Effects of Inadequate Geotechnical Investigation on Civil Engineering Projects

Magdi Zumrawi[1]

[1]University of Khartoum, Department of Civil Engineering, Khartoum, Sudan

Abstract: ***This paper aims to focus on the problems of inadequate geotechnical investigations which lead to unsafe designed foundations, construction delays and extra costs for civil engineering projects. Inadequate geotechnical investigations can arise from lack of client awareness, inadequate finance, insufficient time and lack of geotechnical expertise. The reliability of the information contained in the geotechnical report has strong influence on design, construction, project cost and safety. Thus, it is quite important to have a clear, concise and accurate geotechnical report by qualified geotechnical engineers in order to ensure the reliability of the investigation results. A case is presented to illustrate the problems of inappropriate geotechnical investigation, insufficient knowledge of site condition, and importance of geotechnical supervision.***

Keywords: Inadequate, Geotechnical investigations, Extra cost, Reliability, Unsafe design.

1. Introduction

Geotechnical investigation is normally carried out prior to commencement of design of any project. This investigation is used to assist geotechnical engineers to interpret the surface conditions for design purposes [1]. The site investigations are used in nearly all civil engineering projects, there are currently limited techniques to quantify the effectiveness of one investigation compared with another [2]. Generally, the scope of a site investigation is based on the budget and time constraints placed on the investigation and the experience and judgment of the geotechnical engineer [2].

A good geotechnical investigation involves a proper program of borehole drilling, material sampling and laboratory and in-situ testing. The number, depth and locations of these boreholes, samples and tests is defined qualitatively by the structure size, the loads imposed by the structure and the anticipated subsurface profile. Some guidance is available for planning the scope of a geotechnical investigation (e.g. [3], [4]), in general, the extent is based on engineering judgment and experience.

The site investigation phase of any structure design plays a vital role, where inadequate characterization of the subsurface conditions may contribute to either a significantly over-designed solution which is cost-effective, or an under-designed one, which may lead to potential failures. One of the site investigation important objective is to help to overcome any possible difficulties delays that may arise during construction period due to ground and other local conditions [5]. Insufficient geotechnical investigation is currently the first source of projects' delays, disputes, claims, and projects' cost overruns [6].

Due to lack of guide or code of practice regarding the quality of site investigation work, geotechnical failures often occurred. These failures sometime lead to catastrophic disaster and imposed serious threat to public safety [7].

It is a common practice in many countries to appoint a geotechnical consultant firm based on open or selective competitive bidding with or without any serious prequalification requirements and the contract is invariably awarded to the lowest bidder. This practice may qualify a less experienced firm, thereby affecting quality and reliability of investigations and report. It is important to recognize that it is risky to rely on or trust low fees firm and the most competent is not the one to bid the lowest price.

2. Literature Review

Many researchers have been published over the past 25 years clearly demonstrating that in civil engineering projects, the largest element of technical and financial risk lies normally in the ground [8]–[11]. Indeed, structural foundation failure can often be attributed to inadequate and/or inappropriate geotechnical investigations [12]. Inadequate geotechnical investigations usually force the geotechnical engineer to reduce the risk of failure by over-designing the foundation, thereby increasing the cost of the project. Jaksa [13] presented a case involving many projects where geotechnical investigation in a highly variable soil profile resulted in a foundation failure involving high cost over-runs and a delay of one month. In USA, an analysis of 89 underground projects concluded that, in more than 85% of cases, the level of geotechnical investigation was too low for adequate characterization of site conditions, leading to claims and cost overruns [8].

An assessment report was issued by the National Economic Development Office (NEDO) [14] for industrial building projects. Analysis of a representative group of 56 case study projects showed that about half of the projects overran their planned times by one month or more and 37% suffered delays due to ground problems (water, rock, etc.). The NEDO reported that construction delays, caused by inadequate site investigations, were considerable, it concluded that variations due to unexpected site or soil conditions may be unavoidable and as a consequence, argued that in any particular case a balance should be struck between the substantial cost of an exhaustive site investigation and the risk of extra cost and delay arising from an inadequate one.

Little attention has been paid to ground conditions associated with low-rise buildings, such as domestic houses. Problems which are costly to solve have arisen because these buildings are normally founded on relatively simple foundations at shallow depths where the soil tends to be more variable and compressible than it is at depth. Furthermore, brick structures are particularly sensitive to differential foundation movements [15].

A review of over 200 roads and bridges where early remedial costs exceeded 100,000 Sterling pound was conducted by the National Audit Office (NAO) of United Kingdom [16]. They noted that eight roads and six bridges projects resulted in extra work cost. The NAO examined the procedures for identifying and analyzing the causes of expenditure on maintenance and concluded with that the high remedial costs were associated with inadequate site investigation.

The problem of inadequate site investigation for highway projects has also been highlighted by The Transport and Road Research Laboratory in United Kingdom. They studied ten large highway construction projects and observed that the final cost was on average 35% greater than the tendered sum. Half of this increase was due to inadequate planning of ground investigation or poor interpretation of the results [17].

3. Case Study

The objective of this research is to study the influence of reliable and factual geotechnical investigation data in design and construction of foundations for civil engineering structures. Lack of adequate and accurate ground information from the geotechnical report may lead to problems in design and construction. As cases studied in this research two projects in Khartoum state had been chosen, a multi storey building in Khartoum and Alarda road in Omdurman town.

3.1 A multi storey building

A plot of area 800m^2 located in Khartoum east was proposed for construction of a building of twelve floors. In general the terrain in Khartoum is almost flat without any undulations in ground levels. For construction of a multi storey building, a site investigation should be carried out prior to design.

3.1.1Actual Site Investigation

The geotechnical investigation for the building project was carried out by a contractor and the report was submitted to the design consultant. Four boreholes were drilled in the site area and the standard penetration tests (SPT) were conducted. The tests results and the subsoil profile as reported is shown in Table 1.

Table 1: Typical Borelog of the site investigation as reported.

Depth (m)	*Soil Description*	*Classification*	*Atterberg Limits*		*SPT N value*
			LL (%)	*PI (%)*	
1.5	Dark grey, clayey Sand of low plasticity.	Sc	35	12	23
3			31	9	20
4.5	Light grey, silty Sand with some gravel, non-plastic, dense.	SM	NP		26
6					24
7.5					27
9					30
10.5	Yellowish, fine to medium Sand, non-plastic, loose.	SW	NP		17
12					14
13.5					12
15					8

Borehole bottom at 15m depth, Ground Water at 6m depth.

It can be seen from the soil profile that the top layer is clayey sand encountered up to 3m depth. The next layer is silty sand with some gravel was encountered between 3m to 9m depth. This is followed by fine to medium sand encountered at 9m depth and extended down to the end of the borehole at 15m depth. Encountering ground water level at 6m depth below ground surface. Following are the recommendations reported for the designer of foundation.

For foundation, it is recommended to use raft foundation and to be placed at 4.5m depth below ground level on the layer of silty sand. The foundation soil bearing capacity at 4.5m depth was determined in the range of 250 – 270 KN/m^2.

Since the design engineers were not familiar about the conditions existing at the site, review of the report was done assuming that the data and information given in the report are factual. However, observing the general subsoil profile of the boreholes, the in-situ tests carried out in the area and the soil data submitted in the bore-logs were considered as correct and the foundation depth and the soil bearing capacity recommended were cross checked. The design consultant office recommended to rest the raft foundation on the natural silty sand at 4.5m depth. With this recommendation the geotechnical report was approved and the contractor was ordered to start excavation for foundations.

3.1.2 Site Construction

Excavation work was carried out at the site for the foundations down to the suggested founding depth. During excavation it was noticed that the encountered soil profile was entirely different from that indicated in the report. It was observed by the site engineer that the top layer is stiff sandy clay was existing to 3m depth. The next layer was found to be very stiff silty clay of high plasticity. This is contradictory to 3m thick top layer of clayey sand followed by silty sand as indicated in the report. During the excavation, the subsoil profile observed is shown in the Figure 1.

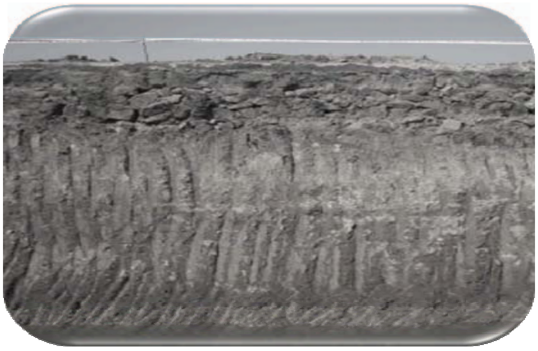

Figure 1: Soil profile observed during site excavation

Considering the mismatch of the subsoil profile between the actual encountered at site and that indicated in the report, a joint site inspection was proposed for the client, contractor and design consultant. During the joint site inspection, observation of the soil conditions existing at site convinced the contractor that the subsoil profile and hence the foundation recommendations indicated in the geotechnical report may be erroneous and agreed to revise the geotechnical report reflecting the actual conditions at site.

3.1.3 Revised Site Investigation

The joint site inspection decided to carry out drilling two boreholes to 20m depth. It was noticed from the subsoil profile that stiff sandy clay of low plasticity is encountered at the top depth of 3m, followed by very stiff silty clay of high plasticity to 9m depth. This underlain by very hard clayey Sand of low plasticity was encountered between 9m and 12m depth. A layer of very hard silty sand was encountered at 12m depth and extended to the end of the borehole at 20m depth. Ground water table was not encountered during drilling. The revised geotechnical report was submitted and the subsoil profile of bore-log shown in Table 1 was revised to that indicated in Table 2. A comparison between the two tables, Table 1 and 2 clearly indicates that the mismatching of the soil profile and characteristics.

Table 2: The borelog of the revised the site investigation.

Depth (m)	*Soil Description*	*Atterberg Limits*		*Shear Strength*		*SPT N value*
		LL (%)	*PI (%)*	Cohesion (KPa)	Friction Angle (°)	
1.5	Stiff sandy clay (CL of low plasticity.	35	14	28	17	23
3		45	17			28
4.5	Very stiff silty clay (CH) of high plasticity, dense.	72	33	40	9	36
6		65	30			39
7.5		59	28			37
9		61	32			45
10.5	hard clayey Sand (SC), low	27	8	52	22	>50
12		31	11			>50
13.5	Very hard silty Sand (SM), non-plastic, very dense.	NP		24	32	>50
15						>50
16.5						>50
18						>50
20						>50

The joint site inspection had revealed the presence of weak soils at the top and harder strata at a depth of 9 m below the ground level. It was decided to rest the foundation at this level for this heavy loaded structure.

On basis of the subsoil profile and the expected superstructure load for this multistory building of twelve floors, it is recommended to use bored concrete pile foundation of length 12m. The ultimate capacity of the pile for suggested diameter can be determined. Depending on the building superstructure load, the number of piles can be calculated and the piles to be arranged in groups to carry the load.

The above experience once again brings out the fact to the importance of reliable and factual soil investigation data to avoid unsafe design, construction delays and extra cost. It also highlights the need for the full time supervision on site by qualified geotechnical engineer for any ground investigation work in order to ensure the quality and reliability of the investigation results. It is important to mention that the above experience is not an isolated incident and several such cases are being encountered frequently leading to an urgent need for developing a process for accreditation of investigation contractors and laboratories.

3.2 Arada Road

Alarda road is one of the most important roads in Omdurman town that connects eastern and central part of the town. The road length is 2.75 km and consists of two carriageways, each of 10.5 m width and four lanes divided by a central island of 1.2 m to 2.0 m width. At early age of the construction, the road has shown sever cracks, potholes, heave and depressions on several spots along the road as indicated in Figure 2. A major cause of the pavement deterioration may be due to improper pavement design. In 2008 the client, ministry of physical planning and public utilities intended to rehabilitate the road.

Figure 2. Severe distresses of potholes and heave

3.2.1 Actual site investigation

The site investigation, which composed of excavating pitholes and taken soil samples, was carried out. The pitholes were excavated to 2m depth and at an interval distance of 500 m along the road. The laboratory tests performed include sieve analysis, Atterberg's limits tests and CBR tests. The tests results showed that the subgrade soil in general is clayey sand of liquid limit, 31 to 43%, plasticity index, 11 to 17% and strength (CBR) 5 to 9%. The soil profile shows variation and includes different layers of soils, which are not uniformly encountered along the road. Based on the site investigation results, the consultant designed the pavement accordingly

3.2.2 Problem description

During the site excavation, it was observed by the site engineer that the encountered subgrade soils at some sections was stiff clay soils which different from that indicated in the report. The road section at chainage 1+200 to 1+600 where sever distresses and failures occurred, it was observed that seepage of sewage water disposed into the subsoil from the neighbor houses as shown in Figure 3. The sewage water may allow water accumulation and subsequent softening of the subgrade in the rutted and heave areas. The zone of water movement leading to soil expansion and ultimately failure of the pavement. Thus, the road damaged and failure in this section may be due to seepage water that soften the subgrade of expansive clay.

(a)

(b)

Figure 3: Sewage water disposed into the subsoil from the neighbor houses.

3.2.3 Revised pavement design

The existence of the seepage water from the neighbor houses is a big hazard for the subgrade of expansive soils. The technical team of the consultant and the contractor agreed to take soil samples and carry out more tests for the sections where problems encountered. The revision tests included Atterberg's limits and swelling tests. The results obtained classified the subgrade soil as high expansive clay. This type of soil is sensitive to water content changes. Swelling may occur upon wetting and shrinkage upon drying and this behavior of soil may lead to weaken and soften the subgrade soil, and becomes unable to support any traffic loading. Thus, it was recommended to remove 1.5m thick of the expansive subgrade soil and to be replaced by selected granular fill materials. The consultant corrected design as followed.

An embankment layer of selected filling materials of 500 mm thick was recommended. On top of it a layer of boulders of 40 cm thick was to be placed with a thin filter layer, 10 cm thick of crushed stone (chipping). The subbase course consisted of three layers of natural granular soils, each layer of 15 cm thick. The base course formed of two layers of natural granular materials, each of 15 cm thick. The surface layer of asphalt concrete mix, 10 cm thick. The designer managed to stop and closed any flow of sewage water into the subsoil. Moreover, impermeable vertical membranes, Fondaline Sheets were suggested to prevent water movement from the road sides and central island to the depth 2m to 2.5m as shown in Figure 4.

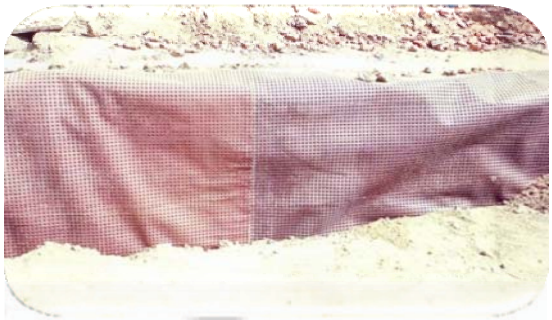

Figure 4: Fondaline Sheets to prevent water movement.

4. Conclusions

Ground is a vital element of most structures and as much care and attention should be given to it as is routinely given to the other aspects of the engineering structure. In this respect geotechnical investigation is an interdisciplinary subject and professionals with special training and experience in geotechnical engineering should be involved. Geotechnical investigations and their planning and design must be fully integrated into the project design and construction process. The contractor is responsible for obtaining reliable data while the geotechnical consultant is responsible for planning and execution of the site investigation work, interpretation and analyses of data, recommendations of design and assumed professional responsibility.

Experienced geotechnical engineers and engineering geologists should be responsible for geotechnical investigations. Where this expertise is not held within the project design group, geotechnical specialists should be added to the team. Factors influencing the outcome of site investigation include the initial pressures of time and money, and also the interrelationships and working climate between clients or land-owners, designers, site investigation specialists and main contractors, as well as the technical aspects of design, execution and interpretation of the results.

The practice of recommending lowest tender as the main criteria for site investigation should not be preferred, on the contrary should be discouraged. Selection should be made on the basis of the geotechnical consultant's competency and investigation contractor's ability to provide reliable factual data.

As Sudan is progressing with infrastructure development, there is an urgent need for a national specification and method of measurement for geotechnical investigations should be created, based on the current international manuals and guidelines specifications for site investigation practice and its supervision.

As the future scope of this study, more researches are required to study the reliability and importance of geotechnical investigations on civil engineering projects.

References

[1] J.E. Bowles, "Foundation analysis and design", 5th ed., McGraw-Hill, Singapore, 1997.
[2] M.B. Jaksa, W.S. Kaggwa, G.A. Fenton, H.G. Poulos, "A framework for quantifying the reliability of geotechnical investigations", 9th International Conference on statistics and probability in civil engineering, San Francisco, USA, 2003.
[3] John III Lowe, P.F. Zaccheo, "Subsurface Exploration and Sampling". In Foundation Engineering, 2nd Edition, H.- Y. Fang (ed.), New York: Chapman Hall, 1991.
[4] J.E. Bowles, "Foundation Analysis and Design", 5th Edition, New York: McGraw-Hill, 1996.
[5] A.H. Albatal, F.R. Zahri F.R., "Financial Risk of Inadequate Soil Investigation (Case Study)", Cairo University, Egypt, 2005.
[6] M.W.B. Temple, G. Stukhart, "Cost Effectiveness of Geotechnical Investigations", Journal of Management in Engineering, Vol. 3, No. 1, pp 8-19, 1987.
[7] Z.C. Moh, "Site Investigation and Geotechnical Failures", Proceeding of International Conference on Structural and Foundation Failures, 2-4 August, 2004, Singapore.
[8] National Research Council, "Geotechnical Site Investigations for Underground Projects", US National Committee on Tunnelling Technology, Vol. 1. Washington: National Academy Press, 1984.
[9] Institution of Civil Engineers, "Inadequate Site Investigation", London: Thomas Telford, 1991.
[10] G.S. Littlejohn, K.W. Cole, T.W. Mellors, T.W., "Without Site Investigation Ground is a Hazard", Proceedings of the Institution of Civil Engineers, Civil Eng., Vol. 102, May 1994, pp. 72–78.
[11] L.L. Whyte, "The Financial Benefit from Site Investigation Strategy", Ground Engineering, Oct., 1995, pp. 33–36.
[12] R.L. Nordlund, D.U. Deere, "Collapse of Fargo Grain Elevator", Journal of Soil Mechanics and Foundations Division, ASCE, Vol. 96 (No. 2), 1970, pp. 585–607.
[13] M.B. Jaksa, "Geotechnical Risk and Inadequate Site Investigations: A Case Study", Australian Geo-mechanics, Vol. 35 (No. 2), June 2000, pp. 39–46.
[14] National Economic Development Office (NEDO), "Faster Building for Industry", London, United Kingdom, 1983.
[15] Building Research Establishment (BRE), "Site Investigation for Low-rise Building: Desk Studies", Bldg. Res. Dig., 1987, No. 318.
[16] National Audit Office (NAO), "Qualify Control of Road and Bridge Construction", HMSO, London, United Kingdom, 1989.
[17] Tyrrell A. P. et al., "An Investigation of the Extra Costs Arising on Highway Contracts". Transport and Road Research Laboratory (TRRL), Crow Thorne, United Kingdom, 1983.

Author Profile

Magdi Zumrawi was born in Omdurman, Sudan, 19 May 1963. He received the B.Sc. degree in Civil Engineering and M.Sc. degree in Road Technology from University of Khartoum in 1987 and 1991, respectively. He achieved Ph.D. in Highway and Railway Engineering, Chang'An University, Xi'an, in Sept. 2000. His present occupation is Head, Soil & Road Section, Civil Eng. Dept., Faculty of Eng., Khartoum University, since 2010. He is a highway expert working with local and international consultant firms. He has published many articles in local and international journals and attended national and international conferences. He is a member of International Society for Soil Mechanics and Geotechnical Engineering. He is a senior member of the APCBEES.