Road Utility Cuts and Repairs – Applying Keyhole Technology

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ABSTRACT

In the early 1990s a major gas utility company in Ontario began the development of keyhole technology using long-handled tools to allow operations such as cast iron pipe leak repairs, service reconnections and the installation of cathodic protection, to be undertaken through a 450 mm diameter core hole in the pavement. This avoided the need for conventional open road cuts and reinstatement. To further enhance the benefits of this technology, a program of laboratory testing and field trials were undertaken in the City of Toronto (City) to allow efficient core removal, followed by vacuum excavation and finally a system that would allow the removed core to be used to permanently reinstate the pavement. Laboratory trials were undertaken on 20 potential bonding agents to identify a product that would be fast-setting with rapid strength gain so that repaired pavements could be opened to traffic in less than an hour. The cementitious bonding compound which was specially designed for the process was used on a number of field trials in the City. The reinstated cores were monitored for performance over a seven year period in sections of composite pavement. Based on the results of these trials, the procedure was approved for use in the City as a permanent utility cut repair. This keyhole technology and core reinstatement technology is now used widely throughout North America by gas utility companies. The cost savings are significant. In 2010, one utility company undertook some 4,500 keyhole cores and reinstatements, with an estimated cost savings of over $4 million when compared to conventional open cut procedures. In addition, with the reduction in materials, equipment time, and less traffic disruption, the sustainability benefits of this technology are significant. In some instances, the road can be re-opened to traffic within 30 minutes of the repair. This paper will review the development of this technology, other areas of application, and the benefits it offers in terms of providing a faster, better and more sustainable method for utility repair and maintenance.

INTRODUCTION

Utility cuts and their repair represent a continual challenge to urban municipalities. Public rights of way are the natural choice of utility companies and agencies to locate underground services. These include wastewater sewers, watermains, electrical cables and conduits, telecommunications and cable television lines, and gas lines. From time to time these need to be accessed for repair, upgrading, routine maintenance and for making new connections. All these operations require road cuts for access. Frequently this requires lane closures and occasionally, entire road closures. The most problematic related component is the subsequent restoration of the road pavement.

In June of 1992, Golder Associates Ltd. (Golder) was retained by The Consumers' Gas Company Ltd. (Consumers) to provide consulting and testing services in the development of a new pavement reinstatement system following gas utility line maintenance. At that time in the City they were using conventional excavation and reinstatement practices. However, the maintenance cut restoration was only regarded as ‘temporary’ by the City. Because of this, in every case, City forces would enlarge the road cut repair area and reconstruct the pavement in accordance with their standards. This resulted in every maintenance repair being performed twice with the associated costs (which were billed to the utility company) and disruption to traffic operations. The plan that was being developed by Consumers was to explore an alternative method for exposing the gas utility involving rotary cutting of the pavement followed by vacuum extraction of the backfill. While this would significantly improve the efficiency of gas service repairs, an added objective was to explore whether the removed pavement core could be reinstated in such a way that it would constitute a permanent pavement repair in the eyes of the City.

After studying the available options, it was considered that reinstating the pavement core by grouting the annular space between the core and the pavement was a necessary element in the development of the pavement reinstatement system. Golder evaluated several different types of grout and recommended a product for use in 1993 field trials [1].

A number of field trials were carried out in the Fall of 1993 with the recommended grout and grout dispensing equipment developed by Consumers' Gas Technology Transfer Division. These trials indicated that the concept of reusing the pavement core was feasible and that a permanent repair by reinstating the pavement core was possible. The field trials also indicated that some modifications were necessary to streamline the operation, improve the safety of the field personnel and maximize the economic benefits to Consumers. For the 1994 field trials, a new mechanical hoist was manufactured. The hoist facilitates lifting the core, temporarily moving the core away from the work area until the completion of the repair, and finally replacing the core prior to grouting. In addition, a new grout was also evaluated. The 1995 field trials evaluated a newly manufactured grout dispensing unit. A new method of crack sealing was also evaluated.

This paper briefly describes the early development of the keyhole technology and describes 10-year field trials to get acceptance for the reinstatement procedure. The paper also describes the development of the technology in terms of state-of-the-art best practice and specification requirements over the past 10 years in North America.

PROBLEMS WITH CONVENTIONAL UTILITY CUTS AND REPAIRS

Problems associated with poor performance of utility cut repairs are faced by every municipality. The conventional method for accessing buried utilities for repair and maintenance is in the form of a cut through the roadway and exposure of the buried utility by way of a trench or rectangular cut hole. This disturbs the various pavement structural layers, i.e. asphalt or concrete, granular base and subbase and underlying subgrade. In addition, a zone beyond the dimensions of the cut is also affected. This ‘zone of influence’ has been shown to be 1 m or more [2] and presents a significant challenge in achieving a proper restoration. The amount of bulging, sloughing and undermining of the pavement structure may be minor with shallow excavations, but becomes significant with deeper cuts beyond about 1 m deep. This ‘zone of influence’ cannot be easily restored and leads to the frequent problem of a zone surrounding the actual cut patch performing worse than the actual patch itself.

The methods of excavation and the way in which the pavement cut is undertaken and the excavation walls supported have an impact on the extent of the disturbance. In theory, keeping the size of the excavation to a minimum should reduce the impact on the pavement; however, the downside of too small a cut is that it is difficult to restore due to the inability to use proper compaction and paving equipment.

Undertaking good quality restoration of a road utility cut is difficult and time consuming. This is the primary reason that most utility cut repairs perform poorly. Most municipalities in North America require the use of high quality granular backfill or lean mix concrete (controlled low strength material) for utility cut repair. However, even with the use of good granular, frequently it is placed in lift thicknesses that prevent adequate compaction and the compaction is performed with plate tampers or ‘Jumping Jacks’ with inadequate effort expended. Further, frequently, the excavated soil, irrespective of moisture condition is used as backfill to avoid the cost of removal and disposal. A study by the Iowa Highway Research Board [3] found that backfill lift thicknesses were frequently 0.6 to 1.2 m, that compaction was performed sporadically using a vibrating plate attached to a backhoe, and that no quality control of the work was performed.

Studies in many cities have shown that differential settlement occurs which has the effect of reducing the life of the pavement above and around utility cuts. The main deterioration modes are:

- Differential settlement due to poor compaction, allowing water to pond and leading to additional deterioration;
- Differential frost heave leading to high points or leaving a patch high to allow for future settlement and allowing the patch to be damaged during snow plow operations;
- Settlement of the zone around the patch ultimately leading to failure of the patch itself; and/or
- Ravelling of the joints between patch and original pavement.

These types of localized pavement distortion can become a traffic hazard, especially for cyclists and requires early maintenance. Frequently, cracks occur around patches thus allowing moisture to infiltrate into a pavement and cause accelerated deterioration. Studies [4] have shown that the effective reduction in pavement life of a repaired utility cut can be up to 50 percent. A study in San Francisco [2] demonstrated that the Pavement Condition Rating (PCR) was reduced from 85 to 64 for pavements less than 5 years old with 10 or more utility cuts (Figure 1).

There has been a lot of work done on developing better methods and best practices for utility cut restoration [3, 5, and 6]. Some of these best practices include good compaction of all layers and the use of straight-sided cut repairs instead of cut-back of 'T' section repairs. Some municipalities (e.g. City of Toronto) require the use of 'non-shrink fill' for all utility cut repairs. However, despite the knowledge being available as to 'best practice', these techniques are difficult to enforce and monitor, with the result of poorly performing cut repairs being the norm, rather than the exception.

In summary, utility cut restoration, especially when poorly performed, results in a reduced pavement serviceable life, increased maintenance costs, can represent a traffic hazard and leads to poor ride quality. The negative impact of utility cuts can be reduced by enforcing appropriate standards and specifications and implementing some form of quality control on the works performed.

In addition, the encouragement of more innovative road excavation and restoration technologies, as described in this paper can also reduce long term impacts on our urban road network condition. In 2009 it was reported that 3.6 million pavement cut permits were issued at the municipal level across North America [7] to facilitate the repair or installation of infrastructure. While these permits also cover extensive trenching and other large open pit projects, it is estimated that between 20 and 25 per cent, or approximately 800,000, are of the smaller utility cut variety for works that could be performed through an opening no larger than about 0.9 m square.

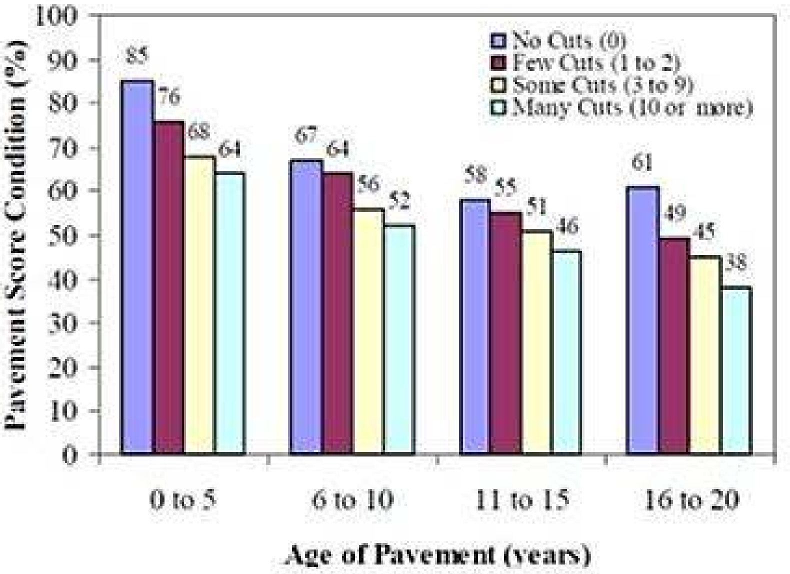

Figure 1 - Utility cut effects on pavement condition [2]

ALTERNATIVE APPROACH TO GAS SERVICE REPAIR

The main objective of the program originally initiated by Consumers in the early 90s was to develop a more cost-effective and streamlined approach for performing routine maintenance activities on buried gas utilities beneath city streets. The main principles to be followed were as follows:

- The road opening was to be as small as possible;
- The restoration was to be regarded as a permanent repair with a quality equal to or greater than the original pavement; and
- The removed section of pavement was to be used in the reinstatement, if possible.

Based on these requirements, Consumers set about perfecting their special tools to undertake repair works effectively from road level, without the need for workers to enter a trench. The supporting tasks were as follows:

- Adapt a truck-mounted coring machine to advance the pavement hole;
- Develop a mechanism to allow the pavement core to be lifted and removed from the hole;
- Develop a process to allow the core to be reinstated in the hole after repair works; and
- Identify or develop a bonding agent or grout product that would allow the core to be permanently reinstated in the pavement.

There were some very specific requirements for the bonding material. These are described as follows:

- It needed to be easy to mix on site;
- It needed to be workable and flowable for at least 15 minutes to allow it to be installed;
- It needed to attain a sufficient compressive and bonding strength to withstand long-term commercial vehicle loading;
- It needed to have low shrinkage characteristics;
- It needed to attain sufficient strength in a period of 30 to 45 minutes to permit the road to be re-opened to traffic; and
- It needed to have a wide temperature range of operation.

With respect to the bonding agent, a plan was developed to evaluate a wide range of commercially available products in the laboratory with respect to the properties listed above. Golder would then identify a shortlist of about 5 products for initial field trials. Further field trials would be carried out on the selected product. It was also recognized that the product eventually selected would need modification to customize its properties for use in a production setting with diverse weather conditions.

LABORATORY TESTING PROGRAM

Phase 1 Testing

Initially, some 15 different commercially available grouts and bonding compounds were evaluated on a preliminary basis. The workability, early strength gain and ease of site mixing were used to shortlist five products for laboratory testing. The bonding compounds were evaluated based on compressive strength at various ages (ASTM C109) and using a specially devised punching shear laboratory test that was designed to simulate to some degree the loading conditions in the field. The test arrangement for this laboratory test is illustrated in Figure 2.

A nominal 100 mm diameter core was cut from concrete slabs 250 mm square by 100 mm thick. The slabs were made from 30 MPa concrete. The cores were bonded back in place using the bonding compound product selected for laboratory testing. The load needed to dislodge the core was measured at various ages. From this study, an epoxy-type bonding compound was initially selected. Based on further discussions with the client, it was decided that this product would be impractical for large-scale use in the field and had some health-related concerns for field crews.

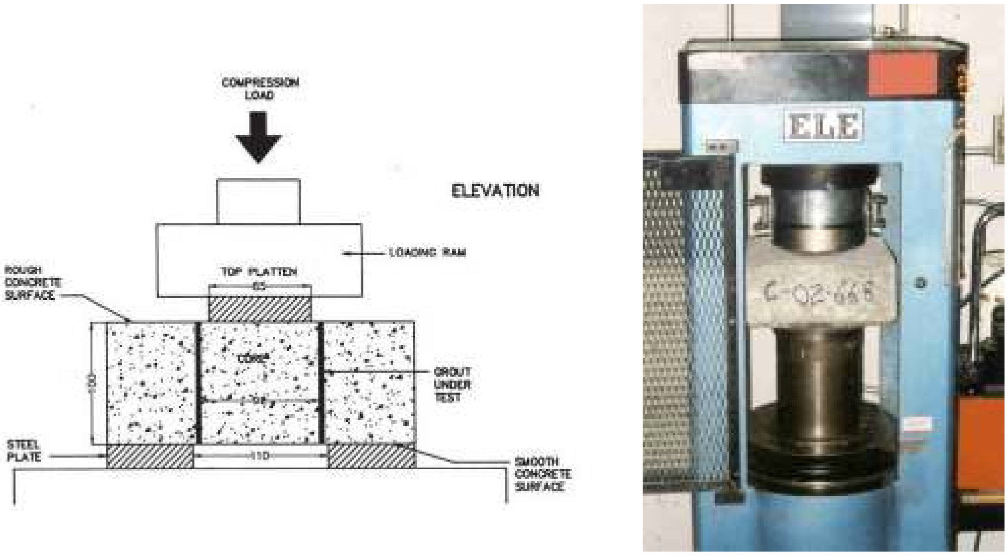

Figure 2 – Test set-up for simulated keyhole testing

Phase 2 Testing

A Phase 2 laboratory study was then initiated using two epoxy grouts and a cementitious-based grout that had only recently come on the market. The results indicated that out of the three grouts studied, only the cementitious product developed adequate strength at early ages (minimum of 30 kN within four hours). The load to dislodge the grouted core was more than 40 kN after only 1.5 hours. The load to failure reached a maximum of 145 kN after 24 hours. A slight reduction in the failure load was noticed at later ages. However, the ultimate load required for failure was much higher than the 30 kN load identified as an appropriate load criteria during the Phase I study. Based on the results of this test, the cementitious fast-setting grout was selected as the best suited for Consumers' needs.

Phase 3 Testing

To improve the overall performance of the product, the mix was reformulated and patented as Utilibond. The main focus with these improvements was to achieve good workability followed by rapid set. It was critical for the efficiency of the keyhole technology that a reinstated core could be opened to traffic within 30 minutes of repair. A third phase of laboratory testing was undertaken and focused on the performance of the improved product. The initial test was to determine the compressive strength of the compound according to ASTM C109. The tests were performed at various ages and at two temperatures, 23°C and 30°C. From the Phase 2 testing the preferred bonding material reached a peak compressive strength of about 30 MPa at an age of about four hours and then little further strength gain was recorded. With the improved formulation, strengths of 35 MPa were achieved at five hours and strengths at 24 hours reached 46 MPa as shown on Figure 3.

As in the previous phases of the laboratory evaluation, the punching shear laboratory tests, or push-out tests, were used to simulate loading conditions in the field. The cores were bonded back in place using the bonding agent being assessed. The test arrangement was designed to determine the load needed to fail the shear bond at the core/core hole interface and dislodge the core. The failure load was recorded over a range of curing times from 1.5 to 48 hours. In many instances, especially at higher failure loads, the concrete test slabs cracked as the core was punched through, indicating that the bond was stronger than the overall concrete substrate.

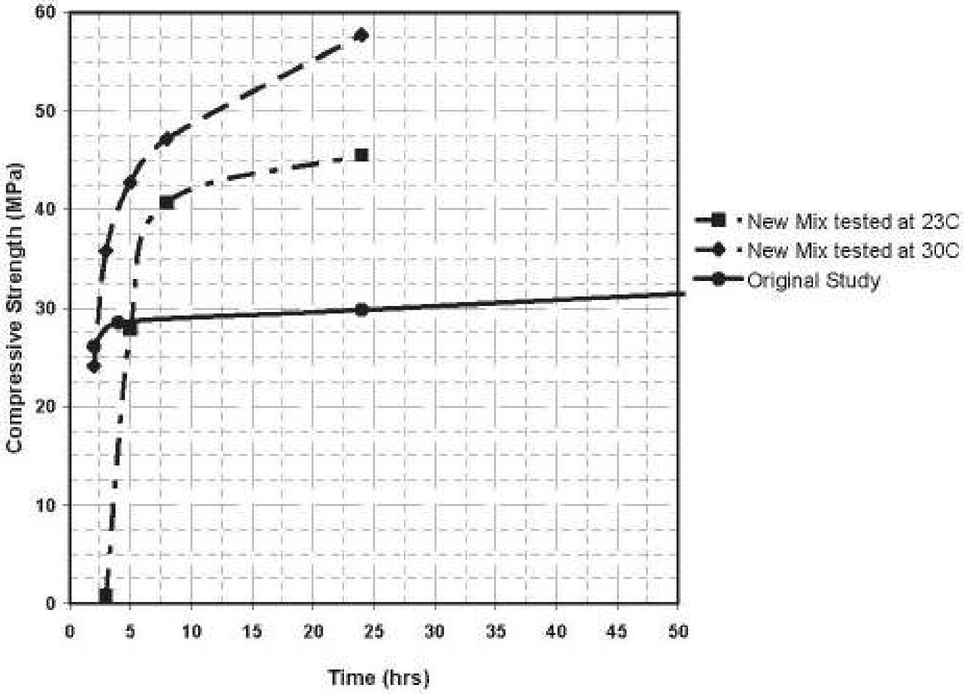

Figure 3 – Cube strength of the Utilibond product

Figure 4 – Core sample being re-instated into slab for push-out testing

In order to evaluate the results of this testing, it was necessary to relate it to the equivalent loads needed to resist punching shear failure under live traffic. The loads in the laboratory were compared to the loads expected in the field by comparing the bonded surface area of a re-instated keyhole core in the field to that tested in the laboratory. Based on this conversion, the loads were compared to the AASHTO H-25 loading which is defined as 178 kN. Typically, this load is carried by four tires resulting in a tire loading of 44.5 kN per tire. Given the geometry of the pavement core (450 mm diameter) the worst case loading is considered to occur when one tire bears directly on the core. In other configurations, part of the tire would bear on the original pavement and so reduce the load transferred to the actual joint. Pro-rating the maximum tire loading on a 450 mm by 200 mm thick keyhole core to a load on a 95 mm diameter by 100 mm thick core in the laboratory, the critical load for the laboratory test set-up is 4.5 kN.

The failure loads for the Phase 3 testing are shown in Figure 5 and indicates that the Utilibond product reached the necessary load capacity to support traffic within one to two hours depending on temperature. It is interesting to note that the load decreases in the short term which is attributed to the initial high heat of hydration which puts the Utilibond annulus in compression resulting in higher support capacity. It should also be noted that in some instances, when the failure load exceeded 100 kN, the substrate slab fractured before the bond sheared and thus the results plotted do not represent the failure load of the bond, in those instances.

For the purposes of comparison, the loads have been normalized by dividing them by the calculated critical load to determine a factor of safety. The Utilibond achieved a factor of safety of five within 2.5 hours at 23^{o}C and 15 within five hours (Figure 6).

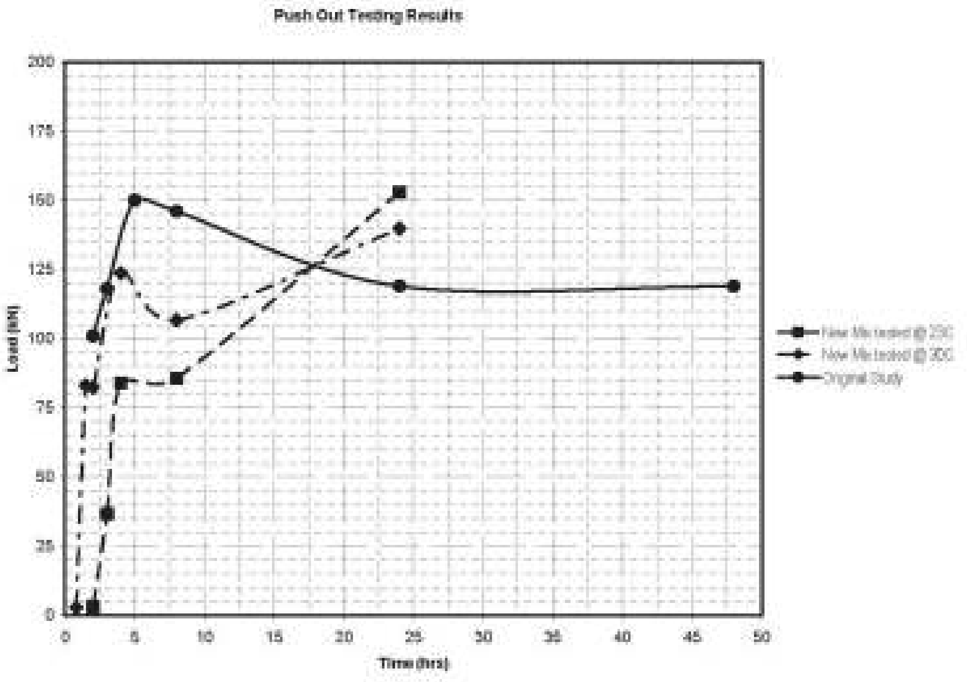

Figure 5 – Results of push-out testing

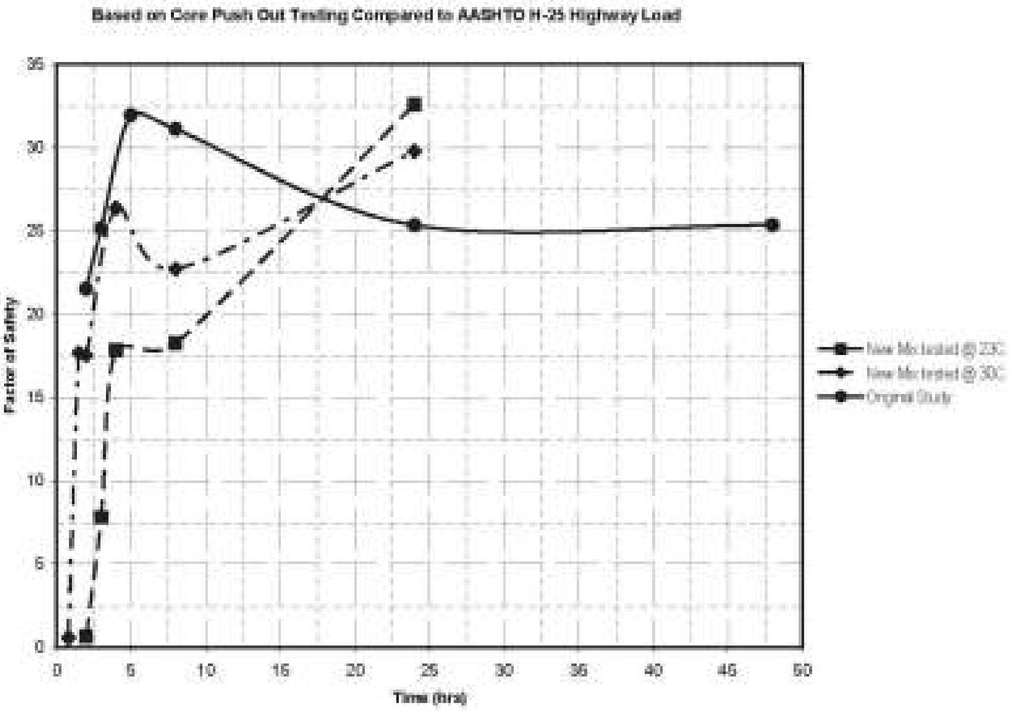

Figure 6 – Factor of Safety vs. AASHTO H-25 Loading

FIELD TRIALS

The reinstatement field trial was conducted in November 1994, at the intersection of Cotton Avenue and Danforth Road in the City of Toronto (then the City of Scarborough). The weather at the time of the trial was cloudy and windy and the expected high temperature for the day was 4°C. The temperature at the start of the repair operation was about –2°C.

As expected, the pavement structure consisted of about 75 mm of asphalt over about 250 mm of concrete base. The coring proceeded well although during the process the asphalt layer debonded from the concrete. To increase the bond between the bonding agent and the pavement core, the walls of the core hole and the pavement core were washed with pressurised water to remove any dust or other deleterious material. The core hole was vacuumed to remove any loose material and ponded water and the walls of the core hole and the pavement core dried with a towel to remove excess moisture from the surface. A layer of pea gravel was placed at the bottom of the core hole. The concrete pavement core was lifted with the hoist and placed in the core hole on top of the pea gravel. With the hoist still carrying the weight of the core, the core was gently rotated back and forth to seat it well and to lightly compact the pea gravel. The core was positioned so as to leave a consistent annulus of about 15 mm between the core and the walls of the core hole. The plug lifter was disengaged from the core and the hoist moved away from the repair area. The concrete portion of the core was held in place by four long screwdrivers wedged into the annular space.

The bonding agent was mixed on site and a dispensing hose inserted into the central hole in the core. A slight pressure was applied to initiate and maintain the flow of grout through the hose and around the walls of the core. The grout holding unit was designed to hold sufficient grout for a 450 mm thick pavement with a 15 mm annular space between the core and the core hole. The time to clean the core hole and pavement core, place the pea gravel and orient the core in the core hole took about 15 minutes. The process of batching, mixing and injecting the grout took another 15 to 20 minutes.

The grout reached adequate strength about two hours after the start of mixing. The asphalt surface was reinstated with cold patch and the roadway was opened to traffic 30 minutes later.

This trial was conducted to evaluate the performance of the hoist, the new grout cement, the mixing and dispensing units for the grout, under field conditions.

SECOND FIELD TRIAL

A second field trial was scheduled for December 1994. The location for the second field trial was a bus bay situated opposite 538 Danforth Road in the City of Scarborough (now City of Toronto). The expected high temperature for the day was 10°C. The Consumers' repair crew carried out the actual repair work at this location the previous day using the keyhole repair technology. At the completion of the repair, the core hole had been temporarily filled with cold patch asphalt. The pavement core was saved for use in the field trial scheduled for the next day.

The cold patch was removed from the hole and the sides of the core hole and the pavement core were washed with pressurised water. The core comprised about 100 mm of asphalt overlying about 200 mm of concrete. Material from the bottom of the core hole was removed to a depth of about 325 mm from the pavement surface and all loose soil and ponded water vacuumed from the hole. A layer of pea gravel about 30 mm in thickness was placed at the bottom of the core hole. The composite (concrete and asphalt) pavement core was lifted with the hoist and placed in the core hole on top of the pea gravel. With the hoist still carrying the weight of the core, the core was gently rotated back and forth to seat it well and lightly compact the pea gravel. As the level of the core was beneath that of the pavement surface, the core was lifted and additional pea gravel was added to the bottom of the hole. The seating operation was repeated until the top surface of the core was flush with the surrounding asphalt pavement surface. The formed steel spacers were wedged into the annular space at four locations around the perimeter to maintain a more or less even clearance of 12 to 15 mm between the core and the walls of the core hole. At the completion of the seating operation, the plug lifter was disengaged from the core and the hoist moved away from the repair area.

Figure 7 – Final seating of the keyhole core into the pavement

The cementitious grout product was mixed with water in a pail for about two minutes using a mixing paddle. The grout was placed in the holding bowl and the dispensing hose inserted into the central hole in the core. A slight pressure (less than 14 kPa) was applied to initiate and maintain the flow of grout through the hose and around the walls of the core. Once the grout level reached a depth of about 50 mm from the top of the pavement surface, the supply of grout was shut off by closing the ball valve located between the grout holding unit and the dispensing hose. A total of about 19 kg of grout was used to carry out the repair.

The time to carry out the repair, including cleaning of the core and core hole, was about 30 minutes. After allowing about 1.5 hours for the grout to set, the dispensing cone was preheated with a propane torch and filled with the hot crack sealant. The top 25 to 30 mm of the annular space around the core and the top of the central hole was filled with the sealant. The sealant was dusted with cement powder to reduce pick up by traffic.

The road was opened to traffic about two hours after starting the reinstatement procedures. The improvements made to the core reinstating operation considerably reduced the time necessary to complete the repairs. A subsequent modification adopted was to eliminate the grout tube and to pour the bonding agent directly into the hole on top of the pea gravel. The core is inserted and agitated on top of the material so that the weight of the core and gentle hand pressure forces the bonding compound up through the kerf and onto the road surface, completely filling the kerf and encapsulating the core.

LONG-TERM TORONTO FIELD STUDY

Consumers began using the keyhole technique for service maintenance and repair on a trial basis in the City from 1991 to 1994 and for the majority of the repairs since that time. Over the period up to about 2002, more than 3000 reinstatements using the rotary cutter and bonding process were made in sidewalks and city streets, all without any reported failures. Many of the reinstatements were made in major arterial routes with high traffic volumes (Average Annual Daily Traffic (AADT) in excess of 20,000 vehicles). As most of the arterial roads are also bus routes for the Toronto Transit Commission (TTC), the pavement loadings are frequently very high.

One of those bus route locations was at 720 Kennedy Road where an excavation, repair and core reinstatement was undertaken in August 1995. Kennedy Road (Figure 8) is a major arterial road in the City with four lanes of traffic and an AADT in excess of 10,000 vehicles in each direction. It is also a major bus route for the TTC with an average of 380 southbound bus trips per week.

The centre of the 450 mm diameter keyhole excavation and reinstatement is positioned one metre from the edge of the pavement, directly in the outside wheel path of the curb or bus lane.

Two weeks after the reinstatement, the site was revisited and the core restoration inspected. Figure 10 and Figure 11 show the appearance of the core after sustaining two weeks of traffic comprising approximately 70,000 vehicles, including 760 bus passes.

In September 1995, about one month after the reinstatement, the site was again revisited and two vertical satellite core samples were taken through the repaired joint from opposite sides of the 450 mm diameter core. The photograph of the cores (Figure 12) shows the light grey line representing the bonding agent.

Figure 8 - View of coring rig at 720 Kennedy Road in 1995

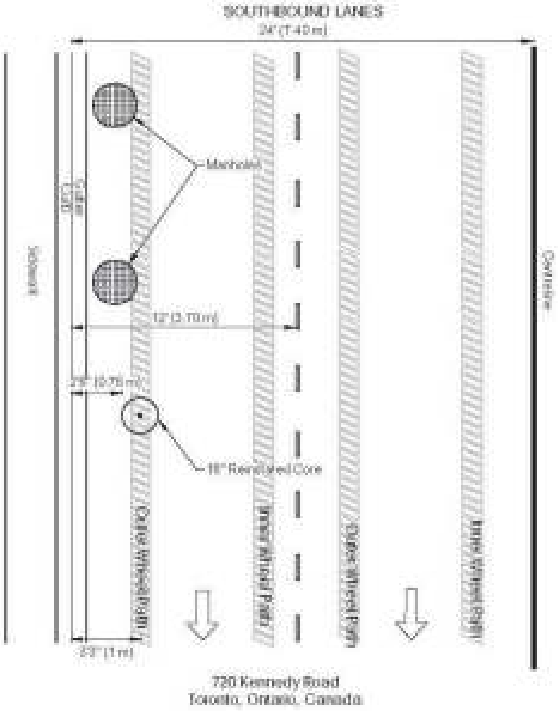

Figure 9 – Schematic of the keyhole repair on Kennedy Road

Figure 10 – View of reinstatement two weeks after installation

Figure 11 – Close-up view of reinstatement two weeks after installation

Figure 11 also confirms an excellent continuous bond within the asphalt surface layer. Crack sealing compound had been used around the surface joint. What was also encouraging was the complete infilling of the voids in the pea gravel bedding showing complete contact between the base of the core and the supporting stabilized pea gravel.

Four years later in October 1999, the photographs shown on Figure 13 and Figure 14 were taken and confirmed no displacement of the reinstated core and no associated degradation of the pavement surface.

Figure 12 – View of satellite cores taken one month after installation

Figure 13 – Kennedy Road four years after reinstatement

Figure 14 – Close-up view of core on Kennedy Road four years after reinstatement

The core reinstatement was again inspected in December 2002, some seven years and four months after the reinstatement.

Figure 15 – Kennedy Road Keyhole Core, over seven years after reinstatement (Dec. 2002)

Figure 16 – Close-up view of Kennedy Road test core (Dec. 2002)

By December 2002, it was estimated that the reinstated keyhole core had withstood more than 145,000 transit buses and more than 13 million commercial and other vehicle passes.

In April 2002, the City approved the Enbridge Consumers Gas keyhole reinstatement process as a permanent repair for composite pavements (asphalt over concrete base).

CURRENT KEYHOLE TECHNOLOGY PROCEDURE

The current methodology for applying keyhole technology to utility maintenance or inspection has evolved over the past 15 years. The current process is described below,

The desired core location is marked on the pavement. Because the core will be preserved for reinstatement, it is important to mark its orientation in the pavement before coring. For best reinstatement results, the same core should be reinstated in the original hole with the original orientation.

A truck-mounted rotary cutting unit or drill is used to advance the access hole through the pavement. The diamond core barrel used has been specifically designed for the purpose. It incorporates two concentric core barrels. The outer one is generally 460 mm in diameter and the inner one about 35 mm in diameter. This inner smaller core barrel provides a pilot hole. The coring is performed with a truck-mounted rig that is capable of adjustment in both planes to ensure that the core is accurately cut vertically, rather than perpendicular to the pavement surface. This provides more uniform reinstatement and avoids damage to the core and pavement. The core is extended through the full thickness of the pavement bound layers. The standard core cutter can penetrate a depth of 560 mm. This can include asphalt, concrete or composite asphalt over concrete. In asphalt pavements, it is recommended that reinstatement should not be undertaken with an asphalt thickness of less than 100 mm.

The cores are heavy and removal needs to be executed carefully to avoid damage. A specially designed core puller has been developed for this purpose. This devise is inserted into the pilot hole and has a rubber stopper at the bottom. By rotating the core puller, the rubber plug expands within the pilot hole and forms a tight friction bond. A 1.5 m long pry bar can then be inserted through the eye-bolt mounted on top of the core puller. A two person crew, with one person stationed at each end of the pry bar, can then lift the core out of the hole and place it to the side.

The underlying aggregate and soils are then removed using vacuum excavation methods. As far as possible, the excavation sides should be vertical in line with the core opening. Once the utility pipe is exposed, the required maintenance activity can be undertaken using specially designed long-handled keyhole tools which allow the workers to access the base of the excavation remotely from ground level.

Without the need to physically put a crew in the excavation to repair the service, the operation is not only safer and less disruptive, but the volume of excavated material that needs to be disposed of is kept to a minimum. The keyhole process also reduces the volume of material that must be subsequently handled and replaced. In addition, the entire process and subsequent vacuum excavation are much faster than conventional techniques. In most situations, the service can be exposed and the repair commenced within half an hour of the lane closure.

Following completion of the maintenance works, the hole can be backfilled with compacted imported granular fill or non-shrink fill, depending on agency specifications. The top of the backfill should be finished about 50 mm below the base of the bound pavement layers. In addition some minor undercutting of the asphalt or concrete should be undertaken over this 50 mm depth.

Prior to core reinstatement, the sides of the core hole are wiped clean with a clean damp sponge to remove any loose grit or debris. The lower 50 mm of the hole should then be filled with pea gravel, i.e. nominal 9 mm clear rounded stone. The voids in this pea gravel layer will be filled with the core bonding material. Using the core puller, the core is re-inserted in the hole so that the surface of the core is at least 3 to 8 mm below the surrounding pavement surface. This may require some adjustments to the pea gravel surface. After confirming the fit, the core is removed.

The bonding compound is then prepared. The Utilibond product comes in prepackaged bags within plastic pails. Water is placed in the pail up to the indicate mark and the powdered bonding material is added and mixing is performed using a mixing blade attached to a portable electric drill. Mixing is performed for about 3 minutes until a smooth and flowable mix is obtained. The entire pail of bonding compound is then poured into the open hole. The core is then slowly inserted back into the hole using the core puller. The core is moved back and forth in the hole until the bonding compound begins to flow up and out around the annular gap between the core and hole. This is referred to as the kerf. At this stage the core puller is removed and the core pushed further in so that the bonding compound comes out through the pilot hole. The excess bonding compound is removed with a flat edged trowel. A straight edge can be used to ensure that the core is completely flush with the adjacent pavement surface. The bonding compound needs to be cleaned away quickly as it will begin to set within about 15 minutes of mixing. The exposed areas of bonding compound in the kerf and pilot hole need to be kept moist to allow proper curing until it is completely set. After the compound has completely set, about 30 minutes at about 21^{o}C, the area should be cleaned off with a high pressure hose and any waste material disposed of. At that stage the pavement can be re-opened to normal traffic.

DEVELOPMENT OF SPECIFICATIONS AND BROADER USAGE

As described previously, this technology was developed in the City in the early 90s, and the first trial installations in city streets were undertaken almost 20 years ago. Since that time it is estimated that over 200,000 installations have been successfully completed in North America.

Based on the results of the long-term performance monitoring of reinstated cores described previously, the City accepted this technology as a permanent repair procedure in 2002. They subsequently developed a specification TS 4.70 [8] entitled *“Construction Specification for Keyhole Excavation and Permanent Reinstatement of Keyhole Cores”*. The scope of this specification “*covers the requirements for keyhole coring, vacuum excavation, backfilling, and reinstatement of the keyhole core in pavements, sidewalks and other improved surfaces as a permanent repair within the City of Toronto road allowance.”* The acceptance criteria for the bonding material comprise satisfactory performance on two components, laboratory testing and field testing. The laboratory testing program comprises the suite of tests summarized in Table 1.

Table 1 – City of Toronto acceptance test requirements for bonding material for keyhole technology

Test Description	Standard
Compressive Strength	ASTM C109 or C39
Freeze/thaw	ASTM 666A and 666B
Set Time	ASTM C266
Bond Strength using Slant Shear	ASTM C882
Thermal Expansion and Shrinkage	ASTM C531

The City also requires that the bonding material reach an equivalent traffic loadable condition that is at a minimum two times greater than the AASHTO H-25 standard on simulated loading slabs, within 30 minutes at 21ºC. The specification requires the bonding material be colour matched as close as possible to the original condition of the pavement surface. In asphalt pavements, keyhole cores cannot be taken where the asphaltic concrete is less than 100 mm thick.

Where the keyhole core is found to be fractured or defective after removal, or becomes damaged after removal and prior to reinstating the keyhole cuts, the defective or damaged core cannot be used to reinstate the pavement. The City allows another equivalent core of sound condition and matching existing pavement of the same diameter, depth and composition as the defective core to be used for reinstatement. If the keyhole core is found to be laminated and composed of two or more successive layers of asphalt concrete, then, such a core can be used for reinstatement provided that all the layers are capable of being re-bonded to each other with the bonding compound during reinstatement. The keyhole contractor is required to warranty the keyhole repair for a period of 3 years.

With commercialization of the keyhole technology by Utilicor, the process is now used extensively in North America. For example, the Regional Transportation Commission, Southern Nevada Section has developed a specification entitled, *"Keyhole Pothole Excavation and Backfill"* [9]. It requires the bonding material, within 30 minutes at an ambient temperature of 21^{o}C, to allow the core to support an equivalent traffic load condition of at least three times the AASHTO H-25 standard. It also sets a minimum bond strength in slant shear (ASTM C882) of 1.38 MPa and a minimum compressive strength (ASTM C109) of 10.3 MPa. Montgomery County, in Maryland has also developed a specification for keyhole technology [10]. In their specification they define the process as follows:

"Keyhole" excavation and pavement restoration consists of coring the existing pavement to excavate and perform the required utility operation and then restoring the pavement. The "keyhole" technique minimizes pavement excavation by coring small excavation openings of 12 to18 inches in diameter through existing pavement. Typically, the operation consists of two vehicles; a truck mounted coring machine and a vacuum truck. The need for other conventional equipment such as backhoes and dump trucks is eliminated. Once the pavement has been cored, high-pressure air tools are used to cut the soil in the excavation below the pavement allowing the vacuum truck to remove the soil. Once the excavation and the work is complete and backfill placed, the removed pavement core is grouted back in place with an approved bonding agent (grout).

The Gas Technology Institute (GTI) has also developed a standard specification entitled, *"Construction Specification for Keyhole Pavement Coring and Reinstatement"* [11].

A success story with respect to the use of keyhole technology is the case of Washington Gas Company. Washington Gas delivers natural gas to more than one million residential, commercial and industrial customers throughout Washington, D.C., and the surrounding region. They are in the midst of a major project to rehabilitate about 143,000 gas service lines and over 3,000 km (1,900 miles) of gas mains [12]. The work involves renewing the steel service lines by inserting plastic pipes into them. In addition, the mechanical fittings that join the 12 m lengths of wrapped steel distribution main are being encapsulated to prevent leaks at the couplings. Washington Gas found that by using a 450 mm diameter keyhole cut rather than a conventional 1 by 1.5 m or 1.2 by 2 m utility cut has reduced their costs by approximately 50 percent. A majority of those savings come from eliminating the need for the extensive pavement restoration work associated with digging a conventional size hole. A further benefit of the keyhole approach is its use to renew the steel service lines. When the plastic pipe is inserted into the existing steel service line, they start the project at the meter rather than at the tee connecting the service line to the main. They worked with a vendor to incorporate a service line tee and an excess flow valve into a single device. The idea was to have a combination tee and valve device that could be maneuvered into place through the keyhole core that works effectively to close off the gas flow if there is damage to the service line. By eliminating the need for a separate contractor to install the meter they lowered the installation cost per service by requiring only one trip per residence service, rather than two, as was needed previously.

National Grid, a major gas and electricity company in the United States currently operates 16 keyhole coring units. They estimate that in 2009 they cut and reinstated 3,443 keyholes with estimated savings of $3 million compared to conventional methods. In 2010, the estimated the savings were $4.5 million on 4,516 keyholes.

Apart from financial savings, keyhole technology allows significant sustainability benefits. Some of these are:

- Worker safety by avoiding need to enter excavations;
- Reduces area of pavement disturbance and associated excavation quantities;
- Reduces waste generation and re-uses the pavement core;
- It avoids the need for temporary patching followed by permanent reinstatement;
- It reduces traffic disruption;
- It eliminates damage around pavement reinstatement; and
- It reduces energy costs by avoiding the need for hot mix reinstatement.

CONCLUSION

Keyhole technology, as a cost-effective and more efficient alternative to conventional excavation and reinstatement for underground utility maintenance, was developed in Toronto in the early 90s. Since being approved by the City in 2002 as a permanent pavement reinstatement method, it has been adopted by gas utility companies across North America. More and more maintenance operations can now be carried out by way of keyhole techniques. The benefits in terms of cost, speed and perfect pavement reinstatement are significant. In addition, there is reduced impact on the environment, since it not only reuses and recycles but it also reduces waste generation and results in a carbon foot print of only a fraction of that of a conventional excavation process. The technology is now covered by well accepted specifications. In recent years, the use of keyhole technology has extended to include some operations on water mains and by overlapping a series of keyhole cuts, access to larger sections of pipe can be achieved. With the current emphasis on sustainability, the applications for keyhole technology and pavement reinstatement are anticipated to grow significantly.

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