Lessons learnt from collapse

Spencer Erling* (M) and Ron Watermeyer, (F)* discuss the causes of the collapse of a three-storey building in Roodepoort, South Africa

This article covers what, in our opinion, were the causes of the collapse. No calculations or forensic investigations to test our opinions have been undertaken. We focus on the lessons that others can learn and take the opportunity to comment on various issues that could have prevented the disaster from happening.

Introduction

A three storey building nearing completion collapsed in the Little Falls area of Roodepoort, South Africa, on Thursday 16 October 2008, killing two workers and injuring 14 others. Half of the nearly completed office block was destroyed when the top two storeys collapsed onto the bottom storey. Emergency workers had to clear rubble by hand around an area where rescue dogs from the police dog unit attempted to locate a missing construction worker. His body was retrieved on the Saturday.

What makes this tragic event different to many of the other building related tragedies is that:

– The event, following a spate of building collapses, triggered the high level Construction Health and Safety Summit hosted by the Minister of Labour on Tuesday 11 November 2008 to take a fresh look at construction safety.

– Andre Bruton photographed the building that collapsed from a balcony of another building in close proximity to the line of the collapse, from the time that the siteworks began to the time that the search began for the missing worker, and published 91 photographs on the website: (http://picasaweb.google.com /andrebruton/HowToBuildAnOfficeParkCollapsedBuildingSite)**. These photographs allow the apparent cause of the failure to be readily determined without having to visit the site, interview the designer, review the calculations or examine working drawings.

What was the cause of the collapse?

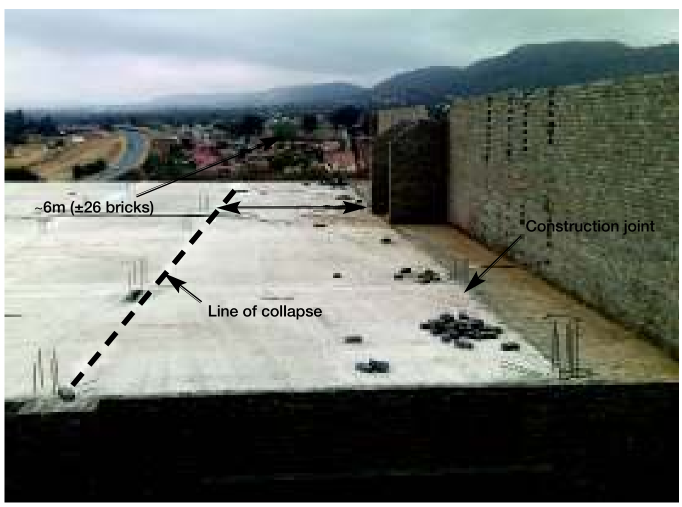
The photographs allowed the geometry of the slab and line of the collapse to be determined i.e., along the line of columns away from a construction joint in the slab, almost directly in front of where the photographer took most of his pictures (Fig 1).

The column bases, most of which are founded on fill, appear to be undersized for a three storey building. These under-designed bases could lead to excessive differential settlement which, apart from causing visible deflections, could redistribute the loads on the reinforced concrete members and in so doing reduce the load-carrying capacity of the slabs in certain areas (Fig 2). The spacing of the links in the columns is very much greater than that recommended in terms of SANS 10100-1, *The structural use of concrete – Part 1: Design*. The larger than allowed spacings of the links could result in the columns splitting vertically when being highly stressed (Fig 3).

Little or no top slab reinforcing steel was provided. Such reinforcement provides rigidity to the beam slab connection, shear resistance in the vicinity of the columns and bending resistance in the slab zones on the columns grid lines. (Fig 3). As a result, the beam / column connection is not a robust one, the slab resistance to punching shear was reduced and the slabs are unlikely to behave as flat slabs as no moment transfer can take place between panels. (This arrangement increases the central bending moment of the slab and prevents loads in one panel being distributed across to another panel. Whilst seldom used, as it is uneconomic, this situation can be designed for by increasing the bottom steel area and increasing the depth of the slab. Additionally, the designer would also, however, have to carefully assess the wall loads which were not on grid lines.

The spans of the slabs, which may be estimated by counting the number of bricks in the photographs (Fig 1) indicates that the slab panels have dimension of about 4 x 6m, 6 x 6m and 7.5 x 6m. Likewise, based on the brick course height, the slab thickness is about 250mm (Fig 4). The thickness of the slab is much thinner than that recommended in terms of SANS 10100-1 for the design opted for. As a result, the deflection of the slabs would most likely to have been visible to the naked eye once the props were removed.

1a



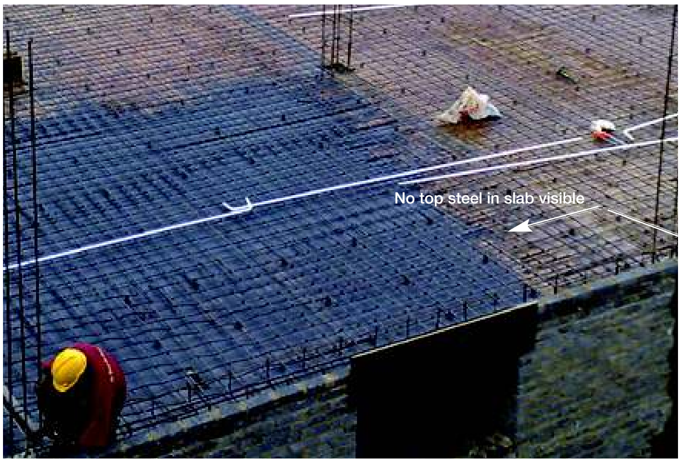
1b

1 a) and 1b) Column spacing and brickwork

2a

2b

2 a) Foundation slabs, b) Detail suggesting undersized foundations on fill
3 a) Reinforcement in slabs: no top steel in slab visible, b) Link spacing significantly greater than structural codes permit



3a

3b

Figure 4 very clearly indicates that saw cuts were provided along the column lines in the concrete slabs. Saw cuts in suspended floors significantly weaken suspended slabs as they introduce a stress concentration at the cut and reduce the effective depth of the slab. Consequently, they are very rarely provided in suspended floor slabs. (Saw cuts are only ever provided in slabs supported on the ground or on fill to control cracking in slabs; the idea being to limit shrinkage cracks to within the cut.)

The combination of a saw cut and little or no top reinforcing steel over the column lines is a catastrophe waiting to happen. The slabs broke along the saw cut lines and collapsed showing the typical yield line breaks that are characteristic of the applied loads exceeding the resistance capacity of the slab (Fig 5). The columns, most of which were still standing after the failure confirm that the slab / column connection was not robust and that the slabs, as opposed to the columns, had failed.

It should also be noted that at the time of collapse the loading on the slabs was substantially lower than would be anticipated for the life of the structure.

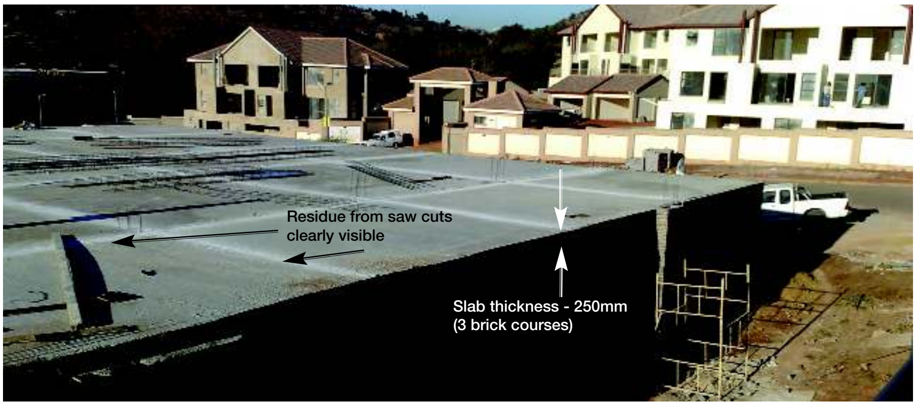
What regulations and or acts should have been considered and how would they impact on the event?

Regulation B1(1) of the National Building Regulations issued in terms of the National Building Regulations and Building Standards Act, 1977 (Act No. 103 of 1977), *and which were applicable at the time of the collapse, require that 'any building and any structural element or component thereof shall be designed to provide strength, stability, serviceability and durability in accordance with accepted principles of structural design, and so that it will not impair the integrity of any other building or property'*... Regulation B1(3) deems this requirement to be satisfied where the design is in accordance with the requirements of SANS 10400 (1990), *The application of National Building Regulations*.

SABS 10400 in Parts J, K and L provides simple rules for the design of concrete floor slabs supported on fills, masonry walls which support their own weight only and simple timber roof trusses having spans of up to 10m. The reinforced concrete columns and slabs and the timber roofs fall outside of the scope of these simple rules. These structural elements accordingly needed to be designed in accordance with South African National Standards for structural design (Rule BB2 of SANS 10400). Rule BB4.1 of SANS 10400 however, requires that '*any rational design of a structural system shall be done or checked by a professional engineer or other competent person, and such person shall certify that such design complies with the requirements contained in regulation B1…..*' Rule BB4.2 requires that '*such person shall, by means of inspections carried out at such intervals as may be necessary in accordance with accepted professional practice, satisfy himself that the structure has been erected in accordance with the approved design and shall furnish to the local authority a certificate to this effect*'.

The Construction Regulations 2003 issued in terms of the Occupational Health and Safety Act, 1993 (Act No.85 of 1993), establish requirements for the design of structures including buildings. Regulation 9 (2) requires the designer in relation to a building to, *inter alia*:

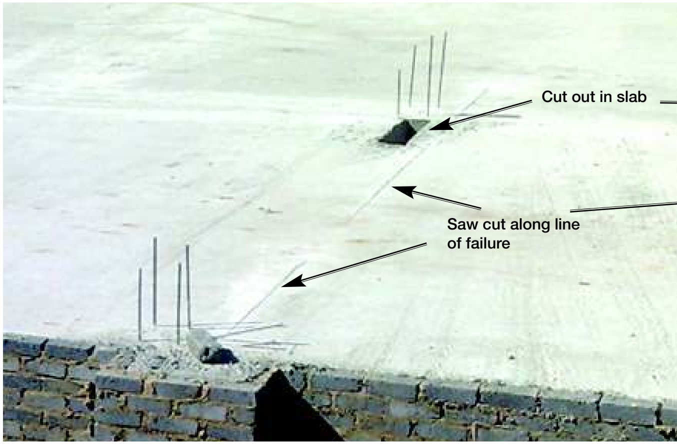
– ensure that the geotechnical report, where appropriate, and information relating to the loading that the building is designed to withstand and the methods and sequence of the construction process is made available to the contractor;
– not include anything in the design necessitating the use of dangerous procedures which could be avoided by modifying the design;
– carry out sufficient inspections at appropriate times of the



4a

4 a) Saw cuts in slabs: residue from saw cuts clearly visible, b) Detail showing saw cut along line of failure, c) Detail showing saw cut along line of failure, straight break along line of saw cut and bottom steel holding slab in place

5 a) Photographer's building, b) Balcony from which the photos were taken prior to the collapse, c) Collapse showing weak connection between slab and column, d) and e) The human cost of the collapse



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5a

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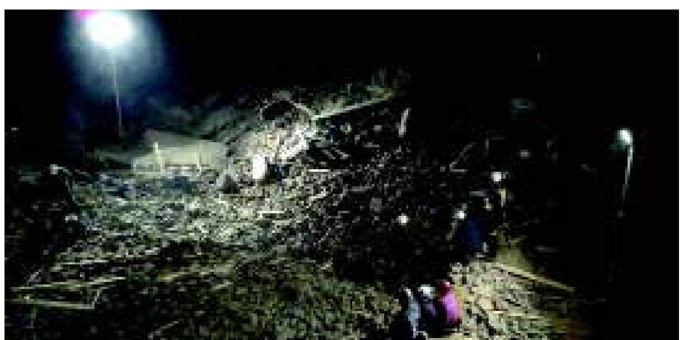

5e

construction work involving the design of the relevant structure in order to ensure compliance with the design;
– stop any contractor from executing any construction work which is not in accordance with the relevant design; and
– conduct a final inspection of the completed building prior to its commissioning to render it safe for commissioning and issue a completion certificate to the contractor.

What can be learnt from international studies into failures?

A recent study conducted at the Swiss Federal Institute of Technology in Zurich (www. matscieng.sunysb.edu/disaster/) analysed 800 cases of structural failure in which people were killed and injured. When engineers were at fault, the researchers classified the causes of failure in order of incidence as follows:
1) Insufficient knowledge.
2) Underestimation of influence.
3) Ignorance, carelessness, negligence.
4) Forgetfulness, error.
5) Relying upon others without sufficient control.
6) Objectively unknown situation.
7) Imprecise definition of responsibilities.
8) Choice of bad quality.

The photographic evidence of the Roodepoort collapse suggests that the causes of the failure would fall into categories 1, 2, 3 and 5.

What is the role of ECSA, have there been other examples in South Africa?

This Roodepoort collapse is not an isolated one. On 17 October, 1996, the third floor of the Northpark Mall in Pretoria collapsed during construction, killing four people and seriously injuring many more. This incident led to a historic decision made by the Engineering Council of South Africa (ECSA) in February 2002 to disqualify for the first time a professional engineer permanently from registration due to gross misconduct. The Committee of Inquiry, consisting of former Judge President Frikkie Eloff (Chair) and two senior professional engineers, found that one or more of the engineer's deficient construction techniques and in particular his failure to exercise proper supervision and to maintain records, contributed to the collapse. The findings of this enquiry suggest that the faults of the engineers fall within similar categories to that which might be ascribed to the engineer involved in the Roodepoort collapse.

How does South Africa compare with other countries in terms of numbers of failures?

ECSA does not publish particulars relating to the nature of the complaint. It is therefore impossible to establish linkages between actions (or lack thereof) of the engineers and particular structural failures. However, information in the public domain as to the number of persons disciplined by ECSA and the Engineering Council (UK) (ECUK) licensed institution, the Institution of Structural Engineers and the Institution of Civil Engineers, suggests that the incidence of transgression of the code of conduct in South Africa is an order of magnitude greater than that of these international bodies. It is well known that the vast majority of complaints dealt with by ECSA involve structural matters. If the number of cases involving structural matters is excluded from the comparison, the number of persons disciplined is of a similar order to that of the aforementioned UK institutions.

The National Registration Board which registers engineers in Australia on a discipline specific basis has, in a recent annual report, noted that many complaints against engineers result from poor business practices rather than failure to provide adequate technical advice. An analysis of published information on the disciplinary actions undertaken by the Institution of Structural Engineers supports this view. Anecdotal evidence and the high incidence of complaints surrounding structural matters suggest that this is not the case in South Africa – the provision of adequate advice relating to structural matters remains a problem.

The current system in South African relating to the management and control of structural safety in buildings failed the Malawian, Arnold Mwale (19) and the Mozambican, Arthur Nombora (24) who lost their lives in the Roodepoort structural failure. This very same system has also failed those who lost their lives in the 1996 Northpark Mall collapse, some 12 years earlier, despite the introduction of the Construction Regulations in 2003.

Can the system of building control and the managing of design risks be improved? Can South Africa benefit from the experience of other countries?

There are a number of international approaches to the regulation of the engineering profession, which fall into one of three broad categories:

Category I

Licensing: In this approach, an area of engineering work is linked to those persons who have demonstrated competence to perform such work. Licensing on a statutory basis prohibits unlicensed persons from performing such work. Non statutory licensing provides the public with lists of persons competent to perform work within an area of engineering, which may also be undertaken by non- licensed persons.

Category II

Registration: In this approach, those persons who demonstrate their competence against a standard and undertake to abide by a code of conduct, are awarded titles and are admitted to a register. Such registration may be governed by the laws of a country (statutory register) or the regulations or the rules set by the governing body of the profession which oversees the registration process and maintains the register (non-statutory register). Where governing bodies operate non-statutory registration, they may only use civil action to prevent non-registrants from using the title and are not empowered to restrict any area of work to registrants. (Statutory registration linked to the reserving of an area of work for registered persons has the same effect as statutory licensing.)

Category III

Specialist lists: In this approach, a professional or trade body administers a non-statutory voluntary listing of professionals who have met a defined standard of competence in a specialist area.

Broadly speaking:
– licensing (category I) authorises eligible persons to practise in a specific area,
– registration (category II) recognises demonstrated achievement of a defined standard of competency, and
– specialist lists (category III) indicate peer recognised competence in a particular area.

All these forms of regulation are linked to codes of conduct. Serious breaches of a code of conduct can lead to the withdrawal of a license, the loss of a title or the removal of the transgressor's name from a specialist list, either on a temporary or permanent basis.

The Engineering Profession Act (Act 46 of 2000) permits the Engineering Council of South Africa to consider and decide on an application for registration, prescribe the period of validity of registration of a registered person and keep a register of registered persons. It also permits the Council to determine competency standards for the purpose of registration and the nature and extent of continuing professional development. Accordingly, this approach to regulating the profession is a category II approach and merely looks at standards of competent performance at the entry level to independent professional practice within the broad engineering profession.

The register administered by the Engineering Council United Kingdom (ECUK) is also a category II register. Entry to this register is through one of it 36 licensed engineering institutes. This allows rigorous entry requirement to be set for specialist disciplines such as structural engineering and fire engineering. For example, admission to the ECUK as a chartered structural engineer normally requires the passing of an 8h written examination. Registers in several countries reflect the ECUK practice and register disciplines and specialist disciplines separately. For example, the United States Council for International Engineering Practice and the Institute of Professional Engineers New Zealand separately register civil, environmental, geotechnical and structural engineers.

Unlike the aforementioned registers, the ECSA register does not recognise specialist disciplines and only has a limited number of standing committees to peer assess candidates for entry to the register in categories such those covering aeronautical, agriculture, chemical, civil, electrical, industrial, mechanical, metallurgical and mining engineering disciplines and lift inspection. Furthermore ECSA does not attempt to define essential competencies or the scope of work associated with a particular discipline.

Building Regulations and codes differ from country to country and in some countries from state to state. There are accordingly no 'international building regulations'. Each jurisdiction approaches the management of health and safety risks associated with buildings differently. At the one end of the spectrum, Building Control Officers or Proof Engineers review the work of professionals who prepare submissions for building approvals for compliance with building ordinances or codes. At the other end of the spectrum, 'competent persons' are permitted to self certify their own work for compliance with requirements.

'What is clearly needed in South Africa is a more proactive approach to assessing the competence of those entrusted to certify structural safety of buildings'

For example, the Scottish Building Act 2003 was introduced by the Scottish Parliament with the aim of modernising the Scottish Buildings Standards system. This legislation has introduced a self certification system as an alternative to the process of submitting a scheme to the Building Control Officer to speed up the process of obtaining a building warrant. Structural Engineers Registration Limited was appointed by the Scottish Buildings Standard Agency (SBSA) to operate a Scheme for registering Approved Certifiers of Design (Building Structures). The Scheme operates on the principle that suitably qualified and experienced Chartered Structural and Chartered Civil Engineers may be made responsible for certifying that designs for building structures comply with the Building (Scotland) Regulations 2004, provided that they work for reputable firms which operate a system of checking.

British Columbia, Canada, on the other hand, started registering structural engineers in 2003. Registration is open to professional engineers who can demonstrate suitable experience in structural design. Applicants have to pass an interview, an in-depth exam and a local codes and practices exam. Registered structural engineers are required to be active in the practice of structural engineering and to comply with CPD requirements to retain registration.

Registration in Washington State as a structural engineer (SE license) requires registration as a professional engineer (PE license) followed by two 8h structural exams: the Structural II exam which is prepared by the National Council of Examiners for Engineering and Surveying (NCEES), and the Structural III exam prepared by the Washington State Board of Registration for Professional Engineers and Land Surveyors. The Structural III exam is focused on seismicity, reflecting the requirements of structural designs in the Pacific Northwest.

The management and control of risks relating to structural safety depends primarily on the competence and integrity of individuals and organisations. The possibility that individuals or organisations might not be competent, or that their competence might be affected by commercial or other pressures is a risk to structural safety. The certification of structural safety-related work should be entrusted only to competent persons i.e. those people who are qualified by virtue of their education, training, experience and contextual knowledge to assume responsibility for structural safety.

Lessons learned

The prevailing self certification system at the time of the Roodepoort collapse in the National Building Regulations, which is linked to the ECSA registration system unfortunately appears to have been an ineffective way, in this case, to regulate structural safety in buildings as it does not recognise structural engineering as a sub discipline of civil engineering. This unfocussed system of registration does not provide a basis for owners or developers of buildings to identify who is competent to assume responsibility for structural safety when procuring the services of built environment professionals.

Self certification in the absence of a registration system as is the case in the Construction Regulations is even less effective as it relies solely on the integrity of the individual in the absence of a code of conduct which is enforceable by a governing body.

What is clearly needed in South Africa is a more proactive approach to assessing the competence of those persons entrusted to certify structural safety of buildings in terms of National Building Regulations and the Construction Regulations. A licensing or specialist list approach is needed. It is interesting to note in this regard that the reports from all three commissions at the Occupational Health and Safety Construction Summit, convened by the Minister of Labour in Boksburg on 11 November 2008, recommended the putting in place of publically accessible lists to enable competent persons to be readily identified.

The issue of an independent review of aspects of the design such as the design philosophy, design assumptions, the robustness of the structure and design interfaces, in large and complex buildings also needs to be considered.

The time is ripe for improving structural safety in South Africa and there are several opportunities to do so. There are a number of initiatives which could potentially contribute to improving the quality of the certification of the structural safety performance of buildings. These include:

– The Built Environment Professions Bill which for the first time recognise specialities within a profession and proposes that the registers of professionals held by the proposed council reflect the speciality of registered persons.
– The amendments to the Construction Regulations 2003 which are currently being finalised by the Minister of Labour.
– The implementation of the recent amendments to the National Building Regulations which have extensively amended the requirements for the appointment of persons responsible for the design, inspection and assessment duties and establish minimum requirements for competent persons to demonstrate their credentials. (These Regulations can only be implemented when the third edition of SANS 10400 is published.)
– The code of practice for structural engineering which is being developed by ECSA.

The decisions that are made in finalising the aforementioned regulatory instruments will determine the level of risk to structural collapse which workers during construction or occupants during the working life of a building will be exposed to.

* The authors are members of the Joint Structural Division of SAICE and IStructE and Fellows of both Institutions.
** All the photos in this article are taken Andre F. Bruton from a website which contains a sequence of photographs showing the development of an office park and then the disaster that happened when half of it collapsed on 16 October 2008. See web: (http://picasaweb.google.com/andrebruton/HowToBuildAnOfficeParkCollapsedBuildingSite). These photographs are in the public domain.

relevant national instititution?

Why should SER be a limited company; surely being a 'trading subsidiary' may be in conflict with the public's interest?

Self certification is a good principle; but surely chartered engineer status is sufficient for this?

Dr Sue Doran, Director, Technical and Engineering, who oversees the SER/SCR scheme at the Institution has replied:

Mr Morrison appears to be misinformed in that the use of an Approved Certifier is not compulsory in Scotland. It is also possible to obtain a Building Warrant by submitting calculations etc to the local authority.

From 1992 until the current system was implemented in 2005 (as a result of the Building (Scotland) Act 2003), a system of self-certification which only required chartered membership of either the Institution of Structural Engineers or the Institution of Civil Engineers in order to be able to sign certificates operated. This was found not to offer the necessary degree of rigour to safeguard public safety.

The Scheme of Certification of Design (Building Structures) operated by SER on behalf of the Scottish Government Building Standards Division (BSD) was developed by a Joint Working Party of both Institutions and has their full support. The members of the Scottish Registration Board who assess applications and undertake audits of the certification practice of scheme members are all senior members of the profession. SER itself is subject to regular audit by BSD.

Certifiers are required to take a holistic view of the design of the entire structure. Appropriate checking procedures are integral to the scheme and it should be noted that except in the case of structures falling into the lowest risk category true self certification is not permitted.

The Scheme requires that all members are of Chartered status within one or other of the Institutions. Membership of both Institutions is open to those who originally qualified in all parts of the world.

Further details of the Scheme and its requirements may be found on the website (www.ser-ltd.com).

Collapse at Roodepoort, South Africa

Ernest Horwood, writing from South Africa, has sent us the following comments on the Viewpoint by Spencer Erling and Ron Watermeyer, published in the journal on 19 May concerning the collapse of a 250mm thick slab at Roodepoort, South Africa.

The Viewpoint mentions that the thickness of the slab in question 'is much thinner than that recommended in terms of SANS 10100-1 for the design opted for'. As a result, the deflection of the slabs would most likely have been visible to the naked eye once the props had been removed. What utter nonsense. Assuming that the span was 7.5m with saw cuts? It is assumed that the member would span in one direction simply supported.

The slab thickness was 250mm. The factored loading would amount to 12.4kN/m^2 assuming a characteristic live load of 2.5kN/m^2 which of course would not be there during construction. The bending moment would be 87.19kNm. Area reinforcement required 1100mm^2 and resistance moment 181.5kNm assuming working stress of 25MPa for concrete and 460MPa for high yield reinforcement.

However, in general I thought the article was concisely written and I have no quarrel with the rest. Why on earth an engineer would specify saw cuts in a suspended slab I cannot imagine. As stated saw cuts are only applicable in ground slabs to relieve stresses due to shrinkage or more properly confine the crack to the joint. In my experience very often the crack appears anywhere but in the joint.

I live in South Africa and I must admit that local authorities are very lax in their approach to checking of calculations or indeed visiting building sites. A 'competent' person is required to sign submission forms and under no circumstances can any responsibility be borne by the city engineer or any of his staff. In the case of the Roodepoort collapse I wonder whether a submission form was ever signed by a qualified engineer or indeed whether a council employee ever visited the site?

I would be interested to know what other engineers think of the 250mm thick slab spanning 7.5m and the probability of excessive deflection.

My thanks to Ernest for these comments which were forwarded in advance of publication to Ron Watermeyer and Spencer Erling for a view on the adequacy of the 250mm thick slab. Their reply is as follows.

The flat slab provisions of SANS 10100-1 (which is derived from BS 8110) could be applied. The actual span-to-depth ratio provided was around 33 (7500 / (255 – 26)). In a conventional flat slab, SANS 10100-1 recommends a basic span:depth ratio in the most critical area (end slab) of 24 × 0.9 = 21.6. Because the actual ratio exceeds this figure, this would require a modification factor for reinforcement of 1.5. This is normally achievable and a 255mm slab would have sufficed.

However, if the slab cannot transfer moments across the columns due to the provision of insufficient top steel, the recommended basic span:depth ratio for a simply supported flat slab reduces to 14.4. The required modification factor in this case would be 2.3 which is above the limiting value of 2 for a slab with tension steel only. The introduction of the saw cuts and the omission of top steel to transfer moment across and to the supports, results in the slab being effectively supported on four corners, in which case the span:depth ratio should be based on the span with the highest stiffness, which is in this case across the diagonal. Accordingly, the effective span is likely to be around 10.5m. Thus the effective span:depth ratio provided increases from 33 to over 45. Excessive deflections are thus most likely to occur.

Site visits by the authors after drafting the article confirmed these predictions. 90 to 100mm deflections were visible to the naked eye. The brickwork on the gable ends indicated that the bricklayers (in their 'structural ignorance') had attempted to compensate for this deflection by cutting bricks and using bricks on edge in the first course above the slab to achieve horizontal brick lines above the compensating level. The reinforcement also appeared to be Y12 at 250mm centres in which case the slabs had 0.2% reinforcement i.e. little more than nominal steel.

Tony Aimer, the vice chair of the Joint Structural Division and chief investigator for the Department of Labour, who was responsible for overseeing the safe collapse of the structure on 13 June 2009, communicated to the authors that '*The demolisher was breaking away the first portion of the north west corner adjacent to the existing building and without warning the whole structure collapsed in not more than 3sec – too short a time for me to get my video camera lifted up from waist level! It was on and ready to roll. This means that the structure was standing on the brink of failure the whole time….*'

Thankfully, the building is now demolished and is no longer a hazard. What is clearly needed in South Africa is a more proactive approach to assessing the competence of those entrusted to certify structural safety of buildings.

I thank both Ron and Spencer for this very detailed response.

A further letter has also been received from Rob Young – the South African representative on the Institution's Council – who has drawn attention to the inadequacies of the registration of structural engineers in a number of countries which can potentially manifest itself in failures such as that which occurred at the three-storey building in Roodepoort, South Africa.

It [the report] highlights the international inadequacy of specific registration for the practice of structural engineering. Linking a tragic collapse to this issue, apparently due to the incompetence of a structural engineer, further focuses this point. Although the individual will be disciplined through a Code of Conduct legislated process in South Africa, potentially with the loss of Professional Engineering Registration, the case could have been prevented at source, had specific registration been in place.

It should be noted that the Institution, through the Joint Structural Division with the South African Institute of Civil Engineering, is actively involved in addressing this issue, particularly with the development of a Code of Practice, as opposed to a Code of Conduct, for Structural Engineering, for issue later this year.

Not withstanding this viewpoint, it should be recorded that the state of structural engineering in South Africa is of high international standard, most structural engineers aspiring to achieve excellence in their field. The problem lies with the shortage and lack of skills at the entry level and inexperienced members of the civil engineering profession dabbling in structures.

The opinion of members of the status of registration of structural engineers in other countries would be a welcome contribution, either through this column or direct to the International Interest Group care of the Council.

My thanks to Rob for this contribution. As Rob says, the opinion of members in other countries (where registration may be mandatory) would be most welcome.

Emails can be sent to Verulam via: (verulam@istructe.org).
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