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Dam Safety Monitoring of Gilgel Gibe III Hydropower Dam Project

BY

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LIST OF ABBREVIATIONS

2-D	*Two dimensional*
CVC	*Conventional Vibrated concrete*
F.D.R.E	*Federal Democratic Republic of Ethiopia*
FEM	*Finite Element Method*
GWh	*Giga watt hour*
ICOLD	*International Commission on large dams*
K	*Hydraulic conductivity*
MLR	*Multiple linear Regression*
MW	*Mega watt*
RCC	*Roller Compacted Concrete*
RMSE	*Root mean square error*
SNNPRS	*Southern Nations and Nationalities People Regional State*
USA	*United States of America*

ABSTRACT

Dam safety monitoring tool determines a functional performance of dams with an extended service time. One of the main dam safety monitoring tools is seepage monitoring system. This research presents assessment of dam safety monitoring technique using seepage observed at Gilgel Gibe III hydropower project the highest RCC dam in the world. SEEP/W a component of GEO-STUDIO 2007 have been used to do the seepage analysis. A number of hydraulic conductivities are used to find out different trial seepage values. Trial seepages were produced for different reservoir water level for trial hydraulic conductivity from SEEP/W model. These calculated seepage values together with the measured seepage from the dam site are an input for Multiple Linear Regression Model (MLR). Then, the MLR coefficients were calculated by optimizing the seep/w results with the measured seepages for a given water level in the dam. The model result concides with the measured result with Mean error of $-4.020\text{x}10^{-2}\text{m}^3/\text{s}$*, mean absolute error of* $5.65\text{x}10^{-3}$ m^3/s *RMSE of* $7.18\text{x}10^{-3}$ m^3/s *and* r^2 *value of 0.91. The RMSE, Mean error and Mean absolute error being closer to zero indicate the quality of model to represent acctual condution. While the* r^2 *value being the 91 % shows the better quality of the representative model. Then a model is developed and accurately predicts the expected seepage with different specific reservoir level. Using the model, safe expected seepage is produced for the safe future monitoring of the dam. By using these calibrated MLR coefficient and seep/w model seepage a monitoring curve is developed. The curve obtained can be used to monitor the dam safety against seepage for future operation.*

Key words

Gilgel Gibe III dam, SEEP/W, MRL, Reservoir water level, Hydraulic conductivity.

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1. Introduction

1.1 General background

Dam is a hydraulic structure built across a river to create a reservoir on its upstream side for impounding water for various purposes. The purposes may be hydro-power, irrigation, water-supply, flood control, navigation, fishing and recreation. Dams may be built to meet one of the above purposes or they may be constructed to fulfill more than one. As such, it can be classified as Single-purpose and Multipurpose. Dames are divide into embankment dams about 70% of the total number contracted in the world, concrete dams about 28 % and masonry dams about 2% covers. [1]

Dam construction has an important role and determines the growth rate of one nation. In history dams are one of the oldest man-made constructions. The history of dam construction dates back to about 3000 B.C. In Egypt and then in middle east cultures associated with the Tigris and Euphrates Rivers [2], but the large dam construction became possible during the 20th century mainly because of advances made in Science and Technology, which enabled mechanization of construction processes and quicker construction. Today, there is a large number of dams and many of them are high with large reservoirs. [3]. In Ethiopia dam construction came to existence at the begging of 1930’s, when Aba Samuel dam scheme was commissioned in 1932. [4]

By construction hydroelectric dam hydropower covers the largest place next to thermal energy by covering 30% of the total power supply of the world [4], currently in Ethiopia the F.D.R.E Government focused on renewable energy policy that is why different dams are constructed. Now a day construct different size of hydropower project on the basins including the grand renaissance dam and Gilgel Gibe IV which is under construction. Gilgel Gibe III hydropower scheme is one of the renewable energy source already constricted in this country that plays a great role in solving the electric scarcity problem in Ethiopia and East Africa.

Special attention and continuous safety assessment is required in dam engineering because dams are one of the most important hydraulic structures due to their importance in multidisciplinary economic and social values, and their heavy investment cost. Dams are should get more attention because of their failure behavior that can result in unacceptable fatalities and economic damage this is due to their catastrophic failure consequence.

Because of problems related to geology, construction techniques and other criteria of dams these structures may also change and exposed for different safety complications. Which is lead for grate unexpected potential catastrophe to downstream life and economic damage. For this reason, analysis such as dam safety monitoring related to seepage analyses are the most common type of analysis in dam engineering. Since safety assessment is obviously a key issue in any project will the structure remain stable or collapse. Recently, many researchers studied and analyzed the dam safety monitoring based on seepage process and they were able to solve many problems by developing appropriate solution for the given dam, and this paper believe that dam safety monitoring must be done for all type of dams including those dams constructed in Ethiopia. So, this paper is engaged for Gilgel Gibe III RCC hydropower dam project which is located on OMO River, owned 243 m of total Hight which is the highest RCC dam in the world.

Stored water represents stored energy that is continually seeking release to downstream. Seepage is simply reservoir water finding its way downstream through pervious material or through imperfections in the dam or its foundation. The force or pressure behind the seeping water can create new or enlarge existing seepage pathways until the dam is breached. Thus, the control of seepage is extremely important in the design, construction, and safe operation of dams [2].

Dams must be prevented from excessive uplift pressures due to seepage piping of materials, removal of material by leakage, or erosion of this material into cracks, joints, and cavities.

Seepage through the foundation dam body and abutments must be controlled and collected to ensure safe operation. The design and construction of RCC gravity dam should include seepage control measures such as adequate foundation treatments like Grouting, proper RCC mix placement, RCC compaction, sufficient Drainage and Inspection Gallery and adequate instrumentations.

Nowadays the significant problem that researchers are interfere which is seepage problem. Seepage phenomenon which is one of the most significant motive of dam's destruction in recent years which is calculated by experimental and numerical methods or by simulating in physical models in laboratories.

1.2 Problem statement

The seepage of water highly influenced by the permeability and the storage characteristic foundation Geology materials. On the top of Gilgel Gibe III dam foundation arrangement there are Slightly Weathered Trachyte (SW-T) with maximum thickness of 120m. The upper foundation rock of the dam site (120m) is somewhat weaker, discontinues and weathered. Such rock foundation is compressible and susceptible for differential settlement because of its character and also exposed for seepage problem due to their permeability and low water tightness, this is one of the reasons for this paper to intend with the Gilgel Gibe III foundation seepage.

Dam Safety monitoring activities of concrete dams using Seepage analysis was not a common methodology in the past experience, In the past, overtopping phenomenon and others are the first reason of dam destruction, but nowadays the significant problem that researchers are interfere is seepage problem. Seepage phenomenon which is one of the most significant motive of dam's destruction in recent years. So, seepage analysis must be done with high attention for gravity dams also.

From recorded history and recent experiences some concrete dams have failed because of a very serious seepage problem. Examples of Concrete dams completely failed due to seepage problem are, Alla Sclla Z. crbino in Italy, Eigiau in Wales and Puentc Kolnbrein dam in Austria. The majority of these failed dams either did not have a monitoring system or had a system that was out of order. Many RCC Gravity dams faced serious Seepage problems like Willow Creek Dam in USA, Xibing in China, Upper Stillwater Dam in USA. These examples are a very clear evidence seepage analysis is very important in concrete dams also.

Gilgel Gibe III dam project is a cascade project since, Gilgel Gibe IV dam is already under construction 108 km far from the Gilgel Gibe III downstream, so such study and analysis are very important to save one or subsequent downstream dams and users. Because if any serious safety problem happened, dam failure can result in undesirable loss of life and economic damage. Which again underscores the importance of seepage analysis in case of dam engineering especially in the case of cascade projects.

In addition, assessing the safety of existing dam condition is important to serve the designed period and in order to decrease potential hazard. Thus, this research tries to define the safe seepage rate of Gilgel Gibe III. Once such safe seepage rate for a given water level in the reservoir is defined any seepage which will occur in the dam body shall comply with this seepage rate. If the observed seepage is beyond what have been proposed it signals that the dam is not safe. Such indicators will warrant further investigation into the causes of such observed seepage variations beyond the expected one and indicative to use other techniques of monitoring to improve the dam safety. By doing so the safety of the dam situation could be identified and monitored. Thus, this research has tried to set a defined seepage quantity for a given water level based on measured seepage data.

1.3 Objectives

General objective

The overall objective of this study is to devise a methodology for Gilgel Gibe III dam through Seepage analysis.

Specific objective

- To develop safe seepage monitoring curve.
- To assess the current state of dam safety monitoring techniques used in Gilgel Gibe III dam
- To asses and evaluate the dam on the base of monitoring.

1.4 Organization of the thesis

This thesis is divided into five main parts. The first chapter provides background information to establish a framework for the research. Chapter two includes, literature review. Chapter three deals with the methodology and material used, over view of the recorded data, data quality, derange galleries locations, selection of typical cross section of the dam and simulation methods for seepage analysis of Gilgel Gibe III dam are included. Chapter four focuses on the results and discussion of the simulated and monitored values and parameters. Finally, in chapter five conclusions and some suggestions for future monitoring activity. The thesis has appendices giving some basic analysis results.

2. Literature review

2.1 Roller compacted concrete dams

These types of dams are widely used and becoming common for high dams as is evident in the construction of Gilgel Gibe III, which has a height of 243 m, the highest RCC dam in the world. Roller Compacted Concrete RCC in dam Engineering came up in early 1970s as an application for the construction of portions of the dam, spillway and for re-habitation uses. Roller compacted concrete is combination of crushed and/or screened gravel rock, Portland cement of low heat of hydration, water and water- reducing/retarder additive, if required added the mix may also include filler produced from natural volcanic ash or other suitable sources. The filler content will be added at the mixer, then these

Materials are damp by roller consistency. A roller-compacted concrete RCC dam that is composed of mixed sand aggregate and cement is constructed with the roller-compacted placement method in thin layers of dry lean concrete [5] .

The first two large RCC gravity dams in the U.S. — Willow Creek in Oregon and Upper Stillwater in Utah with a height of 56 m, which was built in 1982 in the USA, and the Xibing RCC Gravity Dam, with a height of 63.5 m, which was built in 1985 in China. Such type of dams can accommodate spillways within the dam body, allow overtopping, and safely discharge considerable flow during construction and operation. This would minimize size of diversion structures. RCC construction technology is lower making construction time shorter its construction process is much simpler and faster than that of a conventional concrete dam. At present, 450 RCC dams over 30 m are operating in over 30 countries [6].

Dam construction has always looked to three major factors, dam safety, durability and economy. The RCC technology has been developed combining the economical and rapid placement resulting from a high degree of mechanization with the strength and durability of concrete. Construction procedures associated with RCC require particular attention be given in the layout and design to water tightness and seepage control, horizontal and transverse joints, facing elements and appurtenant structures. Roller compacted concrete (RCC) is better than Conventional vibrating concrete (CVC). Because of lower cement consumption, rapid construction and minimized diversion and cofferdams. The most important advantage of proposing an Roller Compacted concrete (RCC) Gravity Dam for dam lies in the maximum Reduce cost 25%-50% as compared us Conventional Vibrated concrete (CVC) and rapid construction for large projects, also many advantages, including high construction speed, short time limit for a project, RCC dams can be finished 1 to 2 years earlier compared to regular mass concrete dams and mechanization, simple construction, adaptability etc. are most RCC dam advantages. [7]

In the case of RCC gravity dam the major case of seepage failure through the dam and foundation is stated due to improper spreading and compaction of RCC at the time of RCC mix placement. It must be applying at least one static and three vibrated (dynamic) passage with 18-ton roller. It increases the strength, lowers the compressibility and reduces the permeability of a Construction material, but if this core activity is at risk water will be leak from Reservoir to the downstream portion during operation period of the Dam, most of the time such problems are happen at both edge of upstream and downstream face because here the place is edge and not suitable for Roller compaction truck and that is why the compaction process is done by Convectional vibrated concrete (CVC) but still there will be some seepage problem.

In concrete dam seepage occurs in most cases through joints and cracks, at the contact with the rock and at poorly constructed joints. In case of evidence of new seepage flows or significant increase in flows, the immediate notification to the person in charge is necessary. The quantity of the seepage flow should be estimated.

In the case of large dams the RCC construction technique is not monolithic, there is Contraction joint, that means the dam is divided in to different block by cutter from the upstream to downstream, actually this is done for controlling of crack during expansion of the concrete due to temperature, then to control transfer of crack from one portion to another portion of the Dam, but it has a negative impact of seepage controlling, and the water coming into the dam from the reservoir through the cut block is controlled by water stop plastic material but these plastic material may come to failure and seepage will have high probability to occurs.

Seepage may happen in RCC dams when contact/ consolidation Grouting is not performing sufficiently, the purpose of contact/ consolidation Grouting is in order to consolidate the dam foundation and to fill the voids between the RCC and rock foundation when bedrock profiles are steep and overlying soils are moderately compressible, unacceptably high differential settlement may occur.

Generally, these dams experienced Seepage through lift joints and at shrinkage cracks. Since that time, design engineers, owners, and contractors have been looking for innovative methods to improve durability of RCC and to limit seepage. [6]

2.1.1 Gilgel Gibe III dam

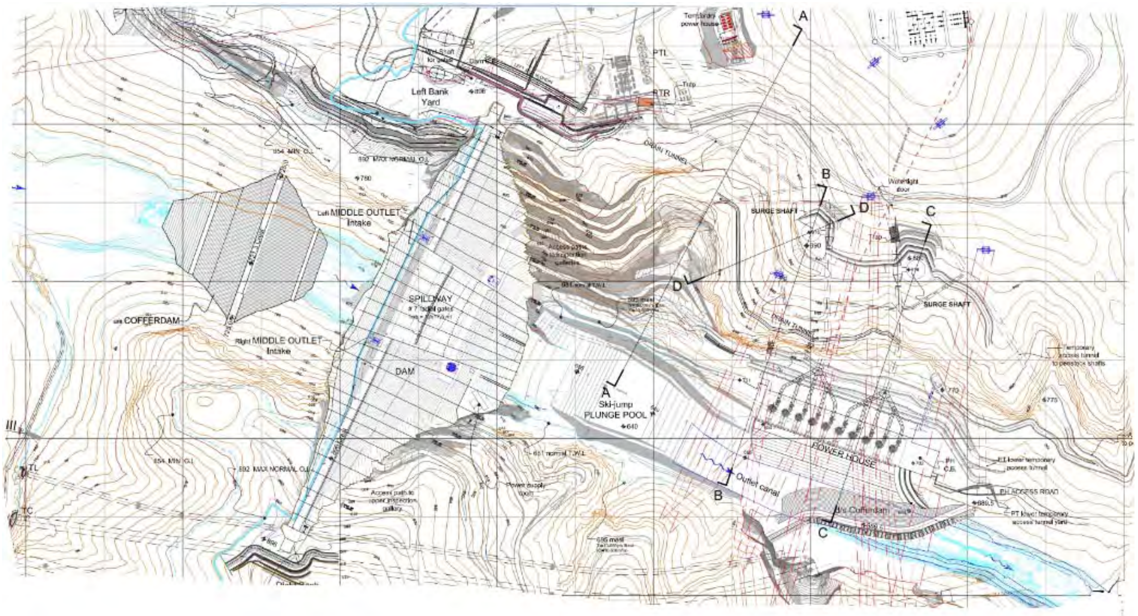

FIGURE 2. 1: Gilgel Gibe III Dam lay out

2.2 Design and construction considerations of RCC dam

- **Water Tightness and Seepage control**

Achieving water tightness and controlling seepage trough Foundation and RCC bam body are particularly important design and construction Consideration. The joint between the concrete lifts and interface with structural elements and segregation are the major pathway for potential seepage through the dam and Foundation. RCC that has been properly proportional, mix placed and compacted should be as impermeable and watertight. Seepage can be controlled by incorporated special design and construction procedures that include contraction between RCC layers, draining and collecting the seepage.

❖ Upstream Facing

Some RCC dams experienced significant seepage through lift joints and/or vertical cracks. RCC cannot be compacted effectively against upstream forms, an upstream facing is required to produce a surface with good appearance and durability. Facing systems now are being used to reduce seepage and to improve durability and appearance. Many facing incorporate a watertight barrier.

❖ Seepage Collection

A collection and drainage system is a method for stopping unsightly seepage water from reaching the downstream face and for preventing excessive hydrostatic pressures against conventional concrete spillway or downstream facing. It will also reduce uplift pressure within the dam and increase stability. Collection method includes vertical drains with water stops at the upstream face and vertical drain holes drilled from within the gallery near the upstream face and vertical drain holes drilled from within the gallery near the upstream or downstream face. Collected water can be channeled to gallery or the dam toe. [5]

❖ Construction joints

Construction joints are required in the Gilgell gibe III RCC dam. The space that is provided by the cutter in the RCC is used to control the cracks during expansion of the concrete due to temperature. If properly designed and installed, contraction joints will not interfere or complication the continuous placement operation of RCC.

❖ Water stop

The main purpose of water stop is to stop the water coming in to the dam and let to go to the drain holes and to gallery. Water stop are installed in internal zone of conventional concrete placed around the joint near the upstream face to continuous watertight barrier. Water stop and joint drains are installed in the same manner.

2.3 Dam zoning and foundation layer

2.3.1 Dam zoning

The dam zoning is must be completed based on the stability analysis and seepage control point of views. For most effective control of seepage, the permeability should progressively increase from the central part to upstream, and the bearing capacity must be high at the downstream and upstream portion of the dam. The six zones envisaged for the dam including.

- RCC 18 MPa mix
- RCC 15 MPa mix
- RCC 12 MPa mix
- RCC 10 MPa mix
- Conventional Concrete
- GE- RCC

Conventional concrete is adopted on the spillway chute to guarantee the required resistance to the high-speed flows, and GE-RCC layer is foreseen at the edge of dam upstream face for constructive reasons this layer is also envisaged all along the downstream face. Four different RCC mixes, varying in characteristic strength from 10 to 18 MPa, are adopted in the dam body. Highest strength mixes are foreseen, as usual, on the upstream and downstream faces and at the toes, where highest stresses are reached during construction and operation. RCC dam zoning depend on the RCC construction mixes and stability analysis.

Table 2. 1 RCC dam zoning classification of Gilgel Gibe III dam project

Zoning number	Bearing Capacity(Mpa)	Cement content $({}^{kg}/_{m^3})$	Beading mix
1	18	125	BM Spread
2	15	110	BM Spread
3	12	90	BM Spread
4	10	80	BM Spread

2.3.2 Foundation layer

The dam site area is situated on the Jima volcanic formation which characterizes the main part of the South Western Ethiopian highland. The formation belongs to the tertiary volcano sedimentary units and is mainly constituted by trachyte, basalts, pyroclastics and rhyolite. The stratigraphy of the Gibe III dam foundation is characterized by the presence of a sequence of volcanic and volcano-sedimentary rocks.

The geological section along the dam foundation is illustrated on Figure below.

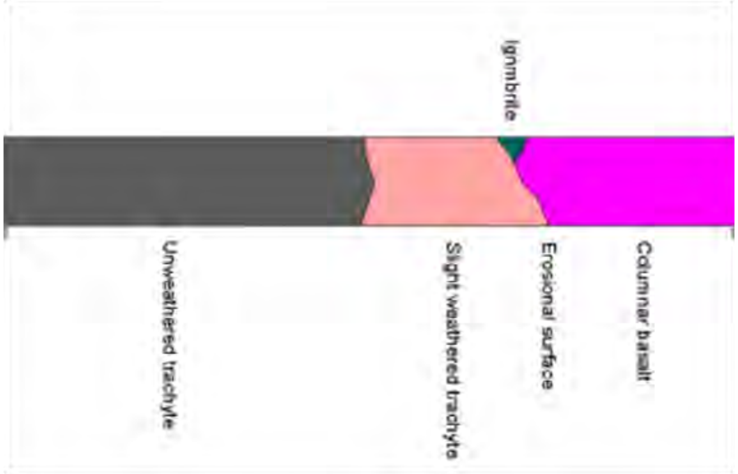

FIGURE 2. 2: Geological section along the dam foundation

TABLE 2. 2: Foundation layer

Locations	Chainage		Main Rock Unit
	From	to	
Lift abutment	0+00	0+200	SW-T
	0+200	0+300	U-T
River bed	0+300	0+460	SW-T
Right abutment	0+460	0+620	SW-T
	0+620	0+710	Basalt

2.4 Grouting and other foundation seepage controls

Grouting is a mixture of cement, water, sand, bentonites, if required, which is forced under pressure in to prepared holes or pipes in order to fill voids or consolidation the roc k mass as a whole to control the seepage. Generally, the grout mix has binding behavior, so that it is penetrating in to the rock through the joint to bind any separated rocks.

Rock grouting consists essentially of drilling a series of grout holes in rock and injecting grout under pressure, which eventually sets in the openings and voids in the rock.

Generally, foundation grouting comprises consolidation grouting and curtain grouting. Depths for a grout curtain should be sufficient to minimize seepage and assist in the reduction of uplift and the need for extensive drainage facilities. Where conditions permit, grout holes should bottom in sound, relatively impervious rock. In general, it may range from 30 to 40 percent of the head of the water on good foundation and to 70 percent of head on poor foundations. Consolidation grouting is introduced by drilled shallow holes with different patterns, depending on the type of the dam and the geological conditions and it is usually restricted to the upper 5m to 20m [8].

During the grouting process the following procedures must be employed.

1. The viscosity must be 29 to 30 sec.
2. The sedimentation limits not greater than 5 %
3. Compressive strength of 28 days must be 10 to 20 Mpa.

The grouting operations foreseen in the Gilgel Gibe III dam project include the following grouting type.

❖ Contact / consolidation grouting

Contact / consolidation grouting is required in order to consolidate the dam foundation and to fill the voids between the RCC and the rock foundation. The Contact / consolidation grouting holes are arranged over the dam foundation and grouting will be done. The total depth of Contact / consolidation grouting is 10m, that is 7m for consolidation grouting and the rest 3m for contact grouting.

❖ Curtain grouting

Curtain grouting is applied in order to establish an effective seepage barrier along the upstream and downstream and it’s done from the drainage galleries. The producers taken in curtain grouting are:

I. Primary injection: The primary curtain grouting is starts by following the prepared holes arranged at interval of 12 m and the depth hole is $2/3$ of the dam Hight.

II. Secondary injection: The Secondary injection grouting follows the primary grouting and those are arranged at distance of 6m alternating with primary grouting holes and the depth of hole is 70% of the primary hole.

III. Tertiary injection: The holes of the tertiary injection are arranged at a spacing of 3m in alternating with the primary and secondary holes. The depth of hole is 40% of the primary hole.

IV. Quaternary injection: This grouting follows the tertiary grouting depending on the result of the tertiary that to be decided whether or not to apply it.

V. Check holes: After tertiary or quaternary injections, the check holes are done in order to assess the efficiency of the grouting applied. The drilling is carried out by continuous lugeon test. The check holes spacing is from 24m up to 50m.

2.4.3 Cut-offs foundation seepage control

Construction of cut-off under the foundation is common in dam engineering. The main importance of provision of cutoff is to prevention of seepage beneath the dam and the effecting of a watertight closure between the dam and the foundation. To prevent seepage beneath foundations usually grouted. [9]

Grout cut-offs are also usually formed in the rock foundation under a concrete dam. Cutoffs are designed to lengthen the seepage path, dissipate reservoir head to reduce exit gradients to safe levels, and reduce seepage quantities. [2]

Cutoff is required for the following functions:

- ❖ To reduce loss of stored water through foundation and abutments and
- ❖ To prevent subsurface erosion by piping. [9]

2.5 Water pressure test

The water pressure test is a method to assess the natural fracture/ permeability of the rock through the lugeon value. This value comprises for each of test runs at increasing and then decreasing pressure is measured in litters/meter/minute (l/m/m). The purpose of water test is to determine the absorption of the drilled hole. Water pressure test is essential to know if grouting is needed or not for a selected hole. The efficiency of the grouted curtain will be checked through water test in control holes. The test is carried out at the base of drill hole using a single inflatable packer and inflating using gas pressure supplied from a nitrogen bottle.

2.6 Couse of RCC dam failures

Due to the stored water and seepage through dam body and foundation condition, there are problems to the dam, its foundation as well as impounded water. Among this:

a. **Foundation deficiencies**.

These defects are associated with the quality of the foundation or with the foundation treatment. Differential settlements, slides, excessive pressures, weak seams or zones, and inadequate control of seepage are all common potential failure mechanisms within a foundation. Visible cracks in a dam can be indicative of foundation movement. Marginal foundation stability can sometimes be identified by a thorough examination of design and construction records [10].

Settlement of the dam and foundation and the resulting cracking can also occur from the collapse of foundation soils caused by loading subsequent wetting of the foundation materials.

This collapse of foundation soils can occur in fine sands and silts with low densities and low natural moisture contents. The settling and subsequent cracking of embankment materials can be especially disastrous if the embankment contains soils which readily crack when deformed. Seepage through the foundation can cause piping of solid materials or the erosion of soluble materials by solutioning. This removal of foundation material forms voids which can increase until a portion of the remaining unsupported material collapses and failure of a section of the foundation occurs [10].

b. **Inadequate seepage control**

Seepage problems can occur in concrete dams as well as through or along the foundations. Uncontrolled seepage through an dam can cause the movement of materials to unprotected exits, creating voids, and leading to piping failures. Improper compaction differential settlements pervious embankment materials, inadequate construction control can cause excessive seepage through dam.

Uncontrolled seepage can result in excessive pore pressures in foundation. This can cause a weakening of the rock mass and can result in abutment failures, upstream or downstream slope failures.

2.7 World experience on dam failures

The failure of dam throughout the world had result in catastrophic damage of life, structure and crops. This could result from poor initial design or construction, lack of maintenance and repair, or the gradual weakening of the dam through the normal aging processes. That it is necessary to have a monitoring and surveillance system established, is highlighted by number of dams which experience accidents and failures, often after many years of operation. As an example, dams failed due to seepage problem are listed below [11].

- Gouhou dam

On August 27, 1993, a Concrete Faced Dam failed in China (Gouhou Dam) after the reservoir level reached the top of the slab the failure was due to failure of the gravel shell. Although many CFRD’s have been built from freely draining rock fill and clean gravels with no stability problems with slopes ranging from 1.3 to 1.6: 1, this particular dam had a 1.5: 1 downstream slope, but it was constructed with sandy gravels with about 40% of the particles finer than 5 mm. With the leakage through the face and perimeter joint, the dirty shell materials were not pervious enough to conduct the flow at low gradients and a phreatic surface raised high enough in the shell that the normal CFRD slopes could not be maintained, and the dam failed [11].

- Baldwin Hills Dam

Baldwin Hills Dam in the Los Angeles area was a 71m high homogeneous earth-fill embankment dam has been constructed on April 18, 1951. The impervious member was a 1.5m thick compacted earth lining which was constructed on an asphaltic membrane. The dam failed by piping on December 14, 1963. Although there was a pea gravel and clay tile drainage system under the bottom of the reservoir, there was not a drain or filter system between the upstream slope of the embankment and the downstream slope of the homogeneous embankment. It is possible that the distortions of the embankment due to the differential settlements in the area due to oil extraction was a factor in cracking the lining which resulted in uncontrolled seepage downstream of the lining on the upstream slope of the embankment because there was no downstream drain or filter zones in the embankment [11].

❖ Walter Bouldin Dam

In February, 1975, the Walter Bouldin Dam in Alabama failed. The 50.1m high embankment dam just to the left of the powerhouse breached. This location is where cretaceous fine sandy silts could have piped undetected into the tailrace channel from seepage lines in the foundation of the left embankment dam, as there was no cutoff to bedrock beneath the left embankment dam immediately adjacent to the left side of the tailrace channel. These seepage lines were not filtered in the design and could have exited into the tailrace channel below water level where the piping would have been uninspected [11].

❖ Teton Dam

On June 5, 1976, the 126 m high Teton Dam of the USBR failed during first filling, which had been initiated in October 1975. The failure of Teton Dam was a clear Case of piping because the silt core in the rock cutoff trench in the right abutment was directly placed against open jointed rhyolite without a filter between the silt and the jointed rock [11].

2.8 Seepage analysis

Dams must be designed and maintained to safely control seepage. Nevertheless, dams experience at least some seepage and many suffer from excessive seepage. Excessive seepage may lead to a problem with the safety of a dam if not treated properly. The effective control of seepage requires that both the dam and its foundation be considered together.

The Kolnbre dam, a concrete arch buttress dam was built in Austria in 1979 but excessive seepage occurred on the first filling, and a large crack appeared in the dam. [12] Seepage was the cause of failure of several modern dams, such as the Teton Dam in 1976 and Quail Creek Dike in 1989. Each failure has brought new understanding and advances in the control of seepage. [12]

2.8.1 Seepage measurement and observation

Seepage must be measured in the dam body and foundation. By observing the location, quantity and quality of seepage emerging from the dam embankment and its foundation, and particularly the changes which occur, one can get early warning of problems.

It is emphasized that routine observation of where seepage is emerging can be as useful guide as the actual measurement. Seepage is preferable to collect the seepage close to the downstream toe of the dam. Smaller dams it is acceptable to measure total seepage downstream of the toe of the dam and for larger dams, it is often impractical to have a system to collect from the top to bottom of the dam.

A change in the total quantity of flow within the conduit or from individual drains or wells is indicative of potential problems developing with the concrete, waterstops, or other seepage control systems of the dam. Unusual seepage may indicate increasing pressures along concrete lift lines or joints within the dam or along the base of the dam that may lead to eventual instability of the dam. A change in seepage quantity is a cause for concern, because it may indicate seepage pressures are approaching levels that exceed the design loads for the structure or that the drainage system is not working properly.

Measurement of seepage may be made by V-notch or similar measuring weirs. This may include continuous recording of data for more important dams. [13]

2.8.2 Drainage galleries

Concrete dams founded on rock may have unique drainage features. Galleries are often used to collect and monitor seepage. Large concrete dams are often constructed with internal galleries. The galleries serve a dual purpose of providing access for inspection and providing for internal drainage. Galleries collect seepage from construction joints through a network of smaller vertical and horizontal drains directed into the structure, and may collect seepage from the foundation through a network of vertical relief wells drilled into the foundation. A conduit may be present in the gallery that directs the combined seepage from all the drains to a low-level downstream outlet. [2]

2.9 Estimation of seepage

To determine the effect seepage may have on a dam, consider the seepage path and the potential for piping, internal erosion, and development of excessive pressures, several methods and techniques are used in making these determinations. In some cases, a review of available information and experienced judgment are adequate, while in other cases, extensive field investigations and detailed analyses are required. The logical analysis of seepage started with the development of Darcy's law in 1856, the flow is applicable to the steady-state flow of an incompressible fluid through porous media [14]. A French engineer Darcy proposed that, what the flow through soils is laminar, the discharge velocity (v) is proportional to the hydraulic gradient, (i). the flow through porous media is proportional to the length of flow path is known as a Darcy's law. [15]

Darcy's law is thus

$$q = kiA$$

K= permeability

I = hydraulic gradient

A= cross sectional area of flow

Darcy's law used in the analysis of seepage conditions today with the aid of computers.

2.9.1 Numerical computer solution

A numerical model is a mathematical simulation of a real physical process. Computer models are used increasingly to make acceptable approximations in complex flow conditions. Finite element is primary methods of numerical solution. It can be used for two-dimensional and three-dimensional problems and software is available from several sources. Very simple problems can be solved by hand, but more difficult problems require a computer. Finite element method uses a grid system to divide the flow region into discrete elements. Element intersections are called nodes. Numerical models should be calibrated to existing field conditions to ensure that they accurately represent actual conditions.

In order to achieve the objectives of this study, Geo-studio software is used. The Geo-studio software is Numerical model mainly based on finite element method that can be used for evaluate the performance of dams. Emphasis is given to demonstration of theories, procedures and techniques through practical application of approaches in dam design. Moreover, application of computer methods and computational software in the proposed solution procedures are essential. Effective numerical modeling requires some careful thought and planning and it requires a good understanding of the underlying fundamental theory and concepts.

2.9.2 Geo-studio software

The Geo-studio software is suitable for eight products. SLOPE/W for slope stability, SEEP/W for ground water seepage, SIGMA/W for stress-deformation, QUAKE/W for dynamic earthquake, TEMP/W for geothermal, CTRAN/W for contaminant transport, AIR/W for air flow, VADOSE/W for vadose zone& covers.

SEEP/W is a finite element software product that can be used to model the movement of water and pore-water pressure distribution within porous materials such as soil and rock. It is formulated on the basis that flow of water through saturated soil follows Darcy’s Law. SEEP/W model is constructed to solve any flow situations with multiple soil or rock layers. With the program, flow of foundation and dam body seepage can be analyzed.

On this research, SEEP/W is used. The product SEEP/W is used for the analysis of seepage through foundation and body of the dam. Read the leak using flax makes the water flow quantitative and Known.

2.9.3 SEEP/W seepage analysis method

In order to do a seepage analysis, a general model describing the phenomena of seepage must be available. Supplied with specific boundary conditions and dam material properties.

SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium. Numerical modeling is purely mathematical and in this sense, that is very different than scaled physical modeling in the laboratory or full-scaled field modeling. Seep/w is a powerful tool that can be used to assist engineers in the design of infrastructures like dams and Brigs. [16]

While the SEEP/W software is an extremely powerful calculator, obtaining useful and meaningful results from this useful tool depends on the guidance provided by the user. It is the user understanding of the input and their ability to interpret the results that make it such a powerful tool.

The problem of leaking of water and the ways of controlling the leakage in dams is one of the most important technical problems in designing, building, well maintaining and use of dams. The model helps us to analyzed water circulation in saturated soils and leakage analysis using mathematical models. The results include velocity vectors, and the location of the water table.

2.10 Dam safety analysis

The purpose of all dam safety analysis/assessments for the whole life cycle of a dam (planning, design, operation, etc.) is to determine the capability of the dam system to retain the stored volume under all conditions and to pass flows around and through the dam in a safe, controlled manner. Dam safety analysis should consider the full range of applicable conditions in order to determine how the structures are expected to perform and what amount of deviation from the normal condition is tolerable. Design, construction, and operation should be integrated in the analysis to ensure that the design intent has been incorporated into the dam. [2]

Due to a problem related to dam safety catastrophic failures involving large modern dams are rare, but major disasters at Malpasset (France 1959), Vaiont (Italy 1963), Teton (USA 1976) and Macchu II (India 1979) in particular had a seminal influence on all matters relating to dam safety. [17]

The surveillance and monitoring program should provide regular monitoring of dam performance, as follows.

- Compare actual and design performance to identify deviations;
- Detect changes in performance or the development of hazardous conditions;
- Confirm that reservoir operations are in compliance with dam safety requirements
- Confirm that adequate maintenance is provided.

Dam surveillance programmers and instrumentation are intended to detect symptoms of distress and, where possible, to relate those symptoms to specific problems at the earliest possible stage. Instruments strategically placed within or on a dam are not of themselves a guarantee against serious incident or failure. Their prime function is to reveal abnormalities in behavior, and so to provide early warning of possible distress which may have the potential to develop into a serious incident or failure [17]

The most significant parameters in monitoring dam behavior are as follows

1. Seepage and leakage (quantity, nature e.g. turbidity), location and source.
2. Settlement and loss of freeboard most all the time this is in the case of embankment dams.
3. External and internal deformation.
4. Porewater pressures and uplift.

2.11 Instrumentation in concrete gravity dams

Instrumentation consists of the various electrical and mechanical instruments or systems used to measure pressure, flow, movement, and temperature. Dam instrumentation and surveillance programmers are intended to detect symptoms of distress and, where possible, to relate those symptoms to specific problems at the earliest possible stage. Instruments strategically placed within or on a dam are not of themselves a guarantee against serious incident or failure. Their prime function is to reveal abnormalities in behavior, and so to provide early warning of possible distress which may have the potential to develop into a serious incident or failure. [17]

Instruments are installed in a concrete gravity dam to measure the various parameters that indicate the structural health of the dam and the state of the foundation.

The following measurements are mandatory for all dams:

a) Uplift pressure at the base of the dam at a sufficient number of transverse sections.

b) Seepage into the dam.

c) Temperature of the interior of the dam and foundation.

The layout of monitoring instruments should be tight combination with the project practice and take into account the comprehensive reasonable. RCC dam monitoring includes the following contents.

- Seepage monitoring, including the foundation, the dam and the uplift pressure through body of the dam, and seepage flow around the dam and groundwater monitoring and water quality analysis.
- Deformation monitoring, including the dam foundation and dam level displacement, vertical displacement, deflection, tilt and crack changes.
- Monitoring, including the upstream or downstream water level, water temperature, air temperature and rainfall, upstream and downstream of river bed deformation.
- Monitoring, including seismic response of dam and dam foundation. [18]

The provision of monitoring instrument is highly accepted practice for RCC Gravity dams. Dam monitoring instruments are installed inside the dam for safety of the dam. Some dam instruments are located below.
RCC gravity dams includes the following type of instruments.

I. **THERMOCOUPLES**: is a temperature measuring device consisting of two dissimilar conductors that contact other at one or more, operation temperature of this device is -200 ^{o}c to 1350 ^{o}c. This device used during the construction time of the dam only and shall be acquired on daily basis.

II. **FOUNDATION DRAINS:** as soon as the concreting and grouting activities are completed, and subsequently drains drilled on the dam foundations, the discharge of the drains crossing the foundation shall be measured. V notches on drain galleries ditches shall be installed and used as soon as available and Discharge measures shall be done every 2 weeks.

III. **DAM PIEZOMETERS**: as soon as the concreting and grouting activities are completed, and subsequently piezometers holes drilled on the dam foundations, piezometers pressures shall be measured.

IV. **Pendulum Shaft**: is used to control dam sliding or rotations and any movement around the foundation or at the body of the dam. The pendulum shaft is placed from the foundation to the top elevation of the dam that is to control the whole body of the dam.

V. **DTS Distributed Temperature Sensing System**: is designed for distributed temperature monitoring over long distance, operating temperature -40 ^{o}c to +85^{o}c. this device is used during the operation period of the dam.

2.12 Monitoring

Monitoring is the collection, reduction, presentation, and evaluation of the instrumentation data Dam monitoring is one means of determining trends in structural performance. This process consists of the collection, recording, analysis and presentation of data from measuring devices installed at or near dams. The findings from the ICOLD studies demonstrate the importance of inspection and an appropriate monitoring system for regular observation of dam performance. Instrumentation and monitoring are tools that must be used with an alert inspection program to continually evaluate the safety of dam. [19]

The items that need to be monitored, and the relevant associated instrumentation in the dam, should be identified by the Approved Dam Engineer undertaking the safety review of the dam and based on the results of the Potential Failure Modes Analysis. The instruments should monitor the key performance indicators that provide early warning of the development of the identified potential failure modes.

2.13 International dam monitoring

The current condition of the visible features at the dam is determined by an onsite examination or instrument reading. The dam, appurtenant structures, and mechanical equipment are examined to performing as expected. Regions of distress, unexpected movements, unusual seepage or leakage, mechanical and electrical equipment malfunctions, and all other observations related to the safety of the dam should be identified and recorded. The results of the instrumentation observations and analyses may reveal or forecast dangerous conditions. In the western world, it is very easy to measure and to give useful information about the safety of the dam this is due to their highly organized monitoring system. [20].

Engineering and other scientific concepts and models are very useful and common in dam monitoring system. In 1965, a concrete dam in Catagunya stressed dam was monitored for deflection. The principal load to concrete dam is water load and temperature. An observed value of temperature and reservoir water level was used as input for multiple linear regressions to predict the deflection. In certain circumstance, it may be possible to establish the regression equation by calculation of deflections for various combinations of temperatures and water load. On continuing plot of deflection against time, values from the regression equation can be compared with observed values, any significant difference can result in detailed investigation [21].

2.13.1 Dam monitoring in Ethiopia

Dam monitoring in Ethiopian situation, there are devices which are installed to measure a particular parameter of interest for monitoring of dam besides the visual inspections. Dam monitoring is one means of determining trends in structural performance.

A Threshold value is used in the analysis or design, or is established from the historic record. An Action Level is the instrument reading that triggers increased surveillance or an emergency action. Threshold and Action limits should be established based on theoretical or analytical studies. [22]

A guideline called (Ethiopia congress on large dams) ETCOLD has been established in 2014 due to;

- Ageing of dams
- More development and expansion of urbanization downstream of dams, which were not existing during the construction period,
- More water storage dams (large and complex) are being planned constructed and operated, which need state of the art design, construction and operational safety guideline
- There had not been any dam safety related guidelines, standard or regulation to guide designers, contractors, dam owner, operators and decision makers, and other reasons.

According to the guideline increased seepage or turbidity could indicate piping of dam.

3. Material and methodology

3.1 General description of the study area

Gilgel Gibe III dam is one of the most attractive potential hydroelectric developments in the country. The project is situated on OMO river, which is located in Mareka gana woreda of the dawro zone and Kindo koyisha woreda of sodo zone of the Southern Nations and Nationalities People Regional State (SNNPRS) about 450km ground distance south west of Addis Ababa, and the dam site is located about 92 km northwest of Arba Minch town.

The Gibe III Hydroelectric Project comprises a 243m high dam with dam crest length of 610 m and create a huge reservoir with a surface area of some 200km² and a total storage of some 11.750 billion m^3. Fetch length of the reservoir is approximately 155 km, with a catchment area about 34,150 km^2. The scheme from the root of its reservoir to its tailrace outfall, extends over a corridor some 155km long, and approximate centroid of the project area lies at 757,225 North and 312,293 East. The annual rainfall of the Gibe-Omo catchments area, measured in the nearest stations, varies from a minimum of 1,200 mm to a maximum of about 1,900 mm and the average annual rainfall calculated over the whole Gibe III basin where the Dam is located is 1,426 mm.

FIGURE 3. 1: location of Gibe III dam

The main objective of this mega project is hydropower generation. Its big role is solving the electric scarcity problem in Ethiopia as well as in east Africa and improves the renaissance of the Ethiopia and our continent. It is the third largest hydroelectric plant in Africa with a power output of about 1870 MW or 6500 GWh, that is occupied with ten Francis turbines, 95% efficiency coupled to synchronous generators of each capacity 187MW. the power produced by the plant will be delivered to the Inter Connected System *(ICS)* through a four-double circuit 400 kv overhead transmission lines, and expected to supply about half of its power to Ethiopia and export the other half to Kenya (500 MW), Sudan (200 MW) and Djibouti 200MW.

The secondary benefit of the project is flood protection. In 2006, a flood claimed the lives of at least 360 people and thousands of livestock in the lower Omo River basin, and the further benefit would be a reduction in the impact of droughts.

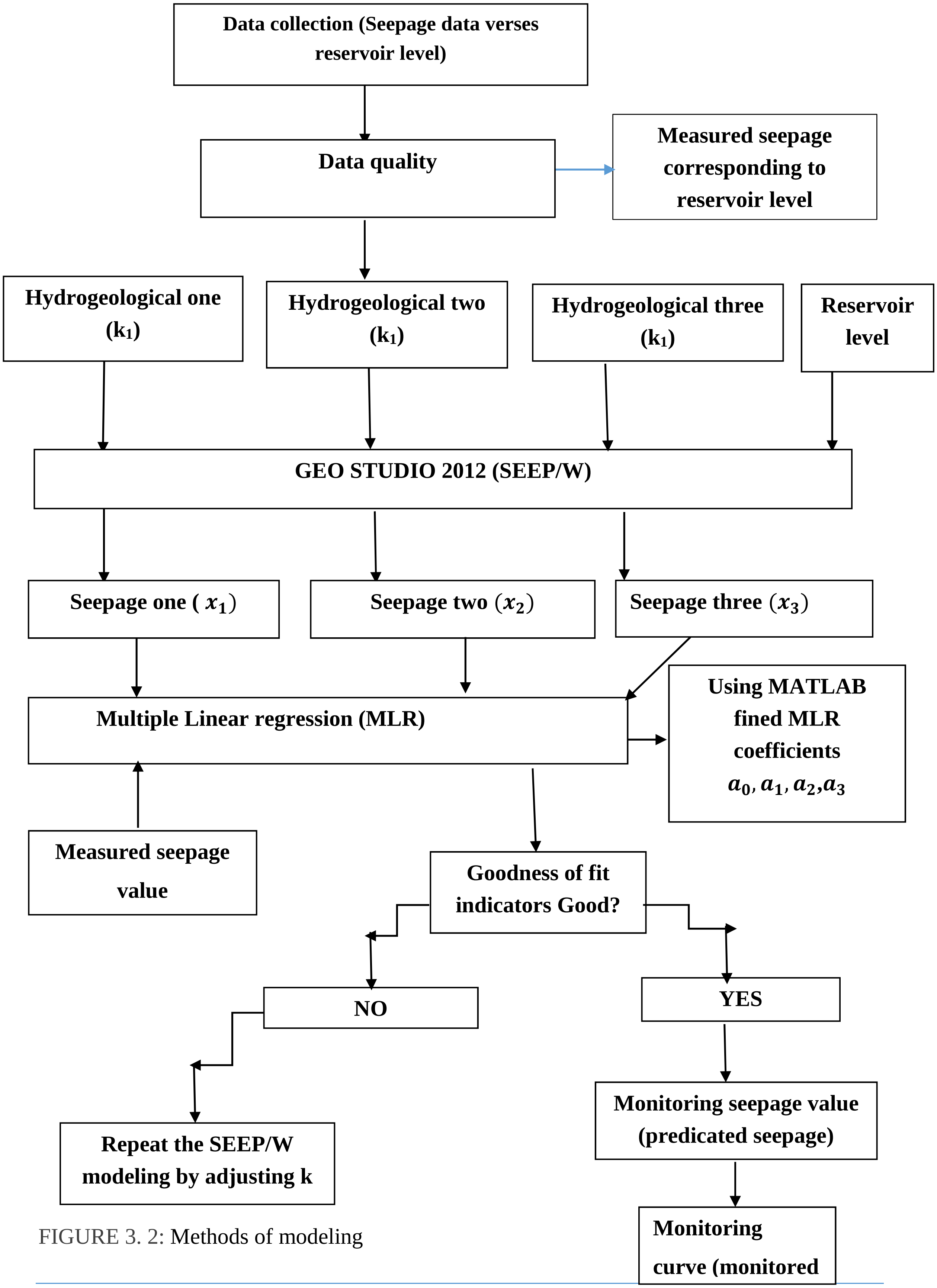

FIGURE 3. 2: Methods of modeling

3.2 Data collection

Before conducting of any research, it is imperative to make a tough search for the data therefore, required data were collected from Head office of Ethiopian Electric Power (EEP) and from Gilgel Gibe III dam site. The main data were used in this paper are:

- ❖ Reservoir head level Vs Seepage
- ❖ Foundation Material properties of the dam
- ❖ Hydrogeology parameters
- ❖ AS built drawing (Construction drawing)
- ❖ Dam Zoning and foundation layer Classification

3.2.1 Primary data

The primary data was collected from Gilgel Gibe III dam site, that included asking a persons who are most familiar with the project they provide information and insights like, resident engineer (hydro geologist and site engineers), operating and maintenance people, the construction contractor documents (SALINI IMPREGILO) provided information needed to assess dam and foundation seepage of the dam site during site visit to cross check of secondary that already have been collected from Ethiopian Electric Power (EEP).

During the Gilgel Gibe III dam site visit the primary data include:

- ❖ Physical observation and location of drainage galleries and seepage measurement instrumentation and observe their recorded data from v-notch.
- ❖ Asking of the resident engineer. Whether the seepage water is ever turbid? and how it looks?
- ❖ Collect pictures that show the reservoir water level, the dam body and its appurtenant structures.

3.2.2 Secondary data

Secondary data that involves the collection of existing data from dam site and reviewing available literature or data. The secondary data were collected from Ethiopian Electric Power head office (EEP) and from Gilgel Gibe III dam site. Important data like, AS build drawing, reservoir elevation verses recorded seepage data, location of derange galleries and instruments, and other essential input data for SEEP/W numerical model are obtained from the above-mentioned organization and dam site.

Secondary data of these research include

- Dam cross-section profiles.
- Data on measured seepage discharges on a daily or monthly basis together with Reservoir level.
- Required Information for Modeling like geological sequence, composition and Propriety of the dam foundation.
- Construction of material properties and construction techniques of all materials used in dam
- drawings
- most important features of the dam
- Method Statement and Specification Document

A systematic review of these records is support in identifying potential seepage related dam safety.

3.3 Data quality

Design, construction, inspection, operating data and records are invaluable when evaluating the seepage safety of a dam. It is important to understand the range of seepage conditions that is the structure may experience during its lifetime.

Measured Seepage data is undoubtedly the best indicator of the overall performance of a dam, because this reflects the performance of entire dam by observing the location, quantity and quality of seepage emerging from the dam body and its foundation. so, such important and safety indicator measurements must be done with highly qualified instrumentations, special devices. Responsible data collectors are required to know the accurate seepage measurement and dam behavior. All observed seepage conditions should be thoroughly investigated and analyzed by qualified individuals. Generally Special attention is required to know detail information about the seepage.

The measured seepage data was taken from the dam site and almost all measured seepage values are increase with the elevation of reservoir water head, that is quite obeys and acceptable that implies the quality of measured seepage data is good. But in some elevation water level the measured seepage is decreased when the reservoir level increase, such condition was happening because of temperature change. The seepage rate varies according to the reservoir elevation and it can also be influenced by atmospheric conditions. Around TEKEMT the measured seepage decreases because the air is cold at the dam site. Since the seasonal temperature variation in the dam has some influence in to seepage rate. That is related with the viscosity of the fluid. Therefore, the data is still acceptable. However, even when extensive records are available, evaluating the safety of the structure with respect to seepage is ultimately dependent on the quality of the data and quality of construction. So before using any of collected data the data must be realistic and the researcher should have check it out.

3.4 Measured seepage inside drainage gallery

Measurement of seepage in the dam is mandatory for all gravity dams. Using seepage measurement instrumentations measured seepage data are collects from the entire dam. To measure the seepage that is drain from the dam and foundation it is provided different gallery.

In Gilgel Gibe III dam there are six drainage and inspection galleries are placed from 660 m.a.s..l to 890 m.a.s.l elevation, all galleries are allocated with 40m vertical interval. Any seepage measurement inside one drainage gallery is covered seepage of water passing along 40m head. The available galleries collect seepage from construction joints through a network of smaller vertical and horizontal drains directed into the structure, and may collect seepage from the foundation through a network of vertical drains into the drainage galleries. All seepage discharges measured separately in each drainage gallery and as close to the source as possible. Gallery 660 is located near to dam foundation so the v-notch seepage measurement inside this gallery is almost originated from the foundation, the rest drainage galleries are allocated above dead storage and covered any seepage measurement entire the dam and foundation. For a single reservoir head, many measurements are done in each gallery. Finally, the different measurements are sum out to take the total flow of seepage passing through the dam and foundation for a given reservoir head, and for the analysis this paper take the total seepage amount.

The measured seepage data Verse elevation was collected from dam site and the available recording data starting from the period of the first reservoir filling reading 1/17/2015 to the 9/26/2016.

FIGURE 3. 3: Seepage from gallery at 660 m.a.s.l

3.5 Seepage analysis using SEEP/W 2007

Seepage is identified at a dam and almost all dams are experienced seepage, but a determination must be made whether the seepage is a problem or not that is by comparing the data with the safe design report seepage limit. So, to identify the condition of seepage models should be used, like Geo studio 2012 power full computer programs.

In order to achieve the objective of this paper, this research has been used SEEP/W finite element method for solving two-dimensional steady state flow problems in saturated and unsaturated media. The model is examined for steady state flow conditions since it is huge stored water behind the dam body and the dam is continuously in contact with the reservoir stored water therefore any void in the dam body and foundation expected to filled by water due to the Stord water that means the body or foundation is saturated and this referred there is no loss or stored water during the passing of seepage flow from the upstream to downstream inside the dam body and foundation such flow conditions mentioned as steady stat type of flow.

The two-dimensional FEM flow system selected to be more accurate based on available data and its simplicity.

SEEP/W software generate FEM mesh to carry out the seepage analysis. FEM meshes for the selected section are developed by using the SEEP/W 2012 software. In this research, finite element approach considers the dam and foundation. Finite element numerical methods are based on the concept of subdividing a continuum into small pieces, describing the behavior or actions of the individual pieces and then reconnecting all the pieces to represent the behavior of the continuum as a whole. This process of subdividing the continuum into smaller pieces is known as discretization or meshing and the pieces are known as finite elements. The mesh is designed in Geo studio model to answer specific questions.

The FEM mesh at the selected section is composed of four types of elements, i.e. triangular only, quads and triangular, rectangular grise of quads and triangular grid quads/triangles type of elements of different sizes. And this modal used quads and triangular type.

The processes that are carried out in the computer software tool during model developing are summarized and listed below.

- Dam and foundation geometry setup.
- Material model (Material characterization and property definition).
- Boundary conditions setup.
- Suitable discretization.

3.6 Material models and properties in SEEP/W

There are different material models to choose from when using SEEP/W.

1. None (used to removed part of a model in an analysis)
2. Saturated / Unsaturated model
3. Saturated only model

This paper selects the saturated/unsaturated model because dams are containing both the saturated and unsaturated conditions. the Saturated / Unsaturated model is very useful for quickly defining a region that will always remain both Below and above of the phreatic surface, it should be used for the material that will at any point during the analysis.

This paper is done, well defined material properties and assigned appropriate boundary condition to obtaining an efficient solution from the model.

1. Hydraulic conductivity: The ability of a material to transport or conduct water under both saturated and unsaturated conditions is reflected by the hydraulic conductivity value. in this paper, hydraulic conductivity function has specified for all materials. SEEP/W has three methods constructed to the model used to predict hydraulic conductivity functions but this paper chose Van Genuchten method because that showed the conductivity graph is estimated based on the volumetric water content function of the material that means the contribution of volumetric water in to the prediction of Hydraulic conductivity is considered.

2. Volumetric water content function: describes the capability of the material to store water under changes in pressures or describes what portion or volume of the voids remains water-filled. Since that is difficult or time consuming to obtain a volumetric water content function because it does require time and it requires finding a geotechnical laboratory and development of the grain-size distribution curve that is the most expensive one. so, this paper it used the range of developed Volumetric water content value based on basic material properties and grain size distribution from SEEP/W available manual, GeoStudio provide several typical water content functions for different types of material. after assigning the volumetric water content next is specifying the residual water content which represents the volumetric water content of a material where a further increase in negative pore-water pressure does not produce significant changes in water content, the value of the residual water content in this model is take as $10\% \ of \ the$ volumetric water.

3. Boundary condition

Specifying boundary conditions in a problem is one of the key components of a numerical analysis. Specifying the limits and conditions in the cross-section is helpful, unless the analysis goes to unlimited and unbounded. Specifying boundary conditions are essential to solve the SEEP/W finite element problems. On upstream the head boundary condition for a seepage analysis have been used from the recorded reservoir water level values at different elevation as fundamental boundary condition. At downstream of the dam toe, the tail water table is at the ground surface that is the water pressure is zero at the ground surface, so in these models the ground surface is assigned as zero pressure boundary condition. In the other hand, a potential seepage face of the downstream portion is identified as seepage face boundary condition, potential seepage face is used to locate for the solver the position of where a seepage face might develop.

3.7 Modeling approach and setting out the lay outing of the dam to the Geo studio software

In order to achieve the dam safety monitoring related to seepage of water passing through foundation and dam body this paper used $Geo\ studio$ 2012. The material properties k, for each section with proper dimensions and the reservoir water head are made as input forth software. In SEEP/W model to draw proper dimension, and dam zoning profile the working area page is provided. Models require some careful geometry, verification and selection of typical cross section. This paper has been select typical cross section at chainage of $0 + 422m$. chainage $0 + 422m$ is most typical chainage of Gilgel Gibe III dam which is located the river bad, the river bade is more fractured and weaker zoon than other foundation sections because the moving river water is passing through this section for several years, during different geological studies, already identified that this section is exposed for seepage than the other

section of foundation, so such sections are important in the case of foundation seepage analysis. By selecting chainage $0 + 420m$ this paper assesses the deep foundation section up to 1.5 times of dam head and extended foundation length with 3 times of dam head. the total hydraulic head that is $243m$, is totally addressed in the selected chainage, in the other hand this typical cross section is contain all drainage galleries from $660m.a.s.l$ – $860m.a.s.l$ so this cross-section is covered all reservoir water head and all measured seepage water value from the different drainage galleries.
The drawing can be done from the auto cade using pointing every necessary coordinate (x, y) to the software then sketch properly.

In the process of analyzing the dam safety based on seepage, from the measured seepage data verses elevation obtained from the instrument readings can made an assumption of that the dam is safe. It is because the measured seepage from dam site is less than the calculated value in the design document that is $2.1\ {m^3}/{s}$ therefore that is acceptable and the paper is starting with the assumption of that is the dam is safe.

3.8 Conceptual model

In dam safety monitoring of seepage using seep/w model analysis conductivity of the different zoning parts of the dam and its foundation has significant role for seepage prediction. Because seepage analysis result is highly depending up on the given hydraulic conductive. Due to geological nature, construction techniques and safety consideration dams and their foundations are constructed with different dam zoning and foundation layers. Gilgel Gibe III dam is constructed with different dam zoning, and foundation layer. According to design document the main dam zonings verified and optimized basing on the RCC mixes detailed design and on the relevant characteristics of the RCC obtained from the different tests. Basically, dam zoning of this project classified based on construction material, aggregate size, cement amount ${kg}/{m^3}$, construction technique (RCC, CVC) and bearing capacity of the dam section. The dam zoning includes, upstream, downstream central and top dam sections, and the foundation layers are classified based on Geological characteristics. The dam foundation is characterized with different rock type totally it has four layers or rock types; Slightly Weathered Trachyte (SW-T), un weathered trachyte (U-T), BASALT and GRANITE.

The SEEP/W model is treated those all section with assigning different reigns, material property and different hydrogeological parameters, $k_1, k_2, k_3, \ldots \ldots \ldots . k_{10}$, the value of k is assigned based on their capacity of water tightness. This research has ten regions both dam zoning and foundation layers. For the nine regions assign a single hydraulic conductivity k because those regions have a good water tightness quality then the rest one region. The thoughtful section is the upper foundation layer because of the higher seepage measurement is occurred at this section. These research give more emphasis to the upper foundation layer called Slightly Weathered Trachyte (SW-T) by assignee more than one hydraulic conductivity (k_1, k_2, k_3) because from the geological investigation and studies this section of the foundation is slightly weathered, discontinues and weaker surfaces such rock types are exposed for seepage problem than other layers since related to their permeability and water tightness problem, that is why this research give more attention in the method process for these section. Nine k values assigned in the model, that are for the six-dam zoning including the cut off and the three-deep foundation section the given k values are highly impervious because of their capacity of water tightness and the value is imported from the existing data based on the hydraulic permeability of material. Typical Hydraulic Conductivity Values assigned in the analysis are listed below.

Table 3. 1: Hydraulic Conductivity Values

Region	Material	Hydraulic conductivity k
Region 1	Upstream section	10^{-9}
Region 2	Downstream section	10^{-10}
Region 3	Central section	10^{-8}
Region 4	Top dam section	10^{-11}
Region 5	Upstream cutoff	10^{-12}
Region 6	Downstream cutoff	10^{-12}
Region 7	Slightly Weathered Trachyte (SW-T)	10^{-6}
		10^{-7}
		10^{-8}
Region 8	Unweather Trachyte (U–T).	10^{-9}
Region 9	Basalts	10^{-9}
Region 10	Granite	10^{-9}

The water level inside the reservoir and hydraulic conductivities are used as an its input for the model. After assigning different hydrogeological parameters two-dimensional seepage flow analysis model SEEP/W 2012 is directly running to estimate the seepage value per unite width. After running the model, using flux section identify amount of flow crossing these elements during the solve process, or estimate the amount of flow passing through the dam and foundation. Finally, simulated results of seepage per mater width obtained from the SEEP/W software for the selected section. The estimated seepage from SEEP/W model should be multiplied by the total crest length of dam because the calculated seepage value from the model gives per unit meter only and this cannot represent the seepage of water passing through the whole dam body and foundation that is why that mast be multiplied by the total crest length of the dam that is $610m$. Finally, a number of estimated seepage value versus their elevation was obtained.

Then the next phase is modeling multiple linear regression model for simulation of both calculated seepage and the measured seepage to find out the safe range or optimize seepage rate for the given dam. The quality of input data like hydraulic conductivity is checked out by calculating the goodness of fit of a regression line r^2, and determine measures the proportion or percentage of the total variation explained by the regression model. the value of r^2 also give an answer for the question of, the selected model (SEEP/W) how much represent the actual condition of Gilgel Gibe III dam. Then, if the good fitness value of r^2 is more than or equal to 75% the analysis is almost good but that is preferable to find out more than 90%. The multiple regression model used the SEEP/W model outputs as an input to predict the seepage value at each reservoir water level and finally, for the Gilgel Gibe III dam project develop a seepage monitoring chart (predicted seepage value Verse reservoir water level). The curve obtained can be used to monitor the dam safety against seepage for future operation.

3.8.1 Multiple linear regression analysis

Models that involve many independent variables are more complex in structure but can still be analyzed using multiple linear regression techniques. This research used multiple linear regression to represent the relationship between a dependent variable and several independent variables that means the seepage data obtained from analysis result of SEEP/W and the actual recorded of seepage data from the site were used in Multiple Linear Regression (MLR) as an input. The link between recorded and simulated results of seepage data was analyzed using multiple linear regression. In this paper, the measured seepage data obtained from the site is dependent and calculated seepages obtained from analysis result of SEEP/W is independent variables.

The general form of multiple linear regressions can be written as follows:

$$\boldsymbol{y = a_o + a_1x_1 + a_2x_2 + a_3x_3 + \cdots \ldots \ldots \ldots a_nx_n}$$

$$where \qquad y = measured\ seepage\ value$$

$x_1, x_2, x_3 \ldots \ldots \ldots \ldots . x_n$ $are\ calculated\ seepages$ for $k_1, k_2, k_3 \ldots k_n$ *respectively*

$$a_o, a_1, a_3 \ldots \ldots \ldots \ldots . a_n \; are \; coefficients$$

Using MATLAB, that is designed to work with matrices, and that can have done some of more sophisticated operations, which correlated the measured values and the results obtained from the analysis of SEEP/W relationship was obtaining the MLR coefficients which is $a_o, a_1, a_3, a_4,$ and then after, calculate measure of the goodness of fit of a regression line r^2. Numerical models should be calibrated to existing field conditions to ensure that they accurately represent actual conditions and this condition checked out by calculating r^2value.

$$r^2 = \frac{\left(\sum y_i \hat{y}_i\right)^2}{\left(\sum y_i^2\right)\left(\sum \hat{y}_i^2\right)}$$

$$\hat{y}_i = calculated \; seepage$$

$$y_i = meaured \; seepage$$

$$r^2 = Cofficent \; of \; determination$$

Determining the perfect fit of the analysis r^2, this value indicate that the given hydraulic conductivity for the SEEP/W model is either it represent the actual ground hydraulic conductivity or not and that clearly show how much percentage the SEEP/W model represent the actual condition of Gilgel Gibe III dam. Its limits are $0 \leq r^2 \leq 1$. The analysis should give a perfect fit. by checking r^2 can identify the deviation between the measured seepage head at any given location to the predicted value. If the result indicates the deviation between measured and calculated is somewhat high, the model must return back to the analysis to adjust the Hydrogeological input parameters, the adjustment continued until get minimum error. In the other hand if the good fitness result is good this result shows the given hydrogeological input parameter for the SEEP/W model is almost represent the actual geological and material parameter of the given dam, additionally that indicate the model parameters used is good, so in such conditions the assessment can done the rest activity.

After checking the quality of the analysis, by taking MLR coefficients, the predicated seepage value of monitoring was assessed and finally the monitoring chart was developed for the Gilgel Gibe III hydroelectric dam project. The graph is predicted seepage verses reservoir water head. This monitoring will have a contribution for the rest operation life of the given dam.

4. Result and discussion

Hydraulic conductivity and reservoir water head was an input for SEEP/W 2007 model to calculate the total seepage. Using flux section identify amount of flow crossing the elements during the solve process, or estimate the amount of flow passing through the dam and foundation. Measured available seepage data at different elevations that is taken from $1/17/2015\ to\ 9/26/2016$, and those data were used for the analysis. Three hydraulic conductivity values (k_1, k_2, k_3)were selected and assigned to the foundation or for the most pervious section because the analysis focuses on this section.

Seepage analysis was successfully carried out with the use of two dimensional models. The graph of measured seepage data versus reservoir water level as well as difference calculated seepage date(x_1, x_2, x_3) from the three hydraulic conductivity inputs (k_1, k_2, k_3) for the upper foundation layer plus the rest nine zoning and layers seepage data vs given reservoir water head is plotted. The plotted graph shows the calculated seepage is lays near above and below of the measured seepage curve this position of the curve show that the given hydraulic conductivity is almost similar with the actual material.

4.1 Result of seepage value from SEEP/W

Total ten hydraulic conductivity are selected for the different dam zoning and foundation layers. For the SEEP/W model single hydraulic conductivity value is assigned as input for one material type or region except the upper foundation section. Three hydraulic conductivity values are assign for the upper foundation layer or for the most pervious section, since modeling is focused on the upper foundation layer. From the three k inputs plus the rest give k values the SEEP/W gives three estimated seepage values x_1, x_2, x_3. The two estimated values are slightly less than the measured seepage value and the remining one calculated seepage value is slightly greater than the measured seepage, those all three values are indicator of the given k value and the setting of model. Calculated seepage value is highly depending on the input trial of k value, especially those three k_1, k_2, k_3 values that is assigned for the upper foundation are highly express the result from the model. Those values have significant value on the calculated seepage value, because the value is pervious than other however the other ten k values have low contribution for the calculated seepage value because those regions are highly impervious but still they are already contained each section within every given reservoir water head in the analysis to identify the amount of seepage value passing through those elements. After knowing the value from the seep/w model, then after give a decision either to include in the further analysis or not. This paper gives a decision the seepage of water passing through the RCC gravity dam body is not include for the further monitoring analysis of Gilgel Gibe III dam because the seepage amount which the software manipulates is too much low that is almost null. So, these analyses cover the seepage of water passing through Gilgel Gibe III dam foundation only.

During Gilgel Gibe III dam seepage analysis using $SEEP/W$ 2007 model, this research used the first reservoir water level of 684m. the single reservoir water level was taken as head boundary condition. Single reservoir water head is given a single calculated seepage value x. The location of phreatic line and determined different seepage for the above head boundary condition which assigned with different hydraulic conductivities is shown in below. And the rest whole analysis is list in appendix A.

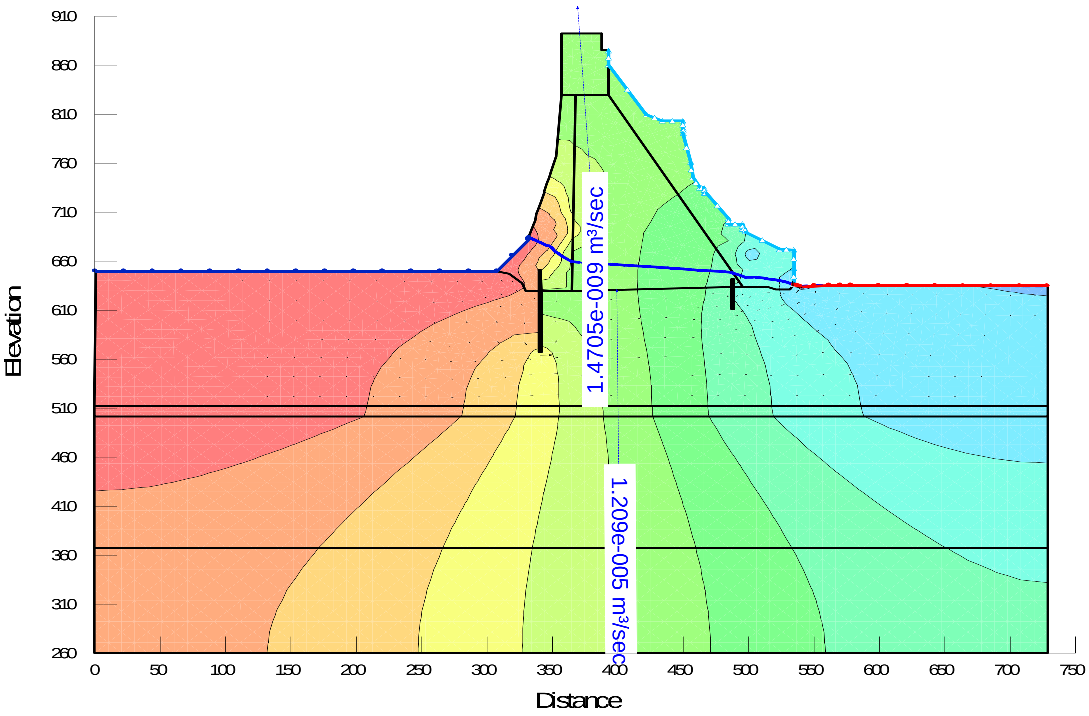

fig 4. 1 Seepage obtained for 684m reservoir level for k 10^{-6}

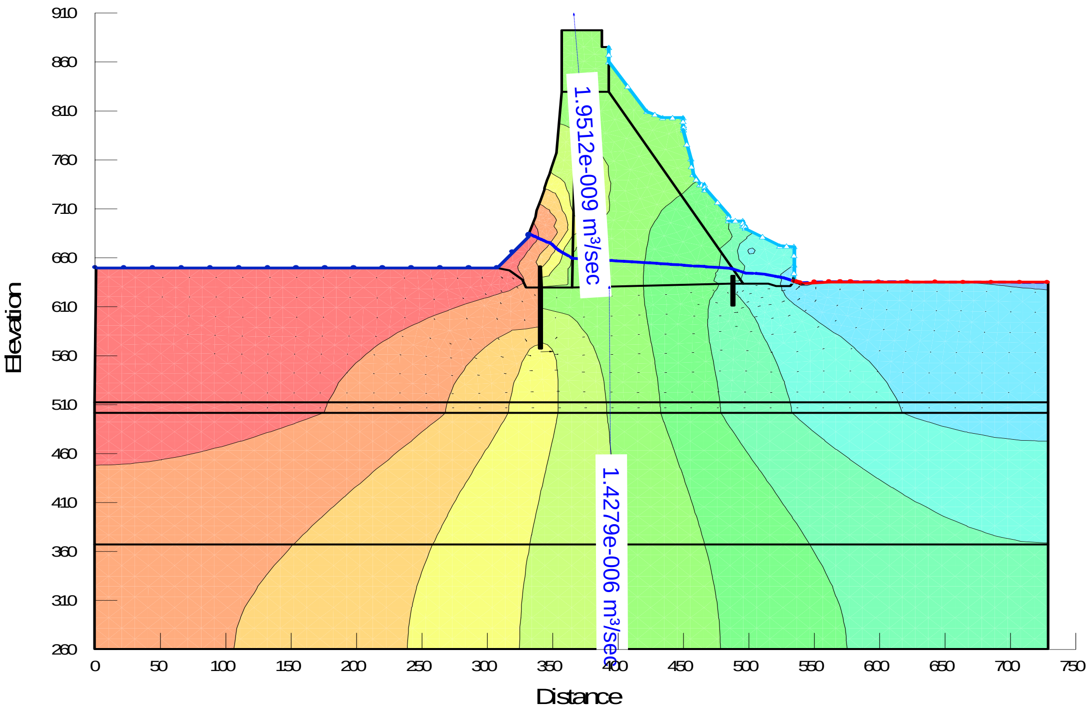

fig 4. 2 Seepage obtained for 684m reservoir level for k 10^{-7}

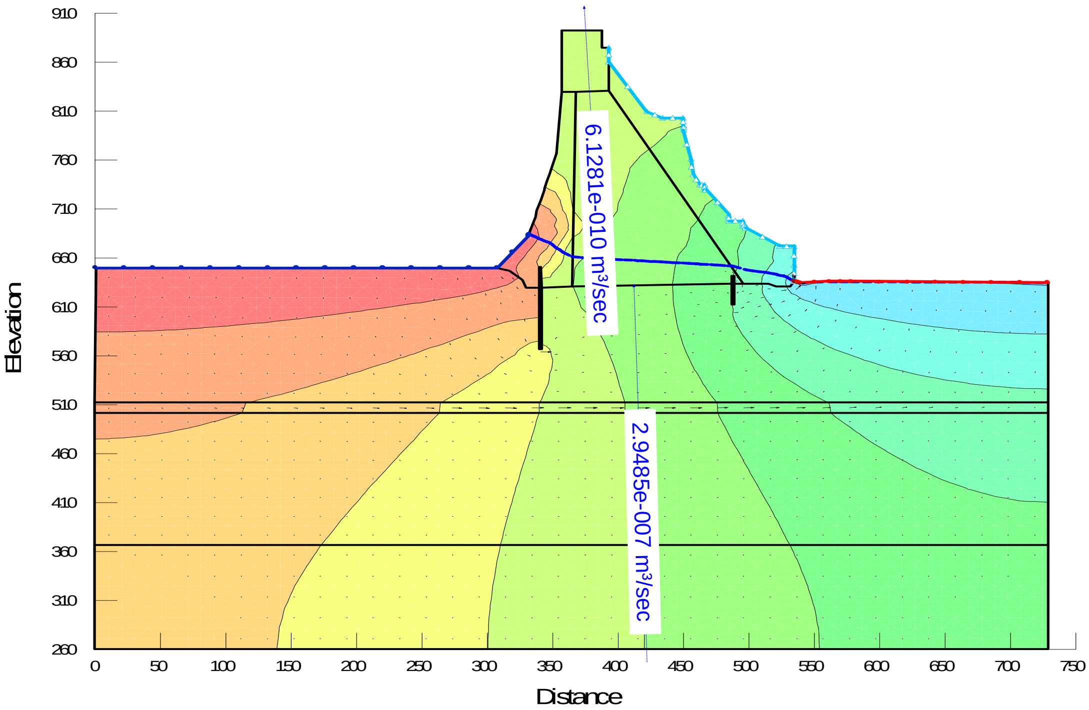

fig 4. 3 Seepage obtained for 684m reservoir level for k 10^{-8}

In the same way for each hydraulic conductivity values and given reservoir water level the phreatic line and calculated seepage is already obtained from the SEEP/W model. To know the total flow passing through the foundation the estimated seepage per unit meter from SEEP/W model is multiplied by the total crest length of dam that is $610m$. Finally, a number of estimated seepage value versus their elevation was obtained.

4.2 Seepage monitoring

Seepage monitoring systems should be considered as a basic and indispensable part of a dam monitoring system and as mandatory for dam safety. So, in order to find out the predicted seepage value, the link between recorded and simulated results of seepage data was analyzed using multiple linear regression. The calculated seepage and measured seepage are inputes for multiple linear regrasion analysis.

$$s_p = a_o + a_1 s_1 + a_2 s_2 + a_3 s_3$$

$$where: \quad s_1 = \ calculated\ seepage\ for\ k_1$$

$$s_2 = \ calculated\ seepage\ for\ k_2$$

$$s_3 = \ calculated\ seepage\ for\ k_3$$

$$s_p = seepage\ to\ be\ determined\ or\ predicted\ seepage$$

$$a_o, a_1, a_2, a_3 \ = adjusted\ regression\ coefficients$$

In such analysis to determine the coefficients a_o, a_1, a_2, a_3 the number of equation must be three times greater the unknown coefficients. This paper has 40 equations with four unknown coefficients that means the number of equation much greater than the four unknown coefficients, so in such conditions in the multiple linear regression analysis by using the measured seepage values in place of s_p the regression coefficients a_o, a_1, a_2, a_3 are easily obtained from MATLAB. The results are $-0.0343, -0.2773, -9.2543$ and 179.85 of a_o, a_1, a_2, a_3 respectively. After analysis, the relationship between the measured and calculated seepage to find the coefficients, the predicted seepage value $s_p$was obtained from MLR by inserting the calculated seepage value from SEEP/W instead of x_1, x_2, x_3 and also by including the known coefficients in the MLR formula.

To ensure that the accuracy of SEEP/W model parameters and hydraulic conductivity input to represent the actual conditions the goodness fit for the multiple regression analysis was checked for RMSE, mean error, mean absolute error and r^2. Those value was checked by statistical formula. This value show that wheather the measured seepage coincides with the calculated seepage or not. The results of r^2value found by applying the stastical formula is shown below.

$$r^2 = \frac{\left(\sum y_i \hat{y}_i\right)^2}{\left(\sum y_i^2\right)\left(\sum \hat{y}_i^2\right)}$$

$$\hat{y}_i = calculated\ seepage$$

$$y_i = meaured\ seepage$$

$$r^2 = cofficent\ of\ determination$$

$$r^2 = 91\%$$

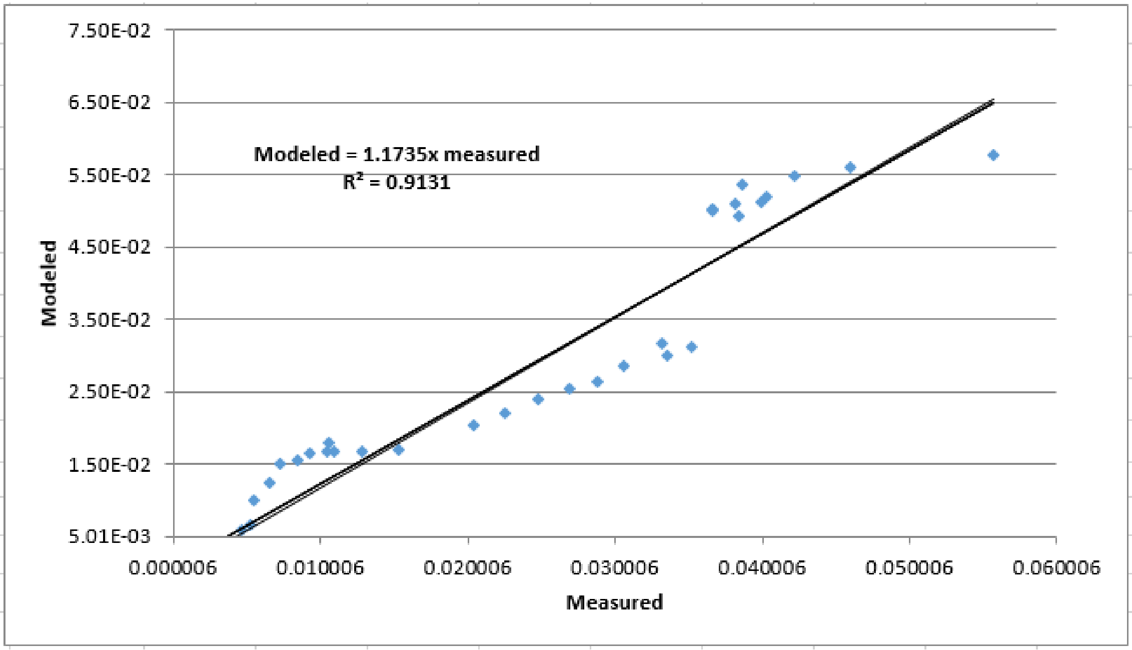

Fig 4. 4: Coefficient of determination

Any result of r^2 value being greater than 0.74 is acceptable and that is clearly shows the better quality of the representative model. [23]

In this resarch the value of r^2 is greater than 74%. So, the predicted seepage value calculates using MRL model.

TABLE 4. 1: Goodness fit indicates and the corresponding values

Mean error	Mean absolute error	RMSE	R^2
-4.020×10^{-2}	5.65×10^{-3}	7.18×10^{-3}	0.91

The goodness of fit identify wheather the measured seepage coincides with the combined seep/w multiple regression analysis seepage or not. It is evident that the model result concides with the measured result with RMSE of 7.18x10^{-3} , Mean error of -4.020x10^{-2} m^3/s mean absolute error of 5.65x10^{-3} m^3/s and r^2 value of 0.913 and the above result shows the used SEEP/W and MLR models substantially represent the actual ground phenomena of Gilgel Gibe III because of good hydrogeological inputs and other parameters but for the given reservoir water level, the measured seepage values and the calculated seepage values from SEEP/W have some little deviation because any model including SEEP/W can't represent 100% of the actual ground phenomena that is because of some assumptions and drawbacks.

The RMSE, Mean error and Mean absolute error being closer to zero indicate the acceptable results. While the r^2 value being greater than 0.74 clearly show the result is again acceptable.

Measured seepage of water that flows from upstream to the downstream at different heads and the monitored or predicted seepage value using SEEP/W and MLR models are show below.

TABLE 4. 2: Measured and Predicted seepage value

R.W.L	Measured seepage $m^3/_s$	Predicted seepage $m^3/_s$
648	0.003047	0.0004
697	0.0032596	0.00067
701	0.003582	0.00069
712	0.003806	0.00135
719	0.004127	0.00157
727	0.00472	0.00441
731	0.005221	0.00466
739	0.005495	0.01006
745	0.006512	0.01255
751	0.007295	0.01514
756	0.008412	0.01559
769	0.009337	0.01664
773	0.010447	0.01678
777	0.010918	0.01678

787	0.01289	0.01687
791	0.015352	0.01692
798	0.010571	0.01794
805	0.020391	0.02042
811	0.0225	0.02205
817	0.0248	0.02395
822	0.0269	0.02548
825	0.02879	0.02647
832	0.0306	0.02869
836	0.0336	0.02996
839	0.0352	0.03122
840	0.03323	0.03169
843	0.0384	0.04932
845	0.036676	0.04994
846	0.036644	0.05036
847	0.038149	0.05093
848	0.039923	0.05122
850	0.040286	0.05203
854	0.038662	0.05363
857	0.042219	0.05487
860	0.045947	0.05608
864	0.05567	0.05768

4.3 Monitoring curve

Using SEEP/W and MLR models predicated Seepage value was successfully carried out. It is now possible to create a monitoring curve which defines the safe seepage rate verses reservoir water level of Gilgel Gibe III dam foundation.

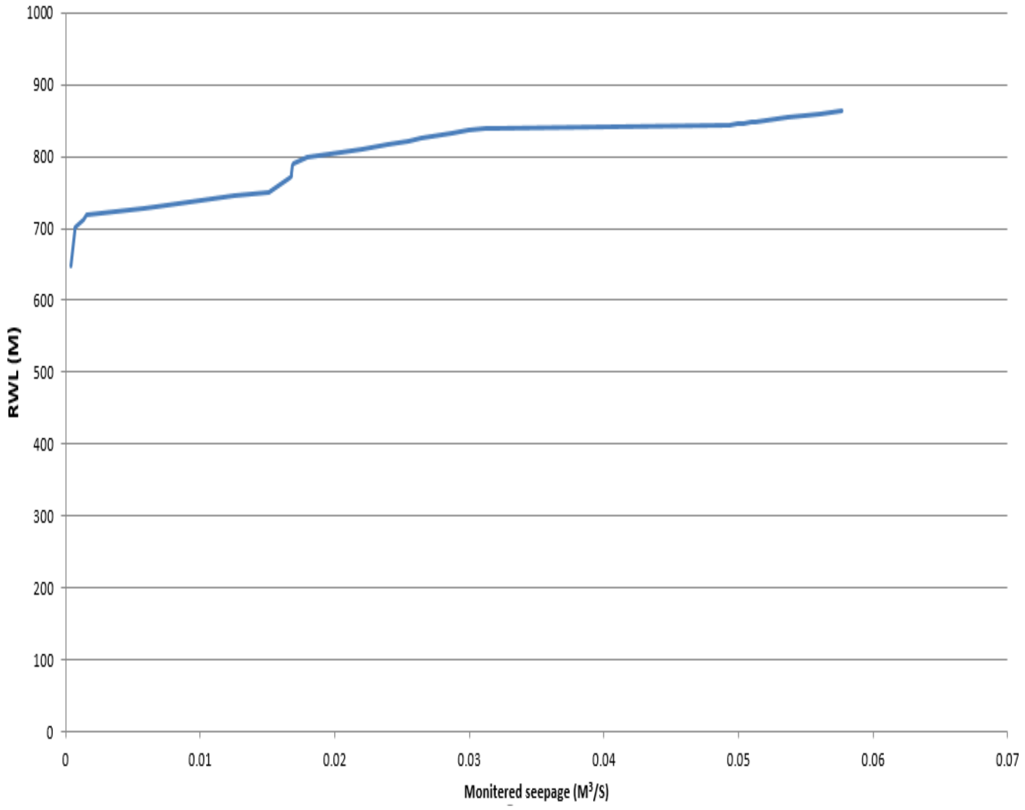

fig 4. 5 Monitoring chart

Once such safe seepage rate for a given water level in the reservoir is defined any seepage which will occur in the dam foundation shall comply with this seepage rate. If the observed seepage is beyond what have been proposed it signals that the dam is not safe. Such indicators will warrant further investigation into the causes of such observed seepage variations beyond the expected one. By doing so the safety of the dam situation could be identified and monitored. Thus, this Research develop a value which defined seepage quantity for a given water level based on measured seepage data. Generally, the curve obtained can be used to monitor whether the dam is safe against foundation seepage or not for future operation. If any result observed out of the monitoring curve that is an indicative to use other techniques of monitoring to improve the dam safety. The monitoring curve reveal abnormalities in behavior, and useful to provide early warning of possible distress which may have the potential to develop into a serious incident or failure.

4.4 Current state of dam safety monitoring of Gilgel Gibe III dam

No specific threshold value of single seepage flow for a single reservoir water level is defined. In particular, it's possible to observe the overall discharge measured at the galleries versus the reservoir water level. And the criteria for Routine or Alert procedure application for Gilgel gibe III dam monitoring are indicated in table. The monitoring condition is divided in to two reservoir conditions.

TABLE 4. 3 Current seepage monitoring criteria of Gilgel gibe III dam for Routine or Alert procedure at stable reservoir condition

Stable Water Level in the Reservoir		
	Routine Procedure	Alert Procedure
Seepage through dam foundation and body	Stable or for foundation drains variable according to rain/dry season trends	• Increasing with time. for foundation drains independently from season trend. • For drains when jetting continuously flow

TABLE 4. 4: Current seepage monitoring criteria of Gilgel gibe III dam criteria for Routine or Alert procedure for raising reservoir condition.

Rising water level		
	Routine Procedure	Alert Procedure
Seepage through dam foundation and body	Foundation drains season dependent increasing	• Time dependent increasing • For local drains when jetting continuously flow.

5. Conclusion and recommendation

5.1 Conclusion

Different reservoir level and trial hydraulic conductivity was used to calculate seepage from seep/w software. MLR was used to define the coefficients by using measured and calculated seepage as input. The calculated result obtained and the measured seepage was checked for deviation and the goodness fit and found to be acceptable. The method of seepage monitoring of the dam foundation can give a good result when the values from the model output is approximately the same or less than the result obtained from the design document. If not, it indicates the monitoring techniques is not good and an indicative to use other techniques of monitoring to improve the dam safety. Accordingly, the methodology adopted in deciding the safe seepage through Gilgel Gibe III dam foundation is good enough. The curve obtained can be used to monitor whether the dam is safe against seepage or not for future operation.

During procedures stated above the calculated seepage passing through RCC gravity dam of Gilgel Gibe III is neglected since the seepage value is too small and such small results does not have significant role in the assessment, this is due to material property of the dam body that is highly impermeable, so this paper is deal with Gilgel Gibe III dam foundation only. The monitoring curve used not only for the present condition of the dam foundation but also used to predict the condition for future.

Finally, Gilgel Gibe III dam foundation monitoring method have no threshold limit for each specific reservoir head. However, this paper has been set a threshold seepage value for different reservoir water level that have a high contribution to provide safe operation of the dam.

5.2 Recommendation

By using the relationship between the result from the model and the recorded seepage values of the v-notch readings the result of the seepage value from models is less than the safe recommended data obtained from the designed document. This result shows that the dam is safe. This modeling result gives not only the current condition of dam monitoring, but also used to monitor the safety of the dam in the future by using reservoir water level as an input and comparing the predicted value with the design document seepage value. According to the result stated above currently the dam foundation is safe, but in the future if the recorded seepage or calculated seepage is greater than the safe range of designed document seepage range and for the next long years of design life of the dam when some unsafe symptoms of seepage problems occur this paper wants to give some recommendation techniques.

A period during which this structure could function properly that is the design life for Gilgel Gibe III hydropower is 100 years. During this long service time if the following signs are happening:

- When the measured seepage amount within the specific reservoir head is greater than the monitoring value.
- Whether the seepage water is ever turbid or water carries particles.
- Whether accumulations of particles occur in the area of seepage.

The following Seepage control measures can be used us REMEDIAL ACTION

- Reduce the hydraulic head and pressure causing the problem (reservoir drawdown).
- Control the exits of the seepage.

One of the first considerations in an emergency situation is to lower the reservoir or restrict reservoir levels in order to stop or reduce seepage and its effects. Lowering the reservoir reduces the hydraulic head producing the seepage and will have an immediate impact on serious seepage problems. For this reason, outlet works and other control structures should always operate properly.

In fact, deciding to lower the reservoir have effects on the purpose of the project that is power generation but if the above seepage problems are happening this paper recommend the remedial action that is stated above must be use because, the objective may be of secondary importance if dam failure is imminent and it is already known that failure would result in loss of life and extensive property damage.

For many dams, the critical failure surfaces will be in the foundation so the foundation safety must continuously assess.

6. References

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7. Appendix A

7.1 Appendix to chapter four

7.1.1 SEEP/W result

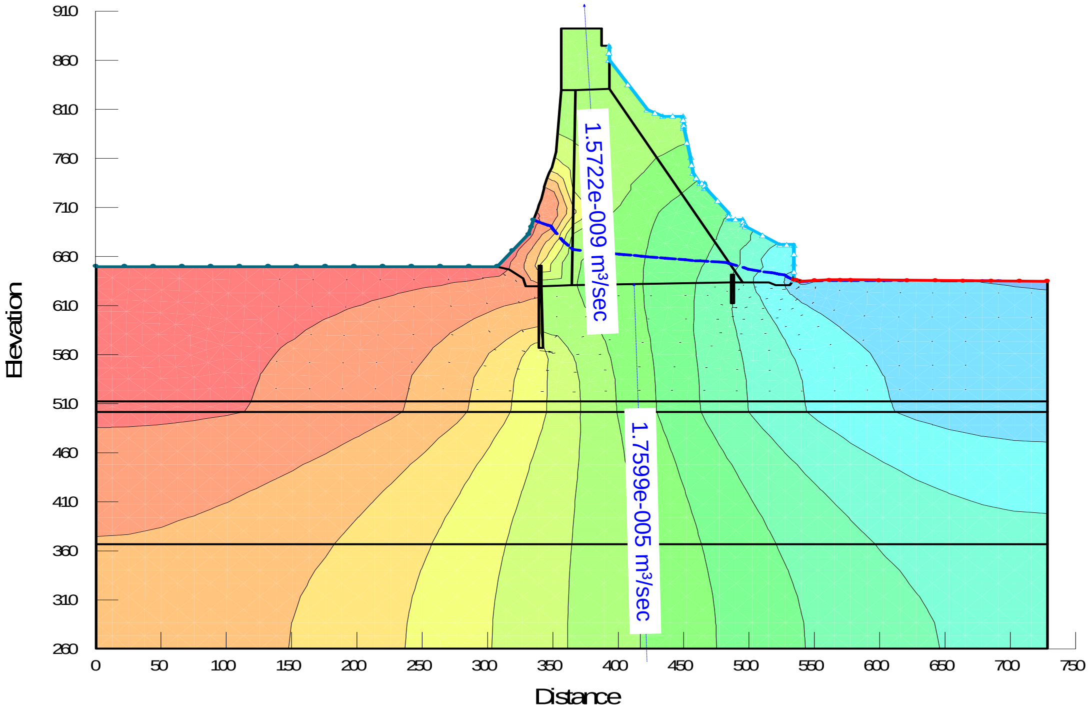

Figure 6. 1: RWL @697m for k 10^{-6}

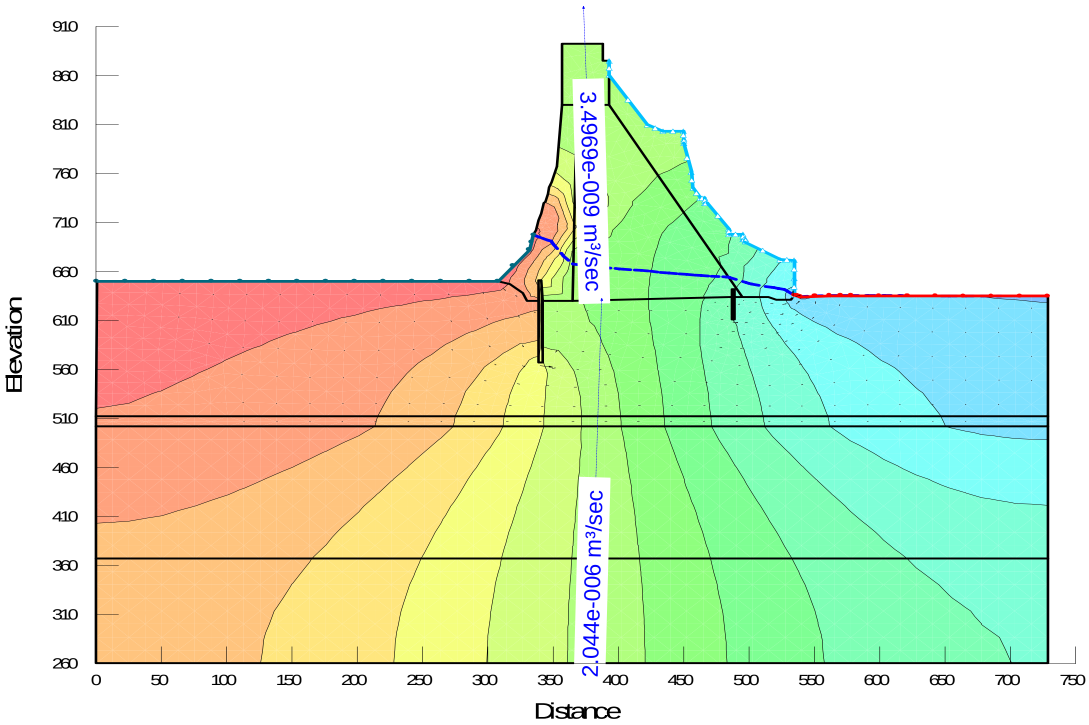

Figure 6. 2: RWL @697m for k 10^{-7}

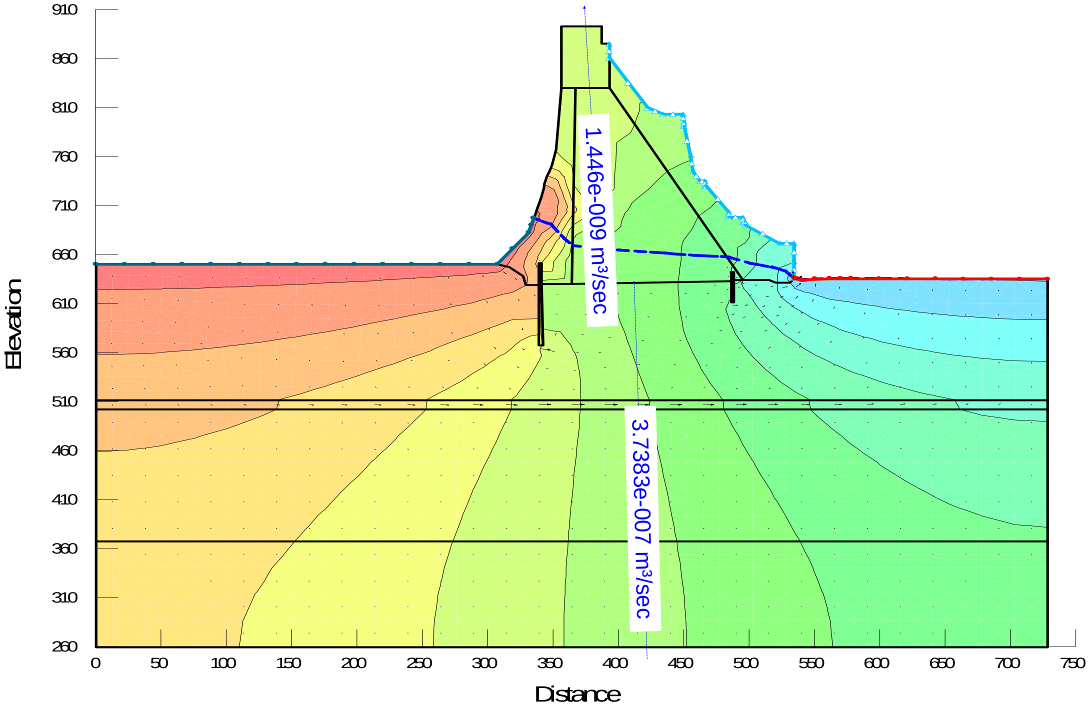

Figure 6. 3: RWL @697m for k 10^{-8}

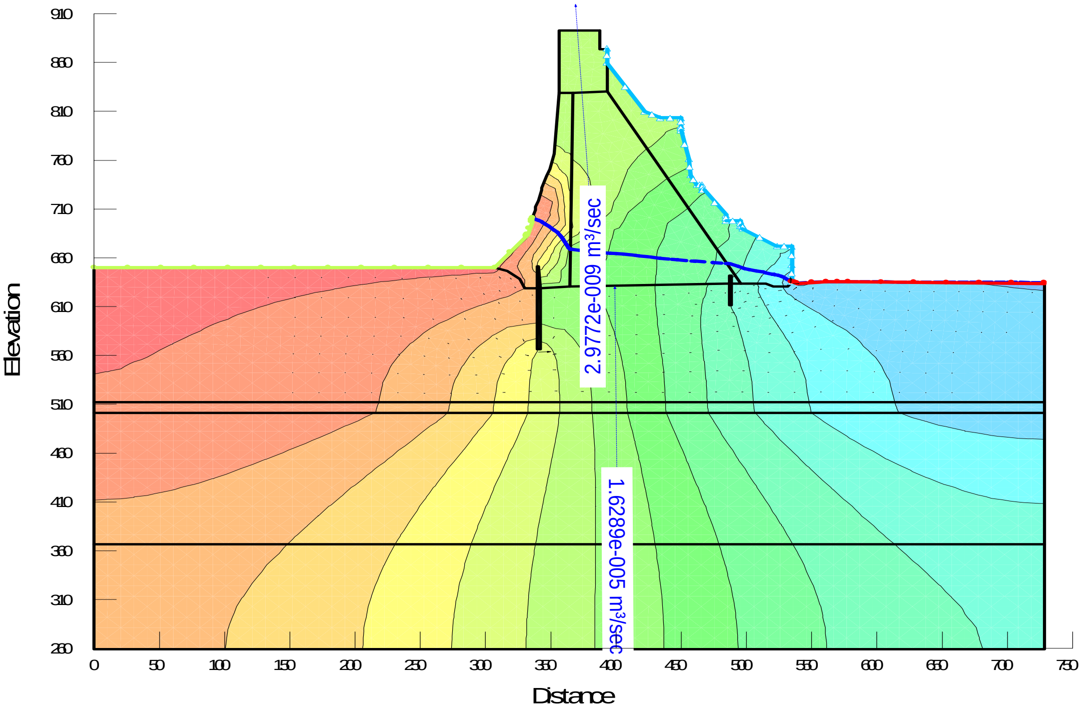

Figure 6. 4: RWL @701m for k 10^{-6}

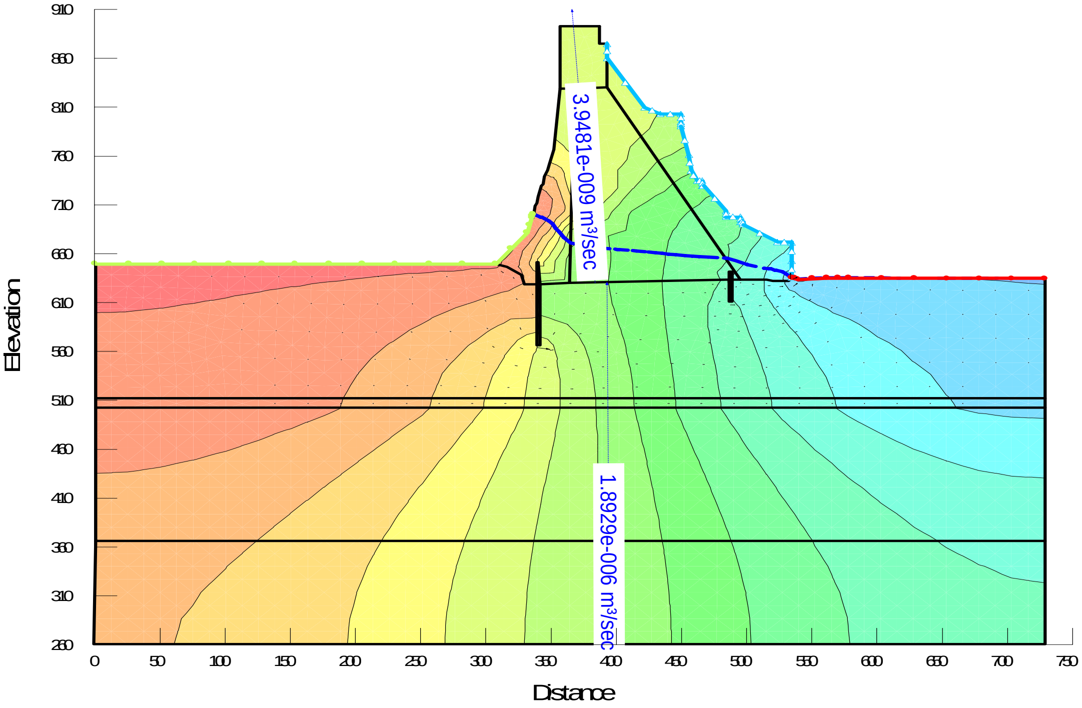

Figure 6. 5: RWL @701m for k 10^{-7}

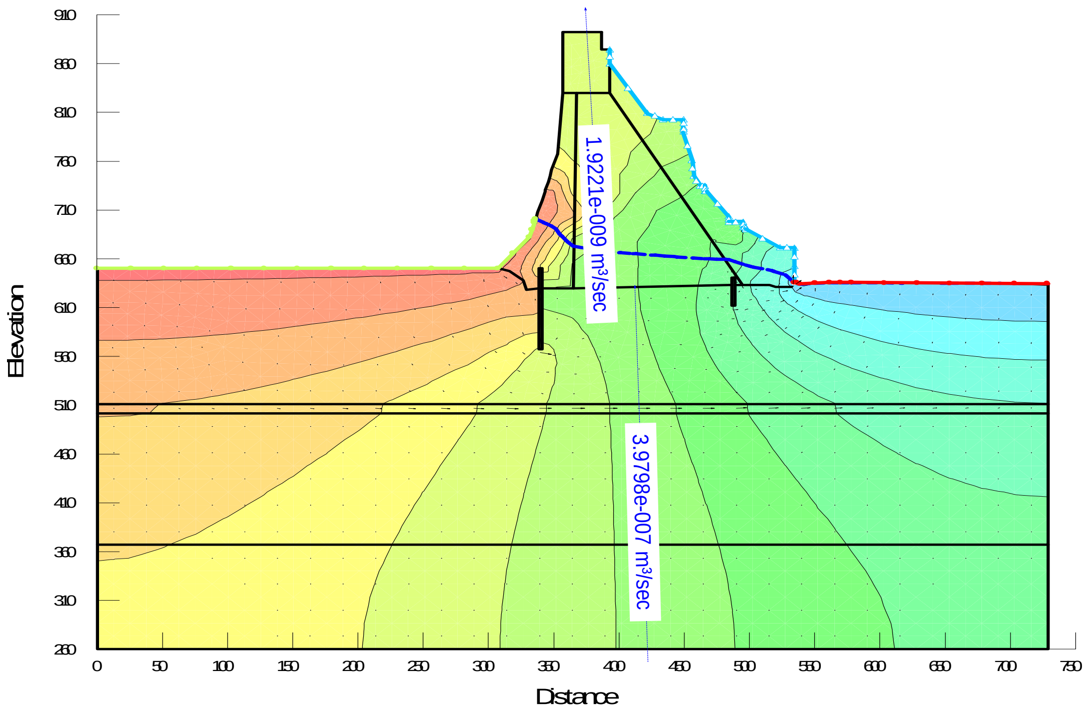

Figure 6.6: RWL @701m for k 10^{-8}

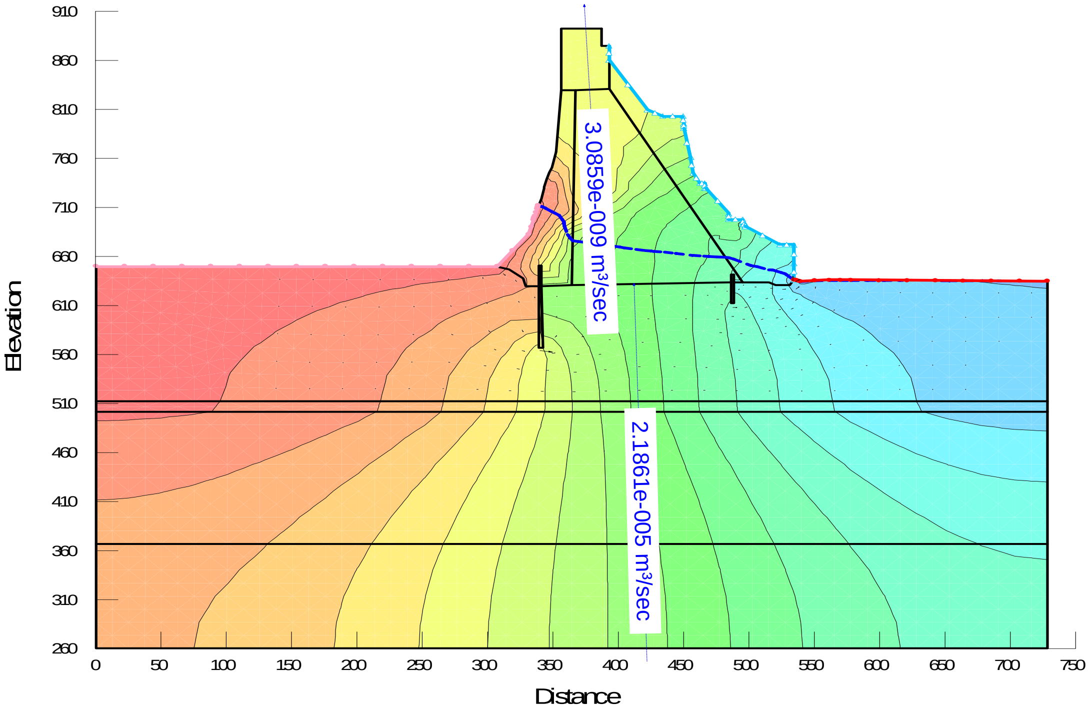

Figure 6. 7: RWL @712m for k 10^{-6}

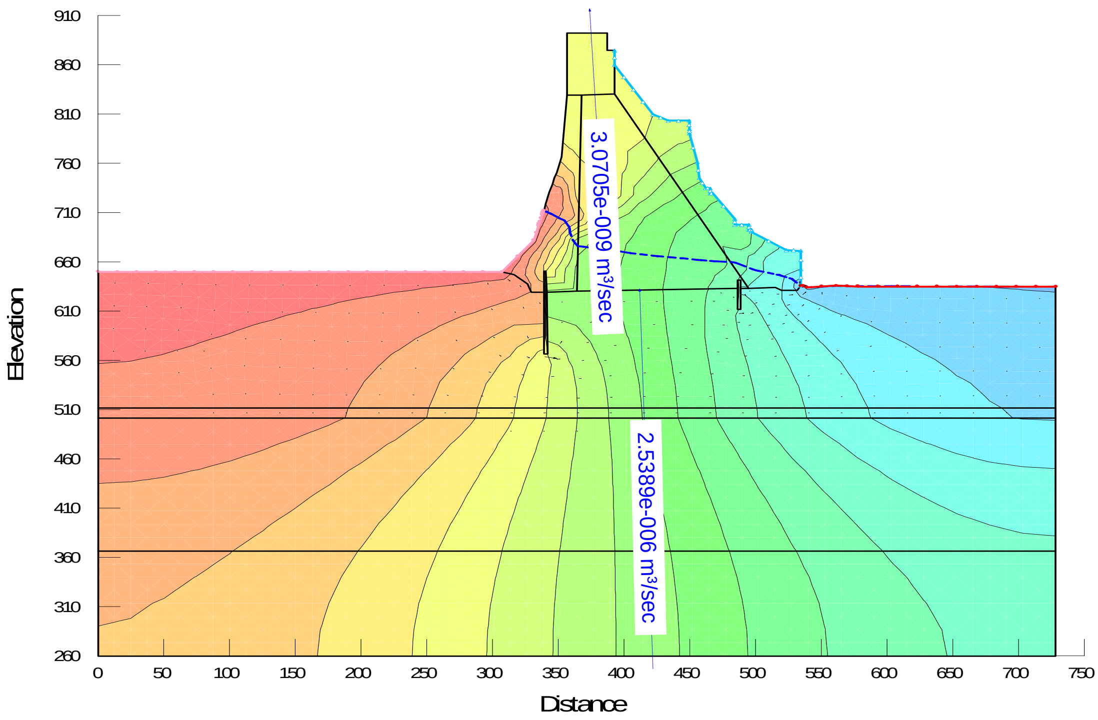

Figure 6. 8: RWL @712m for k 10^{-7}

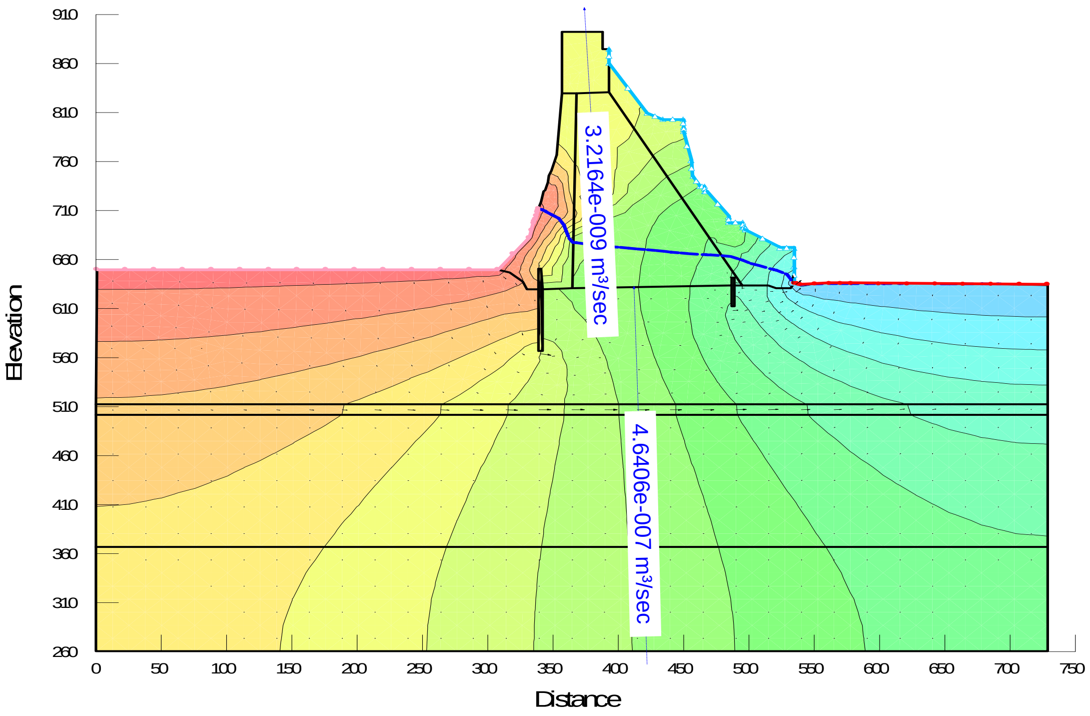

Figure 6. 9: RWL @712 for k 10^{-8}

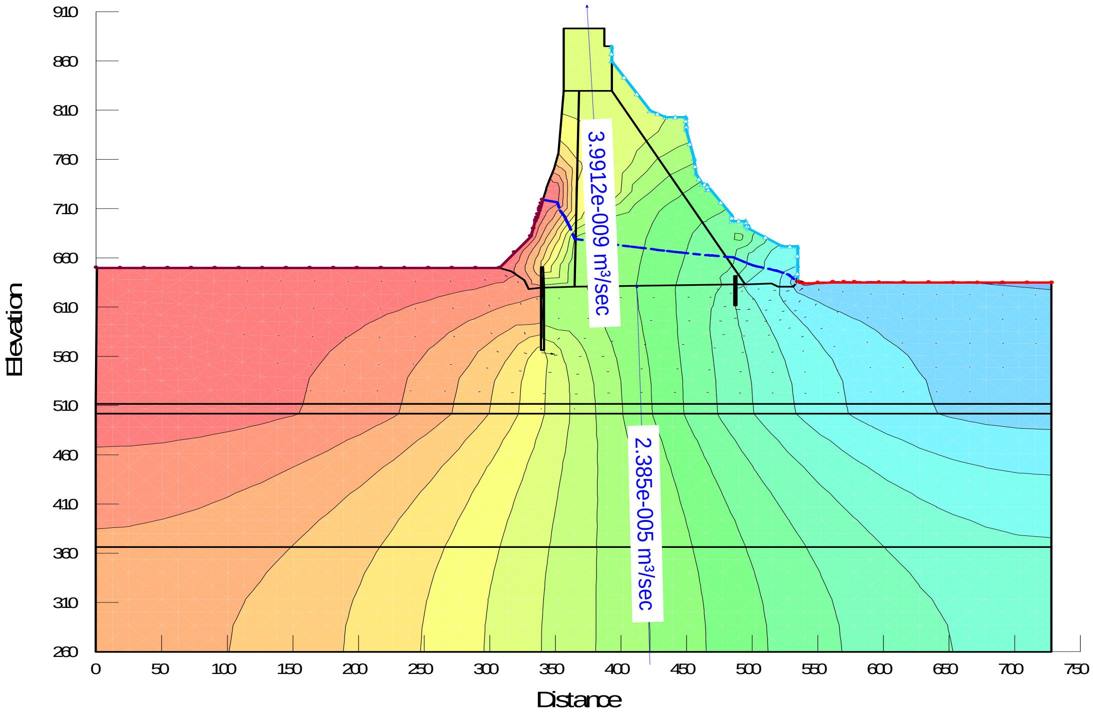

Figure 6. 10: RWL @719m for k 10^{-6}

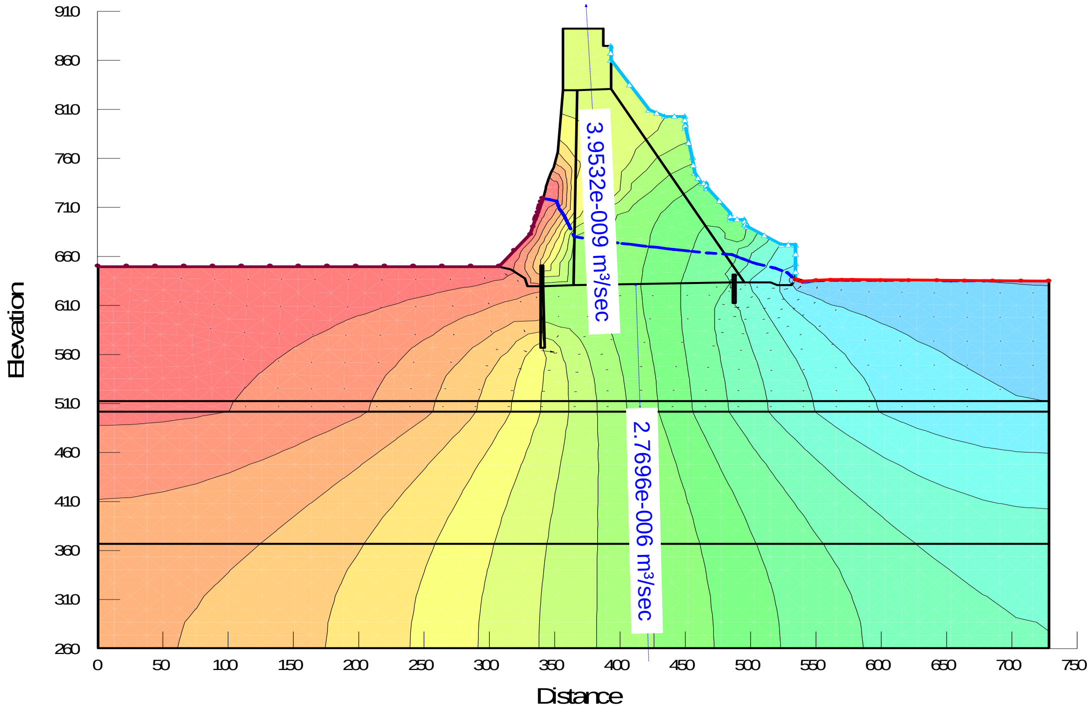

Figure 6. 11: RWL @719m for k 10^{-7}

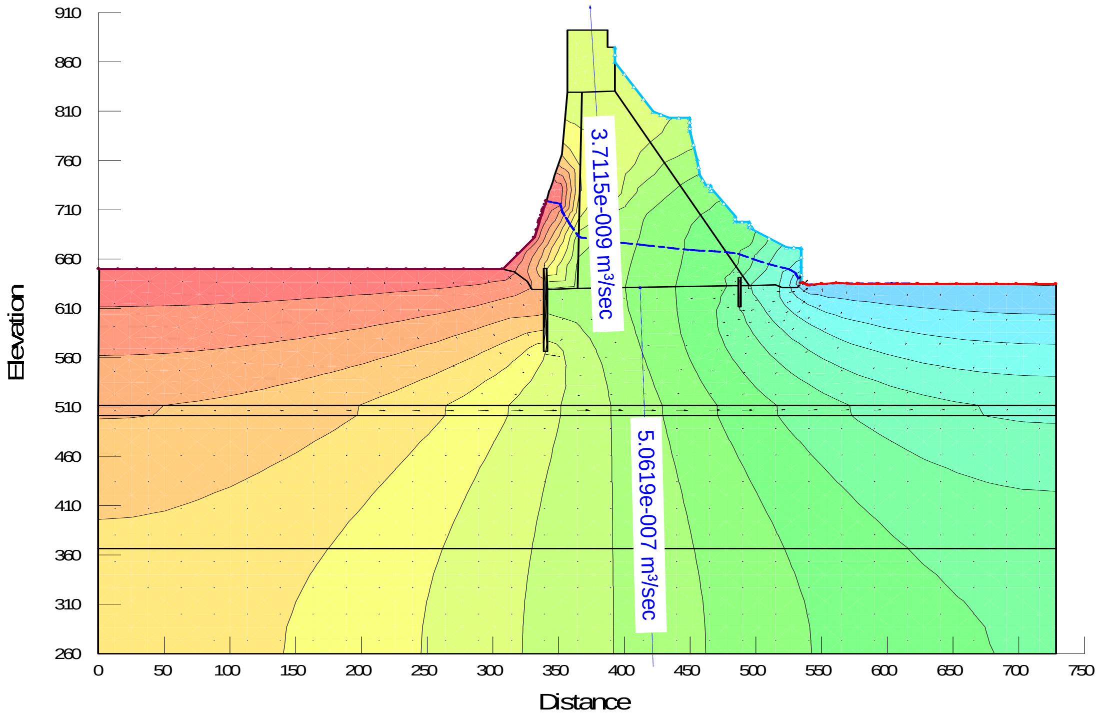

Figure 6. 12: RWL @719m for k 10^{-8}

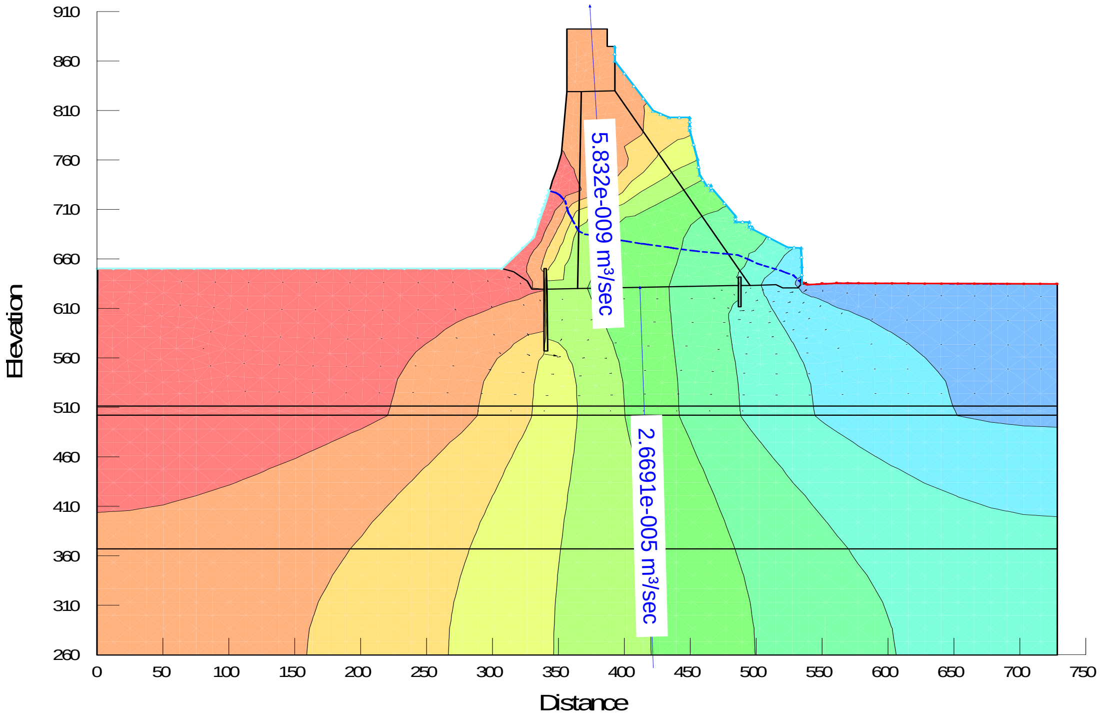

Figure 6. 13: RWL @729m for k 10^{-6}

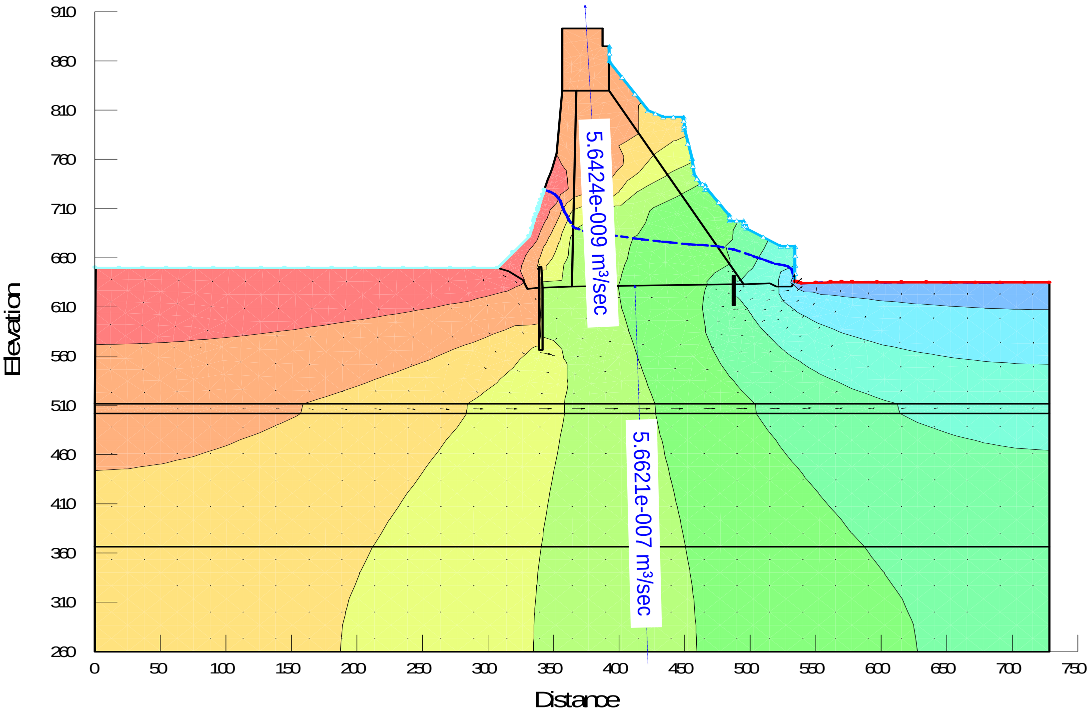

Figure 6. 14: RWL @729m for k 10^{-7}

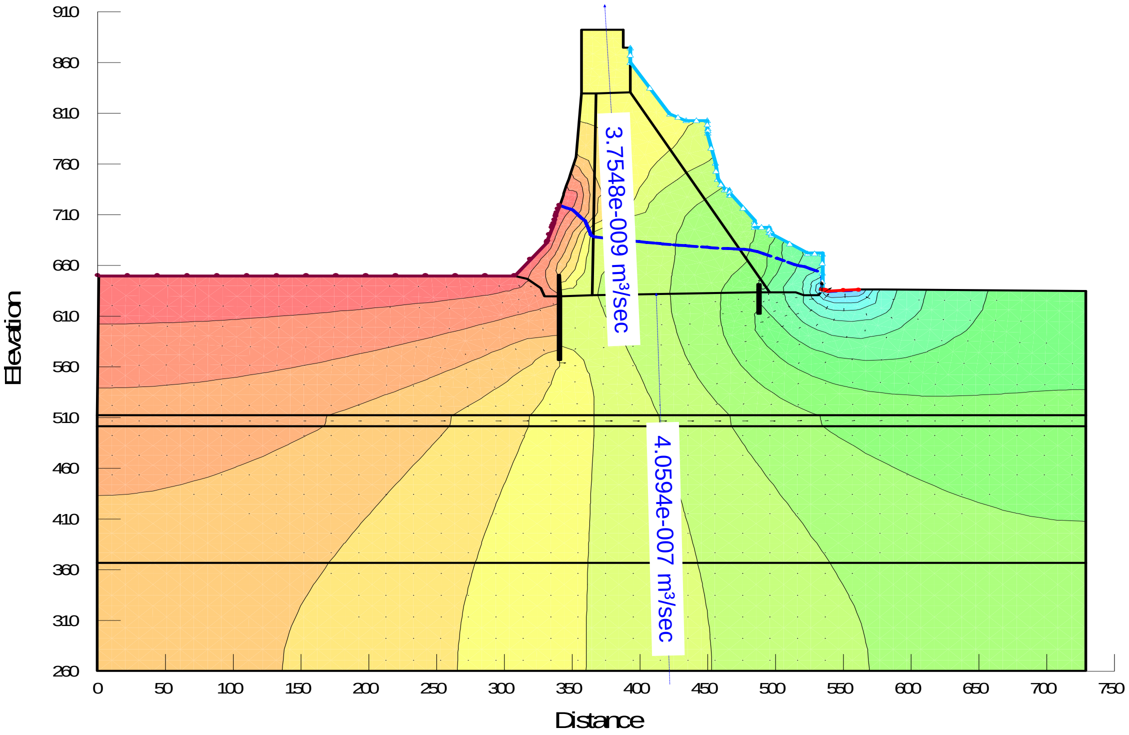

Figure 6. 15: RWL @729m for k 10^{-8}

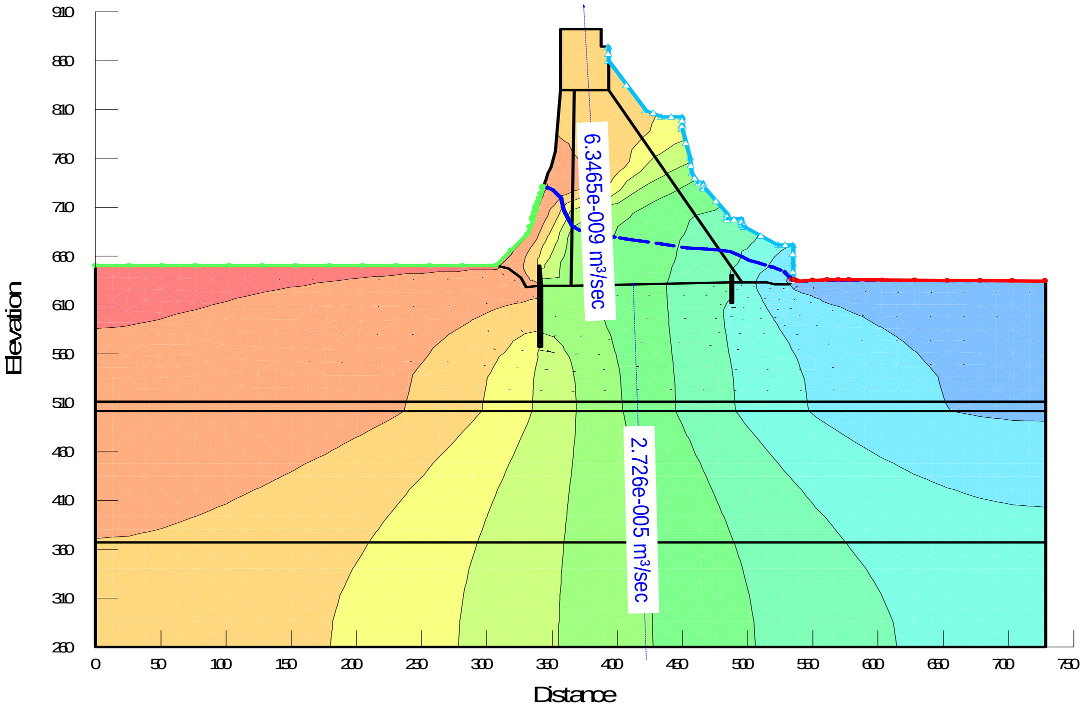

Figure 6. 16: RWL @731m for k 10^{-6}

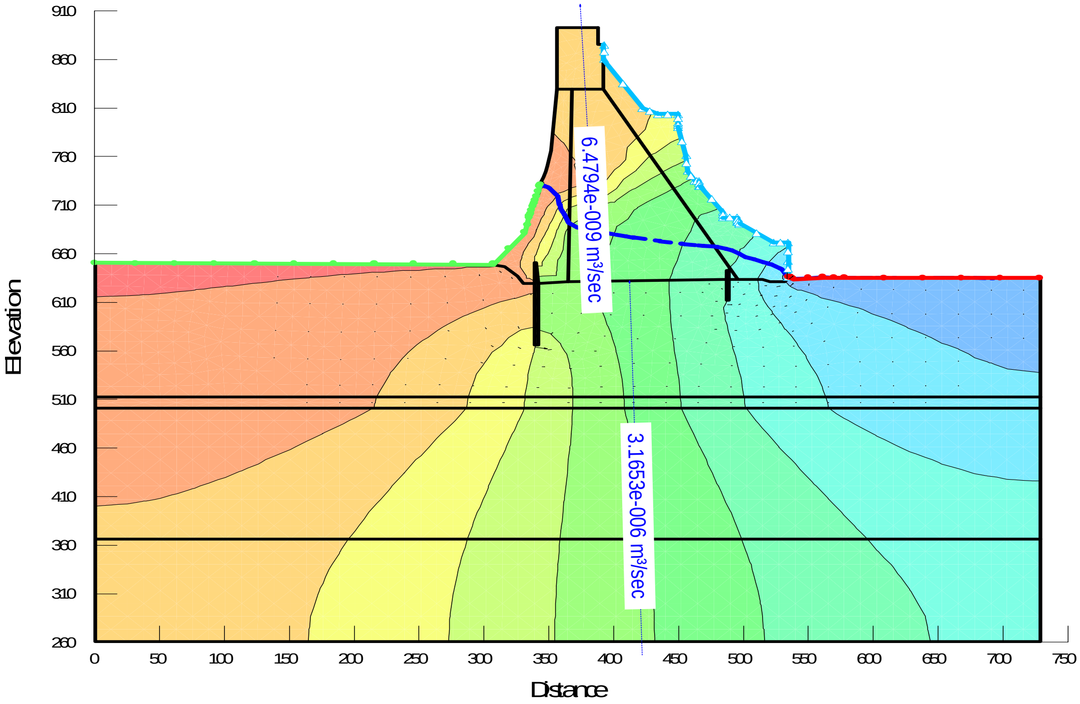

Figure 6. 17: RWL @731m for k 10^{-7}

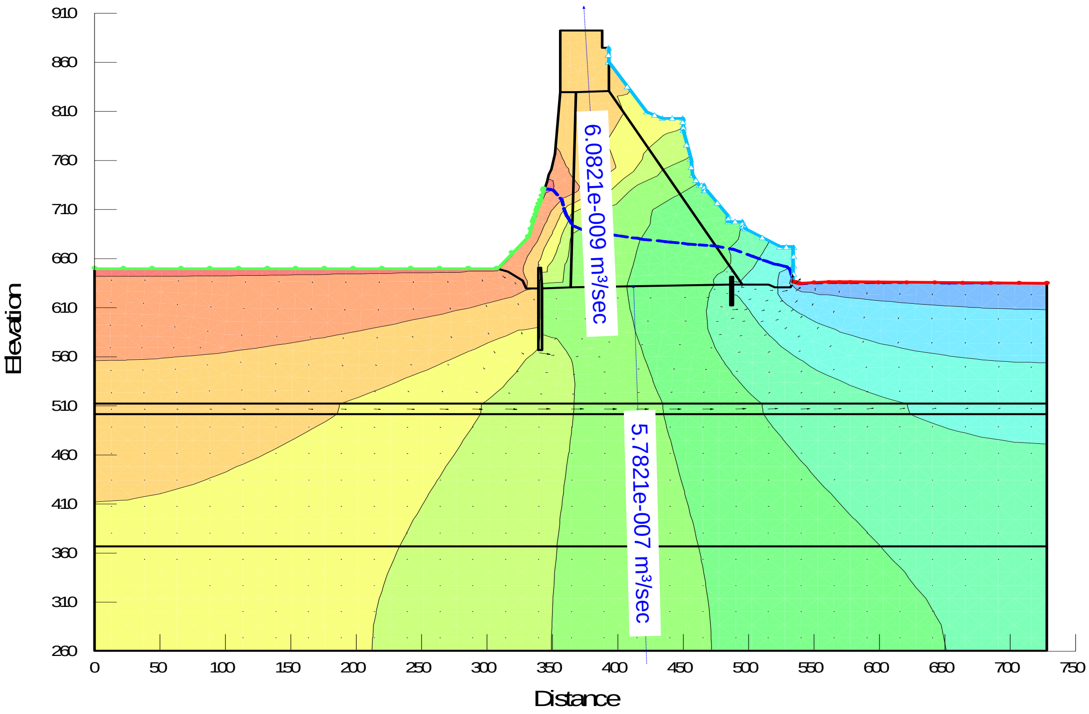

Figure 6. 18: RWL @731m for k 10^{-8}

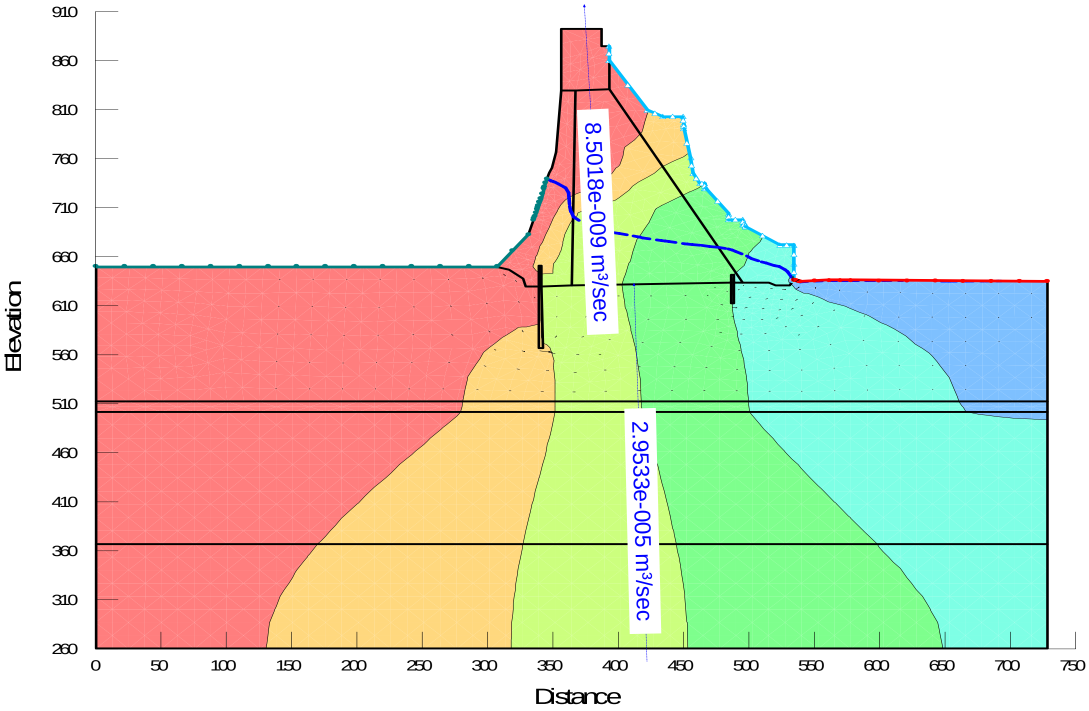

Figure 6. 19: RWL @739m for k 10^{-6}

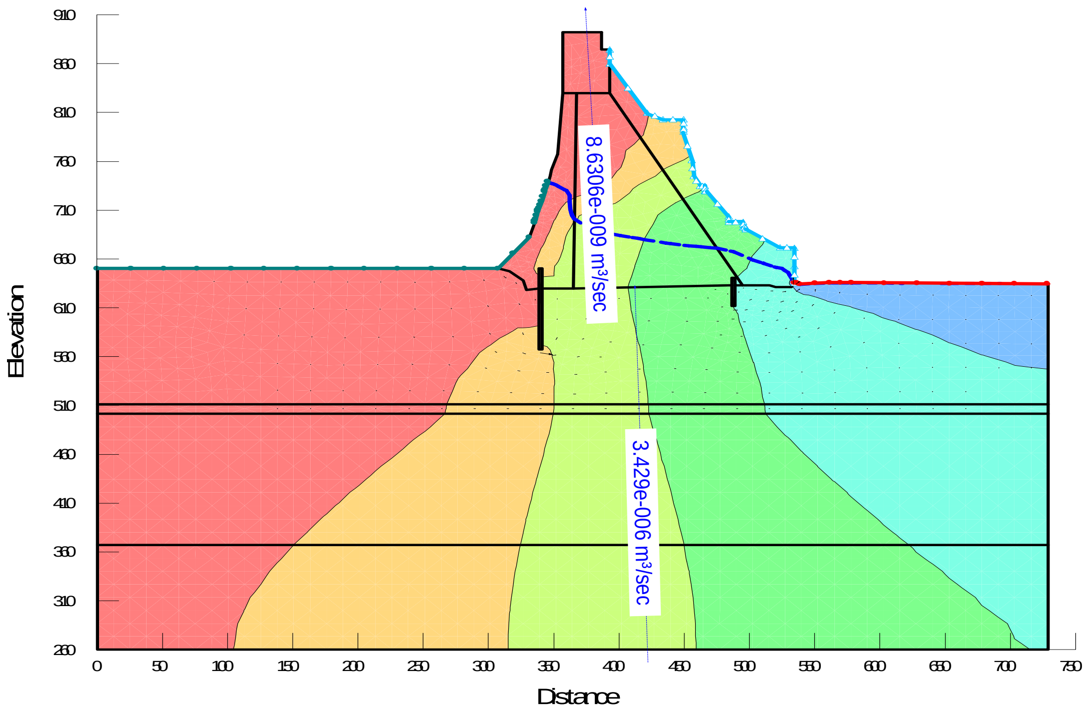

Figure 6. 20: RWL @739m for k 10^{-7}

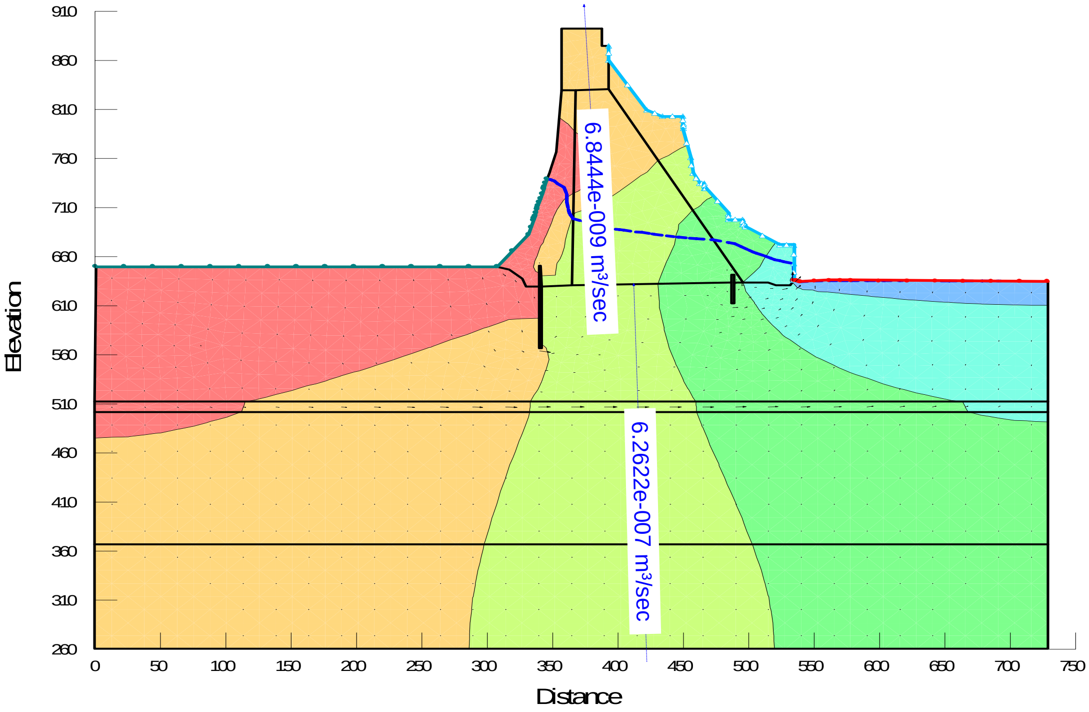

Figure 6. 21: RWL @739m for k 10^{-8}

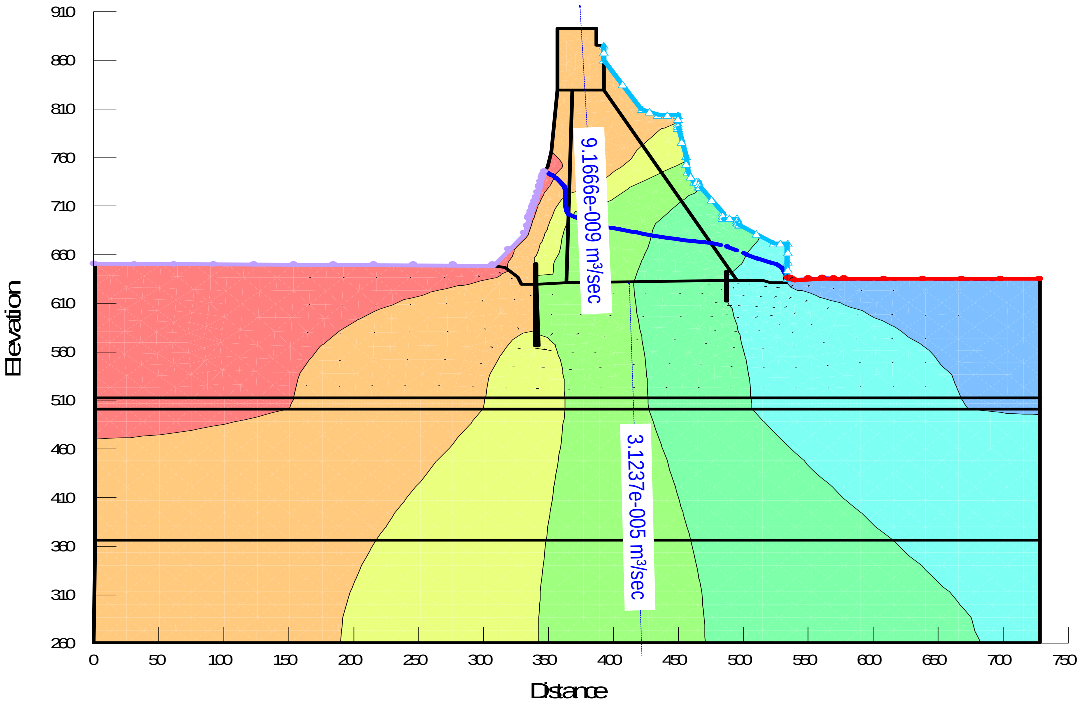

Figure 6. 22: RWL @745m for k 10^{-6}

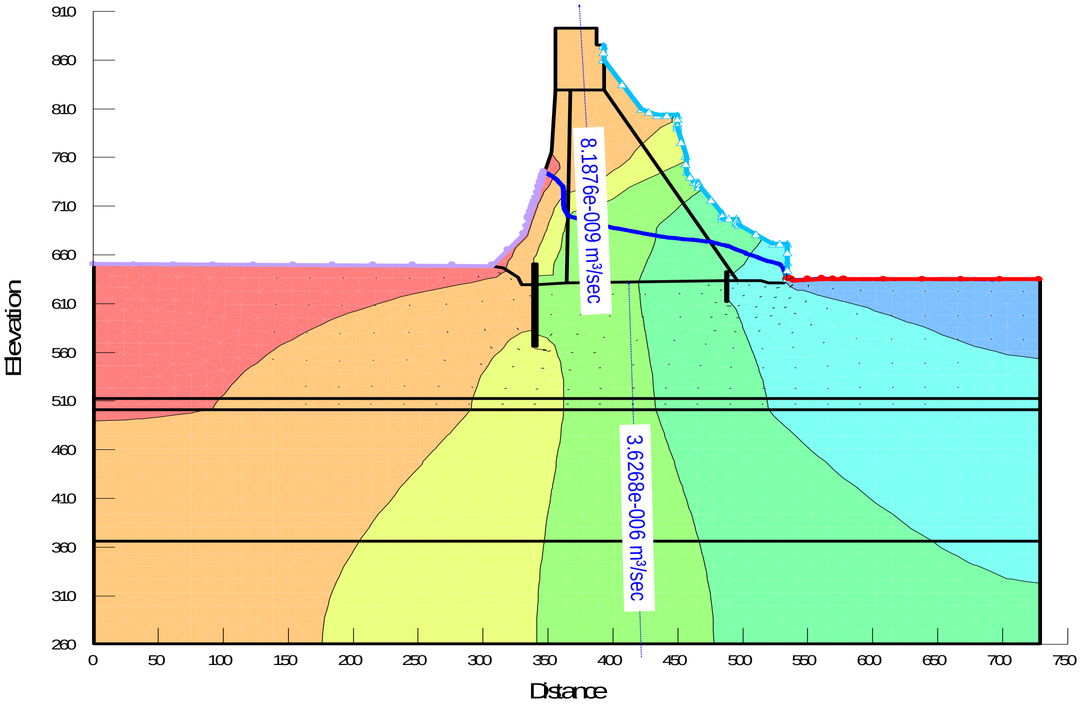

Figure 6. 23: RWL @745m for k 10^{-7}

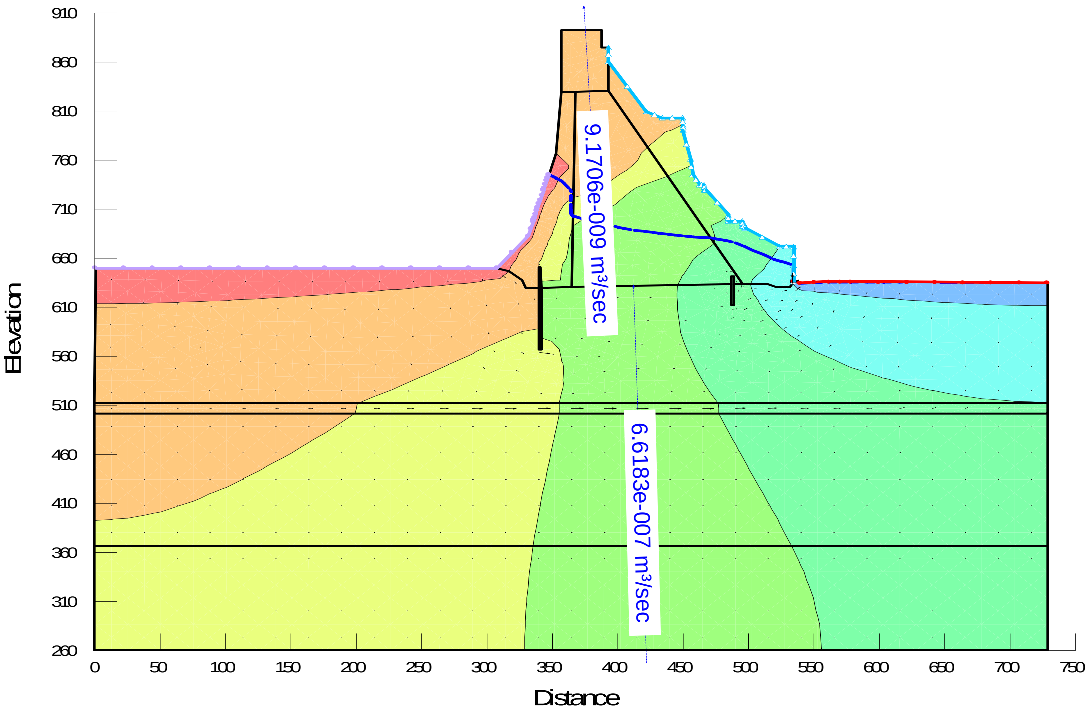

Figure 6. 24: RWL @745m for k 10^{-8}

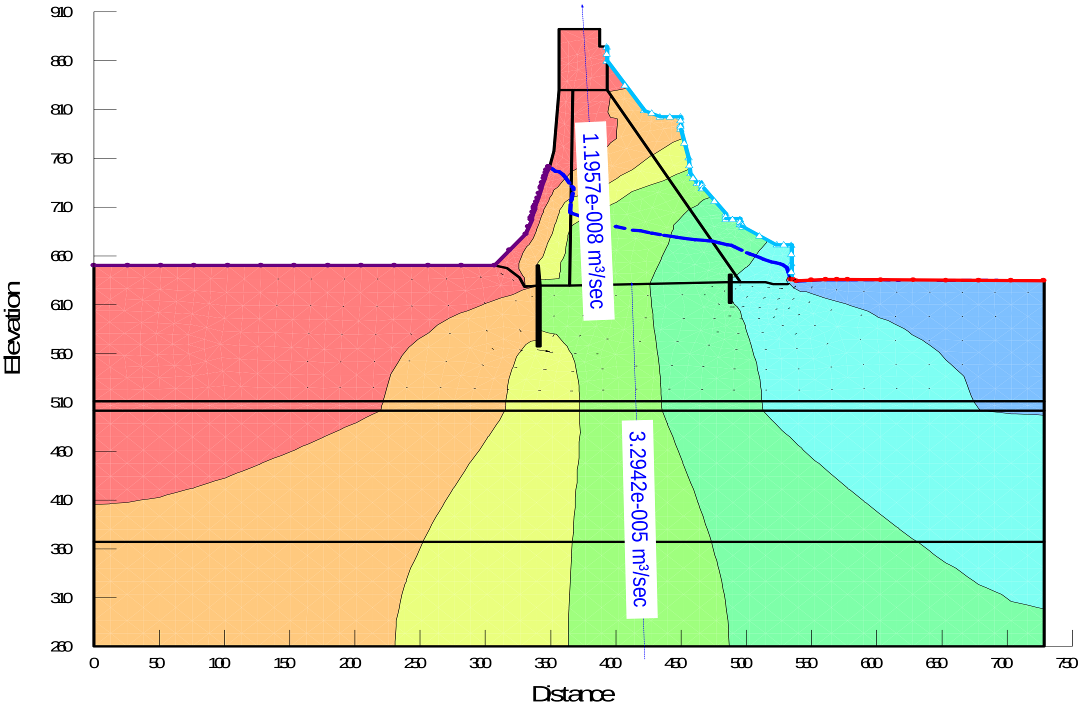

Figure 6. 25: RWL @751m for k 10^{-6}

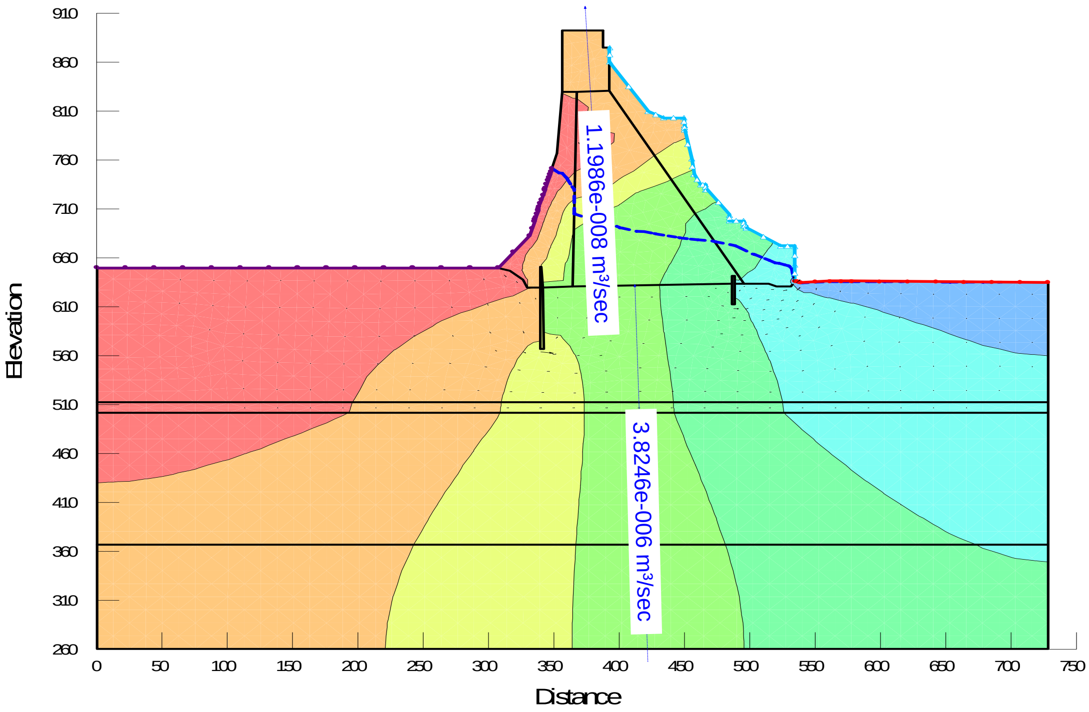

Figure 6. 26: RWL @751m for k 10^{-7}

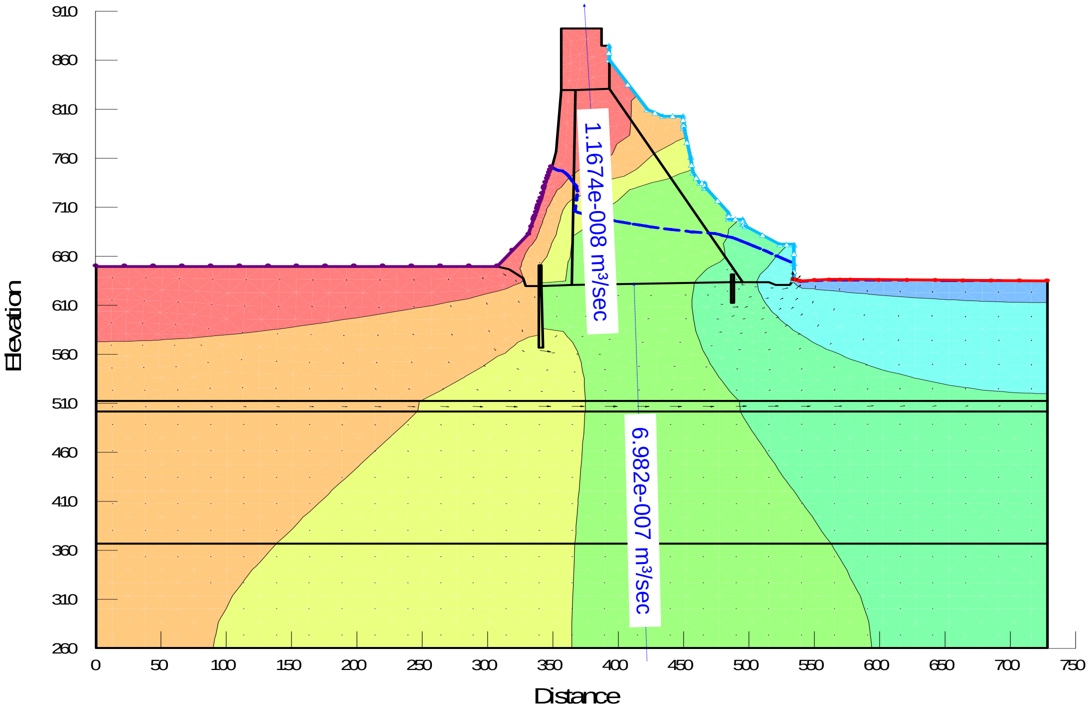

Figure 6. 27: RWL @751m for k 10^{-8}

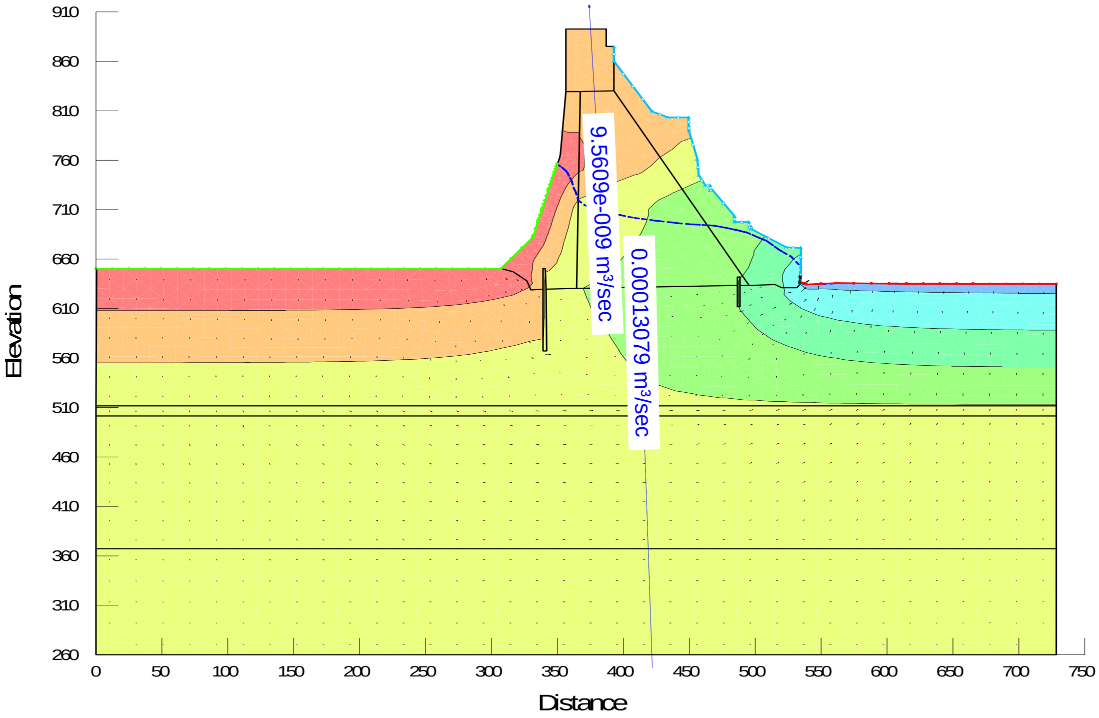

Figure 6. 28: RWL @756m for k 10^{-6}

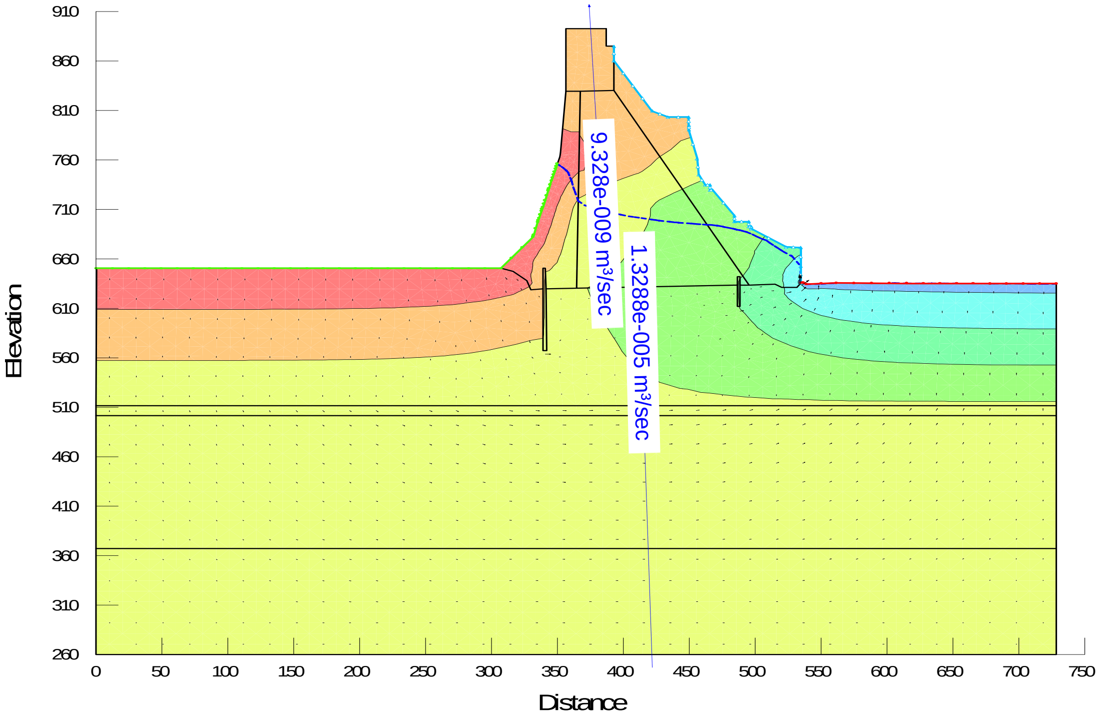

Figure 6. 29: RWL @756m for k 10^{-7}

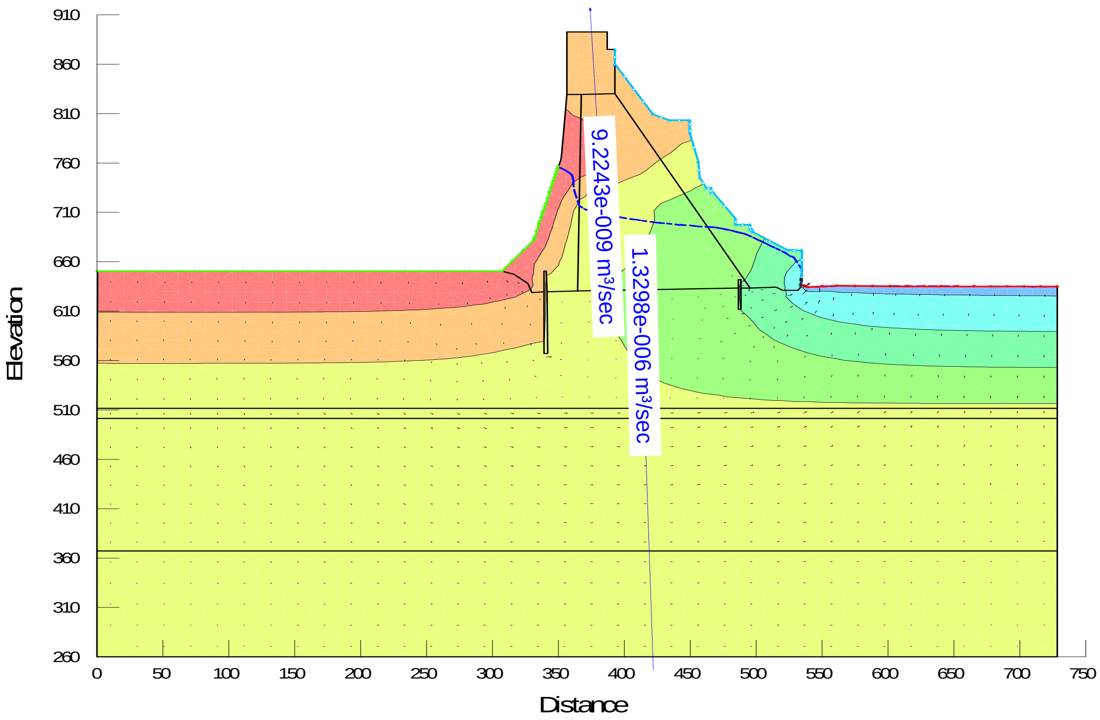

Figure 6. 30: RWL @756m for k 10^{-8}

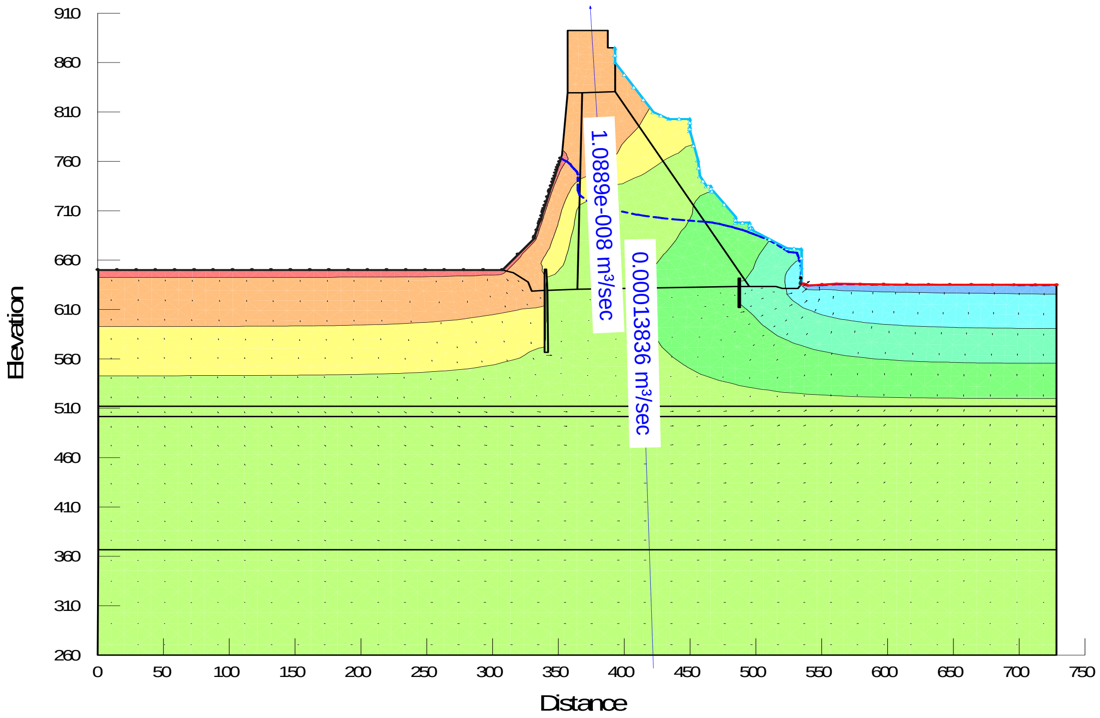

Figure 6. 31: RWL @763m for k 10^{-6}

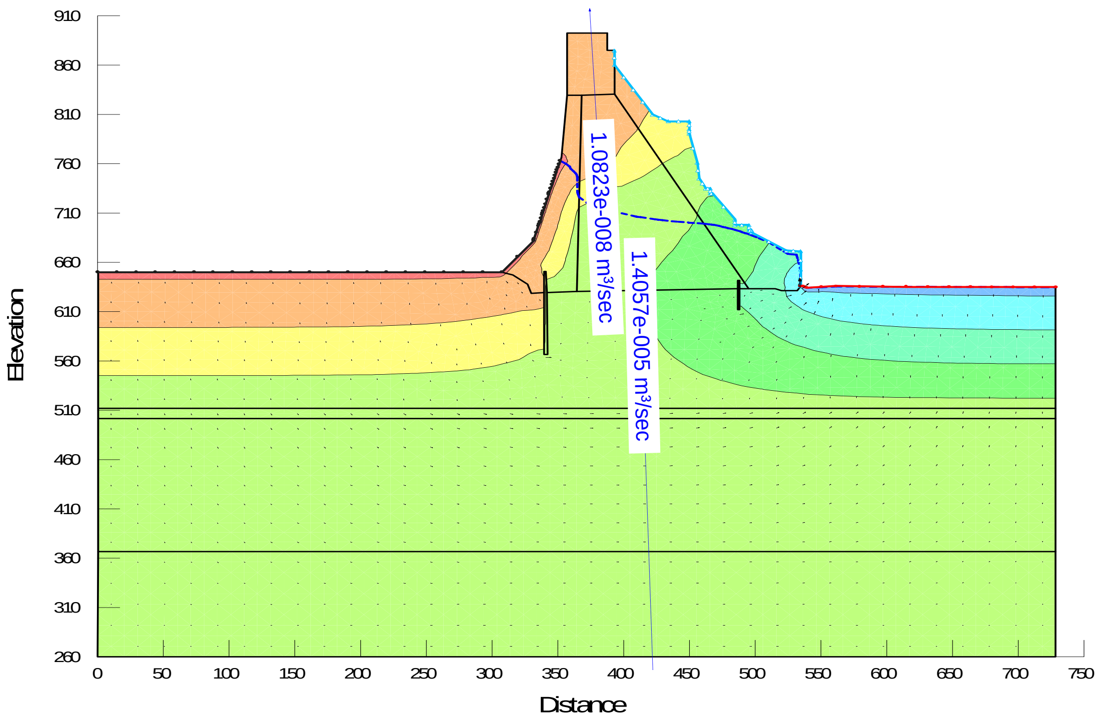

Figure 6. 32: RWL @763m for k 10^{-7}

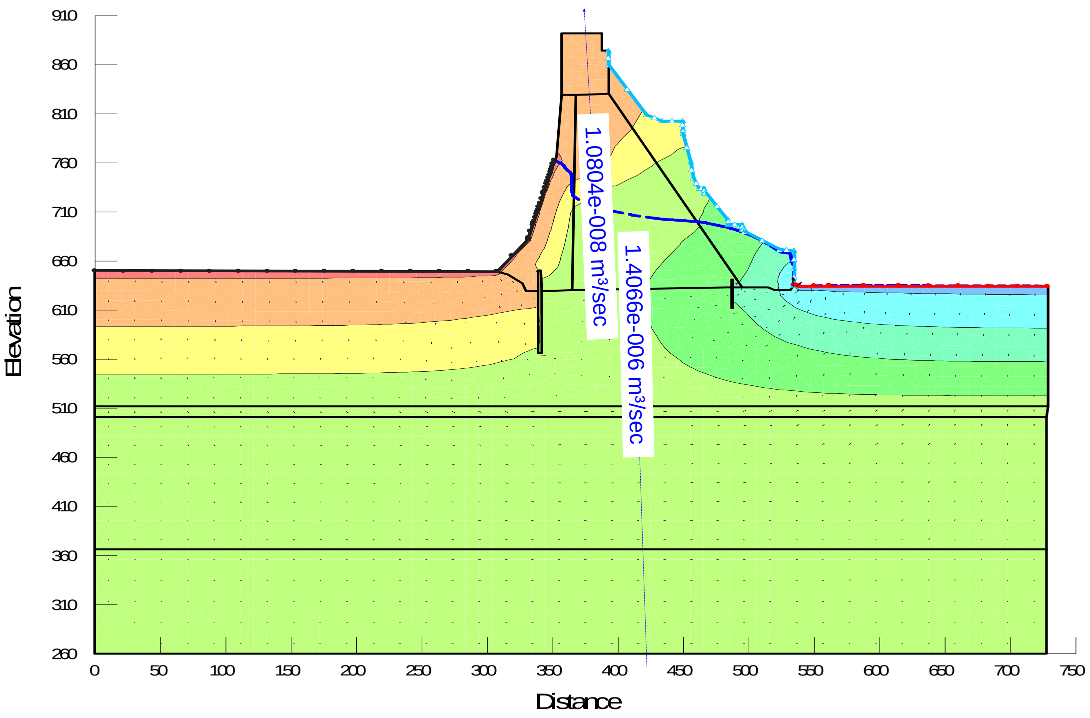

Figure 6.33:RWL @763m for k 10^{-8}

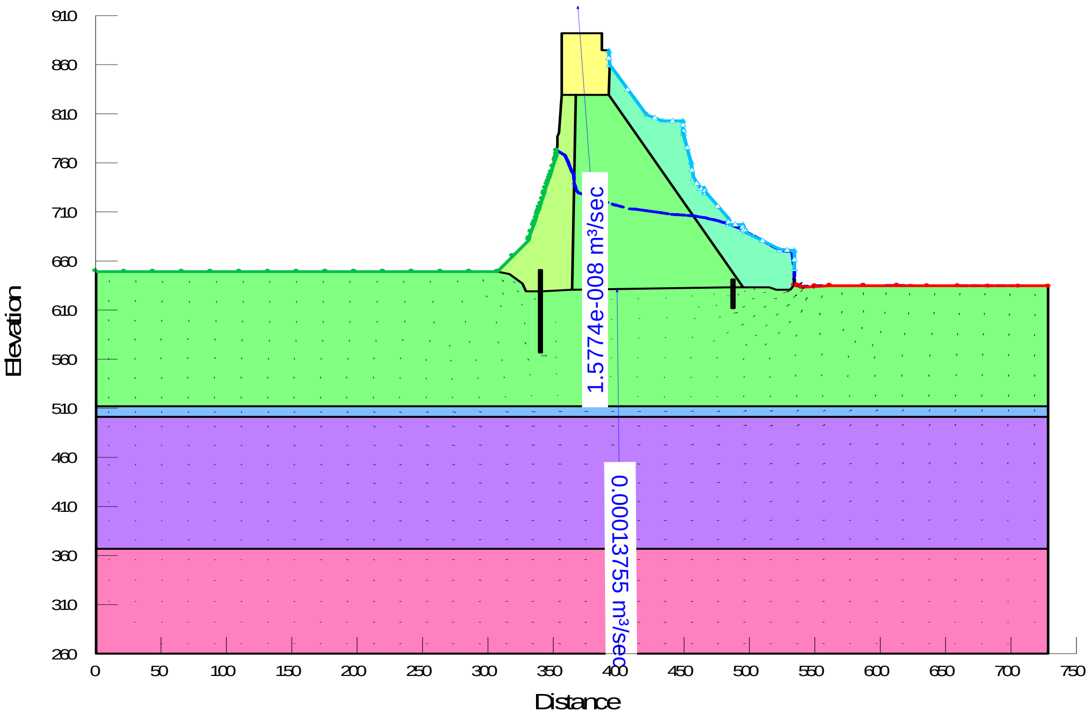

Figure 6. 34: RWL @773m for k 10^{-6}

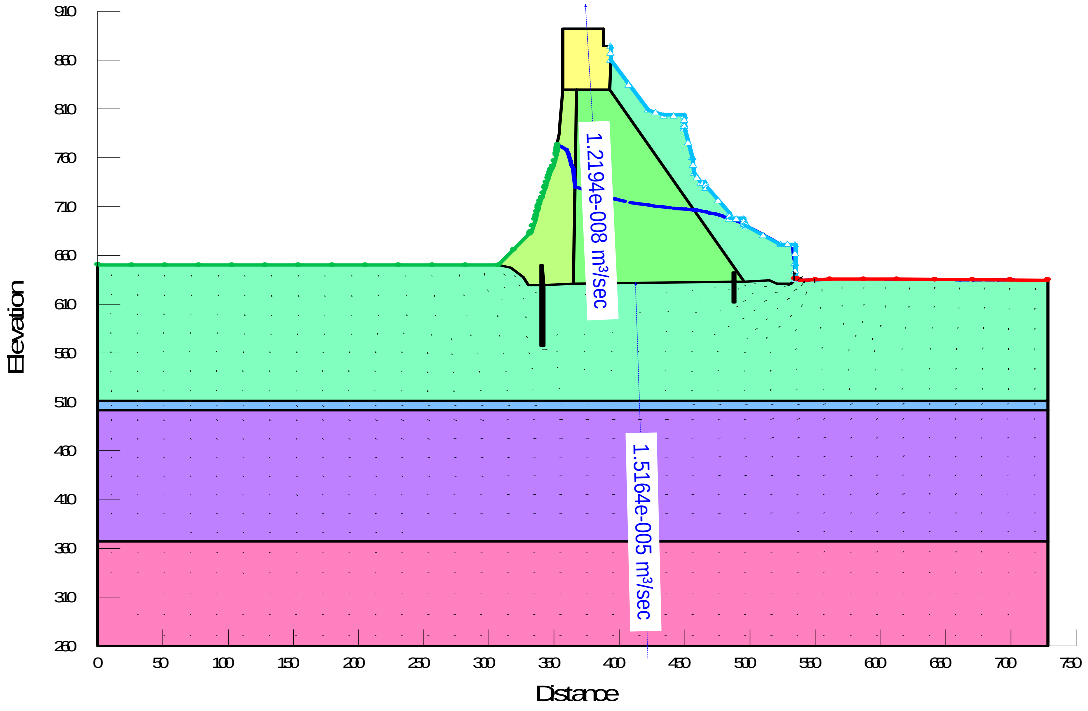

Figure 6. 35: RWL @773m for k 10^{-7}

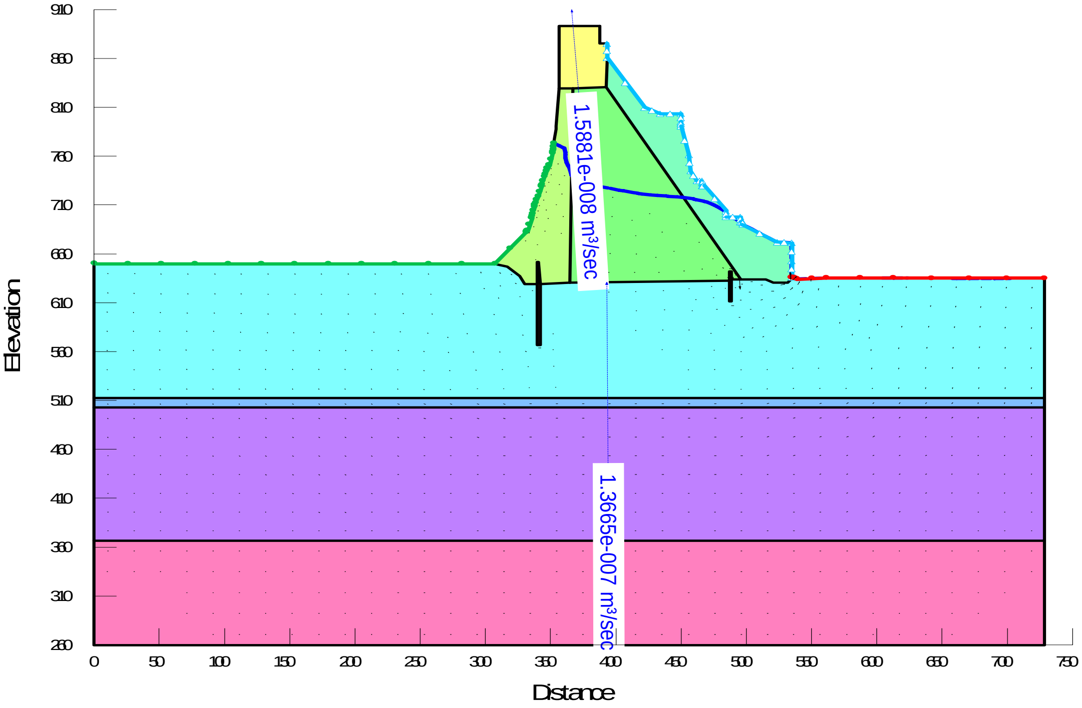

Figure 6. 36: RWL @773m for k 10^{-8}

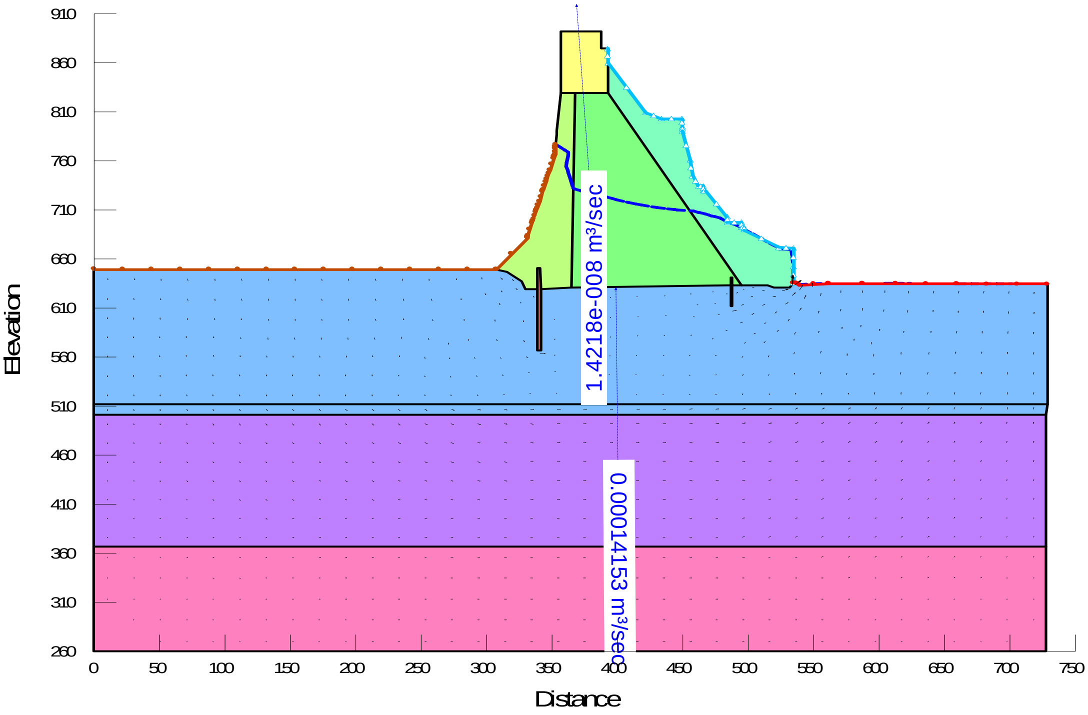

Figure 6. 37: RWL @777m for k 10^{-6}

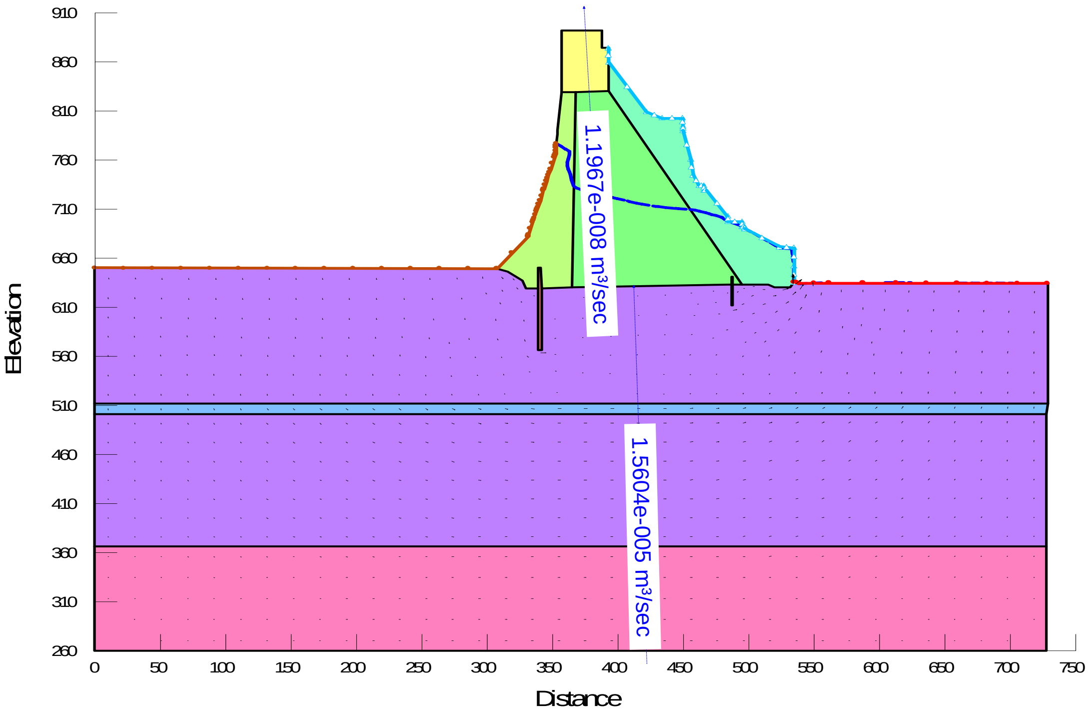

Figure 6. 38: RWL @777m for k 10^{-7}

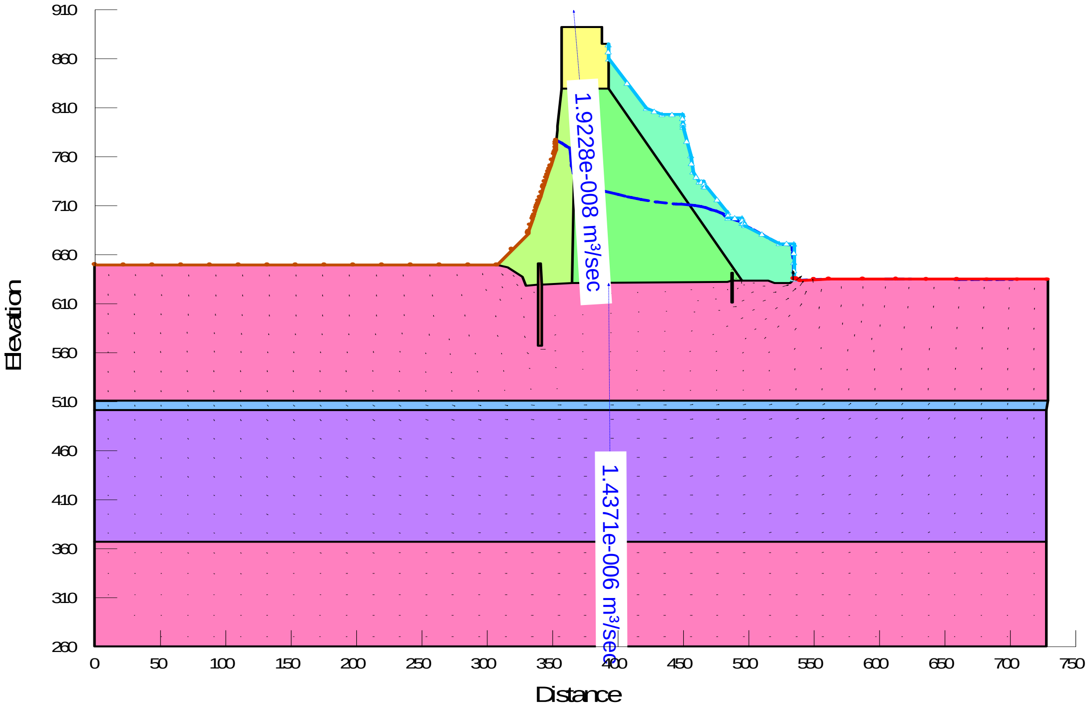

Figure 6. 39: RWL @777m for k 10^{-8}

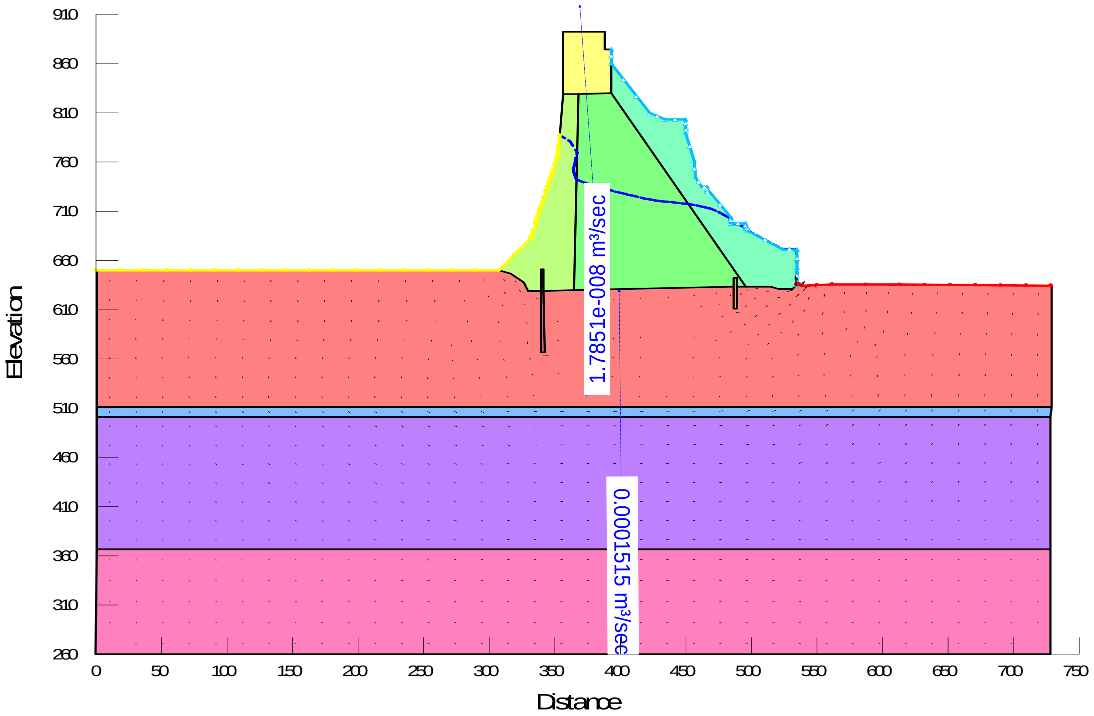

Figure 6. 40: RWL @787m for k 10^{-6}

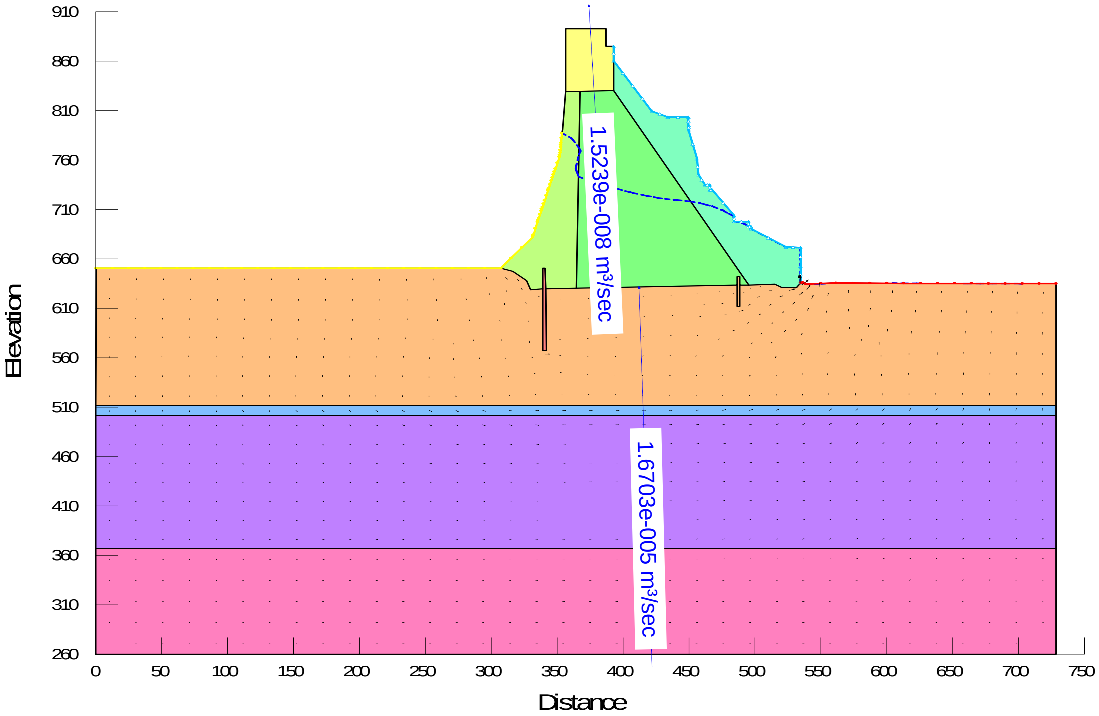

Figure 6. 41: RWL @787m for k 10^{-7}

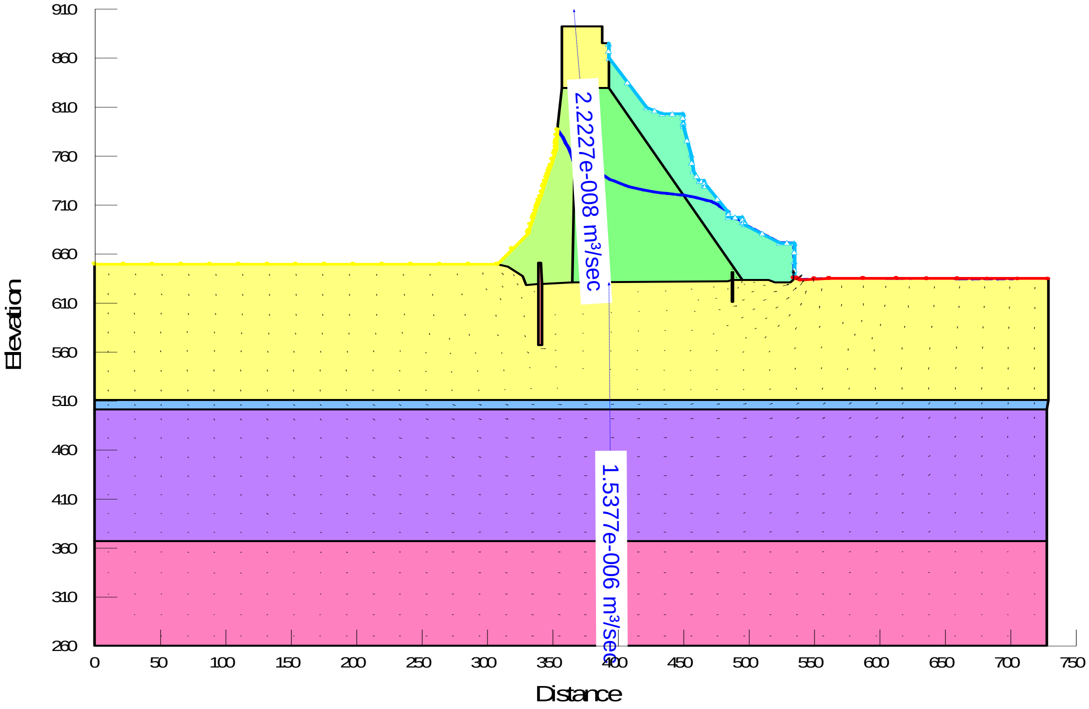

Figure 6. 42: RWL @787m for k 10^{-8}

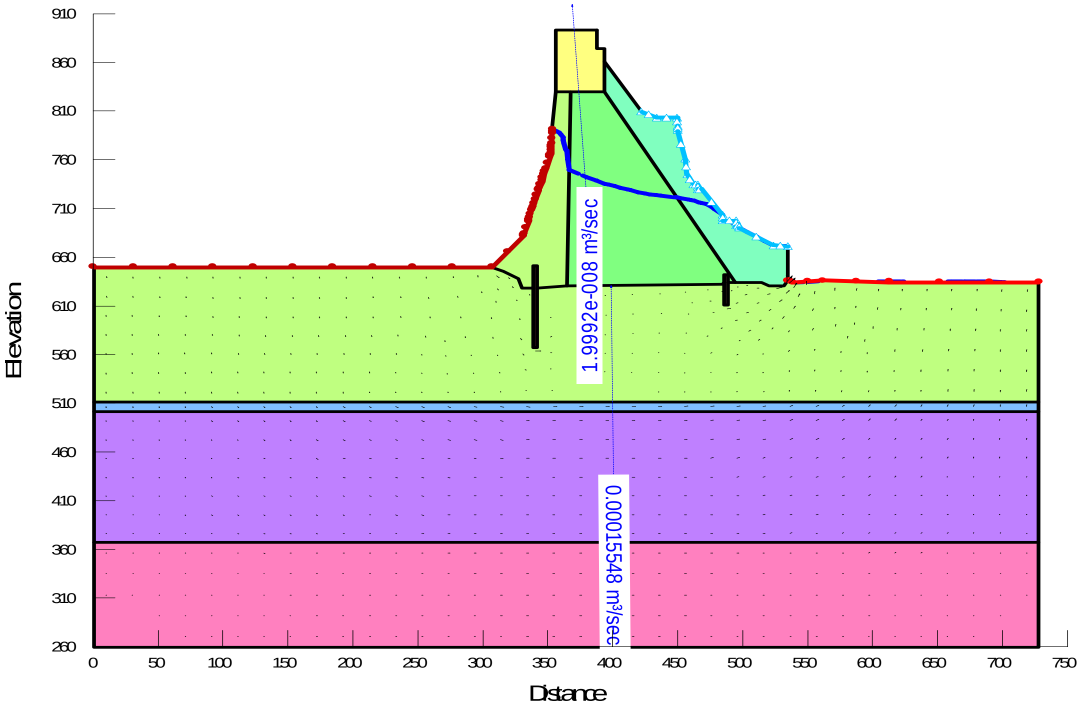

Figure 6. 43: RWL @791m for k 10^{-6}

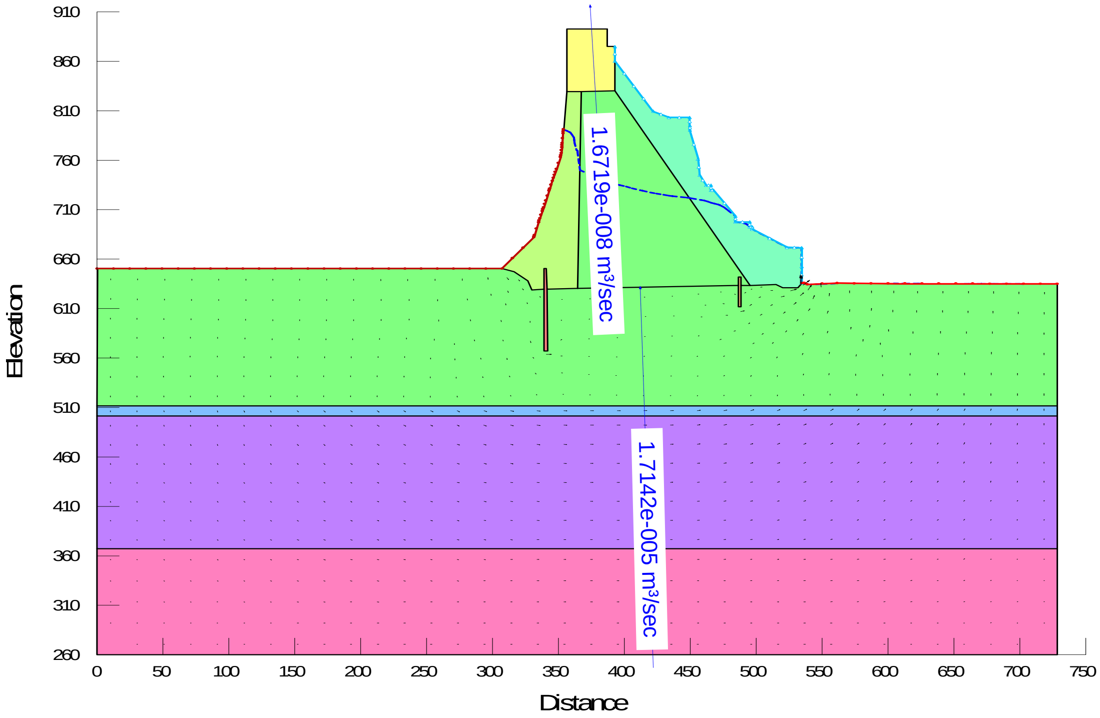

Figure 6. 44: RWL @791m for k 10^{-7}

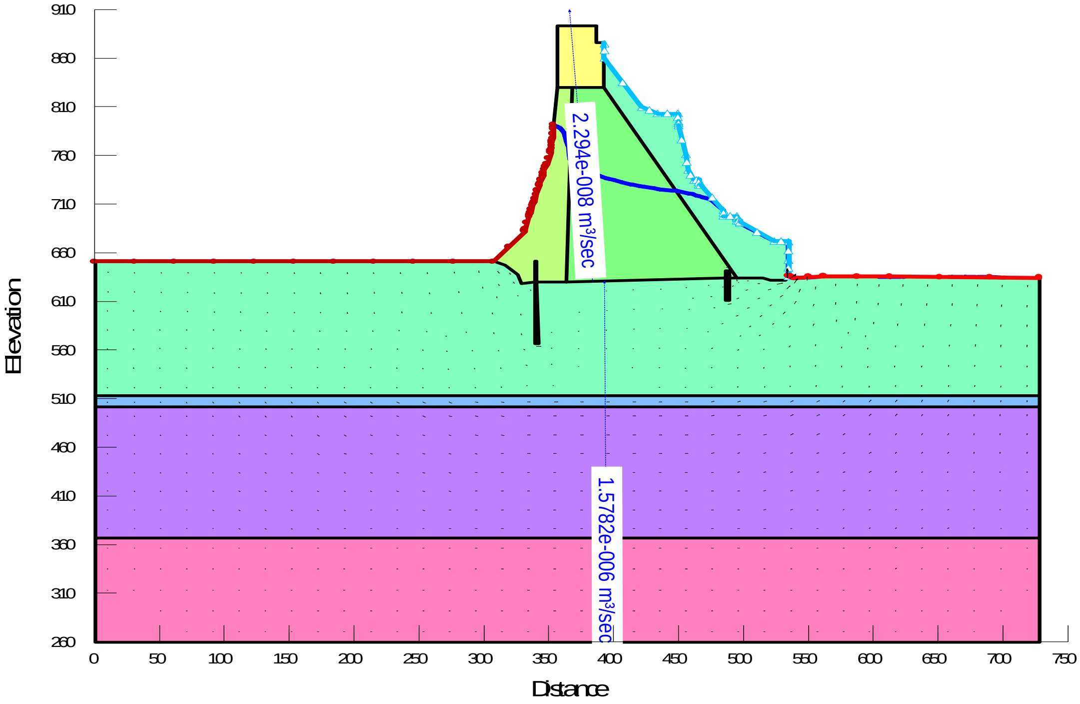

Figure 6. 45: RWL @791m for k 10^{-8}

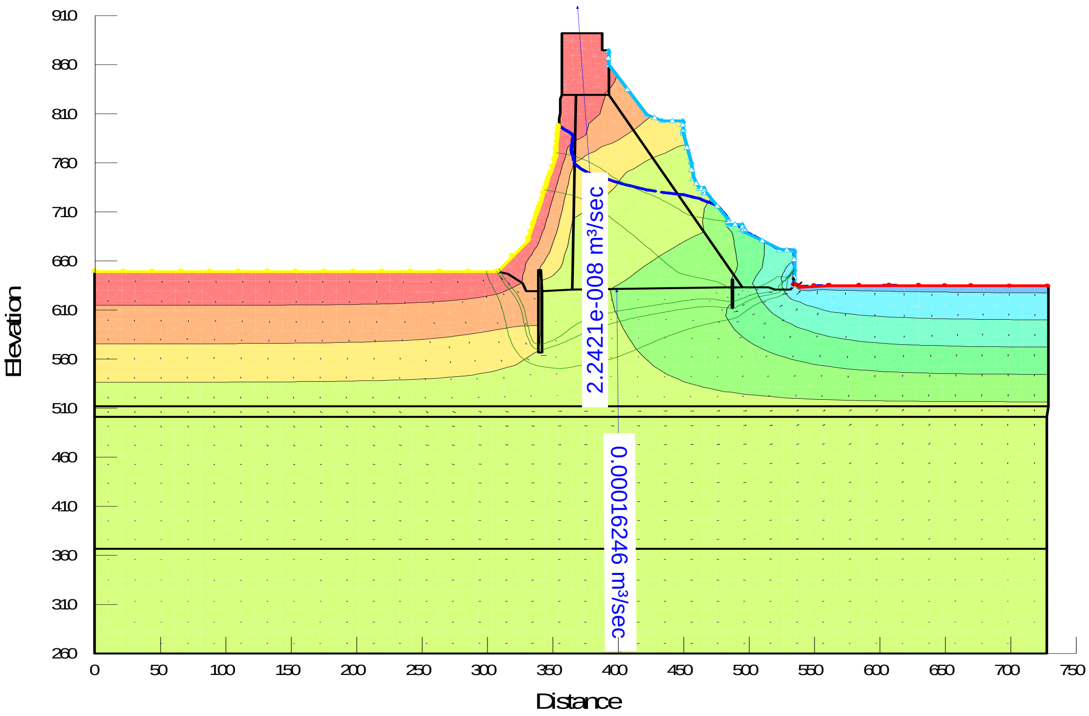

Figure 6. 46: RWL @798m for k 10^{-6}

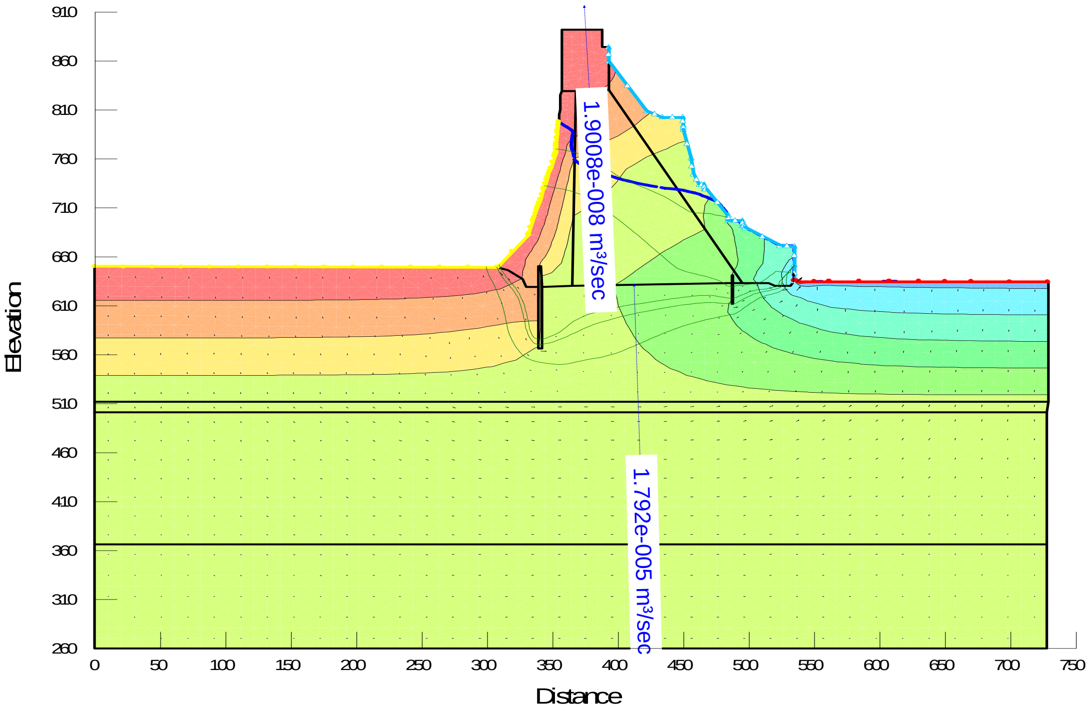

Figure 6. 47: RWL @798m for k 10^{-7}

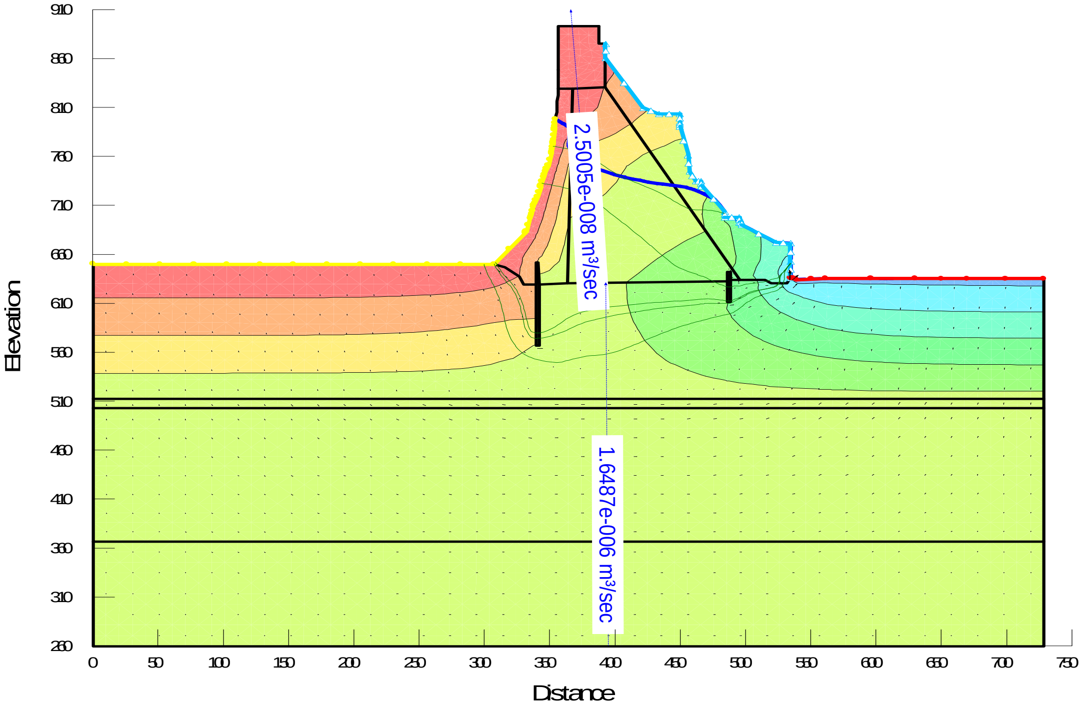

Figure 6. 48: RWL @798m for k 10^{-8}

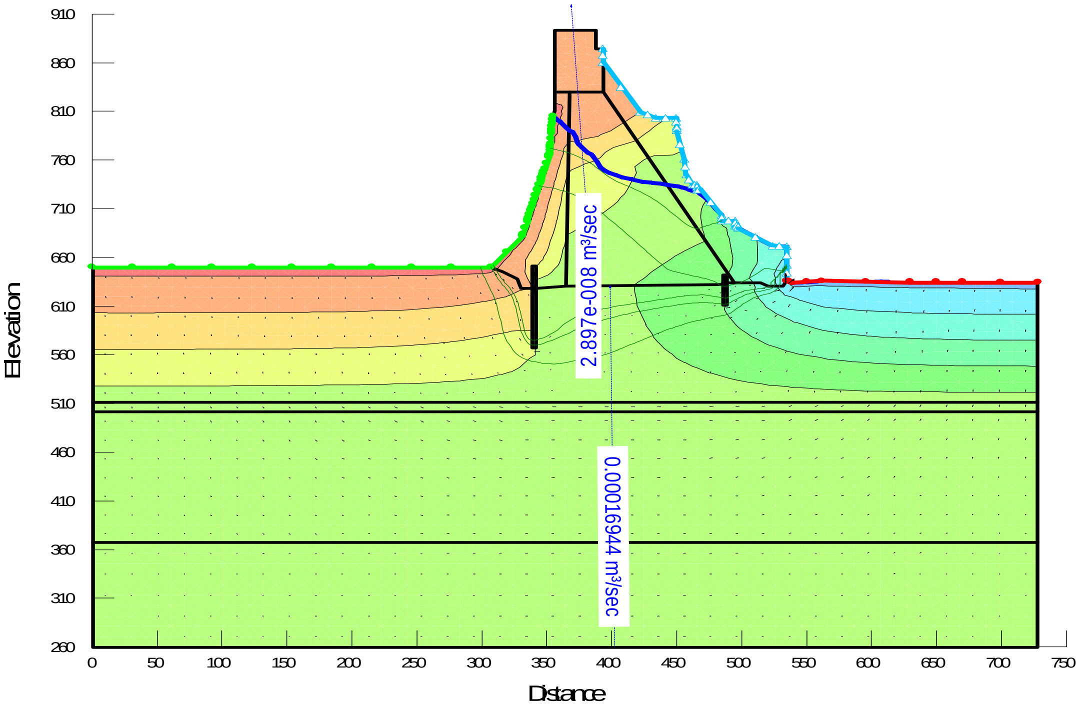

Figure 6. 49: RWL @805m for k 10^{-6}

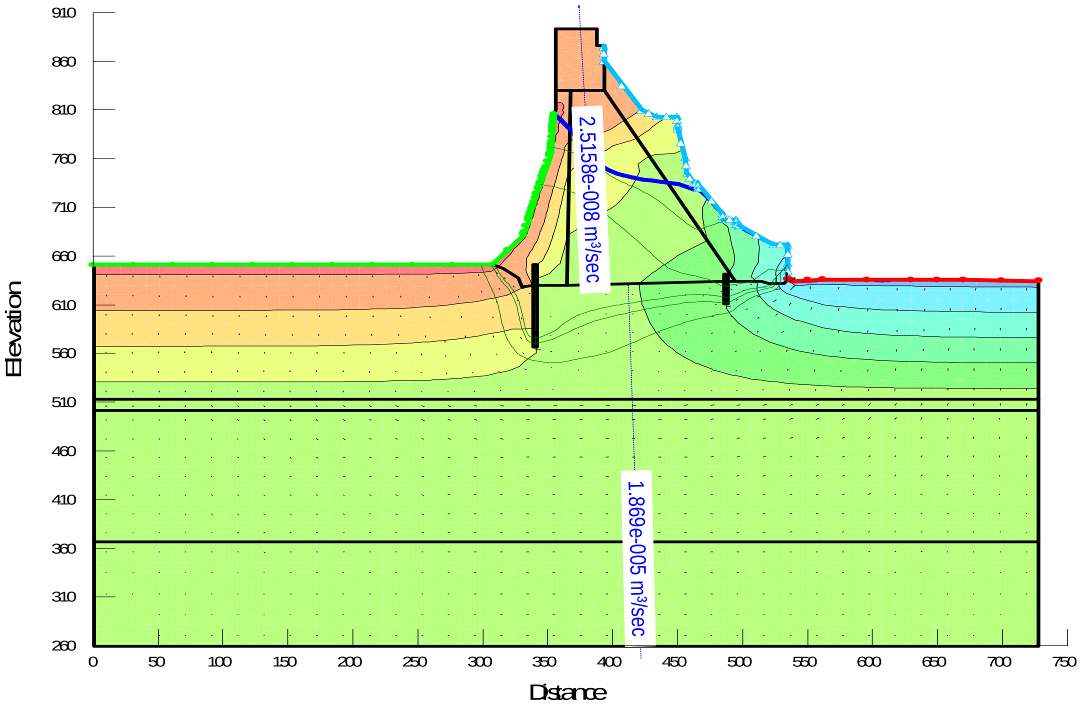

Figure 6. 50: RWL @805m for k 10^{-7}

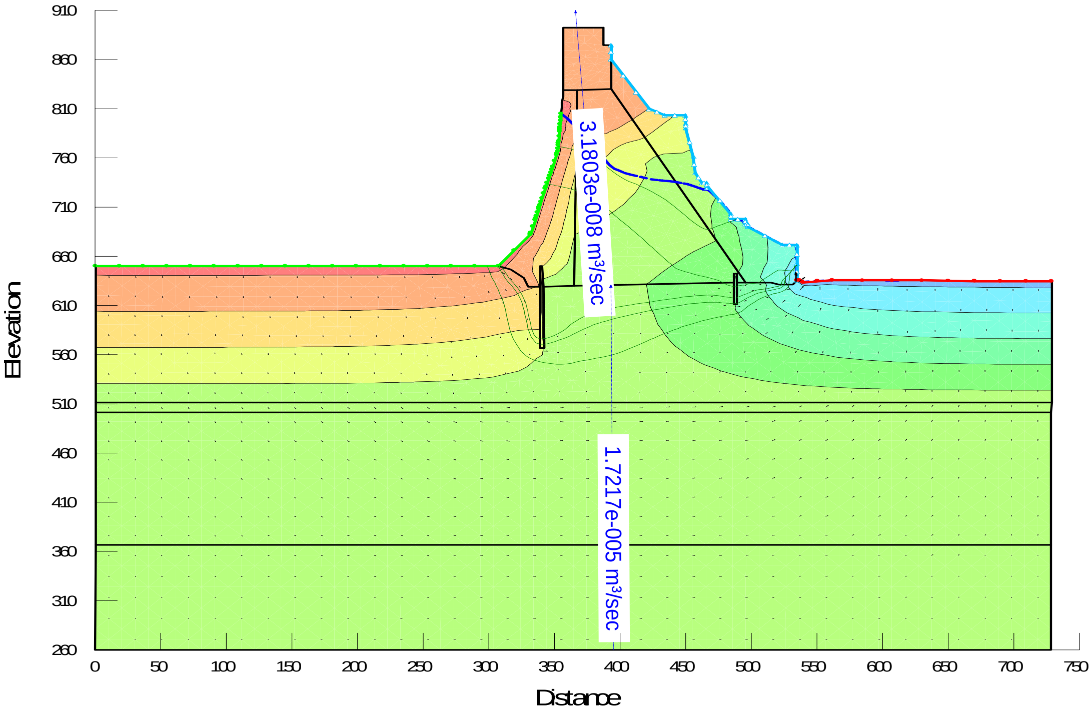

Figure 6. 51: RWL @805m for k 10^{-8}

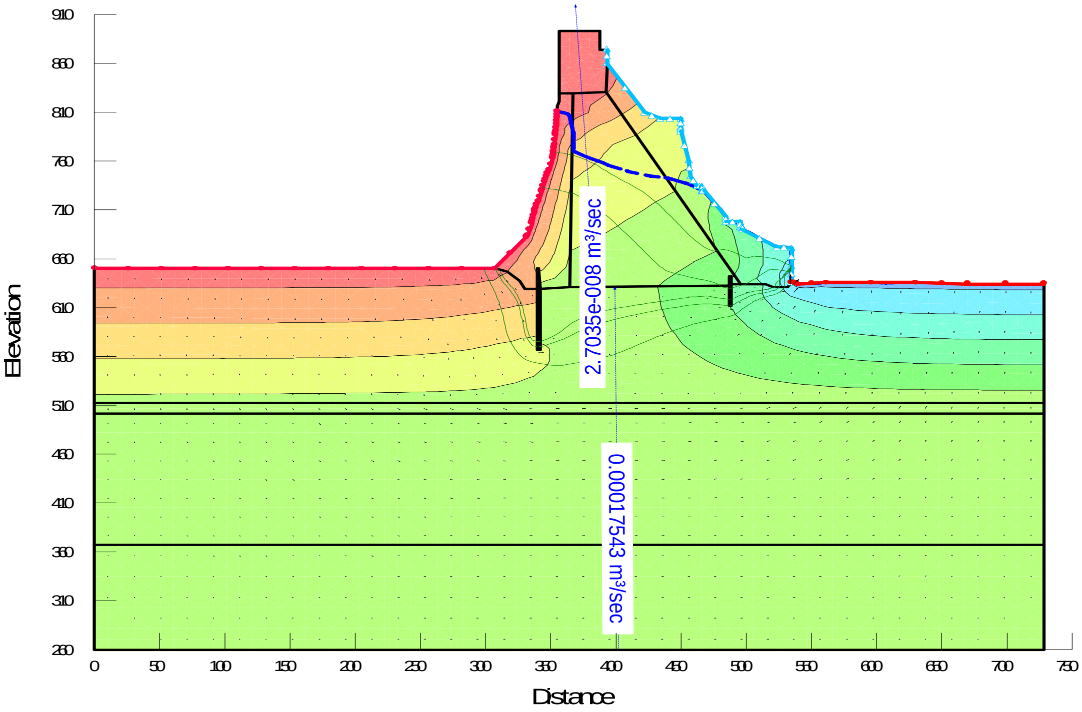

Figure 6. 52: @811 for k 10^{-6}

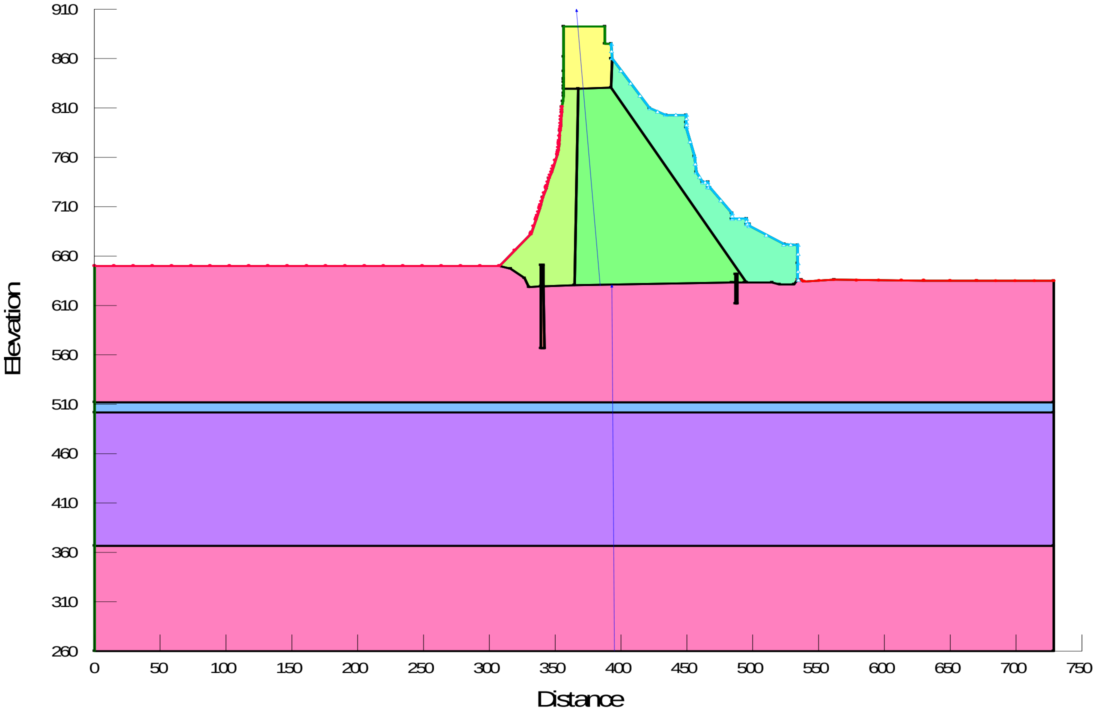

Figure 6. 53: RWL @811m for k 10^{-7}

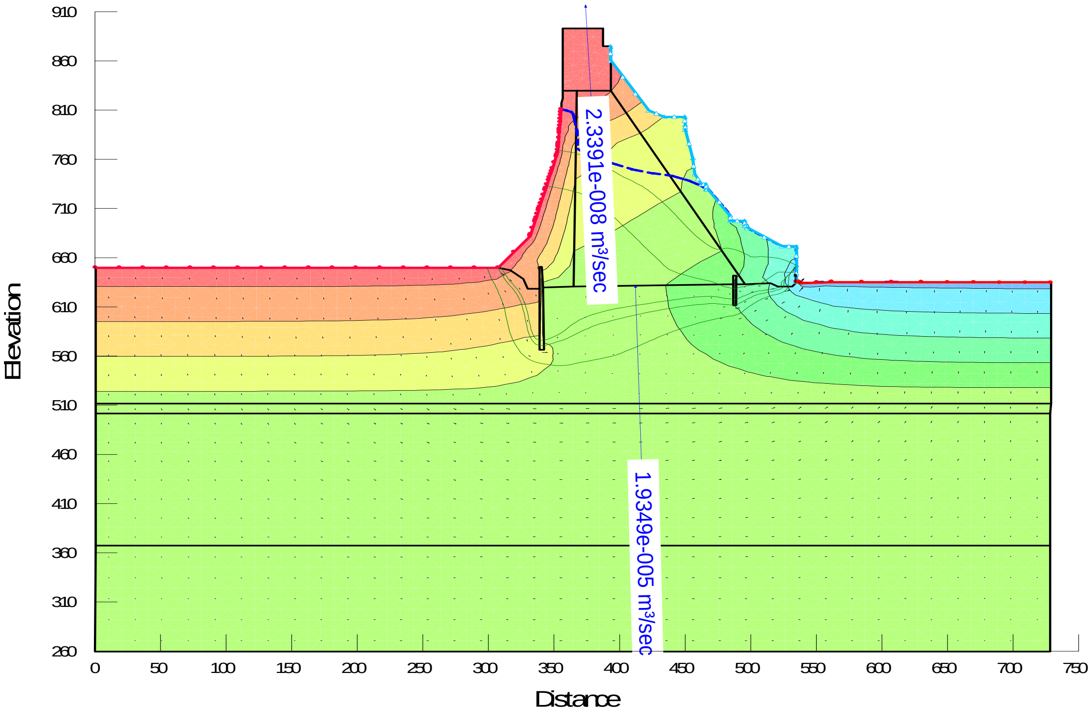

Figure 6. 54: RWL @811m for k 10^{-8}

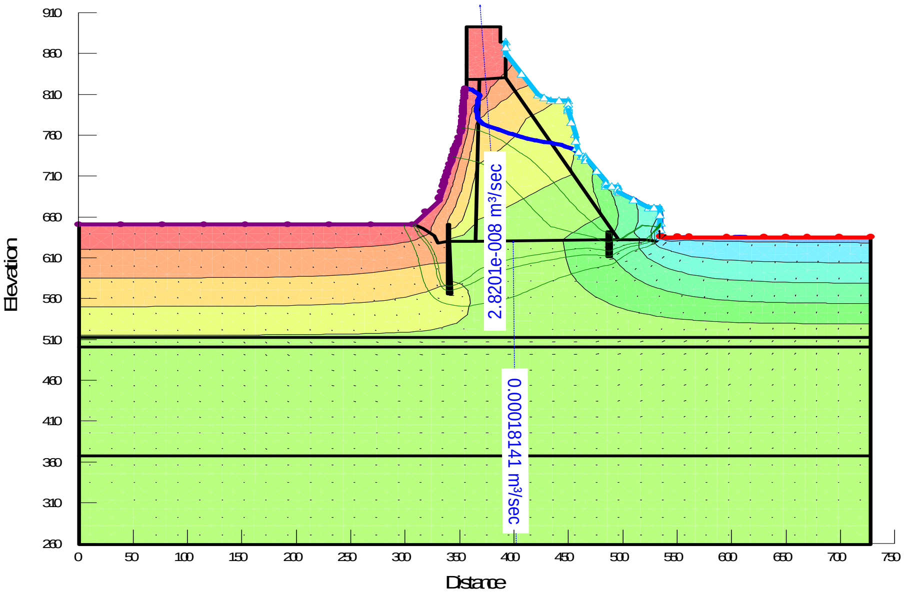

Figure 6. 55: @817 for k 10^{-6}

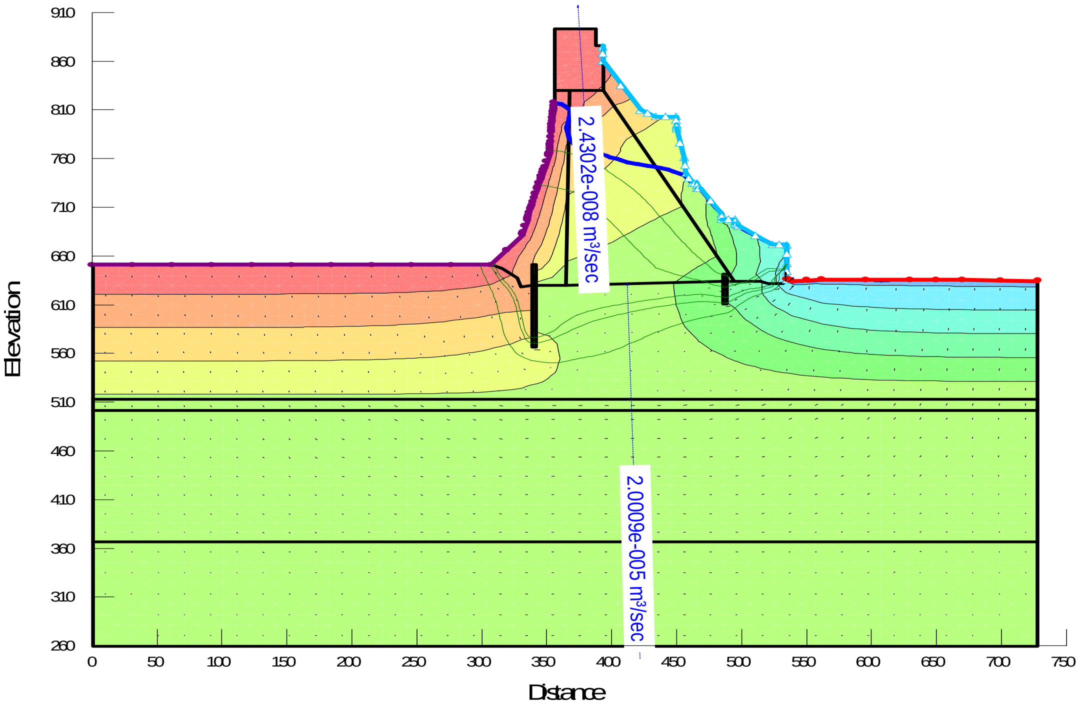

Figure 6. 56: RWL @817m for k 10^{-7}

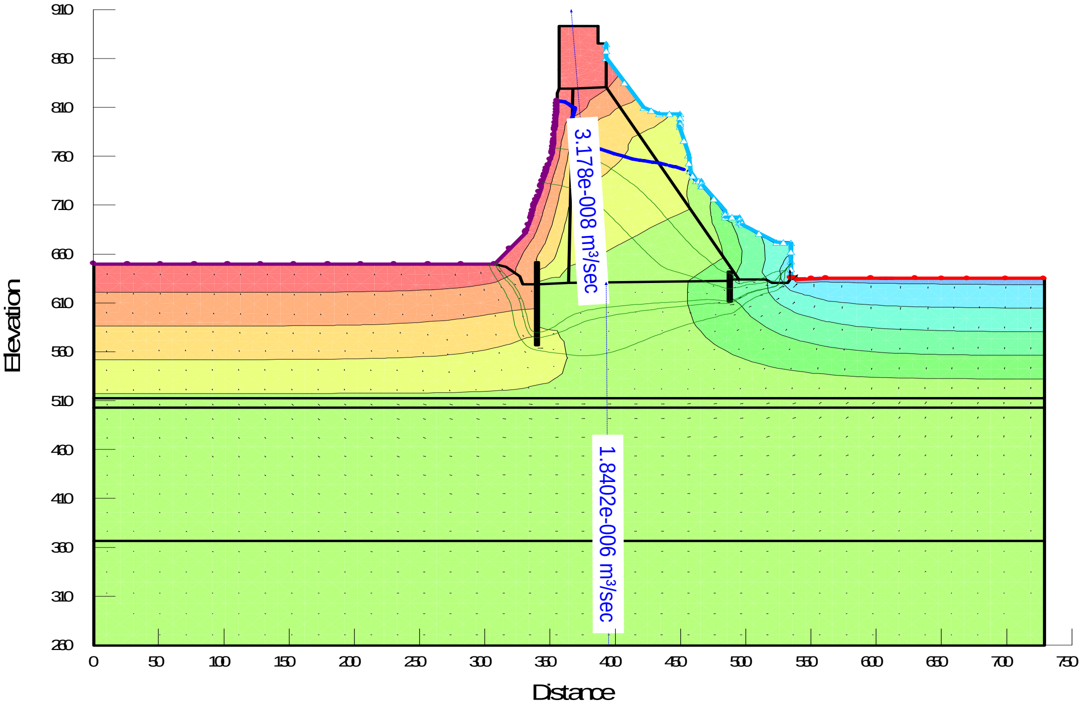

Figure 6. 57: RWL @817m for k 10^{-8}

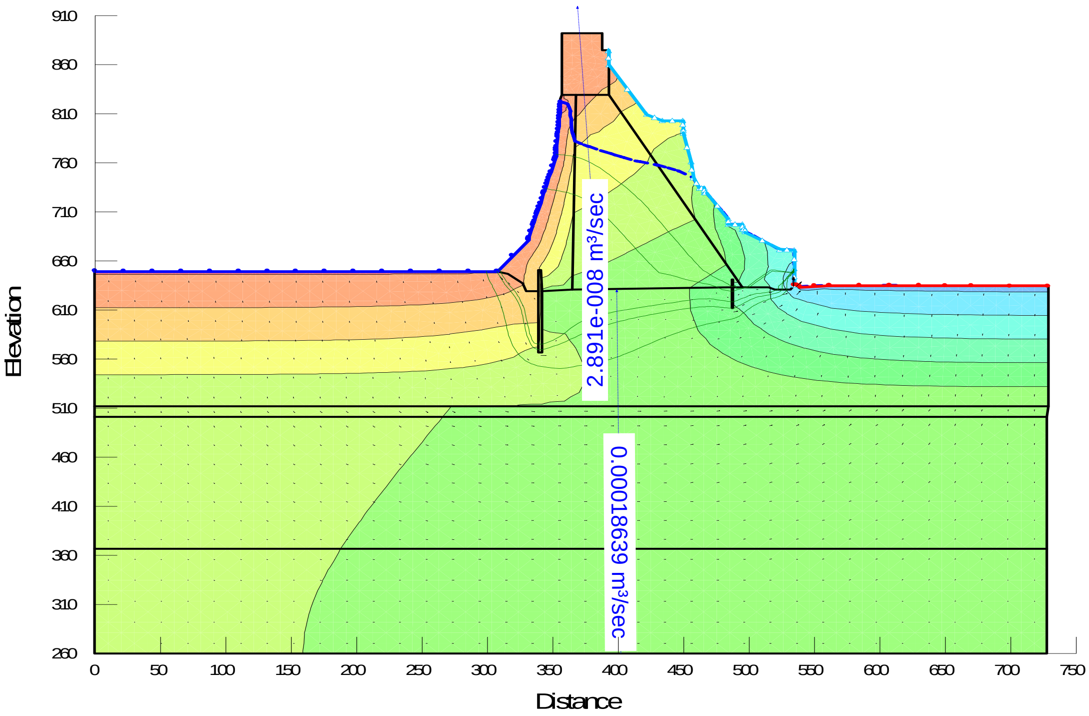

Figure 6. 58: RWL @822m for k 10^{-6}

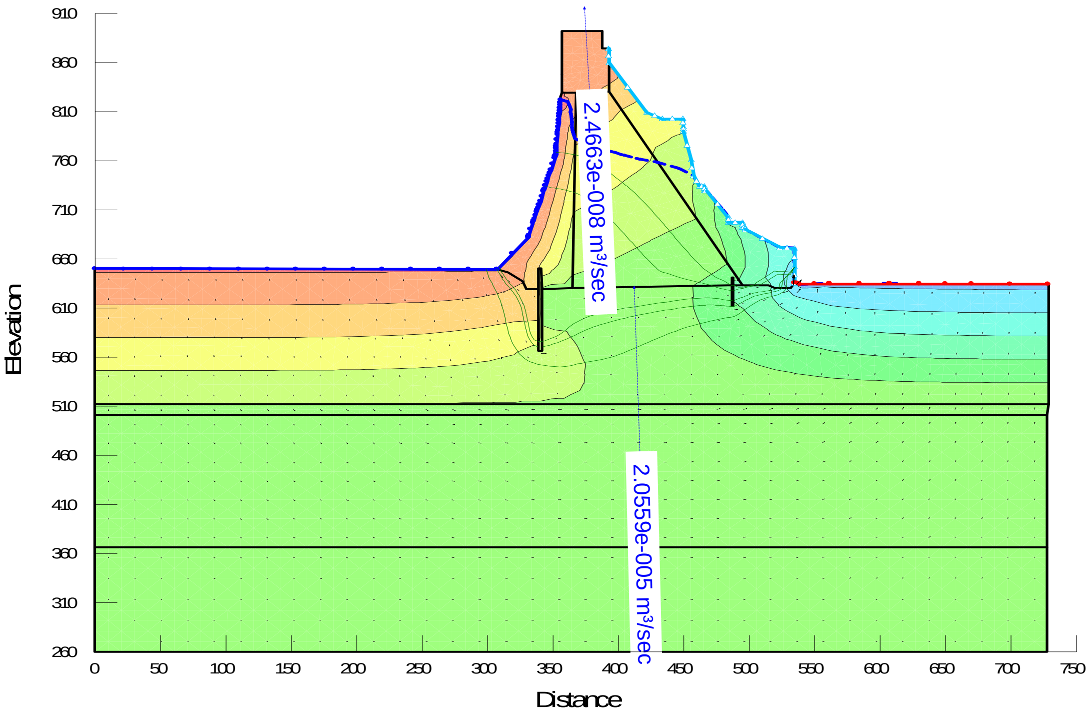

Figure 6. 59: RWL @822m for k 10^{-7}

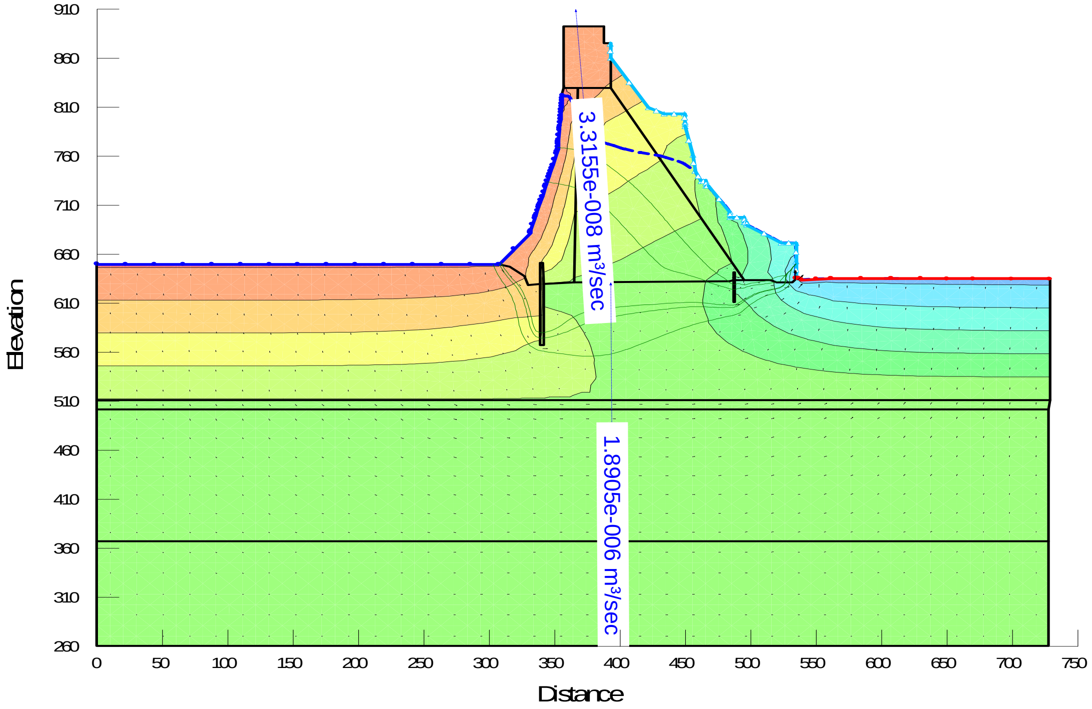

Figure 6. 60: RWL @822m for k 10^{-8}

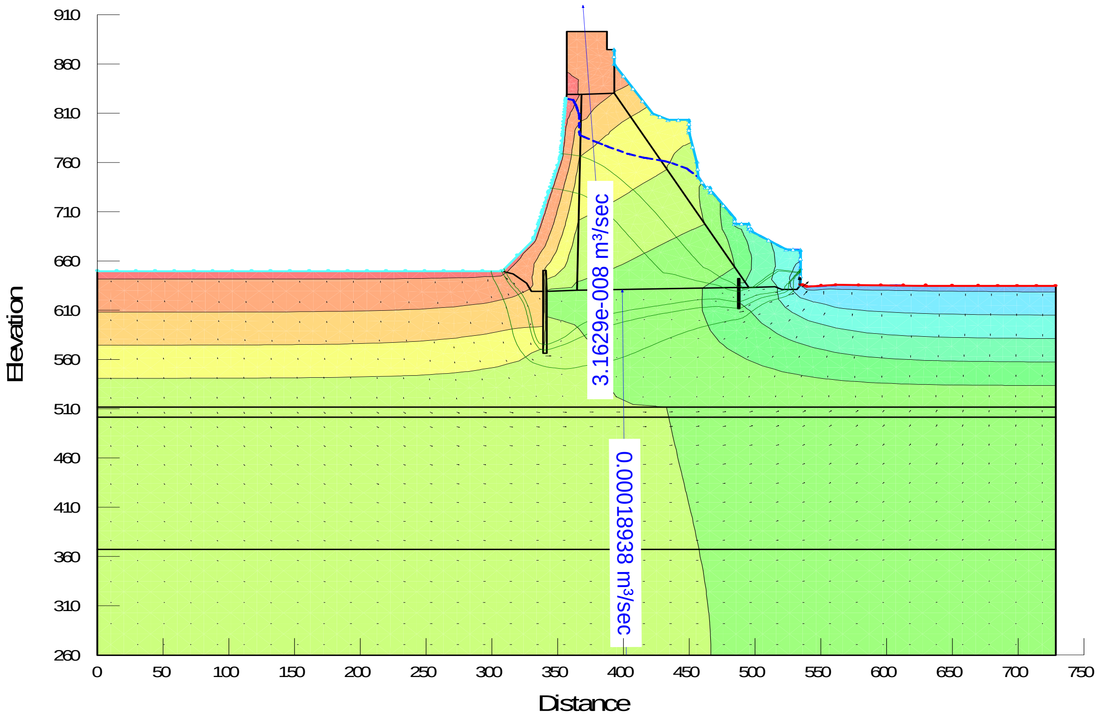

Figure 6. 61: RWL @825m for k 10^{-6}

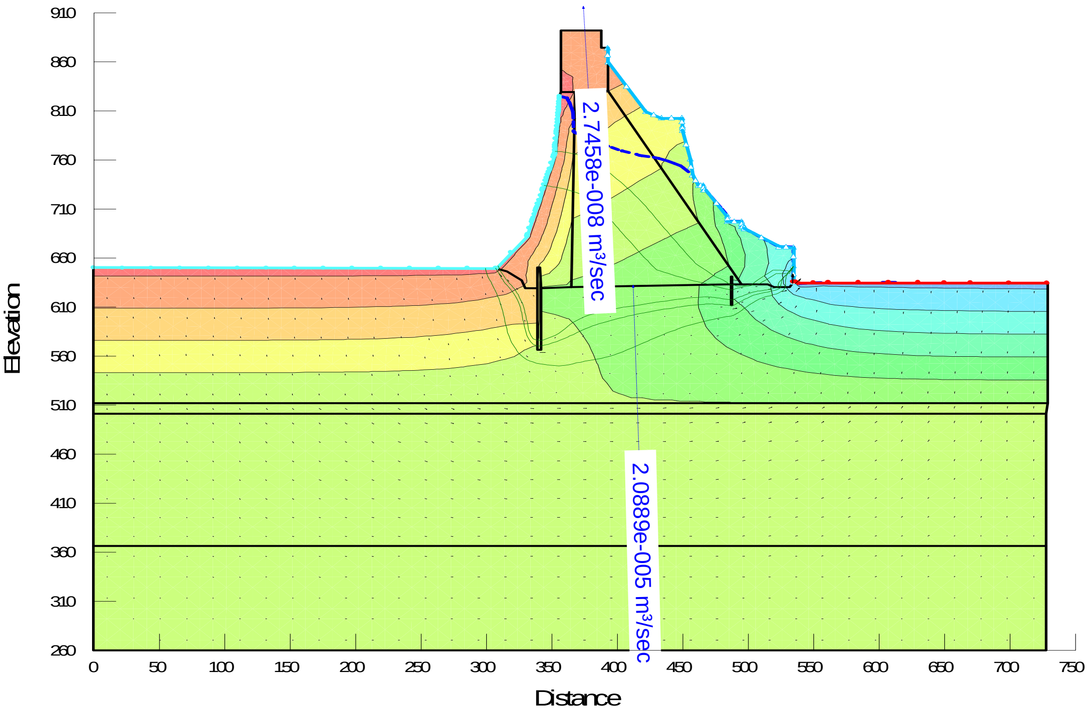

Figure 6. 62: RWL @825m for k 10^{-7}

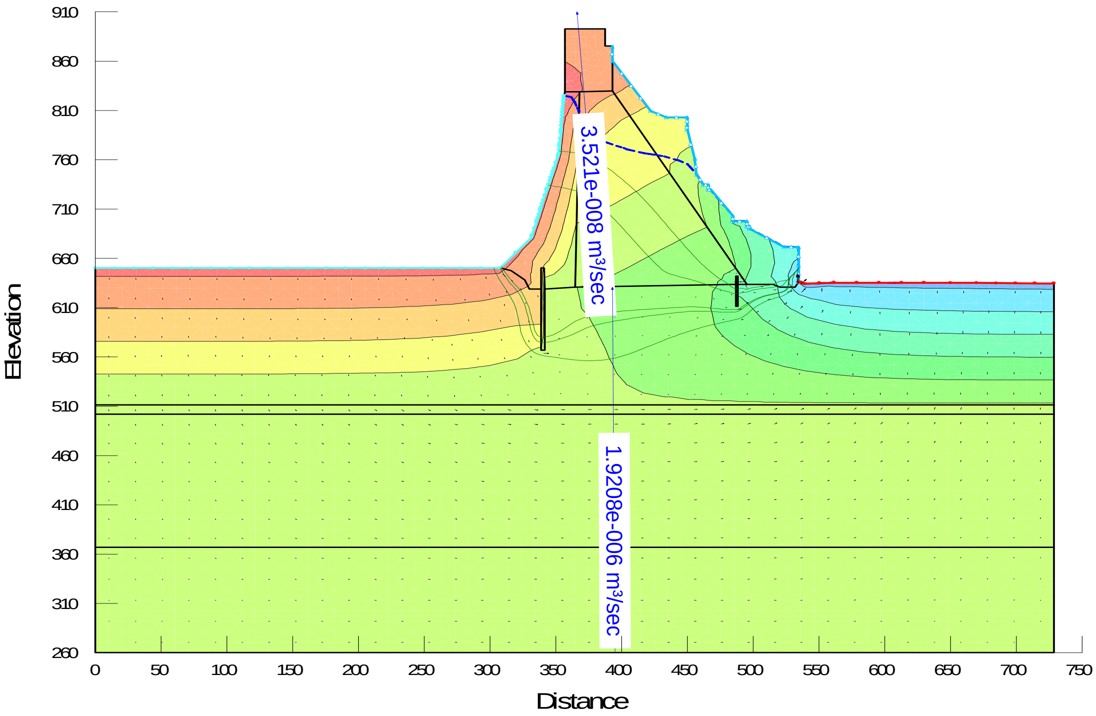

Figure 6. 63: RWL @825m for k 10^{-8}

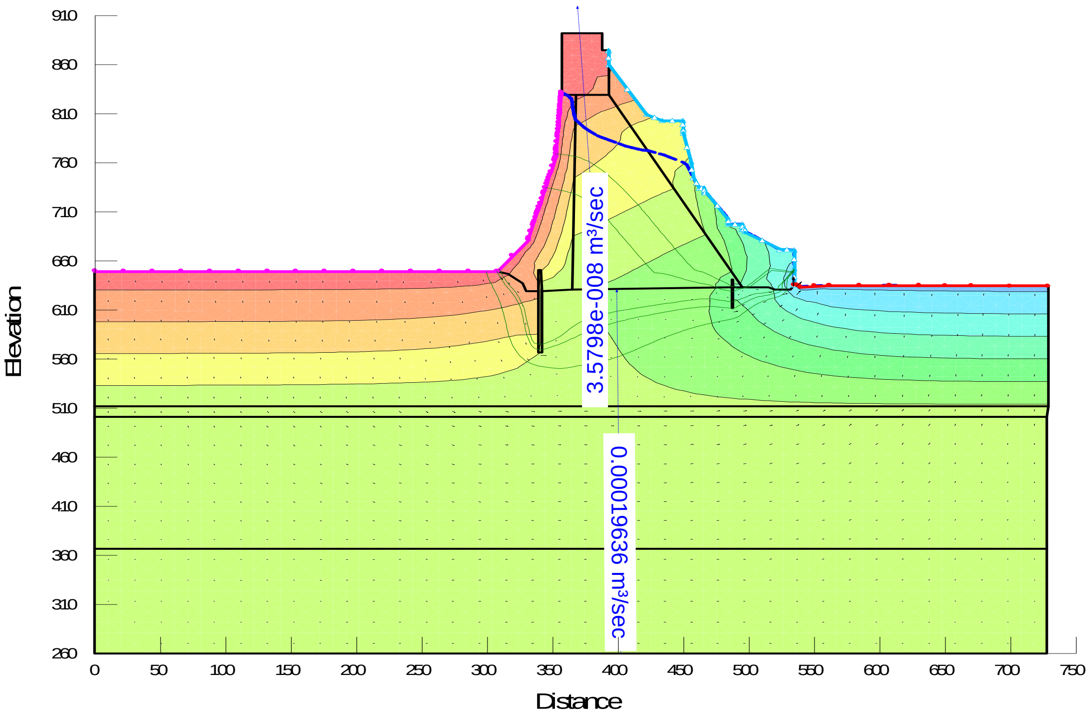

Figure 6. 64: RWL @832m for k 10^{-6}

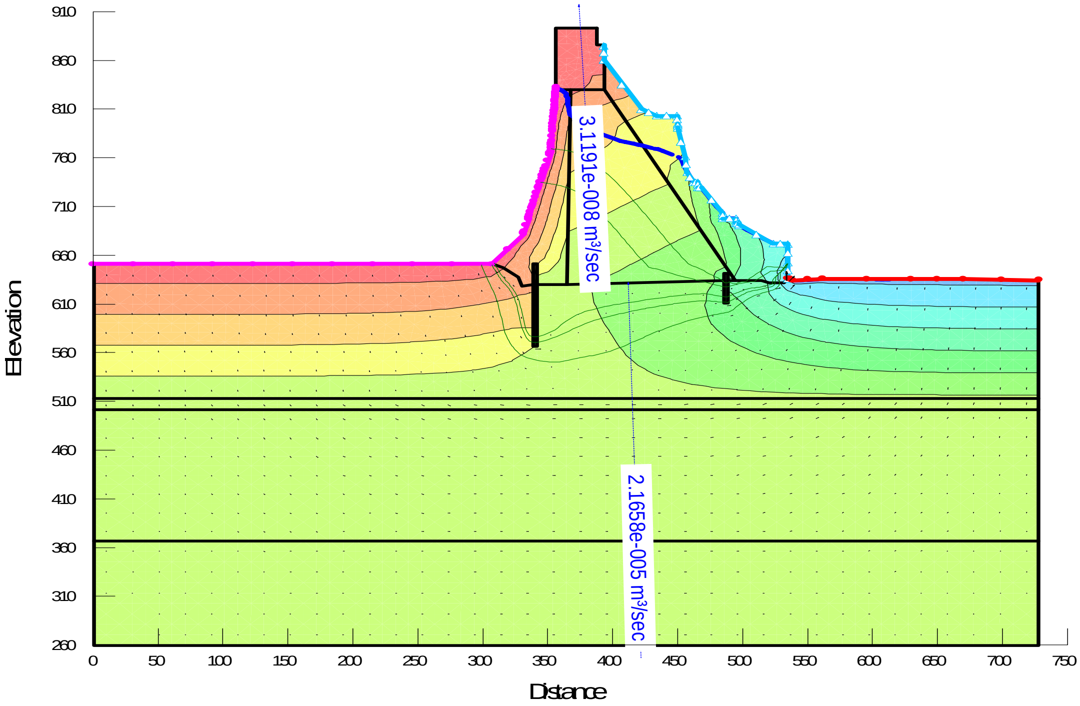

Figure 6. 65: RWL @832 for k 10^{-7}

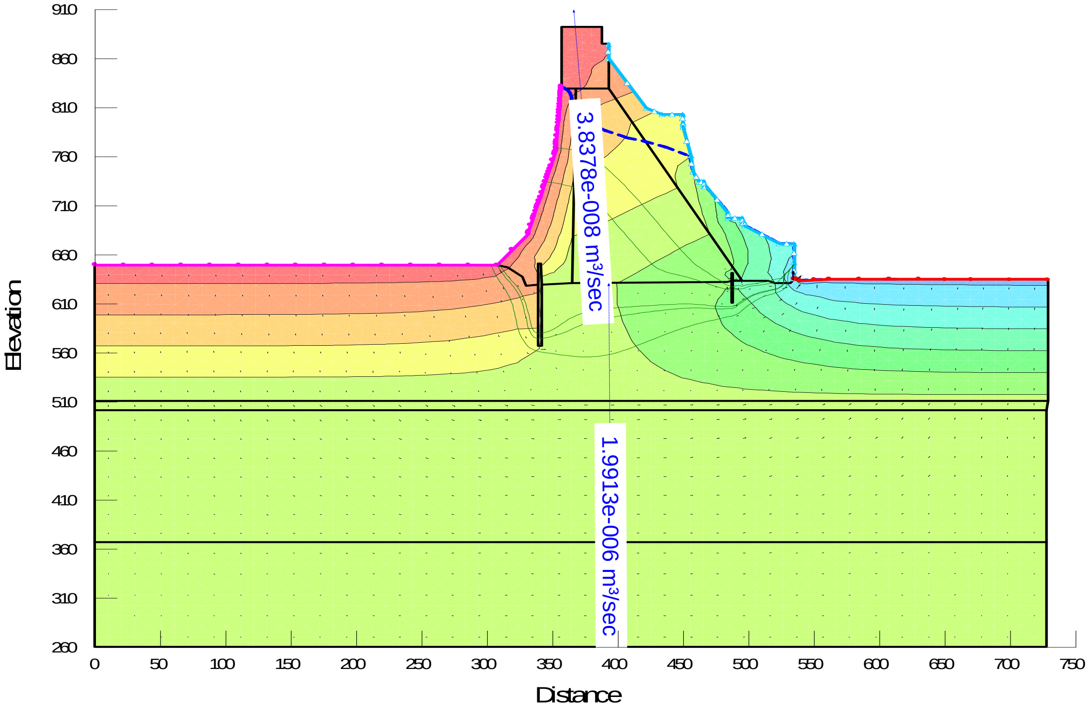

Figure 6. 66: RWL @832m for k 10^{-8}

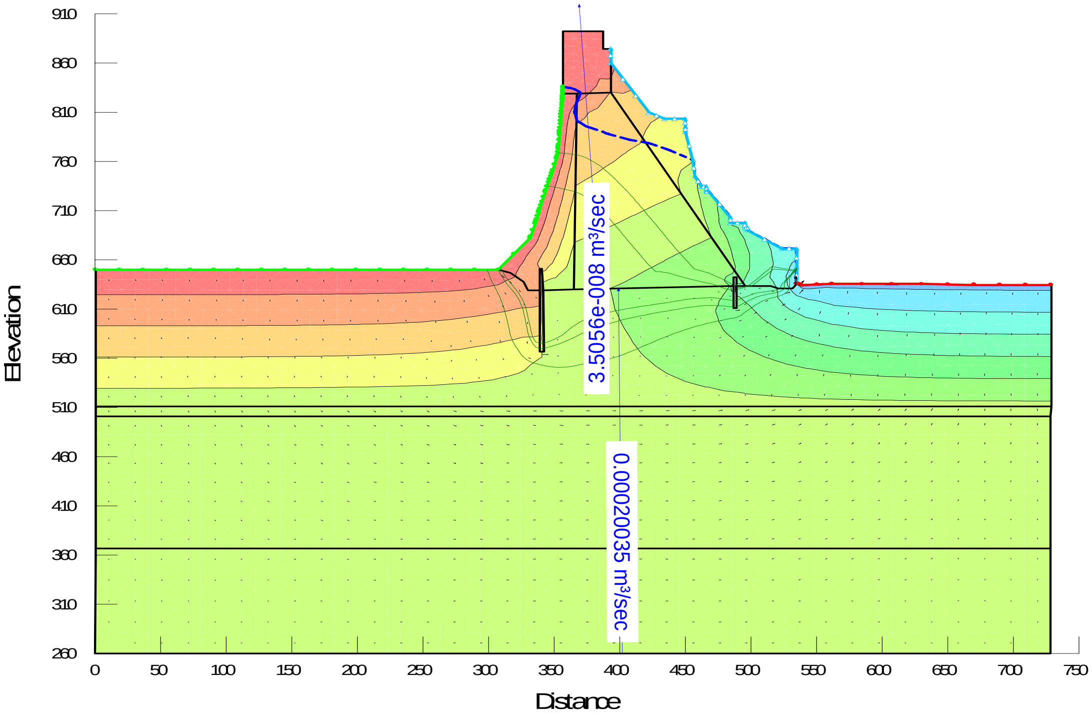

Figure 6. 67: RWL @836m for k 10^{-6}

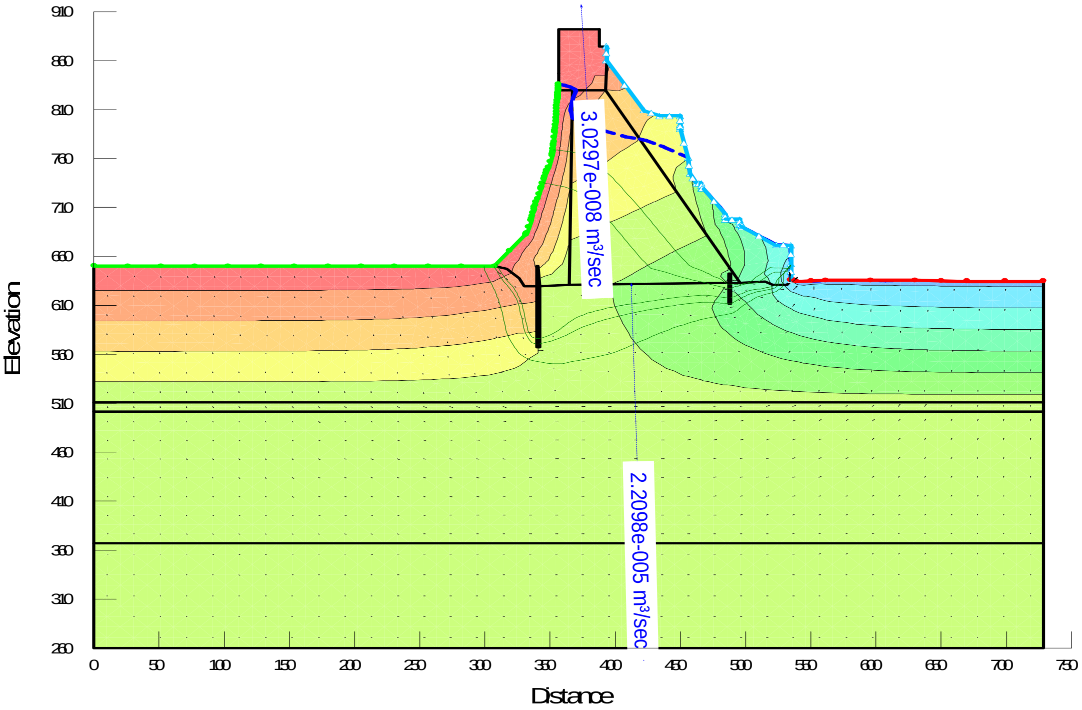

Figure 6. 68: RWL @836m for k 10^{-7}

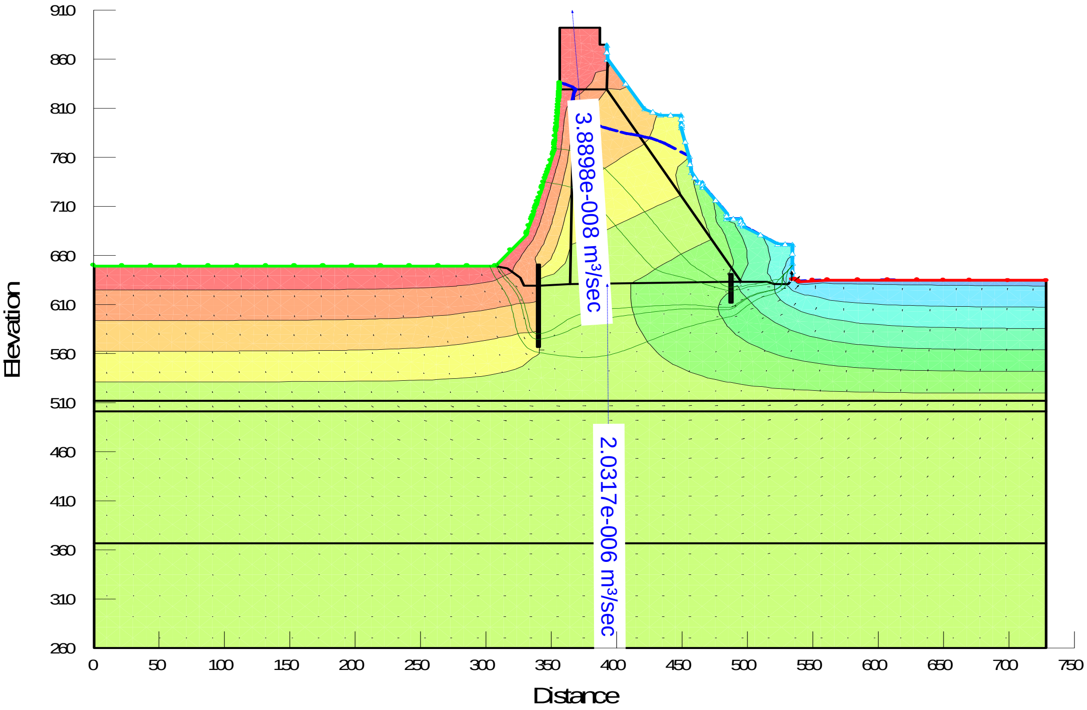

Figure 6. 69: RWL @836m for k 10^{-8}

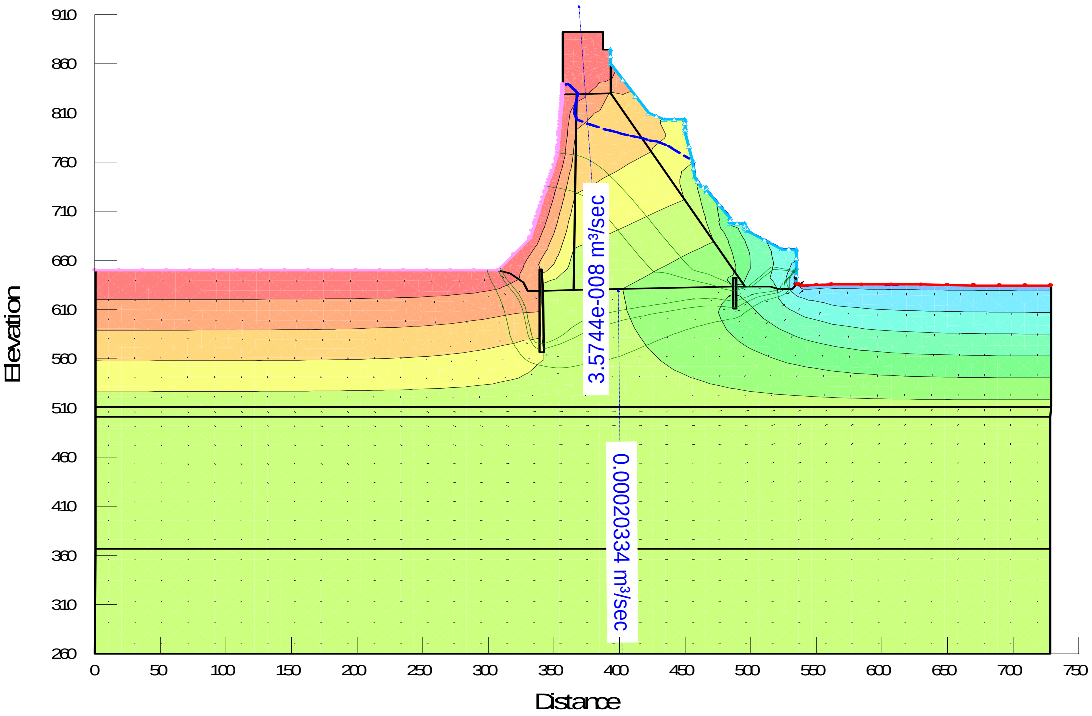

Figure 6. 70: RWL @839m for k 10^{-6}

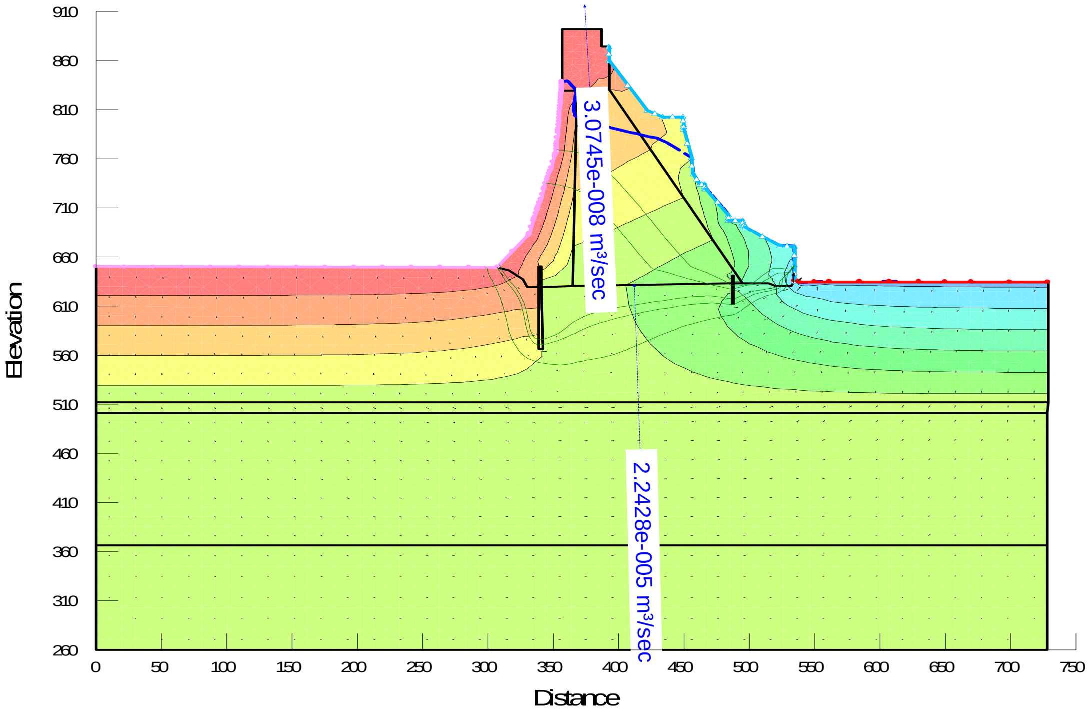

Figure 6. 71: RWL @839m for k 10^{-7}

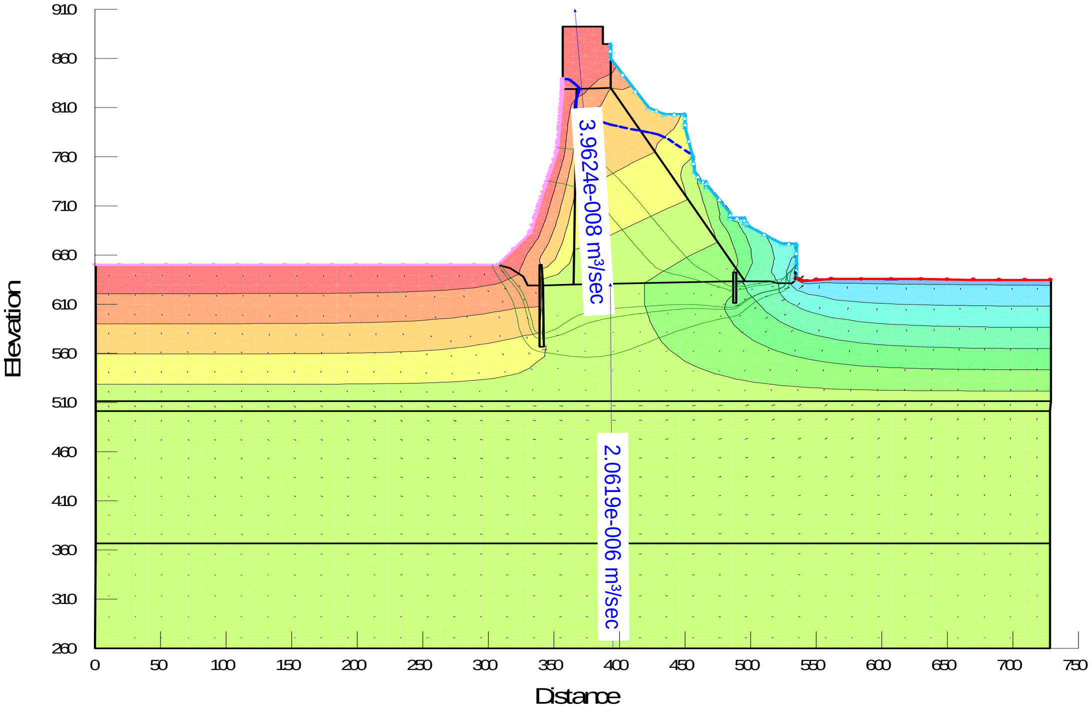

Figure 6. 72: RWL @839m for k 10^{-8}

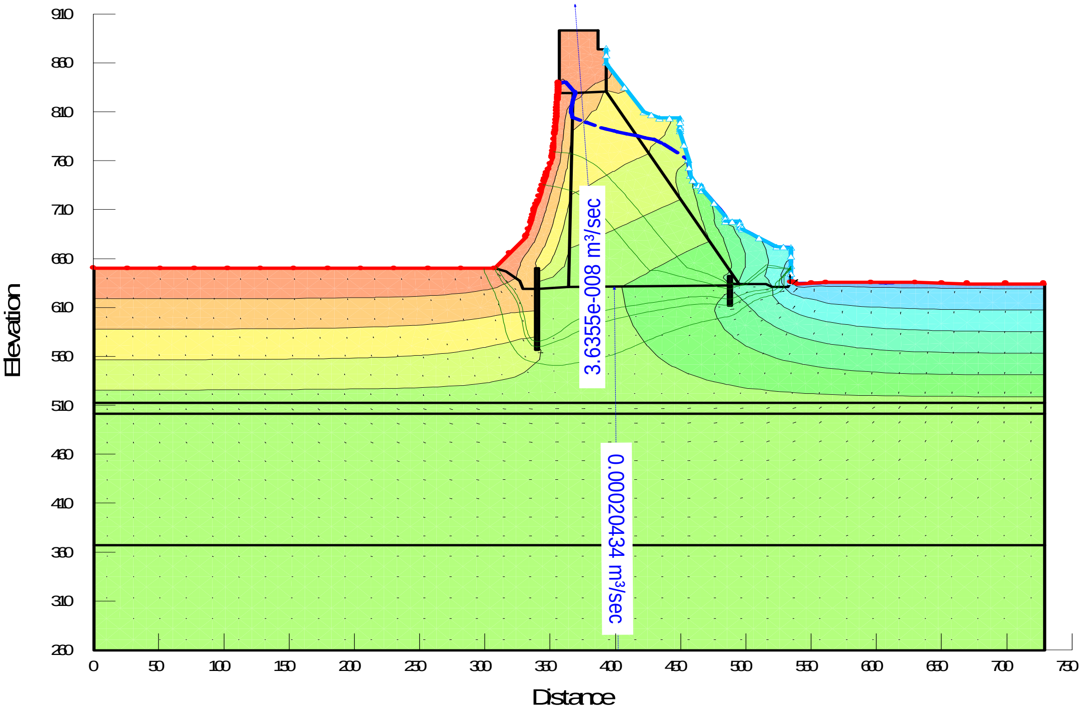

Figure 6.73:RWL @840m for k 10^{-6}

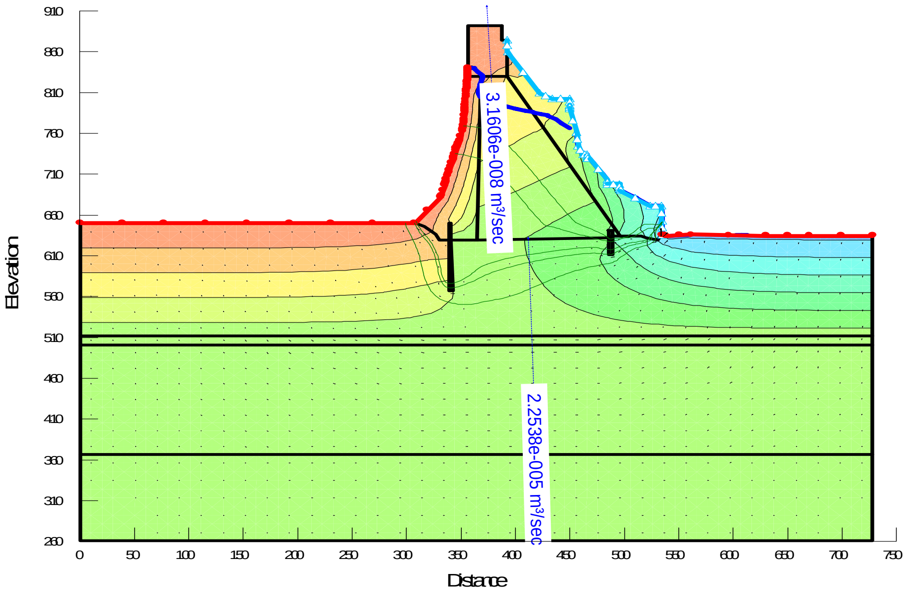

Figure 6. 74: RWL @840m for k 10^{-7}

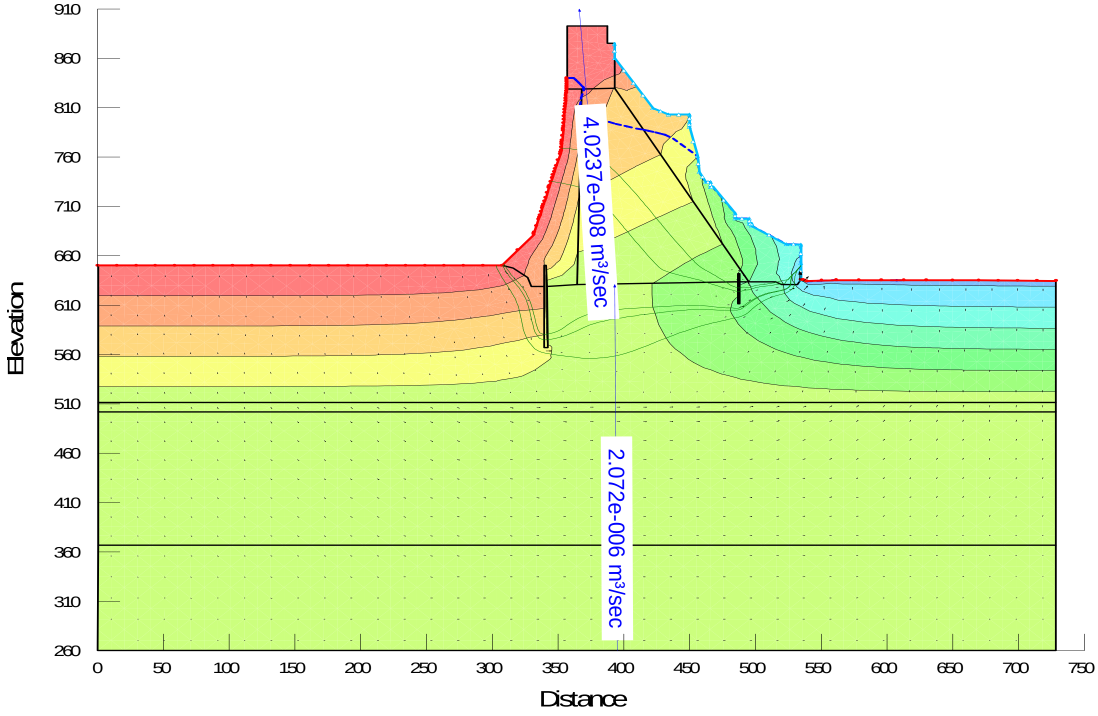

Figure 6. 75: RWL @840m for k 10^{-8}

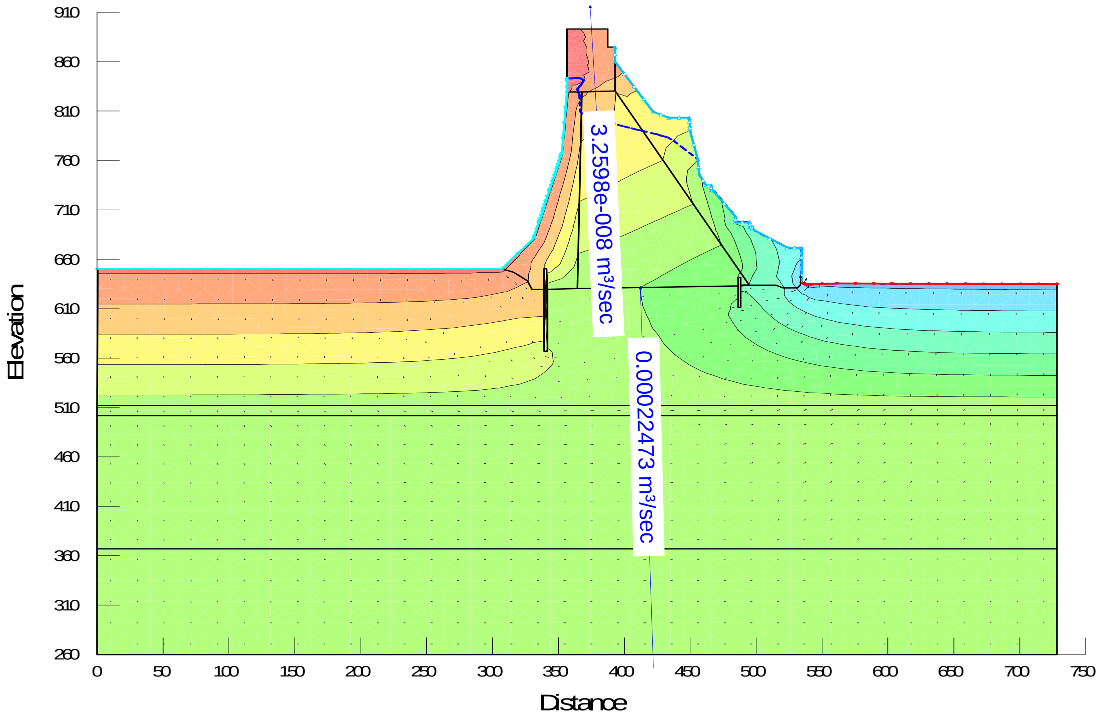

Figure 6. 76: RWL @843m for k 10^{-6}

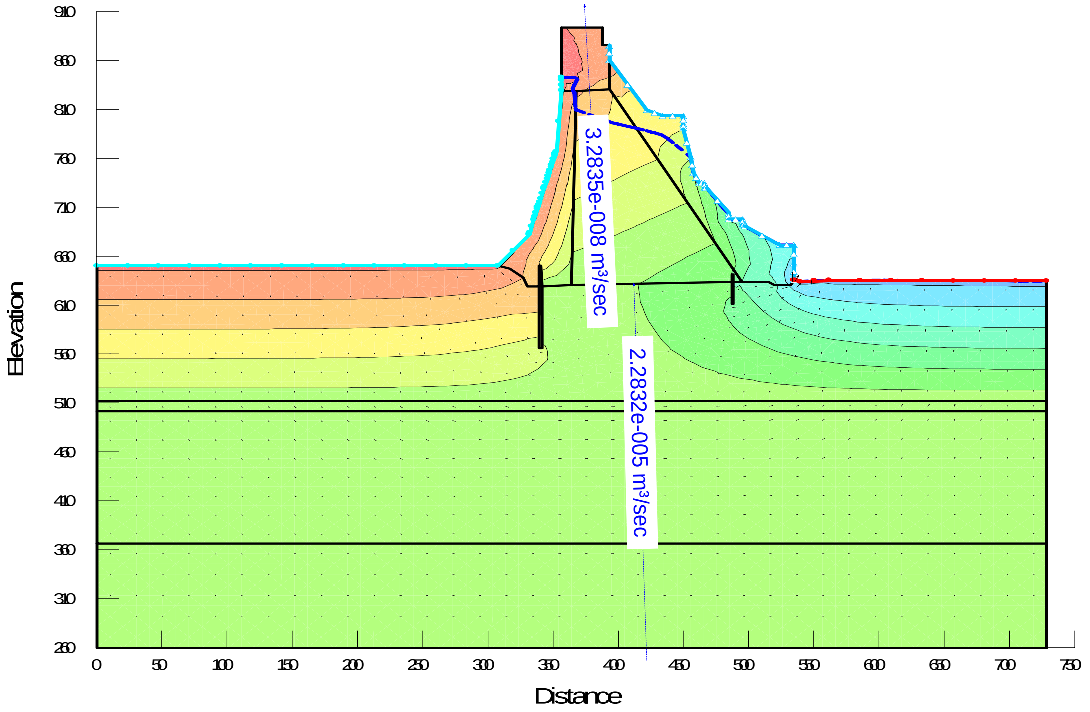

Figure 6. 77: RWL @843m for k 10^{-7}

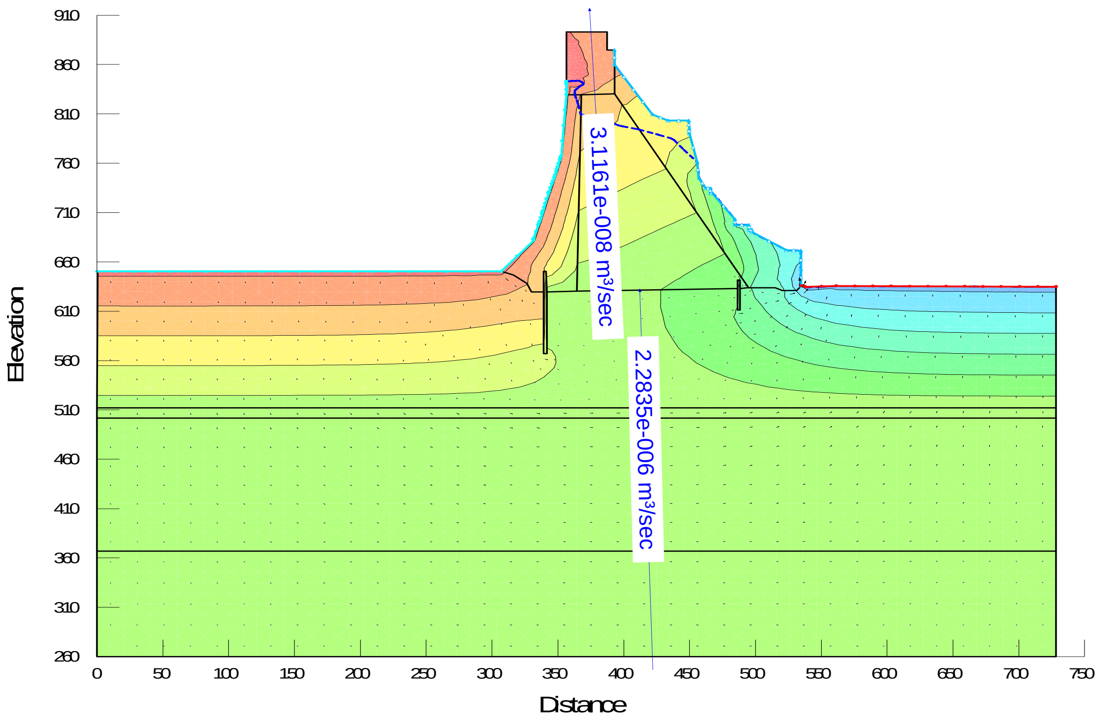

Figure 6. 78: RWL @843m for k 10^{-8}

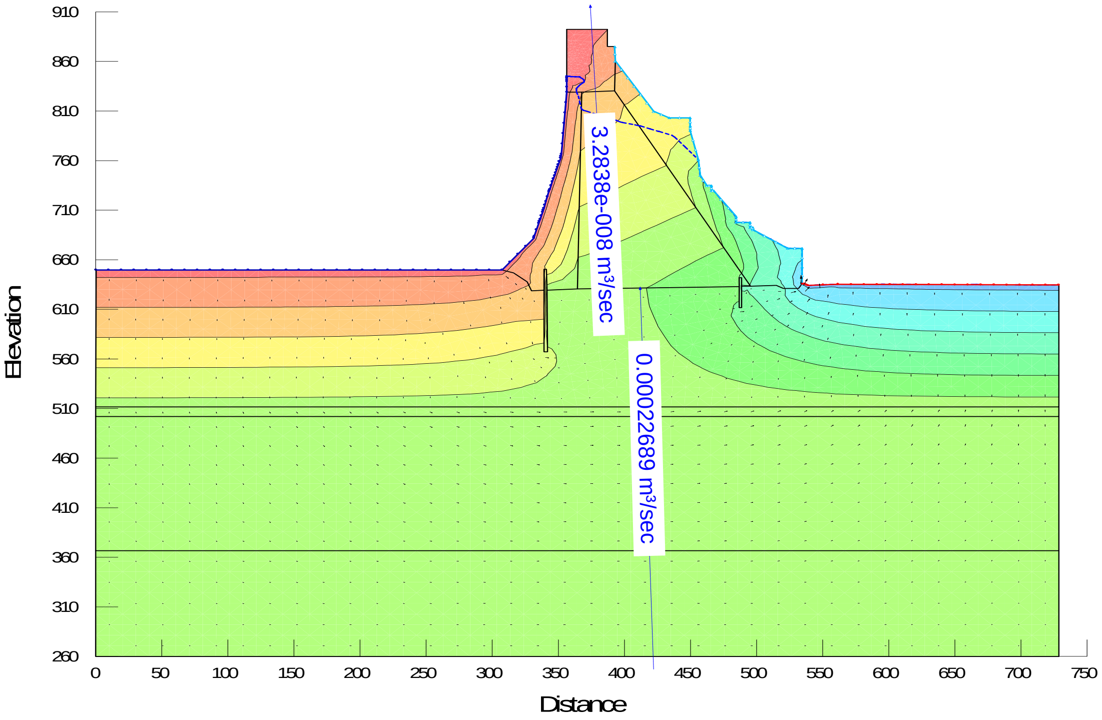

Figure 6. 79: RWL @845m for k 10^{-6}

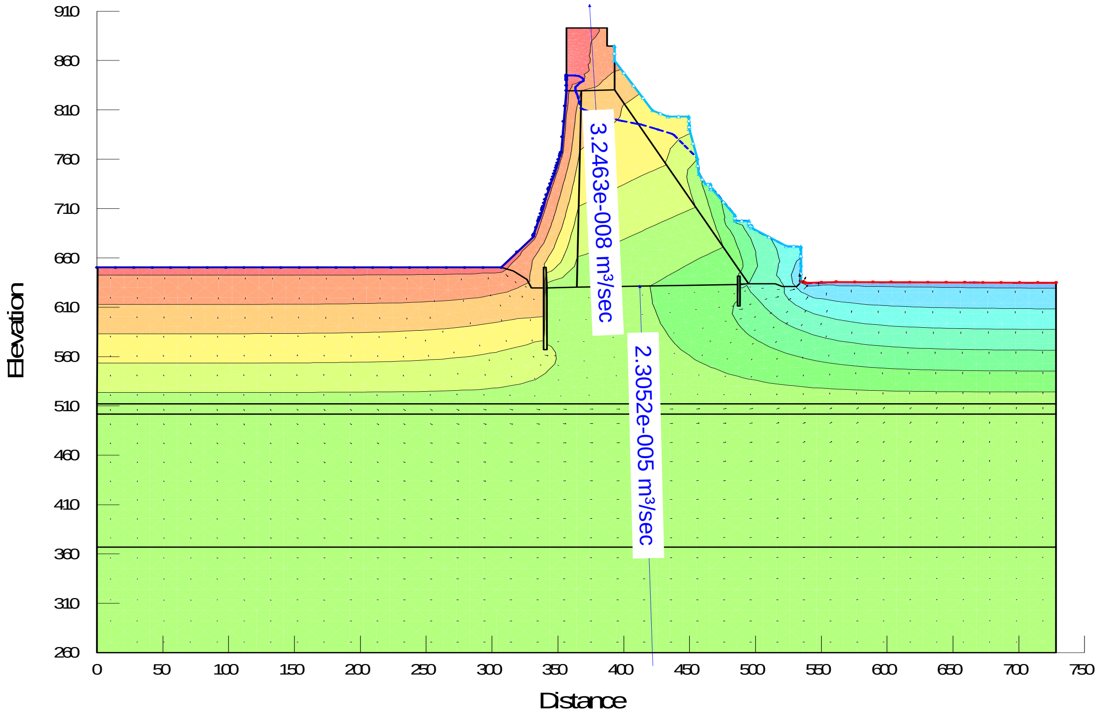

Figure 6. 80 : RWL @845m for k 10^{-7}

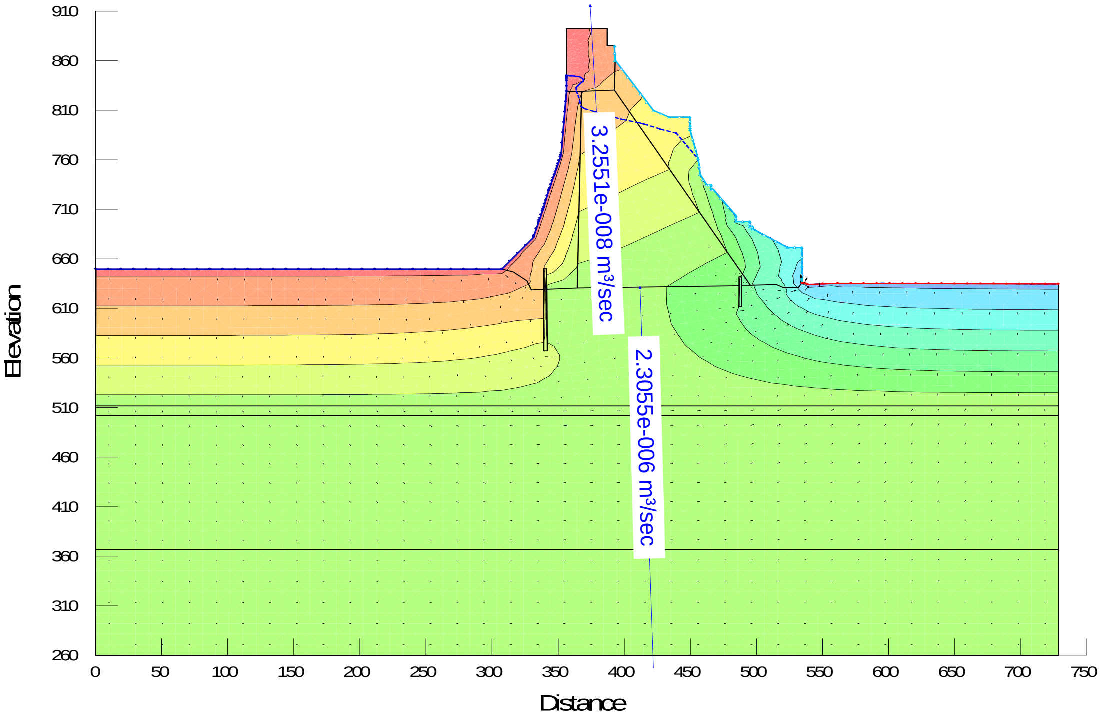

Figure 6. 81: RWL @845m for k 10^{-8}

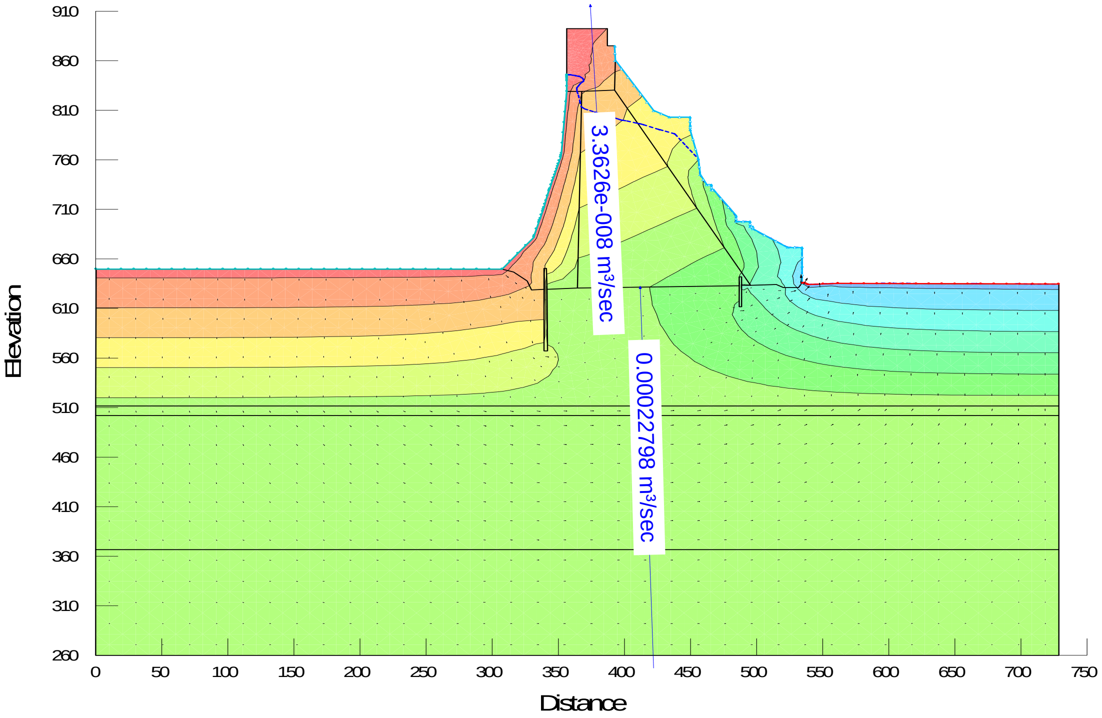

Figure 6. 82: RWL @846m for k 10^{-6}

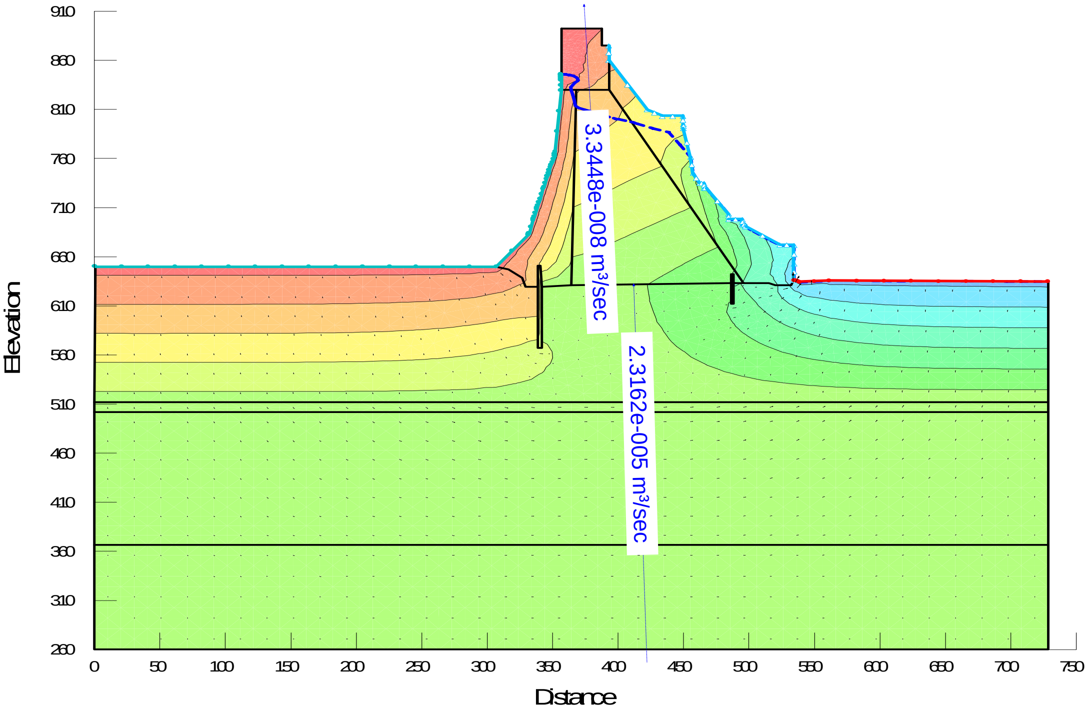

Figure 6. 83: RWL @846m for k 10^{-7}

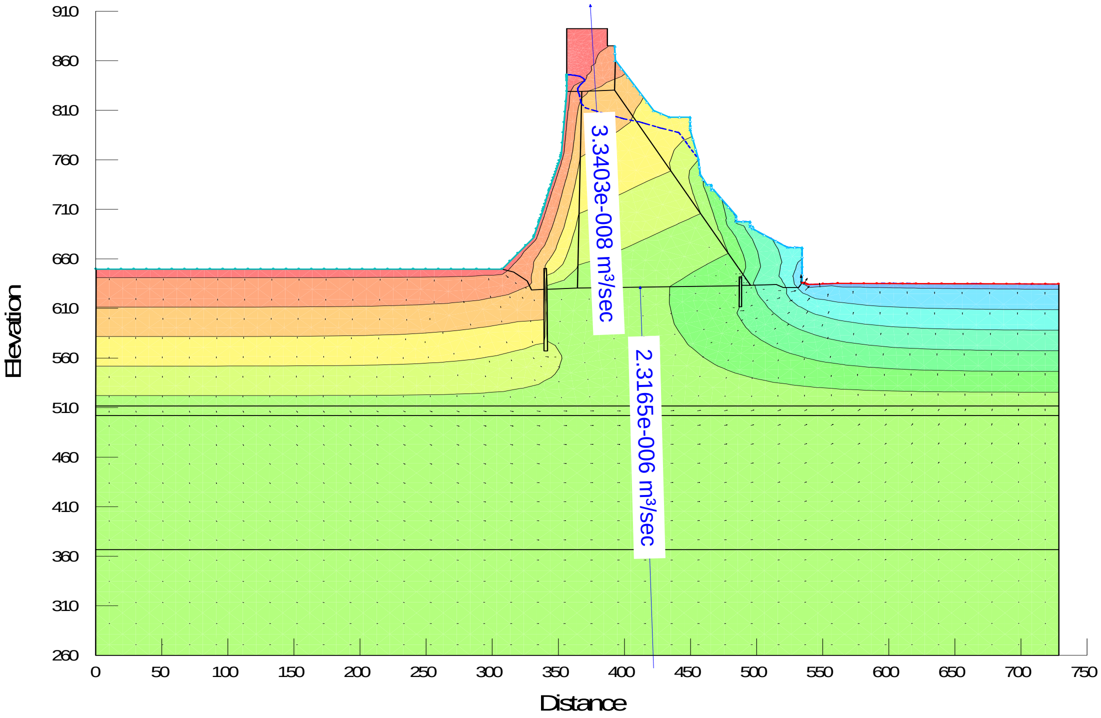

Figure 6. 84: RWL @846m for k 10^{-8}

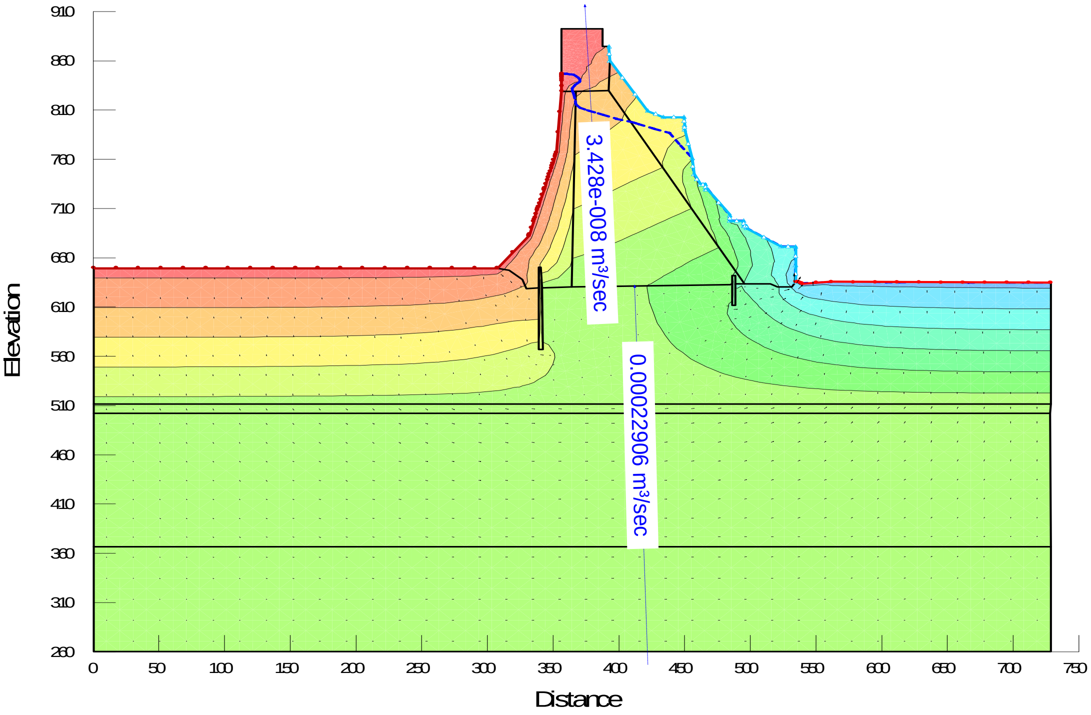

Figure 6. 85: RWL @847m for k 10^{-6}

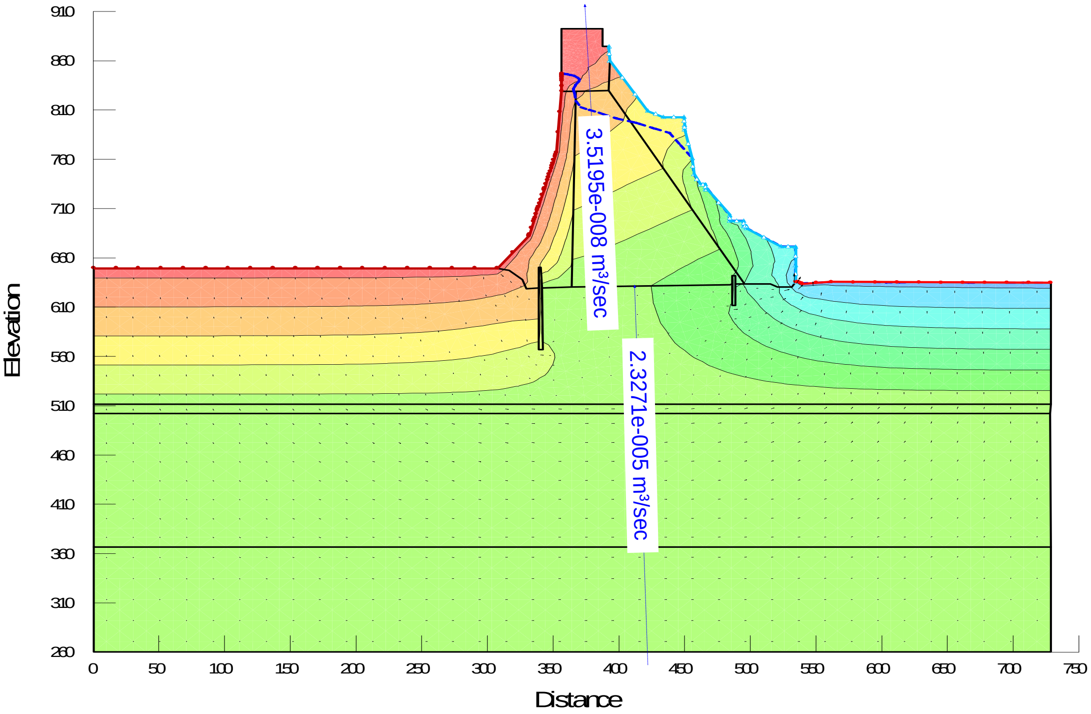

Figure 6. 86: RWL @847m for k 10^{-7}

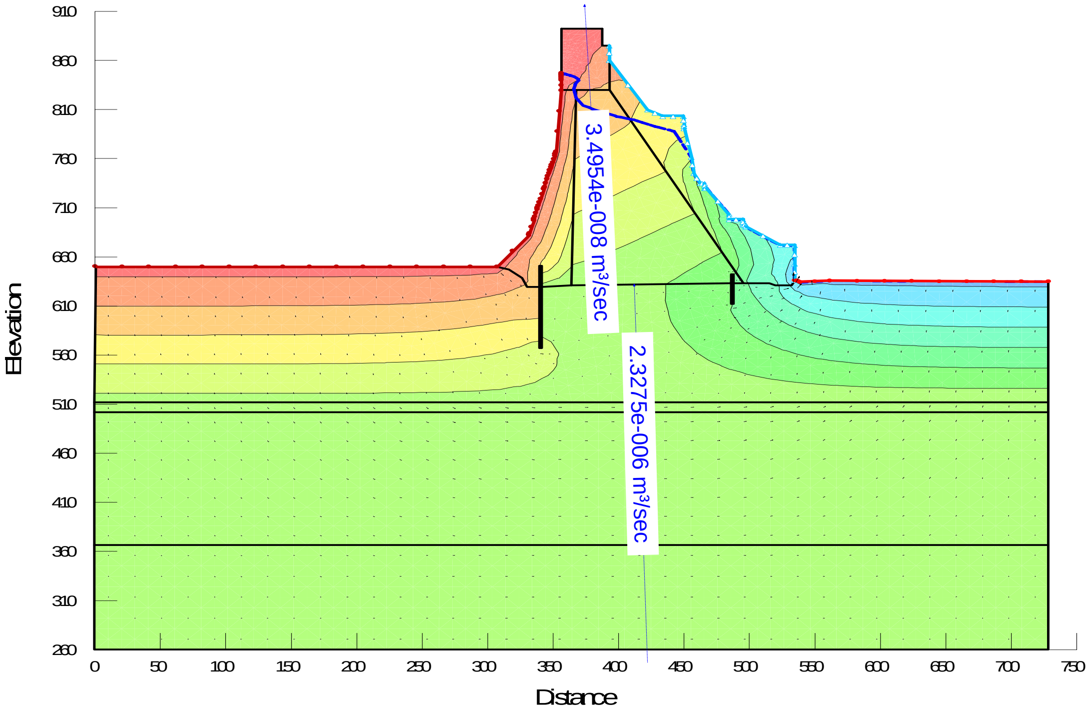

Figure 6. 87: RWL @847m for k 10^{-8}

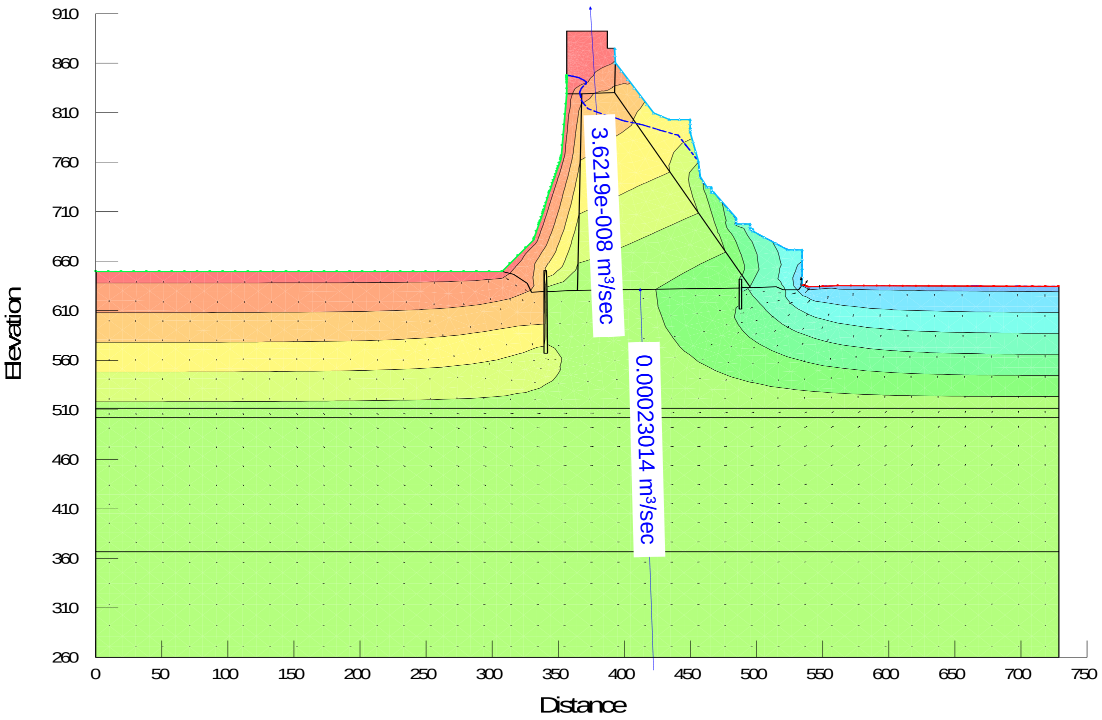

Figure 6. 88: RWL @848m for k 10^{-6}

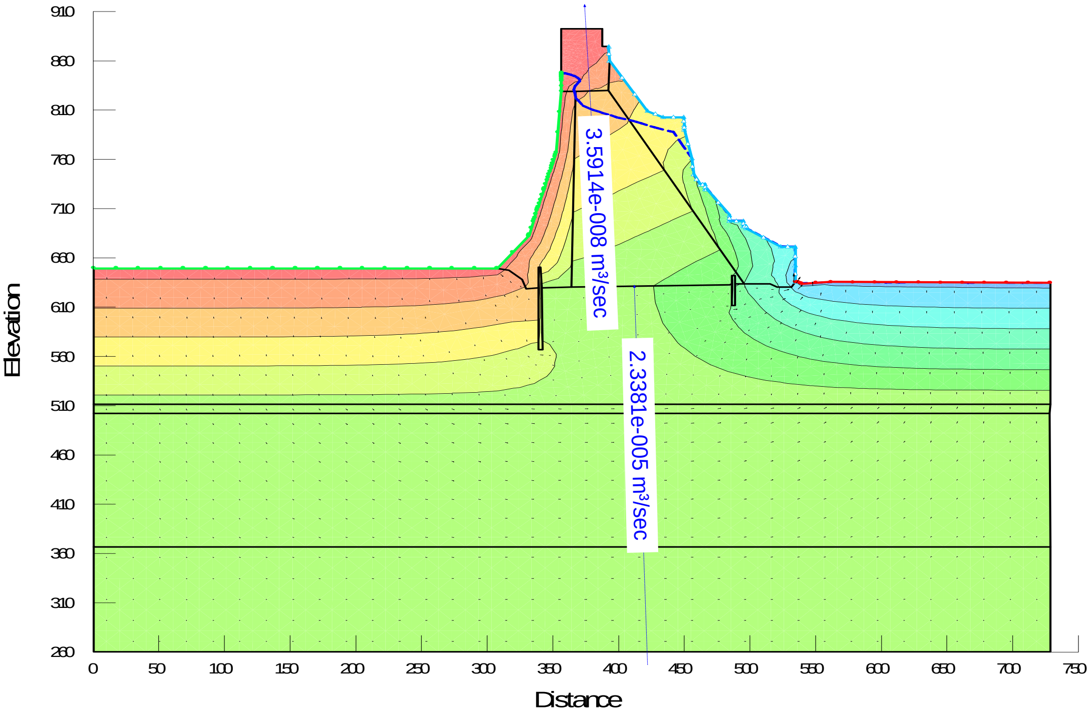

Figure 6. 89: RWL @848m for k 10^{-7}

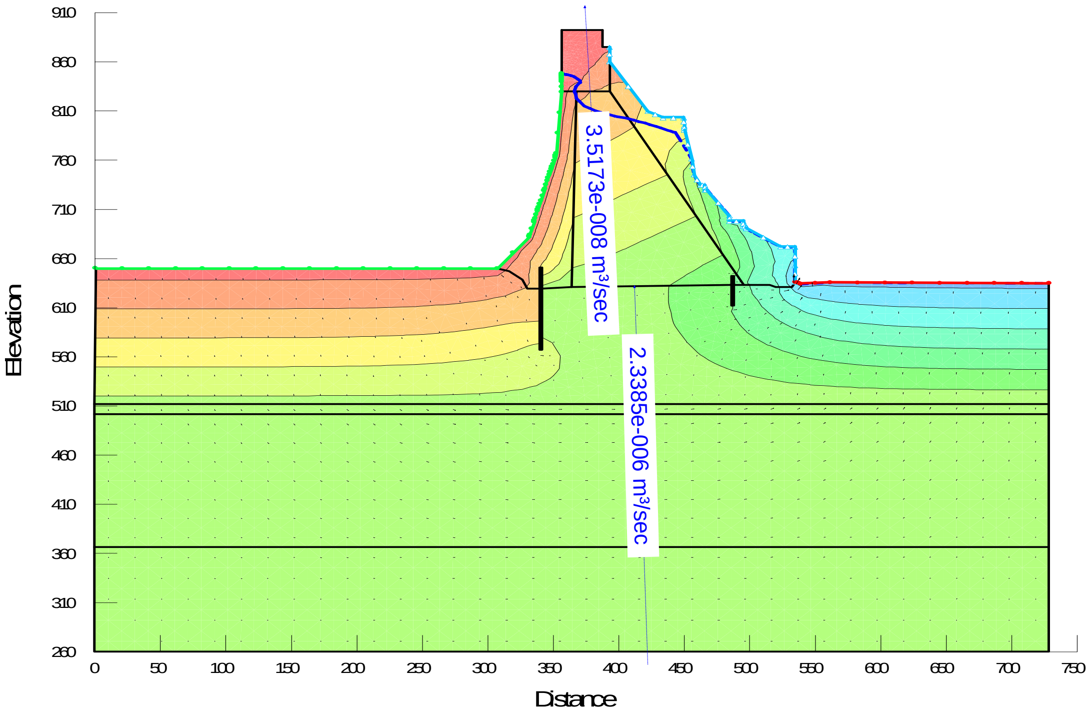

Figure 6. 90: RWL @848m for k 10^{-8}

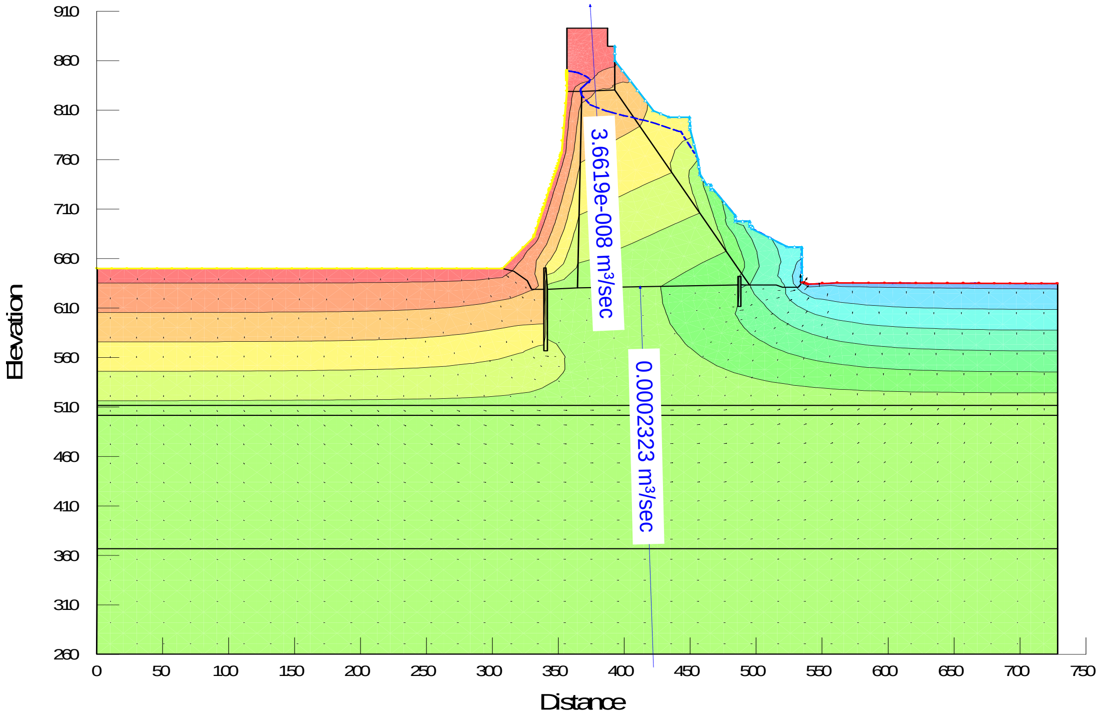

Figure 6. 91: RWL @850m for k 10^{-6}

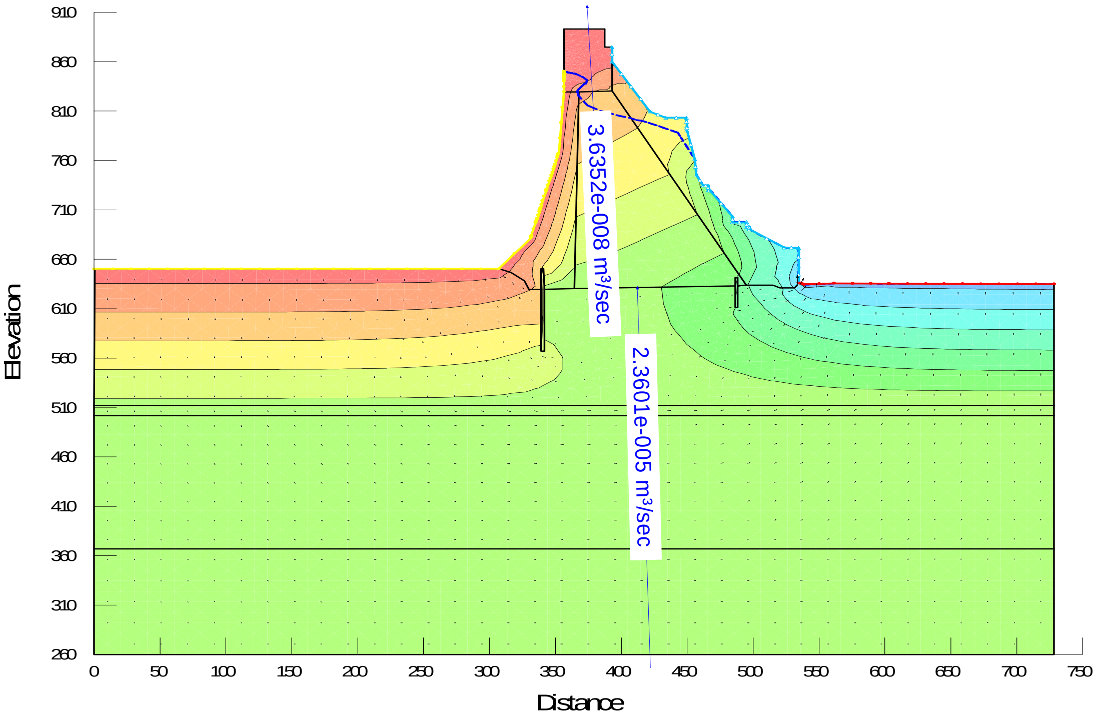

Figure 6. 92: RWL @850m for k 10^{-7}

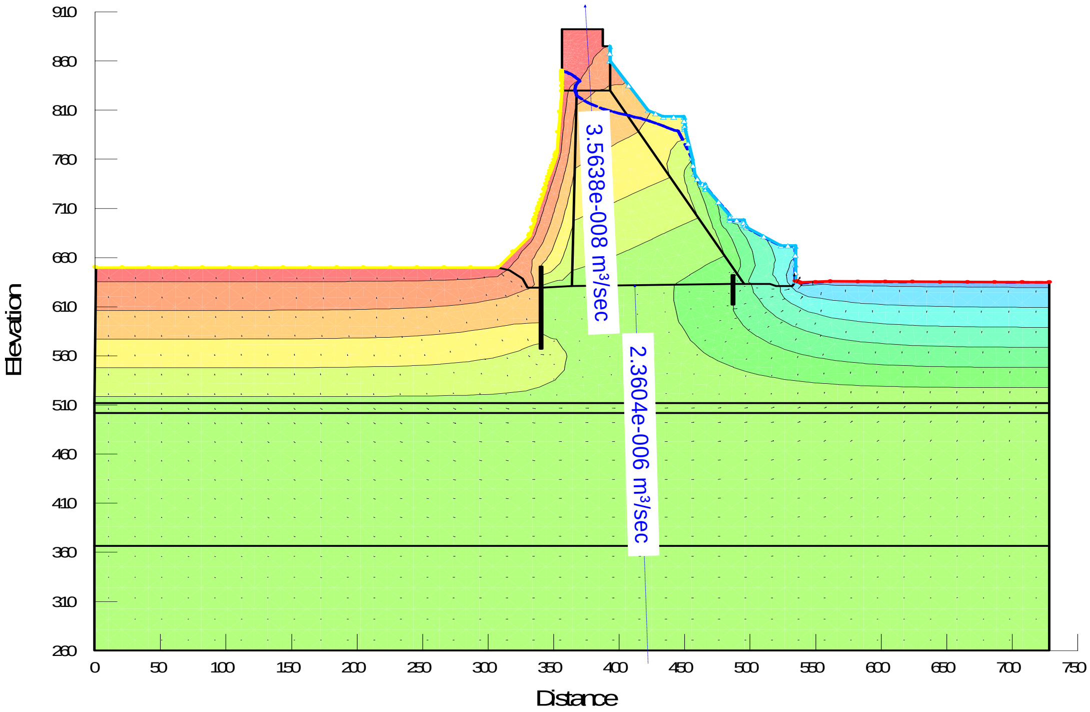

Figure 6. 93: RWL @850m for k 10^{-8}

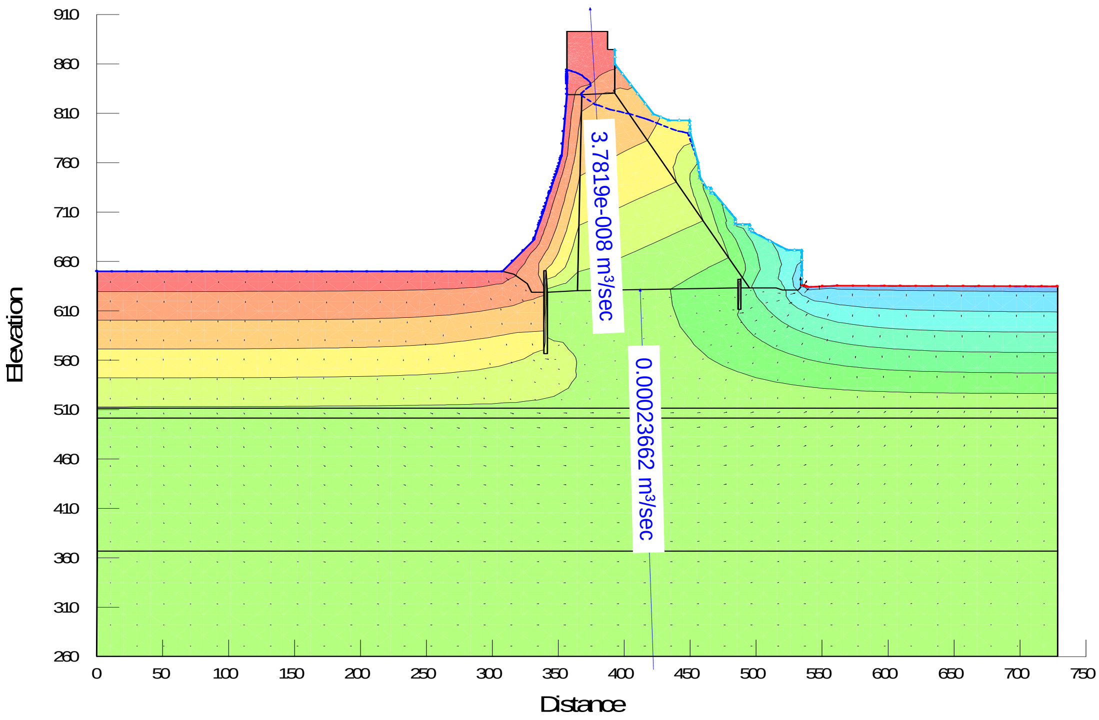

Figure 6. 94: RWL @854m for k 10^{-6}

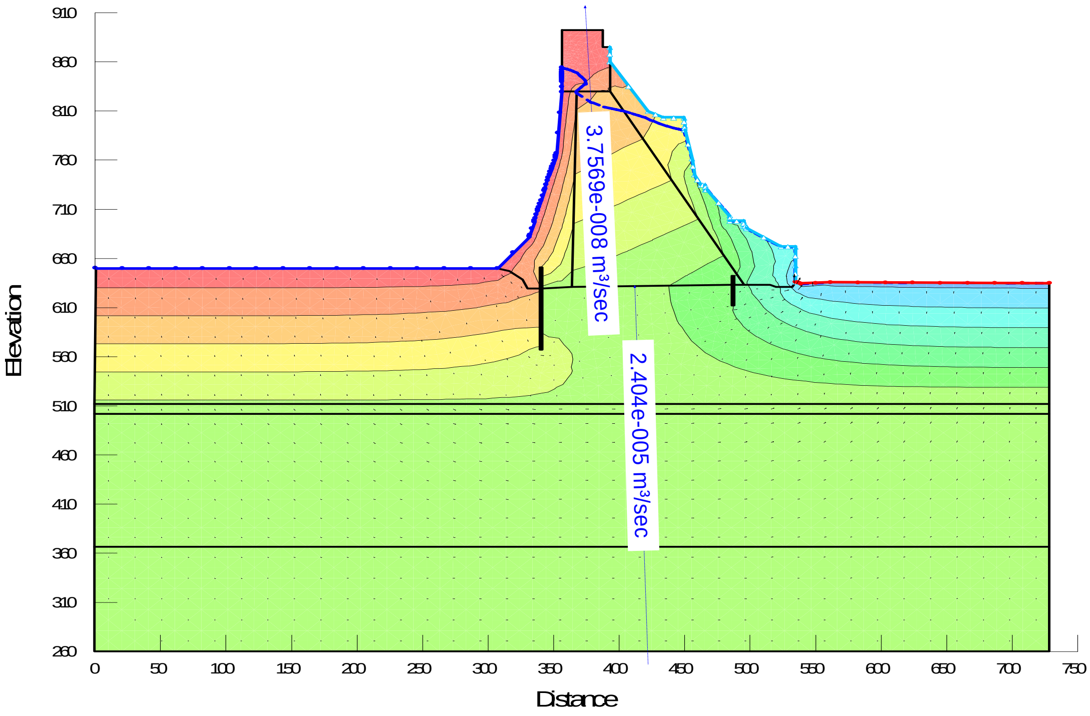

Figure 6. 95: RWL @854m for k 10^{-7}

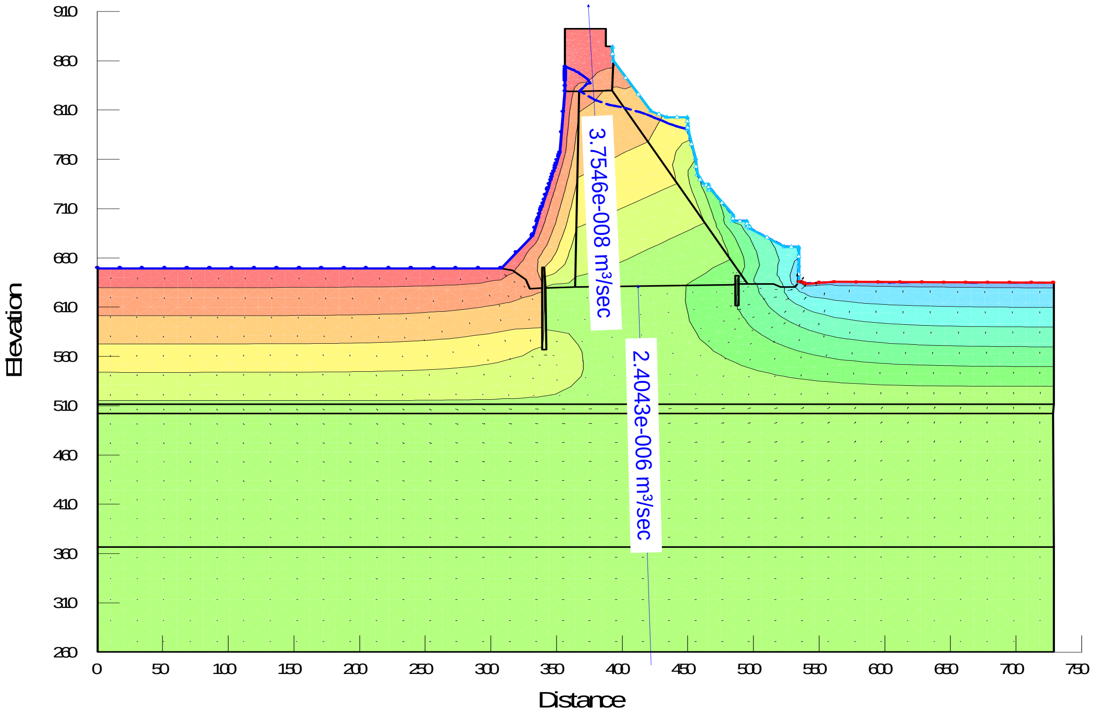

Figure 6. 96: RWL @854m for k 10^{-8}

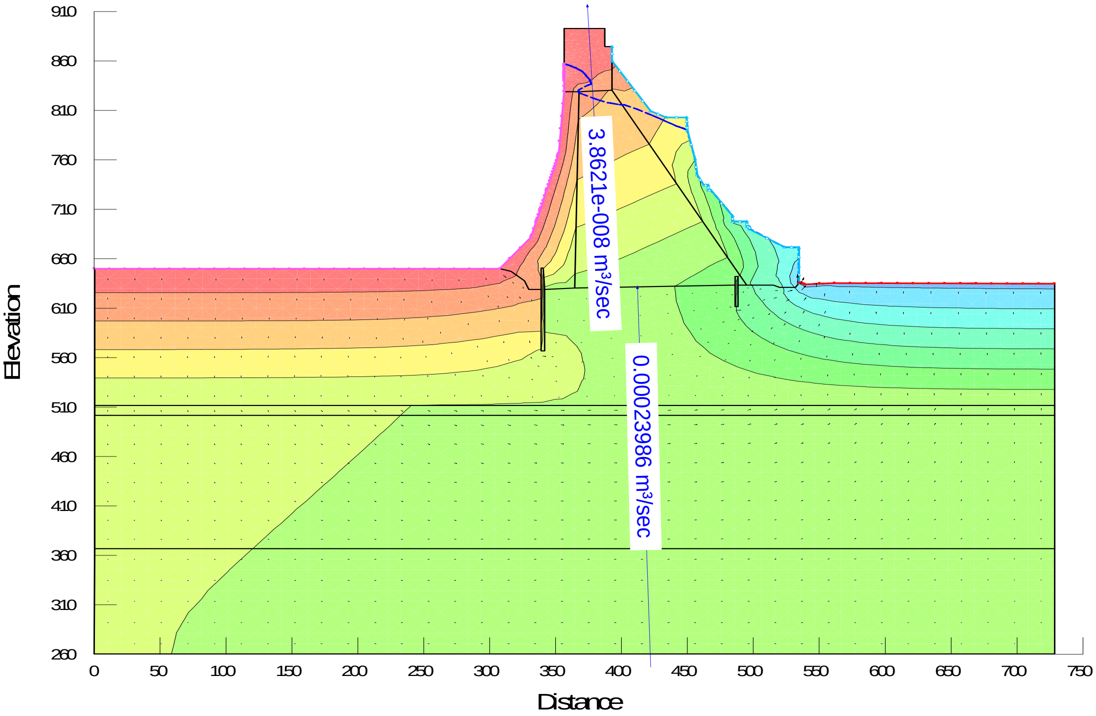

Figure 6. 97: RWL @857m for k 10^{-6}

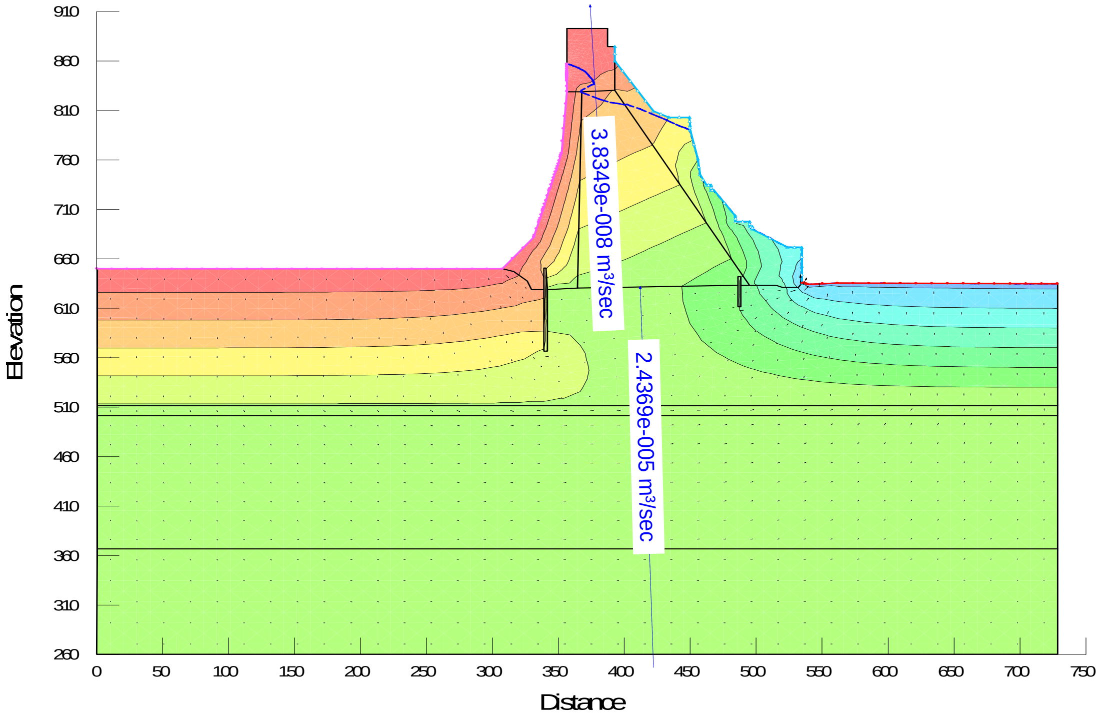

Figure 6. 98: RWL @857m for k 10^{-7}

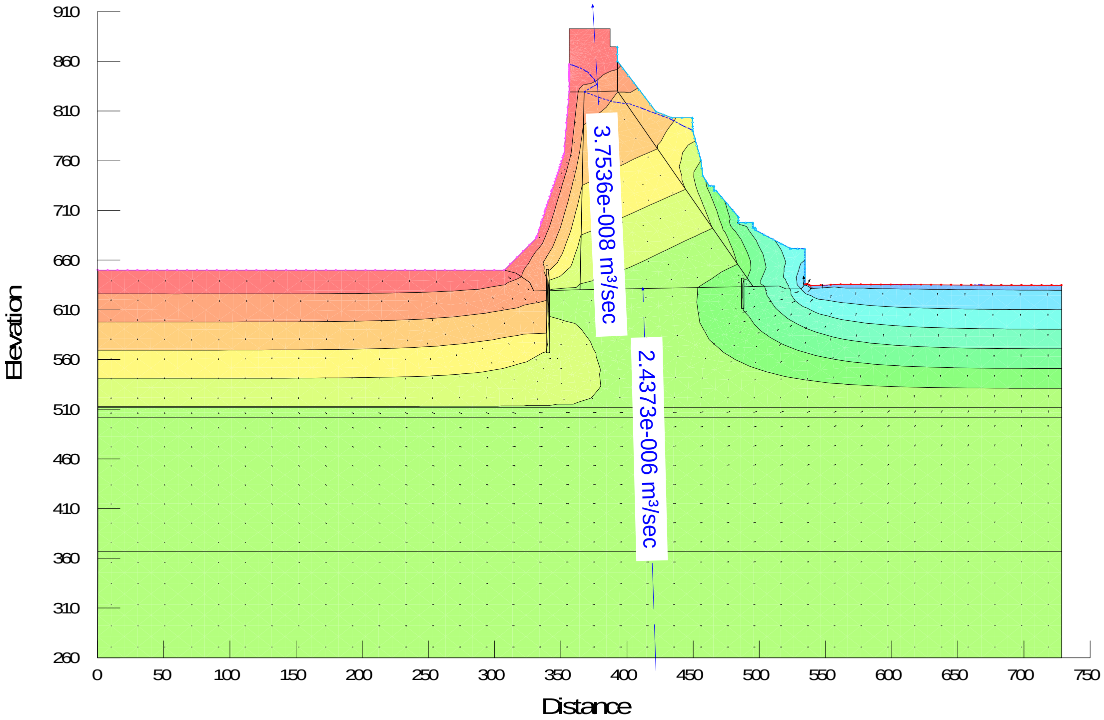

Figure 6. 99: RWL @857m for k 10^{-8}

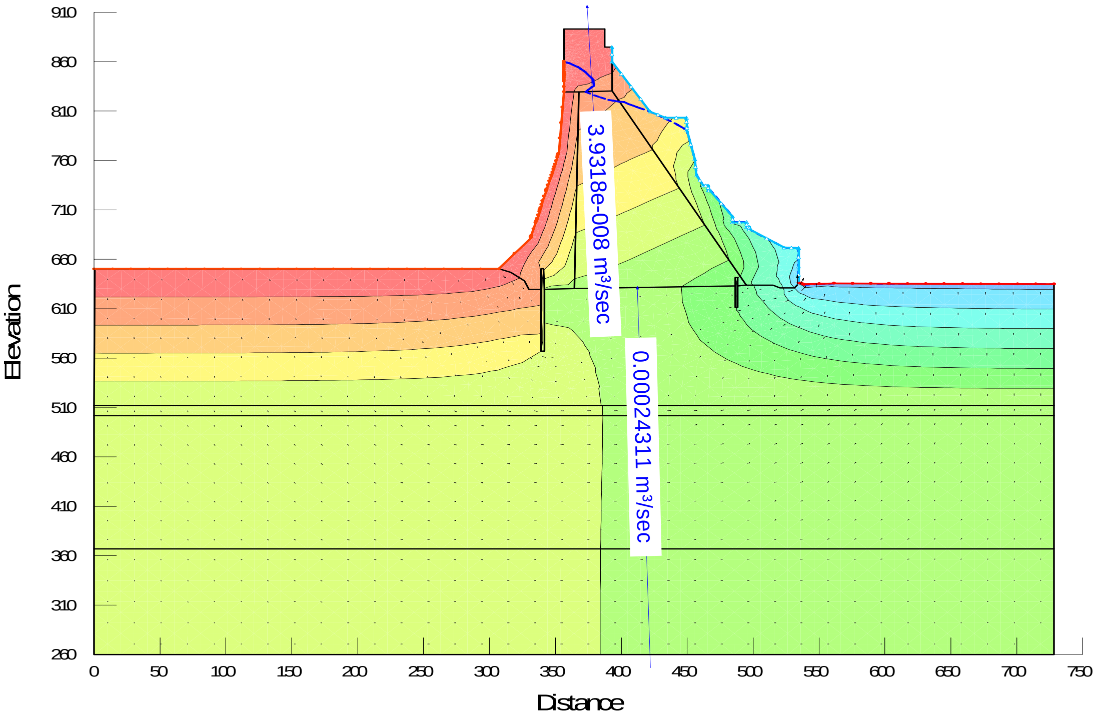

Figure 6. 100: RWL @860m for k 10^{-6}

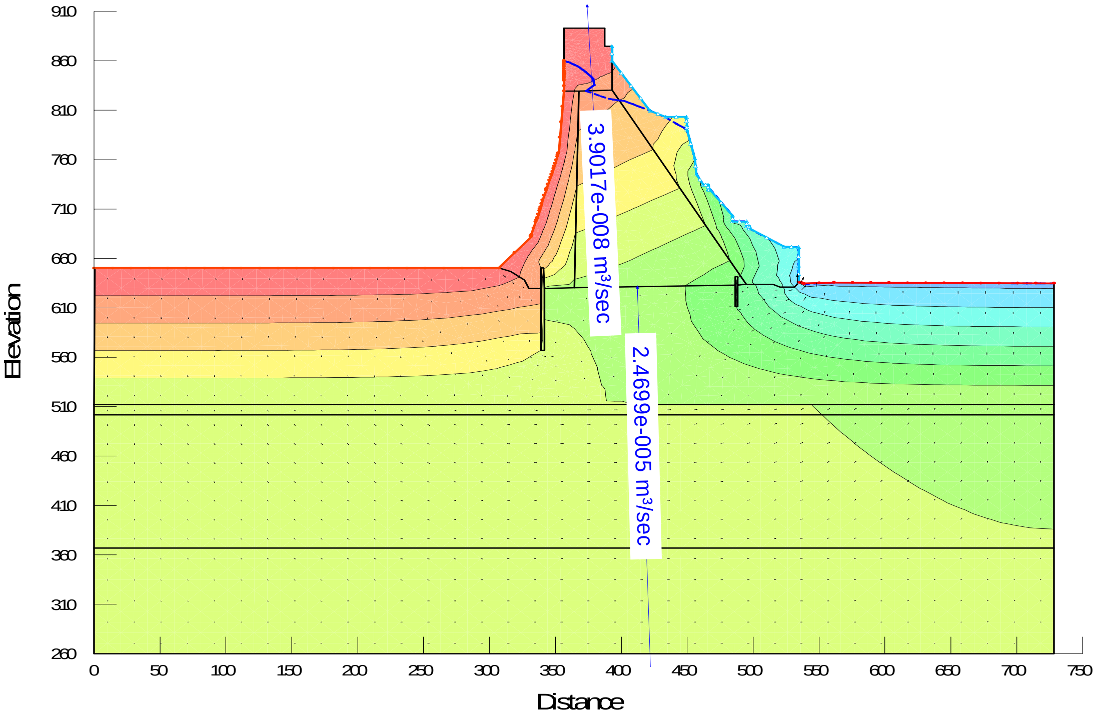

Figure 6. 101: RWL @860m for k 10^{-7}

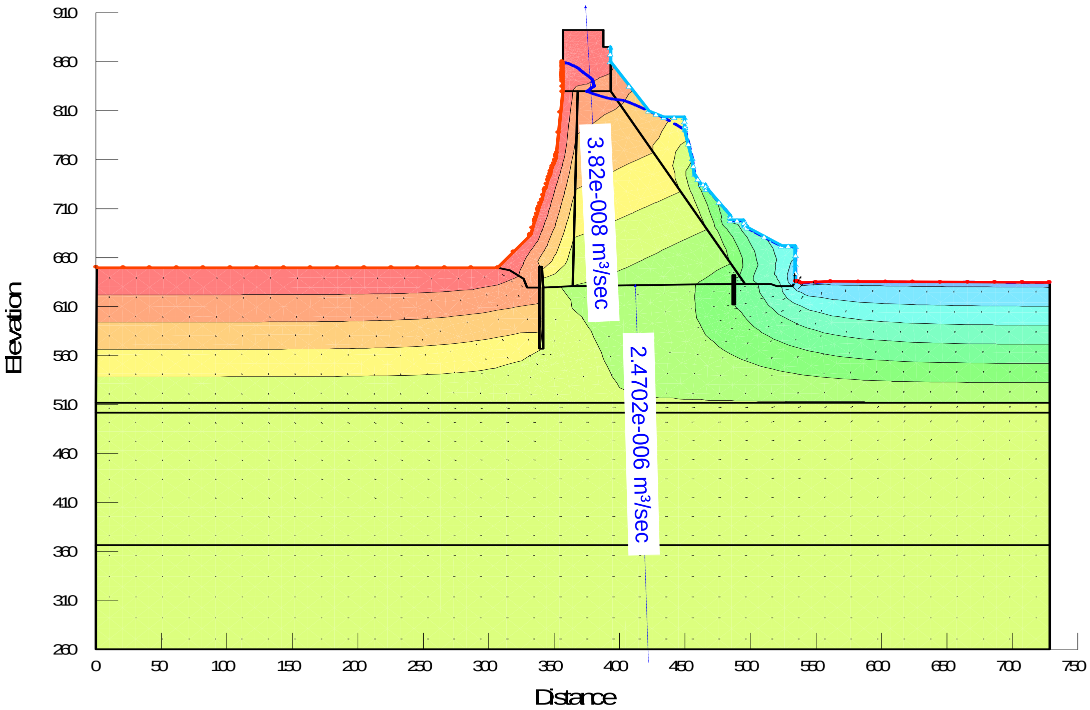

Figure 6. 102: RWL @860m for k 10^{-8}

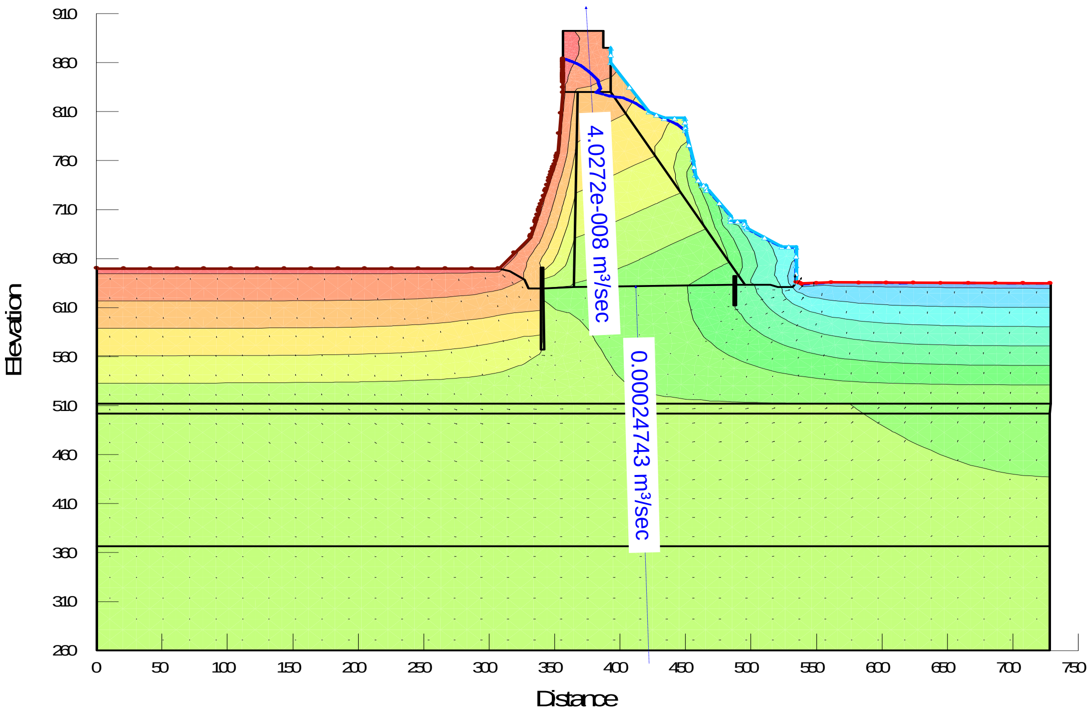

Figure 6. 103: RWL @864m for k 10^{-6}

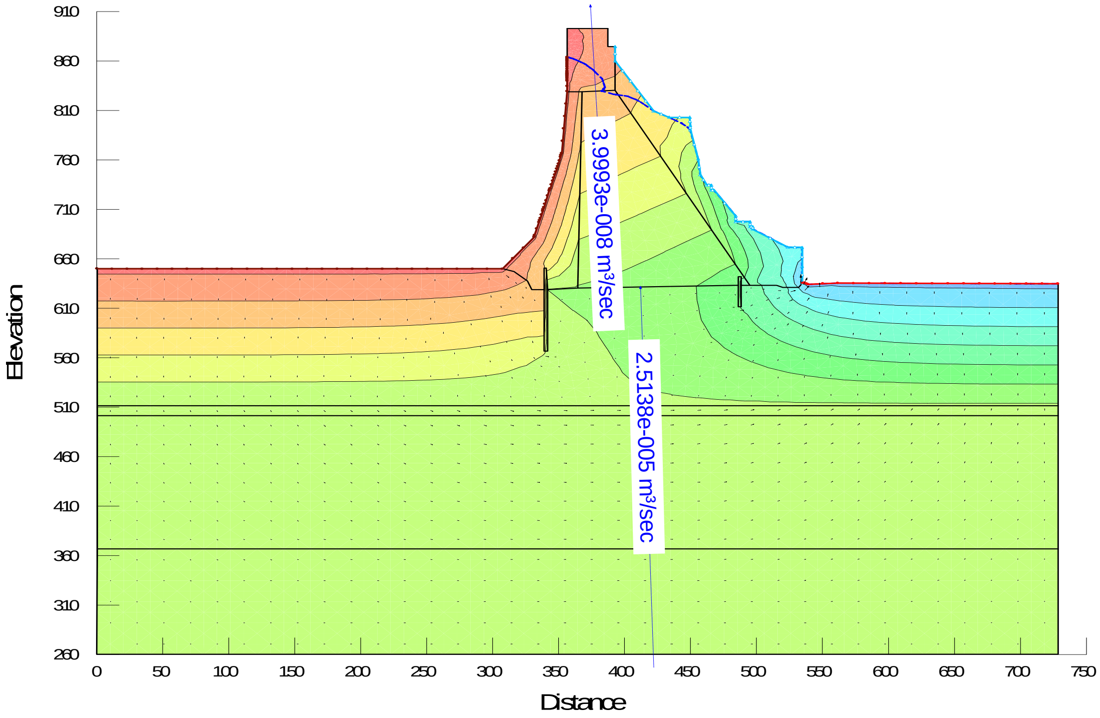

Figure 6. 104: RWL @864m for k 10^{-7}

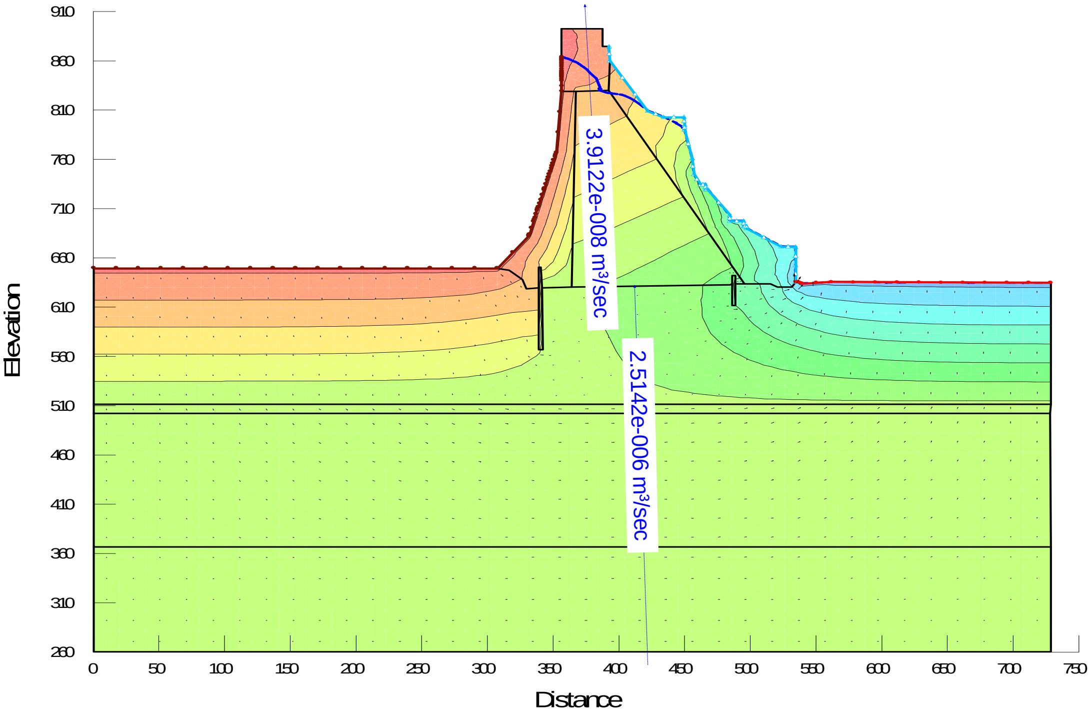

Figure 6. 105: RWL @864m k 10^{-8}

7.2 Appendix B

7.2.1 Multiple linear regression Input data

Table 7. 1: Multiple Linear Regression input

Elivation m.a.s.l	Measured Seepage data $^{m^3}/_s$	*Calculate seepage*$^{m^3}/_s$ *for* k_1 =1x10^{-6}	*Calculate seepage for* k_1 *times* Crest length of the dam	*Calculate seepage*$^{m^3}/_s$ *for* k_2 =1x10^{-7}	*Calculate seepage for* k_2 *times* Crest length of the dam	*Calculate seepage*$^{m^3}/_s$ *for* k_3 =1x10^{-8}
648	0.003047	0.0000121	0.0073749	0.0000014	0.0008710	0.0000003
697	0.0032596	0.0000163	0.00993629	0.0000019	0.0011547	0.0000004
701	0.003582	0.0000176	0.01073539	0.0000020	0.0012468	0.0000004
712	0.003806	0.0000219	0.01333826	0.0000025	0.0015482	0.0000005
719	0.004127	0.0000239	0.0145485	0.0000028	0.0016882	0.0000005
727	0.00472	0.0000267	0.0162748	0.0000031	0.0018904	0.0000006
731	0.005221	0.0000273	0.0166286	0.0000032	0.0019305	0.0000006
739	0.005495	0.0000295	0.0180133	0.0000034	0.0020907	0.0000006
745	0.006512	0.0000312	0.01905457	0.0000036	0.0022123	0.0000007
751	0.007295	0.0000329	0.02009462	0.0000038	0.0023330	0.0000007
756	0.008412	0.0001306	0.079666	0.0000133	0.0081008	0.0000013
769	0.009337	0.0001356	0.0826855	0.0000141	0.0085748	0.0000014
773	0.010447	0.0001384	0.0843996	0.0000147	0.0089426	0.0000014
777	0.010918	0.0001415	0.0863333	0.0000159	0.0097246	0.0000014
787	0.01289	0.0001515	0.092415	0.0000167	0.0101888	0.0000015
791	0.015352	0.0001555	0.0948489	0.0000171	0.0104566	0.0000016
798	0.010571	0.0001625	0.0991006	0.0000179	0.0109312	0.0000016
805	0.020391	0.0001694	0.1033584	0.0000187	0.0114009	0.0000017
811	0.0225	0.0001754	0.1070123	0.0000193	0.0118029	0.0000018
817	0.0248	0.0001814	0.110654	0.0000200	0.0122055	0.0000018
822	0.0269	0.0001863	0.113643	0.0000206	0.0125410	0.0000019
825	0.02879	0.0001894	0.1155218	0.0000209	0.0127423	0.0000019
832	0.0306	0.0001963	0.119743	0.0000217	0.0132120	0.0000020
836	0.0336	0.0002004	0.1222135	0.0000221	0.0134798	0.0000020
839	0.0352	0.0002033	0.1240374	0.0000224	0.0136811	0.0000021
840	0.03323	0.0002043	0.1246474	0.0000225	0.0137482	0.0000021
843	0.0384	0.0002247	0.137067	0.0000228	0.0139275	0.0000023
845	0.036676	0.0002280	0.1390678	0.0000231	0.0140617	0.0000023
846	0.036644	0.0002289	0.139629	0.0000232	0.0141288	0.0000023
847	0.038149	0.0002291	0.1397266	0.0000233	0.0141953	0.0000023

848	0.039923	0.0002301	0.1403854	0.0000234	0.0142508	0.0000023
850	0.040286	0.0002323	0.141703	0.0000236	0.0143844	0.0000024
854	0.038662	0.0002366	0.1443382	0.0000240	0.0146522	0.0000024
857	0.042219	0.0002397	0.1461987	0.0000243	0.0148529	0.0000024
860	0.045947	0.0002429	0.1481751	0.0000247	0.0150536	0.0000025
864	0.05567	0.0002472	0.1508042	0.0000251	0.0153214	0.0000025

Calculate seepage for k_3 *times* Crest length of the dam	Elevation m.a.s.l.	Predicted seepage m^3/s	Predicated times measured seepage m^3/s	Measured seepage squire m^3/s	Predicated squire m^3/s
0.000179859	648	0.00041	0.0000013	0.0000093	0.0000002
0.000228012	697	0.00067	0.0000022	0.0000106	0.0000005
0.000242719	701	0.00069	0.0000025	0.0000128	0.0000005
0.000283077	712	0.00135	0.0000051	0.0000145	0.0000018
0.000308721	719	0.00157	0.0000065	0.0000170	0.0000025
0.000345388	727	0.00581	0.0000274	0.0000223	0.0000338
0.000352708	731	0.00666	0.0000348	0.0000273	0.0000443
0.000381994	739	0.01006	0.0000553	0.0000302	0.0001012
0.000403716	745	0.01255	0.0000817	0.0000424	0.0001575
0.000425902	751	0.01514	0.0001104	0.0000532	0.0002291
0.000810751	756	0.01559	0.0001311	0.0000708	0.0002430
0.000851926	769	0.01664	0.0001553	0.0000872	0.0002768
0.000858026	773	0.01678	0.0001753	0.0001091	0.0002815
0.00087657	777	0.01678	0.0001832	0.0001192	0.0002816
0.000937936	787	0.01687	0.0002175	0.0001662	0.0002847
0.000962702	791	0.01692	0.0002598	0.0002357	0.0002864
0.001005707	798	0.01794	0.0001896	0.0001117	0.0003217
0.001050237	805	0.02042	0.0004163	0.0004158	0.0004169
0.001085617	811	0.02205	0.0004961	0.0005063	0.0004861
0.001122522	817	0.02395	0.0005939	0.0006150	0.0005736
0.0011529	822	0.02548	0.0006854	0.0007236	0.0006492
0.001171688	825	0.02647	0.0007622	0.0008289	0.0007009
0.001214693	832	0.02869	0.0008779	0.0009364	0.0008232
0.001239337	836	0.02996	0.0010067	0.0011290	0.0008976
0.001262151	839	0.03122	0.0010990	0.0012390	0.0009749
0.00126392	840	0.03169	0.0010532	0.0011042	0.0010045
0.001392935	843	0.04932	0.0018940	0.0014746	0.0024327
0.001406355	845	0.04994	0.0018316	0.0013451	0.0024939
0.001413004	846	0.05036	0.0018453	0.0013428	0.0025360
0.001419775	847	0.05093	0.0019431	0.0014553	0.0025943

0.001425265	848	0.05122	0.0020451	0.0015938	0.0026240
0.001438624	850	0.05203	0.0020959	0.0016230	0.0027067
0.001465403	854	0.05363	0.0020736	0.0014948	0.0028765
0.001485472	857	0.05487	0.0023678	0.0017824	0.0031455
0.001505602	860	0.05608	0.0026503	0.0021111	0.0033273
0.00153232	864	0.05768	0.0030546	0.0030991	0.0030107

Table 7. 2: goodness indicator and monitoring seepage range

RWL.	Measured seepage (m^3/s)	Predicted seepage (m^3/s)
648	0.003047	0.00040
697	0.0032596	0.00067
701	0.003582	0.00069
712	0.003806	0.00135
719	0.004127	0.00157
727	0.00472	0.00581
731	0.005221	0.00666
739	0.005495	0.01006
745	0.006512	0.01255
751	0.007295	0.01514
756	0.008412	0.01559
769	0.009337	0.01664
773	0.010447	0.01678
777	0.010918	0.01678
787	0.01289	0.01687
791	0.015352	0.01692
798	0.010571	0.01794
805	0.020391	0.02042
811	0.0225	0.02205
817	0.0248	0.02395
822	0.0269	0.02548
825	0.02879	0.02647
832	0.0306	0.02869
836	0.0336	0.02996
839	0.0352	0.03122

840	0.03323	0.03169
843	0.0384	0.04932
845	0.036676	0.04994
846	0.036644	0.05036
847	0.038149	0.05093
848	0.039923	0.05122
850	0.040286	0.05203
854	0.038662	0.05363
857	0.042219	0.05487
860	0.045947	0.05608
864	0.05567	0.05768