QUALITY CONTROL AND QUALITY ASSURANCE MANAGEMENT IN UPPER-KOTMALE HYDROPOWER PROJECT

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ABSTRACT**:** Upper-Kotmale Hydropower Project has been constructed at the southern highland of Sri Lanka from 2007 to 2013. This project has 150MW capacity and it composed a dam with a height of 35.5m and a crest length of 180m, a headrace tunnel of 4.5m in diameter lined and unlined and 12.89km in length, a surge tank with 12m diameter and 98m height, a penstock formed by an underground incline shaft starting with a diameter of 4.5m and reducing to 1.45m and 793m in length, an underground powerhouse with dimensions of 66.3m L x 18.8m W x 36.5m H, an outdoor switchyard and other facilities. Approximately 300,000m3 of concrete have been used for this project.

This report introduced the management systems for quality control and quality assurance for concrete and other materials. Very careful quality control has been required due to wide variation of raw material quality for construction. Author has constructed the quality control and quality assurance management system and organized the QAQC team. Continuous education and training for team staffs have been carried out to ensure the technical level of testing. All manufacturing records have been input and checked daily. Even these efforts for quality control were carried out, but some quality failures have been observed. These failures are also introduced as case studies in this report.

KEYWORDS: quality control, quality assurance, management system, ODA, hydropower project

1. PROJECT OUTLINE

Upper-Kotmale Hydropower Project has been constructed at the southern highland of Sri Lanka from 2007 to 2013. This project has 150MW capacity and it composed a dam with a height of 35.5m and a crest length of 180m (Fig.-1), a headrace tunnel of 5.0m in diameter lined and unlined and 12.89km in length(Fig.-2), a surge tank with 12m diameter and 98m height (Fig.-3), a penstock formed by an underground incline shaft starting with a diameter of 4.5m and reducing to 1.45m and 793m in length (Fig-4), an underground powerhouse with dimensions of 66.3m L x 18.8m W x 36.5m H (Fig.-5), an outdoor switchyard and other facilities (Fig.-6). Table-1 shows the main structures in this project. Approximately 300,000m3 of concrete have been used for this project.

Fig.-1 Intake Dam

Fig.-2 Headrace Tunnel

Fig.-3 Upstream Surge Tank

Fig.-4 Inclined Penstock Tunnel

Fig.-5 Underground Powerhouse

Fig.-6 Outdoor Switchyard and other Facilities

Table-1 Main Structures in UKHP Project

Structure	Descriptions
Intake Dam	Gravity type concrete dam Height: 35.5m, Length 180m Concrete Volume 67,000m3
Head Pond Area	River Protection work, 2 Bridges, Road relocation, Banking, Land reclamation, etc.
Headrace Tunnel	Diameter: 5.0m Total Length: 12.89km 3 nos. of work adits
Upstream Surge Tank	Diameter: 12m, Height: 98m Bottom 44m: Steel lining Top 54m: RC lining
Penstock Tunnel	Inclined tunnel with Steel lining and Concrete Backfilling, Inclination: 48 deg. Horizontal part:37m+50m+64m Inclined part:220m+400m
Powerhouse Complex	Underground powerhouse: 66.3m L x 18.8m W x 36.5m H Access Tunnel: L=446m Cable Tunnel: L=468m Downstream Surge Chamber & etc.
Tailrace	Concrete lined, L=457m, D=5m
Outdoor Switchyard	Switchyard, Drainage system, Service road, Gate and Fence, etc.
Architectural Works	Control Buildings at ID & SY, other buildings, total 21 nos.

2. QUALITY CONTROL IN SPECIFICATION

2.1 Problems in the Technical Specifications

The quality controlling and quality assurance system has not been specified in the Technical Specifications of this project, but specified as follows.

“The Contractor shall perform the concrete works in accordance with the Specifications, the Drawings and the instructions of the Engineer. At least fifty six (56) days prior to commencement of the concrete work, the Contractor shall submit the details, materials of concrete placing equipment, methods and schedule to the Engineer for approval.”

According to the above sentence, the Engineer have requested to the Contractor to submit the method statement for the quality control and quality assurance before concrete work started. The author has started preparation of the plan for quality controlling and assurance system (QAQC system) in accordance with the Technical Specifications, relevant standards and on-site investigation.

During the on-site investigation, several problems have been found in the Technical Specification which would be very difficult to satisfy the specifications due to technical reason and/or site condition. Table-2 shows the typical problems and reasons. The Technical Specifications have seemed to be written without consideration for construction method and/or proper workability. Most of all, this project has not have quarry site but has planned to use excavated tunnel muck for concrete aggregate. Therefore the variation of aggregate quality has been estimated to be large due to the variation of rock type in the Headrace Tunnel which has 12.5km long. The author should have prepared the master plan of QAQC system with consideration of workability, construction methods and large variation of row material quality. Therefore several inconsistencies have been occurred between the QAQC system and the Technical Specifications.

Several discussions have been carried out between the Engineer and the Contractor, however, some of the problems have not been able to reach consensus. Even though there have been many discrepancies, the Contractor should not stop the work.

2.2 Problems on Material Procurement

Material procurement has been unstable due to four reasons as follows.

(1) Sri Lanka is an island country and port facilities and custom have not been enough capable.

(2) Project was located in the mountain area and road condition from Colombo to site has been very poor. Several army and police check points have been located to prevent suicide attacks by LTTE terrorists.

(3) Cement and admixtures have been imported materials and transporting facilities in this country have been very poor condition. Sea freight schedules have been easily delayed by the bad weather condition.

(4) Aggregate has been specified to be produced from excavated rock material at site, but the excavation work schedule and concreting work schedule have been parallel and the quality of excavated rock has been estimated to be varied because the Headrace tunnel pass through several types of geological layers as shown in Fig.-7.

Fig.-7 Geological Condition at Site

Table-2 Typical incompatibility of the Specifications

Item	Item Descriptions	In-Compatibility
Standards	ASTM, ACI & USBR standards are applied for testing, designing, construction and of other related work of concrete.	All equipments for testing, plant for production, standard books were not abailable in SL market. Therefore these above had to be purchased from foreign coutries. Local staffs were unfamiliar with these standards.
Concrete testing	Compressive strength of concrete by cylindrical concrete specimens	Cylindrical specimens as per ASTM C 39 was uncommon in Sri Lanka. According to the ICTAD specification concrete strength testing commonly done by casting of concrete cubes as per BS 1881 : Part 108.
Cement	Cement should comply with ASTM C 150 "Standard Specification for Portland Cement"	Cement which is complying to ASTM C 150 standard is not available neither importing nor manufacturing in Sri Lanka. Cement testing facilities as per the ASTM standard is not available in the independent institute in Sri Lanka.
Cement source	Cement used in the works shall be from the same manufacture	It was very difficult to depend on single cement manufacture / supplier because of the rapid increment of cement demand and scarcity of cement in local and international market due to supply capacity of cement manufacturers / suppliers.
Cement delivery	The temperature of the cement as delivered to site shall not exceed 60 oC	It is very difficult to deliver bulk cement to site at the temperature less than 60 oC
Cement delivery	When cement is handled by pneumatic means, which involve contact of compressed air with the cement, the temperature of air in contact with the cement shall never exceed 38°C.	Cement bowser mount compressed air pumping equipment which use hot dry air usually. Therefore it is very difficult to use cool air.
Fine aggregate	Material passing sieve No.200 in fine aggregates shall less than 3%	This limit shall be applied for natural sand, but higher limit is specified in ASTM, ACI, BS, JSCE for crushed rock fines. For the crushed rock fines it is difficult to achieve less than 3% unless special washing facilities provided.
Admixture	Concrete admixture must be supplied by the same manufacture	It was difficult to found the all admixtures supplied by the same manufacture, in the special cases such as viscosity modifying agent for SCC concrete
Admixture	The contractor may use an approved air-entraining admixture in all concrete	In Sri Lanka the climate where freezing is not experienced. But the Engineer requested to adopt the air to the concrete which required for the moderate exposure condition in the Table 6.3.3 of the ACI 211.1. AEA's are not available in the market and we had to specially import the AEA for this project from Japan. Since the concrete air testing also not common in Sri Lanka we had to import the testing equipment's as well.
Concrete	Concrete Classes	Concrete classes which stipulated in the Technical Specification for various structures and location were not feasible for the structures compare with the maximum slumps specified
Batching	Admixture weighing accuracy been limited to 1 % (by weight)	This tolerance is too low. In the JIS and ASTM C 94/C 94 M Standard Specification for Ready-Mixed Concrete, weighing accuracy for the admixture is given as +/- 3%.
Concrete temperature	Plug concrete temperature should not exceed 40oC	It is very difficult to reduce the concrete temperature less than 40 oC while hydration even using the pipe cooling system
Slump testing	Slump test frequency; Once every batch of pouring, at the time of sampling of test piece or as required by the Engineer	The Engineer requested to check the slump once every batch of transportation (every track mixer) at both batching plant and site. It affected to the concrete pouring speed.

Under these conditions, QAQC system should have been determined and operated.

2.3 Problems on the Standard

The American Standards (ACI, ASTM, and USBR) have been selected in the Technical Specifications for this Project. However, Sri Lanka is a member of the Commonwealth of Nations, therefore the basic standards in this country (SLS: Sri Lankan Standards) are based on British Standard. In the Technical Specifications, the cement has been specified to comply with the ASTM C 150, but cement in this country has been complied with SLS and BS only. Concrete samples have been specified to be cylinders, but cubes have been common in this country. All other materials, tools and equipment have been likewise. The Contractor has suggested to the Engineer and the Employer to apply BS instead of American Standards, but have not been accepted. Under this condition, QAQC system should have been determined and operated.

2.4 Problems on the Human Resource

The author have interviewed with several engineers, supervisors, technicians, and operators for recruiting of QAQC staffs. None of them have had knowledge or experiment to carry out the material testing according to ASTM Standards. Therefore initial education and training to them have been indispensable for the QAQC system of this Project.

2.5 Master Plan of QAQC System

Fig.-8 shows the structure of master plan for QAQC system. The key points of this system are as follows.

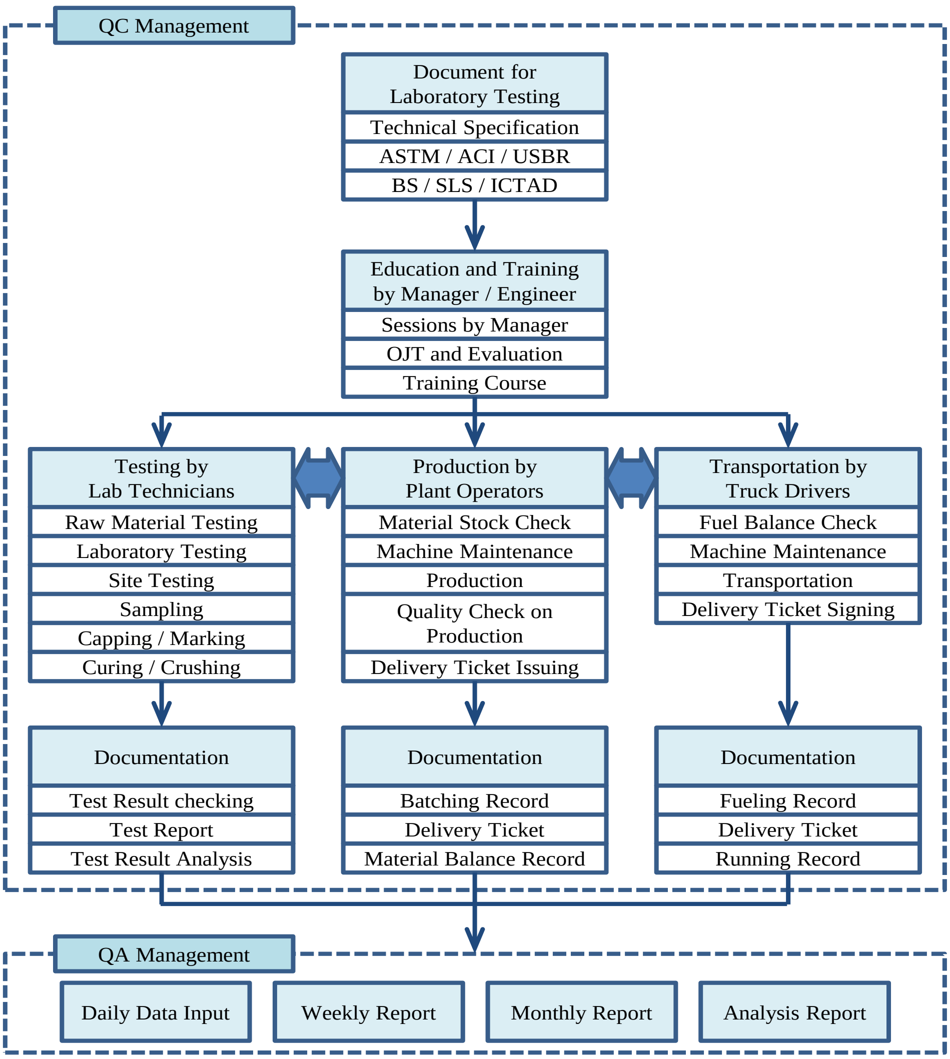

Fig.-8 Structure of master plan for QAQC system

(1) Education and training system

Education and training of each staff have been the most important to satisfy the required quality. Therefore routine educational sessions by the QAQC manager (the author) and on-the-job training by the material engineer have been incorporated into the QAQC system.

(2) Document management system

Documentation should have been quite exact and smooth from testing to filing. Therefore all necessary data should have been collected and inputted into PC by the document controller in daily basis and inputted data should have been checked by the material engineer periodically. This documentation management system has been incorporated into the QAQC system.

(3) Test result analysis system

The quality of material has been estimated to be unstable. Therefore continuous quality stability analysis of material has been very important to control the quality of concrete. The variation of aggregate and cement quality should have been checked continuously by the charts and the mix proportions of concrete should have been reviewed every month according to the test results. Therefore test result analysis has been incorporated into the documentation of the QAQC system.

3. EDUCATION AND TRAINING

This project has had quite large area and several structures, therefore two concrete batching plants, four aggregate crushing plants, one asphalt plant and three laboratories have been erected. Unskilled laboratory helpers, skilled laboratory helpers, assistant technicians, technicians, laboratory supervisor and assistant engineer/assistant manager have been allocated for each laboratory. Fig.-9 shows the total organization of QAQC team.

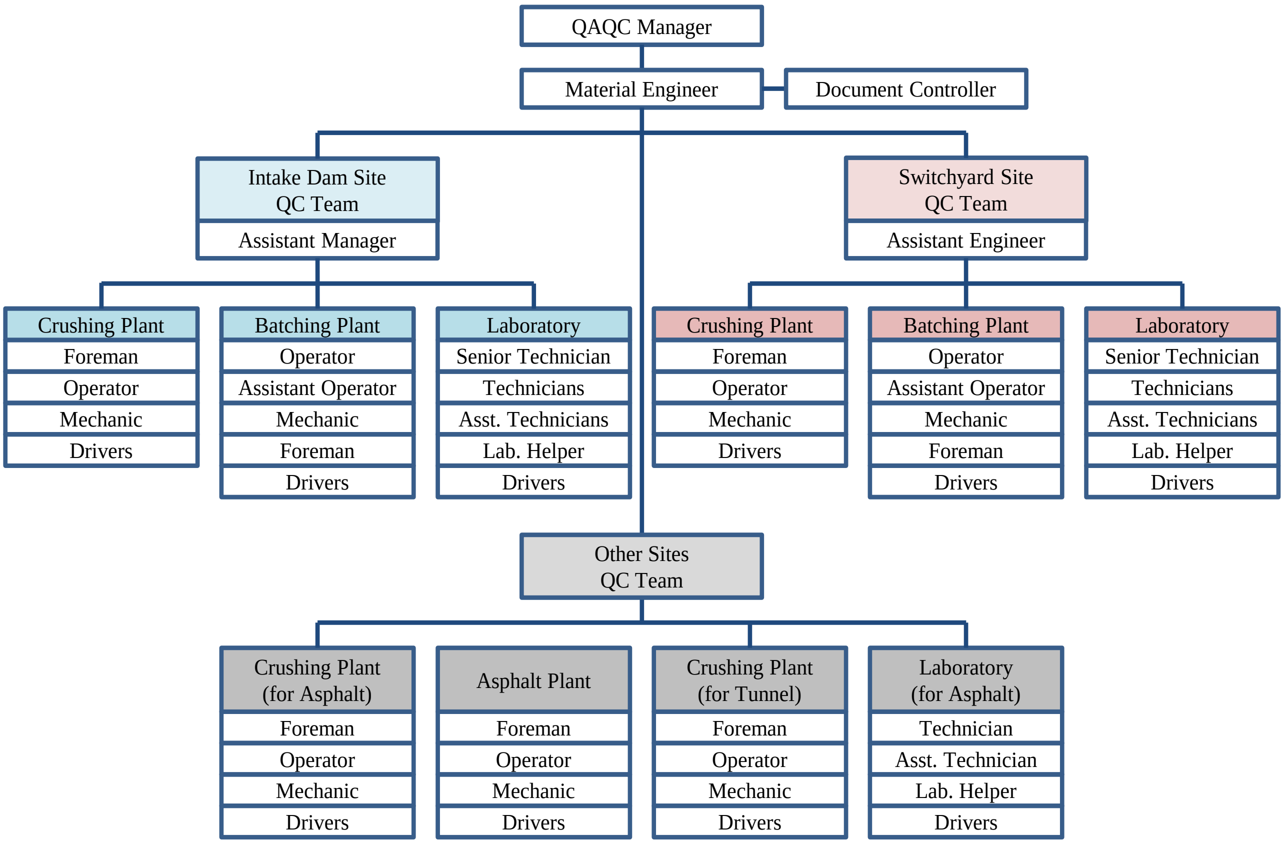

Fig.-9 QAQC Team Organization

3.1 Staff education sessions

Staff education sessions have been carried out by the QAQC manager. Table-3 shows the contents of the session program. Fig.-10 and Fig.-11 show the actual scenes of sessions.

3.2 Staff on-the-job training

Staff on-the-job training has been carried out by the material engineer at both laboratories. The material engineers should check the skill of his staffs on site and evaluated them. Staff promotion has been carried out annually in accordance with this evaluation and manager's judgment.

4. DOCUMENT MANAGEMENT SYSTEM

Table-4 shows the data flow in the documentation management system for quality assurance. Roles of each staff have been clarified by this table and all data have been collected by the document controller

Table-3 Contents of Education Session for QAQC Staff

Session 1	Session 3
What is the "Quality Control"? (Policy & Target) •What is the "Quality Control" of Concrete? •Why Concrete Quality Varies? •Minimization of the Variation •The Role of Laboratory Staff •Policy of Concrete Engineer	How to Check the Aggregate Quality •Material Preparation •How to make Aggregate in SSD condition •Density Test and Absorption •Sieving and Fineness Modulus •Flat particles and Elongated particles •Los Angels Abrasion Test, TFV and AIV •Clay Lumps, Friable Particles and Light weight particles •Soundness
Session 2	**Session 4**
How To Make "Good" Concrete •What is "Good" concrete •Requirement for "Good" Concrete •Materials Affects to Concrete Quality? •Mixes Affects to Concrete Quality? •Mixing Affects to Concrete Quality? •Transportation Affects to Concrete Quality? •Pumping Affects to Concrete Quality? •Placing Affects to Concrete Quality? •Curing Affects to Concrete Quality? •What is Important ? •Can We Know Quality Exactly?	How to do the Trial Mixes •Material Preparation •Checking of Surface moisture content •Determination of Mix Proportion •Weighing of Batch Materials •Charging of Materials •Mixing and Discharging of Concrete •Slump and Air content Testing •Sampling •Capping of Test Cylinders

Fig.-10 Educational session

Fig.-11 Educational session

Table-4 Flow of Test Data Treatment

Material	Person in Charge	Laboratory			Documentation			Analysis			Submission		
	Test Item	Frequency	Test by	Check by	Report by	Check by	Approve by	Input by	Analyze by	Check by	Weekly Rep	Monthly Rep	Analysis Rep
Cement	Specific Density	1 time per 1000 tons	Manufacture	Asst Tech.	Manufacturer's Certificate	Mat. Eng.	Manager	Document Controler	Material Engineer	Manager	Material Engineer	Material Engineer	Manager
	Blane Specific Surface Area			Asst Tech.									
	2 Days Compressive Strength			Asst Tech.									
	7 Days Compressive Strength			Asst Tech.									
	Temperature at Delivery	All deliver	Skiled Helper	Asst Tech.	Tech.	Asst. Eng.	Mat. Eng.						
Coarse Aggregate	Specific Gravity	Weekly	Asst Tech.	Tech.	Tech.	Mat. Eng.	Manager	Document Controler	Material Engineer	Manager	Material Engineer	Material Engineer	Manager
	Absorption		Asst Tech.	Tech.	Tech.								
	Sieve analysis		Asst Tech.	Tech.	Tech.								
	No. 200 sieve passing		Asst Tech.	Tech.	Tech.								
	Clay lumps		Asst Tech.	Tech.	Tech.								
	Light weight material		Asst Tech.	Tech.	Tech.								
	Elongated particles		Asst Tech.	Tech.	Tech.								
	Flat particles		Asst Tech.	Tech.	Tech.								
	LAAV	Monthly	Asst Tech.	Tech.	Tech.								
	TFV		Asst Tech.	Tech.	Tech.								
	AIV		Asst Tech.	Tech.	Tech.								
	Soundness		Asst Tech.	Tech.	Tech.								
	Moisture Content	2 times/day	Asst Tech.	Tech.	Tech.	Asst. Eng.	Mat. Eng.						
Fine Aggregate	Specific Gravity	Weekly	Asst Tech.	Tech.	Tech.	Mat. Eng.	Manager	Document Controler	Material Engineer	Manager	Material Engineer	Material Engineer	Manager
	Absorption		Asst Tech.	Tech.	Tech.								
	Sieve analysis		Asst Tech.	Tech.	Tech.								
	No. 200 sieve passing		Asst Tech.	Tech.	Tech.								
	Clay lumps		Asst Tech.	Tech.	Tech.								
	Light weight material		Asst Tech.	Tech.	Tech.								
	Soundness	Monthly	Asst Tech.	Tech.	Tech.								
	Moisture Content	2 times/day	Asst Tech.	Tech.	Tech.	Asst. Eng.	Mat. Eng.						
Admixtures	Density	All deliver	Asst Tech.	Tech.	Tech.	Asst. Eng.	Mat. Eng.	Document Controler	Material Engineer	Manager	Material Engineer	Material Engineer	Manager
	Color												
Water	Chloride content	when requested	Submit to University	Mat. Eng.	University	Mat. Eng.	Manager	Document Controler	Material Engineer	Manager	Material Engineer	Material Engineer	Manager
	Sulfate content												
	Alkalies content												
	Turbidity												
Fresh Concrete	Slump	All batch	Asst Tech.	Tech.	Tech.	Asst. Eng.	Mat. Eng.	Document Controler	Material Engineer	Manager	Material Engineer	Material Engineer	Manager
	Temperature of Concrete	All batch	Asst Tech.	Tech.	Tech.								
	Ambient temperature	every hour	Asst Tech.	Tech.	Tech.								
	Air Content	every hour	Asst Tech.	Tech.	Tech.								
	Sampling	9nos/150m3	Asst Tech.	Tech.	Tech.								
Hardened Concrete	Compressive Strength 7days	3nos/150m3	Asst Tech.	Tech.	Tech.	Asst. Eng.	Mat. Eng.	Document Controler	Material Engineer	Manager	Material Engineer	Material Engineer	Manager
	Compressive Strength 28days	3nos/150m3	Asst Tech.	Tech.	Tech.								
	Density (7days, 28days)	3nos/150m3	Asst Tech.	Tech.	Tech.								

every day. This kind of daily document controlling is the most important part of quality assurance to keep the reliability of quality control records.

5. CASE STUDIES OF QUALITY FAILURES

Even careful quality control has been carried out but some quality failures have been observed. Case studies of them are introduced as follows.

5.1 Low Compressive Strength due to Cement

Before commencement of the concreting work, a cement supplier in Sri Lanka has been selected. This supplier has had several manufacturers in neighbor countries as cement and clinker sources. In the Technical Specifications, it has been specified that, “all the cement used in the Work shall be from the same manufacturer”. Therefore the Contractor has requested to the supplier to supply the cement from only one source, and the supplier has agreed and selected an Indonesian manufacturer.

One day, suddenly a cement lorry has been delivered with a Thailand manufacturer’s test certificate. The contractor has returned this lorry and requested to the supplier to clarify the reason. The supplier has explained that the cement demand in Indonesia had increased, thus the export cement quantity had been reduced. Due to this problem, the Contractor should suspend concreting work until the trial mixes of all mix proportion have been carried out and the compressive strength have been approved by the Engineer.

A year after this problem, this supplier have informed to the Contractor that the cement supply from Indonesia and Thailand would be suspended due to some reasons, and he would change the cement source to India. He has recommended to use the cement manufactured in his local factory which has produced cement from imported clinker. The Contractor had accepted and started using this cement. But few months later, compressive strength of concrete has been observed to be lower than the specified strength and setting time of concrete have become longer suddenly. The author has took cement samples and checked its quality. Then the fineness of cement has been found very low of only 2400cm^2/g which should be more than 3200 cm^2/g usually. Fig.-12 shows the relationship between cement fineness and setting time of concrete which have been obtained by the trial mixes using sampled cement at site. Fig.-13 shows the relationship between cement fineness and early strength of concrete. Through long and heavy discussions, the

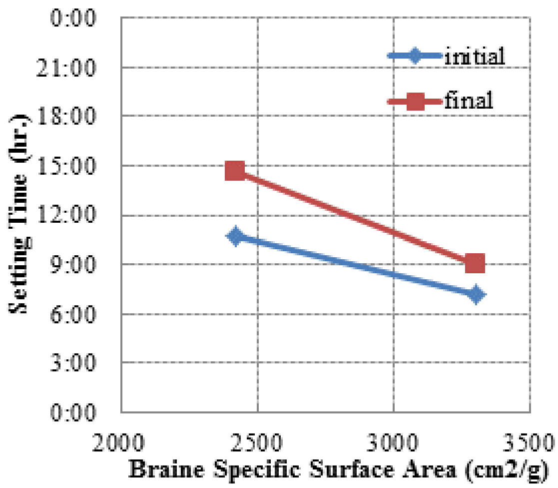

Fig.-12 relationship between cement fineness and setting time of concrete

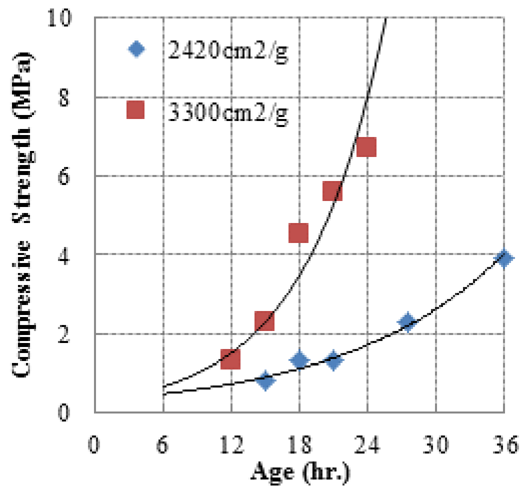

Fig.-13 relationship between cement fineness and early age compressive strength of concrete

Engineer has finally agreed to relax the specification for the cement source, which has limited to be single source, to be multiple sources. Anyway, the Contractor should terminate his contract for cement supply from this supplier and changed to new supplier after a lot of trial mixes again.

From this case, it is clear that the material supply condition of the project shall be carefully investigated by the Contractor before project start, and applicable alternative shall be discussed.

5.2 Variation on the Gradation of River Sand

Most of the river sand in Sri Lankan market is mined and supplied from Mahiyangana town. The gradation of this river sand depends on the location and water level of the mining point in the river. Only manual mining method shown in Fig.-14 or likewise has allowed to prevent environmental destruction, therefore sand supply has suspended frequently due to several floods occurred in the rainy seasons. The Contractor has adjusted the gradation of fine aggregate by mixing river sand and crushed rock fines in accordance with the individual gradations. Therefore the Contractor has keep river sand stock of approximately 5,000m3 in average to prevent shortage.

However, the second rainy season of year 2010, which have started from October and should finish end of the year, have continued to February 2011 due to abnormal weather condition, and it has caused severe floods at Mahiyangana town in January 2011. Due to this incident, river sand supply has suspended from November 2010 to January 2011. Due to the shortage of river sand, the author have had to try to keep river sand content in the mix proportion as small as possible. The gradation of river sand has been varied to coarser side in rainy season, therefore, special mix proportions of concrete have been determined by trial mixes after negotiation with the Engineer and the Client.

Fig.-14 Manual mining of river sand

From this case, it is strongly suggested that the climate change in recent years shall be considered more severely and flexible solution for such problems shall be discussed and studied instead of adhering to the Standard and/or specification only.

6. NEW TECHNOLOGY FOR SOLVING DIFFICULTIES

A new technology, self-compacting concrete (SCC), has been applied to solve the technical difficulties of concrete placing in Intake Dam and Powerhouse.

6.1 SCC Underneath Sand Flashing Way

Sand-Flushing-Way is the steel lined structure beside of water gates at the crest of Intake Dam as shown in Fig.-15. The steel lining structure has been erected on the dam concrete as shown in Fig.-16 and concrete should have been placed underneath the steel structure. The space underneath the Sand-Flashing-Way has been very difficult to place the concrete due to its narrowness and dense reinforcement. Therefore SCC has been proposed and applied as shown in Fig.-17.

6.2 SCC Underneath Spiral Casings

Spiral casing is the center parts of the hydropower system which is generating rotary motion of water in the powerhouse, therefore the spiral casing shall be embedded in the concrete with very dense surrounding reinforcement and other embedded pipes as shown in Fig.-18. Therefore perfect concrete filling surround this structure is usually requested. SCC has been applied at the bottom half of the concrete in this project as shown in Fig.-19.

Fig.-15 Sand-Flushing-Way

6.3 Technical Management for SCC

Technical management for the application of SCC has been carried out as shown in Fig.-20. This SCC application has been the first experience in Sri Lanka, therefore it has taken very long time for discussion with local staffs in the Engineer and the Client to get consent and agreement from them. Several trial mixes, mockup trials and demonstrations have been carried out to show the performance of SCC.

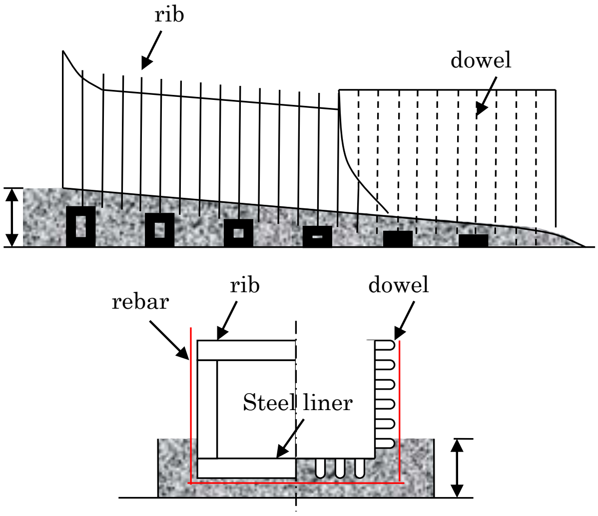

Fig.-16 Steel Structure of Sand-Flashing-Way

Fig.-18 Spiral Casing in Powerhouse

Fig.-17 SCC Placing underneath Sand-Flashing-Way

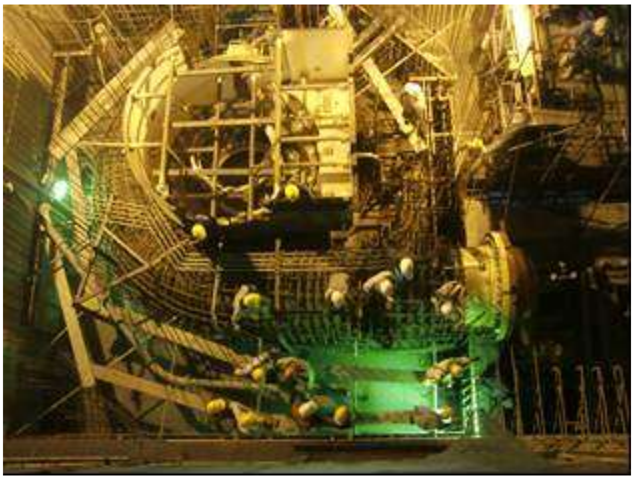

Fig.-19 SCC Placing underneath Spiral Casing

7. CONCLUSIONS

Upper-Kotmale Hydropower Project has been completed under careful quality control even there have been several difficulties and incompatibilities in the Technical Specification and actual construction work. Several lessons can be given from this project, hence it is most important to transmit these stories to the younger engineers. Learning from trouble stories is the best way to understand the importance of the method and ability for solving the difficulties and troubles.

Management systems for the international construction project shall include the training system for trouble shooting which is able to learn from these actual difficulties and/or troubles at site.

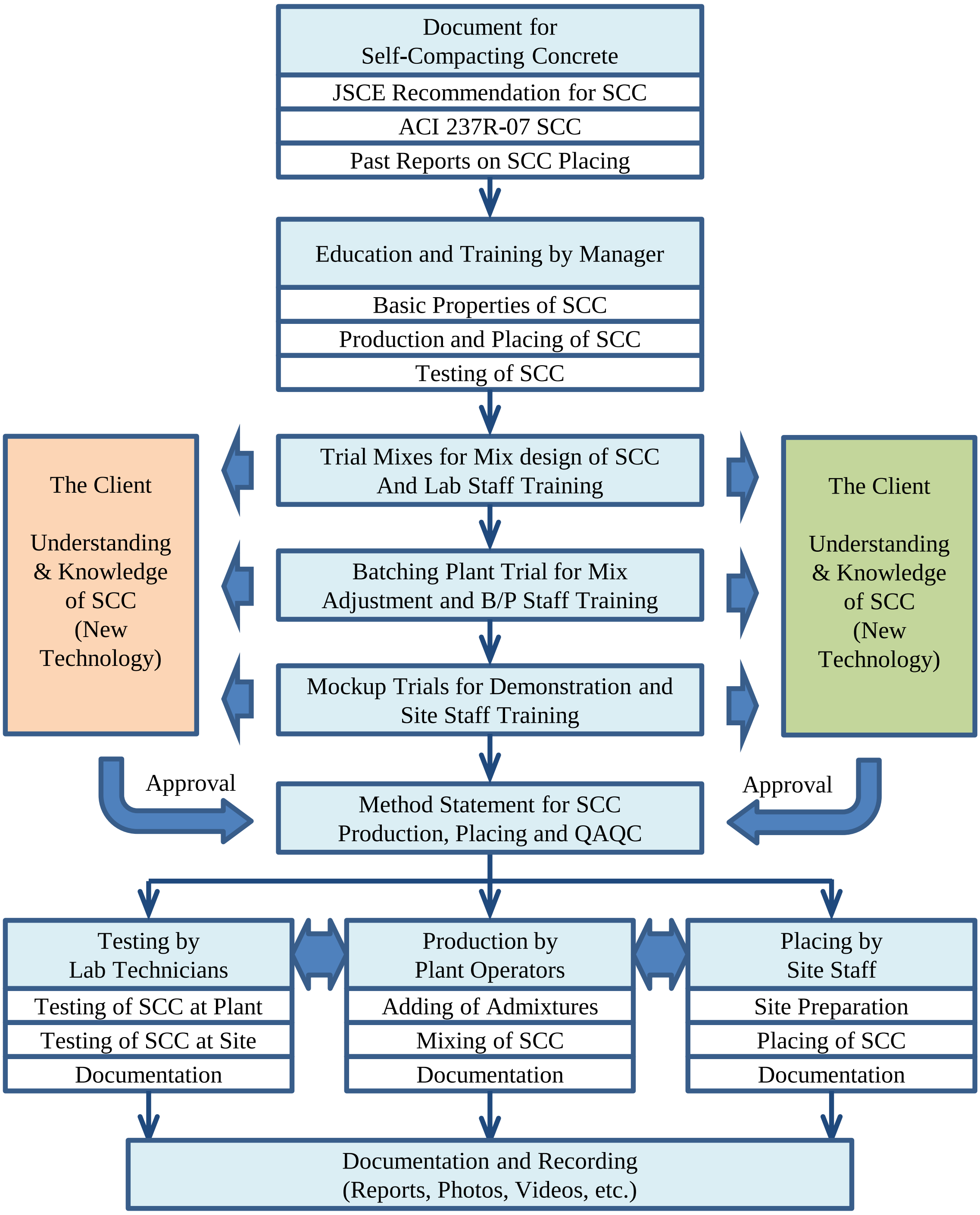

Fig.-20 Management Flow for Self-Compacting Concrete