Big Pipe - Tight Quarters:
Lessons Learned from Large Diameter Urban Pipelines

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ABSTRACT

Large diameter pipelines are a critical component of a utility’s infrastructure. Design and construction of pipelines in an urban environment is a difficult task. Weaving a large, critical piece of infrastructure through city streets, easements, and existing infrastructure has unique challenges that must be studied in the planning, routing and preliminary design of the project. This paper will present an outline for the planning, design and construction of a large diameter pipeline in an urban area based on lessons learned from previous projects. The lessons learned during construction provide valuable insight into how better planning and design can greatly reduce the challenges faced in future construction projects.

Pipeline construction can impact businesses, bring traffic to a halt and jeopardize public safety. To limit these impacts to the community, engineers must consider public involvement initiatives, traffic control and project phasing. Route selection is a critical part of the process and can ultimately have the greatest influence on how challenging construction and maintenance of the pipeline will be. Additionally, engineers can work within the framework of the triple bottom line to balance, environmental, economic and social impacts. This process can be used in evaluating open cut construction versus tunneled construction as well as selecting the best route for the pipeline.

Construction of large diameter pipelines is slow and expensive. Working with contractors to identify work space requirements and construction methods is very important. As a part of this paper, several contractors were contacted to discuss these challenges and a summary of those discussions is included in the paper.

Pipelines, due to the large investment and criticality of service, must be reliable and resilient with a long service life; therefore, they must be engineered with robust design criteria and with operations and maintenance in mind. This effects route selection, pipe material selection, backfill and embedment design and appurtenance
INTRODUCTION

Large diameter pipeline design and construction in an urban environment is a difficult task. Some of the challenges that a designer and contractor face include working in tight spaces, dealing with utility conflicts, minimizing impacts to the public and risks associated with prolonged schedules and escalating costs. Similarly, pipeline owners face challenges in the operation and maintenance of the pipeline including leaks or blow-outs, damage from third parties and difficulty accessing the line in tight spaces with new development.

The purpose of this paper is to provide lessons learned and best practices for dealing with these challenges. The focus of the design engineer should be on providing reliability and flexibility over the long term while balancing the ability to construct the pipeline. This can be accomplished with a thorough route selection process, utilizing robust standards during final design, and considering the future use of the pipeline to make the pipeline easier to operate and maintain.

ROUTE SELECTION

A thorough route selection process can reduce cost of construction, operation, easement acquisition, environmental impacts, impact on landowners and schedule (Hutson, 2006). The schedule savings can be in terms of reducing permitting requirements, shortening the design process and reducing construction time.

Data Collection. Better decisions are made with better data. Engineers must take the time to gather the appropriate data to improve the decision making process. Geographic Information Systems (GIS) provides a perfect platform to collect and utilize the data. Recent aerial photography of the pipeline corridor will provide a great base for the data. Aerial data can be acquired from mapping services such as ESRI, USDA, USGS, Bing, Google, and many others. Owners often have access to recent aerial data as well. Many municipalities have invested in asset management systems for their water and sewer utility systems as well as their other infrastructure. This data is invaluable in determining utility conflicts. Other good data sources include:

- County Appraisal Districts for property lines and landowners
- The railroad commission for buried oil and gas infrastructure (Texas only).
- FEMA for floodplain boundaries
- EPA and Historical Commission for environmental and archeological data
- USDA for soil data
- USGS for land cover and ecological data
- National Wetlands Inventory
- ESRI for general U.S. and World mapping information
- Utility master plans
Engineers should also research future development plans in the form of zoning maps, comprehensive plans, master thoroughfare plans, and capital improvement plans.

**Alternatives Analysis.** This may be the most critical stage of the route selection process. The development of alternatives is a brainstorming process in which no idea is ruled out immediately. Multiple routes, corridors, in streets versus in easements, and installation methods (tunnels versus open cut) should be considered and then screened out using selection criteria. Selection criteria may include the following:

- Initial capital cost
- Life cycle cost including capital, operations, and maintenance costs
- Constructability
- Impacts on schedule
- Vulnerability to 3rd party damage, soil erosion and future development
- Accessibility to perform O&M
- Environmental impact
- Social impact (road closures, lost business, traffic delays, etc.)
- Easement acquisition cost and schedule

The shortest route is not necessarily the best, all factors need to be weighted and assessed to determine the best route for the pipeline. The initial capital costs should be balanced versus life cycle costs and short term and long term impacts on the environment, businesses and community must also be considered. This evaluation process is known as the triple bottom line (TBL). The TBL is an accounting framework with three parts: social, environmental and financial. Utilizing this framework will allow the engineer to make decisions throughout the project life that take into consideration all the stakeholders affected by the project.

**Installation Methods.** There are two options for the installation of large diameter pipelines in urban areas. Open cut will usually have the least cost; however, in an urban environment, some tunneling is usually required to cross obstacles such as highways, railroads, rivers and, other large utilities. The route selection should evaluate how much tunneling will be required versus open cut.

At times, long, deep tunnels can be used to improve hydraulics of the system and reduce power usage by reducing system high points. Other times, tunnels are built out of necessity due to limited space for open cut, substantial critical underground infrastructure, or other severe impacts to the public.

**Easement Needs.** The workspace requirements to construct and maintain the project need to be considered during the route selection phase. In some instances, permanent and/or temporary easements may be required. At other times, the contractor may work in the public right-of-way without requiring easements. Regardless, the following considerations must be made:
• There must be enough room for the contractor to string pipe and embedment materials, move his equipment around for trenching and backfilling as well as room for temporary spoil.
• Remote laydown areas may be needed to string pipe and other materials; however, double handling of pipe and materials results in added cost.
• Access easements may be required where public road access is not available.
• Tunnel pits may require additional temporary workspace and staging area.
• HDD installations have additional site requirements that must be met, currently HDD is limited to about 48-inch diameter pipe
  o Depending on the diameter, each side of the HDD may require as much as a 100’x150’ laydown area.
  o Additional easement may be required to string out the pipe so it can be fused and laid out before it is pulled.
  o The maximum bending radius of the pipe may limit where the pipe can be strung out prior to the pull.
• Room is also needed for the owner to properly provide routine maintenance, repairs to pipe and pipe joints, valves and to make tie-ins.
• Purchase exclusive easements to prevent encroachment from future utilities.
• In some deep tunnel applications, subterranean easements are needed that vary significantly from open cut easements.
• Major appurtenances may require additional easement

Access. It is important to consider how the pipeline site can be accessed both during construction and after it. The contractor will need to be able to access the site, store equipment, and move material, pipe, and appurtenances in and out from the site while the owner will need to be able to perform maintenance or make any repairs that are needed. Many access points are needed for to allow this to happen without negatively impacting production or operations and maintenance.

Traffic control plans are not just important for minimizing traffic delays but also for allowing the contractor to easily access the construction site. Additionally, if a pipeline is to be placed under pavement it is preferable to locate the line in an exterior lane so that only one lane must be shut down in the future for construction and maintenance access.

Subsurface Utility Engineering (SUE). SUE is an invaluable tool for pipeline route selection and design. There are several different quality levels that each provide differing amounts of detail as to the location and/or depth of existing infrastructure. Quality levels are defined in ASCE Standard 38-02. Quality Level D and C can be valuable for route studies. Level D SUE uses data from existing utility records while Level C locates visible facilities such as manholes, valves boxes and pipeline markers to correlate the Level D data. Quality Level B data involves geophysical methods to determine the horizontal location of all underground utilities, while Level A involves potholing utilities to verify the exact horizontal and vertical location. In some instances it may be important to utilize Level B SUE data before completing the final
route selection and alignment determination. Level A should be completed before starting preliminary design.

In numerous instances, engineers have relied on as-built data on waterlines and other utilities to set tunnel depths only to find that the depth of the utility is much deeper than it was shown on the as-builts. In other cases, utility lines that were assumed to be properly centered in their easement were actually installed well outside the easement. When paralleling existing easements, SUE Level A should be used to verify the location of the adjacent utility.

**DESIGN**

Several elements of the pipeline design are critical to the long term performance of the piping system. This section will focus on these key elements and design tips to achieve long, reliable service life with minimal maintenance.

**Pipe Material Selection.** There are a handful of pipe materials suitable for large diameter transmission pipelines. These options include Steel Pipe (AWWA C200), Pre-stressed Concrete Cylinder Pipe (AWWA C301), and up to certain diameters: Ductile Iron (AWWA C151), Bar-Wrapped Concrete Cylinder Pipe (AWWA C303), Polyethylene Pressure Pipe (AWWA C906) and Fiberglass (AWWA C950).

All projects are different and various pipe materials may be suitable for some projects and not for others. In urban environments the mode of failure is also critical as catastrophic failure can put lives and property in danger.

**Embedment and Backfill Design.** In an urban environment, factors that influence the embedment and backfill design include the long-term reliability of the trench system, reduction of settlement especially under pavement, the ability to place materials and backfill quickly, and even the protection of the pipe from third party damage. In some situations, flowable fill can provide superior support, reduce settlement, allow backfilling to proceed in less than an hour, and provide some measure of protection from third party damage. Flowable fill is preferable over lean concrete due to its ability to be excavated without jackhammers. The Engineer and Owner must weigh the additional cost of this embedment system versus the short term and long term benefits.

Large diameter pipelines can create large obstructions for other utilities if sufficient cover is not provided to allow those future utilities to be placed above the pipeline, especially gravity lines for stormwater and sanitary sewer. However, extra depth translates to extra cost so the engineer can’t be so conservative that prices are driven up unnecessarily. Significant effort should be given to coordinating with any future development to determine the correct depth of cover to place the pipeline.

**Tunnel Design.** Quality geotechnical information is critical to the design of tunnels for large diameter pipelines. The risks associated with tunneling can only be assessed once quality data is provided to the Engineer. Factors such as soil classification,
groundwater depth, and other soil strength characteristics must all be evaluated to
determine if tunneling is the correct method of construction for a given location.

If groundwater levels are very high, significant dewatering measures may be required
and potentially the use of tunnel boring machines (TBM) to construct the tunnel.

**Appurtenances.** Special consideration must be given to pipeline appurtenances in an
urban environment. Engineers should plan for future tie-ins and include fittings to
assist with hydrostatic testing and disinfection. Coordination with the Owner and
project stakeholders is crucial to plan for future connections.

A transmission pipeline in an urban setting may require more main line valves to
enhance the ability to maintain the pipe by reducing the amount of dewatering that is
needed if man access is required and can isolate line breaks or sections for repair.

Pipeline construction in an urban environment can be combined with paving
replacements to reduce total costs. In the case of concrete paving, the pipeline can be
positioned where a panel replacement is satisfactory. When the street is in poor
condition, a full replacement may be warranted. Asphalt paving can be upgraded with
a mill and overlay.

Cathodic protection is a must for long term protection of all ferrous pipe materials.
This is particularly true of large diameter pipelines that require a high initial
investment that must be protected. Large pipelines in an urban environment are even
more critical due to the cost to rehab/replace and the consequence of pipe failure. To
make cathodic protection systems more robust, plan for redundant connections to the
pipe with short runs and wire protected in conduit. Isolation of pipelines is critical to
make the cathodic protection system efficient. Corrosion engineers must address
interference with other piping systems and adjacent cathodic protection systems.
Determining a source of power is also a critical planning component and locating the
rectifier for an impressed current system such that it can be easily accessed and
maintained is an important step in the design.

**Constructability.** Constructability is one of the larger challenges associated with
urban construction. What may come easily in a rural pipeline project can be much
more complex and difficult in an urban pipeline project. Caution must be taken when
evacuating near so many existing facilities and that causes construction to take much
longer. Many utilities and pipeline owners require that excavation near their facilities
be done by hand which can significantly slow down construction progress.

Construction equipment can also be limited in the head space available due to
structures or overhead power lines. The equipment may also be limited in its mobility
horizontally due to narrow easements or tight working conditions. Additional
construction equipment may be required on site if some equipment is not able to
freely move around. Site conditions may also require the use of rubber tires instead of
rubber.
tracks to prevent damage to pavement. These are all limitations placed on the contractor which can affect production rates and costs.

Haul routes may also need to be considered to establish how material can be brought to or removed from the construction site as needed. If haul routes require longer trip lengths for trucks it may increase costs and slow production. Counties and municipalities may limit the timing for these operations to off peak times.

In urban areas there is likely a need for continuous access to businesses, residences, and offices that may create many subdivided sections in the construction. Traffic control plans need to provide access to these facilities and the engineer must consider how much space there is between access points to ensure it is adequate for the installation method specified.

All of these constructability issues need to be taken into consideration during design. A good alignment must take into consideration the final location of the pipeline as well as the ability to install the pipeline in that location.

Cost Estimating Considerations. Preparing an accurate opinion of probable construction costs for an urban pipeline is difficult. Some tips that can increase the accuracy of the estimate are as follows:

- Collect data on similar urban pipeline projects to help develop not only unit costs but some big picture perspectives on total project costs.
- Be careful not to use past project bid tabs exclusively. All projects are different and have different bidding environments and markets.
- Material costs are typically similar for urban projects; however, slow construction in a congested environment may increase installation cost.
- Restoration of paving and landscaping is expensive but can be quantified.
- Talk to contractors to get their feedback on crew sizes, production rates, special equipment needs and other factors that influence cost.
- Keep up with pipe and construction market conditions.
- Consider the rate of production in the cost, the longer it takes to install the pipe the more it will cost.
- Account for contractor’s risk associated with working near so many existing facilities, this risk will be reflected in a higher bid price.
- Traffic control may require concrete barriers and flagmen.

It is difficult to quantify how much additional cost may be incurred by the slowed production rate of construction in urban areas which is why it is important to discuss the project early on in design with contractors to remove as many limitations on the construction as possible.

CONSTRUCTION
An Engineer’s work does not end with design. Construction in urban areas requires significant oversight and coordination between all parties involved in the process from planning through construction.

**Risk Assignment.** An important factor to consider when designing and planning for a pipeline project in an urban area is the risk involved in construction.

Working in an urban environment brings additional safety risks that must be considered, such as working near traffic, proximity to pedestrians, hazardous underground utilities, and potentially contaminated soils. Proper barriers or construction fencing is essential for public safety as well as the safety of the construction workers. Thorough geotechnical work can help mitigate some risk.

As previously discussed, SUE can help to clearly identify the existing infrastructure near the project. Leaving the locating up to the contractor during construction can lead to significant design changes, lost time, and increased costs when unforeseen utilities are encountered. If some utilities cannot be located until construction, require that the utility be located at the beginning of construction so that any changes can be made without negatively impacting the schedule.

The project specifications need to clearly address how conflicts are handled and lay out a process to resolve any issues as quickly as possible so the project schedule is not significantly impacted. Additionally, the Owner may consider adding an allowance or contingency in the bid to allow for unforeseen issues.

Another way to mitigate risk is to collect survey information for adjacent structures and facilities that are near the construction site to confirm if there has been any negative impact. Taking good pre-construction photos can also help with this. Tunneling operations are particularly important to monitor due to the potential for settlement.

**Public Involvement/Communication.** As a part of the social considerations in the TBL, pre-construction meetings can be hosted to allow the public to ask questions about the project and understand how the project may impact them. These meetings can also help the project team to understand the concerns of the community so that they can be addressed.

It is also important to keep the public informed on construction progress throughout the life of the project. This can be done through mailings to landowners, door hangers for homeowners, or a public website that is regularly updated with construction status reports. Above all those things though, one on one communication can do the most good in mitigating any issues that may come up with the community.

**Scheduling.** Construction scheduling is an important consideration for the success of the project. Various seasons and events should be considered when laying out the construction schedule. Some of the factors that may require consideration are:
• School year, consider constructing near schools during summer months.
• Peak shopping months.
• Holidays.
• Community events (parades, fun runs, sporting events, etc.).
• Wet weather, allow time in the construction duration for rain delays.

If service connections or other pipeline connections are required, consider the timing of these connections. Some may require night or evening work to reduce service outage impacts.

Construction Data Collection. Since large diameter pipelines are such critical infrastructure, it is important that accurate data be collected and stored for future use in repairs or maintenance. It is also important to properly identify joints and specials as well as keep up-to-date records of the pipe as it is being installed. Accurate record data should be maintained throughout the project.

Survey data is also important to maintain accurate data on elevation and alignment of the pipeline to prevent third party damage in the future and allow maintenance crews to easily find and maintain the system.

Construction Inspection. Generally, construction in urban areas will require more oversight than in less developed areas. A good construction manager can save the owner significant amounts of money by addressing construction issues before they become major problems. The construction manager can also act as the owner’s representative to the community to help address concerns and issues that come up during construction.

Materials testing is also an important part to construction. As previously mentioned, the embedment design is critical to the strength and long term performance of the pipe and ensuring that the contractor uses the proper materials and meets the installation requirements from the design is essential to successful construction of the pipeline.

INPUT FROM CONTRACTORS

As a part of this paper, several contractors were contacted to discuss the challenges faced and important considerations for designing and constructing large diameter pipelines in urban areas. The following points reflect some of the input provided by experienced contractors in this field.

Trucking. The most common challenge voiced by the contractors was the difficulties involved with bringing in and removing construction material. Large pipelines can potentially require huge amounts of embedment and backfill material to be imported to the job site, the contractor’s ability to do this greatly impacts the cost and schedule of the project. It is critical to ensure adequate access to the construction area during allowable working hours. To help address this issue one may consider using native
material or some combination of native and imported material to reduce the amount of imported material. On-site recycling of asphalt and concrete was also suggested as an alternative. Removing material also creates a large demand for trucking. A good rule of thumb is that the maximum amount of material that can be removed in a given day is 1,000 CY.

**Traffic Control Planning.** Early communication and coordination with the public to mitigate traffic concerns can help to reduce scheduling issues and public impact. If it is possible to implement detours and/or complete closures at street and intersection crossings in lieu of constructing the intersection half at a time it will speed up construction and reduce the overall time that traffic is impacted.

**Working Room.** A lack of working room can severely limit the contractor’s ability to move and efficiently construct the pipeline. In an urban area, conditions may require narrow working room but considerations must be given to where the contractor will string out the pipe before it’s installed, how an excavator can move within the working area, and where dump trucks can come in and out to bring in or remove material.

**Depth.** Depth of cut should be minimized to decrease cost and difficulty of construction. Any increase in depth may require larger working rooms and creates more spoil material and import material needed.

**Existing Utilities.** This has been mentioned previously in this paper but the value of locating existing utilities ahead of construction can not be overstated. Any utilities that are unknown to the contractor ahead of construction are likely to slow down construction, increase costs, and create safety risks.

**Overhead Obstructions.** Often overlooked, overhead obstructions can impact the speed of construction and create new safety concerns for the contractor. Overhead power and signalized intersections are the most common source of overhead obstruction and need to be observed carefully during construction and all OSHA requirements for working near these facilities must be observed.

**CASE STUDIES**

**Allen-Plano-Frisco-McKinney (APFM) Pipeline.** A thorough route selection process was used in the planning of the APFM Pipeline for the North Texas Municipal Water District. The four-phase project was 18.6 miles long, with the most critical segments completed in priority order. The first three phases included 13.2 miles of 72-inch pipeline. The design team reviewed multiple corridors in pre-design, some following a longer path to less developed road ways and others following a shorter route but in a fully developed corridor. The cost analysis showed that even though the cost per linear foot would be higher for the more congested route, ultimately the shorter pipeline would be less expensive. In the end, the pipeline
alignment followed a larger parkway that enabled lane closures and use of a median. The project required heavy coordination with various municipalities.

Lessons learned from the project include:

- **Cost Analysis** – Determining the cheapest route is not always clear from the first look, it is worth taking the time to compare. For this project the more congested corridor became the least expensive but this is not always the case, spend the time to do a thorough cost analysis early on in the route selection.
- **Avoiding Developing Areas** – In some cases, designing around known conflicts can be easier than designing for unknown future conflicts.
- **Project Phasing** – phased construction can reduce impacts to the community and spread out the capital costs of the project.

![Figure 1 – Allen-Plano-Frisco-McKinney Pipeline Construction down a median with multiple utility conflicts and partial road closures.](image)

**Regional Carrizo Program 36-inch Water Delivery Pipeline**

The 11.5 mile, 36-inch pipeline crossed four counties and three cities to deliver water to the San Antonio Water System (SAWS) NACO pump station. The project was a fast tracked design and construction with many road and interstate crossings, railroad crossings, construction within a drainage channel, and other existing utilities that required significant coordination and planning.

Lessons learned from the project include:

- **Utility Conflicts** – several unforeseen utilities and utilities located in a different place than the record drawings indicated were encountered. More
significant SUE work and construction contingencies would allow for a smoother construction process.

- **Aerial Topographic Survey** – Surface features were encountered during construction that were not visible from the aerial photography shot before the project. Even if a full topographic survey is not possible, limited ground survey in critical locations can help to reduce construction conflicts.

- **New Development** – New projects that were not identified during design created conflicts with construction. It’s important to identify as many future projects as possible during design and leave a contingency for dealing with unforeseen new development when it is encountered during construction.

![Figure 2 – Water Delivery Pipeline Alignment](image)

**CONCLUSIONS**

The planning, design, and construction of a large diameter pipeline in an urban area comes with many challenges, but those challenges can be addressed if proper thought and foresight is given to the project ahead of time. Following the framework of the triple bottom line allows the engineer to address the economic, environmental, and social issues associated with pipeline construction. Additionally, spending more time on the front end of a project to identify all the risks and stakeholders involved will help to mitigate issues that can arise down the road. With proper planning and design, construction in urban areas does not have to be problematic, but instead can create lasting infrastructure solutions that are simple to maintain while serving the community for many years to come.

**REFERENCES**


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