



## **IMPORTANCE OF HAUNCHING**

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### **ABSTRACT**

Most pipeline designs assume uniform haunch support for the pipe. However, during installation good haunch support is difficult to obtain and to inspect. Research has shown that dumping Class I and Class II soils in beside a pipe creates a void in the lower part of the pipe haunch. Compaction is essential to move the material into this void area and provide the needed uniform support. The current methods of compacting soil into the haunch area are shovel slicing (rodding) or vibration for Class I and Class II soils, and mechanical compaction of Class III and Class IV soils.

Experiments at the US Bureau of Reclamation demonstrated that the amount of support the haunch provides a pipeline depends on the relative stiffness of both the bedding material under the pipe and the haunch soil. The weight of the pipe, water and backfill compresses uncompacted bedding so the pipe is effectively supported by the material around the haunch reducing any concentrated load on the bottom of the pipe.

Early research by the National Clay Pipe Institute demonstrated the importance of shovel slicing. Recent research confirmed the significance of shovel slicing during installation. In this 2013 work, the relative stiffness of crushed rock placed into pipe haunch areas was measured by both pushing rods and pulling straps at the pipe-soil interface. Significant differences in circumferential support were seen between dumped rock and shovel sliced rock. In these experiments, shovel slicing increased the support for the pipe about tenfold.

For Class I and Class II soils, lifts up to 8 feet thick can be compacted using water and internal vibration. Impact compaction of Class III and Class IV is time consuming, labor intensive, and inherently inconsistent. To achieve a high degree of compaction, the soil should be placed in 6-inch lifts and constantly tested. Because of the difficulty of obtaining uniform haunch support, flowable fill (CLSM or Controlled Low-Strength Material) has been used in the haunch areas. For large diameter pipe (6 feet and greater), flowable fill is the only viable option.

### **INTRODUCTION**

Proper haunch support is important for the structural integrity of both rigid and flexible pipe. Lack of proper haunch support is the cause of many pipe failures. The haunch area is illustrated in Figure 1.

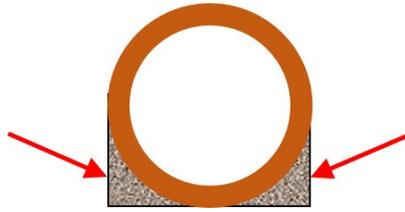


Figure 1 – Haunch Area of Buried Pipe

Proper haunch support depends on two factors:

- Proper compaction of the soil
- Mobilization of the soil within the limits of the haunch area

### **COMPACTION OF HAUNCH SOIL**

Compaction of the soil in the haunch area significantly increases the support for the pipe. Gravels and crushed rock dumped into a trench beside the pipe result in the minimum densities of the soil, which is about 80-85% of their maximum density (Howard, 2013). Compacting the soil to about 95% (D 4253) can increase the stiffness (modulus) of the soil 300 to 600% (Howard, 2013)

For reinforced concrete pipe, increasing the percent compaction of the soil in the haunch areas increases the bedding factor about 2-1/2 times for embankment conditions and about 1-1/2 times for trench conditions (ACPA Design Data No 9). For vitrified clay pipe (VCP), increasing the percent compaction increases the load factor from 1.1 to 1.9, almost doubling the allowable load.

Cohesionless soils (Class I and II) are best compacted by vibration. [For soil classes see ASTM D 2321, D 2774, or D 3839] Surface vibrators, such as vibrating plates and rollers can be used for lifts of 12 inches or less. Internal vibrators (concrete stingers, wiggletails, etc.) combined with water can densify sand and gravel lifts several feet thick, limited only by the length of the vibrator (Howard, 1996) (ASTM Manual 70 2011). In the narrow part of the haunch under the pipe, rodding or shovel slicing can be effective in moving the soil into complete contact with the pipe and providing a denser arrangement of particles.

**Flowable Fill** - Flowable fill (CLSM) is the most effective way of ensuring good haunch support. For a project with a 21-foot diameter pipe, flowable fill provided a viable method of filling the space underneath the pipe (Randolph and Howard, 2010).

### **INCREASED HAUNCH SUPPORT BY SOIL MOBILIZATION**

Haunch support for pipe can be effectively actuated by providing an uncompacted bedding to lay the pipe on. The weight of the pipe, fluid in the pipe and the backfill soil over the pipe help push the pipe into the uncompacted material creating a small cradle. Since uncompacted bedding under the pipe has a low stiffness, minor pipe settlement will mobilize the haunch soil support. Compacted haunch material is not as effective if the pipe is resting on compacted bedding above the foundation. The compacted soil simply acts as a filler. However, if the pipe is raised during compaction of the haunch soil, then the haunch support can be mobilized similar to uncompacted bedding.

## CONFIRMATION TESTS

The effect of compaction and mobilization of the haunch soil has been demonstrated by testing performed by the US Bureau of Reclamation (USBR) and the National Clay Pipe Institute (NCPI) as discussed in the following sections.

### 1966 U.S. BUREAU OF RECLAMATION TESTS

When a pipe is laid directly on a stiff material, the result is a line load on the bottom of the pipe that creates maximum movement in the pipe wall. This line load is illustrated in Figure 2. As discussed below, if the stiffness of the soil beneath the pipe is significantly greater than the haunch soil, then the haunch soil support is not mobilized and is therefore ineffective.

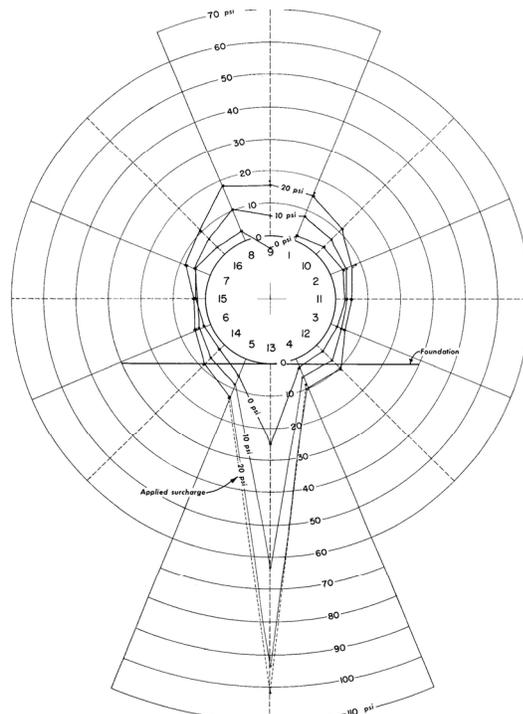


Fig 2a - Soil Box Test

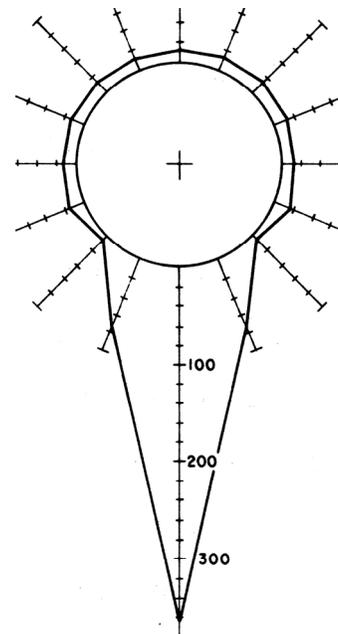


Fig 2b - CAP Field Study

Figure 2 – Soil Pressures (psi) on Concrete Pipe – Line Load

Figure 2a is the result of a soil box test on a 24-inch diameter concrete pipe with embedded soil pressure cells in the pipe wall (Pettibone and Howard, 1966, 1967). The pipe was laid directly on a Class III SANDY LEAN CLAY (sCL) foundation compacted to 105% (D 698) and the soil in the haunch area was a Class II POORLY GRADED SAND (SP) compacted to 95% (D 4253). The sand was compacted using water and internal vibration. The foundation had been previously loaded by several preceding similar tests. The foundation was much stiffer than the haunch soil. The result is a line load on the bottom of the pipe with little support from the haunch soil. When the pipe was loaded it did not settle enough into the foundation to mobilize the supporting strength of the haunch material.

Figure 2b is the result of a field test of a 21-ft internal diameter pre-stressed concrete pipe used on the Central Arizona Project as a siphon under a riverbed for a canal system (Knodel, 1985). The outside diameter was 25 feet. Soil pressure cells were mounted on the exterior of one pipe. The

pipe was laid directly on the trench bottom consisting of a Class II POORLY GRADED SAND (SP) and POORLY GRADED SAND WITH SILT (SP-SM). The foundation was compacted in-place with vibratory rollers to a minimum density of 95% (D 4253). The embedment was a Class II POORLY GRADED GRAVEL WITH SAND (GPs) compacted to 97% (D 4253). The material in the haunch area was compacted with water and internal vibration while the remainder of the embedment was compacted with vibratory sheepsfoot rollers. Each section of pipe was 22-ft long and weighed 225 tons. The weight of the pipe directly on the foundation compressed the soil to a much higher stiffness than the embedment soil. The result is a line load on the bottom of the pipe due to the lack of support from the haunch soil. When the pipe was loaded it did not settle enough into the foundation to mobilize the supporting strength of the haunch materials. The pressures shown in Figure 2b were measured four years after construction.

### UNCOMPACTED BEDDING

If the pipe is laid on uncompacted bedding and has compacted haunch material, the soil beneath the pipe has a much lower stiffness than the haunch soil. The pipe will then settle enough that the haunch support is mobilized so that a more bulb shaped pressure distribution on the bottom of the pipe results. Figure 3a shows the results from one of the USBR soil box tests referred to earlier. In this test, the pipe was laid on a Class III SANDY LEAN CLAY (sCL) foundation compacted to 85% (D 698) and had an embedment of the same soil compacted to 100% (D 698). The loaded pipe was able to settle into the foundation enough that the haunch soil helped support the pipe.

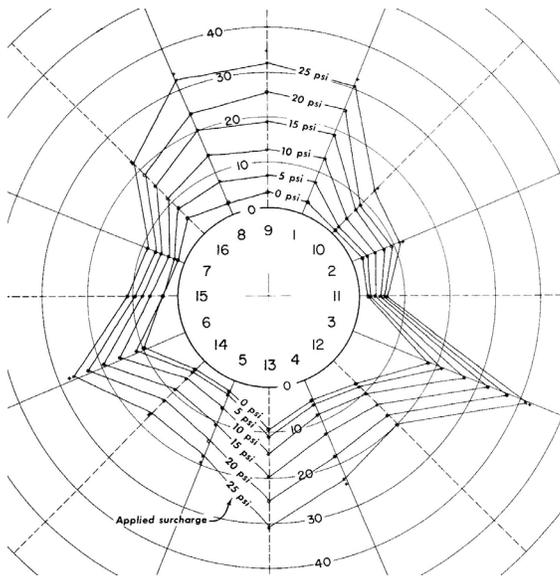


Fig 3a- firm embedment, soft foundation

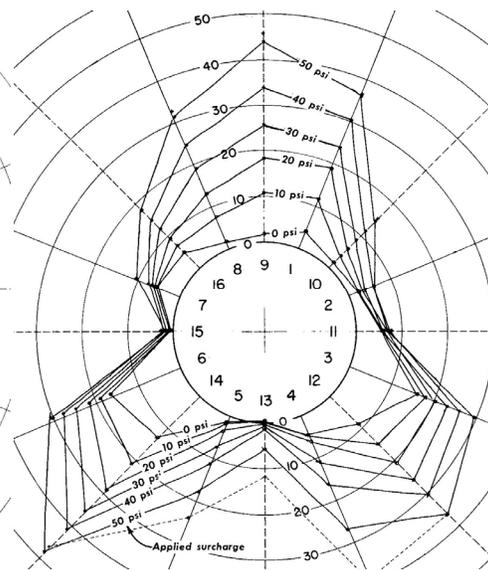


Fig 3b- firm foundation, firm embedment  
(pipe lifted during haunch compaction)

Figure 3 – Soil Pressures (psi) on Buried Concrete Pipe, “Soft Bedding”

Figure 3b shows the pressure distribution for a pipe that was placed on a foundation compacted to 105% (D 698) with the haunch soil compacted to 100% (D 698). However, the impact compaction with hand-held equipment raised the pipe so that it was initially not in contact with the foundation. The pressures on the bottom of the pipe were zero until the load reached 50 psi. This is effectively what would happen with uncompacted bedding beneath the pipe.

## 1978 NCPI LOAD FACTOR RESEARCH

In tests performed by NCPI, a 2-foot-long, 8-inch diameter test pipe was instrumented on the inside with strain gages positioned (Sikora, 1980) circumferentially every 15° from the top of the pipe down one side to the bottom. The strain patterns developed in the pipe body when subjected to load in three-edge bearing and in different classes of bedding were then measured. The fully instrumented pipe had a complete set of circumferential gages and five invert gages. The resulting strain patterns are shown in Figure 4.

These tests used clean rounded and angular gravel (Class I and Class II) as the embedment material.

Maximum strains developed in the test pipe in three-edge bearing were compared to the maximum strains developed in the bedded pipe at the same load. The ratio of the two maximum strains is the load factor and is based on the premise that with increasing load, strains will increase linearly up to the point of failure.

The diagrams in Figure 4 indicate how the strains are altered as the pipe responds to the bedding. A wider support distribution results in a lower strain at the same total load, which enables the pipe to support greater backfill loads. A Class B installation can carry almost twice the load as the Class D installation due to the improved haunch area support.

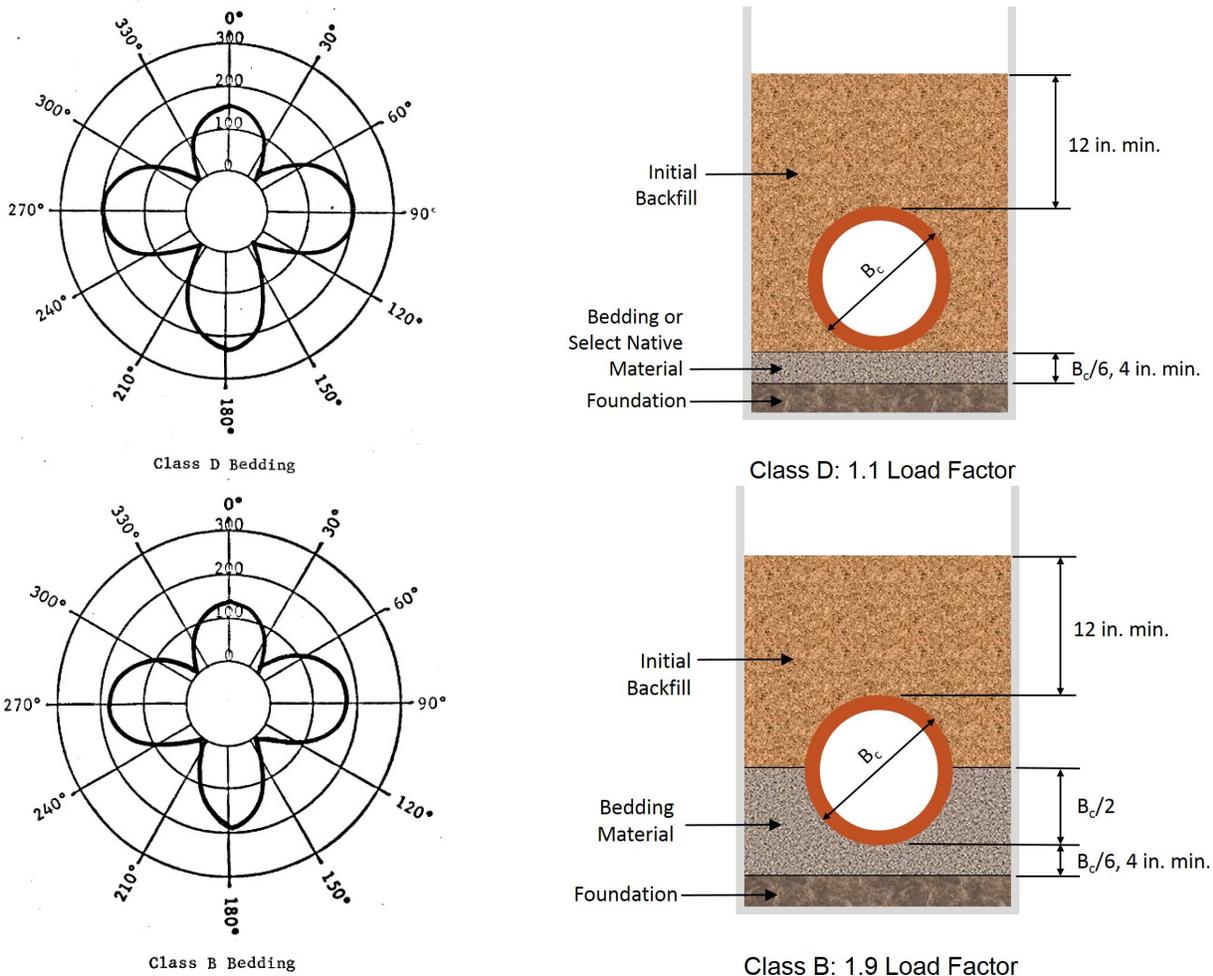


Figure 4 – Comparison of Strains for Class B and Class D

For the Class B tests, strain measurements were made with and without shovel slicing in the haunch area of the pipe. The load factor was about 50% higher for the shovel sliced installation. Increased circumferential pipe support from haunch soil mobilization was also demonstrated in this research. The load factor testing showed that maximum strain occurs in the invert of the loaded pipe. To test for the benefits of haunch soil mobilization; a 2-inch wide strip of 1-inch thick Styrofoam, equal in length to the pipe, was placed beneath the pipe along the invert. Bedding material was placed in the haunch area of the pipe up to one-sixth of the outside diameter ( $B_c$ ) of the pipe. After loading and strain data collection the load factor was increased from 1.7 without foam to 2.1 with foam (an increase in field supporting strength of nearly 24%). The strain patterns indicated increased support in the haunch areas and reduction in the magnitude of stress concentration.

## **2013 NCPI TESTS**

Experiments were conducted in 2013 to demonstrate the significance of shovel slicing during installation of VCP. Resistance to pushing rods and pulling straps at the pipe-soil interface was used to show the relative stiffness of crushed rock placed in the pipe haunch. Significant differences in stiffness were seen between dumped rock and shovel sliced rock.

The soil was a Class I crushed rock (No. 67) with 3/4-inch maximum size with only 25% smaller than the 3/8-inch sieve and only 2% passing the No. 4 sieve. Laboratory tests on the soil included minimum and maximum density (ASTM D 4254 and D 4253), gradation, angle of repose (USBR 5380) and percent of fractured faces (ASTM D 5821). The material had 100% fractured faces.

### **HAUNCH VOID**

Uniformly graded gravel will typically leave a void in the haunches of a pipe when it is loosely placed beside a pipe. The gravel has an angle of repose, which is the angle of the slope of the material when dumped into a pile. A gravel with fractured faces will have a steeper angle than gravel with rounded edges. The crushed rock tested had an angle of repose of 39 degrees.

Figure 5 illustrates the void space left in the haunches of the pipe when the angle of repose is 39 degrees. Figure 6 is a photo from the experimental testing described later and illustrates the reality of the haunch void. The photo was taken after the crushed rock had been dumped in beside the pipe. Daylight can be seen on the other end of the pipe indicating a void running along the full length of the pipe in this lower haunch area. A video was taken at the time of this photo and clearly demonstrated the mechanism of the formation of a void in this area. This video is available for viewing on AmsterHoward.com and on the NCPI YouTube channel.

### **SHOVEL SLICING**

A special section of VCP was embedded with the soil placed using different methods. The stiffness of the soil in the haunch area was tested by either pushing a rod through or by pulling a strap through. The procedure used to install and backfill the pipe plus the method used to measure the soil pressure on the pipe can be found on the reference (Howard and Boschert, 2013).

There were four experiments conducted with each having 6 parts. A part consisted of a push (or pull) at a specific location around the circumference of the pipe. The location of a test is designated by an O'Clock (OC) reading. (Looking at the end of the pipe, twelve OC is at the top of the pipe while 6 OC is at the bottom of the pipe.) The tests were conducted at locations around the bottom half of the pipe at 3, 4, 5, 7, 8, and 9 OC. A test at 6 OC was not done because there is full contact between the pipe and the bedding soil with the pressure of the weight of the pipe. These test locations are shown in Figure 7.

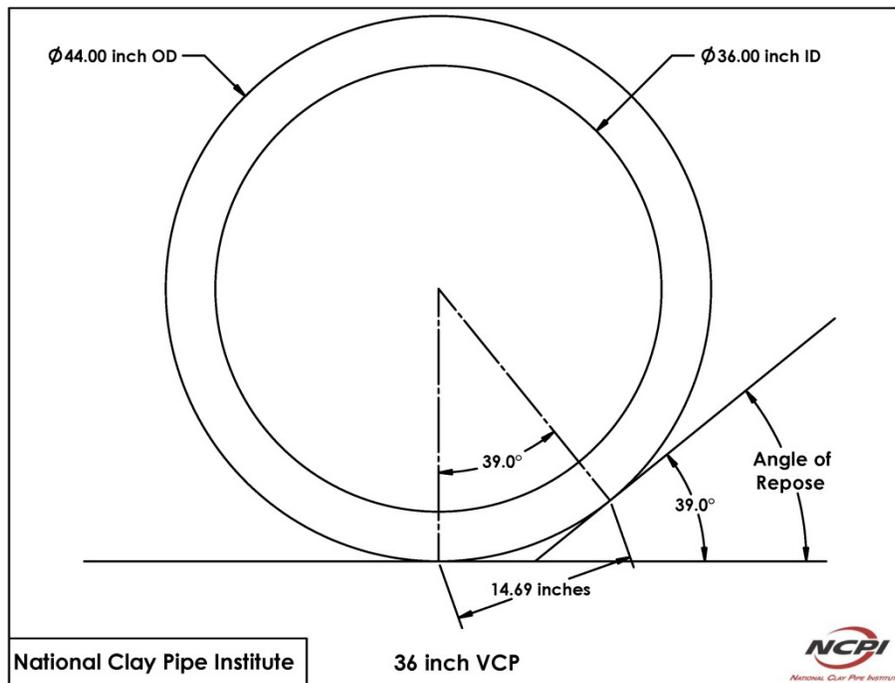


Figure 5 – Void Left in Pipe Haunch Area (5 to 6 O’Clock)



Figure 6 – Photo of Void in Lower Haunch Area (6 to 7 O’Clock)

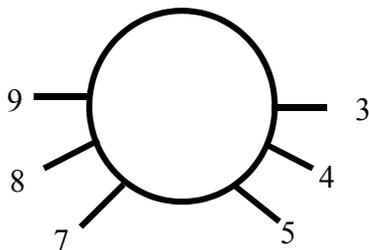


Figure 7 – Test Locations as O’Clock Readings

Resistance to pushing the rod is an indication of the density of the crushed rock. More particles per unit volume means higher density, which is directly related to the stiffness of the soil. The force to push the rod is a crude indication of the density of the soil, thus the stiffness.

Pulling a strap through was an adaptation of the “friction ribbon” method of measuring the soil pressure against buried pipe used at Iowa State University by Professors Marston and Spangler. The force needed to pull the strap is directly proportional to the pressure on the strap. Originally, Marston and Spangler used a one-inch wide stainless steel metal strip to pull back and forth between two layers of canvas. This was useful for the compacted earth used in their tests. However, for the 2013 NCPI tests, the use of crushed rocks meant large voids between particles and point loadings of the edges. A wide fabric strap was used instead and pulled through longitudinal pockets in canvas wrapped around the pipe, as shown in Figures 8 and 9.



Figure 8 – Canvas Wrap with Yellow Pull Straps in Stitched Pockets



Figure 9 – Strap Being Pulled Through Canvas Wrap

A typical result of the test using the push rod is shown in Figure 10. The vertical axis is the hydraulic jack pressure (psi) and the horizontal axis is the time in seconds. Because of the limitations of the stroke of the hydraulic jack, the jack used would be halted and extension rods installed. Therefore, the test would be in segments, each a certain length beside the pipe. In Figure 10, six peaks can be seen, each one a separate push of the jack. The first and last segments were discounted because of the proximity of the sand bags. The peaks are a set of points representing the pressure used to advance the rod along the side of the pipe. The variation is due to pushing crushed rock particles out of the way of the rod or the variable pressure of the crushed rock edges on the strap. The representative value for each peak was an eyeball estimate of the center of the mass of data points. For example, in Figure 10 the value established for the second peak is 100 psi, the third and fourth peaks: 75 psi, and the fifth: 150 psi.

## 2013 NCPI Experiment

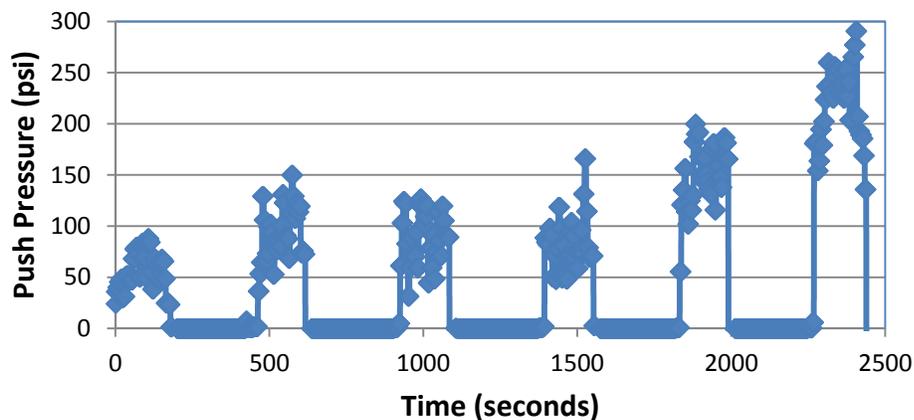


Figure 10 – Typical Data Plot – Push Pressure (psi) versus Time (seconds)

While the rod represents a push at a certain point along the length of the pipe, the strap represents the pressure along the entire length of the pipe. Two pulls of the strap were used to measure the tensile pressure and both were used to indicate the average contact pressure of the rock against the pipe. The results looked like Figure 10 except there were only two peaks. The first pull showed slightly higher pressure.

There were four experiments performed, as follows:

Test A	Dumped Crushed Rock	Push Rod Measurements
Test B	Shovel Sliced Crushed Rock	Push Rod Measurements
Test C	Dumped Crushed Rock	Strap Pull Measurements
Test D	Shovel Sliced Crushed Rock	Strap Pull Measurements

Tests A and C - The crushed rock was dumped in beside the pipe in roughly equal amounts on each side of the pipe using a front-end loader. Once the rock was close to the top of the pipe, it was leveled. One test involved pushing the rod through the rock (Test A) and another used the pull strap method (Test C).

Tests B and D - the crushed rock was dumped in and layers spread out in even lifts beside the pipe. The lifts under the haunches of the pipe were shovel sliced. One test used the push rod method (Test B) and another used the pull strap (Test D).

**Results**

Experiments A and B involved pushing a rod through the crushed rock at the interface of the rock and the pipe. While this is a simple method of measuring the contact pressure, maintaining a straight path of the rod was not a precision operation. Table 1 shows the results of the tests for Experiments A and B.

Table 1 Measured Pressure of Pushing Rod Through Crushed Rock (psi)

<b>Experiment</b>	<b>3 OC</b>	<b>4 OC</b>	<b>5 OC</b>	<b>7 OC</b>	<b>8 OC</b>	<b>9 OC</b>
A (dumped crushed rock)	50	100	25	50	75	200
B (shovel sliced crushed rock)	200	600	400	300	200	150
<b>Ratio B/A</b>		<b>6</b>	<b>16</b>	<b>6</b>	<b>2.67</b>	

The readings at 3 and 9 OC represent the lateral pressure against the pipe of the backfill soil above this level and should be about the same for all tests because this level of rock around the pipe is not shovel sliced. The area of concern is the pipe haunch, or the 3, 4, 5, 7, and 8 OC readings, with the critical locations of 5 and 7 OC as the lower portion of the haunch.

The ratio B/A in Table 1 shows the relative increase in contact pressure between the crushed rock and the pipe. For these two experiments, shovel slicing increased the contact pressure by a multiple of 3 to 16. The largest increase comes at the 5 and 7 OC locations, with an increase in contact pressure of 6 to 16 times.

Experiments C and D involved pulling a strap placed at the interface of the rock and the pipe. With this method of measuring the contact pressure, maintaining the straight pull of the strap at a certain perimeter location was controlled and precise. Table 2 shows the results of the tests for Experiments C and D.

Table 2 Measured Pressure of Pulling Straps Through Crushed Rock (psi)

<b>Experiment</b>	<b>3 OC</b>	<b>4 OC</b>	<b>5 OC</b>	<b>7 OC</b>	<b>8 OC</b>	<b>9 OC</b>
C (dumped crushed rock)	25	20	25	40	20	40
D (shovel sliced crushed rock)	40	40	300	300	50	50
<b>Ratio D/C</b>		<b>2</b>	<b>12</b>	<b>7.5</b>	<b>2.5</b>	

The readings at 3 and 9 OC represent the lateral pressure against the pipe of the backfill soil above this level and should be about the same for all tests because this level of rock around the pipe is not shovel sliced. The area of concern is the pipe haunch, or the 3, 4, 7, and 8 OC readings, with the critical locations of 5 and 7 OC as the lower portion of the haunch.

The ratio D/C in Table 2 shows the relative increase in contact pressure between the crushed rock and the pipe. For these two experiments, shovel slicing increased the contact pressure by 2 to 12 times. The largest increase comes at the 5 and 7 OC locations, with an increase in contact pressure of 7.5 to 12 times. These results are similar to the relative values demonstrated in experiments A and B.

### Comments on Shovel Slicing

Compaction of Class I and Class II soils using water and internal vibration reduces the labor and inconsistency of shovel slicing. Lifts up to 8 feet thick can be compacted using this method. Mechanical compaction of Class III and Class IV is time consuming, labor intensive, and inherently inconsistent. To achieve a high degree of compaction the soil should be placed in 6-inch lifts and constantly tested. Because of the difficulty of obtaining uniform haunch support, flowable fill (CLSM) has been used in the haunch areas. For large diameter pipe (6-feet or greater), flowable fill is the only viable option.

These experiments indicated that shovel slicing increased the support for the 36-inch pipe (44-inch OD) about tenfold. Additionally, observations during the experiments showed that dumping rock in beside a pipe creates a void in the lower part of the pipe haunch such that no rock is in contact with the pipe.

### Summary

While these tests are not precise replicas of field conditions, they are indicative of the large difference in support for the pipe between dumped and shovel sliced crushed rock in the pipe haunch area. Typically in these tests, the shovel slicing results in ten times the support for the pipe.

## **FIELD FAILURE HISTORY**

An internal inspection of an 11-ft diameter RCP conduit constructed in the mid 1970's found severe invert longitudinal cracks and spalling of the cover over the steel reinforcing. The exterior was excavated and companion longitudinal cracking was observed at the springline (shown in Figure 11). The pipe was laid directly on the trench bottom (no bedding) and compacted embedment was specified up to 0.375 OD (dotted line in figure).

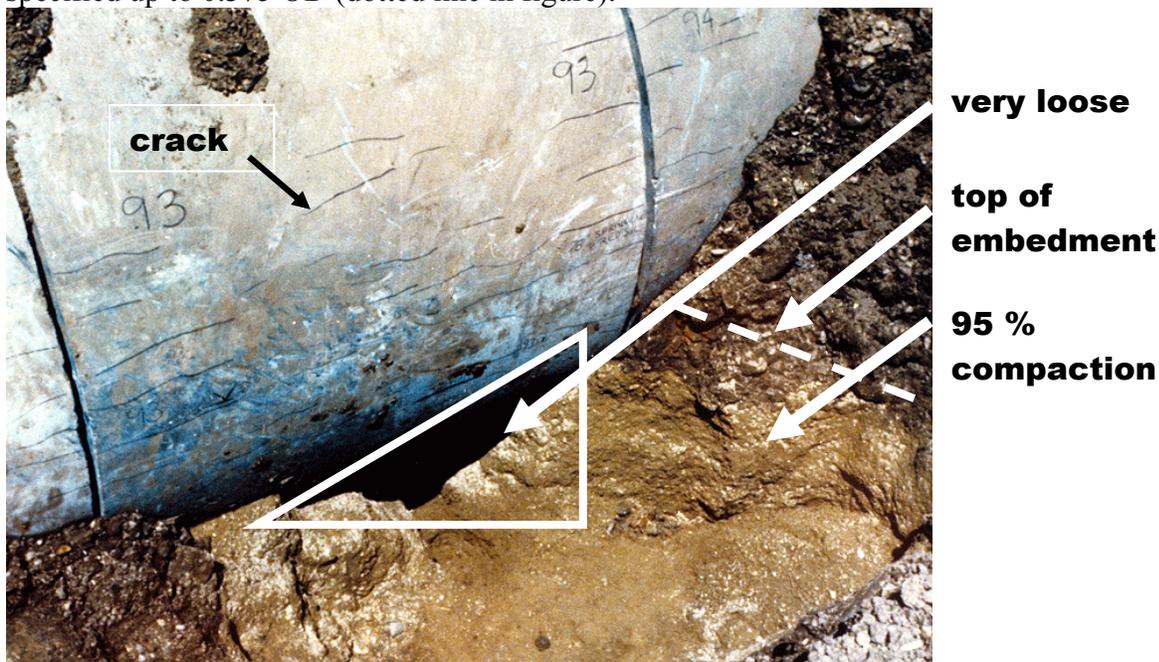


Figure 11 – Eleven Foot Diameter Concrete Pipe Failure

While the embedment soil outside of the footprint of the pipe was indeed compacted to 95% (D 698) and higher, the soil under the haunches of the pipe was so loose it could be scooped out by hand. In effect, the pipe had a line load on the bottom of the pipe. Subsequent calculations confirmed that pipe needed full haunch support to carry the load created by 15 feet of cover over the pipe.

### **SUMMARY**

1. Good haunch support significantly increases the load carrying capacity of buried pipe.
2. Good haunch support requires compacting the soil in the haunch area, or using flowable fill.
3. Good haunch support is not attained by dumping gravels and crushed rock beside the pipe.
4. Good haunch support can be attained by pipe settling into uncompacted bedding and mobilizing the strength of the haunch soil.

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