**CETIN HPP WITH ACRD IN TURKEY**

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**ABSTRACT**

The Cetin Hydro-Power-Project situated in Southeast Anatolia Region of Turkey was acquired as BOOT-license within a project-portfolio by Statkraft of Norway in 2009. The Project utilizes 175m head within a 25km section of Botan River being a major tributary to Tigris River. Due to challenging ground conditions it’s divided in two steps comprising Cetin Main HPP (420MW-1100GWh/year) and Cetin Lower HPP (100MW-300GWh/year).

Cetin Main HPP consists of a 145m high Asphalt-concrete Core Rock-fill Dam (ACRD), gated Spillway with flip-buckets and plunge-pool, twin Diversion tunnels and Cofferdams, Intake with gates and Power-tunnel/penstock towards the Powerhouse at toe of dam.

The Project area is located nearby the East-Anatolian-Fault-Zone (EAFZ) and defined within “First Degree of Earthquake Zone”. Ground conditions in the Project area consist of the geological units Bitlis Metamorphites(PzMz), Maden Complex(Tma) and Guleman Ophiolites(Jkg). The geology at site is briefly Gneiss, Schist, Limestone and some Phyllite being partly covered by slope-wash and with partly highly weathered zones.

The ACRD of Cetin Main was chosen as the preferred dam type taking all local conditions into consideration. The crest width is 10m, length 500m and the dam-body volume approx.11mill.m3. Due to significant high earthquake loading design of the dam is performed by dynamic deformation analysis, resulting in four different slopes of the dam-body (US 1:1.65(v/h) on lower 2/3H, 1:1.75(v/h) on upper 1/3H and DS 1:1.60(v/h) on lower 2/3H, 1:1.70/1(h/v) on upper 1/3H). A Grouting Gallery-system as periphery Galleries are serving for Grout-Curtain execution and a Gallery-system DS of the dam axis serves for access/monitoring/control purposes.

The surficial ground condition demands special attention to the investigation, design- and construction philosophy for all slope excavations/support. A 3D-geological model of the investigations is made by the design consultants. Construction works started in 2012.

![Figure 2. Plate tectonics of the Eastern Mediterranean region (after Taymaz et al., 2007). Location of the Çetin Dam site is marked with a red square. NAF, North Anatolian Fault; EAF, East Anatolian Fault; DSF, Dead Sea Fault; NEAF, North East Anatolian Fault; OF, Ovacik Fault; MT, Muğ Thrust Zone; TuF, Tutak Fault; Kavakbaşı Fault.](image)
CETIN HPP LAYOUT DEVELOPMENT

In 2009 when Statkraft acquired the 400 MW Cetin hydropower project license at the 25km stretch of Botan river in Turkey for further development towards construction and operation, there was already proposed some major changes in the overall layout. The original plan was to utilize the 175m head into one power-plant by a 6km long power-tunnel along the south side of the river from the main dam site. While a new plan from the Due-diligence process promoted to split the head in two steps by utilizing 140m of the head in one main power-plant at foot of the main dam, and the remaining 35m lower head to be utilized in two or three smaller gate-dams including power-plants.

The overall layout development of Cetin project was formed by key constraints like challenging ground conditions, the topography and local villages with farm land.

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Ground investigations has been performed over a long time period by a large number of core drillings resulting in a total of more than 5km bore logs. With this increasing amount of geological information it was realised that these shifting ground conditions were still fairly unpredictable in non-tested areas.

Statkraft however continued the layout development by checking some main alternatives like a 4,5km short northern power-tunnel route from Buyuk Cay, but realized the potential high risks (time and cost) of implementing long large tunnels in the prevailing geological conditions. Further focus was thus on the two step head plan with one large main dam named Cetin Main HPP, and preferably one or max two smaller dams in the lower part named Cetin Lower HPP.
CETIN MAIN HPP AND DAM ALTERNATIVES
The elements of Cetin Main HPP are concentrated within an area of approx. 1x1km at the conflux of Botan and Buyuk Cay thus representing a rather compact layout. It comprises a 145m high Asphalt-concrete Core Rock-fill Dam (ACRD), gated Spillway with flip-buckets and plunge-pool, twin Diversion tunnels and Cofferdams, Intake with gates and Power-tunnel/penstock towards the Powerhouse at toe of the dam.

Different types of the main dam structure have been considered, and the original local plans focused on either a Concrete Face Rock-fill Dam (CFRD) or a Roller Compacted Concrete Dam (RCCD). Shortly summarized pros and cons indicated that a CFRD would have lower construction costs but longer construction time than a RCCD. Additionally many other factors would count into such comparison as ex. a RCCD type choice could simplify the overall layout arrangement. However to keep the faster construction as main advantage of RCCD we learned that it needs to be a simple design preferably without/min. integrated objects.

Due to the significant seismicity of the region Statkraft was encouraged to consider an ACRD as a possible alternative. The ACRD type would likely fall somewhere in between the two other dam types regarding both costs and construction time, but such dam type was not yet constructed in Turkey. A complete three alternatives comparison from a tender competition would have been the optimum approach, but this was not realistic due to needed extensive resources from both owner and tenderers. So to reduce the number of alternatives we made firstly a priority-evaluation between the three dam types focusing on estimated costs and time including availability of materials and risk assessment. This evaluation ended up with RCCD and ACRD as our two alternatives for further development, indicated in Table 1.

Secondly Statkraft used the civil contractor pre-qualification process with indicative pricing as a basis for tender alternatives strategy. That ended up with ACRD as our main tender solution and RCCD as an optional alternative. Almost half of the tenderers submitted quotation on both dam type alternatives giving a fair basis for comparison. Finally after rounds of clarifications the most competitive bids favoured the ACRD solution which then was chosen.

CONSTRUCTION START AND SEISMIC UPDATE
Civil construction works started at Cetin site in 2012 with Camp facilities, Main access road and Diversion tunnels. The two approx. 800m each long Diversion tunnels inlet and outlet cuts then defined the outer layout borders of the area available for remaining objects like Dam, Spillway Power-tunnel and Powerhouse.
An expert quality assurance update of the project Seismic hazardous study was recommended, and when performed it resulted in significantly increased impact values with recommendation on control with some specific historical scenarios. The new seismic factors like Ph=0.56g became larger than expected and implied significant challenges to the dam design update. As standard pseudo-static analysis was not sufficient to solve new documentation of the dam stability, dynamic deformation type of analysis had to be performed. To meet acceptable deformations this resulted in need of decreasing planned dam-fill slope inclinations giving a larger dam-body volume and foot-print. Sensitivity analysis was done to secure acceptable wide ranges of rock-fill material properties expected to be found in available quarries. In order to control maximum available footprint space the dam-fill slope design was fine-tuned with steeper inclinations in the lower 2/3 of dam height. The four different slopes of the dam-body are planned as:

- UpStream 1:1.65(v/h) on lower 2/3H, 1:1.75(v/h) on upper 1/3H
- DownStream 1:1.60(v/h) on lower 2/3H, 1:1.70/1(h/v) on upper 1/3H.

There is planned a camber of 1% of H mid dam on the crest for post-construction settlements and this will be incorporated as slightly increased slope inclinations in the upper 1/3H.

The ACRD will be equipped with a Grouting Gallery-system as periphery Galleries (mostly concrete culverts) serving efficient Grout-Curtain execution, possible additional grouting if needed and for leakage monitoring. Additionally connected Galleries DS of the dam axis serves for access/drainage and monitoring control purposes.

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**OPEN CUTS EXCAVATION CHALLENGE**

The later identified more extensive occurrence of pourer Rock than initially anticipated in the Feasibility Study/Tender Design, resulted in possible need to significantly moderate inclinations of the slope cuts and thus the extent of excavation volume increase severely (doubled/tripled). Such approach would however again challenge both the compact layout constraints and the project cost/time balance. Due to these relative shifting and poor geological conditions the Eurocode 7 Observational method was decided applied. This new approach then optimised the slope cuts design with heavy support and
solved most of the mentioned challenges, but additionally increased the need of focus on continuous slope deformation/displacement monitoring and of quality assurance during the work.

There was later established a 3D-Geological model based on all available investigation results and this model is periodically updated according to new observations during construction.

The Cetin project monitoring approach is currently based on two main systems to document both local and overall level observations. All local site slope excavations are monitored by a Theodolite Lazer scanning system with continuous data collection in active use during construction work. For the overall project area including reservoir monitoring the satellite based INSAR system is used. This system can provide both historical values and new periodically data for comparison of deformations to detect possible active landslide areas, and is planned applied also during the impounding.

CONCLUSIVE REMARKS
In most green-field hydropower development projects there will always be a challenge to find the good balance between how far the planning and investigations need to be brought before the construction work may start. This is naturally a benefit-risk assessment including the factors of cost-time-culture-CSR-HSE etc. in a rather complicated relation. Being in the competitive energy development sector we need to be optimistic and maybe rather eager to get our projects up and running by meeting some expectations at high levels. However if we are not only purely realistic but also too pessimistic the projects will never fly or somebody else grabs it with maybe smarter solutions.

Our quick backlog assessment from the Cetin project so far is that we had some high risk factors remaining from the development stage when construction works started. The severe ground conditions and seismicity not fully clarified became challenges within a project layout boundary that was fixed. This however called for more innovative engineering solutions and seems to be under control. Cetin Main HPP is planned completed within 2018.

TECHNICAL DATA CETIN MAIN HPP
Main elements in the Project include:

- 2 Diversion tunnels (lined ø8m) with lengths approx. 800 m, flushing/bottom outlet and Stilling Basin. Sediment flushing gates in one tunnel with capacity 800 m³/s.
- Main 145 m high Asphalt-Concrete Core Rockfill Dam with a crest length of approx. 500 m at elevation +825.0 masl. Dam body fill-volume approx. 11 mill. m³. Asphalt core thickness 1.3m at plinth and 0.65m in upper 1/3H.
- Spillway with 4 radial gates, discharge capacity of 5500 m³/s and 2 discharge channels of approx. 300 m length with flip-buckets, and a downstream plunge pool.
- Intake with trash-rack, roller gates in vertical shaft, Power tunnel approx. 500 m long including a 1:1 shaft, steel lining and manifold.
- Powerhouse at foot of dam includes 3 units of vertical Francis turbines (402 MW at 333 m³/s) plus 1 ecological flow unit (18 MW at 14 m³/s) and all related equipment for electricity production.
- A common open air 380 kV switchyard
- Cofferdams and permanent access roads
- A 50 km long 380 kV transmission line

REFERENCES/SOURCES
Statkraft main advisors and suppliers in the Cetin project development are listed below.
Advisors:
- NGI - Dr. Kaare Høeg
- Norconsult
- Sweco Norway
- Hidro-Dizayn
- Dr. M. Dunstan
- KGAL
- Veidekke

Designers:
- Dolsar incl. Prof. Erdik and METU
- Sweco Energuide
- Andritz Hydro
- Temelsu
- Pro-Yapi

Investigations/model testing:
- Zemar/Geoma
- University of Vienna