MAGNUM PUSH PIER FOUNDATION
TECHNICAL REFERENCE GUIDE

# MECHANICAL BENDING STRENGTH OF PUSH PIER PIPE SHAFT

## PRODUCT TESTING REPORT

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## INTRODUCTION

Determination of the lateral and buckling resistance of a steel push pier requires knowledge of the mechanical bending strength of the pier shaft. Bending resistance of an empty steel pipe can be estimated by traditional and well known engineering calculations. The bending resistance of a grout filled pipe shaft and the effect of galvanization on bending strength is more difficult to compute theoretically.

An investigation was conducted to measure the mechanical bending resistance of the pipe shaft used for Magnum steel push piers. The investigation included a series of load tests on steel pipe, grout-filled pipe, and galvanized pipe shafts. The bending strength of Magnum steel push pier connectors were also measured. This document represents a sample of the types of testing used by Magnum Piering to determine capacities of its steel push pier foundation products. Other tests that have been conducted include bracket mechanical capacity, bracket concrete anchor capacity, and full-scale field capacity. As part of a manufacturing quality assurance program, Magnum Piering periodically tests various components of its product line. For Magnum Piering, product testing and quality assurance is an ongoing effort. Contact Magnum Piering headquarters for additional information and test results on any product or component.

## TEST METHOD

Shaft bending tests were conducted on 5'-0" long specimens. The specimens were mounted in a load frame with reaction supports spaced 44" apart. Deflection was measured using a dial gage mounted at the center of the pipe specimen. A photograph of the test set-up is shown in Fig. 1.

Some of the load tests were performed with 3 point loading wherein load was applied to a single point at the center of the reaction supports. During these tests, it was noted that the pipe shaft exhibited fairly significant compression at the load point. In order to evaluate the effect of this distortion of the pipe cross-section on the bending strength, later tests were performed using a 4 point loading technique wherein load was applied to two points between the reaction supports. Each of the load application points was located at a distance from respective reaction supports equal to one-third the total distance between the reaction supports. As expected, much higher loads could be applied with considerably less pipe distortion using the 4 point load method. However, the calculated maximum moment and measured deflection for both types of load tests were nearly equivalent, as shown in Fig. 2. The dark or filled points on the graph represent data obtained for the 1/8" thick wall pipe shaft, while the white or open points on the graph represent data obtained for the 1/4" thick wall pipe shaft. As can be seen in the figure, results for 3 point and 4 point loading for the 1/8" thick tube are identical. The load displacement curves obtained for load tests on the 1/4" thick tube display a slight variation, however the maximum moment and total displacement at maximum moment were nearly the same.


Fig. 1  Pipe Shaft Bending Test Apparatus

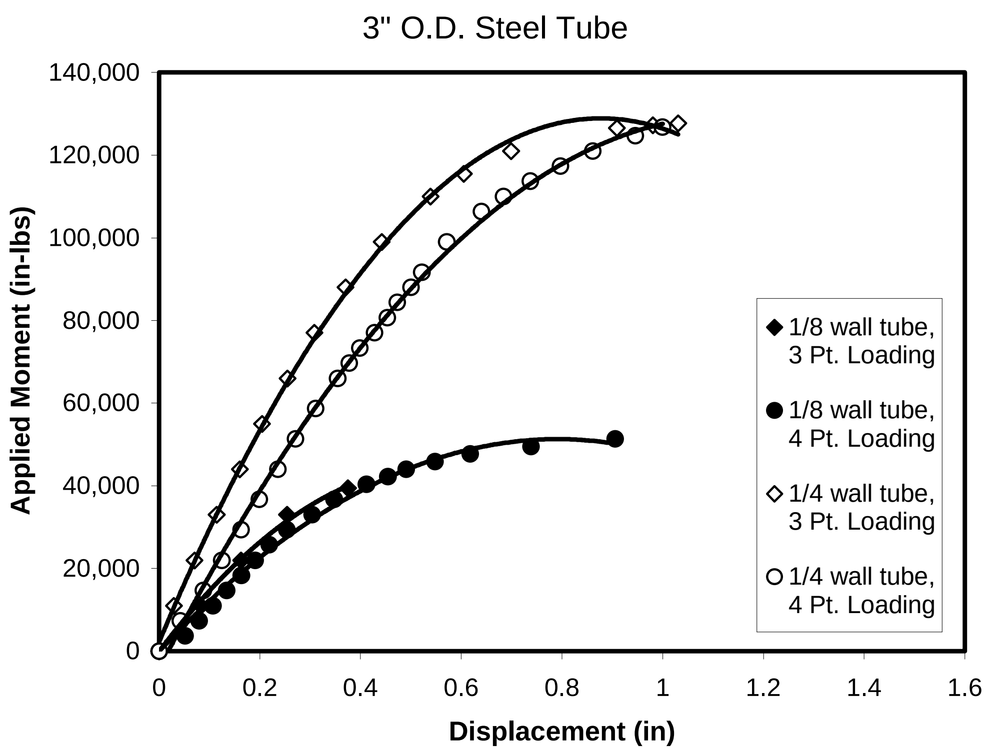


Fig. 2  Effect of Load Application Method

## PIPE SHAFT BENDING RESULTS

Magnum steel push pier pipe shafts are manufactured from high-strength steel, seamless, structural tubing with a 3" O.D. Two different shafts are available with 1/8" and 1/4" thick walls. The steel comprising the structural tube has a minimum yield strength of 40 ksi and ultimate strength of 55 ksi. Section modulus, area moment of inertia, and other properties of Magnum steel push pier pipe shafts are given in Table 1. Area moment of inertia was computed using the well known formula given by

$$I = \frac{\pi(d^4 - d_1^4)}{64}$$

where $I$ = area moment of inertia,
$d$ = outside diameter, and
$d_1$ = inside diameter.

Section modulus was computed by dividing the area moment of inertia, I, by half the outside diameter, d/2. The mechanical bending strengths of the shafts were computed by multiplying the yield and ultimate strength of the pipe steel by the section modulus. Mechanical bending strength is subject to variations in steel strength and tolerances in structural tube thicknesses. Minimum theoretical mechanical bending strength is shown in Table 2.

Table 1. Magnum Push Pier Shaft Specifications

| | 1/8" Wall Pipe | 1/4" Wall Pipe |
|---|---|---|
| Outside Diameter (in) | 3.000 | 3.000 |
| Inside Diameter (in) | 2.750 | 2.500 |
| Area Moment of Inertia ($in^4$) | 1.17 | 2.06 |
| Section Modulus ($in^3$) | 0.78 | 1.37 |
| Cross-Section Area ($in^2$) | 1.13 | 2.16 |

Table 2. Magnum Push Pier Shaft Theoretical Bending Strength

| | 1/8" Wall Pipe | 1/4" Wall Pipe |
|---|---|---|
| Mechanical Bending Yield Strength (kip-in) | 31 | 55 |
| Mechanical Bending Ultimate Strength (kip-in) | 43 | 75 |

Results of bending tests on non-galvanized, non-grouted pier shafts are shown in Fig. 3. As can be seen in this figure, the measured yield and ultimate bending strength of the 1/8" thick wall pier shaft was similar to the calculated values shown in Table 2, whereas, the measured yield and ultimate bending strength of the 1/4" thick wall pier shaft was considerably greater than the calculated values shown in Table 2. This suggests that the mechanical strength of the steel used by Magnum Piering in the construction of their 1/4" thick wall steel push pier shafts was on the order of 73 ksi yield strength and 93 ksi ultimate strength. The values given previously were minimum values. It is suggested that design engineers continue to use minimum values with the understanding that the strength may often be considerably greater. Magnum Piering uses periodic hardness testing and measurement of tube wall thickness for quality assurance.

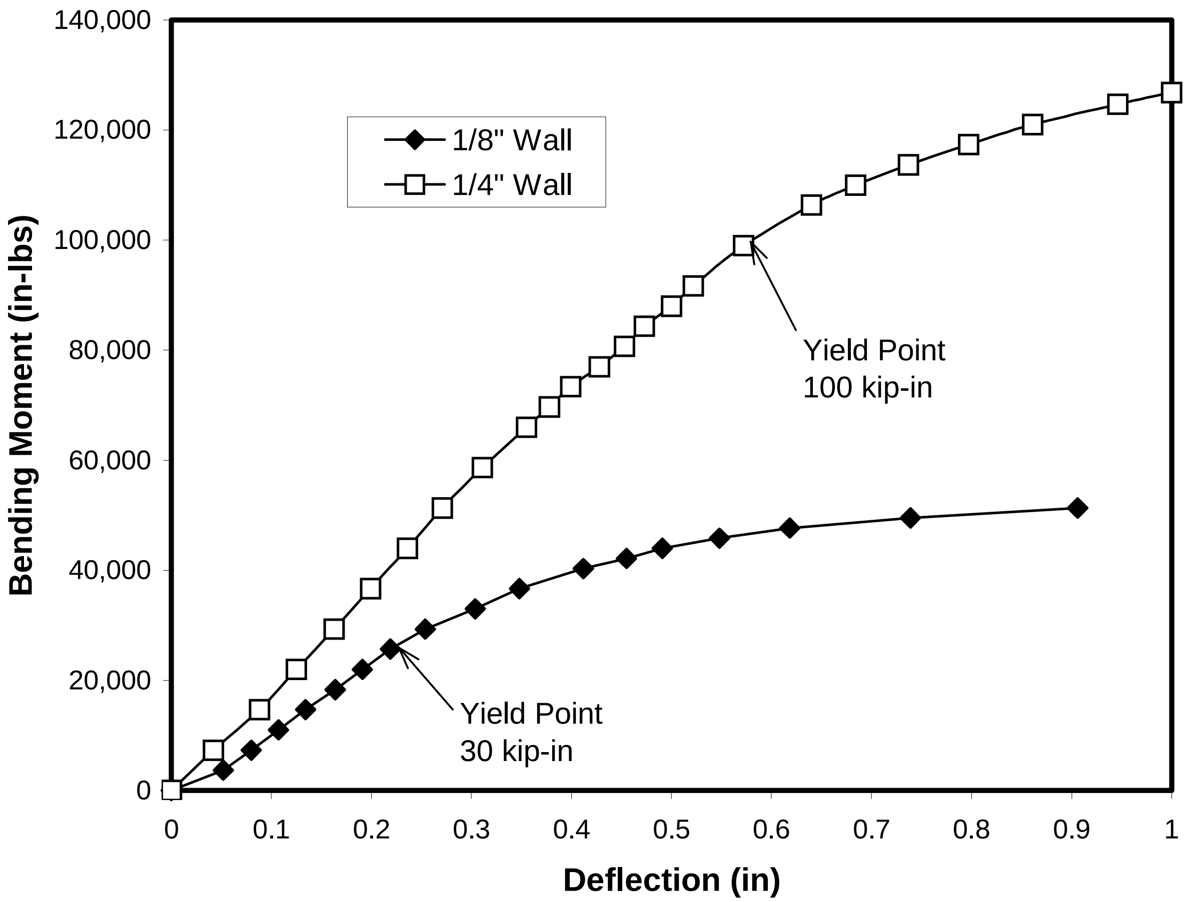


Fig. 3 Bending Resistance of Non-Galvanized, Non-Grouted Steel Pipe Shaft

EFFECT OF GALVANIZATION

For use in highly corrosive soils or when requested by their clients, Magnum Piering utilizes hot-dip galvanization to increase the life expectancy of steel push pier shafts. The process of hot-dip galvanization increases the thickness of the tubular shaft and may increase steel strength due to heat treatment. In order to evaluate the effect of galvanization on the bending resistance of Magnum Push Pier shafts, several specimens were tested that were identical to the specimens described in the previous section except they were galvanized.

Results of these tests are shown in Figs. 4 and 5. As can be seen in the figures, the galvanization process had a considerable effect on the bending strength of the 1/8" thick wall shaft and a negligible effect on the 1/4" thick wall shaft.

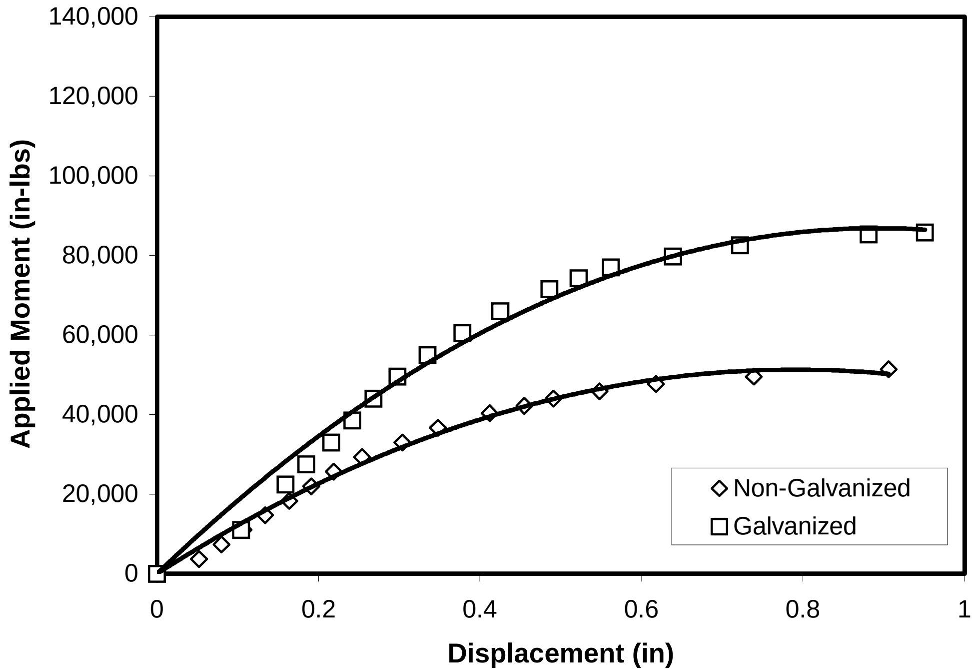


Fig. 4 Effect of Galvanization on Bending Strength of 1/8" Thick Wall Shafts

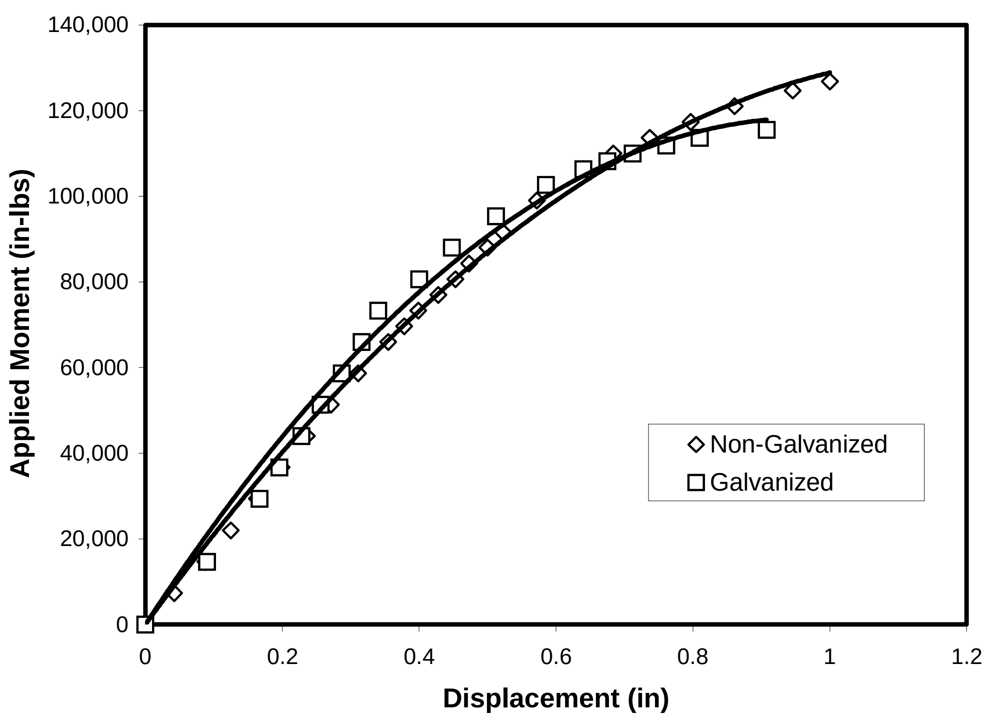


Fig. 5 Effect of Galvanization on Bending Strength of 1/4" Thick Wall Shafts

The galvanization process increased the bending resistance of 1/8" thick wall pier shaft by a factor of approximately 100% (i.e. 2x greater). It is left to the discretion of the design engineer whether to utilize this strength gain in foundation design. Application of galvanization strength gain should be weighed against the life expectancy and corrosion requirements of the project. These strength gains likely will be reduced over time as the zinc coating is sacrificially degraded over time.

## EFFECT OF GROUTING

One method of increasing the bending resistance of steel pier shafts that can be performed after installation is complete is filling the shaft with a high-slump cement grout. A set of tests were performed on non-galvanized pier shaft specimens filled with a minimum 2,000 psi, 28-day compressive strength cement grout. The specimens were allowed to cure in air for 28 days prior to testing. Results of these tests are shown in Figs. 6 and 7. The results indicate that the process of grouting increases the bending yield strength of 1/8" thick wall shafts by approximately 75% (i.e. 1.75x greater) and the bending ultimate strength by approximately 40% (i.e. 1.40x greater). The effect of grouting on the bending strength of 1/4" thick wall tube was considerably less significant with negligible measured increases in the bending yield strength and only 1% increase (i.e. 1.01x greater) in the bending ultimate strength.

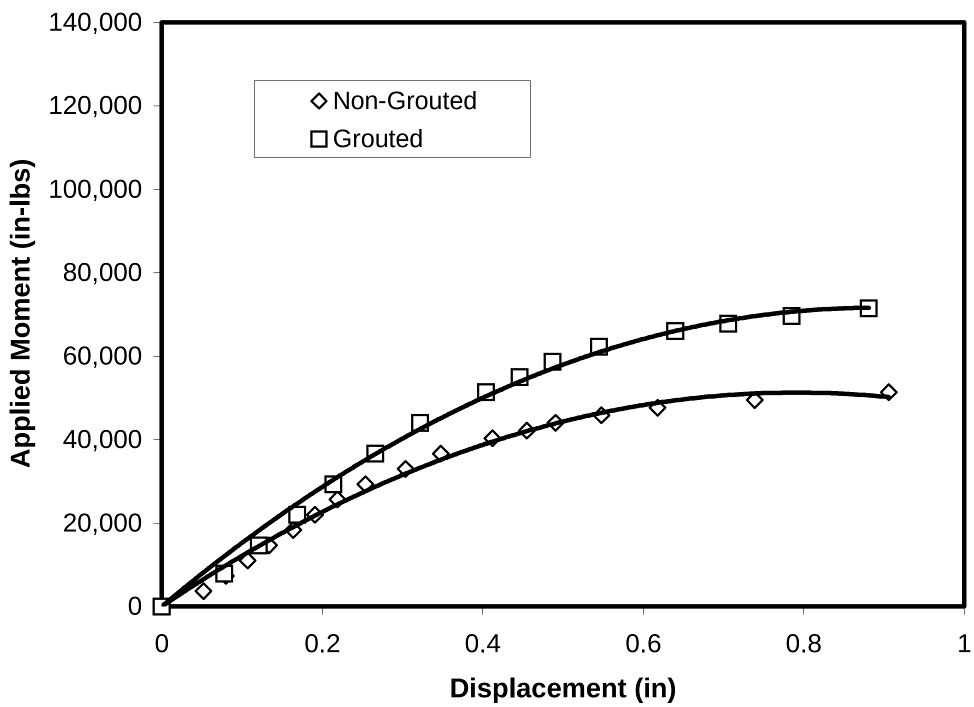


Fig. 6 Effect of Grouting on Bending Strength of 1/8" Thick Wall Shafts

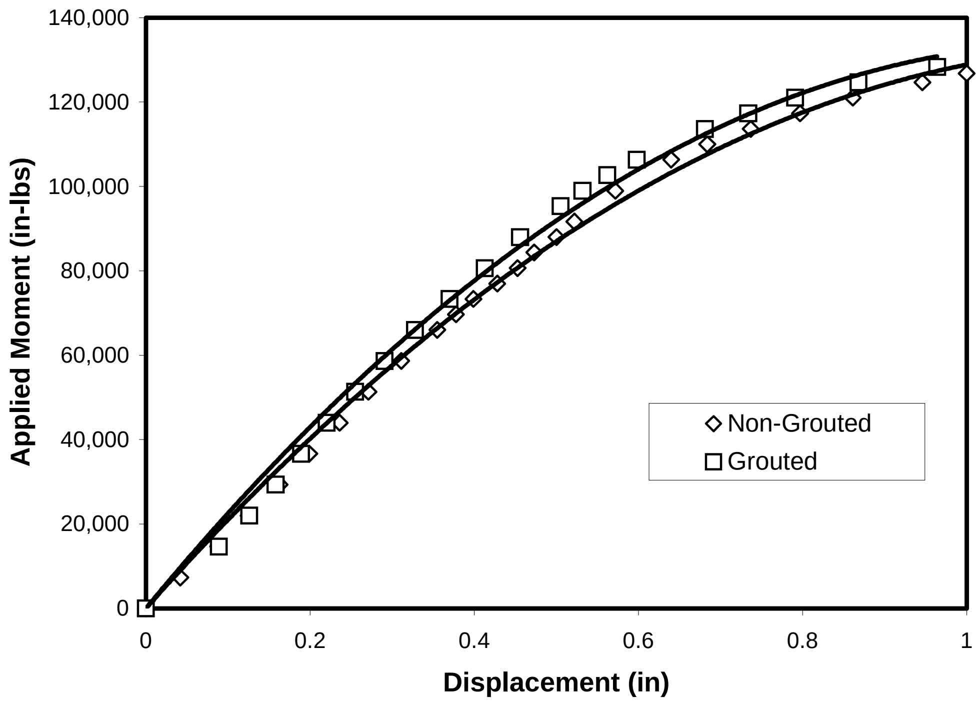


Fig. 7 Effect of Grouting on Bending Strength of 1/4" Thick Wall Shafts

With respect to the ultimate bending strength, the different effect exhibited by the grout in 1/8" and 1/4" thick wall tubular shafts cannot be due to differences in the rigidity of the two pipe sections. Although the 1/4" thick wall pipe shaft has a larger area moment of inertia, as shown in Table 1, and a more steeply sloped moment-displacement curve, as shown in Fig. 2, the displacements at the point of ultimate failure were approximately the same, as shown in Fig. 3. A potential reason for the difference in the effect of the grout is a variation in the diameter of the grouted column. The grout column for the 1/4" thick wall tube is 2.5", whereas the grout column for the 1/8" thick wall tube is 2.75". Since bending strength is a function of the diameter of the column to the $3^{rd}$ power, the smaller diameter grout column should have a bending resistance that is approximately 2/3 that of the larger diameter grout column. When this modification is taken into account, the bending strength of the 1/4" thick wall tube should have been 15% greater than the non-grouted tube with the same wall thickness. However, this value is still greater than the measured result indicating that the interplay of the cement grout and the pipe shaft is more complex and depends on additional factors.

From the foregoing set of tests, it is recommended that the bending yield strength of 1/8" thick wall pier shafts can be increased by a factor of 75% if the shaft is grouted after installation. Similar strength gains were not observed for the 1/4" thick wall shaft.

BENDING STRENGTH OF SHAFT CONNECTORS

Magnum Push Pier shaft sections are manufactured in 36" lengths. Sections are coupled together by means of an internal sleeve that is fixed to one end of the section by two plug welds. Unless otherwise specified, the sleeve is not fixed to the opposing end of the adjoining section, as shown in Fig. 8. At the discretion of the design engineer, the sections can be welded together in the field during installation at additional cost to the project. Welding of galvanized steel push pier sections produces toxic gasses and should only be performed in well ventilated areas using appropriate safety equipment. Most steel push pier installations do not require welding. Hence, it is imperative to determine the bending resistance of the connections between the steel push pier sections.

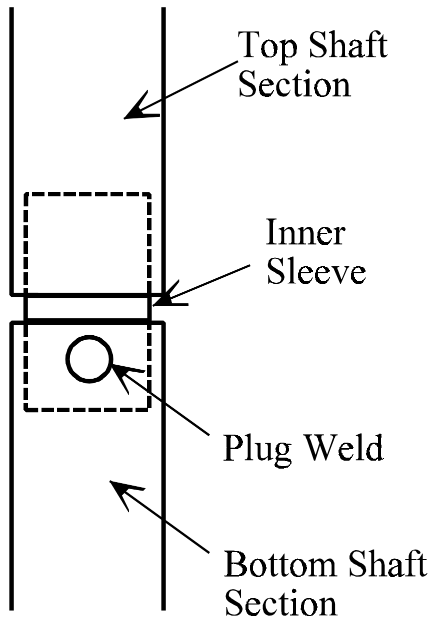


Fig. 8 Magnum Push Pier Connector

The bending strength of the steel push pier connector shown in Fig. 8 is expected to depend in-part on the axial load on the pier. A conservative estimate of the bending strength of the connector supported from buckling by the surrounding soils can be determined by examining the bending strength of the inner sleeve.

Magnum steel push pier pipe shaft connectors are manufactured from high-strength steel, seamless, structural tubing. The outside diameter and thickness of the sleeve depends on the inside diameter of the main pier shaft. The steel comprising the structural tube sleeves has the same minimum yield strength and ultimate strength of the main shaft sections. Dimensional specifications, section modulus, area moment of inertia, and other properties of Magnum steel push pier pipe shaft inner sleeve connectors are given in Table 3. Area moment of inertia was again computed using the well known formula given by

$$I = \frac{\pi (d^4 - d_1^4)}{64}$$

| | | | |
|---|---|---|---|
| where | $I$ | = | area moment of inertia, |
| | $d$ | = | outside diameter, and |
| | $d_1$ | = | inside diameter. |

Section modulus and mechanical bending strength were computed as explained previously. Mechanical bending strength of the inner sleeve connectors is shown in Table 4.

Table 3. Magnum Push Pier Shaft Inner Sleeve Specifications

| | 1/8" Wall Pipe | 1/4" Wall Pipe |
|---|---|---|
| Outside Diameter (in) | 2.750 | 2.500 |
| Inside Diameter (in) | 2.500 | 2.000 |
| Area Moment of Inertia ($in^4$) | 0.89 | 1.13 |
| Section Modulus ($in^3$) | 0.65 | 0.90 |
| Cross-Section Area ($in^2$) | 1.03 | 1.77 |

Table 4. Magnum Push Pier Shaft Inner Sleeve Theoretical Bending Strength

| | 1/8" Wall Pipe | 1/4" Wall Pipe |
|---|---|---|
| Mechanical Bending Yield Strength (kip-in) | 26 | 36 |
| Mechanical Bending Ultimate Strength (kip-in) | 36 | 50 |

Mechanical bending tests were performed on both non-grouted and grouted steel push pier shaft sections. The specimen dimensions, test apparatus, and procedures were as described previously. Results of the tests are shown in Figs. 9 and 10. The measured yield and ultimate bending strength of the 1/8" thick wall shaft connector is similar to the theoretical bending strength of the inner sleeve as given in Table 4, whereas the measured yield and ultimate bending strength of the 1/4" thick wall shaft connector was considerably greater than the theoretical value given in Table 4. These results are again indicative of the typically higher strength steel typically used by Magnum Piering for the construction of its heavy duty 1/4" thick wall piers.

Another conclusion shown by the test data is that grouting of the 1/8" thick wall pier section connectors significantly increased the bending strength (approx. 100% greater), whereas grouting of the 1/4" thick wall pier section connectors produced a smaller effect (approx. 10% greater bending strength).

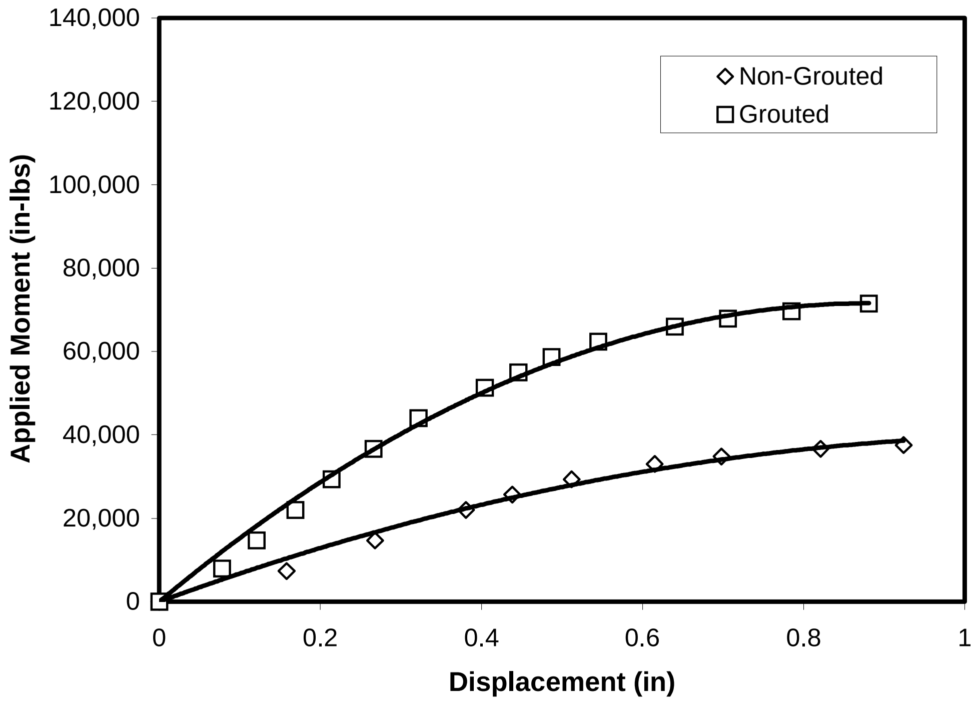


Fig. 9 Bending Strength of 1/8" Thick Wall Shaft Connectors

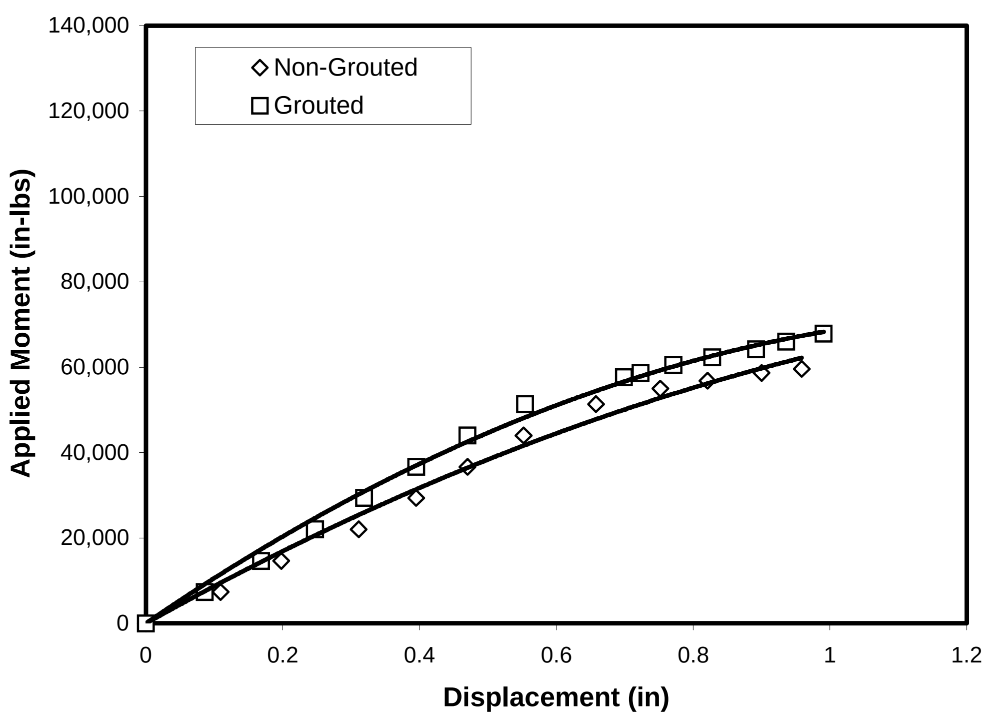


Fig. 10 Bending Strength of 1/4" Thick Wall Shaft Connectors