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17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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MANAGEMENT OF DEFECTIVE WORKS IN INFRASTRUCTURE PROJECTS

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Abstract

Constructing a new building, or any other civil engineering project from scratch, is a challenge for the construction industry as novelty designs may be produced by designers but they are often constructed by low skilled labor on site. The unique and sometimes complex nature of the construction sector arises because a large number of different professional groups have different interests and requirements, which often conflict with one another. In principle, each construction company aims to construct a project without any defects from the very first activity on site right up to final completion. This aim is almost impossible to achieve throughout the entire construction duration because of many factors, including: low skilled labor, difficult site conditions, and incomplete designs, varying quality cultures in each company, poor communication and poor management. Therefore, construction defects are things which we can assume to have occurred on the site. Defects occurring during the construction process are sometimes costly and preventable mistakes. Research has shown that correcting defective components that are identified late in the construction process or during the maintenance period accounts for approximately 15 % of the total construction costs. This paper presents a case study of the defects that occurred during a motorway construction project as a consequence of poor workmanship by an untrained workforce and it aims to raise awareness of the need for on-the-job training for quality managers in order to minimize defective works and reduce the project costs spent on correcting them. It also identifies the various factors that cause construction defects and suggests measures that can be taken to reduce them.

Keywords: Defects, defect costs, human error, infrastructure projects

1 Introduction

Construction defects in infrastructure projects (and engineering projects in general) are a key concern in the construction industry. Differently constructed projects can generate different types of defects and different quality levels are required depending on the function, system, construction methods and the materials used. Various systems have been designed to eliminate defects during the construction process.

Recent developments in traditional manufacturing industries have improved production, increased quality and improved efficiency. The construction industry is often perceived to be slower in developing its production processes. A common explanation (or excuse) is that construction produces a unique product that is often constructed by a low-skilled workforce in geographically widespread locations, which makes the final product a unique and unrepeatable one. If we consider that infrastructure projects are unique and unrepeatable, it is very difficult to design a final product (such as a road or motorway project) that considers every possible detail in order to fit different terrains, so that there are no deficiencies during the design or

construction stages. The use of unskilled labor or poor project control by the contractor can create visible or hidden defects which decrease the project value as well as user satisfaction.
A construction defect is generally defined as a defect in the design, workmanship, and/or the materials or systems used on a project that results in the failure of a component part of a building or structure and causes damage to persons or property, usually resulting in financial harm to the owner or contractor.
In the construction industry, words like “error”, “fault”, “failure”, “defect”, “quality deviation”, “nonconformance”, “snag” or “remedial work” are used to describe imperfections in constructed projects (Love 2002 et al). These words and terms can mean various things to different people but always suggest that the client or project supervisor involved in the project has found the final product to be unsatisfactory in some way.
Nonconformance is a word used in ISO 9000:2005 to define “the failure to fulfill a requirement”. ISO 9000:2005 also defines a defect as “the non-fulfillment of a requirement related to an intended or specified use”. However, Battikha (2008) considers that “non-conformance occurs when the finished state of a project and/or its components deviates from established requirements and necessitates decisions to be made regarding their acceptance and/or rectification”.
Another term which is synonymous with defect is “snag”. Sommerville and McCosh (2006) define snags as possessing two key features: those defects which are “absorbed” during the construction process (which are usually corrected before practical completion) and those which are “visible” to the contractor and project buyer once the project is deemed ready for occupation/operation. This word is rarely used within construction literature even though it is commonly used within the worldwide construction industry. However, the term “post-handover defect” is also used to describe those defects that still remain after handing over the building (or other deliverable) but only during the liability period, which usually lasts between 12 and 36 months (Forcada et al. 2012)
If we consider that the defect liability period in infrastructure projects varies between 12 and 36 months, it is very likely that hidden defects or omissions will become visible or create side-effects as a consequence of bad workmanship or poor materials used during construction. It is the duty of the contractor to remediate those defects or omissions by the completion of the contract. Therefore, remediation teams, equipment and materials need to be mobilized in order to remediate defective works or omissions and bring the project back to an acceptable level, as specified in the initial design or set by construction codes and norms. By reworking snags and/or omissions, the construction company suffers extra expenditure that was not foreseen in the initial project costs.
All of these costs are called defect costs. Defect cost is the value of the resource expenditure for the additional work. Various factors are measured during the additional construction work, such as the time, materials and equipment required to correct the defects. Precious time is lost during the corrective works. Defective construction work not only contributes to the final cost of the project but increased maintenance costs also have to be considered.
This paper aims to improve knowledge of the defect profile in infrastructure projects, with respect to the number of defects, type, location and responsible department, and the cost and time taken to carry out remedial work on uncompleted items or defective works, with specific reference to a motorway project completed in Kosovo (between 2011 and 2016). It also identifies various factors that cause construction defects and attempts to justify measures to reduce them. Therefore, by the elimination of defects and maintaining good quality in the completed works, important cost benefits should result for the contractor, in particular, and society in general.

2 What can cause a defect

Construction defects are generally defined as defects or deficiencies in the design, workmanship, materials or systems used on a project that may not be readily observable and that result in a building, structure or component that is not suitable for the purpose intended. Therefore, the term "construction defect" is broader than just defective construction and includes both design and construction defects that result in financial harm to the owner. In general, defects can be grouped into Design Defects and Construction Defects.

2.1 Design defects

A design defect is typically the result of a design professional's failure to produce a complete, accurate and well-coordinated set of design and construction documents. These design defects are categorized as being a design error or omission and/or a combination of both.
A design error is defined as a mistake in the design where the design element was either constructed or under construction but required retro-fitting and/or the replacement of one of its components in order to correct the error. A design omission is defined as an element that was either missed and/or omitted by the design professional in their design and construction documents but was later discovered and added to the scope of work by a changing order.

2.2 Construction defects

In general, there are two types of construction defect: latent and patent defects. Latent defects are those defects that are concealed and are often not obvious or readily observable upon reasonable inspection. Even with the most comprehensive on-site inspections, sometimes defective construction may go unnoticed. Some of the latent defects which can be considered in infrastructure projects are: soils not properly compacted, geotextile not placed accurately, concrete not vibrated according to specification, improperly installed drainage pipes etc.
Patent defects are those defects that are known or would be readily obvious upon reasonable inspection, such as: missing manhole covers, handrails omitted in New Jersey barriers, missing control and/or expansion joints, missing drainage on a slope, missing horizontal signaling parts etc. A Design and Construction defect algorithm is presented in Figure 1.

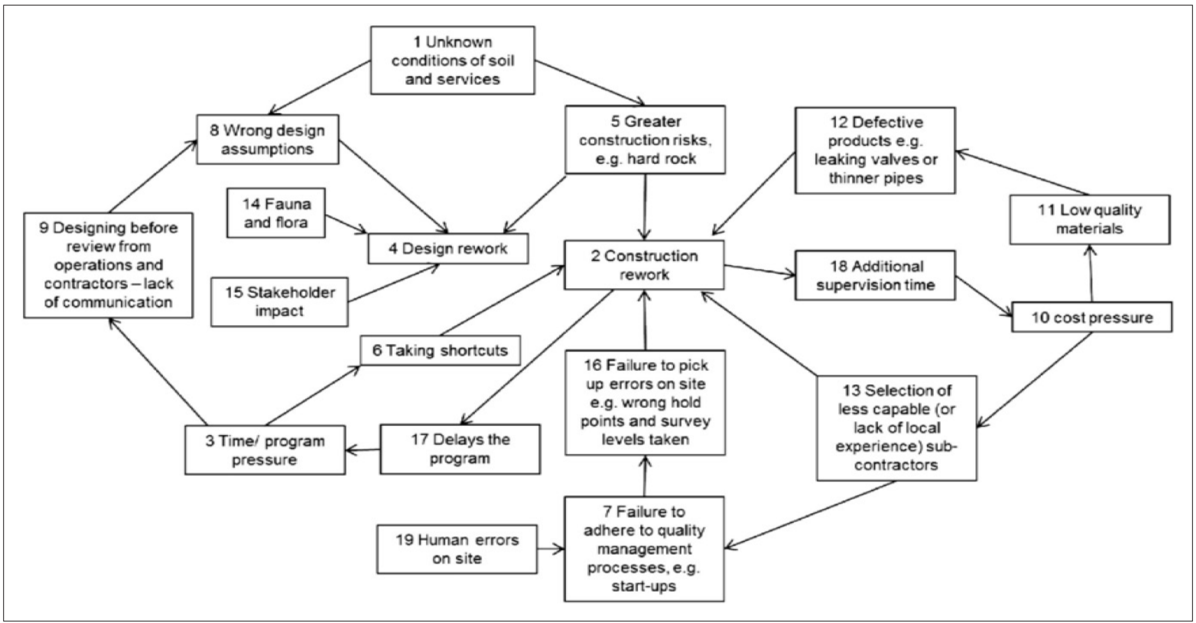

Figure 1 Design and construction defect algorithm in construction projects

An important distinction to understand when analysing construction defects is the difference between the "defect" itself and the "manifestation" of the defect, although, in general terms, both the defect and the manifestation of the defect must ultimately be corrected. In fact, the manifestation of a particular defect is the apparent, visible condition of the project structure or component that gives the observer notice of the possible (and most likely) existence of a defect in construction. Construction defects are, by their very nature, "time dependent" and not all manifestations of a particular problem are necessarily related to a construction defect. The manifestation and/or evidence of a construction defect must be considered in relation to the time of its occurrence. It is of critical importance to establish the distinction between normal wear and tear, the results of poor maintenance and construction defects on each construction project.

3 Defect cost

The defect cost is defined as the value of resource consumption for the additional work required as a consequence of a defect. Work time, materials and equipment time are consumed in order to correct it. Time is also lost as a consequence of a defect.
A distinction can be made between direct and indirect defect costs. Direct defect costs can be internal and external. Internal costs concern defects discovered before delivery, while external costs concern defects discovered after delivery. Previous studies indicated that the costs of reworking poorly managed projects in the construction industry can be as high as 25 % of the total contract value and up to 10 % of the total project cost (e.g. Barber et al. 2000, Love and Li 2000). Infrastructure project defect costs are usually lower than in the high-rise construction industry, varying from between 5.2 % and 5.6 % of the total cost of the project (Love at al. 2010). Defect costs in the construction industry are presented in Figure 2.

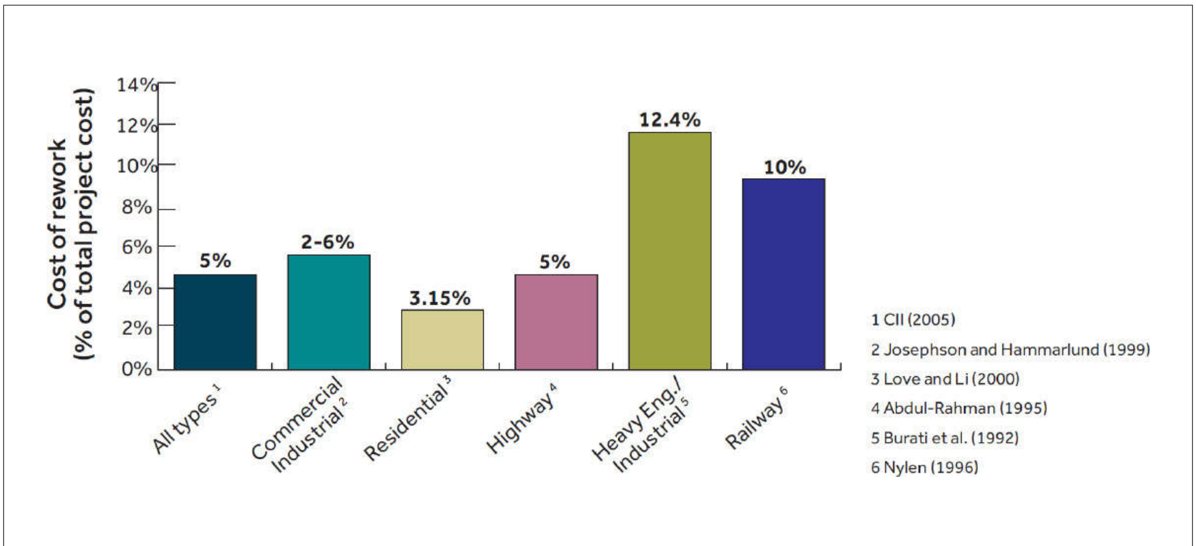

Figure 2 Summary of rework costs from different authors

4 Kosovo Motorway Project (2011-2016) – research methodology

For this paper, a case study of the Kosovo Motorway Project Route 7 has been examined, which was divided into 9 sections for construction purposes. A reputable, international company was hired as a general contractor for the construction of 117 km of new motorway. An internationally experienced company was also hired to provide construction management and supervise the quality and quantities of materials for the works. The client (or 'end user') was the Government and the construction period was from 2011 to 2016. For this paper, only

4 sections were taken into consideration for analysing the defects and defect causes. For this case study, the author visited and interviewed the project stakeholders (i.e. the client, the contractor and the supervisor) instead of simply sending out a questionnaire. This research included the retrieval of data from archive documents and direct discussions about the project, regarding reworking costs.

5 Analysis and results

Works carried out during construction were divided into major disciplines, such as: Earthworks, Drainage, Structures, Finishing and Paving. Defects occurred within all of these disciplines and were called punches/snags as per the FIDIC Contract terminology. Punches were recorded for aesthetic aspects of the works carried out on the slopes as well as much more fundamental, complicated issues like the installation of bridge joints (which were installed improperly). A total of 1989 punches were recorded by teams comprising members from the contractor and the supervising engineers, as presented in Figure 3 and Figure 4.

Table 1 Percentage of defective works per department

Department	Total Snag No	Total Inspected	Closed Snag Items	Closed Percentage in Inspection	Closed Percentage Overall	Remaining	Discipline Snags/Total Snags %
Earthwork	632	606	534	88 %	84 %	98	31.77 %
Drainage	774	767	746	97 %	96 %	28	38.91 %
Structures	120	101	91	90 %	76 %	29	6.03 %
Finishing	401	372	352	95 %	88 %	49	20.16 %
Paving	62	60	57	95 %	92 %	5	3.12 %
Total	**1989**	**1906**	**1780**	**93 %**	**89 %**	**209**	**100.00 %**

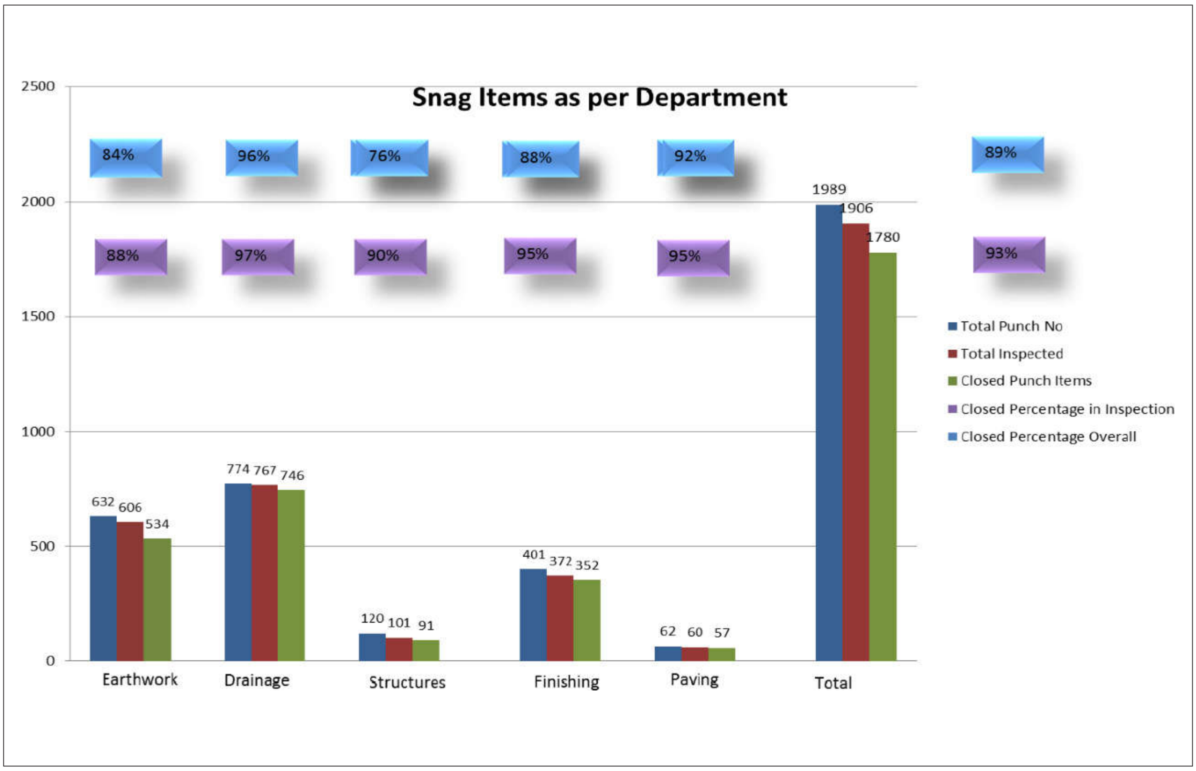

Figure 3 Defective works per department (Kosovo Motorway Project Route 7-data source)

Table 2 Percentage of remediated works per department

Section	Total Snags	Inspected Items	Closed Snag Items	Closed Percentage in Inspection	Closed Percentage Overall	Remaining	Section Snags/Total Snags %
General snag for full length	17	2	2	0 %	12 %	15	1 %
1	620	591	538	91 %	87 %	82	31 %
2	314	310	296	95 %	94 %	18	16 %
3	565	547	523	96 %	93 %	42	28 %
4a	159	157	140	89 %	88 %	19	8 %
4b	314	291	274	94 %	87 %	40	16 %
Total	**1989**	**1898**	**1773**	**93 %**	**89 %**	**216**	**100 %**

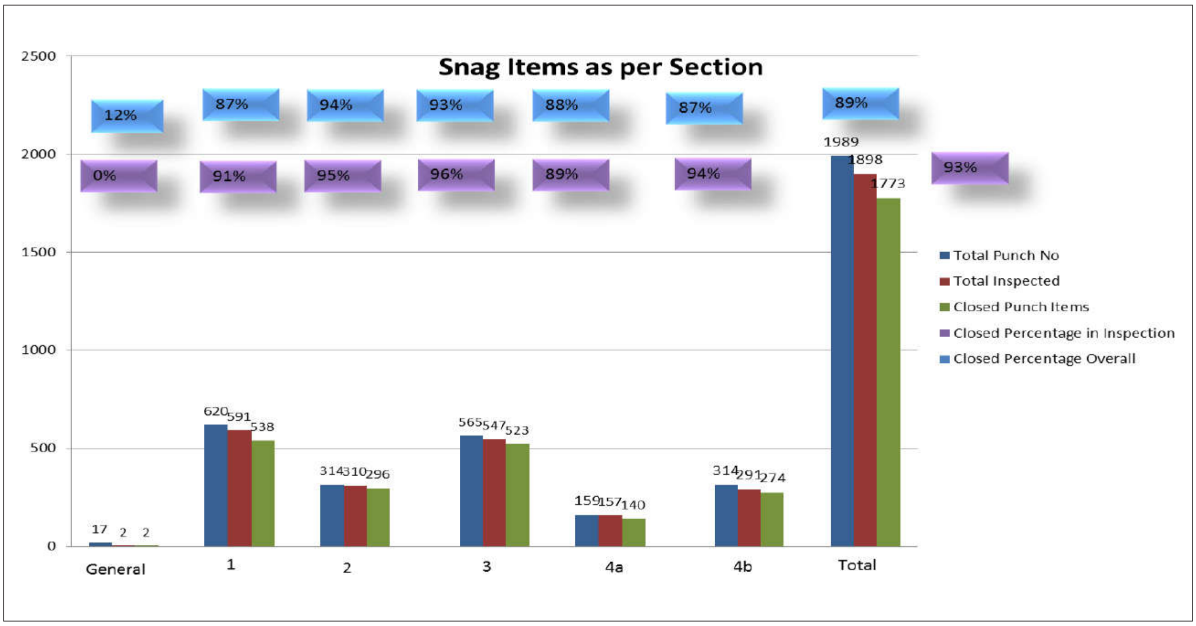

Figure 4 Defect works per sector (Kosovo Motorway Project Route 7-data source)

6 Root defect cause overview

The root defect cause overview was analyzed with the model root cause defect diagram as suggested in Fayek et al. 2003 [4] for five main sources of snag reworking and their associated root causes, as presented in Figure 5. **Leadership and Communication:** Considering that the general contractor was a well-known, international construction company with an adequate, well established quality management manual for this project, no major deficiencies were found in the leadership and communication aspects of the works. Communication circulation between different departments and overall leadership was in line with up-to-date standards for this kind of project. The company strived for a "zero defect strategy" but that did not happen. The international construction management company also had its own quality management manual, which was tailored to suit the needs of the contractor on one side and the end user on the other. While the general contractor and supervising company were internationally experienced companies that were used to large scale infrastructure projects, this was not the case for the client because this was its first large infrastructure project involving international stakeholders. This motorway project was the first implemented project of this scale by far and so the contractor faced significant difficulties in communicating quality management with the client.

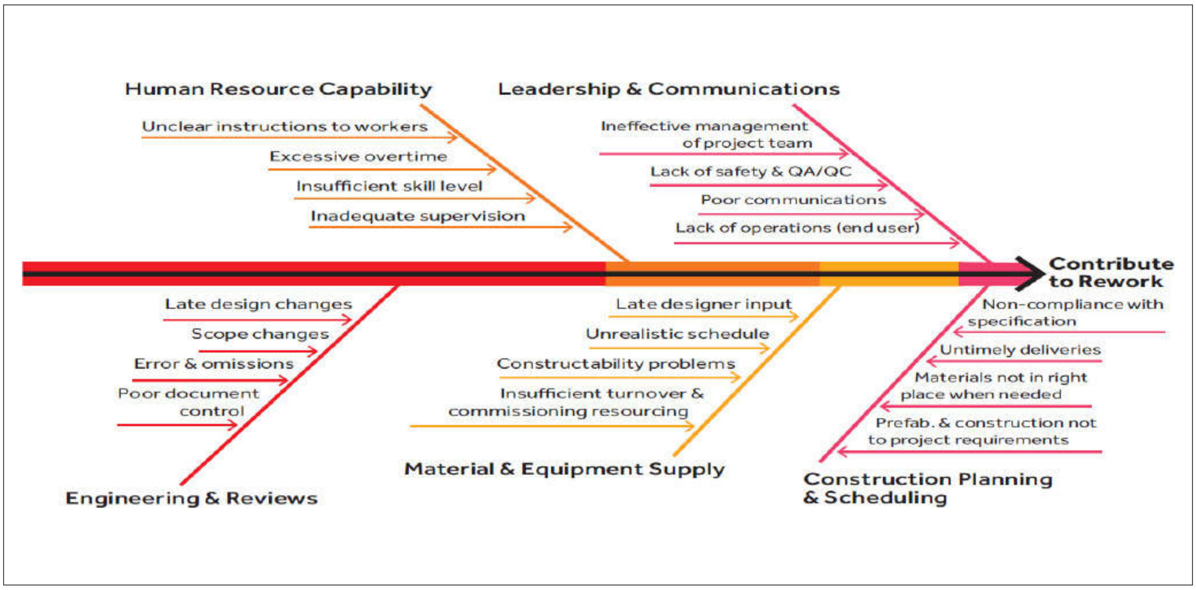

Figure 5 Root cause defect in infrastructure projects (Fayek et al.: 2003)

Construction Planning and Scheduling: This department was the best established department within the contractor's organization, completing each section and the entire project on time.
Material Equipment and Supply: The contractor's procurement team established a large number of subcontractors and suppliers of raw materials for the project. All supply materials were in line with technical specifications for the specified works.
Engineering Design and Reviews: This project was implemented under a fast-track system, with a separate design company working remotely from the design review team which was established at the site office. All project details were based on typical models for motorways using the latest standards for design implementation. As noted by Love (2009), when projects are subject to tight design schedules, design team members often re-use standard details and specifications in order to minimize their task loading. Together with inter-operability issues and information technology applications, this can lead to tentative design information which was the case for this project.
Human Resources Capability: during contract negotiations, the Government imposed a condition on the contractor to employ a local workforce, with the intention of increasing the welfare of local inhabitants along the motorway route. This condition resulted in the contract managers employing a local workforce in the drainage and earthwork department; these were two of the low unit price positions in the contract. This untrained workforce possessed insufficient skill levels and were not in a position to meet the quality levels required by the project. The general contractor for structural, paving and finishing works used their own resources and were familiar with the company's policy for quality, having implemented works on similar projects in the region as well as further afield. Therefore, the major snags were reported in the drainage department (38.91 %), followed by the earthwork department (31.77 %), finishing department (20.16 %) and structures department (with only 3.12 % of the snags). The reason why the structure department had only 3.12 % of the overall snags was because the team comprised a skilled workforce that had worked in the same discipline on at least two other similar projects. An additional reason for the structure team to have had fewer defects was the high unit price cost for concrete works.
An additional reason for the large number of defects identified on this project was the deep involvement of the supervising company in detecting the defects throughout the entire project. The total cost of the defective works for sections 1-4 was 5.32 % of the total project cost. The time duration for remediation of the defective works was 18 months (November 2012 to April 2014). The cost of remedial works was within the generally accepted international margin for this type of project (approximately 4.85 % of the total cost for sections 1-4).

7 Conclusions

Compliance with quality specifications is an important measurement of performance for any construction project. The repercussions and consequences of poor quality can be: loss of productivity; additional expenditure by way of remedial works and repairs; loss of reputation which could lead to a loss of market share and, eventually, complete loss of business. Project managers should take the lead by developing and implementing systems for tracking and controlling construction errors and omissions (on behalf of the client), design change (on behalf of the contractor), ownership changes and design errors (on behalf of both the contractor and the client) in order to try to reduce the amount of remedial works. The underlying message is to remove complacency, address past failures and learn from them by implementing best practice in construction in addition to improving learning capabilities and stimulating organisational learning. In order to reduce defects in design, limit the amount of remediation required on defective works and reduce the overall project cost, construction companies need to consider a six-step process model for managing construction defects, as follows:

- Be aware of quality issues and implement a zero defect company strategy.
- Investigate the root of any defects and immediately remedy the cause of the defects.
- Discover defects as early as possible and remediate errors and omissions.
- Evaluate the cost of defects and try to identify the steps needed so as to avoid repeating them in future.
- Treatment or remedy: treat defects properly and at an early stage of the project (at the design stage if possible).
- Financial recovery: consider the financial impact of the defects to the overall price of the contract; it is preferable for the project manager to plan for the potential cost of remediating any defective works on a project (which in infrastructure projects should be a minimum of 5 %).
- Train the unskilled workforce before involving them on the construction site. Short training periods are not enough to impart a sufficient understanding of the importance of finishing the works to an acceptable quality standard at the first attempt.

This process can be termed the “life cycle” of the investigation and resolution of a construction defect and it can be implemented at all stages of a project.

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