This is to certify that the

Final Year Project titled

DESIGN & ANALYSIS OF 'MOHMAND DAM'

Submitted by

SULEMAN AFZAL -NUST15124115
ALI AKBAR -NUST15134361
MUHAMMAD SHAHBAZ -NUST 15137410
ARSLAN TARIQ -NUST15147352

has been accepted towards the requirements

for the undergraduate degree

in

CIVIL ENGINEERING

Dr. Turab Jafri
Assistant Professor
NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology, Islamabad, Pakistan

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Abstract

Mohmand Dam Project is an ongoing project in Pakistan. It's a CFRD (Concrete Faced Rockfill Dam) being built in response to the flooding conditions in the area. This study deals with the design and construction aspects of the dam. This includes carrying out all the necessary calculations needed for the designing of its embankment such as the hydrological study and dam sectioning. The procedures generally employed for checking the stability are the limit equilibrium methods and this study will delve further into it as well as the finite element modelling of the dam which is done by use of software such as PLAXIS, ABAQUS and SLIDE 2D is done to check the dam body i.e. embankment safety. The cost of its embankment is also drawn with respect to its height while ensuring the best material provision.

The study aims to provide the general guidelines for establishing the embankment of a Concrete Faced Rockfill dam, its zoning and checking its stability against seepage as well as earthquakes. This results in an optimal and sophisticated design which will bear all the undesired conditions as well as providing a range of different heights of dam to be used in accordance with the economic conditions.

Contents

CHAPTER 1: INTRODUCTION

1.1. Background:

Heavy Monsoon rains begin on last week of July which causes to large scale floods and landslide from late July 2010. The impact was first started in the Northern side of Pakistan but later its impact go down following the Indus River to affect the Southern side.

- Estimations shows of affected populations was rapidly gaining to reached more than 20 M in September that is more than 10 percent of the Pakistani population.
- Investigation report show 150 flood displaced families in need of urgent help from Government.
- A total of 1.8 M houses are calculated to be destroyed or damaged leading to the eruption of million of camps.
- Many embankments, dikes and other infrastructure were destroyed which was, link roads, water channels Schools, health facilities and most of the infrastructure in rural areas.
- Access to safe drinking water was greatly affected and due to this water diseases were born.

Why do we need dams?

In ancient times dams were built for the single purpose that is supply water. As humanity grows, there was a greater need for irrigation, water supply, flood control, navigation, sedimentation control and hydropower. A dam is basically foundation in the development and management of water resources. The multipurpose dam is a very important project for developing countries.

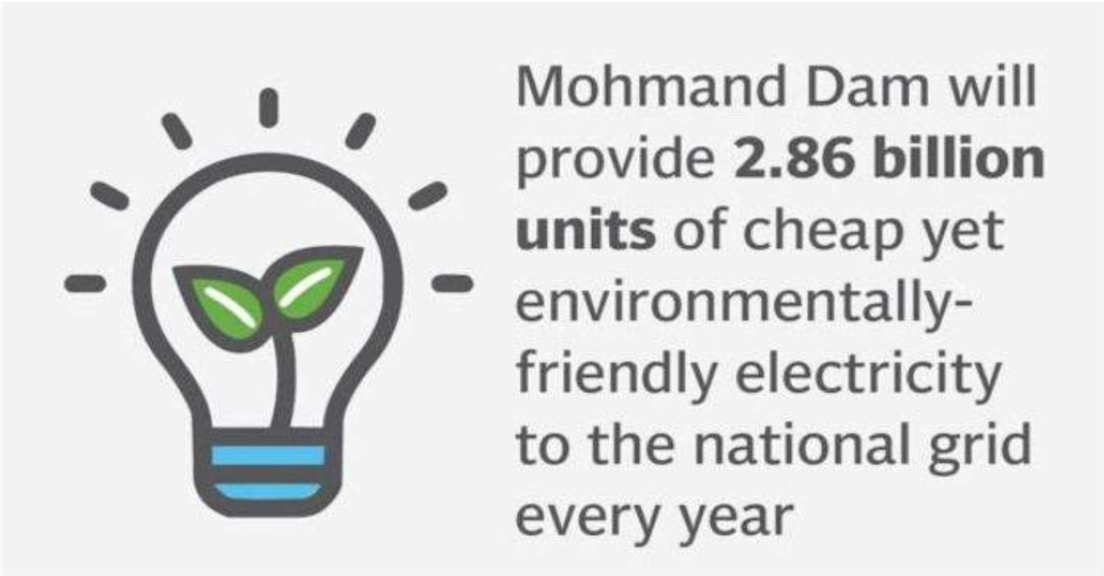
1 *Impacts of Dams:*

- **Flood Control:**

For the past several years, Pakistan has been witnessing a series of floods which not only resulted in loss of lives but also proved to be detrimental to the country's economy. At present, the total water storage capacity of the country is 14 million acre feet (MAF), whereas its annual consumption requirement stands at 117 MAF. Due to a lack of storage, as much as over 10 MAF of water goes into the sea every year. The dam restricts the amount flowing through the opening, decreasing peak —flood flow. Since flow through dams slightly affect rivers natural flows under normal conditions negative environmental and socioeconomic impacts such as sediment accumulation, restriction of water flow to downstream communities and ecosystems, and breaching during very extreme flood events which can be prevented.
The dam will provide 300 million gallons of drinking water per day to areas of Peshawar. Mohmand Dam not only provide fresh water but also of great importance as it is the only only dam that can protect Peshawar, Charsada and Naushehra from life threating floods.

- **Hydropower:**

The capacity of the project to generate power estimated 800 MW and it will provide 2.86 billion units of cheap and also environmentally friendly electricity to the national grid every year. That should also bring a dramatically change for the common man through the generation of cheap electricity.



According to data which is provided to National Power Regulatory Authority (NEPRA)

Sector	Power Generations (%)	Cost (Per Unit)
Hydroelectric``	22.7	2-3
Furnace-oil based Electricity	1.6	11.90
Re-gasified liquefied(RLING)	16.89	9.7
Local Gas	23.8	5.6
Coal	18.7	7.9
Nuclear energy	11.68	0.95

The cost of hydroelectricity generation ranges between Rs2 to Rs3 per unit, therefore the project will generate cheaper electricity.

- **Rural Development:**

Agriculture is important factor of Pakistan economy because it employs 45% of the population and provides basic needs. The gross water storage capacity of this project would be 1.2 million acre feet and provide water to 160,000 acres of exiting land in addition of more than 16,700 acres of new land will also be irrigated with the help of this project. Which will increase economic development by improving the local income, which will help to restore stability of civilian.

The construction of dam will also help resolve the ongoing water conflict between different provinces in Pakistan. Pakistan have been in a tug of war over their water share and have been accusing for stealing water from each other.

This dam will make new opportunity for local people during construction and operation of Project. Due to this it will gradually make their living standard better like development of new sector with all basic modern civilization facilities.

This dam will make an improved tourism opportunities in an areas of Gilgit Balistan and Kohistan.

1.2. Problem Statement:

Problem statement is divided into two parts. The first part includes the geotechnical. Design of Mohmand Dam. The second part is more focused on the analysis approach. In which overall dam stability is to be checked by Limit Equilibrium methods and Finite Element Modelling (FEMs) using software such as PLAXIS and ABAQUS. The Analyses will be conducted to make a comparative study of the both procedures which could help in revision of the original design.

1.3. Objective:

The study of Dam and its modelling will help us achieve following objectives:

1. Categorizing and proposing a suitable dam design. First of all we determine what type of dam we want to design. For choosing a suitable dam type there was various factors on which dam type depends. The following factors are shown below:

- Topography of site
- Construction material
- Seismicity Performance
- Economical
- Availability of large rocks
- Worldwide trend

2. Employing analytic procedures (conventional and advanced) to check the feasibility of proposed dam design. The second part of objective is analysis of

proposed dam design. In order to check the feasibility of proposed dam design we employ two analytic procedures which as limit equilibrium method (LEM) and Finite element analysis (FEA). For Limit equilibrium method SLIDE software are used, and for Finite element analysis ABAQUS and PLAXIS 2D were used.

3. Cost estimation for the proposed dam design.
4. Development of geotechnical baseline report representing the known ground conditions on the project site. GBR contains a summary of the geologic and geotechnical information, a description of the anticipated ground conditions, and a prediction of the ground behaviour during construction of dam.

CHAPTER 2: LITERATURE REVIEW

2.1 General:

The entire spectrum of dam design is segregated into different phases. Knowing the site stratigraphy and the type of dam requires a deep onlook. The materials present on the dam's site are limestone, quartzite and schist. Limestone is available at the quarry site approximately 3km northeast of the dam site with exploitable volume of around 6 million m^3. The quartzite and siliceous schist can be quarried approximately 1km upstream of dam site in an order of 15 million m^3. Since the entire site is in abundance of rocky material as compared to soils. Earth dams are composed mainly of earth material such as clay. So, building earth dam is not appropriate considering the rocky material conditions. Worldwide engineering experience in CFRD construction have proved appropriateness of limestone, quartzite and schist as rockfill material for CFRD. The project area is in a highly active tectonic zone with thrust faults in Himalayan foot-hills and in a region of high seismicity and more than 26 events of significant earthquakes over 5.5 magnitude in the Richter scale have been recorded. CFRD is best suited for such areas.

2.2 CFRD:

Studying basic dam classification tells us that a Rockfill dam is usually made of large rocks and there is an impervious membrane is placed on the Rockfill on the upstream side to effectively reduce the effect of seepage throughout the dam. As a result, it is more resistant to earthquakes. The membrane that is given on the outside is of concrete. Although the construction requires heavy machinery for transporting and compacting rocks but ultimately result in a design that is durable in adverse environments.

2.3 Sectioning:

Concepts related to design of sectioning of dam's components are consulted using different design manuals such as the ICOLD manual on "Concrete Face Rockfill Dams Concepts and Construction". Book "Concrete Face Rockfill Dams- Design, Construction and Performance" by J. Barry Crooke and James L. Sherard is also consulted for design and performance related problem. Book 'Concrete Face Rockfill Dams' by Paulo T. Cruz, Bayardo Materon and Manoel Freitas is consulted for zoning perspectives. ASCE paper "Seepage and Boiling around a Sheet Pile under Different Experimental Configuration" by Mehdi Yousef et. Al was used for cutoff heights.

2.4 Feasibility reports:

The feasibility reports done by WAPDA (1969), NESPAK (pre-feasibility report 1992), JICA feasibility report (2000) and AMZO feasibility report (2006) are also consulted for different design parameters of the dam helping in the modelling of the dam's embankment according to FEMs.

The JICA report compares the design of CFRDs and ECRDs and concluded that CFRDs are cheaper by 12% than in ECRD mainly owing to shorter diversion tunnels. CFRDs construction period is at least one year less than ECRDs owing to smaller embankment volume. Since the entire CFRD embankment is dry, earthquakes cannot cause pore pressure in the rockfill dams.

2.5 Limit Equilibrium Methods:

Limit Equilibrium methods consider the Mohr-Coulomb failure criterion which defines the shear strength by simple relation.

$$S = c + \sigma \tan\phi$$

where (ϕ) and (c) are the angle of internal friction and cohesion respectively, and (σ) is the normal effective stress. The method of limit equilibrium assumes that the shear strength of the soil is partially mobilized along an assumed failure surface. The method defines the factor of safety (FOS) as available shear strength (S) divided by the developed shear stress (τ).

2.6 FEM Modeling:

The other approach is to use FEM modelling to help in better understanding of the different soil and rock parameters that affect the dam design. Research papers pertaining to FEM and their use in CFRDs are highlighted in the following paragraphs.

2.7 Case Studies:

A few of cases pertaining to CFRDs in which FEMs analysis was done are includes the **Miaojiaba CFRD (Wenxian)**'s paper in which dam is subjected to dynamic loading and its 3D FE analysis is done and the other is **Cokal Dam (Turkey)'s** paper primary purpose is to compare 2D and 3D analyses of performance of dam under the dynamic loading conditions.

2.8 Software:

Following software help in the design and analyses of our defined statement and are given in chronological order of their use.

2.8.1 MS CAD 2016:

MICROSURVEY CAD is an optimal tool for the making of maps knowing the coordinates of the location and the z-coordinates i.e. elevation. The result is a 2D map that visually gives a general look onto how the location is.

2.8.2 Settle3D 4.0:

Software used for borehole analysis is Settle3D 4.0. A deep insight of the interpolation methods used for soil profile is done and the method most suitable to used for this purpose is TIN Triangulation i.e. Triangulated Irregular Network Triangulation. The method takes the data points and triangulates them using the Delaunay triangulation method. "To calculate the value at a sample point, the program first determines which triangle the point lies within. Once the triangle that contains the sample point is found, the interpolated value is calculated using linear interpolation." The local thin plate spline is also good for the purpose, but its efficiency is better if we consider large number of data points (>200).

2.8.3 PLAXIS v8.4

PLAXIS software is used for complex soil profile or geological cross-sections. PLAXIS accurately models the construction process with stage construction. PLAXIS can be used for many geotechnical problems with well proven procedures which yield accurate results. Deformations and volumetric strains can be analysed using this software.

2.8.4 SLIDE v6.0

Slide has been in use throughout the world owing to its user-friendly interface and its broad range of stability defining functions. Probabilistic analysis employing different functions of cohesion, angle of internal friction, unit weight and undrained shear strength can be done using the software giving results that would be near to accurate. Newmark procedure can help in seismic stability analyses.

2.8.5 ABAQUS

Abaqus is a 2D and 3D modeling software used for modeling purposes. The software checks for deformations, translations, stresses and various other parameters. It's a good software for checking the stability of different sections.

CHAPTER 3: DESIGN METHODLOGY

3.1: Developing Topographic Map:

The topographic map which includes the dam upstream reservoir , dam body and downstream area. This topographic map will be used for the selection of dam site and height of the dam). For the development of topographic map, **Microsurvey CAD** is used.

The 29 controls points were surveyed whose horizontal control points and vertical control point is tabulated in table 3.1 . Using these points contour map of dam site is develop with interval of 5m. The map is shown in fig 3.1.

Plot#	Horizantal Control Point		Vertical Control Point
	X	Y	Z
1001	3070632.37	1122917.69	440.81
1002	3070689.97	1118151.68	370.57
1003	3074530.97	1122931.91	379.091
1004	3075224.59	1125974.32	418.21
1005	3074057.19	1126764.08	419.023
1006	3075249.36	1120170.98	355.756
1007	3070340.59	1126085.74	564.745
1008	3070139.97	1126301.69	566.057
1009	3068959.4	1128070.23	746.998
1011	3067405.88	1124942.33	385.859
1012	3066157.67	1124467.78	606.482
1014	3065924.34	1119753.94	511.53
1015	3064744.65	1126599.73	599.1
1016	3062689.07	1127308.94	773.406
1021	3060092.28	1132997.14	852.646
1023	3061206.25	1139199.01	626.64
1024	3062061.03	1141687.9	593.137
1025	3065028.17	1140851.13	634.441
1027	3067756.49	1143810.27	660.647
1028	3079669.7	1151218.67	519.005
1029	3077345.99	1152986.57	812.959

TABLE 3.1: Summary of horizontal and vertical control point

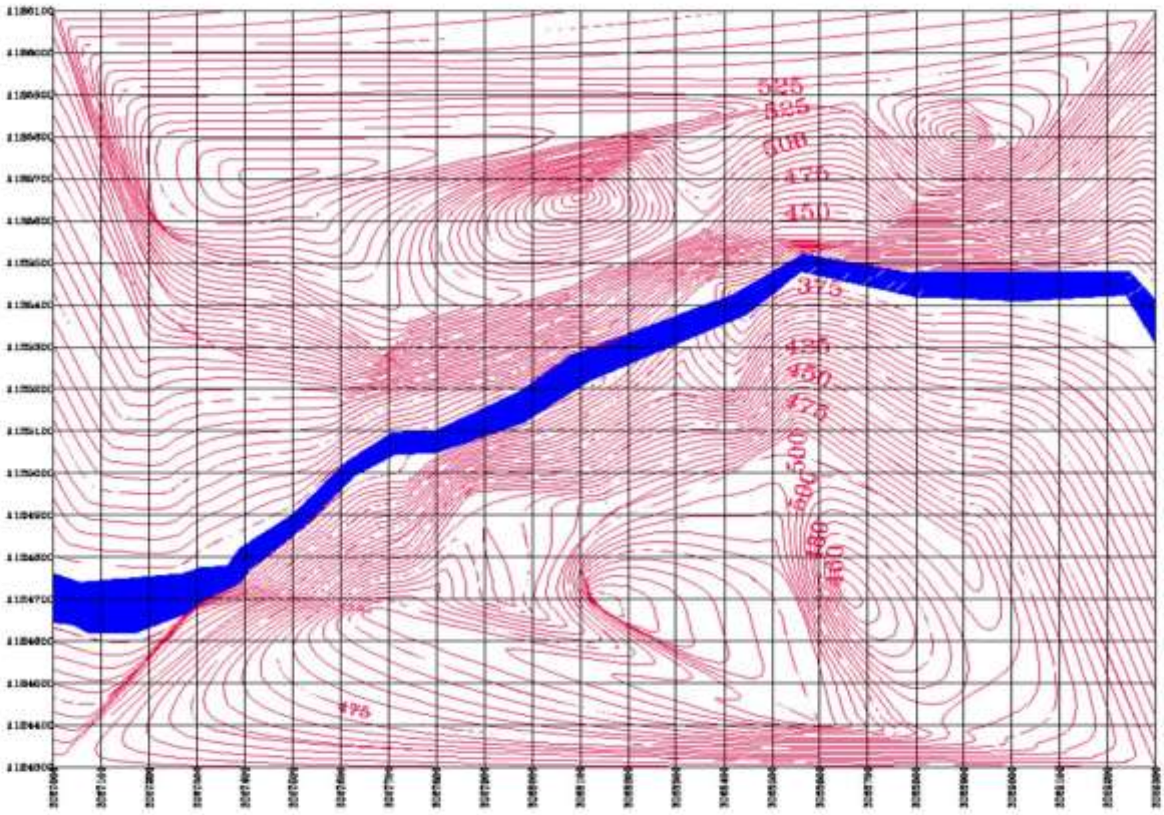


FIG 3.1: Topographic contour map

The survey of river cross section is also done. At dam foundation 5 cross section is surveyed at 100m . From dam downstream slope to munda headworks , 20 cross section were survey at interval of 250m. The data of river cross section surveyed in tabulated. The sample river cross section data is tabulated in table 3.2 is shown below in fig3.2.

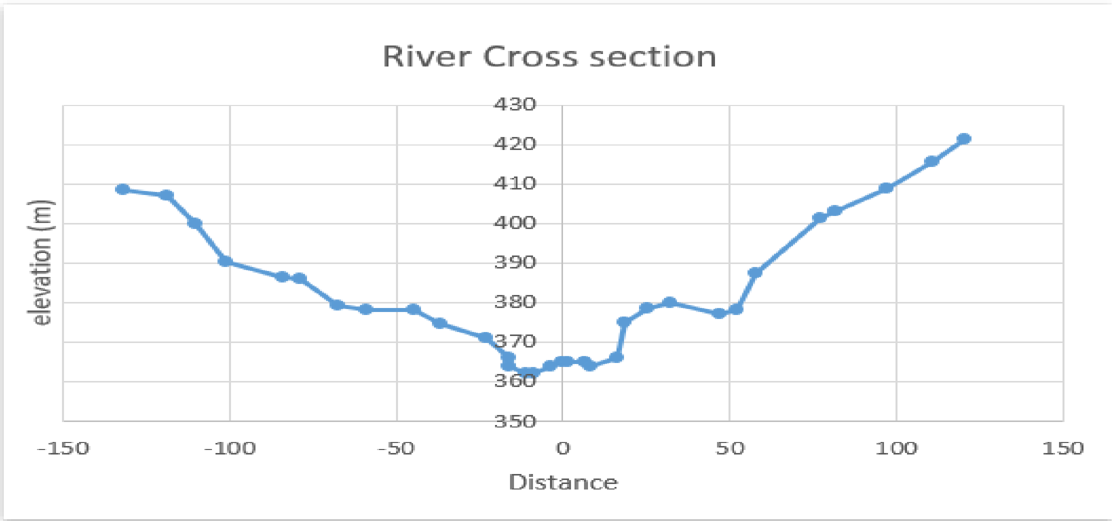


FIG:3.2 River cross section of station Ds 5200

Point	dist(m)	Elve. (m)
1	-132	408.5
2	-119	407.2
3	-110	399.9
4	-101	390.5
5	-84	386.5
6	-79	386.126
7	-67.5	379.16
8	-59	378.279
9	-44.5	378.279
10	-36.5	374.565
11	-23	371.062
12	-16.5	366
13	-16.3	364
14	-11	362.25
15	-9	362
16	-3.5	364
17	0	365
18	1.5	365
19	6.5	365
20	8.5	364
21	16.5	366

TABLE 3.2: Rive cross section data point

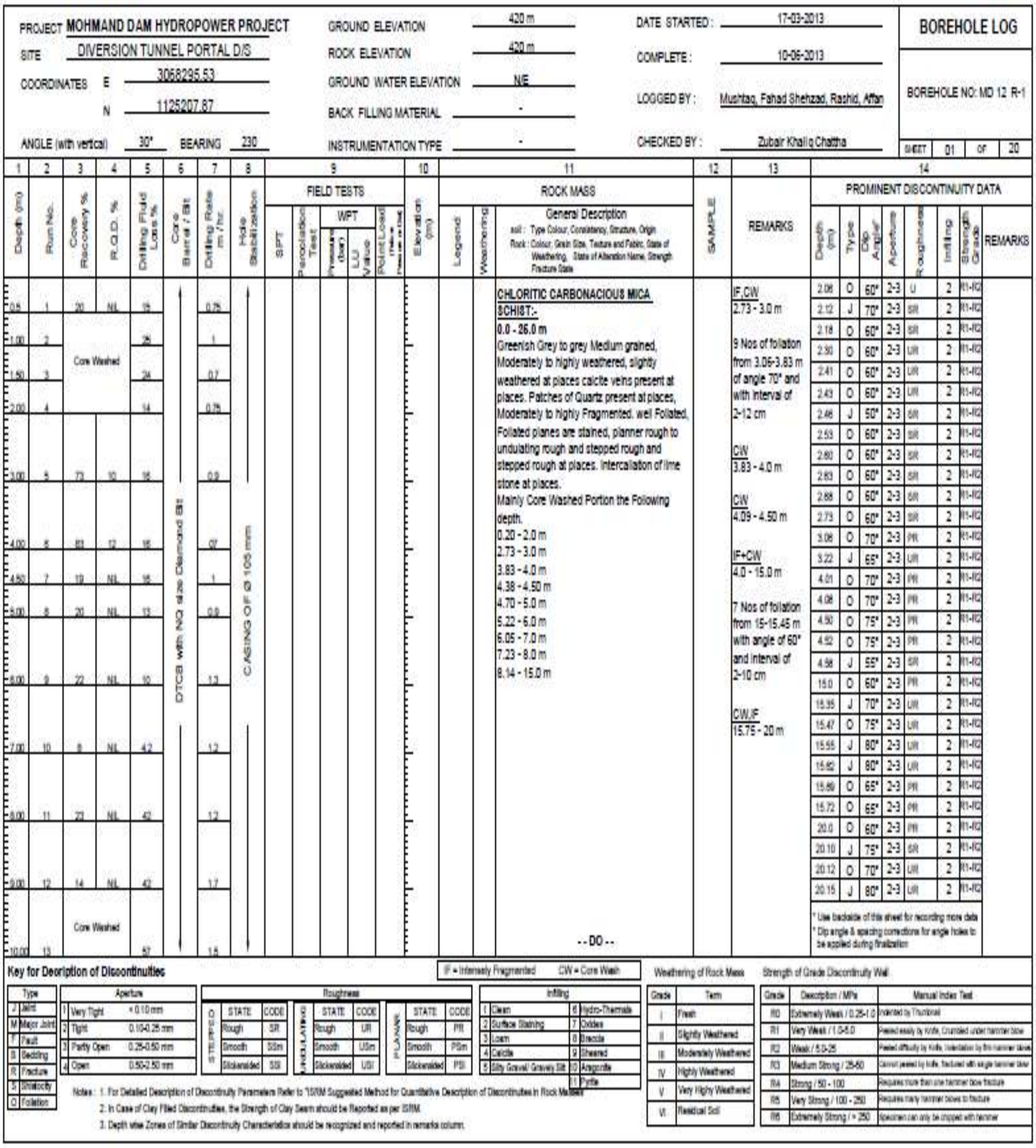
3.2. Stratigraphy:

The stratigraphy map of dam site is develop using the NESPAK borehole log book which include Coordinates (easting, Northing), Ground elevation, Bore hole rock type . The total number of boreholes are 29 which covers the dam foundation, quarry site, abutments and reservoir area. The coordinates of these borehole are is tabulated in table 3.2:

Point Name	Elevation	Easting	Northing	X-Coordinate	Y-Coordinate
Diversion tunnel portal d/s (origin)	420	3068296	1125207.9	0	0
Power house foundation	380.00	3068174	1125228.6	121.88	20.77
Plunge pool	490	3068358	1125581	-62.27	373.15
Surge bank	555	3068119	1124694.9	177.02	-513.02
Diversion tunnel area	490.00	3068154	1124928.2	141.59	-279.69
Main axis r/b	467	3067944	1124695.2	351.94	-512.63
Main DAM r/b	492	3067798	1124722	497.53	-485.87
Main Bank u/s r/b	440	3067730	1124834.3	565.36	-373.6
Main Bank u/s r/b	376	3067744	1124990	551.53	-217.87
Main Bank u/s r/b	421	3067682	1124867	613.53	-340.87
Spillway channel	500	3068068	1125445	227.95	237.13
Random	370.00	3068111	1125235	184.58	27.09
Main Dam Area l/b	423	3067603	1125171	692.53	-36.87
Dam Axis	410	3067718	1125190	577.53	-17.87
Main Dam Plinth	499	3067692	1125282	603.53	74.13
Main Dam Area l/b	519	3067745	1125367.2	550.42	159.37
Main Dam Crest area r/b	470	3067874	1124947.3	421.44	-260.54
Spillaw Plunge Pool	386	3068370	1125457.1	-74.23	249.25
River Valley u/s	370.00	3067687	1125055	608.53	-152.87
River Valley D/s Main Dam	370.00	3067978	1125150.5	317.39	-57.39
Coffer Dam u/s	352.00	3067402	1124807	893.53	-400.87
Dam Site r-abudment	410.00	3068410	1125504.8	-114.67	296.94
Dam site r-abudment	509.00	3067661	1124668.8	634.2	-539.03
Dam site r-abudment	408.00	3067288	1124668.8	1007.56	-539.03
Quarry area	591.00	3069950	1126525	-1654.47	1317.13
Borrow	797.00	3063235	1125230	5060.53	22.13
Dam site r-abudment	778.00	3062905	1126075	5390.53	867.13
comand area r/s	414.00	3069553	1122228.1	-1257.17	-2979.78
comand area l/s	484.00	3072733	1126973.3	-4437.61	1765.43

TABLE 3.2: Coordinates of bore holes

The sample of NESPAK borehole log book is shown in fig 3.4:



PROJECT MOHMAND DAM HYDROPOWER PROJECT
SITE DIVERSION TUNNEL PORTAL D/S
COORDINATES E 3068295.53 N 1125207.87
ANGLE (with vertical) 30° BEARING 230
GROUND ELEVATION 420 m
ROCK ELEVATION 420 m
GROUND WATER ELEVATION N/E
BACK FILLING MATERIAL -
INSTRUMENTATION TYPE -
DATE STARTED: 17-03-2013
COMPLETE: 10-06-2013
LOGGED BY: Mushtaq, Fahad Shehzad, Rashid, Affan
CHECKED BY: Zubair Khaliq Chattha
BOREHOLE LOG
BOREHOLE NO: MD 12 R-1
SHEET 01 OF 20

Depth (m)	Run No.	Core Recovery %	R.Q.D. %	Drilling Fluid Loss %	Core Barrel / Bit	Drilling Rate m/hr.	Hole Stabilization
0.5	1	20	NIL	15	DTCB with NQ size Diamond Bit	0.75	CASING OF Ø 105 mm
1.00	2	Core Washed		25		1	
1.50	3			24		0.7	
2.00	4			14		0.75	
3.00	5	73	10	16		0.9	
4.00	6	83	12	16		0.7	
4.50	7	19	NIL	16		1	
5.00	8	20	NIL	13		0.9	
6.00	9	22	NIL	10		1.3	
7.00	10	8	NIL	4.2		1.2	
8.00	11	23	NIL	42		1.2	
9.00	12	14	NIL	42		1.7	
10.00	13	Core Washed		57		1.5	

FIELD TESTS: SPT, Percolation Test, WPT (Pressure (bar), LU Value), Point Load; Elevation (m)

ROCK MASS — General Description
soil: Type Colour, Consistency, Structure, Origin
Rock: Colour, Grain Size, Texture and Fabric, State of Weathering, State of Alteration Name, Strength Fracture State

CHLORITIC CARBONACIOUS MICA SCHIST:-
0.0 - 26.0 m
Greenish Grey to grey Medium grained, Moderately to highly weathered, slightly weathered at places calcite veins present at places. Patches of Quartz present at places, Moderately to highly Fragmented. well Foliated, Foliated planes are stained, planner rough to undulating rough and stepped rough and stepped rough at places. Intercalation of lime stone at places.
Mainly Core Washed Portion the Following depth.
0.20 - 2.0 m
2.73 - 3.0 m
3.83 - 4.0 m
4.38 - 4.50 m
4.70 - 5.0 m
5.22 - 6.0 m
6.05 - 7.0 m
7.23 - 8.0 m
8.14 - 15.0 m
-- DO --

REMARKS
IF,CW 2.73 - 3.0 m
9 Nos of foliation from 3.06-3.83 m of angle 70° and with interval of 2-12 cm
CW 3.83 - 4.0 m
CW 4.09 - 4.50 m
IF+CW 4.0 - 15.0 m
7 Nos of foliation from 15-15.45 m with angle of 60° and interval of 2-10 cm
CW,IF 15.75 - 20 m

PROMINENT DISCONTINUITY DATA

Depth (m)	Type	Dip Angle	Aperture	Roughness	Infilling	Strength Grade	REMARKS
2.06	O	60°	2-3	U	2	R1-R2	
2.12	J	70°	2-3	SR	2	R1-R2	
2.18	O	60°	2-3	SR	2	R1-R2	
2.30	O	60°	2-3	UR	2	R1-R2	
2.41	O	60°	2-3	UR	2	R1-R2	
2.43	O	60°	2-3	UR	2	R1-R2	
2.46	J	50°	2-3	SR	2	R1-R2	
2.53	O	60°	2-3	SR	2	R1-R2	
2.60	O	60°	2-3	SR	2	R1-R2	
2.63	O	60°	2-3	SR	2	R1-R2	
2.68	O	60°	2-3	SR	2	R1-R2	
2.73	O	60°	2-3	SR	2	R1-R2	
3.06	O	70°	2-3	PR	2	R1-R2	
3.22	J	65°	2-3	UR	2	R1-R2	
4.01	O	70°	2-3	PR	2	R1-R2	
4.08	O	70°	2-3	PR	2	R1-R2	
4.50	O	75°	2-3	PR	2	R1-R2	
4.52	O	75°	2-3	PR	2	R1-R2	
4.58	J	55°	2-3	SR	2	R1-R2	
15.0	O	60°	2-3	PR	2	R1-R2	
15.35	J	70°	2-3	UR	2	R1-R2	
15.47	O	75°	2-3	UR	2	R1-R2	
15.55	J	80°	2-3	UR	2	R1-R2	
15.62	J	80°	2-3	UR	2	R1-R2	
15.69	O	65°	2-3	PR	2	R1-R2	
15.72	O	65°	2-3	PR	2	R1-R2	
20.0	O	60°	2-3	PR	2	R1-R2	
20.10	J	75°	2-3	SR	2	R1-R2	
20.12	O	70°	2-3	UR	2	R1-R2	
20.15	J	80°	2-3	UR	2	R1-R2	

* Use backside of this sheet for recording more data
* Dip angle & spacing corrections for angle holes to be applied during finalization

Key for Deoription of Discontinuities

IF = Intensely Fragmented CW = Core Wash

Type	
J	Joint
M	Major Joint
F	Fault
B	Bedding
R	Fracture
S	Shistocity
O	Foliation

Aperture		
1	Very Tight	< 0.10 mm
2	Tight	0.10-0.25 mm
3	Partly Open	0.25-0.50 mm
4	Open	0.50-2.50 mm

Roughness	STATE	CODE
STEPPED	Rough	SR
	Smooth	SSm
	Slickensided	SSI
UNDULATING	Rough	UR
	Smooth	USm
	Slickensided	USI
PLANAR	Rough	PR
	Smooth	PSm
	Slickensided	PSI

Infilling			
1	Clean	6	Hydro-Thermals
2	Surface Staining	7	Oxides
3	Loam	8	Breccia
4	Calcite	9	Sheared
5	Silty Gravel/ Gravely Silt	10	Aragonite
		11	Pyrite

Weathering of Rock Mass

Grade	Term
I	Fresh
II	Slightly Weathered
III	Moderately Weathered
IV	Highly Weathered
V	Very Highly Weathered
VI	Residual Soil

Strength of Grade Discontinuity Wall

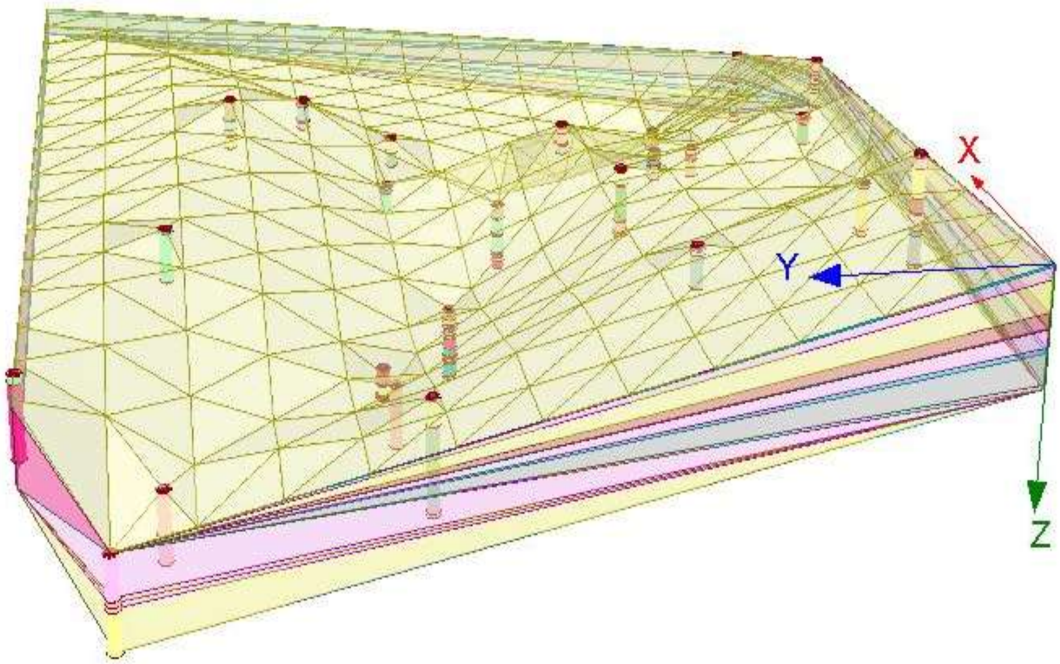
Grade	Description / MPa	Manual Index Test
R0	Extremely Weak / 0.25-1.0	Indented by Thumbnail
R1	Very Weak / 1.0-5.0	Peeled easily by Knife, Crumbled under hammer blow
R2	Weak / 5.0-25	Peeled difficulty by Knife, Indentation by firm hammer blows
R3	Medium Strong / 25-50	Cannot peeled by knife, fractured with single hammer blow
R4	Strong / 50 - 100	Requires more than one hammer blow fracture
R5	Very Strong / 100 - 250	Requires many hammer blows to fracture
R6	Extremely Strong / > 250	Specimen can only be chipped with hammer

Notes: 1. For Detailed Description of Discontinuity Parameters Refer to "ISRM Suggested Method for Quantitative Description of Discontinuities in Rock Masses"
2. In Case of Clay Filled Discontinuities, the Strength of Clay Seam should be Reported as per ISRM.
3. Depth wise Zones of Similar Discontinuity Characteristics should be recognized and reported in remarks column.

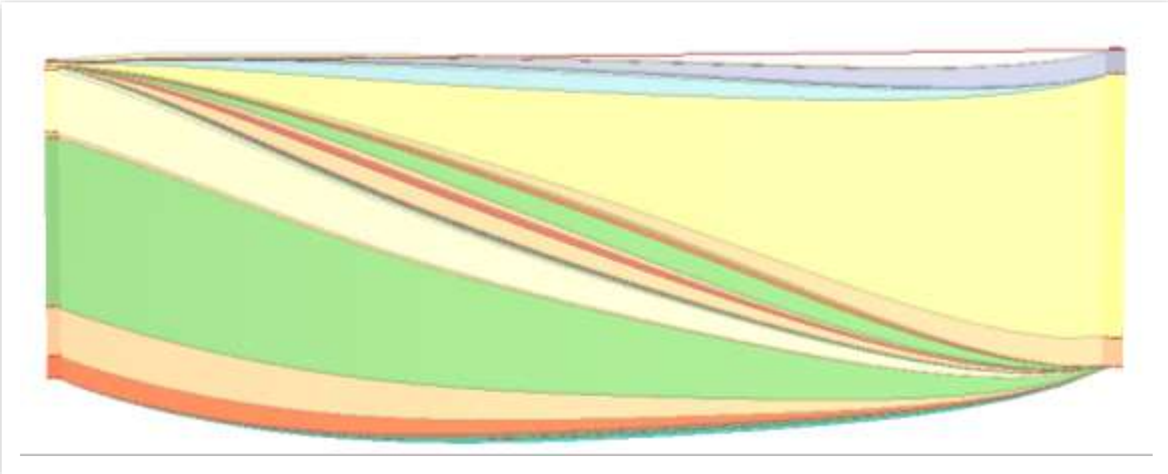
The **SETTLE 3D** is used of plotting stratigraphic map. 5 method techniques are used for plotting the stratigraphy, out of which we choose THIN SPLINE METHOD due to following reasons:

Methods	Utilize	Reason
Inverse Distance	✗	• poor shape properties • undue influence of points
Thin Plate Spline	✓	• infinite thin elastic plate under tension, to determine a spline surface
Chugh's Method	✗	• grid point does not exist in each of the four quadrants
Local Thin Plate Spline	✗	• recommended: data points >200
TIN triangulation	✗	• sample point lies outside the convex hull cannot be interpolated.

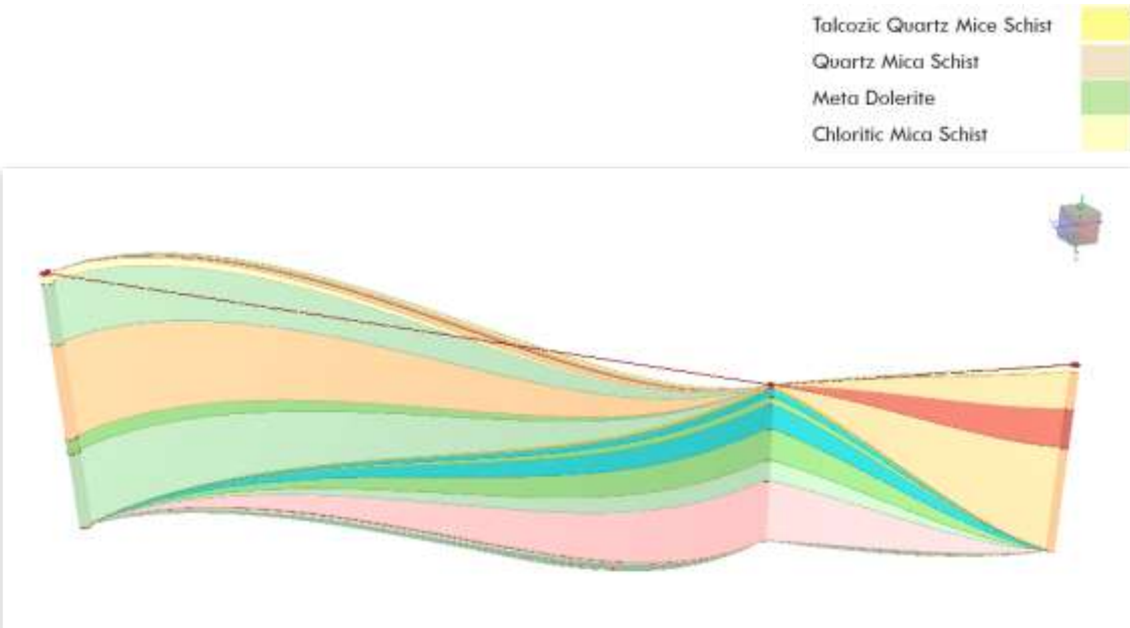
The result of stratigraphy map is shown below:



(a)



(b)



(c)

FIG 3.5: (a) 3D view stratigraphic map, (b) cross section of foundation stratigraphy, (c)) cross section of right abutment stratigraphy.

From the stratigraphic map, following information is deduce:

The bedrock is composed of crystalline schists of Permian Duma Formation that strikes at N30° to 70°W across the river nearly at right angle and dips more than 40' northeast or downstream. Strong Joints of one group are nearly parallel with the schistocity or the bedding plane, and those of the other group strike at IINIJ-WSW in the direction similar to the river course dipping either southeast or northwest. The schist was classified into several groups, that is, chlorite-mica schist, quartz-mica schist with talcosic bands, chlorite-mica schist with limestone bands and carbonaceous graphitic schist. Other than the schist, limestone beds of several meters to several tens of meters thickness are intercalated in the schist downstream and signs of local occurrence of docritic rock in the dam site are reported. Considering the complexity In mineral composition of the schist, a different approach of classification referring to their original rock type Is made as follows:

- coarse pelitic schist or psammitic schist
- fine politic schist
- calcareous pelitic schist
- green schist (coarse and fine)
- siliceous schist
- limestone or marble.

The classification of penile schist Is for the metamorphosed rock originating in muddy sedimentary rock, which includes a major part of the chlorite-mica schist In the Pre-feasibility Report. The green schist covers the dolerhic rock that is more or less metamorphosed and schistose, and schists that are formed by aketation of tuff or other rocks of volcanic origin. The siliceous schist, composed largely of quartz; is nearly correlative with the quartz-mica schist Bedrocks are considerably distorted and disturbed, with bedding planes generally striking north to south but with many and varied local deviations. Folding and fracturing of diverse sizes arc common as Indicated by the frequent and irregular changes in strike and dip of strata. The tectonic movement is reflected also In development of Mesozoic mélange zones, a mixture of volcanic rocks, ultrabasic rocks and other oceanic sediments.

The dam will found mainly on the hard siliceous to psammitic schist on the left bank and the green schist on the right bank. Spillway weir and chute will be put on the siliceous schist and the green schist. The plunge pool will be situated in the calcareous politic schist.

At any classification, the bedrocks in fresh and intact condition are hard or moderately hard. On outcrops, the rock appears more or less weaker on the surface, weathered and slacked by open Joints and foliation planes. In the meantime, the weathering does not appear so deeply developed, and sometimes ineffective at the depth of 5m.

3.3: Hydrological Data:

The Mohmmad Dam is located on the Swat River, which is a main branch of the Kabul River at approximately having coordinates of 34° 21' N and 71° 32' E. The total catchment area of the Mohmmad dam is 13,650 km² and can be divided among three major sub basins of upper and lower Swat (6,579 km², Panjkora (5,724 km²) and Ambahar (1,347 km²). The basin lies between latitude of 34°20' N to 35°96' N and longitude of 71° 20' B to 72'50' E with length of 137 km and 110 km in width. From a confluence of Cabral and Ushu at Kalam the Swat River originates with an average elevation of 4,500 m. Munda headworks is located the proposed dam site and the Swat River joins the Kabul River at about 35 km further downstream of Munda headworks. The hydrological map is shown in fig:

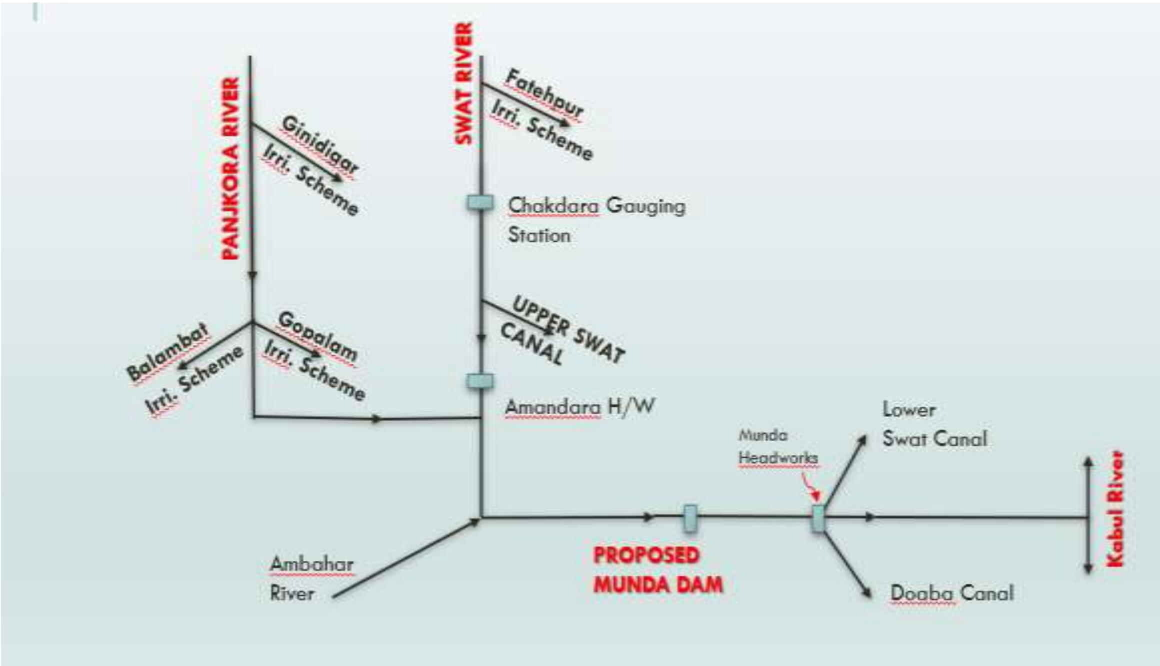


FIG 3.5: hydrological map of Mohmmad Dam

The upper basin of reservoir is relatively cold where freezing winter prevail from mid-November to end of march while the lower basin has prolong summers and winter are less cold. In summer rainfall is due to monsoons which leads to sufficient runoff and causes floods. The rainfall data (mm), discharge flood data (m^3/s), is obtain from Pakistan Metrological Department (PMD).

The rainfall data consist of 4 stations: kalam, Charbagh, Saidu Sharif, Kulang ranging from 1962-1997. The discharge flood data consist of 3 station: Chakdara, Nowshera and Kalam ranging from 1961-1990. The yearly instantons, maximum minimum discharge value of each station is tabulated. The daily an monthly discharge peak of existing

Munda headworks is given below in table 3.3 and trend is shown in fig. 3.6.

MUNDA HEADWORKS		
Year	**Discharge(daily peak)**	**Discharge(montly peak)**
1960	1328.7	22538.9
1961	1215	15359.4
1962	2433.8	14232.5
1964	745.3	19362.3
1966	1260.8	17802.6
1967	1316	20503.4
1968	769.1	18802.9
1969	1389.2	20061.6
1970	456.8	9302.7
1971	718.8	91121.1
1972	1149	20115.7
1973	781.1	19704
1974	1117.9	11097.9
1975	2204.6	16695.7
1976	1152.3	18371.11
1977	1807.3	27512
1978	1236.3	21006.7
1979	1034.3	221195.5
1980	800.9	19096.7
1981	657.1	18784
1982	657	17293
1983	657	18427.2
1985	1229	21427.4
1986	2157.9	24571.2
1988	1534.5	23067.4
1989	931.6	16614.7
1990	2524.2	21053.9
1991	1468.1	28087.8
1992	1231.6	27989.7
1993	1211.5	19808.1
1994	1339.3	26958.5
1995	2349.3	25948.3
1996	840.9	22696.5
1997	1211.5	20049.7
1998	1287.1	21567.2

TABLE 3.3: Daily and Monthly discharge peak of Munda headworks

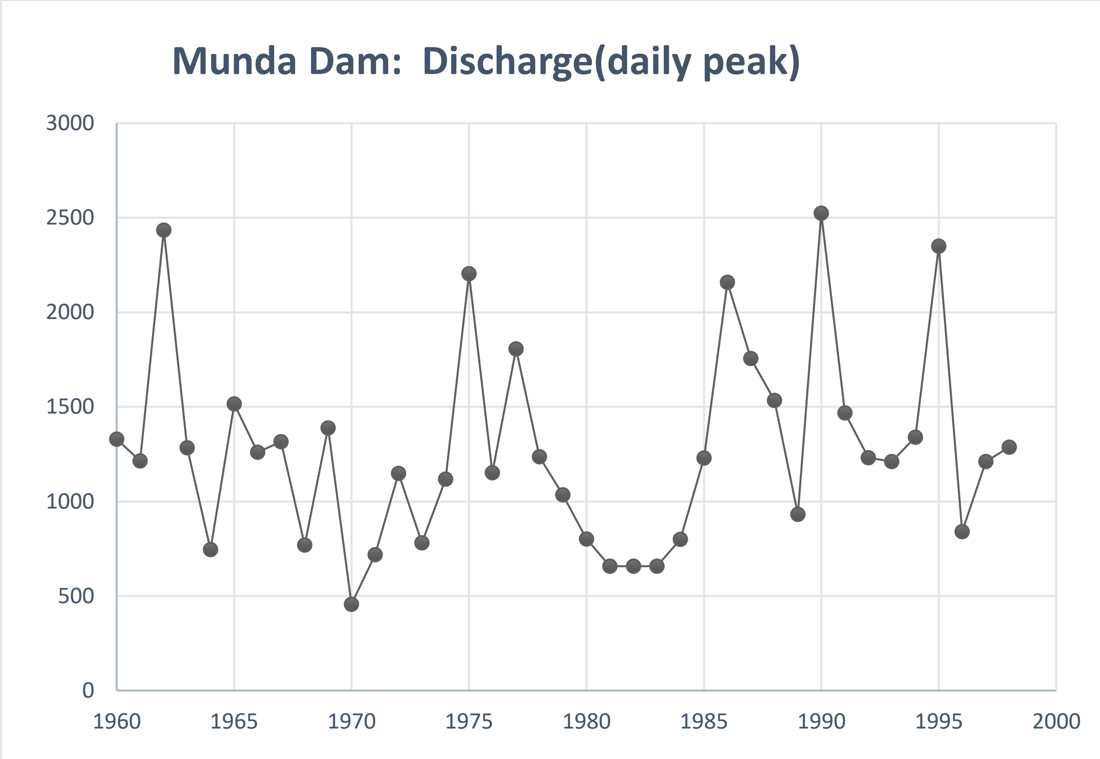


FIG 3.6: Graph of daily discharge of Munda dam

As the graph clearly suggests that after every 4-5 year, theirs is sudden increase in discharge, which leads to floods which enlighten the importance of dam in that particular area.

3.4: Design and Sectioning:

The dam design and sectioning is categorized into following steps:

3.1.4.1: Height

3.1.4.2: Freeboard

3.1.4.3: Zoning

3.1.4.4: Plinth

3.1.4.5: Concrete Slab

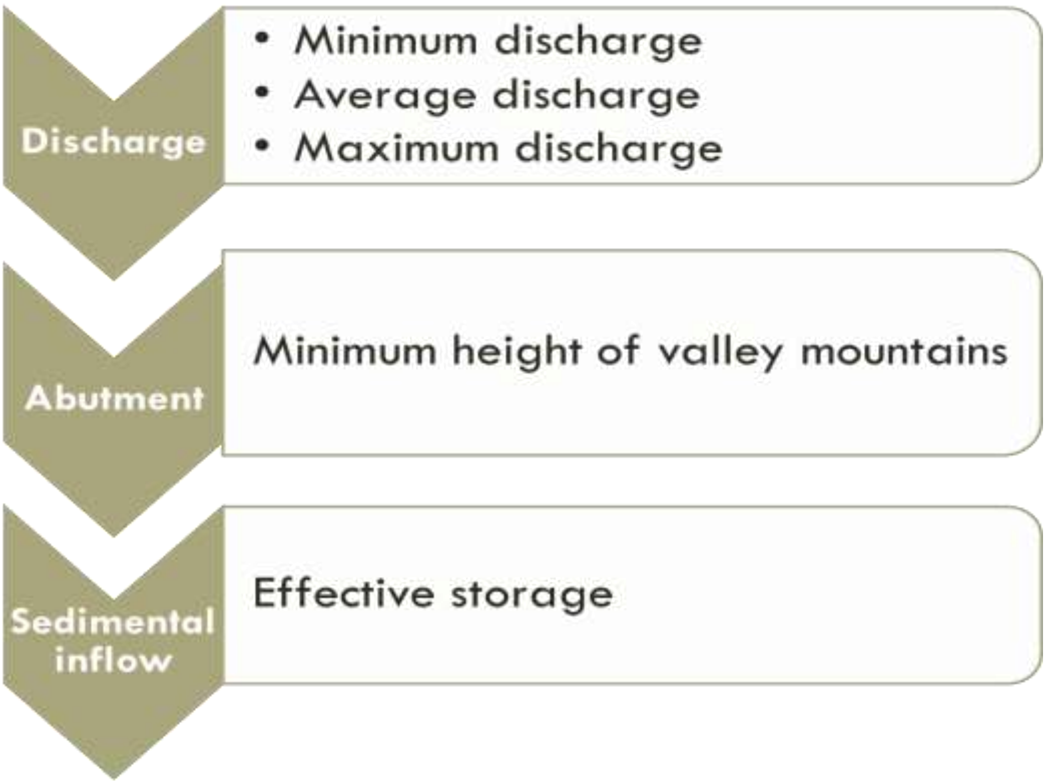
3.1.4.6: Cutoff

3.1.4.7: Filter Gradation

3.4.1 Height:

The ideal advancement scale is by and large the one which produces most extreme net advantage with the financial point of view. The estimation include general benefits of power generation , irrigation and flood .secondly the model scale is Assist through location geography and geography, and sedimentation kept at the upstream of the supply. The conceivable most extreme supply full supply level (ESL) was decided to be EL. 580 m from natural viewpoints, which does not cause wide submergence of the settled zone within the upstream of the supply range as well as topographic restrain at the Munda Dam location where a saddle darn may be required for the higher heights. Sediment level within the dam was expected for each advancement scale elective based on 100 year sediment scale.

General procedure is given in figure below:



3.4.1.1: Discharge:

- The maximum, average and minimum discharge is calculated i in Hydrology chapter which taken account of discharge rating data of following station:

- Chakdara,
- Nowshera,
- Kalam.

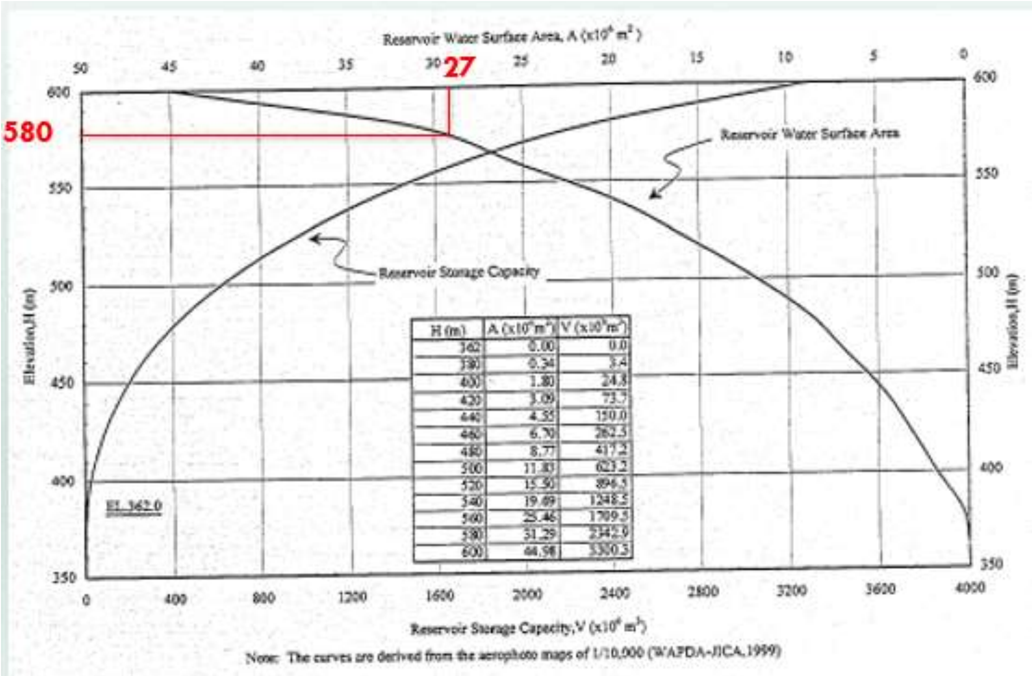
The Munda dam discharge of **25 years is (1985-2010) is given as:**

- ❑ Min discharge: 44 cumec
- ❑ Average discharge: 202 cumec
- ❑ Maximum discharge: 623 cumsec

Height ranges from 150 to 250m.

3.4.1.2: Abutment:

The rating curve of dam site is given by prefeasibility report of Mohmmad dam by JICA , as shown below:



The maximum height obtain from topographic map from the section was 580m which leads to revisor area of 27 million cubic meter. So maximum dam height if limited to 220m.

3.4.1.3: Sediment Accumulations:

The sediment accumulation play important role in development of dam scale. As dam design life is more than 100 years and is backbone of country economy to full fill irrigation and electricity needs. So height of dam should be large enough to overcome the sediment accumulation without compromising the dam reservoir capacity and work effectively.

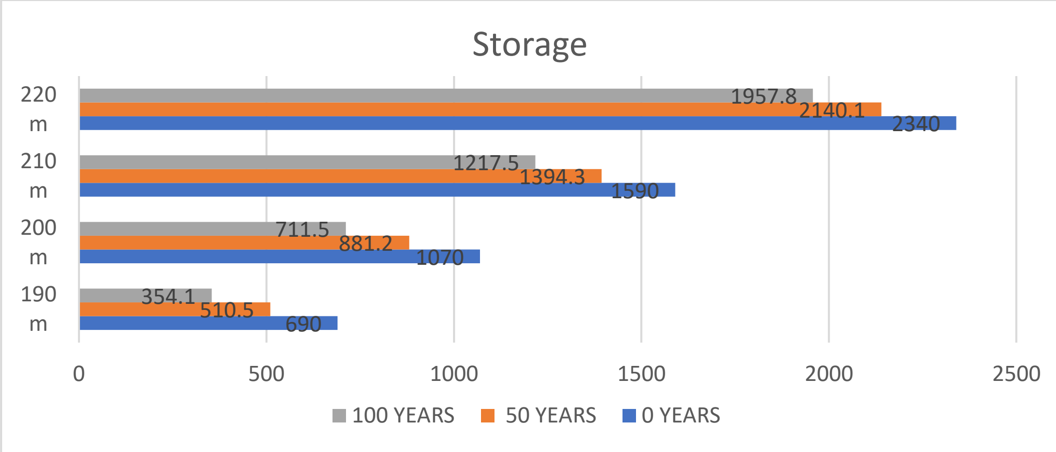
For the calculation of sediment accumulation is consider as 100 year. The calculation of dam height of 190m is given as:

Dam Height	190m
RESERVOIR	690 million m^3
Trap efficiency	76.52%
100 year suspended load	420.45 million ton
100 year Bed Load	80.5 million ton
Unit weight suspended (ton/m3)	0.982
Unit weight suspended (ton/m3)	1.76
100 year sediment	365.79 million
Sediment trapped m^3	32.41
Effective sediment deposit m^3	335.8

Similarly for every dam height sediment is calculated. Then reservoir capacity of dam after 50 and 100 year is calculated and analyse the loss of reservoir which is shown in table below:

Years	190m	200 m	210m	220m
50	179.2 Mm^3	188.8 Mm^3	195.7Mm^3	199.9Mm^3
100	335.1Mm^3	358. Mm^3	372.4Mm^3	382.2Mm^3
% STORAGE LOSS	**49%**	**33%**	**21%**	**17%**

The tabular data shown in histogram .



190m dam height is not feasible as it lost half of dam capacity. 210m dam is most feasible one.

3.4.2: Freeboard:

The vertical distance between the top of the **dam** and the full supply level on the reservoir.' The top of the **dam** is the level of watertightness of the structure and may be the top of a parapet that is watertight throughout its length.

The freeboard consist of wave height, wind run up, wave set up and camber, the calculation of free board is shown in figure below:

3.4.3 Zoning

Zones of Mohmand Dam are divided as such:

Zone 1A:

The zone 1A is basically impervious earthfill material provided over the plinth. It is used as concrete face protection and spans over the upstream side of dam. It also functions as a joint/crack healer.

Zone 1B:

The material provided in zone 1B is random fill that Is placed over the plinth. It is provided on top of zone 1A and provide support for it. One main function of this zone is to resist uplift in the face slab.

Zone 2A:

Zone 2A functions as a fine filter material placed just below the plinth and it limits leakage entry into the dam body.

Zone 2B:

The material of zone 2B is crusher run. It acts as a transition zone where the upper side is plinth covering and below it is the hard rock material. It acts as cushion and provides stability.

Zone 3A:

For the zone 3A, small rock material is provided. Its main purpose is to limit the void size and increases the compatibility with the rocky zones.

Zone 3B:

The material provided in Zone 3B is limestone which is in abundance near the site area. It draws seepage downstream of the downstream zone. It also limits face deflections and water loading.

Zone 3C:

Zone 3C is made of rockfill material mainly quartzite and siliceous schist. It is a non-free draining zone and has less permeability. It is also the major load bearing component of dam body.

Zone 3D:

The material of zone 3D is undesirable excavated rock from the foundations. Zone 3C provides the shield to it. It also limits and controls seepage.

Zone 3E:

It is a small covering made of selected large rock provided on the d/s side of dam. It helps in preventing downstream scouring and as well any tailwater wave action.

The zones data and function is summarized in the following table:

The upstream zones are categized as:

ZONE	DESCRIPTION
ZONE 1A	➢ Impervious Earth fill over plinth ➢ Concrete face protection ➢ Joint/ Crack healer
ZONE 1B	➢ Random fill over Plinth ➢ Supports zone 1A ➢ Resist uplift of face slab
ZONE 2A	➢ Fine Filter ➢ Limits leakage
ZONE 2B	➢ Crusher run ➢ Transition zone ➢ Acts as cushion
Z0NE 3A	➢ Selected small rock ➢ Limit Void Size & Compatibility

The downstream zones are categized as:

ZONE 3B	➢ Rockfill limestone ➢ Bottom of downstream zone, draw seepage downstream ➢ Resist water loading and limit face deflection
ZONE 3C	➢ Rockfill, Quartzite and Siliceous Schist ➢ Non free Draining Zone ➢ Major Load Bearing Component

ZONE 3D	- Rockfill, Excavated rock - Protected by 3C and controls seepage - Undesirable material
ZONE 3E	- Selected large rocks - Protects downstream face scouring and tailwater wave action.

Other Design Considerations:

3.4.4 Plinth:

Plinth width is calculated with following reference:

PLINTH WIDTH= 1/20 TO 1/25 of H (ICOLD)

Where H= Height of Dam

3.4.5. Concrete Slab:

Thickness of slab provided over the u/s is calculated by the formula:

$$T=1+0.003H \text{ (ft) (ICOLD)}$$

$$T=0.3+0.003H \text{ (m)}$$

Where H=Height of Dam

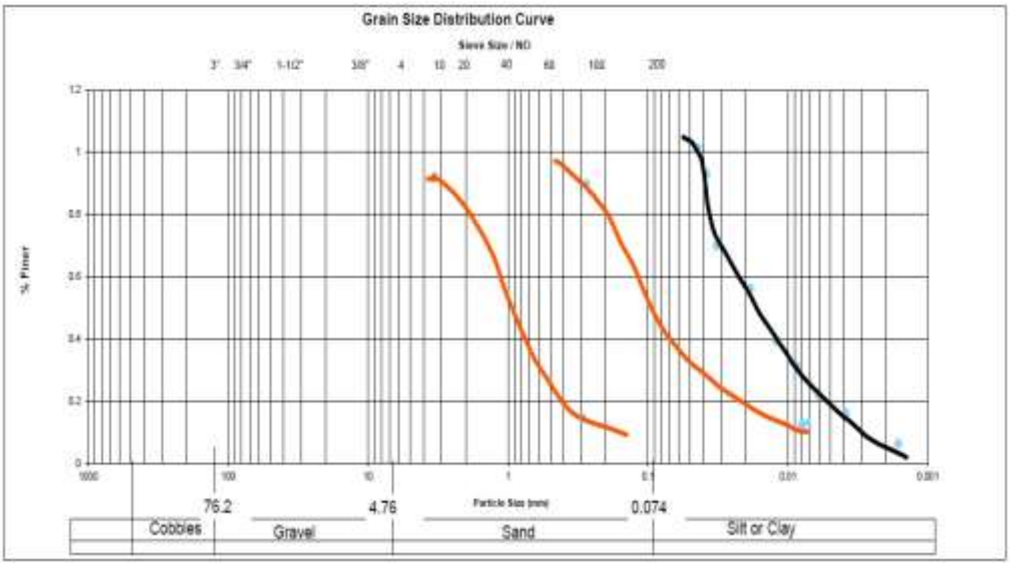
Also T=1m at base and at top T=0.6m is provided on average conditions.

3.4.6 Cutoff:

According a recent ASCE paper “Seepage and Boiling around a Sheet Pile under Different Experimental Configuration” by Mehdi Yousef et. Al, max cutoff efficiency is d=0.44H after which it become non-cost effective. Also the paper highlight that vertical cutoff is to be provided unless site constraints demand inclined cutoffs.

3.4.7 Filter Gradation:

The particle gradation is done according to SHERARD and USCS and given in the following graph:


Grain Size Distribution Curve
Sieve Size / NO
3" 3/4" 1-1/2" 3/8" 4 10 20 40 60 100 200
% Finer
1.2
1
0.8
0.6
0.4
0.2
0
1000
100
10
1
0.1
0.01
0.001
Particle Size (mm)
76.2
4.76
0.074
Cobbles
Gravel
Sand
Silt or Clay

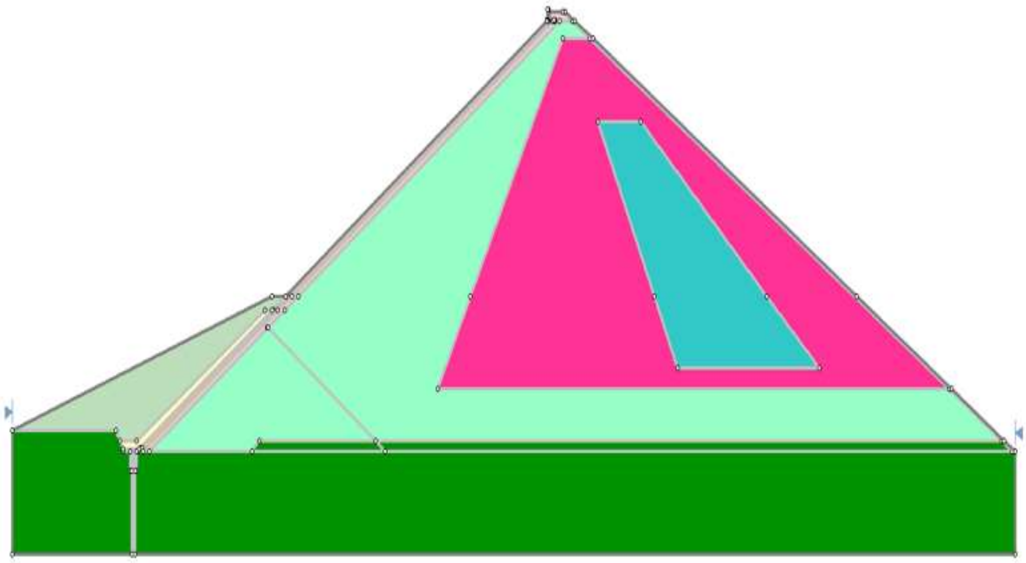
CHAPTER 4: ANALYSES

4.1: Slide analysis:

Slide 2d is used for analysis of slope stability, seepage (through dam or embankment body) and pseudo static analysis of embankment. It is used for all types of soil and rock. It uses limit equilibrium methods like Bishop, Spencer, Janbu, Ordinary Method of Slices, U.S Engineering Corps and Morgenstern and Price. It incorporates different types of failure surfaces e.g. circular, noncircular and composite. For analysis of failure surfaces it considers vertical or inclined slip surfaces methods. For FEA seepage analysis both steady state analysis and transient can be performed.

4.1.1: Slide model:

Slide model for our proposed dam is following.



Different models varying in height, internal zones and slopes were considered for analysis. This model has height 212 m with U/S 1:1.4 and D/S 1:1.5.

Analysis performed in slide:

In this project slide was used for following analysis

- Slope stability
- Seepage analysis (through dam body and foundation)
- Drawdown analysis
- Pseudo static analysis of dam embankment
- Cut off placement and efficiency analysis

4.1.1.1: Loading conditions:

In this project 4 loading conditions were considered.:

- CASE1:

At end of construction i.e. at minimum reservoir level. In this case no water loading was considered.

- CASE2:

Full reservoir level with concrete facing intact. Main function of concrete facing is to prevent seepage through dam body. When concrete facing is completely intact and free of major cracks it is considered safest case.

- CASE3:

Full reservoir level with cracks in concrete facing. This is nightmare for concrete faced rockfill dams. When cracks appear in concrete facing seepage cannot be prevented anymore. Good construction practices and proper gradation of materials for internal zones can come to minimize damages when this case arises.

- CASE4:

Drawdown analysis. This is further divided into 2 scenarios.

  - With intact concrete facing.
  - With cracks in concrete facing.

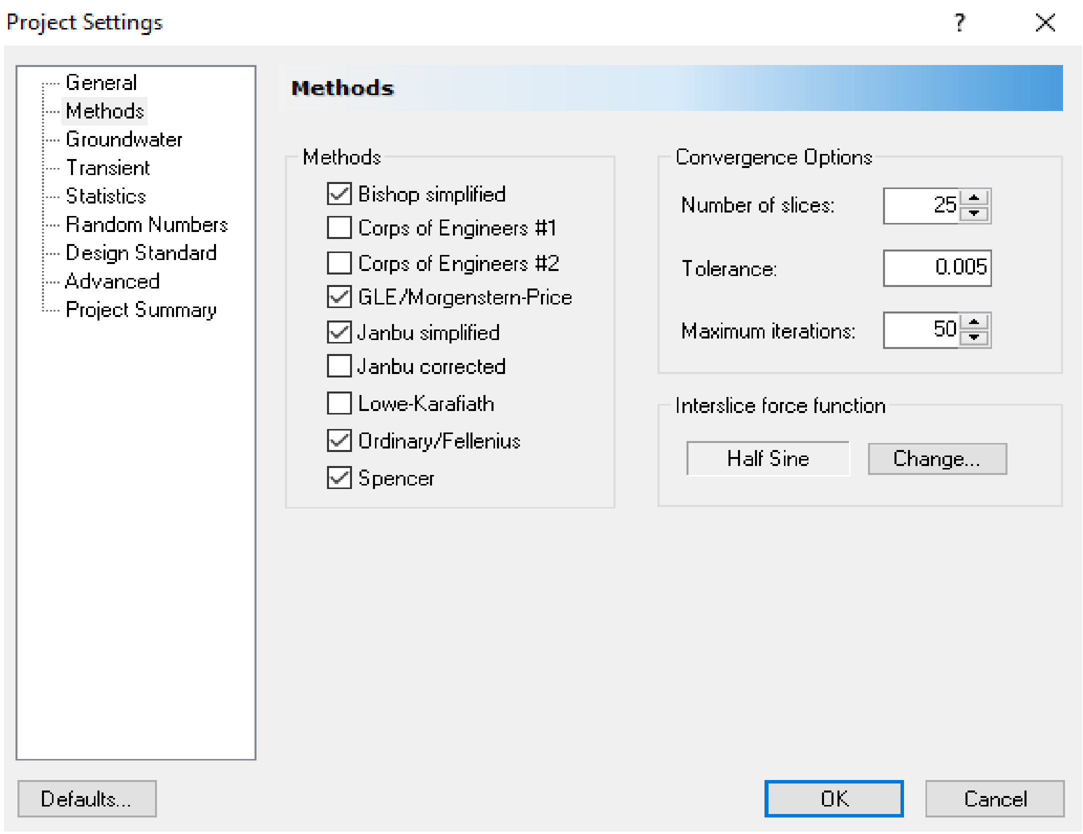
4.1.1.2. Procedure:

Following is general pattern of procedure that was performed.

1. Development of model.

   Model is constructed by using command of “ADD EXTERNAL BOUNDARY and ADD MATERIAL BOUNDARY”. Model has been already shown in “slide model” tab.

2. Project settings:
3. In this step select type of analysis, methods ground water conditions and project details.

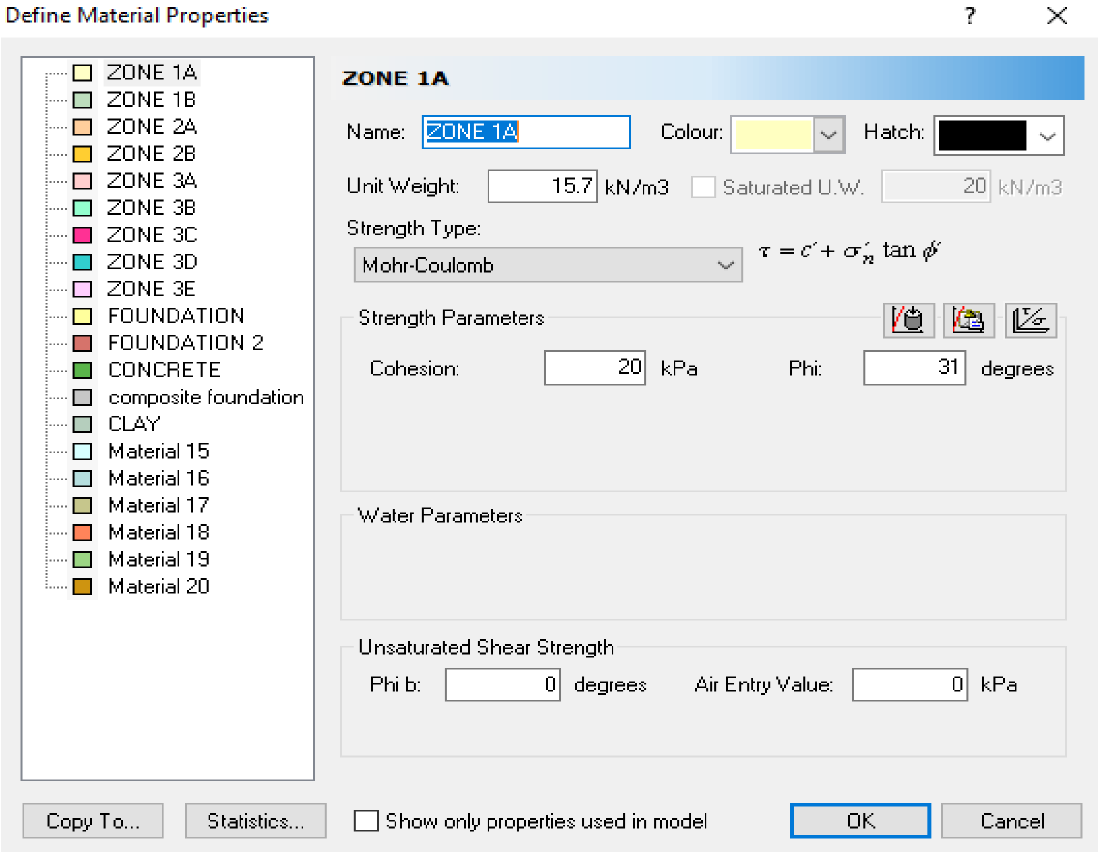


4. Material properties:

From tab "properties" introduce material properties i.e. material models, respective parameters, names, colours etc. we have used 3 models.

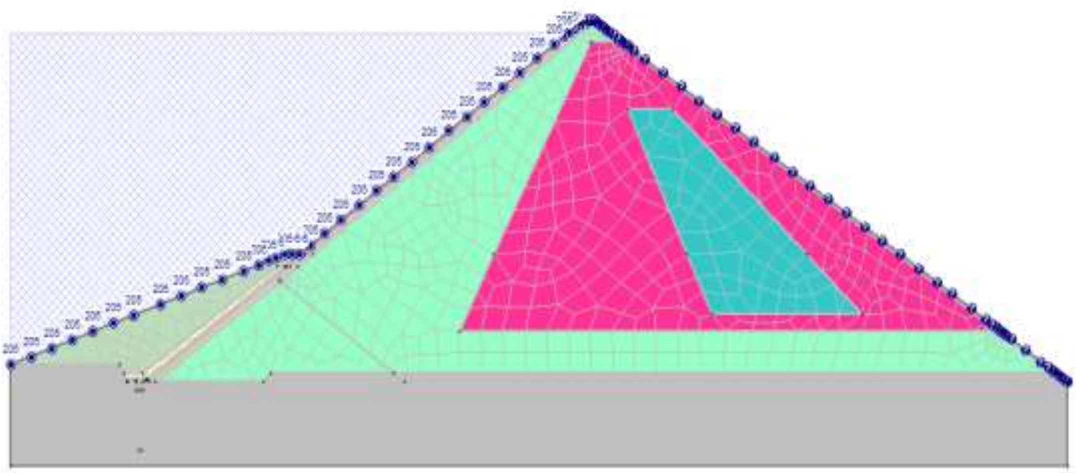
I. Mohr-Coulomb model (for soils)
II. Generalized Hoek-Brown (for rocks)
III. Generalized Anisotropic (for foundation)

For Mohr-coulomb values of parameters like cohesion, unit weight, angle of internal friction were input. For Hoek-Brown parameters like Geological Strength index(GSI), intact unconfined compressive strength, intact rock mass constant and disturbance factor were used. For foundations we have used generalized anisotropic because two major types of rocks were present there. In first step two materials were defined using Hoek-Brown model and composite material with ratio of 30:70 was formed using generalized anisotropic model.



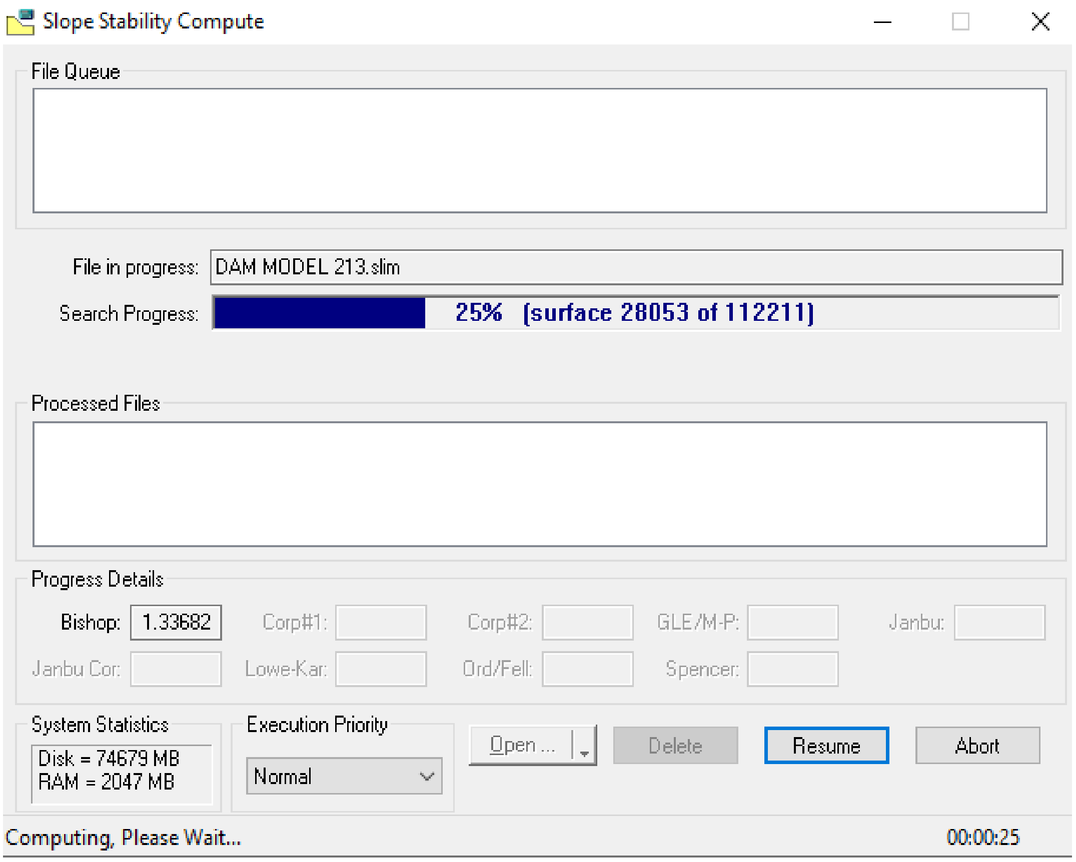
5. Discretise and Mesh:

For mesh setup 1500 approximate number of elements and 4-Nodded Quadrilaterals were selected. Following is mesh and discretise model.



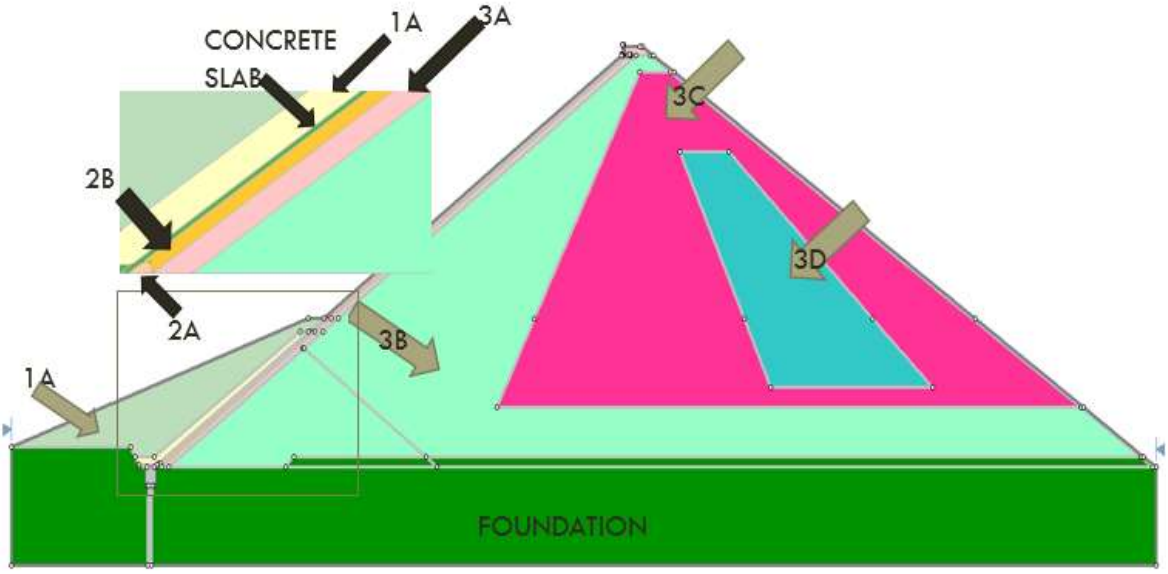
6. Computation and interpretation.

After incorporating all required inputs go to analysis tab and select compute option. This will start the background calculations. After computation select interpret. This will show the results. Below is screen short of computation.



4.1.1.3: Zone's details/properties:

Different types of materials were used in dam embankment. Each zone has different material. Silt, Sand, Gravel and large rocks were used. Different material model were used to define each material. Following figure shows different zones of dam body.



For soils like silt and sand Mohr-Coulomb model was used. Following parameters were used

Zone	Material Type	Unit Weight (kN/m^3)	Cohesion kPa	Angle of Internal Friction (deg)	Permeability m/s
1A	Silt	15.70	20	31	2.39e-6
1B	Sand	18.80	24	29	3.43e-5
2A	Fine Sand	18.80	19	30	2e-5
2B	Crusher run+sand	21.20	0	36	1e-4
Facing	Concrete	23.56	200	54	1e-20

Rocks were used in zones 3A, 3B, 3C, 3D and 3E. Generalized Hoek-Brown model was used to define rocks in slide. Following are the parameters used in rocks.

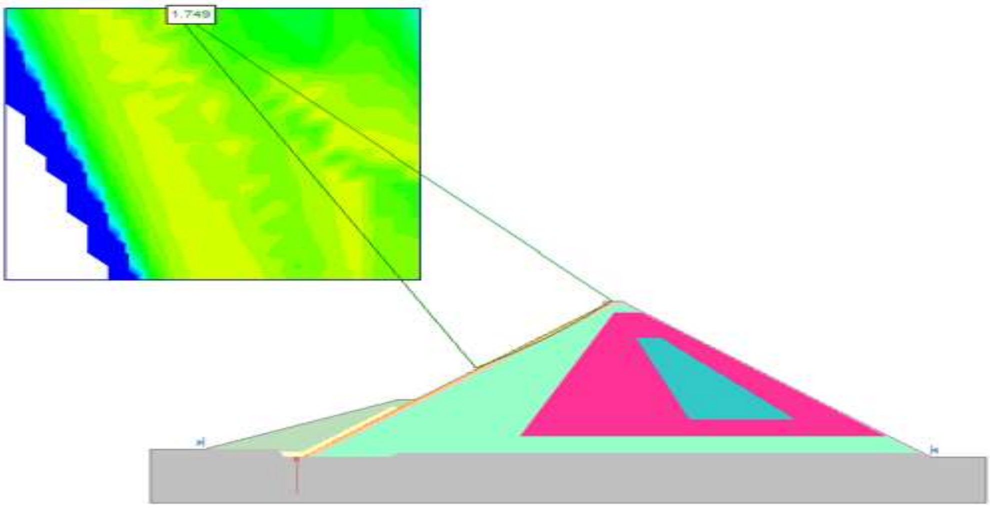
Zone	Material	USC(intact) MPa	GSI	Rock Mass Constant(mi)	Disturbance Factor
Zone 3A	Small Rocks	12	24	10	0.6
Zone 3B	Limestone	35	43	12	0.55
Zone 3C	Shale	90	62	12	0.43
Zone 3D	Excavated Rocks	12	32	10	0.7
Zone 3E	Large Rocks(shale)	70	53	10	0.5

4.1.2: Result and Discussion:

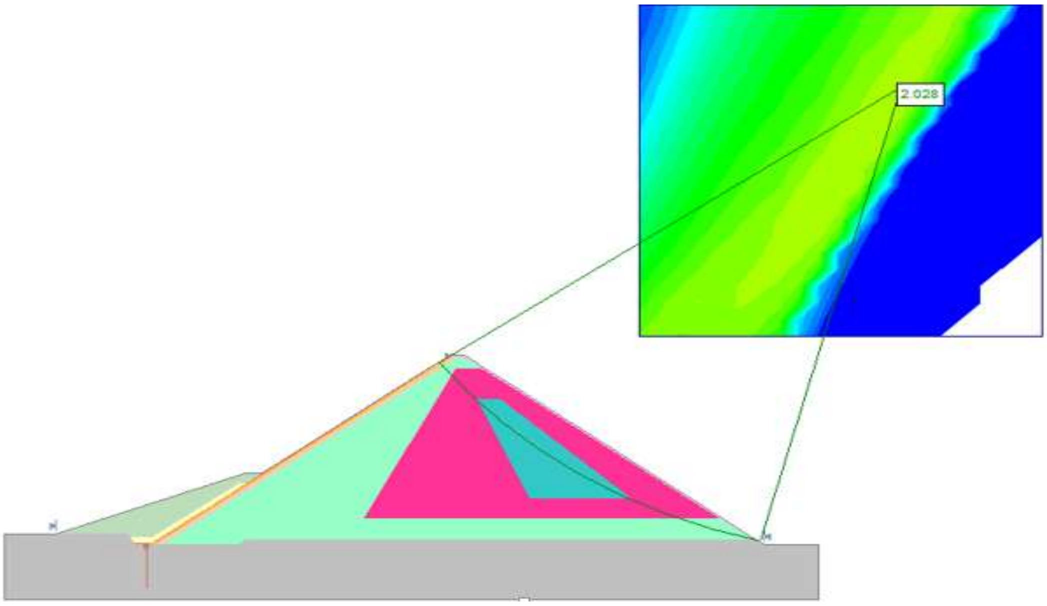
4.1.2.1: Slope stability analysis:

Slope stability analysis was performed on both upstream and downstream side of embankment. Seven models were designed in slide for analysis. These models differ in height, dimensions of internal zones, U/S and D/S slopes of dam body. In first step first three cases were checked. Models that passed first step were further studied for drawdown and cut off analysis. Following are some results slope stability for dam height 190m and 212m.

- Case 1:

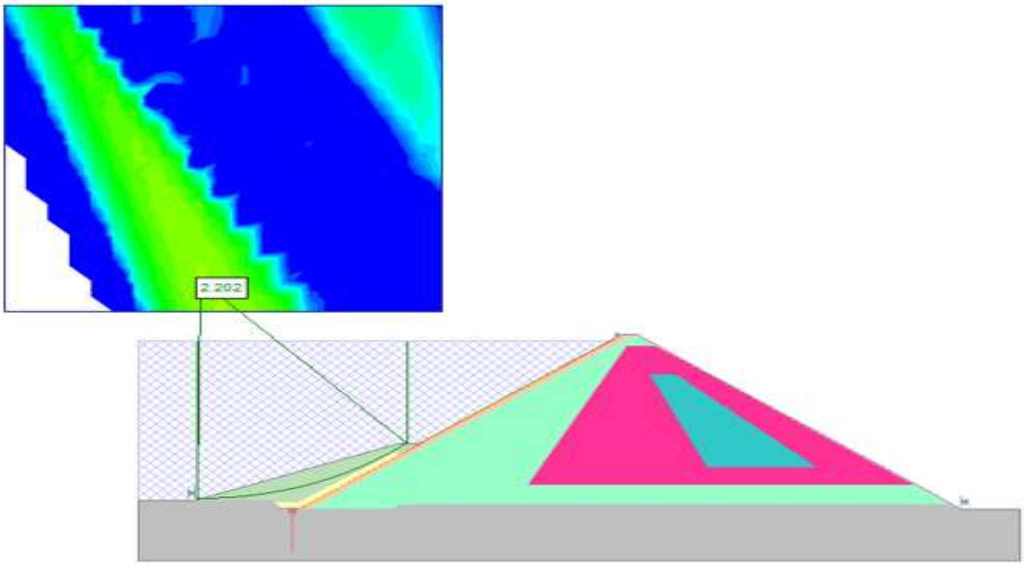


U/S Dam height 190m

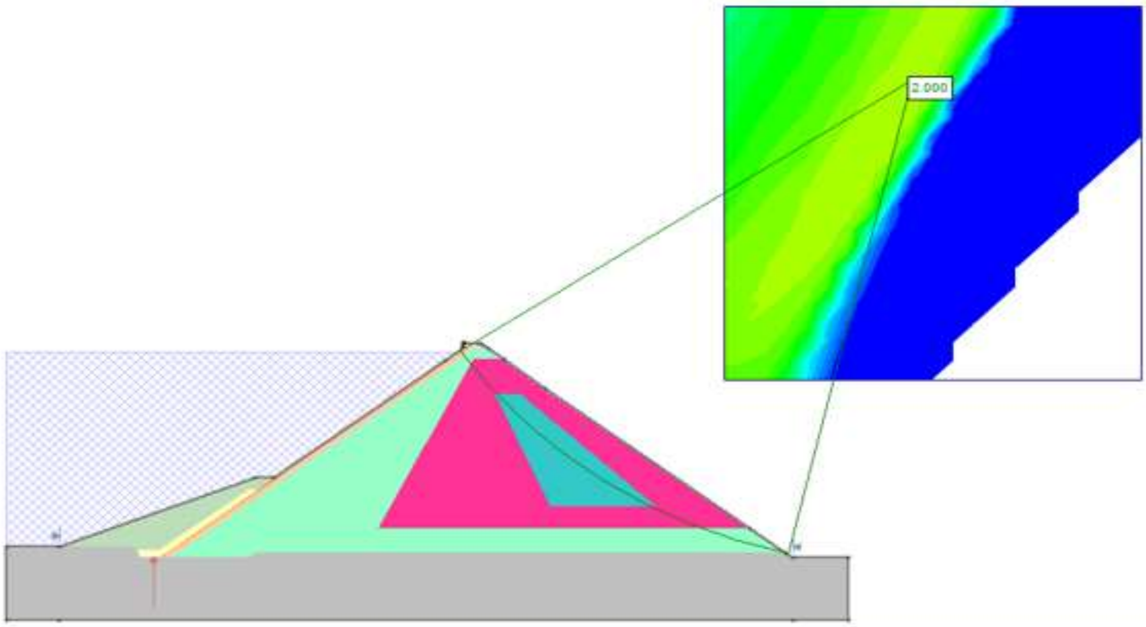


D/S Dam height 190m

- Case 2:

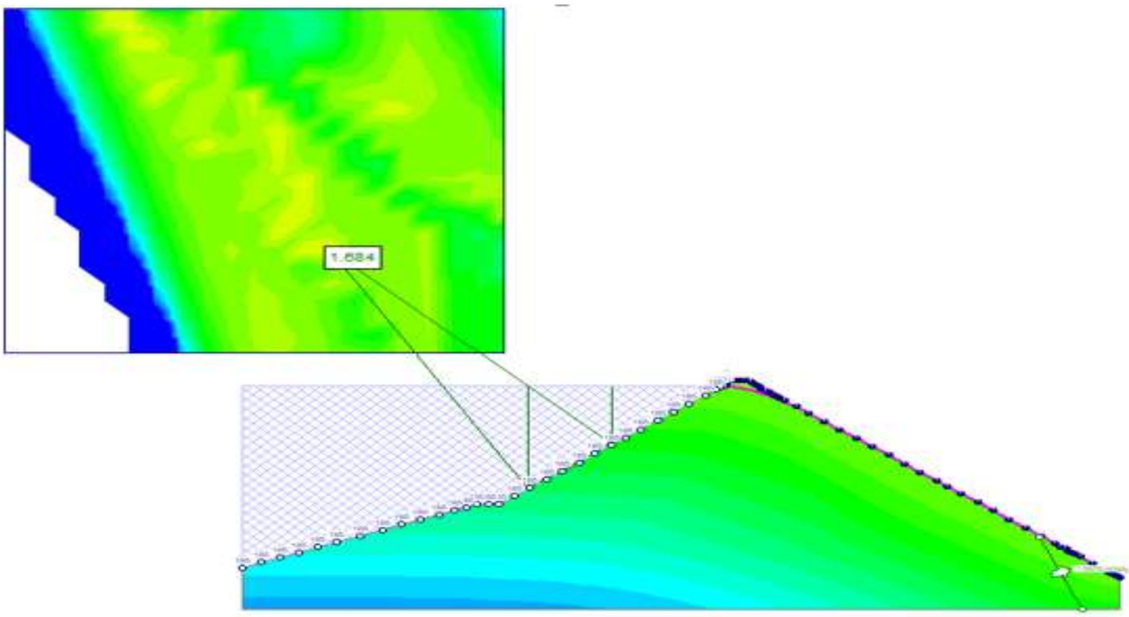


U/S dam height 190m



D/S dam height 190m

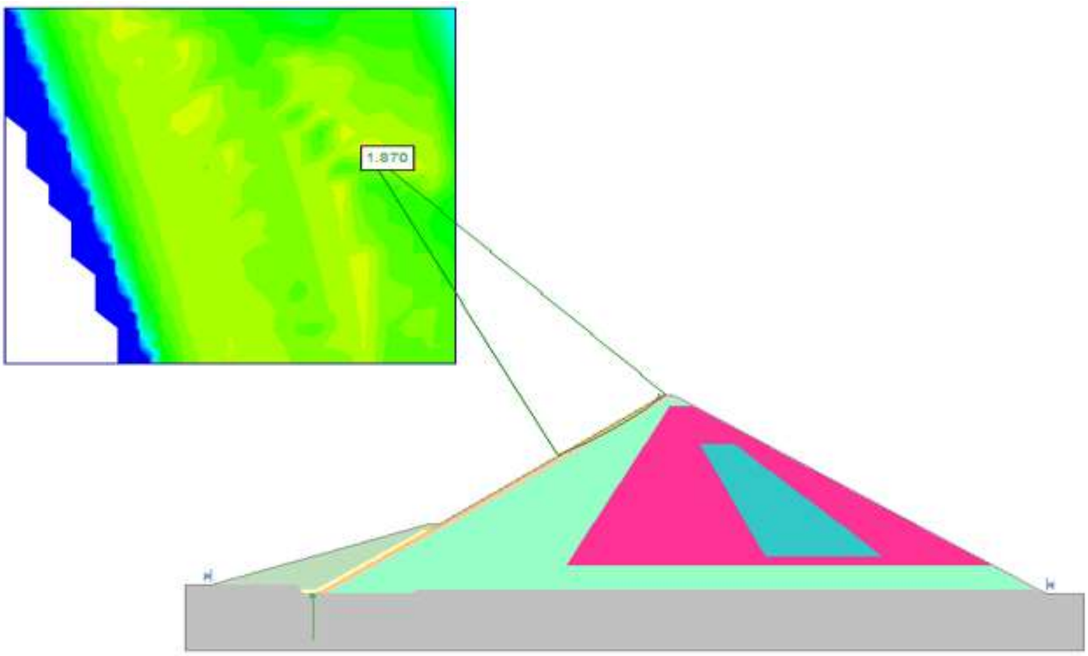
- Case 3:



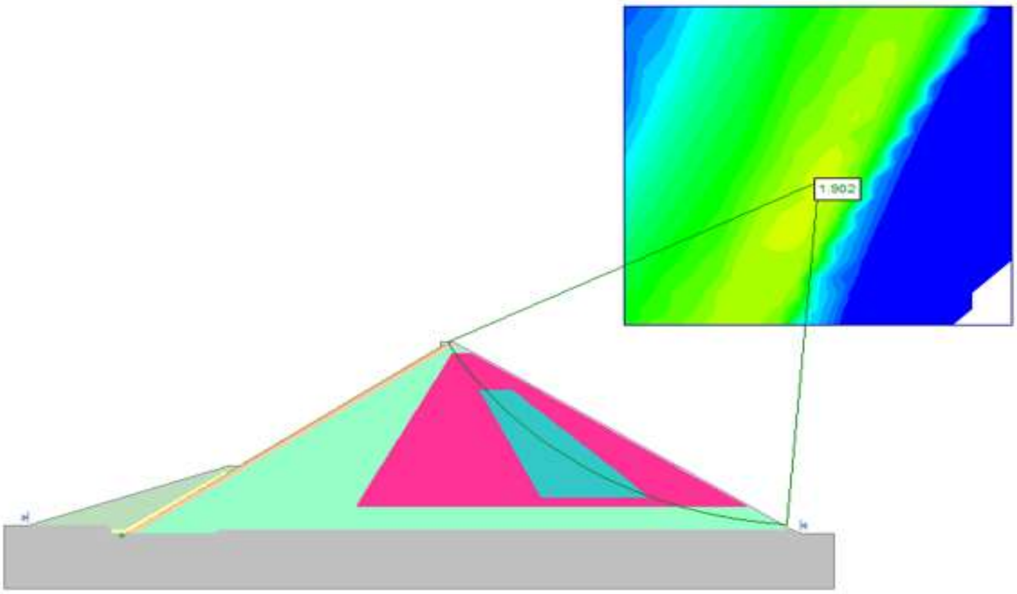
Dam height 190m

Similarly for dam with height 212.

- Case 1

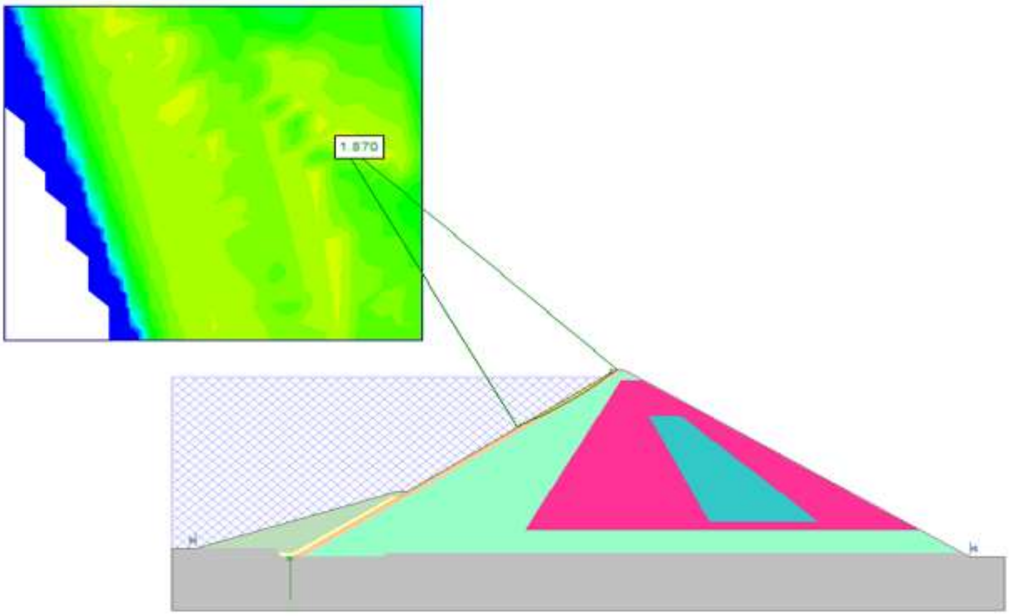


U/S dam height 212

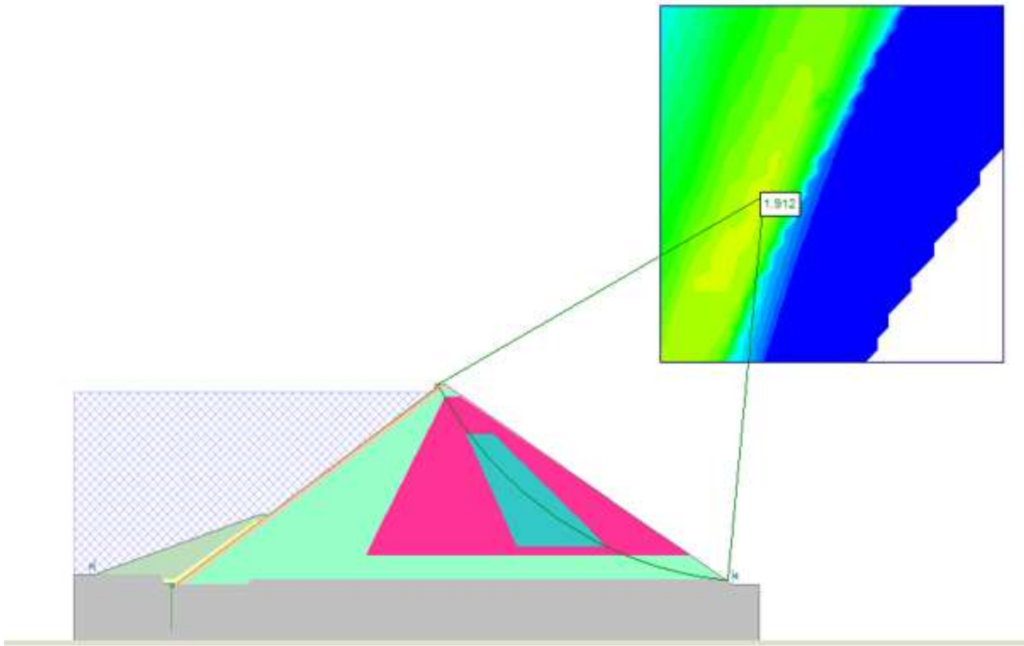


D/S dam height 212m

- Case 2

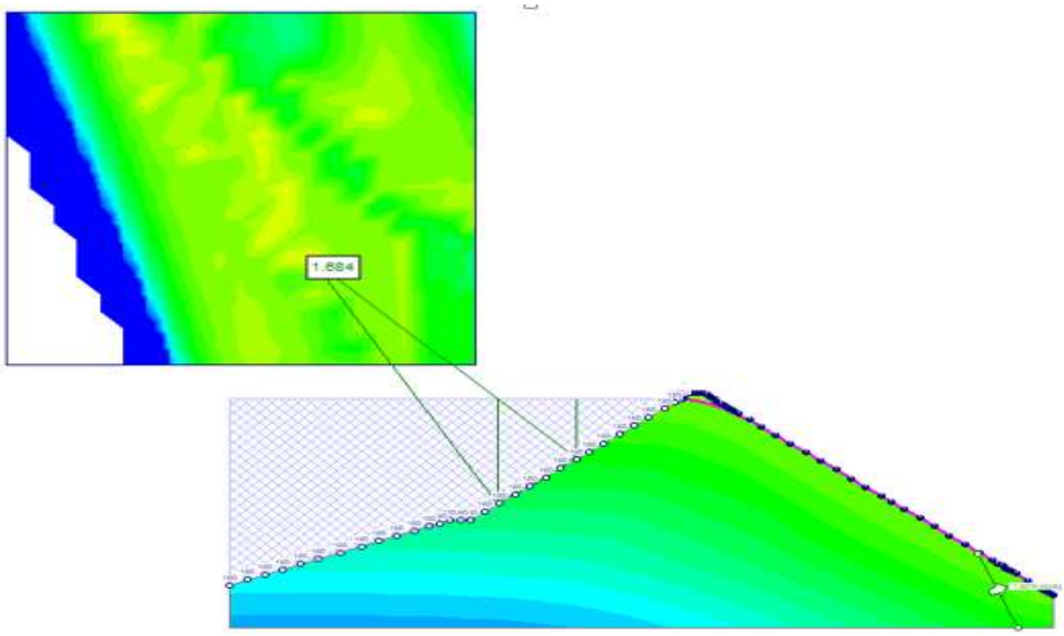


U/S dam height 212m



D/S dam height 212m

- Case 3



Dam height 212m

Similarly slope stability analysis was performed on other models as well. Following is the summary of factor of safety for all models.

Model	CASE 1		CASE 2		CASE 3		REMARKS
	F.S US	**F.S DS**	**F.S US**	**F.S DS**	**F.S US**	**F.S DS**	
190m	**1.79**	**2.03**	**2.02**	**2**	**1.68**	**2**	**OK**
200m	**1.78**	**1.91**	**2.06**	**1.79**	**1.85**	**1.57**	**OK**
213m	**1.87**	**1.92**	**1.87**	**1.91**	**1.97**	**1.43**	**OK**
213m 1.3	**1.67**	**1.51**	**2.18**	**1.03**	**1.75**	**0.92**	**NOT OKAY**
213m DIZ	**1.19**	**1.39**	**2.26**	**1.33**	**1.47**	**0.99**	**NOT OKAY**
213m DIZ-2	**1.87**	**0.99**	**2.1**	**1**	**1.53**	**0.89**	**NOT OKAY**
220m	**1.89**	**1.95**	**2.23**	**2.07**	**1.4**	**1.52**	**OK**

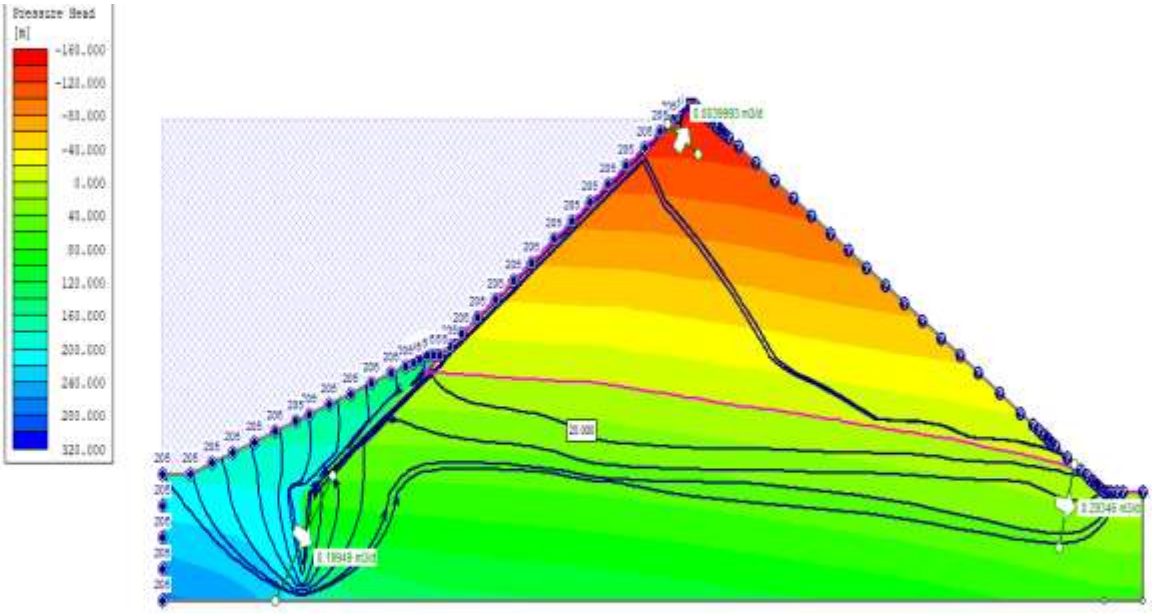
Model number 4, 5, 6 failed the first three steps. Model #4 had steep U/S and D/S slope that's why when cracks were introduced it failed. Model # 5, 6 had different dimensions of internal zones. Their internal slopes were steeper as compared to other models. That's why they fail.

If we compare factor of safety for U/S and D/S sides of dam body than D/S side shows higher factor of safety because at downstream side larger rock mass is present. Dimension of rock blocks are bigger than U/S side. This gives more slope stability. When we move to the upstream side smaller material is present. Although it is stable but lesser than heavy rock blocks.

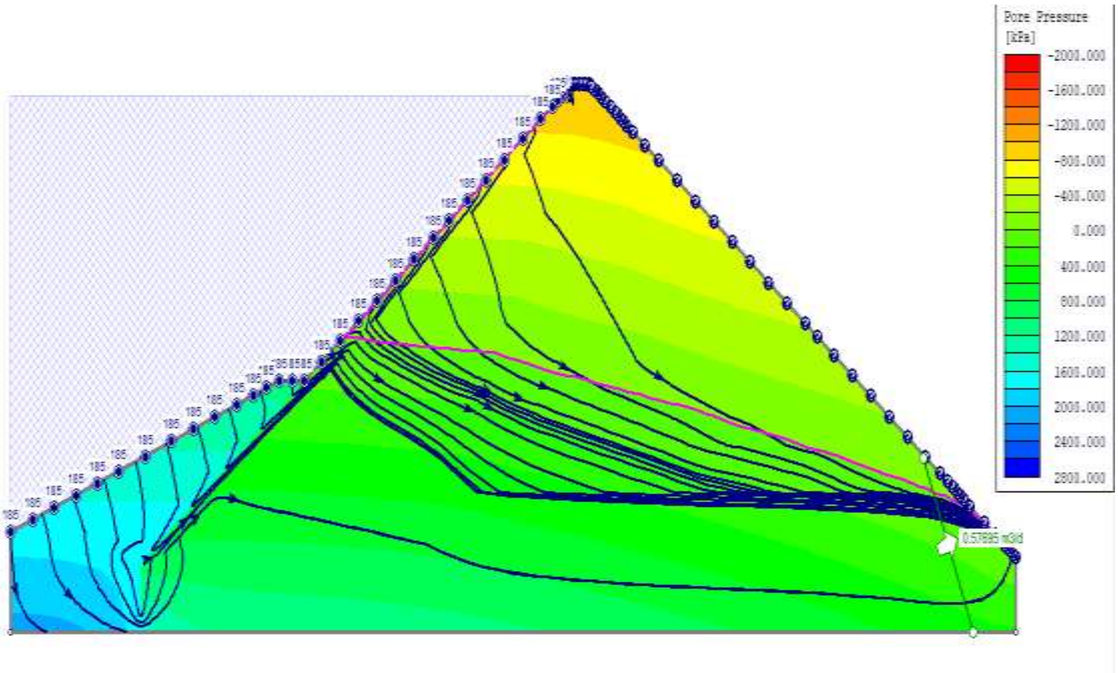
FOS for case 3 is although lesser than case 2 but it is acceptable. FOS decreased because cracks were introduced in concrete facing and seepage can easily happen through dam body. But proper construction techniques and gradation of zone materials can prevent the failure.

4.1.2.2: Seepage analysis and cutoff:

Seepage analysis was performed using finite element analysis for steady state. Discharge through foundation and dam body was calculated using slide. To minimize hydraulic gradient effective cutoff length was provided. Following figures shows flow lines and seepage for case 2 and 3.



Flow lines for case 2



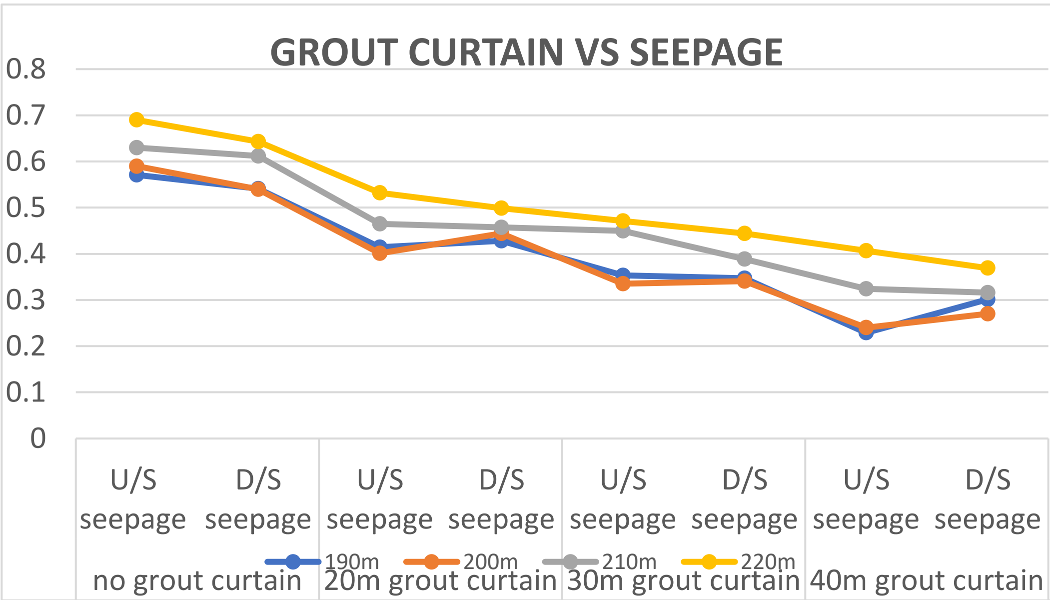
Flow lines for case 3

As we can see that case 3 has higher pore pressure as compared to case 2. The reason is that case 3 has higher seepage value as compared to case 2. When

Case		190m	200m	210m	220m
no grout curtain	U/S seepage	0.571	0.54	0.63	0.69
	D/S seepage	0.541	0.59	0.612	0.643
20m grout curtain	U/S seepage	0.414	0.4009	0.465	0.532
	D/S seepage	0.428	0.444	0.457	0.499
30m grout curtain	U/S seepage	0.353	0.335	0.45	0.471
	D/S seepage	0.347	0.341	0.389	0.444
40m grout curtain	U/S seepage	0.229	0.24	0.324	0.407
	D/S seepage	0.301	0.27	0.316	0.369

cracks were introduced in concrete there is a chance that finer material will migrate with water into rock zones. This will clog openings and pore pressure will increase.

That's why to reduce hydraulic gradient and seepage different cut-off lengths ranging 10-40m were analysed. 40m cut-off length showed the maximum efficiency. Following is the summary of seepage quantity for different cut-off lengths.



4.1.2.3: Drawdown analysis:

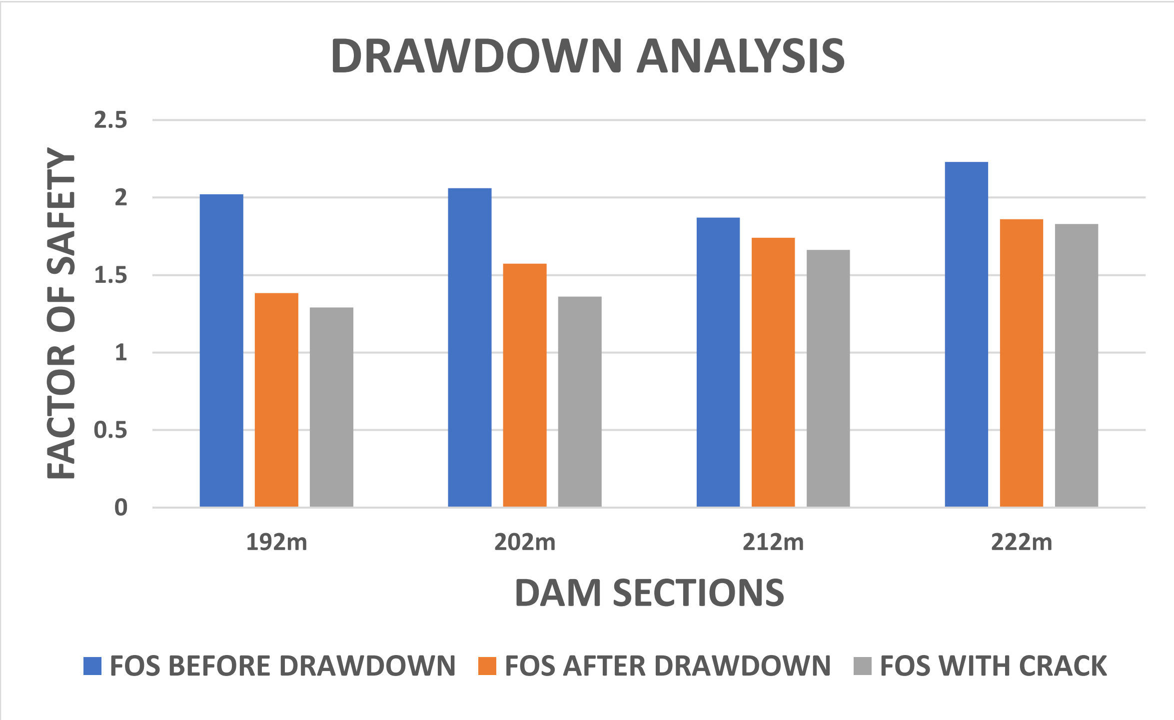
Drawdown analysis was performed on remaining four models. Concrete faced rockfill dams are not critical to rapid drawdown. As described in "SEEPAGE CONTROL OF CONCRETE FACED DAMS WITH

RESPECT TO SURFACE SLAB CRACKING" by Ronald Haselsteriner. Two types of analysis were performed.

- Drawdown with concrete facing intact
- Drawdown with cracks in concrete facing

Following summary shows drawdown analysis for both cases.

MODEL	FOS BEFORE DRAWDOWN	FOS AFTER DRAWDOWN	FOS WITH CRACK
192m	2.022	1.383	1.291
202m	2.06	1.573	1.362
212m	1.87	1.741	1.662
222m	2.23	1.86	1.83



Although FOS has reduced with cracks but it is permissible. Most critical crack position is in zones of 1A and 1B. If cracks are present in concrete facing beneath these zones, fine material will flush in internal zone.

4.2 ABAQUS:

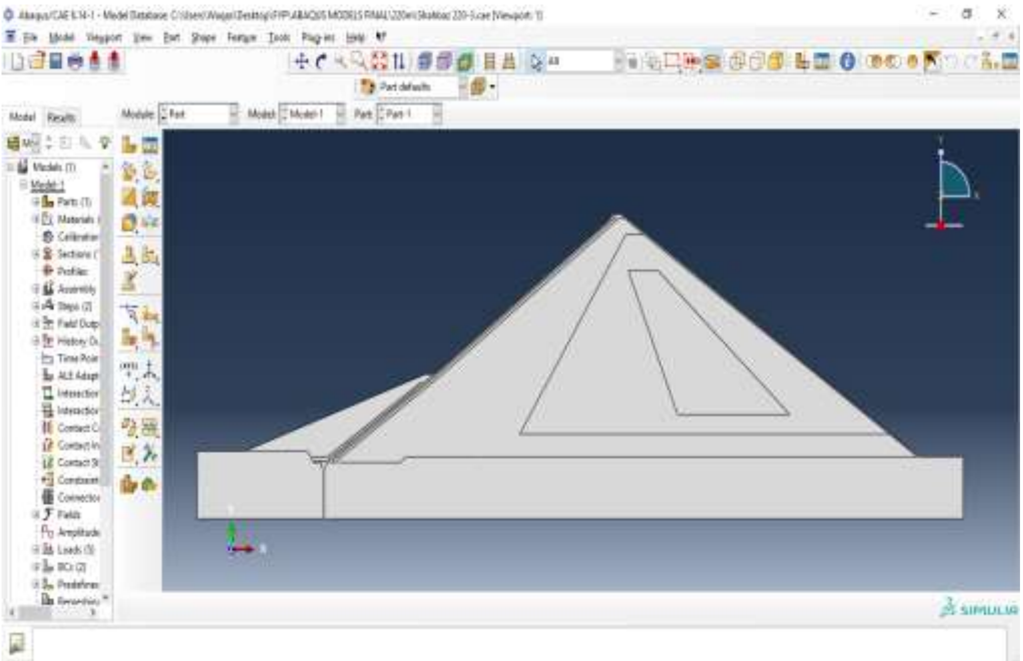
Simulia Abaqus version 6.14 has been used for the Finite Element Modelling of the embankment that we designed. The main parameter to check was to assess the deformation that occurs in the body of dam. Then it is compared with a standard parameter to assess whether the designed embankment is safe or not.

4.2.1 DESIGN PARAMETERS:

The embankment for Abaqus was modelled w.r.t. different heights. Three heights are used to simulate the behaviour of dam and its deformation is known. The procedure outlying is as under:

4.2.1.1 PART:

First, the model is made under the module subheading: PART. Using the 'Create Part' command and choosing 2D model the model procedure is started. The coordinates are put accordingly, and the outline boundary of dam is made.



The inside lines are drawn using the partition command which can be accessed using the Tools->Partition. The method used for partition is using sketch as it is a 2D model and this is the best tool to partition our model.

4.2.1.2 MATERIAL:

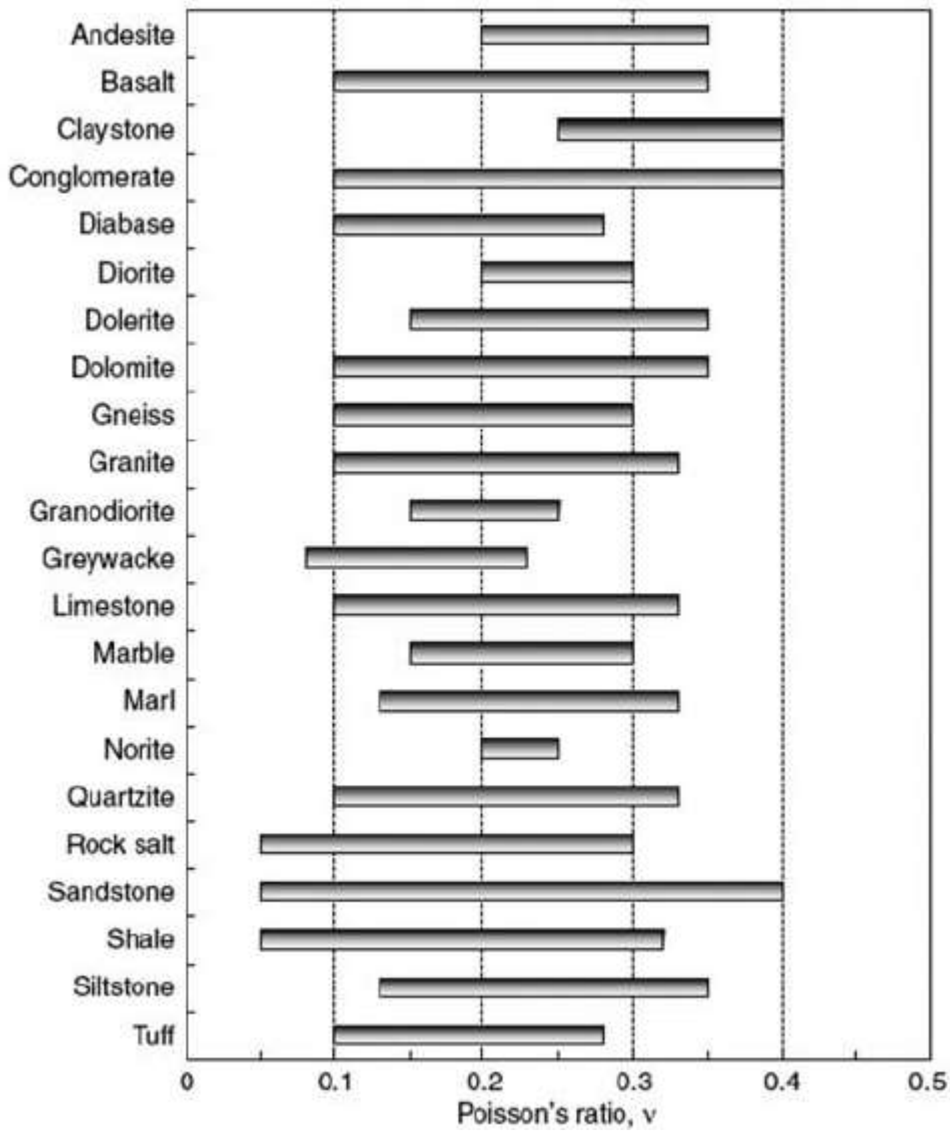
It is assigned under the module: PROPERTY. After the model has been made and partitioned, the second step to do is assign the properties. Different zones are assigned their respective properties. So first we need to define the properties using the 'Create Material'.

For different Zones the properties are presented in the table with their respective properties. The main properties used are the

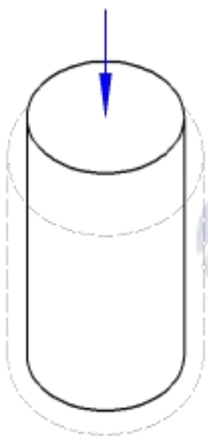
density, elasticity and permeability. The density material behavior considers the mass density which is inputted in units of kg/m^3 and is uniform throughout for the zone considered. For the elasticity, the required parameters are Young's Modulus and Poisson's ratio which for different zones were known and entered. Lastly for the permeability, the value of 'k' i.e. permeability is required as well as the void ratio which are inputted in the respective field.
Specific weight used is 9810 N/m^3 which roughly translates to 9.81 kN/m^3 which is specific weight of water.

Zone	Mass Density (kg/m3)	Young's Modulus (N/mm2)	Poisson's Ratio	Permeability (m/s)	Void Ratio
1A	1600	15000000	0.3	2.2e-5	1
1B	1916	12000000	0.25	3.43e-6	0.5
2A	1916	12000000	0.25	2e-5	0.5
2B	2160	150000000	0.4	0.0001	0.6
3A	2650	400000000	0.1	0.0003	0.5
3B	2650	6375000000	0.11	1e-6	0.5
3C	2650	7355000000	0	2e-6	0.1
3D	2242	3922000000	0.1	1e-7	0.5
3E	2242	7355000000	0.1	2.3e-6	0.5
Foundation	2000	3000000000	0.3	0.0004	0.12
Concrete	2400	18485000000	0.15	0.0001	0.2

The Poisson ratio for Limestones and rocks are used using the following figure:



While for the Soils Poisson ratio utilized is as:



Description	Poisson's Ratio
Sand	0.15 - 0.4
Dense	0.2 - 0.4
Course	0.15
Fine	0.25
Silt	0.3 - 0.35
Clay	0.1 - 0.5
Saturated	0.4 - 0.5
Unsaturated	0.1 - 0.3
Sandy Clay	0.2 - 0.3

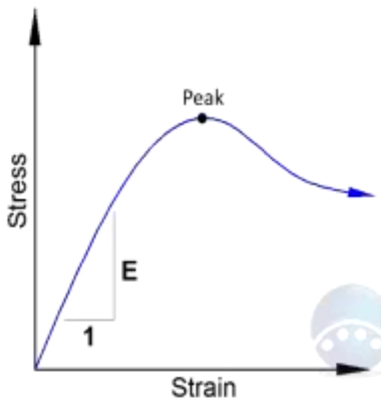
The Void Ratio for Soils zones are used by the following figure:

Typical Values of Void Ratio and Unit Weight

Soil description	Void ratio	Dry unit weight(pcf)	Saturated unit weight(pcf)
Uniform sand	1.0 - 0.4	83 - 118	84 - 136
Silty sand	0.9 - 0.3	87 - 127	88 - 142
Clean, well-graded sand	0.95 - 0.2	85 - 138	86 - 148
Silty sand and gravel	0.85 - 0.14	89 - 146	90 - 155
Sandy or silty clay	1.8 - 0.25	60 - 135	100 - 147
Well-graded gravel, sand, silt, and clay mixture	0.7 - 0.13	100 - 148	125 - 156
Inorganic clay	2.4 - 0.5	50 - 112	94 - 133
Colloidal clay (50%<2μ)	12 - 0.6	13 - 106	71 - 128

(NAVFAC DM 7.1, 1982)

The Young's Modulus Value used are according to the following figure:



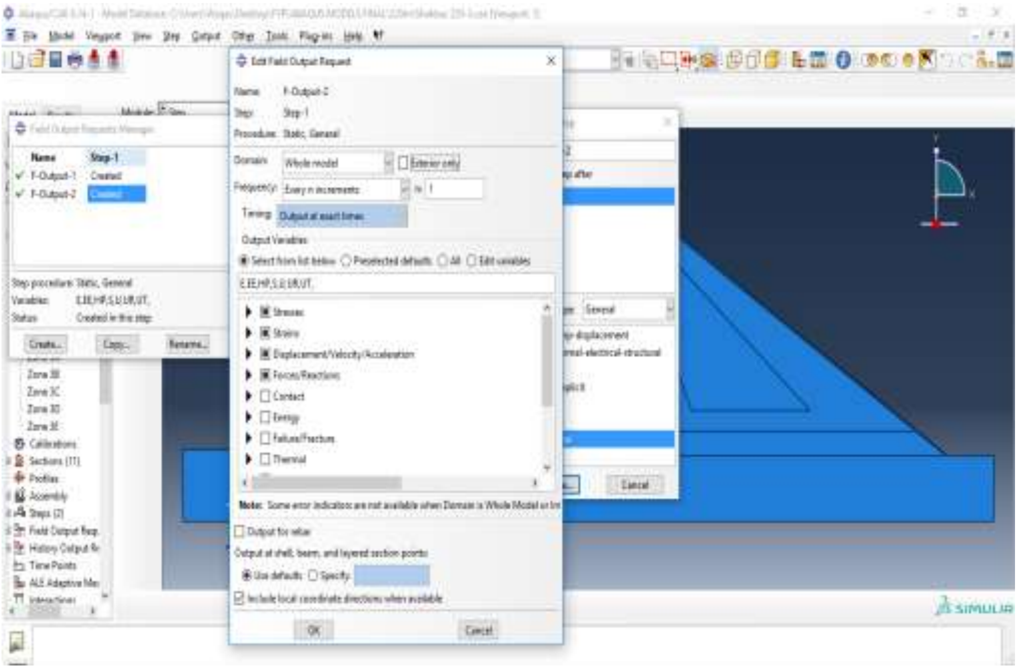
Description	E (ksi) [MPa]
Sand	(0.73 - 11.75) [5 - 81]
Silty	(0.73 - 2.9) [5 - 20]
Loose	(1.45 - 3.63) [10 - 25]
Medium	(4.35 - 7.25) [30 - 50]
Dense	(7.25 - 11.75) [50 - 81]
Sand and Gravel	(4.35 - 46.41) [30 - 320]
Loose	(4.35 - 11.6) [30 - 80]
Medium	(11.6 - 23.21) [80 - 160]
Dense	(23.21 - 46.41) [160 - 320]
Silt	(1.02 - 3.05) [7 - 21]
Clay	(0.29 - 36.26) [2 - 250]
Very Soft	(0.29 - 2.18) [2 - 15]
Soft	(0.73 - 3.63) [5 - 25]
Medium	(2.18 - 5.8) [15 - 40]
Hard	(5.8 - 14.5) [40 - 100]
Sandy	(3.63 - 36.26) [25 - 250]

4.2.1.3. SECTION:

This part consists of creating a section in the embankment which is basically the zone to which the properties we created are assigned. The section made is solid since only one type of material is present in a selective zone. All the zones are created and assigned the respective material properties. After the sections are made, the next step is to assign the section to the respective regions.

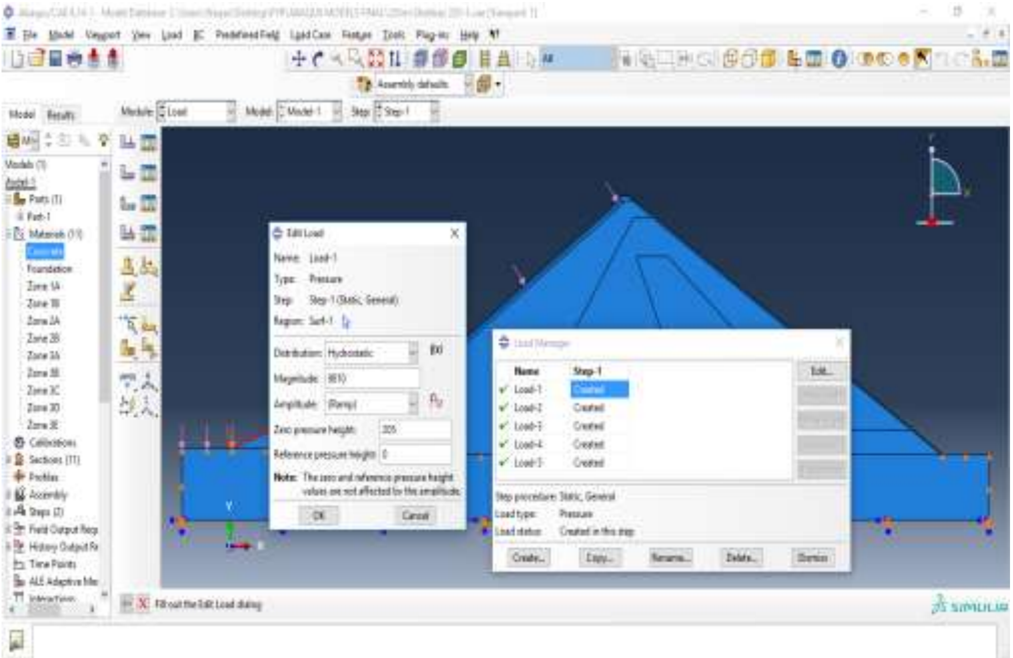
4.2.1.4. STEP:

This part is under the module: STEP. A step static, general is created which will mainly deal with the deformation we require. Also field output is created which includes the stresses and translations which are checked these will be the main key parameters which will be visualized.



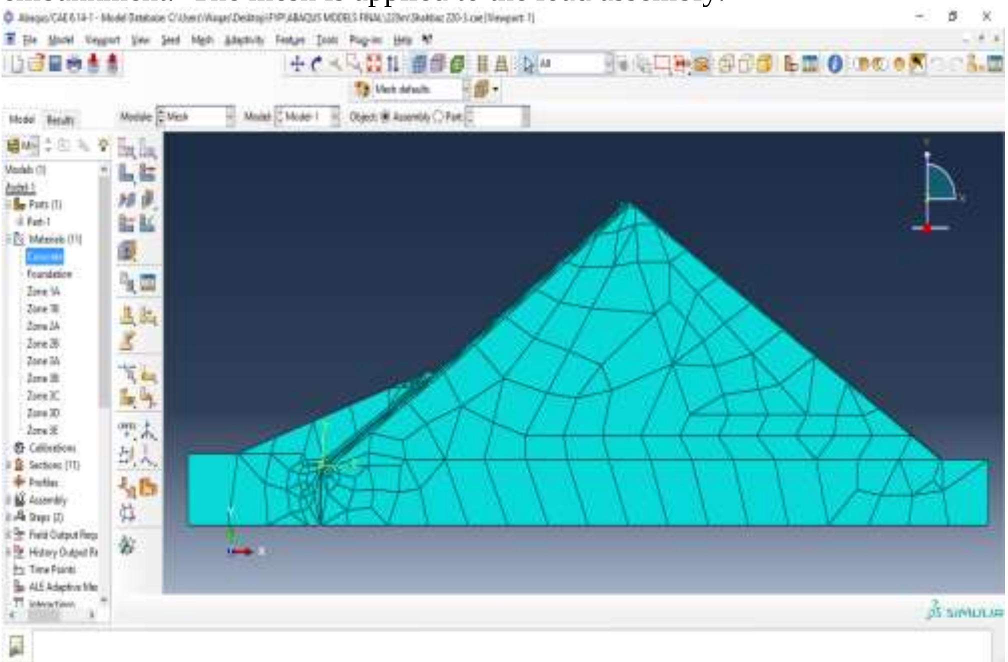
4.2.1.5 LOAD:

This part is under the module: LOAD. A load is created which is basically the hydrostatic load. The magnitude is 9810 which is basically the unit weight of water i.e. 9.81kN/m^3. The zero-pressure height is the height for total height of water which depends on the height of dam and reference pressure height is assigned the value of 0. Also, boundary conditions are applied.



4.2.1.6 MESH:

This part consists of creating the mesh to the whole embankment. The mesh is applied to the load assembly.



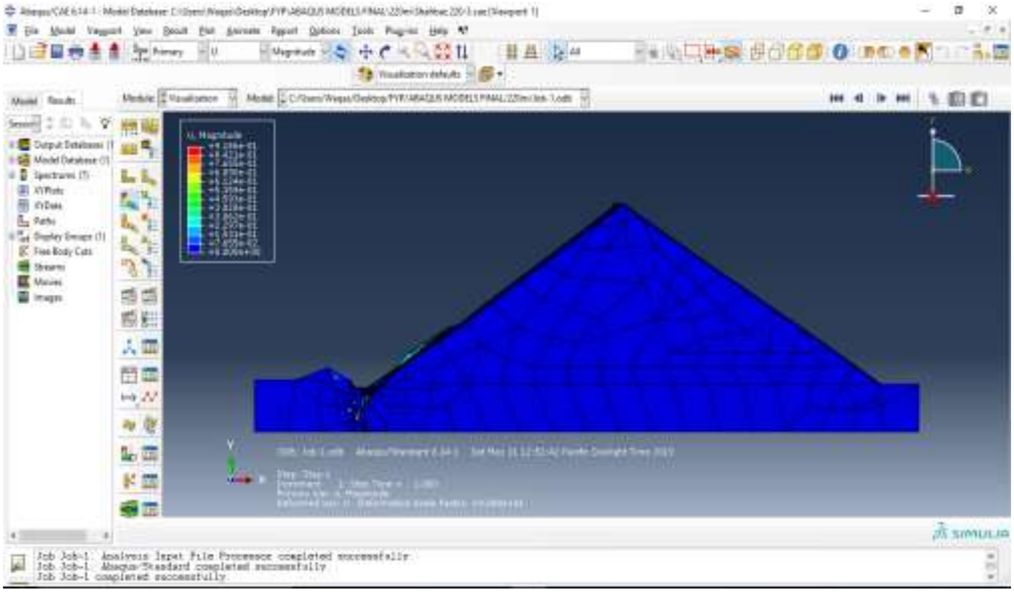
4.2.1.7 JOB:

A job is created under the module: JOB. Then analysis is run. The results are shown in VISUALIZATION tab.

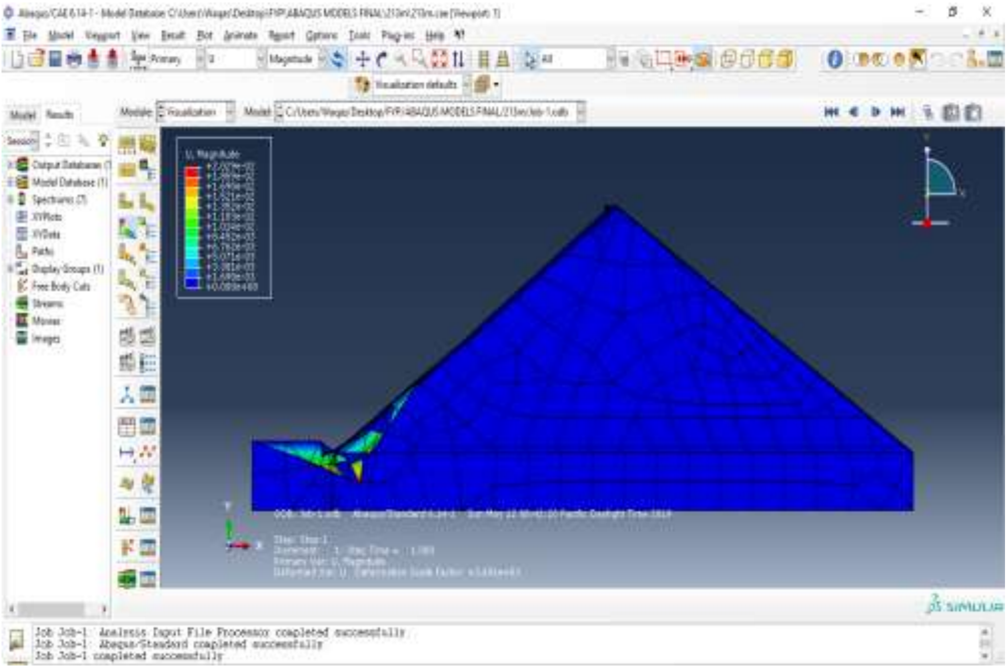
4.2.1.8. RESULTS:

The results show the deformations which are checked with the main face deflection considered using the past case histories.

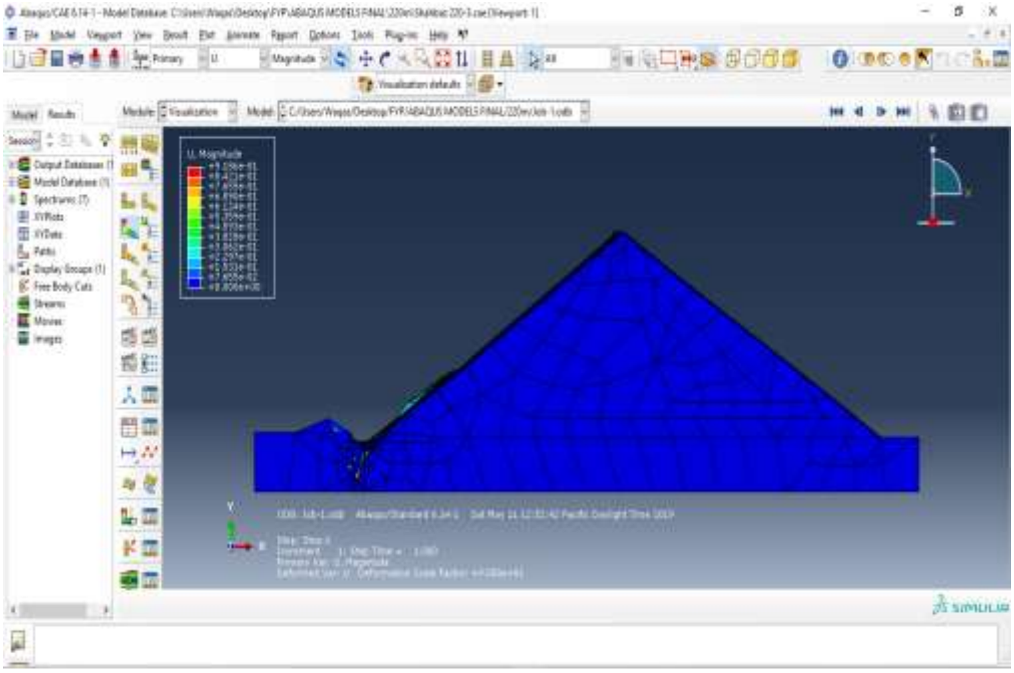
For the 200m Model the deformations are shown as



For the 212m Model the deformations are shown as:



For the 222m Model the deformations are shown as:



The 25 CFRDs are considered and their range are checked. The range lies between 0.2-0.4% of dam height.

Number	Name	Country	Year	Height (m)	Length (m)	Rockfill mineralogy	Void ratio	Crest settlement (m)	Crest settlement H (%)	Face deflection (m)	Face deflection H (%)	Measuring period (year)
1	Cethana[a]	Australia	1971	110	215	Quartzite	0.26	0.18	0.16	0.17	0.16	30
2	Alto Anchicaya[b]	Colombia	1974	140	260	Hornfels	0.22	0.17	0.12	0.16	0.11	10
3	Sugarloaf[c]	Australia	1979	85	1,050	Siltstone	0.30	0.21	0.25	0.16	0.19	15
4	Foz do Areia[b]	Brazil	1980	160	828	Basalt	0.33	0.21	0.13	0.78	0.49	20
5	Mackintosh[a]	Australia	1981	75	465	Greywacke	0.24	0.24	0.32	0.25	0.33	19
6	Mangrove creek[f]	Australia	1981	80	384	Siltstone	0.26	0.08	0.10	0.10	0.13	4
7	Murchison[a]	Australia	1982	94	200	Rhyolite	0.23	0.08	0.09	0.09	0.10	17
8	Bastyan[c]	Australia	1983	75	430	Rhyolite	0.23	0.05	0.07	0.07	0.09	8
9	Khao Laem[d]	Thailand	1984	113	910	Limestone	0.29	0.19	0.17	0.13	0.12	14
10	Shiroro[c]	Nigeria	1984	125	560	Granite	0.20	0.17	0.14	0.09	0.07	2
11	Dongbok[e]	Korea	1985	45	188	Andesite	0.27	0.04	0.09	0.04	0.09	7
12	Lower Pieman[a]	Australia	1986	122	360	Dolerite	0.24	0.22	0.18	0.27	0.22	14
13	Chengbing[g]	China	1989	75	325	Tuff lava	0.28	0.10	0.13	0.19	0.25	10
14	Xibeikou[c]	China	1989	95	222	Limestone	0.28	0.06	0.06	0.08	0.08	7
15	Segredo[b]	Brazil	1993	145	705	Basalt	0.37	0.23	0.16	0.34	0.23	8
16	Xingo[c]	Brazil	1994	150	850	Granite	0.28	0.53	0.35	0.51	0.34	6
17	Tianshenqiao[g]	China	1999	178	1,168	Limestone	0.31	1.06	0.60	1.14	0.64	1.5
18	Ita[c]	Brazil	1999	125	880	Basalt	0.31	0.60	0.48	0.46	0.37	3
19	Namgang[e]	Korea	2001	34	1,126	Gneiss	0.27	0.01	0.04	0.06	0.17	6
20	Yongdam[e]	Korea	2001	70	498	Schist	0.32	0.12	0.17	0.01	0.01	6
21	Miryang[e]	Korea	2001	89	535	Granite	0.18	0.09	0.10	0.16	0.18	6
22	Sancheong(L)[e]	Korea	2002	71	286	Granite	0.27	0.09	0.13	0.01	0.01	4
23	Sancheong(U)[e]	Korea	2002	87	360	Gneiss	0.27	0.30	0.34	0.01	0.01	4
24	Jangheung[e]	Korea	2005	53	403	Tuff	0.28	0.02	0.04	0.03	0.06	1
25	Daegok[e]	Korea	2005	52	190	Gneiss	0.25	0.02	0.04	0.01	0.02	1

[a]Giudici et al. (2000).

Our results tell that it is okay as maximum deflections that occur on face are less than the deflection that can cause any damage.

Dam model	202m	212m	222m
Max. Deformation	0.02114 m	0.02029 m	0.009186 m
Allowable Deformation	0.404	0.424	0.444
Results	OK	OK	OK

4.1.2. .CONCLUSION:

From the FEA analysis of CFRD Mohmand Dam, we see that the max. deformation that can occur is under the allowable range so it is safe to design and will not fail under the conditions considered. There is no need to provide any more support and anchorage than already been present.

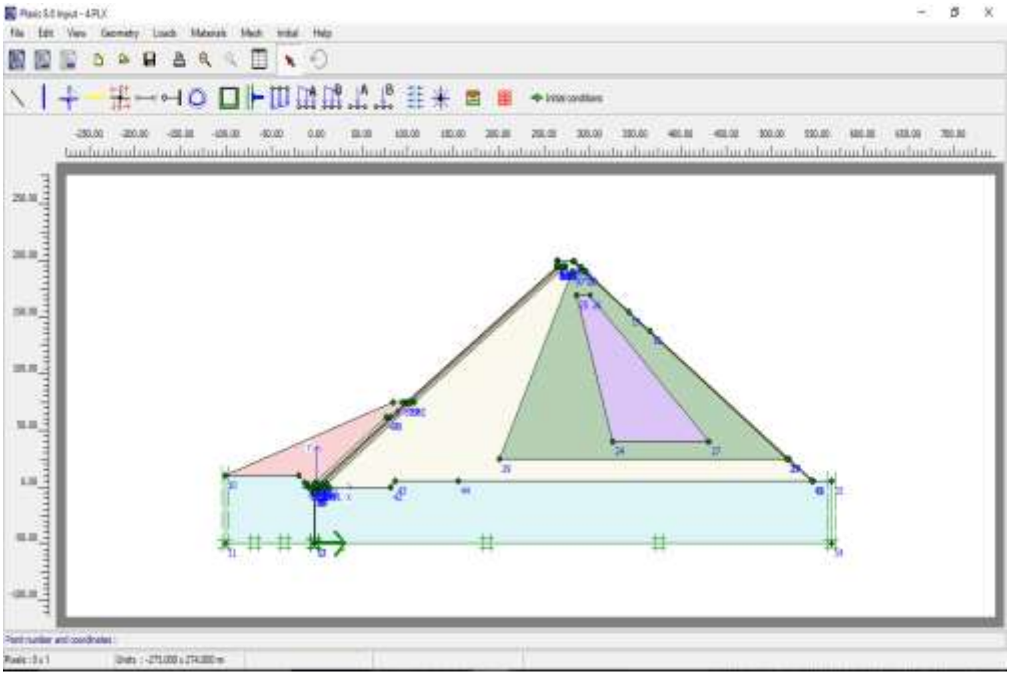
4.2. PLAXIS

Plaxis 8.6 has been used for verifying the results of both SLIDE 2D and ABAQUS. The slope stability provided by SLIDE is verified by using this software as well as the deformation or displacement provided by ABQAUS.

Plaxis 8.6 is a finite element modeling software used for rock and soil analyses. The embankment of dam is modelled into the software with all the required parameters and properties of different materials have been assigned to it.

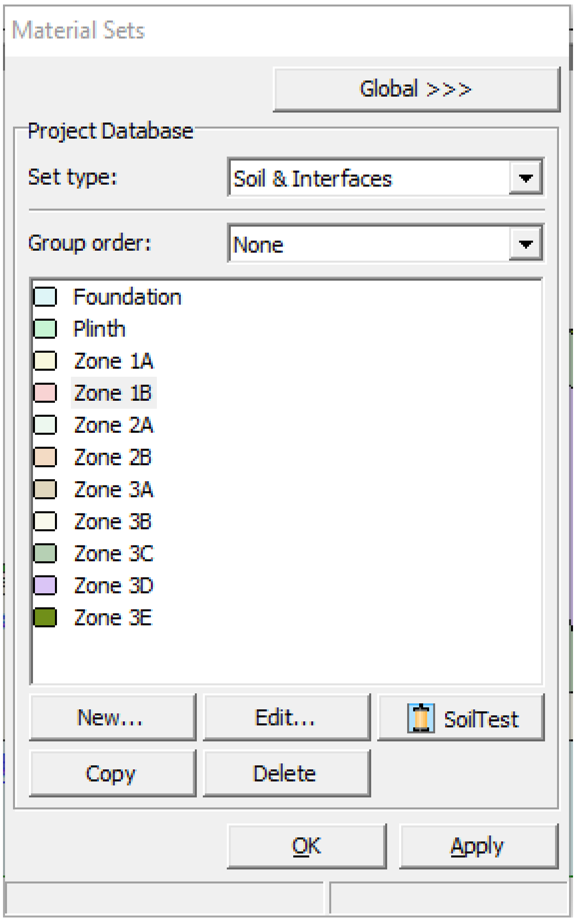
4.2.1. PROCEDURE:

The models that are made in the PLAXIS are with the same properties with varying heights of embankment. The basic model presented in the PLAXIS software is as:



All the zones are given properties which are assigned the values of unit weight, cohesion and angle of internal friction.

The materials provided are:



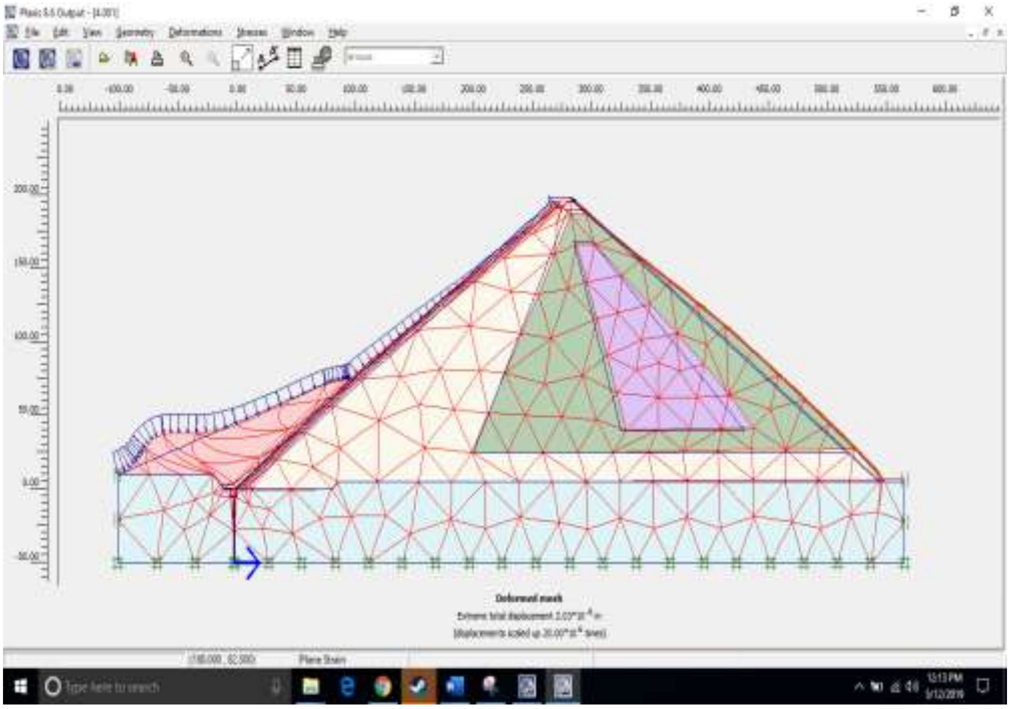
The Properties that are given and assigned to these materials are given in tabular form as:

ZONE	Unit Weight (kN/m3)	Elastic Modulus (kN/m2)	Cohesion (kN/m2)	Angle of internal Friction	Permeability (m/day)
Zone 1A	15.7	1.5e4	20	31	2.06
Zone 1B	18.8	1.2e4	24	20	0.3
Zone 2A	18.8	1.2e4	19	30	2.06
Zone 2B	21.2	1.5e5	0.3	36	8.4
Zone 3A	26	3.92e6	0.2	0	25.92
Zone 3B	25	6.37e6	0.2	0	0.3
Zone 3C	26	7.35e6	0.2	0	8e-3
Zone 3D	22	3.92e6	0.2	0	0.21
Zone 3E	22	7.35e6	0.2	0	2.06
Foundation	18	7.84e6	10.5	41.8	8e-3
Concrete	23.5	1.85e7	0.3	0	8.64e-11

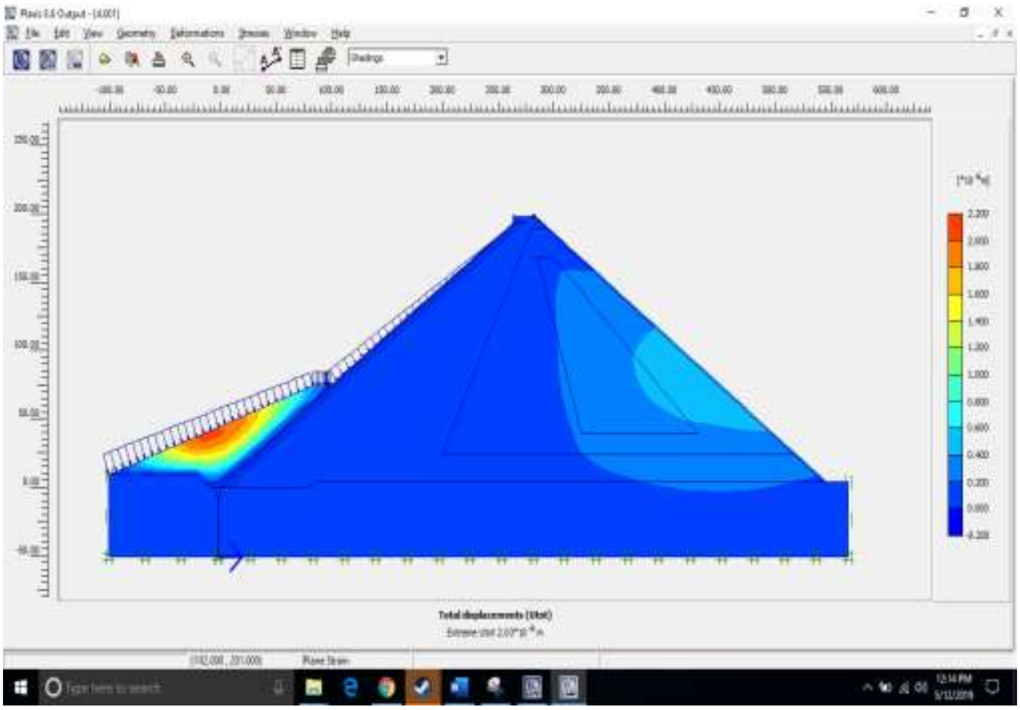
After the properties have been assigned to the respective regions the next step is the provision of water table that's been given according to the height of dam. It's then analysed

and for the different dam heights the results are as:

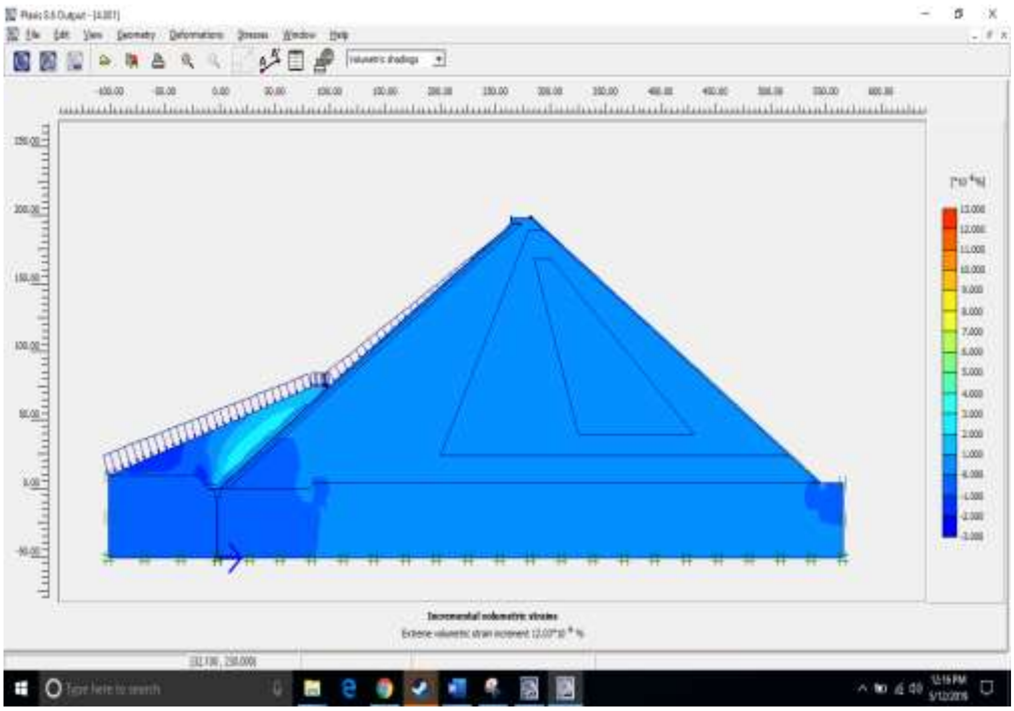
For the 202m dam height it's deformed mesh is as with extreme total displacement of $2.03*10^{-6}$m.



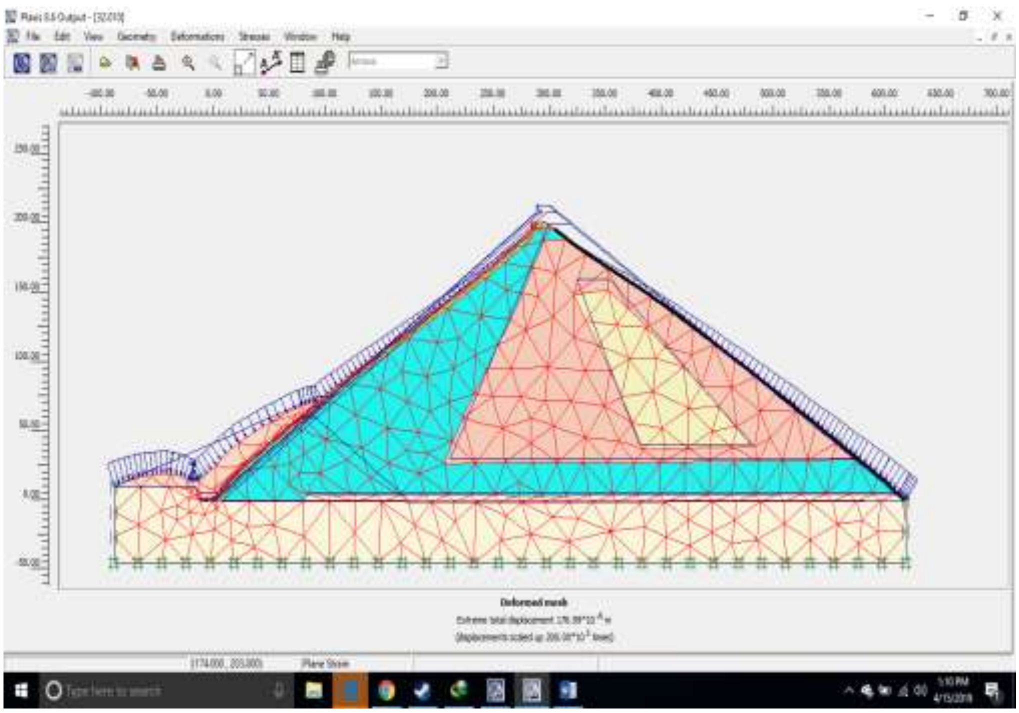
The phreatic surface formed is majorly concentrated in the 1B region of dam which verifies the results of SLIDE software.



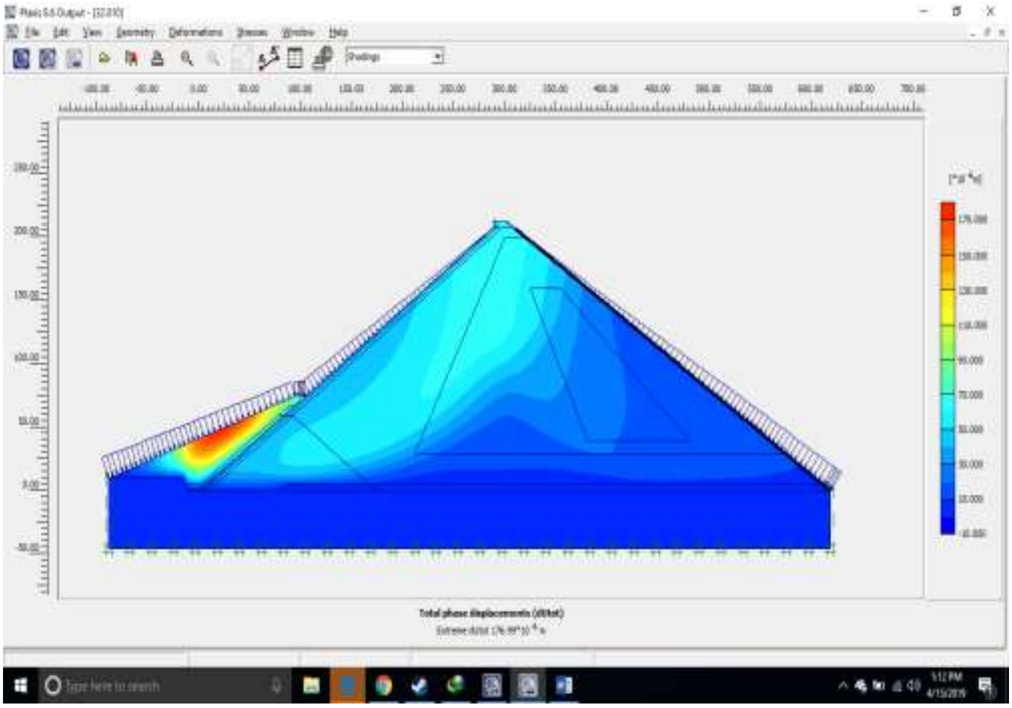
The volumetric strains are also quite lower and are majorly present at the site where the slip surface is formed:



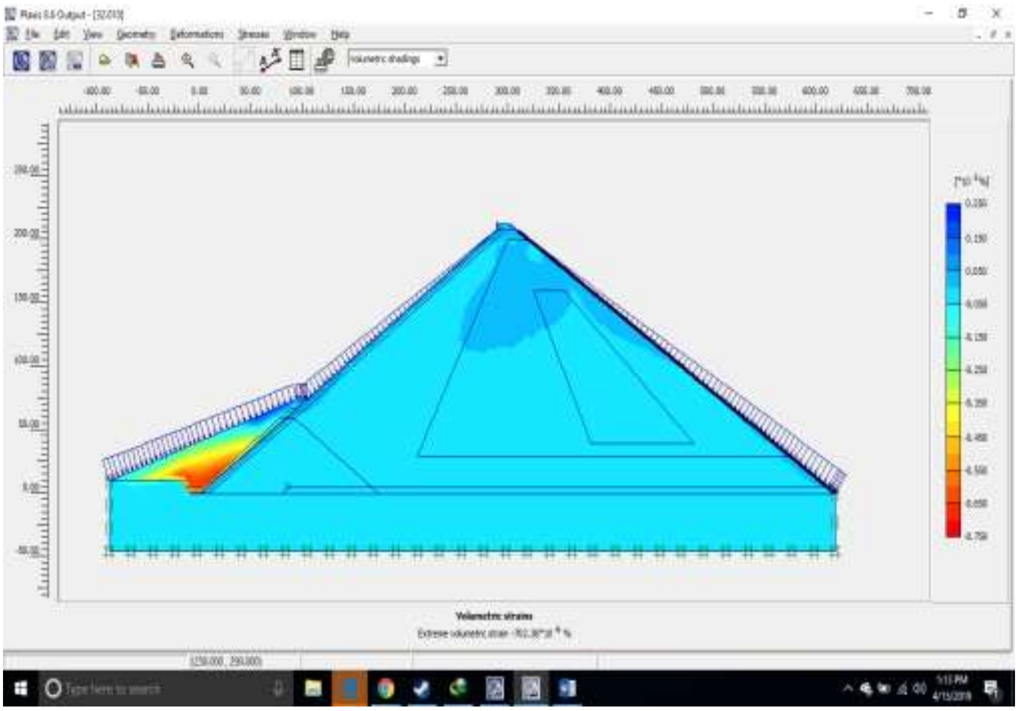
Similarly for the other dam heights the results are computed.
For the 212m model the deformed mesh is as:



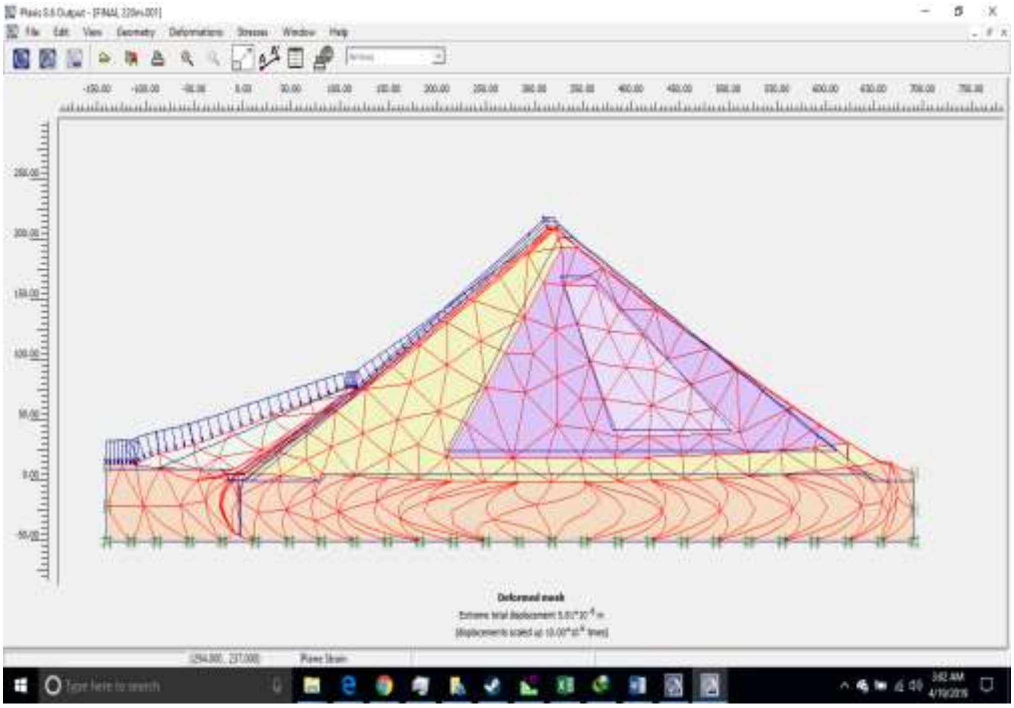
The phreatic surface is also same and concentrated in the upper portion i.e. Zone 1B.



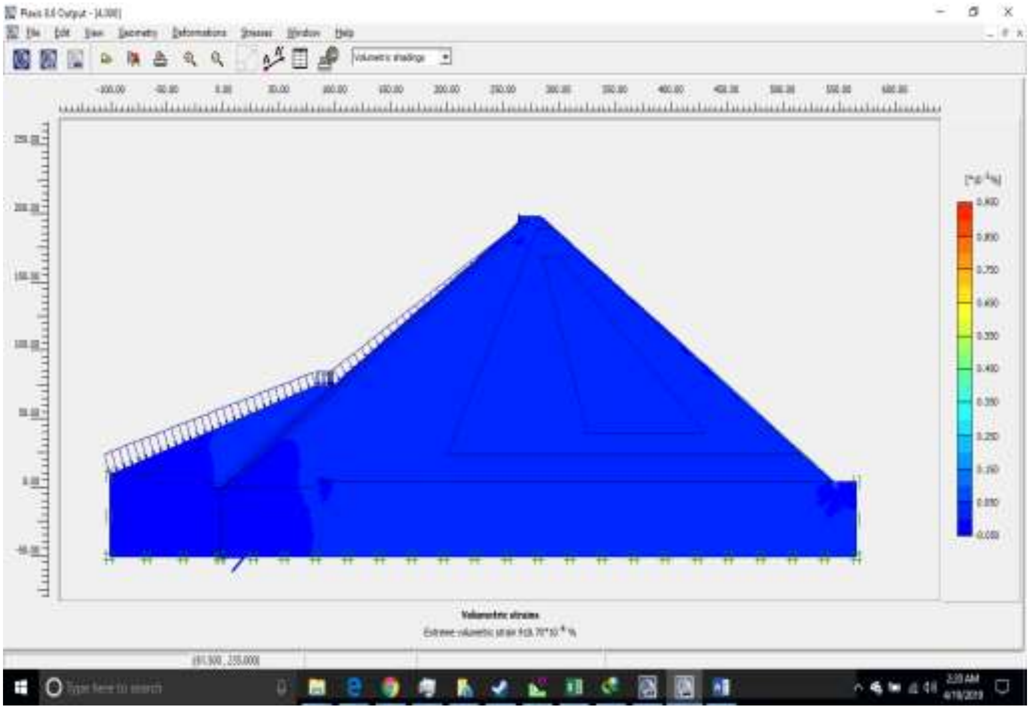
The Volumetric Strains are also lower and fall under the allowable range:



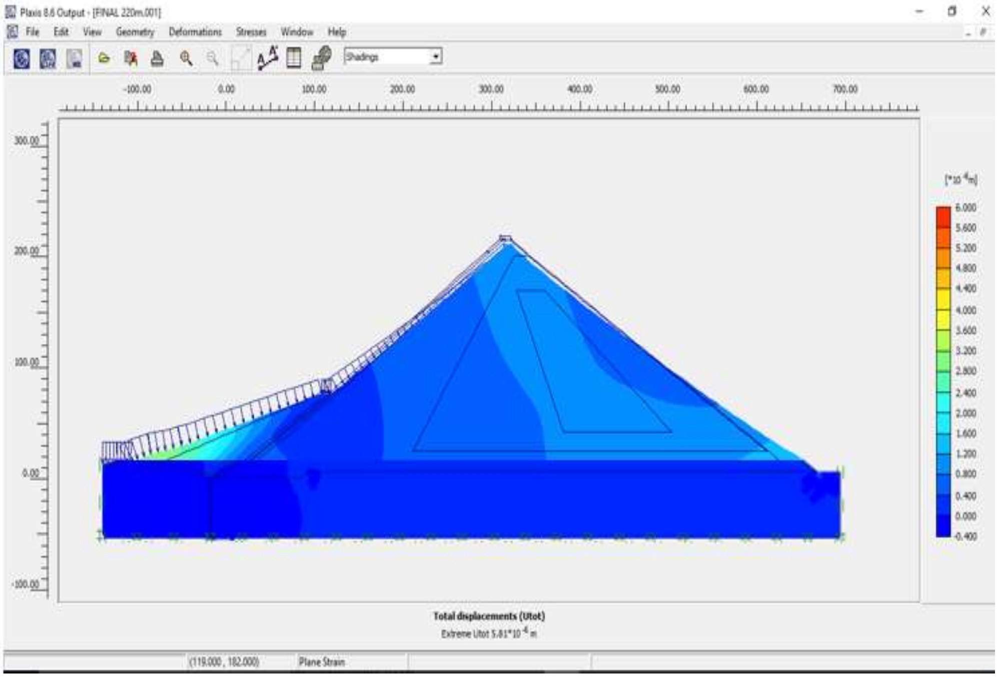
For the 222m Model the deformed mesh is given as:



The volumetric Strains are as:



The slip surface remains same as that of the other models:



The overall summary is given as:

	200m	213m	220m
Volumetric Strains	918e-6%	702e-6%	23.74e-6%
Total Displacements	2.03e-6m	3.19e-6m	5.81e-6m

4.3.2. CONCLUSION:

The results of PLAXIS verifies the results of SLIDE and correspondingly gives the same critical surface as was presented by the SLIDE software. The volumetric strains are also on the lower side which gives the confirmation of the suitable and compact dam design.

4.3.Cost Analysis:

Cost estimation of proposed design section of different heights with FOS above 1.5 is done.

The AREA TRIBUTRY method is used for the calculation of cost of different design cross-section of dams. The area of each zones in cross-section is calculated via AutoCAD The unit cost of material is obtain from the MRS of Punjab Rawalpindi division 20119 due to unviability of KPK MRS. The unit cost includes the material cost, hauling cost, compaction cost and 10% marginal cost. The unit cost used is composite which includes material + workmanship cost also. The calculation is given in table below:

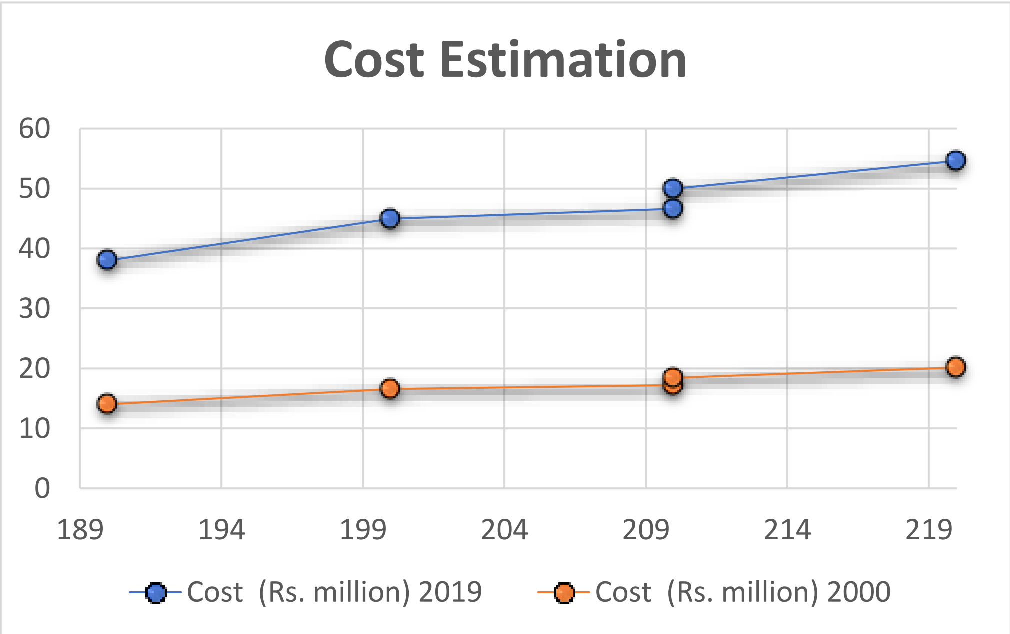
ZONES	QUANTITIES	FT^2	M^2	UNIT COST	TOTAL COST(RS)
1A	436.54	3.03152778	436.54	653.95	285475.333
1B	3375.5	23.4409722	3375.5	605.9	2045215.45
2A	2.5	0.01736111	2.5	525.95	1314.875
2B	622.75	4.32465278	622.75	718.9	447694.975
3A	1095.6	7.60833333	1095.6	647.95	709894.02
3B	29268.7	203.254861	29268.7	647.95	18964654.17
3C	24495	170.104167	24495	647.95	15871535.25
3D	7800	54.1666667	7800	647.95	5054010
3E	426	2.95833333	426	647.95	276026.7
FOUNDATION	2648.9	18.3951389	2648.9	1528.9	4049903.21
CONCRETE	230.4	1.6	230.4	9006.8	2075166.72
				SUM	**49780890.7**

The cost of dam ranges from rs.49.5 million to rs.55.3 million per unit length of dam cross-section.

As the dam was proposed in 2000, so in second part of cost analysis, the dam cost of 2000 is also calculated and then compare with todays cost, the analyze the cost difference between both.

Dam (m)	Cost (Rs. million) 2019	Cost (Rs. million) 2000
192	38.02	14.02
202	44.96	16.59
212	46.63	17.02
212	49.78	18.43
222	54.62	20.15

The graph represents that there's almost 130% increase in dam cost.



CHAPTER 5: GEOTECHNICAL BASELINE REPORT:

It contains a summary of the geologic and geotechnical information, a description of the anticipated ground conditions, and a prediction of the ground behaviour during construction of dam.

Following are the basic point of GBR:

- Flood protection during construction: cylinder gabions of welded steel mesh filled with cobbles.
- Access: Bucyrus erie 61B crane(12tonne with 40m boom length) to cover whole plinth area
- Complete plinth protection well before placement of rockfill.
- Quarry should be on upstream
- Excavation: tracked earth moving equipment especially hydraulic excavator. For drilling and blasting, crawled mounter percussion drills both pneumatic or hydraulics.
- Where possible drilling should be done via pneumatic drills for example: atlas Copco 701
- Rock catcher and steel mesh should be used for safety.

Zone	Max. particle size (mm)	Layer Thickness	Pass
2A	200	0.5	4, 8 hf, 4v
2B	500	0.5	4.6hf, 4v
3A	1000	1.5	2, 4hf, 4v
3B	1500	1.5	4, 4hf , 6v

- Watering should be 10 percent of rock mass.
- 6 wheel 50 ton trucks.
- Concrete done through slipform method with 40 feet wide bay.
- Babcock Weitz tower crane will be used.
- Concrete face slab of 15m vertical strips.
- Differences of 150mm is allowable between design and constructed surfaces.
- Use of stainless steel instead of copper as water stop because copper can easily damage and only handle in 6m length.
- Use of ordinary rubber is prohibited in joint, instead of Hypalon rubber will be used due to its resistance to oxidation and ozone attack in a zone above MOL.
- Prefabrication of reinforcing mat and installation by specialized equipment would be more economical then in situ placement.

- Concrete should have 50 +- 12mm slump, 4% +-0.5% air content and round aggregate is required.
- Zone 2A horizontal layer is compacted by vibrating compactor while slope of zone is done by vibratory plate.
- The compacted sloping surface is protected from rainfall erosion by chicken wire mesh and cement mortar.
- Min. of Instruments installed in dam are following:
    1. 5 piezometers in main foundation dam to monitor effectiveness of grout curtain.
    2. 22 settlement monometer along crest of dam and downstream berms.
    3. 30 min. pair of markers along the perimeter joint and selected vertical joint to measure opening across the joints.
    4. Flow measuring weir at downstream and saddle dam to measure seepage.
    5. Inclinometer on both abutments to monitor ground movement and on face slab on three different location to measure deformation under water load.
- The concrete facing strips are required to placed continuous without horizontal construction joint but if unavoidable stoppage occurred , then construction joint is allowed without water stop, but with proper preparation of surface
- Perimeter joint is most critical one, so PVC material joint should be made because it will allow more movement before rupture and additional sealing is provided to maintain the integrity of joint.
- The material specification is given in table below:
- The different zones grading is shown in fig below:

ROCKFILL ZONES

ZONE	SPECIFICATION
I TRANSITION	WELL GRADED, 12" MAXIMUM SIZE, COMPACTED BY 4 PASSES 10 TON VIBRAT. ROLLER - LAYERS - 20". 8 PASSES OF THE 10 TON VIB. ROLLER UPSLOPE DIRECTION.
2	40" MAXIMUM SIZE - COMPACTED BY 4 PASSES 10 TON - VIB. ROLLER - 40" LAYER.
3	BEST MATERIAL - WELL GRADED - 24" MAXIMUM SIZE, COMPACTED BY 4 PASSES - 10 TON. VIB. ROLLER 2 ft LAYERS - WATERED BY 200 L/m3.
4	SIMILAR TO 3 BUT WITH MORE FINES. COMPACTION AND LAYERS AS FOR 3.
FILTERS	SAND AND GRAVEL 3/4" TO PROVIDE PROTECTION FOR EROSION OF THE ABUTMENTS AND RIVER BED.

Fig 3 - DAM CROSS SECTION AND SPECIFICATIONS

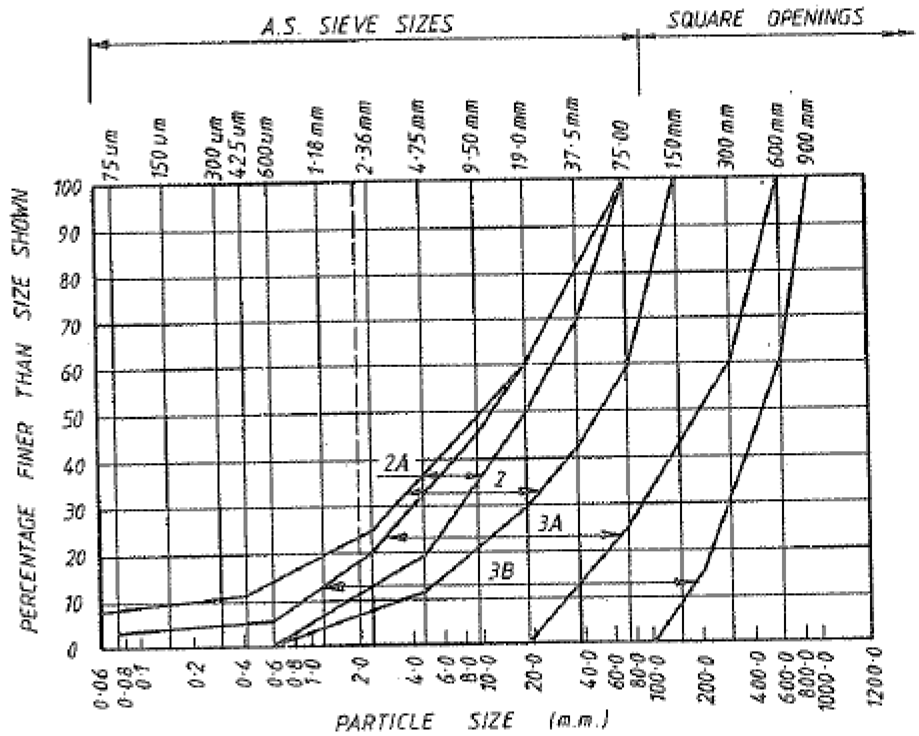


Figure 4 -EMBANKMENT GRADINGS

- further reduce flow through the embankment, again in the event of storage rise.

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