APPLICATION OF CURTAIN GROUTING IN UPPER PAUNGLAUNG DAM*

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Abstract

Upper Paunglaung dam is a 98 m high Roller Compacted Concrete (RCC) gravity dam on Paunglaung River. The main types of dam foundation rocks are meta-sandstone and granite. During the construction of dams, it is necessary to carry out the curtain grouting in order to ensure the seepage cut-off and reducing uplift pressure beneath the dam foundation. Single row curtain grouting with split-spacing method was used in Upper Paunglaung dam. Geological condition and geological model of dam foundation were made in order to get proper grouting design and grouting methods. Trail and final grout mix design was made based on the results of material used in grouting. Single grout mix with a water/cement (W/C) ratio of 0.8~0.75:1 (by weight) as a "stable grout mix" was used for all grouting stages. Based on the geological condition of dam foundation, upstage stage and downstage method were used in curtain grouting. Grout curtain efficiency is one of the most important factors to control seepage flow beneath the dam body to ensure its safety concerns. Hence, all grouting data were analysed in order to know the grout curtain efficiency of dam foundation and then correlation between Lugeon values and cement take. According the results, the correction between Lugeon values and cement take shows poor correction, however, the grout curtain efficiency was achieved 94% in average after grouting. In this paper, the application of curtain grouting in Upper Paunglaung dam and grout curtain efficiency are discussed.

Keywords: dam, geological model, curtain grouting, grout mix design, grout efficiency,

Introduction

The Upper Paunglaung dam was built on Paunglaung River located on about 42 km (26 miles) east of Pyinmana, Pyinmana Township, Dekhinathiri District, Naypyitaw Union Territory. The dam site is located at latitude 19° 45' 17" N, longitude 96° 35' 54" E (U TM 2186257.62 m N, 247931.90 m E) and referred to map index as UTM 1996-09 of 1:50000 scale UTM topographic map. Purpose of the dam construction is to produce electricity and installed capacity is of 140 MW. Location map of Upper Paunglaung dam site is shown in Figure (1).

The main rock types of Upper Paunglaung dam foundation are meta-sandstone and granite. Geotechnical investigation was made to know geological conditions of dam foundation and then detail geological mapping was made during the dam excavation in order to know acceptable rock class of dam foundation. Geological model was made to provide for considerations of proper grouting design. Based on the geological condition of dam foundation, upstage stage and downstage method were used in curtain grouting at Upper Paunglaung dam.

During the construction of dams, it is necessary to carry out the curtain grouting in order to ensure the seepage cut-off and reducing uplift pressure beneath the dam foundation. Single row curtain grouting with split-spacing method was used in Upper Paunglaung dam. Curtain depth at Upper Paunglaung dam was ranged from 40 to 60 m. There are 27 blocks and 2 sub-blocks at left abutment (LA) and right abutment (RA) from left to right for Upper Paunglaung RCC dam construction. Curtain grouting was performed inside the foundation gallery.

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Materials used in grouting were tested to obtain grout mix properties. Based on the results of trial grout mix, proper grout mix design was chosen as a final grout mix design. Single grout mix with a water/cement (W/C) ratio of 0.8~0.75:1 (by weight) as a "stable grout mix" was used for all grouting stages during the dam construction. The correlation of Lugeon vs. cement take and grout curtain efficiency were also attempted.

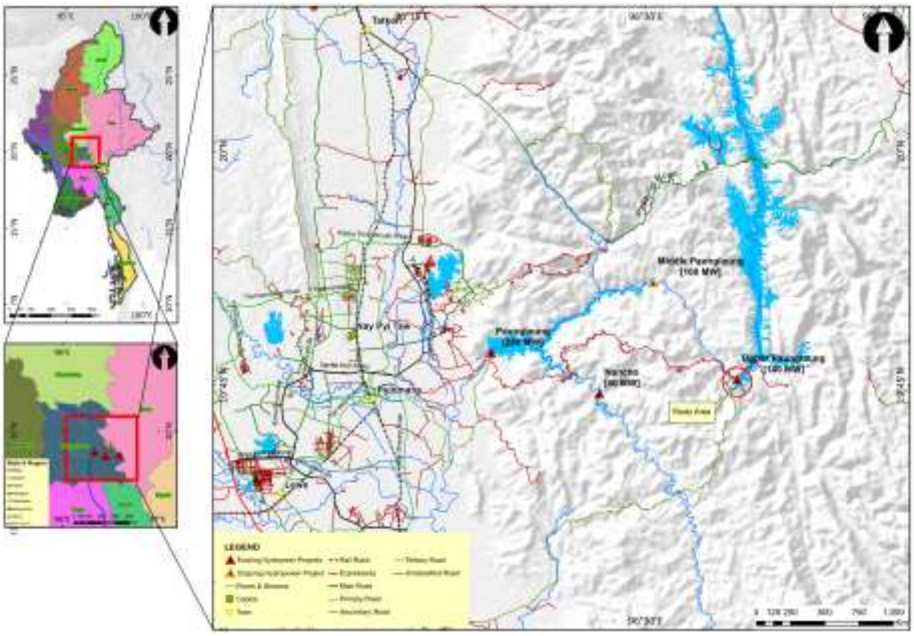

Figure (1) Location map of Upper Paunglaung dam site

Regional Geology of the Study Area

The Upper Paunglaung dam site area consists of Carboniferous-Permian rocks of the Mergui and Mawchi Series, and Ordovician rocks of the Pindaya Group and Mesozoic Granite (DGSE, 2008). The rock sequence is illustrated in Table (1). The Carboniferous rocks are composed mainly of sandstone, siltstone, and mudstone, which are slightly metamorphosed. The Ordovician rocks of Pindaya Group are thick-bedded to massive limestone. The Mesozoic granite exposed in the dam site area is mainly Padat Chaung granite. The granite outcrops are found on the left banks of the Upper Paunglaung dam site and along the Paunglaungnge Chaung and Padat Chaung.

Table (1) Stratigraphic succession of the study area

Formation/Group	Symbol	Age	General Lithology
Quaternary	Q_2	Holocene	Recent/younger Alluvium: River deposit, slope-wash deposit,
	Q_1	Pleistocene	Older Alluvium: Unconsolidated, terrace deposit, residual soil, saprolite
Mergui Group	CP	Carboniferous - Permian	Siltstone, shale, meta-sandstone
Pindaya Group	O	Ordovician	Siltstone, thick bedded to massive limestone
Igneous	Gr2	Mesozoic - Tertiary	Granitic rocks

The major Panlaung Fault runs in the eastern part of the dam site area. It is trending nearly NNW–SSE in direction and is passing through the reservoir area. It is about 5.0 km away from the dam site. Another fault is the Padat Chaung Fault, inferred to be a low-angle fault or thrust fault (Mitchell, 2018). It is trending in the N-S to NNW-SSE direction. It is about 2.2 km away from the west of the dam site. The regional geological map of the study area is shown in Figure (2).

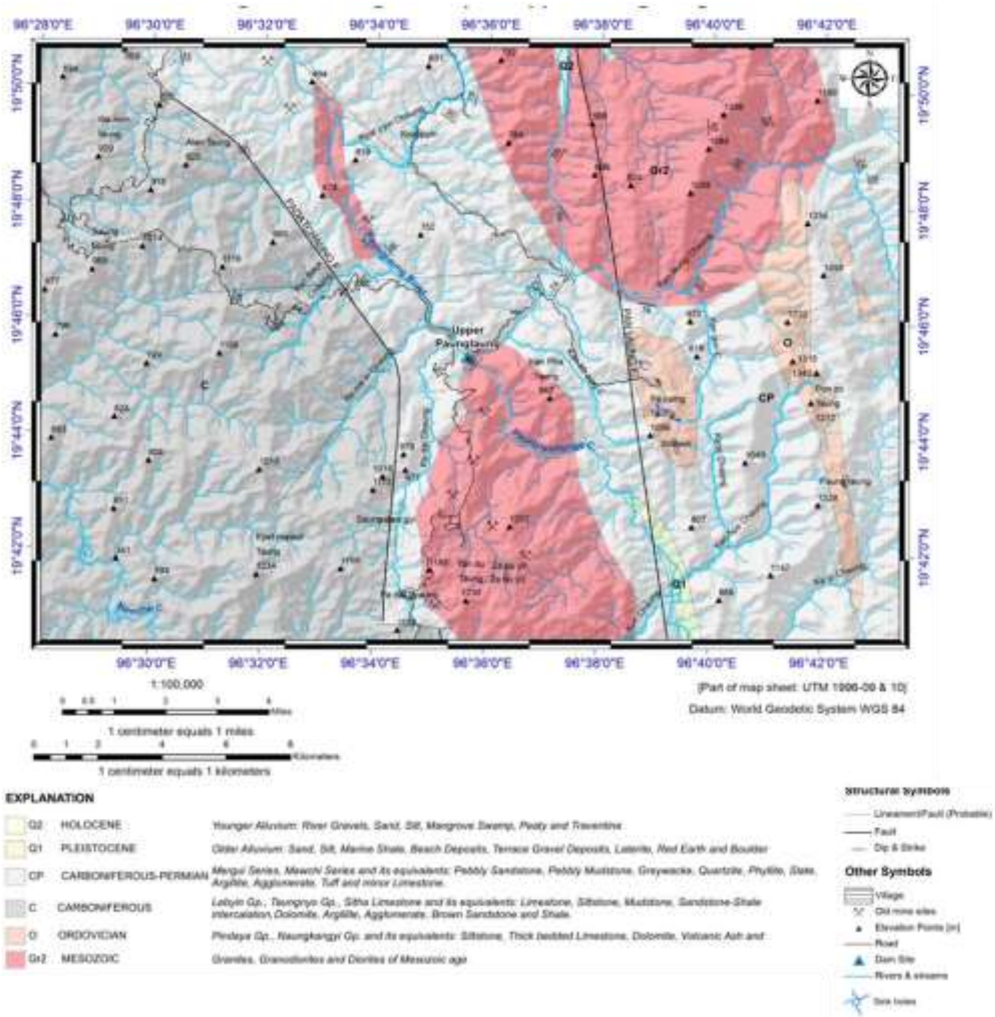

Figure (2) Regional geological map of the study area (After DGSE, 2008)

Dam Foundation Geology

The main rock types of dam foundation are meta-sandstone and granite. According to the drilling investigation results, through the dam alignment and dam foot print area, the thickness of overburden soil and decomposed rock cover is about 29 m. The evidences of the drill hole results show that the dam alignment can be subdivided into the following zones:

- **Left bank, above dam crest** (from EL. 396 m asl to 441 m asl, BH-14, BH-22 and BH-26): Overburden top soil composed of residual soil and decomposed met-sandstone is about 40 to 42 m in thickness. The fresh bedrock is found at elevation of variable depth (EL. 356-398 m asl) below a maximum 6 m thick layer of weathered meta-sandstone.

- **Left bank, dam abutment** (from EL. 312 to 372 m asl, ABH-1, ABH-2, ABH-4, ABH-5, BH-30, and BH-32): The overburden is reached from 7 to 29 m in depth. Weathered zones are variable in thickness of 1 to 7 m and fresh rock levels are ranged from EL. 312 to 360 m asl.
- **River section** (BH-2, ABH-14 and BH-24): River deposits is maximum 4 m thick below EL. 297 m asl. Granite bedrock is found at between EL. 286 m asl (BH-2), 293 m asl (ABH-14) and meta-sandstone is at 283 m asl (BH-24) in deep river section. Bedrock condition depicts that the contact of granite and meta-sandstone is found at the river section.
- **Right bank** (BH-3, BH-12 and BH-13): Overburden thickness is to 13 m. The thickness of weathered zone layer varies from 1 to 20 m and in the dam foot print area is to 13 m. The bedrock is meta-sandstone in drill holes at the right bank.

The overburden soil at the left abutment is thicker than the right abutment of the dam and the bedrock level of the left abutment is deeper than the right abutment.

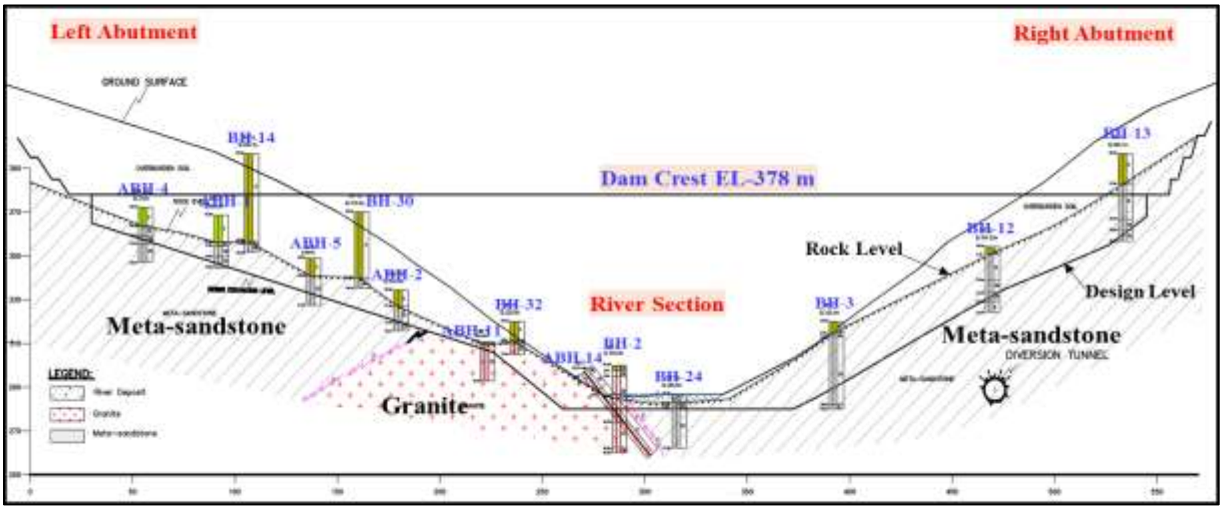

Figure (3) Geological profile along the dam axis

Permeability of Dam Foundation

Water pressure tests were carried out during the drilling investigation. Accordance with the results of water pressure tests, the permeability of dam foundation is ranged from about 2.0 to 8.0 Lu.

Rock Classification of Bedrock

Bedrock condition of dam foundation was classified on the basis of the criteria developed by Central Research Institute of Electric Power Industry (CRIEPI), Japan.

By using CRIEPI rock mass classification, meta-sandstone occurred CL to CH class at left bank and CL to B class at right bank. Granite occurred CH to B class at the left bank. The foundation of Upper Paunglaung dam can be classified into four (4) categories of CH-B, CM, CL, and D in good order. Basically, the acceptable rock class for dam foundation must be higher than CM rock class according to CRIEPI rock mass classification. Therefore, the design excavation level of the dam foundation was made based on the results of bedrock condition.

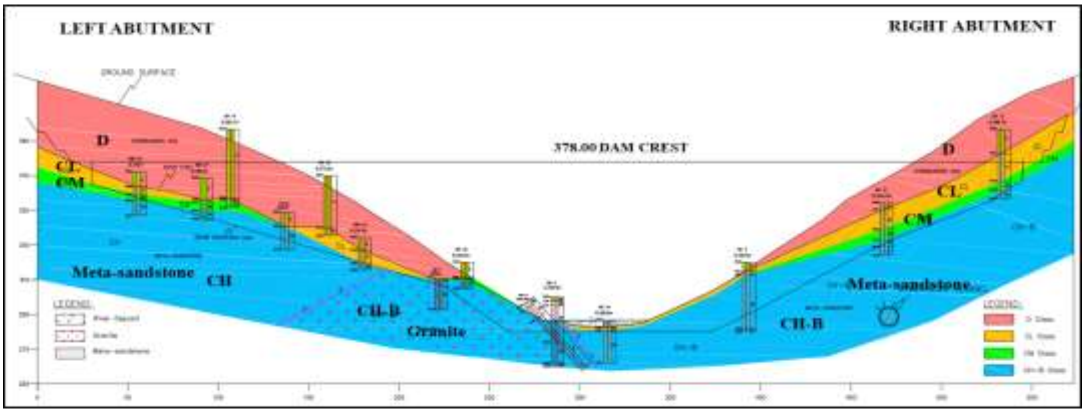

Figure (4) Rock class profile of Upper Paunglaung dam foundation

Geological Model of Dam Foundation

Excavation for the dam foundation was generally executed down to the required dam foundation rock class (CM) level. Based on the geological and geotechnical investigation results, the geological model of dam foundation is summarized as three different foundation conditions as follows:

(A) **Good quality meta-sandstone, slightly weathered** (grade CH), characterized by grey color; appears on the major part of the dam footprint

(B) **Slightly to moderately weathered meta-sandstone** (grade CM) of grey to brownish color; on the D/S part of the footprint, approx. El. 310-335 on the left abutment and approx. El. 295-320 on the right abutment respectively

(C) **Good quality granite** (grade CH), in the left abutment below El.315 m asl.

During the dam foundation excavation, geological mapping of the entire dam foundation including all lithologies, discontinuities and their orientations, and overall competency of the foundation on which the RCC dam was to be built and to be made actual dam geological model and dam foundation treatment.

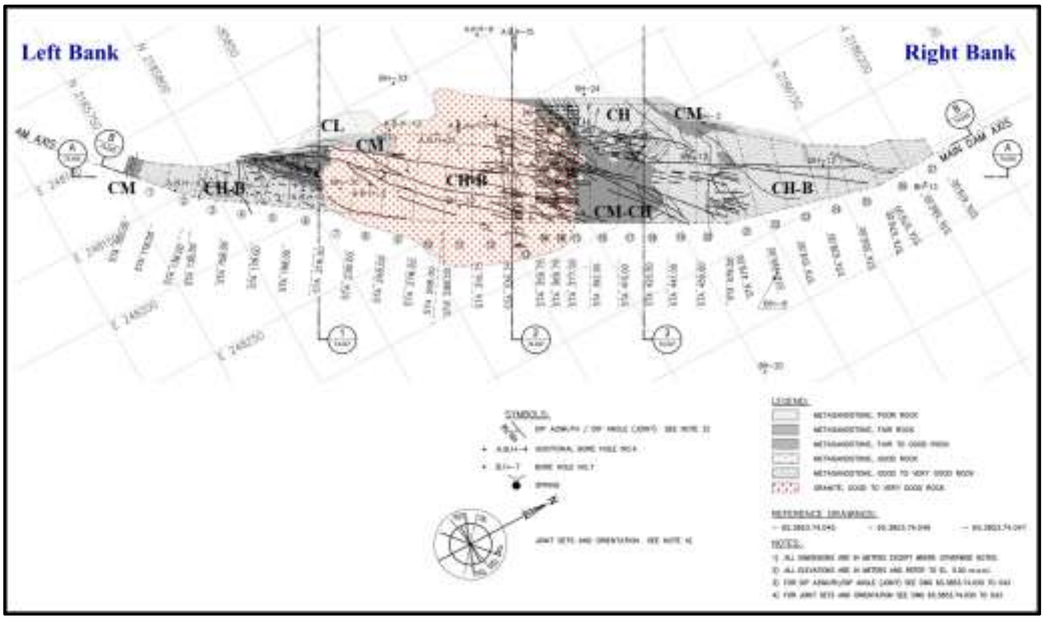

Figure (5) Foundation geological map of Upper Paunglaung dam

Objectives

This research mainly focus to choose proper curtain grouting design and methods based on geological conditions of dam foundation and grout materials. Hence, geotechnical investigation, dam foundation geology, geological model, material testing and grout mix design were carried out prior to carry out the curtain grouting works to correlate grout curtain efficiency related to geological condition with Lugeon values and cement or grout takes.

Methodology

Data collection and reviews of geotechnical investigation, dam foundation geology and geological model were mainly based on consultancy project reports and relevant data of Colenco Power Engineering Co., Ltd. (2005) and Geology Branch, Department of Hydropower Implementation (DHPI) (2008), ICOLD (2015), Frei, H.R. & Voborny, O. (2011) and Voborny, O. (2010 & 2011). CRIEPI Rock Mass Classification (Kikuchi K., Saito K., 1982) was used to classify dam foundation rock class.

Grout materials and grout mix trials were performed on site using the actual grout mixing equipment with OPC cement. Lugeon permeability and cement or grout take of respective grout holes were recorded during the curtain grouting process. The grouting data were collected from Geology Branch, Department of Hydropower Implementation (DHPI). Grouting reviews and analysis were made by using the publications of Bruce, D.A. & George C.R.F. (1982), Ewert, F.K. (1985), Houlsby, A.C. (1990), ISRM (1996), Kutzner, C. (1996), Nonveiller, E. (1989), Rafi, J.Y. (2013), Warner, J. (2004), Weaver, K.D. & Bruce, D.A. (2007) and Fell, J.R. et. al. (2015). Water pressure test was performed to know Lugeon and their jointing system of underlying rocks by using the document of Quiñones-Rozo, C. (2010).

Curtain Grouting

Curtain grouting was executed at the Upper Paunglaung dam during the construction to attain the objective of reducing the permeability of the foundation rock mass and seepage control beneath the dam foundation. The grouting works were performed inside the foundation gallery. There are 27 blocks and 2 sub-blocks at left abutment (LA) and right abutment (RA) from left to right for Upper Paunglaung RCC dam construction. Total work volume of curtain drilling and grouting was 18,032 m and 9,732 m. The quantity of grout holes were 198 holes – there were primary 48 holes, secondary 48 holes, tertiary 95 holes, quaternary 3 holes and check hole 4 holes. Of which, the numbers of exploratory primary pilot holes were 30 holes as cored holes.

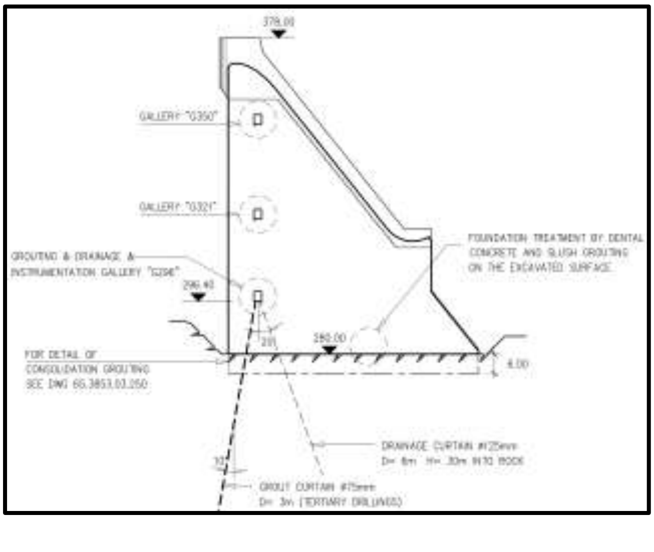

Figure (6) Curtain grouting location at Upper Paunglaung dam

Grout Curtain Depth

Curtain depth at Upper Paunglaung dam was ranged from 40 to 60 m. There were three portion of curtain depth as 60 m depth of all grout holes in river section, 50 m depth in middle portion (lower abutment) and 40 m depth in upper portion of both abutments along the dam axis.

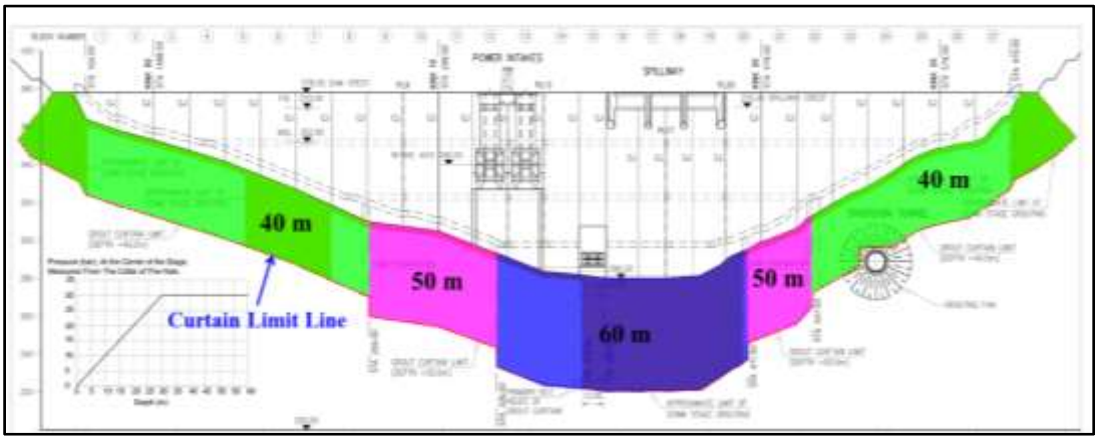

Figure (7) Different grouting depth of curtain grouting at Upper Paunglaung dam

Grouting Methods

Based on the geological condition of dam foundation, upstage stage and downstage method were used in curtain grouting at Upper Paunglaung dam. Downstage grouting method was especially used where contact zone of granite and meta-sandstone in the river section, middle portion of left bank and abutment wing section including interface of dam concrete and foundation rock contact. Then, the upstage grouting was commonly used in the good rock condition except weak zones, contact zone and interface of dam concrete and foundation rock.

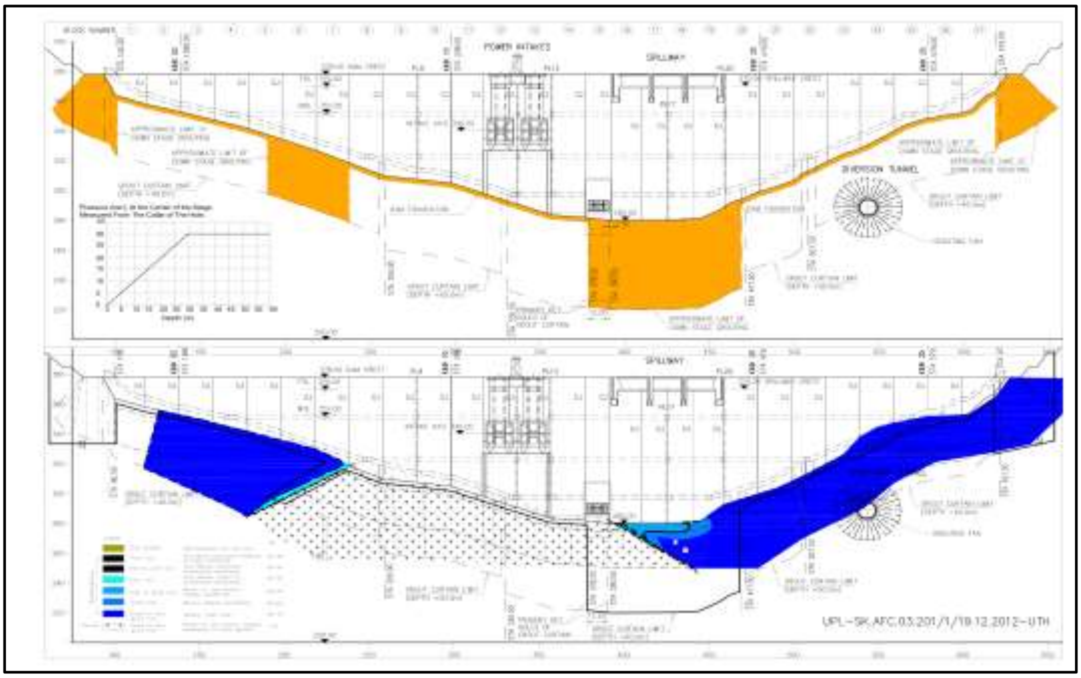

Figure (8) Grouting methods based on geological condition and curtain depth (downstage – orange colour)

Grouting Pattern

Single row curtain grouting with split-spacing method was used in Upper Paunglaung dam. The spacing of grout holes from primary (P) to secondary (S) and secondary (S) to tertiary (T) hole was 3.0 m based on a spacing of 12.0 m for primary holes.

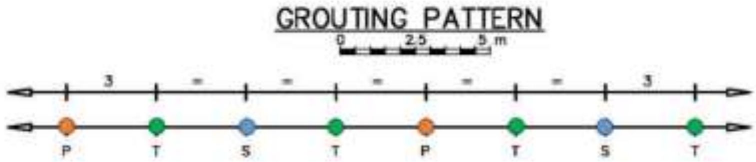

Figure (9) Split-spacing curtain grouting pattern

Arrangement of Boreholes

Direction and spacing of boreholes are of major importance for successful grouting. To determine the optimal direction of boreholes, the average orientation of the joints to be grouted must be assessed. Thus, the curtain grouting at Upper Paunglaung dam was comprised of systematic primary, secondary, and tertiary holes (spaced respectively 12, 6 and 3 m) with a 10° upstream inclination with respect to the vertical for a better intersection with the main nearly vertical joints of the rock mass.

Effective Grout Width or Thickness of Grout Curtain

The spacing of bore holes (s) is optimized using the expected distance the grout will travel or its reach (R_e). Expected grout travel reach (R_e) and effective grout width (d) of a single row of grout holes can be estimated as follows:

$s = R_e.\sqrt{3}$ (ISRM, 1996) ……………… Equation (1)

The expected grout travel reach (R_e) from Equation (1) can be written as

$R_e = \frac{s}{\sqrt{3}}$ (ISRM, 1996) ……………… Equation (2)

ISRM (1996) stated that the effective grout width (d) of a single row of grout holes is 1.33 R_e.

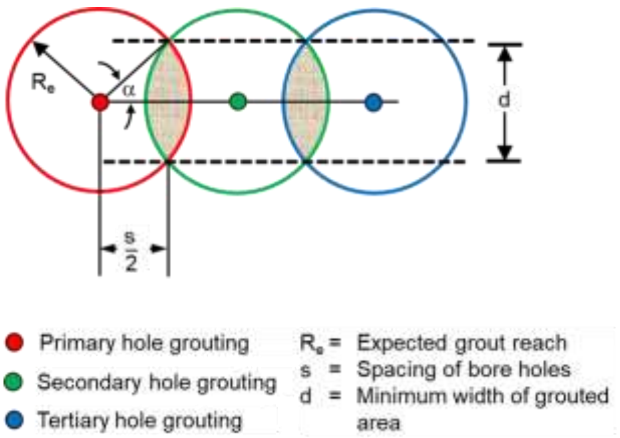

Figure (10) Geometry of borehole alignment

According to above-mentioned facts, the grout curtain was designed with the grout travel reach (R_e) of **1.7 m** and grouted area width (d) of **2.3 m** to deal with the water flow infiltration, making a consistent reduction of the permeability of the foundation rock.

Grouting Pressure

According to rule of thumb of Normal Swedish Practice, the grouting pressure is 1.0 bar/m (4.5 psi/ft) depth. Thus, the grouting pressure were established by calculating the depth to the centre of the stage from the collar of the grout hole in the foundation gallery as shown in Figure (11).

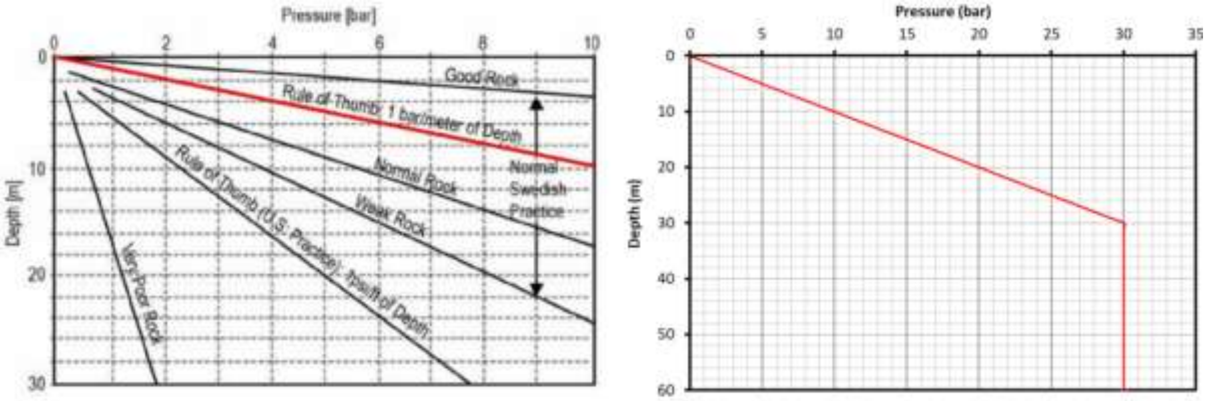

Figure (11) Curtain grouting pressure: Rule of thumb (left) and Upper Paunglaung dam (right)

Curtain grouting pressure was used by 1.0 bar/m depth up to 30 m depth and constant pressure was used for successive depths. Actual grouting pressure (PG) at the borehole mouth was increased in steps of 1.0 bar/m depth measured from the foundation level to the middle of the stage being grouted, starting at 1.0 bar for the top stage up to the respective maximum pressure limit (PL). In case, there were indication of near surface displacements, the pressure steps of 1.0 bar/m were to be lowered to 0.5 bar/m. Ultimate PL never exceed 30 bars as shown in Figure (12).

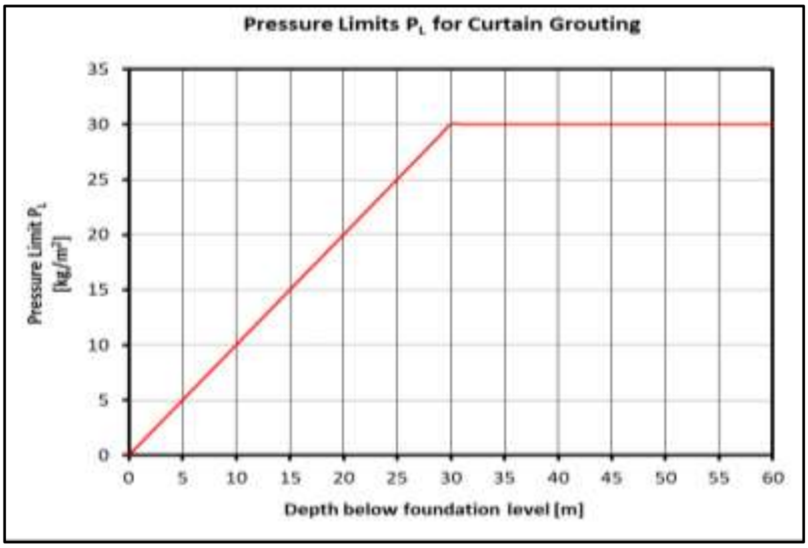

Figure (12) Pressure limits for curtain grouting at Upper Paunglaung dam

Grout Materials

Water and cement are commonly used in dam foundation grouting. Characteristics of grout materials were tested for curtain grouting at Upper Paunglaung dam.

(i) Water

The water to be used for drilling, flushing, testing, and grout mixing has to be clear potable water free of silt or sand. Silty/clayey will be very detrimental to the efficiency and durability of the grout.

(ii) Cement

The cement used for grout mixes is fresh Ordinary Portland cement (OPC) free of lumps. The cement used for pressure grouting has to be Blaine value of at least 3,500 cm^2/g with a maximum of 1.5% retention of cement particles retained on the ASTM sieve no. 200 (0.075 mm or 75 □m) sieve.

Taungphilar cement was used in curtain grouting at Upper Paunglaung dam. Blaine values of the cement are ranged from 3,107 to 4,632 cm^2/g, and average value was 3,673 cm^2/g. Average initial setting time and final setting time of the cement were 2 hr. 39 min and 3 hr. 38 min.

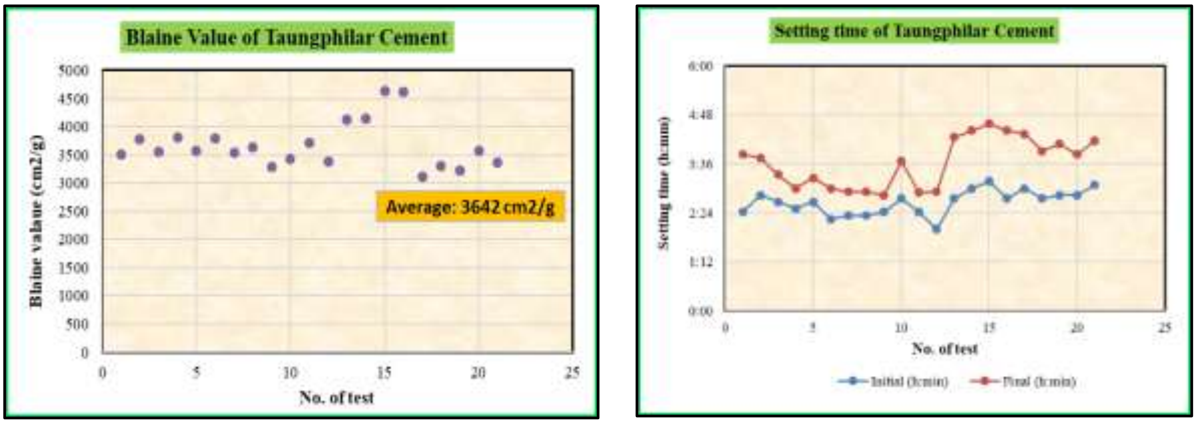

Figure (13) Blaine value and setting time of Taungphilar cement

Trial Grout Mix Design

Single grout mix was attempted to use for the curtain grouting at Upper Paunglaung dam. Grout mix trials were performed on site using the actual grout mixing equipment and with Taungphilar cement. The grout mix is used by fresh Ordinary Portland Cement (OPC), Taungphilar cement having special ordered from Taungphilar cement Factory, Naypyitaw. Blaine (fineness) value is of about 3,900 to 4,100 cm^2/g for curtain grouting at Upper Paunglaung dam. The tests were carried out as follows:

- Grout mixer efficiency test: For this test, a 1:1 w/c grout mix was used and with time zero starting the point when all the cement had been added, the grout mix was taken sample from the same point in the mixer drum at 30 sec intervals for a max time of 3 min (180 sec) and the density of each of the 6 no. of samples measured. The results were plotted for density vs. time and the optimum mixing time to be selected.
- Grout sedimentation/decantation tests
- Grout density test – using a “mud balance”
- Grout flow tests – using ASTM C939 flow cone to measure efflux time
- Grout compressive strength using 50 mm cubes

The above tests were carried out on grout mixes with the following w/c ratios 2:1, 1.5:1, 1:1 and 0.8:1 by weight.

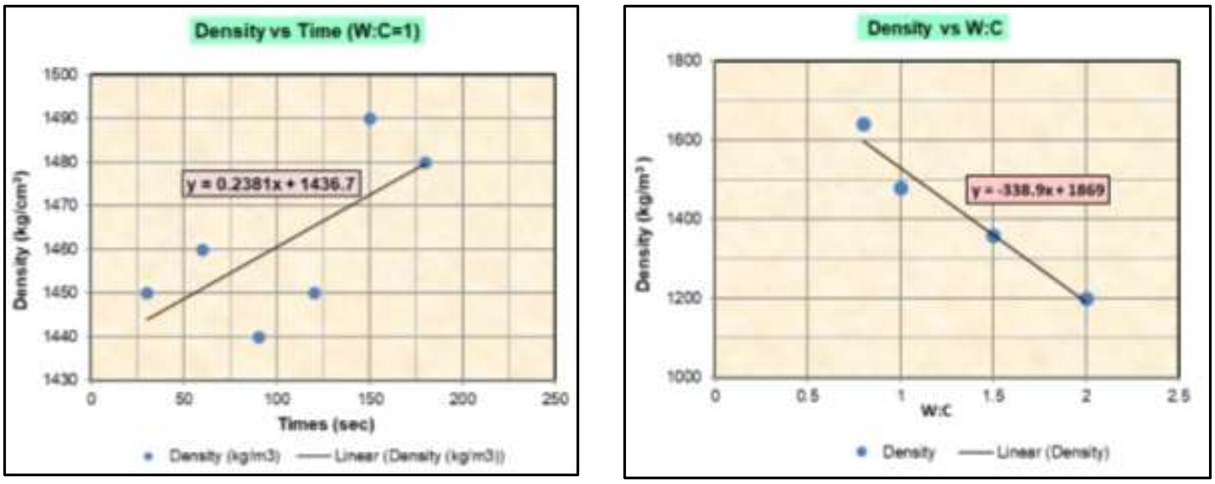

Figure (14) Trial grout mix results: Density vs Time & W/C ratio for curtain grouting

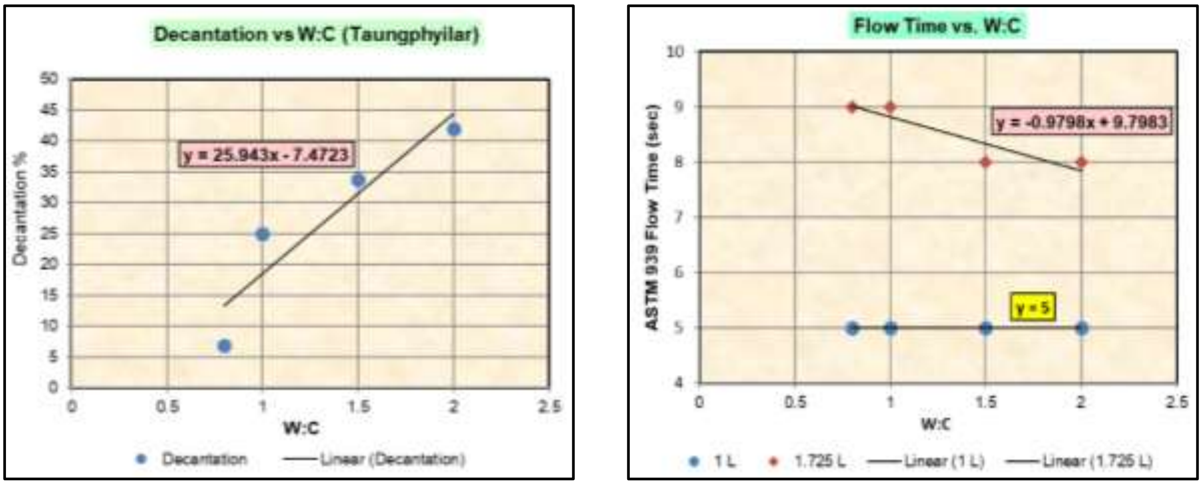

Figure (15) Trial grout mix results: W/C ratio vs. Decantation and Flow time for curtain grouting

Final Grout Mix Design

From the point of view of trial grout mix results, only unique mix was taken into account for the entire curtain grouting process. Thus, a single grout mix with a water/cement (W/C) ratio of 0.8~0.75:1 (by weight) as a “stable grout mix” was used for all stages regardless of the measured Lugeon value for the stages.

Target Lugeon

Based on the depth range measured from the RCC dam concrete and rock interface, the target Lugeon values for the curtain grouting was zoned at Upper Paunglaung dam. In the river section and middle portion (lower abutment), the target Lugeon values were defined ≤ 3 Lu for depth ≤40 m; ≤ 5 Lu for the depth between >40 m and ≤ 50 m; and ≤ 8 Lu for the depth > 50 m. In the upper abutment sections, the target Lugeon values were defined ≤ 5 Lu for the depth ≤ 40 m.

Grout Take Criteria

Deere (1976) created a simple classification system that is convenient to use for this purpose and for statistical purposes. According to

Table (**2**) grout take or cement take consumption classification (Deere, 1976), additional or quaternary/quintenary holes were decided to conduct where the grout takes are “moderate” or “greater” for the grouting stages. Target grout take consumption of curtain grouting at Upper Paunglaung dam was defined as 25 kg/m of grout hole.

Table (2) Cement take classification (after Deere, 1976)

Classification	Symbol	Actual grout takes (kg/m)
Very Low	VL	0 – 12.5
Low	L	12.5 - 25
Moderately Low	ML	25 - 50
Moderate	M	50 - 100
Moderately High	MH	100 - 200
High	H	200 - 400
Very High	VH	> 400

Lugeon Testing

The Lugeon tests were carried out the “downstage” technique. Table (3) describes the conditions typically associated with different Lugeon values, as well as the typical precision used to report these values.

Table (3) Condition of rock mass discontinuities associated with different Lugeon values (after Quiñones-Rozo, 2010)

Lugeon range	Classification	Hydraulic conductivity range (cm/sec)	Condition of rock mass discontinuities	Reporting precision (Lugeons)
<1	Very Low	$<1\times10^{-5}$	Very tight	< 1
1 - 5	Low	1×10^{-5} - 6×10^{-5}	Tight	± 0
5 - 15	Moderate	6×10^{-5} - 2×10^{-4}	Few partly open	± 1
15 - 50	Medium	2×10^{-4} - 6×10^{-4}	Some open	± 5
50 - 100	High	6×10^{-4} - 1×10^{-3}	Many open	± 10
> 100	Very High	$> 1\times10^{-3}$	Open closely spaced or voids	> 100

Water Flushing

Before testing of any stage, the section was thoroughly washed with clean water under pressure to remove all drill cuttings, rock chips, clay, slurry, and other debris. Flushing was carried out under surcharge pressure; the water flow was unrestricted and enough velocity to scour all the drilling detritus. This is particularly important those stages drilled with percussion drilling was being used.

Testing Procedure

Most of the Lugeon water pressure tests were carried out by using Japanese method. Consecutive tests of five (5) minutes were applied. The pressure is increased in three (3) to five (5) steps from the lowest pressure to the peak pressure and reduced again in steps to the lowest pressure. The pressure pattern was used as 2.0 kgf/cm^2 ⇔ 4.0 kgf/cm^2 ⇔ 6.0 kgf/cm^2 ⇔4.0 kgf/cm^2 ⇔ 2.0 kgf/cm^2.

Refusal Criteria

The grouting of any stage was considered as complete when one of the following conditions was achieved:

- If sudden stoppage occurs after three attempts when starting grouting of a stage.
- If grout takes decrease gradually and stop suddenly after one hour of normal grouting operation with any of the mixes and if the grouting pressure is near to the pressure limit P_L
- When the grout take for the stage is at a rate of less than 0.5 liter/m/min at the specified pressure for 15 minutes or more.

Controls of Curtain Grouting

All grouting contractor performed the following routine quality control tests during grouting operation to confirm the consistency of the grout:

- Temperature of mixing water and grout mix by thermometer
- Bleeding of grout by graduated cylinder (ASTM C940)
- Viscosity of grout by marsh cone funnel (API RP 13-B1) and Flow Cone (ASTM C939)
- Density of grout by mud balance (API RP 13-B1)
- Initial and final setting time by vicat needle (ASTM C191) or field cup test.
- Compressive strength test of grout samples in site Laboratory (ASTM C109/C109M-99).

The real time grouting process was continuously recorded by using digital grout flow meter. The parameters controlled for each stage are as follows:

- Actual working pressure P_G and duration of application [from t_1 to t_2]
- Actual grout flow rate “q”
- Total grouting duration T [based on begin and completion of a grouting stage]

Further, the volume “V” of grout mixed [in terms of kg of cement] and pumped to the particular stages in a grout hole was registered at the grout mixing plant. The overall grouting progress and the grout takes were recorded continuously by using digital grout flow meter and manual registered as double checking method.

During the curtain grouting operation, Lugeon test and grout injection were recorded by using digital grout flow meter with SD card and the records were manually registered.

Figure (16) Curtain grouting inside the foundation gallery at UPL dam

Data Analysis of Curtain Grouting

There are 27 blocks and 2 sub blocks at left abutment (LA) and right abutment (RA) from left to right for Upper Paunglaung RCC dam construction. Curtain grouting was performed inside the foundation gallery. Single row curtain grouting and split spacing method including both upstage and downstage methods were used in Upper Paunglaung RCC dam.

There are three curtain grouting zones such as upper portion (left and right abutments) and middle portion (lower abutment of left and right) and river section based on geological condition, grout curtain depth and hydrostatic pressure of impounded water. The results of all grout holes in respective dam blocks of those three zones were analyzed.

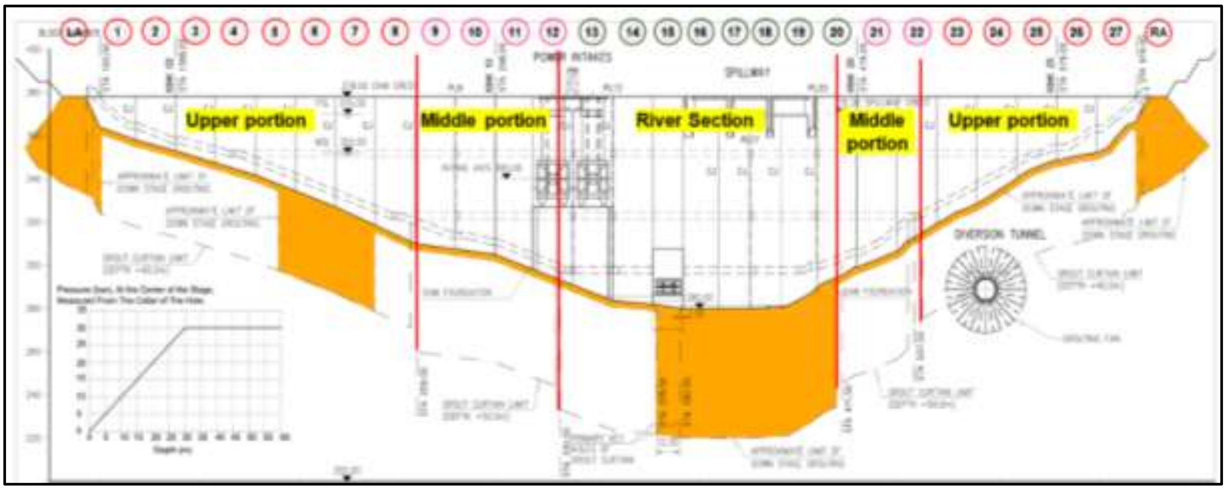

Figure (17) Curtain grouting zones along the dam axis

In curtain grouting at Upper Paunglaung RCC dam, grout mix design of water/cement (W/C) ratio of 0.75~0.8:1 (by weight) as a "stable grout mix" as well as "thick grout mix" was used. Lugeon values and cement takes of each grout hole order were recorded during the grouting process. Curtain grouting pressure was used by 1.0 bar/m depth up to 30 m depth and constant pressure was used for successive depths.

According to Quiñones-Rozo (2010) classification, discontinuity condition of Upper Paunglaung dam foundation rock mass based on the Lugeon results of primary holes shows that average 86% of dam foundation rock mass is “very tight to tight” condition with open discontinuities.

It is difficult to predict the grout penetration because it depends not only on the apertures of discontinuities/fractures, roughness and interaction with other sets of fractures, but also on the grout viscosity, pressure, and duration etc. Bozovic (1985) and Ewart (1985) concluded that the correlation between cement or grout take and Lugeon value is very weak.

In Upper Paunglaung dam, water was injected solely through applied pressure ranging from 2.0 to 6.0 bars during Lugeon permeability testing. For dam foundation grouting, curtain grouting pressures ranging from 1 to 30 bars were utilized. The maximum grouting pressure is five times the maximum pressure of the Lugeon test. Water and grout mix differ in fluid type and properties. The aperture of discontinuity conditions in the dam foundation rock mass varies from very tight to tight. A thick grout mix with a W/C ratio of 0.75~0.8:1 (by weight) was used in the grout mix design. These conditions reflect the relationship between cement or grout takes and Lugeon values for each grout hole order, as shown in Figure (18). The figure reveals that the Lugeon values and grout takes for each grout hole order are widely scattered, indicating a very poor correlation. Thus, it is not possible to establish a direct correlation, and predicting grout penetration based on Lugeon values becomes difficult. It is worth noting that Lugeon values prior to grouting may not provide a general indication of the cement takes during grouting. The finding aligns with the conclusions of Bozovic (1985) and Ewart (1985), who also determined that the correlation between cement or grout take and Lugeon value is very weak.

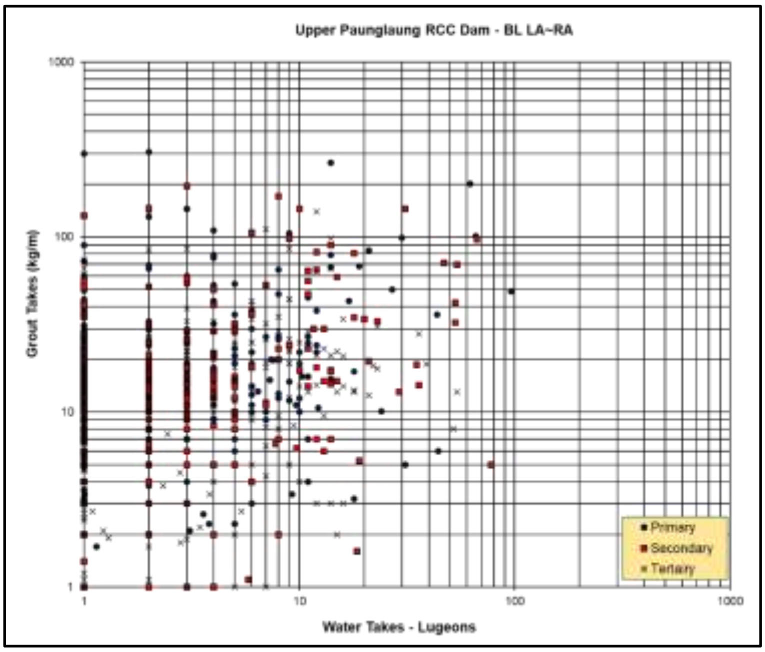

Figure (18) Grout take vs Lugeon value (all blocks)

The grout curtain efficiency was analyzed using frequency distribution analysis. In this analysis, the Lugeon values before and after grouting were considered from the results of the 1st order (primary) holes to the highest order holes. Grout takes before and after grouting were considered from the results of the 2nd order (secondary) holes to the last highest order holes. The analysis results reveal the grout curtain efficiency in the Upper Paunglaung dam, which is presented in Table (4). This table displays the frequency (%) of Lugeon and cement or grout take results before and after grouting, indicating the achievement of the target criteria for Lugeon values and cement or grout takes in each grouting zone and respective grout curtain depths.

Table (4) Efficiency of curtain grouting of each grouting zone

No.	Zone	Depth Range (m)	Before Grouting Lugeon	After Grouting Lugeon	Before Grouting Cement Take	After Grouting Cement Take
1	Upper Portion (Left Abutment)	≤40 m	80%	95%	85%	95%
2	Middle Portion (Left Abutment)	≤40 m	91%	96%	81%	100%
		40-50 m	90%	96%	81%	100%
		>50 m	100%	100%	100%	100%
3	River Section	≤40 m	37%	84%	81%	89%
		40-50 m	89%	90%	81%	95%
		>50 m	100%	97%	71%	89%
4	Middle Portion (Right Abutment)	≤40 m	77%	86%	86%	83%
		40-50 m	83%	100%	67%	92%
		>50 m	100%	100%	67%	100%
5	Upper Portion (Right Abutment)	≤40 m	95%	91%	84%	90%
	Target Achievement Percent	**(Average)**	**86%**	**94%**	**80%**	**94%**

Conclusion and Discussion

Curtain grouting was carried out in Upper Paunglaung dam construction. In this study, geological condition and geological model of dam foundation were made to ensure proper grouting design and grouting methods including determination of borehole inclination, hole arrangement and hole spacing, grouting depth and stage length, as well as grouting pressure. Then, the grout materials were tested to obtain grout mix properties and grout mix trials were made on site. Based on the results, proper grout mix design was chosen as a final grout mix design. Thus, a single grout mix with a water/cement (W/C) ratio of 0.8~0.75:1 (by weight) as a “stable grout mix” was used for all grouting stages. Considering the geological condition of the dam foundation, both the upstage and downstage methods were used in curtain grouting.

Target Lugeon values for the curtain grouting were established based on the depth range measured from the interface between the RCC dam concrete and the rock. The curtain grouting was conducted in accordance with the grouting specification. All grouting data were analysed in to evaluate the efficiency of the grout curtain in the dam foundation and to determine the correlation between Lugeon values and cement takes. According the analysis results, the correction between Lugeon values and cement take shows poor correction, however, the grout curtain efficiency was achieved 94% in average after grouting. Therefore, the application of curtain grouting in Upper Paunglaung dam was successfully completed.

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