MINIDIRECTIONAL DRILLING FOR INSTALLATION OF UNDERGROUND ELECTRICAL CONDUIT

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ABSTRACT: The Salt River Project (SRP), located in Phoenix, Ariz., uses two different construction techniques to install conduit for new underground electrical systems in the Phoenix metropolitan area: open-trench cutting by conventional backhoes or wheel trenchers, and trenchless excavation techniques with minidirectional drilling machines and trenchless technology. This paper presents the results of research conducted to determine the comparative installation costs of conduit for SRP's underground electrical distribution, comparing the cost of conventional open trenching with minidirectional drilling. The study compared cost information that will aid SRP designers in optimizing the selection of site-specific underground electrical-conduit placement techniques. The research considered economies of scale, terrain, soil types, materials, and various common configurations of electrical conduit systems. In the years ahead, utility companies around the country may investigate the feasibility of minidirectional drilling to replace open trenching, especially in congested areas where the maintenance of good public relations is important. The analysis presented in this paper may provide a basis of comparison for other utility companies.

INTRODUCTION

The Salt River Project (SRP), located in Phoenix, Ariz., is a multipurpose reclamation development that provides water and electrical power to a 7520 km^2 (2,900 sq mi) service territory located in Maricopa, Gila, and Pinal counties, Ariz. SRP's electrical system is capable of delivering over 18.3 billion kW·h of power each year to a customer base of approximately 550,000 wired units, and includes 18,185 circuit miles of underground cable.

SRP uses two different construction techniques to install conduit for new underground electrical systems in the Phoenix metropolitan area. Open-trench cutting by conventional backhoes or wheel trenchers is the oldest and most common conduit-placement method. Since 1987, SRP has also been using new trenchless excavation techniques with minidirectional drilling machines to install conduit.

Like most electric utility companies, SRP routinely chooses between open trenching and trenchless technology without the benefit of any cost-comparison data. Such subjective decisions can significantly impact the capital construction budget, because conduit placement generally accounts for 40–60% of the total cost of installing underground electrical systems, based on total job costs at SRP from 1990 to 1993. Conduit-placement decisions also impact owner-provided material requirements, jobsite safety, customer-service levels, and public relations.

This paper presents the results of research conducted to determine the comparative installation costs of conduit for SRP's underground electrical distribution, comparing the cost of conventional open trenching with minidirectional drilling. The study compared cost information that will aid SRP designers in optimizing the selection of site-specific underground electrical-conduit placement techniques. The research considered economies of scale, terrain, soil types, materials, and various common configurations of electrical conduit systems.

The findings of this study are limited to SRP's metropolitan service area, and are based on an evaluation of competitive bids for trenching and minidirectional drilling since 1990.

In the years ahead, utility companies around the country may investigate the feasibility of minidirectional drilling to replace open trenching, especially in congested areas where the maintenance of good public relations is important. The results of this research may be adapted to other locations by utility companies. However, although the analysis presented in this paper may provide a basis of comparison for other utility companies, the methods should not be adopted directly without a study of local costs, soils, availability of equipment, and other factors that could render these cost comparisons invalid in another location.

DIRECTIONAL DRILLING TECHNOLOGY

Directional drilling was developed in the United States and features a steerable tunneling system for the installation of utility lines. The directional drilling process begins with a small diameter pilot hole that is bored through the earth with a steerable mechanical cutter or fluid jetting tool. The location of the bore head is monitored by a portable electronic detection system, which is moved by hand along the ground above the bore head. It senses the depth and horizontal position of the bore head, which transmits a signal. After the pilot hole is complete, it is enlarged to the required diameter by back-pulling a wedge-shaped reamer. A steel, polyethylene, plastic, or cable utility line is attached to the back of the reamer and trails the reamer into the bore hole for final installation.

Directional boring methods have been classified as either *horizontal directional drilling* or *minidirectional drilling*. Horizontal directional drilling rigs are capable of installing large-diameter underground utilities of up to 1.02 m (40 in.) in diameter and of up to 1.83 k (6,000 ft) in length, and are of no concern to this paper. Minidirectional drilling rigs are much smaller and more mobile than horizontal directional drilling rigs (Fig. 1). They can install small diameter utilities (up to 18 in. in diameter) of up to 600 ft in length.

Minidirectional drilling techniques have been used successfully to install underground electrical conduit in urban areas that have narrow utility easements congested with sewer, water, gas, telephone, and cable-television systems. Directional boring techniques are necessary to minimize damage to existing utilities. Minidirectional boring machines are small, versatile, and easily maneuvered.

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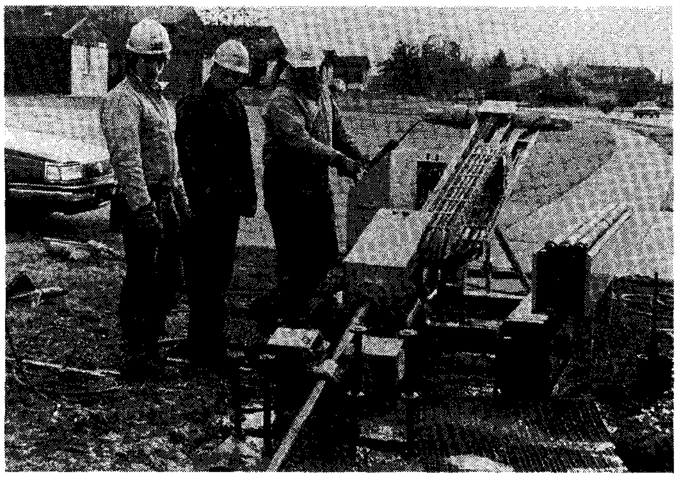

FIG. 1. Minidirectional Drill Rig

FACTORS THAT IMPACT UNIT COSTS

Electrical-conduit placement projects range from very small jobs to major installations of several thousand feet in length. Crew mobilization and demobilization costs dominate the unit costs of relatively small jobs, but these fixed costs contribute relatively less to the unit costs of large jobs. It is important to develop cost-comparison data for conventional trenching and minidirectional drilling that are related by job size.

When installing the underground electrical system, SRP uses high-density polyethylene conduit in most of the minidirectional drilling applications. Polyvinyl chloride (PVC) conduit has been used for most open-trenching jobs. Polyethylene conduit is delivered to jobsites on spools that contain conduit in lengths of 131.1 m (430 ft). This spooled material can be uncoiled easily and pulled through holes that have been bored and reamed by minidirectional boring machines. PVC conduit is delivered in 6.1 m (20 ft) sections that must be glued together at each pipe joint. This research considers the installed costs of these two different conduit materials.

For this study, only the low bidder's prices were analyzed. These prices are the amounts that SRP actually paid for the installation of its conduit systems. None of the contractors' bid prices included the cost of conduit, which was furnished by SRP.

Also, because urban development in the Phoenix area has occurred in a checkerboard fashion, with large blocks of vacant land remaining in the urban core (which is probably true of many urban areas), this research considers cost-comparison data for both urban and rural applications.

Inflation

The year 1993 was selected as the base year for inflationary adjustments. Unit construction costs for each job were converted to current year equivalent amounts using the Handy-Whitman Construction Cost Indices.

The electrical construction-cost information used for this research was derived from data accumulated since 1990 at SRP. The Handy-Whitman Construction Cost Indices for electrical utilities was the primary source of information regarding the impact of inflation. These cost indices have been adopted by SRP's corporate economics and forecasting department, and include regional inflation factors specifically for the construction of electrical conduit systems (*Handy-Whitman* 1993).

Table 1 summarizes the Handy-Whitman Construction Cost Indices for the placement of underground conduit in the plateau region of the United States, which consists of Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming (WEFA 1993).

TABLE 1. Handy-Whitman Construction Cost Indices for Placement of Electrical Underground Conduit in Plateau Region

Year (1)	1989 (2)	1990 (3)	1991 (4)	1992 (5)	1993 (6)
Cost indices	243	245	246	250	252
1993 conversion factor	1.037	1.029	1.024	1.01	1

Soils

In 1986, SRP retained Sergent, Hauskins and Beckwith (SH&B) to identify soil conditions in SRP's service territory. The results of this work are documented on a single scaled drawing. This drawing was used to identify and classify soil conditions for this research (Sergent, Hauskins and Beckwith 1986).

The SH&B Generalized Subsurface Profile Map identifies the eight categories of soil within the SRP service territory:

1. Fine-grained desert alluvial soils of clay, sand, and silt mixtures; occasional gravels; weakly to strongly cemented; low to medium plasticity
2. Clayey to silty sands and gravels, angular, weakly to moderately cemented, low to medium plasticity
3. Fine- to coarse-grained soils, clayey and silty sand and gravel mixtures, angular to subangular, weakly to strongly cemented, very low to medium plasticity
4. Sandy to silty clay soils, weakly to strongly cemented, medium to high plasticity
5. Clay, silt, and sand mixtures with some to considerable gravels; weakly to moderately cemented; low to medium plasticity
6. Sand, clay, and silt mixtures; weakly to moderately cemented; low to medium plasticity
7. Clay, silt, and sand mixtures; trace to considerable gravels; weakly to strongly cemented; low to medium plasticity
8. Shallow to very shallow, gravelly sand and clay mixtures overlying rock

Conventional open trenching has been used to install electrical conduit in all of the soils described. A review of the job files showed that minidirectional drilling has been successfully accomplished in Phoenix area soil types 1, 3, 4, 5, 6, and 7. No minidirectional drilling history was found in soil type 2 or 8. Soil type 2 is relatively rare; it is found in less than 0.25% of SRP's service territory. It is anticipated that minidirectional drilling will be possible in the less gravelly portions of soil types 2 but not in rocky soil type 8, which is found in approximately 15% of the SRP service area. Minidirectional drilling has been performed in all of the common soil types found in SRP's Phoenix metropolitan service territory except for rocky or strongly cemented caliche soils.

Underground Conduit Configurations

SRP typically specifies underground electrical conduit configurations that range from single 5.08-cm (2 in.) diameter conduit runs to large multiple-conduit duct banks with several 5.08-, 6.35-, 7.62-, or 10.16-cm (2, 2.5, 3, or 4 in.) diameter conduits. This paper focuses primarily on three common conduit configurations that have been installed many times by both conventional trenching and minidirectional drilling techniques. The three conduit configurations are single 5.08-cm (2 in.) or 7.62-cm (3 in.) conduits; three-phased systems consisting of a bundle of three 7.62-cm (3 in.) diameter conduits;

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and multiphased configurations consisting of a bundle of six 3-in.-diameter conduits surrounding one 5.08-cm (2 in.) diameter conduit.

PRESENTATION OF DATA

The 1993 cost information was compiled and presented in scatter graphs (see Figs. 2–8). These graphs are categorized by the type of conduit installation, and each graph displays comparative cost information for either minidirectional boring, urban trenching, or rural trenching.

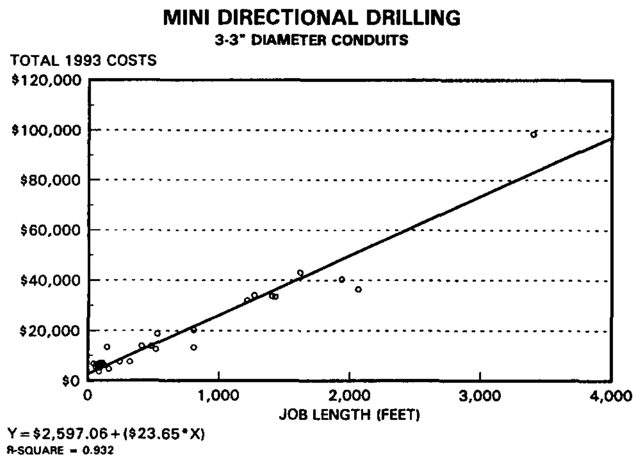

FIG. 2. Minidirectional Drilling, Three 3-in.-Diameter Conduits

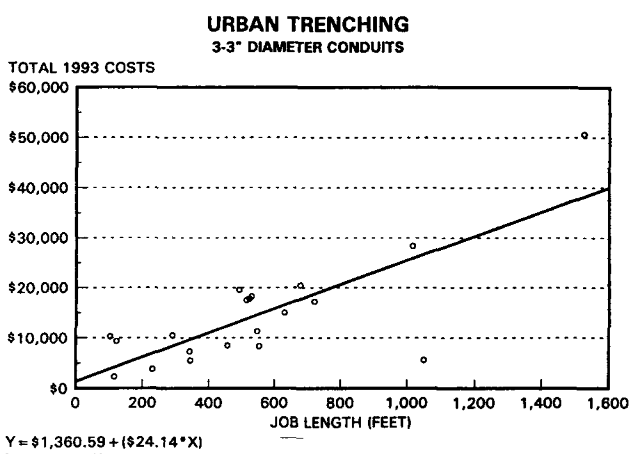

FIG. 3. Urban Trenching, Three 3-in.-Diameter Conduits

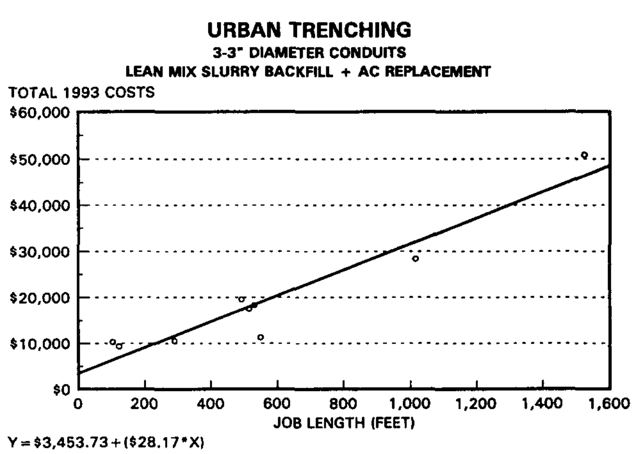

FIG. 4. Urban Trenching, Three 3-in.-Diameter Conduits; Lean Mix Slurry Backfill + AC Replacement

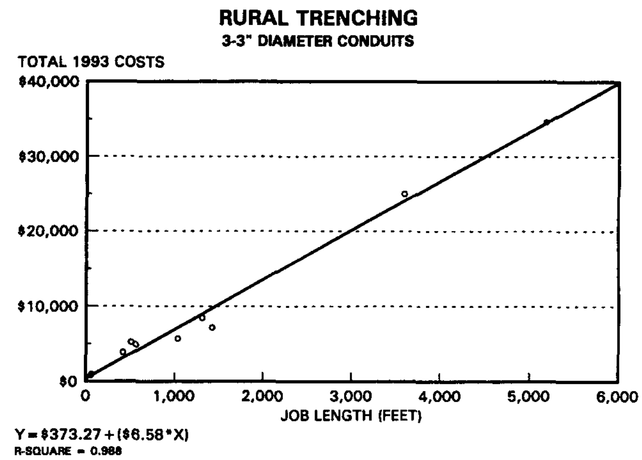

FIG. 5. Rural Trenching, Three 3-in.-Diameter Conduits

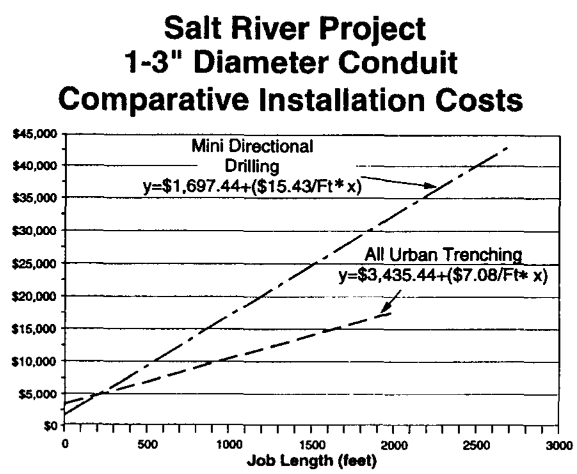

FIG. 6. Salt River Project One 3-in.-Diameter Conduit Comparative Installation Costs

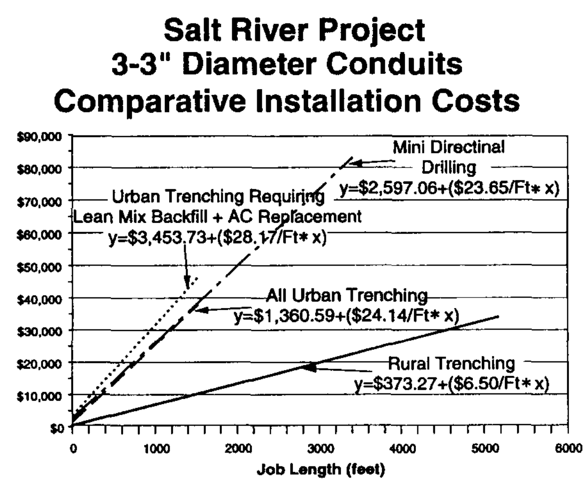

FIG. 7. Salt River Project Three 3-in.-Diameter Conduits Comparative Installation Costs

Each graph was analyzed to compare the costs of trenching versus minidirectional drilling, for three common electrical conduit configurations, in variable site conditions.

Analysis and Results

Approximately 430 contract job files were reviewed to gather actual cost data for this research. These files consisted of

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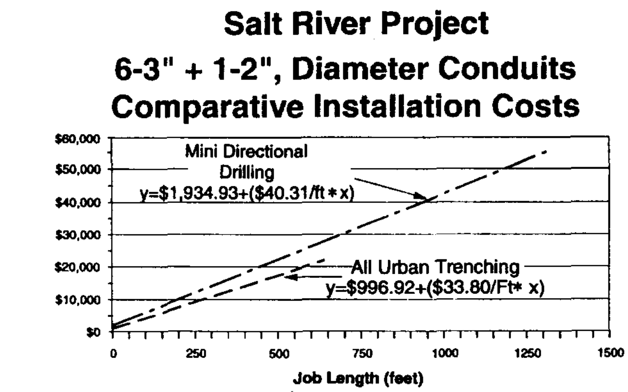

FIG. 8. Salt River Project Six 3-in.- and One 2-in.-Diameter Conduits Comparative Installation Costs

relatively small jobs (all under one mi in length) awarded between 1990 and 1993.

Each conduit-placement job file was reviewed for possible application in this research. Only jobs that included unit-price bid data for the three common conduit configurations were analyzed. Complex conduit-placement jobs, which included unit prices for multiple conduit configurations, were excluded to maintain sample homogeneity. Each low-bid price entry was accompanied by information regarding the year of bidding, the jobsite location, and the soil classification. The unit-bid prices were converted to 1993 prices through conversion factors that considered inflation, contract-administration fees, and Arizona sales taxes. SRP's costs to furnish conduit materials were added to the contractors' costs. The final 1993 total costs were computed by multiplying the 1993 loaded unit prices by the job lengths. Linear-regression analyses were performed to establish relationships between job lengths in linear feet and 1993 total costs for each of the three conduit configurations and the two construction techniques, trenching and minidirectional drilling. Trenching costs were evaluated in both rural and urban environments. The minidirectional drilling projects were located in urban environments only.

Material Costs

The costs of conduit materials that are used in SRP's underground electrical conduit systems were obtained from SRP's Material System computer program (*Material* 1980). A factor of 16% was added to the conduit materials costs to account for SRP's warehouse overhead costs (*Material* 1985).

Polyethylene Conduit

During 1993, 5.08-cm (3 in.) diameter polyethylene conduit cost $1.43 per foot. Contractors working for SRP have been required to splice polyethylene conduit by a heat-shrink coupling process. This process requires the constructor to insert the ends of two polyethylene conduits into a rigid slip coupling. A separate heat-shrink coupling is gloved over the slip coupling and is extended several inches over each adjoining polyethylene conduit. A blowtorch is used to melt and seal the heat-shrink coupling over the splice. The materials cost of each 5.08-cm (3 in.) slip coupling is $1.45. The heat-shrink couplings cost $12.95. For the purposes of this cost study, splices were assumed to occur at 76.2-m (250 ft) intervals.

Alternate splicing methods such as compression couplings and heat fusion techniques are commercially available for polyethylene pipe. A cost and technical comparison of these alternate splicing techniques was considered beyond the scope of this research.

PVC Conduit

As noted earlier, rigid PVC conduit has been used on most conventional trenching jobs. SRP paid $0.51 per foot for 7.62-cm (3 in.) diameter conduit, and $0.18 per foot for 5.08-cm (2 in.) diameter PVC conduit. This conduit is manufactured with integral coupling ends so that separate pipe segments can be glued together. Each pint of PVC primer costs $2.23, and each pint of PVC cement costs $2.71. Approximately one pint of primer and one pint of cement are required to join 76.2 m (250 ft) of PVC pipe segments that are each 6.1 m (20 ft) long.

Large PVC duct banks consisting of over six conduits are generally racked together with grid-shaped PVC spacers that are placed on 1.83-m (6 ft) centers. In 1993, 6-hole spacers used to rack six 7.62-cm (3 in.) diameter PVC conduits with one 5.08-cm (2 in.) diameter conduit cost $0.96.

Regression Analysis of Total Conduit Placement Costs

Scatter graphs and regression lines for the 10 regression analyses, which used job length as the independent variable and total 1993 loaded costs as the dependent variable, are shown. As illustrated on Fig. 2, the y-intercept of the regression line estimates fixed costs such as mobilization and demobilization fees. The slope of the regression line represents the unit cost to install the designated conduit configuration in the given environment. Also, in Figs. 2–8; the correlation factors (R^2) are provided on each scatter graph in order to indicate the closeness of fit between the independent and dependent variables. The correlation factor is a number between 0 and 1. The closer the correlation factor is to 1, the more closely the independent variable is related to the dependent variable. In Fig. 2 the correlation factor is 0.932, indicating a strong correlation between job length and total cost.

In Fig. 3, the correlation factor of 0.604 indicates a much weaker correlation between job length and total cost. There are many types of open-trench jobs represented on this scatter graph because, in an urban environment, different types of trenches may be used. Although it is more expensive to backfill a trench in a street than to backfill a trench in an open field, in an urban environment, both conditions are encountered. The disparity between the costs of backfilling the different types of trenches contributes to the lower correlation.

As seen in Fig. 4, the correlation factor for installing trenches in streets, all back-filled with manufactured lean mix material and topped with asphalt to match the thickness of the original surface, is 0.915.

Fig. 5 provides an indication of the cost to install three, 3-in. diameter conduits in a rural environment. The data was insufficient for the performance of reliable regression analyses in rural trenching conditions for the placement of one 7.62-cm (3 in.) conduit or for the placement of six 7.62-cm (3 in.) diameter conduits with one 5.08-cm (2 in.) diameter conduit. However, the rural trenching regression line for the placement of one 7.62-cm (3 in.) conduit does provide an indication of the order-of-magnitude difference in cost for similar work in an urban environment.

Linear-regression lines comparing minidirectional drilling to urban trenching and rural trenching are summarized for each of the three different conduit configurations in Figs. 6–8.

Fig. 6 shows the costs for installing one 3-inch diameter conduit by either trenching or by minidirectional drilling in an urban environment.

Fig. 7 shows the costs for installing three 7.62-cm (3 in.) diameter conduits by trenching in both urban and rural environments and by minidirectional drilling in an urban en-

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vironment. Urban trenching, which requires lean mix backfill and asphalt replacement, is shown separately.

Fig. 8 shows the costs for installing a bundle of six 7.62-cm (3 in.) and one 5.08-cm (2 in.) diameter conduits, by either trenching or by minidirectional drilling in an urban environment.

As anticipated, Fig. 7 illustrates that it costs less to trench in rural areas than to trench or perform minidirectional drilling in urban environments. The vertical distance on the graphs between the rural trenching line and each of the other regression lines indicates the difference in unit costs associated with working in an urban environment. These additional costs include maintenance and protection of traffic, surface restorations, and productivity losses due to congested work sites.

It appears from the y-intercepts in Figs. 7 and 8 that the fixed costs of mobilizing a trenching crew are lower than those for mobilizing a minidirectional drilling crew. Intuitively, this observation makes sense because a trenching crew is normally equipped with a backhoe and a dump truck, whereas a minidirectional drilling crew is generally equipped with a backhoe and a spoils truck plus the boring equipment. The minidirectional drilling crew uses the backhoe to excavate entrance and exit pits for the drilling rods. It is not known why the y-intercept in Fig. 6 indicates that the fixed costs of rural and urban trenching for the placement of a single 7.62-cm (3 in.) diameter conduit are less than the fixed costs of minidirectional drilling. This anomaly may be caused by the relatively small number of samples that were available to derive the urban and rural regression lines for this case.

It appears, as shown in Fig. 6, that it is less expensive to place a single 7.62-cm (3 in.) diameter conduit by open trenching in urban areas than by minidirectional drilling. Trenches for a single 3-inch diameter conduit are normally only 15.2 cm (6 in.) wide and 91.4 cm (36 in.) deep. A contractor can off-load, warm-up, and place a small backhoe into production on a small trenching job in a fraction of the time that it takes to set up and begin production for a minidirectional drill. This rapid mobilization gives conventional trenching the edge in cost effectiveness for the placement of single 3-in.-diameter conduits. However, trenching's competitive edge decreases as the complexity of the project increases because of requirements such as surface restoration, or working close to other underground utilities. Nothing in this data indicates that this advantage decreases as job length increases.

It appears from Fig. 7 that the cost of urban trenching and minidirectional drilling are nearly equal for the installation of three 7.62-cm (3 in.) diameter conduits. However, minidirectional drilling is sufficiently less costly than urban trenching when the costs of lean mix backfill and patching with asphalt are factored into the costs of the urban trench.

Fig. 8 indicates that it is less expensive to place conduit by open trenching in urban areas than by minidirectional drilling for the placement of bundles consisting of six 7.62-cm (3 in.) and one 5.08-cm (2 in.) diameter conduits.

For the past several years, most of SRP's contractors have used relatively small minidirectional drills that were not designed to install large seven-conduit bundles. However, the contractors modified their small minidirectional drilling machines with oversized reamers and other devices in order to install large seven-conduit bundles. Although these equipment modifications met customer requirements, these advancements were not productive enough to compete with the price of conventional trenching in urban areas.

SOCIAL COSTS OF UTILITY INSTALLATION METHODS

According to Iseley and Trnwani (1990), the social costs associated with underground utility-placement jobs depend on the chosen installation techniques. These authors maintain that trenchless excavation construction methods minimize the social impact of utility installations in congested urban areas when compared to traditional open-trenching techniques. These indirect social costs are difficult to quantify and are therefore never included in the evaluation procedures that are used to determine underground utility installation techniques.

Iseley and Trnwani (1990) have identified the following 11 major social costs that result from traditional open-trench utility installations.

1. Utility open-trench cuts significantly contribute to a decline in the life expectancy of roads. Potholes and other forms of surface subsidence, which result from poorly compacted and patched open trench cuts in roads, can reduce pavement life by up to 40%.
2. Existing utilities are more likely to be damaged during open-trench cutting than during trenchless excavation construction. For example, soil tampers, which are used to compact earth in open-trench cuts, have been known to damage water lines up to 3.05 m (10 ft) from the work site.
3. Adjacent structures are more likely to be damaged by differential foundation settlements following open-trench cuts than after trenchless methods have been employed.
4. Heavy equipment, which is used during trenching operations, causes more noise and vibration problems than does trenchless technology equipment.
5. Air pollution, in the form of wind blown dust, is more prevalent in open-trench cutting than in trenchless excavation methods.
6. Road detours and other forms of traffic disruption are more likely on jobs that utilize conventional earth-moving equipment than on jobs that are constructed with trenchless machinery. The indirect costs associated with traffic delays can result in social costs that are several times the direct cost of work.
7. Pedestrian traffic is more likely to be disrupted on open-trenching jobs than on trenchless jobs.
8. Local businesses lose more customers on open-trenching jobs than on trenchless jobs because there are more serious traffic disruptions on conventional trenching jobs.
9. Most detour roads are not designed for heavy traffic loads. These detour roads may suffer a significant amount of damage during construction of an open-trenching job.
10. Construction accidents due to trench collapse are nearly eliminated on trenchless excavation jobs.
11. Road accidents are less likely to occur on trenchless excavation jobs than on conventional trenching jobs because there is less traffic congestion with heavy equipment and fewer detour roads.

CONCLUSIONS

This research yielded the following results for designing underground electrical conduit placement jobs.

Minidirectional drilling was generally found to be more expensive than urban trenching for the placement of a single 7.62-cm (3 in.) diameter conduit, or for the installation of large seven-conduit bundles consisting of six 7.62-cm (3 in.) with one 5.08-cm (2 in.) diameter conduits.

Minidirectional drilling proved to be economically competitive with urban trenching techniques for the placement of three 7.62-cm (3 in.) diameter conduits. Moreover, minidirectional drilling was generally less costly than urban trenching if the open trench had to be filled with lean mix

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backfill and patched with asphalt to prevent future trench settlements.

It is less expensive to place conduit in rural areas by open trenching than by minidirectional drilling.

Crew mobilization and demobilization fees dominate the overall unit costs of relatively small conduit-placement jobs, whereas these fixed costs contribute relatively less to the unit cost of larger jobs. It generally costs more to mobilize a minidirectional drilling crew than a conventional trenching crew.

Minidirectional drilling can be successfully employed in all of the common soil types found in SRP's Phoenix metropolitan service territory, except for rocky or strongly cemented caliche soils.

Indirect social costs that might impact the general public and jobsite safety should be considered when specifying conduit placement by either open-trenching or minidirectional drilling techniques. These costs may not be included in the contractor's bid, but are costs to the public, if not to the project owner.

During this study period, SRP's contractors were equipped with some of the earliest commercial versions of minidirectional drilling machines. During recent months, several contractors have purchased more powerful minidirectional drilling machines. It is anticipated that the installation costs of minidirectional drilling will decline as contractors become more proficient with these new machines. As these productivity improvements continue, the results of this research should become a baseline for measuring future advances in this dynamic segment of the construction industry.

Recommendations

Designers are often requested to estimate the conduit installation costs of a project. The designers must be aware that the comparative installation cost graphs exclude the costs of auxiliary items such as pole risers and pull boxes. It is recommended that a work sheet be prepared to aid the designers in estimating total conduit-installation costs.

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