Selection of Pipe for a Drinking Water Project; a Case Study

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Abstract

As soon as a decision is made about the system to be used in a project the subsequent optimization technique loses its efficiency and becomes limited to selecting the most favorable materials and/or methods among a few alternatives within a narrow range. Optimization in a narrow range is in fact determining the best option among a few possibilities; this is not necessarily the optimal choice. Obviously selecting the range itself; in other words selecting the system, is the most important decision to be made prior to any detailed analysis. Oftentimes this kind of decision is made at the top level of management in a consulting engineering firm or the owner. It is therefore very important to carefully select the initial viable alternatives before any rigorous life cycle cost analysis is performed. This paper presents a case study on the preliminary selection procedure for the type of pipes to be used in a large drinking water project.

Key words: Prestressed concrete pipe, ductile iron pipe, spiral welded steel pipe, fiberglass pipe, PVC pipe.

Introduction

Up to early 1980s the drinking water network of Tabriz; a city of close to one million inhabitants in northwestern Iran, was mainly supplied by deep wells. On one hand the growing population had dramatically increased the demand for water, and on the other hand the drought of several years had lowered the water table in the deep wells thus reducing the supply. The decrease in the supply and increase in the demand had created a critical problem that needed immediate solution. Temporarily the water department had imposed an unpopular rationing on delivery of water. This unfavorable situation had been predicted years ago and an ambitious project had been proposed to deal with it. However for several reasons beyond the scope of this paper it had not been considered an urgent priority.

The proposed project was designed to supply drinking water from a reservoir dam on Zarrineh Rood river located at Miandoab a distance 180 km south of Tabriz. Two parallel pipelines of 2.00 m. diameter would be constructed in two phases with pumping stations, treatment plants and communication network. The phase one was given green light for construction with an estimated budget of $ 400 millions. The type of pipe for the main line was to be re-evaluated for practical and economical reasons. Initial project was designed for ductile iron (DI) pipe that would cost about $ 200 million to purchase. Figure 1, below shows the start and end point of the project.

Figure 1, Start and end of the project

This paper describes the procedure followed in selection of the best option among a multitude of alternatives.

Common types of pipe

The piping system must be strong enough to withstand induced stresses, have relatively smooth walls, have a tight joining system, and be somewhat chemically inert with respect to soil and water. The piping system must be designed to perform for an extended period. The normal design life for such system should be 50 years minimum. However 50 years is not enough [1].

In order to gather the initial data on the overall scope and feasibility of the project a delegation composed of an administration official, a member of parliament, and three engineers was formed. The author was a member of this delegation. The charge of this delegation was to visit and to study the drinking water networks of several large cities in Europe. The delegation visited Germany, Switzerland, Sweden, Austria, Italy and Spain and submitted a report on the commonly used pipes in the drinking water networks of several large cities. Based on their visits and their research there were six alternatives that needed to be examined in order to make the final decision. The type of pipes commonly used in Western European cities were as follows:

1. Fiberglass pipe,
2. Polyvinyl chloride; PVC pipe,
3. Steel pipe, spirally welded,
4. Ductile iron pipe,
5. Pre-stressed concrete pipe,
    - Post tensioned by bar wrapping,
    - Pre-stressed while casting concrete

1- Fiberglass pipes

Fiberglass pipe is made from glass-fiber reinforcements embedded in, or surrounded by cured thermosetting resins [2]. Other ingredients are frequently included to enhance various properties or characteristics. Some machine-made fiberglass pipes are manufactured by filament winding over a mandrel, and some are produced by centrifugal casting. These pipes do not corrode, they are resistant to chemical attacks and are light-weight. These pipes also have smooth walls that reduce the head loss, and thus require less pumping power.

2- Polyvinylchloride pipes

Polyvinylchloride (PVC) gets its properties from combinations of additives and modifiers which are mixed with PVC resin. These include stabilizers, providing strength and durability; plasticizers, providing varying degrees of flexibility and resistance to Ultra Violet (UV) light degradation; and pigments, used selectively to provide color. Once the additives and modifiers have been combined with the resin, the resulting material is called PVC compound and is in granular form. In the next stage of manufacturing, these granules are melted down, blended thoroughly and extruded into pipe [3].

PVC pipes are corrosion resistant, light-weight, they have smooth surface, and nontoxic qualities. Some grades are used in food and chemical processes due to the inert nature of PVC.

Because of limitations in extrusion technology that is used for production of these pipes, manufacturing large diameter pipe such as the one in this project was not feasible. In most of the manufactures' catalogs the maximum size was 36 in. (914 mm).

3- Welded steel pipes

One type of steel pipe is spirally welded pipe is manufactured by continuous welding. The procedure is briefly explained below:
Coils are loaded on the decoiler of the Spiral Pipe machine. The strip is straightened and edges are milled to desired joint geometry. The strip is guided into a forming station, where it is formed to produce a cylindrical hollow body at a predetermined forming angle, ensuring proper welding gap between the abutting edges. Inside, and later, outside welding is performed by an automatic submerged arc process. Pipes are cut to a predetermined length by an automatic plasma arc cutting device. After accomplishment of inside and outside welding, while on the production machine the full length of pipe is examined by automatic ultrasonic unit for checking welding defects. Flux and slag from inside the pipes is cleaned. Pipes are inspected for any visual defects. At the end facing machine both ends of pipes are machined to suit the joint to be used on the pipe

line. Each pipe is hydrostatically tested to a given pressure as desired standard [4]. The spirally welded steel pipe is coated for corrosion and erosion resistance on the inside and on the outside.

Another type of steel pipe; longitudinally welded steel pipe is manufactured by electric resistance welding and electric fusion welding to convert flat rolled steel bars, plates, sheets and strips to tubular products [5]. The welding seem in this pipe is a straight line.

4- Ductile iron (DI) pipes

Ductile iron has a chemical composition similar to cast iron except for the shape of the graphite content. In cast iron the graphite flakes are elongated while in ductile iron they are nearly spherical [6].

Ductile iron pipes are cast centrifugally into horizontal rotating mold with quantity of metal poured controlling the pipe thickness. For water services it is normally furnished with standard cement lining on the inside [7]. One favorable chemical property of this material is its corrosion resistance. Ductile iron has been used in water networks extensively. It provides considerable stability at the joints. In corrosive soil conditions the pipes are coated with a layer of polyethylene. Cement mortar lining is commonly used on the inside of the pipe for providing protection against aggressive materials, and improving the hydraulic properties. Cement mortar is applied centrifugally; while the pipe is turning in a horizontal position.

5- Pre-stressed concrete pipes

Pre-stressed concrete pipes are manufactured using two different techniques. The most common type is to centrifugally cast a reinforced concrete core and let it set so that the concrete acquires a certain compressive strength. Using autoclave reduces the curing time considerably. Then a high strength post-tensioning wire is wrapped spirally under a predefined tension force around the core. This action creates a large compressive stress in the concrete that enables it to offset the tensile stresses developed by hydraulic pressure. To protect the spiral wire a layer of mortar is sprayed on the surface of the pipe.

Figure 2 below shows a typical cross-section of a centrifugally cast post-tensioned pipe.

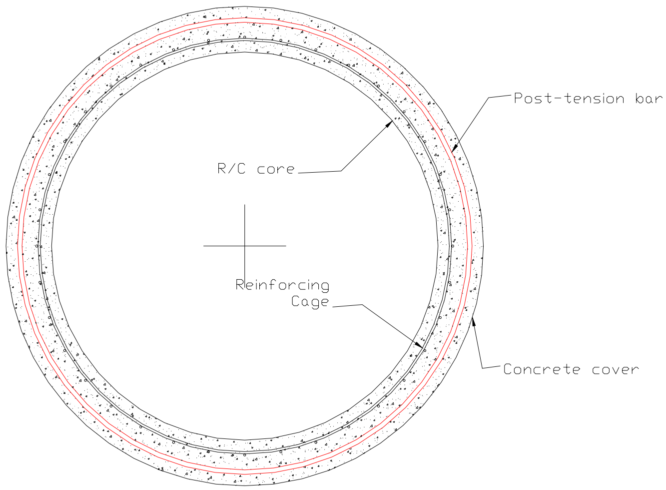

Figure 2, Cross-section of centrifugally cast concrete pipe

In the United States the prestressed concrete pipes have a steel cylindrical core that provides an impervious layer and added strength [8].

Another technique used in production of prestressed concrete pipe is wet cast concrete in an expandable mold. The cylindrical steel mold is composed of three segments connected by means of spring loaded bolts. Inside the steel mold there is an inflatable cylindrical rubber form. High tensile reinforcing steel cage is placed in the space between the steel mold and the rubber form. Concrete is wet cast in a vertically positioned configuration. The assembly is vibrated to consolidate the concrete. At this stage compressed air is introduced in the rubber form. Under the air pressure the form expands and stretches the concrete and the reinforcing thus creating the prestressing in the circular steel bars. The entire assembly is moved to a curing kiln while the compressed air is still applied and monitored automatically to maintain constant air pressure. After the concrete sets and gains the required strength the pipe is de-molded. The result is a monolithic prestressed concrete pipe. Figure 3 shows a typical cross-section of such a pipe.

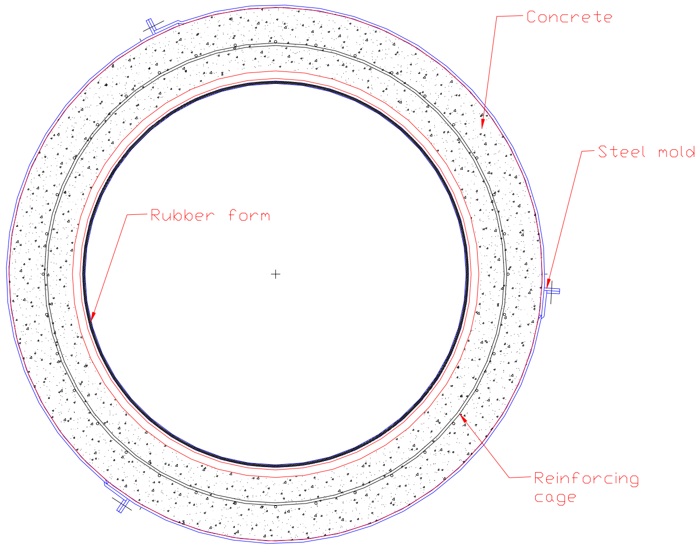

Figure 3, Cross-section of a monolithic prestressed concrete pipe

The delegation did not find any large size projects carried out using the first two alternatives i.e. glass fiber and PVC. Because of the size of the main pipeline; inner diameter of 2000 mm, these options seemed to be too flexible and the concern was that at the connections under the pressure induced by overburden and back-fill the circular cross section may deform to an oval shape and may render the rubber ring (o ring) seals dysfunctional. This concern was confirmed by a few load tests carried out on pieces of filament wound pipes in a laboratory, and the delegation decided to concentrate on the remaining three alternatives.

After visiting and studying several drinking water networks in European cities the delegation was convinced that pre-stressed concrete pipe, ductile iron pipe and welded steel pipe are the three feasible options for the project. The quality of all three alternatives being acceptable then other aspects of the selection needed to be studied in order to select the appropriate type of pipe. Of course there were some distinct differences between the three alternatives. The question now was whether or not to purchase the pipes or to manufacture the pipes close to the location of the project.

To purchase pipes or to build a pipe manufacturing plant?

Manufacturing ductile iron pipes requires heavy industry and to build such a plant close to the project site was cost prohibitive and time prohibitive as well. The cost was estimated about $ 400 millions.

Purchasing the pipes from Europe would cost roughly $ 200 millions. Transporting ductile iron pipes from Europe to the project site was a logistical concern. Each 6 meters long pipe because of its geometry and its weight would require a single tractor trailer. The number of tractor trailers (33000) and the distance of transportation made this alternative cost and time prohibitive. The estimated transportation cost was $ 60 millions. The alternatives of either manufacturing or purchasing DI pipe were eliminated based on extensive cost. The same argument was true for purchasing steel pipe.

The next phase of decision making was to determine whether to manufacture welded steel pipe or to manufacture pre-stressed concrete pipe. This comparison was rather easy. Steel pipe not only will require a manufacturing plant costing around $ 100 millions, it will require importing all the material the main item being steel plates. It didn't take a lot of effort for the delegation to conclude that pre-stressed concrete pipe manufacturing plant with estimated price of $ 40 millions is the favorite choice.

Pre-stressed concrete pipe requires four major materials; stone aggregates, Portland cement, steel reinforcing bars, and high tensile steel wires for prestressing. Stone aggregates were readily available at the projects site and could be easily crushed and sieved to the required specifications. There was a cement factory close to the project site in Sofian, 30 km north of Tabriz, with capability of producing the cement with specific quality and quantity for the project. The reinforcing bars were manufactured in Isfahan steel plant. The high-tensile steel prestressing wire was the only item to be imported.

The delegation submitted a report [9] that recommended purchasing a pre-stressed concrete pipe manufacturing factory. The factory would be installed at Azarshahr a convenient location accessible to the main pipeline. This proposal was approved by the Ministry of Energy. A plant for manufacturing centrifugally cast prestressed concrete pipe was purchased and installed. The production of pipes started shortly after. At the time being the pipeline is providing the major part of drinking water of Tabriz, and the plant is producing pipes for an agricultural project bringing water from Aras River to a major agricultural project.

References

1. A. P. Moser, Buried Pipe Design, second edition, McGraw-Hill Companies, Inc.
2. Fiberglass Pipe Design Manual of Water Supply Practices- M45, American Water Works Association, Second Edition, 6666 West Quincy Avenue, Denver, CO 80235-3098.
3. Handbook of PVC pipe, Design and Construction. Uni-Bell PVC pipe Association, 2655 Villa Creek Drive Suite 155, Dallas, Texas 75234. Library of Congress No. 81-72075.
4. http://www.crescent.com.pk/spiral_welded_steel_pipes.htm
5. Steel Water Pipe: A Guide for Design and Installation, Manual of Water Supply Practices M11. American Water Works Association, Second Edition, 6666 West Quincy Avenue, Denver, CO 80235-3098.
6. http://www.ductile.org/didata/Section2/2intro.htm#History%20of%20Ductile%20Iron%20Development
7. http://www.acipco.com/adip/products/Sect3.pdf
8. http://www.pipesite.com/pbpccp.html
9. Report submitted to the Ministry of Energy by research committee on Drinking Water Project of Tabriz. September 1983.

Biography

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