

Investigating Structural Cracks for Infrastructure: Case Study of Anonymous Hospital, in Zimbabwe

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Abstract. The main objective of the research was to investigate the structural cracks for infrastructure at the anonymous Hospital in the place under study, in Zimbabwe and recommend the appropriate engineering solutions to the structural problems. The specific objectives involved conducting desk studies, geotechnical and materials investigations, investigating the structural designs for the existing infrastructure and producing the construction schedule. A reconnaissance survey was also conducted together with key informant interviews. Geotechnical tests included sieve analysis, shear strength tests, direct cone penetrometer test, chemical dispersive test and California bearing ratio test. Structural analysis and designs were also conducted to model the relevant solutions. Most of the crack widths exceeded the design limits so these are structural cracks. The soil in the vicinity of the site is classified as Clay of Intermediate Plasticity and Clay of Low Plasticity. The soil has adequate bearing capacity and the minimum foundation depth is 1.5 m for a bearing capacity of more than 100 kPa. It is concluded that the first cause of the cracks on some of the buildings were the use of weak construction material such as farm brick which would easily deform under a small load and the depth of the foundation was less than the minimum of 700 mm, which was also on weak soils. The mortar thickness was extensively huge resulting in hyaline horizontal cracks and the bearing capacity and factor of safety were inadequate resulting in foundation failure. The dispersive test also proved that the soils are sodic in nature. The bearing capacity of the soil in some areas is not adequate to carry the imposed loads. It is recommended to use reinforced strip foundations and deep foundations when constructing infrastructure at the site. Heavy duty concrete foundation underpinning is recommended for the existing buildings. The total cost for repairing the damaged infrastructure is valued at US\$456 800.

Keywords: Geotechnical investigations, Structural cracks, Bearing capacity, Sodic soils, Foundation underpinning

1 Introduction

1.1 Background to the Study

Structural failures are part of engineering that deals with the ability of a structure to withstand various forces subjected to the unit. Structural failure is the loss of the load carrying capacity of a component resulting in visible fracture or excessive deformation. The science of interrogating structural failures is not new but is one that has not been fairly researched and practiced in Zimbabwe and the region. This paper seeks to investigate structural problems for an anonymous hospital in Zimbabwe and takes a step in addressing section 7.3 of the Zimbabwe Agenda for Sustainable Socio-Economic Transformation (Zim-ASSET). Infrastructure in the area is facing an uncertain future as the buildings are failing and some are at risk of collapse, therefore there is need to provide remedies to the problem and improve the residents' living conditions. The place under study is located mainly in the mid-altitude areas of the country and is characterized by annual rainfall of 500-750 mm, mid-season dry spells and high temperatures, the bedrock/parent materials are Karoo sandstone/colluviums and the soil is characterized as fine sandy and sodic soils [1]. The erosion hazard for the region is said to be variable having low water holding capacity. The anonymous Hospital is in a small community which supports the locals with provisions such as primary and a secondary school, a hospital which is the biggest in the place under study catering for transfers from the nearby ZIMPLATS mine. Figure 1 shows a map of the study area. Buildings in the anonymous Hospital are showing signs of failure, both the old and the new ones. Some buildings have developed cracks 20-40 cm wide and of varying lengths (Figure 2 & 3), then there are some which are showing signs of settlement.

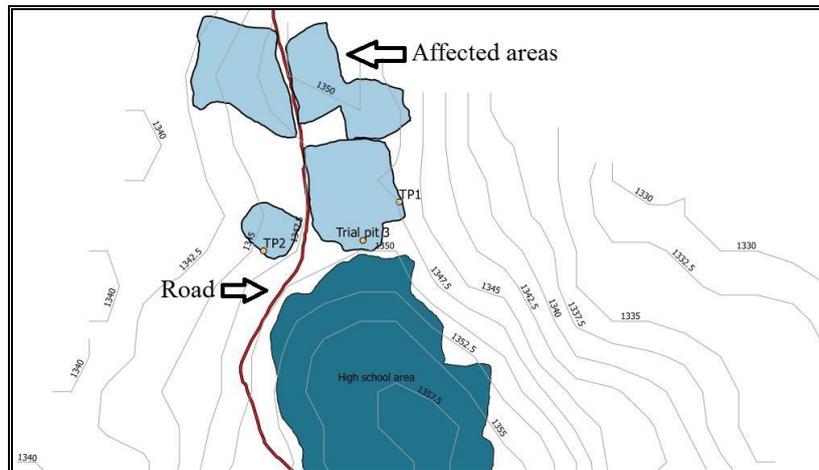


Fig. 1. Map of the Study Area

1.1.1 Causes of Cracks

Cracking due to reinforcement in bed joint reinforcement over openings in masonry facades generates increasing retrofitting needs [2]. The crack frequency can be correlated to the orientation of the walls and height above ground level [2], corrosion is affected by moisture content and temperature in the surrounding of the building.

Most building cracks are non-structural and these include shrinkage cracks and joint cracks, surface cracks on floors caused by improper curing [3]. Plaster thickness, corrosion of reinforcement and inadequate bonding are the other causes of cracks [3]. Some of the geologically derived materials that could lead to building failure and cracks include soluble rocks, shrinkage and swelling of clay, groundwater fluctuations, soil geochemistry (pH, sulphate, and chloride), peat and unconsolidated recent deposits [4]. According to studies [4] soil acidity dissolves the cement of the foundation causing cracks and the solution is to add lime.



Fig. 2. A jagged vertical crack on the wall of a building



Fig. 3. Vertical crack on another building

1.1.2 Current Repair Strategies

Advanced Composite Materials (ACM) in the form of fibre reinforced polymer (FRP) can be applied to strengthen reinforced concrete structures and ageing infrastructure where cracking is caused by corrosion of steel reinforcement [5]. The foundation can be inadequate to fully support the imposed loads [6] and this result in an increase in foundation settlement/differential settlement which may cause structure movement [7]. Wall cracks result from excessive stress on the masonry wall. Studies [8] show the methods of crack repair depend on the width, depth and nature of cracks. The methods vary from no repair to compatible patch repairs, chemical injections and use of reinforcement to close the crack opening. Dry packing, drilling and plugging, chemical grouts, hydraulic cement grouting, stitching (drilling holes on both sides of the crack and anchoring U-shaped metal staples with short legs across the crack). [8]. Other methods of solving foundation problems is underpinning and its various forms [9].

1.1.3 Gully Problems

Soil erosion is widely recognised as a major environmental problem affecting many parts of the world [10]. Soil erosion develops into sheet erosion, rill erosion and gully erosion which is the most advanced stage of soil erosion [11]. Gullies develop because of a decrease in soil surface resistance to erosion or an increase in the erosive

forces acting on the land surface [12]. Presence of gullies in many areas is a threat to the economic way of life of a community and also infrastructure [13].

1.2 Problem Statement

Infrastructure at the place under study is showing signs of failure due to the development of cracks and other defects. This has affected the development in the area since the causes of the current problems and the remedies have not been identified.

1.3 Research Objectives

The main objective of the research was to investigate the structural cracks for infrastructure at the anonymous Hospital in the place under study, in Zimbabwe and recommend the appropriate engineering solutions to the structural problems. The specific objectives involved conducting desk studies and geotechnical and materials investigations to obtain the relevant data required for the design solutions. The work also involved investigating the structural designs for the existing infrastructure and producing the construction schedule.

2 Materials and Methods



Fig. 4. Digging trial pits for geotechnical tests.



Fig. 5. Laboratory testing in progress

Geotechnical analysis needs to be conducted in order to determine the appropriate design approach and minimise potential impact on the adjacent buildings, analytical methods and numerical simulations are used [14], [15]. Calculation of the live loads and quality control of materials uniformity [16] and measurement of cracks is done [3]. The process of data collection was done over a period of one week from the 8th – 15th of January 2017. A reconnaissance survey was undertaken in order to familiarize with the area, identifying the types, extent and severity of the structural damage that buildings in the Mission area are suffering. A qualitative assessment was done; conducting interviews with the locals so as to get an insight of the views of the locals on what is happening in their area. Geotechnical investigations were then conducted

and the task included excavation of trial test pits, collecting soil samples, conducting in-situ tests such as the direct cone penetrometer test (dcp) and conducting laboratory tests on the samples collected. Figure 4 shows excavation of the trial pit.

3 Research Findings

3.1 Results from Fieldwork

3.1.1 Causes of Building Cracks

The vertical wall varied from 1 m to 5 m in length and 0.5 mm to 45 mm in width. Externally applied loads cause horizontal cracks. Settlement problems and heaving cause vertical cracks which are wider at the top and bottom. Table 1 shows the results obtained during fieldwork at the anonymous Hospital. The design limits according to BS5628 [16].

Table 1. Crack length and width

Location	Length (mm)	Width (mm)	Design Limits
B1 (Laboratory-TP3)	1000-2000	15-35	< 15mm
B2 (Washrooms-TP1)	2100-3000	20-40	< 15mm
B3 (Staff House-TP2)	500-3000	20-45	< 15mm
B4 (Staff House)	3000	30-42	< 15mm
B5 (Staff House)	1000-2500	15-30	< 15mm

The crack widths exceeded the design limits so these are structural cracks which need to be repaired urgently, from [17] these are more than 25 mm. Geotechnical and analytical approaches were employed in the collection of the data.

3.1.2 Results from key informant interviews

The building infrastructure is more than 30 years old. The recently constructed houses are less than 10 years old. The cracks were observed long back but they were not as severe as they are now. The latest building to be detected with cracks was the laboratory block completed in 2015 and it has since been condemned. The hospital technical personnel attribute the cracking of infrastructure to presence of weak soil, substandard materials and poor workmanship, the age of the buildings, the gullies and the blasting vibrations from Zimplats Mine.

3.1.3 Construction Materials

The construction materials used when the hospital and staff housing were built could not be accessed as this happened in the 1980's. However, for the recently constructed hospital laboratory a few bricks were still available. Other materials used were no

longer available and only in situ analysis would be feasible. Figure 6 shows the common farm brick used to construct the infrastructure.



Fig. 6. Common Farm Brick collected from site shows weak bearing capacity and would crumble easily.

3.1.4 Gullies

The existence of gullies in the vicinity of the mission area was a popular response as well. However, after mapping the area to determine the location of the gully in relation to the affected buildings, the gullies' development could not have contributed to failure of the structures.

3.2 Results from Laboratory Work

3.2.1 Plasticity Tests (Indicator Tests)

This is a summary of the Atterberg limits results. From the results summarised in Table 2 the soil in the vicinity of Trial Pit 1 (TP1) is predominantly sandy to sodic. The soil sample could not be moulded in order to perform the test and also samples which were tested for shrinkage showed no sign of shrinkage for the different moisture contents. The soil in the vicinity of Trial Pit 2 is classified as Clay of Intermediate Plasticity, and that in the vicinity of Trial Pit 3 is classified as Clay of Low Plasticity. The results are shown in Table 2 and Table 3.

Table 2. Summary of Plasticity Tests

Location	Liquid Limit (WL)	Plastic Limit (WP)	Plasticity Index (Ip)	Linear Shrinkage (Ls)
TP1 @ 1.5 m	-	-	-	0
TP2 @ 2.0 m	40%	19%	21%	9%
TP3 @ FL	30%	17%	13%	7%

3.2.2 Shear Box (Direct Shear) Test Results

Table 3. Shear strength parameters for the soil samples from the trial pits

Location	Cohesion (kN/m ²)	Angle of Friction (degrees)
TP1	13.210	23.6
TP2	29.240	11.7
TP3	12.328	3.6

3.2.3 Sieve (Particle Size) Analysis Test Results

Generally, the soils are sandy soils, there are a few areas with the existence of rocky material but the rock particles are mostly sedimentary rocks. Table 4 shows the summary of sieve analysis test results on the soil samples.

Table 4. Summary of the Sieve Analysis Test Results

Location	Description	Comments
TP1	Poorly graded sandy soil	Sample predominantly of the same size (sand)
TP2	Poorly graded sandy soil	$C_u < 6$ and $1 < C_c < 3$ shows that the soil is poorly graded sand
TP3	Poorly graded sandy soil	$C_u < 6$ and $1 < C_c < 3$ shows that the soil is poorly graded sand

3.2.5 Bearing Capacity Test (DCP and CBR)

A summary of the bearing capacity and California bearing ratios is shown in Table 5. The soil has adequate bearing capacity and the minimum foundation depth is 1.5 m.

Table 5. Summary of the bearing capacity and California bearing ratio Test Results

Trial pit	Ideal depth below ground level (mm)	Bearing Capacity (kPa)	Average %CBR
1	2000	200-300	25
2	2500	300-500	35
3	1500	100-180	15

4 Structural Design Work

4.1 Structural Engineering Design

Checking for structural failure is a complicated science that differs from one project to the next. The anonymous site was subject to depth forensic investigations that resulted in scientific analysis and conclusions to try and solve the challenges of

structural cracks. The components were considered separately and analysed for loads and bearing capacity. A quick estimate of the allowable bearing capacities was computed using equation 1: [17].

$$Q_{\text{allowable}} = \frac{cN_c + q'_0 N + 0.5\gamma BN\gamma_f}{\gamma_f} \quad (1)$$

Where the Factor of safety against bearing capacity γ_f is between 2 and 3 and q'_0 is the effective burden pressure, γ is the unit weight of the soil, B is the width of the foundation, c is the cohesion and the 3 N 's represent the shallow bearing capacity factors. The value of allowable pressure was computed and compared to the DCP values. The flexural strength of the masonry was also computed and analyzed with samples of bricks that had parameters close to the one discovered on site. The overall flexural capacity of a panel depends on the dimensions, orthogonal strength ratio and support conditions [17]. The ultimate flexural strength of a cracked wall spanning vertically was checked for various building units using the equation 2.

$$M_{\text{adm}} = \frac{\gamma_w t^2 h}{2\gamma_f} \quad (2)$$

The chemical composition and properties of the soil were considered using the dispersive test and other various geotechnical test highlighted above.

4.2 Repair Strategies

From [19] for cracks up to 1 mm the damage is only experienced to the wall finishes and the treatment can be done by normal decoration. Cracks with a width from 1 to 5mm can easily be filled. Cracks from 5-15 mm require some opening up and can be patched by a mason, some bricks need to be replaced. For cracks from 15-25 mm this is extensive damage and requires breaking out and replacing sections of the wall especially over doors and windows. The walls will be leaning or bulging. For cracks more than 25 mm this is structural damage that requires a major repair job involving partial or complete rebuilding. If cracking on concrete is due to drying shrinkage the crack will stabilize, if due to foundation settlement the settlement problem must be corrected [9]. For cracks less than 1 mm bonding by injection of epoxy is recommended. Routing and sealing of cracks can be used whereby the crack is enlarged along its exposed face and a joint sealer is used to fill and seal the crack [9]. The other methods recommended include near-surface reinforcing and pinning, additional reinforcement, drilling and plugging, polymer impregnation, grouting and crack arrest [9].

For simple structures presented in this paper it would be inappropriate to use piled underpinning methods or pumping grout or any other polymeric chemicals to repair the buildings as it would be expensive. The solution provided was compared to the cost of demolition and reconstructing and the design concept was made to suit the facet of the project. Cost is a major contributor to the decision and solution provided. Expertise and technical knowhow was also considered.

4.3 Cost of Repairs

The costs for repairing the existing structures is valued at US\$456 800.00 including materials and construction costs. The costs are calculated for the laboratory, one block (including the administration, wards, outpatient), the mortuary, the doctor's residence, the former nurse training building and about five other staff accommodation units. As calculated in our bill of quantity (Not attached in this paper). The repair works would take up to 100 working days according to the designed program of works.

5 Conclusions and Recommendations

5.1 Conclusions

Structural failures for the site in question were investigated and it was noted that:

- The bricks utilised for the construction are of poor flexural strength and the brickwork was not bonded creating fault line vertical cracks
- The soils are sodic in nature and resulted in collapse as the sodium component dissolved with fresh water and subsequent erosion below foundations.
- The Mine company blast could not be directly sidelined though vibrations can be the reason for the increased crack width and effect of topography on foundation erosion.
- The bearing capacity of the soils in some cases was not adequate to carry the load.

Currently there has not been any repair strategies that have been put in place.

5.2 Recommendations

It is recommended to use deep foundations, reinforced strip foundations, allowing for weep holes where terrain is highly differential, foundation underpinning and stabilising the base foundation when constructing buildings at the Anonymous hospital. It is also recommended that the structures with the failures recorded in this paper be treated with caution and repaired as some of the structural failures are far beyond serviceability failures. Using the findings from this paper, such as the repair strategies, similar studies can be done on other buildings experiencing structural failures.

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