STRUCTURAL ENGINEERING TO MEET THE CHALLENGES IN SOUTH AFRICA

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Structural Engineering to meet the challenges in South Africa

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AANGAANDE DIE OUTEUR

Jan Wium is op 15 September 1957 in Johannesburg gebore. Reeds op laerskool in Menlopark in Pretoria het hy meer ambisie gehad om ’n professionele tennisspeler te word as ’n professionele ingenieur, maar toe kies hy die maklike pad en gaan studeer ingenieurswese aan die Universiteit van Pretoria. Na afloop van sy studies, waartydens hy in 1978 die Dirk de Vos toekenning vir die mees veelsydige ingenieurstudent ontvang, volg sy militêre opleiding by Genieskool in Kroonstad.

Sy professionele loopbaan het in 1982 in die brugafdeling by Africon begin (destyds bekend as Van Wyk en Louw Raadgewende Ingenieurs). Tydens die eerste paar jaar van sy loopbaan kon hy sy passie vir brûe as ingenieur-in-opleiding uitleef, o.a. tydens ’n jaar se konstruksieondervinding by LTA.

In 1984 is hy voltyds na die Universiteit van Pretoria om sy meestersgraad, wat oor vibrasie van masjienvoetstukke gehandel het, te voltooi. Terug by Africon het hy by veelvuldige eindige-elementanalises op gebou-projekte betrokke geraak.

In 1985 is hy getroud met Hermien en in 1988 is hulle saam na Lausanne in Switserland waar hy na vier jaar sy PhD aan die staalinstituut van die *Ecole Polytechnique Fédérale de Lausanne* (Switserse Federale Instituut van Tegnologie in Lausanne) behaal het.

Met hulle terugkeer na Suid Afrika in 1992 het Jan Africon se struktuurontwerpe in Durban behartig by die Pinetown kantoor. Toe daar in 1995 ’n geleentheid ontstaan om vir Africon in Maleisië te gaan werk, het hy dit aangegryp. Vir die volgende drie jaar het hy as hoofstruktuuringenieur van ’n projekbestuurspan aan ’n ligtespoorvervoerprojek met ’n waarde van $2 000 miljoen in Kuala Lumpur gewerk. Die verskeidenheid strukture van die projek het onder andere gewissel van bogrondse stasies en brûe tot ondergrondse stasies en tonnels.

In 1998 sluit Jan weer aan by Africon se kantoor in Pretoria waar hy in 2000 ’n divisiedirekteur word. Hy was verantwoordelik vir die ontwerp en skakeling van ’n verskeidenheid gebou-struktuurprojekte en brugbestuurstelsels vir stadsrade en provinsies.

In 2003 het ’n geleentheid by die Universiteit Stellenbosch daartoe gelei dat hy Pretoria en Africon vir Stellenbosch verruil het. Sedertdien is Jan verantwoordelik vir onderrig op voor- en nagraadse vlak. Sy navorsingsbelangstelling is betonstrukture, die seismiese gedrag van strukture en struktuurdinamika. Hy behou steeds goeie kontak met die praktyk.

Jan is die voorsitter van die Suid-Afrikaanse Instituut van Siviele Ingenieurs se subkomitee wat omsien na die hersiening van die belastingskode vir aardbewingkragte op geboue. Hy dien in die redaksionele komitee van *Structural Engineering International*, die kwartaalblad van die *International Association for Bridge and Structural Engineering*.

Jan en Hermien het twee kinders, Danie (13) en Elise (10).

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INTRODUCTION

The ever-evolving world of social, economic and political changes affects the way in which people live. Demands are continuously made on the structural engineering profession to fulfil its task of providing and maintaining infrastructure in this ever-changing world by also having to implement and apply changes in technology and techniques as new developments take place.

The structural engineer applies his profession as a service to the community, where apart from providing resistant and durable structures, demands are made which include the need to provide employment, to ensure work in safe environments, and to perform his tasks in an economical and profitable manner. Within an ever-changing economic and political environment, the structural engineer is not only exposed to technical challenges, but is forced to apply the trade within changing boundaries.

For the uninformed the profession can be seen as one which has developed over many centuries to a well-established and mature activity. Advances in the profession are often thought of as technological improvements in new materials and techniques, and these are often associated with the provision of infrastructure in first world conditions, where sufficient funds are available to implement and use new materials and methods. In the case of a developing country, there may be perceptions that the old and mature profession of construction has been established well enough to fulfil the construction needs of the developing country.

However, the economic and social pressures in the developing country often require new and improved methods to provide much-needed infrastructure to the community, and these markets require innovation as much as developed regions do. Furthermore, it is often the advances in structural engineering which prove vital for protecting exposed communities from the forces of nature.

This paper presents an overview of the way that some of these challenges are addressed for the South African market. Two of the broader research focus areas in structural engineering at the University of Stellenbosch are outlined. The one focus area addresses the challenges to the profession on an economic, social and technical level, while the other considers the risks posed by nature. Although the subjects addressed in the paper are in essence not specifically limited to concrete construction, the focus in this paper is placed on the research as it relates to concrete structures.

First, the concept of Hybrid Concrete Construction is presented. This approach applies recent advances in structural engineering in order to deliver projects in a faster, safer and more economical way, which makes it ideal for current conditions in South Africa. A current research programme is described.

Secondly, the subject of earthquake-resistant structures in South Africa is presented. Although not considered as a region of high seismic activity, there are nevertheless certain areas within the country where structures need to be designed for earthquake action. The challenge is not to be overly conservative by providing expensive facilities, but to provide economical yet safe structures.

HYBRID CONCRETE CONSTRUCTION

Background

South Africa is currently facing a serious shortage of engineers, technicians and other skilled workers in the construction industry. Being a developing country, with a positive growth rate, it is expected that the current growth in construction activities will prevail at least until 2011. Even beyond that date, the demand will be high on the construction industry to provide infrastructure for the growing population (Lawless, 2005).

Research done by Lawless (2005) found that the number of professionals will have to be increased dramatically if the country is to tackle service delivery in all forms, including legal, financial and infrastructural. Unfortunately the number of professionals in South Africa is slowly declining at the expense of service delivery and poverty reduction.

The country currently has approximately one engineer per 3 100 members of the population. This is in contrast to figures of between 125 and 500 for first world countries, and figures of 450 and 680 for Argentina and Chile respectively. In order to bring the number of members of the population per engineer in South Africa to 2 300, approximately the same figure as the ratio for Korea, the number of engineering graduates has to be improved immediately by 50% from the current level over the next ten years. This figure excludes negative influences because of emigrations, retirements and engineers leaving the profession, and discounts the fact that an increase in engineering students can have an effect only 4 years from now.

The shortage of skills in the construction industry clearly places high demands on designers and contractors to provide services and to realise projects in ever-reducing time periods and at less cost. These conditions, in a growing economy, augmented by the shortage of manpower, make it increasingly difficult to maintain quality of construction in an industry where mistakes can lead to disastrous consequences. Some examples can be cited of recent structural failures in South Africa, often a result of inadequate quality control or lack of experience.

A well-recognised need therefore exists to seek and identify ways and means by which the delivery rate of projects can be improved, whilst maintaining (or improving!) the quality of the product and the safety of the process. This will entail devising means to safely deliver construction projects on time, within budget, at a high quality and using techniques and methods of a high technological level.

South Africa is not the first or the only country to experience these challenges. Similar conditions have forced the United Kingdom and other countries to address these problems, and some valuable lessons can be taken from their experience and an approach can be tailor-made for the South African market.

Having recognised these and other problems specific to its own conditions, the United Kingdom investigated the concept of Hybrid Concrete Construction. This document draws attention to this construction method and explores a way forward for introducing it into the South African industry.

Definition

The Concrete Centre is the central development organisation for the United Kingdom cement and concrete industry and its aim is to assist all those involved in design and construction to realise the full potential of concrete.

The Best Practice Guidelines for Hybrid Construction (Goodchild, 2004), published by the Concrete Centre in the United Kingdom, defines Hybrid Concrete Construction (HCC) as "*a method of construction which integrates pre-cast concrete and cast in-situ concrete to take best advantage of their different inherent qualities. The accuracy, speed and high-quality finish of pre-cast components can be combined with the economy and flexibility of cast in-situ concrete.*"

In essence, the advantages of pre-fabrication in terms of quality, form, colour, speed, accuracy and prestressing are combined with the advantages of in-situ construction such as flexibility, mouldability, durability and robustness.

Although the pre-cast industry (pre-fabricating elements of a structure off site) has had various levels of success in the past, attention is once again being drawn to this method in the industry. Recent advances in structural materials, systems and the way in which projects are handled now enable a new look at the possibilities of combining pre-fabrication with on-site work. Experience in the UK has shown cost savings of up to 30% using hybrid construction over more conventional structures.

Benefits

The advantages of hybrid construction are summarised below.

- Cost: The cost of a structural frame for a building often makes up between 10% and 15% of the project cost. However, choosing the correct structural system has implications for external finishes, on ceilings, management of services, and rentable floor areas. Furthermore, execution time is directly associated with project cost. By considering all aspects of a project, definite cost advantages have been shown in the United Kingdom experience.

- Speed: Erection speed is increased by off-site fabrication in controlled conditions. But this requires dedicated attention to details and co-ordination from the start of the conceptual phase of a project.
- Buildability: The system is devised in team context. The nature of the pre-planning and resolution of construction issues at an early stage make this one of the key advantages of hybrid construction.
- Construction: The reduction in on-site formwork as opposed to conventional construction results in time and cost savings. Furthermore, it also reduces the need for skilled on-site labour, which, given the shortage in skilled workers, is one of the main reasons advocated for this type of construction.
- Safety and quality: The potential for accidents is reduced. A high proportion of work is carried out by skilled workers in the factory environment, where safety and quality can be better controlled.

Existing objections and possible solutions

Recognising the benefits of an approach where pre-fabrication and on-site work can be combined, it is now perhaps useful first to identify a broader reason why this method of construction has not yet gained much support in South Africa.

Traditionally, construction projects have been realised by project teams often consisting of a client, various professionals, and a contractor, each working more or less as a separate entity. The nature of this traditional arrangement is most probably the real reason why the concept of hybrid construction has not developed to an extent at which the industry can reap real benefits.

Recent trends are to form project teams in design-build-operate ventures, or in design-build operations. Such an approach enables the concept of hybrid construction to come to its full potential. In this way designers, contractors and clients can be involved as a team from an early stage. Conceptual design can incorporate construction requirements, and the full potential of prefabrication and on-site works can be applied where it is most effective.

Although technical solutions may be needed for which current technology can be applied to address specific issues, the real challenge is understanding customer requirements, and incorporating the strengths and weaknesses of the individual specialist requirements into a design. This calls for managers who are skilful in facilitating communication, co-operation and for evoking a team spirit on a project.

Advances in structural materials and systems

Recent advances in structural materials and systems include the application of high-strength concrete, engineered fibre-reinforced concrete and self-compacting concrete.

Much research has been conducted on these advanced materials, and the knowledge and benefits are now ready to be applied to the advantage of the industry (Barragan *et al*., 2005; Jooste, 2006; Zilch, 2006). Where connections between pre-cast concrete elements have traditionally been an obstacle to its wider application, especially from an aesthetic viewpoint (refer to Figure 1), it is believed that many of the earlier problems can now be addressed successfully by the application of newer technologies and materials.

FIGURE 1*:* Pre-cast elements in conventional building construction.

Current research project

For the above reasons, a study is now being undertaken at the University of Stellenbosch to investigate the concept of Hybrid Concrete Construction for South African conditions. The research project includes an investigation of the following aspects, each of which merits a detailed study on its own:

- International trends (to avoid a re-invention of the wheel!)
- Investigation into the magnitude of the segments making up the South African construction industry, in order to determine where HCC may be of the highest benefit. This may entail a study of any of the following:
  - residential property market
  - commercial property market
  - industrial property market
- Characteristics of high-performance concrete and the quantifying of parameters for:
  - high-strength concrete
  - fibre-reinforced concrete and cement-based composites
  - self-compacting concrete
- Identification of example projects
- Identification of skills required such as:
  - managerial skills
  - technical skills and knowledge
  - special labour skills
- Contractual implications and project delivery models

Early indications are that some of the larger South African construction companies apply the concept of Hybrid Concrete Construction to specific and limited projects. The application is limited to the creativity and initiative of a small number of individual project managers in a company.

In order to make the concept available to a broader base of companies and employees, specific skills will have to be developed. The necessary technical and managerial information needs to be quantified and presented in a format so that the construction industry will be able to reap the benefits across a broad spectrum of projects.

Having now presented a way in which the delivery of projects can be improved in spite of the shortage of skilled manpower, and still maintaining quality and safety, the remainder of the paper will take a look at the effect of earthquake actions on the provision of building structures.

EARTHQUAKE-RESISTANT STRUCTURES IN SOUTH AFRICA

The following paragraphs discuss the design of earthquake-resistant structures in South Africa. It is demonstrated that some areas in the country are subjected to seismic risk and that careful consideration of applied actions and of structural layout and details is required in the design and construction of building structures. On the one hand, structures must be safe and reliable, but on the other hand, earthquake provisions should not be overly conservative, resulting in uneconomic structures in a country which can ill afford it.

Background on seismicity in South Africa

Reports of seismic events in South Africa have been recorded since 1620, but a scientific record of events has largely been kept only for the past 30 to 40 years. The Southern African region is known for its relative seismic stability and only a small number of medium-intensity earthquakes have occurred since the seventeenth century. On the other hand, between 40 and 60 tremors occur monthly, focused primarily in the gold-mining areas of Gauteng, North West Province and the Free State. Although the effects of these events are far from being as serious as those caused by the larger earthquakes, extensive damage has occurred in one or two cases (Milford, 1991). The largest event recorded to date in South Africa was the main shock of the Ceres earthquake of 29 September 1969 which registered a magnitude of 6.3 on the Richter scale.

It may be of interest to note that an earthquake measuring 6.1 on the Richter scale shook western Iran on 31 March 2006, killing at least 70 people and devastating several villages. More than 1 200 people were injured. These effects should, however, be considered in the light of the type of construction in the region, as it was reported that brick buildings collapsed and mud homes were severely damaged.

Internationally the basis of structural design for earthquake action is the expected nominal peak ground acceleration with a probability of exceedance of 10% in 50 years. An updated seismic map for South Africa was published by the South African Council for Geoscience in 2003, showing values of nominal peak ground acceleration (Figure 2). Magnitudes of as high as 0.20 g can be seen on the map, notably in the Western Cape region, in parts of the Free State and in the western part of the Witwatersrand. To provide a perspective on the magnitude of these values, it may be of interest to note that the corresponding design value is 0.40 g for areas of high seismicity in regions such as California and Japan.

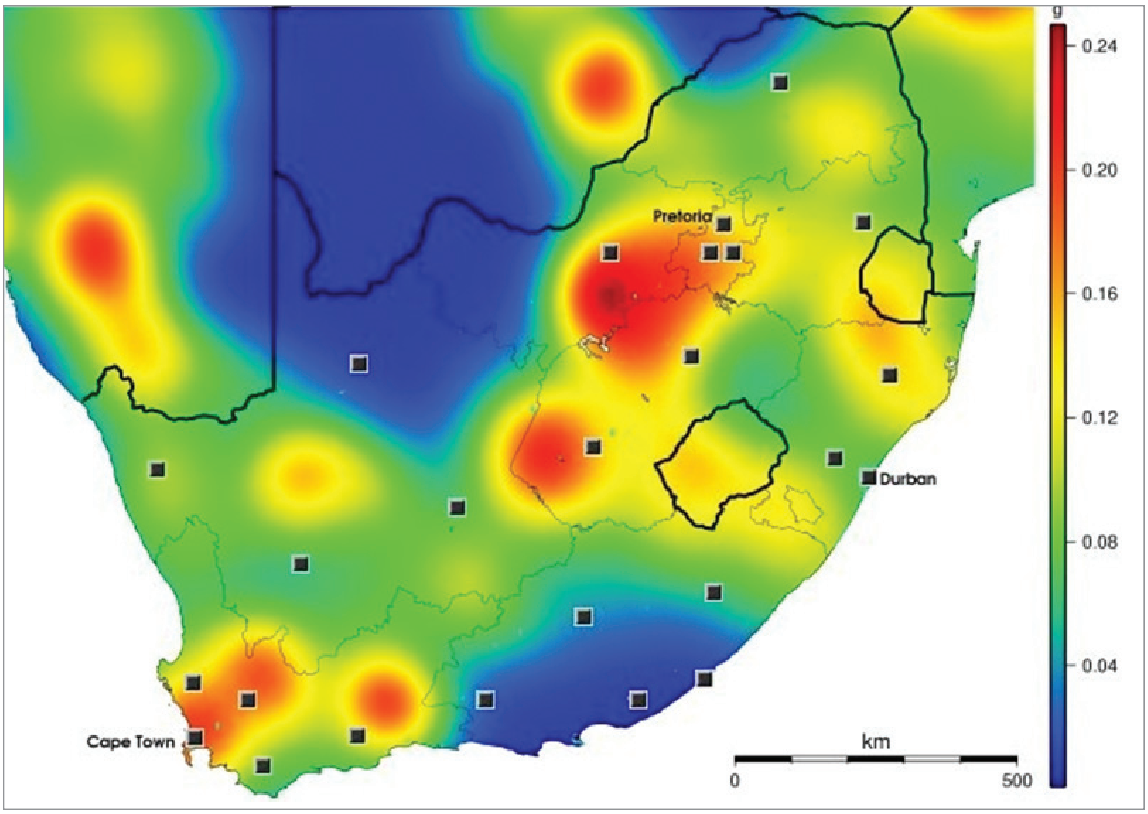

FIGURE 2: South African seismic hazard map: Nominal peak ground acceleration in g (gravity acceleration) with a probability of exceedence of 10% in 50 years (Kijko, 2003).

The seismic-event catalogue used to compile this map for South Africa is based on many different sources, covering a period of time from 1620 to December 2000. The catalogue consists of natural, as well as mining-induced seismicity (Kijko, 2003).

The seismically active areas in South Africa are broadly divided into two groups, namely those where activities are due to natural seismic events, and those due to mining activity. Clearly, regions for mining-induced activity are located in the mining areas of the country. It has been shown that mine tremors are not likely to produce any significant structural response for buildings with first natural frequencies of vibration less than 2 Hz. Stiff structures such as low-rise (1 to 3 storeys) load-bearing masonry structures are therefore influenced the most by mining tremors (Milford, 2003).

It is important, however, to recognise that some parts of South Africa can at most be considered to be located in regions of moderate seismicity (and not high seismicity). Care must be taken not to over-react by providing conservatively strong and expensive buildings. The challenge is to base the design of structures on appropriate estimates of expected seismicity, and furthermore to provide designs which are appropriate for the expected level of activity. It can be shown that appropriate detailing of reinforced concrete and correct conceptual layouts will go a long way towards providing safe seismic-resistant structures in areas of moderate seismicity.

Background on seismic design in South Africa

Provisions for the design of structures against earthquake actions were introduced into the South African Loading Code for buildings in 1989 (SABS 0160, 1989). The Code identified two zones of earthquake activity, namely Zone I areas for those regions with natural seismic activity, and Zone II areas for those regions with mine-induced seismic activity.

The Code requires that conceptual layout of buildings in both Zones follow certain recommendations, but only Zone I areas (natural seismic activity) required seismic design of buildings for a specified nominal peak ground acceleration. The specified value is 0.1 g, which is significantly different from the values published by the Council for Geoscience (Figure 2).

A study by the Federal Emergency Management Agency in the United States (FEMA, 1994) has shown that the costs for seismic rehabilitation of buildings can be between 15% and 28% higher, if the magnitude of the nominal peak ground acceleration is doubled. Similar economic impact figures are required for South Africa, to be used in the process of defining an appropriate nominal peak ground acceleration value for the country.

Ever since the publication of the Code in 1989, designers in the Western Cape have considered the provisions to be unrealistic and too stringent. Under an initiative from the Department of Civil Engineering at Stellenbosch University, a meeting was held in 2003 with a group of designers in the region which revealed that some designers, although being aware of Code requirements, often apply the rules in a way to suit the economic pressures and requirements of clients, rather than to fulfil the spirit of the Code. This practice often occurs because designers do not themselves feel convinced about the Code requirements. It was felt that this situation was the result of inadequate consultation and involvement of the broader engineering fraternity when the provisions were compiled, and without adequate information sessions at which the need for seismic provisions in the Code could be explained. A general lack of knowledge and commitment with regard to seismic design of structures was expressed by several practitioners.

A need was thus established in 2003 to re-evaluate the 1989 Code provisions (SABS 0160, 1989) with three objectives in mind:

- The first objective was to determine whether the Code provisions were realistic.
- The second objective was to gain the support of the industry by either confirming the Code provisions, or by issuing a revision to the existing Code.
- The third objective was to improve knowledge in the industry about the basic principles of seismic design.

Having recognised the historical objections to, and lack of confidence in, the existing Code (SABS, 1989) amongst designers, it was decided in 2004 to establish a local seismic load sub-committee in the Western Cape region. The sub-committee was to report to the South African Institute of Civil Engineers' Committee (SAICE) for the revision of the loading code SABS 0160 (1989), a process which at that time had been in progress for a period of time. The sub-committee consists of academic staff from Stellenbosch University and of representatives from consulting engineering firms in the region. The chosen process ensures that designers become involved in the process themselves, thereby creating legitimate support for any revisions to the Code. The Western Cape sub-committee had monthly meetings and reported to the SAICE Committee tasked with the revision of the entire loading code SABS 0160 (1989).

Once established, the Western Cape sub-committee embarked on a process of revision of the seismic provisions of SABS 0160 (1989). The process consisted of comparison of the existing Code (SABS 0160, 1989) with international codes, including the Eurocode (prEN 1998-1), Uniform Building Code (1997), SIA 261 (2003) and provisions from the ACI Code (2002). Considering the time frame within which a revised code had to be produced, it was decided to use the existing Code as reference document, and to revise provisions where sufficient information merited such changes. Code provisions were therefore not revised unless changes could be justified by reference to other codes or to existing research results. The objective would be to identify those issues which need more clarification, eventually to be addressed in a longer-term research programme.

The process of revision thus had the following results:

- Some provisions of the existing code were identified for revision
- Shortcomings of the existing code were identified
- Items which required further research were identified

Each of these three result groups is briefly discussed in the following paragraphs.

Items to be revised in SABS 0160 (1989)

The comparison with other codes identified the need to update the provisions for several items in the South African code. These included:

- Load factors: International codes consider seismic events to be an accidental condition with a load factor of 1.0 in the ultimate limit state (structural strength), whereas the South African code used a factor of 1.6.
- The limitations of design methods of the simplified methods in the existing Code are not well defined.
- The formula for calculating the value of the first natural period is outdated for a structure constructed with a reinforced concrete shear wall. Considering that the large majority of structures over 3 storeys in height are constructed this way, it was important to revise the formula.
- The design response spectra are outdated. These are curves showing the amplification of the earthquake effect on a building as a function of its lateral rigidity, and as a function of the local soil conditions.
- The importance of certain requirements for conceptual layout is now more emphasised in the revised Code. Figure 3 shows the effect on structures subjected to seismic action when constructed with inappropriate conceptual layouts.

Shortcomings of the provisions in SABS 0160 (1989)

The existing Code (SABS, 1989) gives little or no guidance on some items. These include:

- Detailing rules: the correct detailing (placement of reinforcement) of structures is imperative for the behaviour of structures subjected to seismic action. These detailing rules are now incorporated into a revision of the Code.
- Displacement criteria: The provisions in the code now allow the designer to determine the limits of displacements.
- Load-bearing masonry: Considering the large number of structures built in South Africa using un-reinforced load-bearing masonry construction (such as low-rise housing and commercial developments), additional clauses were added for this type of construction.

FIGURE 3: The importance of correct conceptual design is illustrated by the effect of an earthquake on buildings with soft storeys (Bachmann, 2003; Sezen *et al.*, 2000).

Further research required

During the process of Code revision, several items were identified which could not be resolved without further research. Some of these items are listed below and now form part of the research aims of the department of Civil Engineering:

- Definition of the magnitude of the design nominal peak ground acceleration
- Detailing of reinforced concrete shear walls for South African load magnitude and materials
- Requirements for un-reinforced load-bearing masonry as it applies to South African practice
- Repair mechanism for buildings with soft storeys
- Design of foundations to prevent overturning of structures
- Details for fixing pre-cast floor systems to load-bearing masonry walls.

SUMMARY AND CONCLUSION

The structural engineer plays an important role in the provision of infrastructure for the country. In order to meet the requirements of project delivery, new and improved techniques are required. The search for improved methods is even more important in the light of a reducing skills pool, which results in lack of safety and lack of quality.

The paper presents a research project which investigates an approach where projects can be delivered at a faster rate, at reduced cost, while at the same time improving quality and safety.

The paper also draws attention to the role of the structural engineer in accommodating forces of nature in the design and construction of buildings. Developments in the earthquake design code for South Africa are presented, and the need to develop techniques where the financial impact on projects can be minimised is emphasised.

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