PERCOL: A POLYURETHANE SYSTEM TO SIMPLIFY LAYING OF BURIED CABLE

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ABSTRACT

A liquid polyurethane system developed originally for rapid repair of bomb-damaged Air Force runways may simplify, expedite, and substantially reduce the cost of laying buried cable in urban streets and across highways, according to field tests conducted in a cooperative program between Prime Cable of Austin, Texas, Simpson & Sons, Las Vegas cable contractors, and ARNCO of South Gate, California, developer of the urethane system. Testing has demonstrated that highway traffic can be resumed in 30 minutes after coaxial cable is encapsulated in a (three-inch-wide by six inches deep) trench sawed into the pavement. When optimized, the system could represent a benefit of as much as $100,000,000 to the cable industry.

INTRODUCTION

The cost of installing underground coaxial cable may exceed the cost of the cable itself by an order of magnitude. Depending on specification details, a typical figure for television cable per se, including associated electronics, might average $5,000 per mile. Although stringing on existing poles can run as little as one or two thousand dollars a mile, make-ready costs to provide clearance room on old inner-city aerial routes -- often already overburdened -- can run $10,000 to $15,000 per mile before the cable is hung, and another $4,000 to $12,000 in labor afterward.

Similarly, at two or three dollars per lineal foot, the labor expended to bury cable in soft dirt in the suburbs can be as cheap as $10,000 per mile; but if the cable must be laid under existing urban pavement, this figure can escalate to $50,000 or $60,000 per mile for the labor component alone.

According to recent statistics compiled by **Cable TV Technology**, about 25,000 new miles of cable will be installed during 1987, and another 25,000 miles is slated for rebuild.[1] Resulting capital costs for the nation's cable companies are becoming astronomical.

Some cable companies preparing to serve new communities (many of which prohibit utility poles) have managed to circumvent such costs by working with the land developers, placing cable underground early on (at a total cost of perhaps $15,000 per mile), before streets are graded and paved -- thereby, however, making their investment as speculative as that of the real estate developers who bet their money on the success of the anticipated community. Others in this situation find themselves faced with an impractical time-restricted "no-cut" stipulation that may obviate excavation for cable work beneath streets and sidewalks for years. A cable company in Nevada recently thought they had solved the problem by leasing space in telephone cable conduit, only to be crowded out as community telephone service expanded -- not an uncommon occurrence.

In the downtown areas of major cities there is simply no choice. Streets must be barricaded as the pavement is excavated and traffic can be disrupted for weeks at a time. Common practice involves a ditch eight to twelve inches wide and 18 inches deep -- completely through the pavement (which is usually asphalt, and sometimes asphalt over brick). After the cable is laid, a concrete slurry is poured into the ditch, taking from three days to a week to cure, during which traffic is interrupted. Usually weather conditions dictate a temporary cold patch until it is possible to return and finish the job with a hot T-cap, disrupting traffic once again.

Both Boston and Chicago have recently been through this unhappy, expensive process -- as similar work commences in Philadelphia, Baltimore, Detroit, Washington, D.C., and the boroughs of New York. In Philadelphia alone, some 3000 miles of cable will be laid. In fairness, a number of cable companies are active in pioneering new technologies; but for the most part, antique sewer line and waterworks techniques prevail. Clearly, a better process is needed.

THE PERCOL SYSTEM: BACKGROUND

Prime Cable of Austin, Texas, had been investigating several new technologies when it became managing partner of Community Cable TV of Las Vegas (the Nevada company mentioned above). Prime Cable encouraged its contractor, Simpson & Sons, to carry out field tests on PERCOL, a polyurethane system that Simpson was investigating at the time. PERCOL had been originally developed for the U.S. Air Force by ARNCO, a California company which cooperated in the venture.

The original PERCOL system was developed to meet the Air Force objective of being able to resume flight operations from a bomb-damaged runway within four hours after bombardment, under all weather conditions, including heavy rainfall. The method for repairing bomb craters had been to backfill the crater with debris, followed by a layer of compacted select fill -- after which panels of heavy aluminum matting were installed, interconnected, and anchored to adjoining sound pavement. As Air Base Survivability Reasearch Engineer, Capt. Daniel J. Pierre explained, "...the matting, although structurally sound, is labor-intensive, creates a bump in the pavement that can damage fighter aircraft, does not perform well with large cargo aircraft, and interferes with tailhook barrier engagements by fighter aircraft."[2]

Developed by chemist Ransome Wyman (president of ARNCO and co-author of this paper), PERCOL is a two-component polyurethane system now available in several combinations of physical property criteria, each tailored to the requirements of the paving materials with which it is to be used. In all cases, equal volumes of low-viscosity, low molecular weight, coreactive liquids are pumped from a pair of drums through a static mixer utilizing simple equipment, as pictured in Figure 1.

Fig. 1 - Simple equipment is used to pump liquid polyurethane "A" and "B" components from a pair of drums through a static mixer and nozzle.

Fig. 2 - Air Force technician floods a debris-filled bomb crater with reactive PERCOL mixture, which gels in two minutes and cures in 30 minutes.

Table 1 - INITIAL PHYSICAL PROPERTIES OF PERCOL VS. CONCRETE[2]

Property (psi)	Percol Polymer Concrete (psi)	Portland Cement Concrete (psi)
Flexural Strength	1300	500
Tensile Strength	500	425
Modulus of Elasticity	1.62×10^6	4.065×10^6

AIR FORCE EXPERIENCE

For the Air Force application, the PERCOL chemistry was adjusted to behave hydrophobically, to permit its application during rainfall. The reactive mixture was delivered through a nozzle, flooding the crater and percolating through compacted backfill debris as shown in Figure 2. Catalyzed so as to "gel" in approximately two minutes, the PERCOL hardened and cured to a rigid solid mass in approximately 30 minutes, bonded to the concrete and sufficiently strong to support aircraft take-offs and landings.

Physical properties of ARNCO's original (rigid) PERCOL formulation, after 30 minutes were compared with adjacent cured concrete by the Air Force, and reported as shown in Table 1, above.

It should be noted that the above properties for Portland cement concrete were measured after 28 days; those for Percol R after 30 minutes. Percol R properties may be expected to achieve their maximum values after a week or more of stabilization, depending upon ambient temperatures.

The report also concluded that "Field tests of the polyurethane polymer concrete demonstrated the resolution of problems relating to warpage, expansion, placement technique, and flammability."[2]

CALTRANS TESTING

The performance of PERCOL as an "instant runway repair" system at Tyndall Air Force Base in Florida and elsewhere led to interest in its application as a highway patching medium for repairing chuck holes, bonding alligatored pavement, etc. -- as, indeed, was suggested in the above Air Force report.

Comprehensive testing of PERCOL by the California Department of Transportation (Caltrans) began in January, 1985 under the direction of Senior Materials Engineer Leo Ferroni, P.E. Adhesion to asphalt concrete was extensively investigated both in the laboratory and in the field, with installation temperatures ranging from 22°F to 35°F, at which temperatures it was observed that "the center of the patch set up in five minutes, but the outer edges did not set until 10 minutes," after which a pickup truck was parked on the patch and driven back and forth without visible damage.[3]

Results of laboratory testing, as reported by Caltrans, are shown in Table 2, below.

Table 2 - BOND STRENGTH OF PERCOL TO ASPHALT CONCRETE[3]

California Tentative Test	24 Hours	30 Days
3-Point Modulus of Rupture on 3" X 3" X 9" block samples	2665 psi	1565 psi
Bond Stress to SSDPCC, 1-Point Modulus of Rupture	515 psi	310 psi
Bond Stress to Dry PCC 2-Point Modulus of Rupture	1250 psi	775 psi

Fig. 3 - Crater (near center line) on U.S. 97 repaired with PERCOL and rock aggregate by California Department of Transportation.

It was noted in the above report that only one of the samples broke at the bond line. These results led to additional Caltrans field tests a few weeks later in northern California near the Oregon border. As reported in the trade magazine, **Highway and Heavy Construction**:

"U.S. 97, a favorite shortcut for truckers off I-5, is two lanes of asphalt concrete, puckered by alligator cracks, ruts, potholes, and depressions, subjected to freeze-thaw conditions for nearly six months each year. Though only moderately travelled, (approximately 2100 vehicles per day), half of its load is truck traffic, most with five or more axles.

"In late January, maintenance personnel poured samples of polyurethane cement over 5/16-in rock in two ragged potholes and a deep rut and flooded more resin into a four-in. deep, 10 X 3-in. depression filled with the same aggregate...Heavy traffic was rolling over the patches 20 minutes later. The outside temperature was 35 deg. F."

One of these patched craters may be seen near the center line of the road in Figure 3. During the ensuing nine months, the patches were exposed to heavy rains, snowstorms, and continual freeze-thaw cycles that occasionally exceeded a 40°F temperature change in a single day--from a low of -5°F.[3] [4]

Fig. 4 - Caltrans PERCOL test on Highway 118, which carries average daily traffic load of 75,000 vehicles in each direction.

A year later observers reported the patches to be "still intact, while the asphalt around them continues to spall."[4]

Figure 4 shows another Caltrans test location in which a large area of scaling concrete (caused by reactive aggregate) was repaired on State Highway 118 in the Simi Valley northwest of Los Angeles -- a six-lane thoroughfare carrying an average daily traffic load of 75,000 vehicles in each direction. Here, The crumbling surface of the road (on which temperatures of 125°F have been recorded) was flooded with PERCOL

Fig. 5 - Core sample from above repaired highway pavement shows good bonding at surface and PERCOL penetration up to 2 1/2 inches deep.

to test the product's ability to bond the fractured area together, and to determine if the polyurethane would penetrate sufficiently to seal the cracks and prevent further deterioration. After squeegeeing the liquid material over the area, and before gelation, the road crew broadcast sand to insure a non-skid surface.

Core samples taken from this area six months later (see Figure 5) showed good bonding at the surface, and demonstrated that the polymer had penetrated as deep as 2 1/2 inches as it percolated through the substrate.[4]

REFORMULATION

PERCOL's chemistry involves an addition reaction of an isocyanate group to the hydroxy group in the polyol component. Because of its controllable reactivity, the system can be tailored to provide a variety of physical properties to optimize compatibility with the paving materials with which it is used.

Retrospective analysis of the results of the above Caltrans field tests suggested that for highway service a more flexible form of PERCOL was desirable -- one that could accommodate movement between adjacent slabs of pavement and would also be more compatible with asphalt concrete. To this end, the original PERCOL was reformulated.

Now designated as PERCOL FL (formerly PercoFlex), properties of this elastomeric form of PERCOL are:

Table 3 - PERCOL FL PHYSICAL PROPERTIES

Durometer (Shore A)	95
Tensile Strength	2200 psi
Elongation	175%
Tear Strength (C)	235 pli
Specific Gravity	1.1

As with all PERCOL formulations, PERCOL FL reacts with low exotherm, which results in performance advantages. Since the reactive mixture does not heat up significantly, PERCOL avoids the residual stresses upon cooling which are characteristic of other more-exothermic polymer systems. The addition of elastomeric flexibility coupled with high strength also provide relief of stresses which might otherwise be induced by differences in coefficient of thermal expansion between the polymer and parent pavement.

PERCOL's low-volatility isocyanates obviate any need for protective clothing or other special safety precautions to maintain OSHA air quality standards.

NON-MILITARY AIRCRAFT RUNWAYS

The first real-world applications of PERCOL FL have been on aircraft runways. PERCOL-repaired areas of civilian aircraft runways are currently being evaluated at major international airports. Figure 6 shows a typical section of fractured concrete on an airport taxiway, which has been jack-hammered back to solid concrete. In Figure 7, the cavity has been filled with coarse, dry aggregate, which was then flooded with PERCOL, as seen in Figure 8. Again, the wet polymer was coated with sand to restore surface friction. Figure 9 shows the repaired taxiway supporting a 1200-ton aircraft.

Figure 10 illustrates a squeegeeing technique employed to apply PERCOL to a model airplane runway which had severely deteriorated. After sand was broadcast (Figure 11), the result was an exceptionally smooth, non-skid, aesthetically neutral surface. Figures 12 and 13 compare the condition of the runway before and after repair.

FIELD TESTS WITH CABLE

When some of the above references came to the attention of Simpson & Sons, cable contractors in Las Vegas, Nevada, they invited ARNCO to participtate in a series of pragmatic field tests to evaluate adaptation of PERCOL technology to cable-laying operations. Several demonstrations were arranged during 1986 for cable industry representatives.

The technique employed was a modification of one that has been utilized for installing electrical power conduits for aircraft runway lights: laying the power cable in a shallow trench in the pavement and covering it with a polymer concrete (frequently expoxy in this application).

Figure 14 shows the 36-inch carbide-tipped rock saw, built by J.I. Case, which was used in Simpson's Las Vegas demonstrations. For cable installation in the asphalt surface, the operator rapidly cuts a groove approximately 2 3/4 inches wide by six inches

Fig. 6 - Fractured concrete pot-hole on aircraft runway which has been jack-hammered back to solid concrete.

wide by six inches deep, as shown in Figure 15. After the cable is laid in the shallow trench, asphalt debris from the saw cut is swept back into the groove (Figure 16). If the debris volume is insufficient to fill the trench or is otherwise unsuitable, ARNCO recommends dry, washed pea gravel or recycled asphalt; cold mix has also been successfully used by Simpson.

Utilizing the truck-mounted equipment pictured in Figure 17, a

Fig. 8 - Aggregate filled cavity is flooded with reactive PERCOL polymer.

Fig. 7 - The cavity is filled with coarse, dry aggregate.

double-barrelled positive displacement pump delivers equal volumes of liquid "A" and "B" PERCOL components from a pair of drums through parallel hoses, to the dispensing wand, where they are intimately blended in an integral 21-element motionless mixer before flowing out of the discharge nozzle into the trench, as shown in Figure 18. Percolating through the aggregate, the reactive mixture gels in about two minutes and is capable of supporting traffic 30 minutes later. Sand, broadcast over the surface before gelation of the poymer (Figure 19), restores both surface friction and surface aethetics, making

Fig. 9 - A 1200-ton aircraft taxis over the PERCOL-repaired runway.

Fig. 10 - PERCOL reactive liquid is squeegeed over the surface of a deteriorated model airplane runway.

Fig. 11 - Broadcasting sand over the reactive PERCOL mixture before gelation.

the cut for the installed cable essentially invisible.

Figure 20 is a cross section of PERCOL-encapsulated coaxial cable in asphalt pavement, illustrating bonding to the adjacent asphalt. As has been pointed out by Simpson, such encapsulation provides abrasion protection to the aluminum cable jacket under dynamic traffic loading. Figure 21 shows how cables can be "double-decked" by staggering the process.

Early Simpson field tests revealed moisture sensitivity of the reaction, which was later overcome by (1) adjusting the catalysis of the system, (2) drying the aggregate, and (3) selecting aggregate materials that did not interfere with the reaction. Limestone, for example, should be avoided not only because of its contained water of crystallization, but because of its alkalinity. Both recycled asphalt and cold mix proved to be quite compatible with PERCOL.

ECONOMICS

While the above process represents a substantial reduction in labor and installation time compared with present underground cabling techniques, it may be expected to yield a polymer concrete that is of the order of 50 percent polyurethane. To further improve the economics of the system, work is underway in an effort to substantially decrease polymer content.

Fig. 12 - Showing condition of model airplane runway before repair.

Fig. 13 - Model airplane runway after repair, with bonded-sand surface.

Fig. 14 - 36-inch carbide-tipped Case rock saw used to create 2 3/4 X 6 inch trench in pavement.

Fig. 15 - Trench sawed in asphalt pavement in which cable will be laid.

Fig. 16 - Asphalt pavement debris from saw cut is swept back into trench, supplemented by washed, dry pea gravel, cold mix, or recycled asphalt.

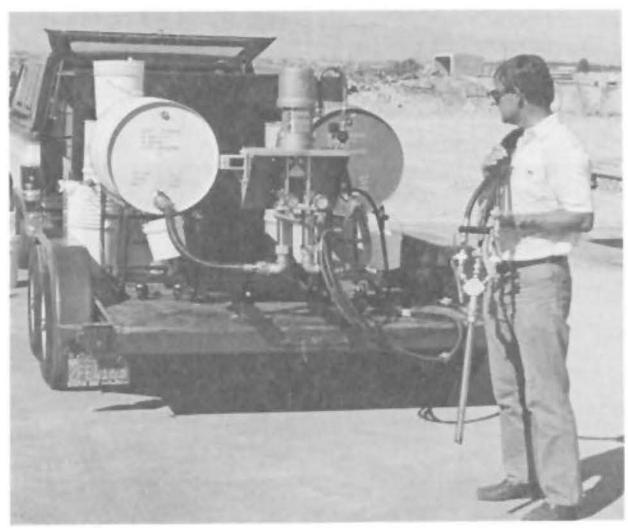

Fig. 17 - Truck-mounted drums containing "A" and "B" components of PERCOL polymer. Equal volumes of coreactant liquids, pumped by a double-barrelled positive-displacement pump, intimately mix in a 21-element motionless mixer in the handle of the operator's nozzle.

Fig. 18 - Reactive PERCOL mixture flows out of nozzle into trench, percolating through the aggregate and encapsulating the cable.

Fig. 19 - Before 2-minute gelation time expires, sand is broadcast over wet surface to restore friction and appearance.

Premixing of polymer concrete with multiple grades of screened aggregate tailored to create minimum voids between particles is an avenue that has been explored. But use of conventional mixing equipment would probably entail lengthening the short pot life of the reactive PERCOL mixture, which is intrinsic to the labor saving and speed of installation offered by the process.

Figure 22 is a polymer concrete machine developed by Respecta, a German firm (with American representation in Chicago), for Dural International Corporation, construction polymer specialists in Deer Park, LI, New York, that appears to offer considerable promise. This equipment meters liquid-polymer components and dry fillers into a mix barrel -- the long cylinder in the

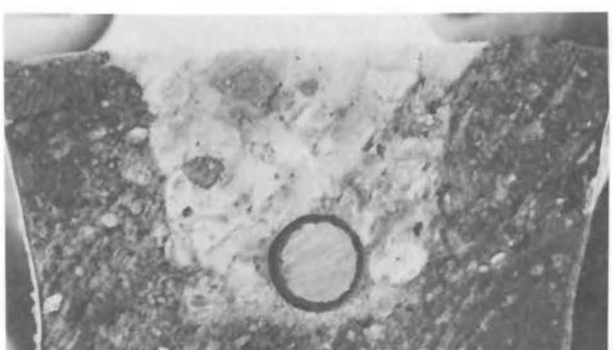

Fig. 20 - Cross-section of PERCOL-encapsulated cable in asphalt pavement, showing intimate bonding of the materials.

Fig. 21 - Showing how cables can be double-decked by repeating the PERCOL process in two stages.

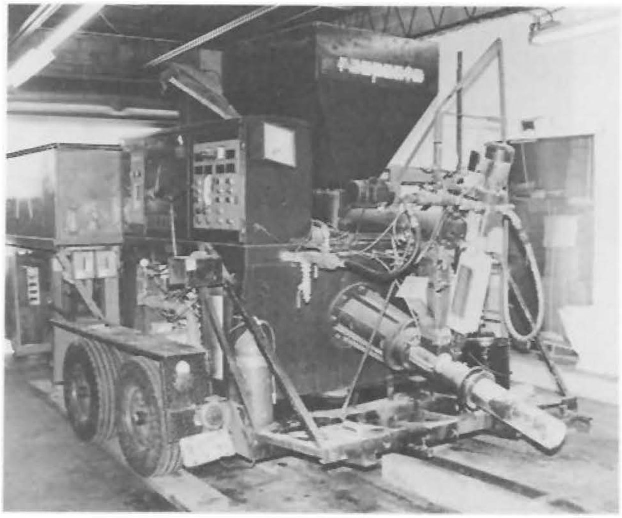

Fig. 22 - Respecta polymer concrete machine developed for Dural Corp., which will continuously meter and mix reactive PERCOL polymer with aggregate and deliver mixture into trench.

foreground, which contains a mechanical mixer. The machine is capable of delivering a continuous stream of reactive polymer concrete effluent into the grooved pavement as the machine is drawn along stradling the ditch, at a productivity rate of up to 8 cubic yards per hour. (Higher productivity rates are available, according to Repecta; depending on output volume and options selected, these machines sell for $100,000 to $200,000.)

Using its Respecta equipment, Dural has developed a five-grade aggregate mixture that contains 15 to 20 percent PERCOL polymer, yielding an estimated total material cost in the range of $3 to $4 per foot for a 3 by 6-inch cable trench. Further reductions in polymer content are possible. After optimization, it is anticipated that the equipment could move along at perhaps 1000 feet per hour, easily laying more than a mile of cable per day.

In a recent issue of **Communications Technology**, Dan Pike, Vice President of Engineering for Prime Cable in Austin, Texas, suggests that, when optimized, the process offers savings "as much as 30 to 60 percent in labor alone," compared to conventional trench installation.[5] Indeed, at an estimated cost reduction of $2,000 per mile after optimization -- and with 50,000 miles of cable currently being installed annually -- the process could represent a benefit of $100,000,000 per year to the cable industry.

PERFORMANCE PROPERTIES

For application with asphalt pavements, PERCOL FL, the somewhat flexible, elastomeric form of the polymer has been the PERCOL material of choice. Room-temperature physical properties of PERCOL FL are listed in Table 3, above. To evaluate the characteristics of this elastomer under a variety of temperature conditions, several series of tests were run in the cold rooms of the Arctic Engineering Department of the University of Alaska, Anchorage, as well as in the facilities of the Akron Rubber Development Laboratory.

After soaking in the University cold room over night at -40°F, although PERCOL FL became quite stiff at 40° below zero (having a Shore A Durometer of 100) it was possible to bend thin (1/16-in.) slabs through 180° at this temperature without fracture. In the same cold room the elastomer was evaluated for brittleness. Struck repeatedly with a heavy hammer on a steel anvil, bars of the polymer (12 in. by 2 in., by 3/4-inch thick) proved impossible to break. Severe hammer blows produced a slight flow at the unfractured surface -- a faint depression that disappeared upon rewarming to 75°F.[6]

At -40°F, both the pure elastomer and aggregates bound together by PERCOL FL exhibited great elasticity, bouncing the hammer back more than a foot, suggesting characteristics reminiscent of an ivory billiard ball.

To measure and evaluate relevant physical properties throughout the temperature spectrum, additional laboratory slabs and buttons were prepared and tested at the Akron Rubber Development Laboratory, with the results shown in Table 4 on the following page.

These data suggest that PERCOL FL maintains physical compatibility with asphalt despite changes in temperature; that is, it decreases in modulus as the temperature increases -- reducing any tendency to separate at the bond line. Moreover, the elastomer would appear to remain stronger (tensile strength is 500 psi even at 120°F) and more flexible than adjacent asphalt concrete pavement at all temperatures.

The flexibility of PERCOL FL is illustrated in Figure 23, which shows the results of an experiment performed by Simpson & Sons. Samples of asphalt pavement and PERCOL concrete approxi-

Table 4 - EFFECT OF TEMPERATURE ON PERCOL FL PROPERTIES[7]

Temperature	Durometer*	Elongation	Tension Modulus
6°F	100/100	15%	N/A
37	100/100	140	N/A
60	100/95	175	1920 psi
75	93/80	180	1075
85	82/70	190	568
100	68/60	165	315
120	60/57	155	267
140	56/56	110	265

* First value indicates initial, instantaneous Durometer reading; second is the value to which reading decays after five seconds.

mating four-inch cubes were respectively compressed in a 60,000-lb. press. While the bituminous concrete crumbled and remained in its compressed condition, the PERCOL sample (with encapsulated cable) returned essentially to its original dimensions.

In addition to PERCOL FL, half a dozen chemical variations of the PERCOL system have been released by ARNCO with physical properties tailored for specific commercial applications that are beyond the scope of this paper.

CURRENT WORK

Field testing of PERCOL is currently in progress under the direction of street authorities and highway departments in California, Arizona, Ohio, Iowa, Kentucky, and Alaska, in which state the polymer system is being utilized in such disparate applications as the containment of asbestos-contaminated soil in an environmentally-sensitive area, and the construction of a roadway comprised entirely of PERCOL and volcanic pumice. A research program at Rutgers University in New Brunswick, New Jersey, is also evaluating the product. A bridge deck over the bay at San Diego has just been completed; and some 5000 pot holes on the Santa Ana Freeway in Los Angeles will be repaired with PERCOL systems in the coming months.

SUMMARY

1. As a means of simplifying the laying of buried cable, particularly in urban paved surfaces, PERCOL polyurethane concrete technology offers significant economic advantages over existing common practice. At an estimated cost reduction of $2,000 per mile when optimized, the process represents a potential benefit of $100,000,000 per year to the industry.

2. The techniques described not only have the potential of reducing labor costs, but also avoid the repeated community disruption caused by prolonged traffic rerouting. Traffic may be resumed in as little as thirty minutes after the cable is encapsulated in PERCOL polymer concrete.

3. PERCOL may obviate rework of cut pavement occasioned by temporary measures presently employed in inclement weather during installation. Similarly, if it becomes necessary to take up the cable, the shallower cut required should reduce the cost of re-excavation.

4. PERCOL-impregnated aggregate adheres well to asphalt concrete and performs well as a compatible load-bearing element.

5. Both the physical properties and the cost-performance benefits of PERCOL polyurethane systems compare favorably with other polymer concrete systems.

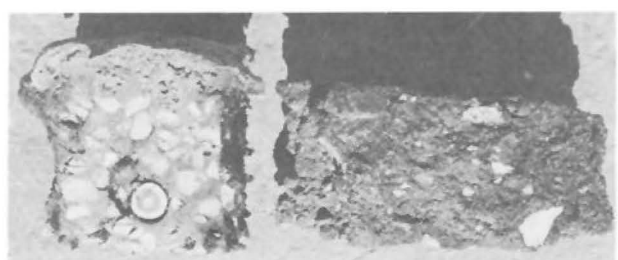

Fig. 23 - After 60,000 lb. squeeze, PERCOL concrete, left, has returned essentially to original shape; asphalt sample, right, remains compressed.

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