Identifying the effects of excessive deflection in reinforced concrete beam

By

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Abstract

In framed reinforced concrete structure, the beams transfers the dead and live loads to the column and then to the foundation. When there are observed structural failure in the systems supported by the beam, especially where the beam has a large unsupported clear span at a lower level, before any further detailed investigations are initiated, the functional state of the beams should be ascertained. The correct diagnosis of the source of problem is essential for the design of effective rehabilitation scheme. Simple visual inspection corroborated with field test for true horizontality of the beam can provide the *lead* information that will guide the client on the scope of further investigations.

The case study method of qualitative research was adopted to address the research questions, while the research data was collected by reviewing previous investigation reports on a three-storey building, physical inspection and conducting simple site experiment to identify the *lead* information. The research outcome reveals that the multiple cracks observed in the partition walls especially in the second floors were as a result of excessive deflections in the beams supporting the first and second floors. Based on recommendation, subsequent investigation confirmed this *lead* information and appropriate rehabilitation scheme was adopted.

Keywords: Rehabilitation, Reinforced concrete beam, Deflection, Lead information, Detailed investigation.

1.0INTRODUCTION

Cracks, in themselves, are not defects but 'symptoms' of distress within and around the fabrics of the structure (Johnson, 2002). The size, shape, orientation, pattern, and frequency, of the visible cracks can provide the *lead* information necessary to unearth the actual source of the defects being advertised by the cracks. Until this *lead* information is properly identified, any remedial solution applied will not be effective; the cracks will appear again, possibly in the same place, or close to it, with greater intensity and cause the structure to deteriorate at a faster rate (Grew, 1996). An incorrect assessment of the cause or causes of cracks can lead to expensive and unnecessary remedial works (Johnson, 2002). It is important to note during preliminary inspection if the cracks are static or active. In the case of static cracks, simple exercise of filling the cracks with appropriate binding materials and repainting may solve the problem. However, if the cracks are active, it requires further investigations to unearth the source, otherwise if treated with levity; the underlying defects might affect the serviceability or the stability of the structure or its components.

Cracks resulting from material shrinkage, response to change in weather, especially when the construction materials are still green, are in the group of simple cracks. These groups of cracks are commonly referred to as 'hair or aesthetic' cracks. They do not have serious damaging effects on the structure or component where they appear. However, cracks resulting from excessive movement of supporting soil, vibrations within or around the structure, deflections of supporting members and change of use require careful site inspection. The rule of the tomb in this case is to work from general to the particular (Johnson, 2002; Pryke, 2007), in order to find the *lead* information, before embarking upon extensive investigations.

This paper reports a site inspection of an abandoned three storey building where the *lead* information from the cracks was correctly identified; it guided the client to embark on a more detailed investigation that resulted in the development of appropriate rehabilitation scheme used to salvage the abandoned building.

2.0 THEORETICAL BACGROUND

This research commenced with desktop search for literature to locate the different causes of defects in constructed facilities. This section will concentrate on literature that deals with identifying the *lead* information for detecting defects in structural members and change of use as advertized by cracks.

2.1 *Defects in structural member or building component*

The shape, pattern and orientation of cracks can provide the *lead* information in determining the source and type of defects in the built facilities. Generally, the sub-soil that supports the imposed structure (building, road, air field, and more) experiences initial settlement and becomes stable, within the first five years after construction (Pryke, 2007). Johnson (2002) identified three scenarios of soil settlement, namely soil subsidence, settlement and differential settlement, noting that "it is differential settlement that causes the more serious damage (Johnson, 2002, p.159). The common picture of differential settlement cracks in a building are either diagonal or vertical cracks from top to the bottom (top left to bottom right, when the movement is towards the left, while in movements to the right, the crack migrates from top right to bottom left). The cracks are usually wider at the top and tapered towards the bottom (Grew, 1996; Johnson, 2002; Pryke, 2007). A large scale differential settlement do occur in areas with underground tunnel, creating trough on the ground surface and cracks of different patterns on the structure within the zone of influence of the tunnel. The size of the trough depends on the soil type and formation above the tunnel; "For practical purposes, the total width of the trough can be taken as approximately three times the depth to the tunnel axis" (Bewick, 2007, p.33).

Furthermore, the location and pattern of cracks in the component parts of a high rise building will provide the *lead* information required for indentifying the source and type of defects. The diagonal cracks appearing close to the end support of beams are indication of share failure; cracks at the bottom face of slab or beams suggests deflection problem at mid span; while the longitudinal cracks appearing on columns indicates bulking of column under excessive load or under reinforcement (Grew, 1996;

Kaklauskas et al, 1999; Johnson, 2002 and Pryke, 2007). On the other hand, if there are no cracks in the main structural members connected to a central column, but there are noticeable undulations on the floor surface, this is an indication that there is differential settlement of the soil around the particular column (Johnson, 2002). However, when the cracks are on other components different from the main structural member, the source of the defects should be traced to other origins.

2.2 *Defects resulting from change of use*

The requests for alteration, modification or extension in the form of refurbishment or up-grade of structures are common experiences of facilities managers in the built environment industry. The situation has become a common experience in urban development and Higher Educational Institutions (HEIs), where old buildings are being converted for use other than it was intended for during the initial design; either to satisfy new legislative requirements, or change of use. The exercise will be difficult if the facility does not have authentic As-Built Documents (ABD) and Facility Operation Documents (FOD). Implementation of any change of use should not be embarked upon arbitrarily, until there is a detailed asset or facility assessment (Kennedy, 2008). The content of specific facility assessment is useful for objective decision making; it guided a suburban university that intended rehabilitating a 1960 building, to accommodate expansion of existing program, to know that "…the best option was to build a new structure" (Hayes, 2006, p. 311). Furthermore, facility assessment enhances the development of functional rehabilitation budget (Hayes, 2006 and Kennedy, 2008).

Though change of use can be suggested or effected at the construction stage or any time within the life cycle of the facility, if the changes are effected without due consideration of the design criteria, the structural integrity of the facility will be compromised; cracks of different pattern appearing in the different parts of the facility's component presents the initial sign of defects. The agency championing the conversion of former office buildings into residential dwellings, for adaptive reuse (Remoy and Van der Voordt, 2014) should be mindful of the construction material. In a typical office building, the internal partition walls are usually designed to be constructed from dry (light weight) materials. If these facilities are to be converted for other use (residential) and if construction materials apart from light weight materials are to be used, additional structural configuration should be introduced to strengthen the existing building, else such neglect will introduce a long chain of defects, heralded by cracks.

The professionals involved in site inspection of built facilities that shows evidence of defects, owe their client the duty to provide the required *lead* information that will educate the client on the severity of the emerging or existing problem. This information will guide further detailed investigations aimed at unearthing the root causes of the problems and produce informed rehabilitation scheme. This principle was used in the research being reported.

3. O RESEARCH METHOD

The desk top search enabled the authors to locate the research within appropriate framework. The literature emphasized the importance of thorough preliminary site inspection as a veritable tool for locating the *lead* information from cracks as they appear on any structure. This *lead* information serves the dual purpose of educating the client as well as guiding other professionals when they embark on more detailed investigation to unearth the underlying problem(s) before developing appropriate rehabilitation scheme. These principles were adopted in identifying the *lead* information that was used to salvage the abandoned three storey building of a Higher Educational (HE) institution.

4. THE FINDINGS AND DISCUSSION

Prior to the year 2006, several detailed investigations were carried out to unearth the root cause of the multiple cracks on the partition walls in the second floor of a three storey building in a HE institution in Nigeria. Some of the consultants concentrated on detailed soil investigations; they found the sub-soil conditions, the design and construction of the foundation to have complied with standard Civil Engineering practice. Therefore, they recommend detailed structural investigations. One comprehensive investigation that embraced both soil and structural investigations carried out in the mid 1980s, recommended that the building was not safe and should be demolished. Fortunately, due to financial constraints, the institution could not implement this recommendation. However, in 2006, due to the need for adequate space to host a new program, the institution had to revisit the issue of this abandoned building.

4.1 Preliminary site inspection

Thorough, non-destructive, site inspections were carried out by studying the intensity, pattern and configuration of the cracks. This approach is in consonance with best practice in building survey and preliminary site inspection (Grew, 1996; Johnson, 2002; Hayes, 2006 and Suffian, 2013). There were no significant cracks on the main structural members (external walls, columns, beams or slab) of the building. The cracks of structural significance appeared on the infilling partition walls. Plate 1 shows the typical picture of the cracks in the partition walls. The cracks migrate from top left in a diagonal pattern to the bottom right of the partition walls of the left wings. Similarly, the cracks on the walls on the right wing had their cracks migrating from top right to bottom left as seen in Plate 1a&b. The cracks on the partition walls along the walk way formed horizontal patterns as shown in Plate 1c. Evaluating these pattern and direction provided initial indication that the problem might be related to deflection around the centre of the building.

Furthermore, a building line was drawn across the soffit of the secondary beams supporting the concrete floor slab (See plate 2), touching the tangent of the beam at the centre. The gap at both ends of the beam confirmed that the beam is no longer maintaining its horizontality due to deflection. The conclusion drawn from these observations was that the building can be salvaged, the cracks observed on the partition walls were no signs of major structural failure but the result of excessive deflection of the floor slab and the supporting secondary beams.

(a) (b) (c)

Plate 1 Diagonal cracks on the left and right wing partition walls

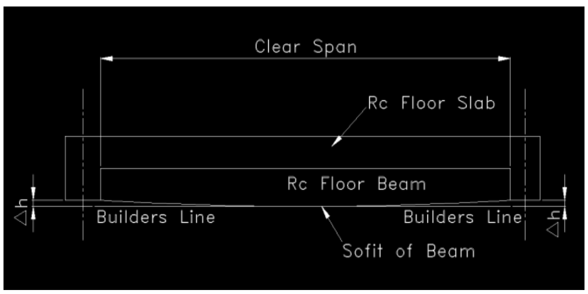

Plate 2: A field test for the horizontality of beam

Grew (1996) observed that “Experience has shown that visual examination alone, even by an experienced observer, is likely to result in erroneous diagnosis” (Grew, 1996, p.4). In this light, recommendation was made to the authority of the institution to commission a firm of Structural Engineers to confirm or refute this *lead* information and there after propose a rehabilitation scheme. This recommendtion was accepted and a firm Structural Engineers was appointed. The firm conducted both soil investigation and structual appraisal, their preliminary inspection upheld the *lead* information. That encouraged them to continue investigations. Conducting destructive (core) test on the concrete floor slab revealed that ‘mesh wire’ were used as the reinforcing rods; this is in consonace with the design of ‘wafle floor’ where only dry (light weight) partitions are used as pannel infillings. The crushing strength of the tested concrete was found to be adequate. However, the partition walls in the buiding under reference were constructed with cement block and plastered on both faces. Thus, instead of the uniformly distributed load of the dry partitions, assumed during design, the block walls were acting as concentrated point loads on the floor slab; this precipitated the deflection that was advertized by the cracks seen on the partition walls. The comprehesive rehabilitation sheme suggested by this consultant include demolishing the block wall partions to be replaced with dry partitions and conducting structural appraisal periodically, to reduce the risk of indescreminate execution of change of use that could be detrimental to the structural integrity of the building.

5. O CONCLUSION AND RECOMMENDATION

The main objective of preliminary site inspection of a built facility showing obvious signs of defects is to provide the *lead* information that will educate the client on the suspected source and nature of the emerging defects and guide other professionals for directed detailed investigations. This exercise requires patience, eyes for details and experience in the behavior of the built facility under different load or configuration for use. Though, cracks, in themselves, are not defects but ‘symptoms’ of distress within and around the fabrics of the structure on which they appear (Johnson, 2002). The size, shape, orientation, pattern, and frequency, of the visible cracks can provide the *lead* information necessary to unearth the actual source of the defects; otherwise, any remedial solution will not be effective but lead to expensive and unnecessary exercise. Therefore, in keeping with the objectives of this conference, that of providing ‘sustainable solutions in Structural Engineering and Construction’, it is being recommended that further research efforts should be channeled towards educating facilities managers, and other built environment practitioners on how to conduct effective site inspection for different built asset that will provide the necessary *lead* information to unearth the defects being advertized on the structure.

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