BRUNEL INTERNATIONAL LECTURES

Institution of Civil Engineers

Shifting agendas:

response to resilience

The role of the engineer in disaster risk reduction

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Executive summary

Background

The scale, frequency and severity of natural disasters have risen progressively over the last 20 years. This trend is likely to continue as rapid urbanisation and climate change combine to create a 'perfect storm' in terms of increasing levels of vulnerability; a storm which will be further compounded by poverty, environmental degradation and resource scarcity. At present earthquakes represent the most deadly hazard, but weather-related hazards affect the greatest number of people – 2 billion between 2000 and 2009. Global losses over the same period averaged US$100 billion per annum and the Japanese earthquake, with losses of US$210-300 billion, was the most costly disaster event in history. The rapidly escalating cost of disasters is an increasing cause for concern for insurers, businesses and governments, but the true costs of a disaster are felt most acutely at community level and are determined by the community's ability to recover and rebuild their lives. Investment in reducing the impact of natural hazards and in enhancing the ability of communities to recover is more cost effective long term than dealing with the consequences of natural hazards.

Future challenges

Four fundamental challenges underpin the changing landscape of disaster risk, making it harder to foresee the consequences of natural hazards and to respond effectively when they occur:

Humanitarian – the finite resources and abilities of governments and humanitarian actors to effectively respond to disasters and assist recovery;

Urbanisation – the implications of rapid growth on urban development and infrastructure which is leading to increased vulnerability;

Complexity – the dynamic nature of urban environments, and implications of cascading failure due to inter-relationships between infrastructure, institutions and ecosystems;

Uncertainty – greater exposure to weather-related hazards and increased vulnerability arising from climate change which cannot be accurately forecast, and limitations in our ability to model complex systems.

Shifting agendas

In the face of the increasing scale, frequency and severity of rapid onset disasters greater emphasis needs to be placed on the effectiveness of humanitarian response through better leadership, accountability, innovation, and partnerships. But 'enhancing the status quo' is insufficient. The scale of the challenge requires a paradigm shift from response to resilience. There is an urgent need to create capacity locally to prepare, withstand and recover from both catastrophic events and accumulating stresses. This requires action throughout the entirety of the disaster management cycle, including embedding disaster risk reduction within development policy and programmes.

A comparable paradigm shift is taking place in disaster risk management in recognition of the complexity and uncertainty generated by urbanisation and climate change. There is growing recognition that alongside hazard-specific measures to reduce disaster risk, more emphasis needs to be placed upon tackling the underlying causes of vulnerability and on developing generic adaptive capacity to respond to both catastrophic events and accumulating stresses.[1] The objective is to create safer and more resilient communities who are able to adapt to changing circumstances, including being able to survive and recover from extreme events.

A complementary approach

Building resilience provides a complementary approach to traditional risk management practices which have typically focussed on preventing particular events occurring, or mitigating the consequences in terms of losses. Resilience adopts a different perspective that is centred on developing strategies to deal with a range of disruptive events if and when they occur. Emphasis is placed on anticipation, preparedness and recovery rather than prevention, and the inherent ability of the system (be it a community, business or city) to respond and adapt to disturbances. Resilience can only be achieved over time as a result of multiple actions and interventions, as well as the gradual accumulation of knowledge which changes behaviour. Research carried out by Arup for the International Federation of the Red Cross in 2011, suggests that the characteristics of a resilient community might include: good health; knowledge and education; reliable services and robust infrastructure; diverse livelihood opportunities; healthy ecosystems; the ability to organise and make decisions; and access to external assistance. There are therefore multiple ways in which engineers can contribute to building resilience.

International commitment

Reducing vulnerability and building resilient communities lies at the heart of international efforts to reduce disaster risk which have been gaining momentum over the past 20 years. International commitment is captured in the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. This framework identifies five building blocks for action:

- **Governance:** Make disaster risk reduction a priority
- **Risk assessment:** Know the risks and take action
- **Knowledge and education:** Build understanding and awareness
- **Risk management and vulnerability reduction:** Reduce risk
- **Preparedness and response:** Be prepared and ready to act.

The Hyogo mid-term evaluation published last year demonstrates there has been positive progress but 'helped by short sighted policies and practices, the vulnerability of our societies continues to grow'. The mid-term evaluation identifies the integration of risk reduction in infrastructure projects, safer schools and hospitals, and urban risk ('making cities resilient') as areas requiring further attention. These are all areas where engineers are able to make an important contribution.

Future horizons

The engineering community has played an important role in the prevention and mitigation of disasters by carrying out risk assessments, and designing structures that can withstand extreme events or major infrastructure projects that keep Nature at bay. Engineers have also played a vital role in humanitarian response by helping to provide clean water, sanitation and shelter, and the infrastructure needed to facilitate delivery of food and medical supplies. The nature and scale of the four challenges presented earlier, matched by the paradigm shift that is taking place in both humanitarian response and disaster management creates an opportunity for more proactive engagement, and demands a more holistic and collaborative approach.

- We must embrace **a more holistic understanding of risk** and fully recognise the potential which our projects afford in reducing vulnerability;
- We must recognise that **appropriate strategies** are needed which reflect local perceptions of risk, and financial and technical resources available;
- We must adopt **a systems perspective** in the design of urban infrastructure, recognising integration and interdependence of projects;
- We should encourage a shift to **a new culture of safety** which acknowledges uncertainty and recognises the possibility of failure;
- We should recognise that **collaboration and partnership** with other professionals, policy makers and decision makers, is essential if our voice is to be heard.

In addition we must ensure that all engineers possess sufficient knowledge and understanding of disaster risk, in order to become critical agents in ensuring the safety and wellbeing of mankind.

Introduction

'By our actions we either compound disasters or diminish them.'

Ban Ki Moon, Global Platform for Disaster Risk Reduction 2011

Isambard Kingdom Brunel's name has come to embody engineering achievement and ingenuity. He was a pioneer with passion and determination to turn his dreams into reality, but in doing so he recognised that there were risks. His projects epitomised the tightrope walked by engineers pursuing innovation in the name of progress, whilst at the same time ensuring public safety. The latter poses the greatest challenge in locations where natural hazards such as earthquakes, cyclones and flooding threaten civilisation.

During the 19th century, Nature was viewed as a limitless resource to be harnessed and redirected for the convenience of mankind. Nature is in fact both a finite resource and a mighty force, with the ability to decimate and destroy communities. Natural disasters are the consequences of events triggered by natural hazards.[2] Volcanic eruptions, earthquakes and cyclones may be considered 'acts of God', but their consequences are a result of mankind's actions; in this the built environment is a critical factor. Collapsed buildings are responsible for the vast majority of deaths and injuries during earthquakes. Flooding is exacerbated by inadequate drainage systems, environmental degradation and development on flood plains. The impact of natural hazards is magnified by weak governance, poverty, corruption and conflict. Each year, they cause significant damage, destruction and human suffering. Natural disasters are becoming more frequent, more complex and more extensive. They affected two billion people between 2000 and 2009.[3] Global losses over the last decade averaged almost US$100 billion per annum.[4]

Over the coming decades, the combination of rapid urbanisation and climate change is set to create a 'perfect storm' in terms of increasing vulnerability.[5] The devastation and human suffering caused by Hurricane Katrina in New Orleans, or by the earthquake in Port-au-Prince, Haiti, on 12 January 2010, are indicative of a future where disasters are increasingly urban phenomena. According to a recent World Bank report, the number of people living in cities exposed to earthquakes and cyclones will reach 1.5 billion by 2050 – more than twice the number exposed in 2000.[6] Climate change will increase mankind's exposure to extreme weather events, and accumulating stresses such as water scarcity, increases in vector-borne disease and food insecurity will increase vulnerability.

Over the past two decades, the importance of reducing disaster risk has been gaining momentum as a global policy issue. The true costs of a disaster are felt most acutely at a community level. The aim of disaster risk reduction is to reduce vulnerability to natural hazards, and to create resilient communities which are aware of, and better able to respond and adapt to, a wide range of shocks and stresses.[7] This requires collaborative and sustained risk reduction efforts across sectors and disciplines at multiple levels – in households, communities, cities, nations, and internationally. No longer can disasters be viewed solely as the concern of policy makers and humanitarian agencies. Many other actors have a role to play, including engineers.

To date, the contribution of the engineering community has largely focussed on hazard-specific mitigation and emergency response. Engineers have prevented disasters by designing structures that can withstand extreme events, and major infrastructure projects that keep Nature at bay. Coastal development has been made possible by dams, dykes and sea walls. Steep slopes are stabilised to prevent landslides. Towns and villages are protected by avalanche barriers. Tall buildings remain standing when major earthquakes strike. Our understanding of natural hazards and our ability to model the natural and man-made environment has, to some extent, enabled us to control Nature.

In areas of the world where codes of practice do not exist, are out of date or are not enforced, the vast majority of structures are non-engineered. Social exclusion and poverty force settlement on marginal lands and in unsafe structures. Deforestation increases the risk of flooding and landslides. Insurance is neither available nor affordable. When hazards strike, the consequences are devastating and humanitarian emergency response provides a critical lifeline for those affected. Over the past thirty years, the vital role played by engineers in the aftermath of disasters has been increasingly recognised. Engineers have helped save thousands of lives and reduced suffering by providing clean water, sanitation and shelter, and the infrastructure needed to facilitate delivery of food and medical supplies (see Figure 1). Their expertise has proven essential to ensuring that 'build back better' becomes a cornerstone of recovery and reconstruction, thereby reducing future vulnerability.[8]

Recent disasters have highlighted the limitations of humanitarian response, and challenged the view that modern cities are some of the 'safest places on earth'.[9] The unpredictability generated by climate change and the complexity of urban areas mean that traditional risk management practices are insufficient. In low- and middle- income nations where the risks are greatest, strategies are needed which recognise financial and technical limitations. These challenges present an opportunity for the engineering community to make an even greater contribution to disaster risk reduction globally. Our role is not to control Nature, but to enable communities to survive and thrive, as we face an increasingly uncertain future.

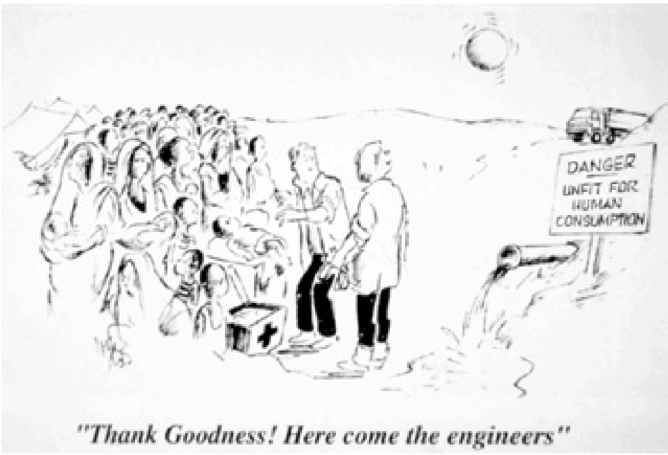

Figure 1: RedR cartoon illustrating the role of engineers in disasters

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Background

Natural hazards already pose a significant threat to mankind globally, resulting in thousands of deaths, substantial economic losses and untold human suffering each year. The number and impact of natural disasters has risen progressively over the last 20 years. There is no reason to doubt that this trend will continue. This chapter provides an overview of the current profile of disaster risk and the costs to society.

Facts and figures

The majority of population growth over the next few decades will take place in hazard-prone countries, mostly in Asia and sub-Saharan Africa.[10] Already, 95% of disaster-related deaths occur in developing countries.[11] Poor communities are particularly vulnerable to disasters as they often live in precarious locations. The daily struggle to meet their basic needs also prevents them from building up assets that might afford some protection.

The vast majority of natural disasters are caused by weather-related hazards – both hydro-meteorological and climatological.[12] These include floods, landslides, cyclones and tornadoes, storms, drought, heat waves, and wildfires. The impact of these hazards is exacerbated by environmental degradation and urban development. Floods alone affected almost one billion people per annum between 2000 and 2008.[13] In 2010, China experienced the worst flooding in recent history which affected 130 million people. In the same year, floods in Pakistan submerged one fifth of the country – an area the size of Italy – and extreme temperatures in Russia caused extensive wildfires and a heat wave which killed almost 56,000 people.[14/15] These very large scale events have been linked to climate change which it is understood will increase the frequency and intensity of extreme events.

Early warning systems have been successful in reducing loss of life from cyclones and tsunamis. They rely on accurate scientific information reaching those who are mostly likely to be affected, with sufficient time to allow them to act. Japan is currently investing in ocean-bottom seismographs and already has a system whereby trains stop automatically to prevent derailment as soon as the earthquake's primary wave is detected. Sophisticated technology such as this is out of reach for many countries. Bangladesh relies on institutional commitment and cooperation across local, regional, and national levels (see Box 1).[16]

Earthquakes are still the most deadly natural hazard mankind faces. Even though they represented only 4% of all hazard events between 2000 and 2009, they were responsible for 60% of disaster-related deaths.[18] This is despite advances in seismic engineering, and greater use of building codes and standards, which have significantly reduced earthquake mortality rates in higher income countries. The high death toll in low- and middle-income nations is due to lack of awareness of earthquake risks and inappropriate or poor quality construction (see Box 2). Building codes and standards are only effective if they are available and enforced, and reflect local perceptions of risk. The reality is that enforcement is often not achievable due to limitations in institutional commitment or endemic corruption.

Masonry and reinforced concrete has become a ubiquitous form of cheap construction for single-storey and low- or medium-rise buildings. In many countries it has replaced more lightweight vernacular construction traditionally used in houses and schools, and has displaced the traditions of local 'good building' which have developed over centuries.[19/20] It is inherently fragile unless properly reinforced, and often it is not due to lack of resources, knowledge, skills, and even in some cases due to corruption. Numerous homes, schools and community buildings are therefore highly vulnerable to earthquakes. There are villages, towns and cities in seismic areas throughout the world which are disasters waiting to happen unless buildings are retro-fitted and safer builder practices introduced.

BOX 1:
THE POWER OF EARLY WARNING - CYCLONE SIDR, BANGLADESH (2007)[17]

The relatively low mortality rate from Cyclone Sidr, in Bangladesh in 2007, illustrates the effectiveness of early warning systems. Although 3,447 people died, the death toll was significantly less than in 1991 when a cyclone of similar magnitude struck the country killing 190,000 people. In the intervening years, early warning systems had been established. Two million people received advance warning of the impending Cyclone Sidr and were able to seek refuge in 2,240 cyclone shelters, thanks to a network of 40,000 trained Red Crescent volunteers with bicycles and mega-phones.

BOX 2: RECOGNISING THE RISK - HAITIAN AND CHILEAN EARTHQUAKES[21/22]

The magnitude 7.0 earthquake which struck Port-au-Prince, the capital of Haiti, on 12 January 2010 killed over 300,000 people. This death toll has only been previously surpassed by the droughts in Africa in the mid-1980s and the Bangladesh tropical cyclone in 1970. One month later, the death toll in Chile, due to the much larger 8.8 magnitude earthquake in February 2010, was less than one thousand. Far fewer buildings collapsed in Chile as seismic building codes had been introduced following a devastating magnitude 9.5 earthquake in 1960 and had since been rigorously enforced. In Haiti, the last significant earthquake to hit the country was in 1842 and had long since been forgotten. Building regulations were non-existent and construction quality was very poor. Efforts to mitigate the impacts of natural hazards in Haiti had instead focused on hurricanes which happen more frequently than earthquakes.

Counting the cost

Disasters cost nations dearly in terms of social and financial losses, and the economic costs of disasters are escalating almost exponentially (see Figure 2). Over the period 2004-2010 global economic losses created by disasters averaged US$115 billion per annum, a figure higher than the national gross domestic product (GDP) of Bangladesh.[23] According to insurance giant Swiss Re, 2011 was the most costly year on record in terms of economic losses caused by natural disasters. The Japanese earthquake in March 2011 had an economic impact estimated as somewhere between US$210-300 billion, making it the most costly disaster event in history.[24]

The human impact of disasters is generally lower in wealthier nations but economic losses are higher in absolute terms as a result of damage to infrastructure. Wealthier nations are better able to recover as even significant losses represent only a small proportion of their GDP. The costs of damages in Chile due to the earthquake in 2010 were estimated at US$30 billion, equating to 18% of GDP.[25] Compare this with Haiti, where losses were estimated as almost US$8 billion which exceeded the country's GDP the previous year. Haiti is the poorest country in the northern hemisphere, crippled by weak governance, poverty and lack of resources. It will take years, if not decades to recover.

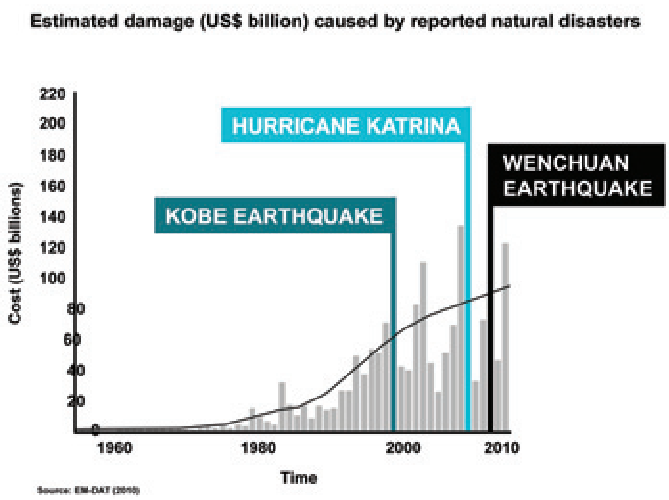

Figure 2: Economic costs of disasters (1900-2010)


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BOX 3: GLOBAL ECONOMIC IMPACTS OF LOCALISED DISASTERS - THE BANGKOK FLOODS (2011)[28]

The 2011 floods in Bangkok cost an estimated US$40 billion. The disaster also set back global industrial production by 2.5%, due to the key manufacturing role Thailand plays in the global technology industry. Thailand is home to the world's biggest names in hard drive manufacturing and is also critical to the global automotive supply chain. Floodwaters swamped thousands of factories in Bangkok leading to a 10% increase globally in the cost of hard drives, and Toyota's car production slowed in several countries.

Following a disaster, interrupted economic activity, loss of employment and reductions in industry output may have cascading repercussions further afield. It is therefore surprising that natural hazards do not feature higher on the list of risk priorities for business. In a recent survey conducted by Aon, 'weather/natural disasters' ranked only 16th in the compiled list of top risks to businesses even though business interruption ranked 5th.[26] The impact of the Thai floods and the recent tsunami in Japan on global supply chains is creating the business case for private sector investment in disaster risk reduction (see Box 3). 'Just in time' manufacturing, which relies on maintaining business continuity, needs to be fortified with 'just in case' systems to limit the damage from disruption.[27]

Loss of life and economic losses are commonly used to describe disasters as these indicators are relatively easy to measure. However, they paint an incomplete and arguably deceptive picture. Beyond these immediate direct costs are longer-lasting, and lingering, indirect costs such as loss of education, cultural heritage, livelihoods, social networks and ecosystems. Twenty million people in Pakistan, almost 12% of the population, were affected by the floods in 2010. Economic losses equated to 5% of GDP. Many people lost everything except the clothes they were wearing.[29]

Those that survive disasters are faced with the task of rebuilding their lives. Immediately after a disaster images of devastation and stories of the human consequences feature in newspapers and on television. Their intent is to encourage those of us watching to reach into our pockets and support humanitarian agencies that rely heavily on public funding. But the ultimate impact of a disaster is determined long after the media spotlight has dimmed and the aid workers have gone home. It is dependent on the ability of communities to recover; to return to work or school, to resume livelihoods, to re-plant crops, to rebuild houses, and to begin once again to invest in the future. The societal costs associated with lost education for students, reduced institutional capacity due to a high death toll or closed businesses due to damaged buildings have a long term impact on economic productivity, and hamper full recovery.

We cannot afford to ignore the possibility of future disasters. Investment in reducing the impact of natural hazards and enhancing the ability of communities to recover is considerably more cost effective long term than just dealing with the consequences of these hazards.[30]

An uncertain future

Four fundamental challenges underpin the changing landscape of disaster risk, making it harder to foresee the consequences of natural hazards and to respond effectively when they occur (see Figure 3):

Humanitarian – the finite resources and abilities of governments and humanitarian actors to effectively respond to disasters and assist recovery;

Urbanisation – the implications of rapid growth on urban development and infrastructure which is leading to increased vulnerability;

Complexity – the dynamic nature of urban environments, and implications of cascading failure due to inter-relationships between infrastructure, institutions and ecosystems;

Uncertainty – greater exposure to weather-related hazards and increased vulnerability arising from climate change which cannot be accurately forecast, and limitations in our ability to model complex systems.

Our traditional way of thinking and dealing with disasters is incomplete and insufficient in the face of these challenges. They demand new approaches and wider engagement involving actors who have not traditionally played a central role in disaster management; these actors include engineers and urban planners.

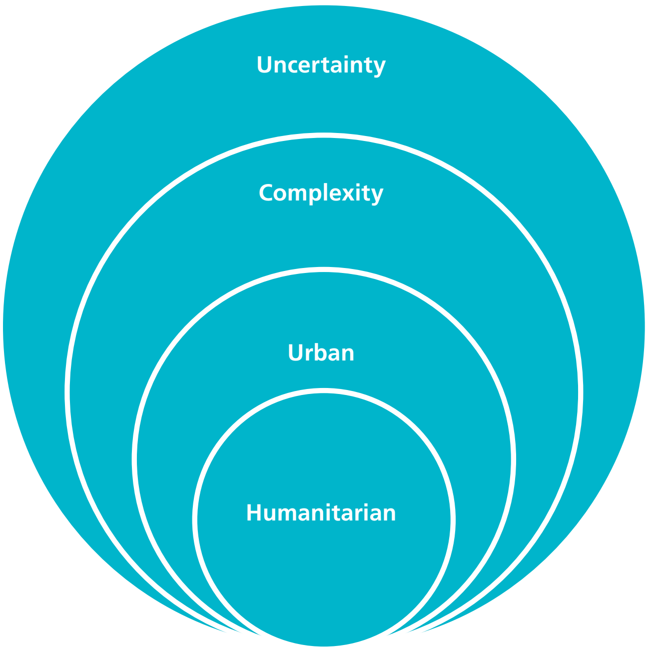


Figure 3: The four key challenges for disaster management

BOX 4: IMPROVING THE EFFECTIVENESS OF HUMANITARIAN RESPONSE - REDR[34]

RedR (previously, REDR – Registered Engineers for Disaster Relief) was founded in 1980 by Peter Guthrie, a Fellow and former Vice-President of the Institution of Civil Engineers. Recognising the importance of engineering expertise in humanitarian relief, Guthrie created a register of engineers who had the necessary skills and motivation to carry out this work. RedR engineers have carried out over a thousand assignments on behalf of the United Nations, the International Federation of Red Cross and Red Crescent Societies, humanitarian agencies and NGOs such as Oxfam and Médecins Sans Frontières. Today, RedR's focus is upon improving the effectiveness of humanitarian response primarily through developing and delivering training programmes to aid workers, and building local capacity to respond. Most recently the organisation has carried out training programmes in Haiti, India, Pakistan, Sri Lanka and Sudan.

The humanitarian challenge

The first challenge is that traditional actors in disaster response – humanitarian and government agencies – are entering into unfamiliar territory. A gap has emerged between the expectations of affected populations for assistance, and the capabilities and capacities of humanitarian agencies, including donors.[31] A key issue is that humanitarian agencies are increasingly expected to engage in recovery and undertake reconstruction efforts, but do not necessarily have the knowledge, resources or capacity to do so, particularly in urban areas. Engineers have many of the requisite skills but play a peripheral role.

The diagram (Figure 4) illustrates how the disaster management cycle – comprising the four phases of relief, recovery, reconstruction, and preparedness – overlays the process of development. Traditionally, it has been governments and humanitarian agencies that have dealt with the consequences of disasters.

The immediate priority in the aftermath of a disaster is humanitarian response (or relief). This plays a critical role in containing the consequences of a disaster by preventing further loss of life and alleviating suffering, primarily by providing food, water, shelter and medical care.[32] Engineers, working with humanitarian agencies, have played an important role in relief efforts ensuring potable water is available, constructing emergency shelter, and providing latrines, drainage and waste disposal in order to prevent the spread of disease. They have been responsible for repairing and constructing roads, bridges and buildings so that food and medical supplies can be delivered and distributed.

Engineers are valued not only for their technical and project management skills but for their ability to create and implement solutions that take into consideration a range of social, technical and logistical realities.[33] Considerable credit for the involvement of engineers in relief efforts should be given to the non-governmental organisation RedR (see Box 4).

In recent years, greater emphasis has been placed upon taking the first steps towards recovery as soon as possible. This is in recognition of the finite resources available, as donor funding is typically limited to a short period after an emergency; also, this approach avoids creating a culture of dependency, either on international aid or government assistance. It is the ability of communities to recover that determines the long term impact of a disaster. Consequently, as soon as they are able to, families are encouraged to return home if they have been displaced, and where possible to resume their livelihoods. Recovery relies on catalysing economic activity and rebuilding local infrastructure. This has taken traditional humanitarian actors into unfamiliar

territory requiring them to develop new skills, and to adopt a different role – as facilitators rather than providers. It became evident following the Indian Ocean tsunami that most humanitarian agencies were unfamiliar with the complexity and risk associated with reconstruction. It took more than 100 agencies over three years to construct 125,000 houses. Opportunities to develop local skills and introduce safer building practices were missed (see Box 5).[35]

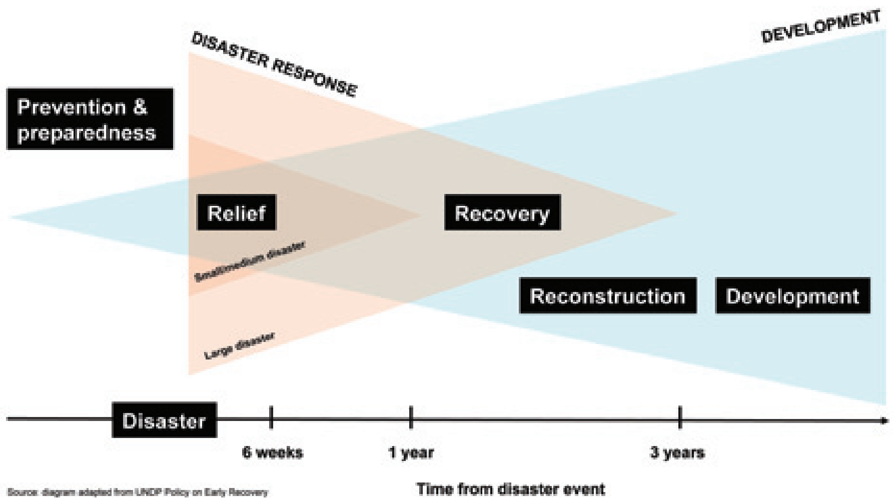


Figure 4: The disaster management cycle

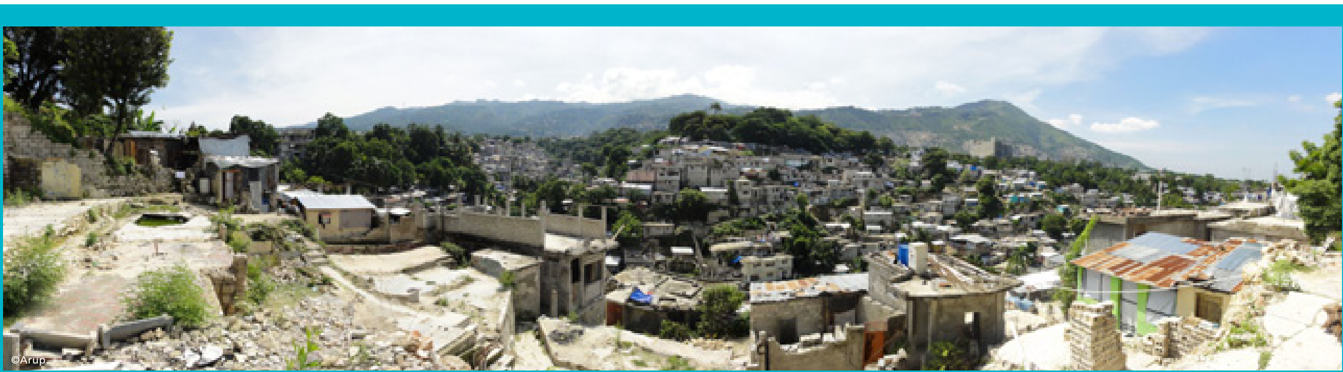
BOX 5: A STEEP LEARNING CURVE - ACEH, INDONESIA (2005-2008)[36]

Following the Indian Ocean tsunami over 125,000 houses and dozens of schools and health centres were built in Aceh. This took more than three years and involved more than 100 humanitarian agencies, as well as the government. These agencies climbed a steep learning curve and faced multiple challenges in delivering and scaling-up their construction activities. They learned through experience that construction of fairly simple structures (houses, schools and health centres) is not straightforward. Particularly so, in post-disaster situations where materials and skilled labour are in short supply, and even simple buildings need to incorporate seismic design principles. The most successful programmes recognised the need for both technical expertise and participatory community engagement. Typically, humanitarian agencies relied on employing individual consultants (mostly architects rather than engineers) for advice. A few engaged local engineering firms or sought advice from Syiah Kuala and Bandung Universities.

The situation is considerably more complex in Port-au-Prince, Haiti, where some houses need to be repaired, some completely rebuilt and others retro-fitted. Integrated urban renewal strategies for individual districts are needed which include provision of basic services (drainage, water, power, sanitation) as well as decent housing. In some areas buildings of three or four storeys will be required in order to accommodate the large number of homeless families. Haiti has highlighted the shortfalls in humanitarian agencies' attempts to deploy traditional, rurally-derived experiences and tools in an urban setting; and they lack the experience to undertake urban planning and redevelopment in a post-disaster context.[37] In some cases this has contributed to inappropriate responses and delays to recovery (see Box 6).

In both Aceh and Haiti humanitarian agencies have engaged engineers (or more frequently architects) as individual consultants, to assist with the implementation of shelter and reconstruction. This is a positive development, but individuals do not necessarily have sufficient technical knowledge or experience to take responsibility for a major construction programme in difficult circumstances. They are often volunteers or on finite short-term contracts. At a strategic level, engineers are notably absent amongst the staff of key decision makers (the World Bank, the UN, bi-lateral donors, governments etc.). Nor do these organisations typically engage experienced engineers or engineering firms as consultants in the early stages of recovery and reconstruction, when their experience is most needed in order to prioritise reinstatement of critical infrastructure, and help develop a road-map for recovery. In the event of a pandemic or a terrorist bomb attack with numerous human casualties, failure to consult medical professionals would be unthinkable. It therefore seems absurd that engineers are not engaged in disasters where there has been considerable loss of infrastructure and thus basic services, and particularly so in an urban context.

Ironically, the reason most frequently cited for not engaging technical experts or forming partnerships with the private sector is their lack of familiarity with the post-disaster context. Technical expertise is essential to ensure that recovery is not delayed, limited funds are spent effectively, and reconstruction efforts successfully reduce vulnerability. Partnerships are needed that bring together the capabilities of humanitarian and built environment professionals.



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BOX 6:
RETRO-FITTING AND REPAIR AS A PATHWAY TO RECOVERY - HAITI (2010)

The earthquake in Port-au-Prince, Haiti, on 12 January 2010 resulted in the collapse of numerous buildings, and left others standing but badly damaged. FEMA[38] guidelines for damage assessment were adapted to classify buildings that had been damaged by the earthquake as green (habitable), yellow (repairable), and red (unsafe). However, due to a lack of technical expertise, this classification was not followed by assistance to repair and retro-fit which would have enabled families to return home. Over 600,000 people were left languishing in camps more than two years after the earthquake.

The urban challenge

As more and more people settle in urban areas, disasters will become increasingly urban phenomena. This is due to the greater concentrations of people, assets and economic activity in exposed locations,[39] and secondly, to increased vulnerability resulting from infrastructure deficits and urban poverty.

The urban population is expected to rise from 3.5 billion today to almost 5 billion by 2030 – nearly two thirds of the world's future population.[40] Many of today's cities are situated in hazard-prone locations adjacent to the coast, on fault-lines or in river valleys; in places originally chosen for their strategic advantages – near water, fertile ground, or with access to trade routes by river, sea or through mountain passes. Fourteen of the world's 19 largest cities are port cities located in river deltas or along coastlines.[41] There are over 3,350 cities in low-elevation coastal zones around the world that are threatened by sea level rise.[42] Modern cities are certainly perceived as being some of the 'safest places on earth.'[43] However, events such as Hurricane Katrina in New Orleans, USA, the 2011 floods in Brisbane, Australia, or the earthquakes in Christchurch, New Zealand, are stark reminders that even modern cities are not immune to disasters. In fact, due to their locations many of them are extremely vulnerable.

The majority of future urban growth will happen in low- and middle-income nations. It is the pace of urban population growth (typically 2-3% across low-income countries, but as high as 5% in some African cities[44]) that poses a major challenge for governments. They lack the financial resources, effective governance, or the political will to invest in the infrastructure and services needed to support and protect a growing population. The result is unplanned urban development, characterised by infrastructure deficits, poor quality buildings and deteriorating ecosystems, which exacerbates natural disaster risk (see Box 7).

Infrastructure (or lack of infrastructure) will play an ever greater role in determining disaster risk. Flood risk is magnified by increased run-off from new developments, destruction of coastal ecosystems, lack of investment in stormwater drainage and inadequate watershed management. This is further compounded by waste dumped in drainage channels and rivers, and unregulated water extraction leading to subsidence.[45] At worst, this can lead to chronic water-logging, creating serious health issues and an increase in vector-borne disease such as malaria and dengue.[46] The consequences of poor quality construction are fatalities, injuries, homelessness and fragmented communities. Evidence of this can be found amongst collapsed buildings following the recent earthquakes in Indonesia, China, Pakistan, and, of course, Haiti.

For politicians and developers, the imperative of economic growth, or profit (or even a desire to secure re-election) in the immediate future is often a more compelling priority than reducing the possibility of a disaster sometime in the future.

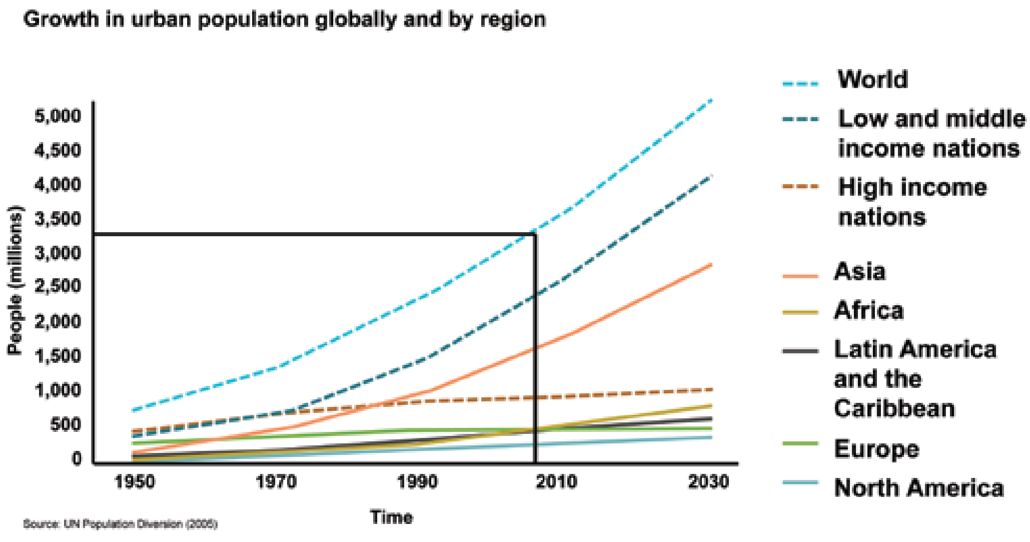

Figure 5: Regional urban growth rates

BOX 7: AN EXAMPLE OF URBAN VULNERABILITY - DA NANG, VIETNAM[47]

The residents of a fishing community in the Vietnamese city of Da Nang are well-used to tropical storms bringing strong winds and storm surges. They have regularly experienced coastal flooding which is worsened by lack of drainage, and suffered damage, including complete loss of roofs due to high winds. Recently the houses closest to the sea have been all but destroyed by wave strike, a new hazard. In part this is due to the increased intensity of storms in the area, but homes have also been made more vulnerable by the widening of the coastal road nearby, removing the dunes and vegetation that afforded some protection. The community was not consulted when this decision was made. The only action residents were able to take was to retreat and move their homes inland, and demand funding to invest in winches so as to be able to move their fishing boats (their key livelihood source) off the beach and out of the way of the destructive waves.

Since it is unlikely that additional funds will be made available for reducing disaster risk, it is imperative that disaster risk is integrated in urban planning and infrastructure investments targeted at improving quality of life or economic growth. Following severe floods, Surat, currently the ninth largest city in India, with a population that has grown from 750,000 to around 5 million in the last 30 years, has prioritised investment in public health and critical infrastructure, and introduced planning regulations which have substantially reduced risk levels and created improved living standards (see Box 8).[48]

Shortfalls in infrastructure and services also affect the ability of slum-dwellers to meet their most basic needs (food, water, shelter) and to access livelihood opportunities, whilst they pay a premium for rent, utilities, education and transport.[49/50] In Kibera, a slum in Nairobi, Kenya, which houses over 700,000 people, the cost of water sold at water kiosks is more than five times what residents in formal urban areas of the city expect to pay, due to the absence of water meters and council provision.[51] Six million people joined the ranks of urban slum-dwellers between 2000 and 2010, and the total number of people living in slums or informal settlements could reach 889 million by 2020.[52] Slums or informal settlements in urban areas are frequently located on marginal land highly susceptible to flooding or landslides.[53] Urban poverty also exacerbates vulnerability as it prohibits people from building up assets or adopting alternative strategies to overcome a lack of access to services, limited political voice and weak social networks.

BOX 8: FLOODING AND HEALTH RISKS - SURAT, INDIA[54]

Monsoon floods are commonplace in the Gujarati city of Surat, India. Whilst floodwaters disrupt infrastructure and industry, and coat the city in mud, they also provide breeding grounds for vector-borne disease. In 1994 a plague outbreak forced 60% of the urban population to flee the city, following which the Surat Municipal Council implemented a public health programme aimed a responding to post-disaster disease outbreaks but also increasing city-wide health. The city has also implemented a number of large infrastructure projects to tackle the effects of flooding. Surat boasts the only power-generating sewage plant in India. This was upgraded following the 1996 flood to ensure that water quality levels could be maintained to prevent further


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disease outbreaks. A large weir-cum-causeway across the River Tapi prevents saline intrusion into the city's main water supply, and provides storage for floodwaters when the monsoon rains arrive. Informal settlements located on the banks of the Tapi, directly in the path of the fluvial floods, have been cleared since 2006 and all the inhabitants have been relocated to safer, newly-built apartment blocks well away from the river. The city has also re-zoned this area as a public space to prevent resettlement on these vulnerable sites.

The complexity challenge

The third challenge is to understand the complexity of the urban system. The dynamic nature of urban environments means that it is harder to predict or prevent the consequences of a disaster. Urban areas comprise a multiplicity of institutions, assets, ecosystems and infrastructure networks, which are mutually interdependent.[55] They collectively support the wellbeing of urban citizens and determine the ability of businesses to flourish.

Conversely, failure in one area or system can lead to consequences in a further area or system. Disasters can therefore occur from indirect effects, arising from disruption or loss of essential assets and services which enable a city to function (e.g. loss of power or damaged facilities), as well as from the direct impact of extreme events (e.g. flooding or heat waves). The consequences of both direct and indirect effects are likely to be felt most acutely by vulnerable groups, such as the poor or elderly. This is illustrated in Figure 6 below.

The direct impacts of natural hazards are relatively straightforward to determine. For instance, spatial risk assessments based on topographical and hydrological information can be used to determine areas prone to flooding. These can be overlaid on socio-economic mapping to determine neighbourhoods where high levels of exposure are compounded by poor drainage or poverty; or businesses that are at risk. The indirect impacts of natural hazards are more complex as they relate to the extent to which the urban system can continue to function. This includes: the ability of people and goods to move around; the availability of food; ongoing operation of utilities (water, power, solid waste management); access to communications networks. Consequently, urban vulnerability exists at multiple levels.

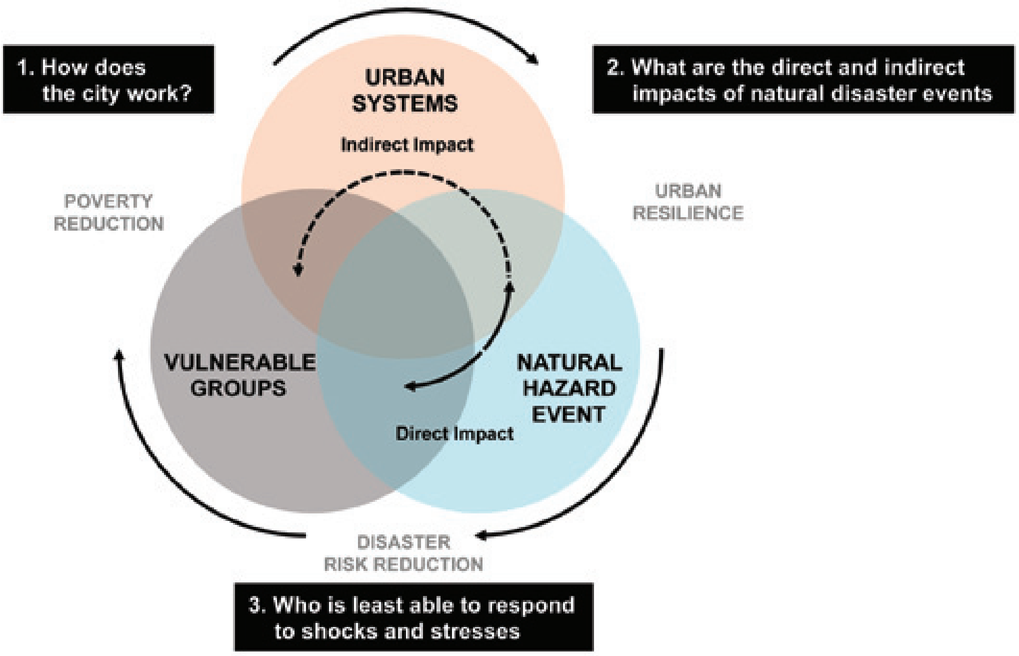

Figure 6: The features of urban complexity[56]

Furthermore, cascading failure due to inter-relationships between infrastructure, institutions and ecosystems means that loss of life, damage and disruption in a localised area can have far-reaching implications, affecting large sections of the urban population.[57] This is illustrated by the blackout which occurred in New York in 1977 (see Box 9) and flooding in Bangkok and Brisbane in 2011 that had global and regional, as well as local, implications. The territorial impact, even of small or medium scale events, may also be significant as a city's economic footprint extends well beyond its administrative boundary. Urban disasters may also be triggered by events further afield since a city relies on resources (food, water, energy, natural materials) drawn from surrounding areas.[58]

Finally, urban disasters also have a temporal dimension. The degree of disaster risk that exists at any one time is the result of cumulative decision making and action throughout the urban development process. Understanding existing levels of vulnerability, such as the quality of buildings and their ability to withstand an earthquake, is essential. Disaster risk management requires corrective action to address historic weaknesses (e.g. retro-fitting buildings), as well as preventative action to prevent future vulnerability. Decisions made today will affect the future, and since this is neither pre-determined nor predictable disaster planning needs to consider future scenarios, particularly in rapidly growing urban areas.

The complexity and dynamic nature of urban environments makes it challenging to foresee the consequence of natural hazards and to respond effectively when they occur. Spatial risk assessments are insufficient, and need to be complemented by a systemic understanding of the urban context encompassing local decision making mechanisms, provision of services, and the role of local ecosystems. However, we must recognise that our ability to accurately predict and prevent the consequences of a disaster is limited by our ability to understand and model the dependencies and interdependencies between different parts of a system. Surprises are inevitable.

BOX 9:
CITY-WIDE SYSTEM COLLAPSE - THE NEW YORK BLACKOUT (1977)[59]

In July 1977 New York suffered a power outage which left nine million people without electricity for periods of between 5 and 24 hours. Due to the geography of New York, and Manhattan in particular, the design of the grid system forced clustering of overground power lines, which makes the system vulnerable to storms. Lightning strike caused a single failure in one section of the system which set in motion a chain of failures, ultimately leading to the blackout, as system components shut down one by one. Recovery was slow as the lack of light made it hard to manually operate substations or examine and repair equipment. Communication to the public was also a challenge as the radio networks shut down due to lack of power.

The uncertainty challenge

The fourth challenge is the additional uncertainty posed by climate change. It is clear that climate change is a reality that needs to be taken into account as we make decisions today, but current predictions do not provide a robust basis on which to plan our future. Multiple efforts to develop future climate scenarios and projections have yet to achieve scientific consensus, although the accepted range of predicted change is 1.1-6.4°C (2-11oF) warmer by 2100.[60] A change in temperature of approximately 5°C (near the upper limits of this range) amounts to the difference between today's climate and that of the last ice age when glaciers reached central Europe and the northern United States. This predicted range is based on current levels of greenhouse gas emissions; if emissions levels continue to rise at current rates we will likely witness a more dramatic temperature rise considerably sooner than 2100.

The ultimate scale of the global challenge will depend on the effectiveness of climate change mitigation – our short-term ability to make the transition to a low carbon global economy and to reduce the concentration of greenhouse gases in the atmosphere to pre-industrial levels. Previous Brunel lectures have highlighted the importance of this, and explored the means by which we might transition to an ecological age[61] and challenges to delivering a low carbon society.[62] But, they have focused on the risk posed by climate change at a global level rather than how climate change risk is manifested at a local level. Climate change mitigation is essential, but it only provides a first line of defence, and is not a robust tactic. Even if global consensus and commitment to radically reduce emissions (at least to limit global temperature rise to 2°C) could be reached at policy level, it will require an unprecedented technological transformation over decades to translate this policy into practice. Mitigation strategies are also swimming against the tide of population increase, and the aspirations of developing economies to emulate the quality of life that currently exists in North America, Europe and Australia.

There is no question that we will have to adapt to Nature, and deal with the local consequences of climate change. Strategically, this adaptation is far harder than mitigation, as the consequences are wide-ranging and context-specific. Our immediate concern is the next 10-20 years in those parts of the world where significant changes to currently accepted levels of climate variability are not only predicted, but are already evident.

More specifically, higher temperatures and changing rainfall patterns are already resulting in a greater frequency and intensity of weather-related shocks (sea level rise, storms, heat waves, flooding, drought) as well as accumulating stresses upon human systems (water scarcity, vector-borne disease, reduced crop yields). More disasters will occur either as a result of extreme events, or from mounting stresses such as water shortages – or a combination of both. Experts predict that climate-related disasters could affect up to 365 million people a year by 2015, up from 263 million in 2010 – a 40% increase in 5 years.[63] This calls for significantly greater alignment of the disaster risk reduction and climate change adaptation agendas.[64]

Taking a longer term perspective, significant shifts in climate trends threaten to undermine the productive base of society and the viability of human existence in some locations. For instance, the threat posed by sea level rise to low-lying island states, like The Maldives, or flooding to river delta settlements such as Ho Chi Minh in Vietnam. This threat is being keenly felt in Asia currently,[65] and ultimately strategies such as managed retreat or relocation may be necessary.

Current planning must factor in the impacts of climate change yet we can no longer forecast, with a meaningful degree of accuracy, the severity or likelihood of weather-related events over the 50-100 year lifespan of new infrastructure. This challenges the 'predict and prevent' paradigm that has underpinned urban planning and infrastructure investments to date.[66] This paradigm is founded on traditional risk management practices, which are focussed on the probability and consequences of particular events occurring. This has three implications. Firstly, 'worst case' design parameters associated with specific hazards (temperature, wind speeds, sea level, and rainfall measurements) are no longer reliable if based on projections that use historical data and statistical analysis of risk. Secondly, 'rigid' designs which respond to a pre-determined performance threshold risk failure (at worst, catastrophic failure) if design criteria are exceeded. Thirdly, if we cannot predict the future, we must design systems that can be adapted as our understanding increases.

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Shifting agendas

A paradigm shift

The scale, frequency and severity of rapid onset disasters (such as hurricanes, storms and earthquakes) will continue to grow in the coming years at an accelerating pace.[67] The reality is that mankind has limited ability to prevent disasters and there are limited resources to respond to disasters as and when they occur. A recent review of humanitarian emergency response - the Humanitarian Emergency Response Review (HERR) - carried out on behalf of the UK government, described this as 'a race between the growing size of the humanitarian challenge and our ability to cope; between humanity and catastrophe – and at present, this is not a race we are winning.'[68] The HERR report recognises that there are limitations in terms of available funding and the capacities and abilities of both governments and humanitarian agencies. It calls for greater emphasis to be placed upon the effectiveness of humanitarian response through better leadership, accountability, innovation, and partnerships – including with the private sector.

But, more importantly, the review also recognises that 'enhancing the status quo', by relying on humanitarian response, is insufficient. The scale of the challenge requires a paradigm shift from response to resilience. In addition to improving the effectiveness of humanitarian response, there is an urgent need to create capacity locally to prepare, withstand and recover from both catastrophic events and accumulating stresses.[69] This requires action throughout the entirety of the disaster management cycle, including embedding disaster risk reduction within development policy and programmes.

A comparable paradigm shift is taking place in disaster risk management in recognition of the complexity and uncertainty generated by urbanisation and climate change. There is growing recognition that alongside hazard-specific measures to reduce disaster risk, more emphasis needs to be placed upon tackling the underlying causes of vulnerability and developing generic adaptive capacity to respond to both catastrophic events and accumulating stresses. The goal is to create safer and more resilient communities that are able to adapt to changing circumstances, including being able to survive and recover from extreme events. Research carried out by Arup for the International Federation of the Red Cross and Red Crescent Societies last year, suggests that the characteristics of a resilient community might include: good health; knowledge and education; reliable services and robust infrastructure; diverse livelihood opportunities; healthy ecosystems; the ability to organise and make decisions; and access to external assistance (see Figure 7).[70] There are therefore multiple ways in which engineers can contribute to building resilience.

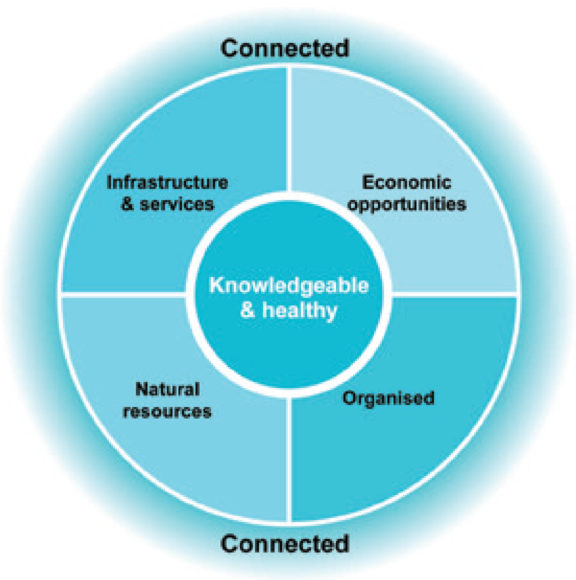

Figure 7 – The characteristics of a safe and resilient community

A complementary approach

The term 'resilience' is increasingly used in the context of disasters, as well as in other disciplines, but there is no commonly accepted definition and few robust case studies to illustrate what it means in practice.[71] The concept originated from the field of ecology in the 1970s, and was originally proposed to describe the ability of complex systems to absorb significant change and disturbance, while maintaining the critical relationships that enable the system to function. This is distinct from stability which is the ability to return to a previous equilibrium state after a temporary disturbance.[72] Resilience is a concept that has subsequently been adopted and interpreted by many different disciplines but retains its association with systems and the extent to which they are able to respond and adapt effectively to changing circumstances, notably shocks and stresses.[73/74] Inherent in the notion of resilience is the acceptance that disruption may occur and result in significant change, but that it should not lead to breakdown or catastrophic failure.

Resilience is an important concept in disaster risk reduction as it is focussed on recovery. It describes the ongoing ability of a system (a community, business or city, for example) to continue to function and achieve its purpose, to the fullest possible extent in the face of stress. It encompasses both pre-existing vulnerability (susceptibility) and the ability to adapt to changing circumstances whether arising from sudden or slow-onset events.[75] The opposite of resilience is breakdown – or disaster - which might manifest itself as cascading failure of infrastructure networks, catastrophic collapse of buildings or social disintegration and conflict.

Traditional disaster risk management focuses on preventing particular events occurring (e.g. dykes to avoid flooding, vaccinations to avoid contracting vector-borne diseases), or by mitigating the consequences (e.g. seismic design, medication to treat illnesses). Instead, resilience approaches risk from a different perspective centred on developing strategies to deal with disruptive events if and when they occur. Emphasis is placed upon anticipation, preparedness and recovery rather than prevention, and on the inherent ability of the system to respond and adapt to disturbances rather than hazard-specific risk mitigation.[76] Risk is accepted, as is failure of one part of the system, provided that the failure remains localised and does not have disproportionate consequences. As such, resilience incorporates concepts of ductile behaviour, redundancy and robustness that are already familiar to most engineers.

Building resilience provides a complementary approach to traditional hazard-specific risk management that is applicable to systems, and accommodates the unknown and uncertain. It is therefore particularly relevant in addressing disaster risk in the context of complex urban environments and an uncertain future. Strategies focussed on building resilience are the antithesis of a 'command and control' approach, or the 'predict and prevent' paradigm referred to in chapter 3. Those approaches are only relevant when sufficient knowledge exists to foresee when events may occur, and how they might play out. As discussed previously, the complexity and dynamic nature of urban environments and uncertainty arising from climate change makes this necessary foresight unattainable; unexpected scenarios and surprises are inevitable.

Finally, it is important to note that resilience describes an ultimate outcome that can only be achieved over time, as a result of multiple actions and interventions, and the accumulation of knowledge which progressively changes behaviour, as well as directly reducing risk.[77] Hence, building resilience is akin to sustainable development in requiring multi-sectoral processes, involving multiple actors. Neither one-off projects nor 'single sector planning can solve the complexity of problems posed by natural hazards, nor build resilience to them'.[78]

A call for action

Reducing vulnerability and building resilient communities lies at the heart of international efforts to reduce disaster risk which have been gaining momentum over the past 20 years. Recognition of the impact of disasters on hard-won development gains in the 1980s shone a global spotlight on this issue, resulting in the 1990s being declared the International Decade for Natural Disaster Risk Reduction by the UN General Assembly. In 1994, the Yokohama Strategy and Plan of Action for a Safer World proposed a more systematic approach to reducing disaster risk. Notably, this plan stressed the significance of socio-economic vulnerability and the crucial role of human actions in reducing (and also increasing) risk. Previously attention had been turned to developing a greater understanding of the scientific basis for predicting hazards and developing technical solutions.

Almost 10 years later, in 2004, a comprehensive review of progress in implementing the Yokohama Strategy and Plan of Action for a Safer World was carried out by the United Nations and its International Secretariat for Disaster Reduction (UNISDR).

This review further highlighted the need for local ownership of reducing disaster risk. It also recommended the mainstreaming of disaster risk reduction within existing processes for decision making – not least because of the lack of dedicated resources to address this issue.

In January 2005, mere weeks after the Indian Ocean tsunami, the World Conference of Disaster Reduction was held in Hyogo, Japan, resulting in agreed international commitment to reducing disaster risk captured in the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. This framework identified five building blocks for action which collectively promote the systematic integration of multi-hazard disaster risk reduction into policies, planning and programming at every level: governance, risk assessment, knowledge and education, risk management and vulnerability reduction, preparedness and response (see Box 10). Collaboration and cooperation between multiple stakeholders – government, civil society and the private sector – are noted as being vital to disaster risk reduction; the message is that 'disasters can affect everyone and are therefore everybody's business.'[79]

BOX 10: HYOGO FRAMEWORK FOR ACTION 2005-2015: PRIORITIES FOR ACTION[81]

1. **Governance:**
   Make disaster risk reduction (DRR) a priority.
   Ensure that DRR is a national and local priority with a strong institutional basis for implementation.
2. **Risk Assessment:**
   Know the risks and take action.
   Identify, assess and monitor disaster risks and enhance early warning.
3: **Knowledge and Education:**
   Build understanding and awareness.
   Use knowledge innovation and education to build a culture of safety and resilience at all levels.
4. **Risk Management and Vulnerability Reduction:**
   Reduce risk.
   Reduce the underlying risk factors.
5. **Preparedness and Response:**
   Be prepared and ready to act.
   Strengthen disaster preparedness for effective response and recovery at all levels.

The Hyogo mid-term evaluation published last year in 2011 demonstrates that there has been considerable progress, but 'the cruel reality is that – helped by short sighted policies and practices – the vulnerability of our societies continues to grow.'[80] To date there has been limited engagement by the engineering community in responding to Hyogo's call for action. The emphasis of response to date has been on developing appropriate governance, raising awareness of disaster risk and tackling the socio-economic factors that create vulnerability. In the mid-term evaluation the integration of risk reduction in infrastructure projects is identified as an area that still requires urgent attention; safer schools and hospitals continue to be a critical priority and 'urban risk' ('making cities resilient') is identified as a key focus area. These are all areas where engineers are able to make an important contribution.

UNISDR's campaign, Making Cities Resilient, involving 928 cities around the world, is a proactive step towards raising awareness of the urban challenge. Over the next three years the campaign proposes to turn its attention to supporting cities taking action that improves their resilience. But what are the mechanisms and strategies for doing so? There are no blueprints, and considerable effort is needed to create an evidence base of how to build urban resilience. This is particularly important in rapidly urbanising cities where funding is limited but an opportunity exists to ensure that urban planning approaches and infrastructure investments reduce risk in the long term. This is the focus of the Rockefeller Foundation's Asian Cities Climate Change Resilience Network (ACCCRN) which is working in ten cities in Asia to build urban resilience to climate change. ACCCRN partners' experiences emphasise the challenges in working across deeply silo-ed systems of urban management, and the importance of multi-stakeholder participatory processes, international examples of best practice and national policy in the formulation of urban resilience strategies.[82]

Future horizons

The intent of this lecture is to highlight the increasing risks posed by natural hazards, and the important role which engineers can play in disaster risk reduction (particularly in urban areas). There is no doubt that engineers have made a very significant contribution to reducing disaster risk to date. This has enabled communities to flourish in locations and situations that would otherwise be untenable. But it also questions why we have not played a more central role to date either in disaster response and recovery or formulating policy and strategy, particularly around efforts to address urban risks and to mainstream disaster risk in infrastructure interventions. Our technical expertise and analytical capability is needed, but perhaps our perspective is blinkered or our approaches are outmoded, making our contributions harder to incorporate within current disaster management mechanisms.

The nature and scale of the four challenges presented earlier, matched by global recognition of the need to improve the effectiveness of humanitarian response, reduce underlying vulnerability and build resilience, creates an opportunity for more proactive engagement by engineers. This does not negate the importance of hazard-specific mitigation, but demands a more holistic and collaborative approach.

› We must embrace a more holistic understanding of risk and fully recognise the potential which our projects afford in reducing vulnerability.

› We must recognise that appropriate strategies are needed which reflect local perceptions of risk, and financial and technical resources available.

› We must adopt a systems perspective in the design of urban infrastructure, recognising integration and interdependence of projects.

› We should encourage a shift to a new culture of safety which acknowledges uncertainty and recognises the possibility of failure.

› We must recognise that collaboration and partnership with other professionals, policy makers and decision makers is essential if our voice is to be heard.

In addition we must ensure that all engineers possess sufficient knowledge and understanding of disaster risk, in order to become critical agents in ensuring the safety and wellbeing of mankind.

A holistic understanding of risk

The mid-term evaluation of the Hyogo Framework criticised current engineering approaches as being 'one-dimensional' in considering the risk to the project, rather than how the project might reconfigure risk territorially (see Box 11).[83] This is not unreasonable. The terms 'disaster risk reduction' and 'reducing vulnerability' have not traditionally been part of the engineer's vocabulary. The engineer's perspective is that disasters are prevented (or at least mitigated) either by reducing exposure to specific hazards, or by designing structures or systems that are less susceptible (or vulnerable) to damage from hazard events.[84] As such, engineers are inclined to see disaster risk through a relatively narrow lens focused on prevention or hazard mitigation, often only related to the performance of physical assets rather than human consequences of damage and losses. The insurance industry plays a role in shaping this perspective, as do donors who fund major infrastructure projects (e.g. dams, dykes, sea walls).

In contrast, disaster risk management is typically viewed through a human lens. Vulnerability is a function of physical exposure that results in loss, and the human capacity to withstand, prepare for and recover from that same event. As such it incorporates susceptibility to disasters as well as the ability to cope in the event of a disaster occurring.[86/87] This duality is important, although frequently vulnerability and capacity assessments (VCA) undertaken by development organisations mistakenly overlook exposure to hazards, just as engineers' risk assessments tend to consider what, rather than who, is vulnerable.

Risk is a function of the severity (or magnitude) and likelihood of a particular hazard event occurring, combined with physical exposure and vulnerability: $R = f\{[S, L]^{hazard} [E, V]\}$. For engineers, the entry point to reducing risk is undoubtedly reducing exposure and physical vulnerability; either by siting buildings away from natural hazards (e.g. unstable slopes or floodplains); building defensive infrastructure (e.g. stormwater drains, sea walls, slope stabilisation); and/or designing structures to be stronger, therefore better able to withstand extreme events. Such actions rely on a robust understanding of hazard risk as applied to the built environment in terms of flood levels, ground accelerations, liquefaction, wind speeds and wave pressures. An environmental or geotechnical engineer will typically focus on where a project is located, whereas a structural engineer will worry about making it stand up. Both views are equally important but they overlook the fact that there may be other socio-economic or environmental factors contributing to an individual or a community's vulnerability. These are factors which engineering projects might have the power to influence if we are able to view disaster risk through a wider lens.

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BOX 11: FLOOD RISK MEASURES WHICH ACTUALLY INCREASE RISK - QUY NHON, VIETNAM[85]

Quy Nhon, a city in central Vietnam, experienced unprecedented floods in 2009. The response to this event, which was implemented very quickly, was to build elevated roads and to raise houses and other structures up to two metres above the ground. However, this has increased flood risk in other areas of the city as the elevated roads and houses block natural drainage channels through the city. This risk is compounded by future trends in the local climate which predict more intense rainfall spells during rainy seasons.

Engineering projects can provide multiple opportunities to reduce vulnerability. For instance, a school that is appropriately designed will withstand a cyclone or earthquake, but if properly located it can also act as an emergency community shelter; and its construction provides an opportunity to promote safe construction practices. The outcome of the project in human terms becomes increased disaster awareness and preparedness, as well as better education. The most effective disaster reduction initiatives are those that offer development benefits in the near term as well as reductions in vulnerability in the long term. For example, introducing solid waste management will provide health benefits short term, but it may also reduce the likelihood that drainage channels will be clogged with garbage when there are heavy rains, reducing flood risk.

The concept of 'build back better' which has become an underlying principle of post-disaster reconstruction embodies this approach. The design, choice of materials and standards of workmanship should reduce physical vulnerability to future hazards. In addition, reconstruction should make the most of the opportunity to raise awareness of risks within the community; and to introduce better construction practices by building local technical capacity through knowledge transfer including partnerships, guidelines and training. In urban environments, building back better should also use the window of opportunity afforded by post-disaster funding to formalise tenure and introduce basic services (water, energy, solid waste management, drainage); ideally, as part of long term neighbourhood renewal plans, developed in consultation with communities as well as governments.[88]

If we take a more holistic view of risk, we are better placed as engineers to articulate a business case to our clients for investment in reducing disaster risk. This is well illustrated by comparing the experiences of two car manufacturers in Turkey (see Box 12). There has been much debate about the role of the private sector in disaster risk reduction. For the Japanese manufacturer in this example there is clearly a strong business case to invest in safer housing for its workers; or at least raise awareness of hazards amongst its employees so they are empowered to make decisions that might reduce risk to themselves and their families.


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BOX 12: A BUSINESS CASE FOR DISASTER RISK REDUCTION – TURKEY (1999)[89]

An American car manufacturer appointed an engineering firm to design its facility in north western Turkey in accordance with the local seismic codes, satisfying the necessary requirements for 'life-safety' criteria. In 1999 the facility was under construction with manufacturing equipment standing within the shell of the building. On the morning of 17 August 1999 a magnitude 7.6 earthquake struck the region which caused considerable damage to structural and non-structural elements (including equipment). The opening of the plant was delayed causing considerable loss of earnings to the manufacturer. In contrast, a Japanese manufacturer, located in the same area, had a better understanding of seismic risk. The design criteria for the facility (including the equipment and non-structural elements) exceeded code requirements, with performance requirements understood to incur minimal damage in a major earthquake. The facility performed as expected and operations could have resumed immediately. However the factory remained closed for several weeks, as most of the workforce lived in housing which collapsed or was badly damaged, causing deaths and injuries. Yet, after a short while, the employees were able to return to work and begin to rebuild their lives, helped by the fact the factory was still able to operate and they had retained their livelihoods.

An appropriate strategy

Engineers are masters of technology. As our understanding of hazards, structural behaviour and hydrological modelling has improved, our ingenuity has kept pace with increasingly sophisticated technical solutions. Some of the world's tallest and most iconic buildings are located in the most hazardous places (see Box 13). Large scale, sophisticated engineering projects, such as the Metropolitan Underground Discharge Channel in Tokyo or the Thames Tideway Tunnel which include passive and active systems, are testament to engineering's ingenuity and technical achievement. But such high-tech engineered solutions require substantial investment, technical and institutional capacity to implement, operate and maintain. As such, they do not represent viable or appropriate solutions in rapidly urbanising low- and middle-income countries where even the introduction of building regulations and land-use zoning pose significant challenges.

Alternative strategies for reducing disaster risk are needed that reflect these realities and rely less on technical prowess and effective governance. In this respect, strategies that rely on the cumulative impact of multiple smaller interventions rather than large one-off projects may be preferable (see Box 14). It is also important that we recognise the vital contribution that local ecosystems play in reducing risk, by regulating run-off, and providing coastal protection for example. It is not only 'grey', but also 'blue' and 'green' infrastructure that contributes to an overall system which mitigates risk.


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BOX 13: WIND AND EARTHQUAKE PROOF TOWERS - MANILA, THE PHILIPPINES[90]

The twin towers of St. Francis Shangri-La Place rise 60 stories high above the city of Manila. One of Manila's premier residential developments, the towers are the highest towers in the Philippines and have rapidly become icons for the city. They are located near an active fault, within a highly seismic area, and are also vulnerable to typhoon winds. In response to these challenging circumstances Arup engineered the building to include an innovative new damping system to minimise both the impact of wind and earthquake risk. This technology has set new standards in terms of seismic design.

BOX 14: BUILDING WATER RESILIENCE - HO CHI MINH CITY, VIETNAM[91]

Ho Chi Minh City is a low-lying Vietnamese city in the Mekong River delta. For centuries, it has dealt with water management and flood challenges. The city boasts a vast dam as well as several other defensive measures to protect the city from floodwaters. However, rapid urbanisation and climate change impacts have increased its vulnerability to flooding and necessitated a more complex water management strategy. To support Ho Chi Minh to identify interventions most likely to build resilience, Arup, through C40 Cities, ran a workshop with the city on global best practices in water and flood management. A series of integrated interventions relating to both flood management and water supply were suggested. Individually these were on smaller scale, and comprised management of ecosystems as well as physical interventions. Overall, their cumulative impact on risk was comparable to the dyke that was originally proposed, but afforded greater options for future adaptation. Additional benefits included enhancing natural water systems, and increasing the city's low green space per capita.


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A systems perspective

In an urban context spatial risk assessments and approaching risk on a project-by-project basis is insufficient. Both ignore the multitude of interactions that occur within and beyond the urban system, which ultimately define the consequences of a particular event. The loss of function in a power station might affect water supply and distribution. The closure of a transport hub will have an impact upon the flow of goods and services. On an individual basis severe damage to a building following a major earthquake event may be acceptable if the occupants can evacuate safely (designed for 'life-safety'). However, if multiple buildings in the central business district are badly damaged following a major event, the impact on the local economy may be devastating. These buildings are part of the urban system.

Spatial risk assessments need to be complemented with systems analysis which recognises the interdependencies between multiple socio-technical networks.[93] Ultimately the wellbeing of urban populations relies on ecosystems, within or outside the urban boundary. This relationship is brokered by various institutions, infrastructure and knowledge networks (see Figure 8).[94] Systems-thinking provides a means to address the dynamic and complex nature of the urban environment, and to explore the possibility of cascading failures which can have far reaching consequences (see Box 15). Identifying, understanding and analysing interdependencies between different elements within the system presents a significant challenge, one which is magnified as cities become larger and incorporate both formal and informal systems.

BOX 15:
A TRIPLE COMPOUND DISASTER - FUKUSHIMA, JAPAN (2011)[92]

On 11 March 2011, an earthquake, measuring 8.9 on the Richter scale, generated a tsunami which swept ashore in the north of Japan, causing widespread flooding. Several thousand people were killed by the effects of the earthquake and the tsunami, which also badly affected the nuclear power station at Fukushima Daiichi. The earthquake suffered structural damage but fortunately its reactors remained intact. However the seismic activity interrupted the power supply to the cooling systems around the reactors. The back-up power system on-site consisted of generators at ground level, which were flooded by the tsunami which breached the sea walls. The stand-by batteries ran out in a mere 8 hours. The reactors began to overheat and soon went into meltdown, radioactive material began to escape into the atmosphere, and nearby towns and villages were evacuated. Despite control finally being gained over the power plant leakages the disaster has forced a national appraisal of Japan's energy production. Japan closed almost all of its 54 nuclear reactors across the country, leading to protracted power shortages, and undertook a major energy review, examining alternative, renewable sources of power for the country.

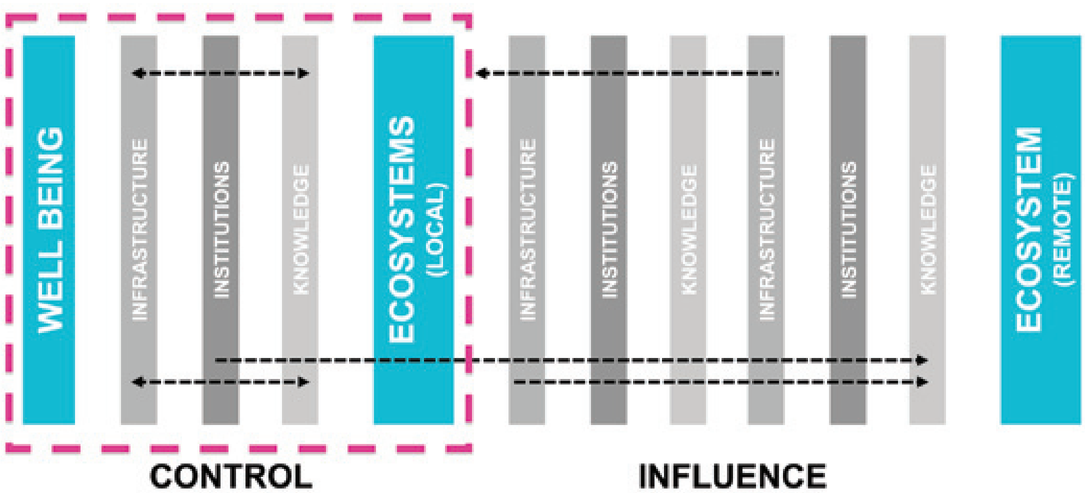

Figure 8 – The city as an open system[95]

As a step towards this, it has been suggested that infrastructure dependencies can be categorised as: physical – where one component relies on the output from another (e.g. water distribution on energy supply); cyber – where the reliable operation of infrastructure relies on information technology; geographic – where proximity means different infrastructures are exposed to the same hazards; or logical – which relate to economic association (e.g. market prices), legislation or human behaviour.[96]

It is not practical to attempt to model this complexity though this does not prevent us trying to improving the performance of the systems in the event of disaster by enhancing their resilience. Resilience is an attribute that relates to the performance of the urban system as a whole and therefore cannot be measured directly, other than by examining changing performance in response to shocks and stresses. As a proxy, it is helpful to consider the characteristics that might describe a resilient system (see Box 16).[97] Whilst these characteristics are generic and qualitative they are a step towards defining what resilience means in practice.

BOX 16: CHARACTERISTICS OF A RESILIENT SYSTEM[98]

1 **Flexibility** – the ability to change, evolve and adapt alternative strategies in either the short or longer term. This favours 'soft' rather than 'hard' solutions.
2 **Redundancy** – superfluous/spare capacity to accommodate increasing or extreme/surge pressures/demands. Redundancy includes diversity, multiple pathways and a variety of options.
3 **Safe failure** – this is related to their ability to absorb shocks and the cumulative effects of slow-onset challenges in ways that avoid catastrophic failure if thresholds are exceeded. When a part of the system fails it does so progressively rather than suddenly, with minimal impact to other systems. Failure itself is accepted.
4 **Resourcefulness** – the capacity to visualise and act, to identify problems, establish priorities, mobilise resources when conditions exist that threaten to disrupt an element of the system.
5 **Responsiveness** – the ability to re-organise, to re-establish function and sense of order following failure.
6 **Capacity to learn** – direct experience and failure plays a key role in triggering learning processes. The systems should have the ability to learn from past experiences and failures, to avoid past mistakes and exercise caution in future decisions.
7 **Dependency on local ecosystems** – valuing the services provided by local and surrounding ecosystems (green and blue infrastructure), and taking steps to increase their health and stability. These services (often undervalued) perform processes such as flood control, temperature regulation pollutant filtration, and local food production.

A new culture of safety

A new culture of safety is required that acknowledges uncertainty and recognises the possibility of failure. Civil engineering, as defined by the ICE's Royal Charter, is 'the art of directing the great sources of power in Nature for the use and convenience of man'.[99] Implicit in this statement is an underlying assumption – reinforced by public perception – that with sufficient resources and ingenuity engineers can also control Nature by designing systems and structures that can withstand or accommodate extreme events. Projects such as the Thames Barrier in London completed in 1982 endorse this viewpoint. But engineers are not omnipotent. Events where engineered systems or defences fail are rare, but when they happen the results can be catastrophic. We have only to look at breaching of the levees in New Orleans during Hurricane Katrina (see Box 17);[100] or the failure of the reactor cooling system at Fukushima following the tsunami in Japan (see Box 15).[101] The world in which we live is increasingly complex and the future more and more uncertain. There is a greater possibility that design criteria will be exceeded, poor quality materials or workmanship may compromise the design intent, or a scenario will occur that we had not envisaged. Failure is a possibility we need to consider and make appropriate contingency for.

If we cannot design fail-safe systems we need to ensure that they fail gracefully in a pre-determined way.[102] This implies that failure is gradual rather than instantaneous (ductile not brittle), and contained within the individual element or area in which it originated, rather than allowing its effects to destroy the entire system (robustness). Probabilistic hazard assessments and performance-based design concepts introduced over the past decade in the seismic design of buildings and infrastructure are a step in this direction. Potentially, they provide a useful framework for tackling the uncertainty that now exists with predicting weather-related hazards.

BOX 17: CATASTROPHIC LEVEE FAILURE - NEW ORLEANS, USA (2005)[103]

The Mississippi river in the United States of America has long ravaged the communities who have lived along its banks, even those inhabitants of sizeable urban settlements, such as the largest city in Louisiana, New Orleans. Conscious of this ever-present risk, New Orleans was defended by a series of highly engineered levees, constructed by the US Army Corps of Engineers. Yet in 2005, shortfalls in design of these levees demonstrated the consequences of design criteria being exceeded. On 29 August 2005, Hurricane Katrina made landfall in Louisiana, forcing a massive storm surge up the Mississippi. As Katrina moved further inland, storm waters breached the levees around New Orleans, killing well over a thousand people and displacing thousands more. In the wake of the disaster, which also caused widespread civil unrest, the US Army Corps of Engineers received a lot of criticism about the failure of their design. Their response was to claim that the system was never intended to be tested by a hurricane of Katrina's ferocity and that urban authorities were well aware of this fact.

Codes of practice are important tools in creating a culture of safety as they formalise the level of risk, with respect to public safety, which society feels is acceptable. As a society's circumstances change and it becomes more developed what is considered acceptable also changes. We know as a result of the terror attacks of 9/11 that the collapse of an iconic tall building is unacceptable to society in the United States of America. Yet, at present in many states there are no specific code requirements that stipulate tall buildings need to be designed to prevent collapse in the most extreme event. Many are designed simply for the minimum 'life-safety' criteria; which assumes there is minimal structural damage so that occupants can egress in a major event. Code requirements for tall buildings in China and Japan are much more onerous. This issue has been taken up by the engineering community which has concluded that acceptable risk is a matter of public concern and should be debated publically, to ensure society's concerns are addressed and allayed.[104]

In the aftermath of a disaster such as the Haiti earthquake, where no codes existed, this is a critical debate; one which can be used to catalyse awareness and begin to build a culture of safety amongst a diverse group of organisations (government, donors, non-governmental agencies, contractors). In the absence of a consistent approach individual agencies (or their donors) are left to determine design standards for the projects they are implementing (or funding). Defaulting to prescriptive criteria based on international codes is not necessarily appropriate, and overly conservative designs result in wasted resources.

Codes and standards have proven an effective tool in reducing disaster risk. As such, they are frequently cited as a universal remedy for reducing risk. We must not forget that codes and standards are effective only if they are part of a culture of safety that includes: engineering education, construction skills, legislation, and enforcement. In many countries codes and standards do not exist, particularly in relation to landslides, floods and cyclones, as compared to earthquakes.[105] Where they do exist common building types may not be covered by them. Indonesia, for instance, has a very comprehensive seismic code which specifically excludes dwellings and single-storey buildings.[106] In order to overcome these challenges, greater emphasis needs to be placed on promoting safe construction practices alongside the introduction of codes of practice. Identifying and promoting designs and construction methods that are likely to result in safe structures for simple buildings is a critical step towards achieving a safer society. It is a strategy that is more likely to ensure that such buildings are affordable, culturally acceptable and can be built, maintained and adapted by local people.

Vernacular buildings which have performed well in natural disasters in the past should not be overlooked. They provide a valuable precedent for future construction and with minor improvements can be made safer, or indeed safe. The challenge is that there is only empirical rather than scientific evidence to justify their performance. This lack of understanding leads to fear and neglect of such structures.[107] A good example is dhajji dewari, a form of timber and masonry infill construction, common in northern Pakistan which has evolved over centuries and that exists in similar forms in other earthquake-prone countries. As no code of practice exists which covers this sort of construction however, donors would not fund dhajji dewari (re)building projects in the aftermath of the 2005 Pakistan earthquake. Subsequently, seismic analysis verified by physical testing has shown that it is possible to model the behaviour of traditional dhajji dewari buildings, and that this form of construction can safely withstand forces associated with earthquakes in areas of high seismicity when built properly. This is an important step towards developing evidence based construction guidelines and training materials for dhajji dewari, which will generate wider acceptance of this type of building.[108]

A collaborative approach

Disaster risk reduction cannot be achieved by top-down processes or one-off projects. Sustained action and intervention is required at multiple levels simultaneously, informed by participatory processes that provide insight into local dynamics and perceptions of risk. Top-down processes need to be complemented by bottom-up approaches which empower local ownership of risk issues. Decision making to reduce disaster risk has to span the silo-ed sectors and departments of governance structures. Engineers cannot make truly effective contributions to reducing disaster risk by working alone. Instead, they need to proactively seek out other professionals, policy makers, and decision makers who share a common ambition to create a safer world. Effort is needed to overcome the cultural barriers and procurement procedures which prevent this happening.

In the context of post-disaster response, the World Economic Forum has been proactive in this respect by establishing the World Economic Forum's Engineering and Construction Disaster Resource Partnership (DRP). This partnership proposes a tri-partite model which brings together members of the engineering and construction industry with humanitarian and development agencies, and government. Importantly, the DRP recognises that partnerships need to be created prior to a disaster, so as to be effective when disaster strikes; and they need to exist at a national and international level. Currently there are three such national networks in India, Indonesia and Mexico. This partnership model 'provides an opportunity for a common language to be developed, raise awareness, [and] share learning'.[109]

An educational agenda

For engineers to adopt the five principles above – a holistic understanding of risk, appropriate strategies, a systems perspective, a new culture of safety, and a collaborative approach – a shift in traditional engineering approaches and education is needed. Engineering graduates typically leave university today and embark on their professional careers with limited or no awareness of disaster risk. Sadly this is true even in some hazard-prone countries such as Indonesia. Even engineers trained in the United Kingdom need a base-level of knowledge on disaster risk as they may find themselves designing infrastructure in countries where significant hazards exist.

Disaster risk reduction must become a core module in the engineering curriculum if we, as a profession, are to become key players in this arena. Systems thinking, risk, resilience, and vulnerability should be core topics covered by all engineering degrees. Without this educational base, the engineers of the future will be ill-equipped to deliver effective and holistic solutions to the real-world challenges society faces.[110] Engineers should also be encouraged to undertake further professional development on topics such as disaster risk reduction, climate change adaptation and environmental resource management. These are the agendas that will shape engineering practice as we face an uncertain future.

Conclusion

'Be the change you want to see in the world'

Mahatma Ghandi

Natural disasters are a reality that we cannot choose to ignore. The ever-increasing scale and cost of natural disasters over the last decade is unprecedented. We cannot predict the future but there is little doubt that the situation will get worse before it gets better. We know that there are parts of the world that are highly exposed to natural hazards, where more and more people are living. We know that climate change will increase the likelihood and severity of extreme events and result in additional stresses. We know that urban areas are expanding rapidly without adequate infrastructure or the benefit of building regulations.

The future is increasingly uncertain and complex, but our role does not have to be. Engineers have made a significant contribution to reducing disaster risk already, both in post-disaster contexts and in designing infrastructure in hazard-prone areas. There is a significant opportunity to build on our experiences and explore how we can contribute to a broader agenda with the ultimate objective of creating resilient communities, businesses and cities that are able to survive extreme events in addition to adapting to changing circumstances. Resilience is initially a difficult concept to grasp – but so too was sustainability. Just as we have learned to accept the challenges posed by an increasing population living on a finite planet, we must rise to the challenges posed by the increasing risk of disasters.

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Glossary of terms

Term	Definition*
Disaster	A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.
Disaster risk reduction	The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.
Disaster management	The organization and management of resources and responsibilities for addressing all aspects of disasters or emergencies, in particular preparedness, response and initial recovery steps.
Hazard	A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.
Mitigation	The lessening or limitation of the adverse impacts of hazards and related disasters.
Recovery	The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.
Resilience	The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.
Risk	The combination of the probability of an event and its negative consequences.
Vulnerability	The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

* Definitions from: UNISDR (2009) UNISDR Terminology on Disaster Risk Reduction. UNISDR: Geneva.

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