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Application of Value Engineering in the Design and Implementation of Dam channel and Storage Pump Power Plant (Case Study of Siah Bishe Project)

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ABSTRACT

Dams and Power Plants of Siah Bisheh are the first projects of the dams and Storage Pump Power Plant in Iran. The project is located 125 kilometers north of Tehran, Mazandaran province, which due to its proximity to the Siah Bisheh village it's called the same name. The purposes of this project are to create a balance in the consumable power grid of the country at high and low consumption hours, reduce the cost of thermal power of amortization, create a recreational and tourism environment in the region, and create job creation during the implementation and operation. This project has been found of two upper and lower dam and a Power Plant which is used of two channels due to the water transformation between the upper and lower dam. according to the relatively large distance between dams from each other and the complex topography of the Siah Bishe project, the design and implementation of channel tunnels have complexity and special importance, which it's more important factors are being long route of the channel, passing the channel from the earthquake-prone and fault areas, high water pressure, the presence of tunnels and geological complexity of the area. According to the above subjects, the Siah Bishe projects had been one of the most complex and difficult parts of the project for design and implementation. In this article has been proceeded to the description of the important points of the value engineering application in the design and implementation of the channels, which its results and achievements will be very useful in designing and constructing of other country's projects.

Key words: Value engineering, Dam and Pump Storage Power Plant, Channel, Siah Bisheh project.

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1. INTRODUCTION

The main purpose of creating the Pump Storage Power Plant is electricity generation at high operating hours and its consumption at low load hours. The operation of the world's first Pump Storage Power Plant began in 1890 in Italy and Switzerland. At the moment, more than 90,000 megawatts of the pump storage power plant is in operation and about 3 percent of the world's generative electrical energy is supplied by these power plants (1). These power plants have good economic efficiency and they usually start from one to four minutes, which is a very short time compared to thermal power plants (2). In Iran, with the aim of power supply in high

load consumption hours and using it in low-load hours, as well as in order to reduce the amortization of thermal power plants, Siah Bishe studies plan began in 1979, and in order to using of the available potential in the Alborz Mountains, the site of the project location was selected in 125 kilometers north of Tehran, located in Mazandaran province. This project was constructed on the Chalus River and near the Siah Bisheh Village and is at the moment is in the final stages of installation and initiation. Another goal of the project is creating a recreational and tourist environment for tourists, providing low water demand and job creation in the area during the implementation of the plan and the operation period (3).

2. A REVIEW OF PREVIOUS STUDIES

The issue of the operation of the Pump Storage Power Plants, according to their various constructional purposes, has been studied and considered in various ways. Hadji Paschalis and et.al (4) have concluded that in the process of studies the using of reservoir pump stations, studies were first undertaken on the optimal performance of Pump Storage Power Plants at first the investigations had been with the aim of uniform the load curve and reduction of the peak consumption regarding the optimal performance of these power plants. Ingram believes that with the entrance of Pump Storage Power Plants to this field, the balance between obtaining usable time maximum of the power plant along with costs should be done by using of value engineering. García et al. (5) expressed that today the need for storage pumping plans has been considered as a help and compensator of lack of energy production finality from new sources in the world. Hu et.al (6) and Jiang et al (7) in their studies concluded that with the entrance of new and renewable energies in the last decade, how to determine the optimal capacity of the needed Pump Storage Power Plant according to the lack of finality conditions of new energy is determinable by using of value engineering. In the Nowak study (8) the combination of power plants entry and exit planning has been presented with consideration to the financial decision makings, and in Gollmer et al.studies (9), the determination of optimal strategy according to the available uncertainty for a hydroelectric power plant has been presented by using of value engineering. Loucks et.al (1) in their study investigated the effects of construction of pumping-storage power plants in improving the performance of the country's electricity production system. these researchers with pointing to that the use of Pump

Storage Power Plants causes the correction of load continuity curve and improvement of the production system performance, have noted numerous benefits to the operation of the electricity grid, Side services, environmental and economic services. Movahed (10), in his study as the economic evaluation of the Pump Storage Power Plants of the Siah Bisheh dam, based on the technical specifications of the power plant in terms of water pumping and power generation, by comparing the various components of the cost of investment, operation and outage, has determined the most suitable year for entering to the power plant's orbit and was announced the plant's performance at 78%.

3. COMPONENTS OF SIAH BISHEH PROJECT

The main components of the plan are the tank of the upper dam and associated structures, the channel tunnels, the Surge Tank, the pressure shaft, the power plant cavern, the transformer cavern, the shoal tunnel, the lower dam and its related structures (11). In Figure 1 the main components of the project has been shown. The approximate length of each of the channels is 2800 meters, which near the power plant each of the channels is divided into two parts (Manifold) by the Y-Branch, and finally, four channels enter to the power plant and bring the water to turbines. The first part of each of the channels has a concrete cover with 7.5 m diagonal and an approximate length of 1900 m., and the second part of the channels has a steel lining with an average diagonal of 5 m and an approximate length of 900 m, including inclined tunnels. The length of each inclined tunnel approximately is 500 meters. In Figure 2, has been shown a schematic view of the position of dams and channels.

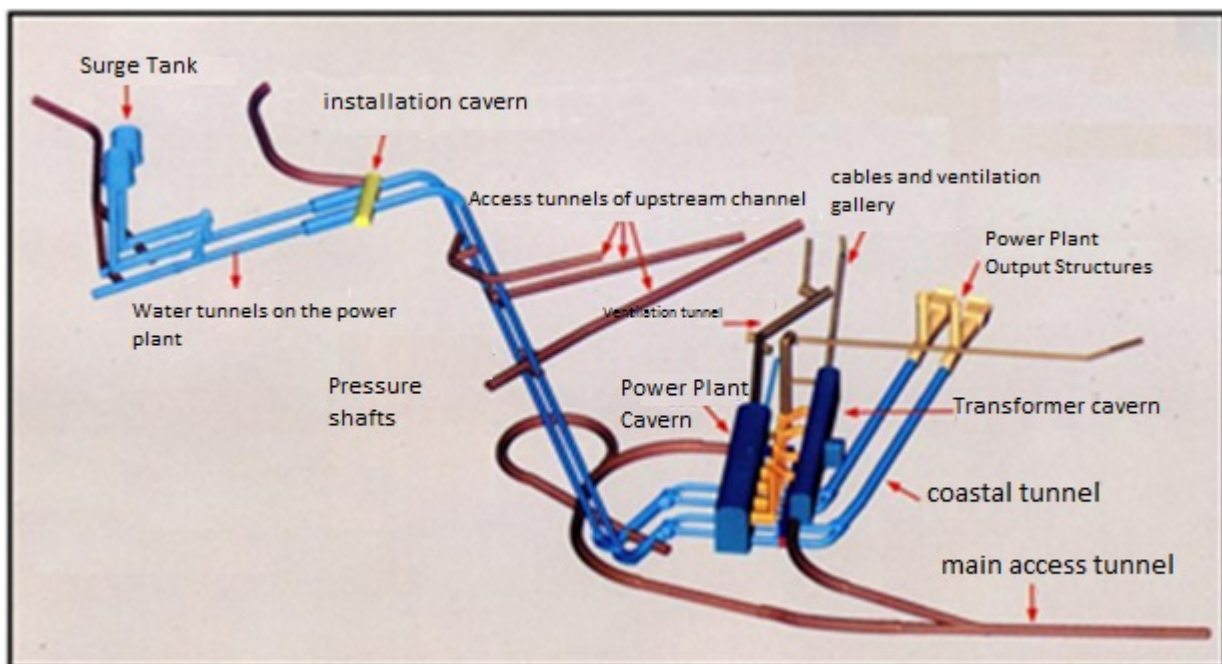


Figure 1. The main components of the Siah Bisheh Project (12)

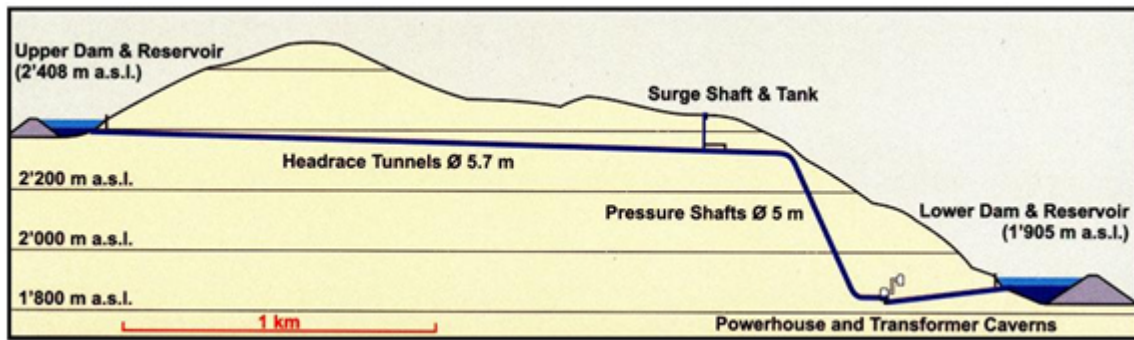


Figure 2. Schematic location of dams and channels of the Siah Bisheh projects (11)

3.1. Value engineering techniques

Value Engineering Techniques in fact, have been introduced as scientific methods into the qualitative development of a project that can be very useful for collecting information, especially in analysis and develop an idea. To familiarity, a summary of some of them is described, in order to with identifying each technology selected in the value engineering investigations.

3.1.1. Functional Analysis System Technique (Fast)

This method is an abbreviation of Function Analysis System Technique and is called Fast. This technique, which has a great use in the value engineering process, is done through three questions designing of why? , How? And when? In connection with the main and extrinsic functions, and the obtained results are drawn as a graph that ultimately, the function or applications which realize the goal can be explained (13).

3.1.2. Analytical Hierarchy Process (AHP)

This method is an abbreviation of the Analytical Hierarchy Process words, which is called AHP briefly. The Analytical Hierarchy Process is a technique that, by analysis the difficult and complex problems, converts them into a simple way and solves them. This method has very used in various issues. In addition, in recent years, it has been used in management and decision-making affairs and its steps to do are as follows:

Hierarchy builds: Create a graphical representation which in it targets, criteria and options are shown.

Weight calculation: Elements of each level are compared to their respective element at a higher level and their weight is calculated.

System compatibility: The degree of compatibility of the

decision is calculated and the alternatives are judged by than being good or bad, being acceptable or failure (14).

3.1.3. Concurrent Engineering (C.E)

This method is abbreviation of the Concurrent Engineering words, and is called C.E. In various processes of design, implementation and operation, should be used of advanced equipment and techniques for efficient control till the project's achievements designed well, and be presented with low cost and in short time, so that in this way we consider economic, qualitative and timely goals inevitably. At the same time, synchronous engineering technology allows us with it application can be successful in this regard (13).

3.1.4. Quality Function Development (Q.F.D)

This method is abbreviation of the "Quality Function Development" words and is called "Q.F.D.". This technique also for realization needs to the all-round cooperation of forces and the sectors involved with the subject, which its goals include the following cases:

- Designing with low cost
- The omission of dilatory changes
- The quick recognition of high-risk areas in designs
- Recognition or determination of designing process needs
- Definitive and effective reduction of the development time of the design
- Effectiveness of resources

In the conducted studies of value engineering for designing and implementation of the Siah Bisheh projects channels, has been used a combination of the above methods. Different stages of value engineering in projects have been presented in the Figure 3.

Preliminary Studies and Gathering Information	
Gathering and definition to the needs and desires of the employer and the beneficiary Supplement of Data set The determination of evaluation criteria The determination of the scope of studies The prepare of the suitable models	
Supplementation Studies	Value studies
The supplementation of changes The implementation of changes Audit	The stage of information supplementation The stage of function analysis The stage of creativity The stage of evaluation The stage of development The stage of presentation

Figure 3. stages of value engineering (15)

4. THE USE OF VALUE ENGINEERING IN THE CHANNELS DESIGN

In the design of channels, according to the internal and external pressures, usually steel lining is used and in some projects, in part of the channel route instead of concrete cover is used of this cover in terms of higher coefficients of confidence. In the Siah Bisheh project, with regards to the high length of the channels and considering this issue that in the first part of the channels there is no much water pressure, by using of value engineering, and to reduce the cost of the project at the creativity stage and due to the speed limit in the concrete ducts about 6 meters per second, the type of cover of this part of the tunnel has been selected circular concrete, with a diameter of 7.5 meters, which according to a maximum volume of 130 m³ / s of each channel, the amount of speed can be calculated as follows (16).

$$(1) \quad V = \frac{Q}{A} = \frac{130}{25.51} = 5.09m/s$$

This speed is lower than the amounts of mentioned allowed

maximum in the standards and is acceptable. In the second part of the channels, also the tunnels cover is selected of a circular steel lining type with a diameter of 5 meters, which a maximum water speed on it will be equal to 6.62 m / s and is acceptable from the point of view of valid references and standards (16). one of the other main issues which should be considered in terms of value engineering in the channels design are the high lengths of the channels and the effects of the water strike on that. The effects of the water strike were calculated by using of the Water Hammer software and the amount of pressure caused by it was considered in the design of the channels at the entrance of the 132 m power plant (16). In order to energy depreciation resulting from the water strike in each stream, also has been used of a surge tank of 6.6 m in diameter almost at the halfway of the channel, which in terms of engineering value, it was a part of the special originality of this project and its cost and time of construction compared with other proposed solutions, is better in terms of engineering value. An example of the results of costs reduction by using of the value engineering is presented below at the stage of implementation and presentation, that as it is clear, costs decreased about 15% by using of this method (Table 1).

Table 1. An example of the value engineering results

Amounts in MUSD	Cost estimate	Cost estimate			
	based on basic design	(After Value engineering)			
EQUIPMENT		Foreign portion	Local portion	Total	Local participation per item %
428.6 rpm alternative – "Lahmeyer-Moshanir" design					
Pump turbines	49.16	16.10	19.60	35.70	55
Speed governors	inc. with Pump	4.00	0.00	4.00	0
Spherical valves	5.76	3.40	1.50	4.90	30
Downstream gates	1.18	0.24	0.96	1.20	80
Generators motors + excitation system	35.28	18.00	12.00	30.00	40
400 kV single phase power transformers	20.30	9.00	3.00	12.00	25
Starting equipment	4.00	4.00	0.00	4.00	0
Electrical & Mechanical equipment including SCADA	34.70	13.40	16.60	30.00	55
Outdoor Substation with GIS equipment	19.00	20.80	4.20	25.00	17
Steel structures	25.20	2.00	18.00	20.00	100
Total	194.58	90.94	75.86	166.80	47

5. THE USE OF ENGINEERING VALUE IN DETERMINING THE THICKNESS AND TYPE OF STEEL LINING

One of the most important uses of value engineering which make the Siah Bisheh project unique is existence the high pressure in the design of the steel lining. In some parts of the channel, the pressure of the steel lining design will be equal to 700 meters with water strike counting, which in comparison with other water plants in Iran has high pressure. In the initial design of project, it was considered that be used of bearing power around the Rock Sharing, but gradually and with the completion of geological studies it became clear that the rock species were very different along the long route of channels and some points of rocks are types of loose and collapsing and have no enough resistance, therefore, according to the value engineering studies at the stage of completion of studies, and in order to avoid making the time of the design and installation of the steel lining long, was ignored from the bearing around

the tunnel and only resisted to the resistance of the steel . The conducted Geotechnical studies report shows that have been spent about 2 years to complete geological information, which reduced the time value of total project from 9 years to 7 years by using of value engineering techniques (17). Also, from the value engineering point of view, if in the designing of steel lining was used of available common steel in market such as the St37-2, the thickness of steel lining calculated very much, which this affair while greatly increasing the cost of the project, practically making the works of implementation and rolling of sheets and steel lining construction impossible, so that the value engineering team in the performance analysis stage concluded that in this project be used of special steels which have high resistance and special properties. The Table 2 shows the profile of common steels and used steels in the Siah Bisheh project, and also the amount of reduction of done costs by using of value engineering.

Table 2. Comparison of St37-2 and S690QL steel from the point of view of value engineering in cost reduction (11)

Required thickness by using of S690QL steel (mm)	Required thickness by using of St37-2 steel (mm)	Rial cost equivalent to St37 steel for each kilogram	Rial cost equivalent to S690QL steel for each kilogram	Cost reduction percentage
30	88	1320000	900000	32%
40	117	1755000	1200000	32%
78	229	3664000	2730000	25%

Table 3. specifications of the used steels in the Siah Bisheh project (17)

Steel name	Surrender Resistance (MPa)	Tensile resistance (MPa)	used thickness in the project(Mm)
S235JR (St37-2)	235	360	-----
S355ML	345	450	20-22-24-26-28-32-34-36-38-40
S460ML	440	530	34-36-38-40-42-54-56

S690QL	650	760	28-30-32-34-36-38-40-42-44-52-78
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Other notable values of value engineering in this project is that in the primary designing of the project (Table 3), it was considered that to determinate thickness of calculation for steel lining added 2 mm for corrosion, but in the stage of supplementary studies and the value engineering changes this amount deleted according to the length of the channels and due to the reduction of the steel weight, and it was decided to use a suitable color system to prevent corrosion, which resulted in a significant cost reductions in the project. High-resistance steels are more expensive than common steels, but due to the reduction of the required thickness, in total cost of the whole project is reduced compared to common steels, and more important point is that the sheets will have the ability to roll. For example, the S690QL steel is a type of building steel with high resistance that has a suitable bending and weldable, and in some parts of the channel, if the St37-2 steel was used

instead of the S690QL, the thickness of the sheets increased about 3 times (17). With the completion of engineering value studies and according to that the number of waste sheets has a direct relationship with costs in project so that the sheets cutting method was designed in a way till the amount of waste sheet reached to the possible minimum. Another important point of value engineering in the design of steel lining is the use of stiffeners. At the beginning of the steel lining, due to the being prevail of the pressure of the underground exterior water in designing and in order to the design optimization, was used of sheets with less thickness with stiffener. The use of stiffeners in the design, while reducing the thickness of the required sheet, increases the resistance of the channel against the external pressure (Table 4) (17).

Table 4. the amount of weight loss by using of stiffeners in Value Engineering Studies (17)

Percentage of weight loss by using of Stiffener	Total weight of steel in tons in the review of value engineering	Total weight of steel in tons in the preliminary design
%15	11237	13112

In pressure shafts, according to that stiffeners welding and its installation making a difficulty during concrete, all parts were designed without stiffener, and pressure shafts concrete was considered a type of self-compacting concrete (SCC). This concrete requires no special measures such as vibration and requires a grouting operation around the steel lining parts (17). Due to the existence of high pressure in the pressure shafts and also non-use of stiffeners in this section, the design of a

drainage system which can reduce the water external pressure around the pieces greatly is very important in terms of value engineering. for this purpose were drilled tunnels around the pressure shafts, which these tunnels in addition to creating tunnels to access to the shafts, has the role of external water drainage around the steel lining in the future. In order to the reduction of the pressure of water and guiding it towards drainage tunnels, were used of four perforated tubes around each shaft (Figure 4) (16).

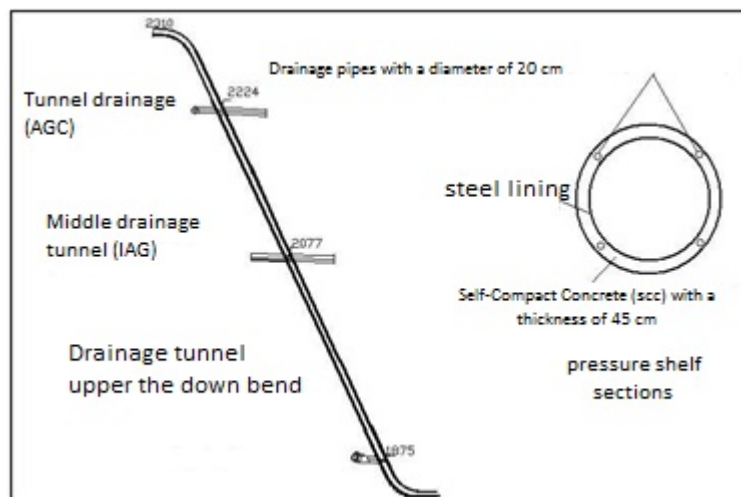


Figure 4. The drainage system around the pressure shaft (16)

6. VALUE ENGINEERING STUDIES FOR THE PASSING OF CHANNEL FROM THE EARTHQUAKE ZONE AND FAULT

According to that, the channels are long and the project

area is in earthquake-prone, passing the channels from the earthquake-prone area and fault is inevitable. the most important faults in the region are Kandovan fault, North Alborz fault, North Tehran fault, and Main Thrust Fault which this fault interrupted the channel diagonally.

According to the conducted studies, the maximum severity of the earthquake caused by these faults will be within the range of the 7.7 magnitude in the project scope, which caused extensive deformations in the channel and also the risk of the channel fracture will have existed (17). According to the results of value engineering studies in the creativity stage, and in order to prevent the channel fracture in the main fault at the time of the earthquake, the

steel lining of this area was designed specially till has a possibility to creating a large deformations (up to 50 cm) without breaking and rupture of the channel. In this design, special components called Compensator were used, that these components are made of S460ML steel and have the possibility of deformation without rupture. The following design has been shown in Figure 5, Figure 6 and Figure 7.

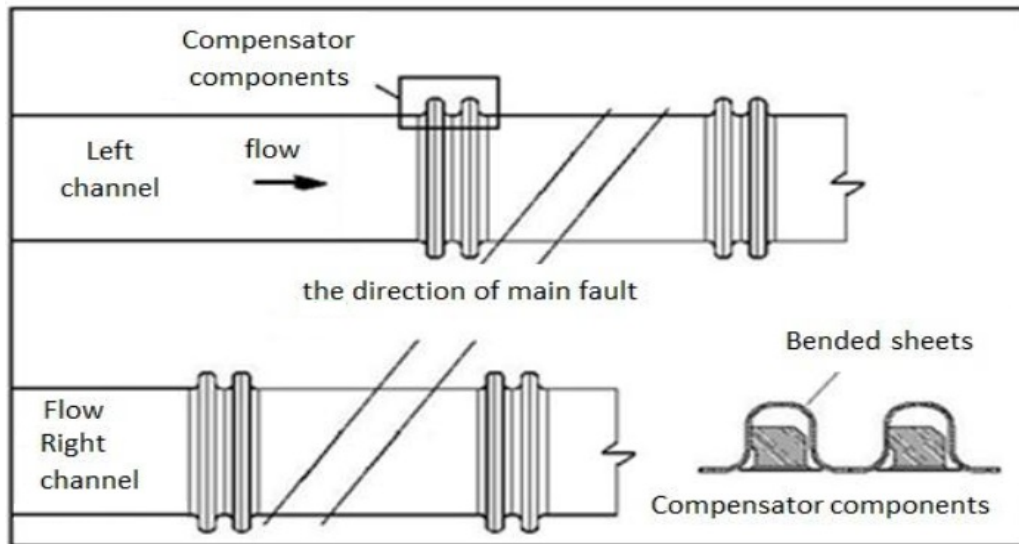


Figure 5. Design of steel lining components in the Main Fault Area (17)

It should be noted that after severe earthquakes and widespread deformations, channels components and Compensators should be replaced. In addition, in order to recognize the probable fracture and its amount in the channels has been used of a monitoring system in the

project that by measuring the volume of water in the drains entrance to the channel and near the units, it makes the recognition the water escape from the channel and probable fracture possible.

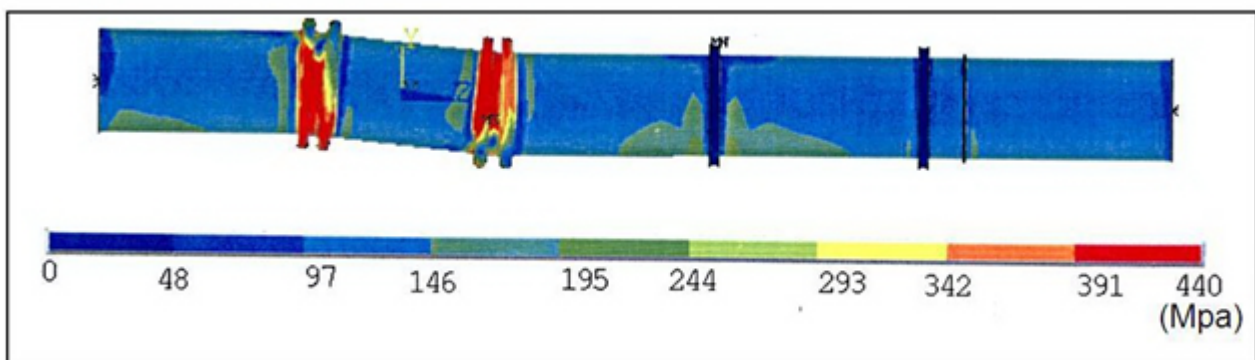


Figure 6. The results of value engineering studies for the special design of a Siah Bisheh project (17)



Figure 7. implemented steel lining in the Siah Bisheh project with a special design at the creativity stage of value engineering studies (17)

7. VALUE ENGINEERING RESULTS AT THE STAGE OF CONSTRUCTION AND INSTALLATION OF STEEL LINING

According to being obliquity of the tunnels and their high length, drilling was carried out with great difficulty and spent plenty of time. During this time, sheets of steel lining in the workshop at the site of the Siah Bisheh project and by using of three-roller roll machine were converted circular and be ready for installation. Due to the difficulty of installation and space constraints inside the shafts, there was no possibility of welding the parts from the back, and all the parts were designed with the back strip till welding be done only from the inside of the components.

According to the different lengths and weights of the components, their transportation and fit up at the site of the installation were the most important challenge ahead of the Siah Bisheh project. For this purpose, at the stage of a performance evaluation of value engineering studies was designed a specific machine. This machine can load parts of different lengths and weights out of the evacuation and by using a cable and winch of 65 tons reached it to an installation position. Finally, by using the jacks and installed attachments on the machine, the components at the installation site were fitted up and were ready to welding with a high accuracy. The machine of carrying parts has been shown in Figure 8.

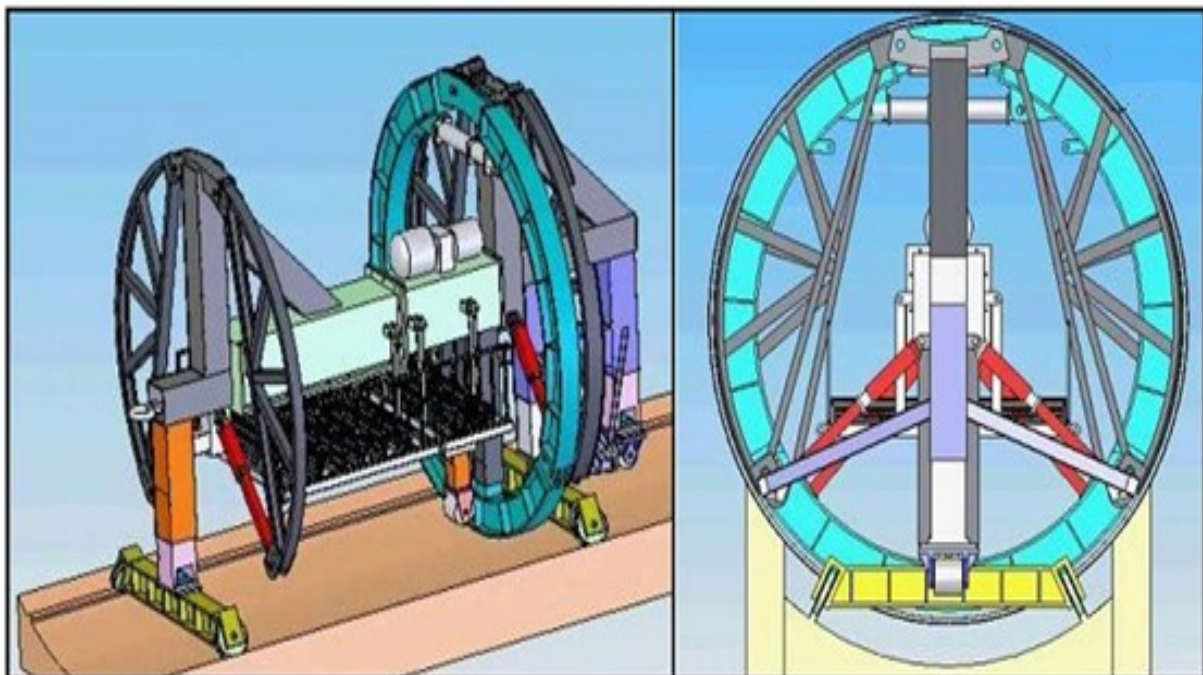


Figure 8. Carrying machine and adjusting steel lining components of the Siah Bisheh project (17)

Other notable points in value engineering studies in this project are the replacement of the radiographic test of

welding lines with the S-Scan 3D ultrasound test. This method does not have the limitation of the radiographic test in terms of harmful radiation and increases the speed of the inspection operations.

8. CONCLUSIONS AND SUGGESTIONS

According to that Siah Bisheh Project is the first Pump Storage Power Plant in Iran, obtained valuable lessons and experiences from value engineering studies can be useful in other projects. The most important obtained results and achievements of the value engineering of this project can be summarized as follows:

- 1- According to the difficulty and being time-consuming of drilling, rolling and installation of the steel lining components in the obliquity tunnels, it is recommended that in other projects, as far as possible, vertical tunnels be used.
- 2- In all projects, especially those projects that have long channels, water strike studies should be done completely and accurately. Lack of accurate modeling and inadequate studies may lead to problems of exploitation and lack of energy loss of water strike in the future, which ultimately will be caused the design being uneconomic and increase the costs.
- 3- In projects that the rock around the channels is suitable and has sufficient resistance, can be used of rock sharing to reduce the thickness of the steel lining.
- 4- By replacing a suitable and high quality color system, can be deleted the thickness of the corrosion (which is common in most of the projects in Iran) and can be implemented the design more economical.
- 5- In projects with high pressure differences, by replacing steels with more resistance instead of common steel in market and optimizing it can be resolved the limitations results from high thickness and make the design executable and economical.
- 6- In projects with high pressure differences, the system designing of an effective and reliable drainage is more important and vital for reducing the exterior pressure of groundwater.
- 7- In such cases which external water pressure be prevail on design, can be calculated the thickness of the steel lining for internal pressure and can be used of the stiffener to bear the external pressure. This will help to optimization the design.
- 8- In most Iranian projects that doing radiography test is common, by using of tridimensional ultrasonic test (S-Scan) can be increased the

accuracy and speed of and resolved harmful radiation limitations.

- 9- In shafts and places where there is a limitation of space and difficulty of installation, by using of back strip can be designed the components in such way that just welding needs to be from the inside.
- 10- In shafts, it is recommended to use of self-compacting concrete for ease of concrete.
- 11- Experiences from the manufacture of carrying components machine can be used in other similar projects.

It is hoped that the results of this article can be the facilitator in other projects of countries' Pump Storage Power Plant.

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AUTHORS CONTRIBUTION

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CONFLICT OF INTEREST

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