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Foundation treatment of Isimba hydropower project

N.A. Rugaba
UEGCL, Kampala, Uganda

ABSTRACT: Uganda is currently implementing hydropower projects as a part of its Vision 2040 to increase electricity supply. The hydropower projects include dams/ reservoir retaining structures namely concrete and earth-rock fill dams. At Isimba Hydro Power Project (HPP), the reservoir is retained by concrete structures and two earth-rock fill embankment dams on both sides of the concrete structures. Isimba HPP adopted the use of the Earth Rock-fill Dam because of availability of suitable rocks for use in the embankment dam. The earth rock fill dam was founded on wide range of foundations namely engineering rock, completely weathered rock etc. Thus, foundation treatment is almost always required to improve a foundation to a suitable condition before a dam is constructed. The decision to grout is usually based on the results of water pressure tests (WPT) and it is assumed that the permeability can be reduced by means of grouting to the desired degree. This paper will discuss the various grouting techniques and methods used for dams on hydro-power projects, with widely varying foundation conditions. The key lessons shall be drawn from the grouting works on the earth Rock fill dams at Isimba HPP in Uganda, East Africa.

1 INTRODUCTION

The grouting activities over the foundation of the Isimba Right Embankment Dam (RED) were done in January 2018. Grouting works over the Left Embankment Dam (LED), Power House and partially over the RED were carried out between 2015 and October 2017. All grouting work activities were carried out by China International Water & Electric Corp, (CWE) the Engineering, Procurement and Construction (EPC) Contractor.

As part of the grouting works, the review of the grouting closure achieved in the RED embankment was required for confirming the adequacy of its foundation treatment, and for allowing the EPC Contractor to start placing the clayey fill in the dam core at the RED. The presence of sub-vertical rock joints along the dam axis originated several technical comments and warnings from the Client's team regarding the efficiency of vertical grouting holes to inject and fill properly these joints.

The specifications for curtain grouting were also revised by the Employer on the advice of the Owner's Engineer. Whereas initially 1 Lugeon was specified as the limit for permeability, so as to save time and cost, and also optimize the grouting operations, 3 - 5 Lungeon was later adopted for the curtain grouting works. It was further indicted that industry best practice for grouting works, adopts permeability values in the range of 3 - 5 Lungeon NOT the 1 Lungeon as had been specified by the project owner/ client.

The curtain grouting was carried out sequentially to achieve a predetermined standard of water tightness in the foundation rock. This required the successive halving of the predetermined spacing of the grout holes. This is called the split spacing method with primary, secondary and tertiary holes. Split-spacing means the system of locating an additional grout hole approximately midway between two grout holes which have previously been drilled and grouted. Primary holes are the first series of holes to be drilled and grouted, usually at the maximum allowable spacing. Secondary holes are the second series of holes to be drilled and grouted, spaced midway between primary holes.

2 GEOLOGICAL FEATURES

2.1 *Geological Mapping*

Extensive geological mapping was carried out along the dam's axis by the Engineering Procurement and Construction (EPC) Contractor during the grouting work activities. Geological mapping included the identification of rock types and discontinuities (i.e. joint sets and fractures) of the rock mass along the dam's axis. The collected geological information was used for assessing the inclination of the grouting holes (i.e. curtain holes, consolidation and contact holes) in the identified shear zones, as discussed below.

The bedrock over the Right Embankment Dam (RED) foundation is comprised of weathered granitic Gneiss and slightly weathered Amphibolite rocks. The Gneiss and Amphibolite rocks are interlayered and overlaid across the dam foundation with ridges and rock contacts following the northeast-southwest direction. In general, the quality of the rock mass improves with the depth from highly weathered rock to fresh rock.

2.2 *Rock Joint System*

Regarding the rock joint system, the rock joint sets were mapped over the RED foundation. Three main regularly spaced and extensive joint sets were identified in the rock mas. One joint set is typically parallel to the original rock structure, a second joint set is parallel to the foliation, and the third joint set represents the fracture surfaces in different directions. Figures 3 and 4 show the general joint system in the Amphibolite and Gneiss rocks respectively. The rock discontinuity data collected by the EPC Contractor over a key section/ shear zone (from Sta. D0+652.5 to Sta. D0+990) and was assessed and plotted in stereonets using the Rock Science's Dips Program. The assessment and plotting were done by the owner's engineer / consulting engineer. Average dip and dip direction of the rock mass is presented in **Error! Reference source not found.**

Table 1. RED Average Rock Joint Sets from Chainage D0+652.5 to D0+990 (CWE, 2018)

Joint Set ID	Preferred Joint Plane Orientations	
	Dip (°)	Dip Direction (°)
J_1	82^0	186
J_2	74^0	303
J_3	72^0	005

The stereographic analysis results are presented in **Error! Reference source not found.** and **Error! Reference source not found.**. The analysis indicate that the key joint structures are vertical to sub-vertical which suggest the use of inclined grout holes for the grout curtain. "Curtain grouting" means grouting of rock in one or more lines of holes spaced to form a curtain barrier.

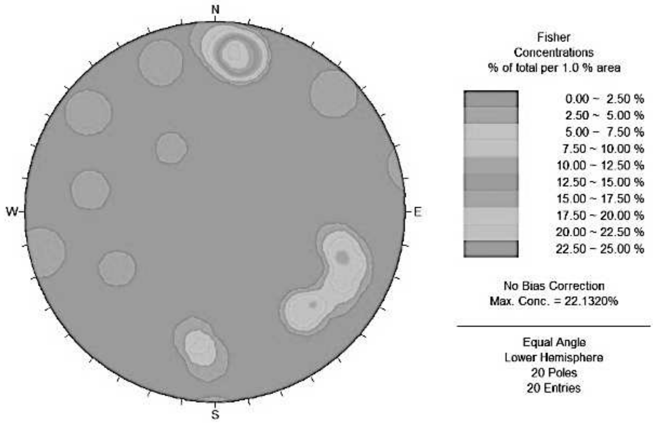

Figure 1. RED Rock Joints Pole Stereonet Plot

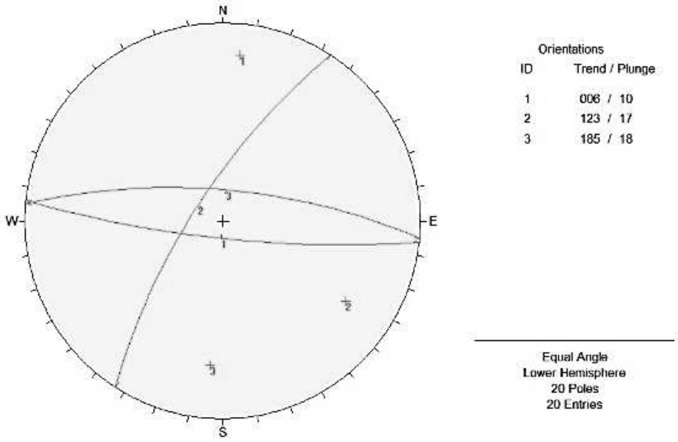

Figure 2. RED Rock Joints Plane Stereonet Plot

The rock jointing system is usually not formed by a single joint set. If primary rock joints are of first importance, other secondary or more joint sets with different orientation exist in the rock mass. This global rock joint configuration allows the grout to enter and fill the joints, since they are all interconnected.

Figure 3. RED Amphibolite Rock Joint Sets

Figure 4. RED Gneiss Rock Vertical Joint Sets

3 GROUTING WORKS

3.1 *Consolidation Grouting*

Consolidation grouting was carried out in the identified shear zones over the RED foundation using inclined grouting holes. Consolidation Grouting means drilling and grouting holes in a regularly spaced array over an area to specified depths to improve bedrock strength, deformability and permeability. However, vertical holes were used along the main grout curtain axis with no leakage or connections identified. According to the mapped joint sets, inclined holes are preferable for such vertical to sub-vertical discontinuities.

The grout curtain of the RED consisted of Primary (P), Secondary (S) and Tertiary (T) vertical grout holes spaced every 2m, as per design. "Primary holes" are initial grout holes drilled at suitable spacing before any grouting has taken place. "Secondary holes" are holes drilled midway between primary holes and parallel thereto. "Tertiary holes" are grout holes drilled midway between adjacent primary and secondary holes and parallel thereto. The depth of the grout curtain varies between 25 and 30 m into bedrock down to the 5 Lugeon Units (LU) limit estimated from previous geotechnical investigations.

Four main Shear Zones (SZs) were identified in the RED foundation during the geological mapping performed by the EPC Contractor and supervised by the Owner's Engineer. Consolidation grouting was carried out in inclined holes drilled 5 to 10 m into bedrock. The holes were located within 10 m downstream and 10 m upstream from the grout curtain's axis.

3.2 *Contact Grouting*

Some sections of the RED also required contact grouting. "Contact grouting" means drilling and grouting holes to any specified depth intersecting an existing rock / concrete or concrete / steel interface to produce an impervious contact. Contact grouting may also mean grouting the void remaining between concrete lining and rock in a tunnel. Contact grouting was carried out in the upper 5 to 7m rock intervals in all holes by installing the packers in the concrete slab (above the concrete / rock contact) with the packer's rubber bottom at about 0.6 m below surface. A packer-in grouting is a device inserted into a hole in which grout or water is to be injected which acts to prevent return of the grout or water around the injection pipe. The EPC Contractor carried out contact grouting only in the grout curtain holes (P, S, T holes) and within the identified shear zones, with no bypass, no holes and no leakage noted during grouting. In order to ensure and complete the contact grouting along the RED grout curtain, two additional rows of contact grouting holes were constructed. These additional grouting rows were located 1.5 m upstream (U/S) and downstream (D/S) from the main grout curtain's alignment.

3.3 *Curtain Grouting*

The Left Embankment Dam (LED) adopted curtain grouting as a part of the foundation treatment works. Curtain grouting means grouting of rock in one or more lines of holes spaced to form a curtain barrier. This method consists of drilling bore holes into the foundation bedrock at some regular spacing along a line or lines parallel to the dam axis and normal to the seepage flow direction. A bore hole is a hole of circular cross-section made in soil or rock.

According to Robin Fell et al. (2015), since rock substance is generally almost impermeable, the permeability determined in the water pressure test represents an indication of the number, continuity and opening of the rock defects which intersect the wall of the borehole in the test section. Curtain grouting is designed to create a narrow barrier (or curtain) through an area of high permeability. It usually consists of a single row of grout holes which are drilled and grouted to the base of the permeable rock, or to such depths that acceptable hydraulic gradients are achieved. For large dams on rock foundations, dams on very permeable rock or where grouting is carried out in soil foundations, 3, 5 or even more lines of grout holes may be adopted. The Left Embankment Dam adopted curtain grouting mainly for dam foundations on sound rock or slightly weathered rock including below the cut off wall. A single line of grout holes was adopted since this was appropriate to achieve the specified permeability parameter / Lugeon value of 1 Lu. The holes were drilled and grouted in sequence to allow testing of the permeability of the foundation (by packer testing) before grouting and to allow a later check on the effectiveness of grouting from the amount of grout accepted by the foundation ("grout take"). Grout take is the measured quantity of grout injected into a unit volume of formation, or a unit length of grout hole. Grout is a mixture of cementitious or non-cementitious material, with or without aggregate, to which sufficient water or other fluid is added to produce a flowing consistency.

The grout holes / boreholes were drilled using percussion drilling - a drilling technique that uses solid or hollow rods for cutting and crushing the rock by repeated blows. Percussion drilling methodology that was applied used hollow steel pipes that allow for rock core recovery to be utilised in the logging of the geological profile of the dam foundation along the dam axis. The employer specified drilling of boreholes by use of either percussion drilling method or rotary type diamond drilling. The EPC Contractor utilized the percussion drilling method since it is more economical. As argued by Fell et al. (2015) grout holes should always be oriented and or inclined so as to intercept the major fractures in the rocks and as many discontinues in the rock foundation. The Employer Requirements for Isimba HPP further specified that check holes should be inclined too, to assess the effectiveness of the grouting works.

After the drilling of the boreholes, they are washed to remove any cuttings that may have clogged the rock fractures around the sides of the hole. The borehole is then water pressure tested to establish the rock mass permeability prior to grouting. Pressure testing is a method of testing the permeability of rock mass using water or grout pumped down hole under pressure. The water pressure test is carried out using pressure testing equipment, water and a packer. A packer-in grouting is a device inserted into a hole in which grout or water is to be injected which acts to prevent return of the grout or water around the injection pipe. It is usually an expandable device actuated mechanically, hydraulically, or pneumatically. The results from the water pressure testing are indicated by a Lugeon value.

4 CONCLUSIONS

All earth and rock-fill dams are subject to seepage through the embankment, foundation, and abutments. However, it is also evident from geological investigations and tests that the permeability of compacted earth fill core materials is far less permeability (< 10 - 8m/ s) compared to the permeability of rock foundations. As argued by Fell et al. (2015), nearly all rock foundations have rock mass permeability greater than 1 Lugeon, and most rocks have permeability greater than 5 Lugeon. It is clear that most seepage occurs through the foundation not the embankment itself. However. Seepage control is necessary to prevent excessive uplift pressures, sloughing of the downstream slope, piping through the embankment and foundation, and erosion of material by loss into open joints in the foundation and abutments.

The purpose of the project, i.e., long-term storage, flood control, etc., may impose limitations on the allowable quantity of seepage. Although the foundation is not actually designed, certain provisions for treatment are made in designs and specifications to ensure that the essential requirements are met. The foundation treatment for embankment dams requires an array of considerations that range from geological and geotechnical expertise to engineering judgment based on experience. A detailed foundation treatment program that includes designs, technical specifications, construction and grouting procedures is critical to sound foundation treatment for dams to ensure dam stability and seepage control.

5 REFERENCES

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