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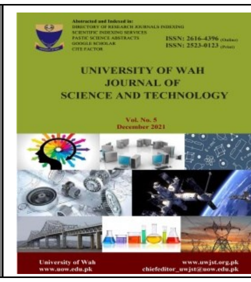

Analysis of Gabion Retaining Wall Using Analytical and Numerical modelling with Plaxis 2D

Ahmad Ayyub, Badee Alshameri*, S. Muhammad Jamil, and Muhammad Naqeeb Nawaz

***Abstract*— A gabion wall of 30 m long and 9 m high for a residential plot at Bahria town Rawalpindi, Pakistan, started bulging right after one month of its construction. In this study, two approaches i.e., analytical and Finite Element Method (FEM) using Plaxis 2D software were carried out to assess the structural stability of the Gabion Retaining Wall. The results of the analytical and numerical analysis show that the Gabion Retaining Wall is marginally safe with the factor of safety (FOS) 1.19 and 1.07 respectively, while displacement at the top was found out to be 0.4 m with the maximum stresses at the toe. Finally, the stepped-faced Gabion Wall along with 200 mm concrete at the toe was found out to be a viable solution for the stabilization of the Gabion Retaining Wall. Consequently, FOS increased to 1.27 with the decrease of displacement at the top from 0.4 m to 0.1 m while stresses at the toe were decreased by 50%.**

***Index Terms*— Gabion wall, Retaining wall, Stability Analysis, Factor of safety.**

I. Introduction

RETAINING wall retains material at the back while maintaining the different elevations where abrupt changes occur and were considered a valuable solution against natural hazards i.e., landslides [1–3]. After Agriculture in Pakistan, construction is the second largest sector [4]. Retaining walls were most commonly used retaining structure for vertical or near to vertical slopes for support against the lateral loads [5]. Retaining walls were applied as support structures d for roads, bridges abutments, foundation walls, and where cut and fill earthwork is carried out for retaining the back earth and maintaining the elevation for two different levels of grounds [6].

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Gabion walls show great strength against active soil thrust and hydraulic pressure without cracking or deforming [7]. Gabion mesh boxes wires have a different material coating i.e., zinc galvanized or non-Galvanized, Polyvinyl chloride (P.V.C.) coated or non-PVC. coated [8]. The gabion box mesh is constructed by welding or twisting, and the boxes were filled with an inorganic material. In Taiwan, after the earthquake of 1999, ecological engineers proposed gabion as an effective solution for rehabilitation works of different structures due to the stability advantages of a gabion wall [9]. An Approximately 38 m high gabion wall is currently present in Taiwan [8]. According to the required conditions, gabions were used in different shapes, e.g., sack shape for emergency protection against floods; the mattress used to prevent channel erosion or scouring, and rectangular shapes baskets used for walls [10]. Gabion walls have two types; (1) stepped face, (2) smooth-faced [11]. The repair and maintenance cost of the Gabions walls is significantly less than the other earth retaining structures [12]. It is environmental friendly and has no weather or water effect on construction, Additionally, no special equipment or skilled labor is required for their construction [12]. The Gabion wall considered the best stabilization method having 50% less cost for the areas where particular equipment types were not available [13].

Gabion Walls were a relatively less common earth retaining structure in Pakistan. Therefore, stability issues of Gabion Walls were often reported after the construction due to inadequate design practices. Gabions are gaining popularity in every corner of the world due to their cost efficiency, environment-friendly, and sustainability [8].

This study aims to analyze a case study of a Gabion Wall construction in Bahria Town Rawalpindi Pakistan for a lawn (30 m x 25 m) of a residential plot. Wall started to bulge after one month of its completion date. The bulging was visible in a column shape. The analytical design was carried out based on the results of detailed site investigations to assess the stability of the Gabion Wall. The design was also analyzed with the help of the Finite Element Method using Plaxis 2D software. In the end, various stabilization techniques were applied and analyzed amongst which the stepped-faced gabion along with the concrete of 200 mm at the wall toe was recommended as the solution for the stability of Gabion Wall.

II. Methodology

A. In-situ and Laboratory investigations

The Preliminary survey was conducted to determine the physical properties of the wall and to analyze the visible structural damage [2]. During the preliminary survey following points were found (see Fig. 1): (1) Gabion mesh Construction was not properly according to ASTM standards [14]. (2) Gabions were not correctly constructed, and some baskets were roughly filled. (3) No mesh wire was broken. (4) No lacing wire, rings, selvage wire, or stiffeners visible at the edges of the basket. (5) Joints were not staggered, the gabions were stacked upon each other, and bulge was visible in a column effect. (6) Sandstone was used as fill material. (7) Mesh opening size found out to be 0.20 m square with 5 mm diameter wire was used. (8) workmanship was found a significant factor for failure.

The laboratory and in-situ geotechnical investigations were carried out to obtain the required parameter for analytical and numerical modeling. A borehole drilling was carried out at some distance from the top edge of the wall as shown in Fig. 2, to investigate the site conditions Standard Penetration Test [15] was performed up to 21 meters as shown in Table I. The groundwater table was not encountered throughout the drilling depth of the borehole i.e., BH-1.

Fig. 1. Edges of gabion baskets (picture taken at the site)

Different gabion boxes were selected, and the unit weight of gabion boxes was found 20 kN/m^3 by using equation 1. The gabion's previous design unit weight was 23 kN/m^3, which was greater than the original design unit weight.

$$\text{Gabion unit weight} = \frac{\text{weight of single gabion box Fill material}}{\text{volume of gabion box}} \quad (1)$$

TABLE I
SUMMARY AND RESULTS OF FIELD INVESTIGATION

Borehole	Depth	Average Description	SPT
BH-1	0-4.8 m	Light brown Silt Clay very stiff.	28
	4.8-6 m	Light brown Silt Clay hard	41
	6-9 m	medium brown Silt Clay hard	48
	9-21 m	medium brown Silt Clay very hard	50

The sand cone method is one of the field density methods (FDT) to determine the in-situ density of soil f as per ASTM standard ASTM D1556 [16], and the values of unit weight for obtained for both materials i.e., backfill and existing soil were found out to be 18 kN/m^3 . The Direct Shear Test (DST) was performed in Laboratory according to ASTM-D3080 [17], to obtain the shear strength parameters of soil i.e., cohesion c and angle of friction (∅). The results of the above-mentioned tests were summarized in Table II.

TABLE II
SUMMARY OF PARAMETERS OBTAINED RESULTS

Description	Cohesion	The angle of internal friction ∅	Unit Weight
UNIT	kN/m^2	Degree	kN/m^3
Back FILL Soil	0	30	18
Existing Soil	5	30	18
Gabion Fill	100*	40*	20

*Gabion values for cohesion and angle of internal friction were assumed[21,**22]**

The analytical design method as presented in various literary works [20–23] was used in this study for analyzing the stability of structure against sliding, overturning, and base pressure. The guidelines of Eurocode [23] do not consider hydrostatic pressure due to draining properties of gabion; surcharge load and passive resistance. These limitations were considered the front soil.

B. Analytical Design Approach

The analytical design approach has been illustrated in the following steps:

The first step is to calculate the forces acting on the gabion wall, as shown in Fig. 2.

The Coulomb equation was used to compute the lateral earth pressure as given in equations 3 to 5:

$$P = \frac{1}{2} . \gamma . H^2 . K_a \quad (2)$$

$$K_a = \frac{\sin^2(\alpha+\emptyset)}{\sin^2\alpha \sin(\alpha-\delta)[1+\sqrt{\frac{\sin(\emptyset+\delta)\sin(\emptyset-\beta)}{\sin(\alpha-\delta)\sin\alpha+\beta)}}]^2} \quad (3)$$

$$P_h = P_a \cos(90 - \alpha + \delta) \quad (4)$$

$$P_v = P_a \sin(90 - \alpha + \delta) \quad (5)$$

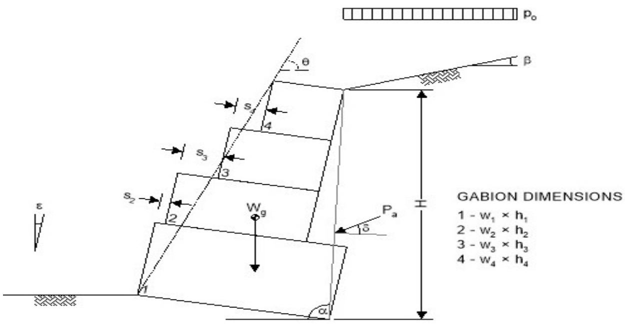


Fig. 2. The Acting Forces on Gabion

Where Pa is the active lateral thrust force on the wall, γ is the backfill Soil density, H is the total wall Height, K_a is the Coulomb active soil pressure Coefficient, β is the slope of backfill, δ is the friction angle of the wall, α is the effective angle, ϕ is the internal friction angle of soil, P_h is the horizontal component of Pa calculated by equation 4 and P_v is the vertical component is calculated by equation 5.

Step 2 Sliding resistance check.

The sliding resistance is checked against the prescribed factor of safety as given in equation 6. F.O.S. sliding 1.5 is considered reasonable [1, 22].

$$FOS = \frac{\mathrm{FR}}{\mathrm{Ff}} = \frac{\mathrm{T}\cos(\varepsilon) - \mathrm{N}\sin(\varepsilon)}{(\mathrm{T}\sin(\varepsilon)+\mathrm{N}\cos(\varepsilon))\tan(\emptyset)} \quad (6)$$

Where T is the total horizontal force factored and N is used for the total vertical forces.

Step 3 Overturning moment check.

This analysis ensures that all forces' results do not overturn the base of the retaining wall. F.O.S. against overturning moment can be taken as 1.5-2. The F.O.S. against overturning moments can be calculated using equation 7:

$$\mathrm{F.O.S.} = \frac{\mathrm{M.R.}}{\mathrm{Mo}} = \frac{\mathrm{Wg\,Xg + Pvbv}}{\mathrm{Ph.dh}} \quad (7)$$

W_g is the gabion self-weight passing from the center of the Wall cross-section, b_v horizontal where soil vertical force acts, X_g distance from the toe for vertical forces. It is calculated by taking a moment at the toe for each gabion course as given by equation 8:

$$X_g = \frac{\sum W_{gn} X_{gn}}{W_g} \quad (8)$$

The following equation use to calculate the distance from the base to the active earth pressure when the surcharge load is acting or having a backslope at some angle; otherwise, H/3 use.

$$d_H = \frac{\mathrm{H}(\mathrm{H}+\frac{3\mathrm{q}}{\mathrm{y}})}{3(\mathrm{H}+\frac{2\mathrm{q}}{\mathrm{y}})} + \alpha \sin B \quad (9)$$

F.O.S for overturning is used 1.5 to 2 [1, 22].

Step 4 Bearing pressure.

Bearing pressure can be estimated using equations 10 to 12.

$$e = \frac{B}{2} - \frac{M_r - M_o}{W_v} \quad (10)$$

$$e \leq \frac{B}{6} \quad (11)$$

The base maximum pressure calculated by:

$$P_{max} = (\frac{W_v}{B})(\frac{1+6e}{B}) \leq \text{allowable bearing pressure } Q_a \quad (12)$$

If the base pressure exceeds the allowable bearing pressure, then the structure is considered safe.

C. *FEM Analysis using Plaxis 2D*

FEM was carried out for stability and deformation analysis of Gabion Retaining Wall to validate the analytical modeling using Plaxis 2D software. Plaxis 2D is a two-dimensional software used for numerical modeling of different geotechnical structures. For numerical modeling in the Plaxis 2D plane strain model was adopted while the Mohr-Coulomb method was used for soil modeling with the undrained condition [9, 24], The input parameters were taken from the geotechnical site investigations described in section 2.1 and some input parameters have been deduced from the literature e.g., Axial stiffness (E.A.) and Flexural stiffness (E.I.) [9, 18, 25]. The input parameters for numerical modeling were summarized in Table III. In this analysis, initial boundary conditions were defined to model the Gabion Wall according to specifications given in Fig. 2 The initial stresses were generated using the K_o procedure, and a staged construction method was adopted to run the plastic analysis. The Plaxis 2D model is presented in Fig. 3 while Fig. 4 presents the cross-section of the Gabion Wall along with stratigraphy.

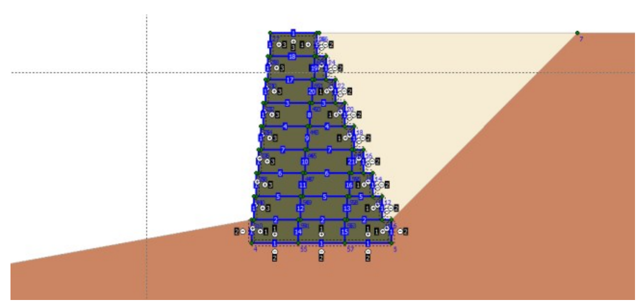


Fig. 3. Geometrical model constructed for stability analysis in Plaxis

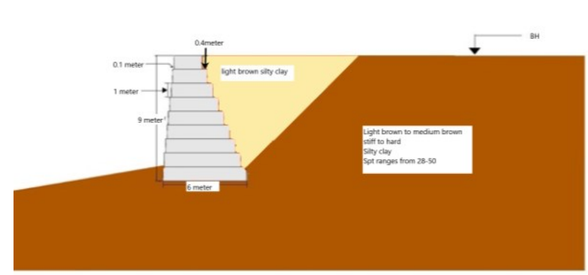


Fig. 4. Cross-section sketch of the gabion wall with the strata found

TABLE III
PARAMETERS PROPERTIES OF BAHRIA TOWN RAWALPINDI SITE

Fill Soil Properties			
S. No	Property/parameters	Estimated Value	Unit
1	Unit weight	18	kN/m^3
2	The angle of Internal friction	30	Degree
3	Backfill slope	0	Degree
4	Wall friction angle	30	Degree
5	Cohesion	0	
6	Modulus of elasticity	5000	kN/m^2
7	Poison s ratio	0.3	
8	Interface value	0.5	

Foundation Soil Material Properties			
S. No	Property	Estimated Value	Unit
1	Unit weight	18	kN/m^3
2	The angle of Internal friction	30	Degrees
3	Cohesion	5	kN/m^2
4	Modulus of elasticity	14000	kN/m^2
5	Poison s ratio	0.3	-
6	Interface value	0.5	-
Gabion			
S. No	Property	Estimated value	unit
1	Unit weight of Gabion Assumed	20	kN/m^3
2	Internal friction b/w gabion	40	degree
3	Cohesion	100	kN/m^2
4	Modulus of Elasticity	8000	kN/m^2
Mesh Properties			
5	EA	4000	kN/m^2
6	EI	2	kN. m/m

The analytical and numerical modeling was performed for selected case study based on the methods presented in previous sections. Fig. 4 presents the cross-section of the Gabion Retaining Wall model in Plaxis 2D with the input parameters.

III. RESULTS AND DISCUSSION

A. Analytical Analysis

The analytical analysis was performed for the actual cross-section of Bahria Town Rawalpindi's gabion wall for the input parameters given in Table III. The analytical design was carried out to assess the stability of the Gabion Retaining Wall against overturning, sliding, and bearing pressure. The summary of results from analytical design as described in section 2.2 is shown in Table IV using the Mohr-Coulomb method [1, 20, 22, 25] for the conventional retaining walls and the Eurocode BS EN1997-1:2004 [23].

TABLE IV
ANALYTICAL STABILITY ANALYSIS DESIGN SUMMARY FOR THE GABION WALL

S.NO	Properties	Resistance	Force	F.O.S Values
1	F.O.S overturning (kN.m/m)	3173.9	948.2	3.347
2	F.O.S Sliding (kN/m)	574.4	316.1	1.817
3	F.O.S Bearing pressure (kN/m^2)	300.0	251.3	1.194
4	Eccentricity (mm)	Eccentricity lies within the middle third of the base		

The results show that the structure was found stable with the unit weight of 20 kN/m^3, which is less than the previously assumed unit weight for the design of the gabion wall. The structure is safe against overturning, sliding, and bearing pressure with the suitable F.O.S. [22]. Eccentric loading is also within the limit. At the toe of the wall, the pressure is found maximum during analytical analysis. It can be concluded from the analytical analysis that the bulging in Gabion Wall could be due to the inappropriate assumption of unit weight for design purposes.

B. Numerical Modelling

Numerical modeling was carried out using the FEM approach with the help of Plaxis 2D software. The results were presented through Figures done by using a Geotechnical engineering professional software Plaxis 2D [26]. The output results were in Fig. 5, 6, and 7. Fig. 5 shows that the structure deformed under stresses in a realistic environment with the maximum deformation was observed at the top against the backfill, and foundation strata act against all those stresses generated from the backfill. Soils were displaced at the toe due to maximum pressures generated at the toe of the wall, and it is the main reason for structure failure (see Fig. 5) [18, 19]. The maximum displacement of 0.4 m occurs at the top as shown in Fig. 6) due to the lateral active soil wedge force (see Fig. 5). It was observed that stresses generated at the gabion walls' toe due to acting forces are more significant than the resisting forces (see Fig. 7). Stability analysis using Plaxis show that the structure was found to be safe with F.O.S. of 1.076 (see Fig. 8) which shows that structure is marginally safe and could be considered as a threshold value [18]. However, in practical design, the structure should have F.O.S. greater than 1.3 considering the circumstances at the site. The results from numerical analysis also show that the horizontal and vertical displacements (362 mm, 335 mm) were more than the allowed displacement of 150 mm [11]. Fig. 8 presents the sum of F.O.S. from the Plaxis 2D.

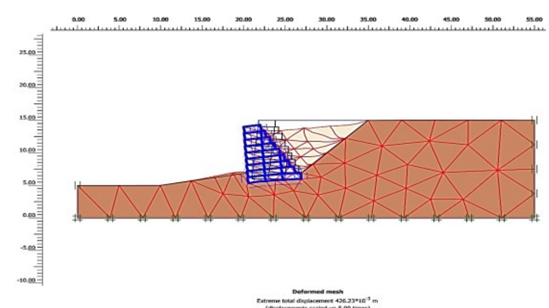
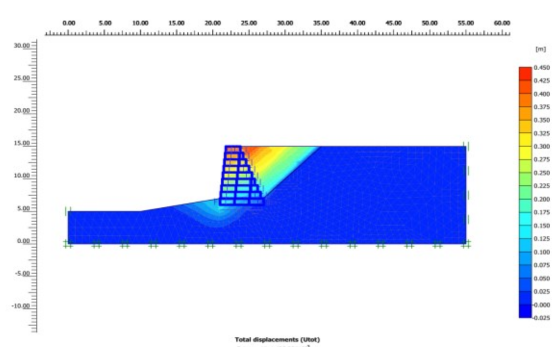
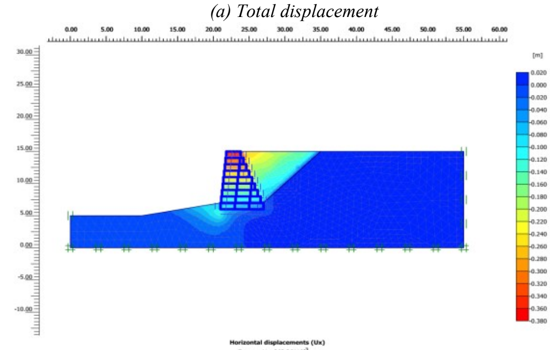


Fig. 5. The deformation of the gabion structure



(a) Total displacement



(b) Horizontal displacement

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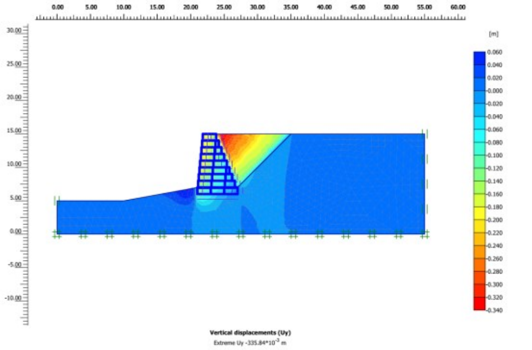


(c) Vertical displacement

Fig. 6. The displacement of the model from Plaxis Stability Analysis

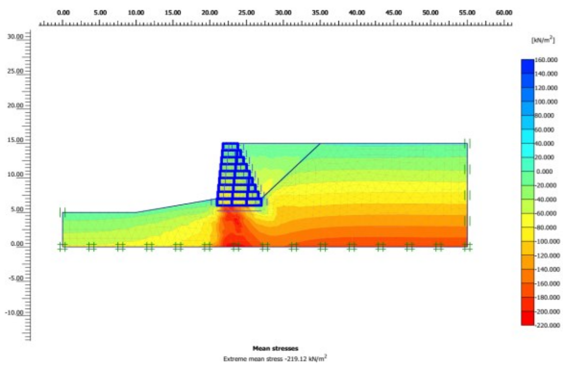


Fig. 7. The mean stresses generate in the model

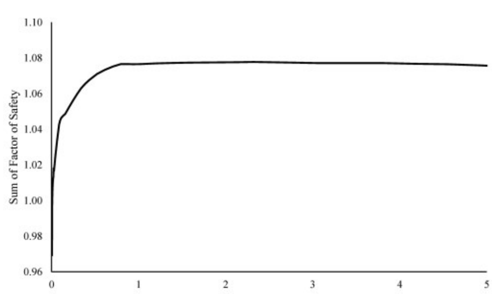


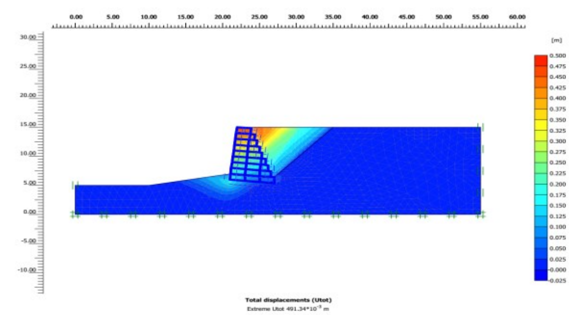
Fig. 8. Curves output results for Sum of Factor of safety from Plaxis

C. Numerical modeling after providing inclination to gabion wall

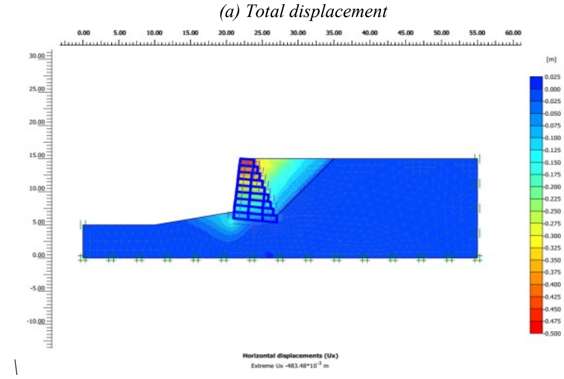
Numerical modeling of the original geometry shows more displacements than the allowable limits, so that is why Modification is required in the model for the increase instability of the structure. One of the solutions was to stabilize the Gabion Wall by providing some inclination to Wall without changing any other properties of structure and stratigraphy. According to BS-8002 [27] gabion should be lent back with 6 degrees. The exact height and width were used for each course. The inclination of 6 degrees was provided. The results from numerical analysis as shown in Fig. 9 indicate no significant improvement in the stability of the structure as displacement at the top was found out to be the same as 0.4 m. Stresses were generated in the middle of the base and eccentricity was moved towards the center due to inclination (see Fig. 10). F.O.S. has increased slightly up to 1.107 (see Fig. 11).

D. Numerical modeling after Modification using the stepped-face of gabion wall

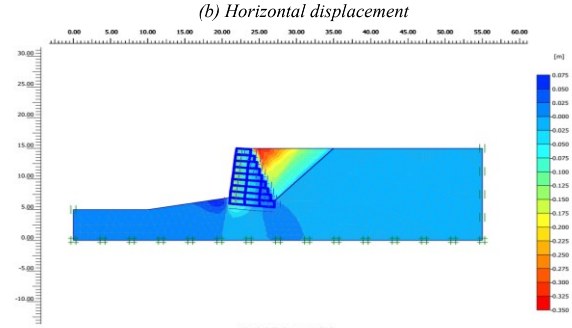
Stepped-faced Gabion Wall can be considered as the solution to stabilize the Earth Retaining Gabion Wall. This is due to the reason that the displacement at the top of the wall and stresses at the toe were found out to be more than the allowable limits [11]. Stepped faced gabion wall for the same height-width, and the parameters were used for simulation in Plaxis. On taller walls, baskets were stepped back to equalize the pressure between the heel and toe of the wall. Stepped faced gabion wall design simulation shows ultimate total displacement decreased by 75% (from 0.4 m to 0.1 m), while horizontal and vertical displacements were found out to be 58 mm, 98 mm respectively which is below the allowable limit (see Fig. 6 and 12) [11]. Ultimate Stresses distribute equally at the bottom of the wall (see Fig. 13). With the step-faced construction of the gabion wall, F.O.S. was increased from 1.077 to 1.279 (see Fig. 8 and 14). The structure is found more stable with a stepped-faced design.



(a) Total displacement



(b) Horizontal displacement



(c) Vertical displacement

Fig. 9. Different displacements on gabion wall from Plaxis

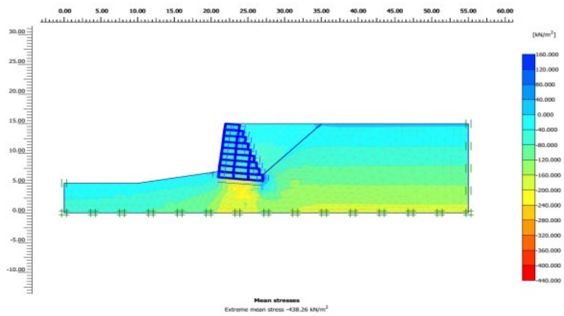


Fig. 10. Mean stresses output from Plaxis (gabion)

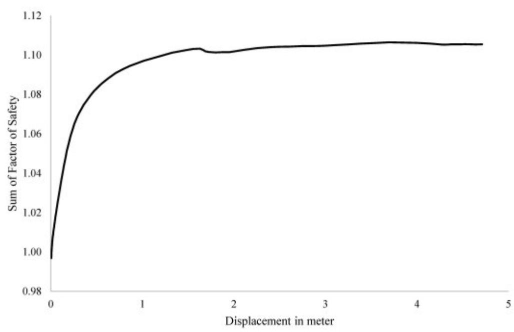
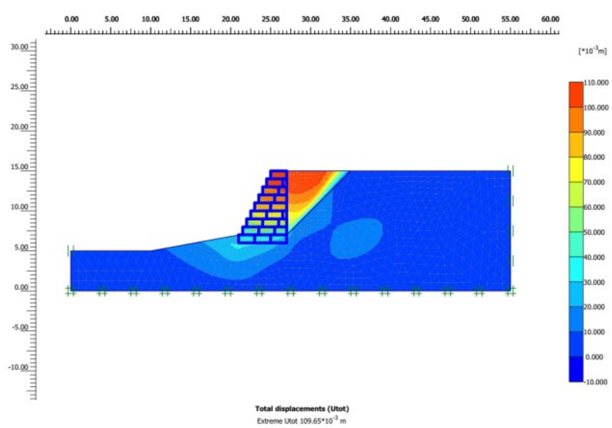
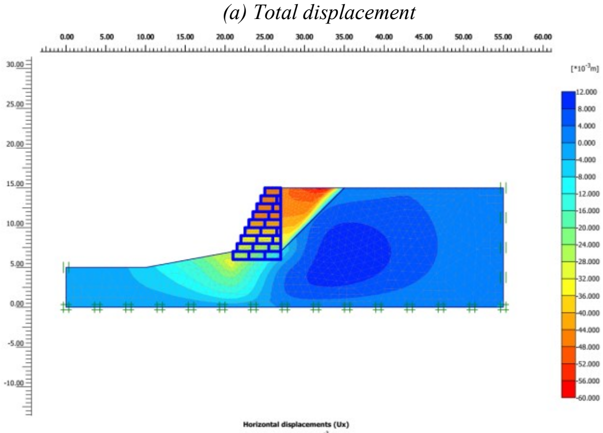


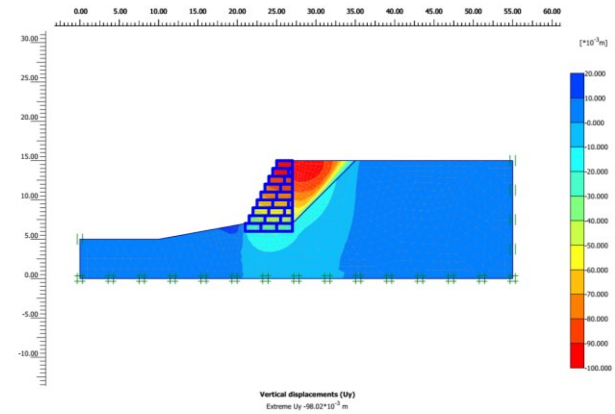
Fig. 11. Curves output results for Sum of Factor of safety from Plaxis (gabion)



(a) Total displacement



(b) Horizontal displacement



(c) Vertical displacement

Fig. 12. The displacement of stepped faced gabion wall from Plaxis

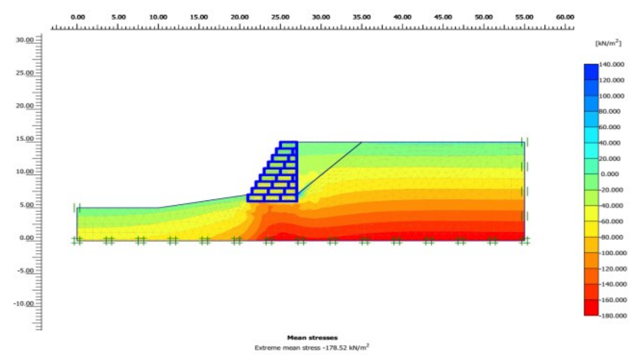


Fig. 13. Mean stresses output from Plaxis (stepped faced gabion)

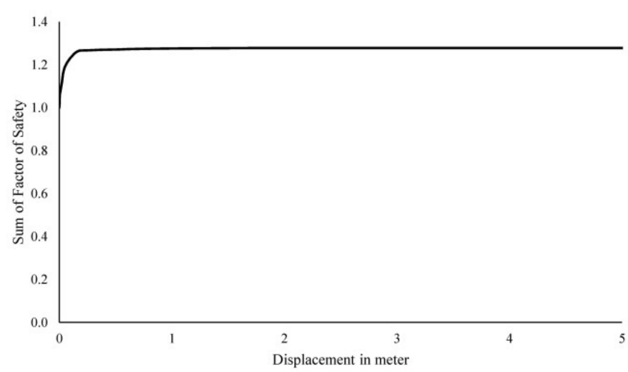


Fig. 14. Curves output results for Sum of Factor of safety from Plaxis (stepped faced gabion)

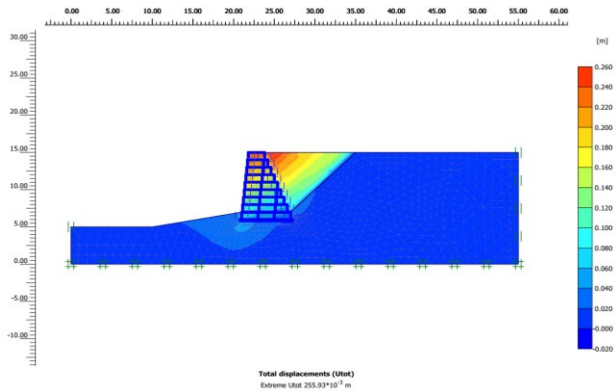
E. Numerical modeling with Reinforced Concrete

A concrete foundation of 200 mm thickness was provided at the bottom of the original design and simulate again in Plaxis. A concrete of 200 mm was used to ensure stability and to decrease the risk of differential settlement due to eccentric loading of the structure. Parameters used for Reinforced Concrete were listed in Table V.

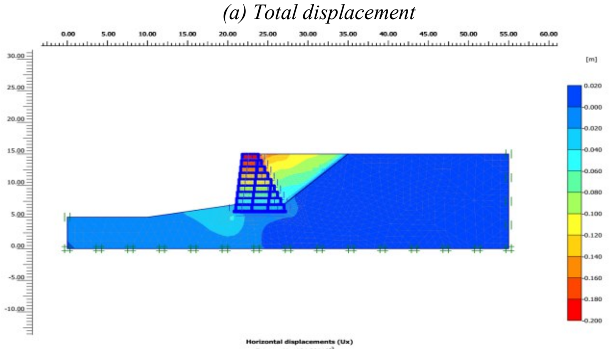
TABLE V
PROPERTIES OF CONCRETE

Reinforced Concrete			
S.No	Property	Estimated value	unit
1	Unit weight of Concrete	23	kN/m^3
2	Modulus of Elasticity	30,000,000	kN/m^2
3	EA	15,000,000	kN/m^2
4	EI	3,125,000	kN.m/m

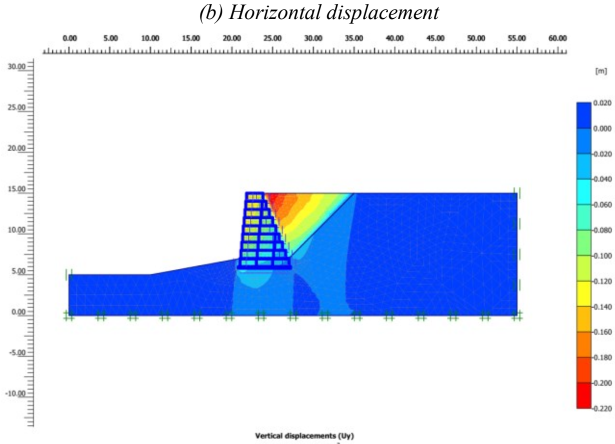
Providing 200 mm thickness of reinforced concrete at the foundation of the wall reduce 50 % of the original design's maximum total displacement from 0.4 m to 0.2 m (see Fig. 15) with the reinforced concrete at the foundation. Stresses distribute equally in each direction and an increase in differential settlement was not observed. and stresses decrease in the foundation soils against the acting forces (Fig. 16). With reinforced concrete Foundation, F.O.S. increased to 1.15 (see Fig. 17). It was observed that the structure is more stable with a concrete foundation and more durable against the lateral earth pressure.



(a) Total displacement



(b) Horizontal displacement



(c) Vertical displacement

Fig. 15. The displacement with the Concrete Foundation installation from Plaxis

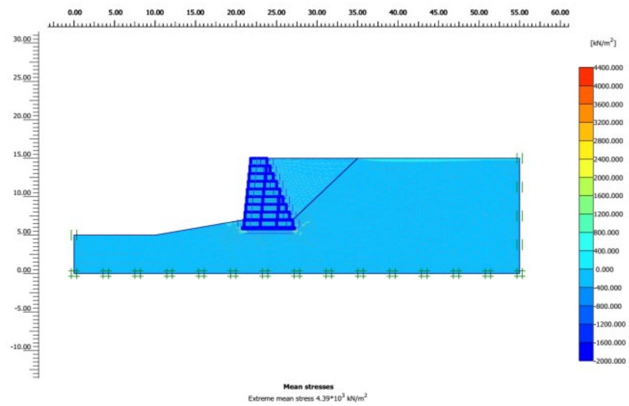


Fig. 16. Mean stresses output from Plaxis (concrete foundation installation)

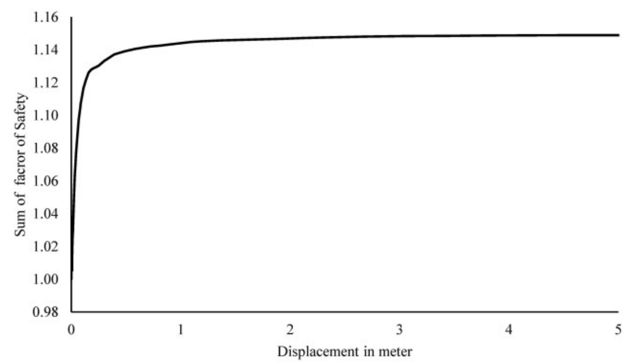


Fig. 17. Curves output results for Sum of Factor of safety from Plaxis (concrete foundation installation)

IV. Conclusions

The following conclusions were drawn from the stability analysis using the analytical approach and numerical modeling:

- The proper design of the gabion's walls is the key to ensuring the stability of the structure. The use of analytical combined with FE-based numerical approaches can enhance the reliability and sustainability of the designed structure
- Lightweight backfill is imperative for the stability of the Gabion Earth Retaining Wall. The study shows that the use of higher unit weight for design can increase deriving forces, which in turn increases instability.
- 200 mm of concrete at the foundation of gabion wall has significant results, total movements decreased up to 50 percent, F.O.S. 10 percent increased.
- The stepped face gabion wall was found out to be an excellent solution if provided with the concrete at the bottom, making it more stable and reducing the maximum displacements

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