Construction of Roller Compacted Concrete Dam: A Case Study at Batu Hampar Dam

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Abstract: Rapid and economical construction are among numerous advantages of the construction of roller compacted concrete (RCC) dam compared to conventional dam. However, the complex process of RCC dam construction is facing difficulties due to lack of understanding and involvement from the local construction industry player since this type of construction in Malaysia is still new. Therefore, this paper presents the process of RCC dam construction in Malaysia. Site observation and the review on literature of RCC dam construction was conducted to get the real view on the construction process of such project. The expert panel interview was conducted to get the view on RCC dam construction. Panel interview result was analysed and supported with the literature to gather the process of RCC dam construction. From the result analysis, the construction processes which consist of determination of mix design, RCC production and RCC placement is presented.

The new technology is adopted for the construction of gravity dam and the technology is known as roller compacted concrete (RCC). Reference [1] stated that RCC has been rapidly developing over the past 40 years and now is commonly used for gravity dam application. Recently, Malaysia started adopting RCC technology to the gravity dam construction. With the fact that the construction of RCC dam is still new in Malaysia, the understanding on such construction is very limited among local construction industry player. The first RCC dam in Malaysia is Kinta dam which is situated in Ipoh and constructed by Japanese contractor (Hazama Corporation). It was completed in 2007. In 2008, the construction of Batu Hampar dam is started which is the second RCC dam project in Malaysia. Dekon Sdn. Bhd, the local contractor who had no previous experience of RCC dams was selected to construct the dam. The government intention to develop local knowledge or expertise of RCC instead of recourse to international contractor is the main reason why Dekon was selected [2].

The understanding and involvement from the local construction player is still at the early stage. Therefore, the construction personnel such as engineer, the supervisor, the technician, until the general workers has very limited knowledge on the RCC dam project that leads to difficulties. Hence, there is a need to capture the knowledge of RCC dam construction.

This study will serve as an avenue for further understanding the construction of RCC dam among the local construction industries player.

This paper presents the process of the construction of Roller Compacted Concrete Dam in Malaysia with Batu Hampar dam in Rembau, Negeri Sembilan as the case study since Malaysia has just started to adopt the RCC dam technology in the construction of the Dam project. The scope of this study is focused on construction stage of RCC dam project. This study involves interview sessions with the professional and semi-professional construction personnel who were involved in RCC dam project in Malaysia. Roller Compacted Concrete Dam

Roller Compacted Concrete Dam

Concrete in general are defined as a composite construction material composed primarily of aggregates, cement and water. According to America Concrete Institute (ACI), Roller compacted concrete (RCC) is defined as concrete compacted by roller compaction [3]. RCC is considered for application where no slump concrete that can be transported, placed and compacted by using the normal construction equipment that being used in earthfill and rockfill works [3]. Parallel to this, [4] defines RCC as no slump consistency concrete that is placed in a thin horizontal lifts and compacted by vibratory rollers. The application of RCC is considered when it is economical competitive with other construction method and in this case the application of RCC method for construction of a gravity type of dam [4].

RCC dam construction requires four basic component which includes ingredient for the concrete, production of the concrete, transportation and placement of the concrete to the dam [5].

RCC Mix Design

The typical RCC mix design contains approximately 5-6 percent water, 5-10 percent cement and flyash, 30-35 percent fine aggregates and 60-65 percent coarse aggregates. This design possesses the characteristic required by the gravity dam which is strength and permeability properties [4]. RCC mixture proportioning procedure is very similar to conventional concrete. According to [6] the general method-
ology of RCC mixes proportion by used soils approach is:

1) Selection of suitable aggregate.
2) Select range of trial mixes which consist of various cement and fly ash content.
3) Determine desirable moisture content.
4) Prepare RCC cylinder and specimen for strength testing and durability testing.
5) Select mix proportion based on laboratory result

RCC Placement

According to [7] the machineries used to construct RCC dam are similar to the construction of earth embankment which is dozer, dump truck and roller compactor. Dump truck used to transport the RCC mixture to the dam site, and dozer used to spread the RCC material at certain thickness, then the roller compacter required to compact the RCC material [7].

According to [3] RCC lift minimum thickness is ranging from 150 mm to 1m but in normal practice in United State is rarely exceeded 0.6m and the thickness is depending on mixture proportions, plant and transport capability, placement rates, spreading and compacting procedure, and the size of placement area.

Methodology

The overall view of the RCC dam construction was captured from the literature review and interview questions were drafted based on site observation. Interview sessions were conducted and the statement given by the respondent was recorded. The interview was recorded using a digital recorder to record opinions provided by the interviewee and were converted into a written form. Furthermore, content analysis was done on the answer and statement given by every respondent during the interview.

Result and Discussion

From the analysis, the processes of RCC construction works as shown in Figure 1 are listed below:

1) Determination of RCC mix (RCC design mix)
2) Aggregates production
3) Foundation preparation and treatment
4) Diversion culvert and river diversion works
5) RCC mix production
6) RCC placement works
7) Instrumentation works

A. Determination of RCC Mix

Three combined mix aggregates grading namely T1(63-25)mm size, T2(25-5)mm size and T3(5-0.75)mm size which is coarse, medium and fine size of aggregates are adopted. This mix aggregates grading meets the specified grading envelope as in specification. Cement with low heat of hydration is the ideal cement to prevent temperature rise in concrete. To lower the heat of hydration of RCC, less amount of cement is used and type F Flyash is used to replace the quantity of cement. It was finalized and approved by RCC dam specialist as follows:

1) T1-28%, T2-34%, and T3-38%
2) Cement- 65kg/m³ and Flyash-105kg/m³
3) Moisture content between 4.5% and 5.4%
4) Vebe time with a 12.5kg surcharge was 15 to 30 second
5) Retarder is used to increase the initial setting time, thereby maintaining fresh lift joint
6) Bedding mortar used to treat the cold joint for RCC lift
B. Aggregates Production

Three types of aggregates produced based on specification namely T1 (63-25)mm, T2 (25-5)mm and T3 (5-0.75)mm which is coarse, medium and fine size of aggregates. Before RCC placement take place, the aggregates needs to be stockpiled at least 80% of total amount of aggregates required to complete the project.

C. Foundation Preparation and Treatment

Site clearing and removing overburden are the first step in preparing the RCC dam foundation. After site clearing and removing the soil or overburden was done, rock scaling works are the next step that to be done. Rock scaling works are to determine the type of rock where the specification state that, dam are to be sit on grade 2 or better rock. Foundation grouting are carried out is to strengthen the foundation and to ensure permeability of the foundation is high. The concept is to seal of the void, crack and fracture inside the rock that will strengthen the foundation for the dam to sit. The granite rock is permeable and as a result, fewer amounts (volume) of grouting are needed.

D. Diversion Culvert and River Diversion

Diversion culvert is a reinforced concrete structure with 15m diameter x 60 m long, complement with upstream and a downstream cofferdam. This is to allow the river flow trough cofferdam into the diversion tunnel and flow to downstream of the river.

E. RCC Mix Production

Continuous pugmill type of production plant is used for RCC production which is able to produce maximum capacity of 400 m$^3$/hour [2]. This plant control proportion of aggregates component by volumetric, and cement and flyash by weight control. Due to weather condition in Malaysia, chill water is used to lower the temperature of RCC mix.

F. RCC Placement Works

At the beginning stage of RCC placement, RCC is to be placed at a series of 15 meter wide strips from downstream to upstream in 6 meter section. The thickness of placement is 300 millimeter and compacted by vibratory roller compacter. The time allowed from mixing of RCC, transport, spreading and compaction is 45 minute. Immediately after RCC has compacted, the field density test (FDT) was carried out using nuclear density meter to measure the density of RCC. Then, if the compaction achieved 98% above, the next layer is continued with the same method and routine. Figure 2 shows the routine of RCC placement works.

2) RCC Surface Preparation

When the RCC surface are left more than 8 hour, normally due to plant breakdown or other issues that RCC placement are needed to be stopped, lift joint treatment needs to be performed before continuing a new layer of RCC. On the surface of old RCC layer, roughening was performed by using high pressure water jet blasting and the time to implement it is determined by hardening time which is 8 hours after compaction. Immediately after green cutting was done, bedding mortar is spread and the new layer of RCC placement is continued. This method was carried out to ensure the good bonding between joint lift which is between the layers of RCC.
3) Transporting, Spreading and Compacting

In the early stage of RCC placement works, RCC was transported by dump truck directly from the RCC mixing plant. The usage of dump truck was recognized as inefficient due to the site was at narrow steep side that lead to frequent needs to change and erect the temporary access for placement works. Therefore, the conveyor system is essential to transport RCC directly to dam site.

Conveyor system is required to transport RCC. However, due to the unavailability of technology in Malaysia, cost and other management issues, the conveyor system was not applied at the beginning of the placement works. The conveyor system was used only when the RCC reached level 95 m (lowest level was RL 75m). Figure 6 shows conveyor system that has been apply at Batu Hampar dam.

RCC that was deposited from dump truck at the dam site was spread with 300 mm thickness by tracked dozer. Single drum vibratory roller compacter was used to compact the RCC. Single Vibratory rollers compacter makes one round trip over the concrete without vibration and continued with at least three round trips with vibration. Practically five (5) to seven (7) passes with vibration is enough to achieve the 98% compaction density. This method is fast and sufficiently accurate which contributes to uniformly compacted RCC [9].

Immediately after compaction was sufficiently carried out, density of the RCC or field density test was tested using nuclear density meter. Figure 5 shows RCC Transporting and spreading and compacting process.

4) GERCC Application

Grout enriched RCC (GERCC) is produced by adding 3:1 or 4:1 water-cement ratio grout to the uncompacted RCC and then concrete vibrator used to compact the concrete. Grout was mixed using mixer and spread manually using bucket that as shown in Figure 4.7. The concept of using GERCC in RCC dam is to be applied at location of RCC placement where difficult to access by vibratory roller compacter. By applying GERCC it fills the void in RCC and create the smooth surface especially for upstream and downstream portion where it can be seen clearly after formworks have been dismantled. According to [10] at Kinta dam, GERCC are applied at the entire upstream and downstream faces (including the stepped spillway), the transition zone between RCC and rock abutments, drainage gallery walls, as well as encasement of waterstops, drains, and reinforcing steel.

5) Transverse Joint, Drainage Hole and Water Stop

At the upstream and downstream edges of the dam, galvanized steel plates were installed in advance as a contraction joint at 15 m spacing. Then, water-stop and drainage holes were set in the upstream face of the dam. The drainage hole and water stop were set at the upstream face of the dam prior the increase of RCC. Drainage hole function is to collect and convey the water that seep thru the dam and the water are drain out from drainage gallery to downstream river.

Transverse joints are installed to prevent temperature cracks in the concrete [11]. The installation took place after the completion of RCC placement layer and before it hardens, and prior to the placement of the next layer. Transverse joint were cut by a vibratory blade machine and galvanized thin plates were installed in the cutting plane to prevent closing that has shown in Figure 7. Figure 8 shows the location of water stop, drainage hole and transverse joint.

6) RCC Curing

After placement, if the commencement of next layer of RCC is more than 24 hour, the concrete is cured by water ponding.

7) Laboratory Testing and Quality Control of the RCC Dam

Various quality control measures were executed at RCC dams so that the quality of materials is monitored carefully. Quality control methods that were applied at Batu Hampar dam is as below:
1) Concrete Strength

Concrete strength is being monitored according to date the cylinder sample was taken and compressive strength test is conducted 7, 14, 28, 56, 96 and 180 day. It was carried out from the determination of RCC mix process until RCC placement works are completed. To monitor the compressive strength of RCC, compressive strength test and indirect tensile strength test is carried out at the stated days.

2) Density of RCC

Nuclear density meter is used to check the density of the RCC after compaction is carried out. The number of passes of the vibratory roller is manually counted to ensure the adequate compaction of RCC layer.

3) Vebe Consistency Test of RCC Mix

RCC concrete is dry and lean, the slump test cannot be used to measure its consistency [12]. The Vebe test with the standard container is conducted to monitor the consistency and workability of RCC mix. The test is conducted once every batch of RCC production. Optimum Vebe time is between 15 to 25 second, where it is the optimum in workability of RCC.

4) RCC Material Testing

RCC material testing is carried out in the early stage of RCC construction until the end of RCC construction works. The RCC material are tested to ensure the consistency of the RCC material. Table 1 shows the major material testing for Batu Hampar dam project.

<table>
<thead>
<tr>
<th>Material</th>
<th>Test</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Chemical composition, moisture content, specific gravity, fines, temperature</td>
<td>Every delivery to site</td>
</tr>
<tr>
<td>Flyash</td>
<td>Same with cement testing</td>
<td>Every delivery to site</td>
</tr>
<tr>
<td>Aggregates</td>
<td>Flakiness test, sieve analysis, specific gravity, soundness, and others testing that related to aggregates. Instructed by engineer</td>
<td>1 per day and every new production of aggregates stackpile</td>
</tr>
</tbody>
</table>

Table 1: Material Testing at Batu Hampar Dam

E. Instrumentation

According to [11], the instrumentations installed in dams are for the purpose of:

1) Monitoring overall performance of the dam structure to ensure dam safety.
2) Monitoring the behaviour of the RCC dam.

Different instrumentation, monitors different character or behavior of the dam. The instrument that has been installed at Batu Hampar dam are as stated in Table 4.2 below:

<table>
<thead>
<tr>
<th>Instrument Type</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibrating wire piezometer</td>
<td>Measure the pore water pressure</td>
</tr>
<tr>
<td>Combine biaxial Inclinometer/magnetic extensometer</td>
<td>Ground lateral movement &amp; settlement</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>Temperature of the dam</td>
</tr>
<tr>
<td>Vibrating wire strain gauge</td>
<td>Measuring strain in mass of RCC</td>
</tr>
<tr>
<td>Vibrating wire pressure cell</td>
<td>Measure the internal stress of RCC</td>
</tr>
<tr>
<td>Surface settlement/ deflection point</td>
<td>Vertical and horizontal displacement of the dam</td>
</tr>
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</table>

Table 2: Instrument Installed at Batu Hampar Dam

Conclusions

The process of RCC dam construction in Malaysia started from determination of RCC mix until RCC placement works. Before RCC placement started, it requires the preparation process which involves the preparation of RCC mix, foundation preparation, and diversion works. Preparation of RCC mix includes finalizing the RCC mix and production of RCC. Further to RCC placement works, it requires the complex of construction method in order to place a large amount of mass concrete to form a gravity type of dam. The instrumentation is installed at the dam during construction stage to monitor overall performance of the dam structure to ensure dam safety.

References