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A Study of Underpinning Methods Used in the Construction Industry in Nigeria

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----------ABSTRACT----------
Foundation and retaining wall failures account for the highest case of structural failures. This is a report on a study of underpinning methods used in the construction industry in Nigeria. In view of the fact that underpinning, just like most engineering decisions, there is no unique solution, the research investigated technique of remedying foundation defects and whether there are innovations as regards to the underpinning methods used in Nigeria. To achieve the desired objective structured questionnaire, oral interviews and case study of an ongoing underpinning work were carried out. Result shows that differential settlement with a mean of 2.28 is the most frequent cause of foundation failure. While the continuous strip and reinforced mat with mean of 2.7 and 2.67 respectively, are most frequently used underpinning methods in Nigerian construction industry. Also 81.3% of the respondents agree that underpinning methods adopted are suitable and effective. Professionals in Nigeria have devised unique method of underpinning. It was recommended that proper and adequate site investigation should be carried out. Heavy penalties and sanctions should be meted on those construction firms that employ quack professionals.

Keywords: Underpinning, foundation failure, building collapse, remedial measure

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I. INTRODUCTION

Building failure and collapse are the most serious problems facing the construction industry in Nigeria. According to Ayedun*et al* (2012), the frequencies of their occurrences and the magnitude of the loses, being recorded in terms of lives and properties are becoming not only, worrisome and alarming, but a major source of concern to government and well-meaning Nigerians, especially the stakeholders. To really appreciate the magnitude of the problem, Adenuga (1999) in olufemi (20008) reported that over 36 reported cases of collapsed building occurred between 1974 and 1999 in Nigeria. While Dimuna (2010) reported 50 different cases of building collapse between 1976 and 2006. Besides that Ayedun*et al* (2012) gave details of 50 cases of collapsed building in Lagos state between just 2000 and 2010.

This explain the reason why a lot of effort was made and still being made, in order to, not only identify the causes of problems, but also came up with a lasting solution to the problem. Some of the numerous researchers include Adebayo (2000), Adedeji (2006), Aniekwu and Orie (2006), Ede (2010) Oloyede*et al* (2010), Dimuna (2010), Ede (2011), Dauda (2011), Ayedun*et al* (2012), etc. in addition, the National Building and Road Research Institute , NBRRI, recently organized a conference At Abuja on the same problem.

Many factors were identified as responsible for building collapse such as use of sub-standard building materials, poor workmanship use of quack professionals and contractors, poor workmanship, faulty construction methodology, non-compliance with specifications or standards, illegal conversion, alterations or additions to existing structures, defective design, "Nigerian factor" etc.

One very important and equally serious problem often neglected by experts is the issue of foundation failure. According to Derek (2009), foundation and retaining wall failure account for the highest structural failure. This probably explains the reason why Bello (2008) noted that the history of foundation failure is as old as the history of buildings. This is especially important considering the fact that foundation is an essential part of any construction process and many buildings in Nigeria are erected without paying serious attention to the condition and requirement of the site. In such situations, problems eventually arise, which ultimately affect the serviceable and function, even stability of the building. Dimuna (2010) noted that there are still defective buildings doting the skyline of many cities in Nigeria.

According to experts, one of the major solutions to building collapse is re-examination of development in building production control process (Dimuna, 2010). Since the root cause of the problem lie in foundation failure, a very important remedy is the development of proactive and remedial measures and this will guide against the problem of building collapse. This is particularly so, considering the fact that the construction industry in Nigeria is still at developing stage, coupled with the fact that there is non-enforcement of building regulation .A study of underpinning so as develop reliable method that would take into consideration the peculiars of Nigeria building industry would help reduce the cost of demolishing and reconstruction

Repairs to failed or deteriorating foundations are frequently the most costly of all building remedial measures. Besides that, just like most engineering decisions, there is no unique 'right' answer to a technical problem. It consist of art as well as science, as matter of fact, the art is even greater in foundations designs and remedial works (such as underpinning). The only essential requirement is the foundation designs and remedial measures must be safe, cost effective durable and buildable.

It is against this important background this paper reports on a study of methods of underpinning with special emphasis on the method used, problem faced and the unique approach/ innovation adopted by indigenous builders/engineers in solving foundation problem. This was achieved using the following steps:

i. To examine the various forms of foundation failures and underpinning methods used as remedy to such failures and prepare a checklist based on this.
ii. To study the different types and causes of foundation failures and underpinning methods used in the Nigerian construction industry using the checklist.
iii. To find out whether there are innovations as regards to the method of remedying foundation failures in the local construction scene.

II. MATERIALS AND METHODS

The sampling method adopted in carrying out this research was the use of well-structured questionnaires by means of random sampling of respondents in the construction industry. The respondents were professionals in the built environment: Professional builders, civil engineers, architects, etc. mostly located in Kaduna, Kano and the Federal Capital Territory.

A total of 40 questionnaires were administered out of which 22 were returned. The survey solicited information on foundation design and construction, causes of foundation failures, remedial measures adopted (underpinning). Also, an investigation was carried out on whether there some new innovations used by professionals in the construction industry in Nigeria which hitherto was unknown and, the effectiveness of such creativities.

The questionnaire was composed of two sections; section 'A' containing information on personal data of respondents whereas section 'Contained questions on underpinning. A case study of an ongoing underpinning was undertaken.

III. PRESENTATION OF RESULT

Breakdown of respondents

The educational qualification of respondents is as follows four (4) have Higher National Diploma certificates (22.7%), 9 have Bachelor's degree (40.9%), while 8 have Master's degree (36.4%). In terms of experience, result of investigation showed that 27.2% of the respondents have between 0 – 5 years' experience while 45.5% have between 6 – 10 years' experience 18.2% have 11 – 15 years' experience while 9% have more than 16 years' experience. Besides that, some construction firms were studied. The breakdown of the firms is shown in table 1

Table 1: Breakdown of Organizations Surveyed

Company category	Frequency	Percentage (%)
Small	2	9.1
Medium	6	27.2
Large	9	40.9
Government Agencies	5	22.7

As it can be observed, most of the organizations surveyed were large construction firms. Thus the professional background and qualifications of the respondents are sufficient for the validation of the survey of the results

CAUSES OF FOUNDATION FAILURE

The study first of all attempt to establish the causes of foundation failure

Table 2: Causes of Foundation Failure.

S/No	Causes	Frequency 1	2	3	∑F	∑Fx	Mean (X')
1	Design/calculation errors	9	9	3	21	36	1.7
2	Workmanship	4	11	6	21	44	2.09
3	Altering use of building	4	12	4	20	40	2.0
4	Low/defective quality materials	3	9	9	21	48	2.28
5	Settlement (differential)	5	5	11	21	48	2.28
6	Nature of site condition	6	8	7	21	43	2.04

1= Not frequent, 2= Frequent, 3= Very frequent.

Table 4.8 indicates the responses as regards likely cause of foundation failures on a scale ranging 1-3 from root frequent to very frequent. Design/calculation errors average 1.7 (frequent), workmanship 2.09 (frequent), altering use of building 2.0 (frequent), low/defective quality materials, and 2.28 (frequent), differential settlement 2.28 (frequent), and nature of site condition averaging 2.04 (frequent). The results reveal that the listed causes of foundation failures are frequent in their occurrence.

IV. UNDERPINNING IN THE CONSTRUCTION INDUSTRY IN NIGERIA

Involvement in Underpinning Operation

The level of involvement of respondents in underpinning operation was investigated. Result showed that 72.7% of respondents have been involved in underpinning procedures while 27.2% have not been involved in underpinning operation.

Methods Used

Using a checklist of the various conventional methods of underpinning, the different techniques applied were investigated. Details is presented in table 3

Table 3: Methods of Underpinning Adopted By Individual Firms/ Organizations

S/No	Consideration	Frequency				∑F	∑FX	Mean (X')
		1	2	3	4			
1	Continuous strip	3	6	5	6	20	54	2.7
2	Jack piles	2	6	3	1	12	27	2.25
3	Needle and pile	3	8	2	-	13	25	1.92
4	Pynford stool	4	3	5	-	12	25	2.08
5	Angle pilling	3	3	6	1	13	31	2.38
6	Reinforced mat	5	3	6	5	19	49	2.57
7	Reinforced mat with piers	3	4	7	4	18	48	2.67

1= Not used, 2= Rarely used, 3= Frequently used, 4 = Very Frequent

Table 3 shows the methods of underpinning adopted by individual firms/organization on a scale ranging 1-4 from not used to very frequently used. Continuous strip averaged 2.7 (frequently used), jack piles 2.25(rarely used) needle and pile 1.92 (rarely used), Pynford stool 2.08 (rarely), angle piling averaged 2.38 (rarely), reinforced mat 2.57 (frequently) and reinforced mat with piers 2.67 (frequently used). The results reveal that jack piles and needle and pile method of underpinning are rarely adopted by the individual firm/organization in which the respondents operate.

Appropriateness of Selected Method of Underpinning

The Suitability of the methods chosen for a specific underpinning work carried out by finding out whether there was problem after carrying out the underpinning and respondents' view on the
Suitability of such methods, were determined. Result shows 81.3% of respondents agreed that the method of underpinning adopted was the most appropriate and suitable while 18.7% disagreed.

Table 4: Awareness of Indigenous Innovations of underpinning procedures

Awareness Response	Frequency	Percentage	Effectiveness Response	Frequency	Percentage
Yes	8	36.3	Yes	11	50
No	14	63.6	No	8	36.3

Table 5 reveals that majority of the professionals were unaware of indigenous innovative underpinning procedures. However most of the respondents ere of the view that the underpinning used are effective.

V. REPORT ON FINDINGS OF SITE VISIT.

Case studies of underpinning in construction sites were also carried out as means of evaluating the whole process and to confirm the information obtained from field survey. During the time of this study, seven sites were identified, located at Abuja (1), Kaduna (1), Kano (2) and Zaria (3). However, in view of the striking similarities as regards to the method adopted, two were chosen for the detailed investigations. The first one, a mosque, was chosen because it was observed it is similar to five of the buildings identified. While the second one, a residential building, there was an innovation in it – an improvement on the conventional method.

VI. CASE STUDY OF UNDERPINNING

Site 1 at Samaru Zaria

The first site chosen for the case study of an underpinning work was at the Bakin - DogoJuma'at mosque. Details are as follows.

Site Location: The mosque is located at Bakin – Dogo area of Samaru Zaria, Kaduna state.

Plate i: Approach elevation of mosque.

Plate ii: Re-constructed portion of wall

Site Description: The mosque was built on an area of land covering approximately 2500 $m^{2.}$ The site was initially a refuse disposal site which was cleared to make space for the construction of the mosque. On the parcel of land includes the main mosque building, constructed with minarets, a dome and parapet walls and concrete drainages. There are toilets, an ablution area and a residential building at the rear of the mosque. A railway line runs about 30m to the front boundary of the mosque with access roads running on all sides of the mosque excluding the rear, with trees in the surrounding.

Plate iii: cracks on the wall

plate iv: Re-constructed column & wall

Description of Construction Work: The building was constructed on strip and pad foundations. Close study shows that the depth of foundation was shallow. It seems from all indications that the desired depth and bearing stratum, was not reached. The construction work of the mosque was initiated through community effort. Later, a philanthropist, decided to undertake the construction of the mosque, as such it was advised that the work be stopped, demolished and restarted. This was because many of the professionals' advice were not followed due, largely, to the shortage of funds. For instance, there was no site clearance that was carried out before excavation. Besides that, only columns were erected and after long period, this was followed by excavation trench for other works.

Nature of Failure: Barely on completion of the construction work, severe cracks began to appear which prompted the mosque committee to seek professional advice to take care of the failure. Severe horizontal and vertical cracks began to appear on the walls and also on the floors. Looking at the nature of cracks, it clearly shows that it was as a result of foundation settlement. This was because the history of site (a refuse dump site) was not considered in the design and construction of the foundation.

Plate v: Cracks on floors

plate vi: cracks on parapet wall

Method Underpinning Used: Corrective measure to arrest the failure was by means of underpinning using traditional continuous strip method and erecting columns at suitable distances to support the loads, while section of 2.0m intervals were demolished and excavated below the existing foundation level and erected upwards to support the walls and roofs.

Site 2 at Mubi

Location: The second site that was studied, is located at Mubi Adamawa State

Description of the Site and Building: It is a one storey residential building. It was initially plan to be a bungalow, however during construction, the client decided to change decision. A floor was added. In addition, the site is a waterlogged area.

Nature of Defects: After the building was put in use, the building started developing problems. Various cracks were observed most of them major ones. These cracks were very serious to the extent that they render parts of the building unserviceable.

Underpinning Method Used: Trial pits were dug, sample of soil collected; subjected to laboratory test and the properties were determined. The building was supported and rectangular trench was excavated/drilled at each corner of the building. Pile foundation was cast then, some other columns were constructed in between the ones at corners. This was followed by casting of beams that connect the piles. The construction of beams was carried out in such a way that they were not constructed at once. Thus, the underpinning consist of piles at each of the four corners and in – between and they were connected with beams

VII. DISCUSSION OF RESULT

Discussions of major findings from the survey conducted.

Foundations Failures.

Result of investigation on causes of foundation failure, shows that there is unanimous agreement among respondents that poor workmanship, altering the use of building, settlement and the type of soil are the main causes of foundation failure.. However, they do not regard errors in design as a major cause of such failures. Thus, one important observation can be made that: most of the problem originates from construction stage. But, in the course of carrying out oral interviews with professionals, they admitted that in most of the design, there was no site and soil investigation carried out before design and construction of buildings. Designers, however, pointed out that they make sure that they make adequate provision against unforeseen problem; by using high factor of safety. Result of case studies of some construction sites clearly shows that lack of site investigation is a major contributory factor to the problem of foundation failure.

Underpinning

Result of investigation showed that professionals in the construction industry in Nigeria are not only aware of the various conventional methods but also make use of them. Continuous strip with a mean value of 2.7 reinforced mat 2.57 and reinforced mat with piers 2.67 are frequently used. While pynford stool (2.08), angle piling (2.38) and, needle and pile (1.92), are the ones that are rarely used. Also it was noted that most of the problem of foundation failure occur on residential and commercial buildings. This could be due to the fact that these are the type of buildings where an informal arrangement is made in the execution of such buildings in which the clients are very reluctant to pay professionals to design and construct for them.

Looking at the methods of underpinning used and the type of projects, it shows that the Nigerian construction industry adopted a straight jacketed approach to the choice of method. There was no much consideration given to the nature of project. This can be attributed to the simplicity of the most popular method used. In addition, lack of knowledge and experience of workers undertaking such work. Thus the response of the professionals as regards to the suitability of the methods used for underpinning work may be the truth but certainly not the whole truth. As regards to the effectiveness, 50% were of the view that the methods used are effective. This result can be relied upon because of one important fact: that the effectiveness was judged based on the ability of such foundation that was underpinned to serve its function successfully. Physical observation and result of oral interviews showed that most of these buildings are in good condition.

As regards to the awareness of indigenous innovative underpinning procedures, 63.6% of respondents noted that they were unaware of such procedures as against 36.3% who claimed they were aware of such innovative indigenous procedures.

VIII. CONCLUSION AND RECOMMENDATION

Conclusion

Observations concluded from the results attest that;

1. Lack or poor site investigation is usually the major cause of failures of foundation as mostly buildings are erected on sites without taking into consideration activities that may have been carried out on the sites which usually decades earlier which may pose threats to the structural stability of foundations.
2. Continuous strip method of underpinning is the most common method of underpinning adopted in the Nigerian construction industry (2.7), as compared to the other methods highlighted in table 4.9. This may be due to its simplicity and ease or the straitjacketed, one – way approach adopted by firms in the construction industry who rarely think outside the box.
3. Commercial and residential buildings are most affected by foundation failures.
4. The respondents (81.3%) agreed that methods of underpinning adopted are effective and suitable as compared to (18.7%) who argued they were unsuitable and ineffective.
5. From interviews conduct, it was observed that it is the common practice in the construction industry for design of foundations to be contracted to firms who are not familiar and in certain cases have no knowledge of the geological composition and geographical location of the sites and who proceed with the design without caring to carry out site investigations, soil tests and reconnaissance visits to determine the most suitable and appropriate foundation type for such construction.
6. From interviews conducted also, there is usually the client's unwillingness to seek professional advice and consultation and rather they patronize quacks who are abundant in the construction industry. This practice is more prevalent in residential and commercial buildings as also indicated in responses from the questionnaires. The resultant outcome is the erection of buildings which may initially seem cheap to the client but when problems eventually occur which more often than not even during the construction, he client then begins to seek the professionals he initially felt were overpriced and remedial measures of any kind then outweigh what would have been done from the onset.
7. The practices of unconventional or indigenous means of underpinning or stabilizing structures are uncommon. However a lower percentage of respondents (36.3%) who admitted having knowledge of such procedures admitted a 50% effectiveness of such procedures signaling more still needs to be done in research and development in that aspect of indigenous construction technology.

Recommendations

Based on results obtained from the research, the following recommendations were arrived at;

1. Proper and adequate site investigation should be conducted and enforced prior to the commencement of construction work on site taking into consideration past use and history of such location and making provisions and allowances for problems which may be encountered. This may be achieved by making it a requirement in the application for planning permits or may be included as a requirement in the building code.

2. Enforcement of the National Building Code which requires that every aspect of construction be carried out under the supervision and inspection of the relevant professionals in such field.

3. Heavier penalties and sanctions on persons found wanting in the discharge of his\her professional duties as regards ensuring necessary standards and specifications are adhered to.

4. More effort should be made in the research and development of cheaper more effective means of construction and underpinning which are at the same time ecologically friendly and enhance sustainability.

5. Enlightenment of the public and intending property owners on the dangers and effects of patronizing quacks in construction.

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APPENDIX 1
QUSTIONNAIRE
DEPARTMENT OF BUILDING
FACULTY OF ENVIRONMENTAL DESIGN
AHMADUBELLOUNIVERSITY, ZARIA

Dear Respondents,

A study is being carried out on underpinning procedures adopted in the Nigerian construction industry. You are kindly requested to fill the questions below and choose from the appropriate options where available.

All information provided would be confidential and used solely for the purpose of the study.

SECTION A (Personal Data)

1. Profession
Architecture [ ] Building [ ] Civil Engineering [ ]
Structural Engineering [ ] Quantity Survey [ ]

2. Years of Experience
0-5 [ ], 6-10 [ ], 11-15 [ ], 16 and Above [ ]

3. Educational Qualification
ND [ ], HND [ ], B.Sc [ ], M.Sc [ ] Ph.D [ ], others

4. Please indicate the size of your firm on the base category of registration with the Federal or State Ministry of Works.
Small [category A: 0-₦50 Million] [ ]
Medium [category B: ₦51- ₦250 million] [ ]
Large [category C: over ₦250 Million] [ ]
Government Organization [ ]

SECTION B (Foundations and Underpinning)

5. Kindly assess the following conditions made in designing foundations according to their level of importance, using scale 1 – 4.

1 = Not important, 2 = Less Important, 3 = Important, 4 = Very Important

Considerations	**1**	**2**	**3**	**4**
Clients taste				
Structural requirement (loading)				
Soil conditions				
Topography				
Cost				
Materials				
Type of structure				

6. In constructing foundations, the following aspects are of utmost importance. In your view, how strictly were/was they adhered to?

1 = Ignored, 2 = Average, 3 = Strict, 4 = Very Strict

	1	**2**	**3**	**4**
Adequate Depth				
Consideration of expansive soil				
Adherence to necessary codes and standards				
Protection against erosion, deterioration and harmful materials				
Provision/allowance for modification of use of structure				

7. Have you been involved in any underpinning operation

Yes [ ] No [ ]

8. If yes, how many _____?

9. If no, what, what may be the reason?

Not necessary [ ]

Cost Implication [ ]

Not an area of practice [ ]

Lack of technical Skills [ ]

10. Were you involved in the initial design and /or construction of the building

Yes [ ], No [ ]

11. If yes, please indicate

Design Only [ ], Construction Only [ ], Design & Construction [ ]

12. The following are some causes of foundation failures; please kindly assess their level of occurrence.

1 = Not frequent, 2 = frequent, 3 = Very frequent

Causes	**1**	**2**	**3**
Design/calculation errors			
Workmanship			
Altering use of the building			
Low/defective quality materials			
Settlement (differential)			
Nature of site conditions			
Others…….pls specify			

13. What types of buildings are most affected?

Residential [ ], Commercial [ ], Institutional [ ], Industrial [ ].

14. The following are some methods of underpinning, which of these do you commonly use?
1 = Not used, 2 = Rarely Used, 3 = Frequently Used, 4 = Very frequently

Underpinning Methods	**1**	**2**	**3**	**4**
Continuous strips (traditional)				
Jack piles				
Needle and Pile				
Pynford stool				
Angle piling				
Reinforced mat				
Reinforced mat with piers				
Others…….pls specify				

15. In your opinion, was is the best option
Yes [ ] No [ ]

16. If no, what was your reason?
Please specify _____

17. Which of the methods is adopted in the Nigeria by other construction firms?
1 = Not Used, 2 = Rarely, 3 = Frequent, 4 = Very Frequent

Underpinning Methods	**1**	**2**	**3**	**4**
Continuous strips (traditional)				
Jack piles				
Needle and pile				
Angle piling				
Pynford stool				
Reinforced mat				
Reinforced mat with piers				
Others,…… pls specify				

18. Do you know any 'unconventional' underpinning method used by your firm or any other firms in Nigeria?
Yes [ ], No [ ].

19. Is/are traditional/indigenous construction methods used in such construction.
Yes [ ], No [ ].

20. if yes, how effective are these methods?
Effective [ ], Quite effective [ ], Effective [ ], Very effective [ ].