VALUE DERIVED THROUGH TUNNELING

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ABSTRACT

This paper outlines a VE study conducted on the design of twin conduits for a force main in a large waste water treatment plant. It describes how VE reduced the construction cost and improved the reliability of the force main by changing the large conduits from open-cut construction to tunnels.

The paper presents the procedure used for managing the VE study and for rapid implementa-tion of the VE study recommendations. It also describes the functional analysis and other phases of the VE workshop sessions.

INTRODUCTION

Overview

VE provided the owner with construction cost savings of 36 percent, by changing the design from an open-cut force main to a tunnel force main, and producing over a $300 savings for each dollar invested in the VE study. This design change satisfied the basic functional requirements of conveying the wastewater flows at less cost and with greater reliability. The North System open-cut force main as originally designed was to be a pair of large-diameter pipes, for the purpose of conveying wastewater from the pump station to the head end of the new treatment works, about half a mile downstream. These structures are partof the expanded Deer Island Related Facilities - Boston Harbor Project (DIRF-BHP), which is beingdeveloped by its owner, the Massachusetts Water Resources Authority (MWRA), to improve the water quality of the Boston harbor.

Compliance with the federal Clean Water Act requires the MWRA to implement a wastewater treatment system incorporating secondary treatment for its service area in the Boston metropolitan area. The wastewater collected from this area is given only primary treatment at two old plants, one at Nut Island and the other at Deer Island. The effluent from both plants is discharged to the shallow waters of the harbor, causing significant burden on the marine ecology and resulting in the deterioration of this vital resource.

The new facilities at Deer Island, when completed by the turn of the century, will convey the clean effluent to the ocean. This large and modern 1.3-billion-gallon-a-day plant will provide the required treatment for all the wastewater collected from the service area. The construction of this project is one of the most challenging undertakings by this industry, because the new facilities are to be constructed on a small island around existing renovated structures, on a tight schedule and while maintaining the operation of the existing treatment works.

North System Force Main

The North System force main will carry the wastewater flows in the range of 400 to 900 million gallons per day, from the renovated North Main Pump Station and the Winthrop Terminal Facility to the new North System Headworks at the expanded Deer Island treatment facility.

This force main was originally designed for open-cut construction as twin 11.5-foot-diameter concrete cylinder pipes. The horizontal alignment and profile of the force main was routed around many obstacles, such as a deep temporary inverted siphon under the existing outfall. The alignment also necessitated constructing a bypass conduit between the proposed Primary Clarifier Battery D and the existing junction chamber connected to the existing outfall. The junction chamber is located close to the old Steam Pump Section, which is designated a historical landmark and will be renovated to become the new Administration and Support Building. The force main as designed was also intended to pass above the 11-foot-diameter influent tunnel which connects the Inter-Island tunnel shaft to the South System Pump Station. The construction of these open cut force main pipes would also have been very disruptive to the construction of several close-by renovated and new structures on the island. The probable construction cost of the North System force main as originally designed was estimated to be $31,400,000.

VE Studies

To minimize the cost of the Deer Island Treatment facilities, the MWRA applied VE studies throughout the design process. VE studies were undertaken at the conceptual design phase of the Boston Harbor project, Deer Island related facilities. These studies showed that the decisions made during the early design phase have the greatest impact on total cost and produce a high return on the invested cost of the studies.[1]

The idea of a single tunnel to replace the twin force mains developed from the VE study of the force main open-cut design concept. This alternative was accepted by the designer and the MWRA. However, upon detailed review of this concept it became evident that two tunnels of the same size of the original open-cut force mains conduits would be required. The soft-ground tunnel design alternative was then developed by the design firms, and presented to a second VE team, which was able to derive additional savings. Even with the two tunnels, the construction cost savings were significant.

VE PROCEDURE

Methodology

The MWRA acting through its Program Management Division (PMD) implemented in 1989 a VE program, as an integral part of the engineering design effort to help achieve optimum value and cost-effective designs for each of the Deer Island Related Facilities - Boston Harbor Project.[2] The MWRA recognized the important contribution of VE studies and established the procedures to derive its maximum benefits. The VE study of the North System force main was one of many VE studies conducted on this project.

Since VE is a concentrated short-term technical evaluation of a design, its primary effort is focused on the high cost items. A review of the project costs showed that a few items, about 20 percent of the elements of the system, contained about 80 percent of the total cost. Thus, by identifying and focusing on a few costly elements, the VE study could derive significant cost savings. The study team strived to identify less costly ways to accomplish the basic function and intended objective. Thereby, the VE process increased the value of the project by finding less costly alternatives to perform the functions that met the project requirements.

Activity and Organization

The VE activity, shown in Table 1, was initiated by the MWRA when the engineering design effort on the North System open-cut force main had reached the 60 percent completion stage. At this stage the project was sufficiently defined to permit a meaningful VE analysis. The directive from the owner was responded by the P/CM with the VE study plan development for scoping and scheduling the study. Upon approval of the VE plan by the MWRA and negotiations of the scope and budget, the P/CM VE Manager implemented the plan and arranged for the design package documentation to be provided by the designer and to be sent to each of the assigned VE team members. The VE team members were instructed to study the design material and cost data provided so as to become generally acquainted with the project scope before the start of the VE workshop.

The VE study workshop session started with a briefing session for the VE team members by staff members of the MWRA, the P/CM and the engineering design firms. Basic project understanding was considered to be essential for achieving a highly successful VE study. The workshop sessions were monitored by the MWRA and the P/CM VE manager. Detailed designinformation was provided by the engineering design firms on an as needed basis. Upon conclusion of the workshop, a briefing session was held by the VE team for the owner, the P/CM and the engineering design firms to present the findings and the preliminary VE report. The preliminary VE report was reviewed by the engineering design firms, and by the P/CM for operability and constructibility.

Implementation of the feasible proposals resulting from the VE studies was considered very important to derive the identified savings. The MWRA relied upon the recommendation of the Lead Engineering Design firm, the VE study team, and the constructibility review of the P/CM to determine the overall merits of the cost-saving proposals. Implementation decisions were made expeditiously to avoid schedule delays. This was achieved through the Resolution Meeting. This meeting was held about three weeks after the workshop to hear out all comments and to determine the acceptability of the VE study recommendations by the owner. Implementation of the accepted VE proposal was then initiated by negotiation with the engineering design firms for the required project modifications from an open-cut force main design to a tunnel force main design.

The VE procedure for the second VE study followed this same outline.

TABLE 1
VALUE ENGINEERING ACTIVITY

Owner MWRA	Program Construction Manager	Value Engineering Team	Engineering Design Firms
INITIATE VALUE ENGINEERI IG STUDY			
• Initiate Request for VE Study	• Respond to Request by Planning VE Study Activities		• Prepare Documentation
SCHEDULING & PLANNING			
• Review Draft Plan • Approve: VE Team Composition, Schedule and Budget	• Develop VE Study Plan, assign Team Members, prepare schedule and budget	• Receive Assignments	• Provide Design Package Documentation
VE STUDY WORKSHOP			
• Instruct VE Team on key issues • Monitor Workshop • Evaluate Study Performance	• Implement VE Study • Coordinate Activities • Monitor Workshop	• Perform VE Study • Review ideas with Designer • Prepare Preliminary VE Report	• Provide Design Information • Evaluate VE Documentation
• Evaluate VE Recommendations • Evaluate P/CM and Designer's Comments	• Coordinate Review comments on: Operability Constructibility	• Distribute Preliminary VE Report • Prepare further comments as requested	• Provide Comments
RESOLUTION MEETING			
• Obtain all relevant information • Determine acceptability of VE recommendations	• Provide all current documentation	• Review Comments from P/CM and Designer	• Initiate implementation activities
DOCUMENTATION			
	• Submit VE Report	• Provide necessary documentation • Provide VE report	• Provide necessary documentation
IMPLEMENTATION			
• Negotiate contract/scope/ budget modifications as required for revisions to Design Packages and Construction Documents			• Prepare scope and contract modification • coordinate and implement changes

VE STUDY OF OPEN-CUT FORCE MAIN

Description

The first VE study evaluated the original design of the twin 11.5-foot-diameter, 3,000-foot-long force main, which was intended to be constructed by the conventional open-cut method. The horizontal alignment was through congested areas around several existing structures, thereby complicating the construction work. The intended profile of the conduits also complicated the construction work. This was particularly the case for a temporary 16-foot square box inverted siphon with an invert about 25 feet under the water table. The massive size of the conduits, their pipe joint restraints and the interfaces with the other ongoing construction work resulted in a probable high construction cost. These high cost considerations prompted the MWRA to conduct the VE study.

Workshop Session

This VE Study Workshop session was conducted in mid December, 1989. After the presentation of the project information and cost data, the VE team evaluated the function. The functional analysis, shown in Table 2, addressed various methods of meeting the basic function of conveying the wastewater from beginning to the end, as well as around the obstacles along the route. For this paper, to highlight the key elements, only the significant issues of the functional analysis are presented in the table. This functional analysis was followed by the creativity phase, which generated numerous alternatives to accomplish the same function, and then by the analytical phase, which consisted of the detailed evaluation of the ideas generated by the team.

TABLE 2
FUNCTION ANALYSIS

Description	Function Verb/Noun	Cost / Worth		Comments
Double Conduit Cast in Place	Convey Flow	$10,000 / $5,000 LF	2	Avoiding sheeting
Surge Control Surge Tank Air release/vacc.	Control Surge	$1.5M / $200 000	7.5	System would be difficult to maintain - not reliable
Alternative Pressure Relie	Control Surge	$200,000 / $200.000	1	Simple reliable blow-back pressure release system/pressure reducing system
High Pressure Pipe	Convey Flow	$5M / $5M	1	Very costly/still does not avoid operating problem with surge in pumps/grit facility
Double Box Precast	Convey Flow	$10,000 / $5,000 LF	2	Eliminates some construction elements connections complex
Combination Box & Pipe	Convey Flow	$10,000 / $5,000	2	Temp. sheeting more space req. than for 14 & 13
Pipe for Forms Concrete	Convey Flow	$10,000 / $5,000 LF	2	Similar to 14 & 13
South P.S. Tunnel Eliminate Piling	Support Conduit	$528,000 / 0		Bridge structure
Siphon Alternatives		$1,390		
• Steel Pipes	Convey Flow	$500	2.6	3-70" dia 150' long
• Other Materials	Convey Flow	$700	2.1	
• Reduce Size	Convey Flow	$1,000	1.4	3-70" dia 130' long with true siphon
• Use a true siphon	Convey Flow	$250	5.6	
Rest. Jnts. for FM	Restrain Conduit	$1,800,000		For add. Jts. vs. $1,280,136 for sheeting
• Use Soldier Piles		$3,315,000		vs. $6,549,000
• Use Soil Stabilization		$1,750,000		vs. $1,280,136
Realign Force Main at Down Stream End				
• Shorten FM	Convey Flow	$1,164,000		Can save 120 LF of 138" dia FM pipe.
• Omit 90 degree bends	Convey Flow	Costs restraint $36,000 add.		Improve flow-less head loss
By-Pass Flow During Construction				
• Reduce Size	Omit interference	$1.6		Present size is larger than the outfall
• Route Over F.M.	Omit interference	$1.6		Elim. exca. dewatering and sheeting
Use Tunnel	Convey Flow	$32M / $13M	2.4	Less disruptive of other construction work. Shorter conduit.

VE Study Proposals

The ideas that survived this rigorous analysis were then developed to determine their merits and life cycle costs. Those developed ideas were documented and presented as the VE Study proposed recommendations in the Preliminary VE Study Report, which was distributed to all interested parties for comments. The recommendations presented from this first VE Study of the open-cut force main design are summarized as follows.

VE Idea No. 14, Proposal: Replace concrete pipes with cast-in-place concrete box conduit. Building the force mains as a monolithic, cast-in-place divided concrete box utilizes movable forms and eliminates many joint restraints and thrust problems and provides other advantages, such as sheet piling that can be removed and reused, reduced excavation and backfill, reduced construction space from 45-foot width to 31-foot width for excavation, and the box conduits would bridge potential settlement areas allowing for elimination of piles. The double box provides true redundancy, whereas the two pipes as proposed would not because the failure of one pipe would result in a washout failure of the other pipe. In addition to a cost reduction, the site disruption of transporting and lifting heavy precast pipes would be eliminated. The life cycle present worth cost savings were estimated at $10,000,000.

VE Ida No. 17, Proposal: Replace concrete pipes with a cast-in-place concrete box that can span the potential settlement area at the South Pump Station like a deep bridge. A concrete box cast inplace identical to the box proposed under Item 14 can span considerable distance due to the deep walls of the box which will act as girders. This will allow the elimination of piles and the bridge structure as proposed. The life cycle present worth cost savings were estimated at $500,000.

VE Idea No. 22, Proposal: Utilize a stabilized soil-cement-backfill around the force mains rather than permanent sheeting as proposed by the designer. Either temporary sheeting or soldier piles and lagging can then be used for temporary support during construction. The stabilized soil backfill could consist of a lean soil-portland-cement mix compacted around the force main sections. The concept of relying on steel sheeting to provide confining pressure around the pipe barrels over the life of the project was questionable because steel sheeting is very flexible. The slightest amount of movement due to a future excavation could have caused a relaxation in the confining pressure. The life cycle present worth cost savings were estimated at $500,000.

VE Idea No. 23, Proposal: A real siphon consisting of three 7-foot-diameter pipes bridging over the force main would eliminate the expensive depressed 16-foot x 16-foot temporary conduit bypass for the outfall crossing. This real siphon temporary facility would allow the force main to remain on a constant grade alignment, and could be abandoned after the existing primary tanks have been decommissioned. This is a much simpler design and has better overall hydraulic performance than does the original design. The head loss through three 7-foot-diameter siphons is approximately 0.5 feet lower than the existing design bypass, which would increase the hydraulic capacity through the existing outfall. This recommendation would also eliminate a very difficult subaqueous connection. The life cycle present worth costs savings were estimated at $900,000.

VE Idea No. 24, Proposal: Modify the outfall bypass connection by connecting it to the top section of the outfall thereby eliminating the need to align the connection underneath the proposed force mains. Keeping the connection conduit above the force mains eliminates deep subaqueous construction and poor hydraulic inlet condition to the outfall. This is a much simpler and less costly alternative with the construction taking place above the groundwater table. The life cycle present worth cost savings were estimated at $1,000,000.

VE Idea No. 2, Proposal: Realignment of force main at the discharge end to shorten the length of the pipelines. Depending on the detailed realignment selected, up to 120 or more linear feet of 11.5-foot-diameter cylinder pipe may be saved over the original design. There would be also be additional savings in the smaller pipe connections and a savings of space at the site. The life cycle present worth cost savings were estimated at $300,000.

VE Idea No. 21, Proposal: Tunnel Alternative. A tunnel for the force main would bypass under all the difficult construction obstructions on Deer Island and would shorten the force main from 3,000 feet to 2,300 feet. The tunnel would extend from a shaft at the North Main Pump Station to the inlet of the grit chambers at the head end of the North System Treatment Works. The tunnel was proposed as a single 20-foot bore, split with a wall to create two conduits, each with 208-square-foot cross section area. The tunnel can be constructed from either end, without interfering with other construction activities. The construction schedule called for the start of construction of the force main in December 1990 and completion by June 1992. There was time to redesign a tunnel alternative and hold to the original construction start data, and the tunnel could be constructed within a year after start date. The original project schedule could be held. The life cycle present worth cost savings were estimated at $13,300,000.

VE STUDY OF TUNNEL FORCE MAIN

Description

The second VE study addressed the tunnel force main design at the conceptual stage and the workshop was conducted in March, 1990. The MWRA had selected the tunnel design recommendation from the first VE study, but wanted the tunnel to duplicate the conduit sizes of the original design. Thus, the tunnel design presented to the VE team consisted of single tunnel or two parallel 11.5-foot-diameter tunnels in soft ground or deeper in rock. These were identified as Alternatives 1, 2, 3 and 4, respectively.

Workshop Section

The VE Study team addressed the alternatives presented and considered other options that met the basic functional requirements. The other alternatives considered were two conduits in a single soft groundor rock bore, a jacked pipe scheme and a single shaft at the outlet. The VE team also re-evaluated the single conduit concepts. These alternatives were then evaluated during the brainstorming phase. The results of this analysis are shown in Table 3.

TABLE 3
VE WORKSHOP EVALUATION OF NORTH SYSTEM TUNNEL

	Idea	Advantages	Disadvantages	Ranking
1a	Soft ground single tunnel with two conduits, low surge divider wall scheme	Shallow shafts Meets O&M criteria	Requires heavy reinforcement More excavation Requires surge tank	No Good
1b	Soft ground single tunnel with two conduits, high surge	Shallow shafts Meets O&M criteria	May require steel liner More excavation Requires surge tank	No Good
1c	Soft ground single tunnel with two circular conduits	Can use lock-joint pipe	Requires very large diameter tunnel	No Good
2	Twin soft ground tunnels	Shallow shafts Meets O&M criteria Can be const. by pipe jacking	Requires heavy reinforcing Requires surge tank	1
3a	Single rock tunnel with two conduits, low surge	Meets O&M criteria Minimum rein. steel reqd. Can use lock-joint pipe	Deep shafts Highest internal pressure More excavation Requires surge tank	No Good
4b	Twin rock tunnels	Minimal rein. steel required No steel liner Meets O&M criteria	Highest internal pressure Deeper shafts Requires surge tank	3
5	Single soft ground tunnel (1 conduit)	Shallow shafts Minimum surge pressure Min. design internal pressure Best schedule No surge tanks required	Requires heavy reinforcing More energy cost Does not meet O&M criteria	2
6	Single rock tunnel (1 conduit)	Minimizes reinforcing steel Minimum surge pressure Least change of leakage No surge tank required No steel liner	Deep shaft Highest pressure More energy cost Does not meet O&M criteria	No Good
7	Jacked pipe scheme	Can withstand any surge. Could be constructed faster. Tunnel & Liner at same time. Shallowest depth. Min. on-site construction. Can be made a bid alternative Min. impact on other contr.	Some handling and logistics problems.	OK
8	Single shaft at grit chamber	Less Cost Minimal impact to abutting contracts.	Could complicate flow distribution at surface. O&M access is difficult.	OK

CONCLUSION

Upon conclusion of each of the VE Study workshops and the review of VE Study preliminary reports, the MWRA conducted the Resolution meetings to evaluate and determine the acceptable VE Study proposals. These meetings were chaired by the MWRA and attended by the designers, the P/CM staff and VE team members. Table 4 lists the proposals presented at both of the Resolution Meetings and the actions taken at these meetings. The first Resolution Meeting, covering the VE Study proposals on the open-cut force main was held in January, 1990. At this meeting, the Lead Design Engineer recommended the approval of the tunnel alternative and this was accepted by the MWRA. The Lead Design Engineer evaluated the tunnel concept and estimated that its construction cost could be less than the construction cost developed by the VE Study team. The second Resolution Meeting covering the force main tunnel VE Study proposals was held in March, 1990. At this meeting, the MWRA accepted the VE Study Option for soft ground twin tunnels, with the provision for allowing the construction contractor to use the jacked pipe construction method.

TABLE 4
SUMMARY OF VALUE ENGINEERING RECOMMENDATIONS

Description and Savings	Designers Comments	Owner's Decision
VE STUDY OF THE OPEN-CUT FORCE MAIN AT 60% DESIGN STAGE		
14. Cast-In-Place Double Box Conduit $10,000,000	Rejected	Required further study from construction viewpoint
17. Double Box Conduit to Replace Bridge $5,000	Rejected	Rejected
22. Use a Stabilized Soil Cement $500,000	Rejected	Rejected
23. Use Real Siphon $900,000	Rejected	Deferred. Evaluate construction methodology and phased construction options
24. Modify Outfall By Pass Connection $1,000,000	Rejected	Defer to Site Committee
2. Realign Discharge End $300,000	Accepted	Defer, re-evaluate cost savings
21. Tunnel Alternative $13,300,000	Required detail study Accepted	Accepted - designer should study and evaluate this option. This alternative overrules all others.
VE STUDY OF THE TUNNEL FORCE MAIN AT CONCEPTUAL DESIGN STAGE		
a) VE Option #1 Designer's Alternative #2 Soft ground twin tunnels w/surge tank Alternative - jacked pipe method $835,000	Recommended	ACCEPTED with the provision for jacked pipe construction method alternative
b) VE Option #2 (new alternative 5) Soft ground, single tunnel w/o surge tank, etc.	Rejected	Rejected
c) VE Option #3 Designer's Alternative #4 Twin rock tunnels w/surge tank, etc. $2,542,000	Rejected	Rejected

Notes for Table 4

* Estimated construction cost for open-cut force main, original design concept = $31,400,000
* Estimated construction cost estimate for soft ground twin tunnels after both VE Studies = $18,800,535
* Actual construction cost of the soft ground twin tunnels was $20,200,000 based on a construction contract awarded December 12, 1990 to a joint venture of Kiewit Construction Co., Guy F. Atkinson Co. and Kenny Construction Co.[4]
* Savings from both the VE Studies = $11,230,00 (36% of original estimated cost)

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The two VE Studies of the North System Force Main resulted in a recommendation to substitute twin soft ground tunnels for the open-cut twin force main. The estimated construction cost of this accepted alternative was $17,970,000. However, the actual construction cost per contract award was $20,200,000. The MWRA's acceptance of this recommendation netted a $11,230,000 construction cost savings from the original open-cut force main concept. This change also resulted in other improvements. The tunnel force main is now constructed and did not interfere with the other ongoing unrelated construction work, which was a concern of the original design. Tunnels are also more secure conducts for wastewater than large open-cut pipelines. Thus, this VE study resulted in cost savings, improved construction sequencing and improved quality for the Boston Harbor Project.[3]

The total cost of the engineering effort to mobilize and conduct these two VE Studies was approximately $35,000 ($13,000 for the open-cut force main VE Study and $22,000 for the tunnel force main VE Study). The net result of the two VE Studies was a cost ratio of $321 derived savings to each dollar of VE Study cost. Thus, it can be stated that these two VE Studies produced direct benefits to the Deer Island Related Facilities - Boston Harbor Project.

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