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Stability Analysis of Slopes Based on Limit Equilibrium and Finite Element Methods for Neelum Jhelum Hydropower Project, Pakistan- Case Study

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ABSTRACT: *Dam failurecan occur due to multiple reasons like structural instability, hydraulic conditions, and rapid drawdown condition. The rapid drawdown is regarded as the most critical condition for the upstream (u/s) slope.The estimation of the factor of safety for dam slope stabilityis crucial to determine the overall dam safety. This paper deals with the stability analysis for the cut (temporary) and permanent slope of the sedimentation basin area slopes and u/s of intake slopes using Slide v 6.0 and Geo-studio. The properties of materials such as hydraulic conditions, unit weight, cohesion and internal friction angle of soil were measured and then used as input data in the programs to analyze the factor of safety under different cases. The slope stability was analyzed basedon four different Limit Equilibrium methods (e.g. Bishop, Janbu simplified method, Janbu corrected method and Spencer method) while the drawdown condition has been analyzed basedon both Finite Element and Limit Equilibrium methods. The factor of safety values for the sedimentation basin area and for upstream slopes satisfies the minimum limits for all cases of operation. The results achieved from numerical modeling also justified a significant influence on the safety factor of the slope stability of the dam and thus it can be concluded that Neelam dam is safe against the danger of slope failure. The study suggested that the numerical methods provide a relatively easy and fast solution to complex geotechnical problems and must be used during the design stage to avoid possibilities of failure.*

KEYWORDS: *Slope stability analysis, Limit Equilibrium method, Finite Element method*

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I. INTRODUCTION

Dams are constructed for various purposes like flood controlling, provide water and producehydroelectricity. Most of the world's largest dams have been constructed in the mid-20th century. Most modern dams are of two basic types: concrete dam and embankment dam (Kirra et al., 2015). The key steps for the construction of a dam are mainly dependent on the investigation of slope stability, accurate assessment of seepage and determination of hydraulic gradients in various parts of the dam to prevent the slope failure (Arslan, 2001; Ismaeel and Noori, 2011). Numerous factors reflect the stability of the dam such as design, constituents, properties of the material used for construction and the forces that act on it in different loading conditions (Kirra et al., 2015; Tatewar and Pawade, 2012; Wudtke, 2008). Analysis of seepage and slope stability is essential for determining the stabilization and strength of the dam structure(LI and LIU, 2010). The most hazardous situation for the u/s slope is stated as drawdown condition. The upstream slope could be effected by the dissipation of water pressure in the reservoir(Fattah et al., 2015).

Berilgen (2007), investigated the drawdown conditions of slope stability. The reduction in the stability of slope values due to rapid drawdown may cause slope failure. The paper describes the stability of slope through drawdown conditions considering the ratio of drawdown, soil permeability, irregularity of materials and some operating conditions. The analysis of slope stability and seepage has been performed by using the finite element method. Zomorodian and Abodollahzadeh (2012), investigated the upstream slope affected by horizontal drains under the rapid drawdown of water. In their study, the factor of safety and pore water pressure have been analyzed by using the finite element method and limit equilibrium method. Keeping in view of the above-mentioned issues, the seepage and stability of slope under various conditions such as saturation, tension cracks and effect of seismicity would be considered in the current research work.The paper focuses on the stability analysis for the cut (temporary) and permanent slope of the sedimentation basin area slopes and u/s of intake slopes under different conditions including ponding, without ponding and drawdown.

1 STUDY AREA

The case study dam is situated at Nauseri in Muzaffarabad. This concrete gravity dam is constructed on the Neelum river to divert around 280 m^3/s of river water through a long tunnel to the powerhouse. That river water is utilized by the power station to generate about 969MW of electricity and subsequently water discharges into Neelum River again as shown in Figure 1. The height of the dam is 47m and the width is 135m.

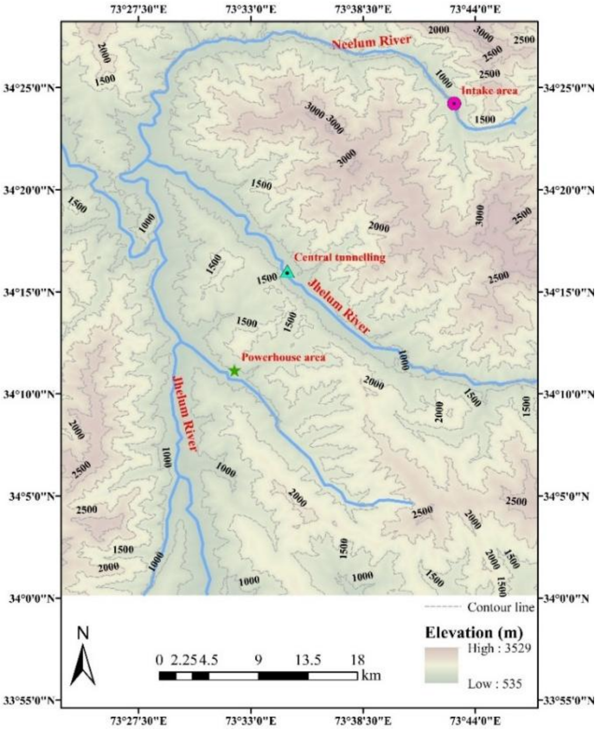

Figure 1: Location map of Neelum Jhelum Hydro Power Project

The site of the dam is situated at the intersection of the Indian and Eurasian plates within a complicated fault zone. Most of the area of the dam is comprised ofMurree Formation (Miocene age). The lithology ofMurree Formation contains grayish sandstone, reddish-brown mudstone, and shale with a lesser amount of conglomerates. In the dam site,Punjal Formation also exists which having lithology of volcanic elastic rocks.Punjal Formation contains different rock units included Marble, Sandstone and Limestone. Nevertheless, it was evident after construction thatinterbeddedsiltstones, as well asmudstones,were observed at all three project sites much more frequently than shales.Murree Formation is structurally highly distorted in the process of tight folds with complex faults and fractures.

II. ANALYSIS METHOD

Slide v 6.0 is used to analyze the stability of slopes on the basis of various conditions. This is one of the geotechnical programs that is based on the limit equilibrium method and can be used for the analysis of safety factor of circular and non-circular failure surfaces in different types of slopes. Firstly, a design is developed for thecross-section to investigate the slope stability problem after that the properties of materials and other geological parameters assigned to the program for numerical modeling. Then the slope stability analysis considering the limit equilibrium method (e.g. Bishop, Janbu simplified, Janbu corrected and Spencer) was performed consequently. The limit equilibrium method uses the perfectly plastic Mohr-Coulomb criterion to model soil stress-strain behavior. This method is a numerical staticanalysis technique, for maintaining the mass in equilibrium, depending on the three basic equations of equilibrium(Inc, 2002).In the end, simulation-based results for the minimum factor of safety acquired from the Slide v 6.0 Software.

Janbu corrected method is an alternative method is accessible in Slide and its brief detail is as follows:

$$\text{JanbuCorrectedSafteyFactor} = f_o * \text{JanbuSimplifiedSafetyFactor}$$

Where$f_o$is the modification factor that defines slope geometry and the strength factors of the soil.Janbusimplified method takes into account only force equilibrium, and interslice shear forces considered to be zero. The Janbu modification factor is an effort to justify these assumptions.

Keeping in view of the above facts, the governing method for analysis of slope stability is Janbu corrected method. One section Z is analyzed for sedimentation basin temporary and permanent slopes as shown in Figure 2.

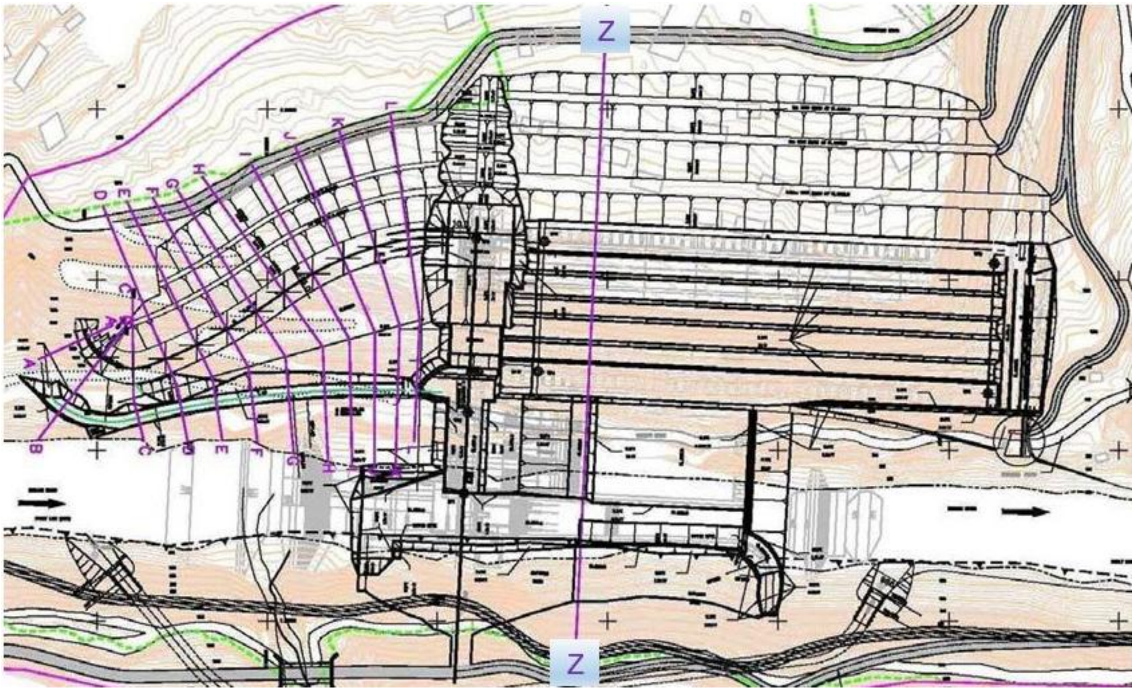

Figure 2: Plan showing sections used for analysis.

The sections A to L are also taken at the right angle to u/s of intake structure and the river training wall simultaneously is shown in Figure 2. In this way, the shortest sections are considered as compared to when simple perpendicular sections are taken u/s of the intake structure.

On the basis of the probability of occurrence, the following cases are considered for analysis are shown in Table 1.

Table 1: Various cases on the basis of different operating conditions.

Cases	Conditions	Saturation	Tension cracks	Seismic coefficient
Case-1	Without Ponding Condition	No	No	No
Case-2	Without Ponding Condition	No	Yes (9.3m)	No
Case-3	Without Ponding Condition	Yes	Yes (9.3m)	Yes (0.23H 0.11V)
Case-4	Ponding Condition	No	No	Yes (0.23H 0.11V)
Case-5	Ponding Condition	Yes	No	Yes (0.23H 0.11V)
Case-6	Drawdown Condition @ (1008 and 980 m)	No	Yes (9.3m)	Yes (0.23H 0.11V)

Furthermore, the finite element method using SEEP/W is applied for the simulation of stress and seepage analysis of the dam only for case-6 as rapid drawdown is the most critical case. While Slope/W based on limit equilibrium (LE) method (e.g. Bishop, Janbu and Spencer) is employed for simulating the slope stability of the dam under rapid drawdown condition. In comparison to LE methods, the shape and position of the failure surface are not assumed in the finite element (FE) method.This is perceived as an advantage over LE methods wherethe factor of safety (FoS) for a predefined failure surface is determined.As there is no slice idea in the FE analysis, presumptions on the lateral interslice forces between adjacent slices are not essential. The FE method maintains global stability unless a failure occursand can track incremental failure up to and beyond complete shear failures.

The FE model divides the template into several sections or meshes components. The stresses and strains for materials that form the slope stability model are determined with the constitutive laws. Failure generally takes place at locations in which the shear strength does not support the shear stresses.

III. PARAMETERS USED FOR ANALYSIS

The methodology includes field data collection through reconnaissance surveys and laboratory testing. The geotechnical laboratory testing program includes the direct shear test for undisturbed samples and disturbed samples. This material consists of slightly to moderately cemented conglomerates/overburden, the gradation of which varies in terms of the presence of fines and coarser material such as gravels and boulders. Excavation for the sedimentation basin is about 80m. On the other hand, u/s of the intake structure about 70 m deep excavation has carried out. This situation demands the careful design of the cut slopes as it may be affected due to earthquakes, floods, and poor drainage problems.
Summary of some of the results obtained from laboratory and field testing are shown in Table (2).

Table 2: Material parameters used for analysis

Material	**Cohesion**	**The angle of internal friction**	**Unit weight**
	KN/m^2	Degree	KN/m^3
Overburden	50	38	22
Backfill low permeable	50	38	22
Backfill high permeable	20	38	22
Rock	5000	37	26

IV. SLOPE STABILITY ANALYSIS

4.1 SLOPE STABILITY ANALYSIS OF SEDIMENTATION BASIN

One section Z is analyzed for the stability of slopes as shown in Figure 2 wherecut slopes are provided 0.6 H, 1V upto an elevation of 1016 m and thereafter 0.95 H, 1 V. For permanent slopes, compacted backfill is considered 1.5 H, 1 V from elevation 1017 m upto elevation 1040 m. For analysis of each case, the critical slip surface yielding the minimum factor of safety as case-6 is shown in Figure 5(a) and 5(b). Furthermore, mesh components of the finite element model and locations of selected points for pore water pressure were calculated by usingthe Geostudio program to analyze slope stability under rapid drawdown conditions is shown in Figure 3. Figure 4shows the pore water pressure is decreasing with time for the sedimentation basin.

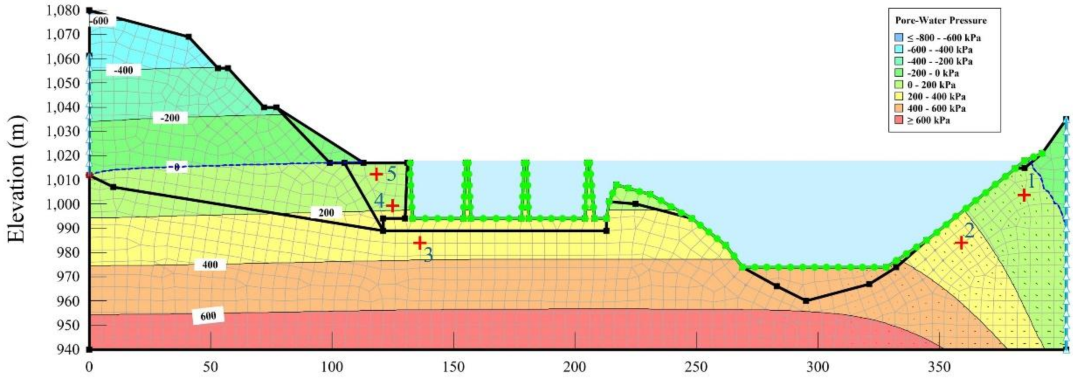

Figure 3: Finite Element Mesh and pore water pressure for the sedimentation basin.

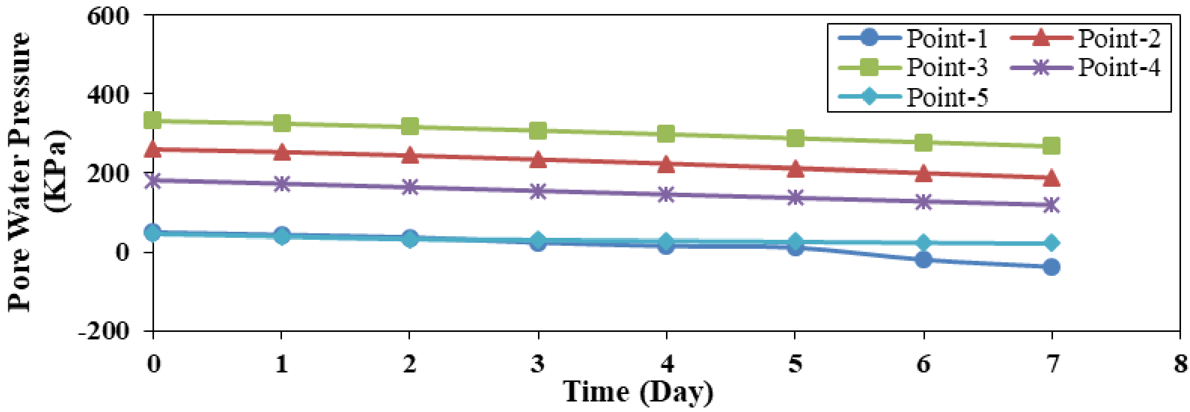

Figure 4: Change in pore water pressure with time for sedimentation basin under drawdown condition.

4.1.1 CUT SLOPES (TEMPORARY SLOPES)

For cut slope, berm of 5m is provided at the elevation of 1056 m, 1040 m, and 1016 m. Case-1 and case-2 are analyzed for cut slopes. In case-1, saturation, tension crack and seismic activity were not considered. While according to case-2, tension crack location with the depth of 9.3m is assumed at the start of the excavated slope and it is considered as completely filled with water. The results of case-1 and case-2 analysis for cut slopes are shown in Table 3.

Table 3: Summary of analysis of Cut slopes (Temporary) of Sedimentation basin

Case	Analysis Method –Slide V6.0			
	Bishop	**Janbu simplified**	**Janbu corrected**	**Spencer**
Case-1	1.303	1.247	1.306	1.295
Case-2	1.295	1.205	1.263	1.285

4.1.2 PERMANENT SLOPES

For permanent slopes, a berm of 5m is provided at the elevation of 1040 m and 1016 m after backfill. There are four cases have been analyzed. Case-3 is similar to drawdown (Case-6) except for the area above EL 1018m was assumed to be saturated without ponding condition. While Case-4 and Case-5 have been analyzed under ponding conditions. As the site of the dam is situated within a complicated fault and a seismically active zone. The value of the seismic coefficient is taken as 0.23 for horizontal and 0.11 for vertical components.Whereas for the rapid drawdown case, it was assumed that the water level is lowered from the estimated maximum level of 1018m to 1008m.

After detailed analysis, four cases (3, 4, 5 and 6 show relatively small factor of safety (FoS) as compared with other cases) comes out to be critical. The summary of their results is shown in Table 4.While the results of the factor of safety for rapid drawdown conditions acquired by the Geostudio program are shown in Table 5.

Table 4: Summary of analysis of slopes (permanent) of Sedimentation basin

Case	Analysis Method –Slide V6.0				Required FoS*
	Bishop	**Janbu simplified**	**Janbu corrected**	**Spencer**	
Case-3	1.207	1.106	1.158	1.208	1.05
Case-4	1.212	1.119	1.177	1.215	1.05
Case-5	1.226	1.089	1.169	1.232	1.05
Case-6	1.230	1.116	1.178	1.237	1.05

Required FoS*, Recommended FoS (NESPAK, 2010)

Table 5: Variation in FoS with time for sedimentation basin under drawdown condition.

Analysis Method for Case-06 – Geostudio				
Time (days)	**Bishop**	**Janbu**	**Spencer**	**Required FoS**
0	1.150	1.109	1.153	1.05
1	1.142	1.102	1.144	1.05
2	1.138	1.100	1.140	1.05
3	1.132	1.097	1.134	1.05
4	1.127	1.094	1.129	1.05
5	1.127	1.096	1.130	1.05
6	1.127	1.097	1.130	1.05
7	1.128	1.098	1.130	1.05

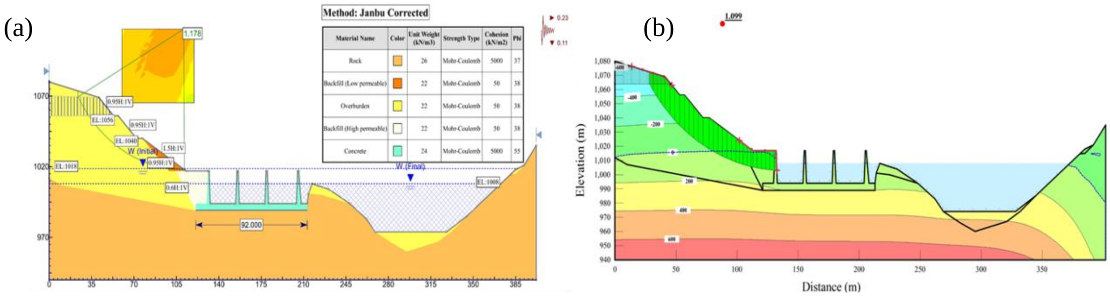

Figure 5: Slope stability analysis of the sedimentation basin (a) using Slide V6.0 (b) using Slope/W.

4.3 SLOPE STABILITY ANALYSIS OF U/S OF AN INTAKE STRUCTURE

Sections (A to L) are taken at the right angle to the u/s of intake structure and river training wall simultaneously. Keeping in view that, the shortest and longest sections are considered as compared to when simple perpendicular sections are taken u/s of the intake structure. Cut slopes are 0.6 H, 1V upto EL 1040 m and thereafter 0.95 H, 1 V. For permanent slopes, compacted backfill is to be considered 1.5 H, 1 V from EL 1018 m upto EL 1040 m. Shorter section D and longer section K are selected for analysis are shown in Figure 2. Furthermore, a uniform distributed load (UDL)is assigned to both counterfort and river training walls at 300 KN/m^2 and 50 KN/m^2, respectively to counterbalance concrete weight. Furthermore, 50 KN/m^2 is used at the bottom slab and slope to counterbalance 2 m of concrete at those portions.

Slope stability analysis of u/s of intake structureis analyzed for shorter section D and longer section K and the critical slip surface yielding the minimum factor of safety are shown in Figure 7 (a, b) and Figure 8 (a, b), respectively. Whereasthe location of selected points for the pore water pressure and mesh of the finite element model for the analysis of u/s of intake structure shorter section D and longer section K using the Geostudio program is shown in Figure 6 (a) and (b) respectively. The variation in pore water pressure during drawdown for shorter section D and longer section K is presented in Figure 9 (a) and (b), respectively.

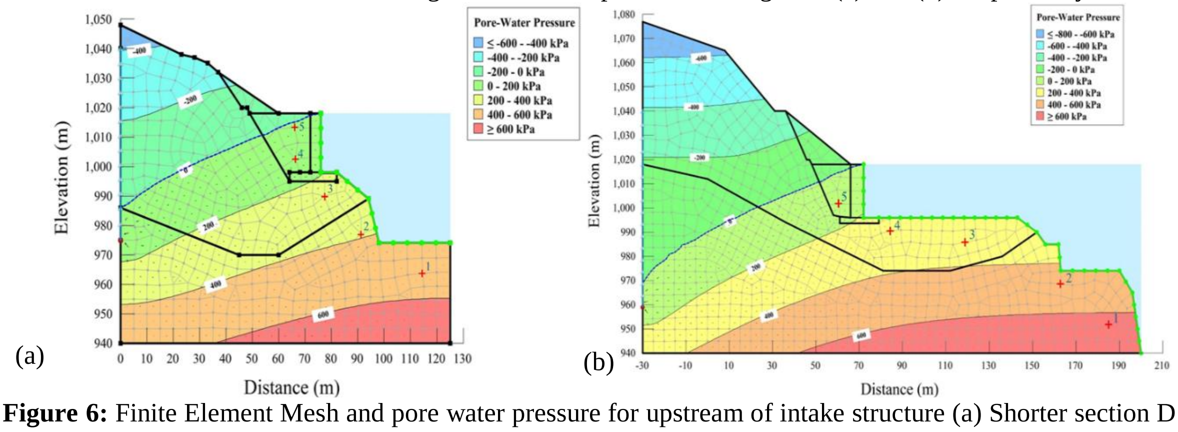

Figure 6: Finite Element Mesh and pore water pressure for upstream of intake structure (a) Shorter section D (b) Longer section K.

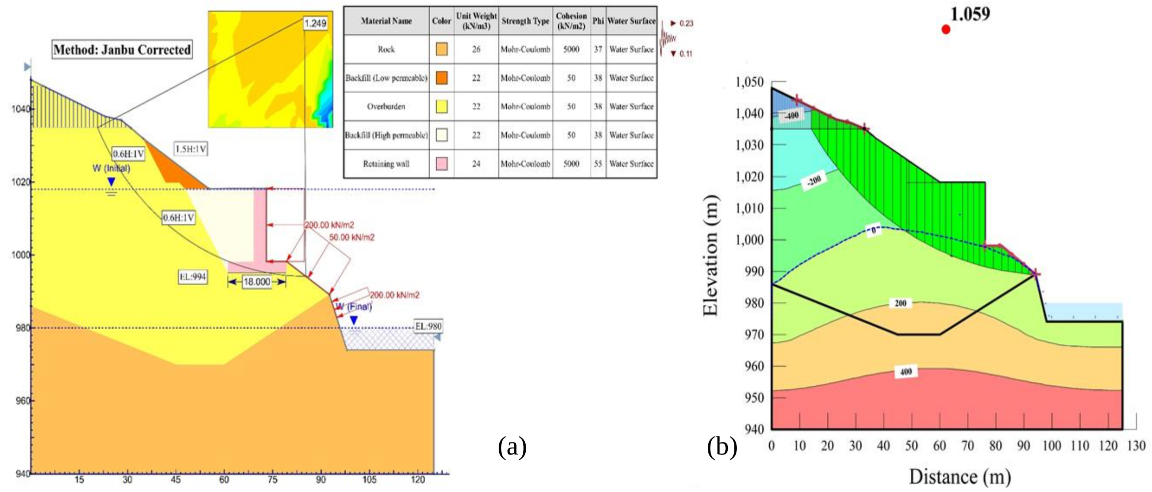

Figure 7: Slope stability analysis of upstream of intake structure for shorter section D (a)using Slide V6.0(b) using Slope/W

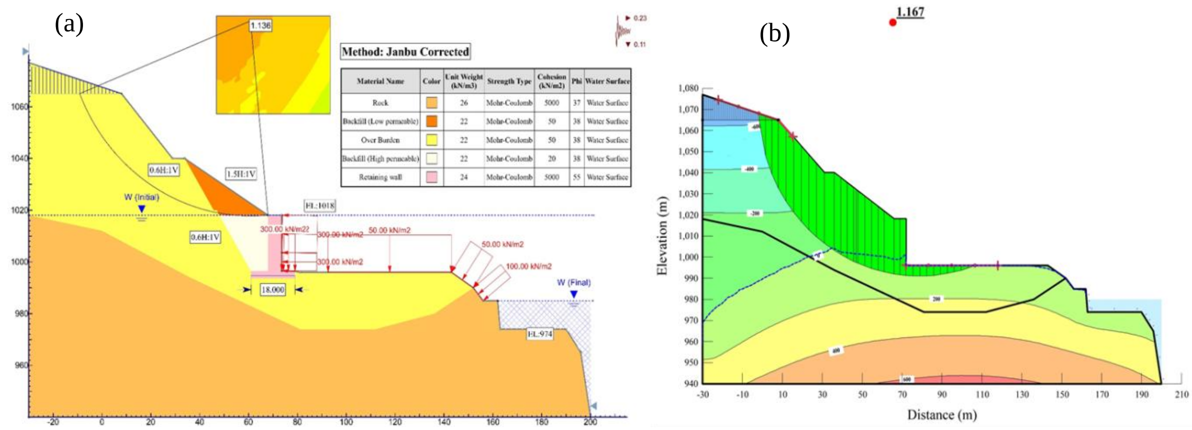

Figure 8: Slope stability analysis of upstream of intake structure for longer section K (a) using Slide V6.0 (b) using Slope/W

4.3.1 CUT SLOPES (TEMPORARY SLOPES)

Similarly, Case-1 and Case-2 are evaluated for the shorter section D and longer section K under without ponding conditions for cut slopes (Temporary slopes). For cut slopes, the berm of 3m is provided at the elevation of 1040 m to 1020 m. The results of Case-1 and Case-2 analysis for cut slopes are shown in Table 6 and Table 7.

Table 6: Summary of analysis of slopes (cut) u/sof intake structure (Shorter Section D)

Case	**Analysis Method –Slide V6.0**			
	Bishop	**Janbu simplified**	**Janbu corrected**	**Spencer**
Case-1	1.125	1.089	1.134	1.125
Case-2	1.081	1.022	1.059	1. 075

Table 7: Summary of analysis of slopes (cut) u/sof intake structure Shorter (Longer Section K)

Case	**Analysis Method –Slide V6.0**			
	Bishop	**Janbu simplified**	**Janbu corrected**	**Spencer**
Case-1	1.116	1.083	1.123	1.110
Case-2	1.076	1.025	1.059	1.067

4.3.2 PERMANENT SLOPES

Case-3 tocase-6 has been investigated for the shorter section D and longer section K based on different scenarios such as without ponding condition, ponding condition and drawdown conditions for the permanent slopes where the berm of 3m is provided at the elevation of 1040 m to 1028 m after backfill. For shorter section D, tension crack and seismic coefficient have been considered in Case-3. Whereas for the rapid drawdown case, it was assumed that the water level is lowered from the estimated maximum level of 1018m to 980m.

After detailed analysis, four cases (3, 6, 9 and 10 show a relatively lower factor of safety as compared with other cases) comes out to be critical. The summary of their results is shown in Table 8 and Table 9.Whereas the results of the factor of safety for rapid drawdown conditions acquired by the Geo-studio program are shown in Table 10 and Table 11.

Table 8: Summary of analysis of slopes (permanent) u/sof intake structure (Shorter Section D)

Case	Analysis Method –Slide V6.0				Required FoS
	Bishop	Janbu simplified	Janbu corrected	Spencer	
Case-3	1.028	1.083	1.163	1.305	1.05
Case-4	1.190	1.267	1.355	1.493	1.05
Case-5	1.133	1.262	1.348	1.491	1.05
Case-6	1.313	1.180	1.249	1.397	1.05

Table 9: Summary of analysis of slopes (permanent) u/sof intake structure (Longer Section K)

Case	Analysis Method –Slide V6.0				Required FoS
	Bishop	Janbu simplified	Janbu corrected	Spencer	
Case-3	1.164	1.028	1.090	1.074	1.05
Case-4	1.175	1.058	1.133	1.181	1.05
Case-5	1.175	1.031	1.095	1.181	1.05
Case-6	1.226	1.068	1.136	1.236	1.05

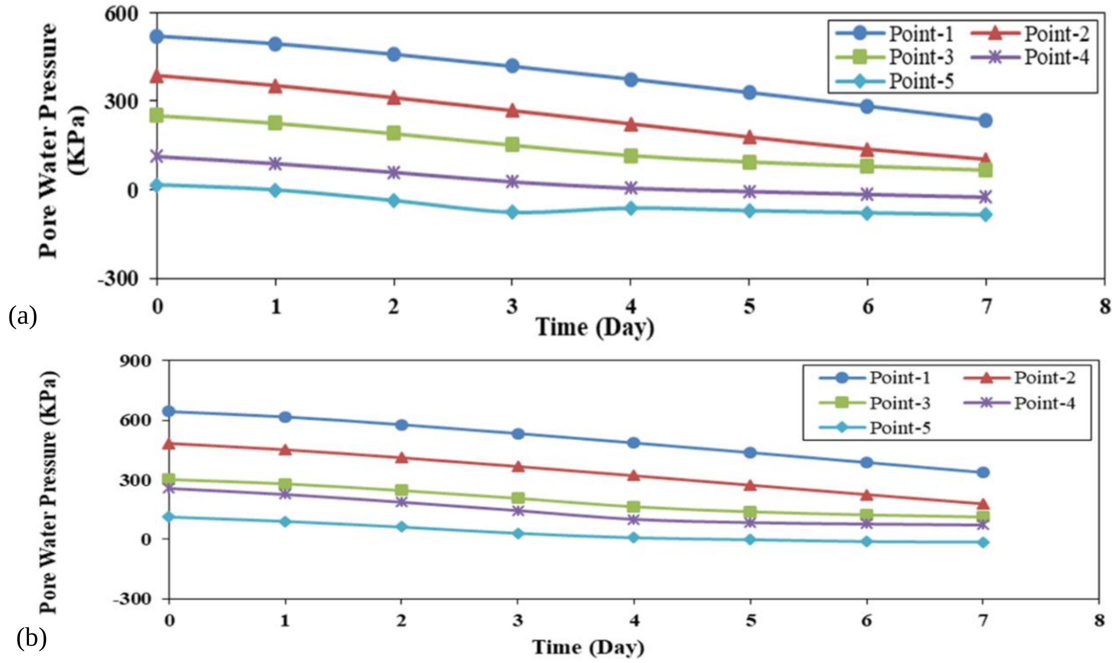

Figure 9: Change in pore water pressure with time for upstream slopes under drawdown condition (a) Shorter section D (b) Longer section K

Table 10: Variation in FoS with time for upstream of intake structure under drawdown condition (Shorter section D).

Analysis Method for Case-06 – Geostudio				
Time (days)	**Bishop**	**Janbu**	**Spencer**	**Required FoS**
0	1.266	1.148	1.278	1.05
1	1.173	1.069	1.188	1.05
2	1.123	1.027	1.138	1.05
3	1.100	1.010	1.114	1.05
4	1.095	1.007	1.107	1.05
5	1.110	1.021	1.12	1.05
6	1.133	1.04	1.143	1.05
7	1.154	1.059	1.164	1.05

Table 11: Variation in FoS with time for upstream of intake structure under drawdown condition (Longer section K).

Analysis Method for Case-06 – Geostudio				
Time (days)	**Bishop**	**Janbu**	**Spencer**	**Required FoS**
0	1.261	1.236	1.296	1.05
1	1.221	1.184	1.259	1.05
2	1.198	1.153	1.235	1.05
3	1.189	1.137	1.227	1.05
4	1.190	1.132	1.225	1.05
5	1.202	1.148	1.237	1.05
6	1.211	1.159	1.245	1.05
7	1.217	1.166	1.250	1.05

V. RESULTS AND DISCUSSION

The Slide v 6.0 software is used to analyze the stability of slopes on the basis of various conditions. Slope stability analysis was carried out based on a limit equilibrium method such as Bishop, Janbu simplified, Janbu corrected and Spencer method to compute the minimum factor of safety and investigate the location of the critical slip surface. Detailed stability for the cut (temporary) and permanent slope of the sedimentation basin area slopes and u/s of intake slopes under different cases were analyzed. Finite Element method using SEEP/W is applied for the simulation of stress and seepage analysis of the dam whereas Slope/W based on Limit Equilibrium method (e.g. Bishop, Janbu and Spencer) is employed for simulating the slope stability of the dam under rapid drawdown condition.

5.1 CUT SLOPES

The results of the factor of safety through all the applied methods for Case-1 and Case-2 either for sedimentation basin or u/s of intake structure indicating the decreasing trends of the factor of safety values in Case-2 due to the presence of tension crack which is similar to the result acquired byLi et al. (2018). However, Figure 10 (a, b and c) represent the factor of safety for both cases is greater than the required values of safety factor which indicates the cut slopes are stable for both Case-1 and Case-2.

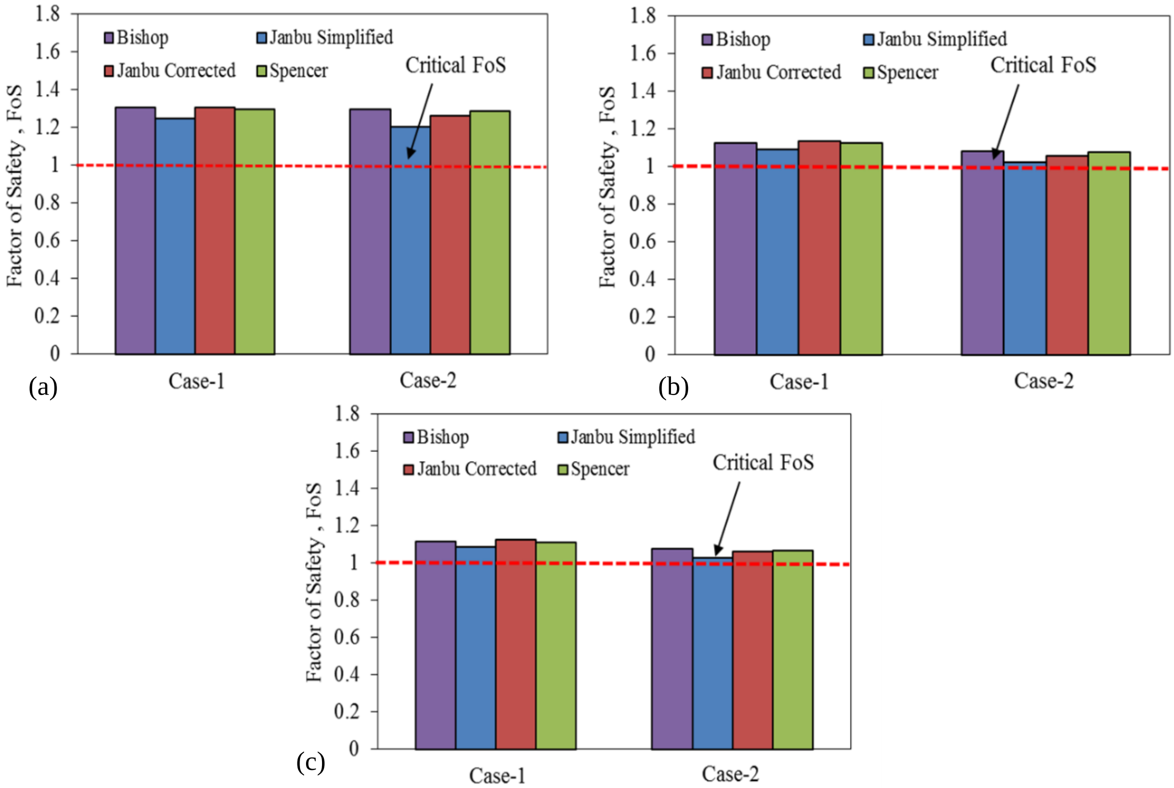

Figure 10: FoS compared with different methods for cut slopes (a) sedimentation basin (b) u/s of intake structure (shorter section D) (c) u/s of intake structure (longer section K).

5.2 PERMANENT SLOPES

The results of the factor of safety for Case-3 to Case-5 are greater than the required values of FoS for sedimentation basin as shown in Figure11. For Case-6, the factor of safety values acquired by the Slide program using the LE method is higher than the values acquired by the Geo-studio program using the FE method which is comparable to the results acquired by (Aryal, 2008; Ghiassian et al., 2009; Khabbaz et al., 2012). The main reason for different values is that the finite element method considered the stress-strain distribution in the soil. Furthermore, the inter-slices forces are larger and more precise that results lower factor of safety.

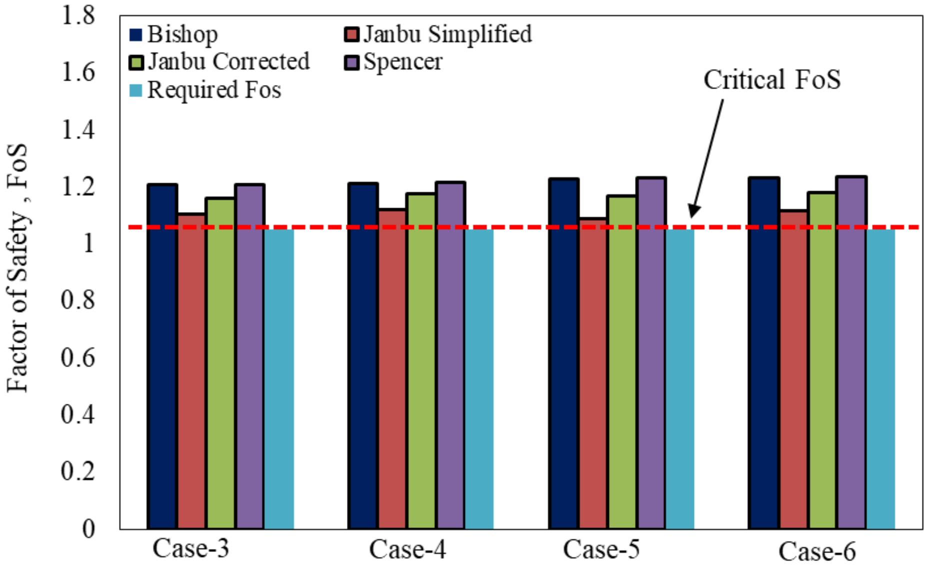

Figure 11: FoS using different methods compared with critical FoS for permanent slopes of the sedimentation basin.

Figure 12 reveals the minimum FoS calculated in Bishop's method is 1.127 at 4 days during the drawdown of water in reservoir within 7 days.The result corresponds to the minimum factor of safety through Spencer's method is 1.129 occurs in 4 days, while in Janbu's method the minimum factor of safety value is 1.094 within the same days.

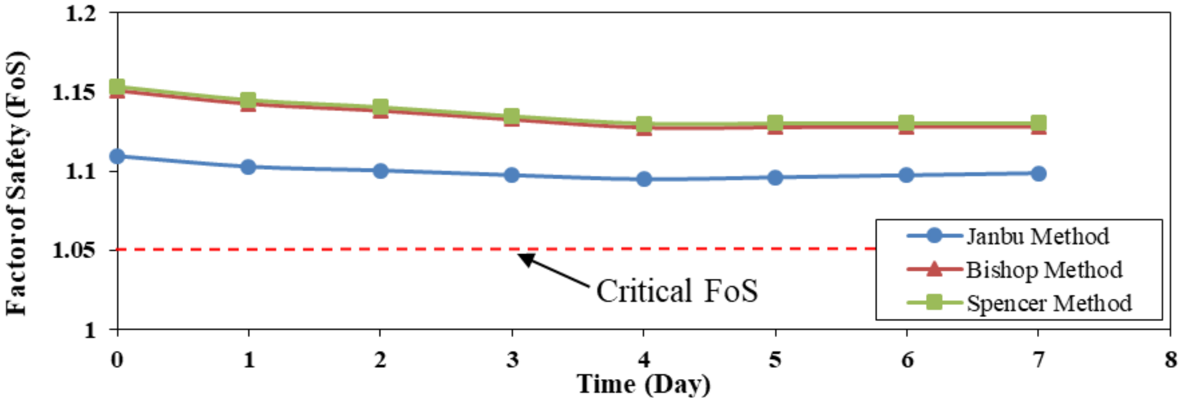

Figure 12: Change in minimum FoS with time for sedimentation basin using SLOPE/W (Drawdown condition)

Sections- A to L are investigated for the slope stability analysis of u/s of the intake structure. For shorter section D, the factor of safety values given by Bishop's method is less than the critical factor of safety as shown in Figure 13.Whichdoes not satisfy the minimum limit of the factor of safety. The other reason for these can be described that the force equilibrium equations that are not satisfied by Bishop's method,while the largest factor of safety values is given by the Spencer method under the same scenarios because Spencer's method satisfies both force and moment equilibrium and is applicable to failure surfaces of any shape.

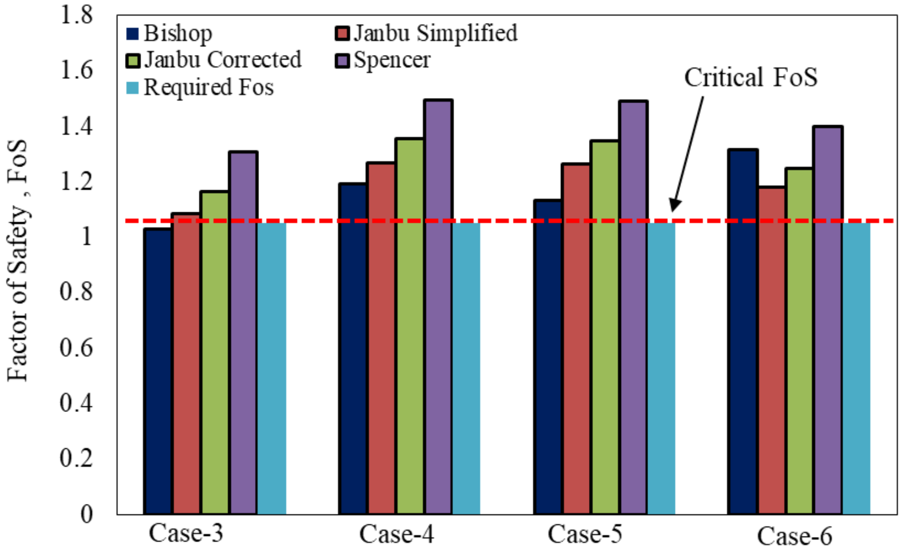

Figure 13: FoS using different methods compared with critical FoS for permanent slopes of u/sof intake structure (Shorter Section D)

Figure 14 shows the minimum factor of safety calculated inBishop's method is 1.095 at time 4 days during the drawdown of water in the reservoir within 7 days.The result inSpencer's method is 1.107 that occurs at 4 days. But in Janbu's method at the time 4 days, the minimum factor of safety value is equal to 1.007 which does not satisfy the required minimum safety factor.

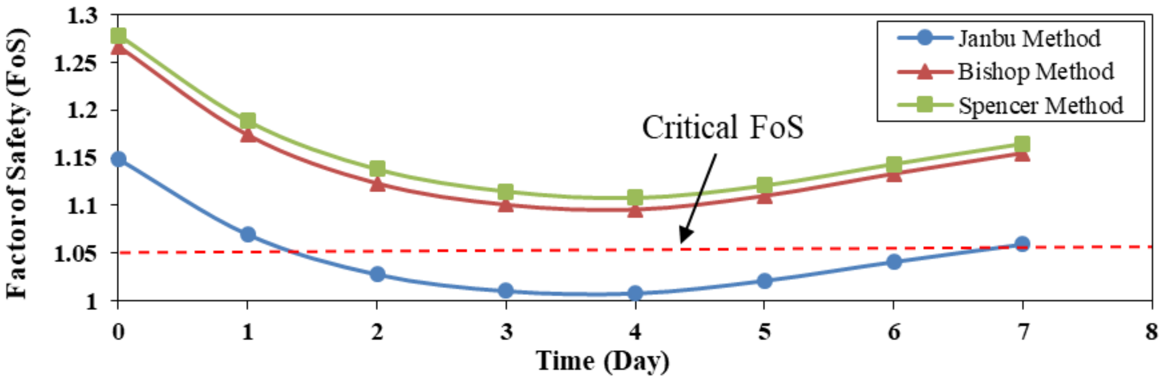

Figure 14: Change in minimum FoS with time for upstream slopes using SLOPE/W under drawdown condition (Shorter section D)

For longer section K, the obtained results show the least factor of safety values are given by Janbu simplified method under the consideration of tension crack and seismic activity for Case-3, ponding condition for Case-5 as shown in Figure 15. While the factor of safety values acquired by the Janbu corrected method satisfies the required minimum limit of the factor of safety. This can be described that Janbu simplified method takes into account only force equilibrium and does not satisfy the moment equilibrium equations. Therefore, it is concluded that the safety factor acquired by the Janbu modification factor compensated these facts in Janbu corrected method. The values are given by the Bishop method and Spencer method also satisfy the minimum limits of the factor of safety.

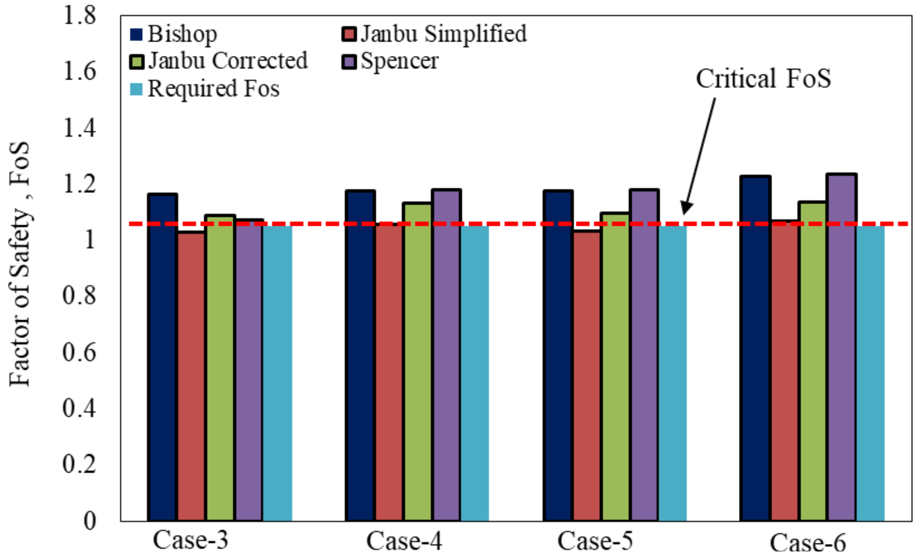

Figure 15: FoS using different methods compared with critical FoS for permanent slopes of u/sof intake structure (Longer Section K)

Figure 16 depicts the minimum FoS calculated in Bishop's method is 1.190 at time 4 days during 7 days drawdown of water in the reservoir and this result resembles the minimum factor of safety through Spencer's method which is 1.225 that occurs at 4 days. But in Janbu's method at the time 4 days, the minimum factor of safety value is 1.132. In the initial stage of drawdown, the factor of safety is decreasing up to 4 days because the pore water pressure dissipate slowly in the early stage of the drawdown process and the factor of safety values increases when the dissipation of pore water pressure increases with time. This increases the soil effective stress and shear strength. However, the factor of safety values is greater than critical values which indicates that the permanent slopes of the sedimentation basin are stable for all the cases under the above conditions.

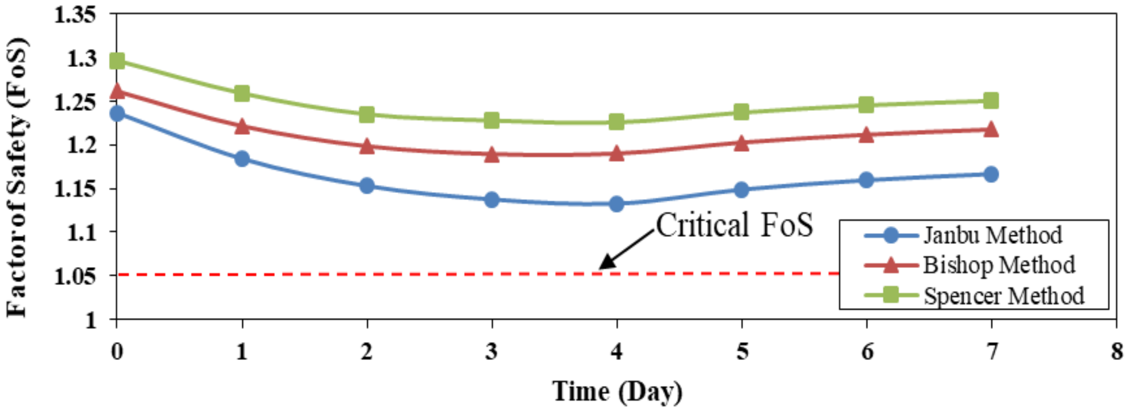

Figure 16: Change in minimum FoS with time for upstream slopes using SLOPE/W under drawdown condition (Longer section K)

VI. CONCLUSIONS

The stability of the dam was evaluated for the cut (temporary) and permanent slope of the sedimentation basin area slopes and u/s of intake slopes based on conditions such as ponding, without ponding and drawdown. For this purpose, Slide v 6.0 and Geostudio programs were used in the present study to compute the minimum factor of safety and investigate the location of the critical slip surface. The stability of slopes was analyzed on the basis of four different limit equilibrium methods including Bishop, Janbu simplified method, Janbu corrected method and Spencer method using the Slide program whereas the Geostudio program was used to analyze the slope stability under drawdown condition as it is the most critical case. There are six different cases of operation were considered. The dam safety analysis was evaluated based onthe minimum required factor of safety. The geometric design of the dam is acceptable according to the results of the factor of safety.For cut slopes, berm of 5 m is provided for the sedimentation basin while berm of 3 m wide is provided for the u/s of intake structure to make the stable slopes. Case-1 and case-2 have been analyzed for cut slopes. For permanent slopes, berm of 5 m is provided for the sedimentation basin while berm of 3 m wide is provided for the u/s of intake structure after backfill to increase the stability of permanent slopes. Case-3 to Case-6 have been analyzed for permanent slopes.For Case-6, the factor of safety values obtained by the Slide program using the LE method is higher than the values obtained by the Geo-studio program using the FE method. The main reason is the finite element method considered the stress-strain distribution inthe soil.The factor of safety values of the cut (temporary) and permanent slope of the sedimentation basin area and u/s of intake structure satisfies the minimum limits for all cases of operation. The results achieved from the numerical modeling found that the parameters studied have a significant influence on the safety factor of the slope stability of the damand thus it can be concluded that Neelum dam is safe against the danger of slope failure under the different cases of operation presented in this paper.

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