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NON-TRADITIONAL USE OF MECHANICALLY STABILIZED EARTH WALLS IN A WATER RETAINING STRUCTURE

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ABSTRACT

There are a variety of choices for retaining systems. Among these choices are the earth retaining walls, gravity walls, reinforced concrete walls, etc. Recently, the use of the Mechanically Stabilized Retaining Walls, MSRW, has experienced great advances. In the present paper, a comparative study is performed to compare different types that can be used for retaining of an artificial lagoon. Though being non-traditional, the current paper concludes that the use of Mechanically Stabilized Retaining Wall system, MSRW for retaining the lagoon proved to be the best option taking into consideration the reduction in construction time, increase in storage area, the considerable saving in construction costs. The considered case study is for a large project in Egypt, where there was a time limitation as well as a space constraint so as not to stop other ongoing activities at the factory under development. The proposed solution showed a good satisfaction with both time and economy of the project.

KEYWORDS: Mechanically stabilized wall, Lagoon, geogrid, Finite element, Water structure.

الاستخدام الغير تقليدى للحوائط الترابية المسلحة لسند منشأ مائي

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الملخص

هن هناك العديد من الاختيارات لنظم السند. وضمن هذه االختيارات السدود الترابية والحوائط التثاقلية والحوائط الخرسانية المسلحة ،...الخ.وقد شهد نظام سند الجوانب باستخدام الحوائط المسلحة باستخدام الشرائح المصنعة تطوراً كبيراً في الاونة األخيرة. في هذا البحث، تم عمل دراسة مقارنة بين الطرق المختلفة التي يمكن استخدامها لسند بحيرة صناعية.وعلي الرغم من كون هذه الطريقة غير تقليدية، فقد خلص البحث إلي كون هذه الطريقة هي الاختيار الافضل أخذا في الاعتبار زمن التنفيذ وزيادة الحجم المستخدم في تخزين المياه باإلضافة إلى التوفير في تكلفة الانشاء. وهذه الحالة الدراسية هي لمشروع بحيرة صناعية بجمهورية مصر العربية حيث كان أمر التنفيذ محدود المدة ومطلوب أقصي استفادة ممكنة من المساحة المحدودة كما أنه كان هناك حدود في المساحة المتاحة لتنفيذ البحيرة الصناعية نظراً لعدم توقف نشاط الموقع أثناء التنفيذ. حقق الحل المقترح نتائج معتبرة من ناحية الوقت والتكلفة الاقتصادية.

1. INTRODUCTION

An industrial factory uses artificial lagoons for washing the material before starting the manufacturing process. The factory contains two artificial lagoons as shown in Fig. (1), however, due to the development progress, an additional artificial lagoon has been required to be constructed close to the existing lagoons.

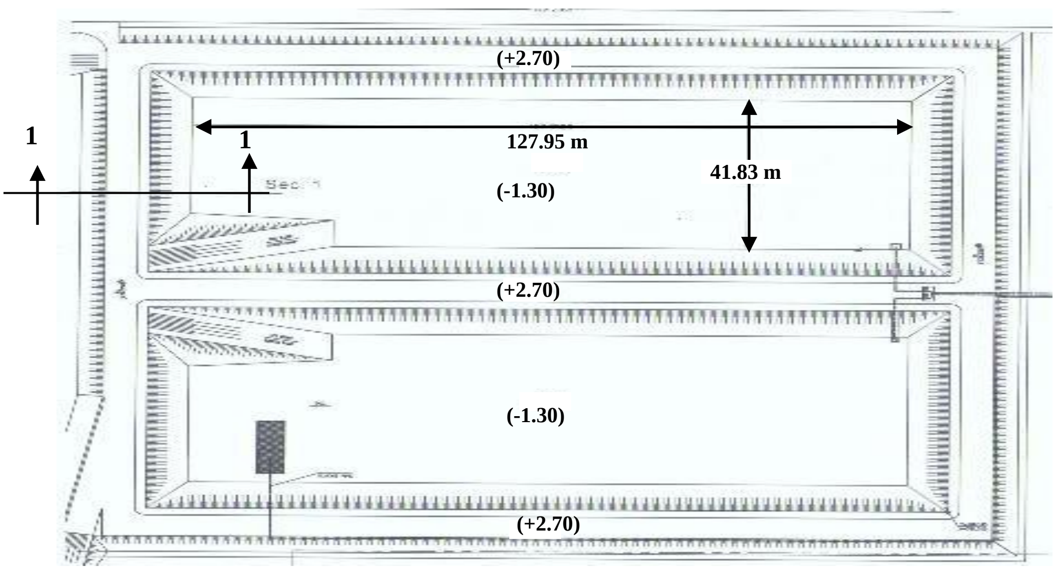

Figure (1) General layout for the existing artificial lagoons

The sides of the existing artificial lagoons are earth embankment with height of 4.00 m, base with length of 23.00 m, and top road with width of 8.00 m. The side slope is about 28° as shownin section 1-1 in Fig. (2).

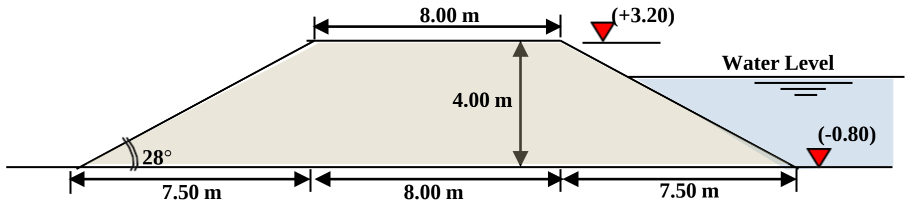

Figure (2) Cross-section (1-1) in the earth side of the existing lagoons

For the lagoon periodical bed cleaning and maintenance, there exist access ramps with slope 12%. The land area of the existing two artificial lagoons is about 26000 m^2 and the storage capacity is about 38000 m^3, with land use of 1.45 m^3 water per square meter.

The available area to construct the additional required artificial lagoon was about 10400 m^2 close to the existing lagoons as shown in Fig. (3).

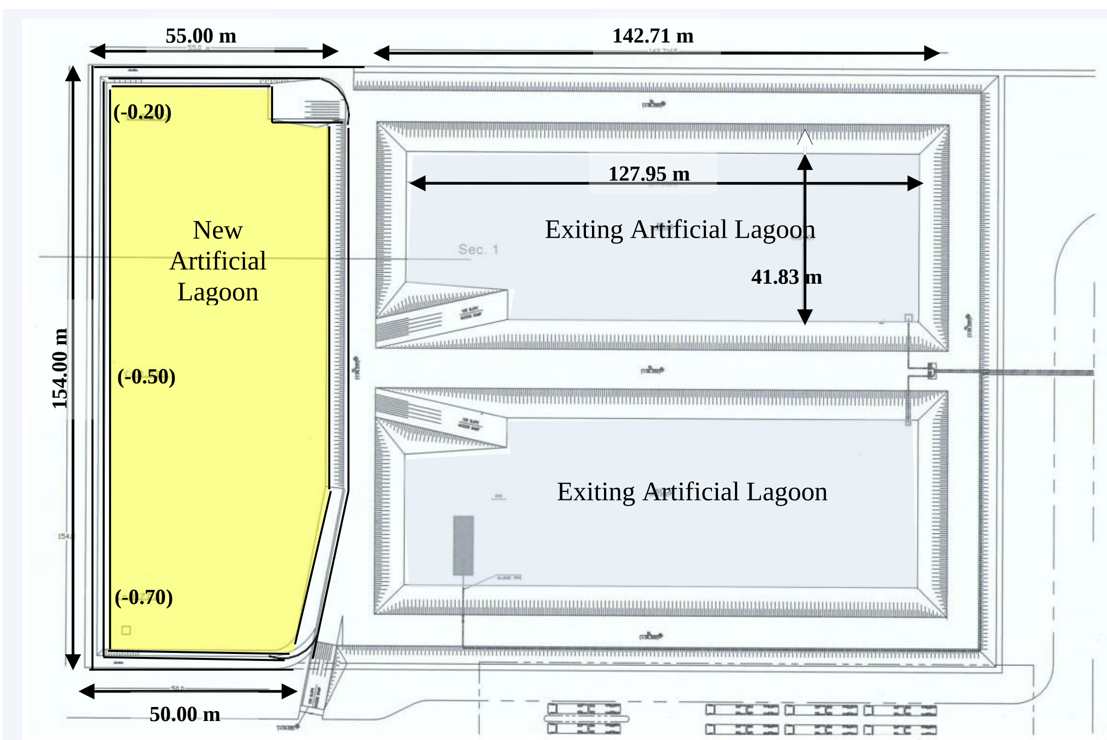

Figure (3) Plan of the position of the new required artificial lagoon close to the existing lagoons

To decide the suitable and economic wall type, taking into consideration the limited time of about one month for construction, to be ready for use for the new season production, a comparative study was carried out between earth, concrete and mechanically stabilized earth (MSE) walls. It was concluded that the earth walls need longer time than what was available, and the concrete wall will cost double that required for MSE wall, as it can also be observed from the comparison of Fig. (4)[1]. On the other hand, the expenses of reinforced concrete retaining walls rise exponentially as the height of soil to be maintained rises and the subsoil levels deteriorate. Therefore, MSE wall was decided to be constructed as a barrier for the new artificial lagoon, taking into consideration the advantage of this wall type since as less site preparation is required, and it can be constructed in confined area [2]. It is worth mentioning that, the high ground water table necessitates that the lagoon shall be mainly above the ground surface rather than being beneath it. Moreover, being above the ground surface, that prevents possible buoyancy whenever the lagoon is empty.

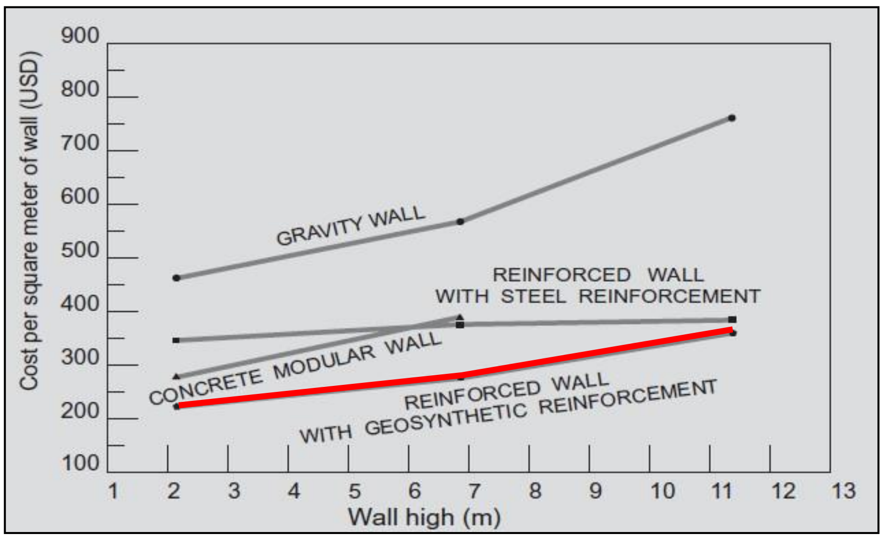

Figure (4) Economic Comparison of Retaining Walls in the USA [3]

2. WALL DESIGN

2.1 Components of MSE Walls

Mechanically stabilized earth walls (MSE) are dependent on reinforcing element such as metal bars, welded wire mats, geosynthetics, or other anchorage systems to improve the mechanical properties of soil mass [4]. Mechanically stabilized Earth walls have theadvantage of flexibility on soft foundation, seismic stability, and faster in construction than conventional retaining walls. Moreover, MSE walls need less site preparation, and can be constructed in confined areas where other retaining walls are impossible to construct [5].

2.2 Stability of MSE Walls

In our study geogrid sheets were used as the reinforced elements. For the reinforced wall two primary forms of stability must be investigated: Internal Stability and ExternalStability.

The problem geometry, internal pull-out and geogrid mechanically stabilized earth (MSE) wall rupture limit states was discussed by [6&7], as illustrated in Fig. 5.

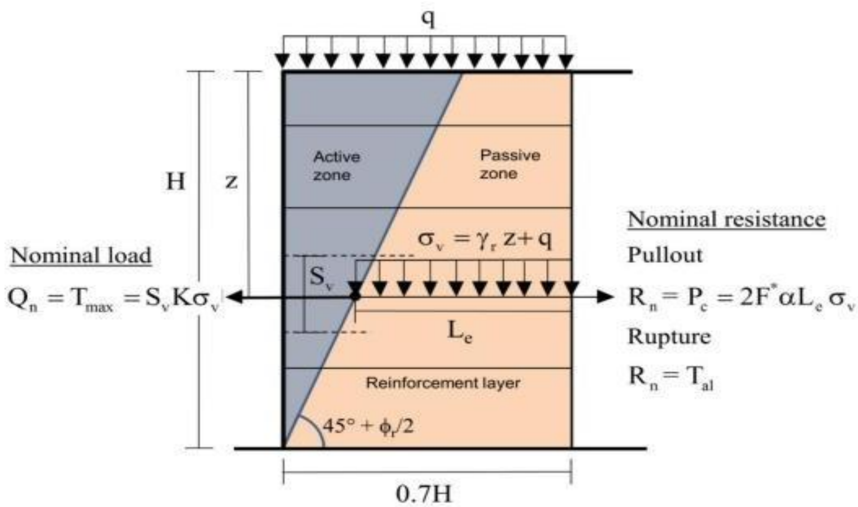

Figure (5) Problem geometry, internal pull-out and geogrid mechanically stabilized earth (MSE) wall rupture limit states

In the Passive Zone, the shear strength developed along the geogrid embedment length (L_e) due to the overburden pressure (σ_v) and surcharge load (q) represents the NominalResistance, while in the Nominal load in the Active zone represents the driving force. Internal soil rupture must be tolerated by a geosynthetic reinforced soil system, andthere must be no slippage at the soil-geosynthetic interface. The internal stability of thesoil mass is ensured by the tensile strength of the geosynthetic reinforcement and theshear strength of the soil. Accordingly, the ability of this composite system to resistpull-out, grid rupture, and bulging may be referred to as internal stability. ~~Because~~Using the minimum required layer spacing [4], prevents these failure phenomena,factors of safety for grid rupture and bulging are not specifically sought after [8].

The external stability includes the safety against sliding, bearing capacity, overturning and deep or overall stability. Numerically, these modes of failure can be checked through the Global factor of safety for Stability of MSE wall.

3- WALL GEOMETRY

The geometry of the proposed MSE wall for the new Lagoon is illustrated in Fig. (6). Taking into consideration that one side of the new artificial lagoon is the same as that of the existing twolagoons, while the other three sides will be constructed based on the proposed geometry of the MSE wall. The level of the MSE wall is adjusted to be at level (+3.20), the same as that for the existing lagoons.

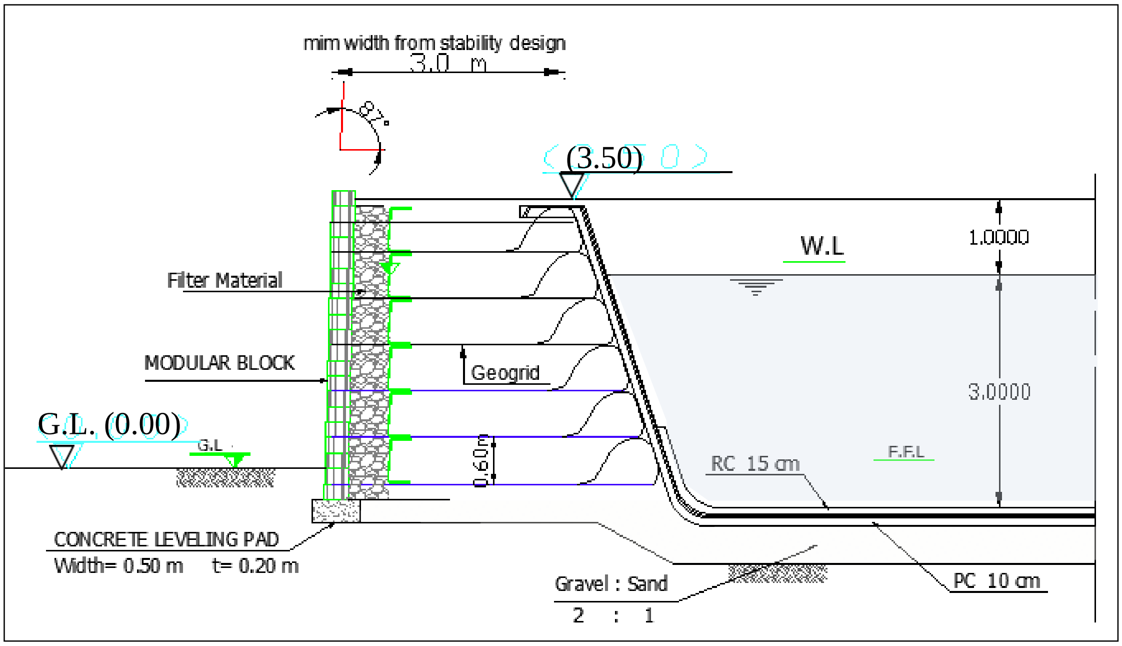

Figure (6) Geometry of the proposed MSE wall for the new artificial lagoon

The modular blocks vertical face of MSE walls represents the lagoon wall back, as opposite to common feature of MSE wall, while the wall face is geosynthetic wrap-face reinforced soilslopes [8 & 9]. The modular blocks were with height of 200 mm.

The wrapped face was formed using sand bags with the aid of relative flexibility of the used geogrid sheets. A minimum overlap of 150 mm is recommended along the edges perpendicular to the slope for wrapped face structures. Alternatively, with grid reinforcement, the edges may be clipped or tied together [8].

The face of the MSE wall towards the water side is semi vertical with slope (3 Vertical: 1 Horizontal) i.e., slope about 18°). The top surface of the wall is assumed to be subjected to additional surcharge load (q) = 20 kN/m^2, corresponding to the expected heavy truck loads as recommended by [5].

The water face side of the MSE wall was sealed by Plain concrete with thickness of 100 mm, and Polyethylene sheet with thickness of 1 mm, and the lower part was covered with

R.C. slab with thickness of 150 mm as illustrated in Fig. 6.

4- NUMERICAL ANALYSIS AND RESULTS

A numerical model was developed by Plaxis -2D program to simulate the geometry of the components of the MSE wall proposed for the new artificial lagoon. The properties of the retained foundations soils and the geogrid characteristics used in this study are listed in Table (1). Mohr-Column model (MC) was used for the analysis of the used materials.

Table 1. Soil Properties and Geogrid Parameters

<table>
<tr><th colspan="4">Soil Properties</th></tr>
<tr><th colspan="2">Property</th><th>Foundation</th><th>Retained</th></tr>
<tr><td colspan="2">Angle of friction (Φ°)</td><td>37°</td><td>35°</td></tr>
<tr><td colspan="2">Unit Weight (γ) kN/m^3</td><td>18.5</td><td>18</td></tr>
<tr><td colspan="2">Cohesion (c) kN/m^2)</td><td>1.00</td><td>1.00</td></tr>
<tr><td colspan="2">Permeability K_x= K_y (m/day)</td><td>1.00</td><td>1.00</td></tr>
<tr><td colspan="2">Poison’s ratio (ν)</td><td>0.30</td><td>0.30</td></tr>
<tr><td colspan="2">Elastic Modulus, E (kN/m^2)</td><td>4000</td><td>2300</td></tr>
<tr><td colspan="2">$R_{interface}$</td><td>1.00</td><td>0.67</td></tr>
<tr><td colspan="2">Dilatancy angle (ψ°)</td><td>6°</td><td>5°</td></tr>
<tr><td colspan="2">Material Type</td><td>Drained</td><td>Drained</td></tr>
<tr><th colspan="3">Geogrid Parameter</th><th>Value</th></tr>
<tr><td rowspan="2">Fortrac 35</td><td colspan="2">Ultimate Tensile Strength (kN/m)</td><td>35</td></tr>
<tr><td colspan="2">Strain at Nominal Tensile strength %</td><td>6.0</td></tr>
<tr><td rowspan="2">Fortrac 55</td><td colspan="2">Ultimate Tensile Strength (kN/m)</td><td>55</td></tr>
<tr><td colspan="2">Strain at Nominal Tensile strength %</td><td>6.0</td></tr>
</table>

The stability of the proposed MSE wall was evaluated based on the minimum required global factor of safety =1.50, and taking into consideration the induced maximum lateral displacementof the wall panel.

It is worth mentioning that, during the successive trials to check the stability of the proposed model, the stiffness of the used Fortrac geogrid was chosen to satisfy the requirements of the Global Factor of Safety and the economic cost. Therefore, the chosen geogrid was with higher stiffness (Fortrac 55) for layers near the wall base with vertical spacing of 0.60 m, while for middle and upper-part, geogrid layers with less stiffness (Fortrac 35) were used. The last uppergeogrid layer was with smaller vertical spacing of 0.40 m. On the other hand, the dimensions ofthe reinforced soil mass were previously shown in Fig. (6) to represent the most economic geometry for the proposed MSE wall.

4.1 Deformed Shape and Distribution of Mean Stresses

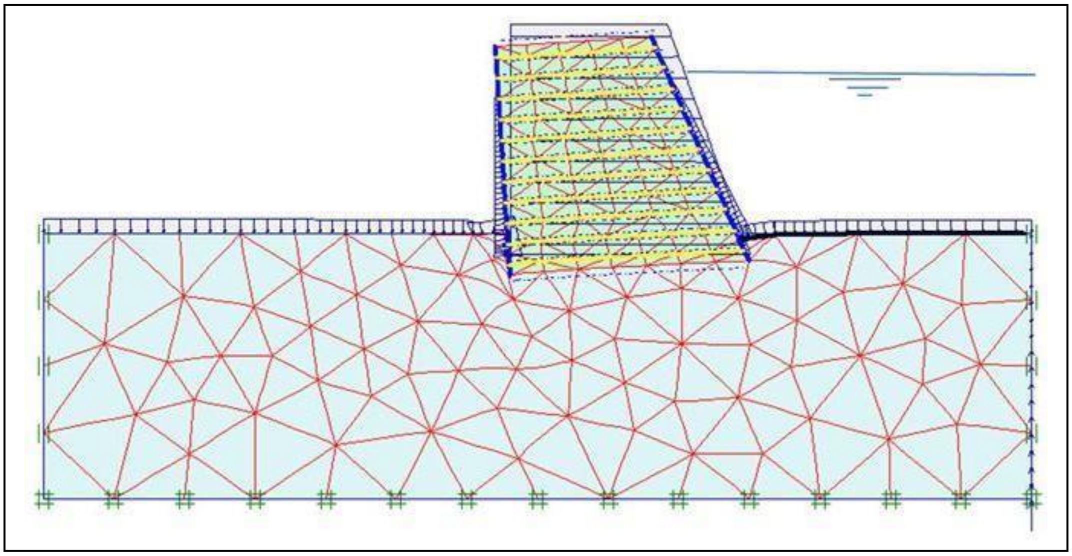

Figure **(7)** Numerical model deformed mesh

The extreme total displacement (δ) of the numerical model was in the order of about 34 mm atthe top of the wall. The wall height (H) is 3.70 m, and the normalized displacement (δ/H) is about 0.009, with an inclination angle of about 0.53°, i.e., less than one degree.

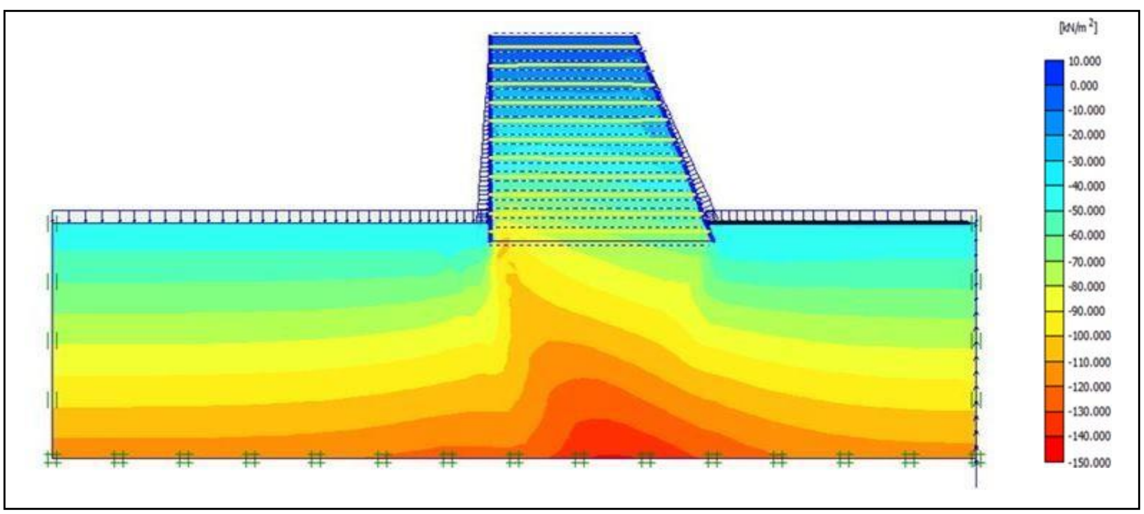

Figure (8) Distribution of mean stress in the MSE body and the foundation soil

The contour distribution of mean stresses in Fig. 8 shows the concentration of stresses in the top part of the reinforced soil mass which gradually decreases towards the bearing soil. This observation is inconsistent with the observed total displacement at the top of the wall.

4.2 Geogrid Axial Tensile Stresses and Displacements

The axial force in the geogrid layers and the corresponding induced total strain are listed inTable (2), and plotted in Figures 9 and 10.

Table (2) Axial Force in Geogrid layers and total displacement

Geogrid Layer Number	Geogrid Ultimate Tensile Strength (kN/m')	Geogrid Length (m)	Axial Force (kN/m')	Lateral displacement (mm)	Axial Force / Ultimate Strength (%)	Elongation in geogrid (%)
5 (Top)	35	4.00	4.55	32.79	13.00	0.82
4	35	4.00	3.38	31.03	9.66	0.78
3	35	4.00	5.25	29.59	15.00	0.74
2	55	4.00	8.17	28.46	14.85	0.71
1(Bottom)	55	4.00	13.60	27.70	24.73	0.70

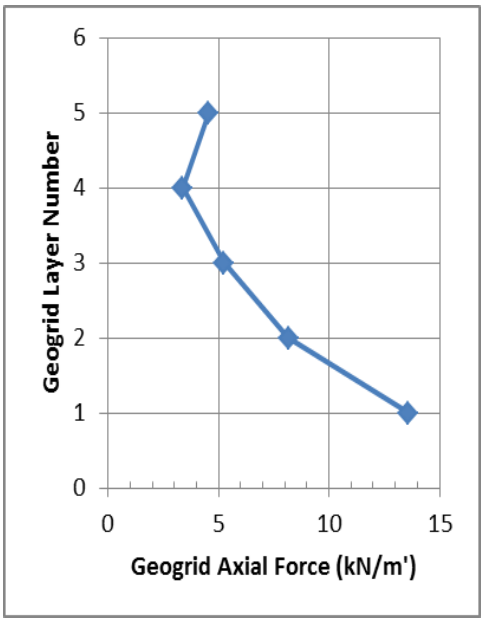

Figure (9) Profile of Axial Force in wall geogrid layers

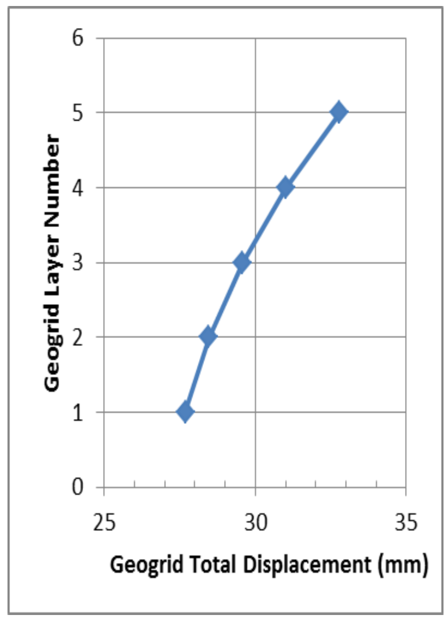

Figure (11) Induced lateral displacement in geogrid layers

The maximum geogrid force is found to be in the lower part of the reinforced soil mass, therefore, geogrid with higher strength was used in the lower part compared with that at the upper part. The geogrid axial force was about 13.00% and 24.73% of the ultimate strength for the upper and lower reinforced layers respectively.

The induced elongation in the geogrid layers was with strain in the range of 0.70% to 0.82% with higher values for the upper geogrid layers. From a practical point of view, restricting geogrid strains from achieving tensile strains more than 3% strain can be used to prevent soil failure and represents an important limit state [4, 6 & 10]. Therefore, the low deformations of the reinforced soil mass under the site loading conditions reflect the adequacy of the designed MSE wall for the new artificial lagoon.

5- LAYOUT OF THE NEW ARTIFICIAL LAGOON AND LAND USED

The general layout for the site of the new artificial lagoon and the existing lagoons is shown inFig. (3).

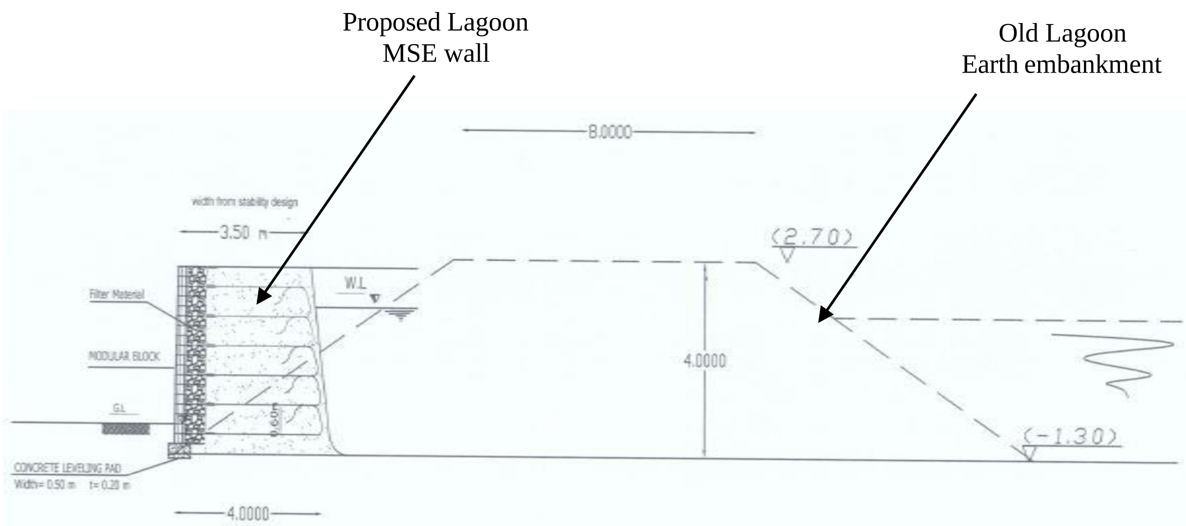

Figure (11**)** Section shows comparison between the geometry of the proposed MSEW and traditional embankment existing earth wall

The bed of the new lagoon was formed to be with slope from (-0.20) to (-0.70) with anaverage level at (-0.50). The volume of the MSE wall is about 14 m^3/m'; while the volume of the embankment of existing lagoons is about 64 m^3/m', i.e., the boundary ofthe MSE walls around the new artificial lagoon had decreased by about 78%. The areaof the existing two lagoons is of about 26000 m^2, with total capacity of 38000 m^3, i.e., land used is 1.45 m^3 water /m^2, while the storage capacity of the new lagoon is 24000 $m^3$for available area with 10400 m^2. Therefore, the land used of the new artificial lagoon increased to 2.40 m^3 water /m^2, i.e., the storage capacity increased by more than 65%. In other words, selecting the MSW rather than the traditional method resulted in efficient land use.

6- SUMMARY AND CONCLUSIONS

In this paper a retaining wall is required to be constructed as barrier for new artificial lagoon in a factory, in the vicinity of exiting two lagoons. The limitations for the construction time and cost were the critical factors to decide the type of the retaining wall. A comparative study was carried out for earth, concrete and mechanically stabilized earth (MSE) walls. It was concluded that the earth wall needs long time than the available, and the concrete wall needs also long time with costs almost double that required for mechanically stabilized earth (MSE). The proposed and designed MSE wall proved to be the best option, with the most important advantage that it increased the land used for water storage capacity by more than 65% compared to the earth embankments of existing lagoons.

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