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Design of Geo-Synthetic Retaining Walls as an Alternative to the Reinforced Concrete Walls in Jordan

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ABSTRACT: *It is well known that the developments of global construction technologies and materials are contributing to enhance the competitive advantages for construction companies. This competition seems to be highly evident in the Jordanian market, especially in the field of construction products. For this reason, the design of "geo-synthetic retaining walls" has been presented through the current research to be an alternative to the reinforced concrete wall.In general, this research presents detailed design for implementing both "the geo-synthetic reinforced soil retaining walls" including the use of geogrid layers, soil layers, and facing elements, and "the conventional reinforced concrete retaining walls" for the Jordanian construction sites. A general comparative study regarding the cost and duration of carrying out each technique has also been provided during this investigation.The methodology of this research comprised two parts. The first part included collecting and reviewing for literature concerning the above subject; whereas, the second part concentrated on the design and adoption for a reinforced earth retaining structure as an alternative to the reinforced concrete one, considering the application of the above alternatives for a case study at a proposed road project in Jordan.Out of the current investigation, it was concluded that the design and adoption of geo-synthetic retaining walls in Jordan showed more advantages than the conventional concrete walls, taking into consideration the costs, duration of execution, used materials, labors, and method of implementation.*

Keywords: *Cost Evaluation, Geogrid, Geo-Synthetic Walls, Stability of Retaining Walls, Structural Design.*

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I. INTRODUCTION

Globally, the reinforced earth retaining structures are widely adopted in structural and geotechnical fields according to their flexibility in construction, and high load carrying capability [1]. In the late of 1960's, a reinforced earth technique was developed. It was generally applied to areas where the existence of very steep slopes, and involved the reinforcement of well compacted soils with metal strips [2] and [3]. In the early of 1970's, polymeric strips and straps, geo-textiles, geo-nets and geo-meshes were introduced as a reinforcement in retaining structures, steep slopes, and embankment side slopes [4]. In general, the basic functions of geo-synthetic reinforced soil retaining structures are to allow for a change in ground level, protection of an existing natural slope and/or resistance to external loading [5] and [6]. To perform these functions, these types of walls required to resist a wide range of loads and imposed deformations which may vary with time.

The available literature concluded the main factors that influence the selection of this type of walls as an alternative to be performed for a proposed project, including:

- Topography of the project site.
- Dimensions of the structure.
- Aesthetic.
- Durability of structure.
- Availability of materials.
- Ease execution.
- Performance.
- Cost.

According to the above discussion, it is to be stated that this research emphasized on the design of geo-synthetic walls, their duration and cost of execution at project's sites in Jordan, and conducting comparative analyses with those known as conventional concrete walls, then showing their benefits in the field of construction.

II. GENERAL DESCRIPTION FOR THE CASE STUDY

The case study of this research is a proposed retaining structure that to be constructed along one side of an existing road located to the north-west of Amman, see Fig. 1, (between Stations 0+540 & 0+691). This road was intended to be expanded from one-lane two direction carriageway to double-lane two direction carriage way. The surficial ground materials that covering the study site were composed of fill materials. Based on the results of laboratory tests related to site investigation study, the engineering parameters of subsurface layers in addition to other selected Fill and Filter materials are shown in Table 1 [7].

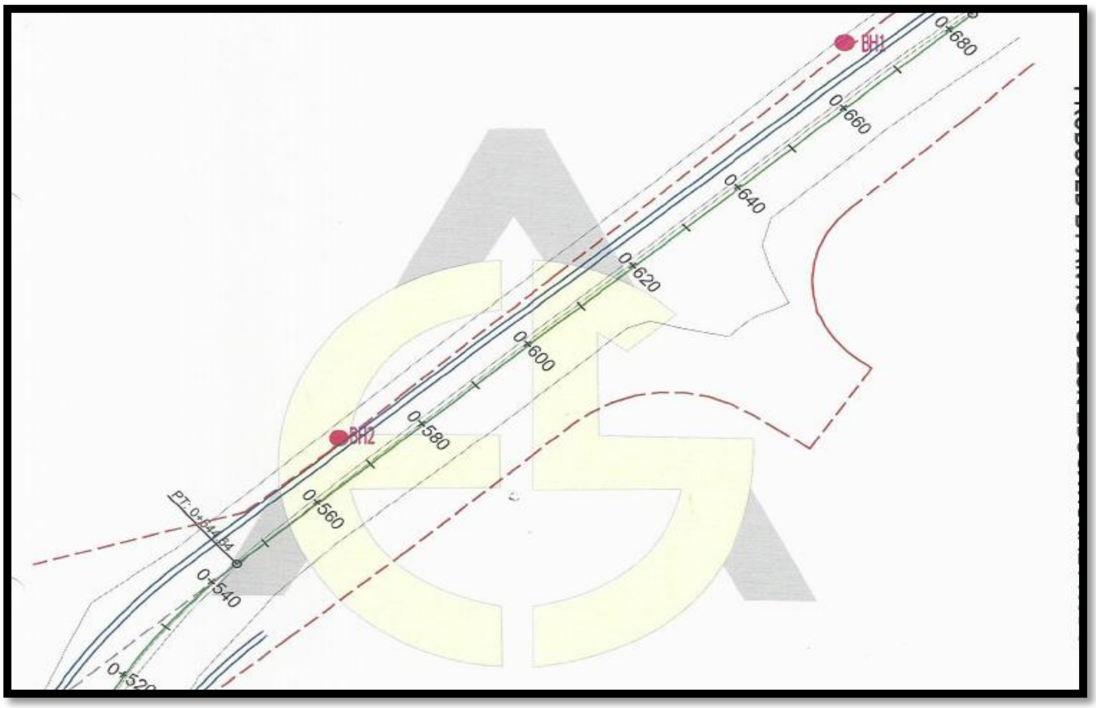

Fig. 1: Site plan for the study project including the location of the proposed retaining wall [7]

Table 1: Engineering parameters of subsurface layers and other selected fill and filter materials at the case study project [7]

Material	Unit Weight (kN/m^3)	Cohesion, (kN/m^2)	Friction Angle (Degree)	Coefficient of Active Earth Pressure (Ka)	Coefficient of Passive Earth Pressure (Kp)
Embankment Fill	14	0	14	0.61	1.64
Buried Topsoil	18	10	21	0.47	2.12
Foundation Soil (Marly Limestone)	22	38	33	0.29	3.39
Selected Fill	19	10	36	0.26	3.0
Filter Materials (Single Size)	16	0	35	0.27	3.69

III. DESIGN OF THE PROPOSED ALTERNATIVES

In order to achieve the objectives of this research, several interviews with companies specialized in the field of this research were conducted (in addition to a revision to the available literature) to obtain the necessary information, documents, and other related data for the design purposes of the intended alternatives. However, the following sections show a detailed presentation for the calculations related to the design steps for both alternatives.

3.1 DESIGN OF GEO-SYNTHETIC WALLS

The design of these walls (in general) require calculating for the following [8] and [9]:

- Defining wall geometry, loading, soil, and reinforcement properties.
- Initial dimensioning of the structure.
- External stability analysis.
- Internal stability analysis

In general, the third and fourth requirements (shown above) are briefly discussed in the following sections.

3.1.1 INTERNAL STABILITY

The analysis of internal stability for these walls includes calculating of the safety factor against "tension failure" and the "pullout failure" for the intended geo-synthetic layers [10]; including the determination of geo-synthetic size, dimension and lengths. However, the following steps are used in the above analysis [8]: Determining of the active earth pressure (at any depth, z):

$$\sigma'_a = K_a \gamma_1 z \quad .. (1)$$

Where:
σ'_a: Active earth pressure
K_a:Coefficient of active earth pressure = $\tan^2\left(45 - \frac{\varphi'_1}{2}\right)$
φ'_1: Angle of internal friction

- Selecting for a geo-synthetic type (i.e., geogrid for the case study), with allowable tensile strength (T_{all}),

$$T_{all} = \frac{T_{ult}}{RF_{id} \times RF_{cr} \times RF_{cbd}} \quad .. (2)$$

Where:
RF_{id} = Reduction factor for installation damage (ranging between 1.1 and 1.4)
RF_{cr} = Reduction factor for creep (ranging between 2.0 and 3.0)
RF_{cbd} = Reduction factor for chemical and biological degradation (ranging between 1.1 and 1.5)

- Determining of the vertical spacing between geogrid layers (S_V);

$$S_V = \frac{T_{all}\, C_r}{\sigma'_a\, FS_{Tension}} \quad .. (3)$$

Where:
C_r:Coverage ratio for geogrid.
σ'_a: Active earth pressure.
$FS_{Tension}$: Factor of safety against tension failure.

- Calculations for the length of each geogrid layer:

$$L = l_r + l_e$$

$$l_r = \frac{H - z}{\tan^2(45 - \frac{\varphi'_1}{2})} \quad .. (4)$$

$$F.S_{(Pullout)} = \frac{2 l_e (C_i \sigma'_0 \tan \varphi'_1)(C_r)}{S_V\, K_a} \quad .. (5)$$

$$l_e = \frac{S_V\, K_a\, FS_{(P)}}{2(C_i\, \sigma'_0 \tan \varphi'_1)(C_r)} \quad .. (6)$$

$$L = l_r + l_e = \frac{H - z}{\tan^2(45 - \frac{\varphi'_1}{2})} + \frac{S_V\, K_a\, FS_{(Pullout)}}{2(C_i\, \sigma'_0 \tan \varphi'_1)(C_r)} \quad .. (7)$$

$$F.S_{(Tension)} = \frac{S_V \sigma'_0}{T_{all}} \quad .. (8)$$

However, for the case study related to this research, the results of internal stability for the designed geogrid layers are shown in Table 2.

Table2: Properties of geogrid layers for the case study at station (00+660)

Layer No.	**Depth Z, (m)**	**σ_v (kPa)**	**σ_h (kPa)**	**T (kPa)**	**T_{all} (kPa)**	**F.S (Tension)**	**l_e (m)**	**l_r (m)**	**F.S (Pullout)**
1	0.6	26.4	6.864	4.118	15.9	7.15	2.95	2.45	16.5
2	1.2	37.8	9.828	5.897	15.9	3.576	3.257	2.143	18.2
3	1.8	49.2	12.792	7.675	15.9	2.384	3.563	1.837	20
4	2.4	60.6	15.756	9.454	25	2.8	3.87	1.53	21.7
5	3	72	18.72	11.232	25	2.249	4.176	1.224	23.4
6	3.6	83.4	21.684	13.01	25	1.88	4.482	0.918	25.1
7	4.2	94.8	24.648	14.789	36.4	2.34	4.788	0.612	26.8
8	4.8	106.2	27.612	16.57	36.4	2.046	5.094	0.306	28.5

3.1.2EXTERNAL STABILITY

In external stability, the wall (including soil layers and their reinforcement) is considered as a rigid mass with earth pressures developed on a vertical pressure plane arising from the back end of the reinforcements, see Fig. 2 [8]. In general, the checking for external stability requires applying the following steps.

3.1.2.1 STABILITY AGAINST SLIDING

$$F.S_{sliding} = \frac{\sum P_R}{\sum P_d} \geq 1.5 \quad .. (9)$$

Where:
$\sum P_R$ = Horizontal resistance forces.
$\sum P_d$ = Horizontal driving forces.

$$\sum P_d = F_T \cos\beta .. (10)$$
$$F_T = 0.5\, Ka\gamma_f h^2 .. (11)$$

Where:
γ_f = density of retained backfill soil
h = H + L tan β
β = Angle of internal friction of the foundation soil

$$\sum P_R = (V_1 + V_2 + F_T \sin\beta)\, \mu \quad .. (12)$$

Where V_1 = Dead load surcharge
V_2 = Live load surcharge
Where:
μ: is the external friction angle= min [tan φ_f, tan φ_r, or (for continuous reinforcement) tan ρ]
φ_f: Angle of internal friction of retained fill.
φ_r: Angle of internal friction of reinforced wall fill.
P: Angle of internal friction of foundation soil.

3.1.2.2 STABILITY AGAINST OVERTURNING

$$\mathbf{F.S_{overturning}} = \frac{\sum \mathbf{M_R}}{\sum \mathbf{M_O}} \geq \mathbf{2} \quad .. (13)$$

Where:
$\sum M_R$ =Sum of the moment forces tending to resist overturning the wall about the toe
$\sum M_O$ = Sum of the moments that are attributed to forces tending to overturn the wall:
Referring to Fig. 2:

$$\mathbf{M_O = P_a\, Z'} \quad .. (14)$$
$$\mathbf{P_a} = \text{Active force} = \int_o^H \boldsymbol{\sigma'_a}\, \mathbf{dz} \quad .. (15)$$
$$\sum \mathbf{M_R} = \mathbf{W_1 x_1 + W_2 x_2 + \cdots + qa'\left(b' + \frac{a'}{2}\right)} \quad .. (16)$$

Where:
$W_1\, x_1$ = Area of (AFEGI) (1) (γ_1)
$W_2\, x_2$ = Area of (FBDE) (1) (γ_2)

3.1.2.3 STABILITY AGAINST BEARING CAPACITY FAILURE

The ultimate bearing capacity of the foundation ground:

$$\mathbf{q_{ult} = C'_2\, N_c + 0.5\, \gamma_2\, L_2 N_\gamma} .. (17)$$

Where N_c&N_γ are bearing capacity factors.
The vertical stress at z = H is:

$$\boldsymbol{\sigma'_{o(H)} = \gamma_1 H + \sigma'_{o(2)}} .. (18)$$

Therefore, the safety factor against bearing capacity is:

$$\mathbf{F.S_{BC}} = \frac{\mathbf{q_{ult}}}{\boldsymbol{\sigma'_{o(H)}}} \geq \mathbf{3} .. (19)$$

However, for the case study related to this research, the design of the reinforced soil wall was conducted based on the previous mentioned steps, then it was rechecked using GGU software. In general, this software allows for slope failure investigations using circular slip surfaces (Bishop) and polygonal slip surfaces (Janbu, General Wedge, and Vertical slice methods). In general, the design of this wall using GGU software is indicated in Fig's. 3a and 3b.

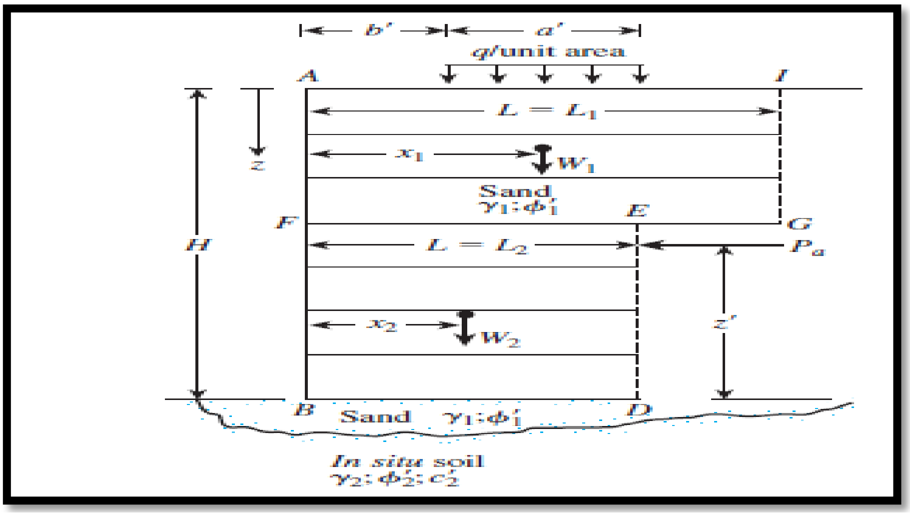

Fig. 2: Details related to external stability of reinforced soil wall [8]

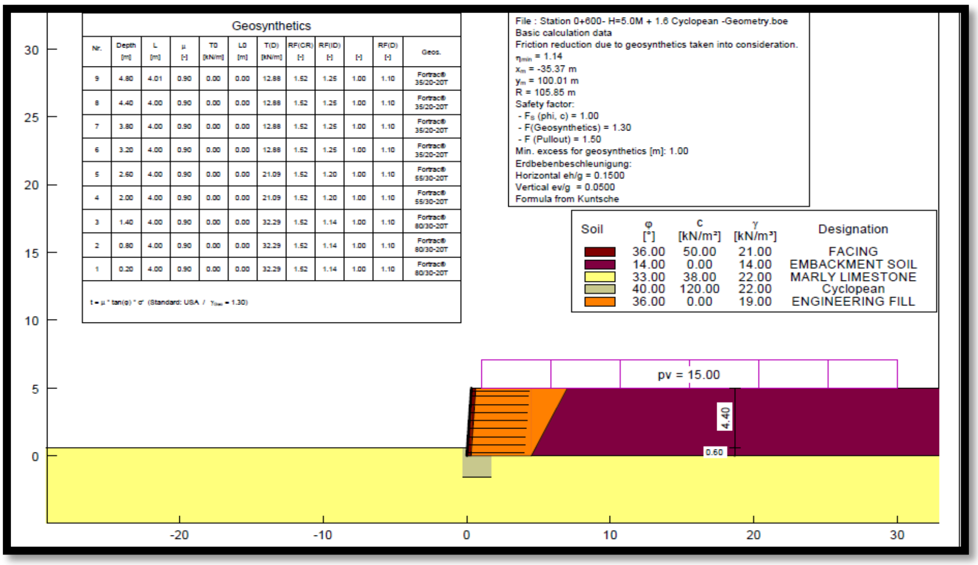

Fig. 3a: Design details for the case study (reinforced soil wall) at station (00+660) using GGU software (step 1)

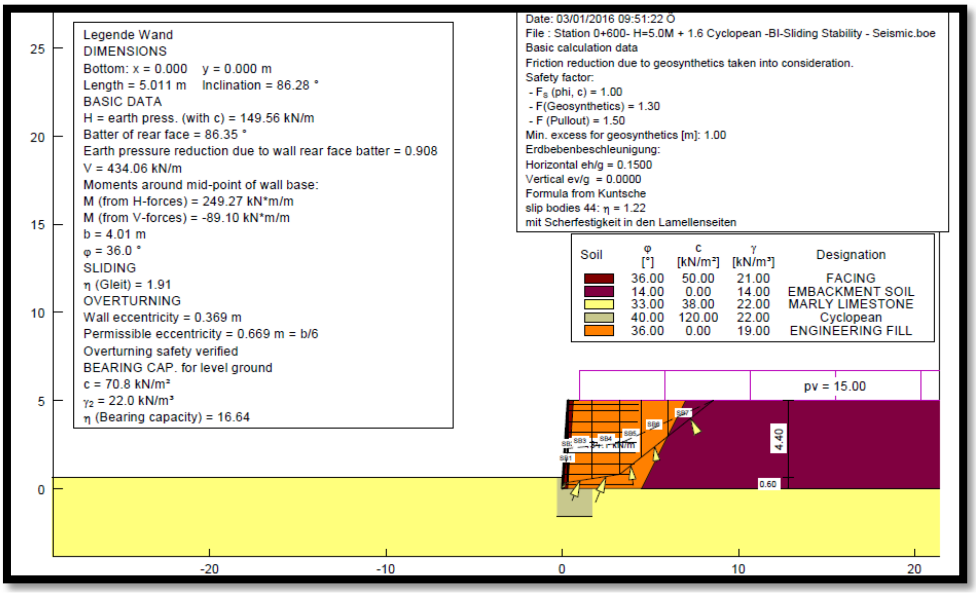

Fig. 3b: Design details for the case study using GGU Software (Step 2)

3.2 DESIGN OF CANTILEVER REINFORCED CONCRETE WALL

All parameters needed in the design of the Reinforced Concrete Wall are indicated in Table 3.

Table 03: Parameters needed in the design of the wall

Parameter	Notation	Value
Height of the wall	H	5.4m
Unit Weight of backfill soil	γ_b	19 kN/m^3
Angle of internal friction of backfill soil	$\emptyset_b$	36^o
Unit Weight of concrete	γ_c	25 kN/m^3
Surcharge	Q	15 kN/m^2
Bearing capacity of soil under the wall	q_a	280 kN/m^2
Angle of internal friction of foundation soil	$\emptyset_f$	33^o
Cohesion of foundation soil	C_f	38 kN/m^2
Compressive strength of concrete	f_c'	25 MPa
Yield stress of steel	F_y	414 MPa

3.2.1 DIMENSIONS OF RETAINING WALL

- The width of the wall base:

$$B = 0.7\,H \quad ..(20)$$
$$= 0.7 \times 5.4 = 3.78\text{m, use } B = 4\text{ m}$$

- The thickness of the stem at the top:

$$T = H/12 \quad ..(21)$$
$$= 5.4/12 = 0.45\text{m}$$

- The thickness of the stem at the bottom:

$$T = H/10 \quad ..(22)$$
$$= 5.4/10 = 0.55\text{m}$$

- The thickness of the base:

$$T = 0.1\,H \quad ..(23)$$
$$= 0.1 \times 5.4 = 0.55\text{ m}$$

3.2.2 LOADS CALCULATIONS

$$K_a = \tan^2\left(45^o - \frac{36^o}{2}\right) = 0.26 \quad ..(24)$$

The active earth pressure (P_a) resulted by the thrust:

$$P_a = \frac{1}{2}\,\gamma\,H^2 K_a ..(25)$$
$$= 0.5 \times 19 \times 5.4^2 \times 0.26 = 72.1\text{ kN}$$

The active earth pressure resulted by surcharge load:

$$Ps = H\,q\,K_a \quad ..(26)$$
$$= 5.4 \times 15 \times 0.26 = 21.1\text{ kN}$$

3.2.3STABILITY OF THE WALL

3.2.3.1 FACTOR OF SAFETY AGAINST OVERTURNING

In order to check the safety factor against overturning, the calculations shown in Table 4 were adopted:

Table 4: The needed data for the factor of safety against overturning

Section No.	Area (m^2)	Weight/Unit Length (kN/m)	Moment Arm (m)	Moment (kN.m/m)
1	0.45*4.85 = 2.18	2.18*25 =54.6	0.325	17.7
2	0.5*0.1*4.85 =0.243	6.1	0.05	0.305
3	0.55*4 =2.2	55	2	110
4	4.85*3.45 =16.732	16.732*19 =318	2.275	723.5
5	3.45	15*3.45=51.8	2.275	117.8
		$\sum V =$ 485.5		$\sum M_R =$ 969.3

$$F.S_{overturning} = P_a\left(\frac{H}{2}\right) + P_a\left(\frac{H}{3}\right) ..(27)$$

$$= 21.1\left(\frac{5.4}{2}\right) + 72.1\left(\frac{5.4}{3}\right) = 186.75\text{ kN.m/m}$$

$$F.S_{overturning} = \frac{M_R}{Mo} = \frac{969.35}{186.75} = 5.2 > 2 \quad Ok$$

3.2.3.2 FACTOR OF SAFETY AGAINST SLIDING

$$F.S_{sliding} = \frac{\sum F_{R'}}{\sum F_d} ..(28)$$

$$\sum F_{R'} = (\sum V)\tan\delta' + B\,K_2 C'_2 + P_p \quad ..(29)$$

In this case, the passive force will be neglected, $\delta' = K_1 \emptyset'_2$
In most cases K_1 and K_2 are in the range from ½ to 2/3

$$F.S = \frac{485.5 \tan\left(\frac{2}{3}*33\right)+\left(4*\frac{2}{3}*38\right)}{21.1+72.1} = 3.2 > 1.5,\ Ok$$

3.2.3.3 FACTOR OF SAFETY AGAINST BEARING CAPACITY FAILURE

$$q_{\substack{max \\ min}} = \frac{\sum v}{B}\left(1 \pm \frac{6e}{B}\right) \quad ..(30)$$

Where e is the eccentricity of the resultant force that acts on the wall and it is given by:

$$e = \frac{B}{2} - \frac{\sum M_R - \sum M_O}{\sum V} \quad ..(31)$$

$$e = \frac{4}{2} - \frac{969.35 - 186.75}{485.5} = 0.39m < \frac{B}{6} = \frac{4}{6} = 0.6 \quad Ok$$

$$q_{\substack{max \\ min}} = \frac{\sum v}{B}\left(1 \pm \frac{6e}{B}\right) = \frac{485.5}{4}\left(1 \pm \frac{2.34}{4}\right) \quad ..(32)$$

$$q_{max} = 192.4\ kN$$

$$q_{min} = 50.37\ kN$$

$$q_u = C_2 N_C F_{cd} F_{ci} + q N_q F_{qd} F_{qi} + \frac{1}{2}\gamma_2 B' N_\gamma F_{\gamma d} F_{\gamma i} \quad ..(33)$$

Where:
$q = \gamma_2\ D = zero$

$$B' = B-2e = 4-2(0.39) = 3.22\ m$$

$$F_{cd} = 1 + 0.4\frac{D}{B'} = 1$$

$$F_{qd} = 1 + 2\tan\emptyset_2(1-\sin\emptyset_2)^2\frac{D}{B'} = 1$$

$$F_{qd} = 1 + 2\tan\emptyset_2(1-\sin\emptyset_2)^2\frac{D}{B'} = 1$$

$$\omega^0 = \tan^{-1}\left(\frac{P_a + P_s}{\sum V}\right) = 10.9$$

$$F_{Ci} = F_{qi} = \left(1 - \frac{\omega}{33}\right) = 0.77$$

$$F_{\gamma i} = \left(1 - \frac{\omega}{\emptyset_2}\right)^2 = 0.45$$

$$q_u = 1691.5 kN/m^2$$

$$F.S_{BC} = \frac{q_u}{q_{max}} = \frac{1691.5}{192.4} = 8.8 > 3\ Ok$$

3.2.4 SAMPLE OF CALCULATIONS FOR THE REINFORCEMENT OF THE STEM

$$M = P_a\left(\frac{H}{2}\right) + P_a\left(\frac{H}{3}\right) = 186.75\ kN.m/m$$

$$Mu = 1.6*M = 1.6*186.75 = 298.8\ kN.m/m$$

$$R_U = \frac{Mu * 10^6}{0.9 * b * d^2} = \frac{298.8 * 10^6}{0.9 * 1000 * 315^2} = 3.35$$

$$\rho = \frac{0.85 f'_c}{fy}\left(1 - \sqrt{1 - \frac{2*Ru}{0.85 f'_c}}\right) = \frac{0.85*24}{414}\left(1 - \sqrt{1 - \frac{2*3.35}{0.85*24}}\right) = 0.00884$$

$$\rho_{min} = 0.002$$

$$\rho_{max} = 0.75\left(0.85 * 0.85\frac{f'_c}{fy}\left(\frac{600}{600+fy}\right)\right) = 0.75\left(0.85*0.85*\frac{24}{414}\left(\frac{600}{600+414}\right)\right) = 0.0186$$

$$\rho_{min} > \rho > \rho_{max}$$

$$As = \rho\ b\ d = 0.00884 * 1000 * 315 = 2784.6$$

$$\text{Use } \emptyset\ 20 \quad Ab = 314\ mm^2$$

Number of bars in one meter of the Stem of the wall = As/Ab = 2784.6/314 = 9 $\emptyset$ 20/m

However, the above calculations for the design of reinforced concrete retaining wall was rechecked by using PROKON Software as shown in Fig's. 5a, 5b, 5c, 5d, 5e and 5f. The general design of the proposed alternatives are shown in Fig's. 6 and 7.

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Retaining Wall Design : Ver W2.3.03 - 10 July 2007
Title :

Input Data
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C14

Wall Dimensions						Unfactored Live Loads			General Parameters			Design Parameters	
H1	(m)	4.4	C	(m)	.55	W	(kN/m²)	15	Soil frict φ	(°)	36	SF Overt.	2.5
H2	(m)		F	(m)		P	(kN)		Fill slope β	(°)		SF Slip	1.5
H3	(m)		xf	(m)		xp	(m)		Wall frict δ	(°)	22	ULS DL Factor	1.6
Hw	(m)		At	(m)	.45	L	(kN/m)		ρ Conc	kN/m³	25	ULS LL Factor	1.4
Hr	(m)		Ab	(m)	.5	xl	(m)		ρ Soil	kN/m³	22	Pmax (kPa)	315
B	(m)		Cov wall	mm	50	Lh	(kN/m)		fc'	(MPa)	25	Soil Poisson υ	.15
D	(m)	3.45	Cov base	mm	50	x	(m)		fy	(MPa)	420	DL Factor Ovt.	1.6

Fig. 5a: Design details for the case study (reinforced concrete wall) at station (00+660) using PROKON Software (step 1)

```
Theory    : Coulomb
Wall type : Cantilever

SEISMIC ANALYSIS SETTINGS:

Seismic Analysis ON/OFF:OFF
```

Hor Accel. (g)	
Vert Accel. (g)	
Include LL's	

```
VALUES OF PRESSURE COEFFICIENTS:

         Active Pressure coefficient Ka :0.260 (User Defined)
        Passive Pressure coefficient Kp :0.000 (User Defined)
             Base frictional constant μ :0.350 (User Defined)

FORCES ACTING ON THE WALL AT SLS:
All forces/moments are per m  width

                                FORCES (kN ) and their LEVER ARMS (m )
Description                 F Horizontal   Lever arm  F Vertical    Lever arm
                              left (+)                 down (+)
Destabilizing forces:
Total Active pressure Pa       51.064        1.467       21.407        0.483
As a result of surcharge w     15.826        2.200        6.634        0.479
```

Fig. 5b: Design details (step 2)

```
FORCES ACTING ON THE WALL AT SLS:
All forces/moments are per m  width

                                FORCES (kN ) and their LEVER ARMS (m )
Description                 F Horizontal   Lever arm  F Vertical    Lever arm
                              left (+)                 down (+)
Destabilizing forces:
Total Active pressure Pa       51.064        1.467       21.407        0.483
As a result of surcharge w     15.826        2.200        6.634        0.479

Stabilizing forces:
Passive pressure on base Pp    -0.000        0.000
Weight of the wall + base                               100.031        1.181
Weight of soil on the base                              294.333        2.212
Point load of  75.00 kN on backfill                       8.523        0.200
UDL of 15.0 kPa                                          52.500        2.200

EQUILIBRIUM CALCULATIONS AT SLS
All forces/moments are per m  width

1.Moment Equilibrium

Point of rotation: bottom front corner of base.

For Overturning moment Mo calculate as follows:
  Mo = Sum(hor. forces x l.a.) - Sum(vert. forces x l.a.)
For Stabilizing moment Mr calculate as follows:
  Mr = -Sum(hor. forces x l.a.) + Sum(vert. forces x l.a.)
where l.a. = lever arm of each force.
```

Fig. 5c: Design details (step 3)

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```
       Stabilizing moment Mr : 888.25 kNm
     Destabilizing moment Mo :  96.19 kNm

Safety factor against overturning = Mr/Mo = 9.234

2.Force Equilibrium at SLS

    Sum of Vertical forces Pv : 491.95 kN
  Frictional resistance Pfric : 172.18 kN
Passive Pressure on shear key :   0.00 kN
     Passive pressure on base :   0.00 kN
=> Total Horiz. resistance Fr : 172.18 kN

     Horizontal sliding force on wall Fhw :  66.89 kN
Horizontal sliding force on shear key Fht :   0.00 kN
     => Total Horizontal sliding force Fh :  66.89 kN

Safety factor against overall sliding = Fr/Fh = 2.574
```

Fig. 5d: Design details (step 4)

```
EQUILIBRIUM CALCULATIONS AT ULS
All forces/moments are per m  width

1.Moment Equilibrium

Point of rotation: bottom front corner of base.

For Overturning moment Mo calculate as follows:
  Mo = Sum(hor. forces x l.a.) - Sum(vert. forces x l.a.)
For Stabilizing moment Mr calculate as follows:
  Mr = -Sum(hor. forces x l.a.) + Sum(vert. forces x l.a.)
where l.a. = lever arm of each force.

        Stabilizing moment Mr : 1421.19 kNm
      Destabilizing moment Mo : 147.57 kNm

Safety factor against overturning = Mr/Mo = 9.630

2.Force Equilibrium at ULS

    Sum of Vertical forces Pv : 787.12 kN
  Frictional resistance Pfric : 275.49 kN
Passive Pressure on shear key :   0.00 kN
     Passive pressure on base :   0.00 kN
=> Total Horiz. resistance Fr : 308.86 kN

     Horizontal sliding force on wall Fhw : 103.86 kN
Horizontal sliding force on shear key Fht :   0.00 kN
     => Total Horizontal sliding force Fh : 103.86 kN

Safety factor against overall sliding = Fr/Fh = 2.974
```

Fig. 5e: Design details (step 5)

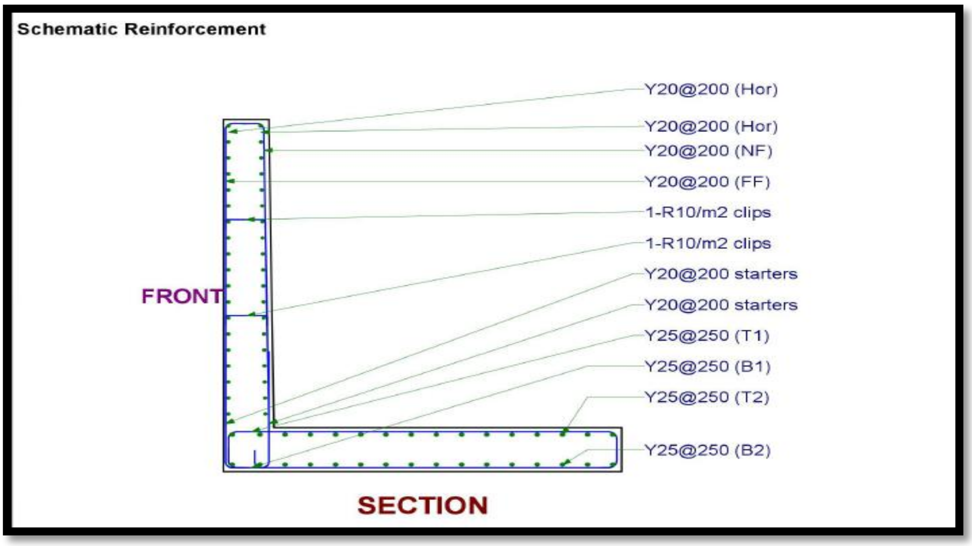

Fig. 5f: Design details (step 6)

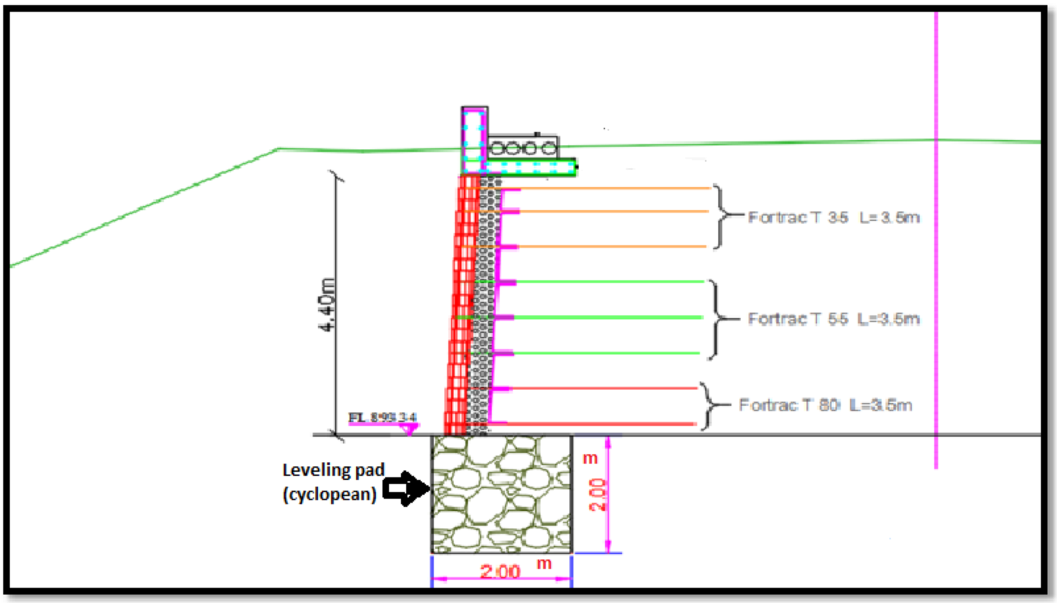

Fig. 6: The General design of the proposed geo-synthetic retaining wall (from station 0+540 to station 0+690) using GGU software

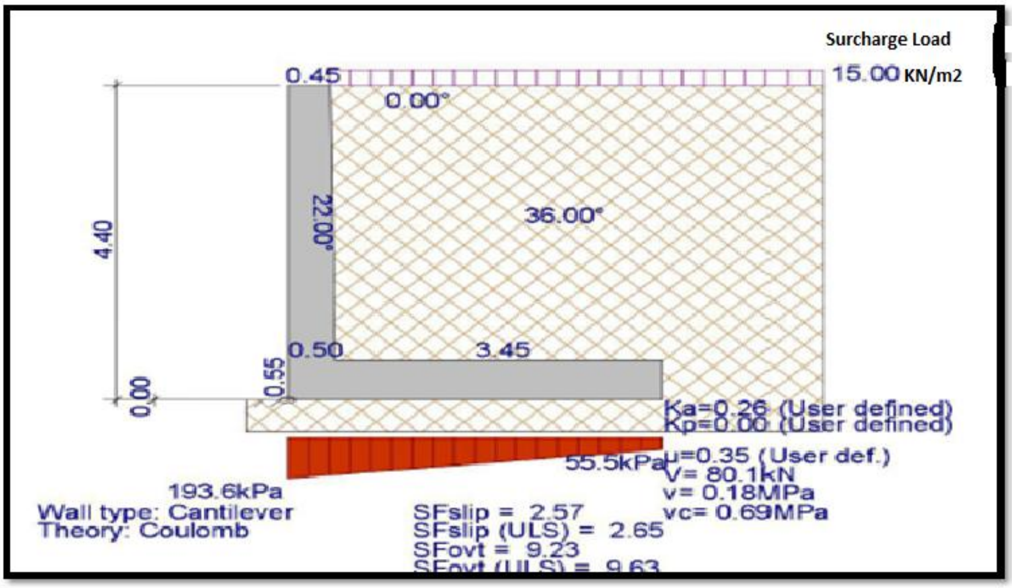

Fig. 7: The General Design of the proposed reinforced concrete retaining wall (from station 0+540 to station 0+690) using PROKON software

IV. DURATION AND COST COMPARISON BETWEEN ALTERNATIVES

In general, the duration and cost of carrying out both proposed alternatives were calculated as discussed in the following two sections [11], [12] and [13].

4.1ESTIMATED DURATION AND COST OF CONDUCTING THE GEO-SYNTHETIC WALL

The final duration of adopting the Geo-Synthetic wall for the case study is found to be 35 working days. Whereas, the cost of performing this wall is briefly summarized below:

- Cost of excavation (150-180) JD/hr; 12 days × 8 hr × 165 JD = 15840 JD
- Lump sum cost of leveling pad (using cyclopean concrete), facing elements, Geo-synthetic rolls, backfilling and compaction is (90-110) JD/m^2; 725 m^2 × 100 JD = 72500 JD

The total cost of performing the Geo-Synthetic wall is = 88340 JD

4.2 ESTIMATED DURATION AND COST OF CONDUCTING REINFORCED CONCRETE WALL

The final duration of performing the concrete wall is found to be 65 working days. Whereas the cost of performing the wall is briefly indicated below:

- Cost of excavation (150-180) JD/hr; 12 days × 8 hr × 165 JD = 15840 JD
- Cost of casting blinding layer; 61 m^3 × 70 JD/m^3 = 4270, cost of labors and equipment = 280 JD; the total cost = 4550 JD
- Cost for framework of foundation using concrete blocks; 150 × 6 JD = 900, cost of labors = 250 JD, total cost = 1150 JD
- Cost of steel reinforcement for foundation; 60 tons of steel × 400 JD/Ton 24000 JD, cost of labors and equipment = 560 JD, total cost =24560 JD.
- Cost of casting concrete for foundation; 330 m^3 × 75 JD/ m^3 = 24750 JD, cost of labors and equipment = 200 JD, total cost = 24950 JD.
- Cost of formwork for wall; 1000 m^2 × 0.7 JD = 700 JD, cost of labors and equipment = 1500 JD, total cost = 2200 JD.
- Cost of steel reinforcement of wall; 65 Tons × 400 JD/Ton = 26000 JD, cost of labors and equipment = 2100 JD, total cost = 28100 JD.
- Cost of concrete for the wall; 370 m^3 × 75 JD = 27750 JD; cost of labors and equipment = 560 JD, total cost = 28310 JD.
- Cost of Curing = 800m^2 × 3 JD/m^2 = 2400 JD; cost of labors = 2200, total cost = 4600 JD.
- Cost of backfilling and compaction; lump sum cost = 6300 JD

The total cost of performing the reinforced concrete wall is = 140560 JD

A summary of the total cost and duration of executing the proposed alternatives is shown in Table 5.

Table 5: A Summary of the total duration and cost of executing the proposed alternatives

Alternative	Duration of Construction, Days	Total Cost, JD
Geo-Synthetic Soil Wall	35	88340
Reinforced Concrete Wall	65	140560

V. CONCLUSIONS

Considering the design of the proposed alternatives and results of this research, the conclusions of this research are summarized below:

1. Referring to the evaluation for rehabilitation and reconstruction the embankments of the study road, several types of retaining walls were proposed; however, the most alternatives that may fit to this project were reinforced concrete wall, and reinforced earth retaining wall.
2. Each proposed alternative was designed in details (using the traditional methods and software methods), and then a work plan was developed for each of them to estimate the cost of execution and the construction duration for each alternative. Referring to the calculations of cost and duration for each alternative, it was concluded that the reinforced earth retaining wall is the most suitable, applicable, and economical alternative to be adopted for construction projects in Jordan especially those concerning road projects.
3. The geo-synthetic retaining walls could be used in case of relatively high vertical cuts rather than those for the traditional walls.
4. Based on site reconnaissance to several performed projects in Amman where geo-synthetic walls had been conducted, this type of retaining structures is characterized to be stable for a long period of time with no signs of settlements or damages.

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