A SOUTH AFRICAN CASE STUDY ON THE CAUSES OF BUILDING COLLAPSE

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ABSTRACT

Purpose: The purpose of the research is to uncover the causal factors that produce injuries and accidents through building collapse. The Tongaat Mall accident that deepened construction health and safety (H&S) as a subject of national discourse provides the opportunity to outline the causes collapse.

Research Method: The case study design was adopted for this study because there is a need to understand the causal factors of the collapse so that mitigations could be suggested for future projects.

Findings: The collapse, which occurred while the mall was still under construction, produced two fatalities and twenty-nine injuries as immediate consequences. Cause and effect diagrams showed that the major factors responsible for the accident pertain to the method, materials, man, and measurement (4M) involved during construction. In other words, failures mushroomed in the project because the method of construction was executed incorrectly and the material use and handling was suspect.

Limitations: The study showed that there was no attempt to measure the implementation of procedures by relevant site operatives.

Implications: To avoid a repeat of the 'wheel of failures', it is apparent that clients, designers (especially engineers), and contractors have to tackle several causal factors under their control. Such causal factors include excessive design changes and irregular work procedures.

KEYWORDS
Buildings, Construction, Design, Failure, Health and Safety

1. INTRODUCTION

Building collapses in South Africa are contributing to fatalities in the construction industry Construction Industry Development Board (CIDB) [1] where the cost of accidents has socio-economic implications [2]. The proportion of that collapse is significantly smaller compared with the vast majority, but the socio-economic impact of such accidents needs serious consideration since the loss of life and money is commonly associated with building collapse [3,4].

The reasons for building collapse could be structural failure, poor supervision and workmanship, the use of sub-standard materials, a lack of competency in building techniques, or faulty designs [3] These causes can be attributed to either natural or man-made conditions. Natural phenomena may be attributable to severe climatic conditions while man-made conditions can be linked to human activities. Man-made conditions may emerge from laxity in areas of geo-technical investigations, over-design design, inadequate foundation design, poor quality building materials to save money, derisory monitoring of craftsmen and poor quality of workmanship, leading to the collapse of buildings [1,3,4,5].

In South Africa, building collapse leads to an increase in construction fatality statistics in the face of non-compliances with regulations [1]. The aim of the article is to highlight the various causal factors that could lead to the collapse of a building at the construction phase of a project life cycle. The article begins with a succinct explanation of possible causal factors of building collapse. The article focuses on the Tongaat accident to illustrate the pervasiveness of the identified causal factors, which appear not to be peculiar to South African construction.

2. OVERVIEW OF BUILDING COLLAPSE

The frequency of building collapses in the recent past has become a major issue as this phenomenon has a detrimental effect on the socio-economic development of South Africa. These accidents have become a major cause for concern to government, construction professionals and stakeholders alike. Empirical work has discovered that trying to reduce the incidence of construction failures is a continuous process, and organizations such as the Occupational Safety and Health Administration (OSHA) and others are dedicated to this goal [6]. It is important to note that the proportion of buildings that collapse is significantly smaller compared with the vast majority in use, but the socio-economic impact of such accidents must be acutely noted [3]. It has also been established that loss of life and monetary loss is most commonly associated with building collapse [3]. Structural collapse is prevalent and occurs worldwide. Several causes of building failure can be attributed to either natural or man-made conditions [3, 7]. Natural phenomena may be attributable to seismic tremors and typhoons, such as the record snowfall in 2010 that collapsed the roof of Minneapolis Metrodome [7]. Often, though, artificial or man-made phenomena consist of accidents, which may be born from man's laxity in areas such as geo-technical investigations, building design and planning for superfluous live and dead loads. Furthermore, inadequate foundation design, poor quality building materials to save money, derisory monitoring of craftsmen and meagre quality of workmanship could lead to the collapse of buildings.

Considering that the incidence of building collapse repudiates the principles of sustainable development, this would suggest that stakeholders do not consider the future of their current undertakings. The predominant reason for building collapse is structural failure, trailed by poor supervision and workmanship, the use of sub-standard materials, carelessness which could be linked to lack of competency in building techniques and supervision skills, and faulty design respectively [3, 4, 7]. Other causes include excessive loading and adaptation and disdain for approved drawings. This suggests that the Tongaat mall building collapse is traceable to human activity or the lack thereof, given the non-occurrence of a natural phenomenon that led to the collapse. The literature indicates a number of reasons for the collapse of buildings. Some of the reasons are highlighted the following sub sections.

3. STRUCTURAL FAILURE

Structural failure is defined as "the reduction of the capability of a structural system or component to such a degree that it cannot safely serve its intended purpose" [6]. Several authors have suggested that much can be learnt through the failure of a structure rather than a study of structures which are successful [6, 8]. The proper appreciation of the causes of failure will assist professionals in refocusing their conceptual understanding of structural behaviour. Through research, it was established that the most prolific teachings in engineering judgments are obtained from studying case history failures, which point out without question, examples of bad judgment. The case studies provide guideposts for negotiating around pitfalls in conceptual design [6]. They also provide invaluable insights into potential trip-wires that could lead to disastrous accidents such as building collapse. Structural failures could be due to [6]:

- Poor communication between the various
- construction professionals.
- Lack of communication between
- fabricators and erectors.
- Poor workmanship.
- Compromises in professional ethics and failure to appreciate the responsibility of a profession.

Other mutual causes of structural failure are considered to be the lack of appropriate professional design and construction experience, especially when innovative structural designs are needed. Other reasons include the intricacy of codes and specifications leading to misinterpretation and misappropriation undeserved belief in calculations and in specified extreme loads and properties, the insufficient provision and evaluation of contract and shop drawings, and inadequate training of field inspectors, and limitations placed on design and construction time [9].

4. CONSTRUCTION FAILURE

A construction failure is a failure that occurs during construction and they are considered to be either "a collapse, or distress, of a structural system to such a degree that it cannot safely serve its intended purpose" [6]. When a component system or structure fails it may occur for many reasons, including changes in materials triggered by deterioration [10]. Research has shown that unsuitable materials are one of the leading factors of failures. These failures may not lead to catastrophic structure collapse, but usually manifest as an unacceptable difference between expected and observed performance of a structural component in the building envelope. The identified changes include [10]:

- Structural members becoming non-supportive, for example a moving component seizing, and
- Components becoming incapable of performing their intended function safely and reliably – loss of a loadbearing member could reduce the load-bearing capacity, which in turn leads to the loss of the factor of safety.

5. INADEQUATE CONSTRUCTION SUPERVISION

Many cases of poor construction supervision related to building failures have been reported [5]. Poor construction supervision related building failures has also been observed to cut across different categories of buildings, namely: private, corporate or public. The cause of building failures related to poor construction supervision is almost always unique to the particular building in question [5]. A significant percentage of these failures are caused by carelessness and greed on the part of contractors [4]. Poor construction supervision-related building failures might not be unconnected with the hasty and care free manner in which private clients handle their building projects with or without government approval [5]. According to literature, 50% of poor construction supervision-related building failures in Nigeria is attributed to design failures, 40% to construction fault and 10% to product failures, also stating that poor construction supervision related building failures is no respecter of the size of a structure [5].

6. FACTORS RELATED TO INSTITUTIONAL REGULATORY FRAMEWORK

The CIDB [1] notes that the poor H&S performance record of the construction industry globally has resulted in H&S regulations being subjected to major revisions. A range of regulations promulgated under the OH&S Act 85 of 1993, Republic of South Africa [11] impact on construction H&S, in particular the construction regulations circulated in July 2003. A range of other legislation impact on the construction industry, some having direct or indirect reference to H&S: the Basic Conditions of Employment Act No. 75 of 1997 and Labour Relations Act N.6.103 of 1977. Reduced budgets and the complexity of building design plan review have become an ever increasing burden for building departments [12]. On-site inspection is intended to ensure that the construction is completed in accordance with the approved contract documents, but empirical work indicates that this is not the case [12]. The CIDB [1] state that the primary construction H&S regulatory and enforcement structures in South Africa are the OH&S Inspectorate within the DoL and the Mine H&S Inspectorate within the Department of Minerals and Energy (DME). Compliance with building regulations falls within the orbit of local authorities and the CIDB's Act also provides for the CIDB to play a regulatory role. However, a study investigating the effectiveness of the DoL Inspectorate showed that the Inspectorate was perceived to be more ineffective than effective [12].

7. FAST-TRACK CONSTRUCTION

Fast track projects are those in which construction begins before all of the architect's drawings and specifications are complete [13]. Also known as phased construction, the method is intended to save time by passing the traditional sequence of documentation, tendering and construction in order to alleviate the effects of inflation [13]. The use of fast-track methods of construction, design build approaches and other techniques to reduce the total elapsed time required from the decision to build to occupation, has had a damaging effect on the structural performance of buildings [14]. In structural components in terms of fast-track construction, the early removal of forms or the application of post-tensioning and the termination of curing in cold weather have safety implications if not applied appropriately [15].

Likewise, the rapidly advancing increase in computational capability has provided mixed blessings, as in the CESA report [14]. With a limited hands-on approach, obscuration of the building process can occur. This problem is most severe, state CESA, in the case of less experienced members of staff who lack the ability to umpire the reasonableness of the final result. The use of timesaving techniques requires greater team effort and co-ordination. In research conducted by CESA [14], it became clear, that confusion arises from these types of time-saving processes in terms of responsibility and accountability.

8. CONSEQUENCES OF BUILDING COLLAPSE

Apart from loss of life, many other people have been rendered disabled as a result of building collapse [16]. Furthermore, building collapse has proven to have palpable consequences on the urban and socio-economic development of a country [4]. Buildings that meet the desired performance requirements add value to the national asset stock and enhance its Gross Domestic Product (GDP) [17]. There is only one alternative to sustainability: unsustainability which underperforming buildings bestow on the country's economy [4]. In South Africa, occupational accidents and diseases account for approximately 3.5% of its GDP, which translates to about R30 billion [17]. Several productive lives and properties have been lost in the various incidents involving building collapse, and these losses have had negative impact on the socio-economic status of the country [8]. Firms in construction fail to accurately accumulate the true costs associated with occupational accidents. There are aspects apart from the obvious financial and economic burden that cannot easily be quantified, namely the loss of a family member or even worse, the breadwinner. The DoL [18] announced that the construction industry has consistently been among those industries with high injury and fatality rates.

9. CASE STUDY – TONGAAT MALL PROJECT, DURBAN, SOUTH AFRICA

The research analysed the 2013 Tongaat building collapse in Durban, South Africa. The case study design was adopted for this study because there is a need to understand the causal factors of the collapse so that mitigations could be suggested for future projects. The case study method enabled the retention of the meaningful characteristics of the real-life events that transpired before the building collapsed. Such events included organisational and managerial processes within the project. The Tongaat Mall collapse can be considered to be a complex functioning unit that has been investigated in its natural context through more than one method of data collection and it is a contemporary case given its current status [19].

A case study is about the explicit rather than the general [20] and in this case, the research study focuses on the causes and effects of events. The Tongaat Mall building collapse is a particularly interesting case by virtue of its size and the extraordinary amount of damage that it wreaked on the town. The Tongaat Mall building project was a multi-storeyed shopping complex situated in the town of Tongaat, 37km north of Durban, as illustrated in Figure 1. The town of Tongaat is known as a sugarcane-growing township near Durban, South Africa. Citations show that Tongaat has a population of 42554 people and a density of 3600 people per km² [21]. The town is situated on the banks of the Tongati River, about 37 km north of Durban and 28 km south of Stanger. Construction of the 16000 m², R220-million shopping mall began in March 2013 and was scheduled for completion in April 2014, but the project was never completed.

From the statistical package quantitative data such as frequencies, means, standard deviations and principal componenet analysis were conducted[36].

Additionally, for the questionnaire a cronbachs alpha was calculated and found to 0.916 for consultants' questionnaire and 0.935 for the contractors' questionnaire. These are acceptable rates of reliability [37], therefore the instrument was a reliable measure.

The population and sample size for clients was less than 30, therefore the sample and population were too small to produce a reliability result for the Cronbach Alpha [38]. Nevertheless, the response rate for clients was 60%. This demonstrates the validity of the results as built environment research normally has a response rate of less than 40%[39].

The minimum qualification was first degree except for procurement officers who had training at advanced diploma level.

The respondents have been involved in various types of projects with a mix of small to large-scale building projects such as hospitals, clinics, health centres, schools, universities, banks, markets, shopping malls, fire stations, offices, residential houses etc.

Figure 1: Illustration of the media coverage of the Tongaat mall accident

10. DATA COLLECTION, ANALYSIS AND INTERPRETATION

Building collapse studies have used a case study research design to interpret the events[22]. The case study approach was also used for this study in order to gain an analytical comprehension of the events [20]. The document sources of evidence consulted for this research study were newspaper clippings and other articles in the media, including website reports by the Department of Labour (DoL). In total, 79 clippings were manually analysed and the dates of publication of these clippings ranged from 20 November 2013 to 17 November 2015 (See Table 1). Newspaper accounts are excellent documentary sources for reconstructing reality [19]. In addition to the analysis of content conducted on the clippings, face-to-face interviews were conducted with nine construction workers who took part in the mall project.

After the content analysis[23], several visits were made to the site of the accident to interview participants of the project. The findings of the analysed document provide the basis for the compilation of the interview protocol, which was made up of 33 questions that interrogated the issues uncovered in the analysed documents. Open-ended questions that interrogated the perceptions of the project participants were used in the interview protocol. The principle of voluntary participation was upheld in the interviews. This principle implies that anyone who declined to be interviewed was not pressurised to do so. Although only nine workers who were employed by the contractor were eventually interviewed, efforts were made to interview the developer, the contractor, the consultants, the municipal inspectors, and subcontractors on the project.

Table 1: Overview of the analysed document

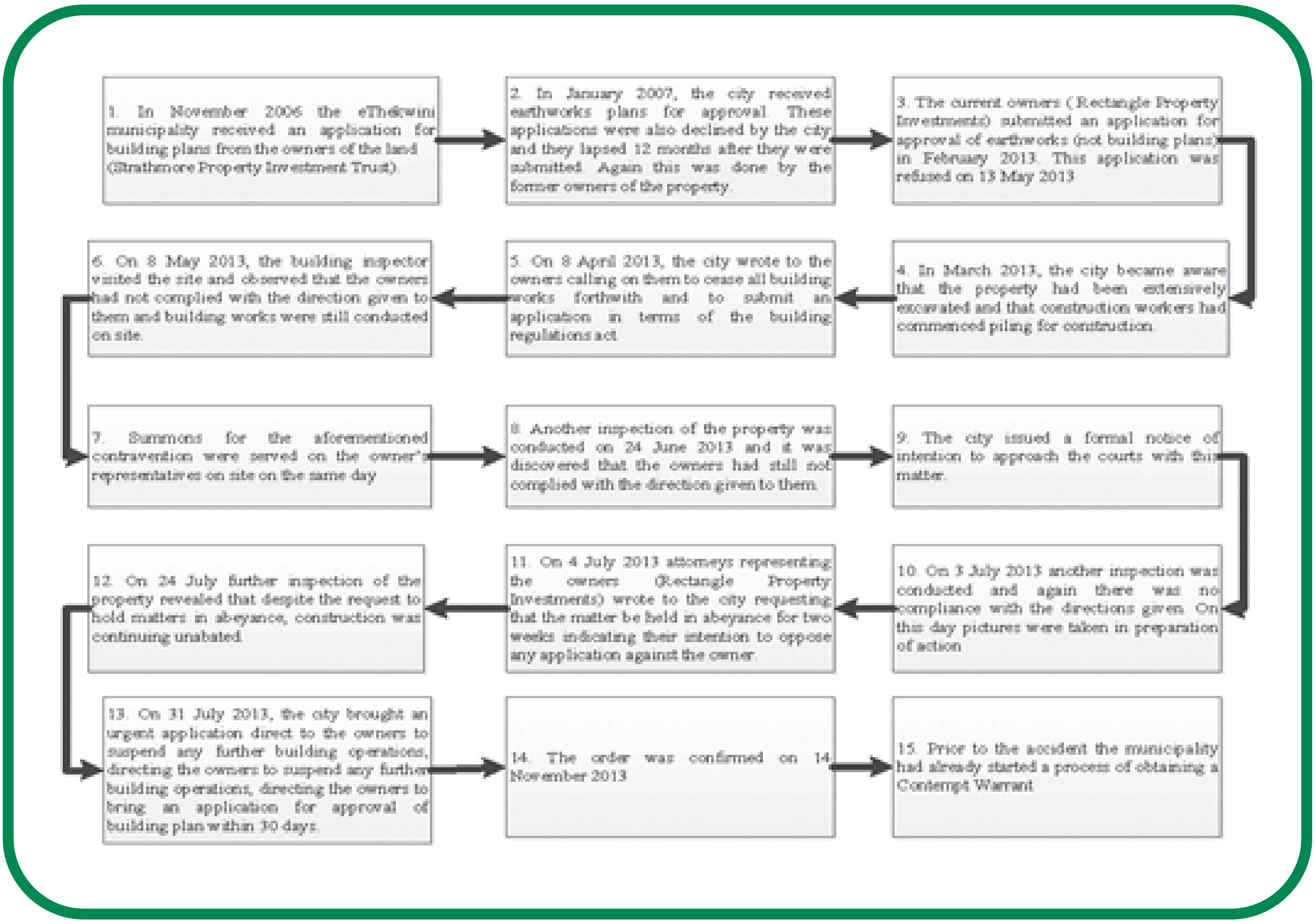
Name of Document	Articles	Timeline
South African DoL website	40	20 November 2013 – 17 November 2015
News24 website	29	24 November 2013 – 25 August 2014
IOL news website	2	21 November 2013 - 30 March 2015
FSPBusiness website	1	13 February 2014
Klass Looch Associates website	1	30 March 2015
Politicsweb website	1	20 November 2013
Construction Review Online website	1	11 September 2014
Infrastructurene.ws and service delivery website	1	10 April 2014
Sowetan website	1	20 November 2013
SAcommercialprop – News website	1	25 November 2013
Timelive website	1	24 November 2013

All the project actors that declined to be interviewed cited the on-going official inquiry into the accident at the time of the fieldwork as a reason for non-participation, and the fact that the accident was a matter of litigation was another factor for declining to participate in the interviews. Recorded interviews were transcribed, organised and tabulated to facilitate cross-analysis so as to observe reoccurring concepts, ideas or phrases as demonstrated in Table 2.

11. RESULTS AND DISCUSSION

As shown in Figure 2, the storyboard of the Tongaat Mall development project began in 2006 when the municipality received an application for a building permit. The timeline in Figure 1 relates to regulatory failures that occurred before the collapse of the building on 19 November 2013. It is evident that if the developer/client and the contractor had complied with the law, the accident may have been averted.

Figure 2: Timeline for regulatory events on the collapsed building



12 4M MODEL OF BUILDING COLLAPSE ACCIDENT CAUSATION

Based on the analysed inquiry documents [23], structural design, quality of construction work and supervision and non-compliance with the requirements of Construction Regulations were the notable failures in the collapsed building (See Table 2). The developer of the project failed to comply with official orders to stop the project before the accident.

In fact, the developer ignored court orders to stop construction six days prior to the collapse of the slab that led to fatalities. Before the court order, the municipality even tried to stop the project because of various contraventions. The municipality reports that it did not grant a "permit to build" to the developer of the mall. The compliance issue is not new in South Africa. The DoL flagged non-compliance in most of the construction sites that were visited by its inspectors[1].

The developer is not alone in terms of regulatory failure. The engineer and the contractor followed the footsteps of the developer in this regard. From the analysed clippings, the engineer may be found wanting concerning full compliance with Section 9 of the South Africa Construction Regulations, which states that "...the designer of a structure shall inform the contractor in writing of any known or anticipated dangers or hazards relating to the construction work, and make available all relevant information required for the safe execution of the work upon being designed or when the design is subsequently altered".

Compliance or non-compliance with this clause influences the triggers of the collapse, which is a slab that was supported by beams and columns that cracked.

The aforesaid preliminary findings were further analysed with the on-site observations recorded as photographs and interviews.

Table 2: A summary of causal factors of the Tongaat mall collapse Source: [23]

Failure (s)	Description
Construction work / supervision	Slab sagged before collapse
Construction work / supervision	Scaffold / formwork / false work removed too soon
Construction work / supervision	Weak concrete used for construction on site
Construction work / supervision	Severe lapses in construction work and supervision
Construction work / supervision	Reasons for construction failure - beams
Structural design	Reasons for construction failure - design
Structural design / construction work	Steel bars are missing in the elements - slabs, beams, etc.
Construction work / supervision	Lack of H&S audit on project site
Regulatory control	Mall plans rejects / failed approval four times
Regulatory control	Demolition of the site was never approved
Regulatory control	Developers was consistently fined for failures
Regulatory control	Workers instructed to keep working despite official notice

Table 3: Cross-tabulation of Tongaat mall accident findings

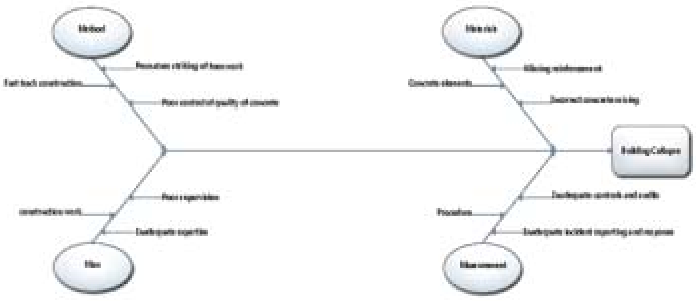
Research Question	Sources: Document	Sources: Interviews	Outcome
What are the contributing factors that led to the collapse of the Tongaat Mall?	- Poor supervision by the management team.	- Poor quality workmanship due to lack of supervision by professional team. - Lack of inspection by the professional team. - Supervisors were not qualified and lacked leadership. - Poor supervision overlooked to enhance productivity.	Confirmed
	- Poor quality control by the management team.	- Quality workmanship was not enforced. - Poor quality workmanship due to lack of supervision by professional team. - Lack of inspection by the professional team. - Material testing done intermittently. - Poor quality overlooked to enhance productivity	Confirmed
	- Lack of regulatory control by local and governmental authority.	- Lack of inspection by regulatory bodies and professional team.	Confirmed
	-Failure of structural elements such as beam and columns.	- Column construction believed to be sub-standard. - Formwork was removed too soon.	Confirmed
	- Failure to abide by construction regulations	- Construction procedures were questionable in order to meet deadlines and to avoid penalties. - Formwork was removed to soon. - Control and regulation of concrete mixing questionable. - Construction flaws were rectified in dubious ways. - Construction workers had little or no knowledge of the construction regulations. - Supervisors were substandard and lacked leadership. - Lack of inspection by regulatory bodies and professional team.	Confirmed
	- Failure to acknowledge Health and Safety Act.	- Appointed safety officer was unknown to construction workers. - Lack of consistent health and safety protocol. - Lack of sufficient PPE on site.	Confirmed
	- Failure by management team to provide safe working environment.	- Appointed safety officer was unknown to construction workers. - Lack of consistent health and safety protocol. - Lack of sufficient PPE on site. - Various site accidents reported before collapse.	Confirmed
	- Failure to ensure proper material testing.	- Material testing done intermittently. - Control and regulation of concrete mixing questionable.	Confirmed

The research questions and associated findings from the analysed documents and interviews are presented in Table 3.

	- Inadequate/under qualified staff placed in management positions.	- Supervisors were substandard and lacked leadership.	Confirmed
	- Management staff had to perform various supervisory and H&S roles.	- GF had to perform various H&S and supervisory tasks.	Confirmed
	- Inadequate foundation and column design by the structural engineer.		Unconfirmed
	- Inadequate design alterations to accommodate variation orders.		Unconfirmed
	- Failure to perform proper construction procedures by the principal contractor.	- Poor quality workmanship due to lack of supervision by professional team. - Construction procedures were questionable and forced to meet deadlines and avoid penalties. - Column construction believed to be sub-standard. - Construction flaws were rectified in dubious ways.	Confirmed

Taken together, the causes of the accident are presented as follows with the aid of the cause and effect diagrams (Figures 3 and 7), which are widely known as fishbone diagrams.

Figure 3: Illustrated 4M fishbone diagram for



13. MATERIALS AND METHOD CONCERNS

The fast paced/fast track construction method contributed to the collapse owing to time pressures. The interviewees perceived that there was not enough emphasis on the quality of workmanship since the work was seen to be rather rushed so as to increase productivity and reduce lagging deadlines. The tight deadline for opening the mall was a factor that may have contributed to the decision to fast track the construction of the building. The decision to fast track the project completion was taken by less experienced site management who were unable to control either quality of work or conformance the premature removal of formwork without regard to the curing of concrete as signs of hurried processes. The interviewees also noted that the general foreman (GF) on the project focused on sporadic instead of regular inspection and monitoring of works. The interviewees noted minimal guidance in terms of induction or 'toolbox talks'. Various interviewees indicated that they could use their own discretion in completing tasks as long as the work was completed before the due date and was of seemingly good quality without major visible defects. Also, they reiterated that supervision as pertaining to material and concrete batch testing was apparently absent. The interviewees were of the opinion that the cast columns on the project were of low standard and the fact that formworks were prematurely removed did not help matters. This scenario was exacerbated by the reported lack of control in terms of concrete mixing on the site. The interviewees also suggested that the collapsed section was as a result of the poor quality concrete in terms of low compressive strength at 28 days. The compressive strength of concrete is the ration of maximum uniaxial load carried by concrete to the cross-sectional area and failure occurs when the maximum stress that a sample concrete element could withstand is exceeded [24].

In addition to the aforementioned, the volume of requests for information began to rise due to constant changes in the design, re-work and modification of cast structural elements. In fact, the exposed concrete elements on the project sites clearly indicated several cases of missing reinforcement, inadequate length and strength of reinforcement, and incorrect pouring of concrete that led to the formation of cold joints [24]. It is notable that these components of the 4M diagram, which is a replica of cause and effect diagrams used for root cause analysis [25], constitute the main trigger for the accident. According to the analysed documents, expert witness opinions highlight three possible weaknesses that contributed to the collapse. Two major weak links were with respect to the beam and columns as illustrated in Figures 4 and 5. An expert witness observes that the foundation of one of the columns that supported the beam had only one pile, which was not deemed to be adequate. It was reported that there should have been three piles instead of one. The experts flagged one beam and two columns as the trigger for the collapse. With regard to the beam, it was perceived that it was not poured once owing to the visible joints. The concrete joints were points of weaknesses that may have led to eventual disintegration. While the design of the beam was not criticised, the fact that its construction deviated from the construction drawing was a concern upon which only the GC can elaborate. Structurally, it was observed that six reinforcing steels had been cast in the concrete beam instead of 19. From a structural viewpoint, the beam failed to withstand the imposed load. Further, the columns were close to their bearing capacity, and as such, their ability to support the slab was questioned by the expert witnesses. It was also noted that the columns' capacity to provide the necessary support to the slab was compromised because they were not perfectly vertical and their dimensions were considered to be very "slender". Therefore, the columns were deemed to have been inadequately designed for their purpose and had also not been built in accordance with specifications. Among other reasons illustrated in Figure 4, the expert witnesses noted that the loads from the slab led to the failure of the column underpinned with a sin

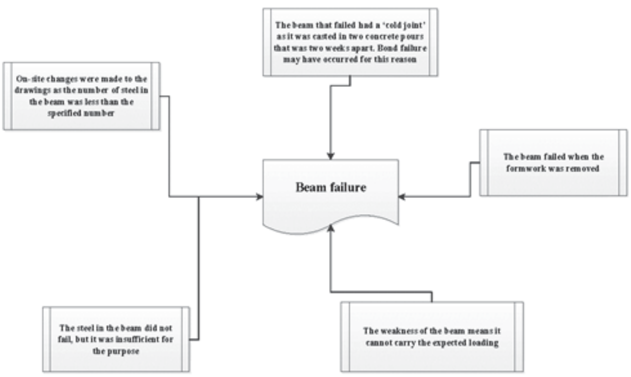


Figure 4: Insights into a failed support beam in the collapsed mall [23]

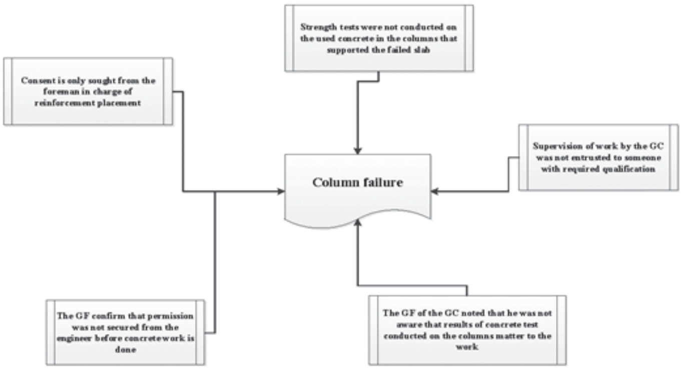


Figure 5: Insights into failed columns in the collapsed mall [23]

14. MAN AND MEASUREMENT CONCERNS

Man and measurement components of the fishbone diagram also contributed in no small way to the collapse. In terms of measurement, it is notable that H&S audits had not been conducted on the project site for four months before the collapse of the building. The H&S consultant for the project stated that formwork, scaffolds, and other false work had not been signed off, either for installation or removal, on the site. In the analysis by the H&S consultant, the findings showed that the H&S file and the officer of the project were missing on the day of the accident. This observation was a clear departure from specific clauses of Construction Regulations in South Africa [26]. There were clear cases of inadequate controls and audits on the report site and the project engineer even recognised the inadequacy of site inspections on his side [27].

The work and supervision of man (developer, contractor, designer) were sub-optimal from the inception of the project. In terms of the regulatory environment, the developer failed to lead the project by example. All the regulatory failures of the developer and even those of the contractors were flagged [23, 28]. In particular, the interviewees were asked: "Based on your opinion, how did you experience the on-site inspection of the Tongaat Mall project? What is your perception on the enforcement of compliance with Construction Regulations (2003) by the local authority/municipality during the Tongaat mall design phase? And what is your perception of compliance enforcement on the Tongaat mall project?" These questions assessed the involvement of the governmental authority in the project in terms of on-site inspections as well as the enforcement of the regulations. The analysis of the data indicates that the interviewees were not really aware of inspections on site. This suggests that there was a limited presence of the local authority on the project site. The interviewees also perceived a major lack of leadership regarding the enforcement of regulations.

More important was the poor supervision recorded on the project. The content analysis and the interviews showed that supervision as a crucial process in construction was poor despite a constant demand for increased site production. For example, the supervisors often overlooked poor workmanship unless a defect was obvious. When defects were obvious, re-work would be mandated. A clear instance was the demolition of columns that had clear deflections. The use of incorrect materials was also a problem on the project, constituting another area in which 'man' was responsible. The analysed data shows that the rate of unemployment among the interviewees was high and that they needed the remuneration – hence their inability to challenge poor work processes. The interviewees pointed out that as work is scarce, they were in dire need of employment: this placed them in a position where compliance with the directives given to them was not negotiable.

The interviewees were of the opinion that scheduling and work sequencing were not properly done because production was chased for the sake of completing on time. Chasing the completion of the project on time led to obvious mistakes and construction flaws in the structural elements as evident in the deflection in columns, cracks in other building elements and the collapse that occurred (Figure 6). The interviewees went on to note that the procedure and methods used for correcting mistakes and defects engender more re-work. As observed, limited know-how concerning the Construction Regulations among the interviewees was observed. If this is the case, the ability to comply with the regulations would appear to be truly limited. In brief, the interviewees were of the opinion that supervision was inadequate as they also indicated that they did not have confidence in the leadership of the GF and had even questioned his qualifications and knowledge of the construction process. The interviewees also noted that the effects of poor leadership from the GF contributed significantly to poor supervision on the project. For instance, the interviewees observed that the GF also functioned as H&S officer of the project. Furthermore, events on the project showed that thorough compliance with H&S practices was lacking on the site and the contractor failed to uphold sound H&S practices on the project [29].

Figure 6: Recorded cracks and deflections in the collapsed building

15. ADDITIONAL CAUSAL FACTORS RESPONSIBLE FOR THE ACCIDENT

Beyond the role of the 4M explained previously, Figure 7 presents a detailed description of several factors that led to the accident. Gaps in compliance regime were evident through the start and continuation of work without the required permit or the sporadic on-site inspections by relevant parties – designers and contractors. The compliance gaps created an environment for poor project decisions on the part of both developer and contractors who were collectively responsible for the violation and payment of fines. The rise in change orders and design revisions indicted the state of work coordination on the project. The poor coordination of design and construction is reflected in the inadequate organisation of work on the project site. As an illustration, if the work had been organised properly, formwork removal would not have been hasty and the trigger for the crack that led to the collapse would have been avoided. Lack of an audit of work procedures contributed in no small measure to defects and re-work on the project site.

Given the profile of the economic circumstance of the host community of the project, employee participation in decisions was minimal and limited significance was placed upon the H&S and well-being of the workers by the contractors. Required training and motivation that would have been helpful in preventing the accident were therefore lacking on the project. Recorded failures in various laboratory tests and the increase in defective beams and columns form signals for addressing quality issues in the project. The sagging of slabs and cracks that manifested in beams, columns and slabs indicated the state of functionality that was compromised in the project. The end result was a building collapse that appeared to be avoidable owing to the fact that natural causes due to climatic conditions did not play a role in this accident. The construction accident led to two fatalities and 29 injuries and genuine concerns for lost revenue for everyone on the project.

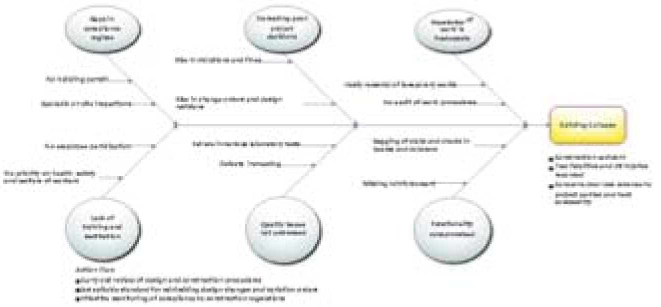


Figure 7: Additional causal factors of the collapsed building

16. ANALYTIC GENERALISATIONS FROM TONGAAT MALL COLLAPSE

The study shows that, in broad terms, the causes of the Tongaat Mall building collapse were inappropriate planning and management of construction activities, poor regulatory control, and structural failure, followed by poor supervision, disregard for engineering drawings and workmanship as well as lack of diligence. These issues were also flagged in past building collapses [8]. The increase in building collapse accidents in South Africa underscores the need to arrest all H&S issues that could lead to accidents when constructing buildings [1]. In general, the analysis showed that a constant revision of designs was rampant on the project. The design of a slender column that was unable to carry the dead weight of the collapsed slab serves as a vivid case. Designers, especially structural engineers, should respond more strongly to H&S situations at the pre-construction stage [30]. These arguments back the use of the time-safety influence curve that explains the relations between the progression of a project through its phases (initiation, design, procurement, implementation, and so forth) and the ability to influence H&S as the project passes through the classical stages of project realisation [31]. In essence, as work progresses on project sites, the ability to influence H&S positively decreases.

Clients have key roles to play in providing and achieving optimum standards in H&S. This is particularly important when compliance is required. As shown in the findings of this building collapse, the client may have been able to avert the loss of lives on the site if compliance had been adhered to as required. The disappearance of the H&S file, which should contain documented H&S plans and specifications for the project, is another area where the Construction Regulations of South Africa flagged the contributions of client/developer [26]. Following the client is the role of the design engineer of the project. The extent to which the design engineer complied with section 9 of the Construction Regulations is unclear [26]. The section states that "...the designer of a structure shall inform the contractor in writing of any known or anticipated dangers or hazards relating to the construction work, and make available all relevant information required for the safe execution of the work upon being designed or when the design is subsequently altered". This clause is relevant to the role of the design engineer in terms of addressing the mentioned triggers of the collapse – beam and columns. The need for a design to consider H&S has been highlighted in the literature, especially in relation to fatalities [32,33]. For instance, a review of over 200 fatalities in the construction industry in the United States of America (USA)[32] suggested that 94 cases can be linked to design. These statistics underscore the impact that design has on construction H&S performance.

Compliance matters were also heightened when the role of the contractors is assessed in the light of the accident. Since the H&S performance of the contractors is influenced by management commitment, communication and feedback, supervisory environment, H&S rules and procedures, training and competence levels, and work pressure [29], the construction work and supervision-related issues discussed earlier could be linked to the contractor. In addition, the perception that H&S is the responsibility of everyone on site is contrary to what happened when the GF asked the workers to continue to work despite a notice to stop work by the municipality [23]. Among others, section 5 of the Construction Regulations of Republic of South Africa, [11, 26] mandates a principal contractor to "...stop any contractor from executing construction work which is not in accordance with the principal contractor's and/or contractor's health and safety plan for the site or which poses a threat to the health and safety of persons". The interpretation of this clause and its compliance are important and it requires the contractors to take steps to mitigate possible failures on the project site.

17. CONCLUDING REMARKS

This study showed that the Tongaat mall building collapse was traceable to human activity. There was no natural causal factor observed in the findings of the study. Through the contributions of methods, materials, measurement and most especially, man, the causal factors for the accident can be observed. It is important to re-examine the design and construction procedure for such projects so that suitable standards that reduce design changes can be adopted in future projects. Based on the refusal of the client/developer and by extension, the contractor, to obey stop orders, the ineffectiveness of compliance enforcement has to be addressed. This is an area that a municipality needs to act upon before an accident occurs. The explained causes of the collapsed building in Durban showed that the industry in South Africa needs to address the H&S ethos of clients/developers, designers, and contractors. This study showed that the accident may have been prevented if the developer, engineer, and contractor had complied with Construction Regulations. The trigger for the collapse – a beam and two columns – emerged from poor H&S management that had been on-going on the project. The roles of the major project actors of the Tongaat mall building collapse have been observed through reports and interviews, and their implication for practice is profound. It is thus crucial to engender optimum management of construction and monitoring of compliance with regulations so that such accidents do not happen in the future.

Notes:

1. Owing to the methodological stance adopted in this study (case study research design), the findings of this study should be treated as inconclusive, thought-provoking, and insightful.
2. This paper is an empirical study that was conducted at the postgraduate level. It is not an official forensic study and the report of the accident investigation conducted by the DoL is available from the Department. See: http://www.labour.gov.za/DOL/media-desk/media-alerts/thongathi-tongaat-mall-structural-collapse-commission-of-inquiry-closes-the-curtain-with-submission-of-closing-arguments/ for more information.
3. Details of the questions asked in the study and the analysed documents are available as appendices in Van Eeden [21]. Interested parties can obtain Van Eeden [21] either from the NMMU website or the authors of this article.

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