ASSESSMENT OF SEEPAGE THROUGH SUBSOIL OF HIDKAL DAM, KARNATAKA AND REMEDIAL MEASURES

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ABSTRACT

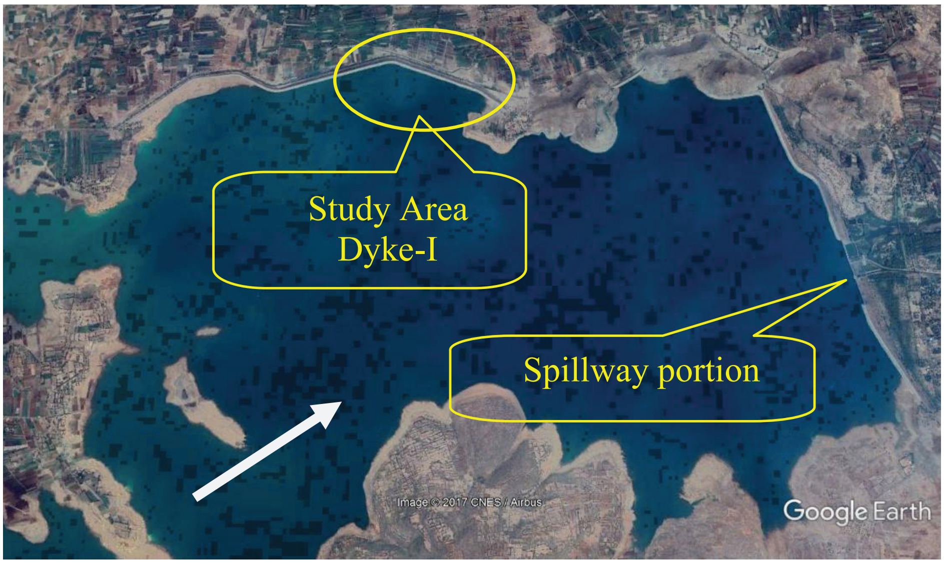
Hidkal (Raja Lakhamgowda reservoir) dam situated near Hidkal in Hukkeri taluka of Belgaum district, Karnataka was constructed in 1974 across the river Ghataprabha, a tributary of river Krishna. The dam is a 53.34 m high and 4481 m long composite dam with 149.35 m long concrete spillway and two earthen Dykes – (I and II) of length 5227 m and 506 m respectively. A reservoir gross storage capacity is 51.16TMC. The FRL and MDDL of the dam are 662.94 m and 633.83 m respectively and excessive seepage on the downstream side at the end stretch of Dyke-I is predominant when the reservoir level rises above 655 m. In order to minimize foundation seepage, rock cores were examined and permeability tests were carried out in the drilled holes. The permeability values varied from 26 to 498 Lugeons. Curtain grouting up to a depth of 15m from Ch. 5100 to 5330 m in five rows 1.5 m apart was recommended. After carrying out the curtain grouting, Post grouting permeability tests at Hidkal dam dyke-1 were conducted at chainage 5273.75, 5248.75, 5223.75, 5198.75, 5173.75, 5148.75, 5123.75, 5098.75 and 5073.75 of 9 nos. NX bore holes. Reduction in the Lugeon values were observed (i.e. between 0.0 to 10), satisfactory. The top 4 m strata consist of weathered medium grained granite in between with soil layers with very poor core recovery. So it was difficult to grout without applying high pressures. The application of high pressure is not possible at initial stages of borehole. So the top 3 m portion was removed to fill the same with impermeable black cotton soil.

Keywords: *Permeability, Pre-grouting, Post grouting, Lugeons values, Curtain grouting.*

1. INTRODUCTION

Hidkal (Raja Lakhamgowda dam reservoir) situated near Hidkal in Hukkeri taluka of Belgaum district, Karnataka (latitude 16˚ 18′ North and longitude 74˚ 38′ East). It was constructed in 1974 as a part of Ghataprabha Project of Karnataka Neeravari Nigam Limited across the river Ghataprabha, a tributary of river Krishna to provide irrigation to 3, 31,000 hectares of land in Belgaum, Bagalkot and Bijapur districts of Karnataka and also to generate 32 megawatts of hydro power. The important features of the 53.34 m high dam are: 4481 m long composite dam with 149.35 m long concrete spillway, two earthen Dykes–I and II of length 5227 m and 506 m respectively and a reservoir with a gross storage capacity of 51.16 TMC. The FRL and MDDL of the dam are 662.94 m and 633.83 m respectively. Excessive seepage on the downstream side at the end stretch of Dyke-1 was predominant when the reservoir level rises above 655 m. Based on the report of the hydro-geological studies conducted by CWPRS during 1994 and 1996 and suggestions of the technical advisory committee of Karnataka Government, the seepage zone was delineated between Ch. 4050 to 5330 m along the downstream toe of Dyke-I. A view of the entire Ghataprabha Project showing the location of the Dyke-1 based on the satellite imagery Earth is shown in Imageries 1.

In order to provide remedial measures to prevent foundation seepage, CWPRS has recommended curtain grouting on the upstream side of Dyke-1 near heel line for the zone vulnerable for seepage. The procedure adopted for preventing the seepage from foundation is (a) initially permeability tests are carried out in the trial boreholes. The recovered material from the boreholes was examined. (b) The permeability values and examined borehole strata features decided the severity of seepage through foundation and further to decide rows and spacing of the curtain grouting. (d) Post grouting permeability tests are also carried out in the new locations of the study area.



Imageries 1. View of the entire Ghataprabha Project showing the location of the Dyke-1.

2. SCOPE

In order to provide remedial measures to prevent foundation seepage, CWPRS has recommended curtain grouting on the upstream side of Dyke-1 near heel line for the zone vulnerable for seepage. The procedure adopted for preventing the seepage from foundation is a) initially permeability tests are carried out in the trial boreholes and the recovered material from the boreholes are examined. In this the scope of work involves making NX size (54 mm dia.) inspection holes at 50 m c/c spacing between chainage 4050 m to 5330 m from top of the dam to the foundation and further extending 10 m deep in the rock strata. The total depth of borehole will be height of the dam strata plus 10 m deep in the foundation rock. During making of the boreholes, permeability of the strata was assessed. After studying the permeability test results and recovered cores, the remedial measures in the form of curtain grouting was suggested. B) The outcome of permeability test and examined bore hole material was used to decide the number of rows and spacing of the curtain grouting. In this the spacing and depth of the curtain grouting holes and number of grout lines will be determined after the completion of the studies of the inspection holes. D) Post grouting permeability tests are also carried out in the new locations of the study area. In this after the curtain grout work is completed, than its efficacy was checked again by carrying out the permeability tests by making new inspection holes. Permeability test conducted before grouting, grouting details and post permeability test results are presented in this paper.

3. LITERATURE SURVEY

Lopez-Molina, Valencia-Quintanar & Espinosa-Guillen (2015) stated that the design and implementation of grouting treatments in rock masses are procedures that require continuous adjustment of parameters and criteria to optimize the results. In this proposal we describe a set of tools that enhance decision-making for this type of jobs particularly in dam projects. The methodology is focused on hydrogeological zoning of the site and its constant update combining engineer's experience with artificial intelligence techniques to integrate the site knowledge; as well as the evaluation of grouting results for different scrutiny scales, with special attention on the relationship between water absorption and grout consumption.

Singh, Dev & Vidyarth (2011) this paper deals with quality control assurance of the grouting operations (contact/consolidation) and permeability tests carried out in head race tunnel (HRT) of Tala Hydroelectric Project in Bhutan. Efficacy of grouting was determined by conducting permeability tests before and after consolidation grouting. Contact grouting is done to fill the cavities/voids between concrete and rock mass on account of shrinkage of concrete and uneven over breaks. Consolidation grouting is done to strengthen the surrounding rock mass by filling up the open joints, fissures, cracks etc. Proper grouting of surrounding rock mass around the opening helps in monolithic behavior of the rock mass. The quality assurance during grouting was ensured by checking the properties of all materials being used and by conducting permeability tests in pre/post grouting stage.

Bidasaria (2004) concludes that curtain grouting is an important component of foundation treatment of dam and other hydraulic structures. The purpose of curtain grouting is to form a zone of low permeability up to a designed depth on the upstream of the dam. This grout curtain along with downstream drainage system controls the uplift pressure and piping which are potential hazards. The present case study deals with providing grout curtain to Almatti masonry dam from Block No. 1 to 52. Besides curtain grouting this case study also deals with the treatment of weak zone (unconformity zone) of thickness up to 6 m, which was existing in the foundation from Block No. 45 to 52 below the joint of base granite rock and overlying quartzite foundation. The single line grout curtain of permeability less than 3 Lugeon has been effectively formed below the foundation, despite very poor strata having maximum pre-grout permeability of 90 Lugeon.

Above all researcher deals with the various researches associated with the concrete gravity dam and cement grouting which has been performed earlier, in this paper also remedial measure to prevent foundation seepage, CWPRS has recommended curtain grouting on upstream side of Dyke-1 near heel line for the zone vulnerable for seepage.

4. GEOLOGY

It was observed that the principal rock formation at the upstream as well as on the downstream side of Dyke-1 is weathered basalt, though stretches of quartzite at depths has also been encountered. The rock mass was found to have undergone various degrees of weathering and disintegration from ground level to depths ranging from 0.6 m to 20 m. After inspecting the rock cores and the permeability test results at the Ch. 4050 to 5330 m, it was observed that core recovery was very poor and the strata was not improving even at depth of 15 m as shown in Figure 1. So, it was suggested to the Project Authorities to arrange to drill the inspection bore holes up to 20 m depth from Ch. 5100 to Ch. 5330 m. All the cores were inspected as per the core logs prepared by the site geologist. The layout of investigation hole of Dyke-1 of Hidkal dam is given in Figure 2 and the details of Borehole data of Dyke-1 of Hidkal dam are shown in Figure 1.

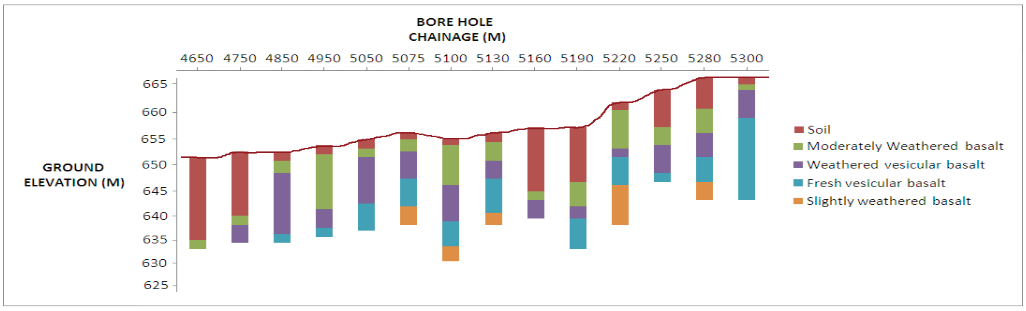


Figure 1 : Borehole data of Dyke-1 of Hidkal dam

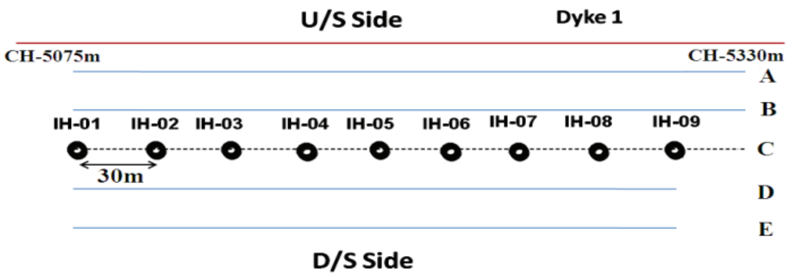


Figure 2 : Layout of investigation hole of Dyke-1 of Hidkal dam

5. PERMEABILITY TESTS

Grouting pattern was decided by visual examining of the cores and core recovery from bore holes, water percolation tests with packers were conducted at each bore hole. The permeability values thus obtained were influenced by the quality of rock mass coupled with the presence of cracks, fissures, joints, cavities etc. at different depths and were fairly accurate to provide an approximate estimation of possible leakage through embankment and foundation after impoundment of reservoir.

In-situ permeability tests were conducted in the drilled holes, starting from the foundation rock mass in a stage wise fashion using `Pumping in' technique. In this method, water was pumped under pressure into the test section defined by position of packer in bedrock in drill holes as per IS 5529 (Part II). For each of the boreholes the tests were conducted in the uncased sections, bottom upward. Double packer test assembly of 54 mm diameter with length of test section as 1.5 m between packers was used for the test. Suitable water pump, pressure gauge and water meter were used for testing. Groundwater table was recorded before proceeding for a test. The tests were based on measuring the amount of water consumed in the test section of the borehole confined by packer/packers while the water is pumped into it under pressure. The tests were conducted applying by three different pressures viz. 1/3 of total pressure, 2/3 of total pressure and total pressure, for testing the rock portion. Each pressure was maintained until the reading of water intake at intervals of 5 minutes show a nearly constant reading of water intake for one particular pressure at the collar. Process for conducting permeability test on site is shown in Photo1 & 2.

Photo 1 : 54 mm dia. Drilling work in progress, **Photo 2** : In-situ permeability test in progress

6. GEOTECHNICAL INVESTIGATIONS OF THE STRATA

Geotechnical investigations of the strata were conducted from chainage 5075 to 5330 m in nine numbers NX size boreholes. The physical properties of strata were identified and permeability test conducted at upstream side of the Dyke-1. Studies were carried out to determine the permeability for three different pressures viz. 1/3 of total pressure, 2/3 of total pressure and total pressure of the strata at Dyke–I of Inspection Holes. The water pressure for permeability tests were taken equivalent to depth of the packer multiplied by the density of the strata. The results of the strata and permeability test conducted are summarized in Table 1.

7. CURTAIN GROUTING OF THE FOUNDATION STRATA (USBR, 2014).

7.1 Grout Curtain Design

7.1.1 Grout *Curtain Location*

For a zoned embankment dam with a central impervious core, the grout curtain is typically located slightly upstream of the midpoint of the base of the impervious core material. The final location of the grout curtain should be based on the type of dam, the configuration of the impervious portion of the dam, seepage gradients, and the geologic conditions below the dam. Some general guidelines for locating a grout curtain, which should be consistent for any embankment dam design, include:

- If the grout curtain is placed closer to the upstream toe of the core, then high gradients may exist from the embankment core into the foundation.
- If the grout curtain is placed closer to the downstream toe of the core, then high gradients may exist from the foundation into the core.
- The location of the grout curtain should be at or upstream of the dam centerline.

7.1.2 *Curtain Depth*

Unless special geologic conditions dictate, general practice for modern Reclamation dams is to extend the primary grout holes to a depth below the surface of the rock equal to about 0.5 to 1.0 times the reservoir head, which lies above the surface of the rock. The selected design depth for the grout curtain should be based on the geology, regional groundwater conditions, permeability test results, potential failure modes and seepage analyses. In many cases, the curtain depth may vary across the damsite, depending on the damsite's geologic conditions.

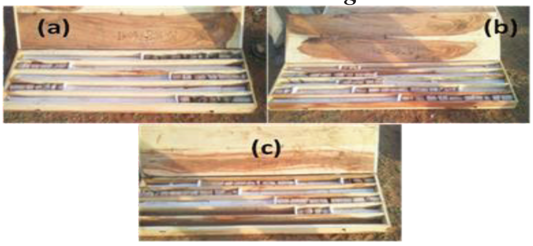
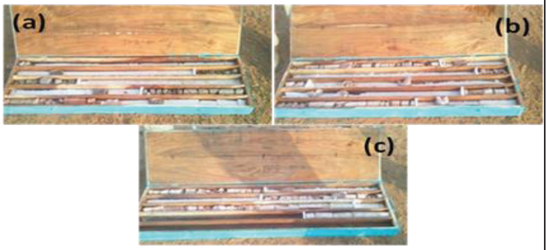
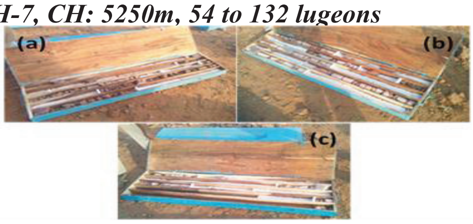
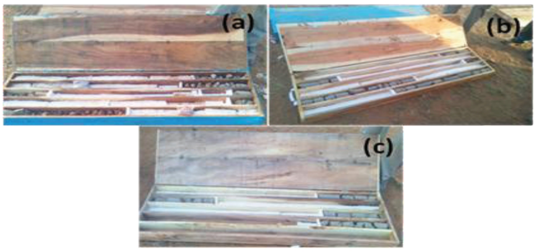
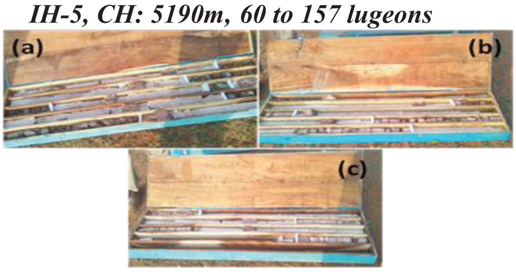
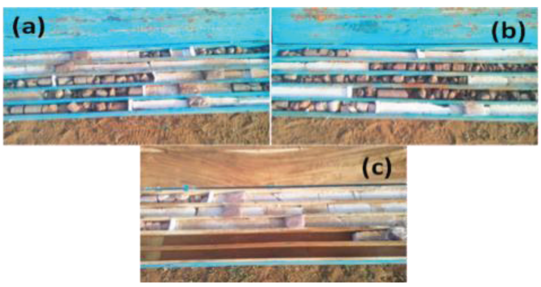
7.1.3 *Injection Pressure*

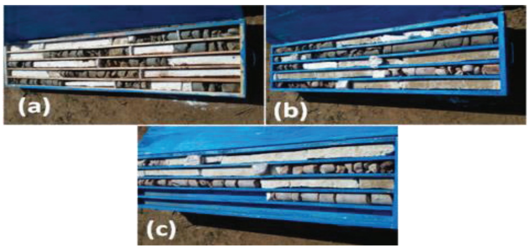
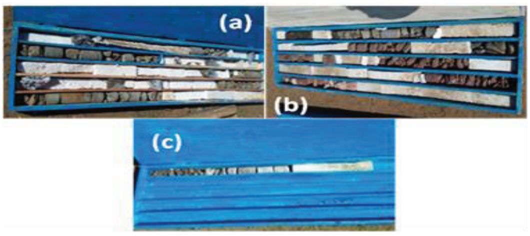
Reclamation practice is to inject the highest quantity of grout at the allowable injection pressure without causing uplift, horizontal movement, fracturing, rupturing, and excessive grout travel. Reclamation typically uses a maximum injection pressure of 0.23 kg per square cm per meter of depth measured from the surface to the packer, plus back pressure due to artesian water flows. Adjustments are made to the maximum injection pressure, if necessary, based on the results of the preconstruction geologic investigations, engineering analyses, the behavior of the rock mass during water testing and grouting, and the results of the grouting program.

7.1.4 *Grouting Methods*

Methods of grouting commonly used by Reclamation include single-stage, upstage, or downstage grouting.

Table 1 : Showing the details of bore log and permeabilty values.

Details of borelogs, permeability values	Description of borelogs
IH-9 CH:5300 26 to 262 lugeons 	➢ 0 to 1 m- soil layer ➢ 1 to 2 m- slight to moderately weathered medium grained granite rock ➢ 5 to 6.5 m- soil layer with grayish to pinkish colour of return water was found ➢ up to depth 20 m - weathered medium grained pinkish granite rock
IH-8, CH: 5280m, 62 to 130 lugeons 	➢ 0 to 5 m- soil layer with in between slight to moderately weathered medium grained granite with grayish colour of return water ➢ 1 to 2 m- slight to moderately weathered medium grained granite rock ➢ 5 to 6.5 m- soil layer with grayish to pinkish colour of return water was found ➢ up to depth 20 m - weathered medium grained pinkish granite rock
IH-7, CH: 5250m, 54 to 132 lugeons 	➢ 0 to 3 m soil layer with grayish colour of return water ➢ 3 to 4.5 m weathered medium grained pinkish grey granite rock ➢ 4.50 m to 15.0 m weathered Medium grain grey granite ➢ 15.0 to 20.0 m weathered medium grained pinkish granite
IH-6, CH: 5220m, 50 to 498 lugeons 	➢ From top to 1.2 m depth. The core log shows up to 1.5m soil layer with black pebbles ➢ From 7.5 to 9 m slight to moderately weathered medium grained granite with pinkish colour is found. ➢ From 9 to 13.5 m soil layer with reddish colour of return water.
IH-5, CH: 5190m, 60 to 157 lugeons 	➢ Up to 9.0 m slight to moderately weathered medium grained granite rock ➢ 9 to 13 m and 14.5 to 15 m there was a soil layer with pinkish colour of return water
IH-4, CH: 5160m, 54 to 203 lugeons 	➢ 0 to 3 m soil with a layer of slight to moderately weathered medium grained granite in between soil with whitish colour of return water. ➢ 3 to 7 m there was slight to moderately weathered medium grained granite with grayish colour. ➢ 7.5 to 12 m slight to moderately weathered medium grained granite with grayish colour is obtained. ➢ 12 to 13.5 m there was slight to moderately weathered medium grained granite with pinkish colour is found. ➢ 13.5 to 15 m there was slight to moderately weathered medium grained granite with whitish colour is obtained. From 15 to 18 m there was slight to moder-

	ately weathered medium grained granite with pinkish ➢ Colour was found 18 to 20 m slight to moderately weathered medium grained granite with pinkish to whitish colour is found.
IH-3, at CH: 5130m, 60 to 147 lugeons 	➢ Top 1.5 m soil with a layer of weathered medium grained granite in between soil. ➢ 1.5 to 4.5 m slightly to moderately weathered medium grained granite. ➢ 5 to 7.5 m slightly to moderately weathered medium grained granite grayish colour. ➢ 7.5 to 11 m there is slightly to moderately weathered medium grained granite with pinkish colour shade is obtained. ➢ 12 to 13 m a soil layer is found. ➢ 13 to 14.5 m there is slightly to moderately weathered medium grained granite. ➢ 14.5 to 15 m there is soil layer with reddish colour of return water.
IH-2, at CH: 5100m, ≥ 60 lugeons 	➢ 1m soil layer. ➢ 1 to 7.5 m-slight to moderately weathered medium grained granite with whitish colour. ➢ 7.5 to 10.5 m slight to moderately weathered medium grained granite with whitish colour. ➢ 10.5 to 13.5 m-slightly weathered medium grained granite with reddish colour. ➢ 13.5 to 15 m colour gradually changes from pinkish to red colour ➢ 15 to 15.5 m slightly weathered medium grained granites reddish to pinkish colour. ➢ 15.5 to 17.5 m soil layer with pinkish to white colour of return water. ➢ 17.5 to 18.5 m slightly weathered medium grained granite ➢ 18.5 to 20 m slightly weathered medium grained granite
IH-1 at CH: 5075m, ≥ 60 lugeons 	➢ Up to 1 m soil layer. ➢ 1 to 2 m soil layer with slight to moderately weathered medium grained granite rock. ➢ 2 to 3 m slight to moderately weathered medium grained ➢ 3 to 6.5 m soil layer with slight to moderately weathered medium grained granite. ➢ 6.5 to 9 m slight to moderately weathered medium grained granite. ➢ 9 to 16 m slightly weathered medium grained granite with pinkish to deep pinkish colour.

(a) ***Single-Stage Grouting***

Single-stage grouting consists of drilling the hole to full depth, washing the hole, water testing, and grouting the hole in one stage. This method should be limited to grouting shallow holes (± 6 meter) in relatively sound rock with no major surface leaks.

(b) ***Upstage Grouting***

Packers permit grouting of predetermined stages at any depth. Upstage grouting consists of drilling the hole to full depth, washing the hole, setting the packer within the drill hole at the top of the lowest stage level, water testing, and grouting the stage. Grouting of additional stages in the drill hole is performed upward using packers. Once refusal is reached on a stage, reclamation practice is to proceed to water testing and grouting the next stage immediately. The Schematic diagram of grouting process is shown in Figure 3 and the grouting equipment's used on site are shown in Photo 3.

Photo 3 : (a) Mixing of cement with water (b) Developing pressure for grouting (c) grouting location

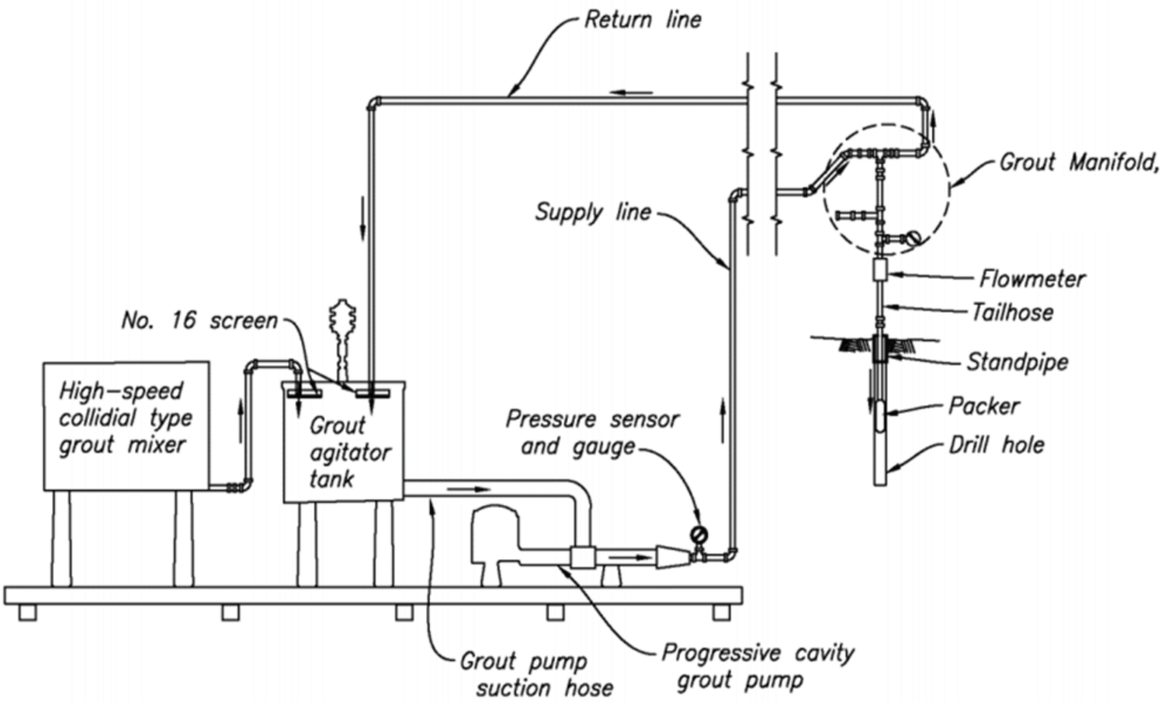


Figure 3 : Schematic diagram of grouting (USBR, 2014).

Curtain grouting was carried out from chainage 5067 m to 5330 m in five rows of boreholes. Row spacing was 1.5 m and grouting pattern are shown in Figure 4. The cement intakes for different chainages are given in Table-2.

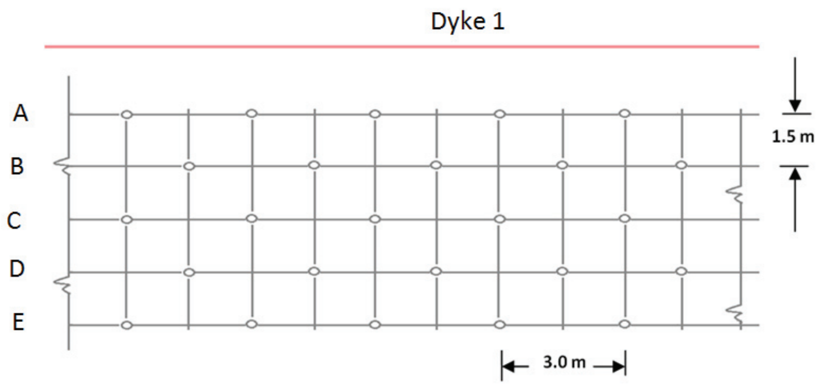


Figure 4 : Sketch showing grouting pattern

Table 2 : Cement consumption details for grouting from Ch. 5067 to 5330 m at Dyke-1.

Sl. No	Chainage (m)	Row No.	Total No. of grouted holes	Net Depth of grouting (m)	Cement grout in kg	Cement consumption in Kg/m
1	5067.5-5100.5	A	11	159.50	7767.06	48.70
		B	11	159.50	6703.62	42.03
		C	11	145.0	6310.07	43.52
		D	11	157.0	7078.26	45.08
		E	11	159.50	9211.92	57.75
2	5100.5-5150	A	17	246.50	11642.99	47.23
		B	17	246.50	11113.40	45.08
		C	19	246.50	10779.64	43.73
		D	17	246.50	10436.87	42.34
		E	17	246.50	12300.81	49.90
3	5150-5201	A	17	250.50	9604.34	38.34
		B	17	246.50	9118.71	37.00
		C	17	250.50	9534.10	38.06
		D	17	250.50	9841.50	39.29
		E	17	250.50	10782.74	43.04
4	5201-5250.5	A	16	296.00	7592.46	25.65
		B	17	314.50	8173.06	25.99
		C	16	296.00	7000.42	23.65
		D	17	314.50	8907.57	28.32
		E	16	296.00	7026.42	23.74
5	5250.5-5300	A	17	314.50	8711.64	27.70
		B	16	286.50	7668.59	26.77
		C	18	323.50	6,806.51	21.04
		D	16	296.00	6396.24	21.61
		E	17	314.50	7961.90	25.32
6	5301.5-5330	A	10	185.00	5968.80	32.26
		B	10	185.00	5300.17	28.95
		C	10	185.00	5942.13	32.12

8. POST GROUTING PERMEABILITY TEST

In order to check the effectiveness of the grouting, post grouting permeability tests were carried out in the center of the grouted holes, at chainages 5073.75, 5098.75, 5123.75, 5148.25, 5173.5, 5198.75, 5223.75, 5248.5, 5273.5 m (Figure-5) in the grouted portion for the entire depth of the boreholes.

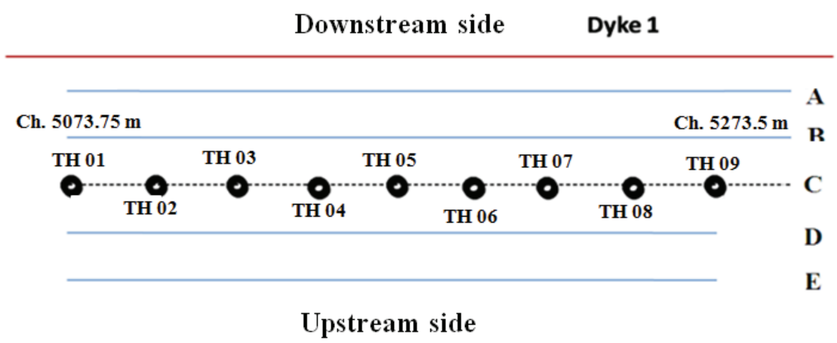


Figure 5 : Sketch showing post-grouting locations

To know the effectiveness of the grouted strata and to supplement the information obtained by visual examination of the cores and core recovery from bore holes, water percolation tests with packers were conducted at each bore hole. The permeability values thus obtained were influenced by the quality of grouting to provide an approximate estimation of reduction in seepage through foundation of Dyke-1 on impoundment of reservoir. Post grouting permeability test results are further useful indices to decide the effect of grouting and requirement of any change in the spacing of the grouted holes.

In-situ permeability tests were conducted in the foundation rock mass in a stage wise fashion using `Pumping in' technique in which the water was pumped under pressure into the test section in bedrock in drill holes as per IS 5529 (Part II). For each of the boreholes the tests were conducted in the uncased sections, bottom upward. Double packer test assembly of 54 mm diameter with length of test section as 3.0 m between packers, suitable water pump, pressure gauge and water meter were used for testing. Groundwater table was recorded before proceeding for a test. The tests were based on measuring the amount of water accepted by the test section of the borehole confined by packer/packers while the water was pumped into it under pressure. A maximum pressure of 0.25 kg/cm2 per meter of rock cover with three different pressures viz. 1/3 of total pressure, 2/3 of total pressure and total pressure was applied for testing the grouted rock portion. The amount of test pressure was applied for testing already grouted portion of rock mass, so that rock stratum is not disturbed. Each pressure are maintained until the reading of water intake at intervals of 5 minutes show a nearly constant reading of water intake for one particular pressure at the collar.

After completion of curtain grouting work, post grouting permeability tests were carried out in the new locations of the study area for checking its efficacy of grouted work. Post grouting permeability tests were conducted in 9 number locations and the details are shown Table -3.

Table 3 : Permeability test results after grouting at the downstream side of Dyke-1

Bore Hole	Chainage (m)	Stage (m)	Permeability (Lugeon)	Type of Flow
TH01	5073.75	02/05	42.10	--
		04/07	8.50-14.55	Laminar
		07/10	2.79-5.13	Turbulent Laminar
		10/13	0.64-1.28	Laminar
		13/16	0.00-1.04	--
TH02	5098.75	02/05	0.00-0.00	--
		04/07	0.00-0.00	---
		07/10	0.00-0.00	--
		10/13	0.00-0.00	---
		13/16	12.38-30.96	Hydraulic Fracture
TH03	5123.75	02/05	10.38-17.54	Void Filling
		04/07	2.43-7.27	Void filling
		07/10	2.09-5.12	Laminar Flow
		10/13	7.69-10.26	Hydraullic fracture
		13/16	0.00-1.02	Laminar flow
TH04	5148.25	02/05	16.15-35.08	Turbulent flow
		04/07	0.00-0.41	Dilation
		07/10	0.00-0.00	Nil
		10/13	1.28-1.28	Laminar
		13/16	0.00-0.18	Zero
TH05	5173.5	02/05	13.31-24.56	Laminar
		04/07	1.23-2.46	Laminar
		07/10	6.16-10.25	Turbulent
		13/10	5.76-7.69	Laminar
		16/13	0.00-0.00	Nil
TH06	5198.75	3.5/6.5	25.77-50.66	Turbulent
		6.5/9.5	0.90-1.80	Laminar
		12.5-9.5	0.00-0.44	Dilation
		12.5-15.5	0.00-0.00	Nil
		18.5-15.5	0.45-0.90	Dilation

TH07	5223.75	04/07	1.21-4.93	Void filling
		07/10	1.68-2.53	Laminar
		10/13	0.00-0.00	Nil
		13/16	0.00-0.00	Nil
		16/19	0.00-0.29	Dilation
TH08	5248.5	03/06	11.90-17.59	Turbulent
		05/08	3.22-4.30	Laminar
		08/11	0.00-0.00	Nil
		11/14	0.00-2.42	Void filling
		14/17	0.00-0.00	Nil
		20/17	0.00-0.28	Laminar
TH09	5273.5	05/08	0.00-2.15	Laminar
		08/11	1.55-7.17	Dilation
		11/14	0.61-2.40	Laminar
		14/17	0.00-1.00	Laminar
		20/17	0.00-1.73	Laminar

From the table, it is observed that Lugeon values in inspection Bore Holes TH-01, TH-03, TH-04, TH-05, TH-06, TH-07, TH-08 and TH-09 were found to be satisfactory except hole no. 2 (TH2) of chainage 5098.75 m of stage I (i.e. from 13 to 16 m), where the Lugeon values are found to be between 12 to 31, which are on higher side. To reduce the Lugeon value in that area, regrouting work was carried out between lines BC and CD at an interval of 3 m. 3 number holes on each side of the borehole no. 2 of chainage 5098.75 m are also drilled and grouted (Figure - 6)

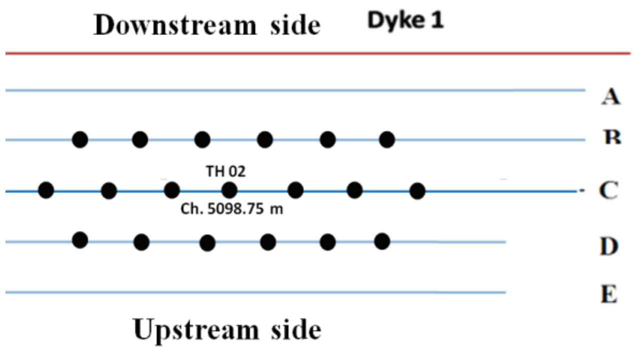


Figure 6 : Sketch showing re-grouting locations at Ch. 5098.75 m

9. DISCUSSION & RECOMMENDATIONS

The Permeability value of a test section of the borehole are expressed in 'Lugeon', which is defined as the water loss of one liter per minute per meter length of drill hole under a pressure of 1 MPa maintained for about 10 minutes in the drill hole.

Post grouting permeability tests at Hidkal dam dyke-1 were conducted at chainage 5273.75, 5248.75, 5223.75, 5198.75, 5173.75, 5148.75, 5123.75, 5098.75 and 5073.75 of 9 nos. NX bore holes. Overall Lugeon values are found to be satisfactory except hole no. 2 (TH2) of chainage 5098.75 m of stage I (i.e. from 13 to 16 m), where the Lugeon values are found to be between 12 to 31, which are on higher side. To reduce the Lugeon value in that area, regrouting work was carried out between lines BC and CD at an interval of 3m. 3 number holes on each side of the borehole no. 2 of chainage 5098.75 m are also drilled and grouted.

The permeability of the strata at the initial stages of the borehole was found to be higher. The top 4 m strata was weathered medium grained granite in between with soil layers with very poor core recovery. So it becomes difficult to grout without applying high pressures. The application of high pressure is not possible at initial stages of borehole. So the top 3 m portion is to be removed to fill the same with impermeable black cotton soil.

At many places the initial values of permeability of the strata before grouting are greater than 100 lugeon. It is obvious that initially high permeable sections are effectively grouted, whereas low permeable sections are less or not effectively grouted. Initial low rock permeability may not vary or improve in the zones of low grout intake.

The installation of grout curtains in the pervious strata results in significant improvements only if these curtains are tied into impervious rock members at a reasonable depth. The grouting was carried out up to 20 m depths to reach to hard stratum. The bed of reservoir from chainage 5000 m to 5330 m is sloping upwards, so hard stratum depth is also increasing. Grout curtains lengthen the seepage path and offer increased resistance to seepage. The primary function of the grout curtains is to intercept and fill water passages. The efficiency of the grouting can be evaluated quantitatively by the comparison of calculated seepage discharges before grouting and after grouting. As per the physical inspection, quantity of seepage has to reduce after grouting, which has to be assessed by regular measurements of seepage water. There is significant improvement in post grouting permeability values (Table-3) as compared to the values prior to grouting.

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