

Keynote Address

Climate change, sustainable development and geotechnical engineering: A New Zealand framework for improvement

R. C. Roberts¹, CGeol, CMENZ, PEngGeol

¹Auckland Council, Engineering and Technical Services, Auckland; email: ross.c.roberts@gmail.com

ABSTRACT

Climatic warming caused by the emissions of anthropogenic greenhouse gases is occurring across the globe. These changes will increase the exposure of the built environment to hazards such as sea level rise and coastal inundation and exacerbate existing hazards such as expansive soils and landslides. In New Zealand, the built environment and its construction is responsible for about 20% of the emissions that are the primary cause of climate change. The way our built environment is designed must change to adapt to these future increases in hazard and must also mitigate emissions where possible to limit future increases in hazard to manageable levels. This paper describes climate change effects where they have overlaps with geotechnical design and hazard assessment (with particular reference to Auckland as an example), discusses the impact that these changes are expected to have on geotechnical practice in the coming years and decades, and presents a framework for managing these in the design processes.

Keywords: climate change, geotechnical engineering, sustainable development, adaptable design

1 INTRODUCTION

1.1 Climate change

Since the last ice age, which ended approximately 12,000 years ago, Earth's climate has been relatively stable. This stability in temperature and sea level was crucial for the development of modern civilisation. However, since about 1900 average temperatures around the globe have been increasing. This warming trend is expected to have a drastic impact on modern life which is tailored to the stable climate in which it developed.

Increasing temperatures have been strongly linked to emissions of anthropogenic greenhouse gases (Figure 1), such as carbon dioxide (CO₂). Since the 1950s many of the observed changes are unprecedented, including environmental changes such as increased atmospheric and oceanic

temperatures, decreased mass volume of snow and ice worldwide, and a significant rise in global mean sea level (IPCC 2014a).

The decisions we make today need to consider the changing environment and the potential disruptions it will cause. A typical structure constructed today will still be in use in 2070 and beyond. However, the climate it encounters will be significantly different. Planning decisions and investment in major infrastructure made today will have consequences over even longer timeframes (for example, once a town is built its existence is near-permanent).

This paper discusses the impact that these climatic changes are expected to have on geotechnical practice in the coming years and decades and presents a framework for managing these in the design process.

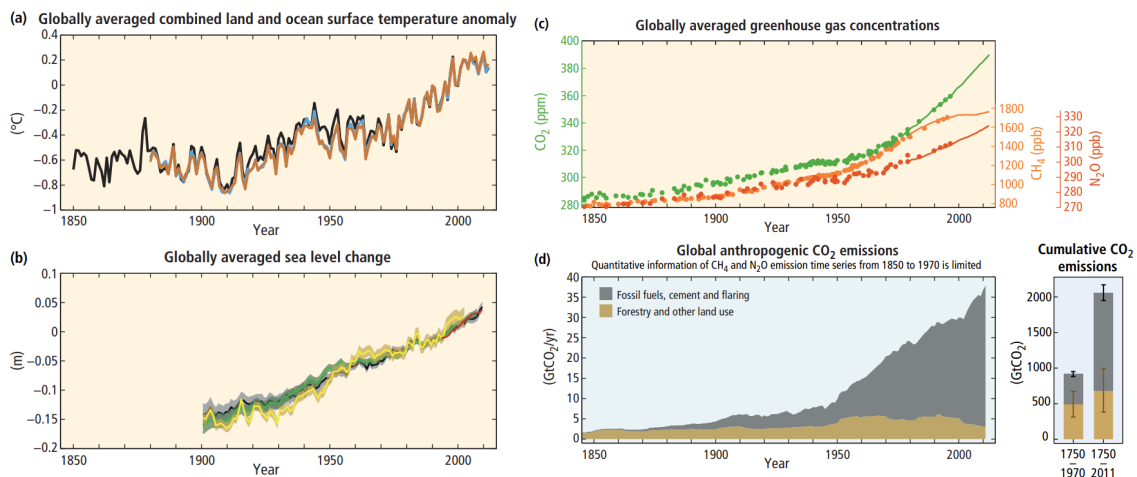


Figure 1. The relationship between observations (panels a, b and c with yellow background) and emissions (panel d, light blue background). After IPCC 2014a Figure SPM.1.

1.2 Sustainable development

Sustainable development is development that meets the needs of the present without compromising the capacity of future generations to meet their own needs (United Nations World Commission on Environment and Development, 1987 “Brundtland Report”). It is the broader framework under which the management of climate change’s impact on the built environment falls.

Published in 1987, the Brundtland Report clearly highlighted the threat posed by climate change:

“Little time is available for corrective action. In some cases we may already be close to transgressing critical thresholds. While scientists continue to research and debate causes and effects, in many cases we already know enough to warrant action. This is true locally and regionally in the cases of such threats as desertification, deforestation, toxic wastes, and acidification; it is true globally for such threats as climate change, ozone depletion, and species loss. The risks increase faster than do our abilities to manage them.”

Seventeen UN Sustainability Goals were adopted by all UN Member States in 2015 as part of the 2030 Agenda for Sustainable Development, which set out a 15-year plan to achieve the goals (United Nations, n.d.). Goal 13 requires member states to “Take urgent action to combat climate change and its impacts”, and includes the following targets:

- (i) 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.
- (ii) 13.2 Integrate climate change measures into national policies, strategies and planning.

Partly because of this, there is a significant effort in member countries to achieve these targets in the coming decade.

2 CLIMATE CHANGE IMPACTS

2.1 General climate change impacts

Goal 15 of the UN Sustainability Goals focuses on land degradation, the loss of life-supporting land resource due to processes such as soil erosion, desertification, deforestation, and acidification.

Land degradation is exacerbated by climate change which can cause increases in:

- Rainfall intensity and changing rainfall patterns.
- Flooding frequency and severity.
- Drought frequency and severity.
- Heat stress.
- Wind strength.
- Coastal erosion and more frequent and extensive inundation caused by sea-level rise and wave action.
- Permafrost thaw.

Land degradation and increasing instability adds significant land use pressure in regions where land suitable for building was already scarce (IPCC, 2019).

2.2 Geotechnical impacts

Land degradation and changes to land stability have a significant impact on the built environment. Climate change impacts of particular relevance to geotechnical engineering in New Zealand include drought and its impact on expansive and settlement-prone soils, coastal erosion and its impact on coastal cliffs, and rainfall intensity and its impact on land stability.

These issues create financial and social problems as well as engineering problems. Properties in hazard zones may struggle to get insurance, exposing the owners to significant loss. Even if the building platform can be protected, the loss of adjacent land can significantly devalue a building.

2.2.1 Drought

Forecasts of future total precipitation rates vary geographically with some areas expecting an increase, and others a reduction. In Auckland, total rainfall is expected to decrease only slightly. However, changes in seasonal patterns may result in wetter autumns and drier springs (Figure 2). An increase in the number and severity of droughts is expected to result in a greater range of groundwater levels, with the seasonal changes expected to result in lower groundwater levels in summer. This effect will be exacerbated by higher rates of evapotranspiration and in some areas because of increasing groundwater abstraction for human use.

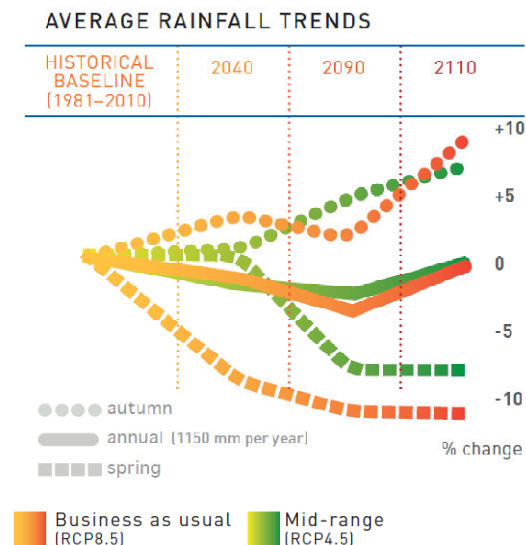


Figure 2. Average rainfall trends for Auckland to 2110 (Lorrey et al, 2018). RCP8.5 represents a scenario where emissions continue to rise at current rates, while RCP4.5 represents an emissions peak at 2040, followed by a slow decline likely to result in global temperatures rising 2°C by 2100.

These more extreme summer lows are expected to increase shrinkage of expansive soils and increase (often irreversibly) settlement in normally consolidated clays and peat. This was highlighted by the Auckland's dry summer of 2020. Between 1 January and 21 May just 126 mm of rain was recorded at NIWA's Mangere weather station - an amount less than two-thirds of normal - making the drought one of the worst since the early 1900s, and resulting in a doubling of reports of building damage (NZ Herald, 2020).

Slope stability is also likely to be affected by drought. Although (as noted below) drier conditions are often advantageous for slope stability, some drought effects can destabilise slopes, particularly:

- Loss of vegetation
- Desiccation cracking
- Reduction in soil suction

Extended droughts will kill some vegetation, particularly species that are adapted to a specific climatic zone. Over time, more drought-tolerant species will likely take over, but in the interim the loss of the stability and erosion control provided by root reinforcement and foliage cover may be significant.

Desiccation cracking due to soil drying is largely governed by the soil's plasticity, the temperature, and the number of volume change cycles experienced. These cracks form natural weaknesses and enhance vertical permeability allowing rainstorms to rapidly saturate specific horizons, particularly along existing weak planes that are common at weathering or lithological boundaries.

In partially saturated soils, reduction in soil suction causes a corresponding reduction in shear strength. This is largely governed by the pore size with fine grained soils retaining strength noticeably longer than soils with larger particles at similar saturation levels (Vahedifard et al, 2018). This loss of strength is challenging to predict and could result in unforeseen failures.

2.2.2 Coastal erosion and sea level rise

Sea levels around Auckland are forecast to increase by between 0.4 m and 1.1 m by 2100 (Figure 3).

An increase in coastal inundation and erosion rates is predicted for most areas. Cliff toe erosion will increase slope instability risks, and geotechnical structures will be more exposed to flooding and erosion.

As high-value land is eroded, demand for coastal protection measures is likely to increase. It is already common to install palisade walls around cliff-top properties to protect them against future erosion, and demand for sea walls is increasing.

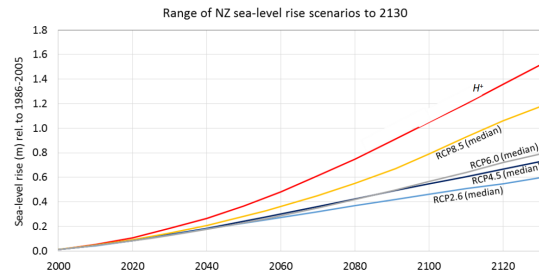


Figure 3. Range of sea level rise scenarios for NZ to 2130 (Stephens, 2017)

2.2.3 Rainfall intensity and storminess

Across New Zealand, many areas are forecast to receive more intense rainfall, including Auckland (Figure 4) where extreme rainfall intensity is forecast to increase by 15-30% by 2090 (Lorrey et al, 2018).

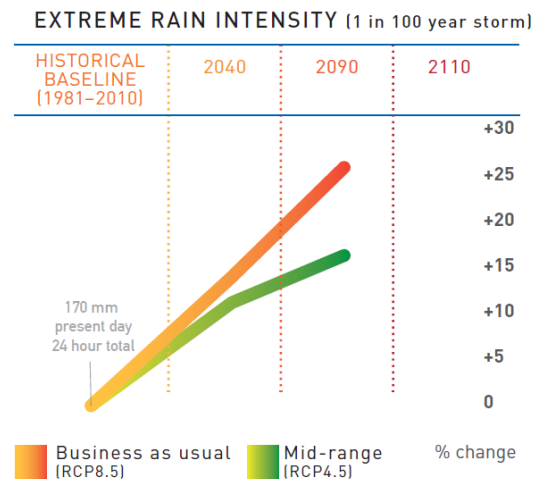


Figure 4. Extreme rain intensity scenarios for Auckland to 2090 (Lorrey et al, 2018).

In areas already forecast to receive an increase in total precipitation, higher groundwater levels and pore water pressures are expected and will contribute to a reduction of shear strength, a reduction in soil suction and cohesion, and an increase in the weight (wet density) of the slope materials, all decreasing slope stability. Therefore, less rain will be required to fall in each event to reach a critical level that can cause a slope to fail. With an increase in the rainfall intensity this is likely to cause a significant increase in landslide susceptibility.

Conversely, a reduction in total precipitation would normally result in more stable conditions. However, the forecast increase in rainfall intensity may cause higher infiltration into dry, cracked ground during storm events (where the soil and bedrock allow it) and an increase in subsurface drainage and throughflow. Together these contribute to the build-up of perched water tables, the reduction of effective normal stresses and the shear strength, again contributing to slope instability (Gariano and Guzzetti, 2016).

Increased rainfall intensity will also increase surface runoff (overland flow) and the related surface erosion processes. These may in turn facilitate debris flow initiation and enlargement, as well as contributing to increased erosion of river banks, increasing bank instability. The instability of the river banks may propagate upslope or laterally, initiating new landslides or reactivating old, dormant ones.

Increases in the number and severity of storms is also forecast, which has implications for wind and wave loadings on structures, as well as increasing rates of coastal erosion. Stronger winds are likely to result in further destabilisation of slopes as instability can be triggered by trees blown over in storms.

2.2.4 Coastal groundwater level rise

As sea levels rise, groundwater in the vicinity of the coast is also likely to rise. In areas where the groundwater is already shallow, such as low-lying alluvial plains, flooding will likely be exacerbated by reduced stormwater infiltration. Shallower water will affect the strength of soils beneath foundations, potentially causing widespread structural damage, and more land will become susceptible to liquefaction during seismic shaking (Quilter et al, 2015).

2.2.5 Multi-hazards

Climate change is predicted to increase the risk posed by individual extreme events. However, multi-hazard scenarios where the occurrence of simultaneous or sequential events is considered to result in a much larger total risk.

For example, a period of intense drought (causing desiccation cracking and vegetation die-back) followed by an intense rainfall event (causing erosion of now unprotected surfaces, and rapid saturation of deep soils through desiccation cracks) would likely lead to much higher risk from landslides than either of these two events alone.

3 CLIMATE CHANGE STRATEGIES

In general responses to climate change responses are split into two categories: mitigation and adaptation.

Mitigation focuses on our ability to control emissions and is a human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014b). The goal of mitigation is to stabilise greenhouse gas levels in a timeframe sufficient to:

- Allow ecosystems to adapt naturally to climate change.
- Ensure that food production is not threatened.
- Enable economic development to proceed in a sustainable manner.

Adaptation is the process of adjustment to actual or expected climate changes and their impacts. In human systems, adaptation seeks to moderate or

avoid harm or exploit beneficial opportunities (IPCC 2014c).

Because of the quantity of greenhouse gases added to the atmosphere in the past few centuries, we are already committed to some level of climate change and therefore to some level of adaptation. Without reducing our current rate of emissions, these changes will become much more severe. Therefore, it is generally accepted that both approaches are required in parallel. Adaptation is essential to respond to the changes that will happen, and mitigation is essential to limit these changes to manageable levels.

Adaptation and mitigation each have the potential to contribute to, or to impede, sustainable development. The best outcomes will occur when adaptation and mitigation work together to reduce risks of disruptions from climate change. Trade-offs between adaptation and mitigation and between economic goals and environmental goals may be required. In some cases, adaptation may increase greenhouse gas emissions (e.g. increased air conditioning in response to higher temperatures). In other cases, mitigation may impede adaptation (e.g. emissions trading may increase the cost of concrete, making it unaffordable for some countries to invest in relocating critical infrastructure away from hazard zones).

Climate change requires new approaches to sustainable development that consider the complex interactions between climatic, social and ecological systems. Climate-resilient pathways need to be defined that show how development can take place over time in a way that combines adaptation and mitigation to realise the goal of sustainable development. These pathways are iterative, continually evolving processes for managing change within complex systems (Denton et. al., 2014).

These approaches have secondary benefits. Strategies for climate change responses and strategies for sustainable development are often highly interactive, and in some cases, reducing the risk related to climate change enhances the capacity to manage other risks (Denton et. al., 2014).

4 ADAPTATION

In the context of geotechnical engineering, adaptation strategies for structures or other assets can be divided into three categories:

- (i) Reducing vulnerability. For example, designing to a higher standard helps structures withstand changes in future loading.
- (ii) Avoiding exposure. For example, this may be achieved by building in a less risky location.
- (iii) Increasing adaptability. By accommodating future change in the design this approach helps avoid locking in investments that could make future adjustments difficult and costly.

4.1 Reducing vulnerability

When assessing the cost/benefit ratio of projects in the built environment, it is normal practice to project the investment life of the project for 30 to 100 years. It is usually assumed (often implicitly) that the distribution of past variations in the environment is a reasonably accurate guide to the range of likely future variations: e.g., historical records of the variations in future river flows, coastal tidal and storm event patterns (Mazmanian et al 2013).

However, future environmental conditions will be dramatically different because of the accelerating rate of climate change and so relying on the past patterns when evaluating development proposals is hazardous.

Loadings and other design criteria specified in national legislation and standards are commonly applied when designing structures. However, these criteria often lag well behind current scientific knowledge and professional best practice as they are usually based on historical conditions and the processes to change them can be quite lengthy. These standards should be seen as setting a minimum standard and should be critically assessed by designers and clients. Clients have a vested interest in ensuring the longevity of their assets and should not assume that compliance with local or national legislation will be enough to meet their long-term requirements in a changing environment.

4.2 Reducing exposure

Reducing the exposure to future climate change risk requires an understanding of how the hazards described in Section 2.2 will affect specific sites proposed for development. This is more challenging for some hazards than others and can be more challenging on a site-specific basis than regionally.

Coastal inundation is complex, but less so than some other hazards. Forecasts of sea level rise are available, and models have been produced for many regions in the world indicating areas that are likely to be inundated under a range of climate change scenarios. These can then be considered in land-use planning and site selection. The models can be used directly in design (e.g. establishing appropriate setbacks from the inundation extent or minimum floor levels above flood levels) with an appropriate scenario selected to match local regulations and the client's risk appetite.

Other hazards are more challenging to model. For example, changes in slope stability are likely to be controlled by changes in total rainfall, changes in rainfall intensity, changes in vegetation and changes in temperature. While models are available for each of these input parameters, there are no readily available tools to assess what impact they will have on a particular slope. Collection of quality open geotechnical datasets will become increasingly important to support modelling of future impacts.

Hazards that are relatively consistent across large areas, such as settlement of expansive soils, can be readily addressed on a regional basis by identifying at risk areas and adapting building codes to be more resilient. However, codification can create unintended negative consequences such as increased construction cost and emissions.

4.3 Increasing adaptability and dealing with uncertainty in decision making

A series of decisions are made when zoning land use, developing land, making infrastructure investment, and designing. These decisions occur at many stages in the process starting with identifying the need for change through business case, concept design, site selection, detailed design, construction, operation, and decommissioning.

Models based on past patterns and events are often inadequate for characterising the effects of global warming and the complex dynamics that will result (Lempert et al, 2000). This places us in an analytical environment of deep uncertainty, which Lempert et al (2000) defines as "a condition where the parties to a decision do not know or do not agree upon the system model relating potential actions to outcomes, the prior probabilities for the value of key uncertain input parameters to the system model(s), and/or the value function that should be used to rank alternative outcomes". A key challenge when dealing with climate change is the lack of certainty about the future timing and rate of change – we cannot easily predict the conditions that our projects will encounter during their design life.

To cope with this deep uncertainty, a host of methods are being developed. These range from simulations to narratives and Delphi and Foresight exercises (in which individuals and groups participate in imagining plausible scenarios about future states, based on alternative projections of climate change), to "no-regrets" strategies and the dynamic adaptive pathways planning approach. All these approaches are intended to help policy makers better gauge what courses of action are preferable, in the light of the deep uncertainties they face.

Dynamic Adaptive Pathway Planning is the preferred approach in New Zealand, and is described further in MfE 2017. It is a decision-making process where multiple possible outcomes are prepared for. Trigger points are defined within the design process that will, at some point in the future, determine which outcome will be followed, or at what time the next stage will take place. In geotechnical terms, this is somewhat analogous to the observational method in geotechnical engineering described by Peck (1969), but with the addition of more formally defined trigger points and subsequent actions.

For example, a building may be designed on land that is currently stable, but which may have its stability reduced below acceptable criteria under certain climate change scenarios. The designer could consider options to create more resilient foundations from the start, or instead could design a

dynamic approach where they set aside a suitable area of land for a future retaining wall to be built when groundwater hits a particular trigger level.

Adaptive management approaches, which enable actions or policies to proceed in the light of uncertainties, are not new. They have been used for resource management decision-making (e.g., water quality) and policy development both internationally and in New Zealand over the last few decades (Lawrence et al, 2020).

In response to rising sea levels around our shores, the New Zealand Coastal Policy Statement and supporting guidance (MfE, 2017) advocate the use of an adaptive planning approach to deal with the uncertainty and change around associated risks in the future. Policy 27 of the NZCPS outlines a strategy for managing the rising risk to existing coastal developments from climate-change effects, where a range of options for reducing coastal hazard risk should be assessed over “at least 100 years” and include “*identifying and planning for transition mechanisms and time frames for moving to more sustainable approaches*”.

5 MITIGATION

5.1 Reduction targets

Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO₂ emissions and projected global temperature change (IPCC 2014). To encourage mitigation, New Zealand has several greenhouse gas emissions reductions targets. Our international targets are:

- Five per cent reduction below 1990 gross emissions for the period 2013-2020
- 30 per cent reduction below 2005 (or 11 per cent below 1990) gross emissions for the period 2021-2030 (MfE, n.d.).

In addition to these international targets, in 2019 the New Zealand Climate Change Response (Zero Carbon) Amendment Act set into law a new domestic target of net zero emissions of all greenhouse gases other than biogenic methane by 2050. This new target brings New Zealand in line with the global ambition set under the Paris Agreement.

5.2 Construction sector impact

The building and construction sector is a large contributor to greenhouse gas emissions from producing materials, constructing buildings and infrastructure, and the energy used in buildings. Globally, energy use in buildings contributed 19% of society’s global carbon footprint in 2010, according to the Intergovernmental Panel on Climate Change.

Vickers et al. 2018 identified that New Zealand follows similar trends to international figures (Figure 5). Considering the full life cycle (construction, use and end-of-life), the contribution of the built environment (i.e. buildings and infrastructure) is

approximately 13% of New Zealand’s gross carbon footprint. However, this value ignores emissions generated overseas during manufacture of construction materials, many of which are imported. Adjusting for the carbon footprint embodied in New Zealand exports and imports, the contribution to CO₂ equivalent from the built environment climbs to 20%.

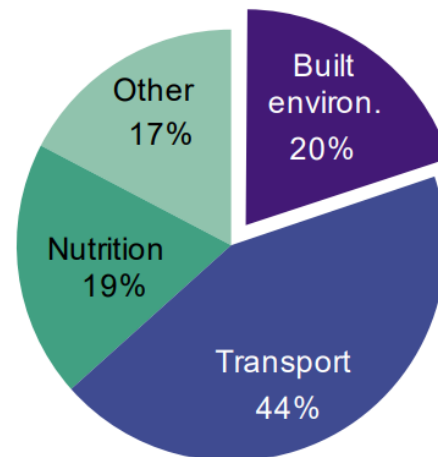


Figure 5. A breakdown of New Zealand’s carbon footprint in 2015 from a life cycle consumption perspective including international trade (Vickers et al. 2018). CO₂e is CO₂ equivalent, a measure of greenhouse gas emissions.

Emissions from buildings and infrastructure are commonly divided into embodied emissions, operational emissions, and end-of-life emissions.

Embodied emissions are the emissions generated during the manufacture of the building products and materials used in construction, maintenance and renovation. They occur upstream of the building itself, are one-off or irregular, are largely invisible to the architect or builder, and are often locked in before the first occupier even steps into the building for the first time. Given that these emissions cannot be changed later, they gain in importance over time as the energy mix used to operate the building decarbonises (reducing the relevance of the operational phase).

In New Zealand, embodied carbon for residential buildings is dominated by emissions from the production of steel and concrete (Figure 6).

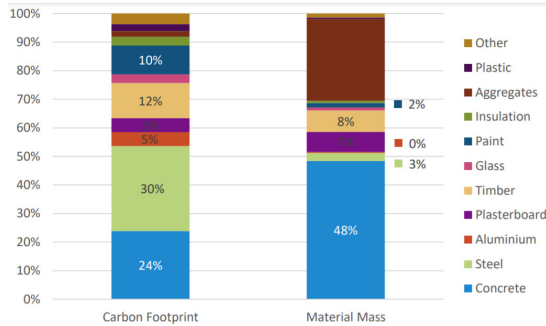


Figure 6. Carbon footprint and material mass breakdown for residential buildings in NZ over their full life (ThinkStep, 2019).

Operational emissions are the emissions produced by running a building (e.g. through heating and cooling). They are very visible as there is an ongoing cost associated with them (utility bills, maintenance bills, etc.), which creates a financial incentive for reduction. They can be improved through retrofits (e.g. replacing electric radiators with high-efficiency heat pumps) and higher-specification newbuilds (e.g. better insulation and air-tightness); however, there are cases where ‘lock-in’ occurs (e.g. under-slab insulation and building orientation).

End-of-life emissions are those generated in the demolition of a structure and the disposal of the resulting material.

Vickers et al. 2018 divided the emissions into these groups and identified that approximately half of all emissions were embodied in building materials (used for both buildings and infrastructure), and half were from operating our building stock (i.e., buildings only). Only a small proportion were from end-of-life. This was also supported by MBIE 2020b (Figure 7).

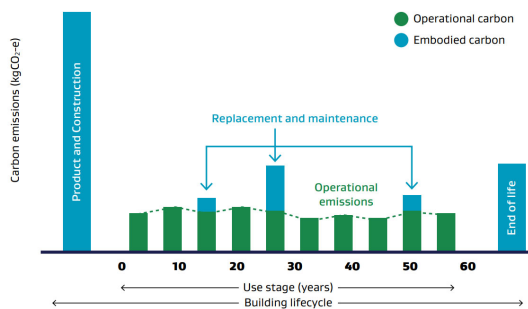


Figure 7. Operational and embodied carbon emissions over the life cycle of a building (MBIE 2020b).

However, for the unoccupied built environment (e.g. roads and other infrastructure), embodied emissions account for over 90% of the life cycle emissions (Huang et al, 2018), and therefore management of embodied emissions in infrastructure is likely to become a significant focus.

Chandrakumar et al (2019) attempted to calculate the acceptable whole-of-life carbon emissions for a residential building in New Zealand to be compatible

with a global warming limit of 2°C. They found that the climate target of a detached New Zealand house over a 90-year lifetime is 71 tonnes CO₂ equivalent, and reported that this would be equivalent to a reduction of 80% relative to current practice. Even in the best-case scenario where operational emissions were eliminated entirely, construction would still need to eliminate 60% of embodied carbon to meet national objectives. This is a very significant challenge, and one we have no current clear pathway to achieve.

5.3 Mitigation in geotechnical engineering

Significant carbon equivalent reductions are required from our construction practices in order to meet our climate change goals. However, advice on achieving these in the geotechnical realm is rare, and it has been reported that emissions from the construction industry in New Zealand have increased by 66 percent in the decade from 2007 to 2017 (NZGBC, n.d.).

Concrete and steel are among the most widely used resources in geotechnical engineering, but efficient use is not always a significant consideration in design. The global production of cement has grown very rapidly in recent years, and after fossil fuels and land-use change, it is the third-largest source of anthropogenic emissions of carbon dioxide (Andrew, 2018).

Despite this, because of the longevity of these materials, the whole-of-life carbon cost can be lower than other, initially less carbon emitting alternatives.

There are few tools to allow a robust comparison between different design alternatives in the geotechnical sphere. The BRANZ “Whole-building whole-of-life framework” provides tools, data and information to support decision making for sustainable building design. It assists calculation of the climate change impacts and other environmental impacts of our buildings (BRANZ, u.d.). This tool does allow a comparison between concrete and other building materials using data valid for New Zealand, but it focusses on structural elements, does not directly consider foundations and has no data for subgrade improvement, earthworks or other geotechnical structures.

6 NZ GOVERNMENT RESPONSE

Partly in response to our governments’ commitment to UN Sustainability Goal 13, the New Zealand Ministry of Business, Innovation & Employment is developing a programme of work (“Building for Climate Change”) designed to reduce emissions from buildings during their construction and operation, while also preparing buildings to withstand changes in the climate (MBIE, n.d.). Their stated goals for 2050 are:

- New Zealand’s buildings are using as little energy and water as possible. They are warmer, drier and better ventilated, and provide a healthier place for us all to work and live.

- The wellbeing of New Zealanders has improved, they're leading healthier lives, and respiratory illnesses from cold and damp houses is uncommon. People also have more money in their pockets due to lower energy bills.
- Our infrastructure finds it easier to respond to demand for water, due to our lower use. This means we cope better with water shortages than we ever have before.
- The efficiencies from the Sector have made it easier for the grid to become more renewable meaning less emissions for the energy we do use.
- Energy efficiency and carbon cost are core considerations for the Sector and designs now meet an emissions budget as well as other regulatory requirements.
- Reusing buildings and recycling materials is an established part of a Sector that is well on the way to having a fully-fledged circular economy well supported by local supply chains.

In July 2020 MBIE released a consultation document describing a proposed framework for change within the building and construction sector (MBIE, 2020a). These changes, currently focused on new buildings, involve defining operational efficiency levels for buildings to be able to get building consent. Of particular relevance to geotechnical practice, they also include plans to reduce whole of life embodied carbon. The framework will set mandatory reporting requirements, and embodied carbon caps that will need to be achieved to get consent.

7 A FRAMEWORK FOR GEOTECHNICAL PRACTITIONERS

Decisions made by geotechnical practitioners, normally in consultation with their clients, colleagues, and supply chain, can have a significant impact on the ability to integrate mitigation and adaptation into a design.

Geotechnical practitioners are likely to have a requirement to change how we decide on sites for development and on design solutions in response to government policy (e.g. the MBIE Building for Climate Change programme).

The following proposals are made to assist with this decision-making process.

7.1 Assess future conditions

Without understanding how conditions affecting our project sites may change in the future, we cannot take them into account in the design. Geotechnical practitioners should take a lead in considering how climate change could affect the ground, and what this means for design and site suitability.

Consider current conditions and a range of plausible future environmental conditions that may exist during the functional life of the structure. Identify how each of these may change:

- The geological model
- Geotechnical parameters
- Vegetation cover, type and density

7.2 Question the scope

Once geotechnical professionals get involved in a project it will often have been scoped, at least at a concept phase, and the geotechnical role is limited to delivering on that scope. However, geotechnical professionals have an understanding of hazards and climate change that might not have been considered in the decisions made.

It is imperative that an understanding of the client's drivers is shared by the whole project team, and that the project scope is regularly re-visited to re-confirm that it is still the best way to solve the client's problem.

7.3 Plan for changes in climate and society

Consideration of how the long-term needs and requirements of clients will change due to the impacts of climate change is rapidly becoming a necessity. If a societal or climate change means that the functionality is partly lost, is the design flexible enough to allow easy adaptation for other likely scenarios?

Bringing climate knowledge into early planning discussions with clients is essential to identify if a more flexible approach may be advantageous for them.

7.4 Consider functional life

Traditional design focuses on providing assurance that the structure will be safe over a specified design life, with little consideration given to what happens after that point. Most structures significantly outlast their design life and so will be subject to changes that did not occur within the design life of the structure. In addition to designing for the specified design life, geotechnical engineers should consider the full functional life of a structure. If a fully functional structure has to be demolished after its design life because the designer did not consider long-term effects, this is a significant waste.

Where possible, we will need to provide better techniques to preserve existing building stock so as to avoid the negative carbon footprint of building new buildings and demolishing the old.

7.5 Use scenario-based design

Dynamic Adaptive Pathway Planning can be used to give an insight into how future changes may affect a structure. A similar approach may be used to identify the range of plausible future scenarios (using the assessment of future conditions recommended in Section 7.1).

In the case of slope stability assessment, it is already normal practice to consider a range of load cases and model each independently, often with differing

requirements for a factor of safety depending on the likelihood of the load case occurring during the design life or the uncertainty of the assumptions made.

This proposal takes the same approach and extends it to considering future climate scenarios which may alter soil properties, groundwater levels, vegetation reinforcement etc.

Scenarios that are only likely after the design life of the building could, with agreement of the client and regulator, accept a lower factor of safety than scenarios likely to occur within the design life.

7.6 Balance longevity and adaptability

We must consider both mitigation and adaptation in our designs. Often these requirements will be in conflict. For example, a very resilient foundation design may require more concrete and therefore have higher embodied emissions.

As geotechnical practitioners, we have the knowledge to offer designs that move beyond the basic 'single design' approach to a more adaptive approach that considers the longer term with a series of staged dynamic changes to ensure that the structure remains useful, resilient, and responsive to its environment.

It is recommended that a suite of options is developed, supported by clear advice to your client about the relative costs and benefits of using more robust (and potentially more carbon intensive and initially expensive) design relative to more adaptable designs which may have lower up-front costs but higher costs over their lifecycle. Consideration must be given to how to avoid the moral hazard of selecting the lower-cost option up front and leaving higher mitigation costs to future owners, particularly where the client is not likely to be a long-term owner of the building.

7.7 Optimise material use with carbon accounting tools

Although development of widely available tools for carbon accounting is still in the relatively early phases, and those that do exist are generally quite limited in the geotechnical sphere, early adoption of these techniques will drive further progress and give a more robust basis for decision making on projects. The whole-building whole-of-life framework may provide a useful starting point (BRANZ u.d.).

There are two primary options to reduce embodied carbon; increase building material efficiency, and reduce carbon intensity.

Increasing building material efficiency means using less material in new buildings, including reducing waste and minimising replacement over the building's life cycle.

Reducing the carbon intensity of the materials used in new buildings is achieved by either by making

design choices to use low-carbon materials over high-carbon alternatives, and/or reducing the embodied carbon of the construction materials (MBIE 2020b).

Both should be considered as part of the design process.

7.8 Assess sustainability throughout design

Safety in design is now becoming common practice. By considering safety from project conception through to decommissioning, safety is being much more deeply considered in design.

The same approach should be standard practice for sustainable development and climate change response. Although geotechnical practitioners are often only involved in a design process after some key decisions have been made, their role in site selection and hazard assessment gives them a rare opportunity to influence the whole design process.

Consider how the materials used in the structure could be re-used or re-purposed at the end of the structure's life, and where appropriate adjust the design to make this process easier. For example, consider how piles might be reused by future buildings, or how a slab footing could be crushed to make aggregate and what effect the reinforcement may have on this. Document these assumptions and make them available in the design documentation so that they can be used at the point of demolition.

8 ROLES AND RESPONSIBILITIES

8.1 Role of central government

In New Zealand the government has a significant unbudgeted exposure to liability for natural hazard impacts, which will increase over time with growth in the values at stake and the anticipated weather effects of climate warming and sea level rise. The mean projections suggest that the Crown's annual contingent liability for natural hazards would grow from \$0.7 billion in 2020 to \$3.3 billion in 2050. That liability could be effectively reduced by investing in natural hazard risk mitigation that reduces risks and hence liability (NZIER, 2020). While insurance and reinsurance can only cover some of the risks of losses caused by hazards, in other cases, government faces an undefined liability for reinstating infrastructure damaged by natural disaster and for providing disaster relief. For the largest events, the impacts are potentially destabilising for government finances. Governments therefore have a huge incentive, and a huge responsibility, to manage these risks.

Governments can influence the energy optimisation of private buildings, transportation and land use through their legal decisions and regulatory instruments. Central government bodies generally set minimum building standards. In New Zealand the central government role is particularly important in driving reductions in embodied carbon.

Reducing operational emissions is of direct benefit to the owner as it can result in reduced whole-of-life costs and is therefore relatively easy to incentivise. However, reducing embodied carbon in structures rarely results in lower whole-of-life costs, and is more likely to require government regulation to drive change.

8.2 Role of local government

Because local government entities are closer to their citizens than central governments, they can play a significant role in launching initiatives and bringing policies into action. However, local governments are limited by different levels of influence and control when they try to tackle global warming issues.

In New Zealand, local governments primary tool is in land-use planning to encourage adaptation measures.

Local governments can also motivate and educate their communities and stakeholders to take action to reduce carbon emissions. In comparison to national governments, local governments leverage proximity to their citizens to maximise motivation and education in this area.

Local governments have a lot of authority to reduce municipal carbon emissions in their own facilities. Although municipal buildings contribute little to overall urban emissions, the public building sector is one of the highest emissions sectors under direct municipal control. Local governments can act as role models for the private and commercial building sector by attempting to meet global climate targets.

8.3 Role of clients

Clients must start to demand buildings which are fit for the coming century and beyond. Requiring sustainability and climate change to be considered throughout the design process by consultants and contractors (in the same manner as safety in design) would make a significant difference. When assessing tenders, consider what suppliers are doing to ensure the structure will not be exposed to future hazards, and will continue to perform as intended throughout its life. Consider specifying design for an agreed emissions scenario (for example, a 2°C global temperature rise) as a minimum with an assessment required to consider the implications of a higher (e.g. 4°C) rise, and require suppliers to describe how this will change the design parameters and decisions.

8.4 Role of consultants and designers

Designers and consultants need to move beyond national standards and guidelines and start considering a range of possible climates that may exist over the real life of a structure rather than only over its design life.

Designers should discuss with their clients the risks and encourage them to embed climate change mitigation and adaptation in their brief.

9 CONCLUSIONS

Our climate is changing, and this change poses many challenges for owners and designers of structures that are usually expected to last for many decades or even centuries.

Geotechnical professionals have an understanding of how climate changes the ground on which these structures stand and can provide insight into how changes in climate may change the natural hazards to which these structures will be exposed.

Geotechnical professionals have the skills to help their clients adapt to, and to some extent to mitigate, the effects of climate change.

A framework is presented that proposes a simple approach to integrate the appropriate thinking process into design.

10 ACKNOWLEDGEMENTS

This paper has been significantly improved by the reviews by Tracy Howe, Natasha Carpenter and James Corbett. It would never have been written without the encouragement of Ross Kristinof, and the kind permission of Sarah Sinclair and Paul Klinac. Thank you. The paper was written in a personal capacity and does not necessarily reflect the position of my employer.

REFERENCES

- Andrew, R. M., (2018). "Global CO₂ emissions from cement production". *Earth Syst. Sci. Data*, 10, 195–217, 2018. <https://doi.org/10.5194/essd-10-195-2018>
- BRANZ (u.d.). "Whole-building whole-of-life framework". Recovered on 30 August 2020 from <https://www.branz.co.nz/environment-zero-carbon-research/framework/>
- Chandrakumar, C., McLaren, S. J., Dowdell, D., and Jaques, R. (2019). "A top-down approach for setting climate targets for buildings: the case of a New Zealand detached house". In: *Proceedings of the Sustainable Built Environment Conference 2019*. IOP Conf. Series: Earth and Environmental Science 323 (2019) 012183. doi:10.1088/1755-1315/323/1/012183.
- Denton, F., T.J.Wilbanks, A.C. Abeyinghe, I. Burton, Q. Gao, M.C. Lemos, T. Masui, K.L. O'Brien, and K.Warner, 2014: *Climate-resilient pathways: adaptation, mitigation, and sustainable development*. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1101-1131.
- Gariano, S. L., and Guzzetti, F. (2016). "Landslides in a changing climate". *Earth-science reviews* 162 (2016) 227-252.
- Huang, L., Krigsvoll, G., Johansen, F., Liu, Y, Zhang, X., 2018. "Carbon emission of global construction sector". *Renewable and Sustainable Energy Reviews* 81 (2018) 1906-1916.

- IPCC (2014a). "Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change" [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
- IPCC (2014b). "Summary for Policymakers". In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- IPCC (2014c). "Summary for policymakers". In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.
- IPCC (2019). "Summary for Policymakers". In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.
- Lawrence, J., Bell, R., Blackett, P., Stephens, S., Collins, D., Cradock-Henry, N., and Hardcastle, M., (2020). "Supporting decision making through adaptive tools in a changing climate Practice guidance on signals and triggers". Wellington: Deep South Challenge.
- Lempert, R., Scheffran, J. and Sprinz, D. F. (2009). "Methods for long-term environmental policy challenges". *Global Environmental Politics* 9:106-133. <http://dx.doi.org/10.1162/glep.2009.9.3.106>
- Lorrey, A.M., Pearce, P.R., Barkus, C., Anderson, S.J., and Clement-Jones, A. (2018). "Auckland Region climate change projections and impacts: Summary report. Revised January 2018". Prepared by the National Institute of Water and Atmospheric Research (NIWA) for Auckland Council. Auckland Council Technical Report, TR2017/031-2.
- Mazmanian, D. A., Jurewitz, J. and Nelson, H. T. (2013). "A governing framework for climate change adaptation in the built environment". *Ecology and Society* 18(4): 56. <http://dx.doi.org/10.5751/ES-05976-180456>
- Ministry for the Environment (2017). "Preparing for coastal change. A summary of coastal hazards and climate change guidance for local government". PO Box 10-362, Wellington, New Zealand. ISBN: 978-1-98-852526-6. Publication number: ME 1335.
- Ministry for the Environment (2020). "New Zealand's Greenhouse Gas Inventory, 1990-2018". Ministry for the Environment Manatū Mō Te Taiao, PO Box 10-362, Wellington, New Zealand. ISSN: 1179-223X (electronic). Volume 1, chapters 1–15. Publication number: ME 1496.
- Ministry for the Environment (n.d.). "About New Zealand's emissions reduction targets. Retrieved 12 August 2020 from <https://www.mfe.govt.nz/climate-change/climate-change-and-government/emissions-reduction-targets/about-our-emissions>
- Ministry of Business, Innovation & Employment, 2020a. "Building for Climate Change: Transforming the building and construction sector to reduce emissions and improve climate resilience". July 2020. ISBN: (online) 978-1-99-001934-0
- Ministry of Business, Innovation & Employment, 2020b. "Whole-of-life embodied carbon emissions reduction framework (Building for climate change programme)". August 2020. ISBN: (online) 978-1-99-001947-0
- Ministry of Business, Innovation & Employment (n.d.). "Building for climate change". Retrieved 19 August 2020 from <https://www.mbie.govt.nz/building-and-energy/building/building-for-climate-change/>
- New Zealand Green Building Council, n.d. "Climate change and building pollution". Recovered on 30 August 2020 from https://www.nzgbc.org.nz/Category?Action=View&Category_id=389
- New Zealand Institute of Economic Research, 2020. "Investment in natural hazards mitigation – forecasts and findings about mitigation investment. Wellington, New Zealand. August 2020.
- NZ Herald, 2020. "Drought causes house problems, Auckland's drought has seen serious land stability problems double, say experts". Retrieved August 2020 from <https://www.nzherald.co.nz/indepth/commercial/drought-causes-house-problems/>
- Quilter, P. W., Ballegooy, S. van., Russ, M., 2015. "The effect of sea level rise on liquefaction vulnerability. Proceedings of the 6th International Conference on Earthquake Geotechnical Engineering, Christchurch, New Zealand.
- Peck, R. B. (1969). "Advantages and limitations of the observational method in applied soil mechanics". *Geotechnique* 19(2)
- Stephens, S. (2017). Tauranga Harbour extreme sea level analysis. NIWA, Hamilton
- ThinkStep, 2019. "Under construction: Hidden emissions and untapped potential of buildings for New Zealand's 2050 zero carbon goal". Report version 1.3, 16 August 2019.
- United Nations (n.d.). "Sustainable Development Goals". Retrieved on 21 August 2020 from <https://www.un.org/sustainabledevelopment/>
- United Nations World Commission on Environment and Development (1987). "Our Common Future". Annex to document A/42/427 - Development and International Cooperation: Environment
- Vahedifard, F., Williams, J. M., and AghaKouchak, A. (2018). "Geotechnical Engineering in the Face of Climate Change: Role of Multi-Physics Processes in Partially Saturated Soils". *Proceedings of IFCEE 2018* 353-364. 10.1061/9780784481585.035.
- Vickers, J., Fisher, B. and Nebel, B. (2018). "The carbon footprint of New Zealand's built environment: Hotspot or not?" Wellington: thinkstep. Available: <https://www.thinkstep.com/content/carbon-footprint-new-zealands-built-environmenthotspot-or-not>