

CASE HISTORY OF THE LIBRARY SQUARE EXCAVATION IN DOWNTOWN VANCOUVER

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ABSTRACT

The recently completed Library Square project in downtown Vancouver involved excavation of a full city block to a maximum depth of 15 m.

The ground conditions at the Library Square site are typical of downtown Vancouver, consisting of silt and sand over glacial till. Sedimentary bedrock is present at depths of about 9 m to 16 m below street level, with the bedrock surface sloping gently down to the southeast. The excavation was predominantly in glacial till with the bottom of the excavation extending into bedrock in some areas. The shoring for the excavation consisted of reinforced shotcrete, with tie-back anchors 6 m to 9 m in length, typically installed at 1.8 m to 2.1 m centres in both the horizontal and vertical directions.

The paper presents the shotcrete and tie-back anchor design that was used and discusses the design philosophy and design criteria, including the prediction of excavation movements based on experience from previous excavations in similar ground conditions.

The case history of the excavation and shoring installation that was completed between January and July, 1993 is presented, including a summary of the inspection and testing that was undertaken as part of the field review during construction. The case history includes the results of survey monitoring of horizontal movements around the perimeter of the excavation and compares the measured movements to the predicted value.

INTRODUCTION

One of the latest landmarks in downtown Vancouver is the impressive Library Square Project, which occupies a full city block between Georgia & Robson Streets and between Hamilton & Homer Streets. The project involves a 9-storey Roman Coliseum style central library and a 21-storey office tower, which covers 3 to 4 levels of underground parking. The excavation for the underground parking was generally tight to the property lines and extended to depths ranging from about 9 m to 15 m below street level. The shoring for the excavation was accomplished using reinforced shotcrete with tie-back anchors, which is a conventional system for excavations in Vancouver.

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GROUND CONDITIONS

In downtown Vancouver, tertiary sedimentary bedrock consisting of sandstone, siltstone, shale and conglomerate is present at depths ranging from less than 3 m to more than 30 m. The bedrock is variable, in some areas being relatively uniform and homogenous and in other areas containing numerous fractures and faults as well as volcanic dykes. Although most of the sedimentary bedrock in downtown Vancouver is soft enough that it can be excavated with heavy construction equipment, the bedrock does contain concretions (floaters) which are dense enough that blasting is required. Lignite seams are often present within the bedrock. Groundwater seepage may occur from fissures or fractured zones within the rock mass. The bedrock is typically covered with glacial deposits consisting of glacial drift, glacial till and glacio-marine till, comprised of silts, sands and gravels, with occasional cobbles and boulders. The glacial materials vary in strength and may contain water bearing sand layers. The glacial deposits are generally covered by relatively dense sands and silts.

The field investigation for the Library Square project involved thirteen drilled test holes to supplement the general information available from previous projects completed in the area. The test holes were completed with a mud rotary drill rig and the bedrock was cored in five of the test holes. The locations of the test holes are shown on Figure 1 and the results of the test holes and the interpreted ground conditions between the test holes are shown on the cross sections presented on Figure 2. The ground conditions consist of less than 1.5 m of fill over medium dense to dense silt and sand. Glacial till was encountered in all the test holes within 3.5 m of ground surface. The glacial till has moisture contents typically in the range of 10% to 12% and SPT blow counts of over 50. Sedimentary bedrock consisting of sandstone and siltstone was encountered at depths ranging from about 9 m to 16 m. The bedrock surface slopes gently from the northwest corner of the site (Georgia & Homer) down to the southeast corner (Hamilton & Robson). The test holes indicated that the sedimentary bedrock is relatively hard by local Vancouver standards, and analysis of the rock core gave a Rock Quality Designation in the range of 80% to 100%.

SHORING DESIGN

Shoring systems involve components to satisfy three main requirements: support at the face of the excavation; resistance to horizontal loads, and drainage. Selection of the appropriate shoring system for a particular project involves consideration of the ground conditions, the groundwater conditions, the excavation geometry, the loading resulting from the ground and adjacent installations, the allowable movements, the appropriate safety factor, the planned monitoring of performance, and the local practice.

The ground conditions at the Library Square site consist predominantly of glacial till over sandstone and siltstone sedimentary bedrock, with minimal expectation of faulting or planes of weakness in the bedrock. Groundwater seepage was not expected in significant amounts from within the glacial till deposit, although it was anticipated that there could be groundwater seepage in localized areas. For the depth of excavation varying from 9 m to 15 m, the majority of the excavation would be in glacial till, with the bottom portion of the excavation extending into sedimentary bedrock in some areas. Based on these conditions, a reinforced shotcrete and tie-back anchor shoring system was considered to be a practical and cost-effective solution which would make use of the experience of local Contractors.

The shotcrete face support was designed with sufficient reinforcement to spread the anchor loads, as well as to support local discontinuities which could be present close to the excavation face. Weep holes were installed through the shotcrete at 1.8 m to 2.4 m centres in both the horizontal and vertical directions in order to provide drainage. Provision was made for installation of 6 m long drains in any area where seepage was encountered.

The resistance to horizontal loads was provided with tie-back anchors. The anchor capacities required in the glacial till and overlying soils were established based on assessment of active pressure, and the anchors near the ground surface were designed to provide increased capacity to support construction loads. The anchor lengths in the glacial till and overlying soils were based on the ability to develop the anchor capacity outside a Coulomb wedge. In the bedrock, nominal capacity anchors were installed since the bedrock was not expected to be significantly faulted. The anchorage for the entire excavation was achieved using relatively low capacity (100 kN) anchors, spaced at 1.8 m to 2.1 m centres, in order to tie the ground mass together in a soil nailing approach.

The anchor lengths for the shoring ranged from about 6 m to 9 m, with an average anchor length of 7.5 m for the project. A section showing a typical anchor configuration is presented on Figure 3. The design involved various anchor configurations in order to account for differences in excavation geometry, ground conditions and the presence of buried services on City property. Where space permitted, the top of the excavation was sloped back to reduce the anchor requirements and to simplify shoring in the near surface soils.

As part of the shoring design, the expected movements of the excavation were estimated, in order to assess possible effects on adjacent installations and to provide a basis for monitoring performance during the excavation and shoring. The estimate was based on analysis of records of movements of excavations which had been previously undertaken by Cook Pickering & Doyle Ltd. in the Vancouver area, as will be discussed in a

subsequent section of this paper. Based on this evaluation, a horizontal movement of 12 mm was predicted at the edge of the excavation.

The planned review and monitoring program during construction is integral to the shoring design. The review and monitoring program planned for Library Square included regular visual inspection of the excavation and shoring installation, strength testing of shotcrete, proof loading of anchors, and survey monitoring of ground movements. The purpose of the review and monitoring program is to assess and evaluate the excavation performance, such that appropriate contingency measures can be implemented to modify the excavation performance if required.

Based on the ground conditions at Library Square, it was expected that the excavation would perform well, and that it would be unlikely that significant modifications to the shoring system would be necessary during construction. Nevertheless, the construction contract did allow for installation of additional drains and for installation of long, high capacity anchors, if necessary.

SHORING INSTALLATION AND FIELD REVIEW

The excavation and shoring installation was completed between January and July, 1993 and involved more than 5000 square meters of shotcrete face and over 1400 tie-back anchors.

The sequencing of the shoring installation generally consisted of anchor installation, followed by trimming the ground and installation of the reinforced shotcrete in panels, then proof testing and locking off the anchors at the design load. The anchor installation, the shotcrete installation, and the anchor loading were each completed about 18 to 24 hours apart to allow curing of the anchor grout and shotcrete prior to loading the anchors. This resulted in a time span of about three working days between anchor installation and anchor lock off for each panel.

The field review involved regular inspection and co-ordination with the Contractors to confirm that the staging and sequencing of the excavation and shoring installation were in general agreement with the intent of the design. This field review is critical, especially in the initial stages of the excavation where ground conditions are typically less competent and where the tie-back anchors and shotcrete must be installed without damaging the adjacent buried services which included water mains, sewers, electrical and telephone ducts, a central heat line, and numerous manholes and catch basins. The field review also involved confirmation that the height and length of the shotcrete panels being installed were appropriate for the ground conditions and groundwater conditions, in order to satisfy the WCB requirements. Detailed inspections of the surrounding sidewalks and

streets were carried out to check for cracks in the asphalt or openings between the curbs and sidewalks, which were sealed to minimize the infiltration of surface water into the ground.

The Contractor was responsible for the mix design of the anchor grout. The adequacy of the anchor installation, including the grout strength, was verified by proof testing every anchor, and anchors not capable of supporting the proof load were replaced. For the Library Square project over 99% of the anchors successfully carried the proof load. In order to verify shotcrete strength, test panels were shot and tests were completed to ensure that the one and seven day compressive strengths were not less than 20 MPa and 30 MPa, respectively, and that the seven day flexural strength was not less than 4 MPa. The shotcrete was tested at the start of the project, to confirm the adequacy of the Contractor's mix, and periodic testing was completed during the progress of the work, and as weather conditions changed.

EXCAVATION MOVEMENTS

Relaxation of the ground resulting in small amounts of movement of the shotcrete face and adjacent ground is expected during excavation. Therefore, as part of the shoring design, the expected horizontal movements of the excavation were estimated, in order to assess possible effects on the adjacent installations and to provide a basis for monitoring performance during the excavation and shoring.

The evaluation of the expected movements at Library Square incorporated previous experience with excavations in downtown Vancouver, including analysis of records of movements of other excavations. Table 1 summarizes measured movements at some of the typical excavations in downtown Vancouver and outlines the depths of the excavations and a brief description of the ground conditions. Considerations in evaluation of the expected movements at Library Square included the details of the ground conditions, ground water conditions, excavation depth and geometry, the effects of adjacent structures, adjacent excavations, service trenches, and the planned shoring design and installation sequence.

Based on this evaluation, a horizontal movement of 12 mm at the top of the excavation was predicted at Library Square. Provisions for monitoring the excavation movements consisted of surveying points at the top of the shotcrete face. A total of 34 points were monitored. The review of the monitoring involved consideration of both the total movements and the rate of movement relative to the progress of the excavation and shoring. At completion of the excavation, the total movements at each side of the excavation ranged from 9 mm to 14 mm, which were close to the predicted value of 12 mm. The average movements of each of the four sides of the excavation are

summarized on Figure 4. The data shows a trend that with increasing depth of excavation, the increment of movement for each lift of excavation and shoring decreases. The total movements measured are approximately proportional to the final depth of excavation at each side.

A key aspect of the review is the change in rate of movement that occurs at each stage of excavation; since a constant or increasing rate of movement without additional excavation would indicate a potential instability which would require immediate remedial action, such as additional anchors, additional drains, or a temporary soil berm to provide stability until other measures could be instituted. At Library Square, the excavation movement occurred in discrete increments related to each stage of excavation and shoring, with minimal creep occurring during the time when there was no excavation taking place in that area.

SUMMARY AND CONCLUSION

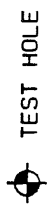
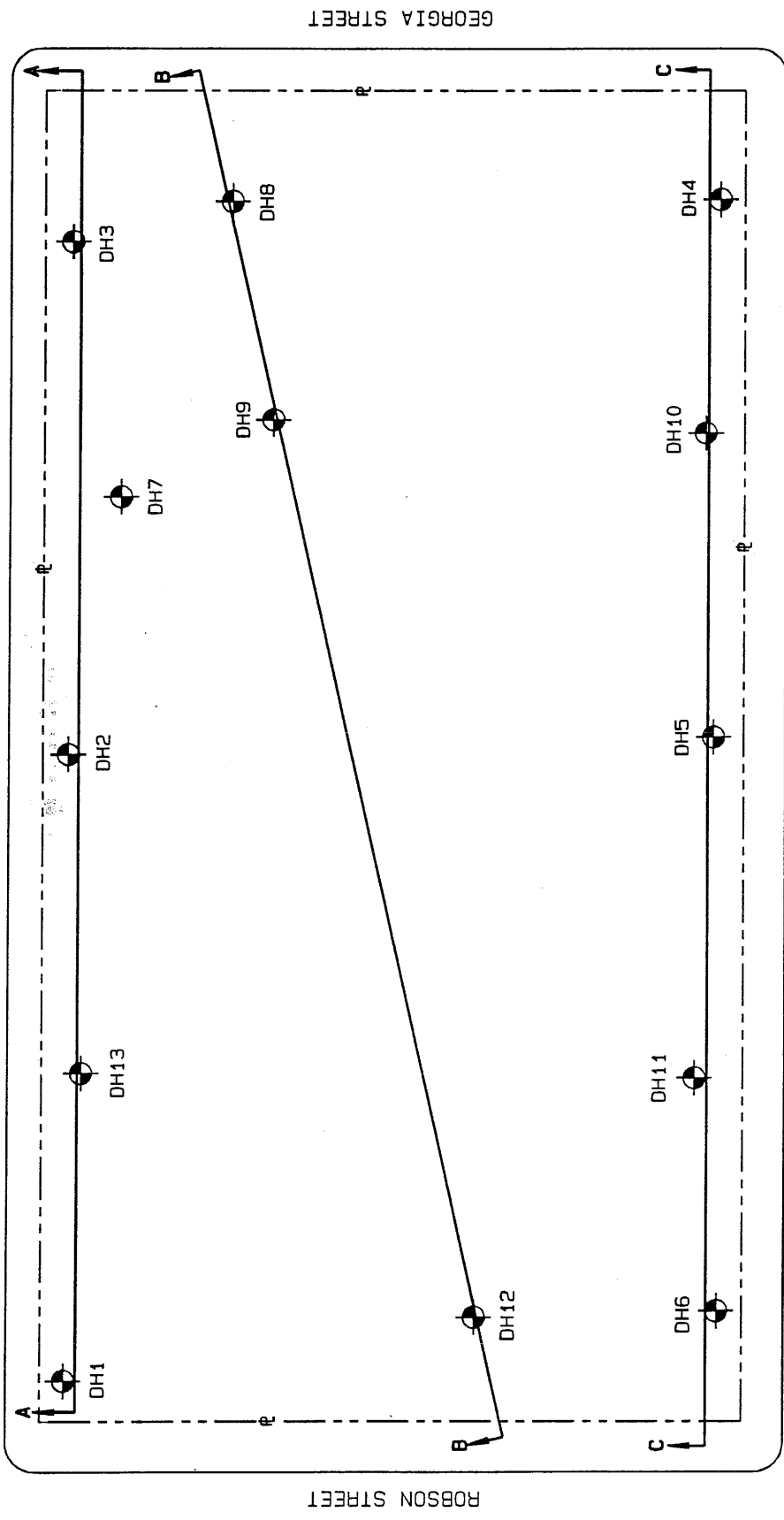
The excavation for the Library Square Project, which involved a full city block and extended to a depth of up to 15 m, was completed with a reinforced shotcrete and tie-back anchor system. As part of the design, the excavation performance was predicted based on information from previous excavations in similar ground conditions. Contingency measures were set up in the event that actual excavation performance did not match the predicted performance. The review and inspection during construction included survey monitoring, anchor testing and shotcrete strength testing. This monitoring confirmed that the excavation performed as expected and the contingency measures were not required.

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- Structural Consultants: Read Jones Christoffersen Ltd.
- General Contractor: PCL Constructors Pacific Inc.
- Excavation Contractor: Bel Construction
- Shoring Contractor: Pacific Blasting Demolition & Shoring Ltd.

Project North



TEST HOLE



Figure 1 Test Hole Location Plan

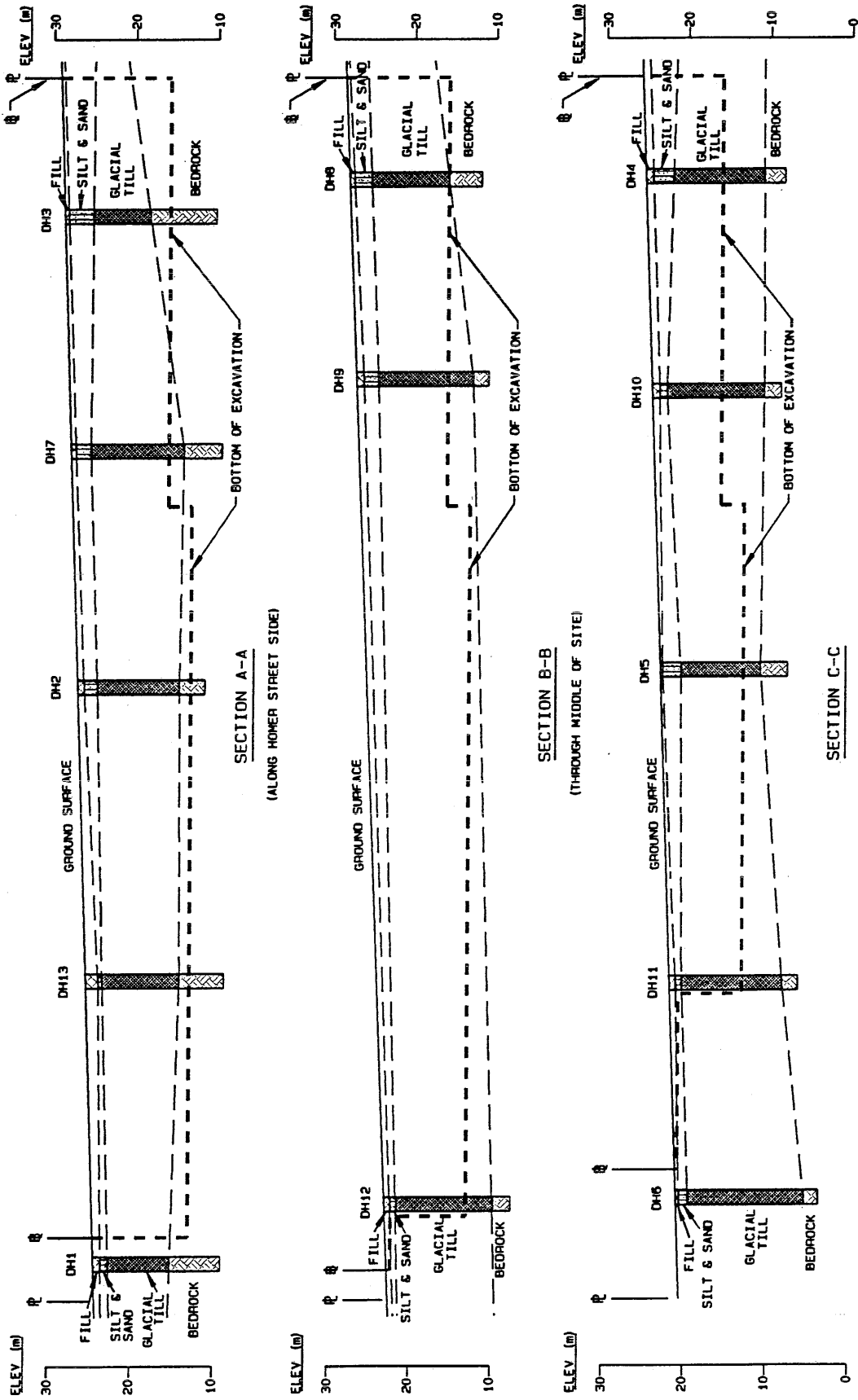


Figure 2. Cross Sections of Ground Conditions

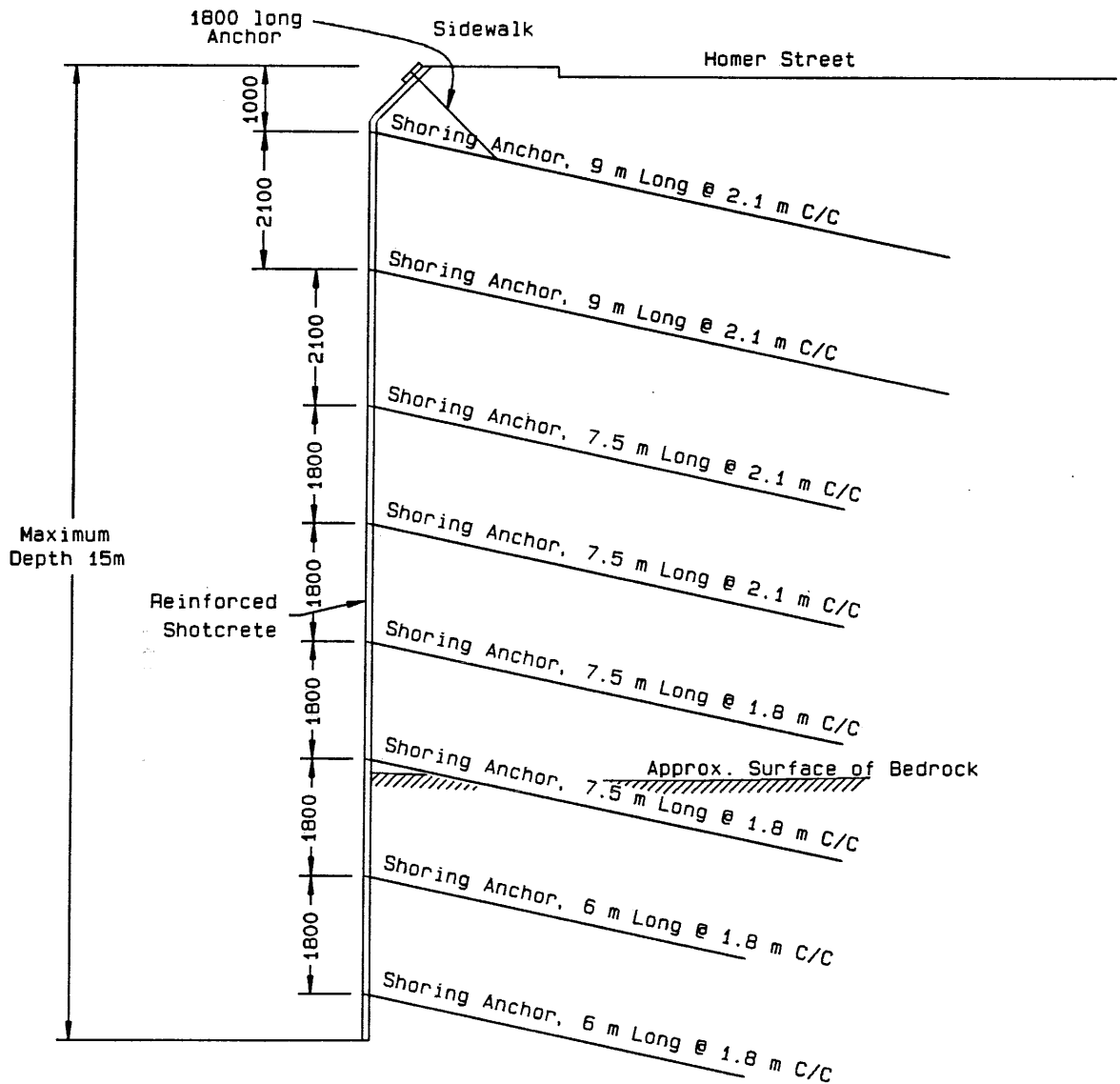


Figure 3 Typical Anchor Configuration

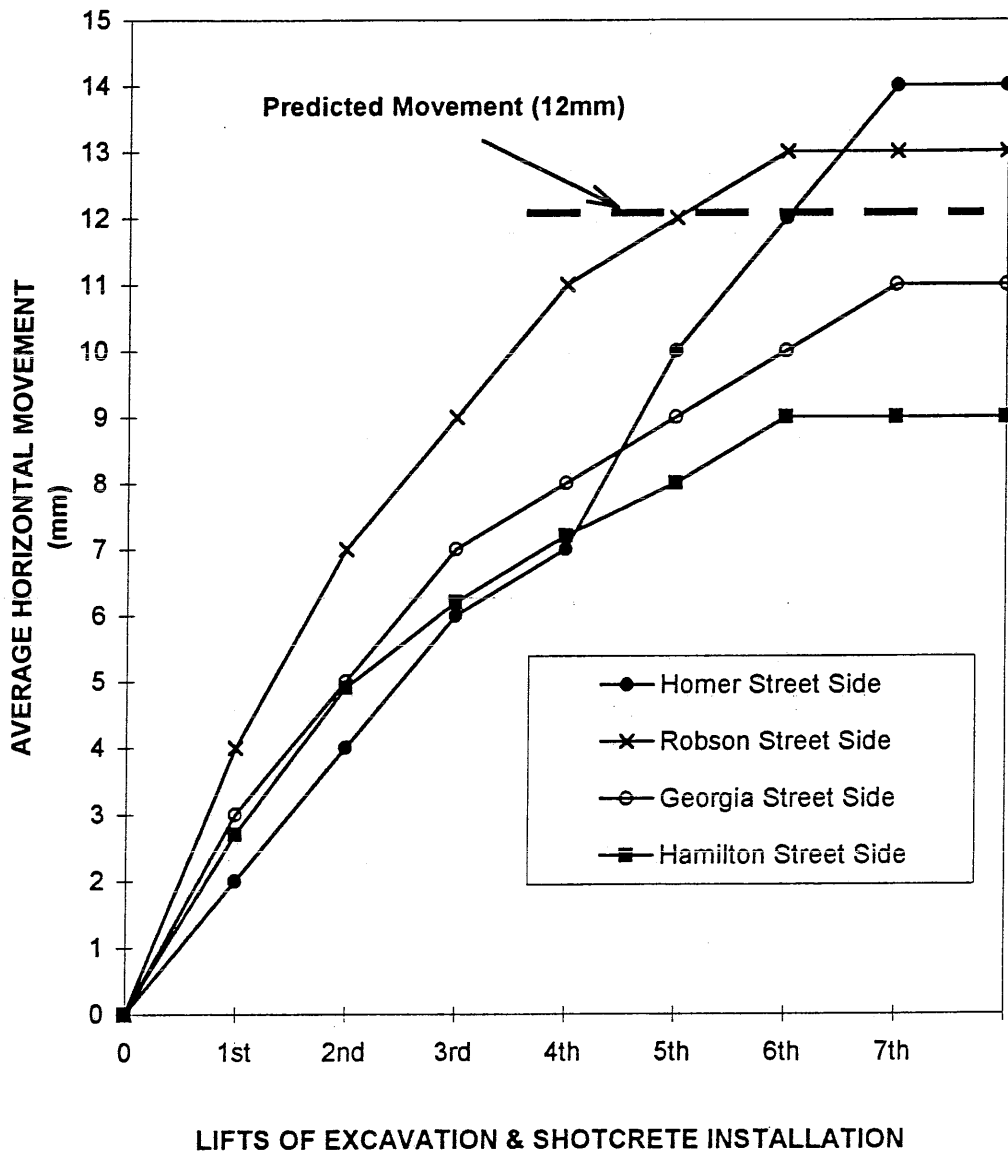


Figure 4 Horizontal Movement of Excavation

Table 1. Summary of Movement of Typical Excavations in Downtown Vancouver

Location	Ground Conditions	Excavation Depth	Average Horizontal Movement (mm)	Maximum Horizontal Movement (mm)
Homer, near Robson	Glacial Till	5 to 7 m	6	8
Hornby & Beach	Glacial Till	9 m	8	10
Granville, near Pender	Bedrock below 4 m	6 to 10 m	5	9
Dunsmuir & Hornby	Bedrock below 2 m	14 to 17 m	10	15
Georgia & Thurlow	Bedrock below 3 m	8 to 14 m	12	23
Howe & Dunsmuir	Bedrock below 5 m	9 to 15 m	18	30
Georgia & Hornby	Bedrock below 3 m	8 to 14.5 m	18	32
Howe & Davie	Bedrock below 4 m	11 to 13 m	18	54
Dunsmuir & Burrard	Bedrock below 5 m	19 to 23 m	30	35

