REDUCING LIQUIFACTION POTENTIAL BY VIBRO-REPLACEMENT

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INTRODUCTION

Saturated, fine, loose sands are abundant in the Fraser Delta. When subjected to earthquake forces, of sufficient magnitude, these sands will liquify.

Recent construction of the Annacis and Richmond E/W Freeways required foundation improvement for 16 associated structures (see Figure 1).

Where economical, the potential for liquifaction was reduced by utilizing vibro-replacement techniques to densify the sand and provide an avenue for pore pressure dissipation.

SOIL CONDITION

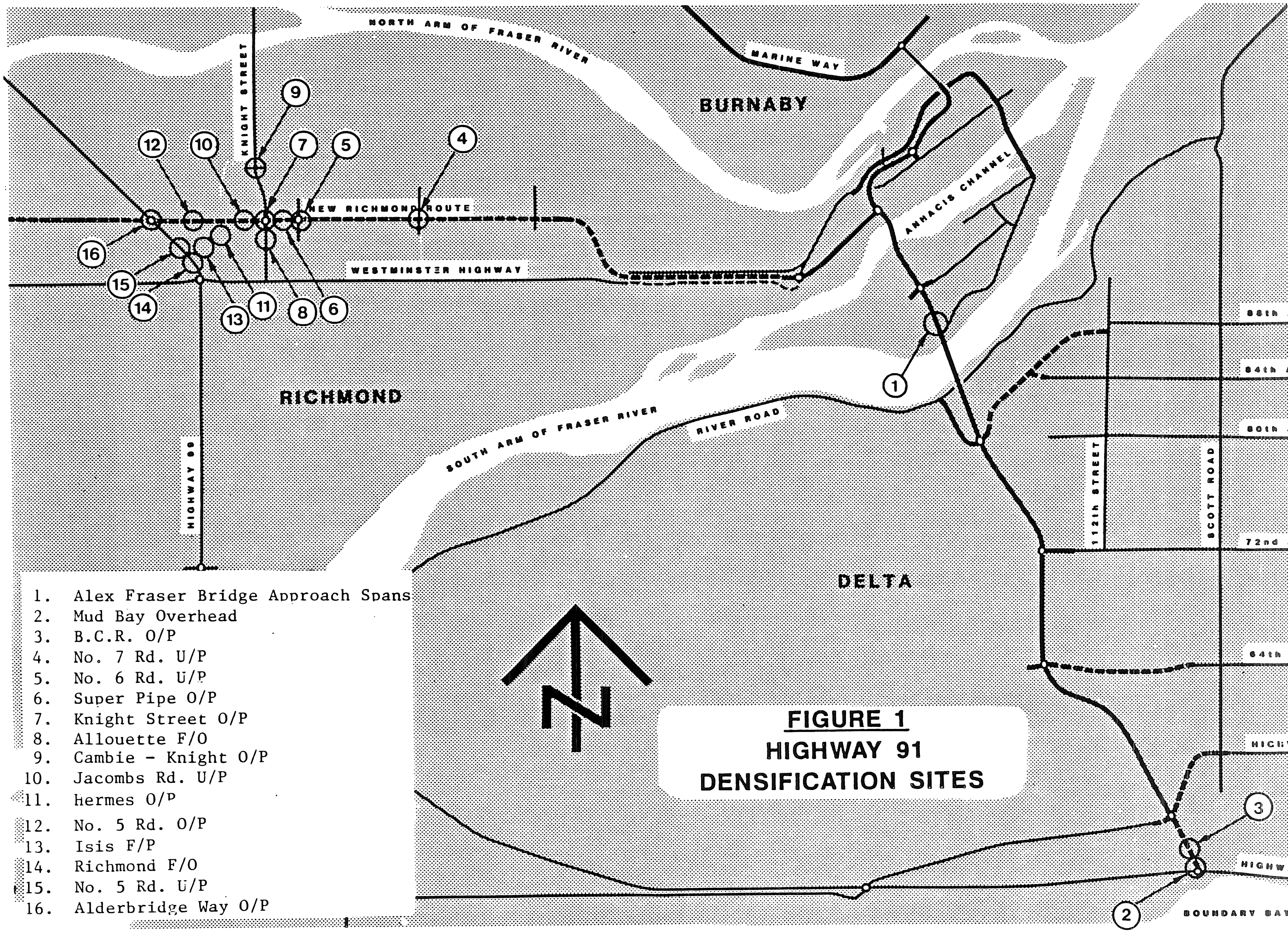
In general the area is covered by a thin, discontinuous layer of clay, silt and peat up to 6 metres in thickness. This is underlain by clean, fine to medium sand (Fraser River Sand) up to about 20 metres in thickness. This is followed by interbedded marine delta deposits of sand, silt and clay and finally glacial till. Bedrock is at depths of 200 - 275 metres.

The Fraser River Sands form the foundation for most of the structures and are the materials of interest in this paper. A typical cone and borehole log are shown in Figure 2.

TYPICAL CONSTRUCTION

With a few exceptions bridge abutments are founded on spread footings within the sand approach fills and piers are supported on pipe piles that terminate within the Fraser River Sand. Typical details are shown on Figure 3.

Under earthquake loading both the stability of the constructed fills and the lateral capacity of the foundation piles are of concern. At the sites underlain by peat and organic silts and clays, stability during construction is marginal.



1. Alex Fraser Bridge Approach Spans
2. Mud Bay Overhead
3. B.C.R. O/P
4. No. 7 Rd. U/P
5. No. 6 Rd. U/P
6. Super Pipe O/P
7. Knight Street O/P
8. Allouette F/O
9. Cambie - Knight O/P
10. Jacombs Rd. U/P
11. Hermes O/P
12. No. 5 Rd. O/P
13. Isis F/P
14. Richmond F/O
15. No. 5 Rd. U/P
16. Alderbridge Way O/P

FIGURE 1
HIGHWAY 91
DENSIFICATION SITES

CONE PENETROMETER LOG

Ministry of Transportation and Highways

Geotechnical and Materials Branch

HOLE NO 85-32

Project RICHMOND EW FRWY #5 ROAD

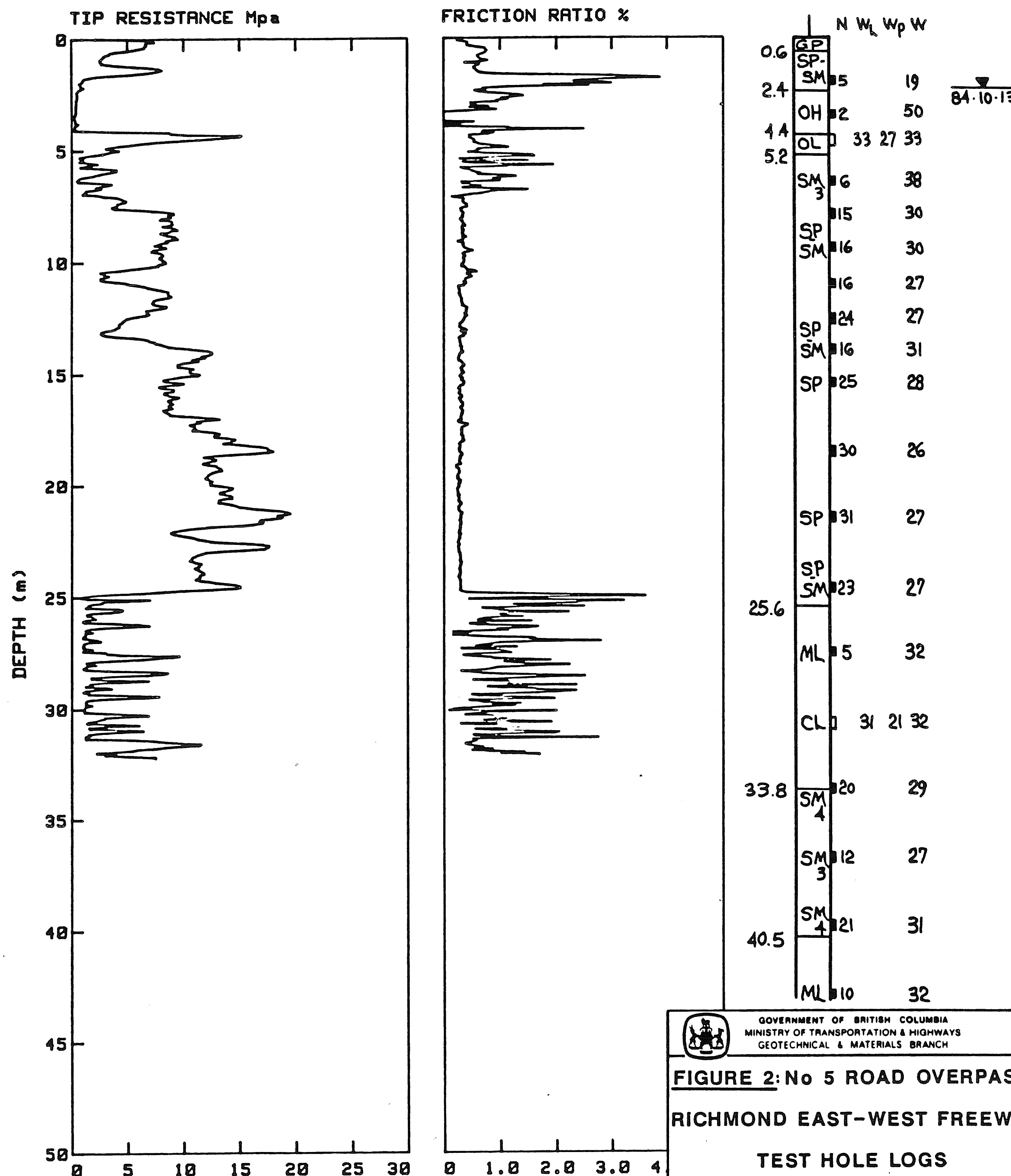
File No ________

Location STA. 107+58,2.5m RT.

Elevation 2.93m

Engineer TOM OXLAND

Date 08/07/85 13:26



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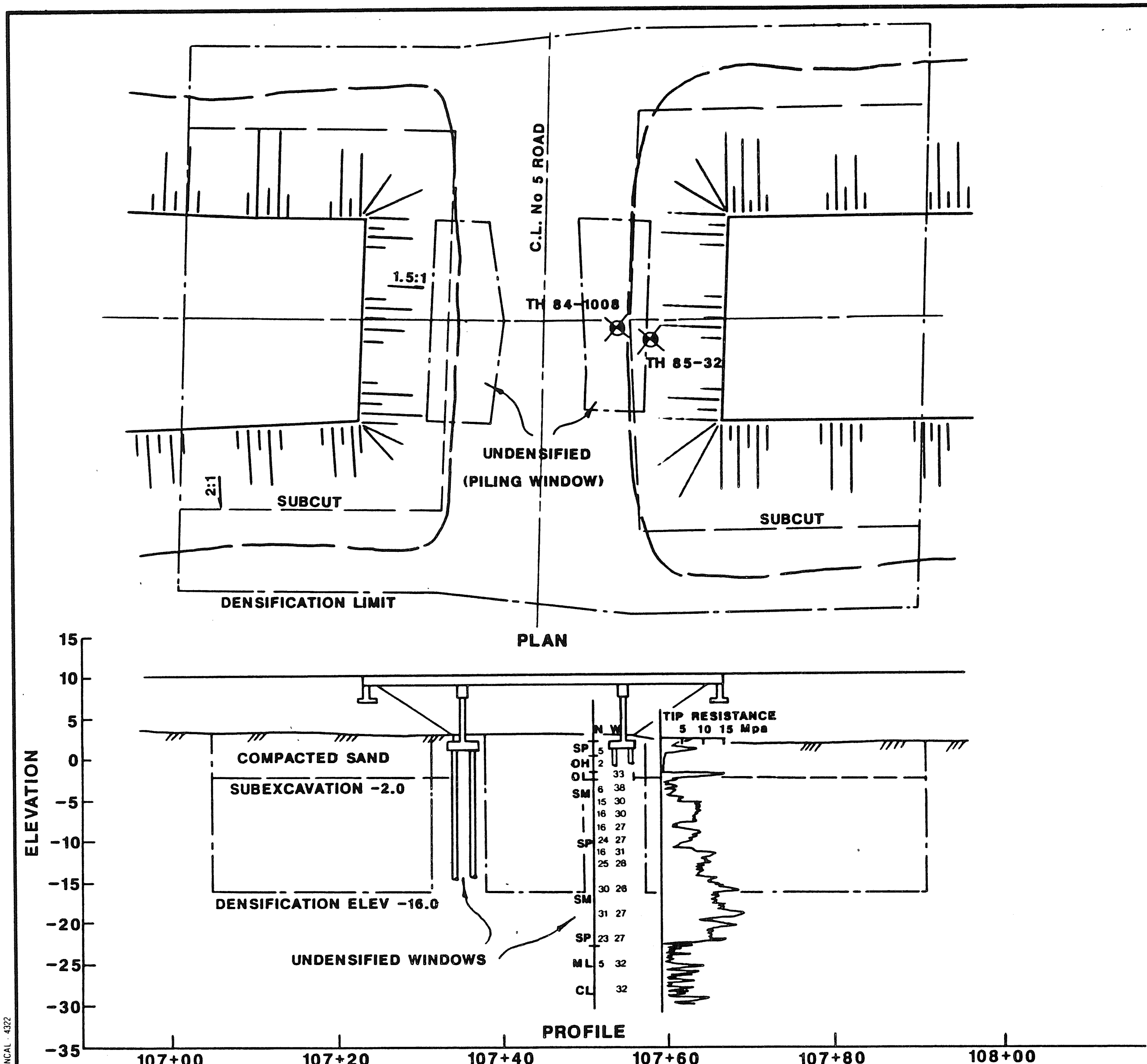
GEOTECHNICAL & MATERIALS BRANCH

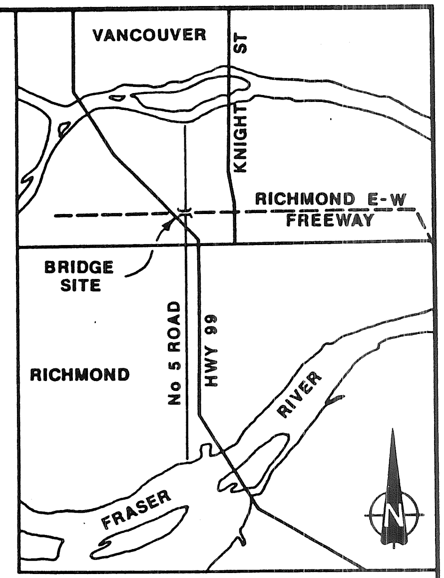
FIGURE 2: No 5 ROAD OVERPASS

RICHMOND EAST-WEST FREEWAY

TEST HOLE LOGS

DRAWN KFR	DATE 87/04/30	SCALE
FILE NO.		





KEY PLAN

FIGURE 3

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No 5 ROAD OVERPASS
RICHMOND EAST-WEST FREEWAY
SITE PLAN

DRAWN KFR	DATE 87/04/24	SCALE 1:500
FILE NO.		

VANCAL · 4322

To speed fill placement, minimize settlements and guarantee stability the area below the fill supporting the abutment is sub-excavated and replaced with sand. To ensure stability during the design earthquake, stone columns are utilized to densify the area shown on Figure 3. Undensified windows are left to accommodate piling for the piers.

LIQUIFACTION POTENTIAL

The potential for liquifaction was evaluated on the basis of 475 year return period accelerations of 0.2 g. Densification criteria were established in a manner similar to that proposed by Seed.

While several methods of densification were considered, stone columns provided the dual benefit of improved density as well as improved drainage.

It was felt that the electric cone would provide the most thorough and consistent measure of density. This in turn would minimize contractual arguments. Figure 4 shows a cone log before and after densification compared to the specified criteria.

SPECIFICATIONS

The most recent version of the Specification is as follows:

DESCRIPTION OF WORK

The work consists of densifying the soils by the vibro-replacement method (installation of stone columns) or as directed by the Engineer at the location and to the detail shown on the drawings.

QUALIFICATIONS

Soil densification shall be carried out by a specialist Contractor of recognized ability having experience in the supervision and execution of soil densification by vibro-replacement techniques as approved by the Engineer.

All work shall be under the direct control of skilled personnel experienced in the use of the equipment chosen.

Ministry of Transportation and Highways

CONE PENETROMETER LOG

Geotechnical and Materials Branch

HOLE NO 87-50

Project #5 ROAD UNDERPASS C-3427

Location 110LL - 110MM - 111M

Engineer TOM OXLAND

File No ______

Elevation 1.98 m

Date 03/14/87 12:11

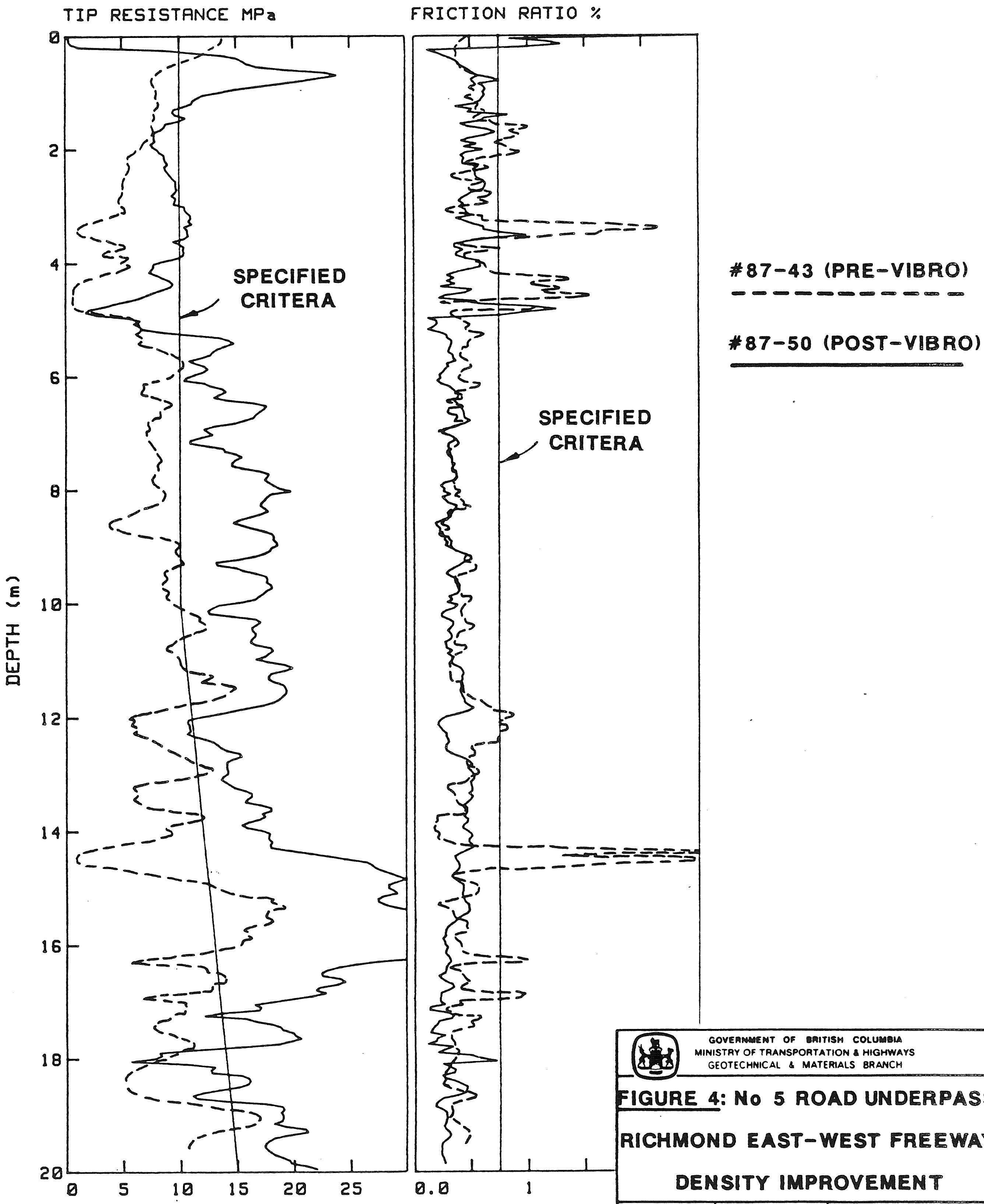

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FIGURE 4: No 5 ROAD UNDERPASS

RICHMOND EAST-WEST FREEWAY

DENSITY IMPROVEMENT

DRAWN KFR	DATE 87/04/30	SCALE
FILE NO.		

EQUIPMENT

Equipment acceptable for this work shall consist of poker-type compaction probes designed to penetrate the soil vertically to the required depths by water jetting and horizontal vibration, and to saturate, vibrate and compact the soil as the probe is withdrawn in stages while adding stone column fill. Equipment shall be adequate to densify the sand by the vibro-replacement method to a maximum depth of 25 m.

DETERMINATION OF PROBE SPACING

The Contractor must use a probe-pattern of equilateral triangles with a centre to centre probe spacing not greater than 2.5 metres. After establishing his ability to achieve the specified density at a 2.5 metre spacing he may increase the spacing, in up to 0.25 metre increments, with the Engineer's Approval, to determine the optimum production pattern. This pattern may be used for the balance of the project subject to consistent performance and the Engineer's approval. Should the specified density not be achieved at 2.5 metre spacing, the Contractor must decrease the spacing as required to ensure the specified results.

A plan identifying each probe location must be submitted to the Engineer. If the Contractor changes his pattern, he shall submit a revised plan to the Engineer.

COMPACTION REQUIREMENTS

The density to be achieved shall be measured by the Engineer using a Static Cone Penetrometer. The Minimum required cone tip resistance, Qc, in the sand, measured in the centroid of each equilateral triangle formed by the compaction probes, shall be 10 MPa to 10 metres depth, and shall increase geometrically at a rate of 0.5 MPa per metre to the maximum depth required. Exceptions to the density criterion may be permitted in small zones where the friction ratio, as calculated from the cone data, exceeds 0.75% which indicates a high silt content. An example of such a zone is on the log CPT 85-07 at 15.3 metres depth, Richmond Flyover, Sta. 807+98.5 (See Appendix 1). Outside the subexcavated and backfilled areas, the stone columns must extend up to the surface of the working mat, although the the densification requirements are not applicable in the organic silts and peat. The average amount of infill stone shall not be less than 0.6 m^3 per metre of penetration. Any loosening of soils below the compacted depth will be unacceptable.

ADDITIONAL STONE COLUMNS

At the Engineer's discretion, stone columns in addition to those required to achieve soil densification may be required. Accordingly, the Contractor will be advised as to the location and depth of the additional stone columns. With the possible exception of the density and spacing criteria, the formation of the additional stone columns will be as per these Special Provisions.

STONE COLUMN MATERIAL

The Contractor shall supply infill for stone columns consisting of broken or rounded stones which are hard, free of cracks or seams, and abrasion resistant. This material when tested according to ASTM Designation C-136, shall have a gradation that falls within the gradation curves shown on Appendix 8 and meets the following limits:

Sieve Size	Percent Passing
37.5 mm	100
19.0 mm	40 - 100
9.5 mm	5 - 60
4.75 mm	0 - 5

In addition, the material shall be well graded.

The Contractor shall supply the Engineer with a sample of the infill material at least seven days before the start of the work so that the Engineer can determine the acceptability of such material.

FIELD TESTS

The Engineer will conduct field tests during the progress of the work. The purpose of these tests is to measure and review the degree of densification achieved by the probe pattern and other operational variables selected by the Contractor. The engineer reserves the right to determine the scheduling and frequency of field testing. If the Contractor wishes to have additional field test results, he may arrange for such additional testing at his own expense.

RECORDS

The Contractor shall co-operate with the Engineer to obtain any or all of the following records for each stone column compaction point or group of points.

A Identification and location
B Date of, and time for completion
C Elevation of the ground surface immediately before and after compaction
D Elevation to lowest penetration of probe
E Quantity of stone column material
F Maximum power consumption used during the compaction process
G Unusual conditions encountered

DISCUSSION & CONCLUSIONS

In most instances the vibro-replacement process has produced the desired results. Figure 4 is indicative of the general improvement.

The following points summarize the principal conclusions from the contracts completed to date:

1. The selection of an appropriate starting probe spacing was originally left up the the Contractor. Inevitably, large areas of substandard work resulted prior to agreement on the appropriate spacing for the site and equipment. Remedial work was awkward, expensive and the source of constant conflict. The specifications were revised to define a starting spacing that had a high probability of success. Increases in probe spacing were dependent upon satisfactory performance.

2. The specified density criteria are "minimum required" values. It was initially felt that this would minimize data manipulation and disagreements between the Contractor and inspector. The Contractors were generally in agreement that they would prefer some type of averaging process that recognized inherent variability in operators and ground conditions. While changes have not yet been instituted, one is being considered that would require compliance over a prescribed length (1 - 3 m) but allow some substandard values within the length (say 80% of Qc minimum).

3. The time required for quality control, with the cone, can become execessive unless some alternate method is used to identify suspected weak areas. Equations were developed that considered rock quantity, power consumption and time at each probe. This data was input into a PC and suspect areas were identified for cone testing.

4. It became evident during the course of the work that a friction ratio of 0.75% approximated the dividing line between easy and difficult densification.

5. Probe spacings from 2.75 m - 3.0 m appeared to be the upper limit for the equipment and soil conditions at the sites.

6. The cost of the densification ranged from $3 to $6 per cubic metre of foundation area.

7. It appeared that probes with a bulbous lower end promoted a constant intake of rock resulting in more consistent density improvement over the length of the probe.