Silvan Dam and Revisions to Adapt for Latest Developments in High CFRD Design and Construction

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ABSTRACT
The concrete faced rockfill dam (CFRD) is one of the most popular and reliable dam type that has been constructed for the last 50 years, recently to heights well above 200 meters. Turkey, one of the leading countries in construction of rockfill dams and hydro potential development, has numerous successful examples of CFRD up to height of 150 meters. The success in the adaptation of CFRD dams is urging the dam owners to choose CFRD type for important projects in Turkey.

Being the most important component of Silvan Irrigation Project, located in Diyarbakır-Turkey with an investment value of $ 3.50 billion and with an estimated annual income of $ 520 million, Silvan Dam will be one of the most assertive one of its type in the region with a height of 175.50 meters, dam body and reservoir volumes of 8.5 million m³ and 7.3 billion m³, respectively. After completion, the dam will provide most of the irrigation water for Silvan Irrigation Project which comprises of 8 dams, 242’000 meters of irrigation channel, 2 tunnels with a total length of 18’400 meters, 1 hydro power station and 21 pumping stations. Due to its importance, the Owner (State Hydraulic Works of Turkey), has decided to revise the dam body design before its construction with the participation of the Contractor and his Engineer by taking into consideration latest developments in CFRD design, construction and experience.

This paper focuses on the steps taken for the enhancement of the 175.50 meter high CFRD dam’s plinth and face slab design, dam zoning and parapet wall to minimize the leakage and other risks related to the safety of the dam. The advantages of the revised design are discussed by comparing with the previous design.

Keywords: CFRD, Plinth, Face Slab, Rockfill

1. INTRODUCTION
Located in Diyarbakır, Turkey, Silvan Project is one of the largest components of GAP (Southeastern Anatolian Project) and it is the last step to complete GAP. The project is comprised of 8 dams, 1 hydropower station, 242’000 meters of irrigation channel, 2 tunnels with a total length of 15’360 meters and 21 pumping stations. The investment value of the project is $ 3.50 billion with an annual income of $ 520.00 million.

Silvan Dam, being the most important component of Silvan Project, will be one of the most assertive one of its type in the region with a height of 175.50 meters, dam body and reservoir volumes of 8.50 million m³ and 7.30 billion m³, respectively. After completion, the dam will provide most of the irrigation water for Silvan Irrigation project.

Due to its importance, the Owner (State Hydraulic Works of Turkey), has decided to revise the dam body design before its construction with the participation of the Contractor and his Engineer by taking into consideration latest developments in CFRD design, construction and experience.

2. SILVAN DAM SCHEME AND GENERAL LAYOUT
Silvan Dam is located in Silvan District of Diyarbakır, Turkey, 900 meters downstream of the junction of Kulp and Göderni creeks. It is the most important component of Silvan Project and the main purpose of the Dam is to provide water for irrigation; i.e., it will be the main source of water for Silvan Irrigation Project. The Dam location and the whole scheme layout is shown in Figure-1 (Özen, Üzücek and Dinçergök, 2014).
The water for irrigation will be taken from the reservoir by Babakaya and Silvan Tunnels. Since the completion of the Silvan Irrigation Project is to be planned to be completed in 4 stages of 6 years, a power house is designed to make the project more feasible. Within completion of each stage, the conveyed water from the reservoir will be increased and the energy production from the powerhouse will decrease to 88.41 GWh from 681.00 GWh.

The most significant component of Silvan Dam Scheme is the 175.50 m high concrete face rock fill dam with a dam body volume of 8.50 million m$^3$ with a crest length of 440 meters. The dam body will create a reservoir of 7.30 billion m$^3$. Construction of the Silvan Dam project has commenced in the late 2012 and scheduled for completion at the end of year 2017. The following figure shows the layout of the scheme.
3. DESIGN AND DESIGN REVISIONS OF THE CFRD BODY

3.1. EMBANKMENT ZONING

CFRD dam type is considered to be safe for most of the weak and strong rockfill materials. For CFRD design it is often assumed that the dam settlements will not exceed 1% of the compacted fill height where horizontal deformations are less than 50% of settlements (Straubaa, Gunsteren and Mall, 2011).

For the embankment zoning of the CFRD 2D and 3D deformation and stability analyses are carried out and the ICOLD recommendations are followed. The previously designed embankment zoning has been slightly revised. The final typical section shown in the following figure is determined after various analyses.

![Figure-3 Typical section of Silvan Dam](image)

The following table shows the materials planned to be used for the dam embankment construction.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Zone</th>
<th>Placing</th>
<th>Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition zone between 2B and 3B, (D_{\text{max}}=400\text{mm})</td>
<td>3A</td>
<td>Compacted in 0.40m layers</td>
<td>6 passes of 10t vibratory roller</td>
</tr>
<tr>
<td>Rockfill zone, (D_{\text{max}}=600\text{mm})</td>
<td>3B</td>
<td>Compacted in 0.90m layers</td>
<td>4 passes of 10t vibratory roller, 25% of water</td>
</tr>
<tr>
<td>Rockfill zone, (D_{\text{max}}=800\text{mm})</td>
<td>3C</td>
<td>Compacted in 1.00m layers</td>
<td>4 passes of 10t vibratory roller, 25% of water</td>
</tr>
<tr>
<td>Rockfill protection zone, (D_{\text{max}}=1000\text{mm})</td>
<td>3D</td>
<td>Placed by mechanical equipment.</td>
<td>-</td>
</tr>
<tr>
<td>Sand and gravel sized particles for support zone for the face slab.</td>
<td>2B</td>
<td>Compacted in 0.40m layers</td>
<td>6 passes of 10t vibratory roller</td>
</tr>
<tr>
<td>Filter zone of sand and gravel around perimeter joint.</td>
<td>2A</td>
<td>Compacted in 0.15m layers</td>
<td>4 passes of 10t vibratory roller</td>
</tr>
<tr>
<td>External sealing zone with Fine grained cohesionless silt with isolated gravel and cobbles sized rock particles to 150mm.</td>
<td>1A</td>
<td>Compacted in 0.20m layers</td>
<td>4 passes of 10t vibratory roller</td>
</tr>
<tr>
<td>Protection zone to zone 1A with mix of silts, clays, sands, gravels and cobbles.</td>
<td>1B</td>
<td>Compacted in 0.30m layers</td>
<td>4 passes of 10t vibratory roller</td>
</tr>
</tbody>
</table>
3.2. PLINTH

Main purpose of the plinth is to connect the face slab to the foundation and to provide a minimum hydraulic gradient. The dimensions of the plinth is determined based on the reservoir head and ground conditions. There are many formulations for the determination of the dimensions of the plinth.

The plinth design of the Silvan Dam has been revised such that the amount of excavation is minimized. For this purpose an external plinth platform of 4 or 5 meters is selected and the rest of the plinth width is obtained by adapting an internal plinth. This method has been adopted for CFRD construction and it decreases the excavation amount and time, thus the construction costs. The following figure shows how the external plinth width effects the excavation amount, schematically.

The following table compares the previous and revised design criteria and gives the related justification for the revision. As can be inferred from the following table, the external plinth width has been decreased significantly which has caused the excavation amount and the consolidation grouting amount significantly.

<table>
<thead>
<tr>
<th>Table-2 Comparison of previous and revised plinth design criteria</th>
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<tbody>
<tr>
<td>Plinth thickness (m)</td>
</tr>
<tr>
<td>t=0.3 + 0.003H</td>
</tr>
<tr>
<td>H: Reservoir head (m)</td>
</tr>
<tr>
<td>Plinth width / Reservoir head</td>
</tr>
<tr>
<td>Max-min plinth thickness (m)</td>
</tr>
<tr>
<td>Max-min plinth width (m)</td>
</tr>
<tr>
<td>4.50 ~ 9.60 plinth platform 0 (internal plinth)</td>
</tr>
</tbody>
</table>

The following figure compares the previous plinth and revised plinth section, the details are not shown for ease of understanding.
The following table shows the effect of reducing the external plinth width on related construction items. The decrease in the external plinth dimension has caused the excavation and consolidation grouting works amount to decrease significantly. The amount of concrete is the same. However, it shall be remembered that the revised plinth width is higher than the revised one and it can be concluded that under the same conditions, the concrete amount would be decreased by 35%. The overall effect of the decrease on the related construction items has caused the construction time of the dam body about 8%.

The plinth layout has been revised according to the current geological investigations. Also the geometrical layout of the plinth is revised such that, all the plinth segments are concave, which in theory, will cause the face slab to behave more similar to the design theory. The following figure shows the layout of the previous plinth and Figure-8 shows the revised layout. As can be seen from the layouts, the convex parts of the previous plinth layout has been revised, such that all the plinth sections are concave. Also it was taken into consideration to revise the plinth such that the plinth types are minimized and the longest plinths lines are obtained for ease of construction.
3.3. FACE SLAB

For the determination of the face slab thickness current guidelines are used.

The minimum design thickness of the face slab is selected as 30cm at the top and the thickness of the face slab is calculated by using the formula:

\[ t(m) = 0.30 + 0.003H \]

where H is the reservoir head in meters. According to this calculation the slab has a minimum thickness of 30cm at the top and 82cm at the maximum cross section. The previous design has also used the same formulation as used for the revised design.

Panel widths for the face slabs are determined as 15 meters. Starter slabs are considered in the areas where the face slab is connected to the plinth. Figure-8 shows the general layout of the face slabs and the plinth for the revised design.

The face slab concrete is designed to be workable, crack resistant, impermeable and durable. The strength of the concrete is 25 MPa with a water cement ratio of 0.5. The allowable slump of the concrete is 3~7 cm. The concrete
of the face slab will also include air entraining admixture and water reducing agent. The setting time of the concrete will be 3–5 hours.

The most salient revision made to the face slab is related with the reinforcement pattern and amount. In the previous design 0.4% reinforcement and 0.35% reinforcement at the middle of the slab in two directions was foreseen for the perimeter and the other parts of the face slab, respectively. However, this pattern is revised so that the reinforcement will be in two layers in two directions with a reinforcement ratio of 0.5% for the perimeter area (25 meters from the plinth line) in both directions, 0.35% for horizontal and 0.4% for vertical direction, for the rest of the face slab. The following table compares the reinforcements for previous and revised design and the following sketch shows typical section for the previous and revised design.

<table>
<thead>
<tr>
<th>Table-3 Reinforcement ratios for previous and revised design</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td>% reinforcement (total)</td>
</tr>
<tr>
<td>0.40</td>
</tr>
<tr>
<td>Double or single layer</td>
</tr>
<tr>
<td>Single</td>
</tr>
</tbody>
</table>

Figure-9 General arrangement for reinforcements (a) previous design (b) revised design

Spalling reinforcement is used at the vertical joints where additional reinforcement is needed due to high stresses as proposed by current guidelines.

3.4. JOINTS

3.4.1. PERIMETER JOINT

The purpose of perimeter joint is to connect the face slab to the plinth and to create a water tight barrier while allowing for anticipated movements between the plinth and the slab.

Three barrier system is adapted for the previous and the revised design. Three barrier system is an extensively used system especially for high CFRDs. It is composed of a lower water barrier (usually copper water stop), middle barrier (PVC water stop) and upper water barrier (a mastic joint sealent). The following figure shows a typical detail for the perimeter joint used for both the previous and the revised design. To provide water tightness between external and internal plinth a Y1 type water stop is used. For ease of construction and to maintain concrete quality around the water stop, the water stop is placed at the bottom of the concrete with a concrete pad.
3.4.2. VERTICAL AND HORIZONTAL JOINTS

The details for vertical and horizontal joints for the previous and revised design are kept principally the same.

The locations of the vertical tension joints are determined by performing 3-D finite element analysis. According to the analysis results the locations of the vertical tension joints are determined to be between km 0+000.00 & km 0+135.00 at the right bank and km 0+300.00 & 0+430.00 at the left bank, respectively. The tension joints are designed with a bottom water copper water stop and a top mastic joint sealant system. An asphaltic bond breaker is applied at the concrete surface at the joint. The compression joints are designed with a copper water stop at the bottom, a compression wood filler between the slabs and a surface mastic sealant system at the surface. Figure-11 shows the general details for the vertical tension and compression joints, respectively.

The horizontal construction joints are used in case there is a corruption at the concreting works, in places where the starter slabs and the concrete face slabs intersect or in case the concrete face slab is planned to be poured in stages. The reinforcement is continuous at the starter slabs. The following figure shows the general details of the horizontal construction joints.
3.5. PARAPET WALL
The shape, construction method and the details for water tightness for the parapet wall are kept principally the same both for the previous and the revised design. Generally accepted and applied joint details between the face slab and the parapet wall are used.

The top elevation of the parapet wall is increased 1.0 meters after detailed fetch analyses combining with settlement analysis during MDE earthquake; i.e., the free board has been increased 1.0 meters after current guidelines and recommendations, since the most likely failure mechanism of a CFRD which is founded on rock is the erosion by overtopping flow. Figure 13 shows the typical section of the parapet wall and the crest.

3.6. FOUNDATION EXCAVATION
Due to its height and being in an earthquake region, the foundation excavation of the Silvan Dam has been further developed once compared with the previous design.

- The plinth excavation has been deepened so that the excavation reaches more component rock
- A platform with a width of 30 meters is created behind the plinth so that the deformation of the face slab due to the difference between the elasticity of the dam body fill and the rock is minimized for crack development minimization.
- For approximately half width of the dam width from upstream, the excavation is extended to the slightly weathered rock
- For the downstream area, the excavation is stopped once the moderately weathered rock is reached
- The geometrical irregularities will be excavated so that a smooth excavation surface is obtained.

The following figure shows the cross section of excavation at the bottom and half height of the dam body.
4. CONCLUSIONS

The design revisions of Silvan Dam has taken into consideration latest developments in CFRD design and construction.

The construction time and cost is minimized by applying the internal plinth concept. The deformation and settlement behaviour of the dam body and the face slab is enhanced by applying special excavation geometry. The free board of the dam body has been increased to prevent erosion due to overtopping. The joint details and opening are calculated based on latest numerical analysis methods.

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