Effect of Inadequate Site Investigation on the Cost of Road Construction (Case Study)

Ali H. Albatal [1], Akram S. Kotb [1] and Hossam H. Mohammad [2]

1. Construction and Building Department, Faculty of Engineering, Arab Academy for Science, Technology & Maritime Transport, Cairo, Egypt.
2. Construction Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt

Abstract

In all construction projects, suitable information or data is required for a successful design. The Transport and Road Research Laboratory in England 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. The purpose of a soil subsurface investigation is to provide data concerning the engineering properties of the soil for the proper design and safe construction of a project (Institution of Civil Engineers, 1991).

The site investigation phase of any highway design plays a vital role, where inadequate characterization of the subsurface conditions may contribute to either road cracks, or total failure. Insufficient geotechnical investigation is currently the first source of projects' delays, disputes, claims, and projects' cost overruns (Temple and Stukhart, 1987).

This paper aims to focus on the impact of varying the scope of the site investigation process, on the financial risk of highways construction projects. Another goal is to compare the cost of extra site investigation with the repairing or reconstruction cost result from improper site investigation.

The results of limited site investigation scope are clearly shown in the Cairo/Alexandria desert free highway, which suffer from cracks problem about one year after the construction. The site investigation cost was only 0.003% of the total road works cost, while the ideal site investigation cost of the total cost of roads should be (0.20% ~ 1.55%), which leads to additional rehabilitation cost of 2.04% of total road works cost.

1. Introduction

Site investigation is normally carried out prior to the commencement of design of any project. Due to lack of or inadequacy of guide/code requirement regarding the extent as well as quality of site investigation work, geotechnical failures often occurred. These failures sometime lead to catastrophic disaster and imposed serious threat to public safety (Moh, 2004).

Baecher and Christian (2003) divided the characterization of ground conditions into two phases. First is a preliminary investigation or desk study, which involves collecting information about the regional geology and geological history. The second phase is a site investigation designed to obtain data based on detailed measurements of soil properties. As a result, the geotechnical data obtained from limited characterization of ground conditions can be both inadequate and/or inappropriate. This situation can lead to failure and a high level of financial and technical risk (Institution of Civil Engineers 1991; Littlejohn *et al*. 1994; National Research Council 1984; Temple and Stukhart 1987). Several studies have been published over the last 30 years or so that clearly demonstrate that, in civil engineering projects, the largest element of financial and technical risk usually lies in the ground (National Research Council 1984, Institution of Civil Engineers 1991, Littlejohn *et al*. 1994, Whyte 1995).

Goldsworthy *et al*. (2007) defined the financial risk as the total cost, which includes costs associated with undertaking the site investigation, constructing, and any works required to rehabilitate the failure. Goldsworthy *et al.* (2004) suggested that the risk of a foundation failure is heavily dependent on the quantity and quality of information obtained from a geotechnical site investigation aimed at characterizing the underlying soil conditions. Project risk is a measure of the potential inability to achieve overall project objectives within defined cost, time schedule, quality, environmental impact and technical constraints and can be estimated as the combination of the probability of a risk event occurring and its consequences for project objectives (Carlsson, 2005).

It is clear that over the last 30 years geotechnical investigation prices have been driven down, with the scope often being governed by minimum cost and time of completion (Institution of Civil Engineers 1991). As a consequence, the Institution of Civil Engineers concluded that: "*You pay for a site investigation whether you have one or not*."

The UK public accounts committee states that the average cost increase for major road projects (1988-1989) was 28% over original tender prices. The main reason was judged to be the undertaking of larger and more complex schemes that involved greater risks, particularly with ground conditions. In another study on ten large highway construction projects, the Transport and Road Research Laboratory in England has observed that the final cost was on average 35%greaterthan the tendered sum. Half of this increase was due to inadequate planning of ground investigation or poor interpretation of the results (Institution of Civil Engineers, 1991)

The cost of site investigations in relation to the total project cost is small. Typical values in roads are (0.20~1.50) percent of total project cost. Site investigations should be continued until the ground conditions are well known enough for work to precede safely. Although a doubling in site investigations' costs can add 1.0% to the total project cost. Unforeseen ground conditions can, and often do, raise the costs by 10% or more (Paul *et al.* 2002). Site investigation costs (0.20~1.55) percent of capital cost of works, (1.60~5.67) percent of earthworks and foundation cost (Rowe 1972).

Ground exploration need generally only proceed to 2~4 m below the finished road level, provided the vertical alignment is fixed. In practice some realignment often occurs in cuttings, and side drains may be dug up to 6 m deep. If site investigation is to allow flexibility in design, it is good practice to bore to at least 5 m below ground level where the finished road level is near existing ground level, 5 m below finished road level in cut, or at least one-and-half times the embankment height in fill areas (Clayton et al. 1995).

The Egyptian code of practice illustrated that the minimum number of boreholes is at least one borehole for each one kilometer of the road. The samples must be taken into depth of 50cm below subgrade layer surface, and not less than six boreholes for the whole road length.

2. Case Study Application

As case study for this paper the Cairo/Alexandria desert freeway had chosen. About one year after the construction (laying out the Pavement) of a segment of about 1 to 2.25 km of the Cairo-Alexandria Road has shown alligator cracks on several spots along the road segment as indicated in figure (1). The laboratory results indicated that the natural soil in the subsurface is collapsible soil.

Problem subgrade materials consisting of collapsible soils are common in arid environments, which have climatic conditions and depositional and weathering processes favorable to their formation (Houston, 1988).

Collapsible soils have high void ratios and low densities and are typically cohesionless or only slightly cohesive collapse of the "cemented" soil structure may occur upon wetting because the bonding material weakens and softens, and the soil is unstable at any stress level that exceeds that at which the soil had been previously wetted. Thus, if the amount of water made available to the soil is increased above that which naturally exists, collapse can occur at fairly low levels of stress, equivalent only to overburden soil pressure. Additional loads, such as traffic loading or the presence of a bridge structure, add to the collapse, especially of shallow collapsible soil. The triggering mechanism for collapse, however, is the addition of water (Houston, 1988).

For pavement structures, it appears that the overburden stresses are not the only important source of loading for the subgrade, so that stressing the subgrade soils to the level anticipated for both overburden stress and heavy truck loading would be important, particularly for densifying the upper two meters of subgrade (Houston, 1988).

Project description

Cairo/Alexandria highway is one of the most important highways in Egypt. For the purpose of increasing its capacity and designed speed the General Authority for Roads, Bridges and Land Transport (GARBLT) made a decision of upgrading this highway to freeway. The length of the targeted segment of road is 169Km (between Km 29 and Km 198). The project was divided into six sectors; each sector has different contractor and consultant. The study is concerned with the conditions of the fifth sector. This sector is 34Km length (From Km126 to Km160). The total cost of this sector including road, bridges, green islands, and lightening works is 703,767,014LE, and the road itself works cost is 335,476,900LE.

Problem description

The following figures represent cracks problem about one year after the construction of Cairo/Alexandria desert freeway:

Figure (1): Cairo/Alexandria Freeway Cracks

Figure (2): Cracks Extended to Base Layer

Figure (3): Core Sample on Cracks Shows Deep Cracks Along Sample


Figure (4): Collapsible Soils Under the Base Layer

Actual site investigation

The geotechnical investigation report was reported in 2006. The report consisted of twenty seven (27) boreholes that were taken up to 20.0 in depth from the ground surface. The report indicated that the soil formation shows variation and includes different layers of fill, sand, clay, limestone and lime mud, which are not uniformly encountered along the site. The laboratory tests include Unconfined Compression test, One-Dimensional Swell test and Chemical analysis of soil samples, it should be noted that no Collapse Potential test were taken.

Problem Causes

Test pits were excavated by the contractor down to a depth between 2.75 m to 3.60m. Samples were collected from test pits and transported to the laboratory for testing to identify the cause the cracks. The laboratory results, specially the collapse potential tests, indicated that the natural soil in the subsurface is sensitive to water and indicated collapse or compression of the soil upon water access to the soil for any reason.

3. Cost Analysis

Introduction

The analysis will be conducted as following:

a) Overview the project original site investigation to determine the site investigation scope.
b) Overview the original site investigation cost, or estimating it if the original cost is unavailable.
c) Determining the percent of the site investigation of the total cost and comparing it with the ideal percentage that is mentioned in the literature review.
d) Evaluating the problems occurs to the projects due to inadequate site investigation, and estimating the rehabilitation cost for these problems.
e) Comparing the cost of extra site investigation with the rehabilitation cost.

a) Original site investigation scope.

This sector site investigation consists of three boreholes, at Km126.3, Km147.5 and Km157. Each borehole was taken up to 20.0 in depth from the ground surface.

b) Original site investigation cost

The cost of site investigation is measure by the cost of the 1m length of the borehole plus transformation the equipment cost. It cost 120 LE per meter length of the borehole in addition to transformation the equipment cost of 2,800 LE. The total cost of site investigation is 10,000 LE.

c) **Percent of the actual site investigation of the total cost of road works comparing to ideal present.**

Ideal site investigation cost of the total cost of roads is (0.20% ~ 1.55%) of road cost

$$= (0.20\% \sim 1.55\%)\ x\ 335{,}476{,}900$$
$$= LE\ (\ 670{,}954 \sim 5{,}199{,}892)$$

The actual site investigation cost is 10,000 LE, so the present of actual site investigation cost to total road cost $= \frac{10{,}000}{335{,}476{,}900}\ x\ 100 = 0.003\%$

d) **Corrective Action**

Because of availability of the collapsible soils under the highway, the best correction action is to remove the first meter of this soil and replace it by structural fill soil as recommended by the project recommendations and specifications. By default the correct action should be including removing the asphalt layers and under-laying layer into the collapsible soils; this means that the cost is removing the asphalt and under-laying layers and reconstruction cost.

e) **Rehabilitation cost for these problems**

The following Figure shows the typical cross section for the road.

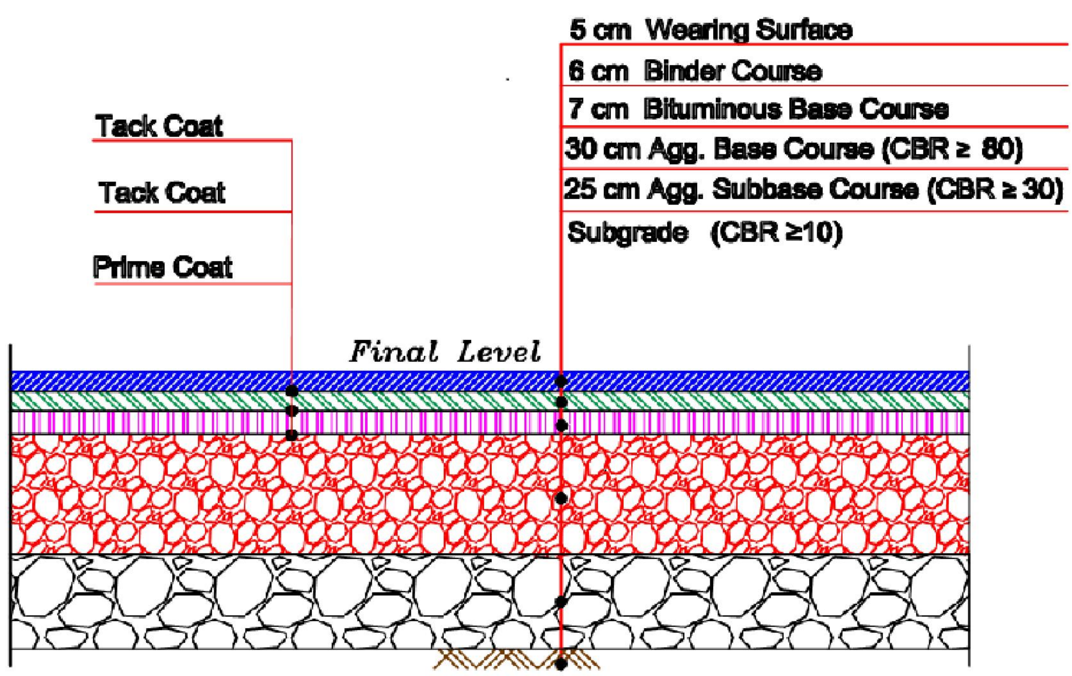

Figure (5): Typical Road cross section

Based on the above cross section, the following table shows Rehabilitation cost calculations:

Sector Length is 2.25Km, and the road consists of 4 Lanes, 3.75m Each → Surface area = 4x3.75x2250=33,750m^2

Item	Unit	Unit Price (LE)	Quantity	Price
Remove the Existed Asphalt Layers for any Depth	m^2	32	33,750	1,080,000
Removing Collapsible Soils (100cm Thickness)	m^3	8.0	33,750	270,000
Replacement by Subgrade CBR ≥10 (100cm Thickness)	m^3	18	33,750	607,500
Subbase CBR ≥30 (25cm Thickness)	m^3	45	8,438	379,688
Base CBR ≥80 (30cm Thickness)	m^3	140	10,125	1,417,500
Prime Coat (MC-30)	m^2	3.5	33,750	118,125
Bituminous Treated Base (7.0cm Thickness)	m^2	28	33,750	945,000
Tack Coat (RC-3000)	m^2	1.5	33,750	50,625
Binder Course (6.0cm Thickness)	m^2	30	33,750	1,012,500
Tack Coat (RC-3000)	m^2	1.5	33,750	50,625
Wearing Surface (5cm)	m^2	27	33,750	911,250

Total	6,842,813 LE

The rehabilitation cost represents 2.04% of total road works cost.

f) Comparing the cost of extra site investigation with the rehabilitation cost.

The ideal site investigation cost ranged between 670,954 LE and 5,199,892 LE. The rehabilitation cost is 10.2 times the minimum ideal site investigation cost and 1.3 times the maximum ideal site investigation cost. If we consider that the ideal site investigation cost was 670,954 LE, which means that number of boreholes to be taken is as following.

$$Total\ length\ of\ boreholes = \frac{670{,}954 - 2800}{120} = 5568m$$

Assuming that the borehole depth is 20m as already taken for actual site investigation, we get:

$$Number\ of\ borholes - \frac{5568}{20} - 278\ borehole$$

This means one borehole for each 122.3 meter.

4. Conclusions and Remarks

The risk of a Construction failure is heavily dependent on the quantity and quality of information obtained from a geotechnical site investigation aimed at characterizing the underlying soil conditions. This research has shown that by increasing the scope of the site investigation, the risk of foundation failure is significantly reduced, potentially saving clients and consultants large amounts of money.

This research also has shown that the cost of site investigation is minor comparing to the cost of rehabilitation or reconstruction. Where the ideal site investigation cost is between 670,954 LE and 5,199,892 LE, while the rehabilitation cost for the road problems cost 6,842,813 LE which represent 10.2 times the minimum ideal site investigation cost and 1.3 times the maximum ideal site investigation cost.

It also should be taken into consideration that the rehabilitation cost which had been taken to consideration is only the road itself rehabilitation, there are additional Costs could be taken to consideration such:-

1- Soil Exploration (Field and Laboratory tests which has been taken to identify the problem causes.
2- Cost of transforming the traffic way into the other Direction (Signs, Barriers …etc.).
3- Environmental cost due to the possible traffic crowed (The two directions volumes will be carried by one direction road lanes).
4- Risk of repetition the same problem in other segments of the road.
5- Any Additional Problems might be appeared later.

5. References

- Baecher, G. B., and Christian, J. T. (2003):"Reliability and Statistics in Geotechnical Engineering", John Wiley & Sons Ltd., Chichester, England.
- Carlsson, M. (2005): "Management of Geotechnical Risks in Infrastructure Projects", Licentiate Thesis, Division of Soil and Rock Mechanics, Royal Institute of Technology, Stockholm, Sweden.
- Clayton, C.R.I., Matthews, M.C., and Simons, N.E. (1995):"Site Investigation". Second Edition, Blackwell Science.
- Goldsworthy, J. S., Jaksa M. B. Kaggwa, W. S., Fenton, G. A., Griffiths, D. V. &Poulos H. G. (2004): "Cost Of Foundation Failures Due To Limited Site Investigations", Proceeding of International Conference on Structural and Foundation Failures, August 2-4, 2004, Singapore, pp. 398-409

- Goldsworthy, J.S., Jaksa, M.B., Fenton, G.A., Griffiths, D.V., Kaggwa, W.S and Poulos, H.G. (2007):" Measuring the risk of geotechnical site investigations", Proceedings of the Geo-Denver 2007 Symposium. K.K. Phoon et al., Eds., ASCE, 2007.
- Houston, S. (1988): ''Pavement problems caused by collapsible subgrades'' Journal Transportation Engineering, ASCE, 114(6), pp. 673–683.
- Institution of Civil Engineers (1991): "Inadequate Site Investigation" Thomas Telford, London.
- Littlejohn, G. S., Cole, K. W. and Mellors, T. W. (1994): "Without Site Investigation Ground is a Hazard" Proceeding of Institute of Civil Engineers, Vol. 102, May, pp. 72–78.
- Moh, Z.C. (2004): "Site Investigation and Geotechnical Failures", Proceeding of International Conference on Structural and Foundation Failures, August 2-4, 2004, Singapore.
- National Research Council (1984): "Geotechnical Site Investigations for Underground Projects" US National Committee on Tunneling Technology, Vol. 1, National Academy Press, Washington.
- Paul, T., Chow, F. &Kjekstad, O. (2002): "Hidden Aspects of urban planning – surface and underground development", Thomas Telford Publishing, London.
- ROWE, P.W. (1972): "The relevance of soil fabric to site investigation practice" 12th Rankine Lecture', Géotechnique, 22 (2), 195—300.
- Temple M. W. B. and Stukhart G. (1987): "Cost Effectiveness of Geotechnical Investigations" Journal of Management in Engineering, 3(1), pp. 8-19.
- Whyte, I.L. (1995): "The Financial Benefit from Site Investigation Strategy", Ground Engineering, 10, 33-36.