# Susitna-Watana Hydroelectric Project Document
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# Watana Project

## Briefing Document on RCC Considerations

1. General

For the Watana dam on the Susitna River, the option of an RCC dam has been suggested for consideration. In the immediate future, during the preparation of the FERC Preliminary Permit application, and the Pre Application Document, a more complete assessment will be drafted and forwarded to AEA with respect to the type of dam to be constructed. This memo, requested by AEA, addresses some of the more pertinent aspects of the choice of an RCC option, including precedence, seismic performance, spillway, and project layout. Other matters of relevance that have not been explored in this memo, but which will influence the choice of the dam type include the availability of aggregate on site for RCC production, availability of cementitious materials (cement and pozzolan), thermal considerations, and schedule comparisons.

2. RCC History

RCC includes the same ingredients as conventional concrete but in different ratios. The technique has been developed based on engineers insight that most traditional concrete dams using normal concrete were slow to construct and laborious because of the multiple placing and moving of the required formwork. A technique was developed (first at the remedial works for Tarbela Dam in Pakistan, but then more formally by the US Army Corps of Engineers) for placing a very low slump concrete in a similar manner to earth fill. Typically it is placed by dump trucks or conveyors, and spread in one-foot-thick layers by bulldozers or special modified asphalt pavers. After placement it is compacted by vibratory rollers.

The use of RCC in dams not only benefits the speed of construction, but in minimizing the heat of hydration by lowering the cement content, it lowers material costs. Ironically the very speed of construction aggravates the thermal challenges, because the heat of hydration cannot dissipate.

For dam applications, RCC is placed lift-by-lift in successive horizontal layers resulting in a downstream slope that resembles a concrete staircase. Once a layer is placed, it can immediately support the earth-moving equipment to place the next layer.

The first RCC dam built in the USA was the Willow Creek Dam on Willow Creek, a tributary of the Columbia River. It was constructed by the Army Corps of Engineers and completed in 1983.

Since 1983, there has been a rapid adoption of the technology all over the world for new dams and for the remediation of old dams.

During the adoption of the technology, the various challenges associated with the methodology have been addressed and a ‘standard practice” has developed for such matters as upstream face, placement, crack inducement, downstream face, foundation preparation etc.

After nearly 30 years, and the construction of more than 420 dams (or rehabilitation of dams) using RCC, the technology can be regarded as mature. Of those 420, over 200 dams have been implemented as part of a hydro project.

## 3. Precedence for high RCC

The 700 ft high RCC dam currently proposed is a significant, high, dam – but as can be seen in Table 1 below, is not beyond precedent for either a traditional concrete dam or an RCC structure. Note the table also includes in red – for context - some examples of the highest dams in the world, as well as the largest RCC dams in the USA at present. There is considerable recent experience in the design and construction of RCC structures above 500 ft, and one dam (Longtan in China), already in service, that is marginally higher than the proposed Watana dam.

Current analytical methods used for dam design are sufficient for the analysis and structural design of such a structure.

**Table 1 – High Concrete (RCC) dams**

_* under construction_

| Dam | Location | Type | | Height (m) | Height (ft) |
|---|---|---|---|---|---|
| Nurek | Tajikestan | Embankment | | 300 | 984 |
| Grand Dixence | Switzerland | Concrete | Gravity | 285 | 935 |
| Oroville | USA | Embankment | | 235 | 770 |
| Hoover | USA | Concrete | Grav/Arch | 221 | 726 |
| Longtan | China | RCC | Gravity | 216.5 | 710 |
| Watana | Alaska | Emb. or RCC | | 213 | 700 |
| Guangzhao | China | RCC | Arch | 198 | 649 |
| Miel | Colombia | RCC | Gravity | 188 | 616 |
| Guanyinyan | China | RCC | Gravity | 168 | 551 |
| Urayama | Japan | RCC | Gravity | 156 | 512 |
| Jinanqiao | China | RCC | Gravity | 156 | 512 |
| Miyagase | Japan | RCC | Gravity | 155 | 509 |
| Ralco | China | RCC | Gravity | 155 | 509 |
| Murum * | Malaysia | RCC | Gravity | 141 | 463 |
| Takizawa | Japan | RCC | Gravity | 140 | 459 |
| Son La * | Vietnam | RCC | Gravity | 139 | 456 |
| Bureiskaya | Russia | RCC | Gravity | 136 | 446 |
| Ban Ve | Vietnam | RCC | Gravity | 135 | 441 |
| Dahuashui | China | RCC | Arch | 134.5 | 441 |

| | | | | | |
|---|---|---|---|---|---|
| Yewa | Myanmar | RCC | Gravity | 135 | 441 |
| Yunlonghe | China | RCC | Gravity | 135 | 441 |
| Gomal Zam | Pakistan | RCC | Gravity | 133 | 436 |
| Shapai | China | RCC | Arch | 132 | 433 |
| Jiangya | China | RCC | Gravity | 131 | 430 |
| Baise | China | RCC | Gravity | 130 | 427 |
| Ban Chat * | Vietnam | RCC | Gravity | 130 | 426 |
| HongKou | China | RCC | Gravity | 130 | 427 |
| Olivenhain | USA | RCC | Gravity | 97 | 318 |
| Upper Stillwater | USA | RCC | Gravity | 91 | 299 |
| Spring Hollow | USA | RCC | Gravity | 74 | 243 |

## 4. Seismic Performance

It can be seen from the list of projects that a number of RCC dams – including the Olivenhain dam in Southern California – have been completed in highly seismic areas. Of note are those in excess of 500 ft in Japan, and the dams in seismic regions of China. We have examined the report on "*RCC Dam cost evaluation"*, dated November 2009 and agree that an RCC dam at Watana could be designed to resist the seismic conditions expected at the site in accordance with FERC requirements for stability. The exact cross section required would be the subject of Finite Element Modeling studies after an updating of the seismic hazard evaluation for the region.

FERC has published guidelines for dam analysis and seismic risk evaluation. These are published in "*Engineering Guidelines for the Evaluation of Hydropower Projects"* and would be included, with other applicable criteria, in the detailed design criteria for the project.

## 5. Dam Failure Experience

The International Commission on Large Dams (ICOLD) has determined that the three major categories of dam failure are:

1) overtopping by floods,
2) foundation defects, and
3) piping.

Earth fill embankments are susceptible to all three types of failure, but concrete dams – including RCC dams - are only susceptible to foundation failure.

There has been an example of the foundation of a small RCC dam failing (in Brazil) but the design of major dams such as Watana routinely include extensive studying, drilling and testing of foundations, which highlights any foundation treatment required to eliminate the risk of foundation failure. Much of the required investigation and analysis for Watana has already been performed during the studies in the 1980s.

According to ICOLD bulletin Number 109, since 1930, (and excluding Russia and China) there have been1500 concrete gravity dams built higher than 30 m (100 ft), and there have been no failures. Prior to 1930, there were a number of failures of concrete dams, including the St Francis dam in California in 1928. However there were some notable successes, such as the Lower Crystal Springs dam in California, which – though only 800 ft from the San Andreas Fault – survived the 1906 San Francisco earthquake with no damage at all.

At Watana, the foundation is diorite, a strong rock, and favorable for the construction of a concrete structure. If an RCC structure is chosen, and in fact for any type of dam, considerable effort in the design process will be focused on the performance of the dam/rock interface and the grouting necessary to address joints and lineaments that are in the rock structure.

It should be noted that although conservative criteria will be adopted for the spillway performance, a concrete structure has an additional built in safety factor against flood damage, being able to withstand overtopping.

## 6. Spillway Design and Considerations

The current conceptual design of Watana dam shows a stepped spillway. Inclusion of a stepped spillway has become a standard feature of many RCC dams, because of the ease with which such a spillway can be incorporated, but their use must always be very carefully considered. Stepped spillways are most efficient if unit discharges (cubic ft per foot of spillway) are low – a condition that occurs when there is substantial reservoir routing that attenuates the peak inflow of floods (to reduce the outflow) and/or if there is a long spillway crest length. High unit discharges- which are a feature of gated spillways and/or reservoirs with little inflow attenuation - are less competently handled by a stepped spillway. At high unit discharges, the energy dissipation associated with the steps can be “overwhelmed” by the flow, and the spillway tends to behave as a chute with a rough surface, with the consequent, unfavorable, transfer of energy dissipation from the steps to the stilling basin.

As with normal chute spillways, aeration of the flow on a high stepped spillway is vital to prevent damage at higher velocities, and designers – particularly Chinese designers - have tended to rely on aeration from the ends of unmodified steps. This is appropriate for spillways of low unit discharge, but examination of model results - both Computational Fluid Dynamics (CFD) models and physical models – shows that higher dams, and increased unit discharges, benefit tremendously from normal positive aeration.

Watana combines a very high dam with large inflow floods. However, the spillway crest length of 550 ft in the current proposal appears to result in unit discharges that could, theoretically, be within precedence for a stepped spillway. The 1980s design of Watana, in contrast, proposed a gated spillway and a traditional “smooth” chute.

At the present time, though MWH will continue to evaluate a stepped spillway, we are concerned that there is a lack of operational experience of high stepped spillways. Relatively few major floods have been recorded on this type of spillway. MWH believe that adopting a stepped spillway would significantly extend precedence in height of stepped spillways, and the need for engineering prudence - together with the benefits on layout discussed below – lead us to conclude that the traditional gated chute spillway should be retained in the study options.

7. Project Layout

The project layout shown in the “*RCC Dam cost evaluation*”, dated November 2009 needs significant optimization. A straightforward comparison between an RCC dam and an embankment dam for a large hydro power complex often does not result in the RCC option being the most economic, particularly when (as in this case) the critical path for construction will almost certainly flow through the manufacture and installation of the generating units. The economic benefits of the use of an RCC option are considerably enhanced if as many of the required structures (i.e. intake, penstocks, spillway and powerhouse) as possible can be included within the dam footprint.

MWH will examine the option of placing the hydraulic passages within the dam, the powerhouse downstream of the dam, and the spillway over the dam (as shown, but perhaps straighter and narrower as a traditional gated chute). Such an arrangement limits work outside the footprint to the diversion tunnels, and - based on our experience elsewhere - promises an excellent chance to minimize the cost of an RCC alternative and render it the favored option.

8. Other Factors – Thermal conditions

   Of the other factors noted in paragraph 1 of this memo, the most significant, and the one that will drive much of the analysis, material testing and mix selection for an RCC structure, is the thermal performance of the dam.

   Temperature control of RCC is vital to prevent or control cracking caused by excessive tensile strains resulting from differential cooling of the concrete. Cracking can be controlled by methods that limit the peak temperature to a safe level, so that the tensile strains developed as the concrete cools to a state of equilibrium are less than the tensile strain capacity. Construction methods and mixes that avoid post placement cooling are, of course, preferable.

   During the design of an RCC structure at Watana, it will be necessary to verify that strain induced by temperature changes in the concrete during and after construction will not exceed the strain capacity of the concrete. Key aspects are the differential temperature between the interior of the concrete and the surface, both during summer and winter conditions, the effects of the relatively stable temperatures in the abutment foundation, and the "shock" load of the cold water upon the upstream face during reservoir filling, which will reorient the isotherms in a relatively short time.

   Computer models will be needed that reflect the expected conditions throughout construction and the possible mixes and placement schedule as well as the near term project operation during and after reservoir filling.