Technology for the Tele-Robotic Laying of Large and Small Pipes

Dr. Leonhard E. Bernold [1], M. ASCE
Dr. Bin Li [2]

Abstract

The labor intensive construction industry has a very high accident rate. One of the key reasons for this is the exposure of workers to a hazardous environment such as heights, confined narrow spaces, and exposure to health threatening fumes, dust, and noise. Teleoperation, which allows a construction worker to control a mechanical tool from a safe location provides a technical alternative. Because of the need to be competitive on every project-bid, contractors have to be assured that new technologies not only work in the rugged environment of a construction site but that they also reduce cost. This paper will present one example of such a technology, a remotely controlled manipulator that allows the installation of large concrete pipes. It is apparent that eliminating the presence of humans in danger zones makes OSHA regulations mute. The resulting cost savings had three sources: 1) reduction in excavation volume, 2) reduction in material to be backfilled and compacted, and 3) reduction in man-hours. While successful, the field tests also highlighted opportunities for improvements which led to a new development phase.

Introduction

According to the Bureau of Labor Statistics (1999), in 1997 there were 1,137 deaths in the construction industry. This number equals 18% of the total fatalities from all industries and indicates that construction has the highest number of fatalities as shown in Fig. 1. Another source shows that the construction industry employed approximately 5% of the industrial work force, but generally accounted for nearly 20% of all accidental deaths (National Safety Council, 1997).

A trench (trench excavating) is defined as a narrow excavation (in relation to its length) made below the surface of the ground (Occupational Safety and Health Administration; OSHA, 1989). In general, the depth is greater than the width, but the width of a trench is not greater than 15 feet (4.6 m). Since the trench normally requires narrow and deep excavation, the working environment is always hazardous.

[1] Associate Professor, Dept. of Civil Engineering, NC State University, Raleigh, NC 27695; phone 919-515-3677; bernold@eos.ncsu.edu
[2] International Scholar, Construction Automation & Research Laboratory, NC State University, Raleigh, NC, 27695; phone 919-515-3677; bli5@unity.ncsu.edu

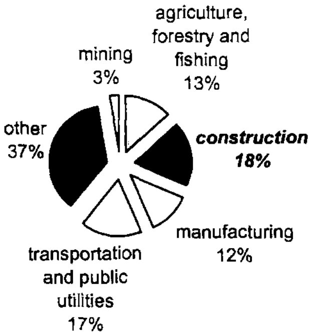


Figure 1. Industrial Fatalities (1997)

The traditional ways to prevent collapse and make working in a trench safe are (1) providing physical supports for each side of the trench using shoring or a trench box, or (2) sloping the sides to a safe angle.

Even though diverse support systems such as shoring, shielding, and sloping are to be applied to protect workers from cave-ins in trench excavating and pipe laying operation, trench cave-in accidents still happen causing fatality or serious injury to workers. The accidents mainly occur because of ignored safety regulations/standards or improper installation of protective systems. One possibility to circumvent this predicament is a technological intervention which would eliminate the need for a worker to enter the hazardous trench.

Overall Design of a Tele-Robotic Pipe-Manipulator

Fig. 2 depicts a schematic of the manipulator. The main components are man-machine interface, actuation system, laser beam system and feedback system. The operator has two different joystick controls to control 1) the actuation of boom, stick, and bucket, and 2) the actuation of manipulator.

The actuation system has the following five functions:

1) *H. Actuator (A_Rot1)*: A hydraulic actuator provides the limited ±100 degrees rotation of the pipe in order to line up the pipe.
2) *H. Actuator (A_Rot2)*: A hydraulic actuator provides a locking mechanism on the back of the manipulator to prevent it from slipping off the bucket.
3) *H. Cylinder (C_Trans)*: A hydraulic cylinder provides a linear activation of the pipe to joint the new pipe to the pipe already laid.
4) *H. Bladders (B_Clamp)*: Hydraulic bladders provide an inflating and deflating mechanism to clamp the manipulator to the bucket.
5) *E. Winch (W_Hold)*: An electric winch is used to attach the pipe with a quick release.

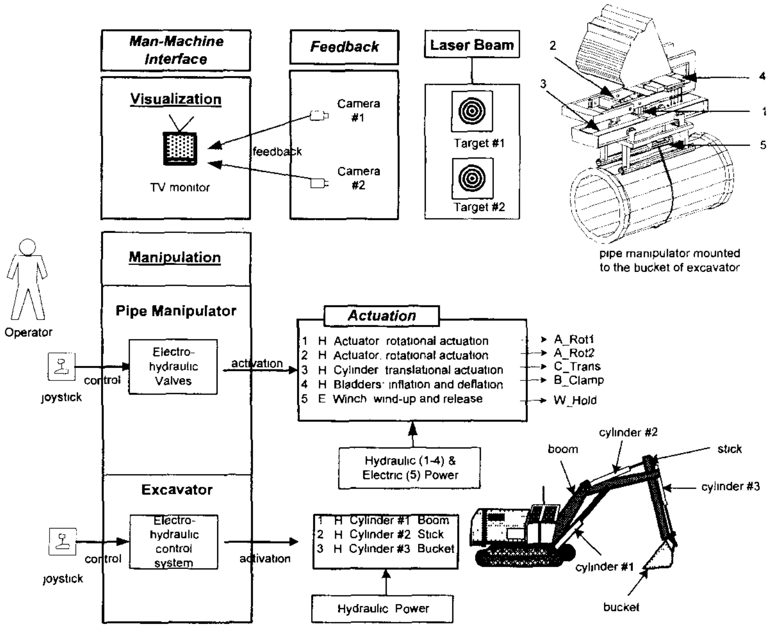
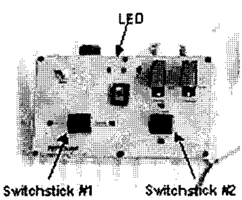


Figure 2. Schematic Overview of Teleoperated System

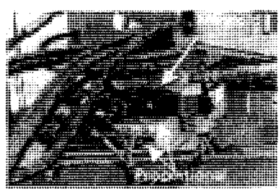
As can be seen from Fig. 2, the main concept is based on creating a strong attachment to the excavator bucket able to carry and manipulate a large pipe (Lee at al., 1999).

Remote Control System

A control box was designed and fabricated for remote control as shown in Fig. 3 (a). The power come from the 24VDC generated by the excavator. The control box includes three three-way switches, and one main power on/off switch. Switchstick #1 controlled rotational actuation of the hydraulic actuator (A_Rot1). Switchstick #2 controlled the hydraulic cylinder (C_Trans) that pushes the pipe into the bell of the previously installed pipe.



a) Control box



b) Manifold and electro-hydraulic valves

Figure 3. Hydraulic Control Electronics

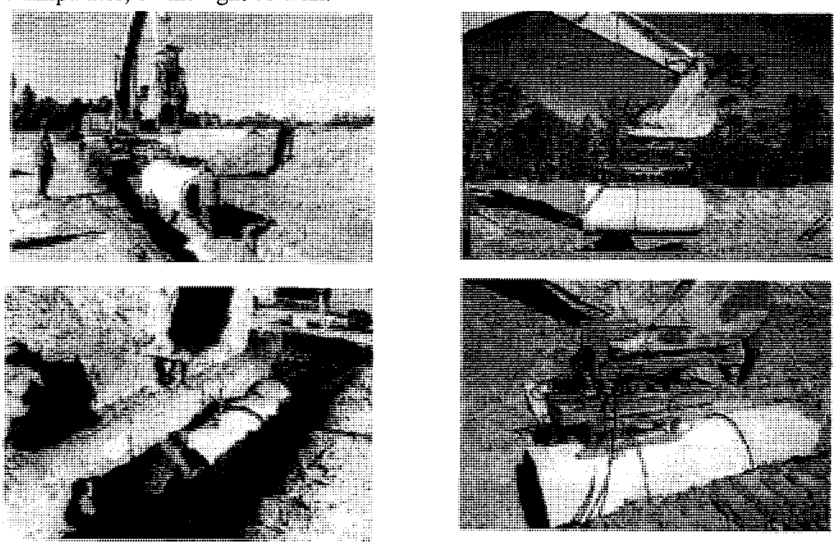
Three proportional electro-hydraulic valves are mounted on a manifold as the only hook-up point for the entire system. In other words, the only action that is needed to deploy the system is the connection of the manifold to the hydraulic system of the excavator via a hose with quick-connect.

Field Test

A comparative field test was conducted on the job-site of East Park Industrial Subdivision in Raleigh, NC comparing two methods of laying pipe: 1) traditional method, and 2) telerobotic. Site conditions including soil, trench width and depth, pipes, crew members, and even the weather as the same.

On the first day the crew members laid concrete pipes the way they normally do one day, and the manipulator was used to do the same tasks the other day. The soil condition of the job site was sandy clay, and a concrete pipe of 36-inch (0.9 m) diameter and 8 feet (2.4 m) long was used as a material. The trench was 6 feet (1.8 m) deep, and a benching method was used as a protective system. The excavator (CAT 330 L) was used to excavate the trench.

Fig. 4 shows pipe laying using both the traditional, on the left side, and with the pipe manipulator, on the right column.



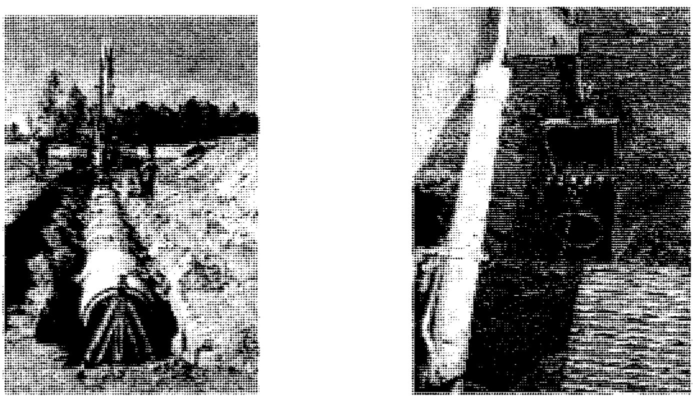
a) Traditional Pipe Transportation and Jointing b) Pipe Installation with Pipemanipulator

Figure 4. Comparing Methods of Pipe Installation

Comparative performance evaluations were conducted from the data collected during the field test in terms quality, productivity, and economics. The cost savings of the new technology had two sources: 1) reduction in excavation volume and 2) reduction in man-hours. Since OSHA regulations do not apply anymore the sloping or trench box requirements no longer have to add "human" safety factor into calculations leading to the reduced cost for excavation, a benefit that increases with depth of the trench. Responses from workers during the comparative field test were evaluated regarding not only the feasibility of the new technology and its limitations but also practical improvements for the next generation.

Technical Performance Evaluation

The main goal of the field test was achieved when, after only 15 minutes of training, the excavator operator was able to line up a pipe with final alignment using teleoperated control and a video system without anybody in the trench. The accuracy of alignment was assessed by the operator's acceptance through comparing the results between the two different laser set-ups (inside of the pipe and on the top of the pipe). Then, the operator activated the linear actuation of the carriage of the manipulator in order to joint the bell of the new section to the spigot of the already laid pipe. The workers learned how to operate the manipulator very quickly because of its ease of operation. The workers became familiar with the new process in several successive repetitions. The workers laid the last 2 pieces of pipes at a consistent shorter cycle time than the first 3 trials.



a) Completion of Comparative Field Test b) Field Test in Deep Trench

Figure 5. Successful Field Tests with Pipeman

As indicated in Fig. 5, several field tests were completed in order to prove feasibility and to find ways to improve the basic concept of telerobotic control.

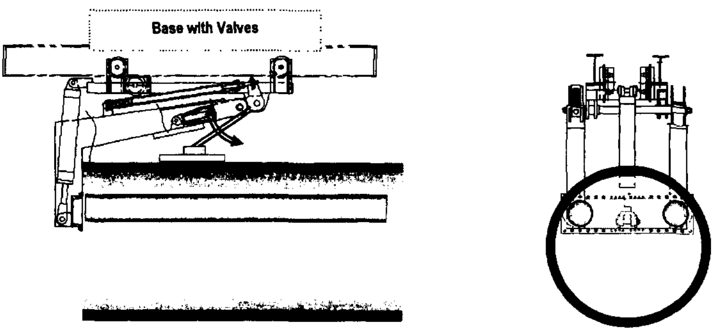
Cost Comparison

The main cost items of a pipe installation job consist of: a) excavation and bedding, b) pipe laying, c) pipe manipulator rental, d) backfill & compaction, and e) insurance. Volume of excavation for the traditional method, 21 m^3, includes the benches as shown in Figure 4 while the volume for the alternative method, 11.6 m^3, is based on vertical trench walls with a minimal width as required for proper haunching. As expected, the resulting cost saving, $ 7.52/m or 54%, was significant.

Overall, the total cost for the excavation and laying of 36 inch (0.9 m) concrete pipes into a 6 feet (1.8 m) deep trench during the field tests are $53.7 per meter ($16.37/ft) for the traditional method and $ 65.54 per meter ($20/ft) for the observed tele-robotic method. As was anticipated, the tele-robotic option turns out to be more expensive mostly as a result of the higher cycle time, the result of the broken winch. However, simple improvements should undoubtedly result in reducing the time for laying one pipe.

Third Generation PipeMan

Based on the encouraging results of the field test, it was felt that the basic concept of PipeMan was solid. One main problem, however, was the weaknesses of the winch that was used to push the pipe to the carriage. A second issue was the inability of adjusting the grade without the bucket. This capability would allow an excavator to be positioned on the side of the trench. The following section will present an alternative method of holding the pipe.

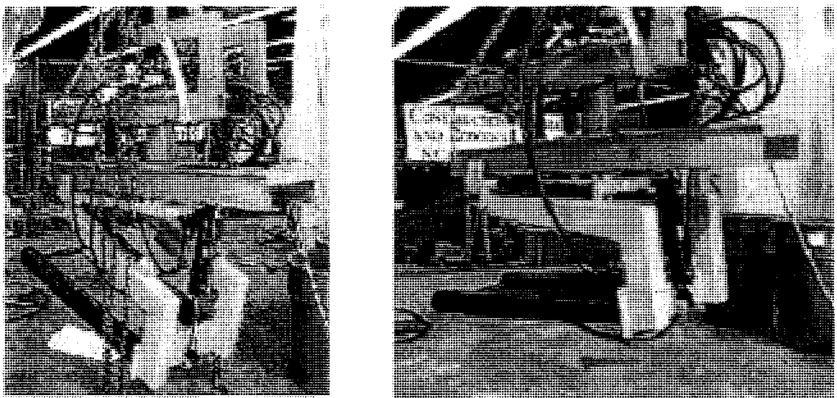


a) Side View with Pipe b) Front View

Figure 6. Pipe Manipulator Carriage With Prongs

The flexibility of the system design allowed us to consider exchanging the carriage holding the winch while keeping the base, holding all the controls. It was decided to fabricate an alternative to the original carriage that was based on the flexibility provided by prongs. Figure 6 presents the new design. As indicated, the pipe will be lifted simply by inserting the prongs into the pipe. A mechanical stopplate is automatically engaged when the weight of the pipe is taken over by the prongs. This stops the pipe from sliding off.

One weakness of PipeMan was the fact that it could only be used in the axis of the trench since the slope of the pipe had be adjusted using the bucket. In order to allow a backhoe to lay pipes from the side of the trench, a degree of freedom had to be added. Figure 7 presents the final solution that allows the flexible adjustment of the pipe inclination with having to rotate the bucket.



a) Maximum Grade b) Minimum Grade

Figure 7. New Flexibility for Achieving Proper Grade

Due to bad the weather since October 2002, the newest version of the Pipe Man has not yet been tested in the field. Most recently, a wireless communication channel between the control box and the valves has been installed and tested.

Conclusion

Traditional trenching and pipe laying requires workers to enter the trench, resulting in many fatalities due to the nature of the soil in the trench walls and other work related circumstances. The telerobotic concept promises to drastically reduce the risk to human life by keeping the worker outside of the trench. This paper presented the major components and functions of the newest version of the teleoperated pipe manipulator that has been designed and fabricated to handle pipes that use o-ring connection. The new technology proved its technical feasibility by laying 8 piece of concrete pipes without any workers in the trench. The field test highlighted too that with the help of technical modifications, the system would also be cost effective. These modifications have been implemented to create the third generation PipeMan.

Acknowledgments

Funding for the work has been provided by Public Health Service-National Institutes of Health under contract 5 R01 CCR413051-02 and 1R01 0H04201-01. Its content is solely the responsibility of the writers and do not necessarily represent the official views of NIH.

Reference

Lee, J., Lorenc, S.J., and Bernold, L.E. (1999). "Saving Lives and Money with Robotic Trenching and Pipe Installation," ASCE Journal of Aerospace Engineering, Vol. 12, No. 2, ISSN 0893-1321, April 1999, pp. 43-49.