than 7.5 resulted in 12 records (including 1985 Mexico and two Japan earthquakes). In addition, the study also examines the potential excitation of relatively moderate ground motions from distant subduction events (>250 km), comprising 10 records from the 1985 Mexico earthquake.

DYNAMIC RESPONSE ANALYSES

The computer program SHAKE was used to compute the response of the soil deposits to the selected input motions. For the NBCC model earthquakes, the selected records were all scaled to the same peak ground velocity for the area (0.21 m/s). For the subduction earthquakes, the closer suite of records (100 to 250 km) were scaled to 0.2 g, while the distant records (>250 km) were scaled to 0.05 g. Attenuation relations proposed by Kawashima et el. (1984) and Youngs et al. (1988) for subduction events were used to arrive at these levels of peak ground motions.

The mean and mean plus one standard deviation (mean + SD) pseudo-acceleration response spectra at the surface and at rock were computed by the SHAKE program for each suite of records. Heidebrecht and Stafford-Smith (1973) showed that the dynamic behaviour of most structural systems lies somewhere between uniform "frame" and "shear wall" type structures. Consequently, the base shear was computed for these two types of structures using simple continuum models (Heidebrecht and Lu 1988). The base shear was obtained by combining the first five modal values using the square root of the sum of the squares method. For each mode, the base shear is the product of the modal mass and the pseudo-acceleration response spectra. To facilitate later discussions, the computed base shears at the surface and at rock are designated as V_{cs} and V_{cr}, respectively.

The elastic base shear, V_e, in the 1990 NBCC is given by: V_e = vSIFW; where v = zonal velocity ratio, S = seismic response factor, I = importance factor, F = foundation factor, and W = dead load. For convenience, assuming a structure of normal importance (I = 1) and unit weight (W = 1), then V_e = vSF.

The 1990 NBCC specifies F = 2 for "very soft and soft fine-grained soils with depth greater than 15 m", which applies to most of the Fraser Delta. The S factor is specified in the code as a function of the structural period. The code further limits the product "FS" to a "caping" value of 3 in the short-period range.

For all NBCC model earthquakes, the computed foundation factor F_c is obtained as the ratio of V_{cs}/vS, where v = 0.21 m/s, and S corresponds to the curve designated as $Z_a = Z_v$ in the code. Figure 5 shows the comparison of computed versus code values of the foundation factor for this suite of events. For the subduction events, since the input motions were not scaled to v = 0.21 m/s, it is more appropriate to compare the computed base shears at rock ,V_{cr}, and at the surface, V_{cs}, with the corresponding code values, vS and vsF, as shown on Fig. 6.

DISCUSSIONS OF RESULTS

The fundamental site periods from the SHAKE analyses are 3 sec for Site A, 2.5 sec for Site B and 1.5 sec for Site C. The computed spectral ratio of surface to rock pseudo-acceleration indicates a maximum amplification at the site periods as well as significant amplification between 1-2 sec for Sites A and B and lesser amplification at about 0.5 sec for Site C. The amplification at these shorter periods is likely due to resonance of higher modes.

In Fig. 5, the 1990 NBCC foundation factor reduces from 2.0 to 1.0 at short periods because of the ceiling imposed on the product "FS". For the mean level, the foundation factor for "frame" buildings at Sites B and C exceeds the code factor at

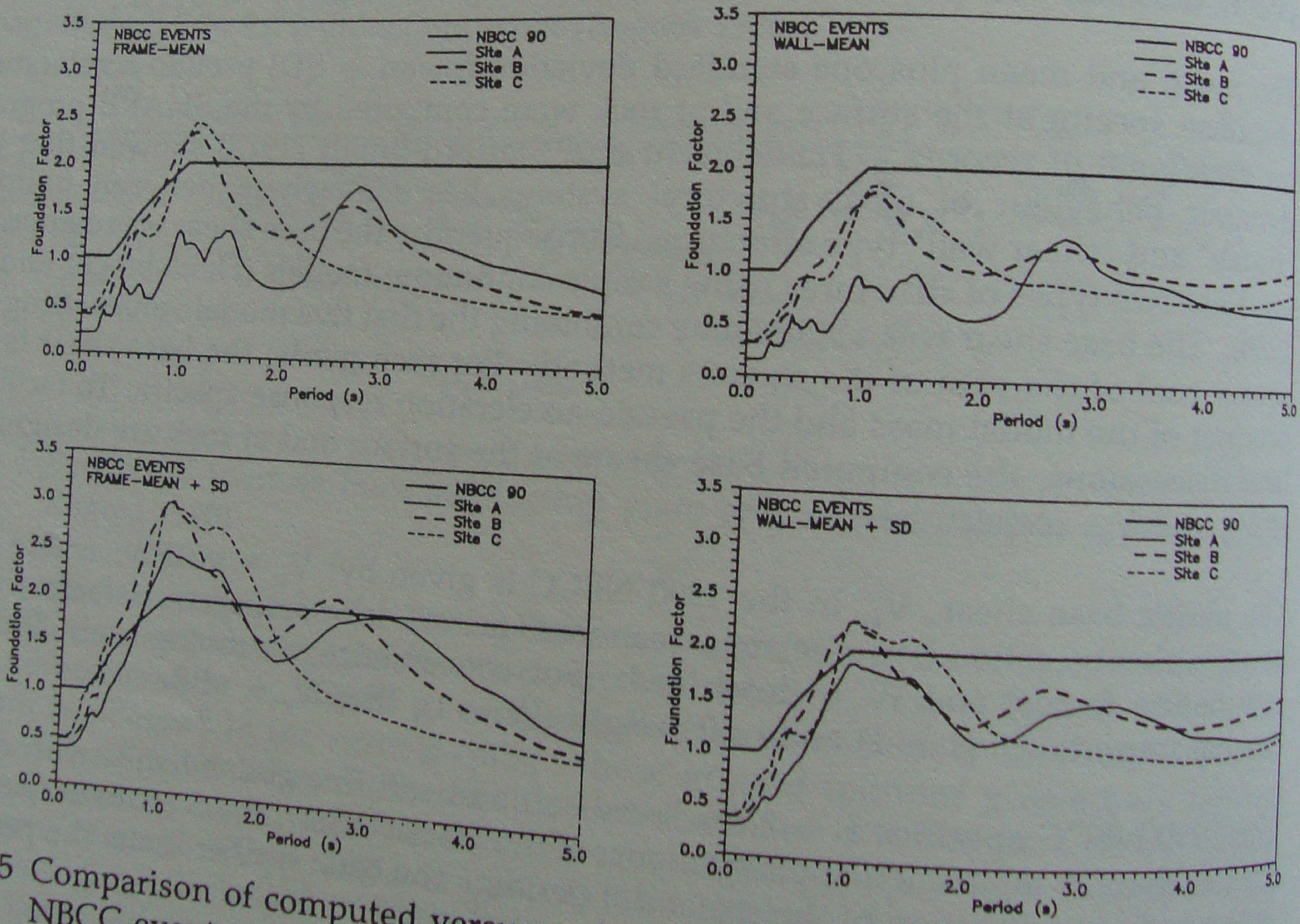


Fig. 5 Comparison of computed versus code values of foundation factor F - NBCC events

periods close to 1 sec, with maximum values of about 2.4. For the mean+SD level, the foundation factor for both types of structures exceeds the code factor for periods between 0.5 and 2 sec, except for "wall" structures on Site A. The peak F values vary between 2.5 and 3 for "frame" buildings and between 1.9 and 2.3 for "wall" buildings.

Only the structural response at Site A was calculated for the two suites of subduction earthquakes. In Fig. 6, the computed rock and surface level base shears are less than the corresponding code values for all periods except for the 'spike' at 0.15 sec for closer subduction events (100-250 km). These 'spikes' are caused by similar spikes present in the response spectra of the accelerograms of two Japanese events recorded at the Miyako Harbour station, and may reflect specific local conditions at that station.

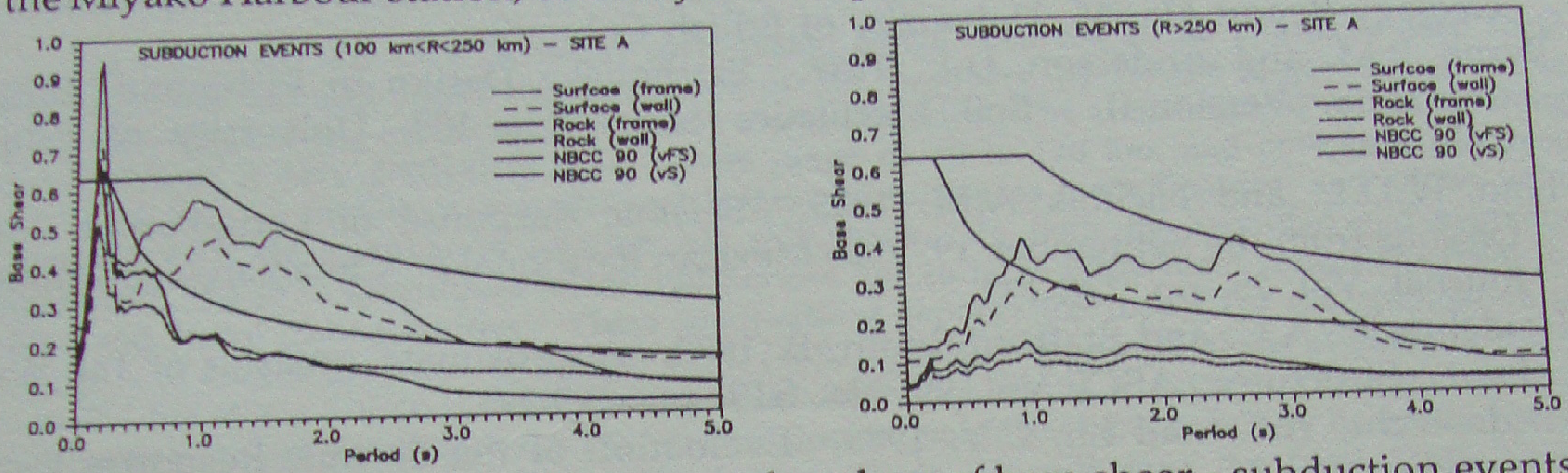


Fig. 6 Comparison of computed versus code values of base shear - subduction events

Currently, no local strong motion records are available to allow for calibration against the results presented herein. However, reasonable inferences can be drawn from these results. In general, for the NBCC model earthquakes, the code foundation factor appears to be adequate, except for the period range of about 0.5 to 2 sec depending on: the type of building, site conditions, and whether the mean or (mean + SD) level spectra are considered. Since this period range corresponds to the majority of buildings in the area, further studies are needed to investigate possible influences on the results from (1) the shortcomings of the equivalent-linear method embodied in the SHAKE analysis currently used in the practice, and (2) the peculiarities of some input motions. For the suites of subduction events, the computed base shears are overall less than the code specified values. This favourable situation, of course, requires further confirmation when more insight into the subduction events and more subduction records become available.

CONCLUSIONS

In summary, for typical deep soil sites in the Fraser Delta the increase of the code foundation factor, F, from 1.5 (NBCC 1985) to the present value of 2, as a result of lessons learned from the 1985 Mexico earthquake, appears to be justified. Further studies are needed to confirm the overall applicability of the present code value of 2 to typical buildings in the Fraser Delta.

ACKNOWLEDGEMENTS

Financial support for this study was provided by the National Research Council under an IRAP-M grant, which was administrated by Mr. Alan Toon. The assistance of Dr. Garry C. Rogers in describing the subduction earthquake scenarios, Dr. Nove Naumoski in providing earthquake records from the MUSE database, and Mr. Adrian Wightman in reviewing the study is also acknowledged.

REFERENCES

Blunden, R.H. 1975. Urban Geology of Richmond, British Columbia. Department of Geology Report No. 15, University of British Columbia.

Byrne, P.M. and Anderson, D.L. 1987. Earthquake Design in Richmond, British Columbia, Version II. Soil Mechanics Series No. 109, University of British Columbia.

Finn, W.D.L. and Nichols, A.M. 1988. Seismic Response of Long-Period Sites: Lessons from the September 19, 1985 Mexican Earthquake. Canadian Geotechnical Journal, Vol. 25, pp. 128-137.

Heidebrecht, A.C. and Stafford-Smith, B. 1973. Approximate Analysis of Tall Wall-Frame Structures, ASCE Vol. 99, No. ST2, pp. 199-221.

Heidebrecht, A.C. and Lu, C.Y. 1988. Evaluation of the Seismic Response Factor Introduced in the 1985 Edition of the National Building Code of Canada. Canadian Journal of Civil Engineering, Vol. 15, No. 3, pp. 283-288.

Kawashima, K., Aizawa, K. and Takahashi, K. 1984. Attenuation of Peak Ground Motion and Absolute Response Spectra. Proceedings of 8th WCEE, Vol. II, pp. 257-264.

Rogers, G.C. 1990. Personal Communications.

Rogers, G.C. 1988. An Assessment of the Megathrust Earthquake Potential of the Cascadia Subduction Zone. Canadian Journal Earth Sciences, Vol. 25, pp. 844-852.

Sy, A., Lo, R.C., Henderson, P.W., Siu, D.Y., Finn, W.D.L. and Heidebrecht, A.C. 1991. Ground Motion Response in Fraser Delta, British Columbia. Proceedings of 4th International Conference on Seismic Zonation, August, San Francisco.

Wallis, D.M. 1979. Ground Surface Motions in the Fraser Delta Due to Earthquakes. M.A.Sc. Thesis, University of British Columbia.

Youngs, R.R., Day, S.M. and Stevens, J.L. 1988. Near Field Ground Motions for Large Subduction Earthquakes. Proceedings of ASCE Specialty Conference - Earthquake Engineering and Soil Dynamics II, June, Utah, pp. 445-462.