SESSION 3B-3

The Equalizer: A Smart Material Approach to the Steering Problem

Thomas M. Garrett, Ph.D.
Serguei Savinov
Robert Lys, Jr., P.E.

NO-DIG, A Division of MCP Industries, Inc.
826 E. Fourth St.
Pittsburg, KS 66762

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Thomas M. Garrett, Ph.D.*; Serguei Savinov; Robert Lys, Ir., P .E.
NO-DIG, A Division of MCP Industries, Inc., 826 E. Fourth St., Pittsburg, KS 66762

Abstract

This paper reports on a new smart material approach to the compression ring used in microtunneling pipe. By combining materials with dissimilar Poisson's ratios, strain in the microtunneling pipe is both reduced and transferred circumferentially. Strain gauge data are presented as well as case histories.

Introduction

Microtunneling is the process of installing nonman-sized pipes by unmanned mechanical methods(2). In theory, the pipe move the mole from the jacking pit to the receiving shaft in a straight line (Figure*1). As long as the pipe string extends outwardly in a straight line and all of the forces that are exerted against the rear of the pipe string are translated parallel to the main axis
of the pipe string, all microtunneling pipes are normally able to withstand almost any force that will be applied. A problem occurs, however, if one piece of pipe in the pipe string begins to become non-coaxially aligned with respect to the pipe adjacent to it. And in practice, this always occurs. The line is never perfectly straight but has many small kinks and bends that come about through a combination of steering the mole and having the pipeline bump offboulders and the like during the microtunneling process (Figure 2). This steering puts several new forces on the pipe(3) and, in some cases, can result in breaking the pipe during installation. Naturally, the industry has taken steps to reduce the steering problem but it has not been eliminated.

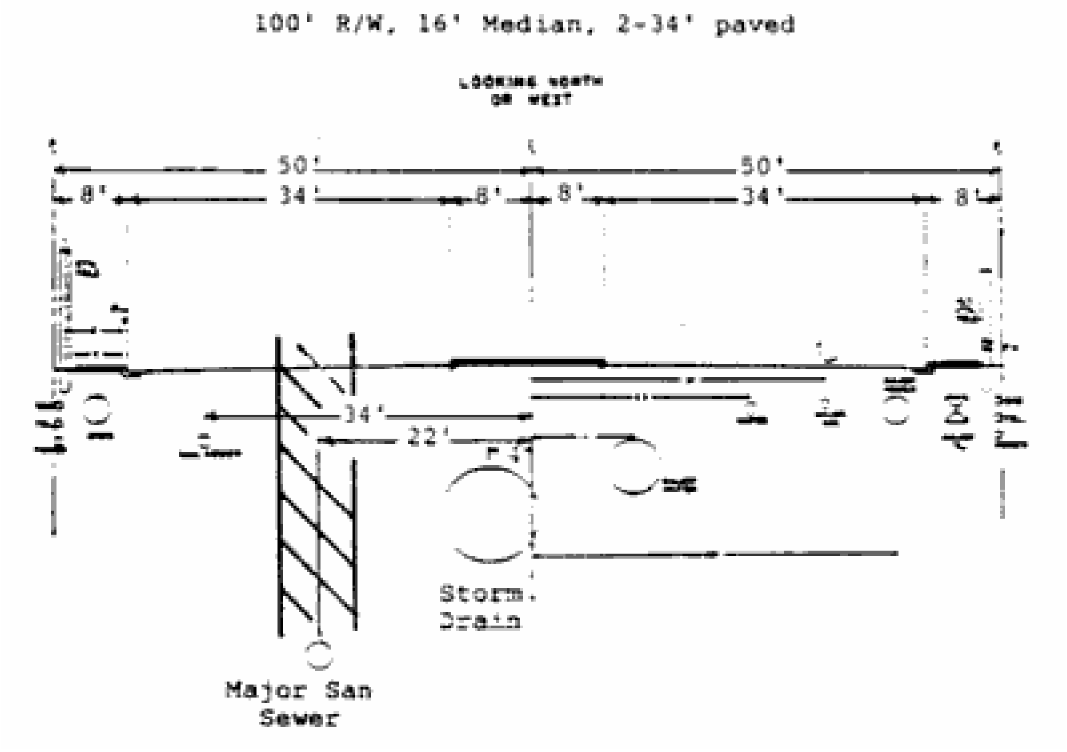


Fig. 1

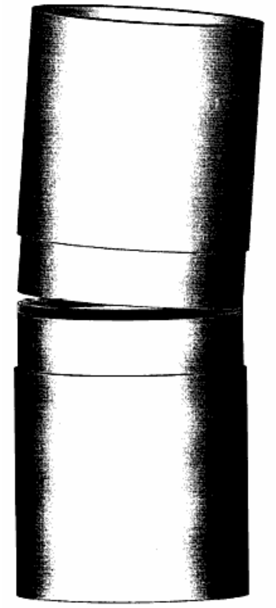


Fig. 2

All microtunneling pipes, made up of whatever material, are designed for axialloads of hundreds of tons. These design loads are given by the minimum surface area that can be jacked against times the compressive strength of the material divided by a safety factor. In other words, the premise for these calculations is that every pipe will be in ruD contact with and mate across the entire surface with every other pipe. Ifthe pipe are deflected relative to each other, even by a small amount, not all of the surface area will be available to take the axial or jacking load delivered by the main jacks (Figure 3). As the deflection increases the load is distributed over a much smaller area than originally designed and can no longer be accommodated by the engineer' s safety factor. Ultimately, deflection results in a point load and the compressive strength of the product can be easily exceeded even under relatively small jacking loads.

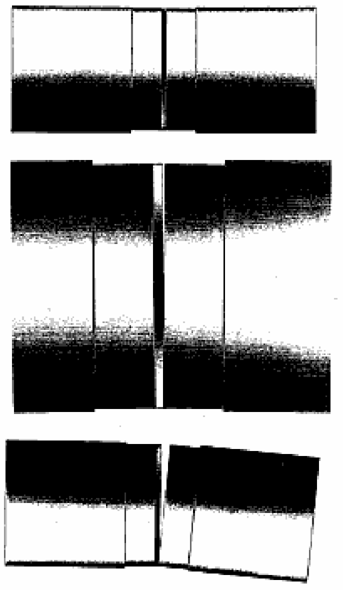


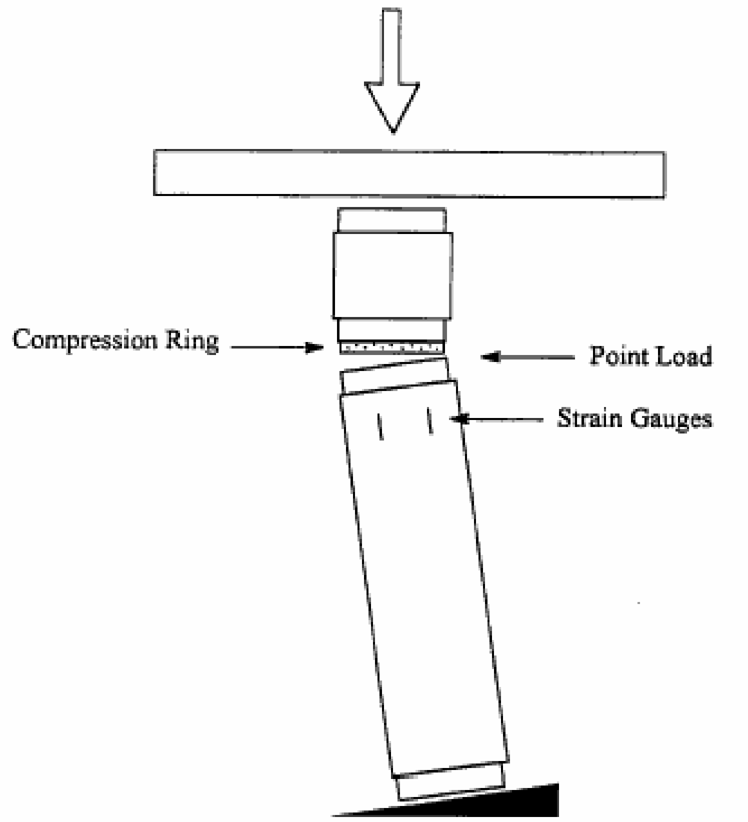
Fig. 3

The compression ring or "packer" is the part of the micro tunneling pipe designed to distribute this load evenly over as much surface area as possible. This ring, as weD as the operator coming back slowly to line and grade (normally no faster than 1" in 25'), have been the industry's traditional response to the steering problem. A perfect ring would take a point load and transform it into a load that is distributed over the full 3600 of available area. Current technology does not begin to approach this ideal, however. This paper will describe our approach of using smart materials to improve the performance of the compression ring, reducing the problems associated with steering.

Experimental

Testing was performed on the rig shown in Figure 4. A four foot 12" NO-DIG pipe was deflected from a true vertical position by a fuD circle steel plate machined with a 50 incline. Force was applied using a 9 inch section of 12" NO-DIG pipe and a calibrated beam and hydraulic jack(4)

in
5,000 pound increments up to 40,000 pounds total. It was fitted with Model CEA-03-S00UW-350 strain gauges(5-7) (Micro Measurement Division, Measurement Group, Raleigh, NC) at 0, 30, 60, 90, and 180 degrees from the point load on both the inside and outside of the pipe. Compressive strain was measured in micro-inches relative to the unstressed state on a Baldwin-Lima-Hamilton model P-3S0A gauge.



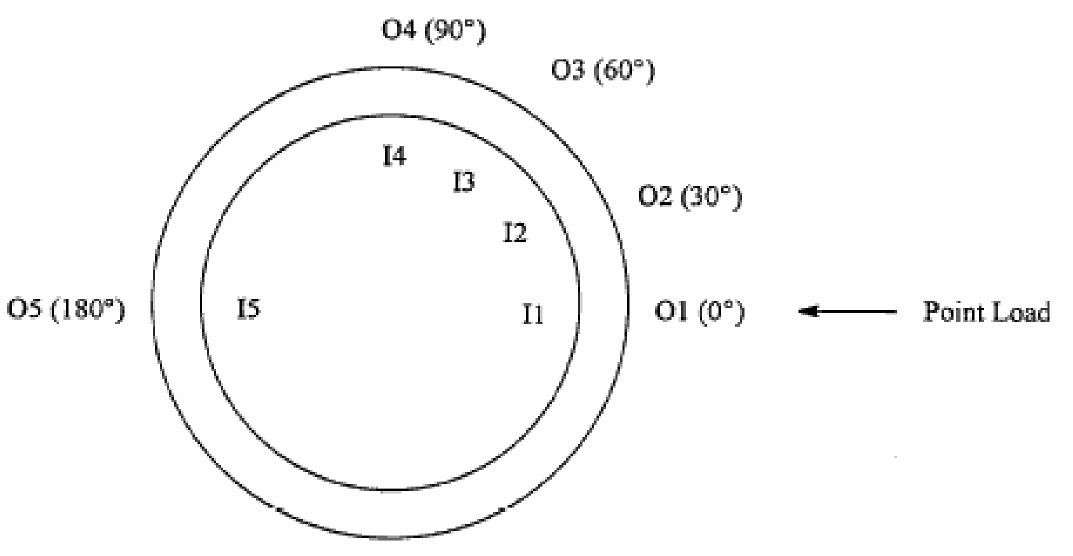
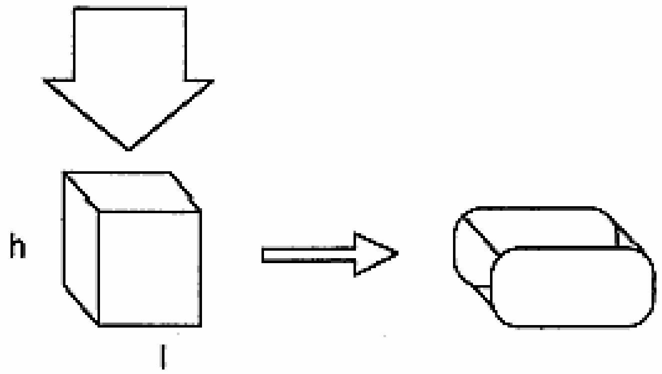


Fig. 4 Strain Guage Testing Rig

Results and Discussion

Materials

Previous workers in this field found that the abilities of the packing ring were correlated to Poisson's ratio(8-13). Poisson's ratio is the longitudinal deformation produced by simple compressive defor mation(14)



$$\frac{\Delta h}{h} = -\sigma \frac{\Delta l}{l}$$

Where σ = Poisson's ratio

Figure 5. Poisson's ratio.

In particular, it was found that the ring material should have a Poisson's ratio in compression near to zero. Fiberboard, chipboard, plywood, wood, elastomers, polyethylene, polypropylene, fiber-reinforced polypropylene, and nylon were all examined. The best materials were thick, wet, and made up of little pieces of wood glued together. Fiberboard, measured as the most compressible, was thought to perform the best, followed by chipboard. Incompressible materials with high Poisson's ratio, such as elastomers, performed miserably and were not thought to be useful materials for compression rings.

Pipe are moved through the soil in only two regimes: straight and bent. We were therefore intrigued by the concept of smart materials. A smart material(15-17) behaves differently under different types of stress. A compression ring made of a smart material would "know" when the pipe were straight and transmit load laterally from one pipe to another (Figure 6a). But it would also "know' when the pipe were deflected relative to one another and would then attempt to spread the point load out around the pipe circumferentially (Figure 6b).

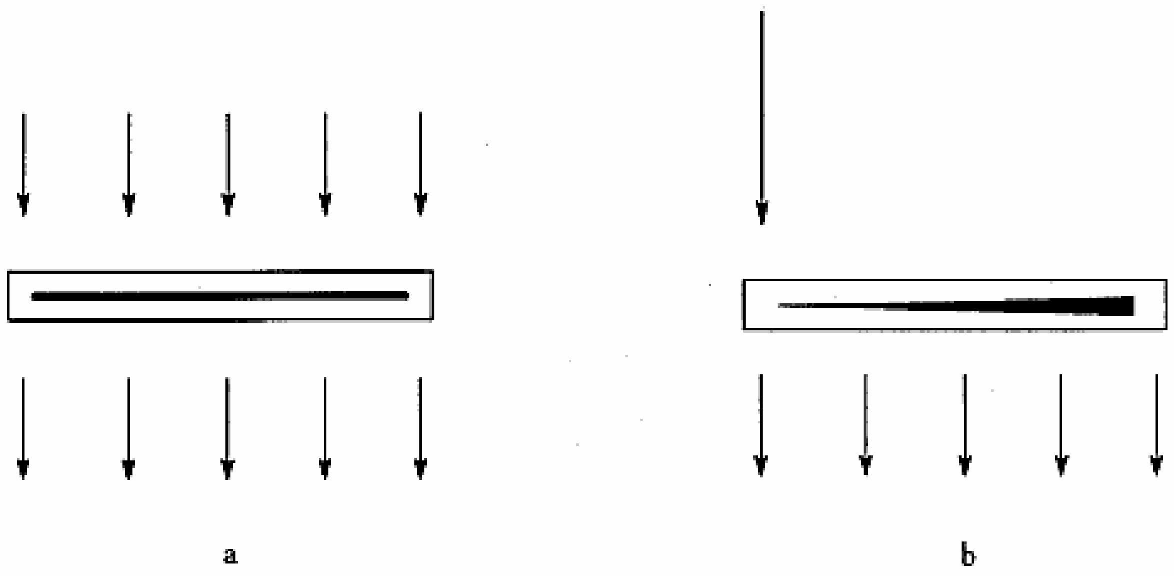


Figure 6. Properties of a compression ring made of a smart material.

The key insight to making a smart material compression ring was to use two dissimilar materials, one of which had to flow like water from the point load circumferentially around the bearing surface bringing the load with it as it came. Both urethane and rubber were investigated (poisson's ratio = 0.5) as it was already well established that they would undergo viscous flow and stress relaxation(18-19). For the matrix in which this "load lazy" material was to be suspended we chose an industry standard chipboard (poisson's ratios 0.3). Prior work had identified this as a suitable material especially for the straight pipe regime. The low Poisson's ratio material was to transfer the stress in both regimes. The high Poisson's ratio material would do nothing when the pipe were aligned but when pinched upon misalignment during steering would act to move the stress away from the point load.

Design

To date 18 different designs have been tested (Figure 7). The strain gauge performance ofthe various designs are summarized in Table 1.

Table 1. Performance of Various Smart Material Designs*

Design	Δμ-inches	Design	Δμ-inches
Chipboard	80-120	11	100
1	92	12	25
2	105	13	90
3	80	14	60
4	125	15	40
5	60	16	100
6	70	17	6
7	130	17a	30
8	72	18	45

9	63
10	25

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*Measured as the difference between strain immediately below the point load and 900 away from below the point load, 40,000 pound load, interior gauges. **Measured as the difference between strain immediately below the point load and 600 away from below the point load, 40,000 pound load, intcrior gauges. (a)Design 17 where rubber is usaf in place of urethane.

A smaller difference between the strains below the point load and those at 900 to the point load indicate a more equal distribution of strain. Since we are striving to equalize strain, a lower number in the table above indicates a superior result. Several important conclusions can be drawn. When urethane(l) and rubber are tested in the same design (17) the difference in strains is less with the urethane, therefore urethane out performs rubber. The worst results (e.g. 7) occur when the urethane is not contained, the best (e.g. 10 and 17) when the urethane is fully contained,
therefore contained urethane is better than free. No difference was seen between plywood and chipboard. Particle board proved unacceptable. Symmetrical designs gave more reproducible results.

Design 17 was chosen to put into production as "The Equalizer" compression ring as it showed a happy combination of both the best results and ease ofmanufacture. It is essentially a composite sandwich of a urethane O-ring between two layers of chipboard. Figure 8 shows a graphic comparison of The Equalizer to the prior art. Maximum strain, at a 40,000 pound point load, has been reduced from 200 micro-inches to just over 150 micro-inches. The load, as shown by the main, is equally shared by over 1800 of pipe circumference. This compares favorably with the performance of the previous technology where the load is shared equally only over 600 on the inside gauges and 300 on the outside gauges. Figure 9 is a strain concentration graphic where the two technologies have been compared. Distribution of the load is shown by shades of grey. The highest strain is shown in black, no strain in white. It can be easily seen by means of this representation that in spite of the fact the pipe has been point loaded and the joints are gaping open, the Equalizer has (1) spread the stress out over the bulk of the available surface area in the joint and (2) lowered the maximum strain experienced by the pipe. The chipboard ring, while avoiding a point load, retains a severe area load. It has been suggested by some that an elastomeric ring would inhibit even transfer of load. These results indicate the opposite, that transfer of load is evened out and improved by The Equalizer.

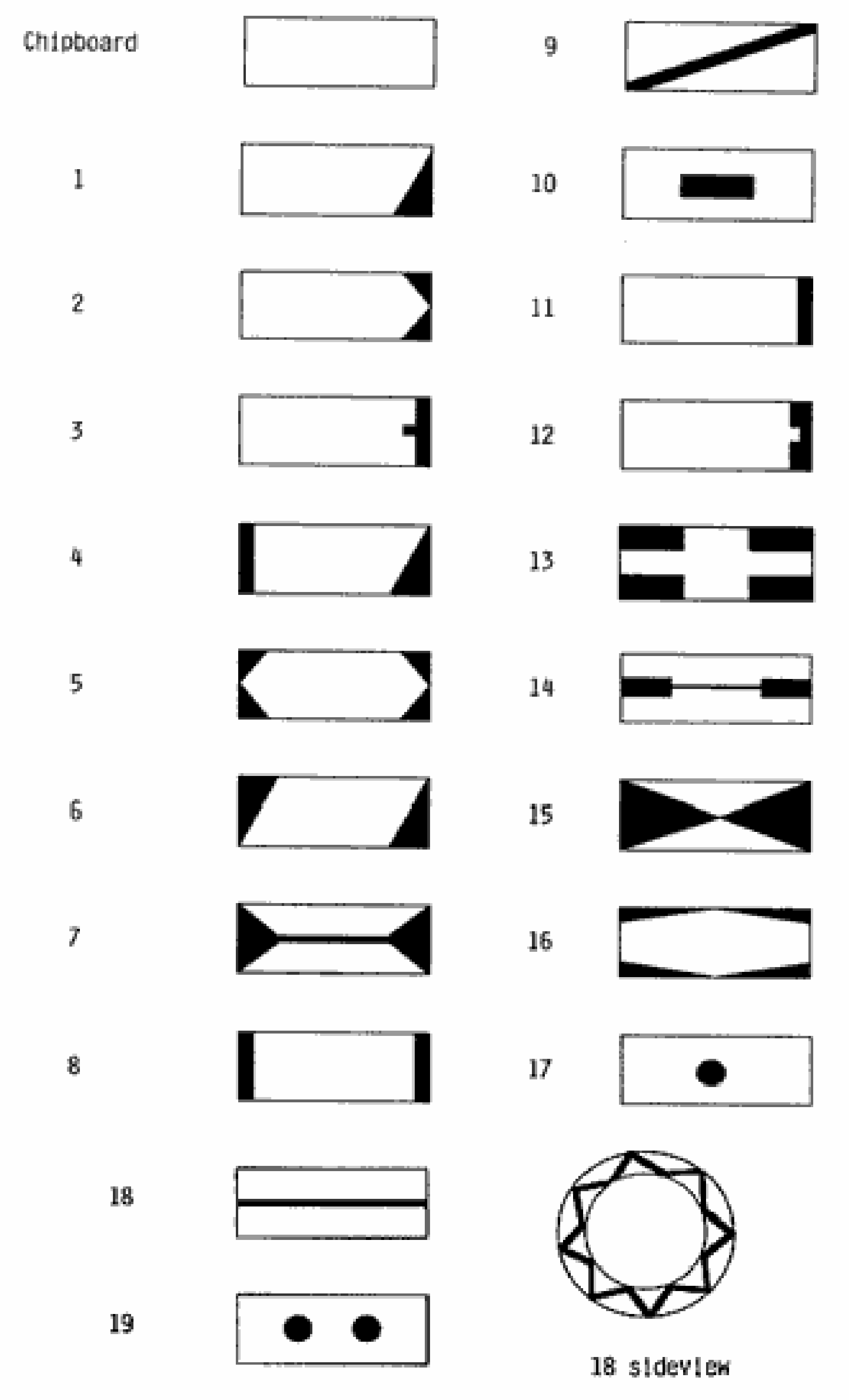
Case Histories

The Equalizer was used on the Rosemond and Nordling Relief Sewers project in Houston, Texas.

This project was unique in that a 586 linear foot drive with 30" pipe was completed with no problems and in the scheduled time frame. Since long drives have a greater likelihood of deviations and steering problems this case was taken as archetypal for the advantages of using smart materials in the compression ring. A total of 5460 linear feet of pipe were installed in a sticky, sandy clay with axial forces of up to 180 tons.

Two projects in the Utoy Creek Basin of Atlanta, Georgia used Equalizer compression rings on two different sizes of pipe, 12" and 500 mm. The 12" pipe was driven 356 feet with a maximum jacking load of35 tons. The 500 mm pipe was driven 455 linear feet with a maximum jacking load of 60 tons. A total of 12,000 linear feet were installed in typical Georgia cJays.

To date over 25,000 linear feet of micro tunneling pipe have been installed using the Equalizer. While job problems have by no means been eliminated, in general these jobs have been characterized by longer drives and fewer broken pipe.



Conclusions

Strain gauge data in the laboratory have shown that a compression ring designed with a smart material approach is superior to conventional technology. Case histories of use in the field demonstrate that such a ring resulted in longer and more successful microtunneling installations. The steering problem has not been fully eliminated, but the point loading involved has been significantly reduced.

Acknowledgments

The authors gratefully acknowledge Lewis Bertalotto without whose work this paper could not have been presented.

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