ROAD UTILITY CUTS

Field Investigation

Toronto Site

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Reference: Agreement with RUC Consortium Clients

Program: Urban Infrastructure Program

Research Précis

[To access the full Report contact the Institute for Research in Construction, National Research Council Canada, 1500 Montreal Road, Ottawa, CANADA K1A 0R6]

US Army Corps of Engineers

National Research Council Canada

EXECUTIVE SUMMARY: TORONTO FIELD EXPERIMENT

The research and development project entitled "Restoration of Utility Cuts (RUC)" is a joint effort involving a number of North American organizations including cities, utility companies and U.S. State departments of transportation. The objective of the project was to develop a guide for best restoration practice based on sound engineering principles. The National Research Council Canada and the U. S. Army Corps of Engineers have joined forces and built a collaborative research project, which investigated the problem and developed the necessary corrective measures for restoration practices that lead to poor performance in the past. The project was managed by a steering committee formed from member organizations contributing to the consortium.

The Toronto field experiment was one of five RUC project sites selected to cover a wide range of utility cut restoration practices and environmental conditions. The Toronto experiment offered an opportunity to investigate the use of unshrinkable fill, a concrete low strength material (CLSM), as a backfill for reinstating utility cuts. City of Toronto specifications for unshrinkable fill follow general flowable fill material guidelines and have been used effectively since 1988. The city manages the quality of this material through a certification system that produces a list of approved unshrinkable fill suppliers (current list includes approximately 20 manufacturing plants). The experimental site included two cut sections, a conventional transverse trench and a keyhole. This report discusses the outcome of in-situ tests conducted in Toronto and laboratory investigations performed at the NRC campus in Ottawa.

The experiment was performed in two stages to conform to City specifications calling for a temporary restoration followed by permanent restoration. These two phases were preceded by pre-construction investigations carried out by JEGEL at the site of the experiment including a road condition survey, geotechnical testing and general survey work.

The temporary restoration was established on September 2001 and the permanent restoration on May 2002. The final set of instrumentation data was collected on April 2003. The report discusses results of in-situ testing and data collected from sensors installed in the restored cuts covering a wide range of engineering parameters and environmental conditions. In-situ tests covered quality control tests included in City specifications. Sensor data was collected in four visits to the site where a test truck and the falling weight deflectometer (FWD) device were used to load the test sections. Data was also collected through remote interrogation of data acquisition systems installed at the site of the experiment from NRC laboratories located in Ottawa. Analysis of distress survey data, in-situ test suits, sensor data and outcome of FWD and laboratory investigations [among other things] revealed the following:

…

- The keyhole cutting and restoration technique that was evaluated in the Toronto field experiment indicate that the process is practical and effective in reducing the potential for damaging the road. It is recommended that keyhole application be encouraged whenever proven feasible.

1.0 INTRODUCTION

The Toronto field experiment was one of five sites used to investigate current utility cut restoration practices as part of a North American R&D project. The objective of the project was to develop construction guidelines that can facilitate durable and cost-effective road restoration.

The Transportation Department of the City of Toronto, the host of this field experiment, encouraged participation by the utility community. Joint meetings involving city representatives, the National Research Council, Enbridge Gas Distribution and JEGEL (consultant retained by the City to perform the field testing) led to the development of the preliminary experimental plan. Funding for the experiment was secured from the RUC consortium project, Enbridge Gas Distribution and the City of Toronto including in-kind contributions related to construction, FWD tests, general surveying work and quality control tests.

2.0 THE SITE

Jarvis Street, an undivided street with four lanes, was selected as the site of the Toronto experiment. JEGEL conducted pre-construction investigations including geotechnical tests to produce borehole logs, non destructive testing based on the use of the falling weight deflectometer (FWD) device, condition survey to document existing road damage and general survey work for establishing the road profile and to prepare a local coordinate system which was used in positioning sensors in the test sections. Preliminary information was included in JEGEL Report No.101191 and was later used by NRC research team to design the experiment and produce the field manual that guided construction activities (See NRC Report No. B5506.7 issued September 2001).

The layout plan of the Jarvis Street site is shown in Figure 2.1. The performed utility work involved a water service line crossing the southbound curb lane (lane 4) to connect with a fire hydrant (see Figure 2.2 showing the road prior to cutting). Beside the water main and service line, a gas main crosses the location of the trench and was accessed by the keyhole located 1.2 meters away from the North edge of the trench.

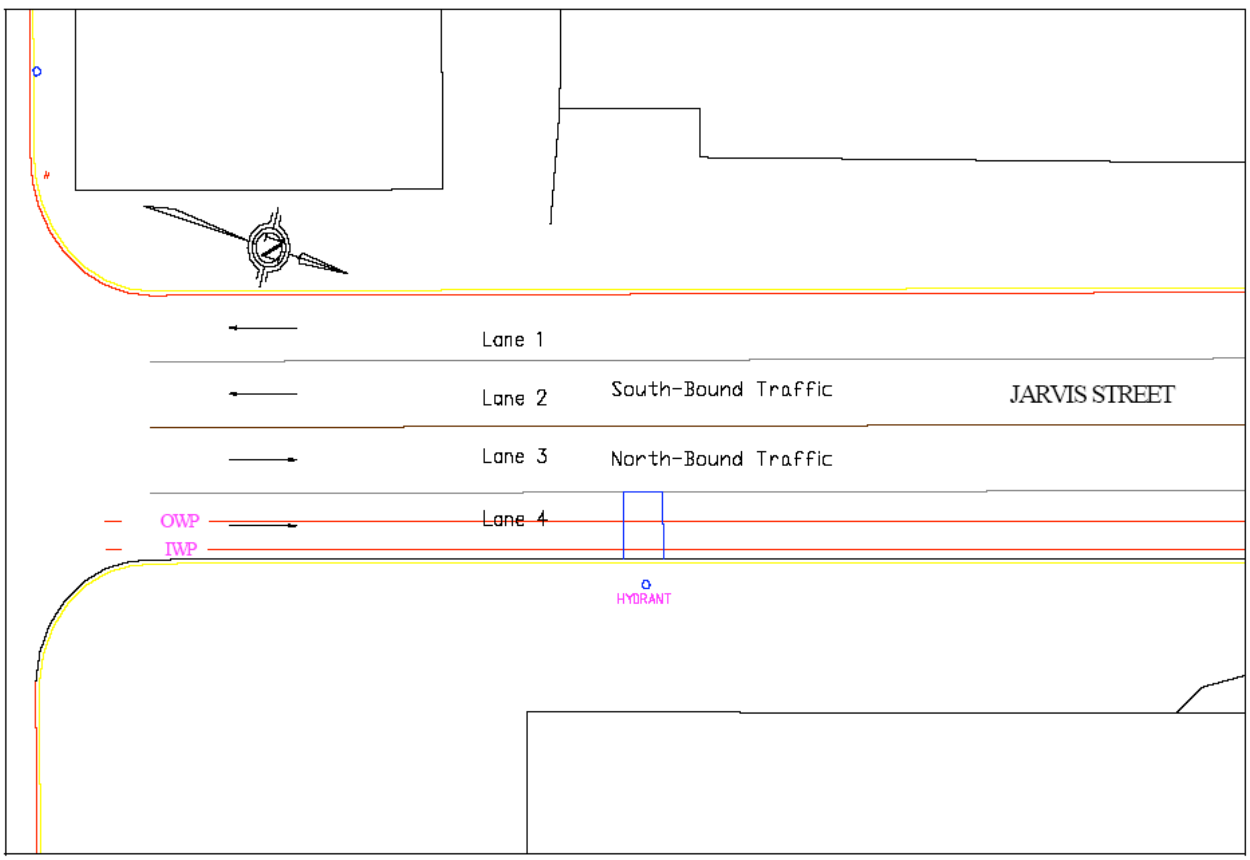


Figure 2.1. Site layout plan

Figure 2.2. Site on Jarvis Street

[NOTE: Sections 3.0 Geotechnical Investigation and 4.0 Pilot Study relating to flowable fill OMITTED]

5.0 CONSTRUCTION

The Toronto field experiment included two cuts, a conventional transverse trench and a keyhole. Construction activities began on September 2001 with Lane 4 closed throughout construction. The trench on Jarvis Street was excavated to replace a hydrant lead pipe connected to an 11.8 in. (300mm) water main. The keyhole was cored 3.94 ft. (1.20m) away from the edge of the trench on top of a 5.9 in. (150mm) gas pipe simulating a repair exercise involving the use of the opening to reach the pipe. The location of the trench and the keyhole with respect to the inner and outer wheel paths of Lane 4 (southbound traffic lane close to the curb) is shown in Figure 5.1. Longitudinal cross-sections AA and BB, transverse cross-section CC and cross-section DD (across the keyhole) are used throughout this report to describe subsurface features within the road and restored cuts including material types and sensors installed in the different layers.

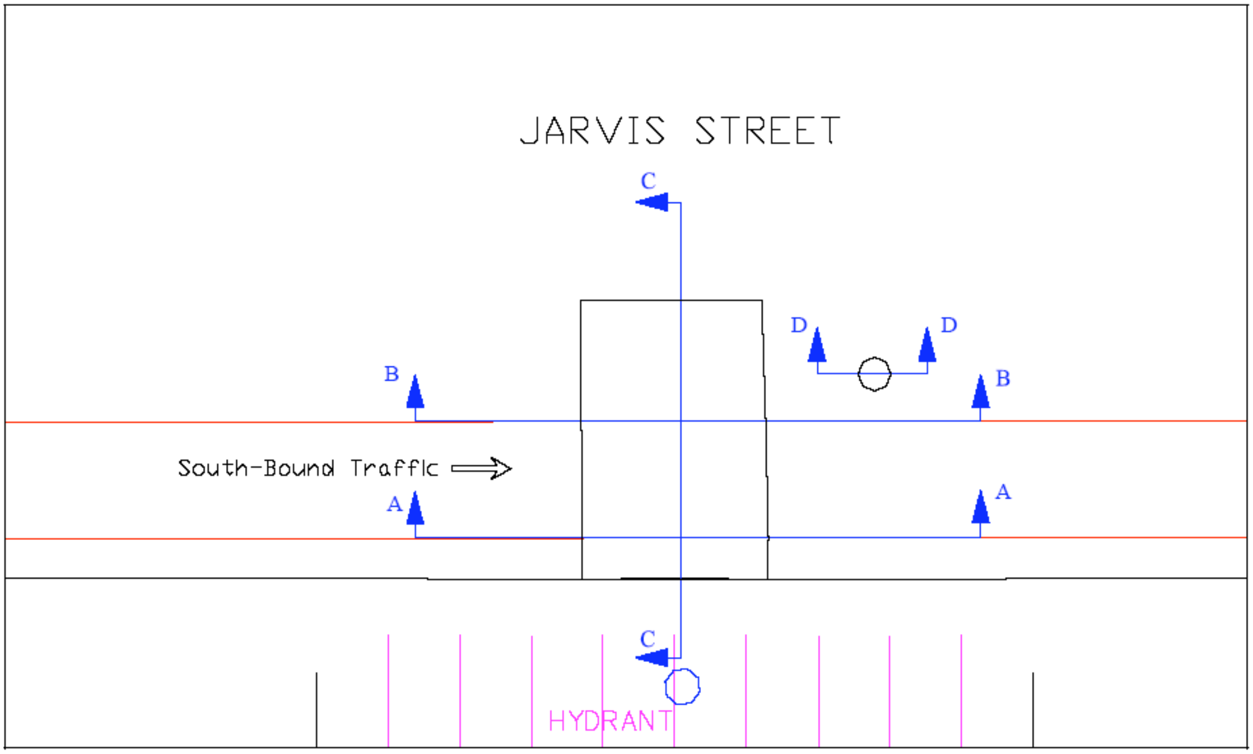


Figure 5.1. Location of the experimental cuts and cross-sections AA, BB, CC and DD

5.1 The trench

The geometry of the trench, orientation of buried pipes and materials encountered during excavation at cross-sections BB and CC are shown in Figures 5.2 and 5.3 respectively. Samples of road materials were collected and shipped to NRC laboratories in Ottawa for testing. These materials were tested to characterize the response of the road structure adjacent to the cut to support model simulations of the experiment. Pavement cutting produced small sections with manageable AC and PCC slab sections (size and weight) for easy removal. Lifting of sawed AC pieces was performed mechanically using a backhoe together with manual removal of sections at the edge of the cut to avoid damage to the road. The cut was deeper near the water main where pipe repairs have been made.

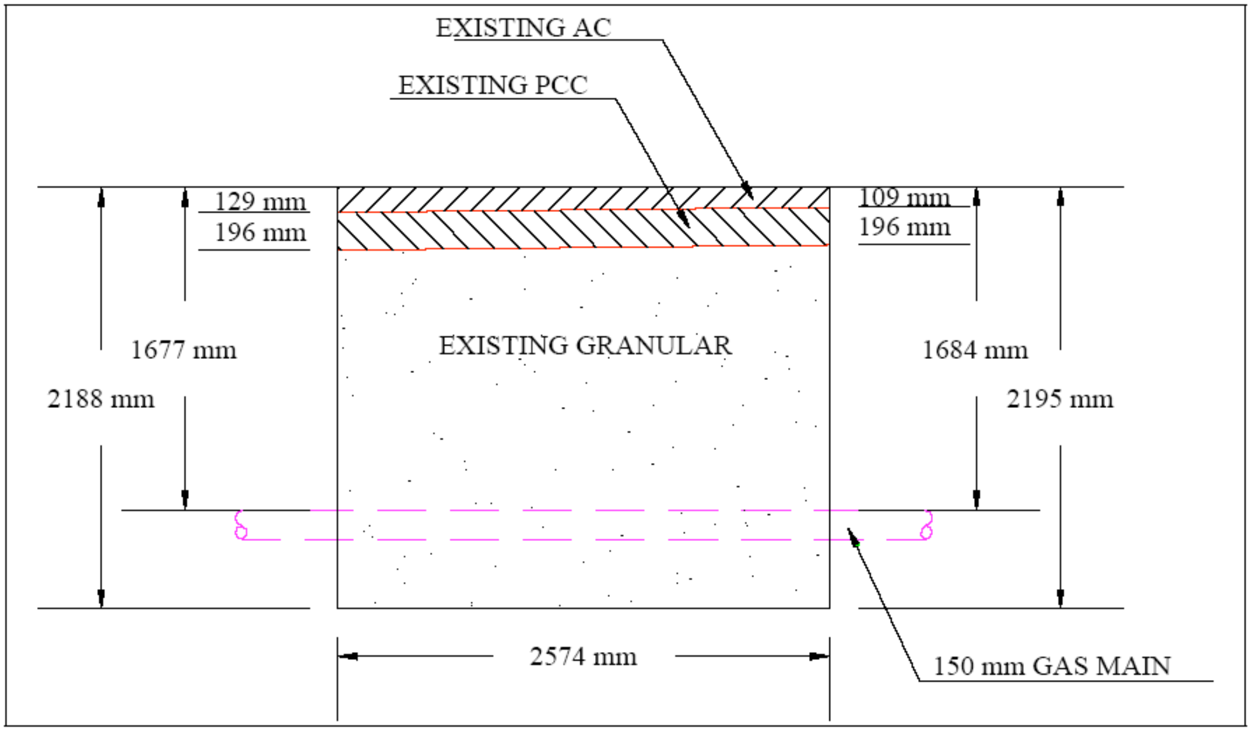


Figure 5.2. Cut details and materials encountered during excavation – cross section BB (1 in. = 25.4 mm)

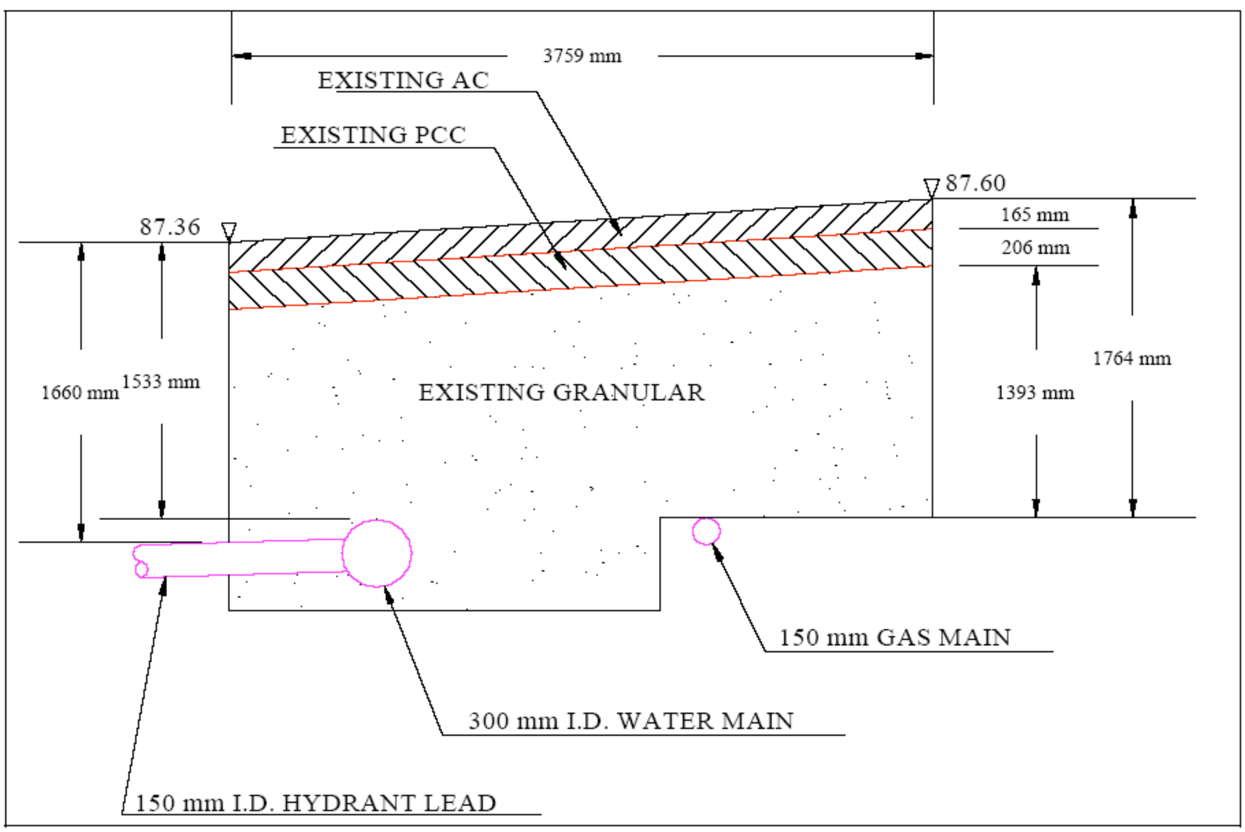


Figure 5.3. Cut details at cross-section CC (1 in. = 25.4 mm)

5.1.1 Temporary restoration

Backfill operations related to temporary restoration commenced after completing repair of the hydrant pipe. Restoration materials used included sand, unshrinkable fill and new asphalt. The entire depth of sand cover (25.2 in., 640mm) was applied in one layer over the pipe. Standard Proctor test was used by the consultant to establish density-moisture relationship, which produced a maximum dry density of 104 lb./ft^2 (1667 Kg/m^3) at an optimum moisture content of 13%. Percentage relative compaction was calculated accordingly to this maximum density. Observations made during compaction suggest that compaction of this thick layer of sand was not adequate and performance monitored by sensors confirmed these observations later.

Unshrinkable fill was poured directly from the agitator truck into the trench in two stages (two truckloads). In accordance with temporary restoration standards, the unshrinkable fill top level was 2.95 in. (75mm) below the road surface to accommodate the asphalt concrete layer to be placed over it.

The temporary asphalt concrete surface was constructed in two lifts using the same mix (HL3). HL3 is a dense hot mix asphalt (HMA) with a maximum aggregate size of 16mm. Specifications call for 3 to 5% air voids. The asphalt concrete compaction test report indicated that relative compaction exceeded 90%

5.1.2 Permanent Restoration

The temporary restored cut was exposed to general traffic for a period of eight months and was loaded with a test truck twice before permanent restoration of the trench on May 2002. Considering the structure of the cut established in the temporary restoration stage, implementing City permanent restoration specifications involved the following:

- Temporary asphalt concrete layer was removed. Asphalt concrete strain gauges fitted at the bottom of the layer were removed and later secured in the AC layer of the permanent restoration stage.
- The surface of the unshrinkable fill was also removed to allow for a thicker AC and PCC layers. This step involved relocation of a number of sensors (see Section 6).

Although permanent restoration was supposed to add an AC layer thickness of 100mm and 200mm of PCC, as-built plans indicate that 150 AC and 161 PCC were actually constructed. The thickness of the PCC slab was less than what exists in the road (PCC average thickness in the road was 200mm).

Toronto city specifications require a T-section configuration where the AC layer is extended approximately 350mm (1 ft) beyond the cut and into the existing road. The AC layer thickness was placed in two lifts. The lower lift was constructed with an HL8 mix. The upper lift was constructed with an HL1 mix (similar to the HL3 mix used in temporary restoration). Based on the use of a fast setting PCC mix, the AC layer was applied on top of the PCC the same day (difference of two hours between the application of the PCC and the HL8 AC).

Figure 5.7. Casting of PCC base

Figure 5.8. Placement of the HL8 layer on top pf the PCC base

5.2 Keyhole

Enbridge Gas Distribution Company introduced the keyhole cutting and restoration technique to minimize the impact on roads caused by excavating relatively large areas such as those associated with conventional trenches. Development of the technology included the introduction of a rotary cutting process, equipment to access facilities and a pavement restoration process involving the reuse of the original core removed from the road which include, in the case of the Toronto experiment, AC and PCC layers. This procedure was used in the Toronto experiment to establish a test section, which was instrumented to monitor traffic-induced stresses and moisture conditions in the lower layer of the pavement associated with this restoration procedure. The geometry of the cut, configuration of structural layers and sensors placed in the keyhole are shown in Figure 5.9.

Coring was performed using a machine mounted on a truck together with other accessories needed for removing material from the keyhole and for restoring the cut. The core, consisting of the road AC and PCC layers, was secured and reused afterward for surfacing the keyhole (See Figure 5.10). It was possible to differentiate between the two AC road layers (HL8 and HL3) present in the core on top of the PCC layer. Schematic reference to the loss of material at the AC/PCC interface observed in the core apparent in Figure 5.10 is shown in Figure 5.9.

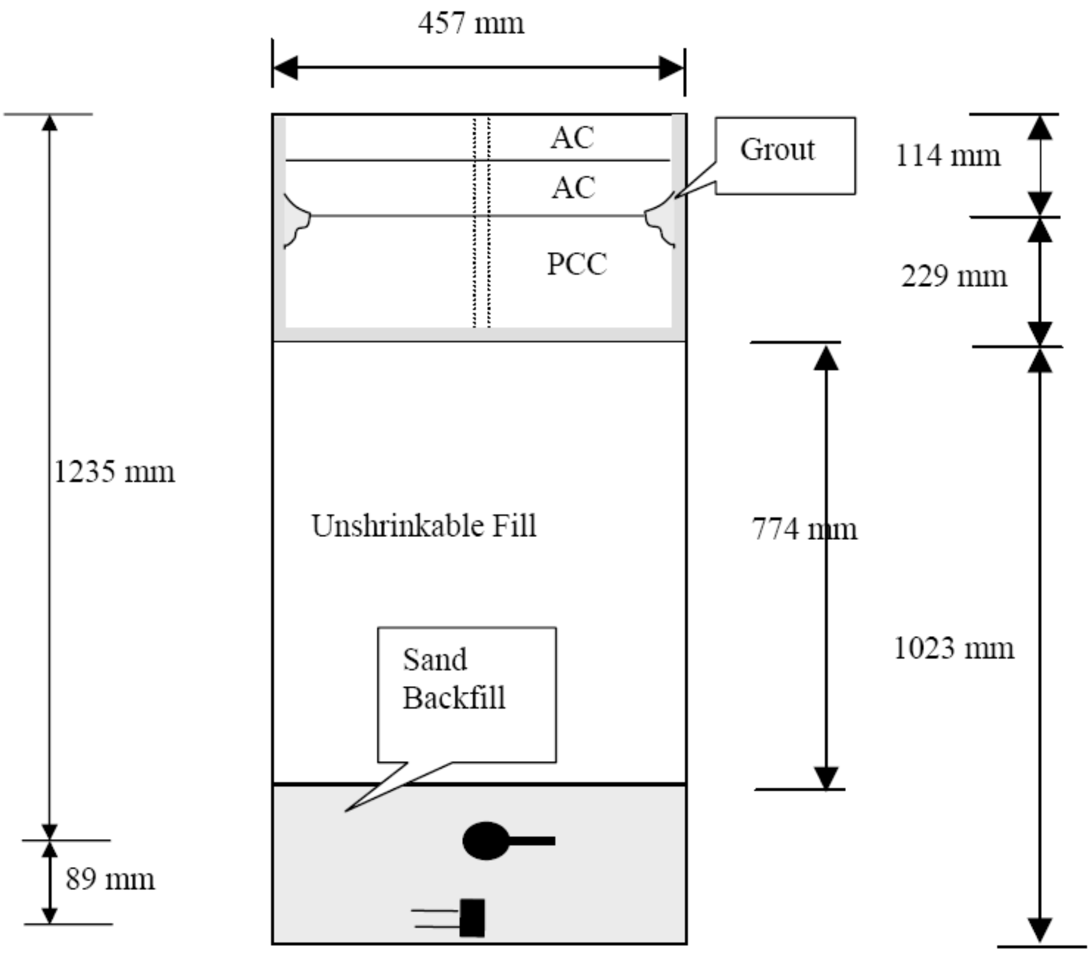


Figure 5.9. Keyhole restored with unshrinkable fill and original core removed during excavation – cross section DD marked in Figure 5.1 (1 in. = 25.4 mm)

During excavation, granular base materials and other soils were conveniently removed by a suction pump (vacuum excavation device) (see Figure 5.11). Larger aggregate particle locked deeply inside the cut were steered to facilitate their removal by the suction pump (see Figure 5.12).

The gas main, exposed at the bottom of the keyhole, was covered with 250mm (10 inches) of sand and compacted manually. After placement of sensors in the sand layer, unshrinkable fill was poured directly from the agitator truck into the keyhole and brought up to the level of the core. The material was allowed time (approximately two hours) for excess water of the unshrinkable fill to drain (see Figure 5.l3 a and b) before replacement of the core and application of the grout. The original PCC section of the core recovered from the road was placed in the keyhole [Note: the core had delaminated between the asphalt layers and the concrete, necessitating a two step reinstatement.]. Special grout was then injected into the keyhole to fill the annular space created by the core and surrounded the PCC section of the core (see Figure 5.14). The grout also occupied the surface of the PCC section of the core. The AC section of the core was then positioned in the keyhole and rammed (tamped) in place (see Figure 5.15). The ramming action pushed the AC section into the grout on top of the PCC section and forced excess material to flow upwards and surround the AC section, [and out to the surface through] the opening in the core used for lifting the core plug. The restored keyhole section of the road was closed for two additional hours of curing time before opening the road to traffic.

Figure 5.10. Original core recovered by coring and used later to restore the keyhole

Figure 5.11. Suction pump for removing soil from the keyhole

Figure 5.12. Manual steering of material in the keyhole to promote pumping action

Figure 5.13. Freshly poured unshrinkable fill

Figure 5.14. Water drained from unshrinkable fill and grout ready for application

Figure 5.15. Grout poured into keyhole on top of PCC delaminated segment

Figure 5.16. AC core tamped into place

6.0 INSTRUMENTATION

The instrumentation plan for the Toronto site was developed following NRC standard protocol. The selection of sensors, their distribution within the trench and the assembly of the components of the data acquisition system were all designed to satisfy the RUC study objectives and conditions prevailing in the Toronto site. Alternatives to overcome limitations associated with the nature of the unshrinkable fills were explored during the pilot study (see Section 4). The type, make and number of sensors installed in the Toronto site are listed in Table 6.1. Instrumentation targeted the determination of the structural response of various pavement layers needed for the evaluation of the impact of traffic on the performance of the restored cut. The outcome determined each layer contribution to the damage observed at the surface. Stresses and strains in asphalt concrete, unshrinkable fill and the sand cover/bed were measured under static and dynamic loading modes.

Table 6.1. List of' sensors installed in the Toronto site

Equipment	**Number**[1]	**Model**	**Manufacturer**
Pressure Cells	5	TP-l 0 I-S-4	RST Instruments LTD. British Columbia, Canada
AC-Strain	2	Past2-AC	Denmark
Extensometer	1 (10m)	EXFO191A	RST Instruments LTD. British Columbia, Canada
Thermocouple	1 Rolls (12 point)	UP/ALPTW K-12-20-TX	Thermo-Electric Wire & Cable, LLC Brook, NJ, USA
Accelerometer	1	PA Amplified Piezoelectric	Hoskin Scientific Burlington, Ontario, Canada
WC Ref1ectometer	5	CS615	Campbell Scientific Inc. Logan/Utah, USA

[1] *Two sensors (one pressure cell and one W.* C *Reflectometer) were used in the keyhole*

The distribution of sensors was originally developed based on the state of stresses and strains predicted using analytical simulations of the road/cut structure and traffic loading. Locations with critical stresses or strains were chosen for positioning sensors dedicated to capturing the response and the temperature and moisture condition of the material at the time of measurement. The distribution of sensors was documented using the results of surveying conducted as part of the task dedicated to the establishment of as-built plans for the site. The distribution of sensors implemented in the temporary restoration stage is shown in Figures 6.1 to 6.5. Permanent restoration forced relocation of some sensors and the changes are shown in Figures 6.6 to 6.8. A plan view showing the location of sensors with respect to cross-sections AA, BB and DD, identified earlier in Figure 5.1, is given in Figure 6.1.

- Sensors for measuring the structural response of various pavement layers (stresses and strains), associated with traffic loading applied at the surface, were positioned along the wheel path.
    - Pressure cells were located along the inner wheel path of Lane 4. cross-sectional view showing the vertical position of these cells is given in Figure 6.2. Pressure cells P3 and P4 were position inside the flowable fill attached to a wood strip while PI and P4 were resting directly in the material. Cell P I rests on top of the flowable fill and P4 inside the sand layer.
    - Asphalt strain gauges were positioned at the bottom of the HL8 layer to measure strain in the direction of traffic and in the transverse direction (see Figure 6.2)
    - The vertical accelerometer was positioned along the inner wheel path of Lane 4 close to the surface of the flowable fill.

- Permanent deformation in the sand layer was measured by an extensometer positioned at the bottom of the cut and extends up to the surface of the sand cover.
- Seasonal variations in moisture and temperature conditions in various pavement layers, which int1uence material condition and structural response, were captured using thermocouples and W.C. reflectometers.
- The infrastructure details including cable conduits and the instrumentation box located on the sidewalk are shown in Figure 6.4, A 3-D representation of all the sensors is shown in Figure 6.5.
- Adjustment in the instrumentation locations associated with the permanent restoration is reflected in the plan view shown in Figure 6.6. Changes in the vertical distributions are shown in Figure 6.7 and Figure 6.8 for structural and environmental sensors, respectively.

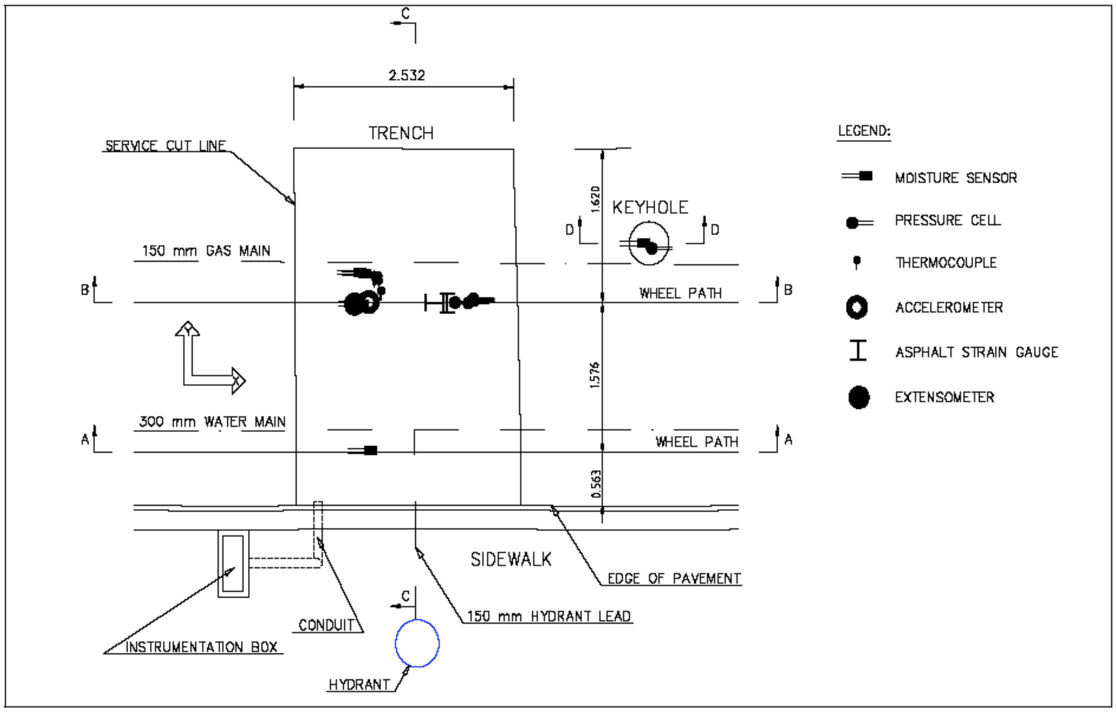
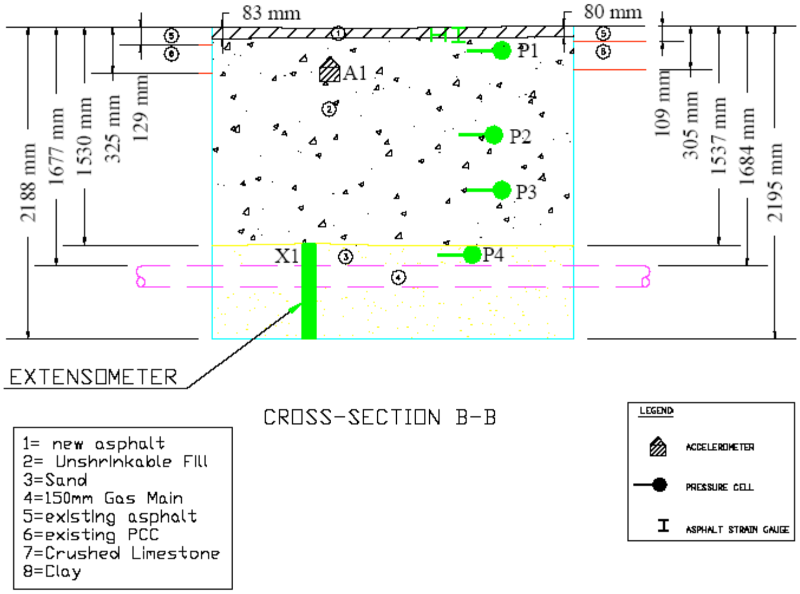
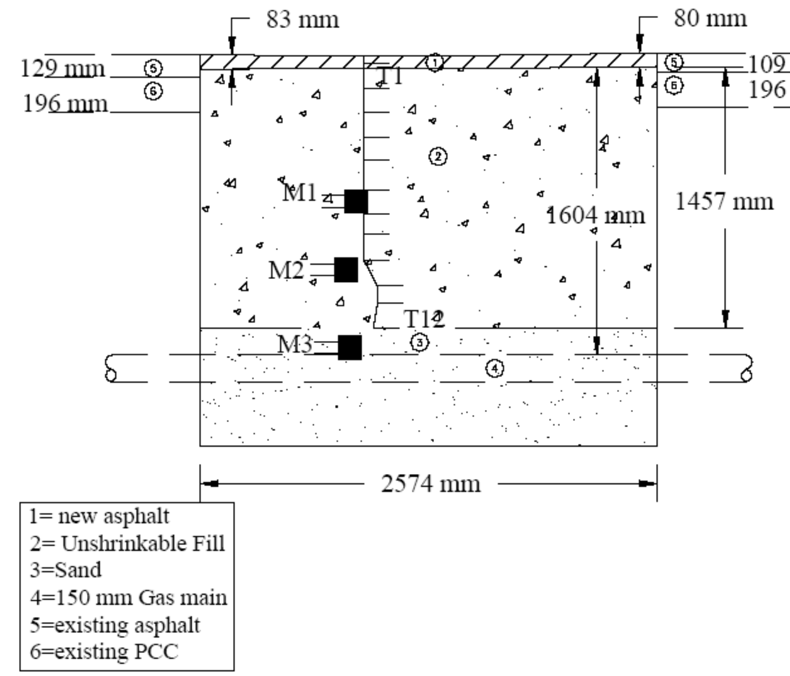


Figure 6.1. Plan view of the instrumented sections



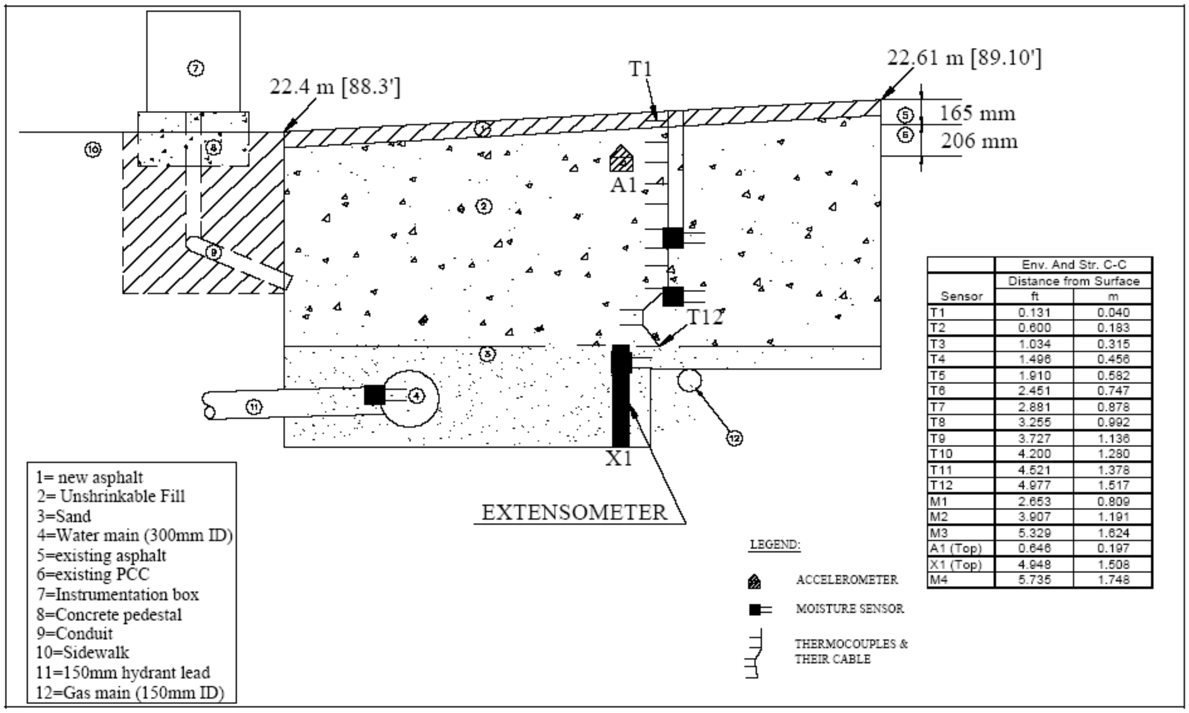
Sensor	Distance from Surface	
	ft	m
P1	0.548	0.167
P2	2.485	0.757
P3	3.757	1.145
P4	5.231	1.594
A1	0.646	0.197
SG	0.177	0.054
X1	4.948	1.508

Figure 6.2. Location of structural sensors – Temporary stage – cross-section BB



Sensor	Environmental B-B Distance from Surface	
	ft	m
T1	0.131	0.040
T2	0.600	0.183
T3	1.034	0.315
T4	1.496	0.456
T5	1.910	0.582
T6	2.451	0.747
T7	2.881	0.878
T8	3.255	0.992
T9	3.727	1.136
T10	4.200	1.280
T11	4.521	1.378
T12	4.977	1.517
M1	2.653	0.809
M2	3.907	1.191
M3	5.329	1.624

Figure 6.3. Location of environmental sensors – Temporary stage – cross-section BB



	Env. And Str. C-C	
	Distance from Surface	
Sensor	ft	m
T1	0.131	0.040
T2	0.600	0.183
T3	1.034	0.315
T4	1.496	0.456
T5	1.910	0.582
T6	2.451	0.747
T7	2.881	0.878
T8	3.255	0.992
T9	3.727	1.136
T10	4.200	1.280
T11	4.521	1.378
T12	4.977	1.517
M1	2.653	0.809
M2	3.907	1.191
M3	5.329	1.624
A1 (Top)	0.646	0.197
X1 (Top)	4.948	1.508
M4	5.735	1.748

Figure 6.4. Instrumentation infrastructure details – cross-section CC (1 in. = 25.4 mm)

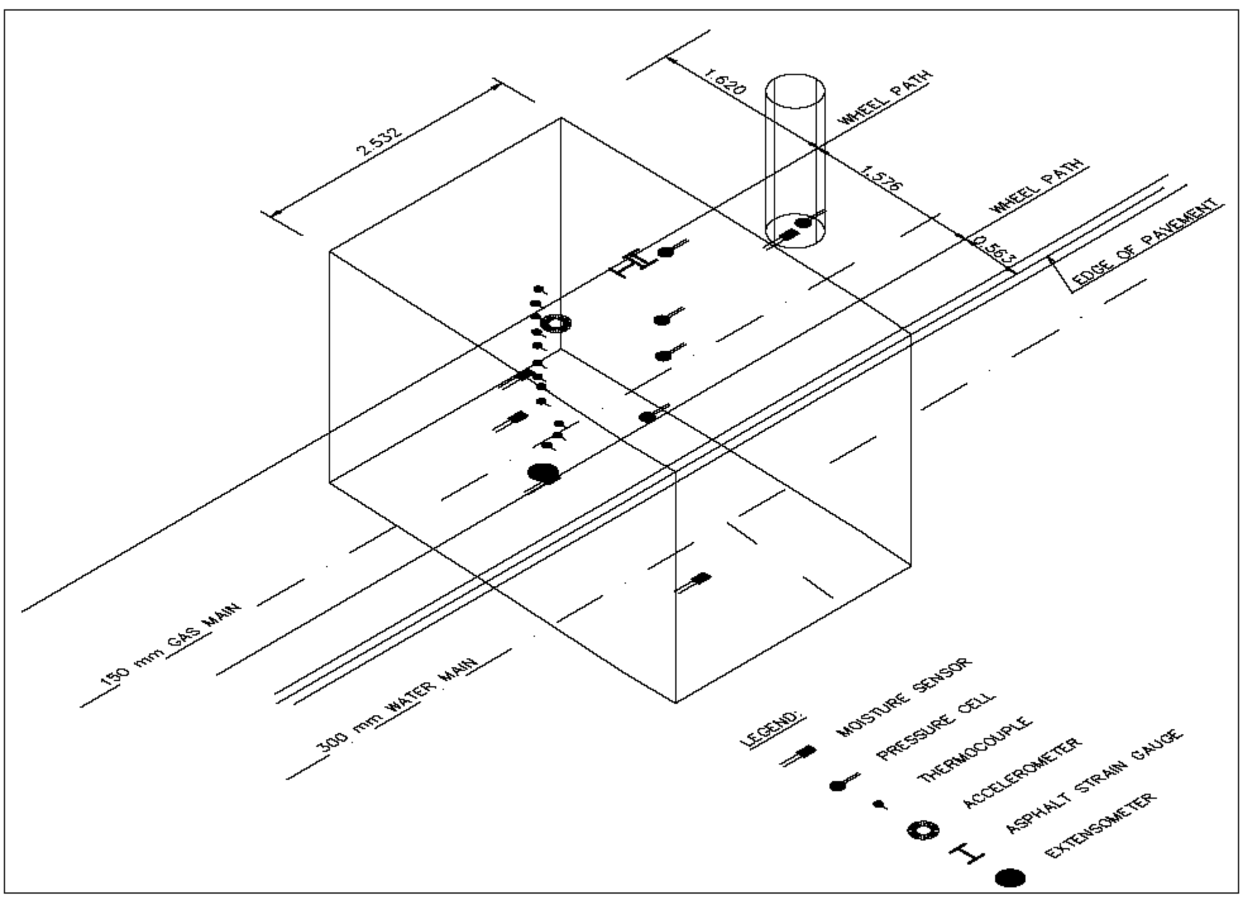


Figure 6.5. 3-D view showing sensor distribution in the trench and keyhole

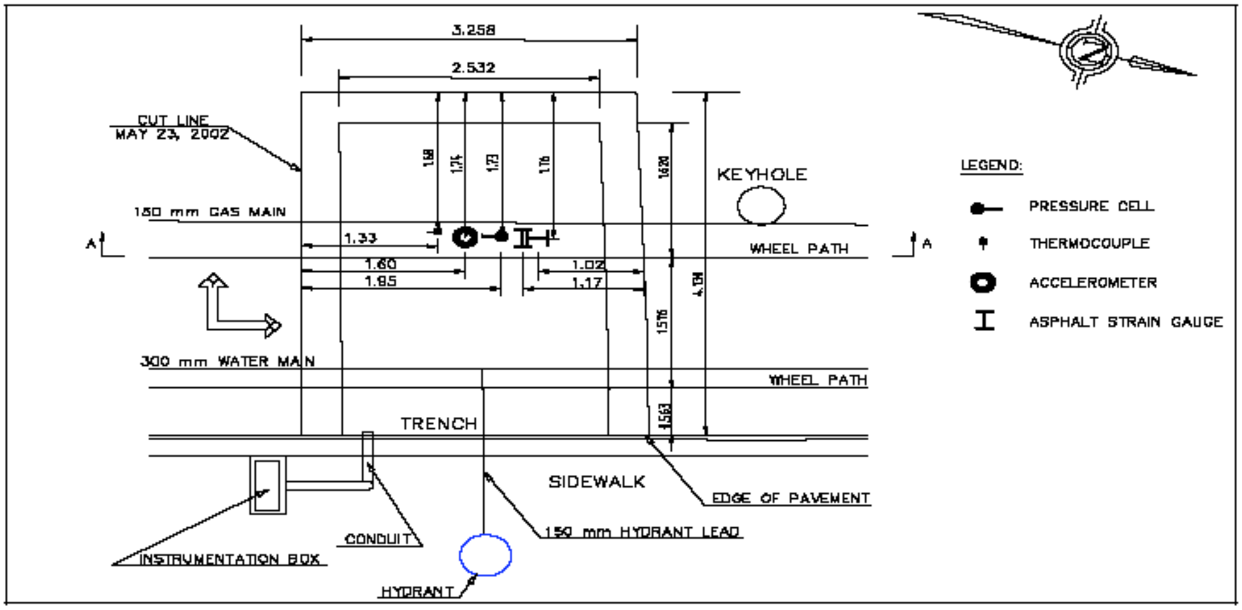
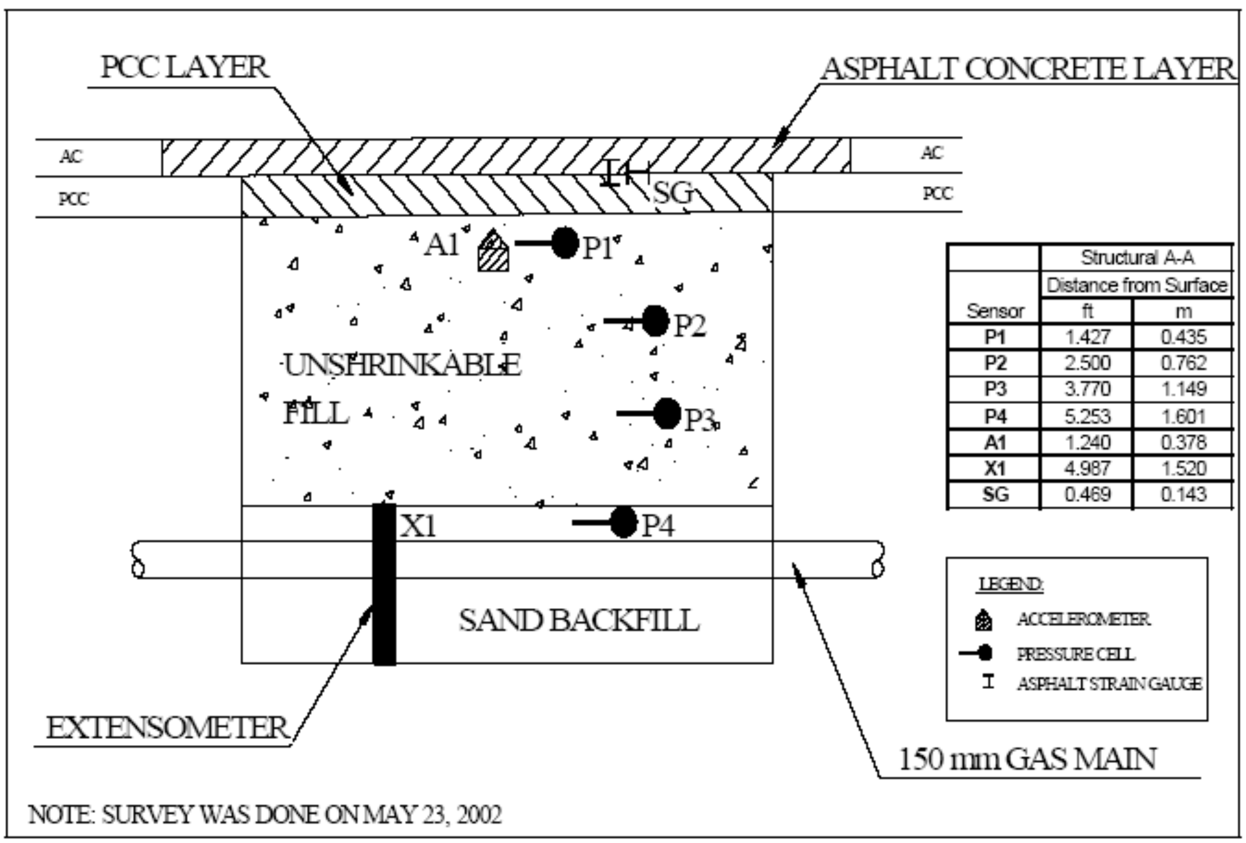
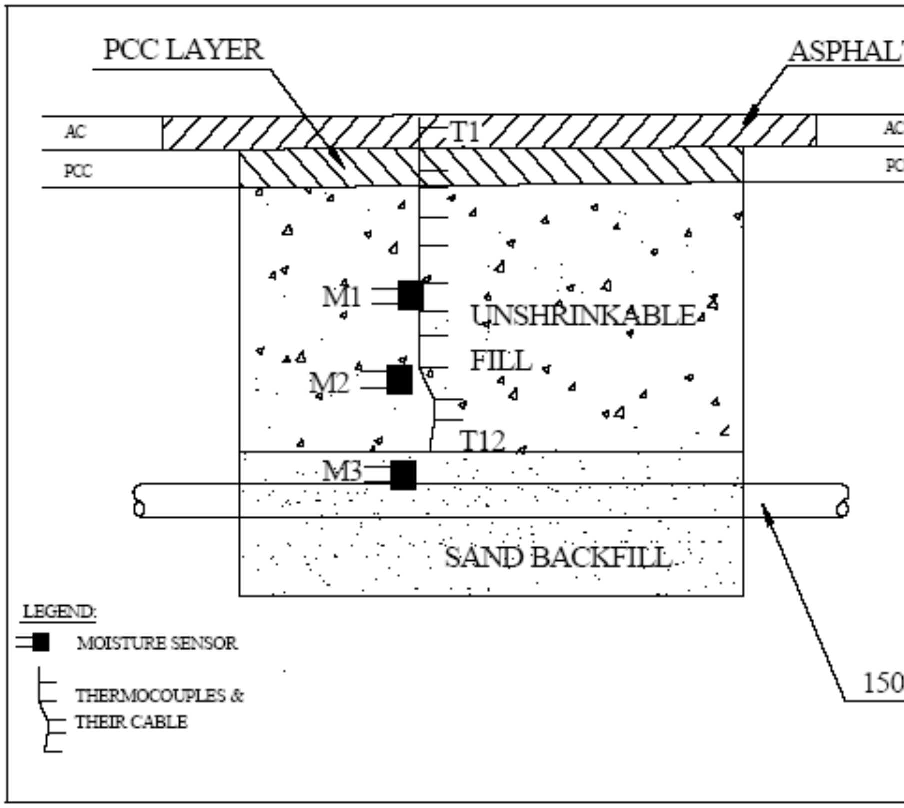


Figure 6.6. Plan view showing location of sensors established during permanent restoration



	Structural A-A	
	Distance from Surface	
Sensor	ft	m
P1	1.427	0.435
P2	2.500	0.762
P3	3.770	1.149
P4	5.253	1.601
A1	1.240	0.378
X1	4.987	1.520
SG	0.469	0.143

Figure 6.7. Location of structural sensors – Permanent stage – cross-section AA



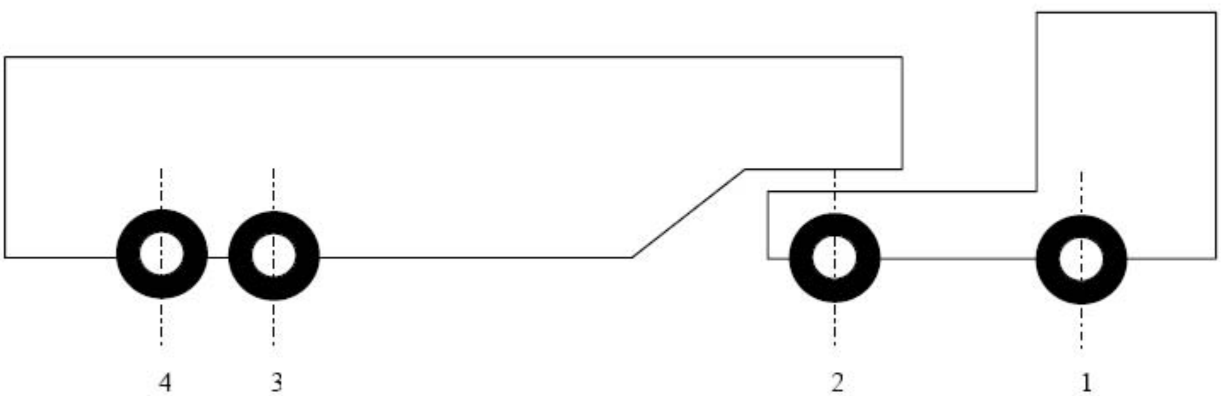
	Env. A-A	
	Distance from Surface	
Sensor	ft	m
T1	0.180	0.055
T2	0.817	0.249
T3	1.076	0.328
T4	1.539	0.469
T5	1.952	0.595
T6	2.494	0.760
T7	2.923	0.891
T8	3.297	1.005
T9	3.770	1.149
T10	4.242	1.293
T11	4.564	1.391
T12	5.020	1.530
M1	2.694	0.821
M2	3.947	1.203
M3	5.371	1.637

Figure 6.8. Location of environmental sensors – Permanent stage – cross-section AA

[NOTE: Section 7.0 Sensor Data and Analysis of Trench OMITTED.]

7.3.1 *Test truck*

The test truck, which was a loaded water tanker (see Figure 7.9), was operate four times over the Toronto experimental road section to collect data from the sensors described earlier in Section 6. Loading tests were conducted in September 2001 immediately after completion of the temporary restoration and afterward in May 2002.



Tractor		Tank	
Front Axle (1)	Rear Axle (2)	Front Axle (3)	Rear Axle (4)
3600 kg	6000 kg	13790 kg	10400 kg

Figure 7.9. Toronto test truck details (1 lb. = 0.45359 kg)

[NOTE: Section 7.4 Environmental Sensor Data OMITTED

7.5 Keyhole sensor data

The two sensors installed in the keyhole are shown in Figure 5.9. The W.C reflectometer M5 was positioned in the sand cover at the bottom of the keyhole. General moisture condition trends in the sand layers of the keyhole and the trench are compared in Figure 7.26. While both reflect an increase with time, moisture content in the trench was much higher than in the keyhole. This may be considered an advantage of the superior joint treatment in the keyhole, which may reduce the infiltration of surface water into the cut. The fact that the cut size and consequently the joint length are much smaller in the keyhole, also contributed to less water infiltration into the keyhole compared with the trench.

The pressure cell P5 positioned in the keyhole was used to collect data throughout the life of the experiment (see figure 7.27). The small size of the road area affected by the cut (a circle 18 in. in diameter) made it difficult to align the test truck path directly over the keyhole. In general, the recorded pressures were low with a maximum value of 7kPa (146.2 psf) measured in Mat 2002. The signal recorded in April 2003 was very faint indicating no stress in the location of P5. Analysis of sensor data combined with damage assessment data discussed in Section 9, confirmed the effectiveness of the keyhole restoration technique.

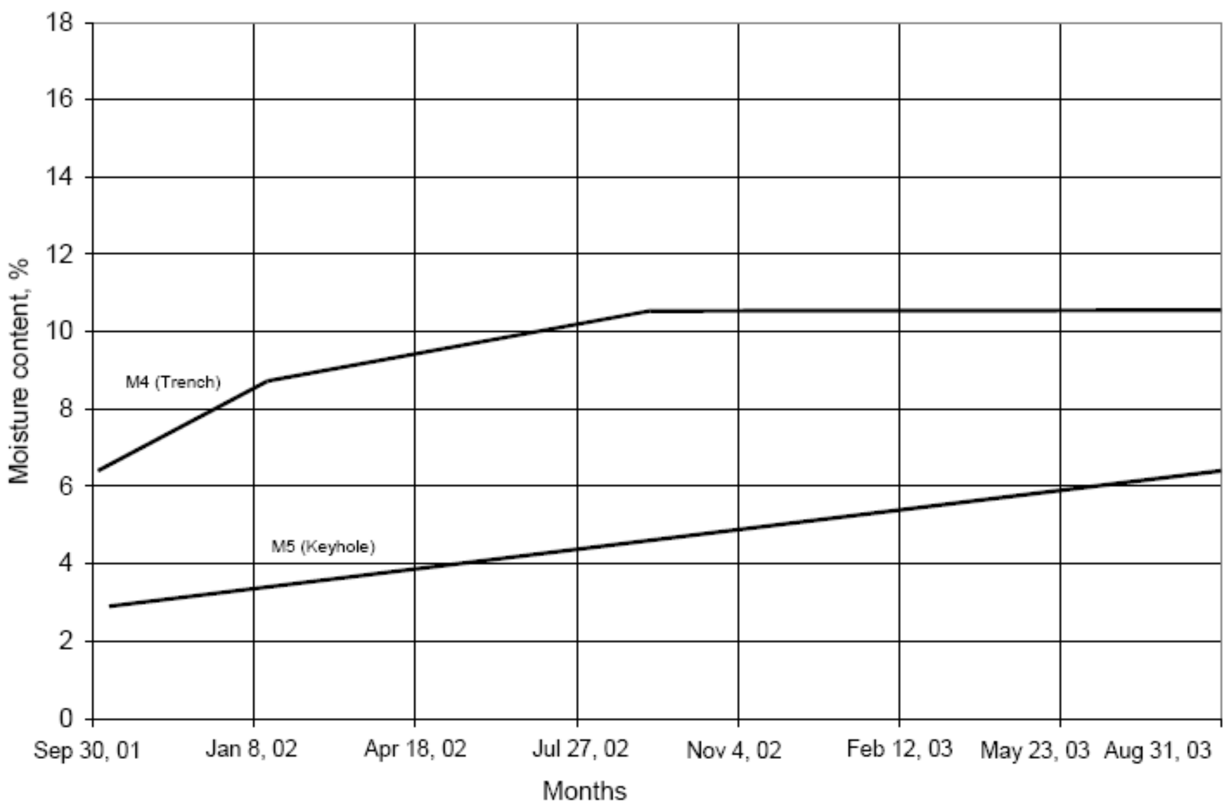
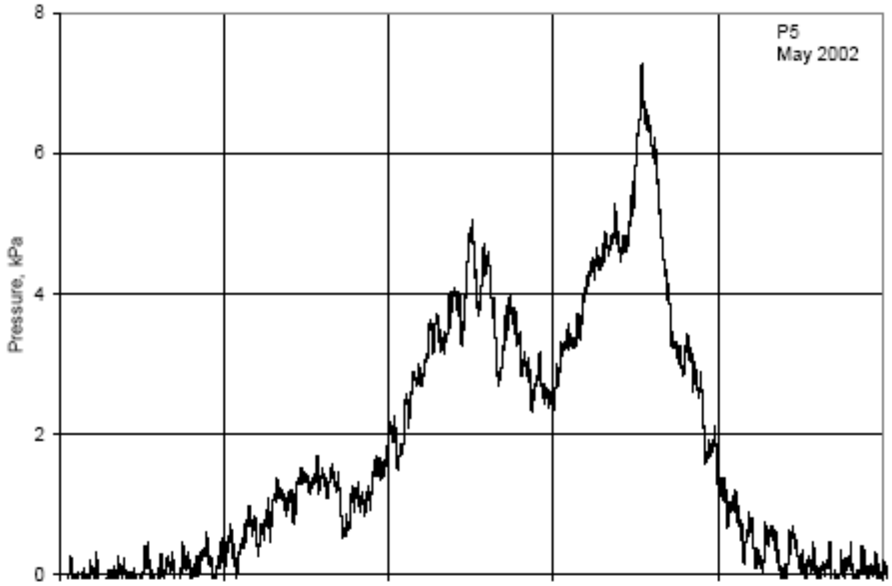
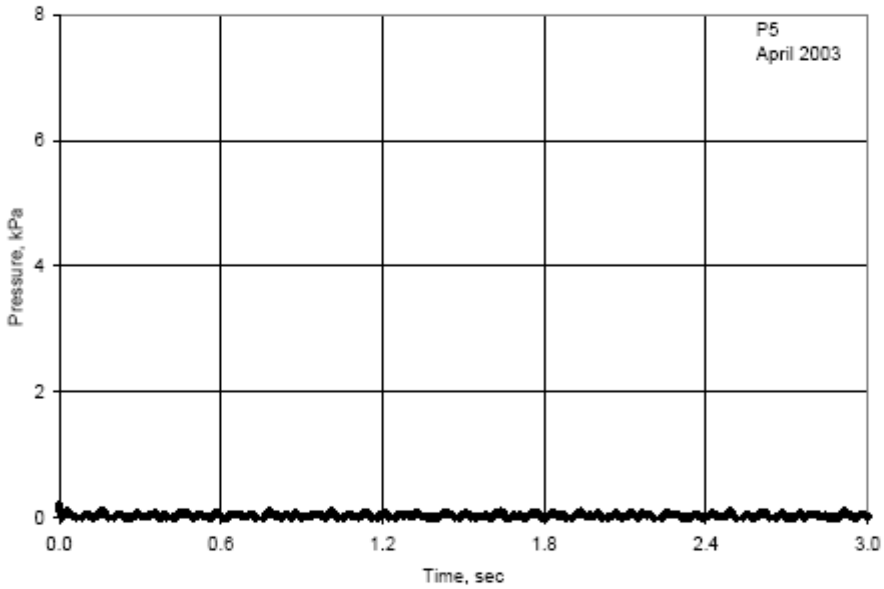


Figure 7.26. Moisture in the sand cover measured in the trench and keyhole



(a) Pressure measured May 2002



(b) Pressure measured on April 2003

Figure 7.27. Pressure measured in the sand layer of the restored keyhole (1 psf = 0.04788 kPa)

8.0 FWD INVESTIGATION

A falling-weight deflectometer (FWD) investigation was performed in the Toronto site using a Dynatest 8000 equipment to evaluate the structural integrity of the road before cutting and after performing cutting and restoration related to the experimental trench. The FWD equipment generates a force on the pavement surface and measures deflections of the pavement surface as far as 1.8 m (5.9 ft) away from the center of the loading plate. The force is applied, through a circular plate with a radius of 150 mm (4.92 ft), by raising a known weight to various heights. The consultant (JEGEL) conducted FWD tests prior to construction (September 2001), after temporary restoration (October 2001), before permanent restoration (May 23,2002), after permanent construction (May 24, 2002), and on April 2003. Test details and results are discussed in the following sections.

8.1 Test Plan

FWD measurements were carried out at points corresponding to inner and outer wheel paths of lane 4 and 3 shown earlier in Figure 2.1. For simplicity, the wheel paths related to these lanes are referred to in this report as WP1, WP2, WP3, and WP4.

Special tests were also performed to evaluate the condition of the road and the cut close to the construction joint. These tests involved the application of the FWD load on one side of the joint and recording deflection on the other side. Results from the special tests were used to evaluate changes in the joint behaviour with time.

8.2 State of the Road before Construction

Results of FWD tests conducted at the site before construction indicate inconsistency in the state of the road structure throughout the site of the experiment. Central deflection values measured at the intersection of the transverse gridlines and wheel paths 1, 2, 3 varied substantially. Measurements made prior to cutting reflected the presence of a weak zone at the location of the trench.

The state of the road structure was relatively consistent along WP 4 as reflected by the similarity of central deflection values at different stations along the wheel path. Central deflection along WP 4 was the lowest compared with other wheel paths, especially at the trench location.

8.3 Changes in the Road Structural Response

Data from central deflection measurements performed at different intervals throughout the life of the experiment was used to assess changes in the road condition associated with cutting and restoration (temporary and permanent). FWD data collected prior to cutting was used as a reference to assess changes associated with cutting and restoration of the experimental trench. Central deflection inside the cut decreased after temporary restoration (October 2001) compared with measurement made before cutting (September 2001). The difference may be attributed to improvement in the structural integrity associated with temporary restoration. Central deflection along WP 1 decreased slightly after permanent restoration compared with that determined prior to cutting. Along WP 2, central deflection decreased after temporary and permanent restoration. Central deflection on the road along WP3 (outside the cut but close to the joint) increased, reflecting a drop in the structural integrity of the road after temporary and permanent restoration. Based on measurements made in May 03 prior to permanent restoration, the road recovered its structural integrity as reflected by the drop in deflection. No significant changes were observed in central deflection on the road along WP4 (outside the cut but close to the joint).

8.4 Impulse Stiffness Modulus (ISM)

Impulse stiffness is a parameter analogous to the spring constant used in modeling, which is defined as the ratio of the applied load to the central deflection. ISM increased initially inside the cut along WP 1 after temporary restoration. Along the same wheel path, permanent restoration resulted in a slight change in ISM at the middle of the cut but showed a large increase at the edge. The ISM along WP 3, which passes close to the cut edge, reflected a substantial drop in the structural integrity of the cut. The ISM dropped 40% after temporary restoration compared with the condition determined before cutting and restoration. The ISM along WP 4 showed very little change.

In summary, analysis of ISM data indicated that the structural integrity of the road dropped after temporary restoration at some locations and increased at other locations. The only critical drop seems to the one along WP 3 measured after permanent restoration, especially close to the free edge of the PCC slab. There is no evidence to suggest that this drop in ISM will be recovered afterward.

8.5 Load transfer investigation

Load transfer tests were performed at the Toronto site to investigate the behaviour of the joint between the utility cut and the road. The test involved application of the load inside the cut or on the road and measuring deflection across the joint.

Results were consistent for both wheel paths WP1 and WP2. The consistency extended to both sides of the cut as reflected in Table 8.8 and Table 8.2 (north and south joints). In general, the load was transferred effectively after temporary restoration (TR higher than 90%). However, load transfer from cut to road dropped substantially after permanent restoration (TR between 60% and 75%). This is expected to be due to the improvement in the road section at the cut location compared with the weakened condition detected prior to cutting (see Figure 8.2). The placement of the unshrinkable fill seemed to be the reason behind the observed behaviour.

9.0 PERFORMANCE DATA

Three sources of information were used to collect performance data from the Toronto site. The first source consisted of sensors installed in the cuts as discussed in Sections 6 and 7 (Not Available). The second source involved visual road condition assessment focusing on the cut and the surrounding road area. The type of information collected during these site visits included evaluation of crack intensity, joint opening and other damage patterns such as spalling and faulting. The last source of information was profile surveys that were used to quantify permanent deformation in the form of settlement and rutting.

The Toronto site included the following unique features:

- Two types of road cuts, a transverse trench and a keyhole;
- Composite road structure and restoration involving a cutback at the AC layer level;
- Thick sand bed/cover;
- Flowable fill (unshrinkable fill) material used as backfill; and
- Two-stage construction strategy involving temporary and permanent restoration stages.

The documented impact of these unique features on the performance of restored cuts added to the information base of the RUC project covering parameters related to design, material and construction.

9.1 Damage Survey

Road condition data collected prior to construction was used to establish a reference for tracing changes associated with cutting (trench and keyhole) and quality of construction.

Damage survey visits included:

- Inspection performed after completion of temporary restoration on October 2001.
- Final assessment of the performance of the temporarily restored trench on May 2002 prior to the second restoration stage.
- Evaluation of the impact of construction activities related to permanent restoration.
- Final assessment of the permanent restoration stage performed April 2003.

Observations made during these site visits are summarized in Table 9.1 and shown in Figure 9.1. Images that captured different distress types are also identified in Table 9.1. Damage types observed at the end of the temporary restoration stage included:

- The joint between the road and the cut opened
- Excessive settlement along the wheel path (further discussion in Section 9.2)

No changes observed in the shape or size of cracks identified during pre-construction damage survey.

The keyhole section established on October 2001 continued to perform well throughout the life of the experiment. The surface of the restored keyhole remained at level with the road profile. The grout surrounding the AC/PCC plug remained intact (no cracking or separation).

<table>
<tr><td colspan="4">Form 1: Damage Survey Form</td></tr>
<tr><td colspan="2">City: Toronto, ON Site: Jarvis Street.</td><td colspan="2">Inspection Dates: Oct 2001,
May 2002,
April 2003</td></tr>
<tr><td rowspan="5">Geometry/Structure
(See Sections 2 and 5)</td><td>ROAD</td><td colspan="2">Utility Cuts</td></tr>
<tr><td></td><td>Trench</td><td>Keyhole</td></tr>
<tr><td>Number of lanes: 4</td><td>Width: 2.532 m</td><td>Diameter: (0.46 m) 18 in.</td></tr>
<tr><td>Lane width: 3.35m</td><td>Length: 3.732 m</td><td></td></tr>
<tr><td>Year of construction: NA</td><td>Date restored:
Temporary: Oct 2001
Permanent: May 2002</td><td>Date restored:
Oct 2001</td></tr>
<tr><td colspan="4">Note: See Damage Survey Map (Figure 9.1) for details including location and orientation of observed damage patterns</td></tr>
</table>

Ref. On Map (Figure 9.1)	**Description**	**Details**
1&2	Theses two long cracks were observed during the distress survey performed before construction. They were sealed and no changes were observed during the May 20002 visit or afterward.	See Figure 9.5
3	The north and south road/cut joints separated at the indicated locations. Openings as wide as 2 mm (0.0787 in.) were observed during the May 2002 visit. The location of joint separation coincided with visible settlement in the trench (See details in Section 9.2). The material used to seal the joint was lost under the action of traffic as a result of shear flow or pullout of the sealant.	See Figures 9.6 and 9.7
Note	During construction related to permanent restoration, the steel roller compacting the lower AC layer (HL8) moved in and out of the cut causing damage at the edge of the cut. Placement of a wood beam eliminated the impact of the steel roller movements	See Figures 9.2 and 9.3.
Keyhole	The keyhole restored October 2001 showed no distress during the inspections performed during the May 2002 and April 2003 visits. The grout remained intact and the surface in level with the road.	See Figure 9.4

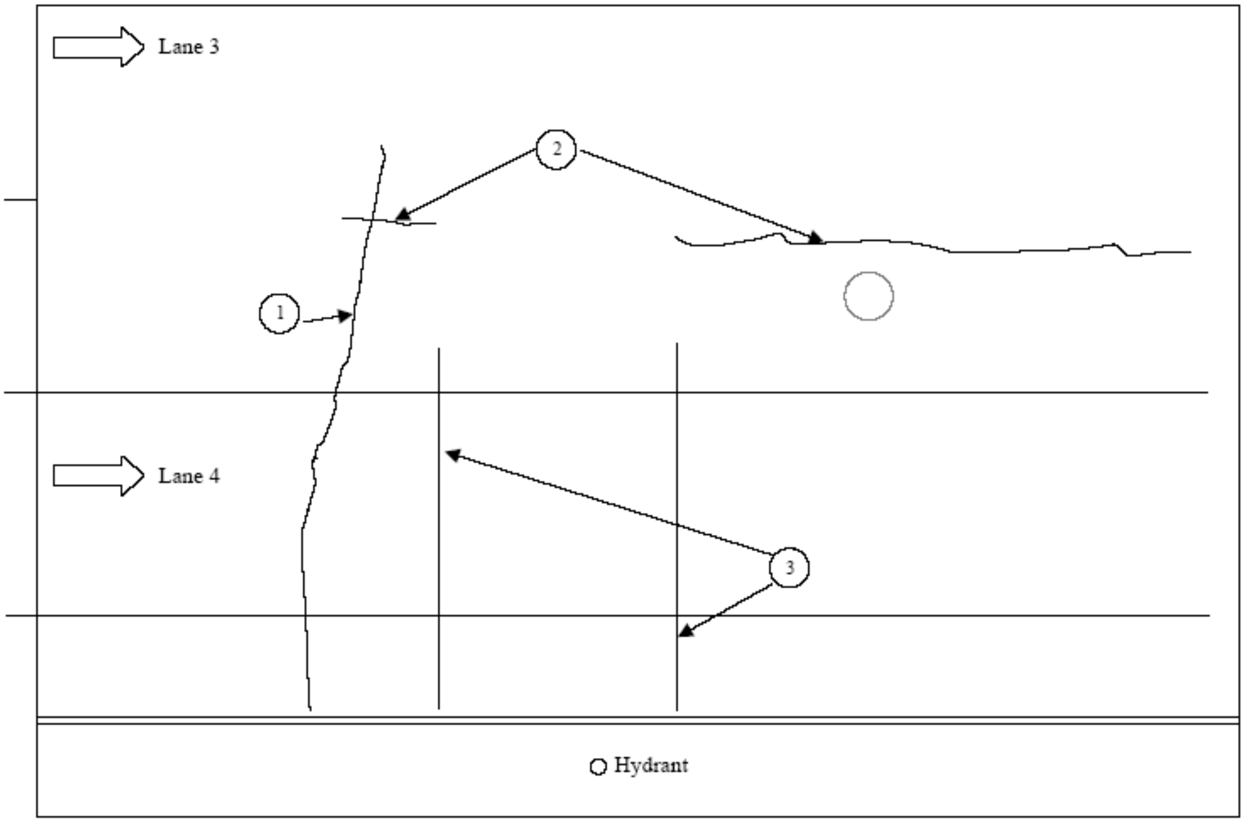


Figure 9.1. Damage survey map

Figure 9.4. Keyhole

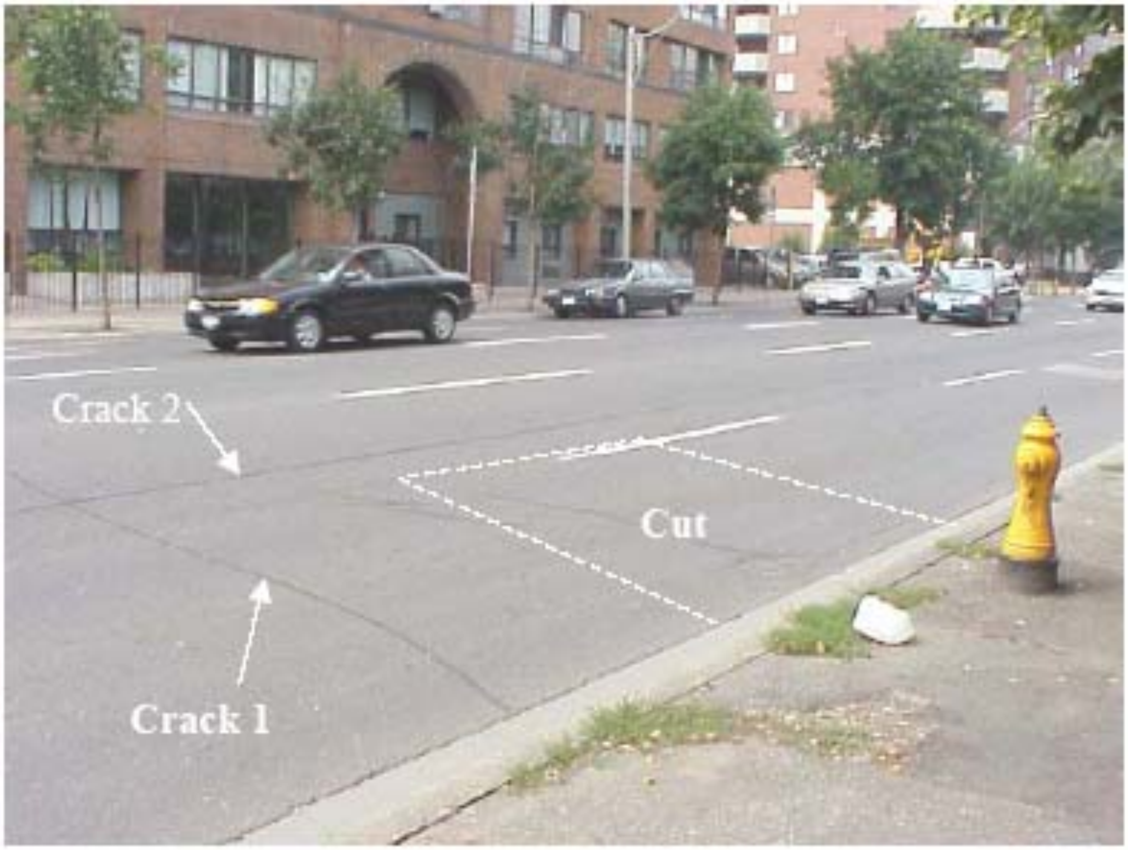


Figure 9.5. Cracks observed before cutting the road

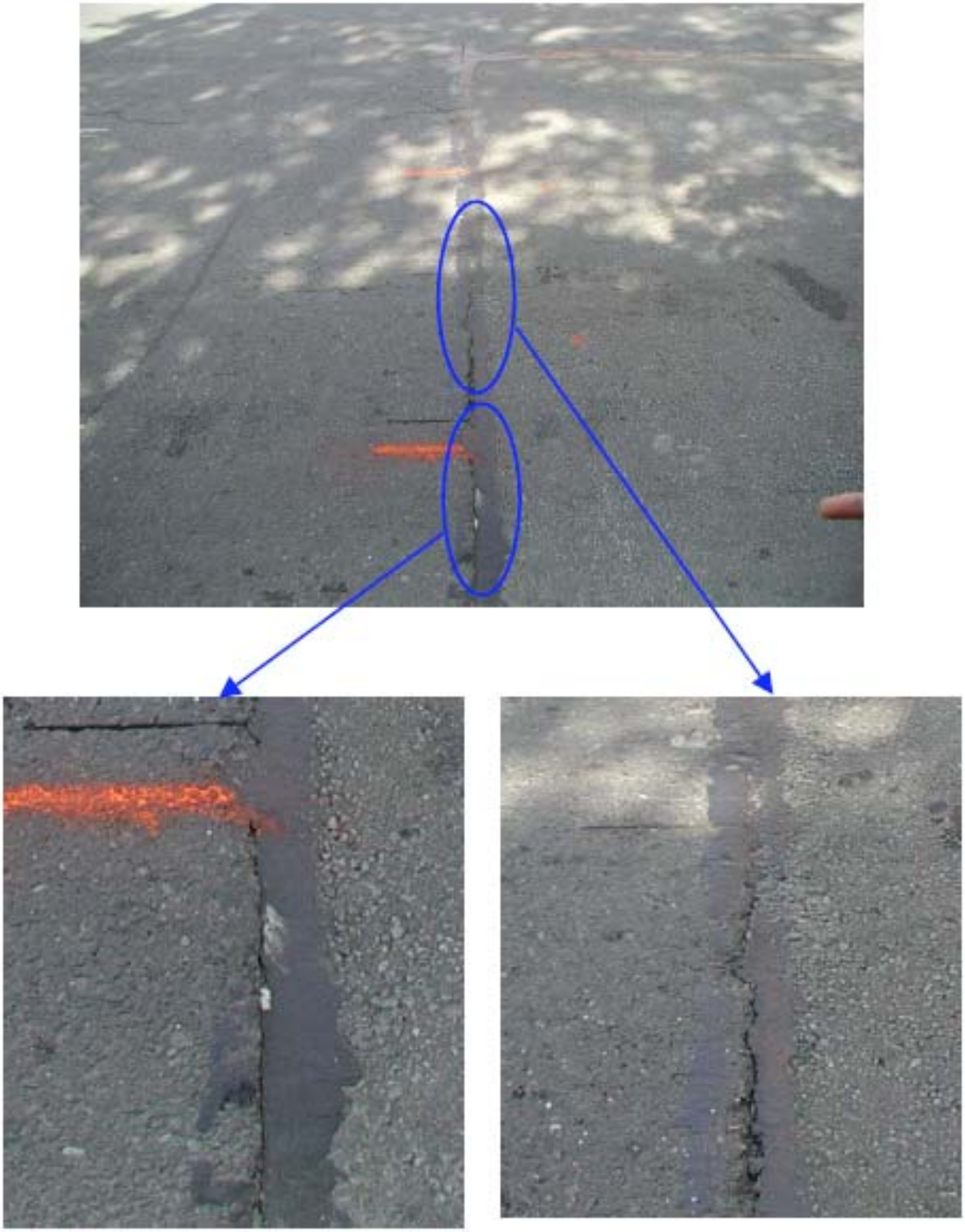


Figure 9.6. Major joint separations along the south edge of the trench

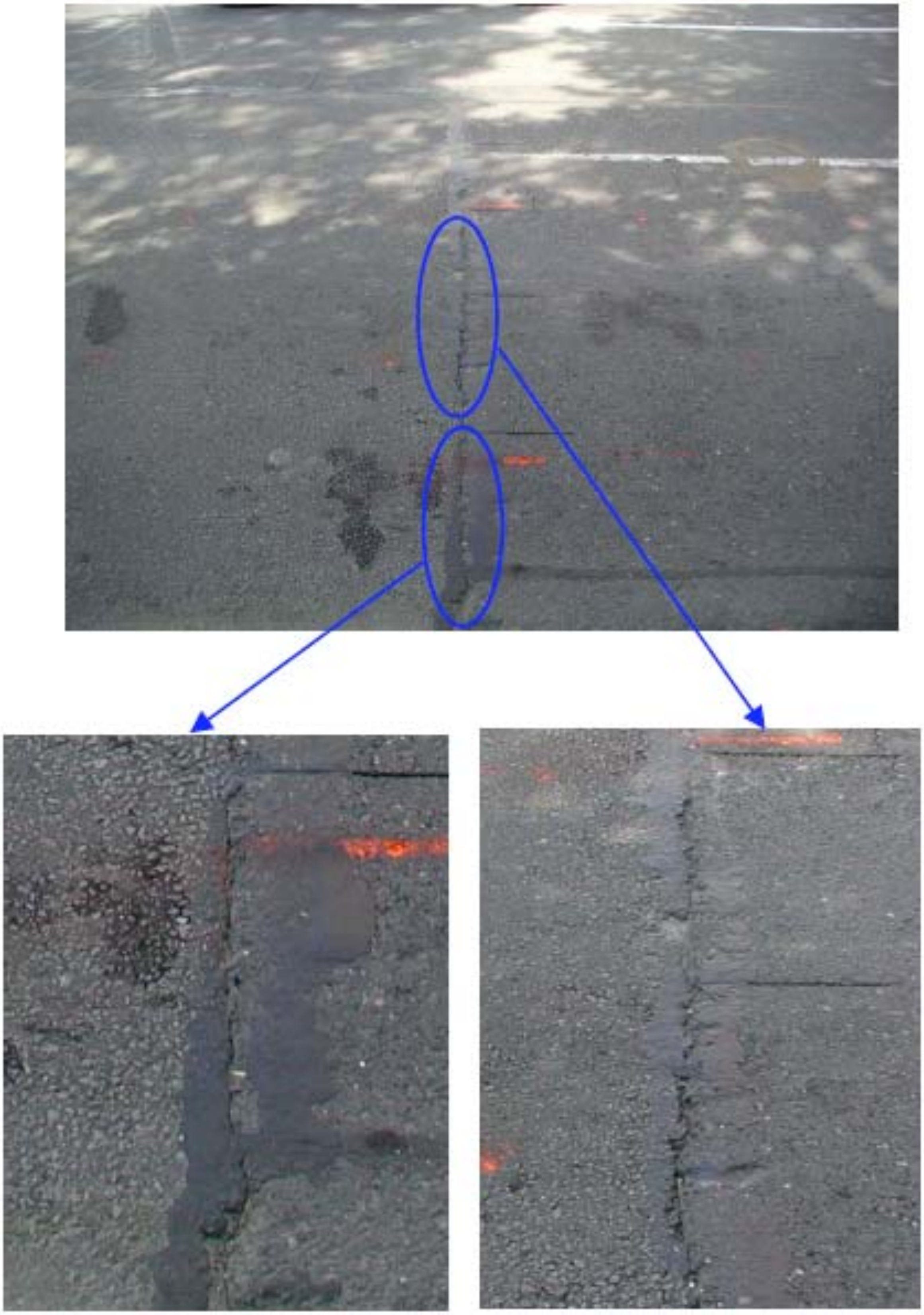


Figure 9.7. Major joint separation along the north edge of the trench

9.2 Profile Survey Data

In addition to visual damage survey performed a number of times by the research team during visits to the Toronto site, the consultant hired by the City of Toronto (JEGEL) conducted profile surveys of the road test section. A total of five surveys were performed. The first general survey work was conducted prior to road cutting. The second and third surveys were performed immediately after temporary restoration (October 2001) and eight months after that (May 2002). The fourth survey was performed immediately after permanent restoration (May 2002) and the fifth was done in April 2003. Discussions in this report treat the temporary and permanent restoration stages as independent operations. The second survey carried out immediately after temporary construction was used as a reference for quantifying the performance of the temporary restoration as if it was permanent; this provided information pertaining to the potential use of flowable fill in a single restoration stage.

9.2.1 Temporary restoration

As mentioned above, surface elevations measured immediately after temporary restoration were used as a reference to determine the performance of the trench in terms of settlement. Settlement along the inner and outer wheel paths of Lane 4 reflected a similar trend as shown in Figure 9.8 and Figure 9.9. The edges of the trench experienced more settlement than the middle of the trench. Furthermore, settlement in the cut edge at which traffic exits the trench (north side) was approximately twice that at entry (14.4 mm, 0.571 in. compared with 7.5 mm, 0.295 in.)

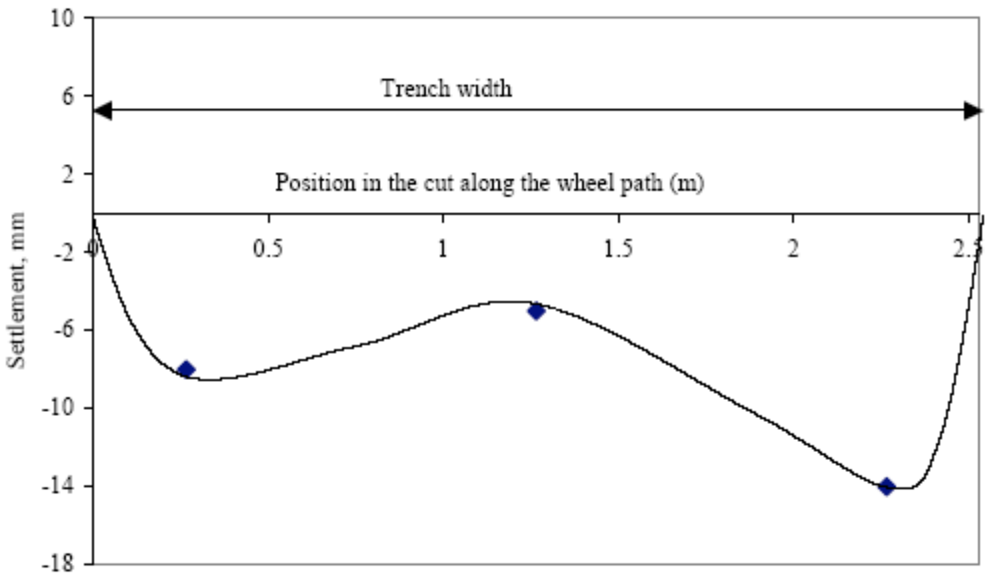


Figure 9.8 Settlement in the trench along IWP – Temporary restoration (1 ft = 0.3048 m, 1 in. = 25.4 mm)

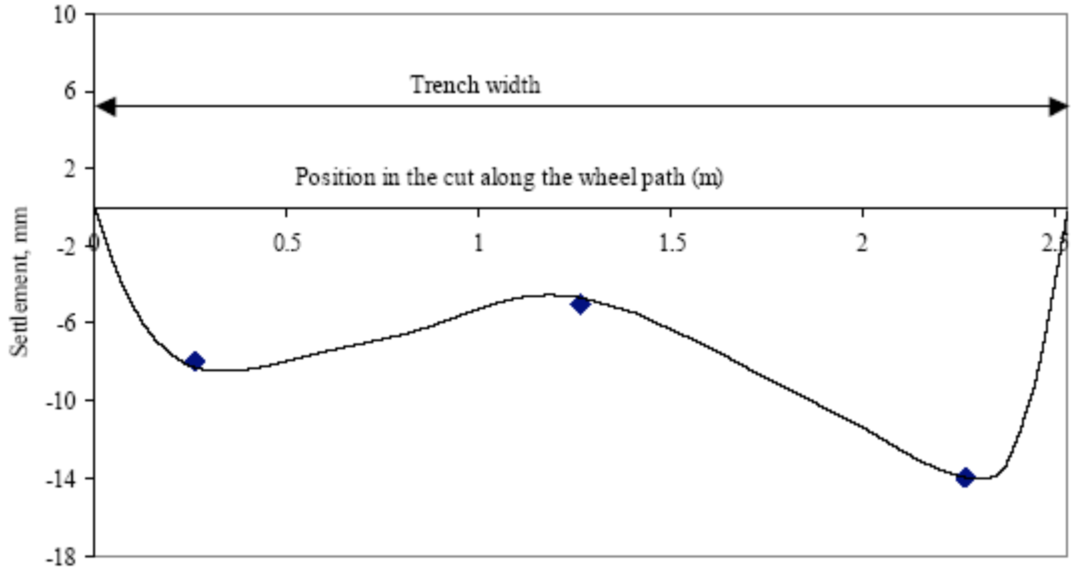


Figure 9.9 Settlement in the trench along OWP – Temporary restoration (1 ft = 0.3048 m, 1 in. = 25.4 mm)

Settlements in the cut, eight months after temporary restoration, established based on surface profile surveys agreed well with those measured by the extensometer. The extensometer, positioned in the sand cover directly below the outer wheel path measured 6mm settlement. Profile survey data showed 8mm settlement at the same location. Analysis of data from these two sources identified the sand layer as the source of the majority of settlement experienced by the cut at the location of measurements (75%). This result suggests that only 2mm deformation may be attributed to f1owable fill and asphalt concrete layers.

9.2.2 Permanent restoration

The road and cut profile established immediately after permanent restoration on May 2002 was used as a reference to trace changes that took place within the first eleven months of service (up to April 2003). In general, the cut profile after permanent restoration showed very little changes. It is clear that after eleven months of service the permanently restored cut suffered negligible damage.

10.0 ANALYSIS

[NOTE: Previous sections of this report that analyzed construction data, sensor data, results of FWD tests, the pilot study and the laboratory investigation not pertinent to Keyhole Technology which were not included in this précis have also been OMITTED from this Analysis except for cursory mention.]

10.1 Unshrinkable Fill

The application of this type of flowable fill, based on concrete low strength material design (CLSM), coupled with a quality system managed by certification of material suppliers and implementation of a restoration strategy based on stage construction, produced a successful utility cut restoration practice.

10.2 Construction Approach

Although not unique to the practice in Toronto, this was the only RUC site where restoration was achieved in two stages, a temporary restoration, followed the next construction season with a permanent restoration. The City strategy seems to be focused on managing directly final restoration involving a number of cuts in order to reduce the cost of enforcing construction quality requirements. Analysis and recommendations offered in this report related to the effectiveness of unshrinkable fill and the restoration process are based on the assumption that the stage construction strategy will be maintained by the City of Toronto. Difference in performance between single and stage construction should be observed when reviewing discussions offered in this section of the report.

Stage construction effectively addressed the behavior of soil-based backfill materials (sand, clay and granular material including unshrinkable fill). Freshly compacted layers constructed with these materials will always deform (settle) and the magnitude depends on compaction quality. In other words, regardless of the achieved relative compaction, there is always a certain amount of deformations that should be expected to accumulate. The maturity period, after which the rate of deformation diminishes substantially, ranges from 6 to 8 months. With exposure of the temporarily restored cut to traffic for that period of time, cuts permanently restored after the maturity period are much less vulnerable to further deformation.

Besides the opportunity to maintain quality and achieve cost effectiveness by grouping a number of restoration jobs in one plan, there are other potential gains from the two-stage construction approach. According to the experience accumulated in Toronto and based on the results of this experiment, permanent restoration after the maturity period could be performed in a cost effective manner. The unbound material (aggregate base) supporting the PCC slab in a restored cut should remain intact for the surface profile to remain at the level of the road. Any deformation in the material supporting the PCC slab will reflect in overall deformation at the cut location. It is not possible to achieve such a situation with freshly placed granular materials. Accordingly, restoration of cuts performed in composite roads commonly involves supporting the PCC on the already stable road base outside the cut. This last option was adopted in the City of Chicago experiment. The use of the T-section configuration at the PCC layer level made it possible in Chicago to establish permanent restoration in a single stage. The practice in Toronto based on stage construction does not require the T -section since the backfill beneath the PCC already stabilized after the maturity period reducing substantially the effort needed to satisfy performance requirements.

Similar to the single restoration approach, the success of the stage construction approach requires maintaining effective quality control during construction to promote good performance. The following are observations made at the Toronto site related to the construction process:

- The PCC curing period allowed was insufficient. Curing not only establishes the solid base needed for effectively placing the AC surface but is also required to sustain critical traffic loading without exposing the vulnerable AC surface to excessive deformations if the weak PCC slab is damaged. A well-cured PCC slab is also needed to limit the magnitude of stresses transferred to underlying backfill layers. The PCC was allowed less than 24 hours for curing, which is less than that needed to achieve adequate flexural strength. Although no adverse effect has been noticed as a result of this action, there is no guarantee that the restored location will continue to perform well in the future. Premature loading of the PCC causes cracking defying the purpose of casting a single continuous slab for effective load distribution capabilities.
- Although designing a pavement thickness commonly includes tolerance for the PCC base and AC surface layers, it is critical to minimize substantial reduction in the thickness of these layers. Construction crew depends on visually matching the existing road structure. As-built plans developed based on surveying measurements performed at the site indicate that at some locations of the restored cut, the PCC base thickness was only 16l mm (6.339 in.) instead of 200mm (7.874 in.), 20% less than design. The quality system should include corrective measures such as increasing thickness requirement in restoration guidelines or adopt a simple measuring tool to be used in preparing the cut for receiving the materials that will satisfy design thickness.
- The use of the T-section configuration at the AC layer level in Toronto is sought to reduce surface water infiltration into the restored cut. However, joint treatment is still needed to a safeguard against moisture effect; mainly weakening the resistance of soil based backfill layers to permanent deformations. Unshrinkable fill will drain surface water properly. However, the performance of the sand cover surrounded by a clayey subgrade material may be influenced by infiltration of surface water. Although there are other sources of moisture (pipe leakage or ground water), there are indications that the sand cover and surrounding clay in the Toronto restored cut were exposed to higher than normal levels of moisture (compared with the keyhole).
- AC compaction temperature is critical for achieving good construction quality. The binder coarse was compacted at a temperature lower than that needed to produce the desired relative compaction level. The mix used was coarse (HL8), which made it more difficult to achieve good compaction. Construction crew gave the surface course more attention and it was compacted at the correct temperature and up to the specified density.
- Similar to other RUC project sites, the road was opened to traffic at a relatively high temperature (60°C), which seems to be due to the rush to clear the road for peak-hour traffic. Measures to delay exposing the AC layer to traffic at such relatively high temperature are needed to avoid immediate and future damage associated with loading the material at a low stiffness state. The immediate damage is in the form of deformation (rutting). Long-term performance will also be influenced by the weakened state of the AC caused by early damage, which in tern will expose the material to further deformation and fatigue.

10.3 Sand Bed/Cover

Buried facilities require protection from critical levels of traffic induced stresses and elements of the environment. The level of protection varies according to the type of facility and its mechanical behavior (pipe material and joint characteristics). The depth of the facility determines the degree of exposure to external stimuli and hence the level of protection needed. Utility companies acquired a great deal of expertise pertaining to the type and level of protection to use, which is outside the scope of this project. However, it is important that the type of protection be maintained without jeopardizing the integrity of the road structure at the location of the cut. Achieving a balance between the two requirements is possible.

In the Toronto experiment, like many other regions, sand was used as bedding and cover to secure the installed connections. It is also common to apply sand in a dry state (to absorbed moisture in the bottom of the cut) and in a single lift regardless of the targeted depth of the sand layer. These two common practices ignore basic requirements for effective compaction needed to produce a well performing structural layer. In the Toronto site, the total depth of the sand bed and cover was 658mm (approximately 2 ft). Although located deep in the cut, 8 kPa pressure reached the sand layer. This may seem as a low level of stress, but actual performance records indicated that the sand layer contributed approximately 75% of total settlement recorded in the location of the restored cut.

Results of laboratory tests performed on samples prepared using sand recovered from the Toronto site support outcome of analysis performed on field data related to the impact of the condition of sand placed in the cut. Laboratory sand samples were compacted to 84% MPD to represent the low relative compaction level that prevailed in the sand layer. Samples that represent the recommended quality were prepared at 92% relative compaction. Results of the MPD test used in this project to characterize soil-based backfill material are shown in Figure 10.3. At the end of test, total deformations accumulating in the sample that replicated the condition that prevailed in the sand layer in the Toronto site were eight times higher than the other sample that represented good compaction quality. The K-value, which depicts the potential for future deformations in the material, also points to the negative impact of low sand density.

Considering the high impact on performance associated with the current treatment of the sand bed/cover, highlighted through the result of the Toronto experiment, there is a need to establish clear guidelines to improve construction practice involving sand. The guidelines should reestablish the need to treat the sand layer as a structural restoration layer. Similar to other backfill layers, sand bed/cover should be placed in thin lifts at optimum moisture content and compacted to above 90% of modified Proctor density. Such action will serve in reducing settlement of restored cuts and protect the buried facility by reducing differential movements that may affect its structural integrity. Not all compaction devices are effective with sand backfill layers. Field trials should be made to evaluate available options to choose one technique or a combination of techniques that will achieve the above proposed quality guideline taking into consideration the prevailing work environment, which differs from one utility type to another.

10.4 Keyhole Cutting and Restoration Technique

Recent advancements made in robotics promoted the development of diagnostic tools and equipment for maintaining facilities and for fitting new devices, which can be performed from the surface through a limited access. Keyholes are currently being used to access buried facilities to perform the intended utility job reducing the need to cut large openings in road. Surface and subsurface data collected from the keyhole established in the Toronto experimental site revealed that the restored keyhole performed well and resulted in no damage to the road.

- The keyhole opening resulting from coring is quite small (18 in., 457 mm, in diameter) compared with the area of a tire print of heavy trucks in contact with the road surface. As a result, low stresses are transmitted to the underlying sections of the restored keyhole.
- Based on basic rules of mechanics, a circular cut shape in the AC is ideal for preventing propagation of cracks into the surrounding road area.
- Effective equipment was developed for cutting and excavation with no potential for causing damage. Cutting is performed by coring and removal of existing road materials is performed by pumping material from inside the keyhole. [vacuum excavation]

- The plug consisting of PCC and AC layers is removed with great care using dedicated equipment and later reinstated at the surface.
- Research conducted by Enbridge Gas Distribution Inc resulted in developing an effective grout for use in the restoration process. The grout is used to attach the PCC/AC plug to the road and for sealing the joint. In the Toronto keyhole section, the grout performed effectively throughout the life of the experiment (September 2001 to April 2003) with no signs of loss of material or separation of the joint.

The combination of keyhole construction technique and unshrinkable fill produced an effective restoration technique that should be encouraged whenever feasible to minimize the need for opening large trenches in the future.

11.0 CONCLUSIONS AND RECOMMENDATIONS

The experiment in Toronto highlighted the significance of a two-stage construction process where the majority of deformations accumulated during a temporary stage. Permanent restoration follows and the cut performs well with all serious levels of deformations absorbed during the maturity period which represent the service life of the temporarily restored cut.

The backfill material prepared according to the specifications of the city of Toronto for unshrinkable fill produced the desirable characteristics for a restoration material, which include stability in the form of high resistance to deformation. Unshrinkable fill achieved this good perfom1ance because of its flow properties that facilitated filling hard to reach places in the cut without the need for a tedious compaction process. Adequate drainage of the mix facilitated the consolidation of the material into a structurally sound layer.

The following are recommendations based on the result of a number of investigations performed at Toronto site.

- New measures for evaluating flow properties and strength of un shrinkable fill are needed to replace those included in the current specifications. The manufacturer may perform these tests under the current certification system, especially if the new test proved to be more elaborate or expensive.
- Extending PCC curing period is necessary to achieve adequate flexural strength that can withstand construction activities (asphalt compaction) and sustain traffic loading. Guidelines developed in the RUC project recommend achieving 24.5 MPa (3500 psi) before loading the PCC base. Utilities may resort to the use of special cement types or admixtures to shorten the curing period.
- The sand bed/cover was responsible for 75% of the settlement recorded during the temporary restoration stage in Toronto. It is reconm1ended that the sand layer be treated as a structural layer with guidelines issued for controlling the quality of construction.
- The use of conventional steel rollers is expected to produce good AC compaction. However, rolling in and out of the cut when compacting lower layers of the AC (binder course) may damage the road close to the edge of the cut. It is recommended that special measures be introduced to reduce the impact of such heavy equipment. The fragility of the AC layer will cause such damage to progress further in the future affecting a larger section of the road.
- Opening the road to traffic at an elevated AC temperature (higher than 40°C) and low stiffness causes the AC layer to deform. The AC layer will then continue to deform at a rapid rate because of the existing state of damage associated with premature opening of the road.
- Future research is needed to investigate the benefit of compacting unshrinkable fill in the field. Laboratory prepared samples, compacted after 24 hours of curing (draining the water out of the mix), were tested at NRC. Results of the mechanical tests revealed that compaction improved the resistance of the material to permanent deformation. Compaction is expected to break weakly bonded particles forming a denser layer to avoid the occurrence of such breakage under traffic loading.
- The Toronto experiment showed that the keyhole cutting and restoration technique is effective in limiting damage to the road and its application should be encouraged.