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Study of the Factors Affecting the Quality and Safety of Deep Excavations in Urban Areas of Casablanca-Settat Province-Morocco

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***Abstract*— Understanding the project environment is essential in managing the works and controlling the risks associated with deep excavations in urban areas. The study was carried out on 33 risks related to the project site (SR) and the company (CR). The projects concerned are located in the Casablanca region. A structured survey questionnaire was sent to 100 project managers, researchers, and construction management experts to attract relevant data, which resulted in a relatively high response rate of 54%. This paper applies the principal component analysis (PCA) method to reduce the original data variables and identify risk factors associated with deep excavations. Spearman rank correlation tests show a good consensus among respondents to corroborate the results further. The PCA results in four principal factors (SR) accounting for 68% of the variance explained. Site geology, geotechnics, and hydrogeology account for 32% of the environmental and social impacts of excavation (17%), natural hazards (10%), and proximity to existing structures (8%). Moreover, four main factors (CR) explain about 72% of all the factors analyzed; non-security of the works (32%), non-quality of project staff (18%), project cost overrun (14%), and non-quality of excavation works (9%). These results are useful for critical thinking in planning excavation projects in urban areas. This study provides the urban development community with valuable information to reassess risk factors and realign project management strategies to ensure the quality and safety of deep excavations.**

***Keywords*— Deep excavations; risk factor; urban areas; principal component analysis (PCA); spearman rank; project site.**

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I. INTRODUCTION

Cities in Morocco have grown with very rapid urbanization. In addition, the construction of high-rise buildings, subways, and tunnels that necessitate deep excavations can present considerable potential risks. According to the Moroccan Ministry of Employment, construction is the sector most affected by work accidents and records the highest mortality; compared to other sectors, accidents on construction sites are frequent in Morocco. In March 2018, the fall of a crane on a construction site in Sidi Moumen (Casablanca) caused two deaths. A similar accident in April 2018 on Al Fourate Street (Casablanca) impacted neighboring residences. At the beginning of October 2018, the walls of a construction site collapsed, threatening in extremis the surrounding buildings. In July 2014, a collapse of three buildings in Casablanca caused eight deaths. In June 2016, 2 children were injured in the partial collapse of a building in the Garage Allal neighborhood due to nearby deep excavations, and in October 2018, a collapse of part of the walls of a building site in the middle of Hay Riad in Rabat caused by the subsidence of the ground, which involved a landslide at the level of the basement walls [1].

According to the Moroccan insurance and social security control authority (ACAPS) statistics, an average of 40,000 work accidents are recorded annually in the construction industry, and 2,000 deaths are declared [2]. Deep excavations in urban sites present risks [3] due to the surrounding structures [3], [4], underground networks, old buildings, nearby roads, and the said risks such as cracking or collapse of nearby buildings [3], [4], degradation of roads and underground networks [5]–[8], soil compaction, landslides, and soil subsidence [9], [10].

Multivariate statistical methods have also been used to identify the major risks that menace an urban excavation's stability [11]. Determining and evaluating the different risks are necessary for good management and planning of excavation works to avoid human and material damage. The objective of this study is to use multivariate statistical techniques such as Principal Component Analysis (PCA) [12] to evaluate the factors influencing the stability of the works.

In order to explore the risks generated by deep excavations in urban areas for constraints linked to the project site (SR) and the company responsible for carrying out the work (CR), the study is focused on the analysis of thirty-three variables using the PCA method.

This article summarizes the main risk factors associated with excavation works in the province of Casablanca-Settat. They have been classified into eight factors: the geology, the geotechnics and the hydrogeology of the site [13], the environmental and social impacts of excavation, the natural risks, the proximity of existing structures, the non-security of the works, the project staff, the risk of project cost overrun and the non-quality of excavation works, These risks demonstrate an urgent need to establish a risk prediction system for deep excavations in urban areas [3], [14], [15], in order to mitigate the damage caused by project failure during excavation works.

II. Materials and Method

A. Study Site

We made this study in Morocco and specifically in the region of the city of Casablanca in the province of Casablanca-Settat, in west-central Morocco.

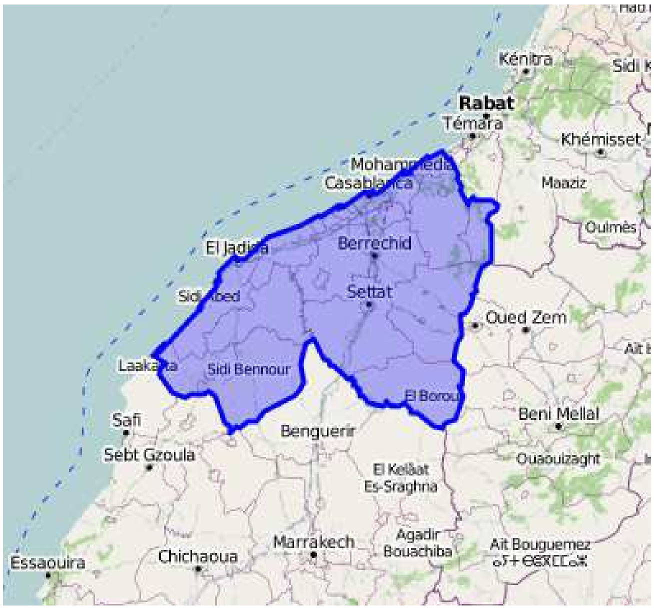

Fig. 1 Location map of the study area, Casablanca, Morocco.

B. Data Collection

We have consulted the different data sources, notably the civil engineering experts, the researchers, the companies and the laboratories, to establish a database that answers the question of the risks linked to the urban development projects in the Casablanca area. The data set contains two categories: RS and RE. A total of thirty-three risks are collected. A questionnaire was set on a Likert scale of 1 to 5 points, where 1 represents a very low risk severity and 5 represents a very high severity.

C. Research Method

This study uses a qualitative method for data collection and analysis based on relevant factors from the existing literature. This approach is considered adequate, and this type of method can also be very beneficial in the risk management of excavation works [16]–[18]. Figure 1 shows the methodological framework, including data collection and analytical processes.

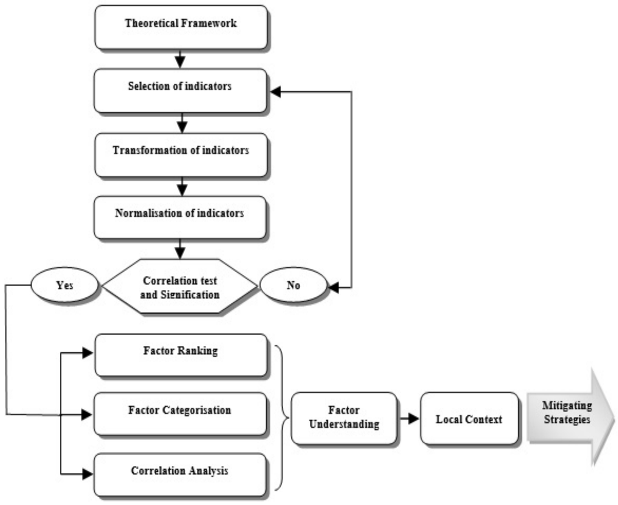

Fig. 2 Diagram showing the research method applied.

The identified factors were classified using principal component analysis, and their correlations were studied. Reliability analysis was carried out on the questionnaire results to validate the internal consistency of the results. Relevant information on the factors explaining the risks. The results obtained can then be analyzed locally, and mitigation strategies can be designed to address the specific risks of deep excavations in the urban area.

D. Qualitative Data Collection

Different meetings were scheduled with experts in the field of civil engineering, project managers, contractors, engineers, and researchers in civil engineering. Thirty-three variables were defined based on the results of the literature review and qualitative analysis (Tables 1 and 2). The final list included the factors most mentioned and discussed during the meetings with experts in the field, and new factors were extracted from the recent literature and were not discussed during the meetings.

E. Principal Component Analysis

Principal component analysis (PCA) [12] was performed to investigate the underlying dimensions of the factors under study and to identify a smaller set of correlated principal factors. PCA is an unsupervised learning technique used to simplify the complexity of high-dimensional data, while retaining relevant models.

In this paper, PCA has been used to generate new risk components related to excavation works in urban areas, based on the conditions of the project site and the executing company.

III. Results and Discussion

A. Bartlett's Sphericity and Adequacy Tests

The Bartlett's test of sphericity is significant ($p < 0.0005$). The null hypothesis H_0 can consequently be rejected; and the correlation matrix is not an identity matrix.

B. Reliability Analysis

In this study, the (SR) factors have a Cronbach's alpha equal to 0.853 and 0.817 for the (CR) factors (tables 1 and 2). This indicates a good internal consistency of the data collected in the questionnaire. Tables 1 and 2 present an analysis of reliability and ranking of the importance of the factors studied, which gives us a quick and clear indication of the distribution of responses for the thirty-three factors studied.

C. Average score Analysis

According to the PCA analysis, the most important factor (SR) is (R10)" in the proximity of the DWN/HEC/MEC/LEC networks, "followed by (R9) " in the proximity of a tunnel. " The least important factors are (R14) "Inadequate site installation plan", followed by (R11) "Blocking of nearby roads". For the (CR) variables, the most important factor is (R29) 'risk related to excavation wall stabilities (depth)', followed by (R28) 'insufficient protective structure'. The least important factors are (R33) 'contract performance' and (R31) 'project cost risk'. The tables below also show the average response for all factors, indicating that all respondents assigned similar importance to all the variables.

TABLE I
RELIABILITY ANALYSIS AND RANKING OF FACTORS (SR)

Code	Risk factor	Moy	Rang	Cron. Alpha*
R10	in the proximity of the DWN/HEC/MEC/LEC networks	8.13	1	0.857
R9	in the proximity of a tunnel	7.53	2	0.851
R15	stability of embankments	6.93	3	0.841
R3	ground subsidence	6.73	4	0.836
R18	Flooding	6.67	5	0.846
R8	in the proximity of a recent building with underground parking	6.53	6	0.867
R5	deformation/displacement of excavation screen	6.47	7	0.838
R4	landslide	6.40	8	0.840
R19	Earthquake	6.33	9	0.848
R2	Soil compaction	6.20	10	0.838
R7	Variation of soil hydrogeology conditions	6.20	11	0.833
R6	existence of a water table at great depth	6.00	12	0.838
R1	Collapses related to underground cavities	5.73	13	0.834
R13	air pollution	4.60	14	0.843
R12	noise pollution	4.47	15	0.843
R17	Discharge of inhabitants	4.40	16	0.849
R16	authorization from the administration	4.20	17	0.848
R14	Inadequate site installation plan	3.73	18	0.856
R11	blocking off nearby roads	3.53	19	0.853

Overall Cronbach's Alpha = 0.853

TABLE II
RELIABILITY ANALYSIS AND RANKING OF FACTORS (CR)

Code	Risk factor	Moy	rang	Cron. Alpha*
R29	risk related to the stability of the excavation walls (depth)	7.73	1	0.798
R28	Insufficient protective structure	7.13	2	0.804
R23	Risk related to precautions and supervision	7.00	3	0.798
R26	lack of worker security	6.87	4	0.796
R32	risk of project time overrun	6.60	5	0.805
R22	Risk related to the competence of the workers	6.47	6	0.794
R24	Construction planning risk	6.47	7	0.797
R25	Inadequate excavation engineering type	6.40	8	0.808
R21	Designer competence risk	6.33	9	0.795
R30	lack of contingency plan	6.33	10	0.773
R20	Risk related to the competence of managers	6.13	11	0.788
R27	lack of signage and public protection	6.00	12	0.802
R31	risk of project cost overrun	5.80	13	0.813
R33	contract management risk	5.33	14	0.822

Overall Cronbach's Alpha = 0.811

D. Correlation Matrix

Spearman rank correlation analysis between the different risk variables examined the linear dependence between the variables (Fig.3). There were strong correlations between different risk factors of deep excavation. For example, for the SR factors, the correlation coefficients (R-values) R13 and R12 = 0.97, R5 and R4 = 0.96, R5 and R2 = 0.91, R4 and R2 = 0.90, for the CR factors, there were strong correlations between R22 and R21 = 0.88, R26 and R28 = 0.67, R31 and R33 = 0.67, R27 and R28 = 0.64.

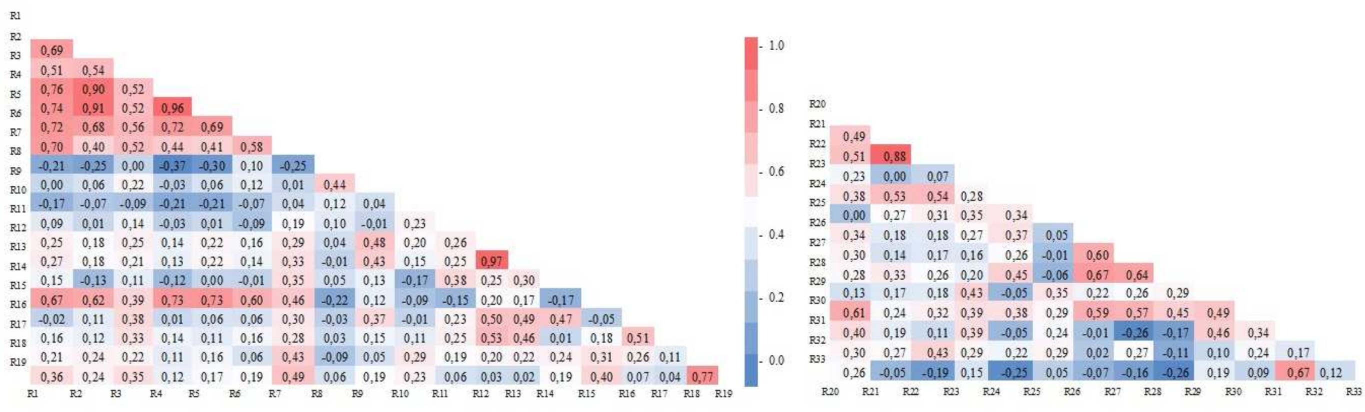

Fig. 3 Spearman rank correlation coefficients for urban excavation risk variables. a. project site, b. company.

E. Variance Explained by the Factorial Axes

The components were interpreted into categories and named according to the attributed factors. The SR factors category (C1) accounts for 32.47% of the variance (% σ2), category (C2) 17.44%, and categories C3, and C4, account for 9.94% and 7.91% (Table 3). In total, these four categories capture and explain about 68% of the underlying characteristics of all the factors analyzed, and this is above the 60% threshold needed to maintain validity [19].

For the CR factors, category (C7) accounts for 31.97% of the variance (% σ2), category (C8) for 17.62%, and categories C9 and C10 account for 13.63% and 9.07% (Table 4). In summary, these four categories capture about 72% of the factors analyzed' underlying characteristics.

TABLE III
FOUR COMPONENTS WERE EXTRACTED (SR). EXTRACTION METHOD: A PRINCIPAL COMPONENT ANALYSIS. EVERY CELL SHOWS THE STANDARD DEVIATION OF EACH COMPONENT.

Code	Categories and factors	% of the variance (% σ^2)	Factor loading (f)	STDEV of every f s(F)
C1	**Site geology geotechnics and hydrogeology**	32.47		
R1	collapses related to underground cavities		0.850	0.434
R2	Soil compaction		0.882	0.391
R3	Ground subsidence		0.646	0.426
R4	landslide		0.942	0.409
R5	deformation / displacement of excavation screen		0.918	0.371
R6	existence of a water table at a great depth		0.863	0.447
R7	Variation of soil hydrogeology conditions		0.551	0.446
R15	embankment stability		0.757	0.352
C2	**environmental and social impacts of deep excavations**	17.44		
R12	noise pollution		0.939	0.383
R13	air pollution		0.912	0.364
R16	authorization from the administration		0.661	0.354
R17	Rejection of the inhabitants		0.649	0.420
C3	**natural hazards**	9.94		
R18	Flooding		0.894	0.451
R19	Earthquake		0.915	0.545
C4	**the proximity of existing structures**	7.91		
R8	in the proximity of a recent building with underground parking		0.917	0.367
R9	in the proximity of a tunnel		0.665	0.252
Cumulative % of the variance		**67.76**		

Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.632. Bartlett's Test of Sphericity; Approx. Chi-Square: 448,871, Degrees of Freedom: 171, Significance Level: 0.000.

TABLE IV
FOUR COMPONENTS WERE EXTRACTED (CR). EXTRACTION METHOD: PRINCIPAL COMPONENT ANALYSIS. EVERY CELL SHOWS THE STANDARD DEVIATION OF EACH COMPONENT.

Code	Categories and factors	% of variance (% σ2)	Factor loading (f)	STDEV of every f s(F)
C5	**Non- security of the works**	31.97		
R26	lack of worker security		0.840	0.331
R27	lack of signage and protection of the public		0.820	0.392
R28	Insufficient protective structure		0.850	0.439
R30	absence of the emergency plan		0.689	0.432
C6	**project staff**	17.61		
R20	Risk related to the competence of managers		0.563	0.328
R21	Designer competence risk		0.896	0.337
R22	Risk related to the competence of workers		0.929	0.345
R24	Construction planning risk		0.658	0.317
R32	risk of project time overrun		0.479	0.351
C7	**risk of project cost overrun**	13.63		
R31	risk of project cost overrun		0.849	0.495
R33	contract management risk		0.850	0.333
C8	**Non-quality of deep excavations**	9.07		
R23	Risk related to precautions and supervision		0.711	0.359
R25	Inadequate excavation engineering type		0.797	0.409
R29	risk related to the stability of the excavation walls (depth)		0.629	0.295
Cumulative % of variance		**72.29**		

Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.623. Bartlett's Test of Sphericity; Approx. Chi-Square: 231,283, Degrees of Freedom: 91, Significance Level: 0.000.

F. Types of Risk-limiting Factors Associated with Excavation Works in Urban Site

In order to identify the number of components to be retained, the eigenvalue threshold is set at the conventional value of 1. The principal component analysis (PCA) for urban excavation risks results in four main factors for each risk category (SR) and (CR) that account for 68% and 72% of the total variance explained (Tables 3 and 4). The Varimax rotation is applied to obtain a clear representation of the factor weights [17], [18], [13], [20], [21]. each factor is interpreted and named consequently to its factor loadings.

1) Geology, geotechnics, and hydrogeology of the site: the instability of the ground depends on the geology, geotechnics, topography, and seismicity. The risk can be of various kinds (collapse, sliding, subsidence, creep, etc.). The dip, the existence of joints, the stratification, the folds, the schistosity, and the slope of the ground excavated are parameters that constitute zones of weakness [22]. The pore pressure can originate from a simple accumulation of rainwater, infiltration due to the degradation of the underground networks, or from an aquifer that filters into the ground, all of which can cause deformations of the excavation screen.

2) Environmental and social impacts of deep excavations: represents the problems associated with excavations, which can lead to delays in project execution and cost overruns, [23], [24], [25]. In our study, several parameters can increase this risk: noise and air pollution, delay in administration, residents' rejection, and blocking nearby roads. To avoid the influence of external forces on the progress of the works, it is necessary to understand the problems between the project and external stakeholders.

3) Natural hazards: It is very important for decision-makers to consider the effect of critical weather conditions (floods and earthquakes) and their direct impact on the stability of deep excavations [26] and on the cost and time of the project.

4) Proximity of existing structures: construction projects involve deep excavation works that can cause serious damage to existing buildings surrounding the project due to ground deformation, settlement, or subsidence. Additional forces are generated in the supports and their connections, as well as additional deformation and displacement [27], [28], [29]. In order to ensure the stability of existing buildings [29], [30], one must understand the identification of soil and seepage water conditions, foundation types of neighboring buildings, and define the requirements for adequate functional and technical solutions;

5) Site security: Construction site accidents can be caused by managers involved in project planning and the management of workers and can also occur due to unsafe works, work pressure, and the inadequate cost of the project to carry out quality works in the planned time [2], [31], [32], [33].

6) Project staff: the risks generated by the project staff concern the difficulties encountered by the project team, which can increase the uncertainty of the results. We mentioned the incompetence of the managers, the designers, the non-qualification of the workers, the lack of communication between the intervening parties, the absence of a cell in charge of precaution and risk forecasting [34]. This study shows that safety risks are the most important factor (32%), which explains the high rate of construction site accidents [35]. The behavior of workers in case of risk, and the absence of safety procedures, are indicators that inform us that the management conditions at the level of companies are ineffective. For this purpose, those responsible for site safety should take preventive rather than reactive measures to improve the project's safety performance.

7) Project cost overrun: This can be characterized as "when the project's final cost exceeds the initial estimate" [36]. It has been shown that cost is an important factor in delivering a project with less risk. The majority of factors that are related to project cost are independent, for example, time overrun, poor planning by the contractor, and non-quality of the works carried out. According to the literature review, cost overruns are a significant problem in both developed and developing countries. Poor quality materials result in higher than normal construction costs due to loss of materials during and after project execution [37], [38], [39]. In the excavation works in the Casablanca region, the main causes of cost overruns were summarized as follows:

- approval delays.
- communication problems between project stakeholders
- incompetence of the subcontractors
- design changes.
- unavailability of experienced personnel.
- non-quality of works.
- delays in payment of subcontractors.
- time overruns

8) Excavation quality: Construction site accidents can be caused by instability of the excavation screen or by the wrong choice of excavation method. Delays in execution and cost overruns limit the quality of deep excavations [3], [40].

IV. Conclusion

This study explored the important factors influencing the stability of deep excavations in the urban area of Casablanca. The degradation of drinking water supply networks (PWS) or high or low voltage electrical cables (HEC/LEC) and the instability of underground structures present the most frequent risks during excavation projects at a great depth. The instability of excavation walls and the type of insufficient protective structure are among the risks that reflect the non-quality of project staff. This study will help stakeholders understand the main factors specific to deep excavations in the Casablanca region and design mitigation strategies to achieve quality deep excavations promptly. The application of artificial intelligence, mega data analysis technology. In addition, implementing an integrated technology system composed of excavation engineering, such as a BIM management platform, is an important approach to achieve intelligent construction in urban excavation engineering [41].

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Nomenclature

DWN drinking water networks
HEC high-voltage electrical cable
MEC medium voltage electrical cable
LEC low-voltage electrical cable
BIM Building Information Modelling

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