BE CIVIL ENGINEERING

PROJECT REPORT

Geotechnical and Seepage Analysis of Khanpur Dam and Recommended Measures for its Safety

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

Submitted By

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This is to certify that the BE Civil Engineering Project titled

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Has been accepted towards the partial fulfillment of the requirements for

Bachelor of Engineering in Civil Engineering Degree

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Colonel

Nawab Ali Dogar

Department of Geotechnical Engineering

DEDICATED TO

OUR PARENTS, TEACHERS & WELL-WISHERS

ACKNOWLEDGEMENT

All thanks and praises to Almighty Allah.

We bow our heads with all humility before Allah for giving opportunity to complete our research work.

Completion of this thesis is the result of cooperation of many dedicated and helpful people. It is difficult to gauge their contribution in helping us to complete this research work.

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Abstract

Seepage is an important phenomenon in the Earth and Rock Filled Dams. These dams are designed to operate under a constant and steady seepage outflow. An unplanned or uncontrolled increase in the seepage may lead to degradation of the structural strength of dam and can lead to its failure.

This project is aimed at the geotechnical analysis of the khanpur dam as well as its seepage analysis to determine whether the dam is safe against any unwanted or unplanned excessive seepage as well as against any deterioration of subsurface strata. The project also covers the effects of the remedial measures taken against the seepage in 2002. It also provides with an idea on what protective measures can be taken to further reduce the seepage and to support the stability of the dam.

The project includes the collection of the latest data and comparison of it with the previously available data using excel to analyze the increase or decrease in the seepage from the Main Dam, Right Embankment and Left Embankment. It also includes collection of data by performing ERT on the different areas of dam to check its geotechnical stability.

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Chapter 1: Introduction

1.1: Location:

Khanpur Dam is constructed on Haro river in the province of Khyber Pakhtunkhwa. It is located about 50 kms from Islamabad and 28 kms from Haripur.

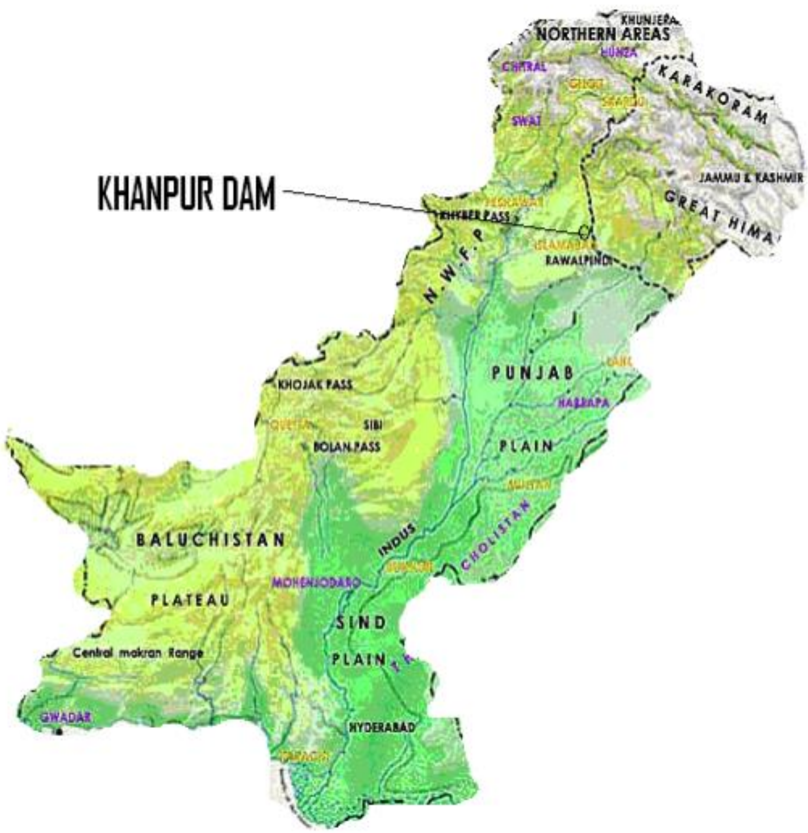


Fig 1.1: Position of Khanpur Dam on Pakistan map

1.2: Construction:

The planning of the Dam began in early 1960s. The first report highlighting the feasibility of the project was prepared in 1962, in the report it was recommended to build a 137 ft high earth filled dam. After the construction had begun it was decided to alter the Dam in such a way that it can also provide water for municipal purposes to Islamabad and Rawalpindi, due to this decision the height of the dam had to be increased to 167 ft.

In the original plan the dam structure was to consist of Main Dam, a left saddle embankment, three right saddle embankments, spillway and an outlet structure to supply irrigation and municipal water. After the revised plan two more auxiliary embankments named Malkanwala Dyke and Check Dam were also made.

Location of the Main dam, Right and Left Embankments, Abutments, Malkanwala Dyke and the Check dam are shown in the figure below:

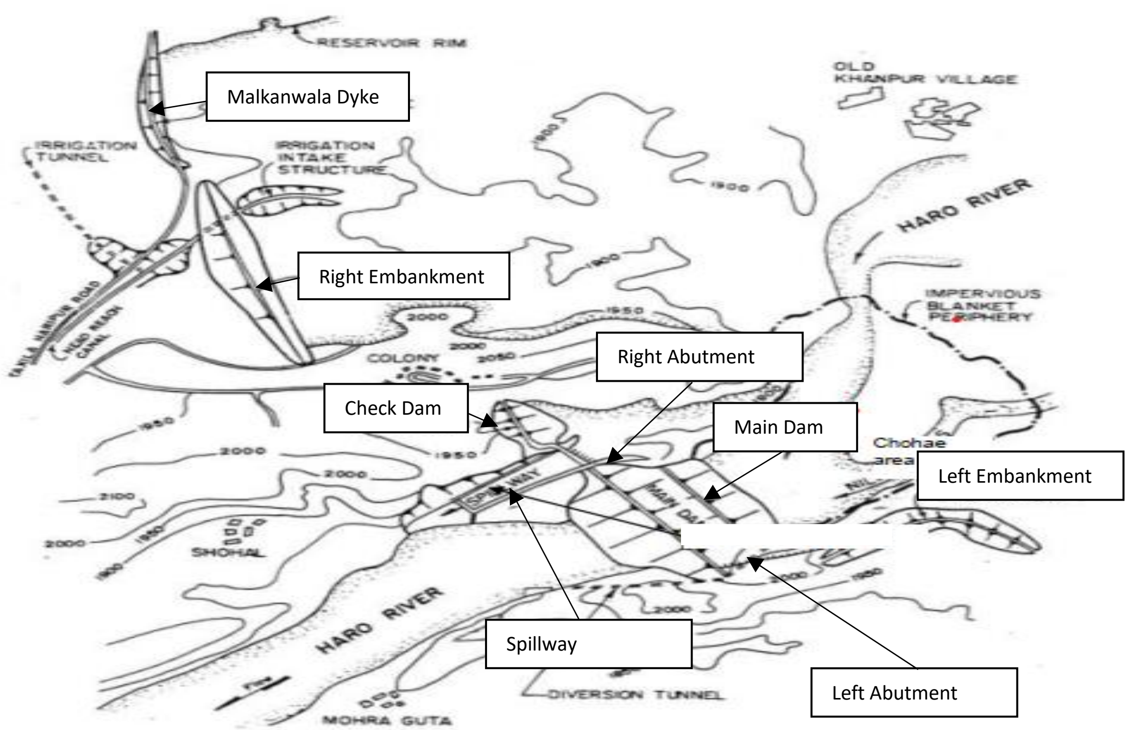


Fig 1.2: Major dam structures of Khanpur dam

All the original Reduced Levels (RL) had to be revised such as, the saddle embankment RL was raised from RL 1965 to RL 1992. The total conservation level of the dam was raised from RL 1995 to RL 1982 (Ali, 2010).

In 1983 heavy rainfalls unmasked issue of uncontrolled large quantities of seepage. After 2 years in 1985 the dam started its operation. According to a rough estimate nearly 50% of inflow of river is lost due to seepage (khan, 2011).

1.3: Provision of Water:

The Khanpur Dam releases its water through two canals, which are named as, the LBBC (Left Bank Branch Canal) and RBBC (Right Bank Branch Canal). RBBC supplies water for irrigation purposes, it has design discharge of 110 cfs and an approx. length of 11 miles. LBBC supplies water for irrigation, industrial and municipal uses, its design discharge is 440 cfs and it is also 11 miles in length.

Table 1.1: Salient features of the Dam.

Descriptions	**Details**
Purpose of Dam	Irrigation and municipal water supply
Type of Dam	Earth and rock fill
Catchments area	308 sq-miles
Gross capacity of Reservoir	94070 acre-feet
Live storage capacity	82080 acre-feet
Irrigation outlet sluice length	665 ft
Number of irrigation canals	2
Purpose of RBBC*	Irrigation
Length of RBBC	11 miles
Capacity of RBBC	110 cfs
Purpose of LBBC**	Irrigation and municipal water supply
Length of LBBC	11 miles
Capacity of LBBC	440 cfs
*RBBC = Right Bank Branch Canal **LBBC = Left Bank Branch Canal	

1.4: Problem Statement:

Engineers consider dams as alive structures; this is because during their life the earthen dams undergo various physical and geological changes. These changes can be due to earthquake, heavy rainfalls etc. or they can be due to underground phenomena such as seepage etc. Hence to prolong the life of earthen dams it is necessary to protect dam against these destructive forces.

Properly designed earthen dams do not eliminate seepage completely but are intended to control the seepage to protect the dam against excessive uplift pressure by water, piping phenomena, erosion of material from under the foundation of Dam and so on. The excessive seepage can be controlled by numerous methods. Making internal drain systems, Toe drains, Horizontal Drainage blanket, Chimney Drains, Partial Cutoffs etc. are the few of the more common ones. All of the methods have their own set of advantages and disadvantages, and it is more than a possibility that a method which has been effective in one case will not be effective in another case.

Khanpur Dam is an earthen dam constructed on deep sedimentary deposits having an impenetrable blanket on upstream side. When first impartial impounding was done almost 50% of water was lost due to seepage. To reduce this remedial measure were taken were in two phases; first phase (1983 – 1985) and second phase (1999 – 2002). The measures included grouting, dental concreting in the abutments and provision of adequate drain system.

Purpose of this study is to evaluate the effectiveness of the undertaken remedial works for seepage control, which includes grouting and drainage works through the geotechnical evaluation to give recommended measures for the safety of the dam.

1.5: Project Objectives:

The project has following objectives;

1.5.1: Seepage Analysis:

- Collection of the latest available data from the piezometers.
- Analyzing the data using different software such as RocScience slide 6.0.
- Graphing the seepage values and comparing them with previous data.
- Determining the effectiveness of the remedial measures taken.
- Recommending if any added remedial measures are required.

1.5.2: Recommend Measures:

- Using the data analyzed remedial measures to further prolong the life of the dam.
- Letting the authorities know if any major fault are found.

1.6: Scope:

The scope of work envisioned for the project is as follows:

1.6.1: Seepage Analysis:

The seepage analysis is focused on the main dam and spillway but the data for other dam structures is also analyzed to find out if there is an increase or decrease in seepage.

Chapter 2: Dam Site Characterization

2.1: Geological Studies:

2.1.1: Overall Geology of zone:

The Khanpur Dam mainly consists of water coming from the Haro River. This Haro river starts its journey from the Hills of Moshipur. And tract of this river come across through the rock of different ages, that is, from rocks of present Era to the rocks formed millions of years ago. Mainly folded and faulted sedimentary rocks are present here. These sedimentary rocks belong from Precambrian to the Miocene period. Hill limestones are also one of the limestone types that are abundantly found here (Shah, 1977). These hill limestones further consist of argillaceous, nodular, massive limestones with shales interbedded (ACE, 1984).

2.1.2: Project Geology:

The hill limestones are the most dominant form of rocks found in the Khanpur Dam region. Most commonly these limestones are found in the following forms Argillaceous limestone, Nodular Limestone, Massive limestone and Shale embedded in rocks.

There exist joints between massive limestones with varying spaces from 12 inches to 60 inches. These joints are major source of seepage (Uromeithy, 2007). Syncline and anticline structures are found here (M.S, Khan, M.A, Gul., and M, Aziz, 2012).

2.2: Major components of the Dam:

2.2.1: Main Embankment Dam:

The length of the main embankment is 1560 feet at its crest and height is 167 feet. The cross-sectional details of the main embankment are given below.

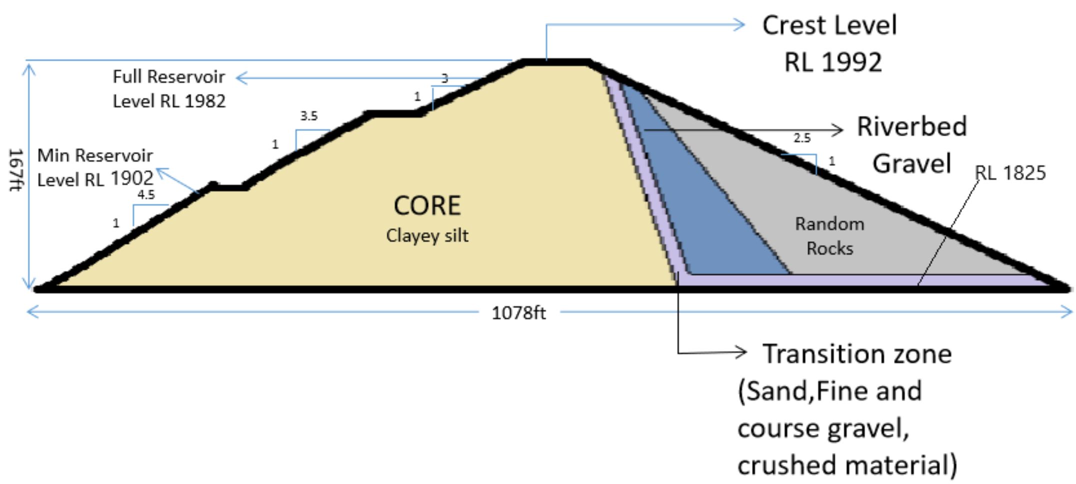


Fig 2.1: Cross-section of Khanpur Dam

- Impervious and rockfill zone is present on the upstream and downstream sides respectively. After seismic stability analysis, the drainage was provided. On downstream sides, Chimney drains are provided with 5 feet thick two zones followed by gravel type material 8 feet wide zone. There also exists 2.5 feet dumped rock zone that is present on the upstream side.

- Clayey silt makes the most of impervious zone with the small amount of sand whose 55% can pass sieve No 200. Permeability and density values of this is 10^{-6} cm/s and 110 lb/ft^3.For material to be used as Foundation Sheer strength parameters are calculated as c'=0, θ =32°.

- By the above parameter calculations, we have concluded that sections are stable, seepage is steady under Static and pseudo-static condition.

2.2.2: Check Dam:

Spillway and right abutment Hills have a check dam of 622.5 feet x 70 feet (Length x height) between them. Shale rocks are present on the bed of check Dam. The embankment of the check dam is composed of clayey silt material (upstream side) whereas the zone of random rocks on the other side. Between impervious and rockfill zone 3 stage filter Chimney drain is present. River material is also present with an effective thickness of 3 feet under rockfill zone.

2.2.3: Left Saddle Embankment:

The length of the left saddle at its crest is 1842 feet with a height of 46 feet. It is mostly oriented perpendicular to the main Dam axis with only 600 feet length of it across the Mohragotta Valley. Left abutment has an alternate bed of shale and limestone. Clayey silt is dominant in valley section with Shale lie beneath under which massive limestone bed is present. Here alluvial soil has a thickness of 25 feet to 30 feet. The right ridge covers most of the saddle length and is consists of a massive limestone bed which has calcareous Shale and argillaceous limestone intervening bed to prevent seepage.

2.2.4: Right Saddle Embankment:

The length and height of the right saddle embankment are 2334 feet and 54 feet respectively. Saddle embankment covers an irrigation outlet structure at running distance 400. Most of the length of its embankment is of clayey silt with little sand. Rock are the main components of the abutment. The upstream and downstream slope is 3: 1 and 2.5: 1 respectively.

2.2.5: Spillway:

Spillway is designed for 166, 000 cusec discharge which can be controlled by 5 radial gates of dimensions 40 feet x 35 feet. The spillway is consisting of Approach channel, Upper and lower chute, Control head work and Plunge pool. Plunge pool is causing nearly 65 percent of whole seepage losses at all levels (Khan et al., 2011).

2.2.6: Irrigation Outlet:

Irrigation outlet is a conduit with the maximum discharge capacity of 650 cusecs present at RD 400 (beneath the right saddle embankment). It consists of a pressure conduit and a downstream conduit. Canal access water from irrigation outlet with the help of the stilling basin and chute.

2.3: Instrumentation:

Standpipe, hydraulic and electric piezometers are used in this effort. Hydraulic pressure meters are not working. Horizontal and vertical variations are measured by the help of Survey techniques. The following data has been obtained regarding the installed and working number of instruments of the main embankment and abutment.

Table 2.1: State of instrumentation at MED and Abutments

Instrument	MED		Left Abutment		Right Abutment	
	Installed	Working	Installed	Working	Installed	Working
Standpipe Piezometer	71	47	31	23	-	-
Relief Well	38	16	-	-	-	-
Drainage Hole	-	-	22	18	19	8
PF	3	1	1	1	-	-
Total	112	64	54	42	19	8

Chapter 3: Literature Review

3.1: General:

Dams are used worldwide for the catchment of water and its effective storage at large scale. Seepage in dams is a common issue which not only reduces the water level but also results in increasing the groundwater level above normal reducing the effectiveness of land nearby in regards to stability, strength, and agricultural properties. Research has shown that there are mainly three problems related to the seepage of water from dams which can result in structural failure of dams in severe cases along with the common remedial and it involves the following:

- Seepage through the phenomena of piping in which water during inflow or outflow creates channels by the erosion of soil bed causing seepage. It can be controlled by using the filters.
- The presence of induced forces during seepage can cause slope failures and heave failures. It can be controlled by controlling the seepage.
- Loss of water above the required level can be due to seepage as well as structural damage to the dam. It can be controlled by strategically maintaining the drainage.

3.2: Criticality of Controlling the Seepage:

Seepage can be a serious issue if it results in excessive water loss or structural damage (Casagrande, 1935) but the extent of the measures to be taken involves the answer of the following questions:

- What are the results of the failure and its criticality?
- What is the extent of unsurety while determining the factor of safety for the structure?

Earth fill dams are most economical dams worldwide and have a considerable capacity of storing water, but seepage can result in dam failure by many issues some of which involve the erosion of fine-grained soils internally along with the process of overtopping (Cadergren, 1968).

3.3: Failure Prevention:

Water moving at the base of the dam results in the transportation of the soil particles at the soil bed of the Earth filled dam and creates zones of the soft rocks and soil due to erosion as a result of the forces induced due to seepage. Piping can result in the minimization of the seepage through this process when used with filters to separate the fine-grained soil particles (Cadergren, 1968).

3.3.1: Criteria of Filters:

To minimize the seepage, the spaces of the pores in the zones which are pervious are installed with filters to stop the smaller sized soil particles to percolate in the pores as filters restrict its movement (Bertram, 1940). The criteria for the use of filters can be expressed as:

$$\frac{D_{15\,Filter}}{D_{85\,Base}} \leq 5$$

And,

$$\frac{D_{15\,Filter}}{D_{15\,Base}} \leq 5$$

The numbers 15 and 85 represent the percentage of the fine particles concerning the total weight of the grain size. Both criteria must be fulfilled to stop the seepage through the piping technique and stop the soil erosion due to the movement of water.

3.3.2: Blow-up and Heave Prevention:

The stress of the blowup heave along with the safety factor can be expressed as:

$$Blowup/Heave\ Stress = Vertical\ Stress - Pore\ Water\ Pressure$$

And,

$$Factor\ of\ Safety = \frac{Vertical\ Stress}{Pore\ Water\ Pressure}$$

The heave stress can be observed and identified at the downstream and it can be evaluated by determining the forces which are acting on the columns of soil at variable depth.

3.3.3: Issues Related to Natural Formations:

The most stable parts of the dam involve the foundation of the dam and the abutment of dams as it is designed to withstand heavy loads and the impact of seepage is minimum on these parts but as the water impoundment in the reservoir changes the regime of water in the dam, the erosion internally along with the process of piping if filters are not installed can damage these secure parts of the dam as well which can lead to the failure of dams in many cases. The rock joints, open cracks, and spaces at the bedrock and soil bed of the dam along with the cavities formed as a result of deposition and decomposition of organic matter can be the causes of this (U.S. ACE;, 1995).

3.3.4: Piping Conservation in the Natural Formations:

The process of piping in the natural formations is common and must be treated by gathering information through the process of exploration of the field and its mapping in the projects of dams specifically to take the remedial measures in the areas where the potential chances of piping are greater than normal. Constant and accurate monitoring of dams is also necessary to identify the areas of increased seepage and piping to take the prevention measures in time to eradicate the possibility of extreme damages (Cadergren, 1968).

3.3.5: Drain and Embankment Construction and Problems:

The foundation of the dam is generally taken as the soil or rock bed whereas its construction and control can disbalance the economy of the project greatly but the embankments of the dam can be improved to control seepage and sustain the structure of the dam against the damages caused by seepage. The process of piping encouraging the seepage can occur even if the criteria of filtration mentioned in the earlier section are satisfied and to control it, constant monitoring and maintenance to the structure of dam are required throughout its lifecycle (Cadergren, 1968).

3.4: Seepage Reduction Strategies:

3.4.1: Primary Concern:

The pressure of water on the embankments, abutments, and the foundation of dam is considerable as dams store a large amount of water, but seepage reduction strategies at upstream, downstream, and drainage along with various grouting mechanisms aid in limiting the seepage to the desired level. Furthermore, the foundation of the dam cannot be altered completely, so improvements in abutments and embankments can reduce the level of seepage effectively.

3.4.2: Impervious Blanket at Upstream:

If the sides and the bed of the reservoir under consideration are made seepage proof by taking the remedial measures, the seepage on the upstream can be controlled considerably by minimizing the unwanted seepage by controlling the pressure of water below embankment and in this manner, and impervious blanket at upstream is utilized. For the best utilization of impervious blanket, the impervious materials are placed beneath the reservoir and the fine-grained soil particles can be removed from the upstream while the drawdown of water (Barron, 1977).

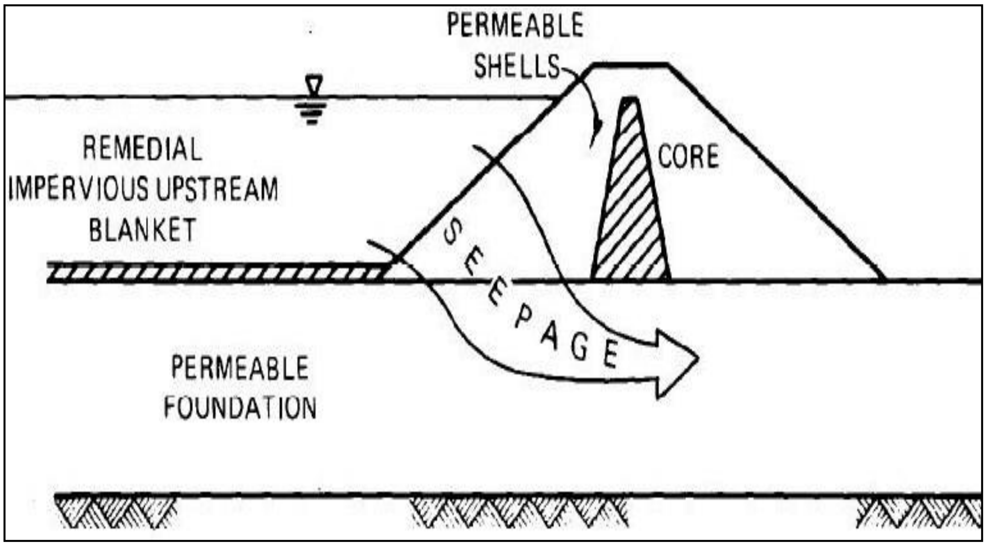


Fig 3.1: Possible problem if existing and remedial seepage control measures are not properly coordinated (prepared by WES)

3.4.3: Berm at Downstream:

To control the seepage in reservoirs, berms are effective as it increases the weight of the stratum at the top as the total weight consists of the berm along with the total weight of the top stratum which effectively resists the pressure of uplift as the total weight is increased and it increases the pressure resisting capability. Berms can be designed both in impervious and previous forms depending upon the on-site conditions (ETL 1110-2-569, 2005). Furthermore, the impervious berm decreases the overall permeability which reduces the extent of seepage greatly. If pervious berms are designed, the utilization of filters according to the filter criteria can control seepage to an optimum level as it minimizes the process of piping (Coffman & Franks, 1982).

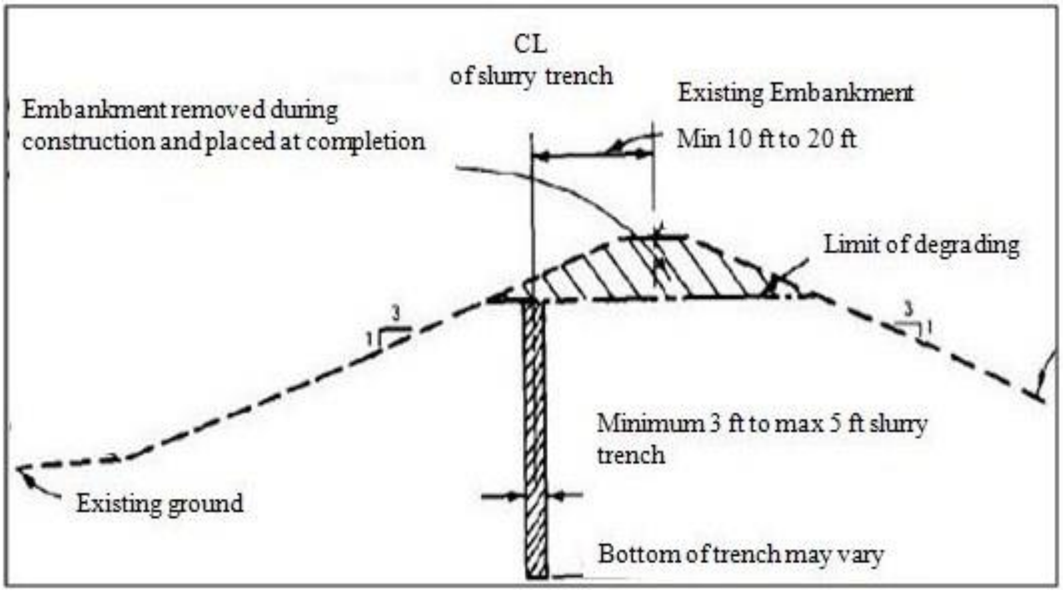


Fig 3.2: Typical layout of Slurry Trench (EM 1110-2-1901)

3.4.4: Slurry Cutoff of Trench:

In the presence of the blanket at the upstream, keeping in view the conditions of stability of the embankment, the trench can be formed either with the embankment itself of it that can be formed in the reservoir as well.

3.4.5: Downstream Slope Drainage:

Drilling of drains in horizontal fashion can effectively enhance the seepage control if the area of the reservoir or dam is smaller. It must be noted that drilling of drains is the temporary method of controlling the seepage in a reservoir, but it can give engineers some time to come up and utilize better seepage control strategies (Royster, 1977).

3.4.6: Foundation Grouting:

Grouting refers to the maintenance and leakage control on the embankment and rocks with cracks. It is accomplished by filling the leakage cracks of the areas of potential damage including the impervious foundation and embankments along with the abutments of the reservoir. Seepage can also be increased by the clogging of the drains which can be effectively controlled by the process of grouting (Moseley & Kirsch, 2004). Figure shows the sketch of grouting types for ground engineering.

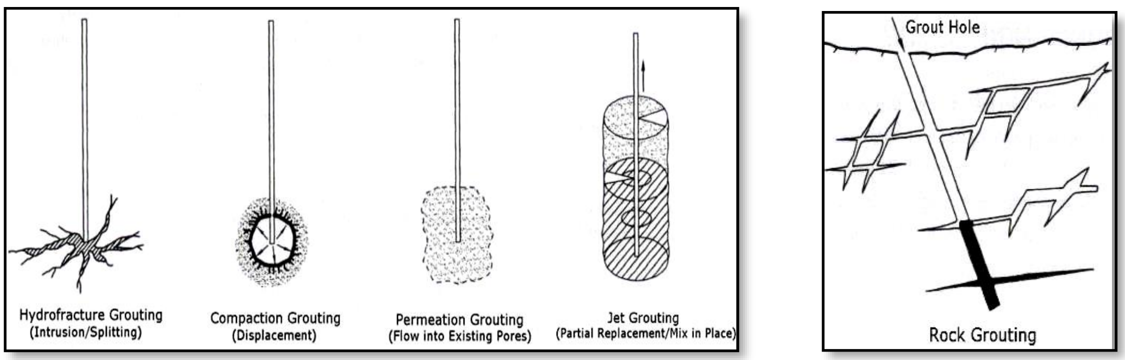


Fig 3.3: Types of grouting (Moseley and Kirsch, 2004)

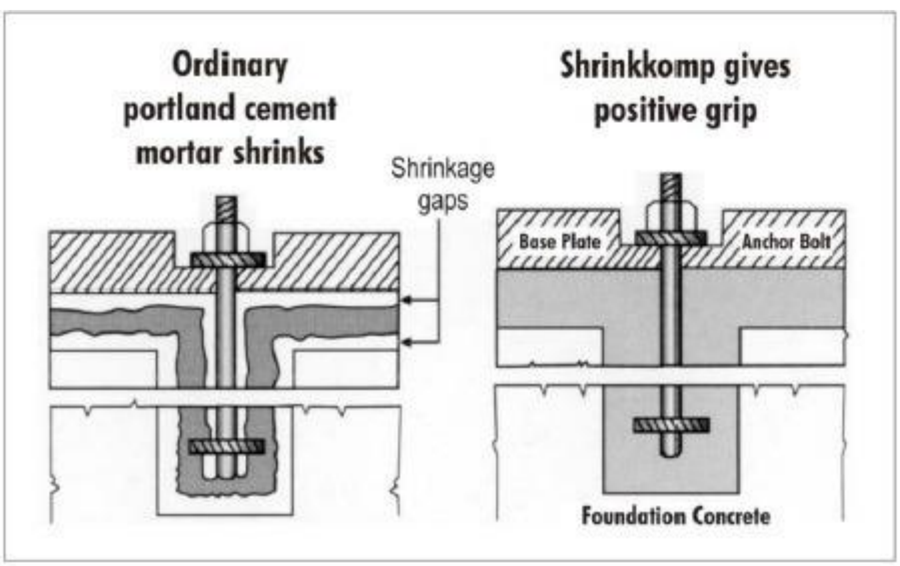


Fig 3.4: Foundation Grouting.

3.4.7: Permeation Grouting:

Permeation grouting can be defined as the process of filling the cracks and joints in the rocks and permeable strata in the reservoirs and dams which is achieved without any potential damage and disruptions of the formation itself (Manfred, 1990). Permeation grouting can be explained as a process in which the water in a crack or joint is replaced at low pressure by the grout fluid with the help of injections and it effectively reduces the permeability of the ground as the water flow of the ground is controlled (CIRA, 2000).

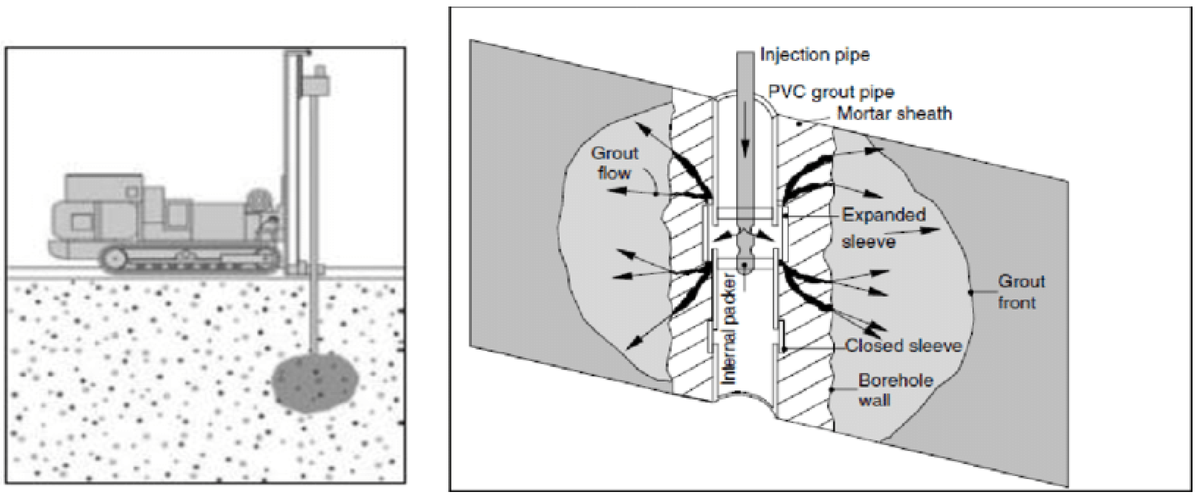


Fig 3.5: Types of grouting (Moseley & Kirsch, 2004)

3.4.8: Compaction Grouting:

Compaction grouting can be defined as the process of grouting in which the soil is displaced by the grouted soil in the medium in which the grout is injected instead of the mixing of soil in the permeable voids of soil. In this technique, if the deposit is not at the maximized density, it will result in the reduction of the voids volume and the void deposit is densified locally (Reuben, 2003).

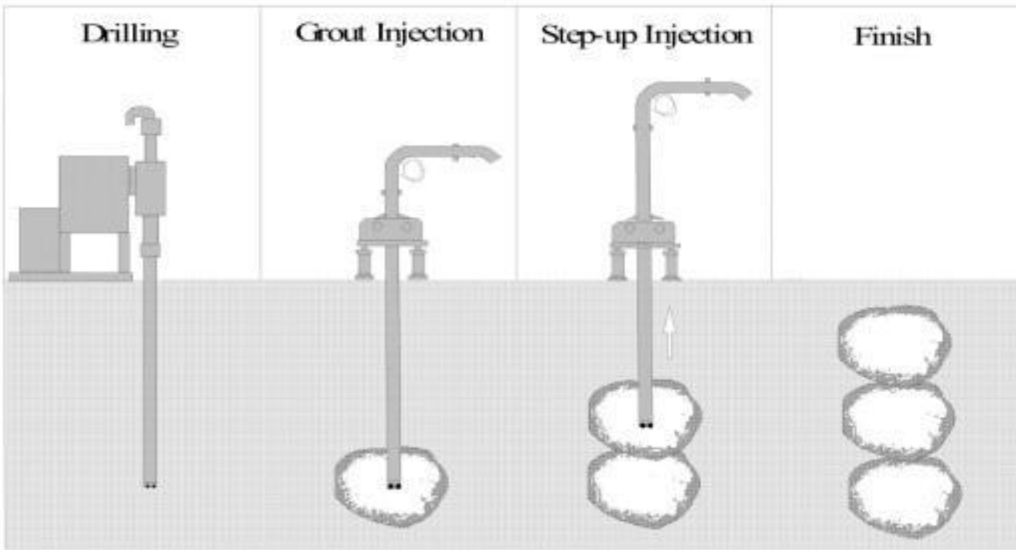


Fig 3.6: Stages of Compaction Grouting

3.4.9: Hydro-Fracture Grouting:

In this method, the rock or soil surface is fractured under a high grout pressure intentionally so that the ground or rock bed can be stiffened by grouting the places which initially were not available for grouting due to the overlying layer of soil or rocks (Cambefort, 1977).

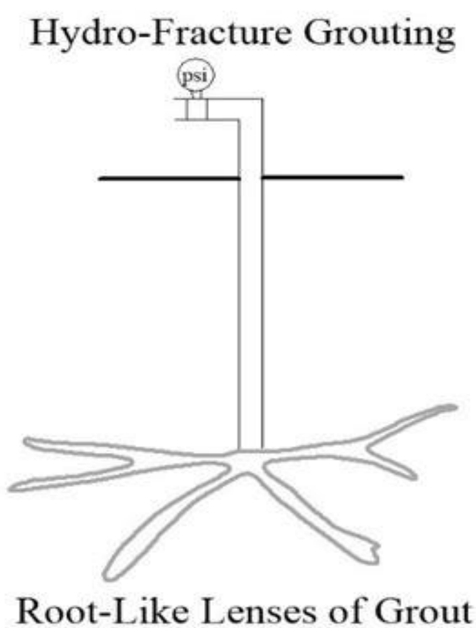


Fig 3.7: Hydro-Fracture Grouting.

3.5: Designed Seepage Control Measures at Khanpur Dam:

Due to deep alluvial deposits in the main riverbed, the most important factor in foundation design was its permeability. Two well pump-out tests were performed in the riverbed by converting percussion exploratory holes into wells. These tests indicated that the permeability of riverbed gravels ranged between 3.3x10-3 to 3.3x10-5 ft/sec, which meant that the excessive seepage could be expected from these deposits and a thorough seepage control design was essential. The permeability of foundation rock was determined though pressure tests in an exploratory hole at every 10 or 15 ft interval performed at 0, 14, 28, 56 psi pressure, respectively.

The presence of deep deposits of pervious materials and jointed limestone presented a difficult problem in the control of seepage. Following are the seepage control and drainage arrangements provided at the Khanpur Dam project:

- Treatment of foundation.
- Impervious blanket at upstream.
- Grout Curtain at the left abutment.
- Extra Grout Curtains.

3.5.1: Treatment of Foundation:

At the left abutment, the core trench was badly jointed. These open joints were filled with sand-cement mortar and lean concrete to avoid any leakage through the joints which could produce piping in the impervious fill. Surface rocks of both abutments were deeply weathered. These were removed during stripping and sound rock was exposed for dental treatment.

3.5.2: Impervious Blanket at Upstream:

Since the main embankment is founded on deep deposits of sandy gravels extending to a depth of about 200 ft below the bed level of the Haro river, a positive cut off was not economically feasible as an under-seepage control measure for the embankment. Therefore, a horizontal upstream impervious blanket connected to the core is provided. The upstream impervious blanket, 2850 ft long, is based on a gradient of 1:18.

3.5.3: Grout Curtain at Left Abutment:

The 30 ft deep additional grout holes 5 ft upstream of the main grout curtain were drilled and gravity grouted with 30 to 50 ft depth in massive limestone to seal any joint that opened as a result of some limited controlled blasting in the vicinity of the grout curtain and to fill any cavity and solution channel in the upstream. A total number of 19 holes were drilled and grouted at 10 ft spacing. The grout intake was generally very low i.e. less than 10.0 1bs/ft.

3.5.4: Extra Grout Curtains:

To reduce seepage through the left abutment, 26 grout holes of 300 ft depth were drilled to strengthen the already existing grout curtain. In all 7,981 ft of drilling was done and the average grout intake was 198.1 1bs.rft.

3.6: Recently undertaken Seepage Control Measures at Khanpur Dam:

In September 1992, the reservoir filling up to RL 1982 ft was incidental because of unprecedented monsoon floods. This filling created very high pore pressures in the left abutment and as a result, a new seepage burst was observed 2000 ft downstream of the main dam. The spillway was operated at 60000 ft3 /sec which caused erosion in the plunge pool at the right flank and undermined the right extended wall. Implementation status of the Khanpur Dam Safety Works (KSW) is given below in Table 3.1

Table 3.1: Implementation Status of Khanpur Dam Safety Works

Works	Proposed	Completed	Year
Drilling and Grouting	43040 rft	23908 rft	1999 -2003
Dental Concrete	97000 sft	57000 sft	1999-2002
Drainage at Left Abutment	5 drain holes	5 drain holes	2004
	8 piezometers	7 piezometers	2004-2005

3.6.1: Seepage Control at Left Abutment:

The seepage control in the left abutment by grouting involves the following:

- In the left abutment total of 13097 rft with 13743 bags of cement, grouting in 65 holes at an average 1 bag/rft has been carried out.
- Each batch was composed of 1 bag cement 1% Bentonite and 35 liters of water with cement sand ratio of 1:2.
- In 243 ft long adit the grouting has been done in 3 rows spaced 2 ft apart with staggered holes at average 10 ft C/C
- Additional 6 holes were made in each row at 7.5 degrees with the vertical to strengthen the rock towards the dam embankment.
- An average 4 ft wide, 243 ft long and 200 ft deep curtain was made.

3.6.2: Seepage Control at Right Abutment:

The seepage control in the right abutment involved the following grouting techniques:

- In the right abutment total of 10811 rft with 78333 bags of cement, grouting in 54 holes at an average 0.72 bag/rft has been carried out.

3.6.3: Dental Concreting:

The dental concreting in the Khanpur dam consisted of:

- Dental concreting was done on selected exposed faces of limestone from RL 1910 to RL 1960.
- 37050 ft^2. of dental concrete has been done on the left bank in the vicinity of left abutment upstream.
- 19950 ft^2. of dental concrete has been done on the right side close to the spillway upstream.

3.7: Advanced Dam Monitoring Techniques:

- **Borehole Radar**

Borehole radar is a high-resolution tool, used for detection and evaluation of deep seepage/leakage paths.

- **Fiber Optic Sensing**

It is a real time monitoring technique and continuously mapped seepage paths. It also records parameters like strain and temperature to understand subsurface processes.

Chapter 4: Methodology

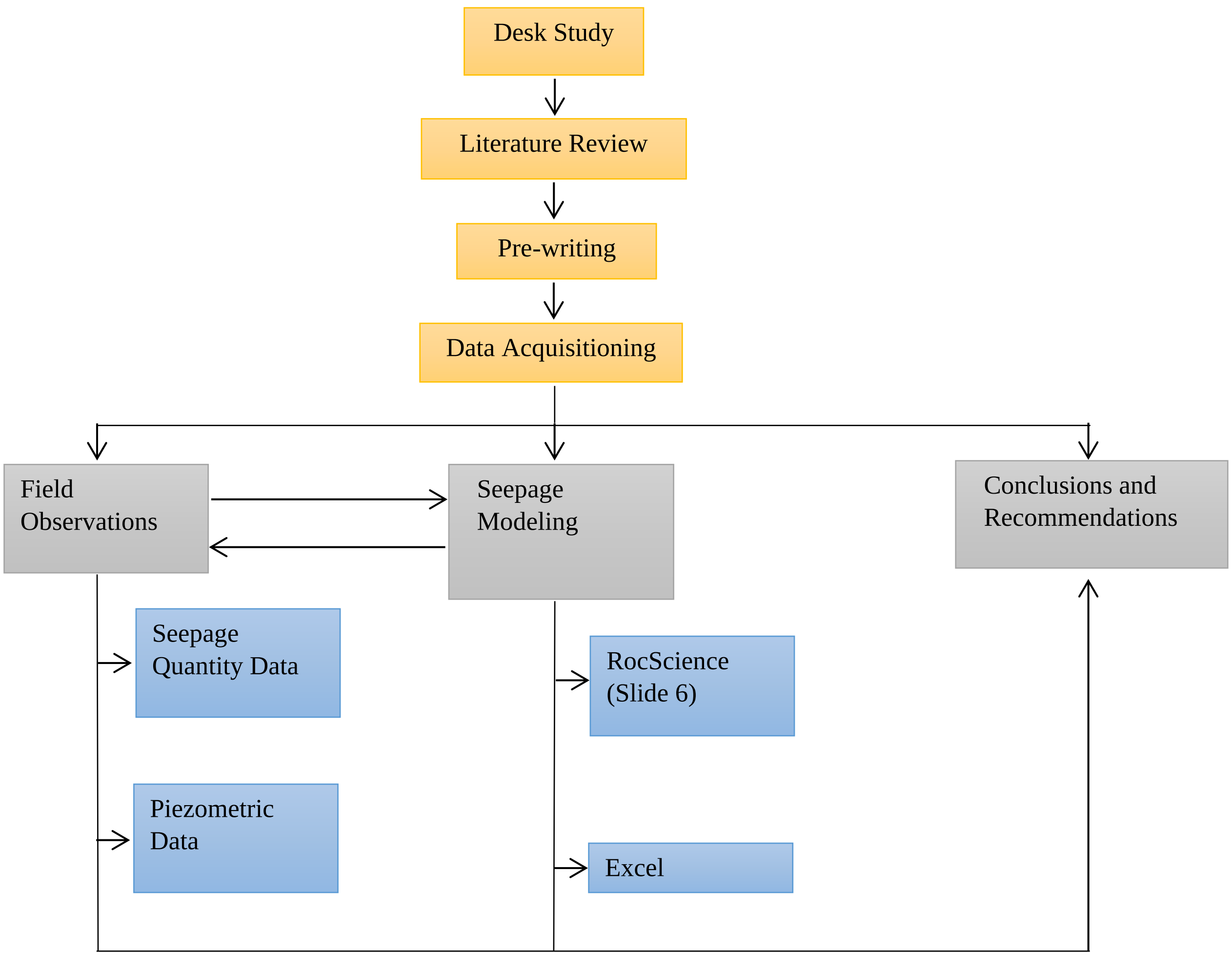
4.1: Introduction:

The seepage issue is one of the significant tasks to be settled related with bank dams. Frequently preconstruction courses of action are made to lessen the drainage through the dam's projections and valley fill stores. The typical treatment incorporates grouting; cut-off walls, dirt covering and dental treatments which are embraced to chop down the conceivable drainage ways. The measure of seepage and sort of treatments are legitimately identified with the idea of topographical developments and related structural highlights.

Starting from its first restoration, the Khanpur dam, has challenged the issue of generally a lot of seepage even up to half of its base stream, happening under the foundations and around the abutments of the dam. On events, these leakage streams have shipped suspended fine silt too. The motivation behind this study is to assess the viability of the attempted therapeutic works especially grouting and dental concreting embraced from July 1999 to June 2010, through geotechnical evaluation to empower execution of remaining grouting works. This included research and assessment of literature, examination of the seepage and piezometer information/data, field perceptions, and computer modelling through SEEP/W 2005 software (ACE, 1984).

4.2: Methodology Flow Chart:

The following adapted methodology can be represented as followed through a simple flow chart:



4.3: Study Methodology:

There are three main parts of study/research methodology:

- Desk Study
- Literature Review.
- Data Acquisitioning
    a. Seepage quantity data
    b. Piezometric data

4.3.1: Desk Study:

It is the check and review of data efficiently available about a site and is completed at a start period of site evaluation to brighten and direct the rest of the site examination.

In our case, it included investigation of the dam with the view to realize the current drainage control measures at the site to have top to bottom information on the issue. This further empowered to discover the presently embraced seepage control measures with the view to discover the impact of these measures on seepage control.

4.3.2: Literature Review/Evaluation:

Reviewing and evaluating previous journals, scholarly articles, books, web pages similar to the topic of research is generally known as literature review. is an extensive synopsis of past research on a point.

Significant literature regarding the matter of dam seepage was made accessible from library, web, diaries, and distributions on geotechnical designing, Khanpur dam venture webpage, WAPDA online material, Dam Safety Organization, and NESPAK online material.

4.3.3: Data Acquisitioning:

Data acquisitioning is getting hold of required data, numerical values, computer processed data for further investigation in a research.

In case of our research, we divided data by following two ways:

- **4.3.3.1: Seepage Quantity Data:**

The information was accumulated from the dam site and dissected at various Reservoir levels of 10 ft span to see the viability of remedial works. This information was readily made available by the concerned department at the dam site.

- **4.3.3.2: Piezometric data:**

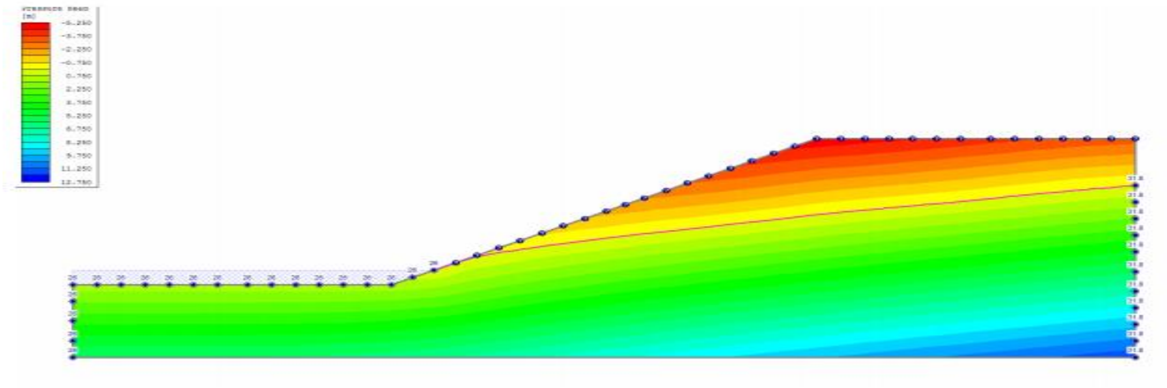
The piezometric readings of various piezometers were investigated in similar lines at 20 ft contrast of store level to see the viability of corrective works. This information was also readily made available by the concerned department at the dam site.

4.4: Seepage Modelling:

Using RocScience (Slide 2018) Software

Inside the Slide program, Slide can do a finite element groundwater seepage investigation for consistent state or transient conditions. Finite element groundwater seepage investigation in Slide permits you to characterize and break down a groundwater issue utilizing a similar model with slope stability issue. The limits of the issue just should be characterized once and will be utilized for both the groundwater examination and the incline soundness investigation.

After a groundwater leakage examination is played out, the outcomes (pore pressures), can be naturally used by the incline steadiness investigation motor in Slide (Ali, 1993).



Pressure Head contours.

Fig 4.1: Figure shows the results of the groundwater analysis in the Slide Interpret program interface.

NOTE:

- The groundwater examination ability in Slide can be viewed as a totally self-contained groundwater analysis program and can be utilized freely of the slope soundness functionality of Slide.
- You may play out a groundwater examination in Slide, without fundamentally playing out a slope stability examination.
- Although the Slide groundwater analysis is outfitted towards the figuring of pore pressures for slope stability issues, it isn't limited to slope geometry designs. The groundwater demonstrating and analysis abilities in Slide can be used to break down a self-assertive, 2-dimensional groundwater issue, for soaked/unsaturated stream conditions (Khan, et al., 2011).

Using SEEP/W 2020 Software

Examinations of groundwater stream have concentrated on stream in soaked soils and stream issues were regularly classified as being restricted or unconfined circumstances. Stream underneath a structure would be a kept stream issue, while course through a homogeneous bank would be an unconfined stream issue. Unconfined stream issues were regularly viewed as progressively hard to examine on the grounds that the assurance of the area of the phreatic surface (i.e., the progress from positive to negative pore water pressures) was essential to the examinations. The phreatic surface was viewed as an upper limit and any stream that may have existed in the slender zone over the phreatic line was overlooked.

It is not, at this point adequate to just disregard the development of water in unsaturated soils over the phreatic surface. In addition to the fact that it ignores a significant segment of dampness stream in soils, however, it enormously confines the sorts of issues that can be examined. It is fundamental to the investigation of issues including penetration and dampness redistribution in the vadose zone. Transient stream issues, for example, the development of a wetting front inside an earth structure after quick filling are commonplace instances of circumstances in which it is difficult to mimic field conduct without accurately thinking about the material science of course through unsaturated soils. Luckily, it is not, at this point important to overlook the unsaturated zone (Shah, 1977).

As a rule, all water stream is driven by vitality slopes related with the all-out head of water as spoken to by the segments of weight head (or pore water weight) and rise. The term drainage frequently is utilized to portray stream issues in which the predominant driving vitality is gravity, for example, a case wherein drainage misfortunes happen from a supply to a downstream leave point. In different circumstances such as solidification, the essential driving vitality might be related to the formation of overabundance pore-water pressures because of outside stacking. In any case, both of these circumstances would all be able to be portrayed by a basic arrangement of numerical conditions depicting the water development. Accordingly, the plan utilized to examine leakage issues can likewise be utilized to investigate the scattering of abundance pore-water pressures coming about because of changes in pressure conditions. With regards to the conversations and models in this record and in utilizing the SEEP/W programming, the term drainage is utilized to depict all development of water through soil paying little mind to the creation or wellspring of the driving vitality or whether the stream is through soaked or unsaturated soils (Romanov, et al., 2003).

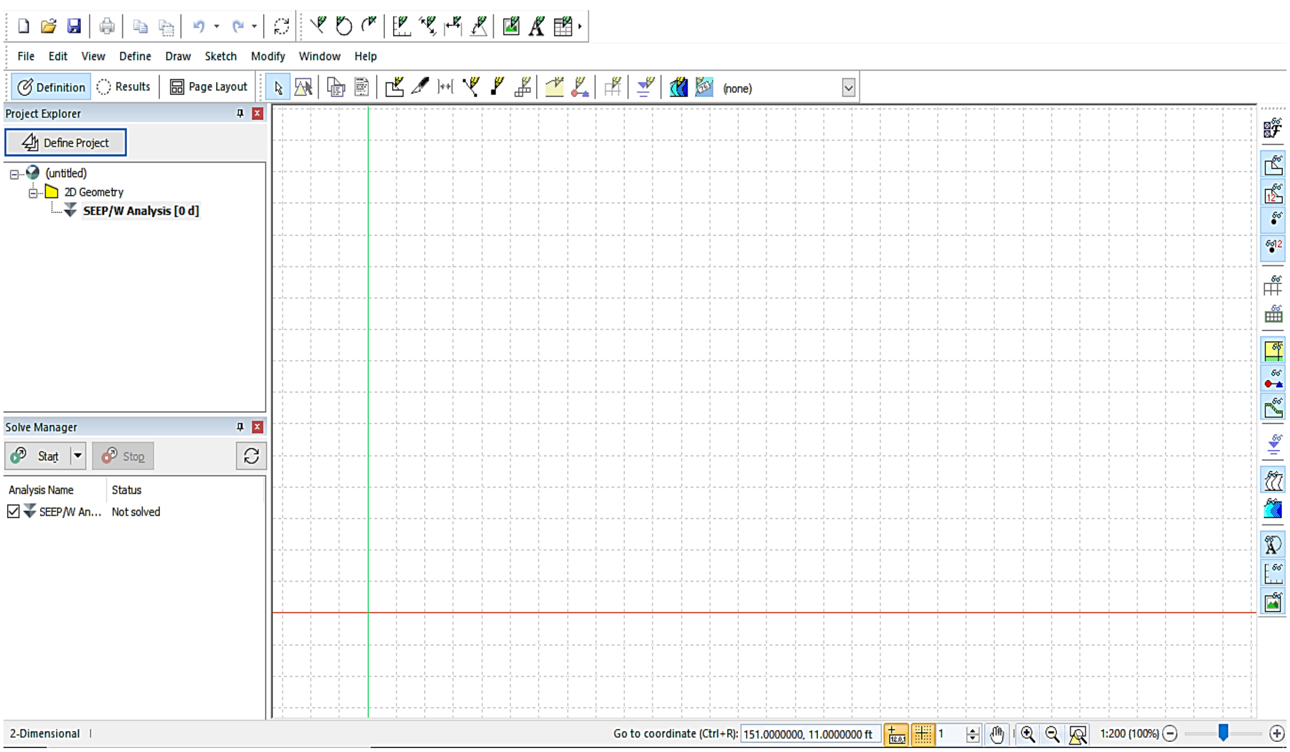


Fig 4.2: Seep/W 2020 Interface

Chapter 5: Results and Calculations

5.1: General

Data is being managed in tabulated form and analyze them through different methods. Data is represented in Graphical form under every respective heading. Main Embankment Dam seepage consists of three main parts that are being further broken down into sub-parts as given below: -

5.1.1: Right Abutment Seepage

This is the seepage through Spillway that is being calculated at plunge pool area. Right abutment is a most monitoring part as maximum seepage recorded there due to presence of Spillway.

5.1.2: Left Abutment Seepage

It includes seepage occurred through new seepage area and diversion tunnel. Both seepages are measured separately and together constitute total left abutment seepage.

5.1.3: Main Dam Seepage

Seepage is being measured through relief wells that are constructed at the downstream toe of embankment. Abutment and foundation are the weakest part in every dam. Special attention is being given to these structures since first reservoir impounding occurred. Numerous measures were taken to control and reduced seepage. These measurements involve grouting and limestone bed treatment of abutments, also providing drain holes and relief wells to stop erosion. Piping phenomenon is a major cause of dam seepage. As time passed, with advancement in measurements, added measures were also taken to make it safe. In 1986, Turbidity was recorded in drain holes and relief wells that last for 2-3 years, but not presently as there is no sign of it. A seepage comparison of different years like 1985/86, 1990/91, 1993/94, 1998/99, 2005/06, 2009/10, 2015/16 and 2019 at **reservoir level (RL) of 1950 ft** is being graphically presented in below Figure and compared values in table listed below.

Table 5.1: Seepage values at RL 1950ft over the years

Year	1985	1990	1995	1998	2000	2005	2010	2015	2019
Seepage (cusec)	42.71	31.31	35.87	49.26	48.9	48.71	48	46.4	40.75

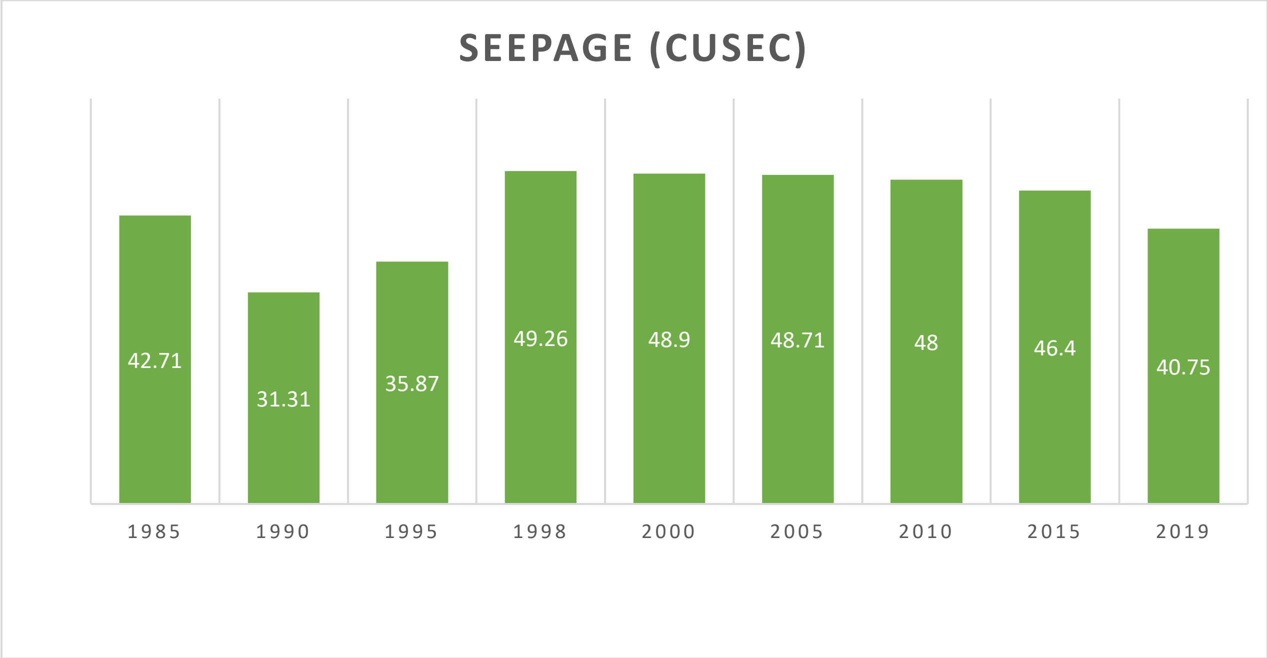


Fig 5.1: Trend of overall seepage through the dam

From the analysis of data it can be concluded that seepage after 2010 has decreased to some extent without taking any additional measures, this may be due to filling of cracks by silt, also known as the self-healing phenomena of dam.

5.2: Seepage Analysis w.r.t Remedial measures

5.2.1: Right Abutment

Plunge pool located at downstream of spillway. Total seepage of Right abutment is measured there; consist of plunge pool and spillway seepage. Bed rock strata also directed seepage path towards plunge pool area. After remedial works, very less effectiveness on plunge pool area but it gradually increases with time. In last five years, graph shows us some reduction in seepage magnitude that's a positive sign. Seepage reduction is 23% at R.L 1970 and its reduction in

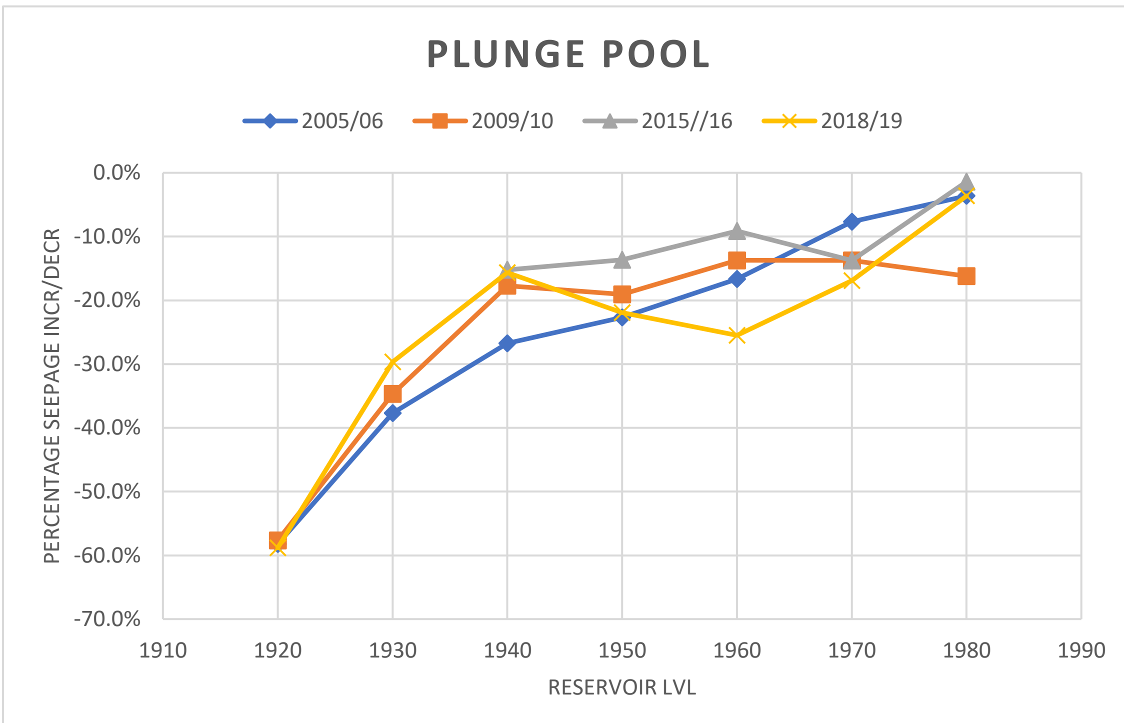


Fig 5.2: Seepage Percentage Increment/Decrement in Percentage w.r.t Pre-Grouting

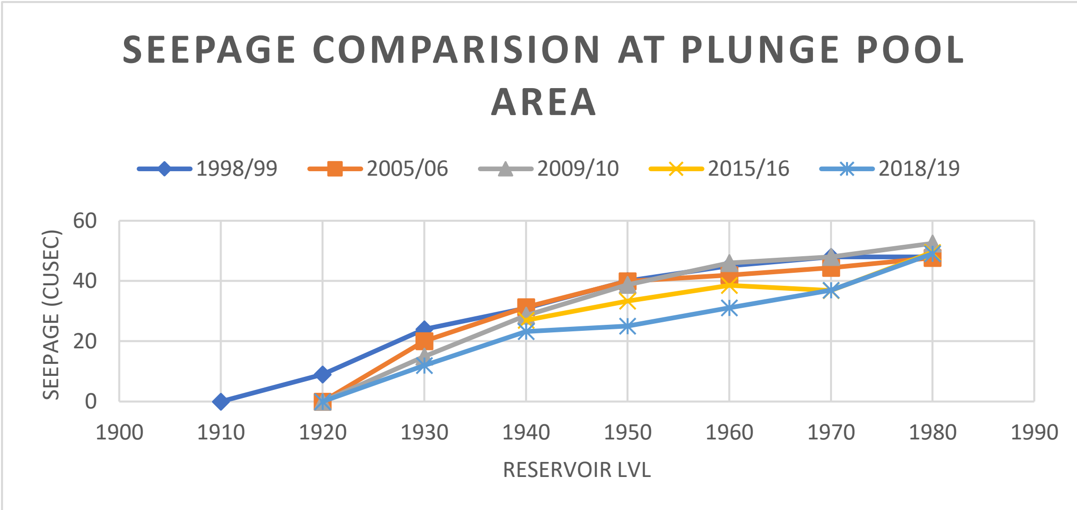


Fig 5.3: Plunge Pool Seepage Comparison at Different Reservoir LVL

5.2.2: Left Abutment

In left abutment, weak beds present in substrata that cause excessive seepage in abutment area. Weak beds include two inverted syncline beds of limestone, Lm-6 & Lm-8 extended from upstream to downstream shown in Fig. These beds present 20-40 Ft. below dead level of dam. Limestone beds present between Elevation Level of 1860-1880 ft. Lm-6 run along upstream side of diversion tunnel b/w Elevation level of 1875-1910 ft. Lm-6 extended about 800ft along upstream.

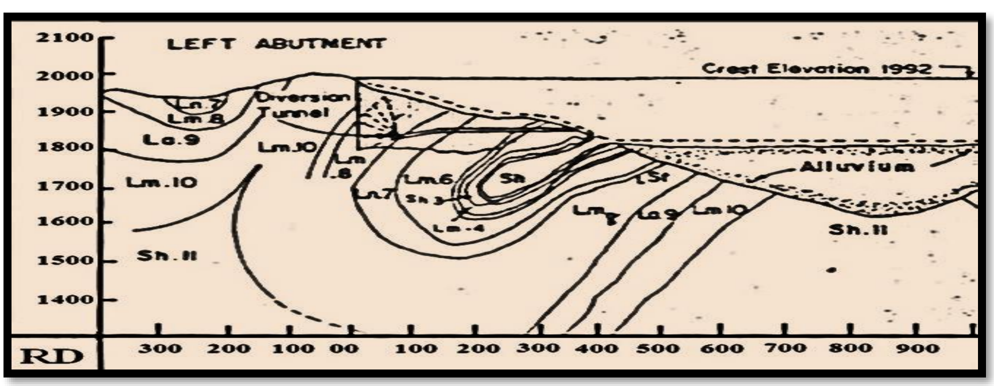


Fig 5.4: Cross sectional view of Left abutment

Due to accessibility issues, these beds remain untreated, that's why seepage occurs in this part of dam. But seepage is under control as shown in below figures. Left abutment seepage includes diversion tunnel and new seepage area. Diversion tunnel seepage measured at outlet of tunnel while seepage from "new seepage area" is collected and measured separately at downstream. From 1999-2004, remedial measures were taken, dental concreting and grouting was done under supervision of KSW. After remedial work, seepage reduces about 60% in diversion tunnel at RL 1920ft and its percentage reduction decreases as reservoir level increases. These results show that grouting is very effective in diversion tunnel. While in new seepage area, increment in seepage is recorded.

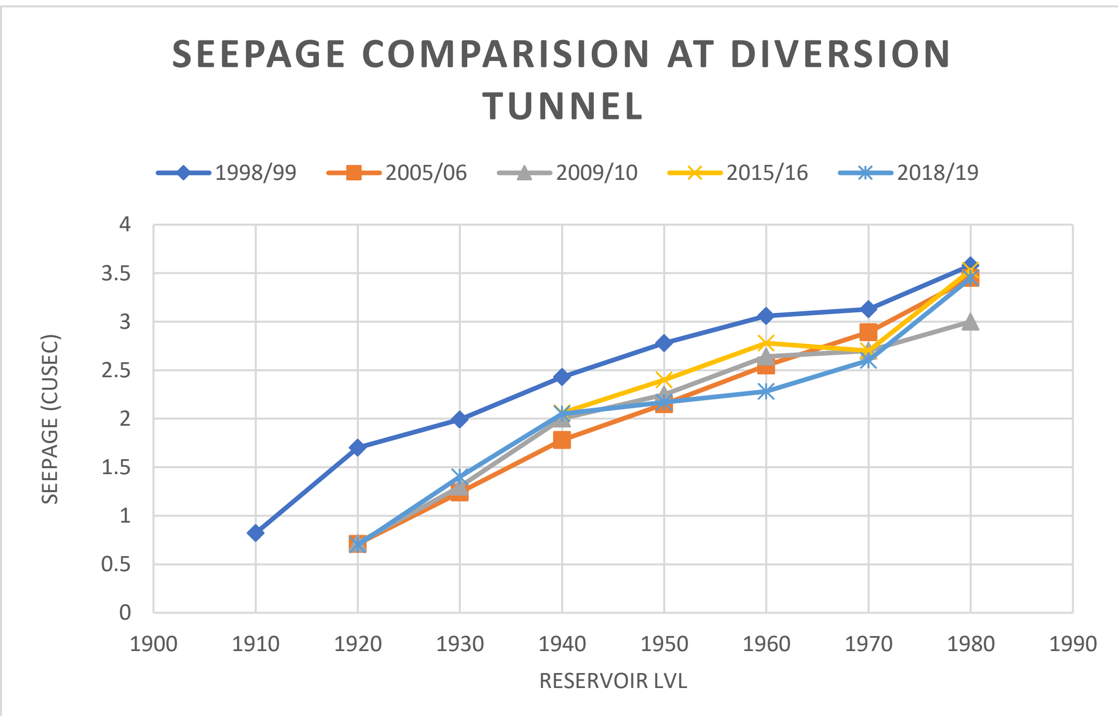


Fig 5.5: Seepage Comparison of diversion tunnel at Different Reservoir Levels

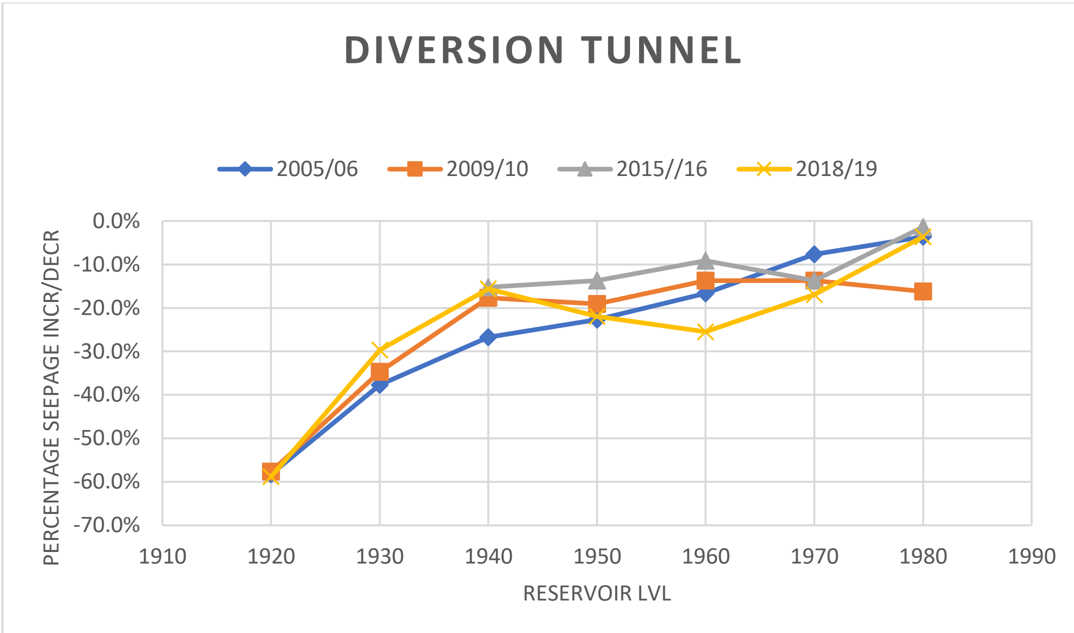


Fig 5.6: Seepage in percentage increases/decreases w.r.t Year 1998-99 at Diversion tunnel

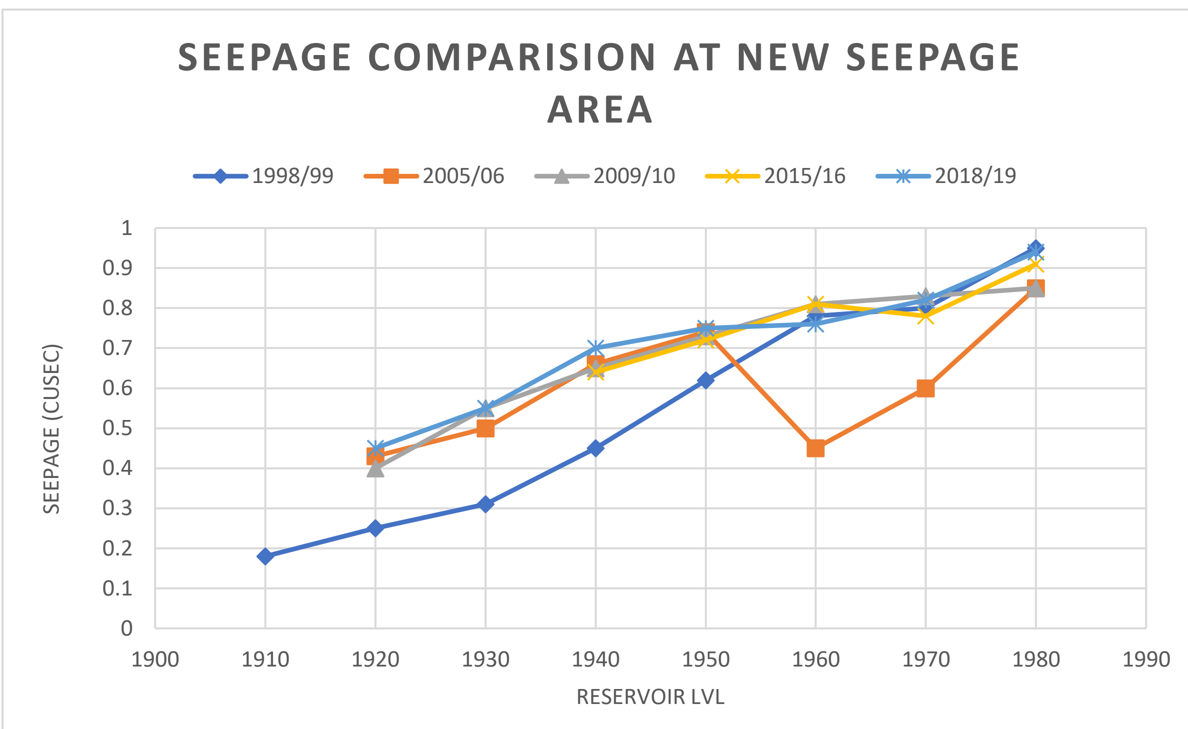


Fig 5.7: Seepage Comparison of New Seepage Area at Different Reservoir Levels

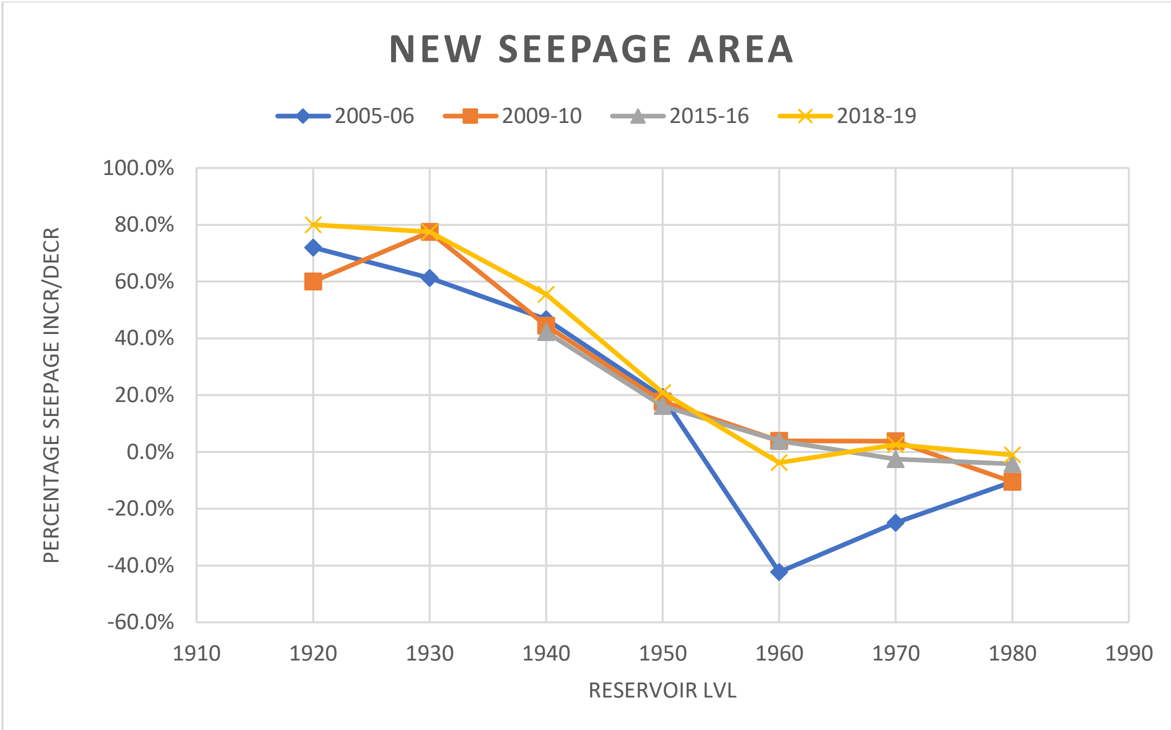


Fig 5.8: Seepage in percentage increases/decreases w.r.t Year 1998-99 at New Seepage Area

5.2.3: Main Dam

Seepage reduction at high reservoir level is very effective in main dam. Remedial work taken at main dam was casing with shrouding material. Upstream blanket was also strengthened with time as deposition of sediments present in water. These measures helped in Seepage reduction. After remedial works, seepage reduces up to 30% at average reservoir level 1950-1960ft.

Main dam seepage includes Partial flumes, New seepage area, Diversion tunnel and Plunge pool seepages.

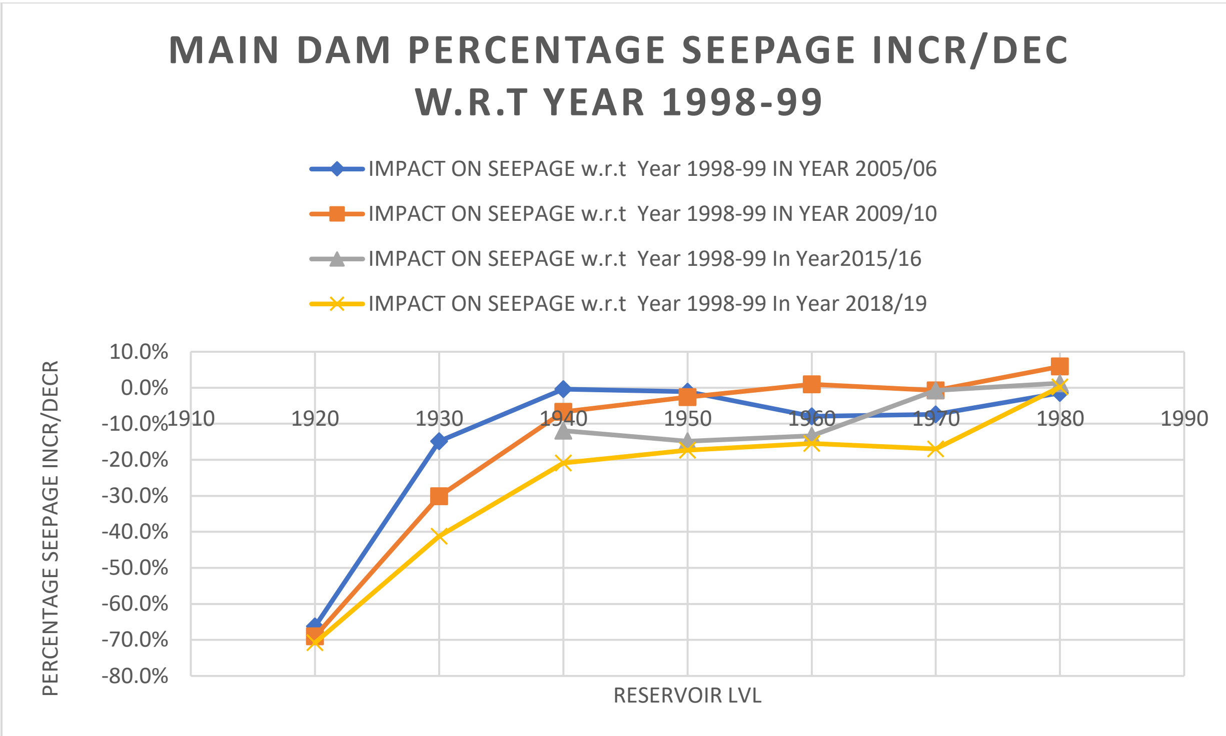


Fig 5.9: Seepage in percentage increases/decreases w.r.t Year 1998-99 at Main Dam

5.2.4: Total Seepage Comparison

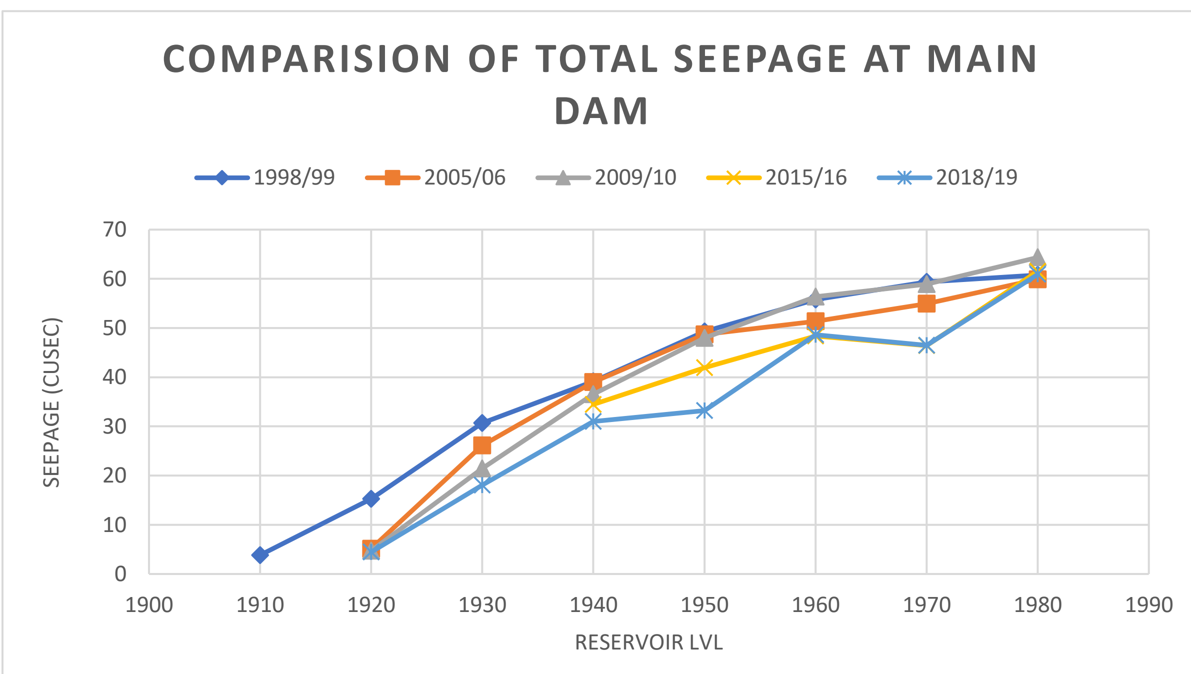


Fig 5.10: Total Seepage Comparison at Different Reservoir Levels

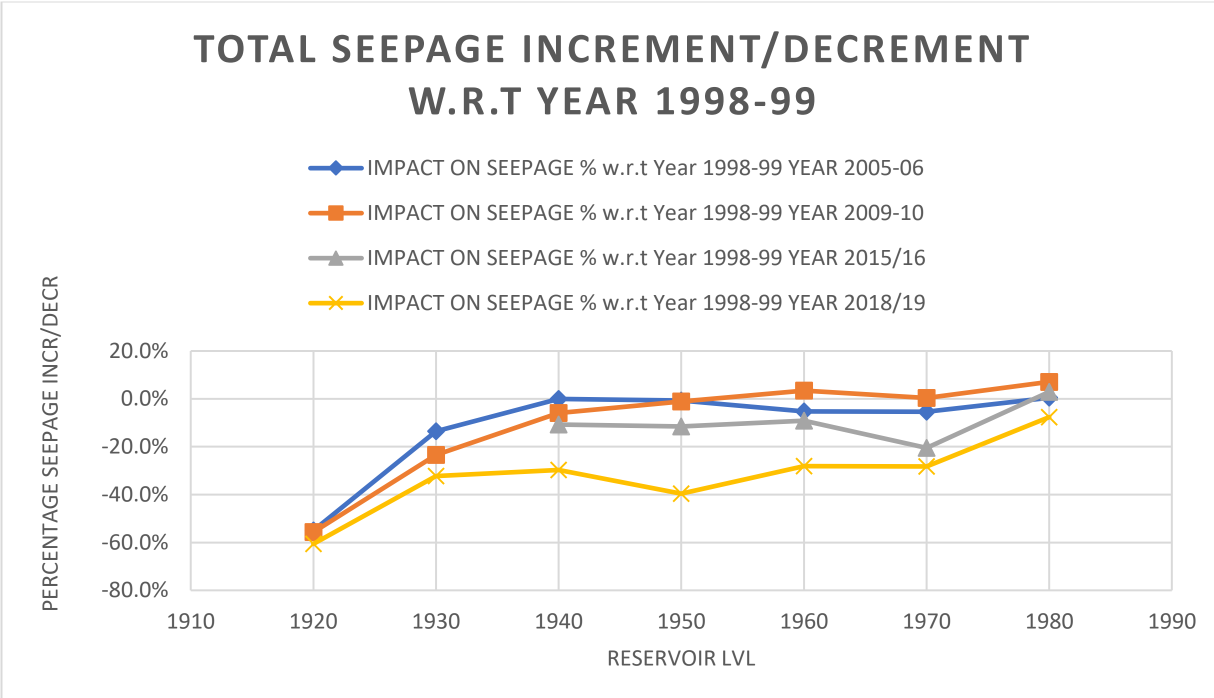


Fig 5.11: Total Seepage in percentage increases/decreases w.r.t Year 1998-99

5.3: Piezometer Data Analysis

5.3.1: Piezometer data at Left Abutment

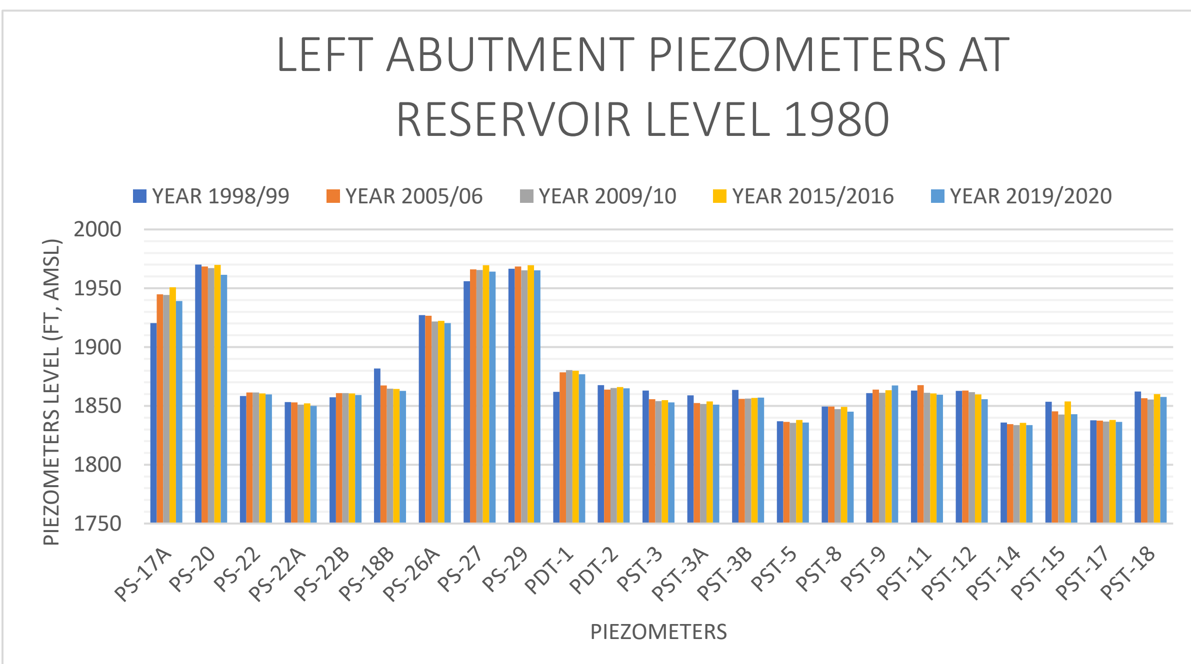


Fig 5.12: Comparison of Left Abutment Piezometers Levels at RL 1980

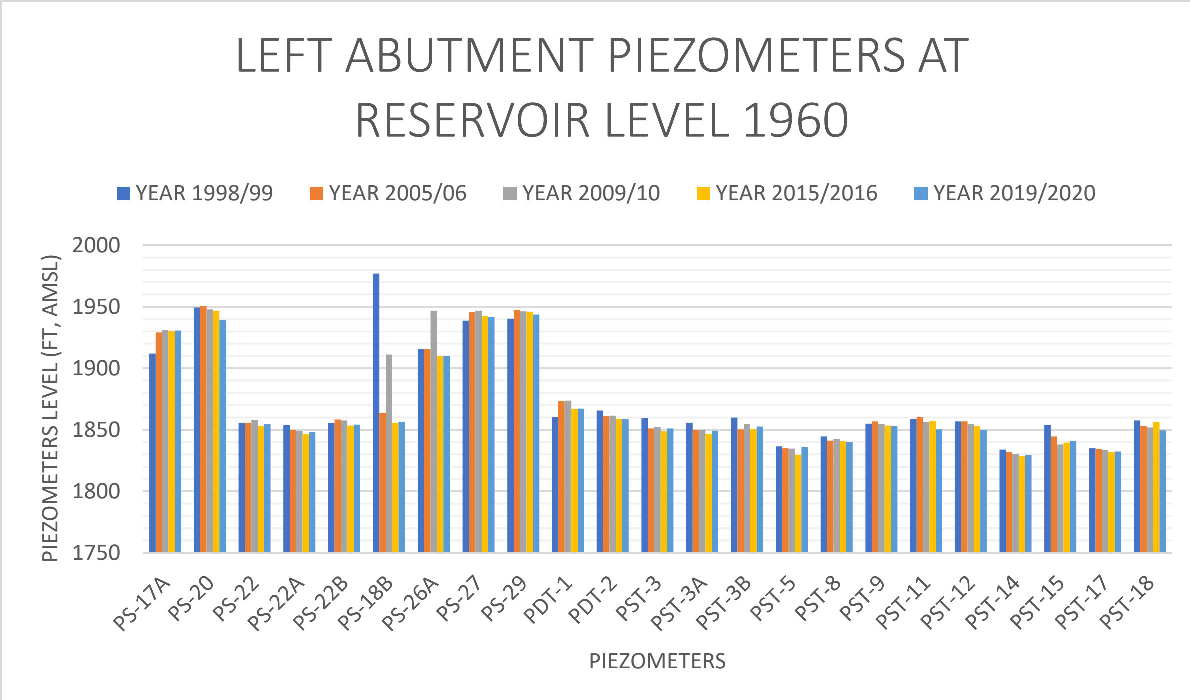


Fig 5.13: Comparison of Left Abutment Piezometers Levels at RL 1960

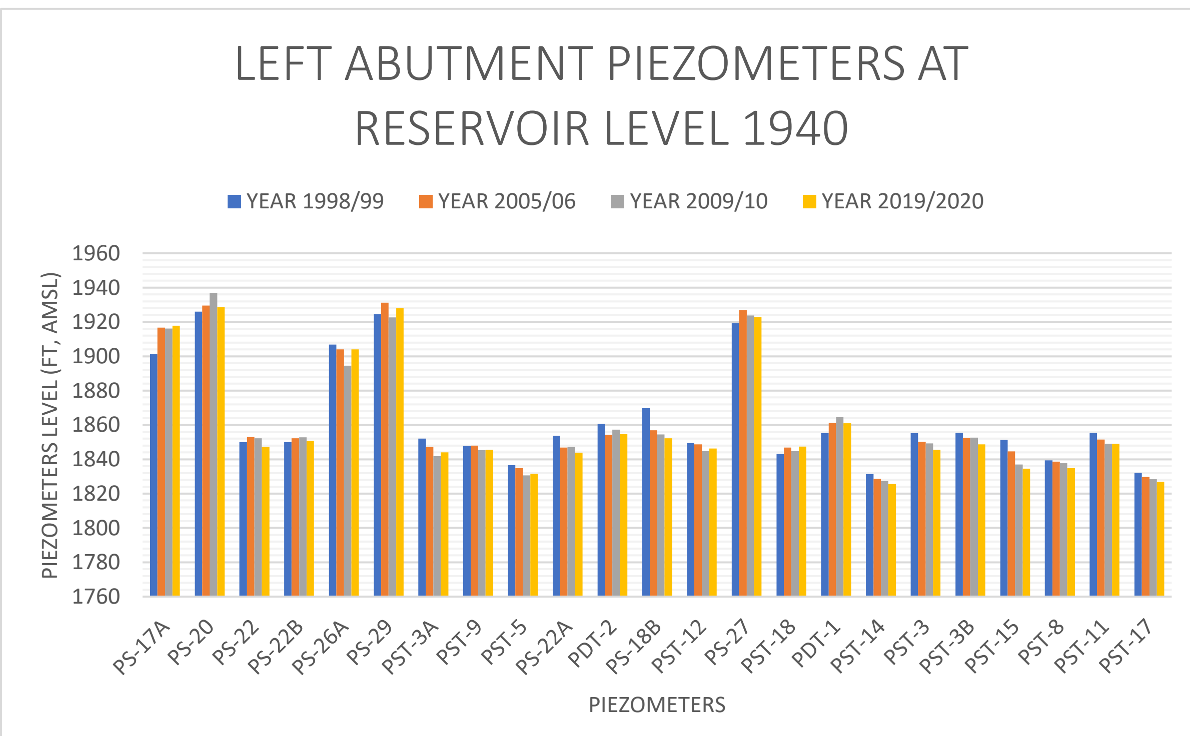


Fig 5.14: Comparison of Left Abutment Piezometers Levels at RL 1940

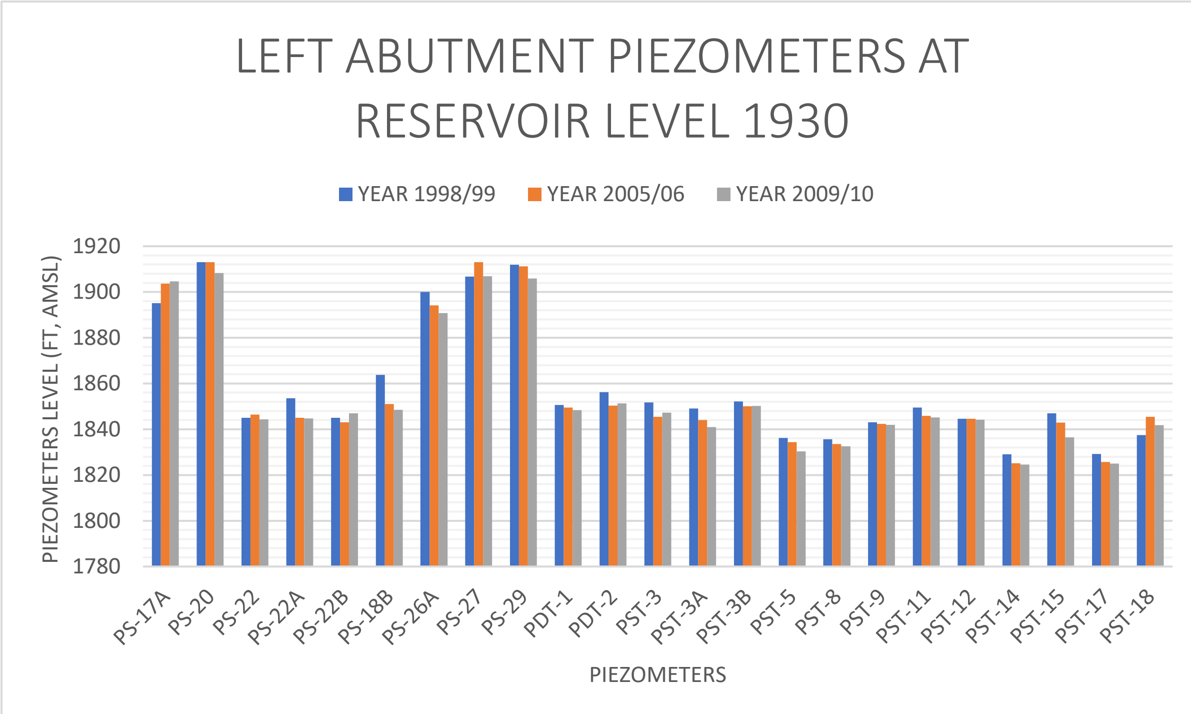


Fig 5.15: Comparison of Left Abutment Piezometers Levels at RL 1930

5.3.2: Piezometer Levels at Right Abutment

There are 8 drain holes in the spillway. Remedial work like grouting and dental concreting at right abutment very effective as piezometer levels of drain holes reduces 5-10 percent. As evident from below graphs the Drain Hole DH-13 has the highest values in 1998/99, seepage effectively reduces after remedial work and graph values becomes stable.

The Drain Hole DH- 8 also had comparatively higher values at high reservoir levels. This was also taken care of and now the values as shown in graph are under control evident by similar level during the remaining years.

Drain holes in Spillway at right abutment now becomes safe and no need of remedial work needed. Seepage is under control over last 20 years.

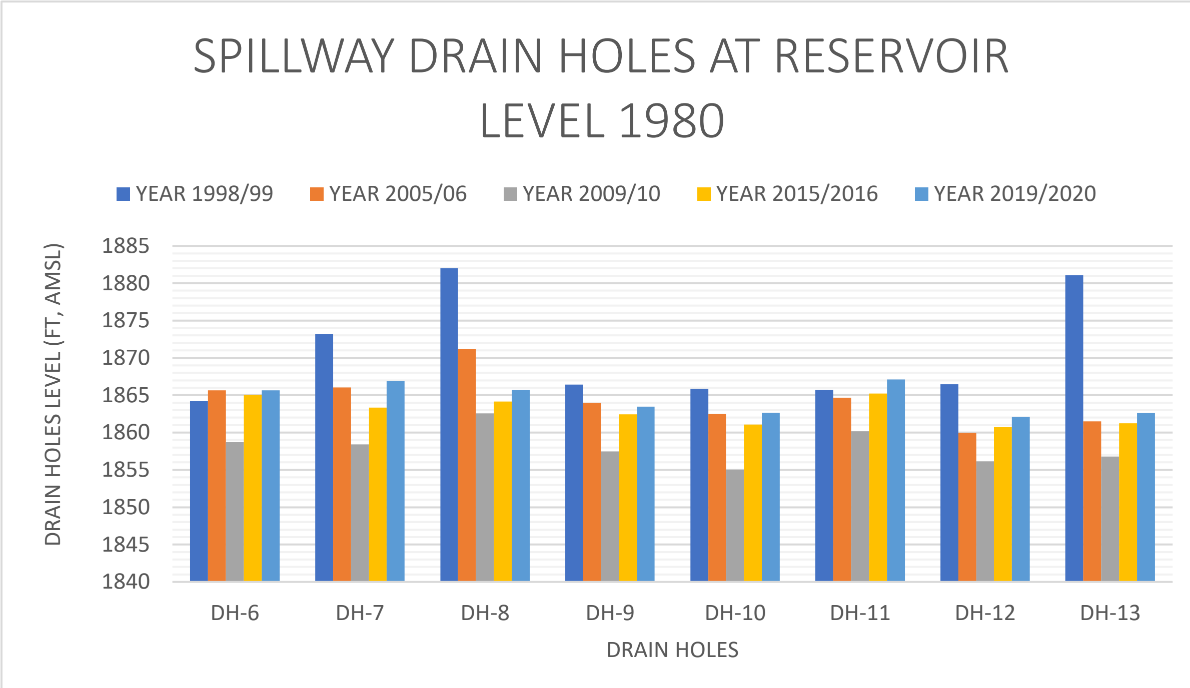


Fig 5.16: Comparison of Right Abutment Drain Holes Levels at RL 1980

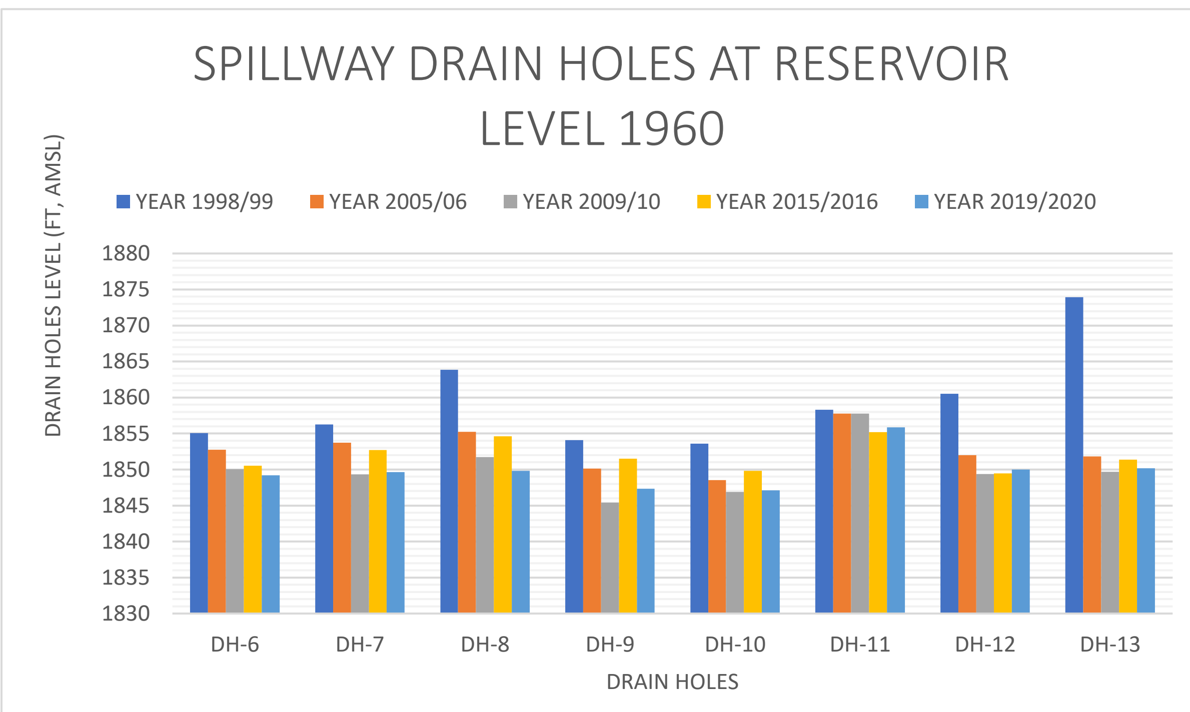


Fig 5.17: Comparison of Right Abutment Drain Holes Levels at RL 1960

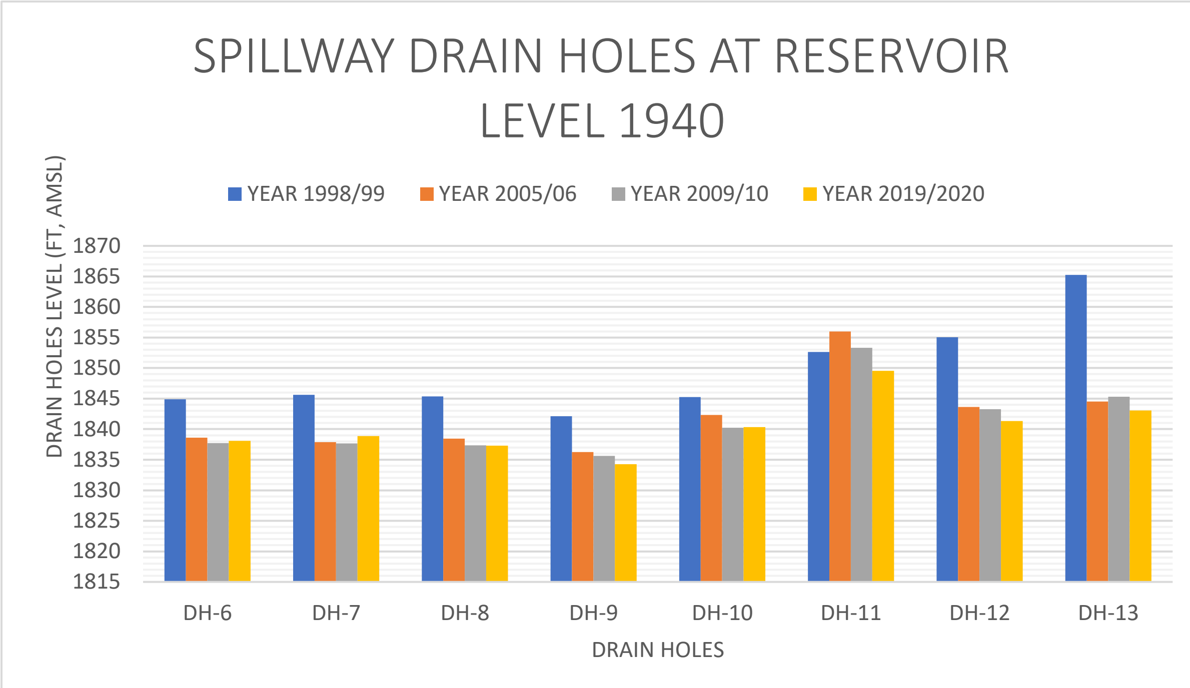


Fig 5.18: Comparison of Right Abutment Drain Holes Levels at RL 1940

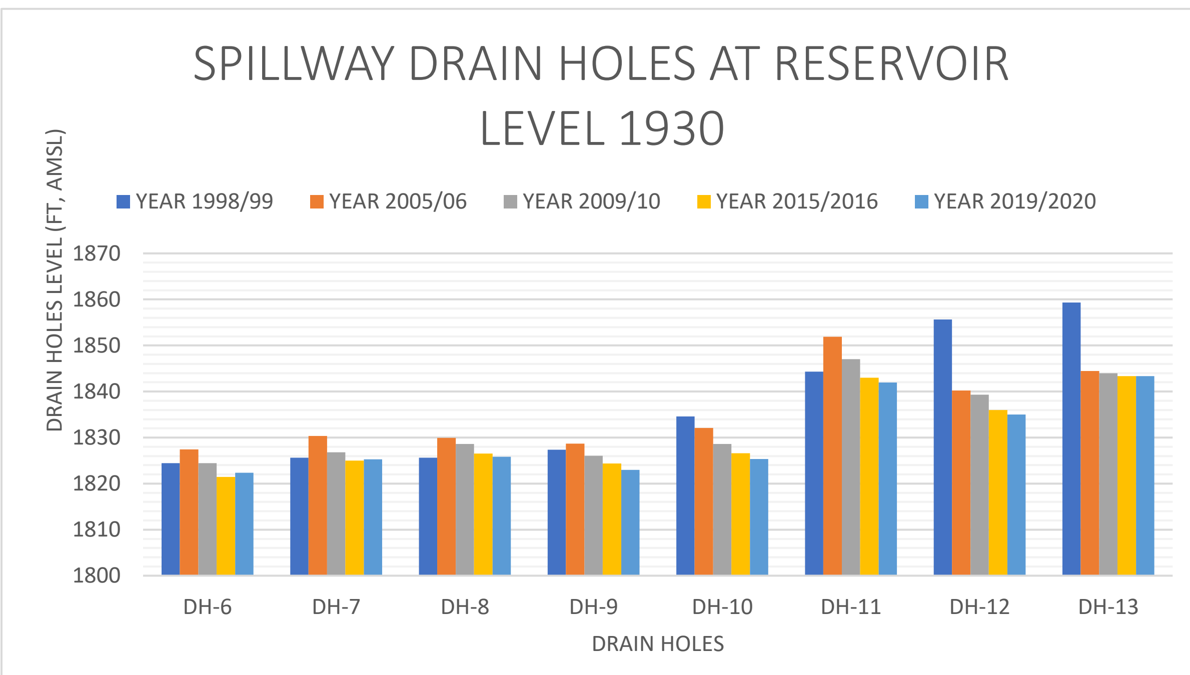


Fig 5.19: Comparison of Right Abutment Drain Holes Levels at RL 1930

5.3.3: Main Embankment Dam

MED consist of piezometer and relief wells installed at downstream toe, with exception of one piezometer installed at upstream level. Both of them compared below at different reservoir levels.

- **5.3.3.1: Piezometers levels Comparison**

There are 47 instruments used in the Main Dam. As evident from graph, there are very minor changes in all piezometers levels over last 23 years data. Seepage at Main Dam is in under control as its piezometer level values similar in all years shows below in Graph.

Two instruments CD-1 and PS-24 shows a different behavior than other 45 instruments. Graph illustrate that CD-1 and PS-24 are two weak points of Main Dam. Both these instruments are under special supervisions. That’s why CD-1 and PS-24 readings same today as in year 1998 over the period of 23 years.

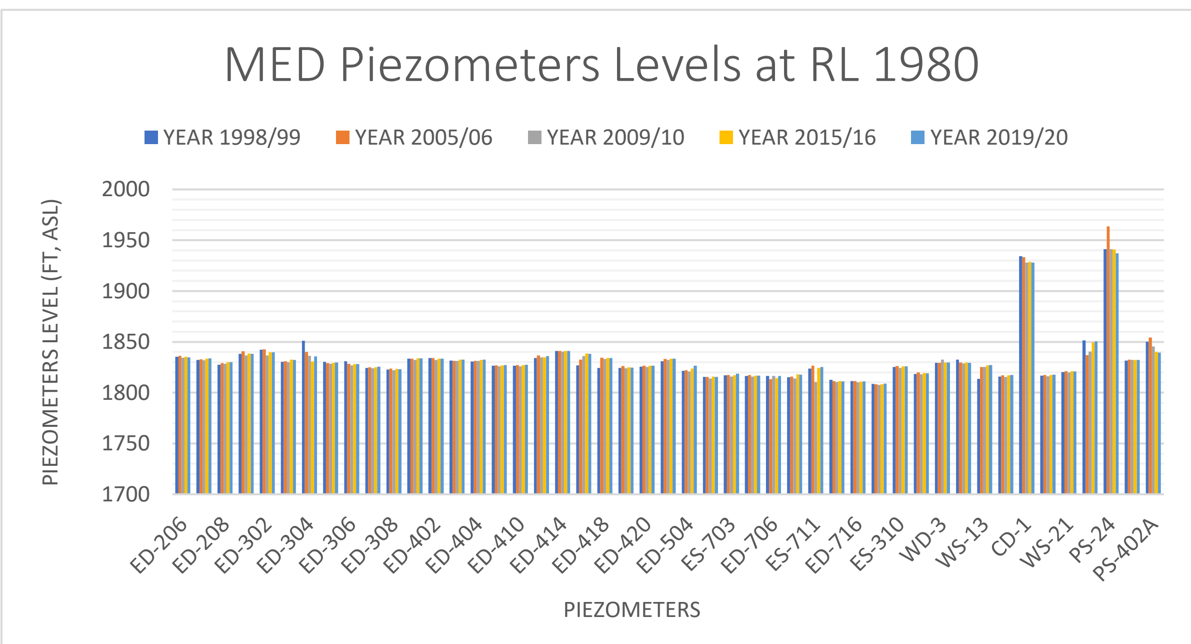


Fig 5.20: Comparison of Med Piezometers Levels at RL 1980

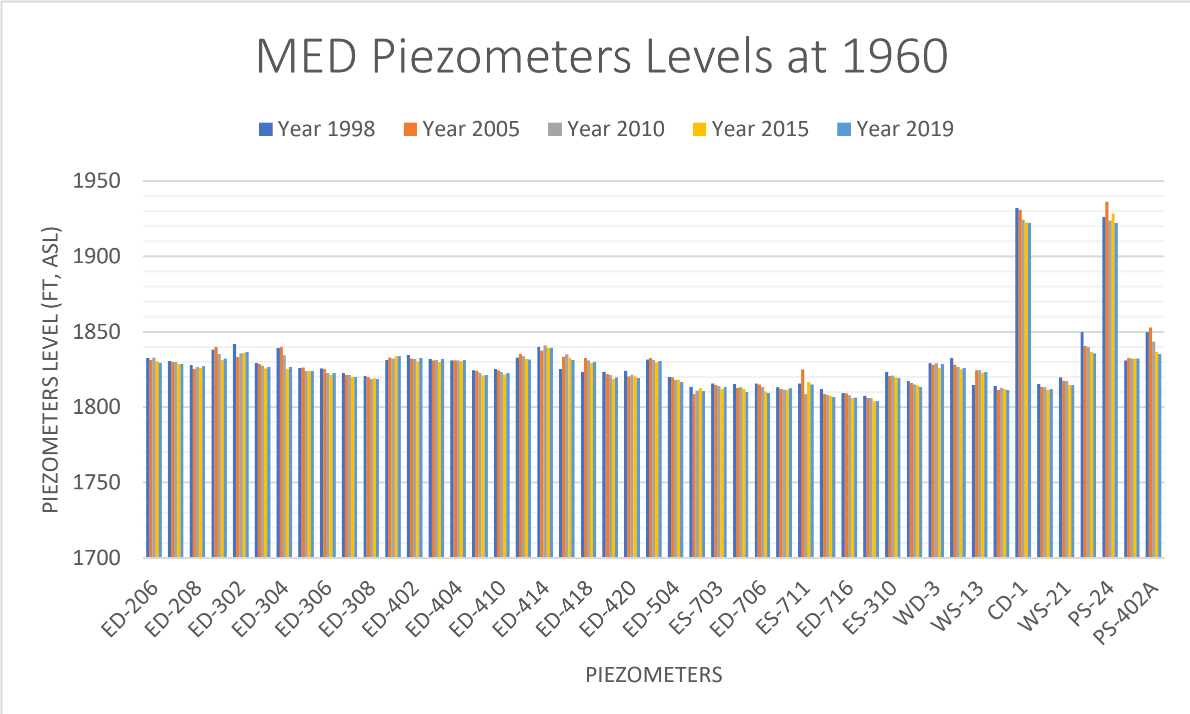


Fig 5.21: Comparison of Med Piezometers Levels at RL 1960

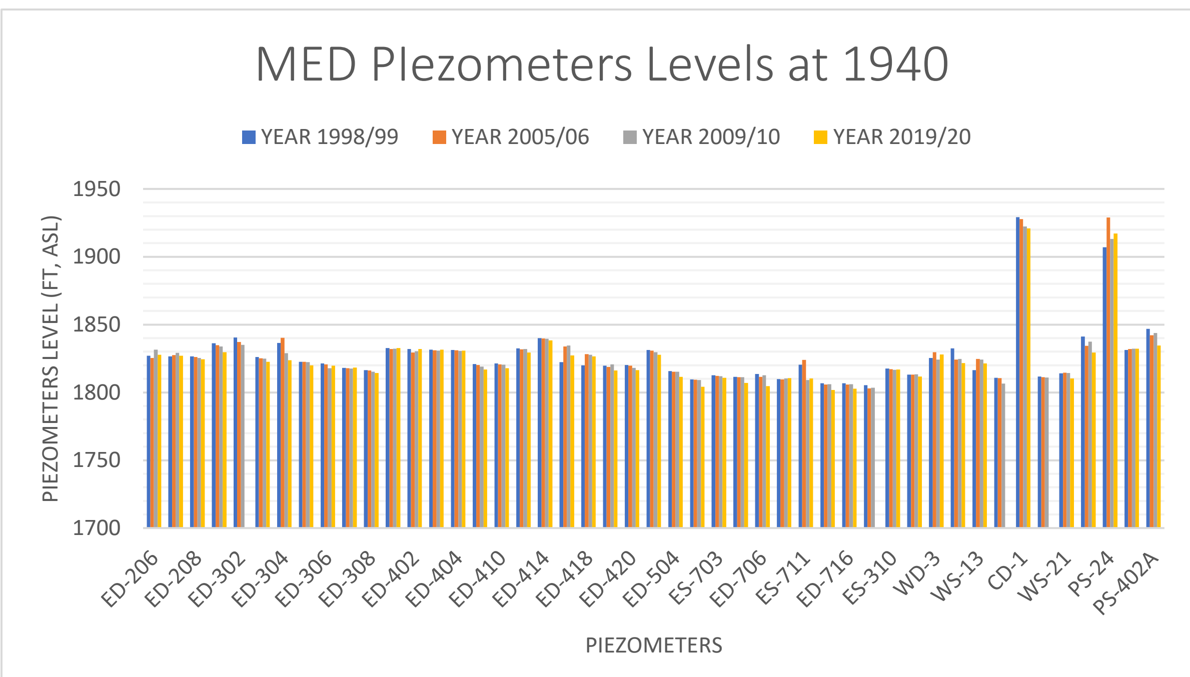


Fig 5.22: Comparison of Med Piezometers Levels at RL 1940

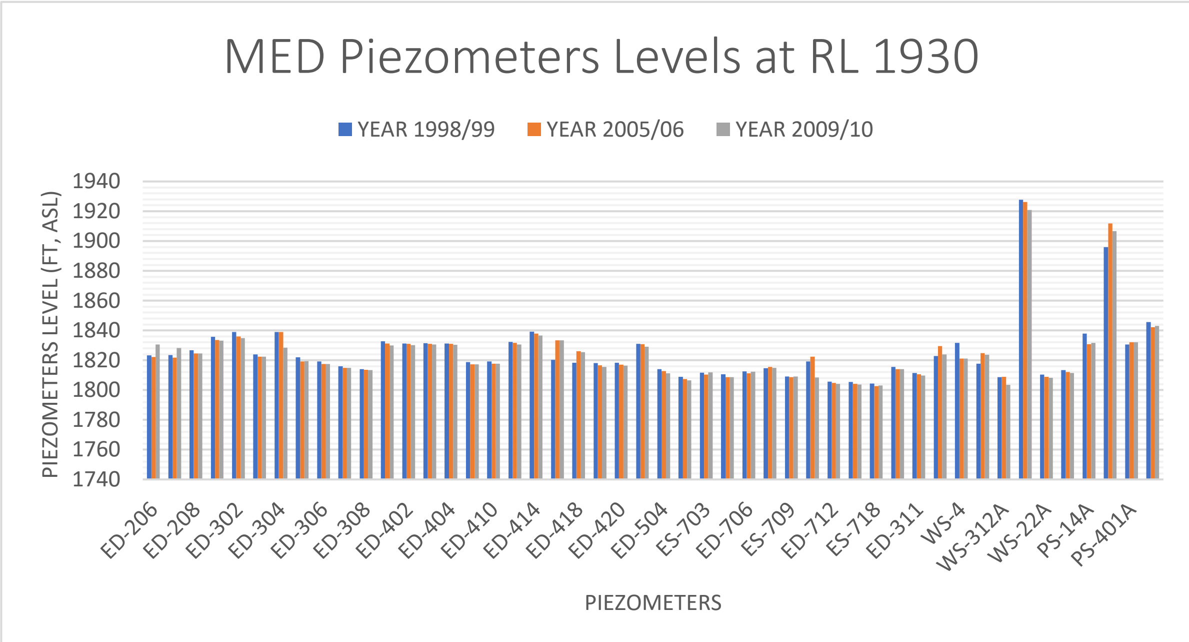


Fig 5.23: Comparison of Med Piezometers Levels at RL 1930

- **5.3.3.2: Relief Wells Comparison**

There are total of 16 relief wells. The Relief Well RW-31 showed higher readings in 1998/99. After the seepage control measures were taken the piezometer reading were decreased and the graph remained linear afterwards.

The values of the data from the remaining relief wells shows that as a general trend the seepage is controlled, and this part of the dam doesn't have any particular seepage problem.

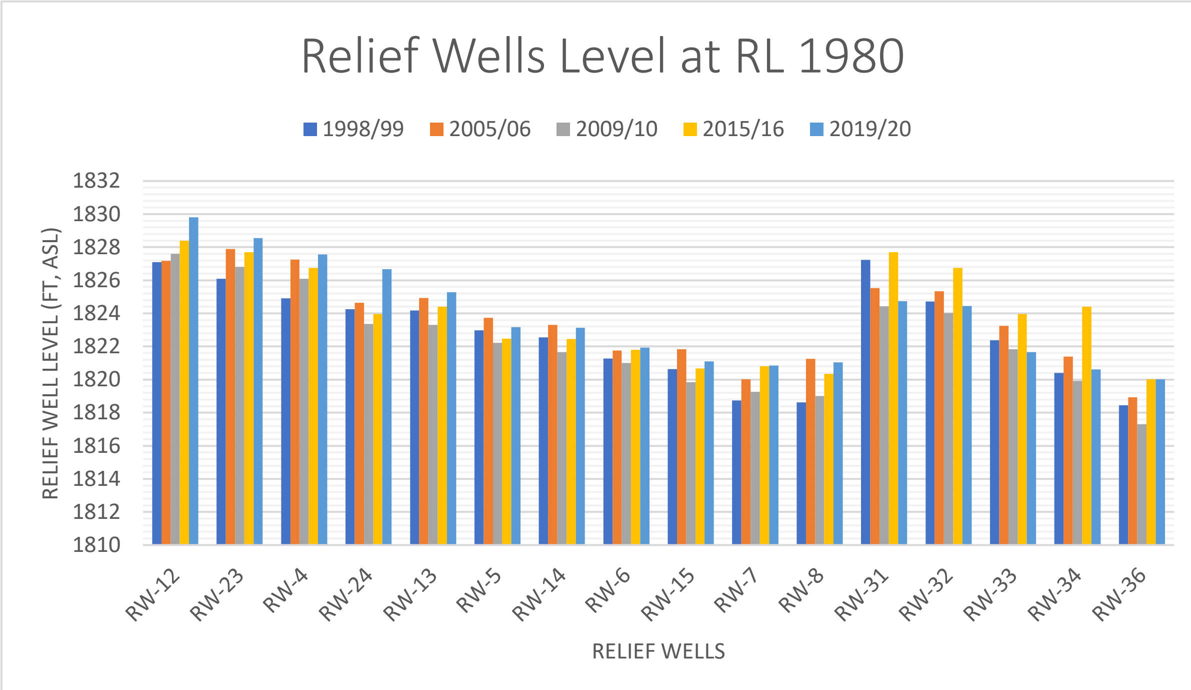


Fig 5.24: Comparison of MED Relief Wells Levels at Reservoir Level 1980

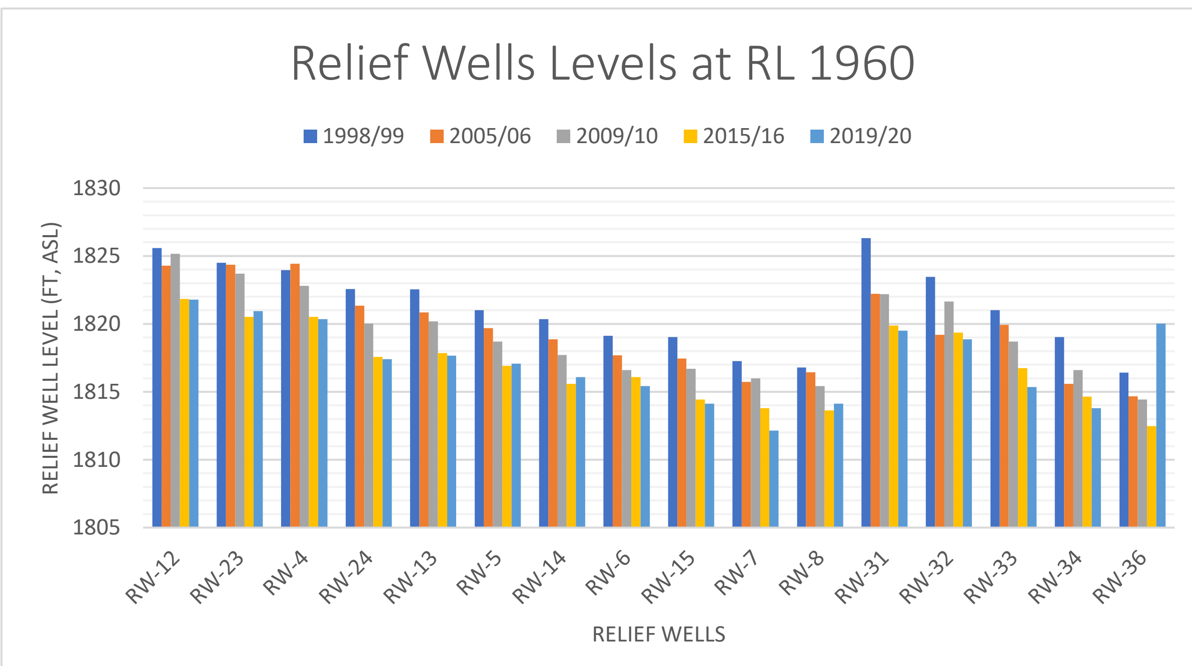


Fig 5.25: Comparison of MED Relief Wells Levels at Reservoir Level 1960

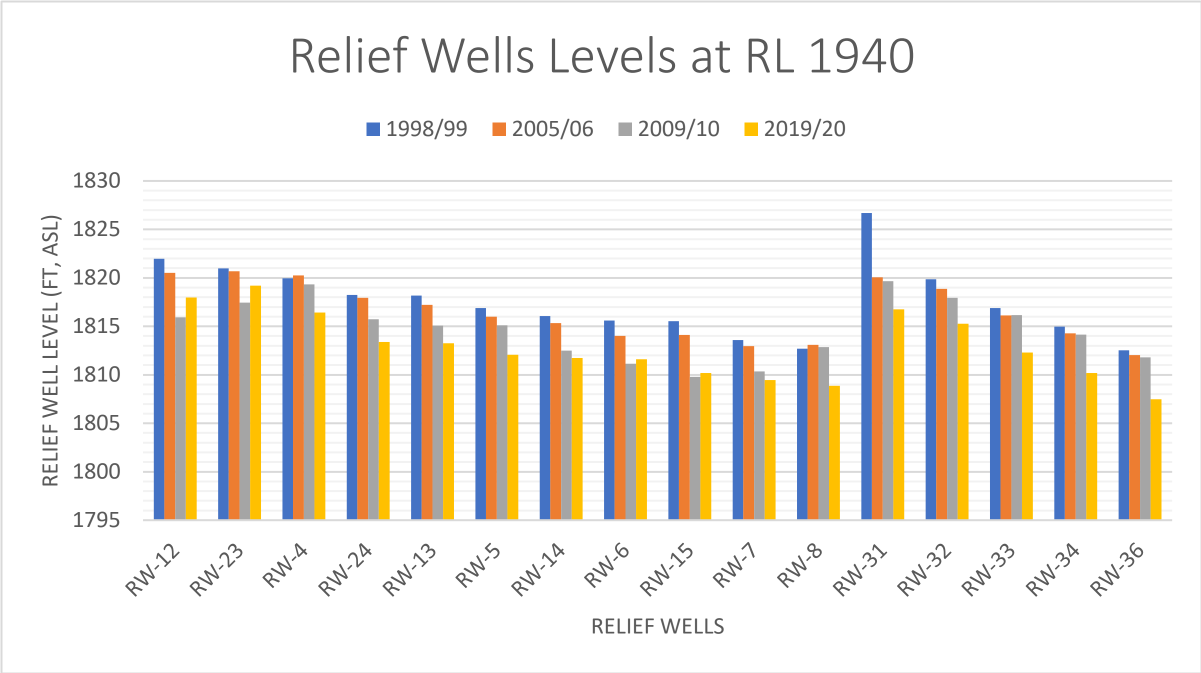


Fig 5.26: Comparison of MED Relief Wells Levels at Reservoir Level 1940

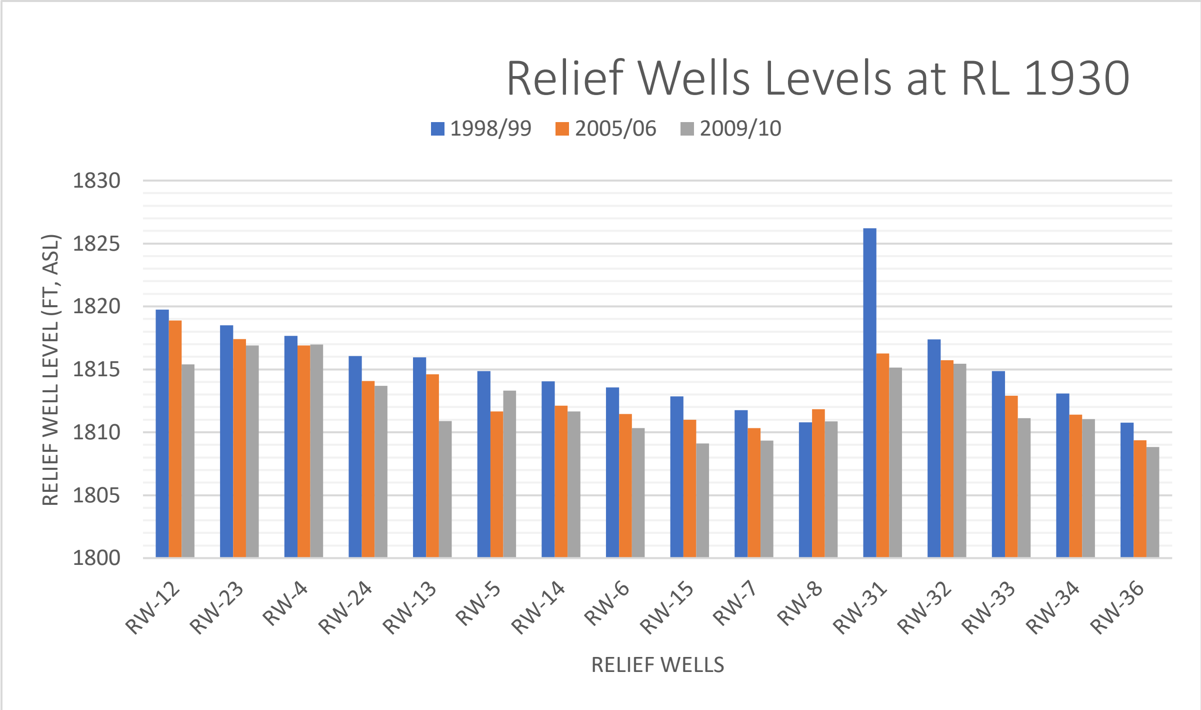


Fig 5.27: Comparison of MED Relief Wells Levels at Reservoir Level 1930

5.4: Geotechnical Behavior Modelling

5.4.1: General seepage Comparison

For Geotechnical behavior assessment, Rocscience slide 6.0 is being used for seepage analysis. Additionally, manual hand calculations are also done and results are compared with software output which resembles with negligible differences. These results are base line for comparison with actual seepage results. Seepage comparison results illustrate whether dam is safe, or it needs remedial/precaution measures.

Table 5.2: Comparison of Seepage Quantities at Different Reservoir Levels for Year 2019

Mode/Methods	Seepage (Cusec) at Different Reservoir Level (ft, AMSL)			
	1980	1960	1940	1920
Actual Seepage	60.9	47.15	30.977	4.45
Rocscience Slide	32.3	27.41	22.27	17.46
Manual Calculations	30.82	26.96	22.97	18.85

5.4.2: RocScience slide Seepage Results

Analysis is done by making cross-section, defining problem, assigning properties, analysis method, meshing, permeability value of 1.67×10^{-7} for impervious core and 1.067×10^{-3} for foundation. Finite Element Analysis is used. Then compute and interpret results that shown below.

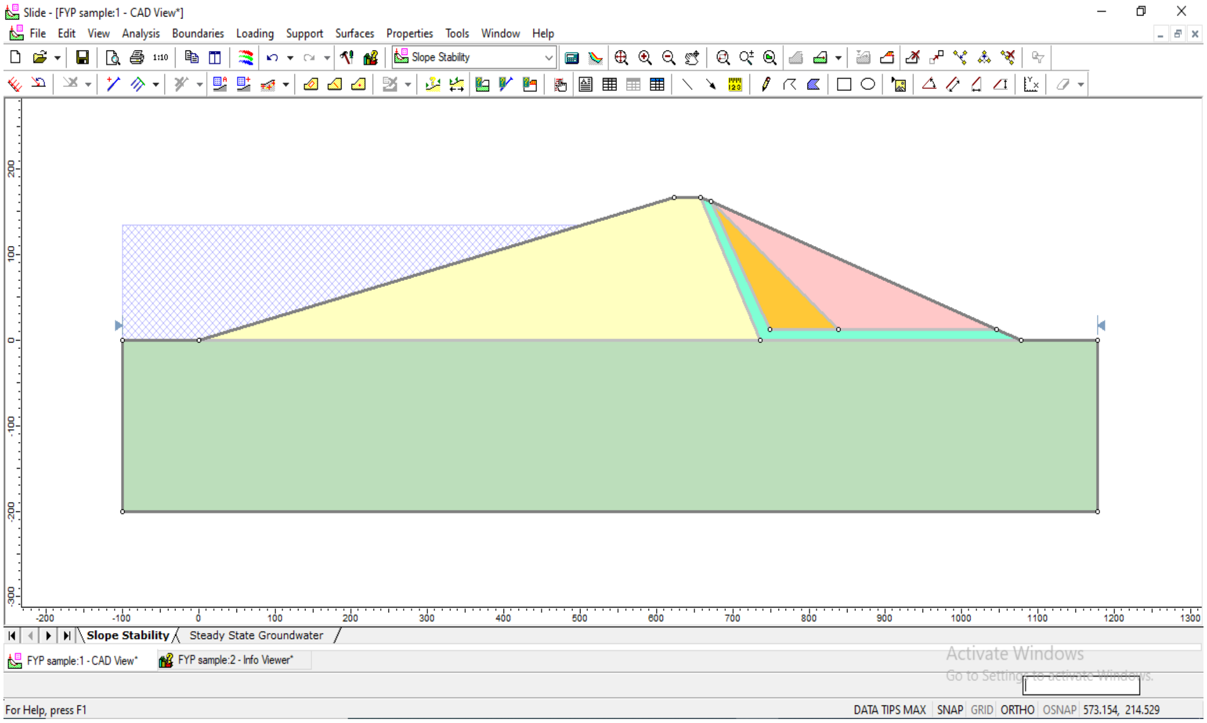


Fig 5.28: Assigning Material properties for Analysis

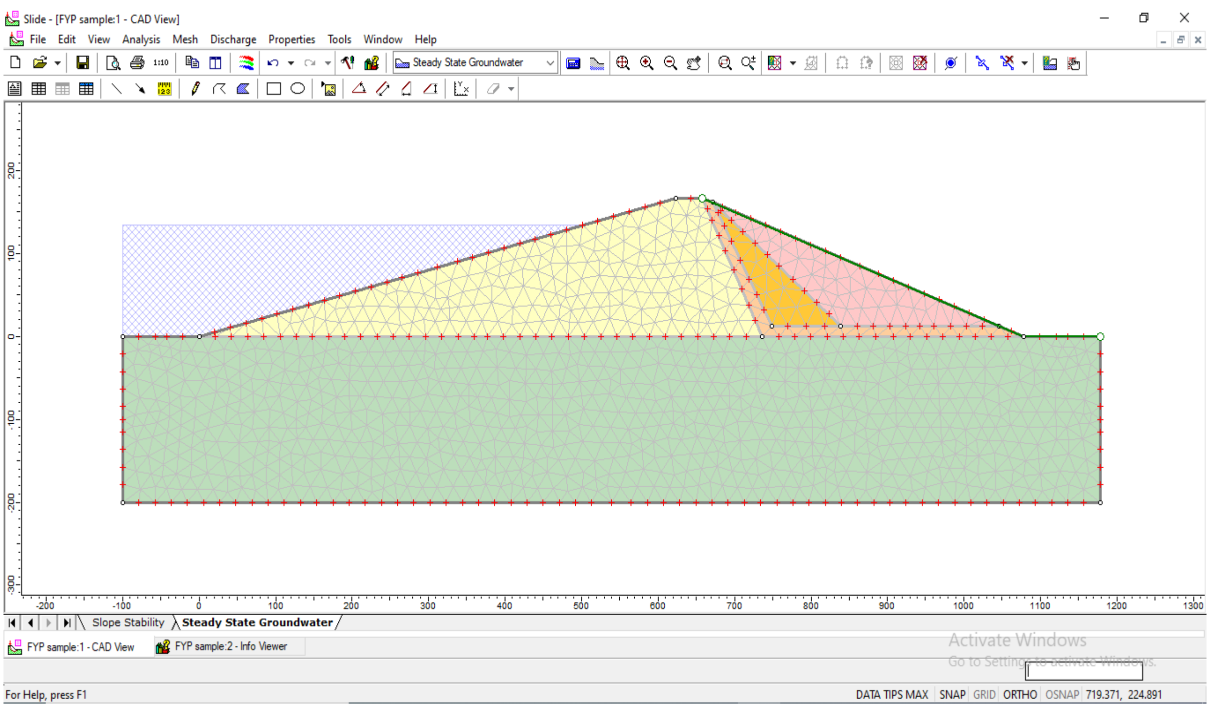


Fig 5.29: Meshing and Assigning Material properties for Analysis

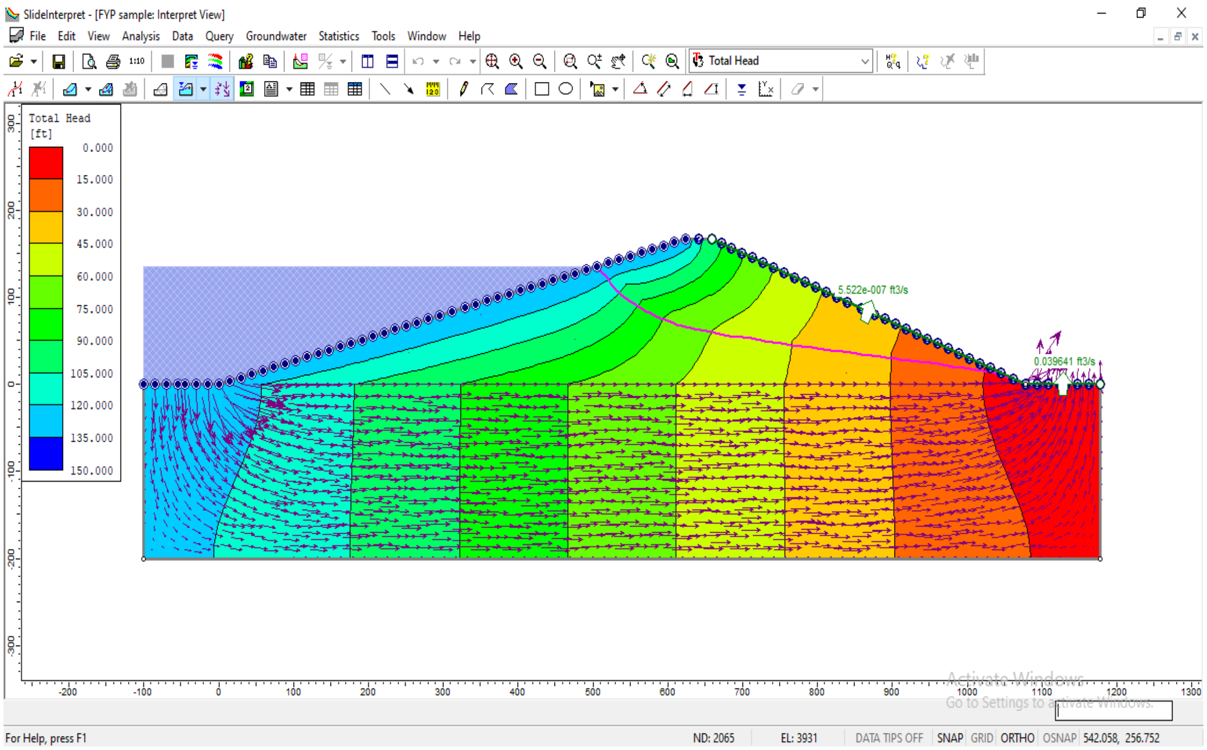


Fig 5.30: Seepage Result at RL 1980

→ Seepage Result at RL 1980

Seepage per unit length = 3.96x10^{-2} cusec

Total Seepage at dam = (3.96x10^{-2}) x (1560) = 61.78 cusec

By including Dam Foundation shape Compensation,

Total seepage = 61.78 x 0.523 = 32.3 cusec

→ Seepage Result at RL 1960

Seepage per unit length = 3.36x10^{-2} cusec

Total Seepage at dam = (3.36x10^{-2}) x (1560) = 52.41 cusec

By including Dam Foundation shape Compensation, Total seepage = 52.41 x 0.523 = 27.41 cusec

→ **Seepage Result at RL 1940**

Seepage per unit length = 2.73×10^{-2} cusec

Total Seepage at dam = (2.73×10^{-2}) x (1560) = 42.59 cusec

By including Dam Foundation shape Compensation,

Total seepage = 42.59 x 0.523 = 22.27 cusec

→ **Seepage Result at RL 1920**

Seepage per unit length = 2.14×10^{-2} cusec

Total Seepage at dam = (2.14×10^{-2}) x (1560) = 33.38 cusec

By including Dam Foundation shape Compensation,

Total seepage = 33.38 x 0.523 = 17.46 cusec

5.4.3: Manual Seepage Calculations

We use L Casagrande Method for manual seepage calculations. There are parts, one is seepage though dam while second part is seepage through foundation.

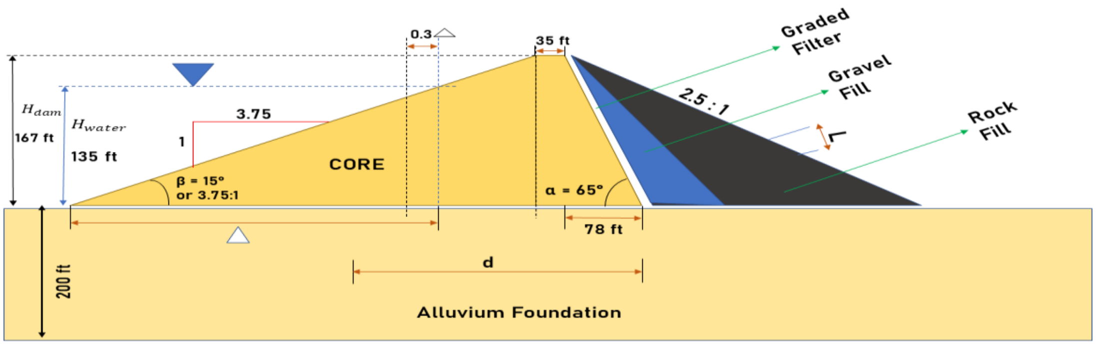


Figure: *Calculation of Seepage using L. Casagrande, through the dam*

- **5.4.3.1: Seepage Calculations through Main Dam**

→ **At Reservoir Level 1980**

$\Delta = \frac{H_{Water}}{\tan 15} = \frac{135}{\tan 15}$ =503.8 ft

0.3 Δ = 151.14 ft

d = 151.14 +120+35+78= 384.14 ft

Applying L. Casagrande Solution, when α > 30°

$$L = \sqrt{d^2 + H_{Water}{}^2} - \sqrt{d^2 - H^2 (\cot\alpha)^2}$$

$$L = \sqrt{(384.14)^2 + 135^2} - \sqrt{(384.14)^2 - 135^2(\cot 65)^2} = 28.22 \text{ ft}$$

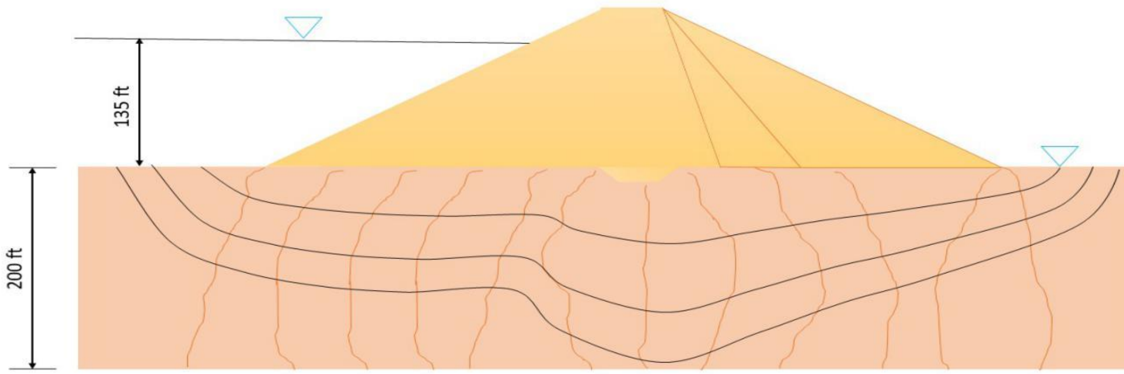
Seepage, per unit length;

$q_1 = KL\,(\sin\alpha)^2 = 1.67 \times 10^{-7} \times 28.22 \times (\sin 65)^2 = 3.87\times10^{-6}$ cusec/ft

Total Seepage of the Dam;

$Q_{1(dam)} = 3.87 \times 10^{-6} \times 1560 = 6\times 10^{-3}$ cusec

▪ 5.4.3.2: Seepage Calculations through Alluvium Foundation



No of flow lines, N_f = 3

No of equipotential lines, N_d = 13

Head Difference h = 135 ft

Permeability of alluvium Foundation, K = 1.067 x 10^{-3} ft/sec

Seepage through the Foundation;

$q_2 = Kh\frac{N_f}{N_d}$

q_2= 1.067 x 10^{-3} x135 x3/13 = 0.033 cusec/ft

Seepage through foundation = Q_2 =0.033 x 1560 = 51.48 cusec

Total Seepage = Q_1+$Q_{2=}$ 51.486 cusec

Total Seepage with compensation of the dam foundation shape

= 51.486 x 0.523 =26.96 cusec

Chapter 6: Conclusions and Recommendations

6.1: Conclusions:

The location and geology of Khanpur Dam is predominantly composed of weak rocks that wear off by the action of water quite easily, most commonly shale and limestone are present. These formations are the part of the Margalla Hill Limestone formation of Eocene age (Shah, 1977). Most of these rock formations have eroded and faults have developed in them. These faults are the main cause of large quantity of seepage which greatly effects the water level in the dam. Most of this seepage is unaccounted for since there are no piezometers or instruments to measure the water lost. One of the main sources is from the Chohea area where number of faults are responsible for the huge amount of water loss due to seepage (Muhammad Saleem Khan, 2012).

A report on the success of the grouting and the remedial measures carried out with reference to Khanpur dam indicates that there was an overall 59%, 29% and 20% reduction in seepage corresponding to reservoir levels of 1920, 1930 and 1940 ft (Khan, 2004). Since no grouting was carried out above 1950 ft hence the control of seepage above this level has been in significant.

The following conclusions can be derived from the research:

- The area of the dam site is prone to earthquakes, the dam site has been very successful in resisting the harmful effects of these earthquakes.
- From the analysis of data it can be concluded the seepage after 2010 has decreased to some extent (48 cusecs in 2010 compared to 40.75 in 2019; this is a **decrease of 15.10% in seepage** in **9 years**) without taking any additional measures, this may be due to filling of cracks by silt, also known as the self-healing phenomena of dam.

- The measures taken to reduce the seepage in 2002 have worked so far by reducing the seepage below the 1950 ft reservoir level.
- The data of nearly all of the piezometers have remained same or increased / decreased by very small extent in comparison with the previous years, from this it is safe to assume that no new faults have developed in the dam structure.
- The plunge pool area of the dam is showing higher reading than the other structures, due to this it is under constant supervision of dam authorities.

6.2: Recommendations:

The following actions are recommended based on the research;

- Deliberate testing by the Dam Safety Organization of WAPDA is recommended to find the seepage flow paths for future remedial works having maximum effectiveness.
- More accurate deep 3D scan and modelling of the dam should be done to calculate the exact seepage paths and to perform recommended measures.
- This project was aimed at finding any faults in the main dam and the spillway, further examination of other embankments and abutments is recommended to find any faults in them.
- The effectiveness of remedial works decreases above RL 1950, hence further study is recommended to carry out remedial works above this level.

- Water samples should be periodically collected, and laboratory tested to check for any colloidal or suspended particles, which may point towards formation of piping phenomena in the dam.
- The dam should be equipped with latest sensors and the data collection system should be automated \ computerized to minimize the errors.
    - Fiber optic leakage detection
    - Distributed Temperature Sensing.
- A system should be installed to automatically analyze the data and alert if any anomaly is detected.

References

ACE, 1984. *Geological Maps and related file record of Khanpur Dam Project ,* s.l.: Associated Consulting Engineers (ACE).

Ali, N., 2010. *Geotechnical Evaluation of Seepage Remedial measures at Khanpur Dam,* Islamabad: s.n.

Ali, S. M., 1993. *Third Periodic Inspection Report on Khanpur Dam Project,* Lahore, Pakistan: Associated Consulting Enginers.

Barron, 1977. Blanket of Dams at Upstream.

Bertram, D., 1940. Filter Ciriteria of Earthen Dams.

Cadergren, H. R., 1968. Seepage Control in Earth Dams.

Cambefort, 1977. Hydro-Fracture Grouting in Adaptive Structures.

Casagrande, A., 1935. Seepage Through Dams.

CIRA, 2000. *Adaptive Structures.* [Online]
Available at: https://www.cira.it/en/competences/strutture-adattive/Adaptive%20Structure

Coffman & Franks, 1982. Berms Control.

ETL 1110-2-569, 2005. Design Guidance for Levee Under Seepage.

Khan, M., Gillani, T. & Gul, A., 2011. Post impounding problems and management measures in carbonate geology at Khanpur Dam Project. *Journal of Science International,* pp. 23, 1232-1236.

Khan, M. Q. M., 2004. Application of grouting for seepage reduction and dam safety in carbonate geology, its management and evaluation. *Journal of Science International,* Issue 16, pp. 265-270.

khan, M. S. Q. M. S., 2011. Post impounding problems and management measures in carbonate geology at khanpur Dam project. *Journal of Science international,* Issue 23, pp. 1232-1236.

Manfred, 1990. Premation Grouting; Method and Remedies.

Moseley & Kirsch, 2004. Grouting for Betterment.

Muhammad Saleem Khan, M. A. G. M. A., 2012. Geological aspects of seepage problem and its management at Khanpur dam project, Pakistan. *Journal of Himalayan Sciences,* 45(1), p. 6.

Reuben, 2003. Comapction Grouting.

Romanov, D., Gabrovesk, F. & Dreybrodt, W., 2003. Dam sites in soluble rocks, a model of increasing leakage by dissolutional widening of fractures beneath a dam. *Engineering Geology,* pp. 70, 17-35.

Royster, H., 1977. Piping Phenomenon of Drainage in structures.

Shah, S., 1977. Statigraphy of Pakistan. In: *Geological Survey of Pakistan.* s.l.:s.n.

Shah, S., 1977. *Stratigraphy of Pakistan,* s.l.: Geological Survey of Pakistan,.

Taskforce 27, 1990. *Technique of Rock Grouting and Calculations,* s.l.: U.S. ACE.

U.S. ACE;, 1995. In: *Geophysical Exploration for Engineering and Environmental Investigations.* s.l.:U.S Army Corps of Engineers, pp. 4-8 - 4-29.

Shah, S.M.I., 1977.Stratigraphy of Pakistan. Geological survey of Pakistan, Quetta, Memoirs.

Uromeithy, A., Barzegari, G.,2007. Evaluation and treatment of seepage problems at Chapar Abad Dam, Iran. Engineering Geology, 91 ,219-228.

ACE, 1984.Geological map and related file record, Khanpur Dam Project by Associated Consulting Engineers (ACE).

Khan, M. S, Gillani, T.A., Gul, A., 2011.Post impounding problems and management measures in carbonate geology at Khanpur Dam Project.Journal of Science International,23,1232-1236.

M.S, Khan.,M.A, Gul., and M, Aziz.,2012.Geological aspect of seepage problem and its management at Khanpur Dam Project, Pakistan.Journal of Himalayan Earth Sciences, 45,77-81

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