INJECTED POLYURETHANE SLAB JACKING

Interim Report

SPR 306-261

Oregon Department of Transportation

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by

Steven Soltesz
Oregon Department of Transportation
Research Group
200 Hawthorne Ave. SE, Suite B-240
Salem, OR 97301-5192

for

Oregon Department of Transportation
Research Group
200 Hawthorne Ave. SE, Suite B-240
Salem, OR 97301-5192

and

Federal Highway Administration
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16. Abstract

Conventional methods for raising in-place concrete slabs to align roadway sections or to counteract subsidence requires pressure-injecting grout under the slab. As other transportation organizations have had success with the URETEK Method, which utilizes injected polyurethane, Oregon DOT elected use this method to raise and stabilize a bridge end panel and adjacent concrete slab. A two-year project was initiated to monitor the stability of the injected slabs and to evaluate the material. Benchmark elevation measurements were made for comparison with future elevation data. Density and strength of the polyurethane material was documented and will be compared to similar measurements after approximately 22 months of underground exposure. The ability of the injected polyurethane to penetrate through holes was characterized. An attempt was made to measure the water permeability of the material.

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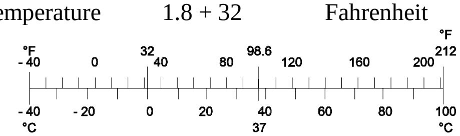
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



***** SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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1.0 INTRODUCTION

1.1 BACKGROUND

Water in the subgrade under a roadway can cause sections of the roadway to settle. The water suspends soil particles that are subsequently pumped out when traffic drives over the concrete slab causing a void to develop. This mechanism was probably responsible for the settling at the end panel of the southbound I-205 Glenn Jackson Bridge and the adjacent slab of the exit ramp, as shown in Figure 1.1. A leak in a 305 mm (12 in) drainpipe at the site was the source of water. The extent of the settling is shown in Figure 1.2.

As part of a maintenance project on the Bridge, the leaking drainpipe was repaired and the slabs were raised to a smoother profile. Injected polyurethane was used to raise the slabs to the desired profile using The URETEK Method, a technique relatively new in Oregon.

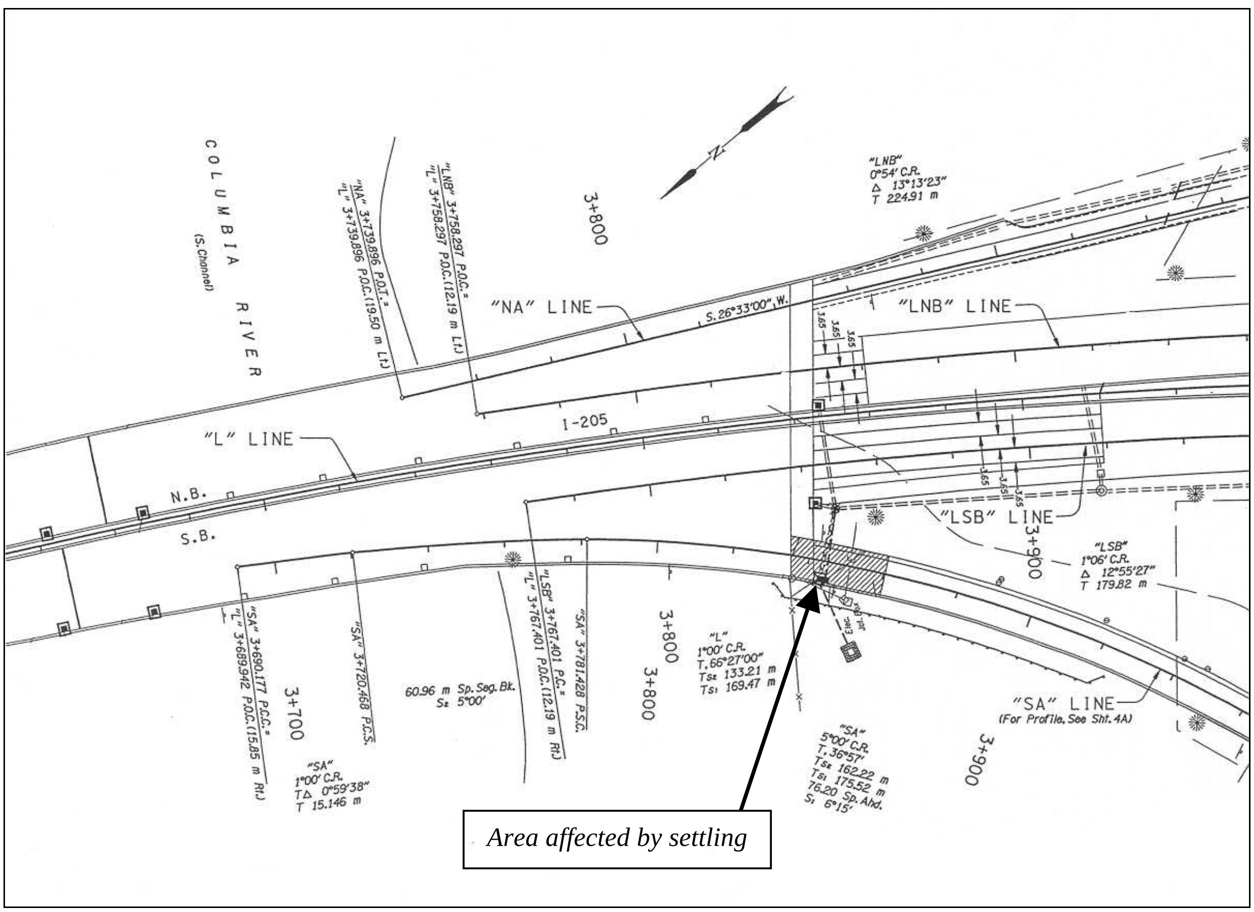


Figure 1.1: Location of slab jacking

Figure 1.2: Side view of joint between the end panel and the adjacent slab before slab jacking

1.2 THE URETEK METHOD

Conventional methods for raising in-place concrete slabs to align roadway sections or to counteract subsidence requires pressure injecting grout under the slab. Holes 50 to 75 mm (2 to 3 in) in diameter are drilled through the concrete to the base soil, and the grout is injected through the holes. The amount of lift is controlled by the injection pressure. Generally, the grout fills voids only near the injection hole.

An alternative method employed by URETEK, USA, Inc. – the URETEK Method – uses high-density polyurethane for the injected material. Many transportation organizations have had success with the URETEK Method (*Crawley 1996, Brewer 1994*); thus Oregon DOT decided to use the URETEK Method to realign the sections at the Glenn Jackson Bridge.

The process steps of the URETEK Method are outlined below:

1. Profiling – An initial profile of the roadway is made to determine where the pavement needs to be raised.

2. Drilling – Injection holes 16 mm (0.63 in) in diameter are drilled through the pavement and into the soil below.

3. Injecting – A two component system is used to create the polyurethane. One component consists of a mixture of a polyhydroxy compound, catalysts, and water; the second component is an isocyanate compound. The two components are injected simultaneously through the drilled holes. The chemicals start reacting immediately to form a rigid polyurethane foam in situ with carbon dioxide given off as a by-product. The volume of the foam is several times that of the reactants; consequently, the reaction produces an expansive force that lifts the slab.

   Two workers perform the injection process to minimize the risk of cracking. The amount of rise is controlled by the rate at which the reactants are injected through the holes. Multiple lifts can be used to reach the desired profile if necessary. A taught string or laser level is used to monitor elevations during the process.

4. Clean-up – After each hole is injected, any excess foam is removed from the hole. The hole may be sealed with cementitious grout. Quite often, the hole is not sealed because it is believed that the polyurethane foam itself creates an effective seal.

The polyurethane foam expands into voids in the subgrade, improving the stability of the subgrade and increasing the capacity of the subgrade to withstand weight. In addition, because the foam has a closed cellular structure, water infiltration that can cause subgrade instability should be reduced. Because the foam has low density in comparison to grout or mud, the polyurethane should cause less weight-induced settling.

URETEK lists the following advantages of the URETEK Method compared to conventional slab jacking techniques (*URETEK 1998*):

- Shorter repair time. The polyurethane reaches 90% of its full compressive strength within 15 minutes from injection, at which time the roadway can be opened to traffic.
- Good void filling characteristics.
- High compressive and tensile strengths.
- Fewer holes and smaller holes reduce the chance of weakening the slab.
- Injected material is lightweight, reducing the likelihood of settling or further subsidence.
- Void-filling characteristics of the material reduce the chance of water infiltration.
- Inert behavior in many environments provides a long-term, stable support for the slab.
- Repair process is more controllable. Successive lifts can be applied easily and quickly, which provides the means to incrementally raise slabs.

1.3 OBJECTIVE

It is expected that slabs raised with the injected polyurethane will remain in position for many years; however, ODOT has very limited experience with the technology to verify the long-term stability. Consequently, ODOT will monitor the stability of the Glenn Jackson Bridge site for two years. In addition, ODOT will evaluate the void size that can be penetrated by the foam and the water permeability of the foam. The technique may have other uses such as stabilizing areas prone to chronic settling. The interim results of the investigation are provided in this report.

2.0 TESTING METHODS

2.1 ELEVATION MONITORING

Twelve surveying caps were drilled into the slabs, as shown in Figure 2.1, to monitor vertical displacement over time. Baseline elevation measurements were made 4 days after the slab jacking. Future measurements will be made 3, 6, 12, 18, and 24 months after injection.

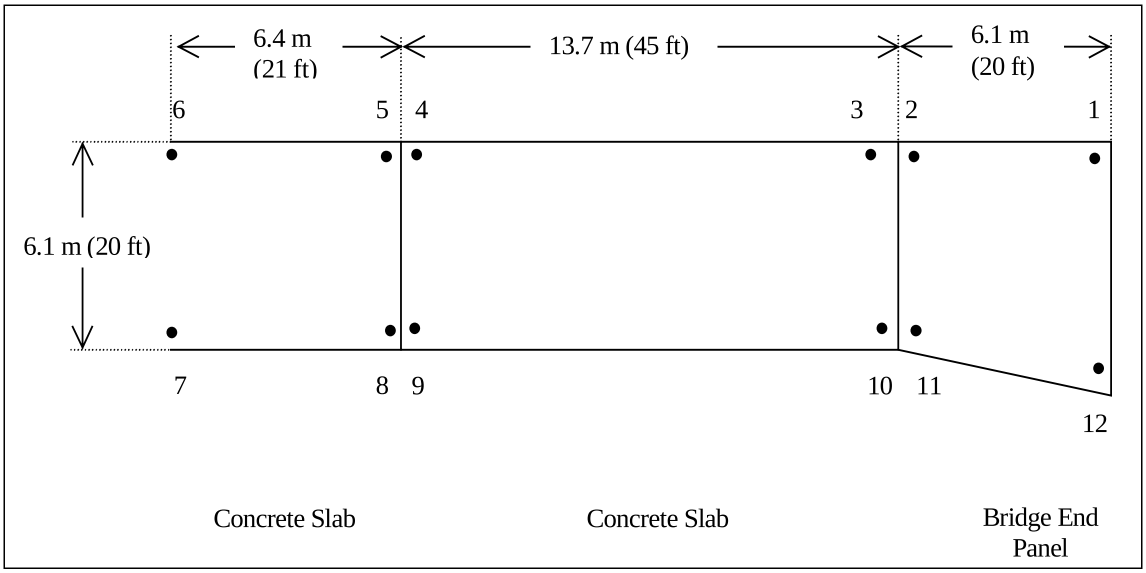


Figure 2.1: Layout of the surveying nails

2.2 HOLE INFILTRATION

An expected characteristic of polyurethane injection is that the material infiltrates small openings as it stabilizes the subgrade. The capacity to fill small voids also reduces the overall water permeability of a grade, which can protect the grade from further instability. Part of this project was to determine the smallest hole that the material could pass through as a function of the distance from the injection point.

Two fixtures based on the design shown in Figure 2.2 were constructed to quantify the invasiveness of the polyurethane foam. One fixture, Tube 1, was 1640 mm (64.6 in) long from the injection pipe to the end of the large-diameter PVC pipe. The other fixture, Tube 2, was 1410 mm (55.5 in) long, cut lengthwise along the top of the large-diameter pipe, and fitted with ten band clamps spaced along the pipe. There was a concern that the pressure due to the expanding foam would break the pipes; the intent of the split pipe was to relieve some of the expansion pressure while the band clamps maintained constraint. A 16 mm (0.63 in) ID injection pipe was used to be compatible with the URETEK equipment. Both tubes were injected with polyurethane foam.

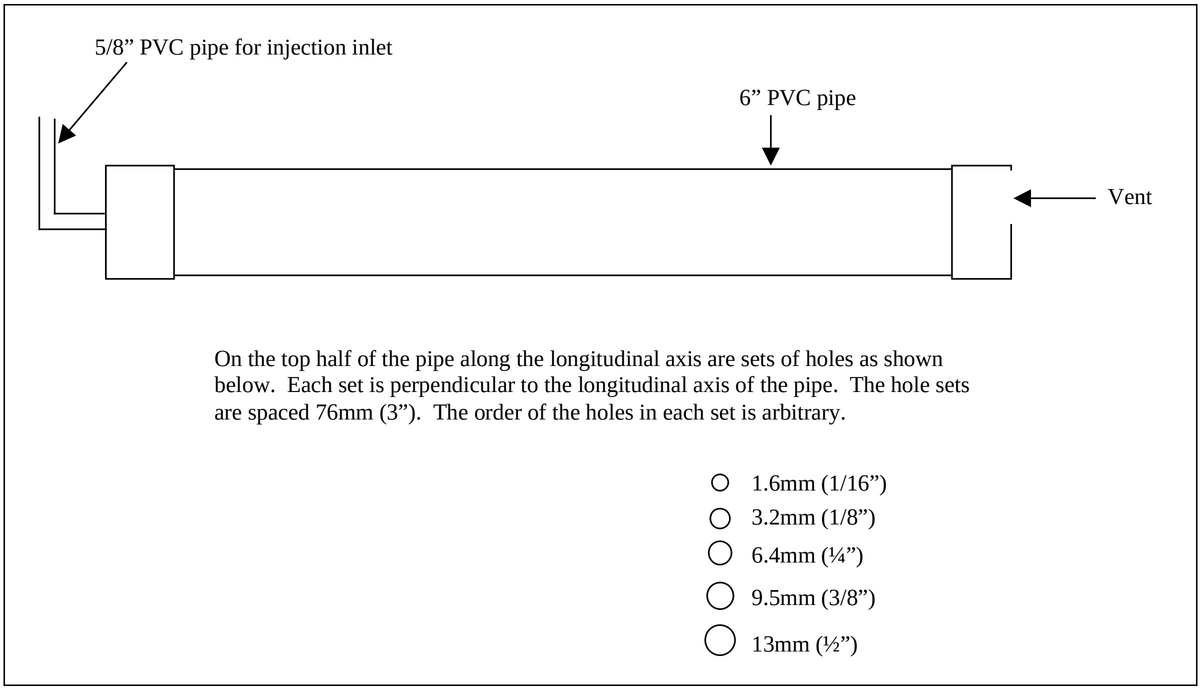


Figure 2.2: Fixture design for measuring invasiveness of injected polyurethane

2.3 COMPRESSIVE STRENGTH

One of the advantages of polyurethane is that it has excellent degradation resistance in many environments. In this project, compressive strength measurements are being used to monitor the extent of degradation. A total of twenty-three slices 51 mm (2 in) thick were cut from the 6-inch diameter PVC pipes used for the hole infiltration experiments. Thirteen slices were cut from Tube 1, and ten slices were cut from Tube 2. The PVC rings were removed and the foam samples were randomized per pipe to eliminate any bias due to position effects within the pipes. The density of all the samples was measured according to ASTM D 1622 (*ASTM 1994b*).

The samples were divided into three groups, with each group comprised of four samples from Tube 1 and three samples from Tube 2 as shown in Table 2.1. One slice from each tube was left for an extra. The testing of each group of samples for compressive strength according to ASTM D 1621 was planned as follows (*ASTM 1994a*):

1. Group 1 samples were immediately tested.

2. Group 2 samples have been stored indoors, and the compressive strength will be measured approximately 22 months after injection.

3. Group 3 samples were buried approximately 100 mm (4 in) underground 38 days after injection. They will remain underground for approximately 22 months after injection, at which time compressive strength testing will be conducted.

The strength results from the three groups will be compared to determine if any time dependent degradation occurs and if an underground environment has any influence on degradation.

Table 2.1: Identification and source for the density and compressive strength samples

Sample No.	Tube Source	Assigned Group
1	2	3
2	2	3
3	2	1
4	2	1
5	2	1
6	2	3
7	2	2
8	2	2
9	2	2
10	2	Extra
11	1	3
12	1	2
13	1	3
14	1	1
15	1	1
16	1	1
17	1	3
18	1	1
19	1	2
20	1	3
21	1	2
22	1	2
23	1	Extra

It should be noted that the density and strength data should not be used as a measure of these properties in actual field projects. The constraint during expansion and curing would vary widely over the volume of foam and would not be the same as the constraint provided by the PVC pipe. More constraint would provide a more dense, stronger foam.

2.4 WATER PERMEABILITY

The ability of the polyurethane material to behave as a water barrier is important in preventing instability caused by water infiltration. Consequently, one effort of the study was to measure the water permeability of the material using the apparatus shown in Figure 2.3 and the following equation:

$$V = \frac{K}{\mu} \times \frac{P}{l} \qquad \textbf{(2-1)}$$

where:

V is the volumetric flow rate in volume/time;
K is the permeability of the material in $(\text{length})^2$;
μ is the kinematic viscosity of water in mass/(length*time);
P is the pressure; and
l is the length of the section under test.

In the equation, V, P, and l can be measured in the test, and μ is a value available in handbooks. Consequently, the permeability can be calculated.

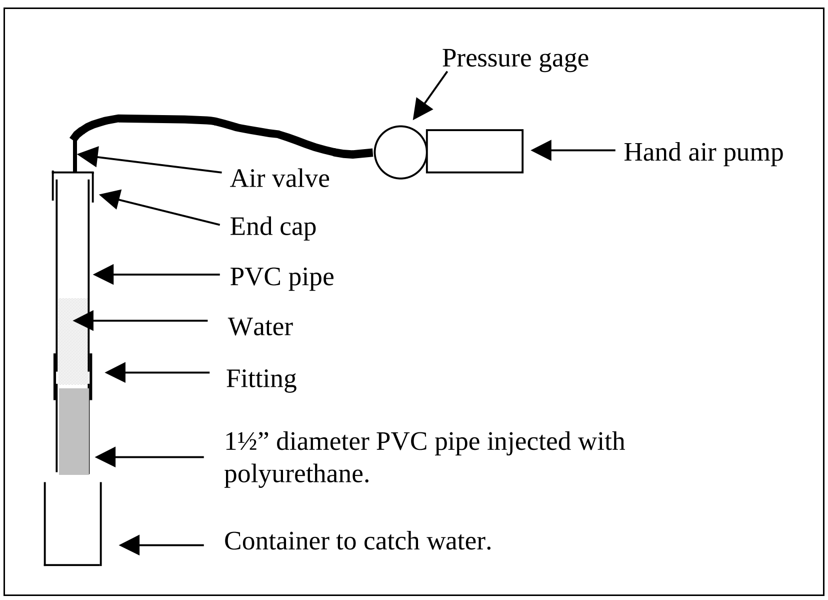


Figure 2.3: Apparatus to measure water permeability

Polyurethane was injected into 1 1/2 in (38 mm) diameter PVC pipes to make specimens for the permeability tests. It was expected that the polyurethane would expand tightly against the sides of the pipe creating a watertight seal. It was observed, however, that a slight space developed between the foam and the pipe.

To address this problem, several sections were cut from the filled pipes, and the polyurethane core was pushed out. Some of these foam cores were cemented back into their respective pipe sections with PVC cement. Other cores were put back in place with silicone sealer. In all cases, however, water still leaked from between the polyurethane and the pipe. Consequently, the permeability measurements were not made.

3.0 CONSTRUCTION

3.1 INJECTION

For the Glenn Jackson Bridge, the URETEK representatives determined that a lift of 90 – 100 mm (3.5 – 4 in) was required, based on initial profiles along the two sides and the center of the exit ramp. String lines were put in place to guide the technicians during injection.

Six 16 mm (0.62 in) holes approximately 500 mm (20 in) deep were drilled in various locations for the lifting operation. Working from one side of the ramp to the other, the holes were injected with URETEK 486 to raise the slabs. Using the same six holes, the process was repeated several times until the desired profile was obtained.

After the lift was completed, holes spaced approximately 1.2 m (4 ft) apart were drilled over the entire work area. These holes were injected to fill voids that formed during the lifting operation or any preexisting voids. After all injection was completed, all the holes were sealed with a cementitious grout.

3.2 COST

The entire operation required approximately 10.5 hours and cost $42,260. URETEK generally determines project costs by applying a unit price per kilogram of injected material. For this project, 2113 kg (4649 lb) of polyurethane was used at a unit price of $20 per kilogram.

4.0 POST-CONSTRUCTION ANALYSIS AND MONITORING

4.1 BRIDGE OBSERVATIONS

Figure 4.1 shows a hole after injection and 4 days of traffic exposure. Like many of the other injection points, the polyurethane was exposed, indicating that the grout seal either had not been applied or had popped off.

Figure 4.1: Injection point four days after injection

The aligning effect of the injection project is visually illustrated in Figure 4.2, which is a photograph of the same location as Figure 1.2 after polyurethane injection.

Figure 4.2: Side view of joint between the end panel and the adjacent slab after slab jacking

The elevations for each of the 12 locations on the slabs were measured 4 days after injection and are reported in Table 4.1. All measurements were made relative to the nearby survey marker, which was assigned an elevation of 1000 m. Future elevation measurements will be conducted in September 2000, December 2000, June 2001, December 2001 and June 2002. The relative change in elevation as a function of time will be shown in the final report.

Table 4.1: Relative elevation of slabs after injection

Position	Elevation (m)
Survey reference BM N 684	1000
1	999.3034
2	999.1568
3	999.1290
4	998.8224
5	998.8083
6	998.5837
7	999.1691
8	999.4311
9	999.4379
10	999.7943
11	999.8299
12	1000.1013

4.2 LABORATORY ANALYSIS

4.2.1 Hole Penetration

Figure 4.3 and Tables 4.2 and 4.3 show the results of the hole penetration trials. To be considered penetrated, a hole had to be completely filled. The polyurethane penetrated through all holes 6.4 mm (0.25 in) in diameter and larger. None of the 1.6 mm (0.062 in) holes were filled. Based on these results, it is expected that with injection holes drilled every 1.2 m (4 ft), the foam should penetrate all openings (based on the smallest dimension) as small as 6.4 mm (0.25 in). Openings with a minimum dimension of 3.0 mm (0.12 in) will be penetrated up to 0.62 m (2 ft) from the injection point. It is anticipated that actual field injection would produce greater penetration due to higher pressures that would result from the constraining weight of the slab.

Figure 4.3: Penetration tubes after injection

Table 4.2: Description of hole penetration tubes

	Tube 1	Tube 2
Restraint	No added restraint	Cut lengthwise; restrained with 10 band clamps
Distance from injection tube to 1st hole set	190 mm	235 mm
Distance from injection tube to last hole set.	1480 mm	1230 mm
Distance between hole sets	78 mm	78 mm

Table 4.3: Hole penetration as a function of hole size and distance from the injection point

Hole Size	Farthest Distance from Injection Point	
	Tube 1	Tube 2
1/16 in (1.6 mm)	No holes filled	No holes filled
1/8 in (3.2 mm)	1100 mm except at 950 mm	620 mm
1/4 in (6.4 mm)	All holes filled	All holes filled
3/8 in (9.5 mm)	All holes filled	All holes filled
1/2 in (13 mm)	All holes filled	All holes filled

4.2.2 Density and Compressive Strength

The density of the polyurethane was found to be greater in Tube 1 than in Tube 2, as shown in Table 4.4. Originally, it was anticipated that the density of the samples from each tube would be nearly the same, and subsequent compressive strength testing would be conducted on the samples randomly selected from the two tubes. However, the actual density difference between the tubes would produce relatively large variance within the groups that might mask any differences between groups. Consequently, the tube source was added as another factor in the compressive strength comparisons.

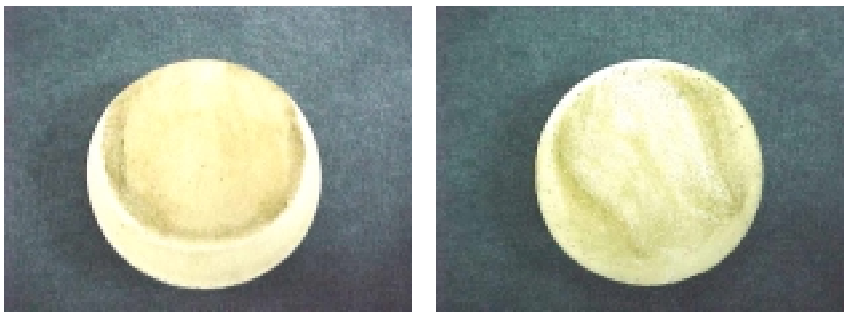
Table 4.4: Density and strength measurements

Sample No.	Tube Source	Assigned Group	Density 40 Days after Injection 10^{-5} g/mm^3 (lb/ft^3)	Compressive Strength MPa (psi)
1	2	3	6.49 (4.05)	
2	2	3	6.85 (4.27)	
3	2	1	6.58 (4.10)	Not valid. Sample 10 used instead
4	2	1	6.91 (4.31)	0.342 (49.7)
5	2	1	6.20 (3.87)	0.266 (38.6)
6	2	3	6.77 (4.22)	
7	2	2	6.68 (4.16)	
8	2	2	7.07 (4.41)	
9	2	2	6.29 (3.92)	
10	2	1	6.77 (4.22)	0.319 (46.2)
			mean = 6.66 (4.15) s = 0.27 (0.17)	
11	1	3	9.61 (5.99)	
12	1	2	9.81 (6.12)	
13	1	3	9.71 (6.05)	
14	1	1	9.84 (6.13)	0.645 (92.8)
15	1	1	9.56 (5.96)	0.674 (97.5)
16	1	1	9.52 (5.94)	0.663 (96.3)
17	1	3	9.75 (6.08)	
18	1	1	9.70 (6.04)	0.589 (85.3)
19	1	2	9.79 (6.10)	
20	1	3	9.74 (6.07)	
21	1	2	9.86 (6.14)	
22	1	2	9.68 (6.03)	
23	1	Extra	9.86 (6.15)	
			mean = 9.72 (6.08) s = 0.11 (0.07)	

Based on the judgement of the technician, a sufficient quantity of polyurethane was injected into each tube so that the material would expand to fill the volume without fracturing the pipe. In filling a similar void to lift a slab, more material would have been injected, producing a denser foam than what was obtained in the PVC pipes. URETEK reports the density of their expanded product as 8.02 x 10^{-5} to 3.21 x 10^{-4} g/mm^3 (5 to 20 lb/ft^3) (*URETEK 1998*). The samples from Tube 2 were below the reported density range, and the samples from Tube 1 were at the lower end of this range.

The characteristic of the expanded foam having a higher density under conditions of higher constraint can reduce material usage. More material is situated where it is needed, such as in load-bearing locations. Voids that are not supporting a load are filled with a lower density foam, which is still adequate to stabilize the surrounding soil.

Two distinct regions were visible in all the samples cut from the tubes as shown in Figure 4.4. One section was relatively dense and extended around much of the circumference. The second region occupied the interior of the samples and was less dense than the first region. The samples cut from Tube 1 had a greater volume of the relatively dense section, which resulted in the higher measured density values reported in Table 4.4.



(a) (b)

Figure 4.4: Samples cut from (a) Tube 1 and (b) Tube 2

Compressive strength was measured for the Group 1 samples, as reported in Tables 4.4 and 4.5. The comparison in compressive strength between Groups 1, 2, and 3 will be presented in the final report.

Table 4.5: Comparison of compressive strength between sample groups

	Low density samples from tube 2 MPa (psi)	**High density samples from Tube 1 MPa (psi)**
Group 1 40 days after injection	mean = 0.309 (44.8) s = 0.039 (5.7) n = 3	mean = 0.643 (93.0) s = 0.038 (5.5) n = 4
Group 2	To be measured	To be measured
Group 3	To be measured	To be measured

5.0 CONCLUSIONS

This project was undertaken to determine the long-term stability of injected polyurethane foam, used to raise an end panel and adjacent concrete slab on the Glenn Jackson Bridge. Following the slab jacking process using the URETEK Method, ODOT is monitoring the site for two years. In addition, lab testing of the material is also being conducted.

The following conclusions may be drawn for this interim report:

- Based on the short-term construction results, the URETEK Method can successfully raise concrete slabs to a target profile.

- Based on the laboratory tests, the injected polyurethane will consistently penetrate openings as small as 6.4 mm (0.25 in) and will penetrate some openings as small as 3.2 mm (0.125 in).

A final report is expected in 2002, following the conclusion of the field measurements and laboratory testing.

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