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Risk Management of Executing Deep Excavations of Large Scale Projects in Jordan

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***Abstract* — Numerous risks are associated with carrying out deep excavations especially those for areas with proximity, including affecting the overall stability for the project site, adjacent existing structures, utilities, and other infrastructure. The hypothesis for this research is the existence of wrong practices through executing deep excavations leading to different engineering problems concerning the performance for large scale projects in Jordan. The practical part of this research included conducting different activities. The first of these is reviewing for previous reports concerning site investigations for residential buildings in Jordan, and conducting site visits to several construction projects. The second activity was the design of the survey questionnaire that was distributed afterwards to group of expert engineers, designers, and consultant companies. The third activity was related to analyzing the collected data using a statistical package for social sciences (SPSS) for quality evaluations. And finally, the fourth activity was submitting of guidelines and recommendations for improving the management to deal with such excavations. Based on the results of the research survey, and questionnaire analysis, it was concluded that a lot of risks may be caused by performing deep excavations represented by the response of adjacent structures to ground movements due to inducing large stresses and strains beneath these structures, ground settlements, and their effects on the labors who work inside those sites, etc. Accordingly, the need of risk management for such large infrastructural works is now largely recognized through the evaluation of risk resources and setting up for precautionary and contingency measures to reduce and eliminate these risks.**

***Keywords*— Deep Excavations, Excavation Methods, Excavation Equipment, Planning for Excavation Works, Quality Management, Risk Management, Shoring Systems.**

I. Introduction

Every increasing of migration to urban areas and expanding urban development, the need for large-scale developments is on the rise all over the world. The problem is exacerbated by the inadequate existing infrastructure of the older areas of the cities. In Jordan, the problem is even more severe due to the entrance of refugees from neighboring countries and unplanned urban sprawling.

Carrying out deep excavations depends on multiple factors, including: type of proposed retaining walls, lateral earth pressure, water pressure (if any), types of existing geological formations, and adjacent utilities infrastructure, etc. Despite contributing to the urban development in a significant way, deep excavations could also be detrimental due to the number of risks associated with them comprising increase of bending moments along retaining walls, ground settlements with the presence of groundwater (if any), and sides' collapse. Furthermore, poor management of deep excavations could potentially be hazardous to environment and public safety especially its effects on the labors who work at these sites. Additionally, inadequate waste management and control for them could potentially lead to increase of projects' costs and duration. These risks are intensified when there is no adequate engineering management in place. Insufficient planning and management for several large-scale developments in Jordan has resulted in the delays of project completion or even complete stoppage, such as that occurred at Al Abdali Compound in Amman. Therefore, there is a definite need for planning and for implementing the mitigation measures while executing deep excavations.

II. Literature Review

Several studies were carried out by researchers to investigate the design, planning, and management of deep excavations and their wastes for construction projects. However, some of these are summarized below.

Zhoue H. (2003) presented a design of deep excavation for executing foundations on saturated soil. The author stated that the case study was of interest because it was located above and beside the Shanghai Metro tunnels, in addition, the twin Shanghai Metro tunnels had to be in full operation during conducting the deep excavation. Large deformations of the twin tunnels were expected to be one of the main concerns during the design and construction for the deep excavation. The author discussed the criteria and measures for controlling the soil and tunnel deformations.

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However, these measures included cast-in-place concrete diaphragm walls with bracing structural members, pumping consolidation, cement–soil mix pile systems, and rational excavation procedures. In this research, a simplified theoretical method was suggested to estimate the shear strength for the soft clay layer due to pumping consolidation. Also, finite element methods were used in this research to calculate the soil displacements that resulted by the excavation. Considering the design and construction methods that proposed by the author, the settlement and horizontal displacement of the tunnels were controlled within 5 mm and 9 mm, respectively, and accordingly the horizontal displacement of the braced diaphragm walls was calculated to be less than 0.12% of the total excavated depth.

Cao L. (2013) presented the findings of designing soldier piles with tiebacks to support a deep excavation in downtown Toronto. The structures (located adjacent to the deep excavation) are potentially at risk of damage due to significant amount of stress generated by the excavations. However, to monitor the movements of shoring walls during and after the excavation, the author suggested installing two inclinometers and twenty-seven reflective targets to measure the wall bending movements.

Simon (2015) presented a development method represented by a conceptual model for the urban flow of excavated soil and rock, and studied the management of excavated soil and rock in construction projects. The conceptual model was subsequently used to clarify the different perspectives of the scientific literature and knowledge gaps. Conclusions drawn are that there is little knowledge about the quantities and the fate of excavated soil and rock in urban areas. The study concluded that the excavated soil and rock materials are often disposed at landfills and the recycling rate for high quality purposes is low, and therefore there is a need to evaluate the potential for an increased use of excavated soil and rock as construction material.

Alison and Kieran (2015) studied waste management especially that concerned with the results of excavations. It was stated that the contractor must examine the results of drilling to verify their validity. As an example, if the soil resulting from the drilling was clean, free of organic materials, therefore, it may be used as a backfill. On the other hand, if the soil is not suitable; therefore, the contractor must dispose them outside the project location, and that may be useful to improve resource efficiency and environmental performance; and reduce cost.

However, the study clarified that there is a lot of bad practices carried out by the contractor such as placing soil resulting from excavations on the streets that could cause accidents, or do not testing the soil to make sure of their validity.

III. Field Study (Questionnaire)

The field investigation of this research included designing of a questionnaire that consisted of many items related to executing deep excavations. The questionnaire was distributed to practicing and professional engineers who work at construction projects in Jordan (that need deep excavations) to evaluate the following:

- The extent of the right application for deep excavation management in Jordan.
- The most important factors that influencing deep excavations.
- The methods to be used to support deep excavations in Jordan (Shoring Systems).
- The procedures to protect labors who work at deep excavations in Jordan.

IV. Reliability

To calculate the stability of a questioner study, the researcher used the equation of internal consistency of Cronbach's Alpha (equation 1) and presented the results as shown in Table 1. The results showed that the values of Cronbach Alpha for all variables of the study were generally higher than (60%) which are acceptable in the research and studies. However, the overall reliability coefficient was ranging between (0.72-0.91%).

$$\text{Cronbach Alpha} = \frac{\mathbf{K \times r}}{\mathbf{1+(K-1)r}} \quad \ldots (1)$$

Where: K is the number of items in the test., and

r: is the mean of the correlations between items.

TABLE 1
CRONBACH ALPHA FOR THE VARIABLES OF THE STUDY

Variables	Statements	Cronbach Alpha
The degree of influence factors on deep excavations	13	0.80
Shoring Systems	10	0.72
Procedures to protect workers in the deep excavations in Jordan	13	0.91

(Cronbach Alpha: According to Abebe A., Daniels J. and et al, 2002)

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V. Research Sample Size

The study population was the civil engineers in Jordanian construction companies. The data was collected from companies that execute deep excavation projects, which represented all the study population. The researcher distributed (80) questionnaire, (65) of them were received, whereas (15) questionnaires were excluded from the analysis due to their unfinished information. So, the questionnaires that valid for analysis were (65), and the response rate was (81%).

VI. Sample Characteristics

More than half of the respondents have an experience that exceeds 10 years; therefore, the responses are valid for the research since they were based on quite extensive experience of respondents in management of deep excavations in Jordan and controlling to their wastes. Table 2 shows the sample's demographic variables, such as type of organization, educational level, and years of experience.

TABLE 2
SAMPLE'S DEMOGRAPHIC VARIABLES

Variable	Category	Counts	%
Organization's Type	Consultant	31	47.4
	Contractor	27	41.5
	Sub-Contractor	7	10.8
	Total	65	100
Scientific Expertise and Qualifications	Master Degree	12	18.5
	Bachelor Degree	51	78.5
	Diploma Degree	2	3.1
	Total	65	100
Years of Experience	1-5 Years	16	24.6
	6-10 Years	11	16.9
	More than 10 Years	38	58.5
	Total	65	100
	More than 10 projects	8	15.7
	Total	65	100
Number of Projects	1-5 Projects	16	31.4
	6-10 Projects	5	9.8
	More than 10 projects	8	15.7
	Total	65	100
The depth of the Current Project	7-10 m	18	27.7
	11-20 m	41	63.1
	>20 m	6	9.2
	Total	65	100

VII. Data Analysis Techniques

A Statistical Package for Social Sciences (SPSS) was used to analyze the collected data. In general, the following statistical techniques and tests were used in this research for data analysis:

1- Cronbach's Alpha reliability is a measure of internal consistency, that is, how closely related a set of items are as a group.

2- Descriptive Statistical Techniques: including means and standard deviations. However, these techniques can be conducted using Equation 2 and Equation 3 indicated below:

$$\text{Mean} = \Sigma X / N \quad \ldots (2)$$

Where:

ΣX: is the sum frequency of the sample.

N: is the total number of samples.

$$\text{Standard deviation} = \sqrt{\frac{\sum_{i=1}^{N} (Xi - \bar{X})^2}{N}} \quad \ldots (3)$$

Where:

Xi: is frequency of each sample.

$\bar{X}$: is mean of sample.

N: is the total number of samples.

One (T-test) sample was used to test the hypotheses of this research, therefore the researcher used (t value = 2). It is to be noted that in (T-test) the value of (t calculated) should be within the solution of the area which is (±1.96) in which the Sample will be located at two trail areas, however the (t calculated) is shown in Equation (4):

$$t = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{N}}} \quad \ldots (4)$$

Where:

$\bar{X}$: is the mean of sample.

μ: is t-value(tabulated) = 2.

σ: is the standard deviation of sample.

N: is the total number of sample.

The responses are tabulated in accordance with a five-point Likert Scale, as shown in Table 3:

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TABLE 3
FIVE POINT LIKERT SCALE FOR THE RESPONSES

Very Low	Low	Medium	High	Very High
1	2	3	4	5

(Likert Scale: According to Abebe A., Daniels J. and et al, 2002)

The relative importance is measured through the application of Class Interval (CI) indicated in Equation (5):

$$\text{CI} = \frac{(\text{Maximum class} - \text{Minimum class})}{\text{Number of level}} \quad ...(5)$$

$$\text{Class Interval} = \frac{5-1}{3} = 1.33$$

- The Low degree range is 1.00- 2.33
- The Medium degree range is 2.34 – 3.67
- The High degree range is 3.68 – 5.00

VIII. Results Of The Survey Questionnaire

The mean, standard deviation, ranking, and importance level for each item in the questioner are shown in Tables 4 through 9.

In Table 4, the mean of this factor (Degree of Influence Factors on Deep Excavations) ranged between (3.78–2.35), where the overall variable resulted of a total mean of (3.19), which is a level of Medium. variable (7) (project land containing clay soil or other types of soil) has obtained the highest mean reaching (3.78), with standard deviation (0.98), which is a level of High, and variable (8) (thickness of clay soil or filling soil in the project area) came in second with a mean of (3.63), with standard deviation (1.18), which is a level of High, variable (9) (Presence or occurrence of strange geological phenomena at the project site) came in last with a mean of (2.35), and a standard deviation (1.30), which is a level of Low.

In Table 5, the mean of this factor (Shoring System), ranged between (3.60) and (1.94), where the overall variable resulted of a total mean of (2.85), which is a level of Medium. variable (9) (Using Wire Mesh (only) has obtained the highest mean reaching (3.60), with standard deviation (1.14), which is a level of High, and variable (10) (Using Shot-Create (only)) came in the second with a mean of (3.51), and standard deviation of (1.26), which is a level of High. variable (5) (Using Diaphragm Walls) came in last with a mean of (1.94), and a standard deviation (1.03), which is a level of Low.

In Table 6 the mean of this factor (Procedures to Protect Workers in The Deep Excavations in Jordan), ranged between (3.29) and (2.22), where the overall variable resulted of a total mean of (2.88), which is a level of Medium. Variable (9) (Responsible personnel regularly warn the workers to keep the distance from the earth moving equipment's during loading or unloading operations) has obtained the highest mean reaching (3.29), with standard deviation (1.09), which is a level of Medium. Variable (10) (The site management warns workers to keep the distance from deep excavation sides while working inside the excavated area) came in the second with a mean of (3.29), with standard deviation (1.10), which is a level of medium. Variable (8) (Project management hires experienced staff with experience in risk management, evaluation, and prevention of risks) came in last with a mean of (2.22), and a standard deviation (1.23), which is a level of low.

From Table 7 the results shown that the total mean of factors on deep excavations was (3.19), with standard deviation (0.63), and (t) calculated was (15.23), and its more than value of (t) Tabulated. The results showed that there is a statistically significant Differences between the mean of the scale and the default mean (2.00), and the result shown that (t) calculated more than (t) tabulated, that assure reject null hypothesis and Accept alternative.

From Table 8 the results shown that the total mean of shoring systems on deep excavations was (2.85), with standard deviation (0.64), and (t) calculated was (10.65), and its more than value of (t) Tabulated. The results shown that there is a statistically significant Differences between the mean of the scale and the default mean, and the result shown that (t) calculated more than (t) tabulated, that assure reject the null hypothesis and Accept alternative.

From Table 9 the results shown that the total mean of procedures on protect workers on deep excavations was (2.88), with standard deviation (0.81), and (t) calculated was (8.69), and its more than value of (t) Tabulated. The results shown that there is a statistically significant Differences between the mean of the scale and the default mean, and the result shown that (t) calculated more than (t) tabulated, that assure reject the null hypothesis and accept the alternative.

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TABLE 4
ATTITUDES TOWARDS "INFLUENCE FACTORS ON DEEP EXCAVATION"

No.	Statement	Mean	Std. Deviation	Ranking	Importance Level
7	Project land containing clay soil or other types of soil.	3.78	0.98	1	High
8	Thickness of clay soil or filling soil in the project area.	3.63	1.18	2	High
3	The horizontal distance between the deep excavations project and the existing adjacent buildings of the site.	3.55	1.21	3	High
2	Types of facilities adjacent to the project Site.	3.54	1.00	4	High
1	Provision of roads leading to the project site in addition to other services.	3.42	1.03	5	Medium
6	Types of geological formations of the project site.	3.42	1.09	6	Medium
13	Depth of groundwater in the project area.	3.42	1.37	7	Medium
12	The existence of groundwater in the project area.	3.35	1.41	8	Medium
5	The availability of suitable area for merchandise and materials that will be used in executing the excavations or to protect it.	3.05	0.99	9	Medium
4	Total acquired area of the site (belonging to the project which is out of the boundaries of the deep excavations).	2.88	1.15	10	Medium
11	Presence or occurrence of cracks and other deformations at the project site.	2.75	1.21	11	Medium
10	Seismic characteristics of the project area (the level of seismic activity).	2.45	1.15	12	Low
9	Presence or occurrence of strange geological phenomena at the project site.	2.35	1.30	13	Low
Total		3.19	0.63		Medium

TABLE 5
ATTITUDES TOWARDS "SHORING SYSTEMS"

No.	Statement	Mean	Std. Deviation	Ranking	Importance Level
9	Using Wire Mesh (only)	3.60	1.14	1	High
10	Using Shot-Create (only)	3.51	1.26	2	High
2	Using Reinforced Concrete Retaining Walls (by the method of Segments).	3.25	1.28	3	Medium
8	Using Sheet-piling (only).	3.22	1.33	4	Medium
1	Changing the Angle of Side Slopes (for Vertical Excavations).	3.06	1.18	5	Medium
4	Using Soil Nailing Technique.	2.94	1.31	6	Medium
7	Using Gabions (or Surcharge).	2.69	1.12	7	Medium
3	Using Soldier Piles with Steel Plates and Anchored Tie-Back System.	2.35	1.30	8	Low
6	Using Cofferdams.	1.97	1.02	9	Low
5	Using Diaphragm Walls.	1.94	1.03	10	Low
Total		2.85	0.64		Medium

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TABLE 6
ATTITUDES TOWARDS "PROCEDURES TO PROTECT WORKERS AT DEEP EXCAVATIONS IN JORDAN

No.	Statement	Mean	Std. Deviation	Ranking	Importance Level
9	Responsible personnel regularly warn the workers to keep the distance from the earth moving equipment's during loading or unloading operations.	3.29	1.09	1	Medium
10	The site management warns workers to keep the distance from deep excavation sides while working inside the excavated area.	3.29	1.10	2	Medium
3	The project management follows up with the warning signs that identify the deep excavated locations.	3.26	1.14	3	Medium
6	Special escort or other means are provided to facilitate worker's entrances and exits to and from deep excavations.	3.25	1.25	4	Medium
5	The project management provides bright colored uniforms for the workers in general especially to those who work with earth-moving equipment.	3.23	1.07	5	Medium
11	Workers are prevented from entering the deep excavated cavities when there is a possibility of water flow from the sides of the cavities.	3.14	1.16	6	Medium
12	Project management estimates and evaluates the danger potentially caused by not supporting the deep excavation sides to protect the workers.	2.86	1.13	7	Medium
4	The deep excavation workers are committed to wear PPE according to safety applicable protective requirements (such as safety helmets, footwear, etc.)	2.83	1.22	8	Medium
13	Project management choses the right and suitable engineering procedures that suit the project case to provide the proper retaining walls.	2.80	1.26	9	Medium
1	Project management provides specific precautions to protect workers from collapsing of sides (walls) in deep excavation areas.	2.55	1.29	10	Low
2	The project management provides the machineries and equipment for emergency cases	2.46	1.16	11	Low
7	The project management provides training programs for the workers in deep excavations to avoid the collapse of the excavations sides (walls).	2.26	1.18	12	Low
8	Project management hires experienced staff with experience in risk management, evaluation, and prevention of risks.	2.22	1.23	13	Low
Total		2.80	0.82		Medium

TABLE 7
THE EFFECT OF FACTORS ON DEEP EXCAVATIONS

Mean	St. Deviation	T- Tabulated	T-calculated	DF	Sig	Result
3.19	0.63	±1.96	15.230	64	0.000*	effect

*(t) value = 2.00 * Significant at (0.05)*

TABLE 8
THE EFFECT OF SHORING SYSTEMS ON DEEP EXCAVATIONS

Mean	St. Deviation	T- Tabulated	T-calculated	DF	Sig	Result
2.85	0.64	±1.96	10.654	64	0.000*	effect

*(t) value = 2.00 * Significant at (0.05)*

TABLE 9
THE EFFECT OF PROCEDURES TO PROTECT WORKERS ON DEEP EXCAVATIONS

Mean	St. Deviation	T- Tabulated	T-calculated	DF	Sig	Result
2.88	0.81	±1.96	8.699	64	0.000*	effect

*(t) value = 2.00 * Significant at (0.05)*

IX. CONCLUSIONS

1- Several severe factors affecting on executing deep excavations and could cause the above-mentioned failures such as:

a. Types of adjacent existing structures or utilities and their clear distance that separates beyond the location of deep excavation. However, this factor necessitates the designer engineers to focus on conducting a general survey for any surroundings to the project site and to consider the availability of clear distances (as stated above) in their design.

b. The nature of subsoil layers is highly affecting the design and implementation of deep excavations. Therefore, proper and accurate geotechnical investigations needed to be performed to identify and clarify all types of subsurface layers and their thicknesses. However, fine grained soils (such as clay, silt, and marl) are the most problematic soils that responsible for sliding of cuts. Therefore, the existence of such formations through the deep excavation may produce risks to the whole site, equipment, and labors.

c. The availability of access roads leading to the project site (i.e., to the excavation): this factor contributes for better implementation of excavations due to the availability of the appropriate roads to reach the project facilitates, entry and exit of workers to the excavation, and helps loading and unloading for construction materials into the excavation.

d. The presence of groundwater at the project site (or a case of saturation of soil with water) is also considered as a major factor that could cause a risk in the implementation of deep excavations. However, ground water could affect the overall stability of the excavation through its expected high lateral pressures that could lead to collapse of deep excavations.

e. Other minor factors that affect the implementation of deep excavations such as the availability of areas for projects' equipment and materials in addition to the site seismicity.

2- There are several deficiencies in conducting engineering management for deep excavations in Jordan as follows:

a. Indetermination for the optimum location of the output of excavations (wastes) especially for those to be used as backfill materials, where this variable achieved mean (2.75) and standard deviation (1.28).

b. Poor plans concerning the health and safety systems of labors and engineers in the site, where this variable achieved mean (2.98) and standard deviation (1.21).

c. Lack of commitment of the projects' workers to apply the general safety requirements, where this variable achieved mean (2.98) and standard deviation (1.08).

d. Lack of interest for the project management to train the workers in dealing with deep excavations to avoid the risk of a collapse, where this variable achieved mean (2.26) and standard deviation (1.18).

e. Lack of interest of project management to employ people who have the experience in matters of risk management where this variable achieved mean (2.22) and standard deviation (1.23).

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