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Evaluating The Causes of Building Collapse in Kampala District, Uganda

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Abstract

Building collapse have become a recurring problem in urban areas, including Kampala District, Uganda. This study has evaluated the causes of building collapse in Kampala District and identified the underlying factors contributing to these disasters. A comprehensive investigation was conducted, encompassing the examination of collapsed buildings, assessment of construction practices, and analysis of construction materials using nondestructive testing (NDT). Field inspections, interviews with stakeholders, questionnaire administration and data analysis were employed to gather relevant information. The findings highlight several key causes, such as poor construction quality, lack of adherence to building codes, and inadequate supervision during construction. Two sites in the study area were examined thoroughly by laboratory experiments on the soil samples and evaluation of the strength properties of the building elements. Results obtained from the experimental investigation showed that the soil collected from case study one possessed inadequate engineering properties with AASHTO classification of A-7 with liquid, plastic, and shrinkage limit results of 51.7, 25.9 and 11.7 respectively, and OMC of 16.14% and MDD of 1.930 g/cm3 which indicated a silty clay soil. Moreover, the results for the soil samples collected from case two showed satisfactory strength performance with AASHTO classification of A-2-7, Atterberg results which showed 10.7%, 14.5%, and 45.4% were obtained for linear shrinkage, plastic and liquid limits respectively. Also, 9.7% and 2.168 g/cm^3 was also obtained for the OMC and MDD respectively. Additionally, issues related to substandard materials and unstable foundation conditions were identified with strength properties of the distressed building evaluated using NDT showed average compressive strength of 5 N/mm^2. In conclusion, the study emphasizes the importance of robust building regulations, proper construction practices, and increased public awareness to mitigate building collapses and enhance structural safety in Kampala District.

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1.0 Introduction

Building is described as an enclosure for spaces designed for specific use, meant to control local climate, distribute services, and evacuate waste (Fadamiro, 2012). Buildings are structural objects that may secure themselves by transferring weights to the earth. Furthermore, according to Odulami (2011), buildings are structures for human activities, which must be safe for the occupants. Building construction involves a series of processes, including architectural design, engineering analysis, obtaining permits, site preparation, foundation construction, framing, installation of building systems (such as electrical, plumbing, and HVAC), interior finishing, and exterior cladding (Carpenter et al., 1997). The construction materials used can vary depending on factors such as building type, location, and budget. The planning, design, construction, and maintenance of structures and infrastructure are all included in the building business, commonly referred to as the construction industry (Dare et al., 2016). It is a sizable and diverse industry that is essential to the global economic growth of all Nations. Residential and non-residential construction projects are both included in the construction sector. It is the most complicated industry in the economy, and its complexity stems from the fact that it is essential to the environment in which all other industries and sectors of the socio-economy work. In real actuality, anyone may work in the construction sector (Akindoyeni, 2012). In order to produce high-quality structures, a variety of domestic and foreign materials as well as specialists coexist in this business. Due to its scale and complexity, the building industry plays a significant and dynamic part in the process of a country's sustainable economic growth and development (Alinaitwe et al., 2013). Buildings across the world are the most important human assets, regardless of whether a Nation is impoverished like Uganda, expanding quickly like Nigeria, or fully developed like Britain (Chinwokwu, 2010). In addition, these structures offer both skilled and unskilled workers' jobs in addition to housing for people in the shape of homes, mosques, churches, offices, schools, industries, hospitals, stadiums, ports, hotels, and so on. Due to its scale and complexity, the building industry contributes significantly to the process of any country's sustainable economic growth and development (Olubi et al., 2018).

A failure in a building is an unacceptable discrepancy between intended and observed performance. When a construction component can no longer be depended upon to perform its primary tasks, it might be seen as happening in that component. By conducting a structural study and getting the necessary approvals, building failures can be reduced (Olagunju et al., 2013). Buildings can collapse as a result of poor design processes caused by inappropriate and flawed designs (Kobielak et al., 2015).

2.0 Study Experimentation

2.1 Study Area

This research study was limited to Kampala district comprised of five administrative divisions namely; Rubaga division, Nakawa division, Central division, Makindye division and Kawempe division. Fig. 1 shows geographical map illustrating this location.

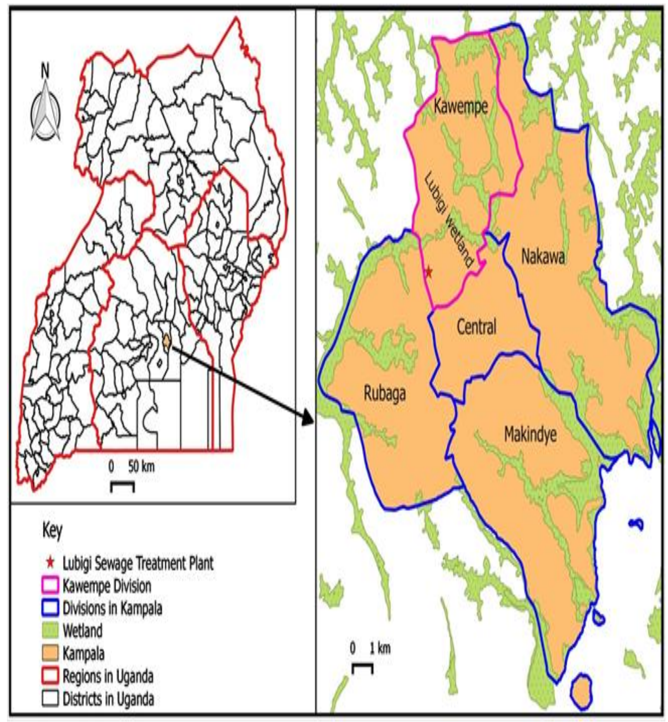

Figure 1 Geographical location of study areas

2.2 Qualitative Method

In qualitative method, questionnaires were prepared that targeted Civil Engineers, Architects, Project Managers and Quality Assurance/Quality control who were directly involved during the design and implementation of collapsed buildings in five administrative divisions in Kampala district. Questionnaires were utilized as a data collection method for evaluating the causes of building collapse due to their efficiency, standardization, and broad reach. This provided structured framework for systematically gathering information from various stakeholders involved in construction and regulation. This approach ensured consistent data collection, allowing for quantitative and qualitative insights into the multifaceted factors contributing to building collapses. Questionnaires were distributed to a diverse range of professionals, including engineers, architects, contractors, and regulatory authorities, enabling a comprehensive understanding of the issue. Respondents' anonymity encourages candid responses, especially in cases involving potential negligence or regulatory concerns. With cost-effective distribution and ease of analysis, questionnaires expedited the accumulation of data from a large number of sources. Careful design and validation of questionnaires ensured the quality and reliability of data, making them a valuable tool for gaining insights into the complex causes of building collapses. Selecting the people of Kampala as respondents is driven by the need for localized insights and perspectives in the research.

2.3 Quantitative Method

This research proposed to employ quantitative methods which involved carrying out nondestructive tests on concrete that was used to obtain compressive strength. Also, soil materials were collected at foundation depth and analyzed to examine its engineering behavior and suitability for structural foundation works. Tests such as sieve analysis to assess the samples particle size distribution, Atterberg limit tests, specific gravity tests, and compaction tests which were carried out in the laboratory facilities in Kampala International University, Uganda. Derived experimental results would be compared with the standard values for the design in line with code requirements.

3.0 Result Analysis and Discussions

The data collection instrument was survey and experimental results. Questionnaire was carefully designed to answer the research questions and distributed to target population and these included Architects, Project Managers, Civil Engineers, Quality control/Quality assurance (QC/QA). A total of 161 respondents participated in the survey exercise and their profile is presented in Table 1. The results indicated 91.9% and 8.1% for male and female participants respectively, also, their years of experience showed that about 84.47% of them less than 10 years while 14.29% have experience between 11-25 years.

The distribution of respondents' education levels showed that 15% held a Diploma, 77.02% had a Bachelor's degree (BSc.), and 7.45% possessed a Master's degree (MSc.). Notably, a significant 99.4% of the respondents acknowledged their awareness of building collapse incidents in the study area. Moreover, it's noteworthy that the occurrences of these collapses have intensified in recent times. Approximately 65% of respondents concurred that these incidents primarily happened between the year 2020 and 2023 as shown in Fig. 2.

3.1 Probable Causes of Building Collapse

To comprehensively analyze the potential causes of the building collapse, the identified factors were intelligently categorized into four main groups: Material, Project Management, Technical and Design, and Environmental factors. This systematic grouping facilitated a thorough evaluation of the responses provided by the respondents. The outcomes were then presented in both Table 2 and Fig. 3 for better visualization. Upon examination, the findings revealed that 68% of the participants attributed the collapse primarily to poor quality of construction material, signifying that issues with construction materials played a major role in the failure. On the other hand, a smaller proportion of respondents, 7%, pointed towards environmental factors, especially the impact of increased precipitation which subsequently affect the foundations as a significant contributor to the collapse. The quality of materials used in construction is of paramount importance as it directly influences the structural integrity, safety, and longevity of buildings.

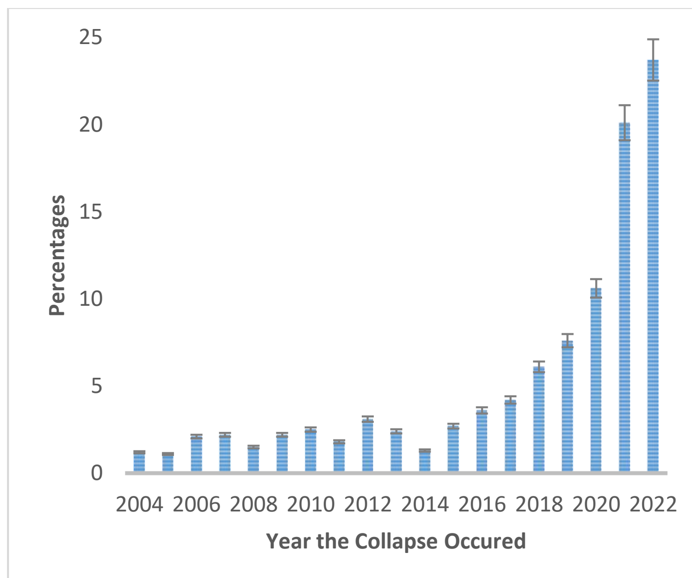

Figure 2 Participant’s response on the year collapse case occurred

Table 1 Demography of Respondents

Respondents Details		**Civil Engineer**		**Q C/Q A**		**Architects**		**P M**		**Total**	
		Freq.	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***
	M	51	34.46	39	26.35	34	22.97	24	16.22	148	91.9
	F	4	30.77	2	15.38	4	30.77	3	23.08	13	8.1
Sex	Total	55	65.23	41	41.74	38	53.74	27	39.29	161	100
	<20	1	1.82	0	0.00	0	0.00	0	0.00	1	0.62
	21-30	32	58.18	26	63.41	24	63.16	19	70.37	101	62.73
	31-40	19	34.55	12	29.27	14	36.84	7	25.93	52	32.30
	41-50	2	3.64	2	4.88	0	0.00	0	0.00	4	2.48
	>50	1	1.82	1	2.44	0	0.00	1	3.70	3	1.86
Age	Total	55	100	41	100	38	100	27	100	161	100
	<10	45	81.82	35	85.37	31	81.58	25	92.59	136	84.47
	11-25	9	16.36	5	12.20	7	18.42	2	7.41	23	14.29
	26-35	0	0.00	1	2.44	0	0.00	0	0.00	1	0.62
Years of	>35	1	1.82	0	0.00	0	0.00	0	0.00	1	0.62
Experience	Total	55	100	41	100	38	100	27	100	161	100
	Diploma	8	14.55	9	21.95	6	15.79	2	7.41	25	15.53
	BSc.	43	78.18	30	73.17	28	73.68	23	85.19	124	77.02
	MSc.	4	7.27	2	4.88	4	10.53	2	7.41	12	7.45
Level of	PhD	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	Total	55	100	41	100	38	100	27	100	161	100

Table 1 Respondents feedback summary on the probable cause of collapse

	Material		Project Management		Technical Inadequacy		Environment		Total	
Respondents	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***	***Freq.***	***%***
Civil Engr.	24	43.64	18	32.73	10	18.18	3	5.45	55.00	100
QC/QA	8	19.51	12	29.27	20	48.78	1	2.44	41.00	100
Architects	21	55.26	5	13.16	11	28.95	1	2.63	38.00	100
PM	15	55.56	3	11.11	7	25.93	2	7.41	27.00	100
Total	68	42.24	38	23.60	48	29.81	7	4.35	161	100

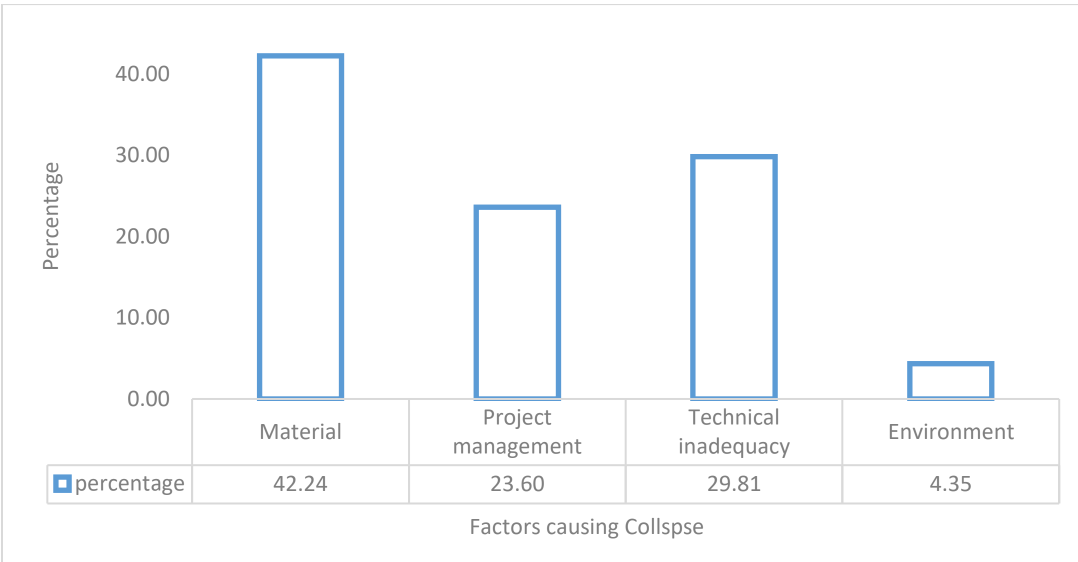

Figure 3 Factors responsible for building collapse

3.2 Evaluation of the Causes of Building Collapse

The analysis of the respondents' feedback was conducted using a 5-point Likert scale, which facilitated the assessment of the severity of different attributes, ranging from "very low" to "very high." The weighted scores were then calculated from the participants' responses and utilized to determine the Relative Importance Index (RII). The collected data was categorized based on the professional roles of the respondents, namely Civil Engineers, QC/QA professionals, Architects, and Project Managers. The outcomes of the survey, which aimed to understand participants' perceptions about the causes of building collapses, are presented in both Table 3 and Fig. 4. The results revealed that Architects and QC/QA professionals identified "Poor Quality Control" and "Foundation Failure" as the most influential factors contributing to building collapses. On the other hand, Civil Engineers and Project Managers attributed "substandard materials" and "Poor Compliance with Standard Specification" as the most critical contributors to the occurrences of collapses.

In contrast, Project Managers, Architects, and QC/QA professionals considered "Unexpected Failure Modes" and "Overloading and Lack of Maintenance" to be the least severe factors. However, Civil Engineers expressed a different view, suggesting that "Natural Disaster" was of lesser concern. Additionally, when averaging the reports, it became evident that "Substandard Materials" held the highest rank among the identified attributes, while "Natural Disaster" was considered the least impactful factor. This diversity in viewpoints among professionals underscores the intricate nature of the causes behind building collapses and emphasizes the influence of individual perspectives. The findings offer valuable insights into the nuanced perceptions of experts from various fields, contributing to a holistic understanding of the complex factors leading to building collapses.

Table 3 Respondents feedback to examine the causes of building collapse

Factors	Civil Engr.		Q C/Q A		Architects		P M		Average	
	RII	*Rank*	*RII*	*Rank*	*RII*	*Rank*	*RII*	*Rank*	*RII*	*Rank*
Inadequate Structural Design (CBC1)	3.71	8	4.03	4	3.91	5	3.89	5	3.885	6
Poor Quality Control (CBC2)	4.08	5	4.68	1	4.65	1	4.52	3	4.4825	2
Foundation Failure (CBC3)	3.98	6	4.49	2	4.29	3	3.74	6	4.125	5
Faulty Construction Methodology (CBC4)	4.22	4	3.81	6	4.18	4	4.43	4	4.16	4
Poor Compliance with Standard Specs. (CBC5)	4.32	2	3.94	5	3.87	6	4.69	1	4.205	3
Natural Disaster (CBC6)	2.54	9	3.43	7	3.33	7	2.67	8	2.9925	9
Substandard Materials (CBC7)	4.74	1	4.48	3	4.35	2	4.54	2	4.5275	1
Unexpected Failure Modes (CBC8)	3.86	7	2.25	9	3.17	8	2.89	7	3.0425	7
Overloading and Lack of Maintenance (CBC9)	4.42	3	2.42	8	2.54	9	2.68	9	3.015	8

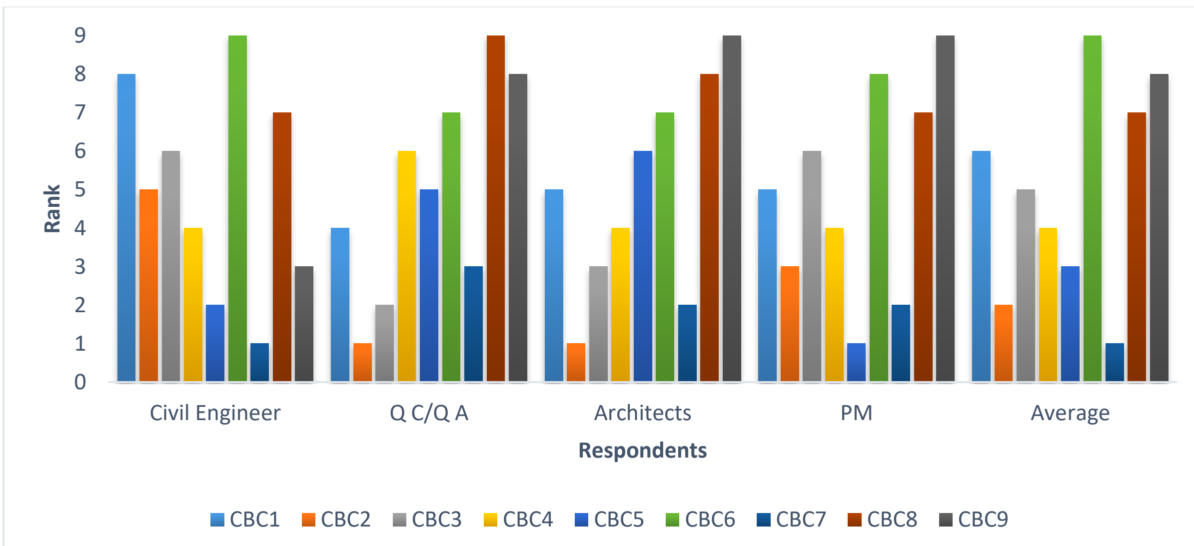

Figure 4 Evaluation of the causes of building collapse

3.3 Evaluation of the Frequency of Building Collapse

The collected responses from the participants were compiled to present the findings in both Table 4 and Fig. 5. The results indicated that overall, the occurrence rate of building collapses was perceived to be low, with a Relative Importance Index (RII) value of 3.4. Specifically, among the professional categories, Civil Engineers and Architects demonstrated a strong consensus in their opinions. Civil Engineers strongly agreed that the frequency of building collapses is "very low," while Architects expressed a similar viewpoint by categorizing the frequency as "low." However, there was a discrepancy in opinion among Project Managers. They believed that the occurrence rate of building collapses was relatively high. On the other hand, QC/QA professionals remained undecided, suggesting that they did not hold a clear stance on the frequency of building collapses.

These results offer insights into how different professionals perceive the frequency of building collapses. While some professionals view the occurrence rate as low, others hold different perspectives, with Project Managers being particularly concerned about a higher frequency. This diversity in perception highlights the need for comprehensive analyses and discussions when evaluating the occurrence of building collapses.

Table 4: Respondents feedback to assess the frequency of building collapse cases

Factors	Civil Engineer		Q C/Q A		Architects		P M		Average	
	RII	*Rank*	*RII*	*Rank*	*RII*	*Rank*	*RII*	*Rank*	*RII*	*Rank*
Very Low (FBC1)	3.50	1	2.98	3	3.3	2	3.3	3	3.27	2
Low (FBC2)	3.40	2	3.20	2	3.6	1	3.4	2	3.4	1
Medium (FBC3)	2.99	3	3.50	1	3	4	3.1	4	3.15	3
High (FBC4)	2.26	5	2.83	4	3.1	3	3.6	1	2.95	4
Very High (FBC5)	2.64	4	2.32	5	2.8	5	3	5	2.69	5

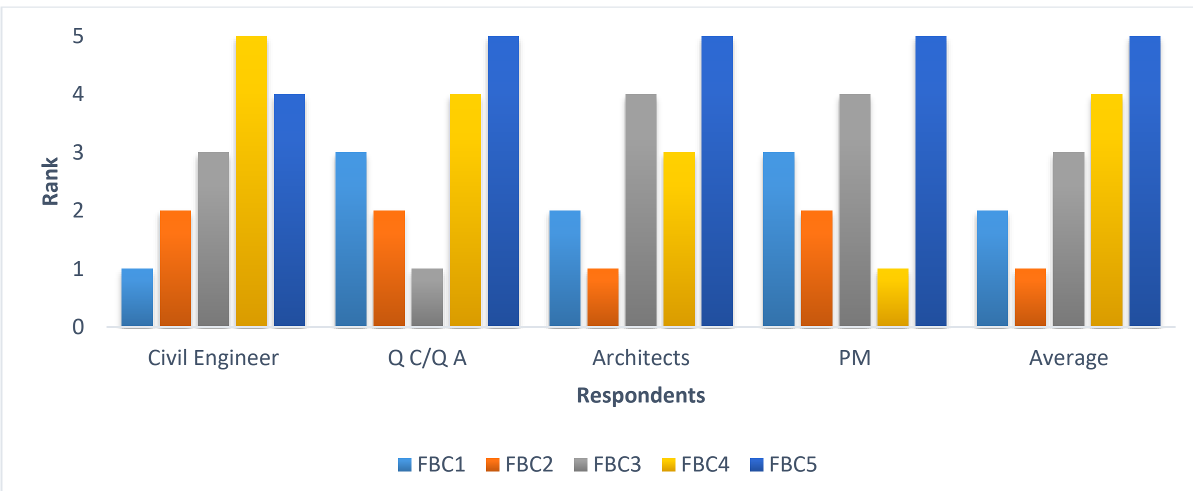

Figure 5 Evaluating the Frequency of Building Collapse

3.4 Evaluation of the Effects of Building Collapse

In the conducted survey, an exploration of the notable repercussions of building collapses was undertaken. This investigation focused on specific attributes that were expertly chosen as factors to gauge the impacts. The collected responses from the participants were meticulously compiled, and the outcomes are presented in both Table 5 and Fig. 6. The results obtained from this analysis revealed valuable insights into how different professional categories perceive the significant impacts of building collapses. Among these impacts, economic loss emerged as the most severe effect, as indicated by both Civil Engineers and Project Managers. Their perspectives were reflected in high Relative Importance Index (RII) scores of 4.74 and 4.62, respectively.

In contrast, Architects and QC/QA professionals expressed a distinct viewpoint. They contended that Material/Structural Damage stands out as the most significant factor contributing to the impacts of building collapse. This perspective was highlighted by their RII scores of 4.71 and 4.61, respectively. These findings highlight the varying opinions among professionals regarding the most substantial consequences of building collapses. In summary, Civil Engineers and Project Managers emphasize economic loss, Architects and QC/QA professionals emphasize material and structural damage. This diversity underscores the multifaceted nature of building collapse impacts, emphasizing the importance of comprehensive evaluations when assessing the aftermath of such incidents.

Table 5 Respondents feedback to examine the impact of building collapse

Factors	Civil Engineer		Q C/Q A		Architects		P M		Average	
	RII	*Rank*	*RII*	*Rank*	*RII*	*Rank*	*RII*	*Rank*	*RII*	*Rank*
Loss of Engineers/Contractor's Reputation and Integrity (EBC1)	3.11	5	1.25	6	1.22	6	1.23	6	1.703	5
Human Injuries (EBC1)	2.12	6	1.35	5	1.26	5	1.28	5	1.503	6
Material/Structural Damage (EBC1)	4.13	3	4.61	1	4.71	1	4.35	2	4.45	2
Environmental Impact (EBC1)	3.86	4	4.2	3	4.14	4	3.98	4	4.05	4
Economic Loss (EBC1)	4.74	1	4.57	2	4.39	3	4.62	1	4.58	1
Psychological Trauma (EBC1)	4.35	2	4.05	4	4.63	2	4.21	3	4.31	3

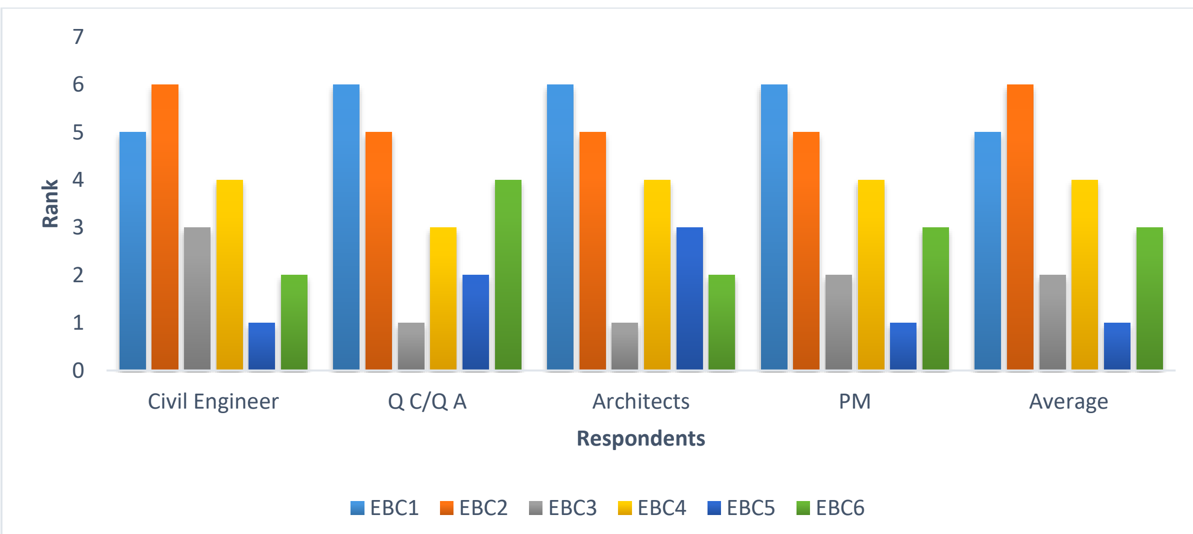

Figure 6 Evaluating the Impacts of Building Collapse

3.5 Spearman Correlation Ranking Analysis of the Respondents' Feedback

Spearman correlation ranking analysis is a statistical method employed to gauge the strength and direction of the connection between two sets of rankings offered by respondents. This approach proves especially valuable when dealing with ordinal data, where the ranks hold importance, yet the gaps between them might not be uniform. The rankings provided by various groups of respondents, including Civil Engineers, QC/QA, Architects, and Project Managers, were subject to statistical examination. This evaluation seeks to uncover the consistency of respondents' rankings and ascertain the extent of their agreement or disagreement.

The rankings were divided into three sections: causes of building collapse (CBC), frequency of building collapse (FBC), and impact of building collapse (IBC). These rankings were computed using Minitab 21 software. The outcomes for the CBC are presented in Fig. 7, Tables 6 (a) and (b). In the IBC section, the analysis showed a strong correlation of 0.917 between Architects and QC/QA, while the lowest correlation of 0.183 was observed between QC/QA and Civil Engineers. Additionally, moderate correlations of 0.600 were found between QC/QA and Project Managers, and 0.667 between Project Managers and Architects.

The results for the FBC section, displayed in Fig. 8, Tables 7 (a) and (b), indicated that the respondents' feedback on the attributes within this section lacked consistency. The strongest correlation, with a value of 0.7, was observed between Architects and Project Managers. A correlation of 0.6 was found between Architects and Civil Engineers, while the lowest correlations were calculated for Civil Engineers and Project Managers (0.1) and QC/QA and Project Managers (-0.1).

Furthermore, the analysis of the IBC section, as depicted in Fig. 9, Tables 8 (a) and (b), suggested a general alignment among the respondent groups participating in the survey. The average correlation coefficients of 0.8 demonstrate a certain level of consistency. The highest correlation value of 0.886 emerged from QC/QA and Project Managers, whereas the lowest correlation of 0.657 was found between QC/QA and Civil Engineers.

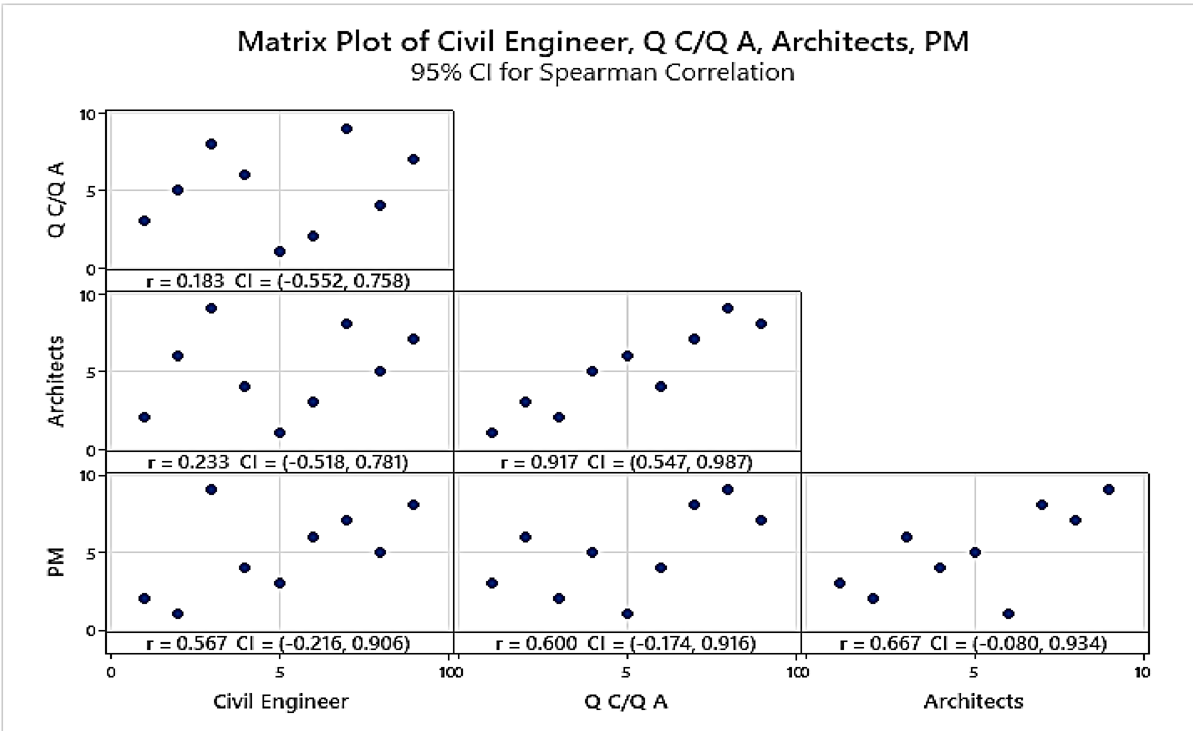

Figure 7 Matrix Plot showing the Spearman correlation results for CBC section

Table 6a Results of correlations analysis

Personnel	Civil Engineer	Q C/Q A	Architects
Q C/Q A	0.183		
Architects	0.233	0.917	
PM	0.567	0.600	0.667

Table 6b Pairwise Spearman correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Q C/Q A	Civil Engineer	9	0.183	(-0.552, 0.758)	0.637
Architects	Civil Engineer	9	0.233	(-0.518, 0.781)	0.546
PM	Civil Engineer	9	0.567	(-0.216, 0.906)	0.112
Architects	Q C/Q A	9	0.917	(0.547, 0.987)	0.001
PM	Q C/Q A	9	0.600	(-0.174, 0.916)	0.088
PM	Architects	9	0.667	(-0.080, 0.934)	0.050

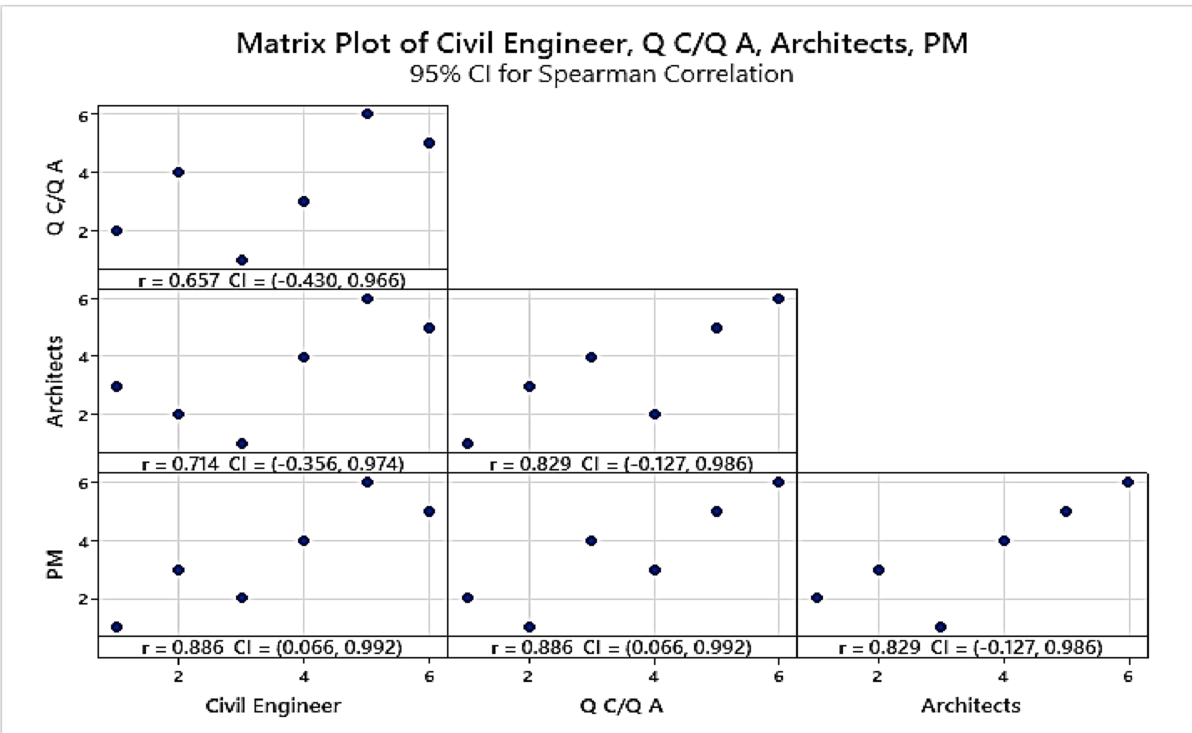

Figure 1 Matrix Plot showing the Spearman correlation results for FBC section

Table 7a Results of Correlations Analysis

Personnel	Civil Engineer	Q C/Q A	Architects
Q C/Q A	0.500		
Architects	0.600	0.400	
PM	-0.100	0.100	0.700

Table 2b Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Q C/Q A	Civil Engineer	5	0.500	(-0.726, 0.965)	0.391
Architects	Civil Engineer	5	0.600	(-0.671, 0.976)	0.285
PM	Civil Engineer	5	-0.100	(-0.903, 0.859)	0.873
Architects	Q C/Q A	5	0.400	(-0.768, 0.953)	0.505
PM	Q C/Q A	5	0.100	(-0.859, 0.903)	0.873
PM	Architects	5	0.700	(-0.591, 0.984)	0.188

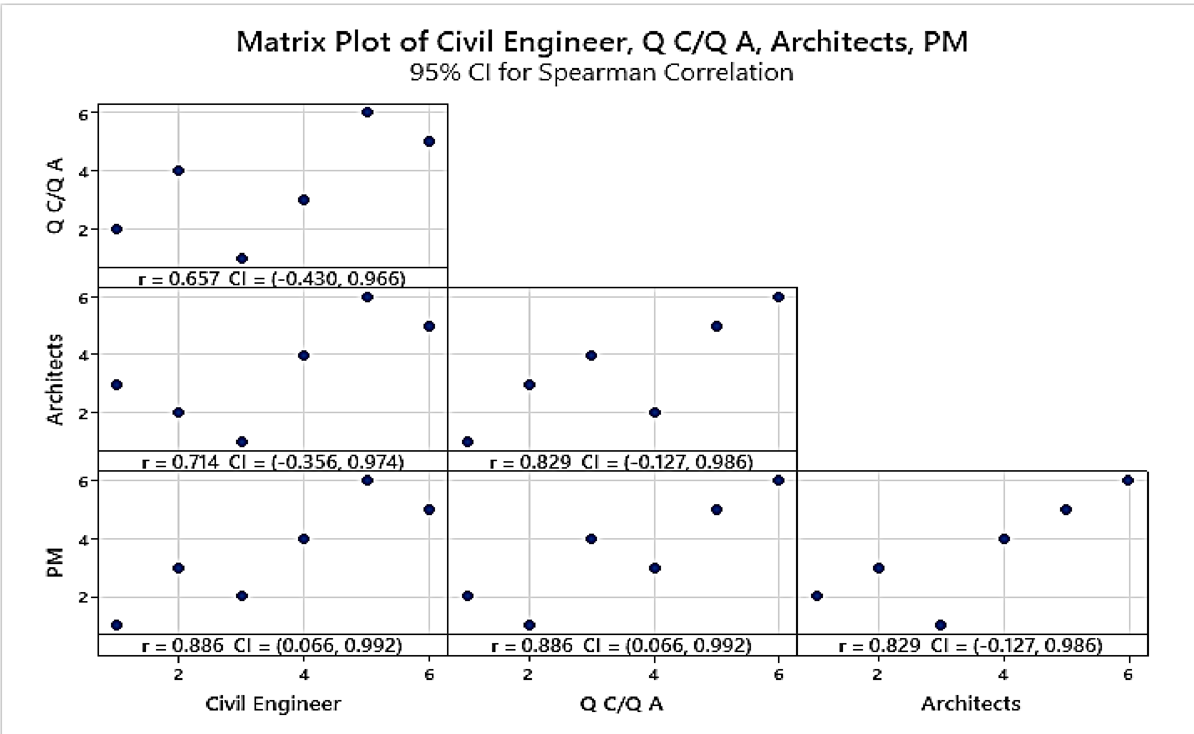

Figure 9 Matrix Plot showing the Spearman correlation results for IBC section

Table 8a: Results of Correlation Analysis

Personnel	Civil Engineer	Q C/Q A	Architects
Q C/Q A	0.657		
Architects	0.714	0.829	
PM	0.886	0.886	0.829

Table 3b Pairwise Spearman Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Q C/Q A	Civil Engineer	6	0.657	(-0.430, 0.966)	0.156
Architects	Civil Engineer	6	0.714	(-0.356, 0.974)	0.111
PM	Civil Engineer	6	0.886	(0.066, 0.992)	0.019
Architects	Q C/Q A	6	0.829	(-0.127, 0.986)	0.042
PM	Q C/Q A	6	0.886	(0.066, 0.992)	0.019
PM	Architects	6	0.829	(-0.127, 0.986)	0.042

3.6 Soil Investigation for Case Study One

Soil investigation of case study one (Mbiro zone, Kafumbe Mukasa-Kisenyi, Central Division of Kampala district) was carried out by laboratory testing to examine the engineering behavior and determine its suitability for framed structural works at foundation. Sieve analysis, specific gravity, Atterberg limits, and compaction tests were experiments deployed to characterize the soil samples. The particle distribution test results obtained is shown in the Table 9 and the semi log plot in Fig. 10. The result obtained indicated 97.8% passing through sieve size 2 mm, and 76.7% passing through sieve size 0.075 mm and a grading modulus (GM) of 0.34 which helps us assess the uniformity or gradation (particle size distribution) of the material. The result signified poorly graded soil and based on AASHTO (2003) system of soil classification, the test soils were not good engineering soil samples because the percentage by weight passing BS sieve No. 200 (0.075 mm) for the soil exceed 35 percent. The soil can therefore be classified as A-7 soil with liquid, plastic, and shrinkage limit results of 51.7, 25.9 and 11.7 respectively as shown in Table 10 and Fig. 11 which showed a high plasticity and cohesive soil property.

Also, the particle density value of 2.292 Mg/m^3 which is less than 2.55-2.70 Mg/m^3 for engineering soils. The experimental results obtained inform the engineers the need for soil stabilization and application of specially designed foundation for the structure under study. From the compaction test, the optimum moisture content (OMC) and maximum dry density (MDD) were found to be 16.14% and MDD of 1.930 g/cm^3 respectively, which indicated a silty clay soil as shown in Fig. 12. The reason for the high moisture content could be attributed to the occurrence of high precipitation leading to increase in the water table. Based on the observed experimental results on the test soil, it showed the soils are not suitable and requires further engineering action to make it useful.

Table 4: Sieve analysis results for soil collected from case study one

Location	Mbiro zone, Kafumbe Mukasa-Kisenyi 2			Sampling date: 5/11/2022 Testing date: 14/11/2022	
Initial wet. Weight	4689.0			Material Description	Dark greyish brown soil
Dry wt. before washing	4223.6				
Dry wt. after washing	985.8			Moisture Content	9.8
Sieve size Standard mm	**Partial Retained G**	**cumulative Retained g**	**cumulative Retained %age %**	**Passing %**	
50	0.0	0.0	0.0	100.0	
37.5	0.0	0.0	0.0	100.0	
28	0.0	0.0	0.0	100.0	
20	0.0	0.0	0.0	100.0	
14	0.0	0.0	0.0	100.0	
10	9.8	9.8	0.2	99.8	
6.3	10.9	20.7	0.5	99.5	
5	8.2	28.9	0.7	99.3	
2	64.6	93.5	2.2	97.8	
1.18	77.2	170.7	4.0	96.0	
0.600	116.9	287.6	6.8	93.2	
0.425	81.0	368.6	8.7	91.3	
0.300	101.1	469.7	11.1	88.9	
0.150	311.0	780.7	18.5	81.5	
0.075	194.8	975.5	23.3	76.7	
Pan	7.3	982.8			
GM			**0.34**		

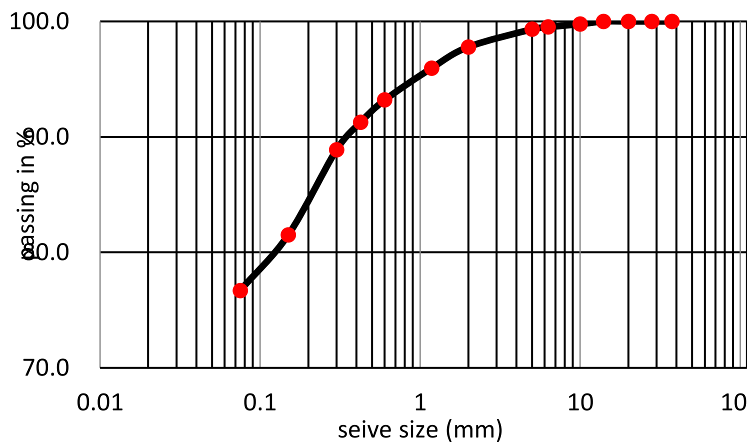

Figure 10 Particle size distribution plot of soil collected from case study one

Table 5: Physical properties for AASHTO classification

Test Parameter		Unit	Test Method	Test results
Maximum Dry Density		kg/m^3	BS 1377:Part 2:1990	1.930
Optimum Moisture Content		%	BS 1377:Part 2:1990	16.1
Atterberg Limits	LL	%	BS 1377:Part 2:1990	51.7
	PL	%		25.9
	PI	%		25.8
	LS	%		11.7

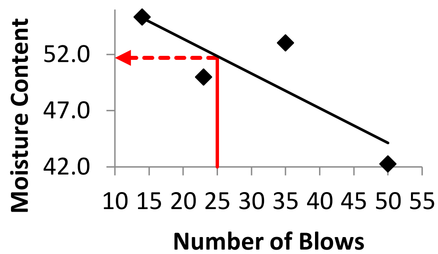

Figure 11 Liquid Limit result plot for soil samples sourced from case study one

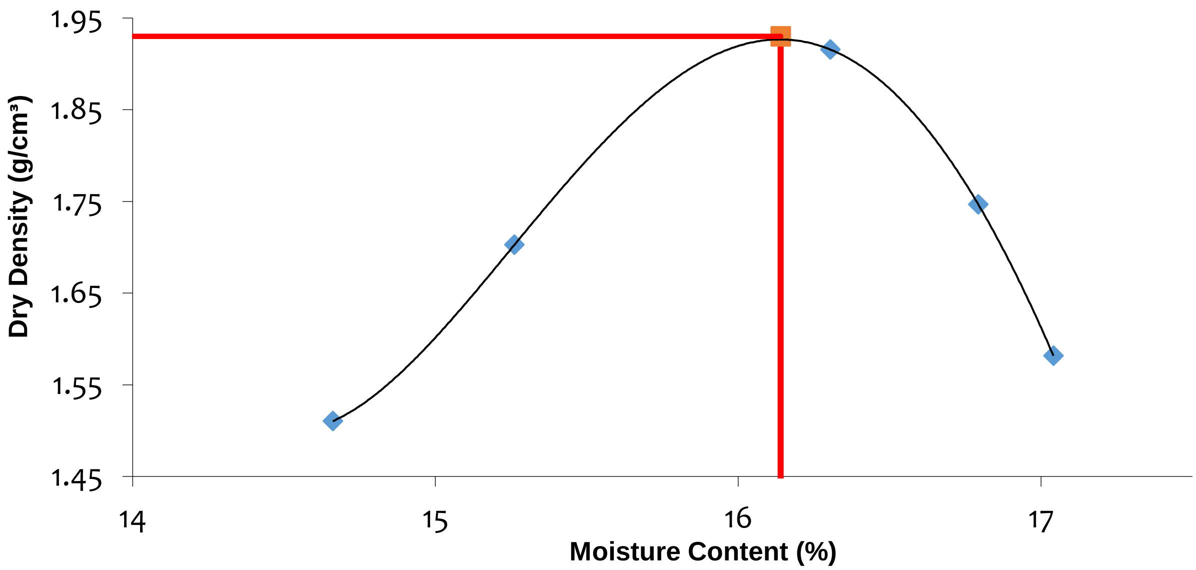

Figure 22 Compaction result plot for soil samples sourced from case study one

3.7 Soil Investigation for Case Study Two

Soil collected from the site of case study two (Nakawa Division, along Kireka-Kamuli road) were examined in the laboratory to assess its engineering behavior and determine its appropriateness for foundation of framed structures. Sieve analysis, specific gravity, Atterberg limits, and compaction tests were carried out on the soil from case study two for classification of soil. The soil samples were obtained at a depth of 1.5m and prepared for the tests which evaluates its physical and engineering behavior. The sieve analysis results calculated were presented in the Table 11 and the semi-log plot in Fig. 13. Details derived from the result showed that 92.6%, 32.8%, and 13.3% are passing through BS sieve sizes 20, 2, and 0.075mm respectively. From the Atterberg results 10.7%, 14.5%, and 45.4% were calculated for linear shrinkage, plastic and liquid limits respectively. The classification using AASHTO indicated A-2-7 soil which implies that the soil is of good quality for engineering works which indicated that it is a fine-coarse grained soil with medium to low plasticity and a group index of 7 as presented in Table 12.

Moreover, particle density results for the test soil is 2.423 Mg/m^3 which is satisfactory when compared to the research findings of (Arilesere, 2022). The compaction results for the test soil is 9.7% and 2.168 g/cm^3 was calculated for the OMC and MDD respectively which is of acceptable limit for geotechnical works as shown in Figures 14 and 15 . The physical and gradation testing result obtained indicated that the soil samples from the case study two poses good engineering properties and can be used for foundation works. More so, on physical inspection of the distressed structure, the foundation depth was observed to be 1.15 m, but the materials used for the construction looked very weak and hence the need to carry out non-destructive testing on the structural elements.

Table 6 Sieve analysis Results for soil sourced from case study two

Sample description: Reddish brown soil

Location: Along Kireka-Kamuli road

Initial wet.weight		4600.0		
Dry wt. before washing		3235.0		
Dry wt.after washing		3235.0	Moisture Content	8.5

Sieve size Standard mm	Partial Retained g	cumulative Retained g	Cumulative Retained %age %	Passing %
50	0.0	0.0	0.0	100.0
37.54.6	0.0	0.0	0.0	100.0
28	0.0	0.0	0.0	100.0
20	238.0	238.0	7.4	92.6
14	330.0	568.0	17.6	82.4
10	457.0	1025.0	31.7	68.3
6.3	648.0	1673.0	51.7	48.3
5	225.0	1898.0	58.7	41.3
2	276.0	2174.0	67.2	32.8
1.18	195.0	2369.0	73.2	26.8
0.600	41.7	2410.7	74.5	25.5
0.425	25.0	2435.7	75.3	24.7
0.300	27.0	2462.7	76.1	23.9
0.150	307.0	2769.7	85.6	14.4
0.075	36.0	2805.7	86.7	13.3
Pan	82.0	2887.7		
GM		**2.29**		

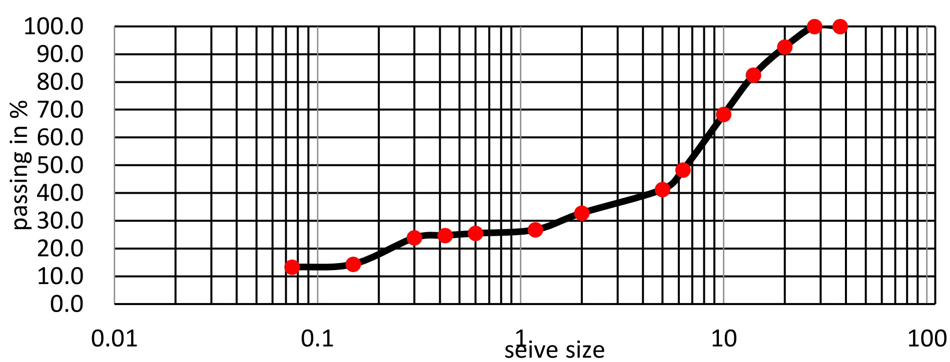

Figure 33 Particle size distribution plot of soil collected from case study two

Table 12 Physical properties for AASHTO classification

Test Parameter		Unit	Test Method	Test results
Maximum Dry Density		kg/m^3	BS 1377:Part 2:1990	2.168
Optimum Moisture Content		%	BS 1377:Part 2:1990	9.7
Atterberg Limits	LL	%	BS 1377:Part 2:1990	45.4
	PL	%		14.5
	PI	%		30.9
	LS	%		10.7

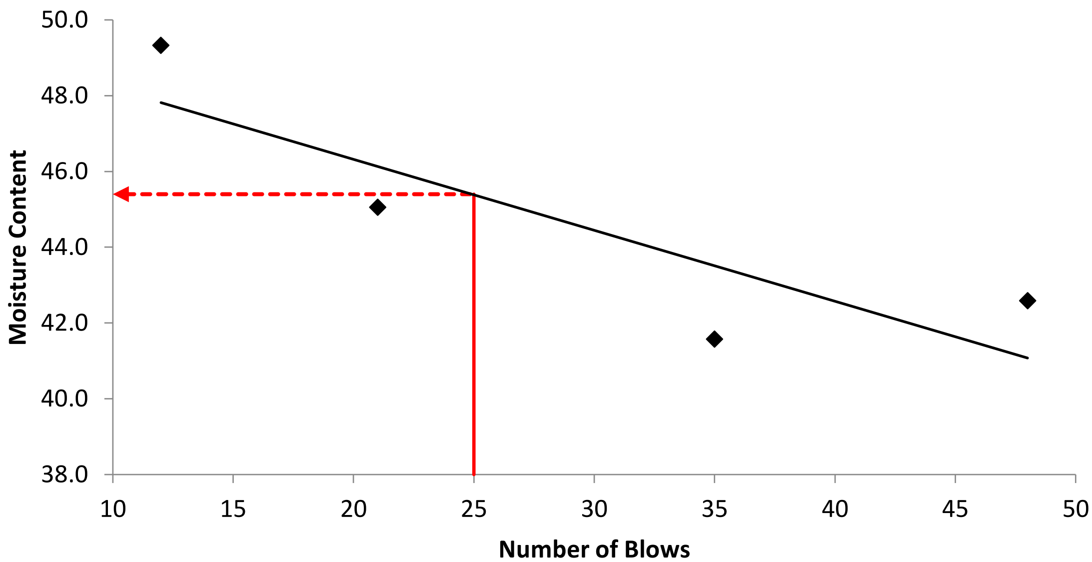

Figure 14 Liquid Limit result plot for soil samples sourced from case study two

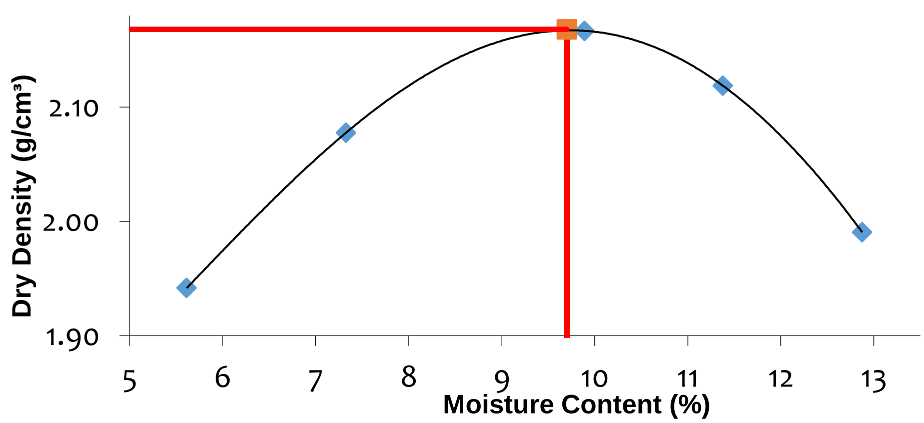

Figure 15 Compaction result plot for soil samples sourced from case study two

4.0 Non-destructive Testing of Slabs, Beams and Columns from Case Study Two

Non-destructive testing on concrete is a set of techniques used to assess the properties and quality of the concrete structure without causing damage to the concrete itself. These methods are valuable for evaluating the condition of existing concrete structures, detecting defects and verifying its integrity. Distressed building for Partial collapse of apartments of three storeyed description is summarized as follows:

Depth of footing = 1150mm, type of Foundation-Pad foundation, size of the pad (1200x1200mm), thickness of concrete-350mm, Reinforcement Bars-High yield T16mm and T8mm tied at a spacing of (150mm center to center), some at (200mm center to center), concrete cover to reinforcement bars for foundations and columns = 30mm and concrete cover to reinforcements for slabs and beams = 15mm. Materials used; hand crushed aggregates, fine aggregates/sand, solid blocks for superstructure. Results of the NDT conducted is shown in Table 13.

The results obtained showed that the strength properties of the structural components of the partially collapsed building are not satisfactory as they are not within the specified strength for structural concrete with average strength result of 13.84, 14.12 and 14.03 N/mm^2 for the ground floor mass concrete, first floor slabs, and for the first floor beams respectively. While 18.52 and 15.62 N/mm^2 for the slender circular column and second floor slabs respectively. Unable to attain characteristic strength requirements for the reinforced concrete material in building can lead to instability which makes the structural components not strong enough to resist intended loads. Also, from interviews conducted on the site during survey, it was observed that proper approval was not secured before the commencement of the project. The building partial collapse could be attributed to poor decision making in terms of hiring qualified engineers to manage the project and ensure strict adherence to standard specifications. Also, inadequate strength properties for the concrete used for the structural components which have greatly affected to the buildings capacity to carry designed loads leading to failure.

Table 13 Compressive strength (N/mm^2) results obtained using nondestructive test

S/N	Ground Floor			First Floor Slab			First Floor Beam			Circular Column			2nd Floor slabs		
	Rebound No	Compr. Str.	Avr. Compr. Str.	Rebound No	Compr. Str.	Avr. Compr. Str.	Rebound No	Compr. Str.	Avr. Compr. Str.	Rebound No	Compr. Str.	Avr. Comp Str.	Rebound No	Compr. Str.	Avr. Comp. Str.
1	22	18.24		18	14.87		13	10.66		30	24.99		18	14.87	
2	20	16.56		20	16.56		19	15.71		27	22.46		19	15.71	
3	16	13.18		15	12.34		15	12.34		26	21.62		17	14.03	
4	14	11.50		14	11.50		20	16.56		24	19.93		19	15.71	
5	16	13.18	13.84	15	12.34	14.12	16	13.18	14.03	18	14.87	18.52	15	12.34	15.62
6	13	10.66		16	13.18		18	14.87		17	14.03		17	14.03	
7	17	14.03		17	14.03		19	15.71		15	12.34		14	11.50	
8	15	12.34		18	14.87		16	13.18		16	13.18		22	18.24	
9	18	14.87		21	17.40		17	14.03		28	23.30		29	24.15	

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5.0 Research Findings

Building failure, if not detected and addressed promptly, often leads to collapse, resulting in the loss of both property and lives. In this study, two case studies were considered, one with an issue failure at substructure or foundation level and the other a challenge of partially collapsed story building. Technical investigations, survey exercises and analyses were carried out to determine the cause of the partial collapse and propose potential solutions. The analysis involves a detailed assessment of the building's structural elements and the identification of remedial measures. Field inspections, interviews with stakeholders, and data analysis were employed to gather relevant information to assess the possible causes of collapse from key stakeholders. The findings highlight several key causes, such as poor construction practices, lack of adherence to building codes, and inadequate supervision during construction. Field inspections which include soil excavation to evaluate the foundation condition, as well as collecting soil samples from the collapsed site for laboratory analysis and nondestructive testing were carried out. The inspections revealed inadequate supervision during construction, leading to under-reinforcement and causing excessive cracks and deflection. The soil test results from the study area one indicated an expansive soil and classified by AASHTO as A-7 which is unsuitable for geotechnical or foundation works. However, the soil samples obtained from study area two showed a better engineering soil as classified by AASHTO as A-2-7. The measured compressive strength of the structural elements in the distressed structure at case study two using the rebound hammer indicated weak concrete inadequate for structural works. These factors are categorized from the research findings as poor construction practices, foundation problems, design flaws, poor land use planning, aging and lack of maintenance as the reason behind the failure of the buildings.

5.0 Conclusions

The evaluation of the causes of building collapse in Kampala District, Uganda was carried out in this study. Questionnaires were expertly designed and administered to major stakeholders in construction industry namely; Architects, Quality Control and Quality Assurance, Project Managers and Civil Engineers within the study area of Kampala in Uganda to investigate the causes, frequency and effects of building collapse. The study has identified several key conclusions as follows:

i. One of the primary reasons for building collapses in Kampala District is poor construction quality, Inadequate workmanship, the use of substandard materials, and insufficient Quality Control during construction have all played a role in compromising the structural integrity of buildings.
ii. The soil test results from the study area one indicated an expansive soil and classified by AASHTO as A-7 which is unsuitable for geotechnical or foundation works.
iii. The results indicated that overall, the occurrence rate of building collapses was perceived to be low, with a Relative Importance Index (RII) value of 3.4.
iv. The soil samples obtained from study area two showed a better engineering property as classified by AASHTO as A-2-7.
v. The measured compressive strength of the structural elements in the distressed structure at case study two using the rebound hammer indicated weak concrete inadequate for structural works.

6.0 Recommendations

The evaluation of the causes of building collapse in Kampala District, Uganda, has revealed significant deficiencies in construction practices and regulatory oversight. Building collapses in the region are largely attributed to poor construction quality, non-compliance with building codes, inadequate supervision, unstable foundation conditions, and the use of substandard materials. These findings underscore the urgent need for comprehensive measures to address the issue and enhance building safety. To address the issue of building collapse in Kampala District, a multi-faceted approach is recommended as follows:

- Enhancing construction practices through capacity building and training programs for builders, contractors and engineers
- There is a need for increased public awareness campaigns to promote building safety and compliance with regulations.
- A collaborative effort involving government agencies, construction professionals, stakeholders, and the public is essential.
- Strict enforcement of building regulations and regular inspections are critical to ensure that construction projects meet safety standards.
- Building professionals should be encouraged to adopt best practices, and proper training and certification programs should be provided to enhance their skills and knowledge.
- Public awareness campaigns must be intensified to educate citizens about the importance of safe construction practices and the risks associated with building collapses.

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Declaration of conflict of interest

No conflict of interest among the authors.

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