NEW ZEALAND GEOTECHNICAL SOCIETY INC

A Collaborating Technical Group of The Institution of Professional Engineers New Zealand

Canterbury Earthquakes Royal Commission
NZGS Submission on Discussion Paper: Roles and Responsibilities
13 August 2012

INTRODUCTION

The New Zealand Geotechnical Society (NZGS) is a Collaborating Technical Society affiliated to IPENZ and represents geotechnical practitioners and academics (engineers, engineering geologists and other geoscientists). The Society's principal aims are to promote the study and knowledge of geotechnical engineering and geosciences, to disseminate that knowledge and to provide a forum for those interested in the geotechnical field to communicate among themselves and with others outside the field in an effort to promote education and the advancement of both geotechnical engineering and geosciences.

As such NZGS is interested in the technical and scientific 'lessons learned' relating to ground behaviour, the performance and adequacy of existing codes, standards and statutes relating to building development and other land use, and the improvements/changes to codes, standards and statutes that might be warranted.

SUBMISSION

The following paragraphs contain the response of NZGS to the questions raised by the Royal Commission in the document 'Discussion Paper: Roles and Responsibilities'. We have responded only to those questions that the Society considers relevant to the geotechnical profession and where it is felt we can be of assistance to the Commission.

Efficacy of Building Regulatory Framework

Question 3. What are your views on the model proposed by IPENZ?
NZGS concurs with the model proposed by IPENZ, as clarified in its submission on this question, and in particular that a new standards model is needed that differentiates between regulation-driven standards and standards that are voluntary and business-enabling.

Standards Development

Question 1. What, if any, are the weaknesses, (e.g. omissions, failures, impediments) in the current building regulatory framework in relation to the process for developing requirements for design and performance of buildings for or in earthquakes?
The ground on which a building is located is integral to the building's performance in an earthquake. The ground is an inseparable part of the building, and foundation design needs to be integrated into a building's structural design to ensure adequate performance. In effect, the performance requirements of the ground must be equal to or better than the performance requirements of the building and its foundations. This typically occurs in practice but the quality of the integration of geotechnical foundation design and structural design can vary. A gap in design and construction can occur because foundation performance of a building also depends on the performance of the ground adjacent to a building and possibly extending for some distance beyond. Thus a geotechnical assessment broader than just assessing the foundation requirements of a building may be necessary.

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Whilst geotechnical elements of building design can have a fundamental bearing on the performance of a building in an earthquake, there are no minimum standards and little guidance on the approach for geotechnical assessment and performance expectations, e.g. liquefaction effects on building foundations (bearing capacity, settlement), effects of lateral spreading on building foundations and land surrounding buildings, slope stability of ground underlying or adjacent to buildings on which a building may rely for support of its foundations.

At present "industry practice" is used, which can result in designers using differing design performance requirements for building foundations and consequent difficulties for Territorial Local Authorities in assessing compliance of designs with the Building Code.

Current building standards and guidelines are inadequate in terms of identifying and evaluating geotechnical issues and risks to buildings during earthquakes and also other non-earthquake geotechnical hazards. The Building Code lists some issues (earth pressure, earthquake, differential movement) but does not include other common hazards such as ground movement, liquefaction, soft ground and geothermal conditions. Some of these hazards are related to earthquakes and some are not.

Structural design of buildings is reasonably easy to codify and a well-developed set of structural design standards has been developed for New Zealand. Geotechnical design however, is significantly more difficult to codify. Some elements can be codified and both normative and informative standards developed as seen in other countries. The current building regulatory framework is weak because of the current exclusion of geotechnical issues from structural codes and the Building Code and the lack of complementary geotechnical standards or appropriately developed guidelines. Another weakness in the existing regulatory framework is ensuring that adequate geotechnical assessment of land is carried out at earlier stages of land development, e.g. at the zoning and subdivision stages. For example it is difficult or not practicable to mitigate a liquefaction hazard for an individual residential building on a small site when a whole subdivision is at risk from the same the hazard.

The lack of minimum standards will in the future hinder, to a degree, improvement of the design and performance of buildings in earthquakes especially if there are corresponding moves to improve aspects of structural design of buildings.

Appended to this submission is a paper prepared by an NZGS member who is completing research into soil liquefaction for a PhD degree at Canterbury University. The paper discusses many issues around the regulation of geotechnical design for buildings and while not all views necessarily would be supported by the Society, the paper provides a useful summary and background to those issues.

Responsibilities

Question2. If a work programme is needed for the development of building related Standards to ensure performance in an earthquake, (as discussed above in section 3), who should lead this, what are the priority areas, and how should this be funded?

Priority areas for guidance on geotechnical aspects of building design and performance are:

a. Liquefaction assessment and mitigation
b. Retaining wall design for earthquake loads
c. Slope stability assessment for earthquake conditions, including lateral spreading
d. Foundation design, incorporating liquefaction and seismic slope stability considerations.

NZGS notes the difficulty in development of geotechnical standards because of the variability of ground conditions. However some elements can be codified and both normative and informative

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standards developed. Funding and direction could usefully follow the United Kingdom Construction Industry Research and Information Association (CIRIA) approach.

Capability

Question 2. What skills are needed in the private building sector to ensure seismically resistant buildings?
The society would like to see that the private sector has ready access to ably skilled geotechnical professionals, in particular Chartered Professional Engineers and 'Professional Engineering Geologists'. The NZGS, in collaboration with IPENZ, currently is preparing a process for the professional recognition of engineering geologists to ensure the full range of ground engineering skills are available.

CPEng status is assessed on the basis of demonstrated competence in a self-declared practice area. In the past, Members of IPENZ could append a practice field (aligned to one's practice area) to the MIPENZ designation. However, the publication of practice fields in any way by IPENZ has been discontinued in recent years. While we agree in general with the IPENZ view that it is unnecessary to publicise individual practice fields and practice areas, the NZGS strongly believes that geotechnical engineering is a special case. It requires particular training and experience in a field that is not well codified. As such, we believe that either publication of a geotechnical practice field for CPEng should be reconsidered or a special competence register for geotechnical engineering be developed, in order that clients and regulatory officials are aware of a practitioner's expertise in this field.

There is variable quality of geotechnical work performed in relation to buildings and the development of land on which buildings are sited. This variable quality is in part related to the competence of professionals working in geotechnical engineering, which requires specialist geotechnical skills.

Resourcing Standards Development

Question 3. Should primary reliance continue to be made on volunteers?
In the NZGS's experience, effective development of new guidelines and updating of existing ones takes far too long if left to well-intentioned but often over-committed volunteers. Learned societies should have input to the development of relevant documents, as they can present good state of practice and knowledge of the state of the art. Industry funded guideline development following the UK's CIRIA model or similar is likely to achieve equally valuable results but in a more timely manner. A secondary issue hindering voluntary guideline development is concern over liability for such advice.

NZGS is also aware that robust peer review of guidelines produced by volunteers within a learned society is required and that learned societies such as NZGS can have variable approaches to peer and industry review of guidelines. It would be better for guidelines to be prepared on a commercial basis with oversight by the appropriate learned society, regulators and end user groups. Funding and direction could usefully follow the UK CIRIA approach.

Question 5. Should there be more use or less use of mechanisms other than Standards to develop and provide methodologies for compliance; why or why not? Who would or should do this work and how should it be funded?

From a geotechnical perspective, formally recognised guidelines to good practice are more suited than standards to the wide variety of problems that geotechnical practitioners are called upon to

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solve. The guidelines should be prepared on a commercial basis with oversight by the appropriate learned society, regulators and end user groups. As noted, funding and direction could usefully follow the UK CIRIA approach.

The Standards do however need to be extended to include a clear and complete definition of geotechnical items and hazards to be considered in design. Appropriate and approved guidelines for their evaluation need to be referenced in the Standards. It is of particular relevance that the loading standard (NZS 1170.5: 2004) specifically excludes the use of the code seismic loading for liquefaction analysis, and no alternative is provided.

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Appendix

Technical Article in Geomechanics News, Issue 83, June 2012.

'Geohazard Mitigation in New Zealand – in search of a normative and informative balance'. Merrick Taylor.

TECHNICAL ARTICLES

Geohazard Mitigation in New Zealand – In search of a normative and informative balance.

Introduction

THE CANTERBURY EARTHQUAKE sequence (2010-2011) has caused significant, extensive, and costly damage to buildings and infrastructure in Christchurch and surrounding townships on account of shaking induced ground failure (predominantly liquefaction related, but also slope movement and rockfalls). Clearly there is a need for revision of the management of ground failure hazards going forward. This includes how the evaluation of the hazard is carried out by geotechnical professionals (geotechnical engineers and engineering geologists), as well as the communication of the nature of that hazard to decision makers in society - government, business and private individuals, and other engineering disciplines. Using Christchurch as a case study, the aim of this letter is to address some deficiencies present in the systems used to manage geotechnical hazards in New Zealand, but also to encourage the profession to improve the systems we have in place. The purpose is not to ascribe blame on individuals or organisations which would detract from the intention of the letter (recalling that hindsight is always 20:20, and no one willingly intends a hazard to be realised), but to expose weaknesses in the philosophy and current state of practice, and to propose a pragmatic means by which these may be best strengthened, in ways we as geotechnical professionals can provide an appropriate contribution.

Though what may be termed 'systemic failure' features strongly in the review presented, the author as a geotechnical engineer is most concerned with the lack of stipulated requirements to evaluate and mitigate liquefaction ground failure hazards in New Zealand's engineering codes of practice, which is out of step with best international practice. Explicit, normative clauses in codes requiring the assessment and mitigation of such hazards should act to provide an objective or apolitical tool to assist both engineers and regulators to manage the hazard more effectively than merely a reliance on land use planning regulations. This may be at odds with an apparent culture or desire to maintain a state of low prescriptive requirements within the New Zealand geotechnical profession; however in the case of geohazard mitigation in Christchurch, a reliance on this philosophy has been I believe detrimental, especially given the reliance that regulators have placed on the building code to manage these hazards.

In the opinion of the author it is the role of the engineering profession to ensure quality standards are followed and adhered to. Review of regulations going forward should be undertaken proactively rather than merely on an ad hoc or reactionary basis. Guidelines developed for performing earthquake geotechnical design (for example) are useful developments currently being undertaken by the New Zealand Geotechnical Society (NZGS), but further work is required to implement the necessary normative clauses in building codes, that facilitate the quality assurance role undertaken by regulatory bodies. The NZGS and the profession in general are strongly encouraged to take an active role to facilitate the necessary changes being implemented to NZ codes to ensure robust geohazard management is carried out as part of day to day engineering practice.

Canterbury 2010-2011 Earthquake Sequence

It is useful, following the recent quakes, to take a step back and see how the situation we face now in Christchurch developed, what worked well, and what could have or should have been done to mitigate the hazard better. Where do disconnects exist between knowledge and practice? What are the most obvious targets for changing how knowledge is reflected in how planning, design and construction work is carried out? These and many other questions are currently being evaluated by the Royal Commission of Enquiry into the Canterbury earthquakes, and specifically the failures that occurred in the Christchurch CBD during the Mw 6.1 22nd February 2011 earthquake. That event caused MMI (Modified Mercalli Intensity) VIII+ level shaking across much of the city, and liquefaction effects including extensive sand boils and surface flooding, lateral spreading damage extending 10's to 100's of meters from nearby waterways, damaging services, bridges, and homes. The effects included severe differential settlement to buildings, and significant ground settlement and river channel constriction that has dramatically increased the flood risk to suburbs in close proximity to the Avon River and Estuary. Suburbs on geologically recent, low energy fluvio-estuarine deposits were most severely affected during the preceding Mw 7.1 September 4 2010 earthquake (MMI VII shaking), 22nd February and subsequent significant aftershocks on 13 June and 23 December 2011, including Bexley, Avondale, Burwood, Parklands, Avonside, Dallington, Opawa/ St. Martins, Ferrymead, North Kaiapoi, Brooklands, and Courtenay Downs. Some of these parts of the city were long established suburbs, having been developed pre and post War; others were recent and current developments in the last decade.

Questions are also being asked by the Ministry for the Environment in relation to the performance of the Resource Management Act, responsible for the building development consent process, and Department of Building and Housing in relation to the Building Act, responsible for ensuring safe construction with acceptable performance under expected environmental loads including earthquake.

Liquefaction Hazard. Pre-September 2010 – What Was Known?

The recognition amongst engineers and scientists that widespread liquefaction[1] may be triggered by earthquakes is relatively recent; specifically within the last 50 years. The key events which precipitated significant interest and study by engineers into this phenomenon of earthquake induced liquefaction, were the devastating earthquakes in Niigata, Japan and Anchorage, Alaska in 1964, leading to landmark publications on liquefaction in the years that immediately followed [1-5], with continued research and development until the present day. These early studies sought to explain the phenomenon and understand the mechanism and driving causes of liquefaction, define failure criteria, and enable methodologies to be developed so that engineers might assess the potential for liquefaction to occur in soils under a certain sized earthquake in the future, and to design accordingly to mitigate the hazard.

These developments established internationally the knowledge base of the engineering profession on the hazard posed by earthquake-induced liquefaction of soils. For example, in the early 1970's the hazard posed by liquefaction was considered in consulting reports for the foundation design of buildings in the centre of Christchurch [6]. A series of academic research studies reviewing historical evidence of the hazard in New Zealand were undertaken in the mid to late 1980's [7-11], and in 1987 an elevation of interest in the phenomenon of liquefaction in New Zealand occurred, when liquefaction in pumice sands and effects including lateral spreading, ground settlement and foundation damage were observed in the Bay of Plenty during the ML 6.3 Edgecumbe earthquake [12, 13]. Other significant international events occurred in San Francisco, California (1989); Luzon, Philippines (1990); Kobe, Japan (1995); Chi Chi, Taiwan (1999); and Koeceli, Turkey (1999), keeping it a major source of interest to geotechnical engineers and an area of active research.

Hazard Mapping and Regulatory Disconnect

In Canterbury, a number of regional and site-specific hazard studies were conducted during the 1990's - early 2000's period, highlighting the significant risk in Christchurch and producing maps of risk for the city. Landmark publications were:

1. Elder et al. 1991, Natural Hazards in Canterbury (EQC funded report) [14]. See also McCahon et al. [15].
2. Brown and Weeber 1992, Geological Map of Christchurch 1: 25,000, GNS Science (incorporates a liquefaction hazard map within the text). [16]

A later study [17] also considered the risk and potential impact of liquefaction, primarily to Christchurch lifelines, but not commercial or residential structures. Academic studies at the University of Canterbury, some associated with the lifelines study, occurred throughout the decade [e.g. 18, 19-21]. A raised awareness of liquefaction amongst regional authorities at this time culminated in the commissioning of studies carried out by consultants and publication of liquefaction hazard maps for Waimakiriri District [22] and Christchurch City [23, 24]. These studies conducted on a regional/ citywide scale were among the first of their kind in the country, however as noted by the peer reviewers, these studies were significantly limited in applicability by the extent of the available data used in the study [25]. Due to significant ground variability across the city, with changes occurring often over short distances, it was advised that characterising the liquefaction risk for a site could only be carried out on a property-by-property (i.e. site specific) basis.

Impact on Regulations

The Environment Canterbury study informed the inclusion of the relative risk in terms of "liquefaction potential" and a "liquefaction ground damage rating" on Christchurch City Council Land Information Memorandums (LIM) and Environment Canterbury Land Information Requests (LIR) for properties in the city. Every time a property changed hands, due diligence by solicitors would inform the property purchaser of the risk, amongst other potential hazards that may have been documented for the site (e.g. flood risk). Anecdotal evidence from discussions with property owners was that, sometimes on advice of their solicitors, they by-and-large dismissed the liquefaction hazard as "unimportant" as "half of Christchurch has the same thing written on their LIM reports", and perhaps more significantly no codified requirements (Building Act) or limitations on developments (Resource Management Act, or RMA) existed for sites deemed to have an elevated risk of earthquake induced liquefaction ground damage. This in spite of the RMA, which allows the consenting authority to refuse subdivision consent if the land is subject to certain, specified geotechnical hazards (though not explicitly mentioning liquefaction). The Building Act states performance requirements for buildings, and contains the requirement to consider earthquake, and compliance is achieved through the various codes of practice (NZ

Standards) and compliance documents (B1 Structure). However these also do not consider liquefaction explicitly (more is discussed on this later). Consequently there appears to have been no pricing of this risk in the housing market, or by insurers and therefore also by the EQC levy (charged as a percentage of house and contents insurance premiums).

A recent *Canterbury Fact Finding Project* [26] was commissioned by the Ministry for the Environment (MfE) to determine *"the extent to which liquefaction and lateral spreading hazards were known, available and factored into the planning and development process"*, prior to the 4 September 2010 earthquake. Findings from this investigation made available to the Royal Commission, show that under the RMA, the main development issues considered by councils in the consenting process were:

- Flooding (from Avon River and tidal, ensuring minimum ground levels and floor heights);
- Services (ensuring sufficient fall for sewers, and servicing by mains sewer and water);
- Foundations (that land was suitable for the construction of light framed dwellings –i.e. compliance with the Building Act).

There are two potential opportunities within the regulatory framework to address the risk posed by liquefaction hazard:At time of land subdivision and building (i.e. by design via conformance with the Building Act), or through strategic land use planning (i.e. zonation). The latter provides a means to ensure mitigation is included in the land use consent conditions whilst managing expectations of owners in relation to subsequent development proposals. Enfocus, a policy consultancy, also reported to the Royal Commission on the operational behavior of regulatory authorities with respect to their obligations under the RMA. Their report indicates that Environment Canterbury policy generally relied on the former, i.e. compliance with the Building Act, which was the responsibility of the local territorial authority i.e. Christchurch City, Waimakiriri and Selwyn District Councils [25]. The MfE fact finding report also showed that most of land that has been shown to be highly susceptible to liquefaction in the afore-mentioned studies had already been zoned as suitable for residential development in the late 1970's, although subdivision development in some cases did not occur until well into the 2000's. Once the land had been zoned, it was presumed that it was suitable for development, and became difficult to refuse a subdivision, even if the legislative authority existed.

On the reports public release, the then Minister for the Environment, Hon. Dr. Nick Smith, a geotechnical engineer by training (and politician in practice), publically blamed the RMA for its unbalanced focus on ecological issues in the consideration of building consents over pragmatic issues such as the impact of natural hazards, and promised a thorough review [27].

The City Plan & Varying Appreciation of the Liquefaction Risk

In reviewing the Christchurch City Plan, Enfocus noted the lack of explicit mention of earthquake hazards such as liquefaction, and the difficulties councils face enforcing opposition to subdivision developments on the basis of city-area wide mapping of liquefaction risk:

> *"The plan's approach to earthquake risk is best characterized by what it does not include. It does not include identified liquefaction zones nor does it include a risk assessment or risk standards notwithstanding that one policy refers to limiting development in areas of "moderate to high risk". Having noted those issues it should be pointed out that the author is not aware of any other district plan that contains such matters. This is likely to be due to the stringent evidential basis that would be needed to defend an assessment and mapping of risk given the inevitability of challenges a council would face to taking such an approach."*
>
> *-Enfocus Ltd. (2011)*

Furthermore, with the revised seismic hazard model for the new structures loading code (NZS1170, 2004), the risk of significant ground motion was estimated to be much lower than the earlier studies had indicated. This lowering of the perception of seismic risk was reported to the council before the codes publication. The Christchurch City Council (CCC), requested further comment from seismologists (from a crown research institute) on a University of Canterbury BE(Hons) research report [28], which considered the impact of liquefaction induced differential settlement on concrete slab foundations of domestic buildings. In their response, the seismologists downplayed the risk posed by the effects of liquefaction on Christchurch. The advice CCC received, was that (summarised from [25]):

- In the case of a MM7 level earthquake shaking, they "would not expect to see major damage to buildings as a result of liquefaction."
- The probability of an MM9 or MM10 earthquake shaking "is sufficiently low that, in our opinion, it would not be reasonable to require ordinary structure, like house, be constructed to withstand all the adverse effects of such strong shaking" (sic). This was estimated to have a return period of > 70,000 years.
- "the majority of houses in Christchurch will not be affected by liquefaction, even during the strongest shaking (MM8) likely to be experienced."

Of the anticipated effects of liquefaction for MM7 level shaking (which was the "design level" estimated by the revised model for the city), the severity and extent would be limited to "evidence of liquefaction common with small sand boils and water ejections on alluvium, and localized lateral spreading and settlements along banks of rivers..." and that due to the flatness of Christchurch, the extent of the effects of spreading was considered to be only within a few meters of waterways. The anticipated cost of damage from such an event was estimated to be around $1 Billion.[25]

Perhaps as a consequence of both this scientific advice downplaying the risk compared to earlier studies, and the real political difficulties with implementation (revoking rights from owners to residential development, risking protracted legal challenges to any Council opposition on the basis of liquefaction mapping based on sparse data), liquefaction zoning never entered the City Plan, and the indicative zones in the Environment Canterbury study only triggered a requirement for detailed geotechnical site investigation at the time of significant new developments.

Rezoning Applications and Liquefaction Hazard Consideration

The MfE fact finding report noted that the first inclusion of liquefaction countermeasures for a development was a private plan change to the Waimakiriri District Plan for the Pegasus New Town in 2000. Pegasus is a new satellite township located 30 km north of Christchurch City, on the Pacific coast. In response to opposition from Environment Canterbury, Waimakiriri District Council incorporated liquefaction hazard mitigation into the development conditions. In the review by Enfocus of post 2002 developments in Christchurch City itself, very few were assessed for liquefaction and lateral spreading risk. Essentially the only consideration of liquefaction risk was made in relation to again a private plan change request to rezone land in Ferrymead. Here the original geotechnical report provided with the submission did not consider liquefaction ground failure hazards. CCC sought peer review advice from another consulting practice in the city who highlighted the liquefaction and lateral spreading risk. This prompted a request for further information from the developer to address these concerns, and consequently a follow up report from the developer's geotechnical consultant was produced. The final hearing decision weighed up the concerns of the peer reviewers and the outlined risks posed by lateral spreading with the developers desire to have minimal set-back from the river for building construction, and agreed to a compromise. It appears the above cases are very much exceptions rather than the rule. Enfocus comment that City Council officers do not have expertise in risk assessment and therefore must rely on information provided by applicants, and that it was not clear what triggered the requirement for applicants to provide geotechnical/risk information.

Building Codes

The Department of Building and Housing, through advice from the recently formed *Engineering Advisory Group* (which includes input from, among other technical groups, the New Zealand Geotechnical Society), is likewise reviewing its regulatory documents. The *B1 Structure* document has been hastily revised in the interim, specifically the definitions of what does not constitute "good ground" for building foundations in the relevant New Zealand Standards. Site conditions which are excluded from "good ground" include peat, soft clay, and expansive clay, but (prior to August 2011) not liquefiable soils. From August 2011 this has been altered to explicitly include liquefaction and lateral spreading [29]. However, this is currently only for the "Canterbury earthquake region", reflecting the elevated seismicity and therefore risk of further liquefaction occurrence, rather than implying that the conditions that may lead to liquefaction are not similarly present in other parts of the country. This highlights the interim nature of the changes, and more permanent and further reaching amendments to the codes of practice will no doubt be forthcoming in due course.

Clauses have and currently do exist to exclude the use of the *B1 Structure* verification method for foundation design (B1/VM4) from application to loose saturated sands and sensitive clays, amended to include dense saturated sands (in 2008), with a comment that such conditions required "special consideration". However, as a compliance document the nature of these comments is *informative* only, separate from the *normative* definitions of "good ground" in the codes of practice (NZ Standards), and therefore appear to have had little impact.

A Reliance on Individual Engineers

The current structures loading standard NZS 1170:2004 likewise does not consider liquefaction hazard, in fact it explicitly removes it from the scope on page 1. However, in spite of the *explicit* omissions in NZ codes of practice and verification documents, some engineers have considered the implications of liquefaction based on the perception that the hazard posed at a specific site would breach the *performance requirements* stipulated for structures in those standards. Thus the hazard has in such cases been evaluated and liquefaction countermeasures designed as part of what individual engineers considered was compliance with those loading codes [e.g. the development of Pegasus Township, 30]. Such an *interpretation* of the code relies heavily on engineers undertaking their work with full awareness of such hazards and international best practice with regard to the evaluation and mitigation of the hazard. Without explicitly clear regulatory requirements for developers to consider the hazard and ensure its mitigation to a pre-defined set of performance requirements (whether via consent conditions or from the building code), it may be readily observed that few will choose to do so. This has significantly compounded the unfortunate situation we now have in Christchurch, with many new developments among the most vulnerable and thus worst affected areas.

New Zealand and International Best Practice

It is somewhat disappointing to note that this omission of liquefaction hazard from building regulations is completely at odds with international best practice, where codes clearly and specifically require assessment and mitigation of liquefaction hazard as part of design. What's more, some stipulate the methodology for its evaluation and foundation performance requirements. Some examples from Eurocode 8 [31] and the International Building Code [32] are appended.

NZGS Guidelines

It is because of these noted omissions (among others related to ground engineering) in the then newly issued structures loading code NZS 1170 [33] that the New Zealand Geotechnical Society established a working group in 2006 to provide guidance to the profession on earthquake geotechnical design in general, with the first output being "Module 1: Liquefaction hazard identification, evaluation and mitigation" [34]. In Section 3 they outline the key performance requirements of the Building Act and the importance of geotechnical considerations in meeting those requirements, and those of the Resource Management Act. NZGS note that there *"is a strong need to raise awareness of the importance of the application of geotechnical skills and knowledge in every aspect of building developments"* before expanding on what those geotechnical considerations should entail, paraphrased here as: Desk-study review; site-specific investigation; geotechnical interpretation; analysis to assess compliance with Building Code performance requirements; geo-hazard assessment (all prior to Building Consent); followed by review during construction. Noting that earthquakes and their effects must be included in all such geotechnical assessments.

From the absence of any such requirements in building codes and regulations, this leaves one to surmise that these interpreted geotechnical requirements for compliance with the Building Act, are in fact *only made clear in this document,* and that many (i.e. civil engineers, planners, regulators) are perhaps not uniformly aware of these requirements for demonstrating compliance with the Building Act. They are not specifically stated in Acts of Parliament, Compliance Documents or Standards themselves.

These guidelines were published in July 2010, only 2 months before the September 4 earthquake - too soon to have any favourable impact on the industry with regards to Christchurch. It was noted in the preface to that document that guidelines were strongly desired over codes or standards by the NZGS committee, based on the need for "flexibility", as the "technology in this area is rapidly developing".

It is understood a revision of the NZGS guidelines is planned based on lessons learnt from Canterbury, and questions raised by practitioners when faced with real problems of evaluation and mitigation of the hazard in the repair and rebuild of Christchurch. With this pending review in mind – for the entire country, not just DBH's interim "Canterbury Earthquake Region" – it is timely to review whether NZGS continue to develop guidelines only, without also stipulating necessary clauses to be included in relevant codes of practice. Surely the two (both *informative* and *normative*) can go hand in hand without adversely impacting on the stated desire to maintain flexibility of analysis approach. Supplementary commentaries to be read in parallel alongside the code itself are often provided (e.g. NZS1170.5 has one, likewise in FEMA450, and informative guidance is included within the Annexes to Eurocode 8).

Summary & Conclusion

Despite the growing body of work to identify the hazard posed by liquefaction ground failure in Christchurch prior to 2010, the implications in terms of damage to infrastructure and facilities was, with the wonder of hindsight, inadequately appreciated by the government, city planners, geoscientists, civil engineers or their clients, the insurance industry and the population in general. The legacy of historic development on highly liquefaction prone areas of Christchurch up to and including early 2011, has 'built in' a high vulnerability to liquefaction hazard. An acceptance of past practice of building on such land, reluctance to challenge land-owners rights to continue to do so, and allowing further developments to occur beyond the published hazard studies suggests a *failure to transfer knowledge into practice.* It is realised this is as much a political failure as an engineering one (Enfocus call it a "systemic failure"). The level of damage sustained in those areas of Canterbury severely affected by liquefaction implies that the 'do-minimum required' option was often the default action taken by developers, all too often signed off by civil engineers, without challenge by regulators. Clearly this has not been an acceptable risk mitigation strategy. It is recognised that the responsibility ultimately lies with regulators, but there exists a concern by this author that it likewise implicates a passive engineering profession which has not led the effective management of geohazards through codes of practice, allowing them to become embarrassingly out of step with international best practice.

The approach to develop flexible guidelines for the geotechnical profession is welcomed, but it is suggested that NZGS should also recommend and if necessary husband the required changes to our codes through the appropriate standards committees to ensure best practice is followed going forward. The desired flexibility of *informative* guidelines may be maintained alongside necessary explicit *normative* statements in codes. This may be either within the current format of guidelines remaining separate but referenced by codes, or through use of official supplementary documents (for example the Commentaries to NZS 1170.5, FEMA 450, and Annexes to Eurocode 8).

It is anticipated that following these events, with risk turned into reality, that societal expectations would most certainly be raised with respect to what is deemed to be acceptable performance of land used for development. Though change to regulations are promised by the government, there will always be economic and therefore political resistance to challenging land use rights to develop in locations vulnerable to natural hazards. A reliable risk mitigation strategy must also involve strengthening our codes of practice to ensure sufficient resilience is built in during design, and thereby factored into the economics of developing on vulnerable land with follow-on implications for insurance premiums and the EQC levy. It is the public duty of the engineering profession to ensure codes of practice are adequate, clear, and auditable by regulators, particularly since we are the most well placed to do so. The challenge therefore falls to the NZGS to do this for geotechnical hazards and how they are mitigated within the framework of New Zealand codes of practice.

The author welcomes comments and any factual corrections to this review from members of the society.

APPENDIX

EN1998-1:2004; Eurocode 8; Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings. Section 3.1.1 clause (3):

"The construction site and the nature of the supporting ground should normally be free from risks of ground rupture, slope instability and permanent settlements caused by ★liquefaction★ or densification in the event of an earthquake. The possibility of occurrence of such phenomena shall be investigated in accordance with EN 1998- 5:2004, Section 4."

Further, in the selection of soil site class, EC8 part 1 provides a special site class (S2) for liquefiable soils and sensitive clays. Section 3.1.2 clause (4):

"For sites with ground conditions matching either one of the two special ground types S1 or S2, special studies for the definition of the seismic action are required. For these types, and particularly for S2, the possibility of soil failure under the seismic action shall be taken into account"

Part 5 of Eurocode 8 (EN1998-5) deals specifically with the seismic design of geotechnical structures, which includes in Section 4.1.4: "Potentially Liquefiable Soils", which outlines the requirements to establish liquefaction susceptibility, followed by Section 4.1.5 :"Excessive Settlement of Soils under Cyclic loads" - outlining requirements to assess the impact of liquefaction on designed foundations.

The International Building Code (IBC 2006), is similar to EC8 in requiring consideration of liquefaction, though is less prescriptive in terms of methods adopted:

Section 1802.2.6 Seismic Design Category C. Where a structure is determined to be in Seismic Design Category C in accordance with Section 1613, an investigation shall be conducted and shall include an evaluation of the following potential hazards resulting from earthquake motions: slope instability, ★liquefaction★ and surface rupture due to faulting or lateral spreading.

Section 1802.4 Investigation. Soil classification shall be based on observation and any necessary tests of the materials disclosed by borings, test pits or other subsurface exploration made in appropriate locations. Additional studies shall be made as necessary to evaluate slope stability, soil strength, position and adequacy of load-bearing soils, the effect of moisture variation on soil-bearing capacity, compressibility, ★liquefaction★ and expansiveness.

Section J104.4 Liquefaction study. For sites with mapped maximum considered earthquake spectral response accelerations at short periods (Ss) greater than 0.5g as determined by Section 1613, a study of the liquefaction potential of the site shall be provided, and the recommendations incorporated in the plans.

Exception: A ★liquefaction★ study is not required where the building official determines from established local data that the liquefaction potential is low.

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