ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, *Vol 8(28), DOI: 10.17485/ijst/2015/v8i28/81828, October 2015* ISSN (Online) : 0974-5645

Applying of Value Engineering in EZGELEH Dam with Focus on Rock Slopes Stabilization and Underground Support

Afshin Rezaei Khezeli* and Alireza Rahai

Department of Civil and Environmental Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran; a-rezaei@aut.ac.ir, rahai@aut.ac.ir

Abstract

In this research we try to propose a new method for rock slopes stabilization and underground structures support of a real project that uses mesh reinforced shotcrete to improve value index of it. For this we applied value engineering technique on a real project of IRAN (EZGELEH dam) to help us use specific and accurate data. Also we used a laboratory research in same field to evaluate effect of project on quality and efficiency of final result. At the end we constructed a part of tunnel by suggested method of value engineering and similar part by old method to compare these methods together based on time, cost and quality. Final result of research has three major parts that has been reached by studying on major parameters of project (time, cost, quality). Final result has been presented by specific data and statistics. The results of our investigation show that using polypropylene fiber reinforced shotcrete instead of mesh reinforced shotcrete for rock slopes stabilization and underground structures support upgrade value index of this project significantly. Also it can be used in similar development projects.

Keywords: Concrete, Fiber, Shotcrete, Slope, Tunnel, Value Engineering

1. Introduction

Every year a considerable amount of Iran's budget will invests in development particularly in water supplies on the other hand so many reasons like shortage in resources will expand the duration of project and this delay will cost a lot more than the considered budget. The mentioned reasons will divide in two categories internal and external problems. External problems are mainly caused by major financial problems and environmental reasons but internal problems generally have an obvious reason, the management thus a manager is in charge that has no ability to control the cost of the project and he can't organize the cost reduction with the special ways and techniques when it's needed. In major and unique development project like dam construction improvement in construction and cost control is an important deal and it's important to consider the highest profit and quality from the designing part. For achieving this accomplishment, we can use value engineering. Special studies in value engineering field at schematic development of project design. Afterwards we should do the studies in details. But the major part of the studies because of unknown nature of underground particles in the construction zone of the dam that will be known in the progress of the construction should be done in this phase. By studying different phases of value engineering in proper time zones we can expect to obtain the goals of the project by using the lowest budget. It's also recommended to work on cultural bases of society to use value engineering and try to promote this field. It's necessary to work on legal obligations of the consulting and constructing to make the authorities and responsibilities of development projects to belief that in addition to using worthy designers and accurate calculations there is also extra potential to reduce the cost of the project by using creative ways and innovation in designing and building[1].

Underground structures such as tunnels and trenches have important and various usage development projects

**Author for correspondence*

and their role in dam projects is really important both in technical and economical ways. Despite fast and vast growth of modern technologies in stabilization of this structure unfortunately traditional methods are still applied in IRAN. In IRAN used multiple passes of shotcrete along wire mesh and installment of rock bolts in order to temporary stabilization of tunnel walls and trenches. In this research we try to make an improvement in stabilization method and find a substitute method for mesh reinforced shotcrete. Our studies are based on real project in order to having reliable and useful results.

2. Constructed Method in Order to Rock Slopes Stabilization and Underground Structures Support in EZGELEH Dam

In specific study on EZGELEH dam has been observed that they used a layer of pre-welded wire mesh (W8 × 8 × 150 × 150mm) and two passes of shotcrete in order to rock slopes stabilization and underground structures support. Detail of used concrete mix design for shotcrete in EZGELEH dam has been shown in Table 1. It's considerable that this method is main way to stabilization of structures in most of IRAN's development projects.

3. Technical, Safety and Quality Criticize of Rock Slopes Stabilization and Underground Structures Support by using Mesh Reinforced Shotcrete

Most important high lights based on quality of this method are:

- It takes a long time to install wire mesh and stabilize the tunnel by shotcrete after tunnel boring so it's possible that rock mass move and create a huge danger for workers in construction site[2].
- Wire mesh installment operation in trenches specially is dangerous because of their height and topography situation. There are various reports that inform these installments caused damages to workers.
- In various cases problems such as high temperature, long time between work shifts suspension of project because of wreckage of equipment or shortage of materials and long period between constructing first and second passes of shotcrete so this matter set first pass of shotcrete and causes non uniformity between first and second passes of shotcrete[3].
- Tunnel environment is "corrosive". Diversion tunnels of EZGELE dam have inappropriate environment because shotcrete is constantly effected by water that contains harmful ions such as phosphate, Magnesium, Chloride, etc. so these ions corrosion mesh and spoils shotceret. Corrosion of shotcrete will influence to lining concrete and cause serious damages to structure concrete.

4. Studies about Time, Cost and Sustainable Development in Rock Slopes Stabilization and Underground Structures Support by Mesh Reinforced Shotcrete

Most important high light based on time and cost of this method are:

- Fixing mesh to tunnel walls and trenches especially in high height areas is difficult, time consuming, costly and sometimes hazardous[3].
- Rate of waste is much higher than normal rate (5–10%) in first pass of shotcrete because of conflict between shotcrete and wire mesh. Waste rate of first pass has been up to 30% in sometimes and that adds a massive amount to project's cost.
- In addition to massive cost high rate of waste has a massive effect on environment because it contains a high amount of cement that is known as an extremely pollutant materials.

Table 1. Used concrete mix design for shotcrete in EZGELEH dam (grade of concrete - C25)

Slump (cm)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Cement (kg/m^3)	Water (Lit)	Water Cement Ratio (W/C)	Super plasticizer (kg/m^3)
0	1107	557	448	257	0.57	0

5. Value Engineering Workshop

The workshop of value engineering was held in the site in order to find a way to upgrade value index of project by improve rock slopes stabilization and underground structures support method. Summary report of this workshop (value engineering workshop) is described below.

5.1 Pre-study Phase

In first step of this phase we gathered data and information about rock slopes stabilization and underground structures support of EZGELE dam in shop drawings, designing details and zero phase studies. In next phase we collected a team formed by five experts in construction management, structure, geography, planning and contract fields. At the end we prepared Table 2 that indicates costs of rock slopes stabilization and underground structures support by using mesh reinforced shotcrete in EZGELEH dam.

5.2 Study Phase

This phase has been divided into five steps:

Table 2. Cost of mesh reinforced shotcrete in EZGELEH dam

Labor	Unit	Quantity	Unit Cost ($)	Factor	Total Cost ($)
Subcontractor Payment	m^2	1.0000000	6.06	1.00	6.06
Executive Engineer	man hour	0.2400000	2	1.00	0.48
Batching Operator	man hour	0.0160000	1.56	1.00	0.02
Worker	man hour	0.0160000	1.07	1.00	0.02
Surveyor	man hour	0.0240000	3.74	1.00	0.09
Electrician	man hour	0.0240000	1.34	1.00	0.03
Air Compressor Operator	man hour	0.1600000	1.17	1.00	0.19
				Total Cost of Labor ($)	6.89
Equipment	**Unit**	**Quantity**	**Unit Cost ($)**	**Factor**	**Total Cost ($)**
Batching Plant	machine hour	0.0160000	8.34	1.00	0.13
Shovel or Loader	machine hour	0.2400000	10.01	1.00	2.4
Truck Mixer	machine hour	0.1600000	8.34	1.00	1.33
Tank	machine hour	0.1600000	8.34	1.00	1.33
Air Compressor	machine hour	0.1600000	6.9	1.00	1.1
Generator	machine hour	0.1600000	8.34	1.00	1.33
				Total Cost of Equipment ($)	7.62
Material	**Unit**	**Quantity**	**Unit Cost ($)**	**Factor**	**Total Cost ($)**
Coarse Aggregate	Ton	0.0557000	3.19	1.20	0.21
Fine Aggregate	Ton	0.1107000	3.19	1.20	0.42
Cement	Ton	0.0448000	28.04	1.20	1.51
Water	m^3	0.0257000	.17	1.20	0.01
Wire Mesh (8x8x150x150mm)	kg	5.2300000	0.73	1.20	4.58
				Total Cost of Material ($)	6.73
Transportation	**Unit**	**Quantity**	**Unit Cost ($)**	**Factor**	**Total Cost ($)**
Handling of Cement	Ton	0.0448000	11.38	1.30	0.66
Handling of Wire Mesh	Kg	5.2300000	0.02	1.20	0.13
Inside Transportation	m^2	2.0000000	0.03	1.30	0.08
Total Cost of Transportation ($)					0.87

Total Cost of One Square Meter of Mesh Reinforced Shotcrete	$22.11
Total Cost of One Square Meter of Mesh Reinforced Shotcrete by Overhead Cost (20%)	$26.53
Total Cost of Mesh Reinforced Shotcrete in EZGELEH Dam (Estimate: 40000 m^2)	$1061280

5.2.1 Information

In first step of study phase we shared gathered data with team members then during a session with team members and project Stakeholders we represented value engineering goals and profits.

5.2.2 Function Analysis

In second step of study phase we drew FAST diagram in order to recognition functions of mesh reinforced shotcrete method. This diagram has been shown at Figure 1.

5.2.3 Generate Ideas (Creativity)

In third step of study we held a brain storming session and asked members to focus on functions that had been reached in FAST diagram and offer their ideas. In that meeting members offered 8 ideas that could been used to improve or replace mesh reinforced shotcrete method.

- Stabilizing surfaces of trenches and tunnels by using geo membrane and geo textile.
- Tunnel temporary support by using lattice.
- Rock slopes stabilization by using steel retaining structure.

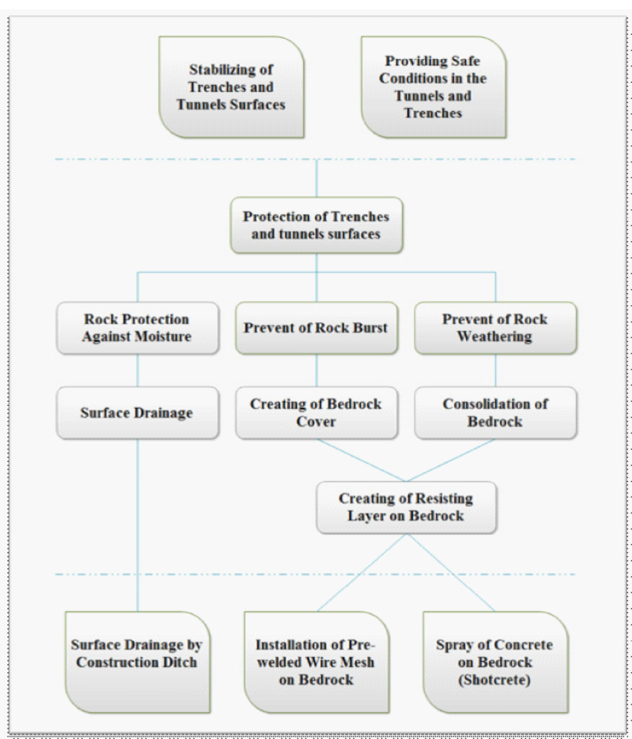

Figure 1. FAST diagram of mesh reinforced shotcrete.

- Rock slopes stabilization and underground structures support by using precast concrete elements.
- Stabilization by using steel and cast iron retainers.
- Rock slopes stabilization by reducing slope (increase of horizontal length).
- Rock slopes stabilization and underground structures support by micro piles (grouting cement and bentonite into rock veins).
- Rock slopes stabilization and underground structures support with fiber reinforced shotcrete.

5.2.4 Evaluation (Evaluate and Rank Ideas)

In fourth step of study phase we intended to choose best option between possible options so with help of the team we picked three options from mentioned options and we tried to find best option with help of AHP technique. In order to summaries the result and ease drawing of diagram and weight table we show options with alphabetical letters.

- Rock slopes stabilization and underground structures support with fiber reinforced shotcrete.
- Rock slopes stabilization and underground structures support by using precast concrete elements.
- Rock slopes stabilization and underground structures support by micro piles (grouting cement and bentonite into rock veins).

Evaluation criteria are time, cost, quality and construction comfort. The rock slopes stabilization and underground structures support hierarchy could be diagrammed as shown in Figure 2. Calculates of AHP technique has been shown in Tables 3–5.

As we can see in Table 5 method "A" (rock slopes stabilization and underground structures support with fiber

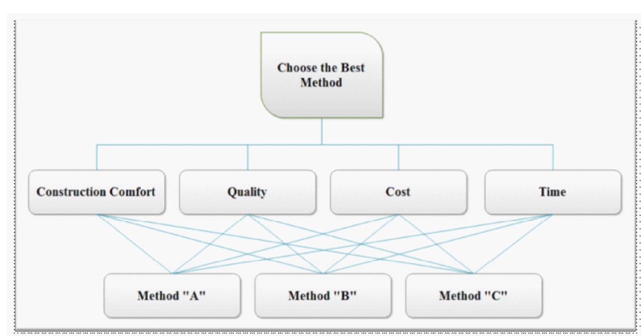

Figure 2. AHP hierarchy for the rock slopes and underground structures stabilizing decision.

Table 3. Weights on criteria

Average	Comfort	Quality	Cost	Time	
0.279	0.3	0.389	0.203	0.223	Time
0.570	0.5	0.5	0.608	0.67	Cost
0.064	0.1	0.056	0.068	0.032	Quality
0.088	0.1	0.056	0.122	0.075	Comfort

Table 4. Relative Score for each criteria

Comfort	Quality	Cost	Time	
0.295	0.143	0.633	0.643	A
0.649	0.143	0.261	0.283	B
0.057	0.714	0.106	0.074	C

Table 5. The value for each method

Priority	Weight	
First	0.575	A
Second	0.294	B
Third	0.132	C

reinforced shotcrete) with 0.575 weight is way ahead compare to others. So at the end of evaluation we choose this method to work on.

5.2.5 Development (Develop and Expand Idea)

In this chapter we try to reach an improved mix design for fiber reinforced shotcrete relevant to EZGELE dam design. We used a research from Sharbatdar and Ghasemi[5] and we reached a real sample relevant to mix design in EZGELE project lab. in this research many parameters have been investigated such as type of fibers, volume% of fiber and etc. 29 one and two layer one way slab with 135 × 30 × 10 cm dimension in two forms (with and without rebar) were armed with plane concrete and polypropylene and steel fiber reinforced concrete with different volume percentage were build and were tested by flexural test. At the end flexural strength, bearing capacity, flexural toughness, energy absorption rates were compared[4].

5.2.5.1 Test Specimen Introduction

From 29 test specimen made by Sharbatdar and Ghasemi[5] six were selected for this research. These six slabs were divided into two groups 3 were made by steel fiber with 0.5, 1, 2 volume% (SS-0.5, SS-1, SS-2) and others were made by polypropylene fiber with 0.5, 1, 2 volume % (PP-0.5, PP-1, PP2).

2 kinds of sand were used during test: first type passed through sieve No.4 but didn't pass through sieve No.8 (bigger than 2.36mm, smaller than 4.75mm) second type passed through sieve No.4 and No.8 (smaller than 2.36mm). Cement that was used in this test was Portland type (II)[4].

Properties of steel fibers, polypropylene fibers and concrete mix design of test specimens had been shown in Tables 6–8.

Table 6. Properties of steel fibers used in SS-0.5, SS-1, SS-2

Tensile Strength (MPa)	Aspect Ratio (L/D)	Diameter (mm)	Length (mm)	Fiber Type
1000	47.62	1.05	50	Steel

Table 7. Properties of polypropylene fibers used in PP-0.5, PP-1, PP-2

Tensile Strength (MPa)	Elastic Modulus (GPa)	Density (kg/m^3)	Length (mm)	Fiber Type
600	5	910	12	Polypropylene

Table 8. Concrete mix design used in test specimens

Specimen Name	Sand (passive sieve No.8) (kg/m^3)	Sand (remain sieve No.8) (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)	Fiber Type	Fiber Volume %	Fiber Weight (kg)
PP-0.5	609	362	812	325	4.06	polypropylene	0.5	4.6
PP-1	609	362	812	325	4.06	polypropylene	1.0	9.2
PP-2	609	362	812	325	4.06	polypropylene	2.0	18.4
SS-0.5	609	362	812	325	4.06	steel	0.5	39.5
SS-1	609	362	812	325	4.06	steel	1.0	78.5
SS-2	609	362	812	325	4.06	steel	2.0	158

5.2.5.2 Testing System

Based on ASTM and Iran's 490 manuals in order to investigating slab's bending behavior we used a system like Figure 3 that shows behavior of simple-supported slab under two concentrated loads on 1/3 span.

In test on each specimen that was continued until failure under applied load deflection, crack location and load bearing were recorded by equipments[4].

5.2.5.3 Test Results

Specimens were put under pure bending to find and measure loading and deflection information by using specific devices. At the end we calculated and compared flexural strength, maximum load and energy absorption rates information are mentioned in Table 9 and Figures 4–7[4].

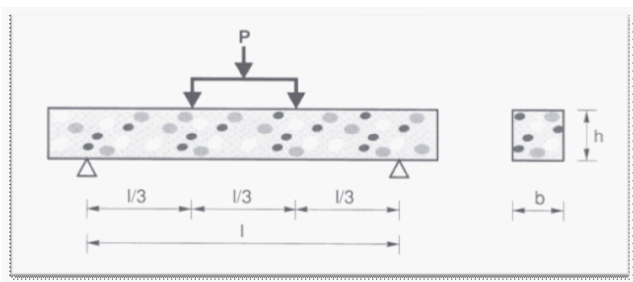

Figure 3. Flexural test set-up.

Table 9. Flexural test results

MAX. Moment (KN.m)	Energy Absorption (J)	MAX. Load (KN)	Compressive Strength (KN)	Specimen Name
1.28	28.21	7.67	49.36	PP-0.5
2.0	36.77	11.73	55.5	PP-1
2.32	74.15	13.93	45.27	PP-2
2.4	329.76	14.4	46.91	SS-0.5
3.03	596.06	18.2	68.44	SS-1
3.21	717.61	19.24	70.69	SS-2

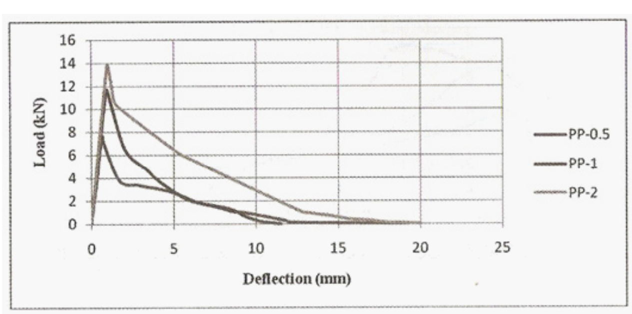

Figure 4. Comparison of load-deflection diagrams of (PP-0.5, PP-1, PP-2).

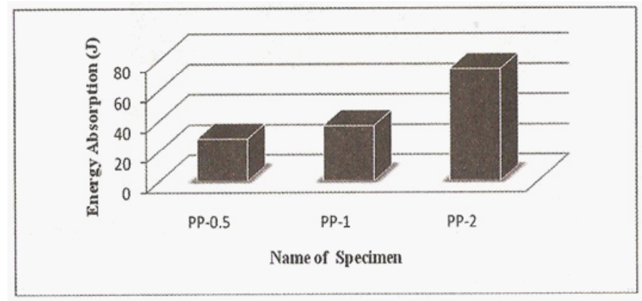

Figure 5. Comparison of energy absorption rates of (PP-0.5, PP-1, PP-2).

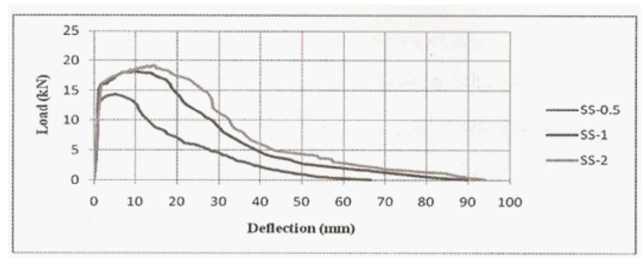

Figure 6. Comparison of load-deflection diagrams of (SS-0.5, SS-1, SS-2).

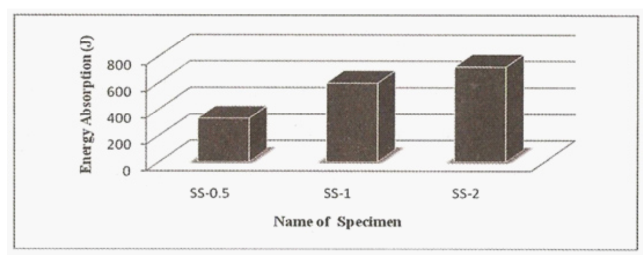

Figure 7. Comparison of energy absorption rates of (SS-0.5, SS-1, SS-2).

5.2.5.4 Fiber Reinforced Shotcrete Mix Design Final Selection

We want to choose finest option considering technical and economical parameters between 6 test specimens. Considering reasons below option PP-1 (polypropylene fiber reinforced concrete with 1volume %) were choose in order to using in fiber reinforced shotcrete for rock slopes stabilization and underground structures support.

- However mechanical properties of steel fiber reinforced concrete is way ahead in Table 7, but considering that maximum moment rate in mesh reinforced shotcrete design is less than 2KN.m. Our chosen has required specifications so it can be used.

- Price of polypropylene in market is more than steel fiber but density of this fiber is less than 0.1 compare to steel fiber. Because percentage of fiber in concrete evaluate in volume ratio so final price of polypropylene fiber is less than steel fiber.
- As one of our discussion matters in this research was using of fiber reinforced shotcrete in tunnels and as we mentioned before the tunnel that was research contained high a amounts of harmful ions such as sulfate and had corrosive environment for concrete that could cause serious damages to steel fibers we can find out polypropylene fibers as better function in this situation[5].
- Final advantage of polypropylene fibers over steel fibers is that deprecation cost of polypropylene is way lower than steel fibers so this note has a huge effect on economical aspect of project.

5.2.5.5 *Trial Run of Fiber Reinforced Shotcrete and Mesh Reinforced Shotcrete*

In order to compare progress of fiber reinforced shotcrete and mesh reinforced shotcrete and also material waste we managed to construct mesh reinforced shotcrete and fiber reinforced shotcrete in exactly similar areas of diversion tunnel number 2 of EZGELEH dam. Results of this operation that has been specified in work shift are:

- Stabilizing (125 m^2) of tunnel walls by fiber reinforced shotcrete took two work shifts (8 hours) but it took three work shifts (1 hours) to do same amount of wall by mesh reinforced shotcrete. Research shows that wiring time took a long part in mesh reinforced shotcrert progress and that's because of height of tunnel and curves of the wall we also should consider safety dangers that may happen to workers that work in this situation.
- Amount of material waste in fiber reinforced shotcrete was estimated about 10% but the percent was 20% for mesh reinforced shotcrete. Major part of waste belongs to first pass of shotcrete. in first pass because of encounter of concrete with wire mesh waste rate has a major growth (around 30%) that this amount after covering of mesh in second pass reaches normal amount (around 10%). Noteworthy matter here is that during constructing fiber reinforced shotcrete we observe that fiber going to waste more than other materials and this matter may cause shortage in volume ratio of fibers in walls on final mix. We have to consider higher volume % in our calculations to prevent this problem happen.

6. Cost of Value Engineering Suggestion

At the end we prepared Table 10 that indicates costs of rock slopes stabilization and underground structures support by using polypropylene fiber reinforced shotcrete.

Table 10. Cost of polypropylene fiber reinforced shotcrete

Labor	Unit	Quantity	Unit Cost ($)	Factor	Total Cost ($)
Subcontractor Payment	m^2	1.0000000	3.34	1.00	3.34
Executive Engineer	man hour	0.1800000	2	1.00	0.36
Batching Operator	man hour	0.0160000	1.56	1.00	0.02
Worker	man hour	0.0160000	1.07	1.00	0.02
Surveyor	man hour	0.0240000	3.74	1.00	0.09
Electrician	man hour	0.0240000	1.34	1.00	0.03
Air Compressor Operator	man hour	0.1600000	1.17	1.00	0.19
				Total Cost of Labor ($)	4.05
Equipment	**Unit**	**Quantity**	**Unit Cost ($)**	**Factor**	**Total Cost ($)**
Batching Plant	machine hour	0.0160000	8.34	1.00	0.13
Shovel or Loader	machine hour	0.1800000	10.01	1.00	1.8
Truck Mixer	machine hour	0.1600000	8.34	1.00	1.33
Tank	machine hour	0.1200000	8.34	1.00	1.0
Air Compressor	machine hour	0.1200000	6.9	1.00	0.83
Generator	machine hour	0.1200000	8.34	1.00	1.0
				Total Cost of Equipment ($)	6.09

(*Continued*)

Table 10. Continued

Material	Unit	Quantity	Unit Cost ($)	Factor	Total Cost ($)
Coarse Aggregate	Ton	0.0362000	3.19	1.10	0.13
Fine Aggregate	Ton	0.0609000	3.19	1.10	0.21
Cement	Ton	0.0812000	28.04	1.10	2.50
Water	m^3	0.0325000	0.17	1.10	0.01
Super Plasticizer	kg	0.4060000	1.34	1.10	0.60
Polypropylene Fiber	kg	0.9200000	2.27	1.10	2.30
				Total Cost of Material ($)	5.75
Transportation	**Unit**	**Quantity**	**Unit Cost ($)**	**Factor**	**Total Cost ($)**
Handling of Cement	Ton	0.0812000	11.38	1.30	1.2
Handling of Fibers	Kg	0.9200000	0.02	1.20	0.02
Inside Transportation	m^2	1.0000000	0.03	1.30	0.04
				Total Cost of Transportation ($)	1.26

Total Cost of One Square Meter of Mesh Reinforced Shotcrete	$17.15
Total Cost of One Square Meter of Mesh Reinforced Shotcrete by Overhead Cost (20%)	$20.58
Total Cost of Mesh Reinforced Shotcrete in EZGELEH Dam (Estimate: 40000 m^2)	$823200

7. Conclusion

In final step of this research we gathered our study results based on three important factors (time, cost, quality) that are both important in project and value engineering:

7.1 Time

This part was important because it could be improved by value engineering. 426 days were considered in project schedule for mesh reinforced shotcrete operation. usually this activity gets done at same time with other activities except No.196 and 197 activities in schedule that are vertical shafts shotcerete that takes 130 days to get done and it on critical path of schedule. So if we do fiber reinforced shotcrete we save 32 days based on test records and that's a valuable time for a project.

7.2 Cost

Importance of this factor divides in two parts according to value engineering plans:

- Budget for fiber reinforced shotcrete ($823200) compare to mesh reinforced shotcrete budget ($1061280) is less than $238080.
- If we use fiber reinforced shotcrete we save 32 days and reduction costs of constructing site such as food, fuel for machines, staff payment, residence and etc. are over $270'000 (based on $8500 per each day) make profit for project.

Based on mentioned reasons value engineering saved $510'000 for project.

7.3 Quality

Advantages and disadvantages of fiber reinforced shotcrete compare to mesh reinforced shotcrete are:

- In corrosive environment of tunnel mesh reinforced shotcrete gets oxidation and causes serious damages to reinforced and lining concrete but polypropylene has a great resistance in corrosive environment so the reasonable option for tunnels is fiber reinforced shotcrete.
- Installment of mesh inside tunnels is really dangerous because possibility of rock burst and lack of safety factors and height of project. On the other hand fiber reinforced shotcrete danger risks are really low and right after tunnel boring can be started to prevent movement of rock mass.
- Vertical movements of rock mass for fiber shotcerete are less than mesh reinforced shotcrete and that may be for one of this reasons:
    - Direct counter of fiber with rock mass.
    - Spray of fiber reinforced shotcrete is faster because it does not require a time for installing frame and mesh so rock mass does not have time to move.
- Because of ductility and crack resistance fiber reinforced shotcrete bears load after transformation.

- It is possible that during installment of fiber reinforced shotcrete fibers gather in same spot and occur balling. This is a negative point for this method[6].
- It is possible that fiber reinforced shotcrete cracks before shotcrete sets and this accident is another flaw for fiber reinforced shotcrete method.

8. References

1. Khezeli AR. Opportunities and challenges of using value engineering in IRAN's Dam Projects. Curr World Environ. 2015 April 1; 10(spl issue 1):389–96.
2. Vandewalle M. NV Bekaert SA Belgium: Tunneling the World; 1996.
3. Tafreshi ST, Mahdavi E, Armanpur F. Using fiber reinforced shotcrete for lining of tunnels. Babolsar, Iran: National Congress on the structure, Earthquake and Geo Technic; 2010 Dec.
4. Sharbatdar MK, Naghib Dehi MG. Layered fiber reinforced concrete flexural slabs. 1st ed. Semnan University Press; 2014.
5. Keyvani A, Saeki N, Notoya T. Corrosion of steel fiber reinforced concrete. Australia: Fourth ACI/CANMET International Conference on Durability of Concrete; 1997. p. 451–66.
6. ACI Committee. Report on Fiber Reinforced Concrete. Farmington Hills, MI, USA: American Concrete Institute; 2002.