Analysis of Slope Failure: A Case Study from the Pump House Cut Slope Wall of Lift Irrigation Scheme, Telangana State, India

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Abstract. During the excavation of pump house-II of Kaleshwaram Lift Irrigation Scheme (KLIS) Link-II, sudden slope failure happened on the upstream wall from existing ground level +274.00 to +225.00 m level. In this paper the cause of slope failure at the upstream right-side wall of the pump house and support recommendations for the failure zone are discussed. 126 m long, 50 m wide (including annexure building) and 75.00 m deep, vertical shaft type pump house is being constructed for lifting the 361 cumecs water. Kinematic analysis was carried out to define the shape of the wedge, the orientation of the line of intersection and the direction of sliding. Equal angle projection was used for the analysis. Stability analysis was also done using the stability charts and Swedge RocScience software. The factor of safety (FOS) calculated using the stability chart is 0.44 and using Swedge is 0.4367. Mohr-Coulomb method of failure criterion is used for the analysis. After detailed analysis suitable engineering measures which include rock bolts, grouting and retaining RCC wall were recommended for the stabilization of the wedge portion of the upstream wall of the pump house and the same are being executed at the site.

Keywords: Pump House · Wedge Failure · Swedge Software

1 Introduction

Kaleshwaram Lift Irrigation Scheme (KLIS) Link-II, for drawl and lifting of additional 1.10 TMC of water/day (361 cumecs) from foreshore of Sripada Yellampally Project (FRL +148 m) to drop into Mid Manair Reservoir (FRL +318 m) with intermediate Devikonda Reservoir (FRL +247.470 m) is being constructed in Jagtiyal District of Telangana State, India. The main civil structural components of the project are approach channel, forebay, pressure tunnel, two surge pools, draft tubes, two pump houses and delivery mains. Vertical shaft type pump house-II is being constructed between Ch. 26.700 and 26.750 km near Namapur village. In structural design 1.50 m thick RCC lining is proposed as protection work for four sides of the pump house. In the pump house, four numbers of pumps, 130 MW capacity each will be installed for lifting 1.10 TMC of water per day. Dynamic head is 108 m while the static head is 92.18 m.

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Fig. 1. Development of tension crack and before monitoring crack was sealed and glass strips were put

During excavation it was observed that from ground surface (EL 274.00 m) to EL 268.50 m, soil and highly weathered rock mass was there. Hence, excavation was done with 1:1 (H:V) side slope providing 6.0 m wide berm and there afterwards excavation was done vertically. During benching down from EL 225.00 m, crack was observed on the upstream right side wall top berm at RL 268.50 m. From the initiation of a crack 5 mm wide, the monitoring of the crack was started (Fig. 1). Further as the top layer consists of soils and highly weathered rock mass, it was decided to remove the overburden to avoid further development of widening of the crack. While removal of overburden, sudden wedge failure happened from existing ground level +274.00 to +225.00 m level i.e., for an average depth of 18 m having width 43 m at top and 3 m at bottom level +225.00 m. The failure happened despite preliminary protection works of 25 mm diameter, 6 m length rock bolts at 2.3 m c/c with 100 mm thick shotcrete with wire mesh/SFRS. After detailed investigations/analysis and site geological conditions suitable engineering measures were recommended and are being executed at site.

2 Joints Characteristics and Kinematic Analysis

In the pump house complex of package-2 area coarse to very coarse grained pinkish grey granite and coarse to very coarse grained greyish pink granite with occasional porphyritic texture are exposed and these litho units are belonging to Peninsular Gneisses Complex of Archaean age [1, 2]. Wedge failure was along the prominent two joints and their details are given in Table 1. The orientations of tension crack, upper slope and slope face measured at site were 85° (dip) / 210° (dip direction), 45°/245° and 90°/245° respectively. The persistence of J1 was very high while J2 was high. J2 was widely spaced and rock mass comes under the massive category ISRM [3]. J1 was rough planar while J2 was smooth and undulating. Clay filling was not recorded while ground condition was dry. Between chainage 80 to 123 m, at RL 267.300 m, the maximum depth mapped was 28.89 m while minimum was 10.05 m. At RL 260.000 m, the maximum depth mapped

Table 1. Details of wedge forming joints

ID	Feature	Dip direction /amount	Persistence (m)	Spacing (cm)	Roughness	Aperture (mm)	Infilling	Ground Water	Weathering grade
1	Joint - J1	270/70	30–40	-	Rough planar	1–5	Hard filling	Dry	W-I
2	Joint - J2	170/85	> 15	30–90	Smooth undulating	Tight-2	Coated	Dry	W-II
3	Tension Crack	210/85	43	-	Smooth planar	5	Nil	Dry	W-I
4	Upper Slope	245/45	5.5	-	-	-	-	Dry	W-II to W-III
5	Slope Face	245/90	43.50	-	Rough Undulating	-	-	Dry	W-I to W-II

was 22.36 m while minimum depth was 3.50 m. The average depth of wedge from the excavated pay line was 18 m. Maximum wedge height was 43.50 m i.e. from EL 268.50 m to 225.00 m.

Kinematic analysis is carried out using RocScience Dips software to define the shape of the wedge, the orientation of the line of intersection and the direction of sliding. Kinematic analysis also gives an indication of stability conditions. Dips is a program designed for the interactive analysis of orientation-based discontinuities. Equal angle projection is used for the analysis. The plunge of the line of intersection is 68.45 degrees towards N247.19 direction (Fig. 2).

3 Stability Analysis Using Stability Chart and Swedge Software

Stability analysis is done using the stability charts of Hoek and Bray [4] using the Eq. 1. This method can be used if the slope is drained and there is no cohesion on both the side planes [5]. The dimensionless factors A and B are found to depend upon the dips and dip directions of the two planes. The parameters used for the analysis are given in Table 2.

$$FS = A\ \tan\phi_A + B\ \tan\phi_B \tag{1}$$

where: FS = Factor of Safety, tan ϕ_A = Friction angle for joint plane A, tan ϕ_B = Friction angle for joint plane B, A & B = Dimensionless factors

The first step in the analysis is to calculate the absolute values of the difference in the dip angles, and the difference in the dip direction angles. For a dip difference of 15°, the values of ratios of A and B are determined from the two charts for a difference in dip direction of 100°. The values of A and B are 0.39 and 0.15 respectively, and substitution in the above equation given the factor of safety of 0.44. The factor of safety calculated from Eq. 1 is independent of the slope height, the angle of the slope face and the inclination of the upper slope surface.

The Swedge RocScience software is used for the analysis of wedge failure. Swedge is an interactive and simple analysis tool for evaluating the stability of surface wedges in

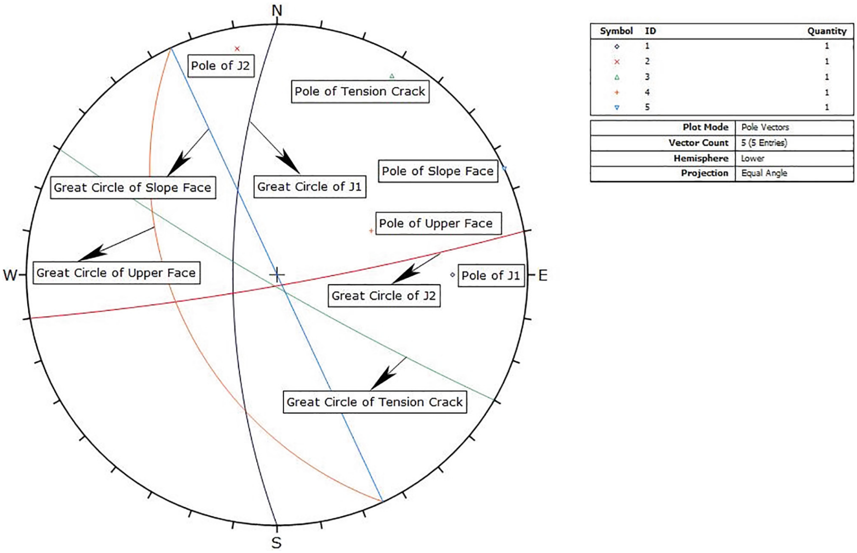

Fig. 2. Stereonet view showing the poles and great circles of joints, tension crack, slope face and upper face

Table 2. Wedge stability analysis for friction only

	Dip (degrees)	Dip Direction	Friction only
Plane A	70	270	37
Plane B	85	170	45
Difference	15	100	-

rock slopes, defined by two intersecting discontinuity planes, the slope surface, and an optional tension crack. Deterministic analysis is done for the determination of factors of safety. Mohr-Coulomb method of failure criterion is used for the analysis. The summary of the analysis result is given in Table 3. The factor of safety calculated is 0.4367 (Fig. 3).

4 Discussions and Conclusion

This type of failure during the benching down of deep excavation sometimes happened under unexpected geological occurrences. Such failure zones should be stabilised and protected properly to avoid such failures in due course of time. Because of this incident the excavation of the pump house was delayed by 4 months. For the stabilization of slope, it was recommended to make a ramp on fallen muck and put 7.5 m long, 25 mm diameter tensioned rock bolts of Fe $\geq$500 at 5-to-10-degree upward inclination at 2.0 m spacing on both joint planes. Size of the bearing plate recommended was 200 $\times$ 200 $\times$ 10 mm. After putting the rock bolts, it was recommended to remove muck at a 10 m

Table 3. Summary of the analysis result.

Sr. No.	Parameter / Units	Values
1.	Wedge height (on slope) [m]	43.50
2.	Rock unit weight [MN/m3]	0.027
3.	Wedge volume [m3]	8508.68
4.	Wedge weight [MN]	229.734
5.	Normal Force (joint 1) [MN]	82.689
6.	Normal Force (joint 2) [MN]	30.999
7.	Normal Stress (joint 1) [MPa]	0.053
8.	Normal Stress (joint 2) [MPa]	0.048
9.	Shear Strength (joint 1) [MPa]	0.040
10.	Shear Strength (joint 2) [MPa]	0.048
11.	Driving Force [MN]	213.68
12.	Resisting Force [MN]	93.31
13.	Mode: Sliding on Joints	1 & 2

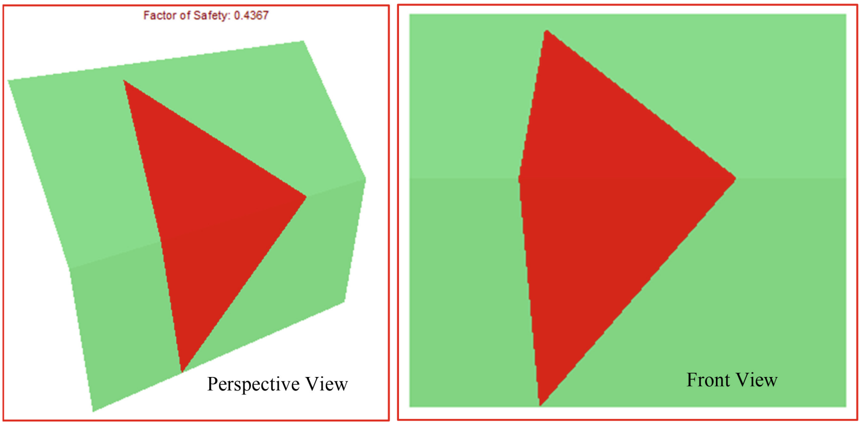

Fig. 3. Schematics of the identified wedge

interval height, then again rock bolts were put then again muck was removed. From the top surface, 6.0 m long, 25 mm diameter tensioned rock bolts at 5-to-10-degree upward inclination (Fe $\geq$500) at 2.0 m spacing on both joint planes were recommended. Curtain grouting (with 2.5 to 3.5 kg/cm^2 pressure) up to 25 m depth from the EL + 268.50 m was recommended using primary and secondary holes which will be done after the construction of the design concrete wall. 6 m spacing for the primary and 3 m for secondary holes was recommended. Grouting was recommended from 2.0 m away from the excavated face in a single row. After the completion of rock slope protection measures, construction of a concrete retaining wall was recommended which is under construction (Fig. 4). Detail of a concrete retaining wall at different chainages is given in Fig. 5. For the different chainages i.e. from 80 to 85 m, 90 to 95 m, 100 to 115 m and 120 to 123 m details are given in the Fig. 5. It was recommended that lining above rock toe shall be taken up only after completion of lining below. For the design of slope stabilization measures, site geological conditions, the data from kinematic analysis and geometry of wall was taken into consideration and in view of importance of the structure, FOS 2 was taken.

Fig. 4. View of wedge failure and concrete retaining wall is under construction

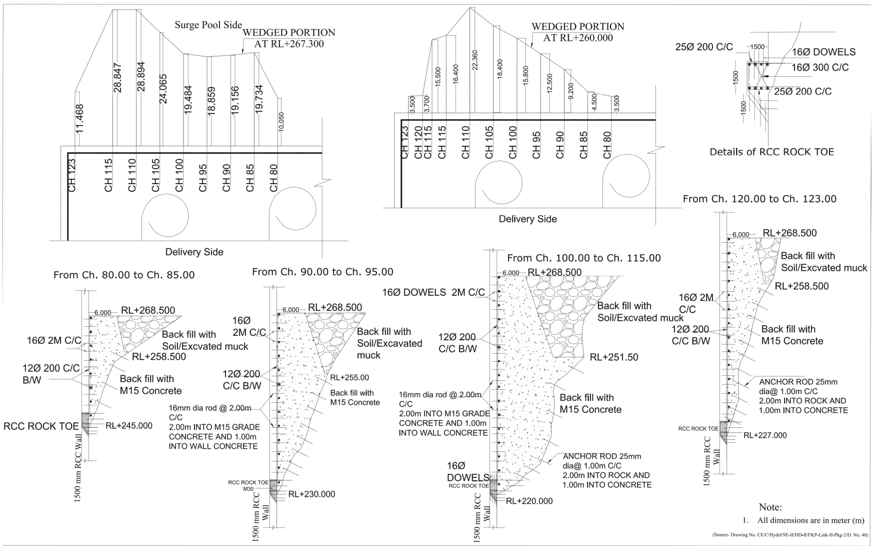

Fig. 5. Details of a reinforced cement concrete retaining wall at different sections

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