Sustainable Solutions in Structural Engineering and Construction
Edited by Chantawarangul, K., Suanpaga, W., Yazdani, S., Vimonsatit, V., and Singh, A.

ISBN: 978-0-9960437-0-0

IDENTIFYING THE EFFECTS OF EXCESSIVE DEFLECTION IN REINFORCED CONCRETE BEAMS

E. OGBEIFUN, J. H. PRETORIUS, and C. MBOHWA

University of Johannesburg, Johannesburg, South Africa

In framed reinforced concrete structures, the beams transfer the dead and live loads to the column and then to the foundation. When there are observed structural failures in systems supported by the beam, the functional state of the beams should be ascertained before any further detailed investigations are initiated. The correct diagnosis of the source of the problem is essential to design an effective rehabilitation scheme. Simple visual inspections corroborated with field tests for true beam horizontality can provide the lead information that will guide the clients' scope of further investigations. Case studies addressed the research questions; the research data was collected by reviewing previous investigation reports on a three-story building, then conducting physical inspections and simple site experiments to identify the lead information. The results reveal that 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. Subsequent investigations confirmed this lead information and appropriate rehabilitation schemes were adopted.

Keywords: Rehabilitation, Lead information, Detailed investigation.

1 INTRODUCTION

Cracks, in themselves, are not "defects" but symptoms of distress within and around the fabric of the structure (Johnson 2002). The size, shape, orientation, pattern, and frequency of the visible cracks can provide the lead information necessary to discover the actual source of the defects. Until this lead information is properly identified, any remedial solution will not be effective; the cracks will appear again, possibly in the same place, or close to it, with greater intensity, causing the structure to deteriorate at a faster rate (Grew 1996). An incorrect assessment of the 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, a 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; if left untreated, the underlying defects might affect the serviceability or the stability of the structure or its components.

Cracks resulting from material shrinkage due to changes in the weather, especially when the construction materials are still green, are in the group of simple cracks. These cracks are commonly referred to as "hair" or "aesthetic" cracks. They do not cause serious damage to the structure or component where they appear. However, cracks resulting from excessive movement of the supporting soil, vibrations within or around the structure, deflections of supporting members, and change in use require careful site inspection. The rule of thumb in this case is to work from the 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-story 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 an appropriate rehabilitation scheme used to salvage the abandoned building.

2 THEORETICAL BACKGROUND

This section will concentrate on literature that deals with identifying the lead information for detecting defects in structural members as advertised by cracks.

2.1 Defects in Structural Members or Building Components

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 structure (e.g., a building, road, airfield, etc.) experiences initial settlement, becoming stable within the first five years after construction (Pryke 2007). Johnson 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: 159). The common picture of differential settlement cracks in a building are either diagonal or vertical cracks from top to bottom (top left to bottom right, when the movement is towards the left; 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). Large-scale differential settlements do occur in areas with underground tunnels, creating troughs on the ground surface and cracks of differing 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 1992: 33).

Furthermore, the location and pattern of cracks in the component parts of a high-rise building will provide the lead information required for identifying the source and type of defects. The diagonal cracks appearing close to the end support of beams are an indication of share failure; cracks at the bottom face of slabs or beams suggests deflection problem at mid span; 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

Requests for alteration, modification, or extension in the form of refurbishment or upgrades 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 a use different from what was intended during the initial design (either to satisfy new legislative requirements, or change of use). The task will be difficult if the facility does not have authentic As-Built Documents (ABD) and Facility Operation Documents (FOD). There should be no change of use 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 to rehabilitate a 1960 building, to accommodate expansion of existing program, and to know that "the best option was to build a new structure" (Hayes 2006: 311). Furthermore, facility assessment enhances the development of functional rehabilitation budgets (Hayes 2006, Kennedy 2008).

Though change of use can be suggested or effected at the construction stage, or at 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 differing patterns appearing in different parts of the facility's component indicates the initial sign of defects. An 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 (lightweight) materials. If these facilities are to be converted for other uses (e.g., residential), and if construction materials apart from lightweight materials are to be used, additional structural configurations should be introduced to strengthen the existing building. Otherwise, neglect will introduce a long chain of defects, heralded by cracks.

Professionals involved in site inspection of built facilities with evidence of defects are obligated to provide their client with the required lead information on the severity of an emerging or existing problem. This information will guide further detailed investigations aimed at unearthing the root causes of the problems, and produce informed rehabilitation schemes. This principle was used in this research.

3 RESEARCH METHOD

A desktop search enabled the authors to locate research within an appropriate framework. The literature emphasized the importance of a thorough preliminary site inspection to locate 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 investigations, to uncover the underlying problem(s) before developing schemes. These principles were used to salvage the abandoned three-story HEI building.

4 FINDINGS AND DISCUSSION

Before 2006, several detailed investigations were carried out to discover the root cause of multiple cracks on the partition walls in the second floor of a three-story building in a Nigerian HEI. 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 recommended 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. However, this was not carried out due to financial constraints. 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 and non-destructive site inspections were carried out by studying the intensity, pattern, and configuration of the cracks. This approach is in consonance with best practices in building surveys and preliminary site inspections (Grew 1996, Johnson 2002, Hayes 2006, Suffian 2013). There were no significant cracks on the main structural members (i.e., external walls, columns, beams, or slab) of the building. The cracks of structural significance appeared on the infilling partition walls. Figure 1 shows a picture of typical cracks in the partition walls. They migrate from top left in a diagonal pattern to the bottom right of the left wings of the partition walls. Similarly, the cracks on the walls on the right wing had their cracks migrating from top right to bottom left, as seen in Figures 1 a and b. The cracks on the partition walls along the walkway formed horizontal patterns, as shown in Figure 1c. Evaluating these patterns and directions provided initial indication that the problem might be related to deflection around the center of the building.

Furthermore, a building line was drawn across the soffit of the secondary beams supporting the concrete floor slab (See Figure 2), touching the tangent of the beam at the center. 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 showed no signs of major structural failure, rather the result of excessive deflection of the floor slab and the supporting secondary beams.

(a) (b) (c)

Figure 1. Diagonal cracks on the left and right wing partition walls.

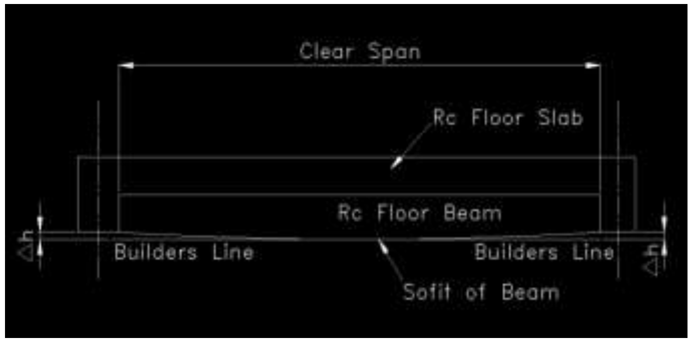

Figure 2. A field test for the horizontality of beams.

Grew observed that “experience has shown that visual examination alone, even by an experienced observer, is likely to result in erroneous diagnosis” (1996: 4). In this light, a recommendation was made to the authority of the institution to commission a firm of Structural Engineers to confirm or refute this lead information, and thereafter propose a rehabilitation scheme. This recommendation was accepted, and a firm of Structural Engineers was hired. After the firm conducted both soil investigations and structual appraisals, their preliminary inspection upheld the lead information. That led to continued investigations. Conducting a destructive (core) test on the concrete floor slab revealed that “mesh wire” were used as the reinforcing rods; this is in consonance with a “waffle floor” design, where only dry (lightweight) partitions are used as panel 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 as seen in the cracks on the partition walls. The comprehesive rehabilitation scheme suggested by this consultant included replacing the block-wall partitions with dry partitions, and conducting periodical structural appraisals to reduce the risk of indiscriminate changes of use that could be detrimental to the structural integrity of the building.

5 CONCLUSION

The main objective of a preliminary site inspection is to provide lead information that will educate the client on the suspected source and nature of the emerging defects in a building, and guide other professionals for further directed investigations. This exercise requires patience, an eye for details, and experience in the behavior of the built facility under different loads or configurations for use. However, cracks, in themselves, are not “defects” but symptoms of distress on the structure. The size, shape, orientation, pattern, and frequency of the visible cracks can provide the lead information necessary to uncover the actual source of the defects; otherwise, any remedial solution will not only be ineffective but also lead to expensive and unnecessary work.

Therefore, in keeping with the objectives of this conference, it is recommended that further research efforts be channeled towards educating facilities managers and other built-environment practitioners on how to conduct effective site inspections for the necessary lead information.

References

Bewick, E. R., Underground railways/tunneling and the effects on building, *Structural Survey*, 10(1), 29-37, 1992

Grew, R., The surveying of structural damage, *Structural Survey*, Emerald 14(4) 4-9, 1996.

Hayes, F. X., A proactive solution, *American School and University*, 2006.

Johnson, R. W., The significance of cracks in low-rise buildings, *Structural Survey*, Emerald 20(5), 155-161, 2002.

Kaklauskas, G., Bacinskas, D., and Simkus, R., Deflection estimates of reinforced concrete beams by different methods, *STATYBA – Civil Engineering*, V(4) 258-264, 1999.

Kennedy, M., Ready to renovate, *American School and University*. 14-18. July, 2008

Pryke, J. F. S., Understanding cracks in houses, *Structural Survey*, Emerald, 1(1) 37-45, 1983.

Remoy, H., and Van der Voordt, T., Adaptive reuse of office buildings into housing: opportunities and risks, *Building Research and Information*, Taylor & Francis 1-10, 2014.

Suffian A., Some common maintenance problems and building defects: Our experiences, *Procedia Engineering* 54, 101-108, 2013.