__Original Research Article__

Appraisal of Structural Integrity Assessment Methodology and Reports of Existing RC Building Structures in Ghana

Abstract

This study reviewed 83 structural integrity reports obtained from two (2) Metropolitan and 6 Municipal Assemblies in the Greater Accra Region of Ghana to investigate the availability of national standard assessment and reporting format for structural integrity of existing building structures in Ghana, evaluate test methods and techniques used in the assessment and justification for recommended intervention levels. A case study with special form/instrument designed to collect the needed data from reports reviewed for responding to the study objectives. The study revealed that there were no national standards or published guidelines available for structural integrity assessment or reporting format for existing building structures in Ghana, resulting in a wide variation in the reporting structure. Visual inspections, Non destructive Schmidt Hammer rebound, Covermeter, Dynamic Cone Penetration (DCPT), and Trial Pits for physical exposure and inspection of foundations were the test methods and techniques in use, but equipment specifications for test methods and techniques were generally not stated. Justification for the report was largely for structural adequacy and safety assessment for repair, rehabilitation, upgrading, extension or change of use, hence most report recommended ‘safe structure’ contrary to depth/adequacy of information provided in the reviewed report. A national standard reporting format was therefore developed and recommended for adoption in the activity of Structural Integrity Assessment and reporting for existing RC building structures in Ghana and beyond.

Keywords: *Structural intergrity, report guideline, existing national reporting format, test methods/techniques*

1. Introduction

Building and civil engineering structures are designed for specified design working life and minimum design loads based on design codes and standards. The objective of structural design is to ensure overall stability, robustness, safety, serviceability and economy. The basic principles of the design of new structures are similar to structural integrity assessment of existing structures. However, the approach is quite different because Structural Integrity Assessment involves systematic collection and analysis of data, evaluation, and recommendations regarding the portions of an existing structure affected by its intended use or occupancy (SEI/ASCE 11-99, 2000). Therefore, the overall aim is to assess the structure's adequacy (safety and serviceability) for its intended use or occupancy. Depending on the type of structure and the client's brief, specific objectives of Structural Integrity Assessment may include but not limited to developing a performance report, establishing building use, serviceability, code compliance, life safety, durability, structural alterations; defects in design and construction; change of use or loading regime; and historic preservation (IStructE, 2010; SEI/ASCE 11-99, 2000).

According to Hille et al. (2006), procedures for the structural condition assessment can be classified into three groups: non-formal assessment (Level 0), measurement-based assessment (Level 1) and model-based assessment (Level 2-5), as shown in Chart 1 . The procedure depends on the assessment objectives, the scope of work, and specific circumstances such as availability of design documents, observation of damage, the use of the structure, and the time required for the assessment.

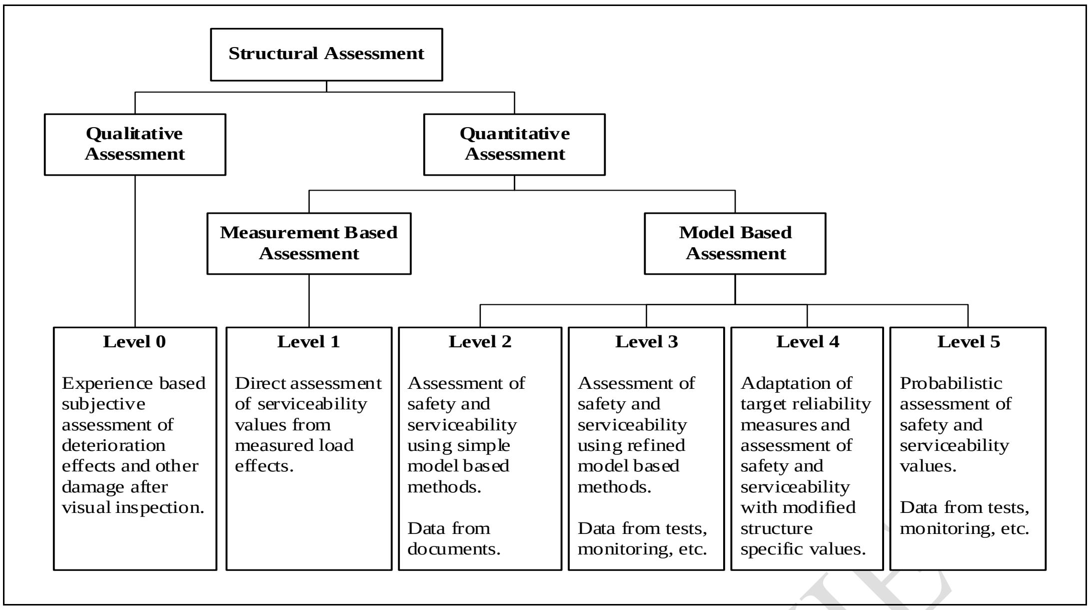


Chart1 . Context of the Structural Assessment Levels (Hille et al., 2006)

Level 0 is essentially a qualitative assessment based on visual inspection mostly used for pre-assessment (cursory assessment) of the structures. Levels 1-4 assessments are based on semi-probabilistic methods (partial safety factors), whilst Level 5 assessment is based on full probabilistic methods based on limit state principle.

The increase in the collapse of buildings in Ghana over the last two decades with associated fatalities has raised concerns about the integrity of building structures in the country. In addition, rural-urban migration, restricted land use, and economic growth have resulted in a change of use of buildings, especially within the cities in Ghana. In recent years, a trend in the country has been the transformation of the lower floors of residential buildings into commercial retail stores (Yeboah, 2000). A study conducted in Kumasi Central revealed that 85% of residential land-use had been converted into commercial and mixed land-use (Cobbinah & Niminga-Beka, 2017). Another study conducted by Asante and Sasu (2018) also showed that more commercial buildings collapsed in the last two decades than residential and other buildings in Ghana, with the majority of the collapses recorded in Accra and Kumasi, the two largest cities in the country. These, among other reasons, had resulted in increasing demand by the regulating authorities—Metropolitan, Municipal, and District Assemblies (MMDAs)—for developers to submit structural integrity assessment report as part of the requirements for obtaining permits for regularization, repair, rehabilitation, alterations, extension, change of use and occupancy of existing buildings.

Regularization of existing structures and extension of existing buildings requires developers to submit a Structural Integrity Assessment Report in addition to other relevant documents to obtain a permit. A Building Permit allows buildings or structures to be constructed on the condition that they comply with the requirements of relevant building codes and standards. The addition of a usable area or utility space to an existing structure constitutes an extension. Regularization of permits is also required for all structures developed without permits, including an application for a permit for an extension of existing structures that do not have a prior permit (Accra Metropolitan Assembly, 2020).

Findings, conclusions, and recommendations from the assessment should be adequately communicated to the client or owner in the form of a written report. To this end, preparation of the report requires the same level of professionalism and expertise as used in the investigation to ensure that it is consistent with the assessment's purpose and scope (IStructE, 2010).

The approach for integrity assessment of existing structures is different from structural design because it requires an appraisal of the as-built structure condition (IStructE, 2010). Again, existing structures reflect the state of knowledge at the time of their construction and are subject to different degrees of uncertainties compared with the design of new structures (BS EN 1998-3, 2005), (see Table 1A in the appendices). To this end, the engineer who undertakes the Structural Integrity Assessment needs to know how to prepare and coordinate the assessment; how to inspect the structure; what to look for; how to identify different conditions; what techniques are appropriate for field inspection and examination, laboratory testing, and analytical evaluations; what to recommend; and how to report the results (Ratay, 2006).

Lack of standards would result in significant variations in the assessment methodology and structure of the reports. It is worth mentioning that professional engineering bodies such as the Ghana Institution of Engineering (GhIE) over the last decade had organized few seminars on Structural Integrity Assessment of existing building structures, including issuing certificates to participants. However, from available literature and practice, there is no standard adoptable by all in Ghana. The reporting style of various organizations, engineering firms, owners, and even individuals may differ; nevertheless, it is of utmost importance to provide a standard format to which the consultants may adhere. Conversely, there exist some varied sample reporting formats, required test types, conclusion and recommendation adopted by various engineering bodies across the world as shown in Tables 2A to 4A in the appendices, show some similarities about main sections expected to be included in a typical assessment report.

The number of building collapses over the last decade and the increasing demand for structural integrity assessment reports by the local authorities as a requirement for issuing a permit for various intervention levels of building structures infer that there is the need to have a standard guideline for structural integrity assessment and reporting.

The selection of the type of technique, extent, and urgency of the interventions is greatly influenced by the structural information collected during the building's assessment (BS EN 1998-3, 2005). Hence, the need for adopting a national standard or guideline and standard reporting format for Structural Integrity Assessment of existing building structures for various intervention levels cannot be overemphasized. Hence, the aim of this study was to review Structural Integrity Assessment Reports of existing RC building structures in Ghana to ascertain the availabity of national assessment methodology and reporting structure, evaluate test methods and techniques used in the assessment and justification for recommended intervention levels, and develop a national standard reporting format for structural integrity assessment in Ghana and beyond.

2 METHODOLOGY

2.1 Study Design and Prosedure

The Greater Accra Region of the Republic of Ghana was selected as the case study area due to its rapid expansion of population and commercial activities with attendance increasing physical infrastructural development. A qualitative research approach and purposive sampling method were used to obtain sample Structural Integrity Assessment Reports from the Metropolitan, Municipal and District Assemblies (MMDAs) and copies of existing standards or guidelines from professional engineering bodies and organizations for data analysis. A total of twenty-five (25) out of twenty-nine (29) Municipal and Metropolitan assemblies in the Greater Accra Region served as the population for data collection. A special form (instrument) was designed to collect data (information) such as date; structure/format of report; the purpose of assessment; available documents; type of structure (number of stories/use/location); field/laboratory tests; design codes/analysis software; recommendations (keywords/phrases); and remarks. The appropriate departments at Assemblies were contacted for the sample structural intergrity reports submitted by clients and evaluated by the assembly engineers for building permit. Hence, eighty-three (83) reports obtained were reviewed, and the information sought was recorded using the specially designed form/instrument for analysis. On the other hand, existing standards or guidelines for structural integrity assessment were officially requested from the Ghana Institution of Engineering (GhIE), Institution of Engineering and Technology, Ghana (IET Ghana) and the Architectural and Engineering Services Limited (AESL) for comparison and review. The GhIE and IET were the only professional engineering bodies considered because they were the only professional bodies certified by the Engineering Council to license engineering practitioners in Ghana (Engineering Council Act, 2011).

2.2 Study Area

The Greater Accra Region (see Figure 1) is one of the sixteen (16) administrative regions of Ghana, with Accra as its regional capital as well as the national capital of Ghana. It is bounded on the north by the Eastern Region, east by the Volta Region, the Gulf of Guinea to the south, and the Central Region to the west. It consists of twenty-nine (29) Metropolitan, Municipal and District Assemblies (MMDAs). According to the 2019 census, it is the second most populated region in Ghana, with a population size of 4,943,075, accounting for about 16.32% of Ghana's total population (Ghana Statistical Service, 2019). The Greater Accra Region has the smallest land area of 3,245 square kilometres with the highest population density (persons per sq. km) of 1,235.8 and the most urbanized with 90.5% of its total population living in urban centres according to the 2010 census (Ghana Statistical Service, 2012).

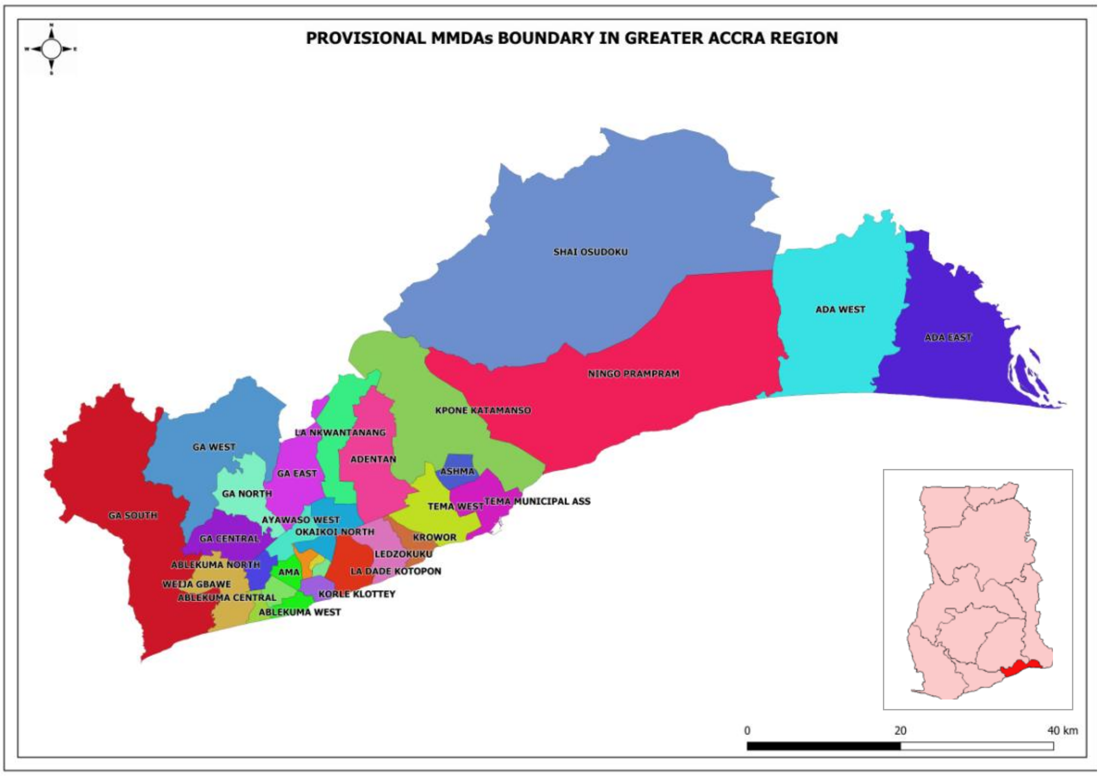


Figure 1Map of Greater Accra Region showing the Metropolitan, Municipal and District Assemblies (MMDAs). Source: Land Use and Spatial Planning Authority (LUSPA) – Greater Accra Regional Office.

3.0. RESULTS AND DISCUSSION

3.1. Introduction andDemographics

The study aims to review existing Structural Integrity Assessment Reports to evaluate the assessment methodology and reporting format, and to develop a recommended national standard reporting format to be adopted for reporting the outcome of structural integrity assessment of existing building structures. Out of the MMDAs, fifteen (15) assemblies made up of two (2) Metropolitan and thirteen (13) Municipal Assemblies were contacted. However, data was obtained from eight (8) earliest and most vibrant of the assemblies contacted (see table 1). The results and discussion of eighty-three (83) structural integrity assessment reports obtained and analized are presented as follows.

From

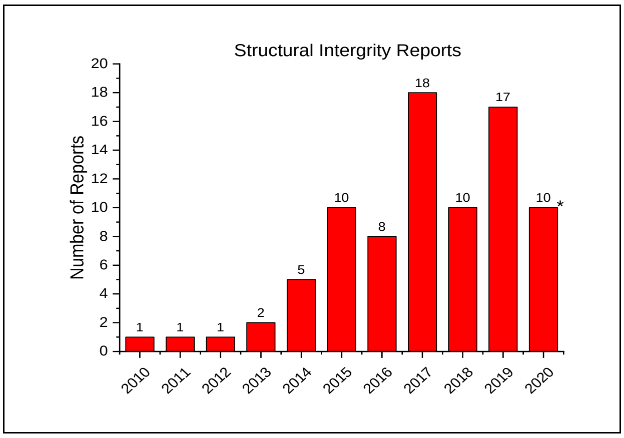
Table 1, it can be observed that the majority (65.1%) of the reports were obtained from the Accra Metropolitan Assembly (AMA). This was expected because the AMA formerly consisted of ten (10) Sub-Metros of which 7 of them were upgraded to autonomous Municipal Assemblies. Next, La Dade Kotopon Municipal Assembly of 16 report (19.3%) while the others had few reports of 4 or less. The distribution of the structural integrity reports ranges from 2010 to 2020, as shown in

Figure 2, indicating majority (42%) of the reports obtained submitted were in 2017 and 2019. It also suggests an increasing demand for structural integrity assessment in the Greater Accra Region, because, it is a mandated support document for permit regularization. Figure 3&4 portrays the various structure categories including residential, apartments, offices, churches, and schools, amongst others, while figure 4 depicts category of floor stories of buildings.

Table 1. Structural Integrity Reports obtained from the Metropolitan and Municipal Assemblies in the Greater Accra Region

S/N.	Assembly	Category	Qty of Reports	Percentage
1.	Accra Metropolitan Assembly	Metropolitan	54	65.1
2.	Ga East Municipal Assembly	Municipal	2	2.4
3.	Ga West Municipal Assembly	Municipal	4	4.8
4.	Korle Klottey Municipal Assembly	Municipal	0	0
5.	Krowor Municipal Assembly	Municipal	3	3.6
6.	La Dade Kotopon Municipal Assembly	Municipal	16	19.3

7.	Tema Metropolitan Assembly	Metropolitan	1	1.2
8.	Tema West Municipal Assembly	Municipal	3	3.6
	Total		**83**	**100**



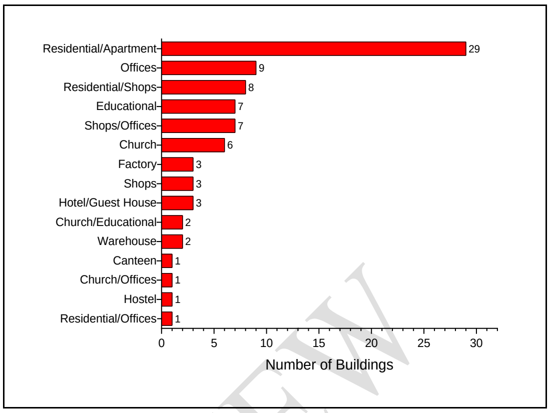


Figure 2. Data Distribution (*data was collected between August to November 2020; hence, data for 2020 does not represent reports for the entire year)

Figure 3. Categories of Buildings

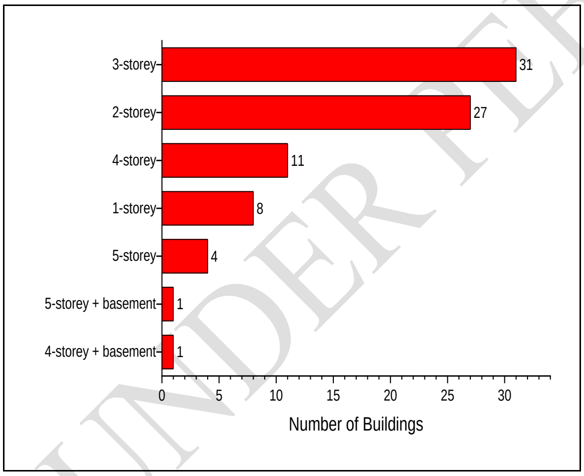


Figure 4Category of Stories

3.2. Status of Availability of National Standards or Guidelines for Structural Integrity Assessment in Ghana.

Official responses from GhIE, IET Ghana and AESL suggest that there are no existing national standards or published guidelines available for structural integrity assessment of existing building structures in Ghana. They further suggest that there are no existing standard reporting formats. However, the AESL offered a typical report sample which could reasonably assist an independent peer-review. Extracts of the report format/outline are as shown in Table 2. A typical report based on AESL format (table 2) was reviewed. The purpose of that assessment was explicitly stated, survey dates given and the status of the existing structure under investigation was adequately described with photographs. The appendix in that report included loads, load combination, materials, structural model, analysis results, and standards and regulations. Similarly, enquiries from the assemblies also revealed that there are no standard format nor criteria adopted by the assemblies for approval of structural integrity assessment reports and that the onus lies on the engineer responsible for the approval of such reports to determine their acceptability. Some engineers were also of the view that the onus lies on the assessment engineer for both the format and reliability of the reports.

These findings further indicate that even though few seminars on Continuing Professional Development (CPD) had been organized in the area of structural integrity assessment by the professional engineering bodies over the last decade, there are, however, no available standards nor published guidelines for the structural integrity assessment of existing building structures in Ghana. It, therefore, suggests that the assessment methodology and reporting format is mostly dependent on the consulting engineer or the firm responsible for the assessment (Agudze, 2020).

Table 2: Extracts of the format/outline of the typical report obtained from the Architectural and Engineering Services Limited (AESL)

Report Format/Outline:

- Executive Summary
- Introduction and Context
- Scope and Objectives
- Report Background
- Summary from previous Structural Integrity Assessment Report
- Additional Structural Integrity Assessment
    - Standard Penetration Test
    - Unconfined Compressive Test results
- Structural Safety Assessment
    - Results of the surveys and tests
    - Geometry of the structural elements and reinforcement details
    - Structural safety assessment of columns
    - Structural safety assessment of shear walls
    - Structural safety assessment of beams
    - Structural safety assessment of slabs
    - Structural safety assessment of foundation
    - Conclusion of the structural safety assessment
- Conclusions
- Appendices
    - Loads and combination
    - Materials
    - Structural model and analysis results
    - Standards and Regulations

3.3 Structure/Format of the Structural Integrity Assessment Reports

Figure 5. shows the outline of the main sections in the 83 repots reviewed. Due to the wide variation of the report format, the outline was based on the main sections categorized based on keywords and similarities. The structure of the reports indicates that most of the reports outline included an introduction, table of contents, the investigations, methodology/approach, conclusions and appendices.

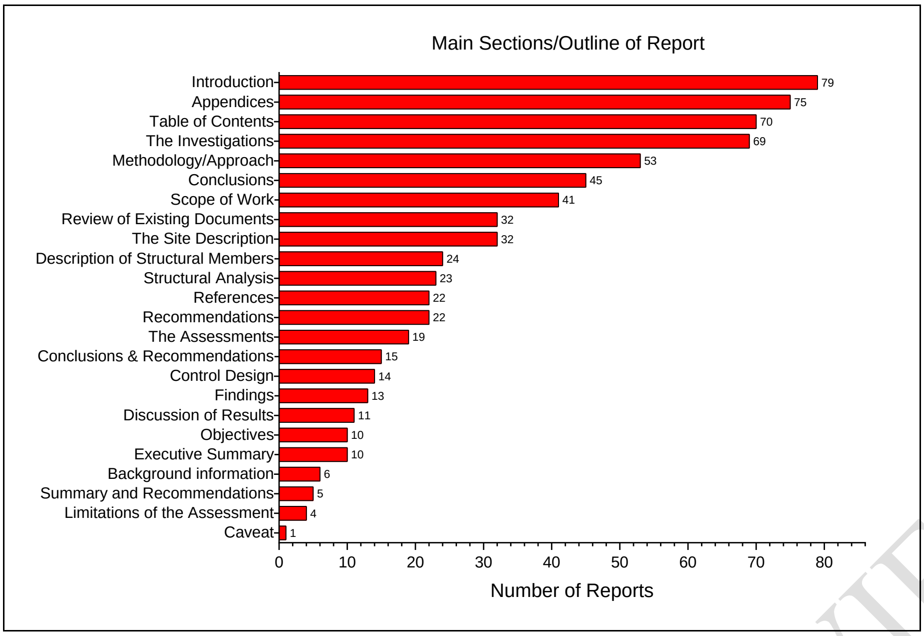


Figure 5. Structure/Outline of the Structural Integrity Reports

Observations from the review of the eighty-three (83) sample structural integrity assessment reports include the following:

- Out of the eighty-three reports reviewed, only 65% indicated the review of existing documents. The existing documents reviewed include architectural drawings (45.36%), structural drawings (43.30%), geotechnical reports (6.19%), and other documents (5.15%).
- Inadequate description of the structure under investigation. While most photographs in the reports were of low quality with no captions, majority did not include status photographs of the structure under investigation. Meanwhile according to Bungey et al. (2006), comprehensive site photographs and site records are invaluable sources of reference in the event of future disputes and litigations. Hence, there is the need to include quality photographs with appropriate captions in the report and well cross-referenced.
- Inadequate logical and serial numbering of main and subsections was observed in some of the reports
- Analysis and verification of the structural system were generally based on gravity loads only. The type of Codes of practice and standards for the analysis and design was indicated by only 51.81% of the reports reviewed, while only 27.71% indicated the method of analysis and the type of design software adopted for the assessment.

- Information provided under some main and subsections did not agree with the title of the main or subsections. Similarly, the table of contents provided in some reports was at variance with the actual sections and subsections in the report
- The appendices generally consisted of design calculations, field and laboratory test reports, and site photographs. However, most of the information included in the appendices were not cross-referenced in the main text, while only 31.33% of the eighty-three reports included design/calculation reports in their appendices.
- The methodology/approach adopted for the assessment was not adequately described in most of the reports despite its inclusion as the main section in the reports, as shown in Figure 5
- Some reports provided recommendations before conclusions, and with typographical mistakes.
- Some reports were based on qualitative assessment only; meanwhile, the status (whether preliminary or final) of such reports were not indicated
- Some reports did not indicate the type of intervention level required
- The review also indicates that most of the reports did not include sufficient details of design data and parameters.

The above observations indicate the need to adopt a national standard reporting format for structural integrity assessment to maintain some level of national and international standards in practice. Also, since structural integrity assessment reports, most often than not, can be used as litigation documents, it is essential to prepare them with much caution and in accordance with a standard format or a reporting guide. That is, the issues of mistakes and errors as observed in some of the reports can be avoided by carefully drafting and proofreading the reports before final submission as recommended by the Institution of Structural Engineers (IStructE, 2010).

Furthermore, research works by Building and Road Research Institute (1990), Kumapley (1996), Grunthal et al. (1999), Amponsah et al. (2008) and Ahulu et al. (2018) show that the maximum peak ground acceleration (PGA) in Greater Accra is 0.35g, 0.15g, 0.16g, 0.57g and 0.2g respectively, as cited in Ahulu et al. (2018). According to the seismic risk map of Ghana, Greater Accra Region has the highest level of seismic hazard located in seismic zone 3 with a PGA of 0.35g (Ghana Building Code, 2018). Therefore, assessing structural safety and serviceability of existing buildings in the region based on analysis and verification of gravity loads only is considered not adequate. Clause 1.1(3) of BS EN 1998-3 (2005) recommends that structural assessment to provide adequate resistance against seismic action should include verification for seismic and non-seismic load combinations. Hence, the same principle should be applied for the structural assessment of buildings in Greater Accra in accordance with their importance class.

3.4. Test Methods and Techniques

Extracts of test methods and techniques based on the review of the eighty-three reports are as shown in 7. It was observed that all reports reviewed indicated visual inspection was done during the assessment but very little information in the reports regarding the inspection items and the extent of the inspection.

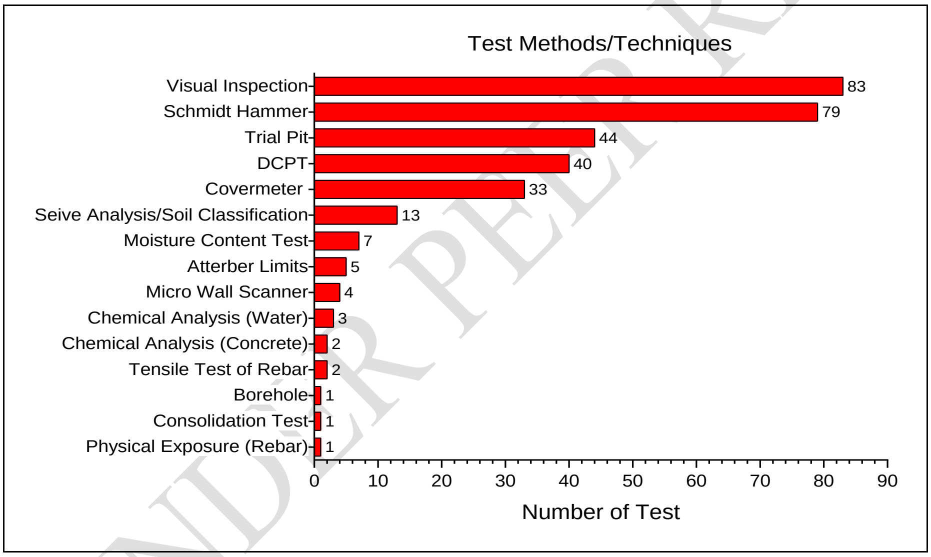


Figure 6. Test Methods and Techniques

Other observations made were that:

- Most widely used non-destructive (NDT) test methods and techniques for the assessment were the Schmidt Hammer and Covermeter while destructive test (DT) method used was widely trial pit for physical exposure and inspection of selected foundations.
- Commonly used test methods for the geotechnical assessment include Trial pit, Dynamic Cone Penetration Test (DCPT) and sieve analysis/soil classification

- Standards for performing the various tests were generally not stated
- Seventy-nine (79) out of the eighty-three (83) reports reviewed used the Schmidt Hammer test for determining the concrete strength in-situ.
- Some Schmidt Hammer tests were performed on plastered and painted surfaces while significant number of the buildings assessed were at various stages of construction/completion, with exposed reinforcement bars as observed from some site photographs included in the appendices.
- There were variations observed in the minimum readings required for the Schmidt Hammer test in the reports: typically, ten (10), nine (9), six (6) and five (5) readings per test area. Hence, most Schmidt Hammer test results (rebound number) were based on average of 10, 9, 6 or 5 readings per test area, whilst others were based on the difference between the average and the standard deviation of the readings.
- Only two (2) tensile strength tests on steel reinforcement were conducted, as reported in two of the eighty-three reports reviewed.
- Test locations and members tested were not adequately described, justified nor indicated by drawing in almost all reports
- An adequate description of the methodology adopted, equipment specification during testing were generally not indicated; while stated test methods that were not used in the assessment nor had data in the main text or appendices as evidence.

The Schmidt Hammer tests performed and interpretation of results were generally not in accordance with standard practice. The standard practice requires that the test surface is adequately prepared with a grinding stone before commencing the test. The European standard (BS EN 12504-2, 2001) requires the rebound number to be taken as the median of a minimum of nine (9) readings, whilst the American standard (ASTM C805, 1998) requires the rebound number to be taken as the average of ten (10) readings taken per test area. Again, from Figure 6, it can be inferred that overall, there was much effort committed to material testing and geotechnical aspects compared with the analysis and verification of the structural system. Conversely, the objective is to assess the structural adequacy and safety of the entire structural system but not only material testing and inspection of foundations. The same is true comparing the content of the geotechnical aspect of the report as opposed to evaluation, analysis and verification of the structural members. This is consistent with the fact that only 31% of the reports reviewed included analysis/design calculations in the report as appendices.

3.5. Justification for Recommended Levels of Interventions

The purpose of structural integrity assessment of existing buildings is to assess the structural adequacy and safety for its intended use; and to recommend appropriate levels of intervention where necessary based on the assessment findings by a qualified and experienced engineer professionally. Most of the recommendations indicate that the structure is safe, contrary to the findings that only 31% of the reports reviewed included analysis/design calculations of the assessment, and only 52% indicated the codes of practice and standards adopted for the analysis and verification of the structural system. Also, contrary to Professional Engineers Ontario (2016) advise against the use of phrases such as “structurally safe” (instead of excellent, good, fair, poor or extremely poor) in the assessment reports due to its potential to convey a wrong impression and misinterpretation of the results. It, therefore, suggests that most of the assessments were essentially qualitative without rigorous analysis and verification of the structural system, especially the structures under construction.

During the review, specific keywords or phrases used in the recommendations were found as categorized in Table 3. Phrases used in *A* may be considered more appropriate compared to those used in *B*. Whilst it is essential to provide an overall status of the condition of the structure under investigation, it is vital to choose such words with caution, consistent with the scope of work and the level of details adopted for the assessment to reduce its risk of being misconstrued or used as litigation documents. According to Professional Engineers Ontario (2016), many engineering terminologies and phrases have the potential of being misunderstood and misinterpreted by clients, insurers, building officials and the public.

Table 3 Extract of keywords/phrases used in the recommendations of the reports

A	○ ‘structure integrity is good’ ○ ‘satisfactory’; ○ ‘structurally good condition’ ○ ‘structural integrity of the building is good’
B	○ ‘integrity of the structure is solid and well grounded’ ○ ‘passed structural integrity test’

	○ 'sound structural integrity' ○ 'structural integrity is reliable and assured' ○ 'structurally sound' ○ 'structure is in accordance with sound engineering principles and practice' ○ 'structure is safe' ○ 'structure is statically stable' ○ 'very good standard'

3.6. Recommended National Standard Reporting Format for Structural Integrity Assessment

Reporting styles of various organizations, engineering firms, owners, and even individuals may differ; however, it is of utmost importance to provide a standard format to which the consultants may adhere. In principle, reporting format may also vary depending on the purpose and scope of the assessment. Given the wide variation in the reporting format and the increasing level of demand for assessing existing structures based on the review of the eighty-three reports, it suggests that the need to develop and adopt a standard reporting format for structural integrity assessment in Ghana and beyond cannot be overemphasized. Hence, recommended national standard reporting format was formulated for consideration, as shown in Table 0. The format had been developed based on existing standards and guidelines including: ES ISO 13822 (2012), IStructE (2010), Professional Engineers Ontario (2016), and SEI/ASCE 11-99 (2000). For the format to also serve as a guide to the assessment engineer, a brief comment (commentary) is included to highlight the essential information required to be provided under various sections and subsections.

The adoption would again ensure uniformity and standard practice for engineers, and serve as evaluation criteria for the Metropolitan, Municipal and District Assemblies (MMDAs) for issuing of permits for structural adequacy and safety assessment of existing buildings for regularization, repair, rehabilitation, upgrading, extension or change of use.

Table 0 Recommended National Standard Reporting Format for Structural Integrity Assessment

Recommended Outline/Format	**Commentary**
Title Page	Clearly state the name of the report <**Structural Integrity Assessment Report**>; full title: *Structural Integrity Assessment of*<*Name of Structure or Building*>; name and address of Client; name and address of Engineer [or Firm]; Registration number, stamp/seal and signature of the Lead Engineer; and date (month and Year). The status of the report may be given where applicable (e.g. cursory preliminary, final, confidential, etc.)
Table of Contents	Table of Contents of all main sections and subsections with page numbers must be included to serve as an essential guide to readers. The sections included in the table of content must be consistent with the actual sections in the main text.
List of Tables	Include a list of all Tables included in the report. All tables included in the report must be given appropriate captions.
List of Figures	Include a list of all Figures included in the report. All Figures included in the report must be given appropriate captions.
Executive Summary	The Executive Summary or Synopsis should be written to give a general overview of the assessment. It should include a summary of the purpose of the assessment, scope, key findings, conclusions, and recommendations. It should also include appropriate caveats, reservations, or exclusions.
1.0 Introduction	The introduction should be concise, comprising a summary of the client's brief (or terms of reference); the firm or engineer responsible for the assessment and brief background should be given.
2.0 Purpose of Assessment	The purpose of the structural integrity assessment should be clearly stated. It should clearly indicate the objectives of the assessment. It should be clearly stated whether the assessment is for the entire structure or limited to localized part(s) of the structure.
3.0 Scope of Investigation	The scope of the investigation should be clearly stated. The scope of work should be consistent with the purpose and objectives of the assessment and the extent of the investigation (cursory, preliminary, or detailed assessment). It is instructive to note that the scope of work may be revised in the course of the investigation but must be a mutual agreement between the Engineer and the Client or Owner.
4.0 Description of the Structure	Specific details may include information such as the location of the structure, type of architecture, type of structural systems; type of materials (concrete, steel, composite, timber, masonry); floor area; the number of stories; use and occupancy; date of construction, original contractor and consultants; dates of repair, rehabilitation, and upgrading; environmental conditions; site conditions and other factors. It should include photographs of the current state of the structure under investigation. The description must be clear, concise, and unambiguous.
5.0 Methodology	The approach, methods, and techniques used for the assessment should be indicated and covered in more detail to include the purpose of the selected methods and techniques. A chronological summary of activities and meetings held during the investigation phase should also be stated. A list of relevant technical standards and guidelines applicable to the methodology should also be stated. Specialists engaged in the assessment should also be stated, including their role and their full report included in the appendices (if any). Indicate the Knowledge Level (Limited, Normal or Full knowledge).
6.0 Investigations 6.1 Review of Existing Documents 6.2 Visual Inspection 6.3 In-situ Tests 6.4 Laboratory Tests 6.5 Summary of Findings	An official request for existing documents (drawings, geotechnical report, specifications, maintenance records, previous structural assessment reports, etc.) should be made from available sources such as the client, original contractor, and consultants, local authorities, etc. All available documents reviewed, including those not provided per the request (but may be considered relevant to assist the assessment), should be included in the report with remarks. Reviewed documents, as far as is reasonably practicable, should be verified for their correctness. Details of all inspection items, in-situ, and laboratory tests conducted should be fully provided. All relevant codes and standards must be stated. The methods and techniques may include visual inspection/examination, non-destructive testing (NDT), destructive testing (DT), photographs and videos, interviews, sampling methods and procedures. The manufacturer's details of equipment used must be provided. Only relevant photographs of structural defects

Recommended Outline/Format	**Commentary**
	and distress with appropriate captions and illustrations should be included in the main text and all others as appendices.
7.0 Analysis and Control Design 7.1 Analysis and Design Information 7.2 Analysis 7.3 Control Design 7.4 Findings and Discussion	The methods of analysis may vary depending on the purpose, scope, and extent of the investigation. Typical analysis and design information may include design codes and standards, material properties, structure geometry, applied loads and combinations. Method of analysis and design philosophy should be stated. Information provided should be detailed enough to allow for independent peer-review without the need for a further site visit or inspection. It is instructive to note that structural analysis is an iterative process; hence various scenarios must be considered in the analysis and verification. If inadequacies are identified, their nature, extent, and significance, including an explanation of any safety concerns and associated risks, should be indicated.
8.0 Conclusions and Recommendations 8.1 Conclusions 8.2 Recommendations	The conclusions and recommendations should be based on the assessment findings (observations, testing, analysis, control design, and evaluation). This part essentially requires experience and *professional engineering judgment* and must answer the purpose and objectives of the assessment. The recommendations must be based on the conclusions. Various intervention levels (repair, rehabilitation, upgrading, or demolishing) may be recommended, including preliminary estimates depending on the scope and terms of reference (TOR)
References	A list of all relevant standards, codes of practice, guidelines, books, and all related literature used as references in the assessment should be included. Only references used must be listed.
Appendices	Appendices should include all relevant supporting data/documents such as record drawings, survey information, photographs, test data and reports, calculations and specialist reports. All appendices included *must* be well labelled (captions) with an appropriate *cross-reference* in the main text.

KEYNOTES

1. Engineers must recognize that Structural Integrity Assessment Reports can be used in future litigation; hence, they must be prepared with caution and adequately proofread before final submission to the client or owner as a way of managing the engineer's potential liability.
2. The report should be written in a manner that is unbiased, accurate, and understandable by a non-engineer while maintaining sufficient technical data and documentation for an independent peer-review.
3. The content of the report must be consistent with the purpose, objectives, and scope of the investigation and analysis
4. The reports must be appropriately formatted, and the numbering of sections and subsections must be consistent and logical
5. A carefully worded *disclaimer* may be included in the report as a way of managing potential liability to third parties. It is instructive to note that a disclaimer is not a relief from unprofessional work.
6. Keywords, terminologies or phrases used in the report, especially in the conclusions and recommendations in the overall assessment of the condition of the structure, must be carefully evaluated because assessment reports can be used as litigation documents.
7. It is recommended that criteria for the assessment of the overall condition state of the structure should be included in the report.
8. Structures in seismic zones should be assessed with both non-seismic (e.g., gravity loads, wind loads, etc.) and seismic load combinations.
9. It is prudent to review existing documents before site visit for preliminary and detailed inspection
10. Prior to the site inspection, it may be helpful to develop a checklist of structural defects and distress to assist and facilitate the recording of observations.
11. Depending on the purpose of assessment and the amount and quality of information obtained about the structure geometry, details, and mechanical properties of materials used for the construction based on the available existing documents, it may be useful to carry out a preliminary analysis of the structure before site investigation works to identify critical areas for the assessment.

4.0. Conclusions

In conclusion, the study revealed that:

- There were no national standards or published guidelines available for structural integrity assessment of existing building structures in Ghana, leading to wide variety in the structure of the reports reviewed by all for structural integrity assessment of existing building structures in the Greater Accra Region.
- The purpose of the assessment was for structural adequacy and safety assessment for repair, rehabilitation, upgrading, extension or change of use.
- The most widely used test methods and techniques were visual inspections, Schmidt Hammer, Covermeter, Dynamic Cone Penetration (DCPT), and Trial Pits for physical exposure and inspection of foundations.
- The operation and interpretation of the Schmidt Hammer test results in some reports fell short of standard practice in comparison with relevant standards and codes of practice while equipment specifications for test methods and techniques were generally not stated.
- The assessment of almost all the structures comprising of one-storey to five-storey buildings was based on analysis and verification under gravity loads only to the neglect of other loads like seismic, nonetheless the study area is in seismic zone 3.
- Almost 50% of the reports reviewed did not indicate the standards and codes of practice used for the analysis and design while only 31.33% of the reports included their analysis/design calculations as appendices.
- There is urgent need for a national standard guideline and reporting format to regulate structural integrity activities and reporting.

It is therefore recommended that the Recommended National Standard Reporting Format for Structural Integrity Assessment formulated (Table 4) due to the outcome of this study be considered or adopted for the practice in Ghana and beyond.

REFERENCES

Accra Metropolitan Assembly (2020) *Development & Building Permit* [Online]. Available from: <https://ama.gov.gh/building-permit.php> [Accessed 22 August 2020].

Agudze, S. (2020) Appraisal of Structural Integrity Assessment Methodology and Reports of Existing RC Building Structures in Ghana (Case study of Greater Accra Region). MPhilThesis presented to Kwame Nkrumah University of Science and Technology, College of Engineering Faculty of Civil and Geo-Engineering

Ahulu, S. T., Danuor, S. K. & Asiedu, D. K. (2018) Probabilistic Seismic Hazard Assessment of Southern Part of Ghana. *Journal of Seismology*, 22 (3), pp. 539–557.

Amponsah, P. E., Banoeng-Yakubo, B. K., Asiedu, D., Vaccari, F. & Panza, G. F. (2008) Seismic Ground Motion and Hazard Assessment of the Greater Accra Metropolitan Area, Southeastern Ghana. *International Nuclear Information System (INIS)* [Online], 40 (17), pp. 1–19. Available from: <https://inis.iaea.org/search/search.aspx?orig_q=RN:40040488>.

Asante, L. A. & Sasu, A. (2018) The Challenge of Reducing the Incidence of Building Collapse in Ghana: Analyzing the Perspectives of Building Inspectors in Kumasi. *SAGE Open*, 8 (2), pp. 1–12.

ASTM C805 (1998) *Test Method for Rebound Number of Hardened Concrete*. 14. West Conshohocken, Pennsylvania: American Society for Testing and Materials.

Atlantic Engineering Services (2016) *Structural Condition Assessment: Key West Diesel Plant (AES Project No. 316-048)*. Jacksonville.

BS EN 12504-2 (2001) *Testing Concrete in Structures—Part 2: Non-Destructive Testing—Determination of Rebound Number*. London: British Standards Institution.

BS EN 1998-3 (2005) *Eurocode 8: Design of Structures for Earthquake Resistance. Part 3: Assessment and Retrofitting of Buildings*. London: British Standards Institution.

Building and Road Research Institute (1990) *Code for Seismic Design of Concrete Structures. Published by the Building and Road Research Institute, Kumasi, Pp 45–46*. Kumasi: Building and Road Research Institute.

Bungey, J. H., Millard, S. G. & Granthan, M. G. (2006) *Testing of Concrete in Structures*. 4th ed. Abingdon: Taylor & Francis.

Cobbinah, P. B. & Niminga-Beka, R. (2017) Urbanisation in Ghana: Residential Land Use under Siege in Kumasi Central. *The International Journal of Urban Policy and Planning* [Online], 60, pp. 388–401. Available from: <http://dx.doi.org/10.1016/j.cities.2016.10.011>.

ES ISO 13822 (2012) *Bases for Design of Structures – Assessment of Existing Structures*. 1st ed. Addis Ababa: Ethiopian Standards Agency.

Engineering Council Act (2011) *Engineering Council Act, Act (819)*. Accra: Ghana Publishing Company.

Ghana Building Code (2018) *Ghana Building Code*. Accra: Ghana Standards Authority.

Ghana Statistical Service (2012) *2010 Population and Housing Census: Summary Report of Final Results*. Accra: Ghana Statistical Service.

Ghana Statistical Service (2019) *Population by Regions* [Online]. Available from: <https://www.statsghana.gov.gh/regionalpopulation.php?population=MTM0NTk2MjQzOS4yMDE1&&Greater Accra&regid=3> [Accessed 12 November 2020].

Grunthal, G., Bosse, C., Sellami, S., Mayer-Rosa, D. & Giardini, D. (1999) Compilation of the GSHAP Regional Seismic Hazard for Europe, Africa and the Middle East. *Annali di Geofisica*, 42 (6), pp. 1215–1223.

Hille, F., Rohrmann, R. & Rücker, W. (2006) *Guideline for the Assessment of Existing Structures. SAMCO Final Report (F08a)*.

IStructE (2010) *Appraisal of Existing Structures*. 3rd ed. London: Institution of Structural Engineers.

Kumapley, N. K. (1996) Seismicity of Southern Ghana: Causes, Engineering Implications and Mitigation Strategies. *Ghana Min J*, 2 (1), pp. 33–41.

Professional Engineers Ontario (2016) *Structural Condition Assessments of Existing Buildings and Designated Structures Guideline* [Online]. Toronto: Professional Engineers Ontario. Available from: <http://www.peo.on.ca/index.php/ci_id/31399/la_id/1.htm>.

Ratay, R. T. (2006) Structural Condition Assessments. *STRUCTURE magazine*, pp. 1–4.

SEI/ASCE 11-99 (2000) *Guideline for Structural Condition Assessment of Existing Buildings*. Reston, Virginia: American Society of Civil Engineers.

Yeboah, I. E. A. (2000) Structural Adjustment and Emerging Urban Form in Accra, Ghana. *Africa Today*, 47 (2), pp. 59–89.

APPENDICES

Table 1A: Knowledge Levels and methods of analysis based on the extent of the investigation (BS EN 1998-3, 2005)

Knowledge Level	Extent of Investigation			Analysis
	Geometry	**Details**	**Materials**	
Limited Knowledge (KL1)	Structural geometry and member sizes obtained from: (a) Original outline construction drawings complemented by on-site check of geometry and member sizes for the correctness of the information, or (b) Visual survey (c) Conduct a full survey if significant discrepancies exist in outline construction drawings	Structural details: (a) Not available from detailed construction drawings (drawings not available) (b) Simulated design based on the standard practice at the time of construction complemented by limited inspection of most critical elements on-site to check the validity of assumptions (c) An extensive in-situ inspection may be used instead of simulated design	Information on properties of the construction materials obtained from: (a) Original design specifications or original test reports (b) Use default values from standards and code of practice at the time of construction complemented by Limited in-situ testing in most critical elements	Linear analysis (static or dynamic)
Normal Knowledge (KL2)	Overall structural geometry and member sizes from: (a) Outline construction drawings or extended survey (b) Cross-check overall geometry and member sizes on-site to complement information obtained from outline construction drawings (c) Conduct a full survey if significant discrepancies exist in the outline construction drawings	Structural details obtained from: (a) Incomplete detailed construction drawings accompanied by limited in-situ inspection of most critical elements to check the correctness of the information, or (b) Extended in-situ inspection	Information on properties of the construction materials obtained from: (a) Original design specifications complemented by limited in-situ testing, or (b) Extended in-situ testing	Linear or non-linear analysis (static or dynamic)
Full Knowledge (KL3)	Overall geometry and member sizes obtained from: (a) Complete set of outline construction drawings supplemented by on-site check for correctness of the information, or (b) Comprehensive survey (c) Conduct a full survey if significant discrepancies exist in outline construction drawings	Structural details obtained from: (a) Complete set of detailed construction drawings supplemented by limited in-situ inspection in most critical elements (b) Comprehensive in-situ inspection	Information on properties of the construction materials obtained from: (a) Original test reports complemented by limited in-situ testing, or (b) Comprehensive in-situ testing	Linear or non-linear analysis (static or dynamic)

NOTES

1. *Outline Construction Drawings*: Are essentially general arrangement or layout drawings that describe the structure geometry, structural components and dimensions, and structural system.

2. *Detailed Construction Drawings*: Documents that describe the structure geometry, structural components and dimensions, structural system, and details of structural components.
3. *Visual Survey*: Procedure for checking similarities between actual geometry of the structure with the available outline construction drawings.
4. *Full Survey*: Involves visual survey and production of outline construction drawings of the as-built structure.
5. *Simulated Design*: Design based on the quantity and layout of rebar in all structural elements based on existing standards and practice at the time of construction.
6. *Limited In-situ Inspection*: Procedure for checking similarities between details of the as-built structure with either detailed construction drawings or simulated design.
7. *Extended In-situ Inspection*: Method of inspection used when original detailed construction drawings are not available.
8. *Comprehensive In-situ Inspection*: Used when original detailed construction drawings are not available and a higher knowledge level is desired.
9. *Limited In-situ Testing*: Testing procedure for complementing information on materials properties obtained from standards at the time of construction, original specifications or original test reports.
10. *Extended In-situ Testing*: Procedure for obtaining information when neither original design specifications nor original test reports are available.
11. *Comprehensive In-situ Testing*: Procedure for obtaining information when neither original design specifications nor original test reports are available, and a higher knowledge level is required.

References	Recommended Report Format
Professional Engineers Ontario (2016)	• Introduction • Background Information • Purpose • Methodology • Document Review • Building Examination • Analysis • Discussion • Conclusions and Recommendations • Appendices

IStructE (2010)	• Title Page
	• Synopsis
	• Contents
	• Introduction
	  ○ Client’s Brief
	  ○ Investigation Procedures
	  ○ Guide to the Report
	  ○ Background Description of the Structure
	• Sections on Specific Issues
	• Conclusions
	• Summary of Recommendations
	• Appendices

ES ISO 13822 (2012)	• Title page
	• Name of engineer and/or firm
	• Synopsis
	• Table of contents
	• Scope of assessment
	• Description of the structure
	• Investigations
	  ○ Documents examined
	  ○ Inspection items
	  ○ Sampling and testing procedure
	• Analysis
	• Verification
	• Discussion of evidence
	• Review of intervention options
	• Conclusions and recommendations
	• Annexes

References	Recommended Report Format
Professional Engineers Ontario (2016)	• Introduction • Background Information • Purpose • Methodology • Document Review • Building Examination • Analysis • Discussion • Conclusions and Recommendations • Appendices

References	Recommended Report Format

SEI/ASCE 11-99 (2000)	• Executive Summary
	• Introduction
	  ○ Purpose of assessment
	  ○ Scope of investigation
	    — Cursory Assessment
	    — Preliminary Assessment
	    — Detailed Assessment
	    — Testing
	  ○ Methods and Techniques
	    — Data Collection and Documentations
	    — Testing
	    — Meetings
	• Description of Structure
	  ○ General
	  ○ Dates of Construction, Alteration and Repair
	  ○ History
	  ○ Collected Data
	• Discussion of Site Visit
	  ○ Overview
	  ○ Survey
	  ○ Observations and Their Significance
	• Preliminary Office Analysis
	  ○ Computational analysis
	  ○ Code conformance
	• Test Programme
	• Final Computational Analysis
	• Input from other disciplines
	• Summary of Study
	• Conclusions and Recommendations
	• Appendices

Table 2A: Outlines of typically recommended report formats

IStructE (2010)	• Title Page
	• Synopsis
	• Contents
	• Introduction
	  ○ Client's Brief
	  ○ Investigation Procedures
	  ○ Guide to the Report
	  ○ Background Description of the Structure
	• Sections on Specific Issues
	• Conclusions
	• Summary of Recommendations
	• Appendices

ES ISO 13822 (2012)	• Title page
	• Name of engineer and/or firm
	• Synopsis
	• Table of contents
	• Scope of assessment
	• Description of the structure
	• Investigations
	  ○ Documents examined
	  ○ Inspection items
	  ○ Sampling and testing procedure
	• Analysis
	• Verification
	• Discussion of evidence
	• Review of intervention options
	• Conclusions and recommendations
	  ○ Conclusions
	  ○ Recommendations
	• Annexes

Table 2A *Continued*

References	Recommended Report Format

SEI/ASCE 11-99 (2000)	• Executive Summary
	• Introduction
	  ○ Purpose of assessment
	  ○ Scope of investigation
	    – Cursory Assessment
	    – Preliminary Assessment
	    – Detailed Assessment
	    – Testing
	  ○ Methods and Techniques
	    – Data Collection and Documentations
	    – Testing
	    – Meetings
	• Description of Structure
	  ○ General
	  ○ Dates of Construction, Alteration and Repair
	  ○ History
	  ○ Collected Data
	• Discussion of Site Visit
	  ○ Overview
	  ○ Survey
	  ○ Observations and Their Significance
	• Preliminary Office Analysis
	  ○ Computational analysis
	  ○ Code conformance
	• Test Programme
	• Final Computational Analysis
	• Input from other disciplines
	• Summary of Study
	• Conclusions and Recommendations
	• Appendices

Table 3A: Overall structural conditions evaluation criteria. Adapted from Atlantic Engineering Services (2016)

Excellent	**Meets or exceeds the requirements of current Codes and Standards** • Structurally adequate for proposed use or occupancy • No significant vibrations, cracking or deflections. • No repairs or retrofitting required. • Very minor, if any, maintenance required.
Good	**Meets the requirements of current Codes and Standards** • Structurally adequate for proposed use or occupancy. • Deflections, cracking, vibrations may be observable. • No retrofitting or rehabilitation required. • Minor structural repairs and maintenance required.
Fair	**Majority of structural elements meet the requirements of current Codes and Standards.** • Demand/capacity ratio of some primary structural elements exceeded. • Structure not adequate for proposed use or occupancy. • Deflections, cracking, vibrations, structural distress is observable. • Retrofitting or rehabilitation required in limited portions of the structure. Structural repairs required generally.
Poor	**Majority of structural elements do not meet the requirement of current Codes and Standards** • The demand/capacity of most structural elements exceeded. • Deflections, cracking, vibrations, and structural distress commonly observable throughout the structure. • Major retrofitting or rehabilitation of the structure is required.
Extremely Poor	**Does not meet the requirements of current Codes and Standards** • Structurally not adequate • The collapse of the structure is imminent. • Significant deflections, cracking, vibrations, or structural distress visible • The structure requires extensive retrofitting or rehabilitation • Cost of retrofitting or rehabilitation likely to be too expensive

Table 4A: Conventional Test Methods and Techniques and Selection Guide. Adapted from IStructE (2010)

Information Sought	Test Methods and Techniques	Selection Guide[a]	Remarks[b]
Mix proportions, cement content, cement type	Petrographic analysis	V	1, 2, 3, 6
	Chemical analysis	D	2
Type and grading of aggregate (susceptibility to ASR)	Petrographic analysis	V	
	Chemical analysis	D	2, 5
The measure of size, cover, and location of steel reinforcement; and location of embedded metals	Covermeter, Ferroscan, Pachometer, etc.	V	2
	Physical exposure	V	
Mechanical properties of steel reinforcement	Tensile tests	V, D	2
Strength	Schmidt Hammer	D	6
	Compressive strength	V	2
	Internal fracture test	D	2, 6
	Windsor probe	D	2, 6
	Break-off test	D	2, 6
	Petrographic analysis	H	2, 3, 6
Quality of placed concrete	Ultrasonic pulse velocity	V	2, 6
	Examination of cores	V	2
	Petrographic analysis	D	2, 3
Depth of carbonation	Phenolphthalein test (not applicable to HAC concretes)	V	
	Petrographic analysis	D	1, 2, 3, 6
Free lime content	Petrographic analysis	H	1, 2
Permeability	Initial Surface Absorption Test (ISAT)	D	2, 6
	Water and gas permeability tests	V	2
	Absorption test on intact cores	D	2, 6
Presence of chlorides	Tests for chlorides – standard laboratory test or field-based methods using test strips	D	2
Presence of sulphates	Chemical analysis – standard laboratory test of samples	V	2
Presence of admixtures and contaminants	Chemical analysis - standard laboratory test	H	1, 2, 3, 7
Moisture content	Direct moisture measurement	D	1
	Monitoring	H	
Abrasion resistance	Accelerated wearing test	V	2
Air entrainment	Microscopy	V	2, 3
Risk of corrosion of reinforcement	Half-cell potential	V	2, 6

Table 4A:4A: *Continued*

Information Sought	Test Methods and Techniques	Selection Guide[a]	Remarks[b]
Areas experiencing corrosion of reinforcement	Physical exposure	D	3
	Half-cell potential	V	2, 6
The severity of reinforcement corrosion and the rate of corrosion	Physical exposure	V	3
	Polarization resistance	D	2, 3, 5
	X-ray permeability	D	2, 3, 5
	Monitoring methods or techniques	D	2, 3, 5
Delamination	Sounding surveys (soniscoping, chain-dragging or tapping)	V	
	Ultrasonic pulse velocity	D	2, 5, 6
	Core examination	D	3
	Petrographic analysis	H	3
	Other specialist techniques such as Radar and Thermal Imaging	D	2, 3, 6

Notes

a Simplified Selection Guide

- V Extremely valuable: usually employed where circumstances permit
- D Desirable in some circumstances but not usually deemed to be essential
- H May be helpful in some cases.

b Remarks

1. Not in common use
2. Specialist equipment and expertise required
3. Relatively expensive
4. Special safety precautions required
5. Check probable performance for a particular application
6. Provides indirect measurement or assessment only
7. Reliability of results may be of concern (test validation may be necessary).

Note: Laboratory tests on concrete may be performed on either intact cores or crushed cores and drillings