Shahrood University of Technology

Journal of Mining and Environment (JME)

Journal homepage: www.jme.shahroodut.ac.ir

Iranian Society of Mining Engineering (IRSME)

Stability Analysis and Construction of Highest Gabion Wall of its own Kind in India - a Case Study

Avinash Bhardwaj*, Ajay Bhardwaj, Madhusudan Sarda and Namrata Bichewar

Gabion Technologies India Private Limited, India

Article Info

Received 13 October 2023

Received in Revised form 29 October 2023

Accepted 13 November 2023

Published online 13 November 2023

DOI: 10.22044/jme.2023.13720.2538

Keywords

Slope stability

Gabion retaining wall

Bishop method

GEO5

Mitigation measure

Abstract

Narmada valley development authority proposed a scheme under, which 12.6 cumecs of water from the Hathani River (Tributary of Narmada) will be lifted to irrigate the command area. At the pumping station lies near Alirajpur, Madhya Pradesh, India. There was a need to protect the slope on both sides as water thrust from the upstream side may lead to failure of the slope. This paper presents the stability analysis of the slope using the GEO5 software. It was observed that the terrain at the site was a mixture of soil and rocks. The unit weight of the rock and backfill soil observed was 21 kN/m3 and 18 kN/m3. Using numerous techniques factor of safety was calculated for the particular slope, and it was observed that a suitable mitigation measure needs to be provided to prevent the failure of the slope. The inclusion of a gabion retaining wall increased the slope's safety factor significantly. The proposed mitigation measure was executed at the site, and the completed wall has not shown any damage till date. The analysis of the slope's stability results, as well as its construction of the gabion retaining wall recommended as a protective measure, are presented in this work.

1. Introduction

Slopes are affected by a variety of phenomena including soil erosion, weathering, seismic activity, and changes in groundwater levels, whether present in natural landscapes or created as part of construction activities. These factors can cause a slope to lose its structural strength, which can result in landslides, erosion-related damage, and serious safety risks. Slope stabilization techniques are essential for protecting infrastructure, property, and the environment. Slope stabilization is a fundamental part of geo-technical and civil engineering that aims to minimize or mitigate the dangers associated with the instability of natural and man-made slopes. They provide long-term stability of slopes in a sustainable and economical way, in addition to protecting against erosion and landslides. The choice of a particular slope stabilization technique depends on various factors including the slope's characteristics, geological conditions, environmental impact, and project goals. Numerous research studies have been conducted in the past to stabilize unstable slopes by using various techniques [1-6].

Slope stabilization using gabion walls is an innovative and environmentally friendly approach to address a common problem in civil engineering and land management [7-8]. Gabion walls are sustainable structures that have been employed worldwide to prevent erosion and enhance slope stability. Gabion walls are composed of wire mesh containers filled with various types of natural stone or rock materials. The containers are typically rectangular or box-shaped, and are interconnected to form a coherent structure. They are often cost-effective, especially for smaller-scale projects, due to their use of readily available materials like rocks or stones and relatively simple construction processes [9]. From an environmental perspective, gabion walls have a relatively low impact, as they

Corresponding author: avinash@gabionindia.com (A. Bhardwaj)

utilize natural materials and promote plant growth, minimizing disruption to ecosystems [10].

A successful case study of a 3 m high gabion wall reported at the Mussoorie-Chamba bye-pass to protect buildings on the slopes. The performance of the gabion wall was examined for three years, and no discomfort or tilting was noted in the structures [11]. The influence of factors such as wall height, wall inclination, backfill slope, and surcharge load investigated on the stability of the gabion retaining wall analytically for different parameter values [12]. A case study of a slope failure suggested gabion retaining wall remedial measures at the Chorla Ghat [13]. A mechanically stabilized earth Gabion wall is recommended because it is very permeable and prevents the build-up of water pressure, while taking into account the site's terrain and circumstances. The resilience of the gabion wall evaluated against lateral loads in terms of gabion wall basket arrangement and gabion basket geometry modification, which is utilized efficiently to prevent erosion in flood zones [14]. Elastic and plastic deformation for various types of reinforced soil structures investigated under load by subjecting the loading-unloading cycle to different loading levels [15]. The lateral and vertical deformation behavior of green reinforced gabion retaining walls examined experimentally by applying dynamic loads with varied frequencies and amplitudes to predict fatigue damage and fatigue life with train load and speed [16]. Amato *et al*. [17] experimentally and analytically investigated the shear and bending deformation of a multibody of gabion blocks that are planned to be employed as a roadside impact absorption device. The failures and defects of gabion walls analyzed as a result of failure types including bulging, corrosion, stone erosion, backfill fractures or erosion foundation soil acquired by watching walls in various areas [18]. An analytical study conducted using statistics to examine the impact of characteristics like wall height, base length, angle of internal friction, wall angle, and backfill slope on the construction of gabion retaining walls [19]. Stability analysis using the GEO5 software performed with inclusion of retaining wall. The results showed a significant increase in factor of safety of the slope. The gabion wall was constructed finally at the site because of its better stability and cost effectiveness. The constructed wall has not shown any damage, and resisted the slope from further sliding as per the field observation in December 2015 [20]. For the best slope stabilization infrastructure, parametric studies of the slope height, the ratio of the embedded length of the pile to the thickness of the unstable soil layer, and the ratio of the spacing to the diameter of the pile have been conducted using the GEO5 software [21]. This type of gabion-faced geogrid-reinforced retaining walls has been used to protect the road against slope stability. A real-scale gabion retaining wall with a 4.5 m wall height was analysed using the GEO5 software under the effect of water pressure in a loaded-unloaded case and its crest displacement was measured for comparing the experimental one [22]. Pereira and Fernandes [23] performed a cost comparison between gabion wall and concrete gravity retaining wall. It was found that the total construction cost of gabion retaining wall was comparatively less as compared to cost of concrete gravity retaining wall. The total cost of concrete gravity wall is 47.93% higher than the total cost of gabion wall.

As observed in the preceding literature study, there are various factors that impact the safety factor of a slope strengthened by retaining walls such as gabion retaining walls. In the present study, the effectiveness of the slope stability using the GEO5 software from a safety perspective was determined for both the static and dynamic situations.

2. Project description

Narmada valley development authority (NVDA) proposed a scheme under which 12.6 cumecs of water from the Hathani River (Tributary of Narmada) will be lifted to irrigate the command area. The objective of the project was to increase the production of agriculture and improve the living standards of farmers in the designed command area of Alirajpur district in Madhya Pradesh, India. At the pumping station, there was a need to protect the slope on both sides as water thrust from the upstream side may lead to failure of the slope. Thus, the primary objective of this work included stability analysis and construction of a 38-meter-high wall with a limited base area, which can resist the water thrust and slope movement on both sides.

Gabion Technologies India Private Limited (GTIPL) team visited the site to provide a site-specific design solution. It was observed that the terrain at the site was a mixture of soil and rocks. In general, upper strata rock was fragmented and highly weathered, but with depth, weathering decreased, and fractured to hard rock was encountered. The hill was partially cut, and at the middle portion, a pumphouse was to be constructed by Larsen and Toubro (L&T) and the cutting side slope of height 38 m was to be stabilized with a suitable preventive measure by GTIPL.

3. Preventive measure

A decrease in driving forces or an increase in resisting forces determines the effectiveness of a control measure for landslides. According to Holtz & Schuster [24], the choice of an effective corrective action is based on: (a) engineering feasibility, (b) economic feasibility, (c) social acceptability, and (d) environmental acceptability. The measures are divided into four categories: drainage, retaining walls, internal slope strengthening, and alteration of slope geometry. The most common approach for giving an adequate stability to an unstable slope is the construction of retaining walls. In the present situation, it was decided to design a 38 m high retaining wall on each side of the pump-house to resist water thrust and prevent the slope movement. The type of retaining wall suitable for the respective slope depends on the situation, design expertise, material availability, cost, etc. Gravity retaining walls made of concrete and stone masonry are held together by their mass. There are several possibilities for selecting an appropriate retaining wall to sustain the failing slope. Chikute & Sonar [25] compared the per running meter cost of 5 types of retaining walls such as stone masonry, cantilever, counterfort, buttress, and gabion retaining wall. From the comparative study, it is found that the Gabion wall is one of the most economical alternatives of retaining wall next to a stone masonry wall for 5 m height. The percentage variation in cost per running meter length observed for gabion retaining wall was 30%, 54% for buttress, 61% for counterfort, and 80% for cantilever when compared with stone masonry.

After considering all site factors, a gabion retaining wall of height 38 m was recommended by GTIPL on each side of the pumphouse, so that the hill slope will remain stable in both submerged and dry conditions. Gabions are flexible walls that allow for some movement to the supported structure. It is made up of stacked stone-filled gabions tied together with wire and it takes less time to build as no curing period is needed. Gabion walls are usually battered (angled back towards the slope) or stepped back with the slope, rather than stacked vertically. Gabion wall method of slope stabilization offers a unique set of advantages and considerations when compared to other commonly used techniques [10]. Its adaptability to a variety of slope shapes and sizes is one of its distinguishing qualities. Gabion walls, in comparison with rigid retaining walls, can tolerate ground movement and settlement, making them particularly appropriate for dynamic conditions. Although gabion walls provide a number of advantages, a more thorough evaluation must take into account their shortcomings and possible disadvantages. For gabion barriers to remain effective, regular maintenance may be necessary. The stability of the wall may be impacted over time by the corroding wire mesh and shifting or deteriorating stones [26]. To remedy these problems, routine maintenance and inspections are required, which may incur extra expenses.

4. Slope Stability analysis

Evaluation of geotechnical properties, particularly the shear strength parameters of soil strata, are critical for assessing the stability of slopes. Laboratory testing was performed on the soil samples that were obtained from the field. For a better representation of the variation in the soil profile in the slope, representative samples were collected from both side of the pumphouse site. The geo-technical parameters of the soil used for the analysis are shown in Table 1.

Slope stability analysis is used to assess the safety of both natural and man-made slopes (embankments, excavations, mining, etc.) under external and internal loads. The stability of slope can be investigated by using a variety of techniques such as limit analysis, limit equilibrium analysis, and different numerical approaches. The approach that is most often employed among these is limit equilibrium. The limit equilibrium approach analyses the equilibrium of the slope using several computational techniques for circular or non-circular cross sections (also known as slip surfaces) perpendicular to the length of slope.

There are several limit equilibrium techniques that differ mostly in satisfying the equilibrium criteria. The most popular of these techniques are the Bishop method of slope stability analysis. Bishop's simplified method satisfy the moment equilibrium and force equilibrium in vertical direction. In the current study, other techniques including Morgenstern-Price (M-P), Janbu's, Fellenius, and Spencer method were also utilized to assess the slope's stability. In the present case, the failure mode appears to be circular as inferred from field observations. Circular failure is the most prevalent kind of failure when the material is soft and weak and has no preferred planes of weakness. To account for the seismic effect, the study was performed in both static and pseudo-static circumstances.

5. GEO5 software

The stability of the slopes under consideration is assessed using the FEM-based software GEO5. GEO5 is a reliable software package that solves geo-technical issues using standard analytical methods and the Finite Element Method (FEM). GEO5 has been designed to solve the vast majority of geotechnical projects, ranging from the most fundamental (foundation, wall, and slope stability verification) to highly specialist programs (tunnel analysis, building damage due to tunnelling, and rock stability). The geo-technical techniques incorporated into the GEO5 program are utilized globally. GEO5 employs a novel approach of implementing standards and partial factors that are independent of the structure input. The geometry of the slope, inclination, height, and soil parameters for soil in each zone are the input parameters for GEO5. In past many researchers have worked with GEO5 software and recommended to use it [27-29].

The analysis was done on a trial-and-error basis. Gabion structures were developed for slopes by employing the rigid body option and applying it to the structure. The analysis was performed for different approaches employed in the software. The GEO5 'Gabion Wall' and 'Slope Stability' software was applied in this investigation. The geometric coordinates of the slope to be studied were then entered. To ascertain the type of soil classification offered according to GEO5, soil characteristics, namely the unit weight, the angle of internal friction, and the cohesiveness were used as input data. Using the coordinates of the slip circle's radius and centre (x, y), the initial slip surface was generated. The Bishop/ Morgenstern-Price (M-P)/Janbu/Fellenius/Spencer approach was then applied to the study. As per the analysis, the sliding and the resisting moments were found out. The stability of the slope is expressed in the form of a 'Factor of Safety' (FS), which is defined as the ratio of shear strength (or equivalent force or moment) to shear stress (or corresponding force or moment) along the predicted slip surface. The stability of the slope is shown by the corresponding FS for each slip surface that assumes the minimal factor of safety, known as the critical slip surface for the slope. When the factor of safety is less than 1.50, it suggests unstable situations, and when it is larger than 1.50, it shows stable conditions. The target factor of safety for a certain slope is determined by the type of the slope, its significance, and functions.

6. Slope stability analysis using GEO5 software

The two-dimensional slope stability analysis software GEO5 was used to compare the stability of the slope with and without preventive measures. The position of critical slip surfaces was determined using an algorithm built into the program. For a more accurate stability assessment, the static and pseudo-static analysis was conducted utilizing numerous techniques. Mononobe-Okabe technique was used for earthquake analysis. IS:1893-2002 [30] standards were used to determine the corresponding pseudo-static forces acting on the slope. According to IS 1893- 2002 [30], the location in Alirajpur, Madhya Pradesh is in seismic zone III. The horizontal seismic coefficient for the particular site was determined to be $K_h = 0.16$ and coefficient of vertical acceleration is taken half of horizontal acceleration i.e. Kv = 0.08. Table 1 depicts the geo-technical characteristics of the fractured rock, hard rock, and gabion in fill material. The tensile strength of mesh and joint bearing capacity of gabion boxes are 52 kN/m and 40 kN/m, respectively. For active earth pressure analysis coulomb method used and Caquot-Kerisel method used for passive earth pressure analysis. Ground water table in front and behind of the structure lies at a depth of 2.00 m.

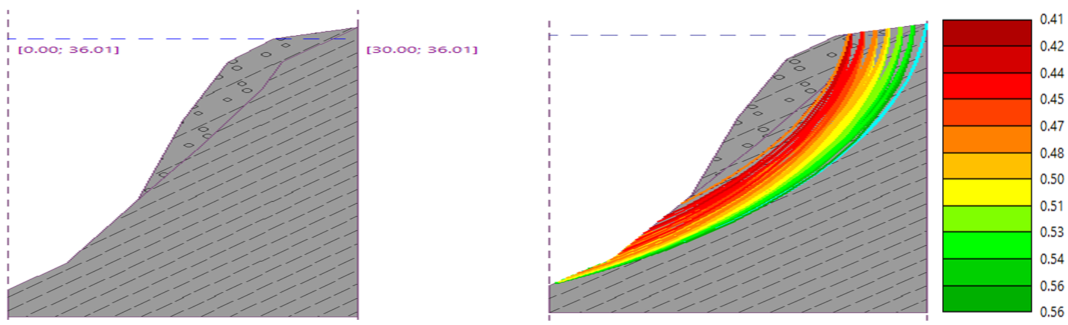
Table 1. Geo-technical characteristics of rock, backfill, and gabion in fill material.

Property	Rock	Back fill material	Gabion infill material
Unit weight (kN/m^3)	21	18	17
Angle of internal friction (^{o})	34	30	34
Cohesion (kPa)	60	10	0
Saturated unit weight (kN/m^3)	22.5	19	-

Figures 1 and 2 display the profile and stability analysis for the slope under consideration. From the stability analysis, it has been found that factor of safety observed using different methods is very less than minimum factor of safety value, i.e. 1.50 for both type of forces (static and pseudo-static), and it is almost equal to zero for pseudo-static condition (Table 2). This shows that it was very important to stable the slope with a gabion retaining wall to stop the movement of the slope towards pumphouse.

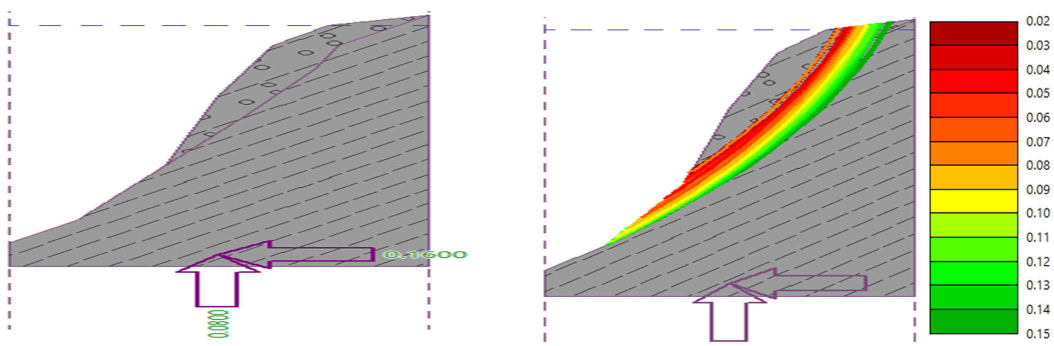
Table 2. Factor of safety observed for slope under consideration

Method	FS for static forces	FS for pseudo-static forces
Bishop	0.22	0.02
Morgenstern- Price	0.20	0.12
Fellenius	0.21	0.01
Spencer	0.19	0.13
Janbu	0.19	0.13



(a) (b)

Figure 1 (a). Cross-section showing profile of slope: (b) Critical slip surfaces of respective section shown using Bishop analysis under static forces.



(a) (b)

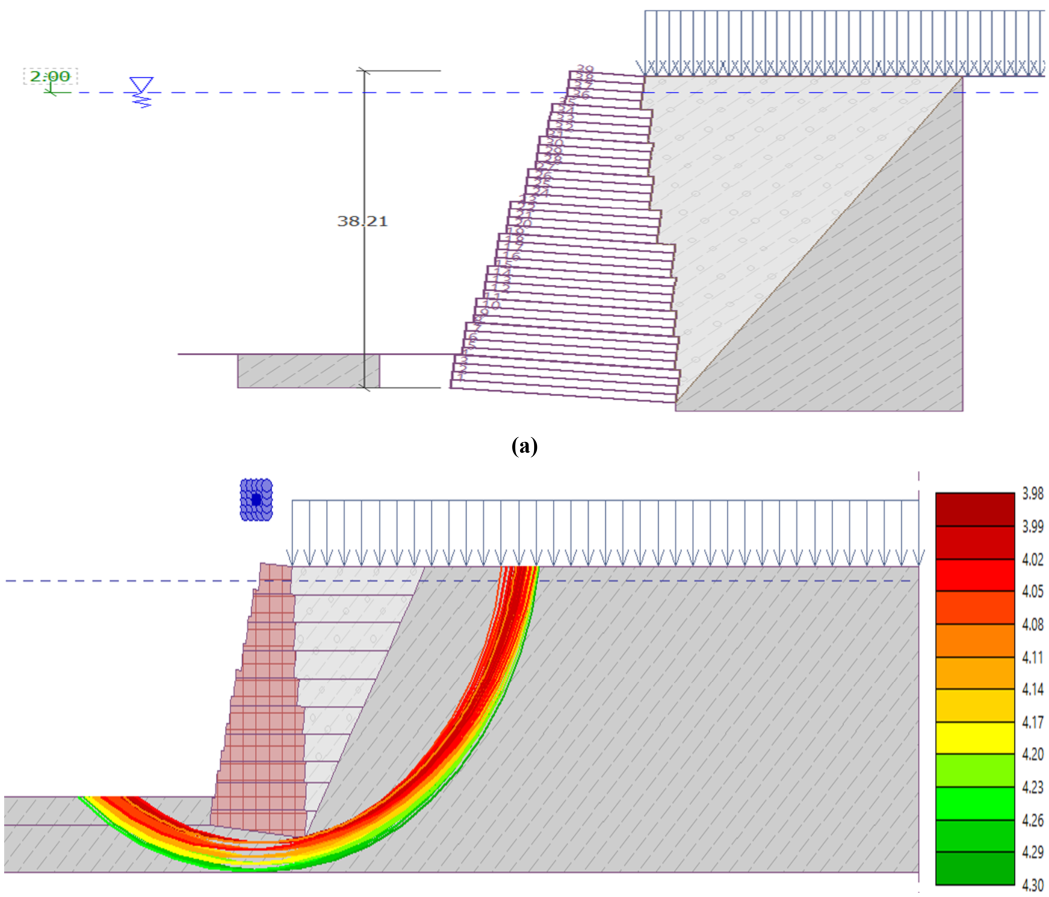
Figure 2 (a). Cross-section showing profile of slope. (b) Critical slip surfaces of respective section shown using Bishop analysis under pseudo-static forces.

The gabion wall was designed as a flexible retaining structure battered at 6^o with the vertical towards the slope face. A permanent surcharge of magnitude 10 kN/m^2 was placed on terrain. To obtain a desired factor of safety, many analyses were performed by changing the height, width, and placement of the gabion wall. Additionally, the minimum specified values given in IS 14458 [31] were used to compare the external and internal stability of gabion walls. Table 3 presents the factor of safety values observed using different methods for the typical section of the slope with gabion retaining wall for both static and pseudo-static forces. From the stability analysis, it has been found that factor of safety observed is very much satisfactory, and about 165% and 78% more than minimum factor of safety (1.5) for both static and pseudo-static conditions, respectively. Figures 3 and 4 display the profile and stability analysis for the slope under consideration with a gabion retaining wall battered at 6^o with the vertical towards the slope face. The dimension details of the gabion retaining wall designed for unstable slope are given in Table 4. The results of stability analysis of the gabion retaining wall shows that it can be constructed for the respective section of the unstable slope. The important safety factors computed for the gabion wall are given below:

Check for overturning stability	Check for slip
Resisting moment = 72665.38 kNm/m	Resisting horizontal force = 3087.56 kN/m
Overturning moment = 42274.29 kNm/m	Active horizontal force = 1246.67 kN/m
Safety factor = 1.72 > 1.50	Safety factor = 2.48 > 1.50

Table 3. Factor of safety observed for slope with the inclusion of gabion retaining wall.

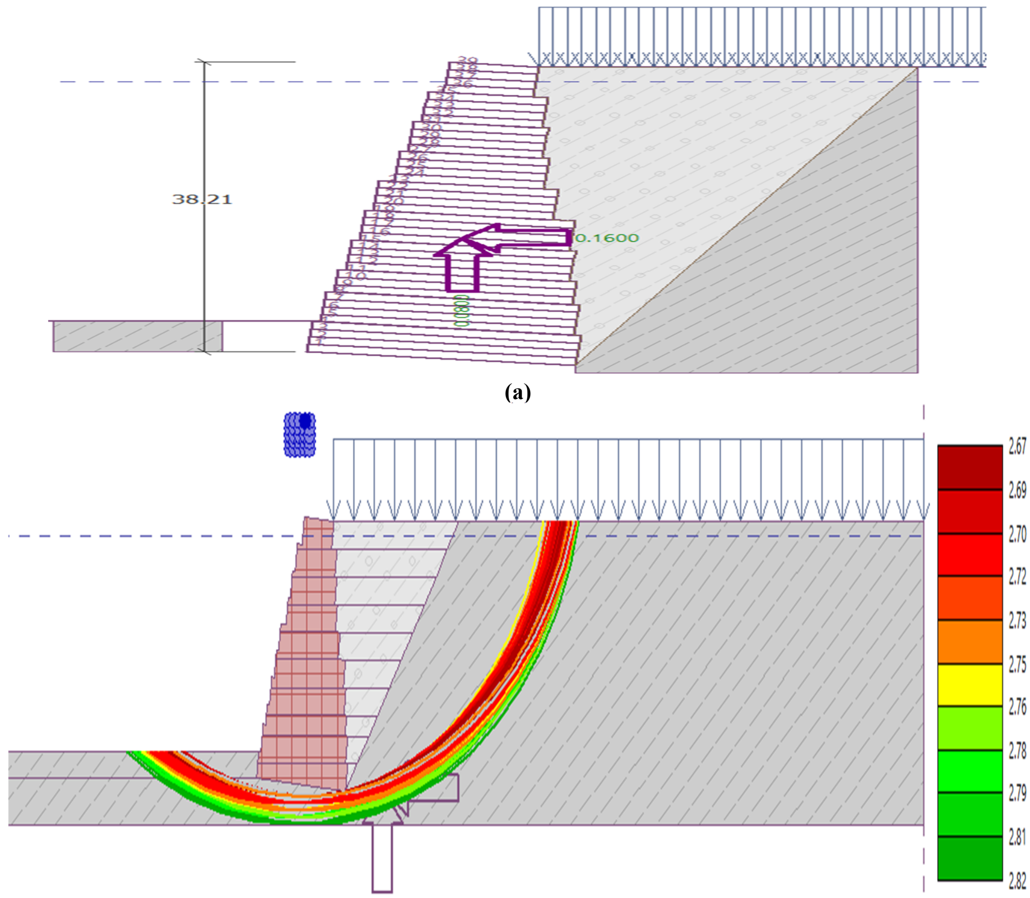
Method	FS for static forces	FS for pseudo-static forces
Bishop	3.98	2.67
Morgenstern- Price	3.97	2.73
Fellenius	3.68	2.43
Spencer	3.97	2.67
Janbu	3.97	2.68



(a)

(b)

Figure 3 (a). Cross-section showing profile of slope with gabion retaining wall: (b) Critical slip surfaces for respective section shown using Bishop analysis under static forces.

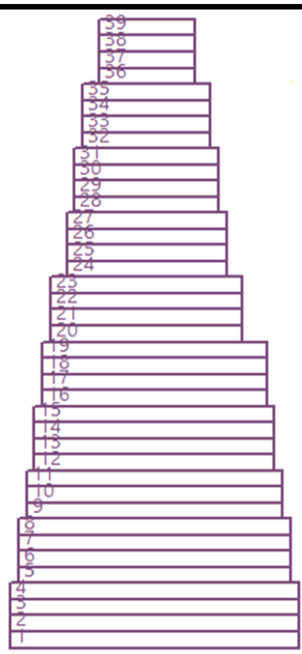


(a)

(b)

Figure 4 (a). Cross-section showing profile of slope with gabion retaining wall: (b) Critical slip surfaces for respective section shown using Bishop analysis under pseudo-static forces.

Table 4. Dimensions details of gabion retaining wall.



Gabion retaining wall

No.	Width, b (m)	Height, h (m)	Offset (m)	No.	Width, b (m)	Height, h (m)	Offset (m)
39	6	1	0	19	14	1	0
38	6	1	0	18	14	1	0
37	6	1	0	17	14	1	0
36	6	1	1	16	14	1	0.5
35	8	1	0	15	15	1	0
34	8	1	0	14	15	1	0
33	8	1	0	13	15	1	0
32	8	1	0.5	12	15	1	0.5
31	9	1	0	11	16	1	0
30	9	1	0	10	16	1	0
29	9	1	0	9	16	1	0.5
28	9	1	0.5	8	17	1	0
27	10	1	0	7	17	1	0
26	10	1	0	6	17	1	0
25	10	1	0	5	17	1	0.5
24	10	1	1	4	18	1	0
23	12	1	0	3	18	1	0
22	12	1	0	2	18	1	0
21	12	1	0	1	18	1	
20	12	1	0.5				

7. Construction of gabion retaining wall

Based on the design analysis construction, drawings of the gabion retaining wall were plotted by GTIPL designers using AUTOCAD-3D. Figure 5 shows the key plan of the pump-house with gabion wall on both side, and Figure 6 shows the elevation and cross-section of the gabion retaining wall.

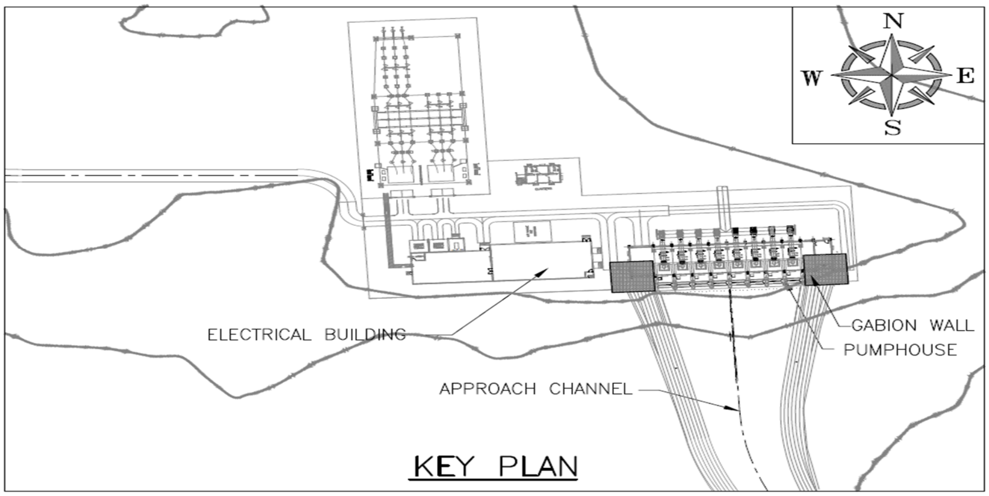


Figure 5. Key plan of pumphouse.

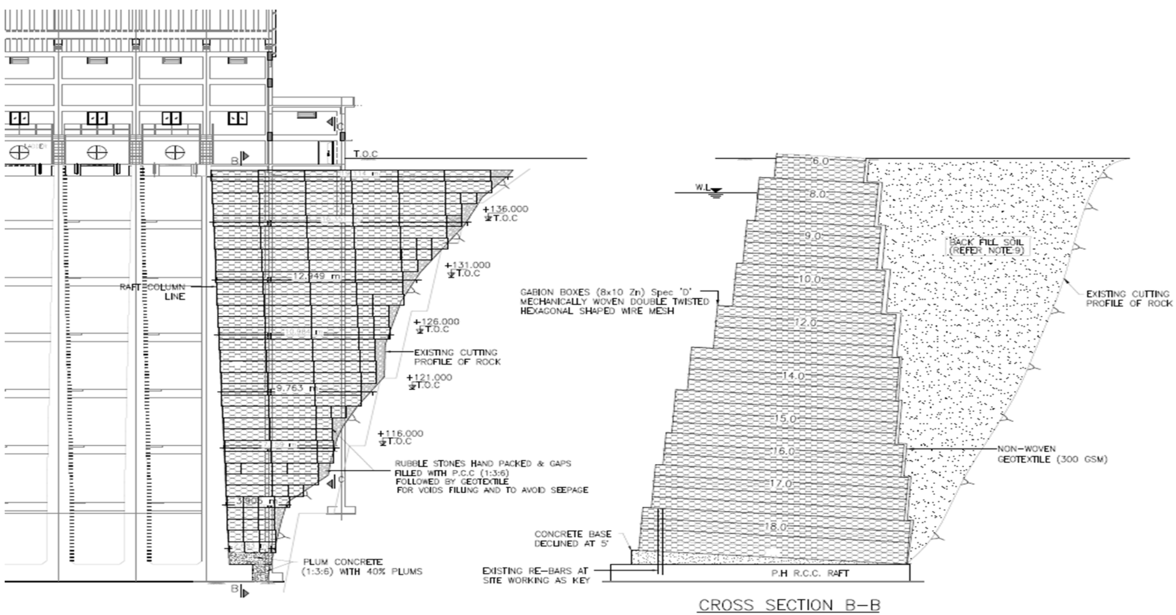


Figure 6. Elevation and cross-section at B-B of gabion retaining wall.

The construction work of the gabion retaining wall was commenced from March, 2020. For fast and efficient execution, it was recommended to use a bucket/basket attached to the cranes to reduce the time required for mobilization of boulders at 38 m depth (Figure 7). The process begins by selecting a sturdy basket made of materials like steel, equipped with attachment points or lifting hooks for connection to the crane. The basket is then securely attached to the crane's hook or lifting points with robust cables or chains. With the basket properly rigged, the boulders are carefully loaded, ensuring they are centred and balanced to prevent instability during lifting. During lifting and transportation, constant communication between the crane operator and ground crew is vital for precise placement. After the boulders are set, the crane operator lowers the basket to the ground, and the cables or chains are detached. Mobilizing boulders using a basket attached to a crane is a reliable and effective method that minimizes the physical effort needed to move large rocks, while ensuring safety and accuracy in the placement of these formidable natural elements.

GTIPL manufactures all gabion units in accordance with the international standards: EN 10223-3 [32], ASTM A 975 [33], and IS 16014:2012 [34]. Mechanically woven double-twisted hexagonal steel wire mesh (8 × 10 cm), with Zn-coated mesh wire of diameter 3.0 mm, selvedge wire of diameter 3.90 mm, and lacing wire of diameter 2.2 mm are used to make gabions. Diaphragms are positioned at intervals of 1.0 m. Gabion boxes are filled with stones that range in size from 150 mm to 300 mm, and are compressed into a 250 mm-thick layer. The backfill compaction carried out in layer of 250 mm thick to achieve 95% of MDD. Project work was huge and GTIPL team worked day and night to complete the remarkable project. This remarkable project of 38 m high gabion wall was successfully constructed by GTIPL in June, 2020 (Figure 8).

Figure 7. Mobilization of boulders using basket attached to the crane.

Figure 8. Gabion wall after completion submerged under backwater.

8. Conclusions

In NVDA project slope stability analysis for a slope lies near pumphouse at Alirajpur, Madhya Pradesh, India was investigated using the GEO 5 software. For both static and pseudo-static forces, a thorough stability analysis was conducted, and FS were found using numerous techniques. The FS revealed that the slope is unstable and appropriate mitigating measures must be taken to protect the failing slope.

Slope stability with mitigation measure (gabion wall) was checked for fully submerged and unsubmerged condition. A gabion retaining wall of height 38 m was designed using Geo5 and built by GTIPL. Gabions wall can be very effective solution for cut slope portion (exposed to submerged and unsubmerged condition) in lift irrigation projects. As it is easy to install and maintain gabion walls. Gabion wall allows for efficient water drainage, reducing the risk of hydrostatic pressure building up behind the wall. Gabion walls can adapt to the terrain and ground movement. They are flexible and can settle without cracking, making them suitable for areas prone to soil shifting or minor seismic activity. Gabions gabion walls offer a cost-effective, durable, and environmentally friendly.

During first monsoon, 38 m high gabion wall was fully submerged under the dam's backwater for many days, and the constructed Gabion wall has been standing strong as per the field observation in October, 2023. This validates the selection and design of the control measure. Until this date, Alirajpur lift irrigation has highest gabion wall constructed. This study has collectively expanded the use of gabion retaining walls for taller structures, making them a viable solution for a wide range of applications including highway and railway embankments, coastal protection, and retaining walls in urban environments.

L&T team was very happy with the technical support provided by GTIPL, i.e. site-specific design solution, timely, and good quality supply of material, and also provided fast and efficient

execution of highest gabion wall of its kind in India.

Acknowledgements

Authors are grateful to the NVDA and L&T team for their immense support throughout this important project.

References

[1]. Sarfarazi, V., Haeri, H., Fatehi Marji, M., Saeedi, G., & Namdarmanesh, A. (2023). Investigation of Shear Properties of Open Non-persistent Latitudinal Discontinuities of Same Level. *Journal of Mining and Environment*, 14(4), 1361-1371.

[2]. Rezaei, A., Sarfarazi, V., Babanouri, N., Omidi Manesh, M., & Jahanmiri, S. (2023). Failure Mechanism of Rock Pillar Containing Two Edge Notches: Experimental Test and Numerical Simulation. *Journal of Mining and Environment*, 14(3), 961-971.

[3]. Omidi Manesh, M., Sarfarazi, V., Babanouri, N., & Rezaei, A. (2023). Investigation of External Work, Fracture Energy, and Fracture Toughness of Oil Well Cement Sheath using HCCD Test and CSTBD Test. *Journal of Mining and Environment*, 14(2), 619-634.

[4]. Bhardwaj, A., & Sharma, R.K. (2022). Bearing Capacity Evaluation of Shallow Foundations on Stabilized Layered Soil using ABAQUS. *Studia Geotechnica et Mechanica*, 45(1): 55-71.

[1]. Bhardwaj, A., & Sharma, R.K. (2023a). Experimental and Numerical Investigations on the Bearing Capacity of Footings on the Layered Soil. *International Journal of Geosynthetics and Ground Engineering*, 9, 35.

[2]. Bhardwaj, A., & Sharma, R. K. (2023b). Influence of industrial wastes and lime on strength characteristics of clayey soil. *Magazine of Civil Engineering*, 120(4): 5-13.

[3]. Siddique, T., & Pradhan, S.P. (2018). Stability and sensitivity analysis of Himalayan Road cut debris slopes: an investigation along NH-58, India. *Natural Hazards*, 93: 577–600.

[4]. Ray, A., Kumar, R.E.S.C., Bharati, A.K., Rai, R., & Singh, T.N. (2019). Hazard chart for identification of potential landslide due to the presence of residual soil in the Himalayas. *Indian Geotechnical Journal*.

[5]. Pradhan, S.P. & Siddique, T. (2020). Stability assessment of landslide-prone road cut rock slopes in Himalayan terrain: a finite element method-based approach. *Journal of Rock Mechanics and Geotechnical Engineering,* 12: 59–73,

[6]. Uray, E. & Tan, O. (2015a). Gabion tipi dayanma yapıları. Türkiye Mühendislik Haberleri, 60(2): 19–29. Retrieved from:

[7]. Mehrotra, G.S., Bhagat, N.C., & Sarkar, S. (1991). Landslide hazards in Garhwal Himalayas, Mussoorie slide – A case study. Proceedings of the Ninth Asian Regional Conference on Soil Mechanics and Foundation Engineering, 1: 409-414 December, Bangkok, Thailand.

[8]. Peerdawood, C. T. & Mawlood, Y. (2010). Analytical Study for Stability of Gabion Walls. *Journal of Pure and Applied Sciences*, 22(5).

[9]. Karpe, V., Sarang, P., & Dias, N. (2010). Stabilization of slope for hill road at Chorla Ghat. *In Indian geotechnical conference*-2010, GEO trendz.

[10]. Ramli, M., Karasu, T. J. R., & Dawood, E. T. (2013). The stability of gabion walls for earth retaining structures. *Alexandria Engineering Journal*, 52(4): 705–710.

[11]. Lin, Y. & Fang, Y. (2013a). Settlement Behavior of New Reinforced Earth Retaining Walls under Loading-Unloading Cycles. *Applied Mechanics and Materials*, 256–259 (PART 1): 215–219.

[12]. Lin, Y. & Yang, G. (2013b). Dynamic Deformation Behavior and Life Analysis of Green Reinforced Gabion Retaining Wall. Applied Mechanics and Materials, 256–259 (PART1): 251–255.

[13]. Amato, G., Obrien, F., Simms, C. K., & Ghosh, B. (2013). Multibody modelling of gabion beams for impact applications. *International Journal of Crashworthiness*, 18(3): 237–250.

[18]. Chikute, G. C. & Sonar, I. P. (2019). Failures of gabion walls. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 8(11): 1384–1390.

[19]. Uray, E. & Tan, O. (2015(b). Investigation of design criteria for the type of gabion walls. Digital Proceeding of International Conference on Civil and Environmental Engineering ICOCEE, 1571–1581.

[20]. Sarkar, S. & Samanta, M. (2017). Stability analysis and remedial measures of a landslip at Keifang, Mizoram–a case study. *Journal of the Geological Society of India*, 89: 697-704.

[21]. Wang, Y., Smith, J. V, & Nazem, M. (2021). Optimisation of a Slope-Stabilisation System Combining Gabion-Faced Geogrid-Reinforced Retaining Wall with Embedded Piles. *KSCE Journal of Civil Engineering*, 25(12): 4535–4551.

[22]. Grodecki, M. (2021). Numerical modelling of gabion retaining wall under loading and unloading. *Archives of Civil Engineering*, 67(2): 155–164.

[23]. Pereira, B. & Fernandes, W. (2021). Gabion Walls—A Remedial Measure for Slope Stabilization. *In Indian Geotechnical Conference* (pp. 409-419). Singapore: Springer Nature Singapore.

[24]. Holtz, R.D. & Schuster, R.L. (1996). Stabilization of soil slopes. In Landslides Investigation and Mitigation, Eds. Turner A.K. and Schuster, R.L., Special Report 247, *Transportation Research Board*.

[25]. Chikute, G.C. & Sonar, I.P. (2021). Gabion Wall: Eco-friendly and Cost-Efficient Retaining Wall. *In Advances in Sustainable Construction Materials*: Select Proceedings of ASCM 2020 (pp. 229-249). Singapore: Springer Singapore.

[26]. Chikute, G.C. & Sonar, I.P. (2019). Failures of Gabion walls. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*. ISSN: 2278–3075, 8(1).

[27]. Sharma, P. (2017). Evaluation and comparison of classical earth pressure theories for cohesionless backfill using professional software. *International journal of Creative Research thoughts (IJCRT)* 5(4).

[28]. Keskin, I. (2017). Stability analysis of a high stone retaining wall: a case of Eskipazar/Turkey. *International Journal of Advanced Research* 3(2).

[29]. Asadpour, H. & Akhlaghi, T. (2017). Stability analysis of Gabion wall with tieback in seismic regions. Civil Engineering Journal 3(5):319–33.

[30]. IS - 1893. (2002) Criteria for earthquake resistant design of structures. Indian Standard, New Delhi.

[31]. IS - 14458. (1998) Retaining wall for hill area guidelines: Construction of gabion walls.

[32]. EN 10223-3: Steel wire and wire products for fencing and netting - Part 3: Hexagonal steel wire mesh products for civil engineering purposes

[33]. ASTM A 975: Standard Specification for Double-Twisted Hexagonal Mesh Gabions and Revet Mattresses (Metallic-Coated Steel Wire or Metallic-Coated Steel Wire with Poly (Vinyl Chloride) (PVC) Coating).

[34]. IS - 16014: Mechanically woven, double -twisted, hexagonal Wire Mesh Gabions, Revet Mattresses, and Rock fall Netting (Galvanized steel wire or Galvanized steel wore with PVC coating) – Specification.

تجزیه و تحلیل پایداری و ساخت بلندترین دیوار گابیون در نوع خود در هند - یک مطالعه موردی

آویناش بهاردواج*، آجی بهاردواج، مادوسودان ساردا و نامراتا بیچوار

Gabion Technologies India Private Limited، هند

ارسال ۲۰۲۳/۱۰/۱۳، پذیرش ۲۰۲۳/۱۱/۱۳

* نویسنده مسئول مکاتبات: avinash@gabionindia.com

چکیده:

مرجع توسعه دره نارمادا طرحی را پیشنهاد کرد که بر اساس آن ۱۲.۶ کومک آب از رودخانه هاتانی (شاخه نارمادا) برای آبیاری منطقه فرماندهی برداشته می‌شود. در ایستگاه پمپاژ در نزدیکی علیراجپور، مادهیا پرادش، هند قرار دارد. نیاز به حفاظت از شیب در دو طرف وجود داشت زیرا رانش آب از سمت بالادست ممکن است منجر به شکست شیب شود. این مقاله تجزیه و تحلیل پایداری شیب را با استفاده از نرم افزار GEO5 ارائه می‌کند. مشاهده شد که زمین در سایت مخلوطی از خاک و سنگ است. وزن واحد سنگ و خاک پس‌پوش مشاهده‌شده ۲۱ کیلو نیوتن بر متر مکعب و ۱۸ کیلو نیوتن بر متر مکعب بود. با استفاده از تکنیک‌های متعدد ضریب ایمنی برای شیب خاص محاسبه شد و مشاهده شد که برای جلوگیری از شکست شیب باید اقدامات کاهشی مناسبی ارائه شود. گنجاندن دیوار حائل گابیون ضریب ایمنی شیب را به طور قابل توجهی افزایش داد. اقدام کاهشی پیشنهادی در محل اجرا شد و دیوار تکمیل شده تا به امروز هیچ آسیبی دیده نشده است. تجزیه و تحلیل نتایج پایداری شیب، و همچنین ساخت آن از دیوار حائل گابیون توصیه شده به عنوان یک اقدام حفاظتی، در این کار ارائه شده است.

کلمات کلیدی: پایداری شیب، دیوار حائل گابیون، روش Bishop، GEO5، اندازه‌گیری کاهش.