NATURAL DISASTERS
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Institution of MECHANICAL ENGINEERS

Improving the world through engineering

"IN THE PAST DECADE, DISASTERS FROM NATURAL EVENTS HAVE ON AVERAGE AFFECTED 200 MILLION PEOPLE EACH YEAR."

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Every year, natural events, such as earthquakes, floods, storms, heatwaves and droughts cause huge humanitarian and economic damage around the world. Although we are now better able to identify and respond to such natural disasters, in many cases lack of knowledge and poor planning, resourcing and deployment of relief systems can create problems for both the local and global community. This report examines the three key aspects of disaster response and the need for engineers to be at the heart of efforts to reduce the impact of these events, from initial humanitarian aid through to building resilience for the future.

This report has been produced in the context of the Institution's strategic themes of Energy, Environment, Education, Manufacturing and Transport, and its vision of 'Improving the world through engineering.'

Cover image shows residential suburbs inundated by the swollen Brisbane River as flood waters devastate much of Brisbane on 13 January 2011. Australia's third-largest city Brisbane turned into a 'war zone' with whole suburbs under water and infrastructure smashed as the worst flood in decades hit 30,000 properties.

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EXECUTIVE SUMMARY

MOVING TOWARDS DISASTERS

Every year disasters resulting from earthquakes, volcanoes, storms, floods, heatwaves, droughts and other extreme natural events leave a trail of deaths, destroyed homes, shattered communities and far-reaching damage to national economies. Often the consequences extend far beyond the directly impacted country or region, extending to international markets and supply chains and increasing the range of people affected right across the globe. In this regard, the 2010 earthquake in Haiti affected or killed 40% of the island's population, the impact of the Kalimantan fires on Indonesia's GDP in 1982-83 was a 9.3% loss, while the effects of the 2011 earthquake and tsunami in Japan were felt in industrial supply chains across the globe. Currently, on average, about 78,000 people are killed annually in such disasters, with a further 200 million (or about 3% of the human population) directly affected and economic losses running to about US$100 billion.

Although the number of people killed by natural disasters has actually been falling in recent decades, the number affected has been increasing. This is partly due to a mass migration of human population into vulnerable urban landscapes, such as coastal cities, man-made changes to the environment, for example the removal of natural barriers to protect against floods, and as a result of an increase in extreme weather events and detrimental climatic conditions.

The rapid growth of economic activity, human population numbers and urbanisation in Asian-Pacific countries means this region is particularly susceptible to the effects of extreme natural events. In the three decades 1980–2009, about 38% of disaster-related global economic losses occurred here and the region is 25 times more likely to experience a natural disaster than Europe. With much of the world's current and, potentially, future manufacturing and finance located in this region, the implications for stable markets and trade on a global scale are clear.

With economic development comes expansion of cities and urban areas, which in turn can often lead to the degradation of natural barriers to the impacts of extreme natural events. In Asia-Pacific much of this growth is coalescing around existing settlements located on already vulnerable sites. It is predicted that 75% of the global population will be living in towns and cities by 2050, and that 95% of the anticipated expansion in urban living will be in developing countries.

The vulnerability of these urban areas is further exacerbated by the fact that many of the rapidly developing cities also contain substantial areas of informal settlement, or slums, with inadequate levels of engineered infrastructure and poor provisions for sanitation, water and food. About 18% of all urban housing around the world is non-permanent and the UN estimates that about a third of the world's population is living in slum conditions. Both the fragility of these communities and their informal economic relationship with the wider urban area contribute to their potential for forming the core of a disaster.

In the face of such emerging trends, it is clear that if the global community is to avoid moving into a future characterised by frequent and wide-ranging disasters, it needs to provide a robust and effective response to extreme natural events worldwide. This becomes ever more important in a world in which increased globalisation means that, through disruptions to trade and commerce, events in one location can have significant effects on the other side of the planet.

AN INADEQUATE RESPONSE

The current human response to extreme natural events that have the potential to create disaster can broadly be divided into three aspects, two of which are essentially phases of response in reaction to an event that has occurred, and the third being of a pre-emptive nature in anticipation of an event occurring. The first of the two reactive phases is emergency relief and recovery, which normally occurs in the hours and days immediately after the event and is initially focused on activity such as freeing people trapped in rubble and transporting the injured to hospital. In this short-term period the focus then shifts to finding temporary solutions to basic human needs such as shelter and the provision of water, food and waste disposal. Over time this subsequently leads to the second reactive phase of reconstruction and redevelopment of buildings and infrastructure destroyed by the event. The third, pre-emptive, aspect is building preparedness and resilience before an extreme natural event actually occurs. This involves increasing public awareness of the potential for the occurrence of a natural disaster, ensuring that risks and appropriate responses are understood. Consideration needs to be given to the engineering of buildings, infrastructure and roads with a long-term view, as well as potential localised failures due to the dependence of one system upon another.

The challenge for the future is that worldwide, society currently places a greater focus on the two reactive phases of response rather than the third, pre-emptive aspect. This is understandable, given that it is much easier in the context of our existing political culture to justify immediate action when it is critical to saving lives and communities, rather than when it offers no immediate obvious benefits to people's lives.

But while it cannot be denied that rescuing people trapped in rubble is urgent and rightly deserves to be focused on, if investment were made into adequate preparedness and resilience too, fewer people might end up trapped in rubble in the first place. In the long term such action also leads to reduced overall economic impact, in that every $1 spent on building preparedness and resilience can save as much as $4 in relief, recovery and reconstruction later.

The reality is that an extreme natural event, such as an earthquake or storm, need not become a disaster at all if there is adequate resilience and preparedness in place.

THE WAY FORWARD

When extreme natural events with disaster potential do occur, it is crucial that engineers are embedded into early response activities, not only to assess damage and the safety of remaining buildings and structures, but also to ensure a long-term view is taken right at the start of decision-making. Satisfying immediate short-term needs such as providing water, food and hygiene, and planning the location of temporary shelter, often set in place foundations that can define and even constrain engineering of the best reconstruction options in the future. Such short-term choices will therefore benefit immensely in the long run from engineering knowledge at the point of decision.

When the focus turns to reconstruction and redevelopment, the role of engineers continues to remain critical. At this time the immediate humanitarian crisis might be under control, but the vulnerability of communities is very much at the forefront of people's minds. This momentary period of attention should be harnessed to encourage resilience-thinking to be integrated into infrastructure and buildings, and preparedness developed using lessons learnt from the disaster. The reconstruction period also represents an opportunity to incorporate know-how from around the world, as substantial foreign knowledge, skills and support are often readily available to an area impacted by an extreme natural event that has become a disaster. It is important though to stress that in the case of post-disaster adoption of new engineering techniques, codes of practice and building standards, local capacity must also be built for proper implementation, enforcement and maintenance. This requires not just the transfer of technical engineering capability to local populations, but also the political will by those in government for adoption and implementation in the long term. Currently the UN is failing to deliver these changes through the Hyogo Framework.

The tragedy is that currently in rich and poor countries alike reconstruction can be slow – in rich countries largely as a result of political and bureaucratic considerations, and in poorer countries largely as a result of a lack of finance and local capacity to rebuild. It is imperative that these bureaucratic, financial and capacity hurdles are overcome, as it is often at this point when the opportunity to embed resilience and preparedness into a community is at its best. In the richer group, the long-term view and pragmatic approach of engineers can act as a counter balance to the short-termism and risk aversion of current politics and bureaucracy. In poorer nations, through utilising local labour and establishing partnerships, building of local capacity by engineers in the transfer of knowledge on resilience, skills and practice know-how can help prepare those vulnerable to disaster to cope better with future events.

A whirlpool is seen near Oarai City, Ibaraki Prefecture, northeastern Japan, 11 March 2011. The biggest earthquake to hit Japan on record struck the northeast coast on Friday, triggering a 10-metre tsunami that swept away everything in its path.

RECOMMENDATIONS

It is crucial for the future of people's lives, their properties and communities, as well as local, national and global economic activity, that the third, pre-emptive aspect, resilience building, is incorporated more vigorously in the human response to extreme natural events. The Institution of Mechanical Engineers therefore makes the following key recommendations:

1. **To focus more international development funding on building future resilience.** Currently only 4% of all international humanitarian aid is channelled to helping build resilience in disaster hotspots, well below the UN's recommended 10%. As it is estimated that every $1 spent on making communities more resilient can save as much as $4 in disaster relief in the future, by spending now, donor nations such as that of the UK could maximise their development aid. Doing so would provide better living for residents, ensure more effective use of UK taxpayers' money and help ensure a more secure future for all.
2. **Build local capacity through knowledge transfer.** Governments, the private sector and all those with a stake in global supply chains need to prioritise the transfer of knowledge, information and skills for the building of local resilience capacity. Technical knowledge for embedding resilience thinking, improved building standards and codes, engineering practice know-how and appropriate relevant training builds local expertise and indigenous capability. To facilitate international knowledge transfer partnerships, the Hyogo Framework priority for action to reduce the underlying risk factors must be reinvigorated by the UN, and DFID and its international counterparts should create long-term engineering placements (three or more years) that enable effective transfer of relevant skills and know-how. By helping to ensure nations are able to cope more effectively with extreme natural events, the prospects for the future stability and continuity of worldwide supply chains are improved.
3. **Embed the long-term engineering view in the short-term response.** NGOs, national governments, the UN and others involved in co-ordinating the short-term response to natural disasters should seek the early involvement of engineers in their activities. Decisions made in the immediate recovery stage of a response set the engineering foundations and constraints for eventual reconstruction and redevelopment. The quicker engineers can begin infrastructure assessment and longer-term reconstruction planning, the better short-term decision-making will be and the more likely a successful overall outcome that increases a community's resilience.

"" EVERY $1 SPENT ON BUILDING PREPAREDNESS AND RESILIENCE CAN SAVE AS MUCH AS $4 IN RELIEF, RECOVERY AND RECONSTRUCTION LATER.

Sukuiso, Japan, 18 March 2011 – Japanese fire trucks line a road in this aerial photo.

THE HUMAN AND ECONOMIC IMPACT OF NATURAL DISASTERS

With what seems like increasing regularity, we watch people from the latest unfortunate part of the globe be impacted by a natural event and struggle to come to terms with lost loved ones and shattered lives. In the past decade, disasters from natural events of all types have on average affected approximately 200 million people every year[1,2], or about 3% of the world's population, while killing an additional 78,000 a year[2], based on a 10-year average. More than 370,000 people alone died in the period 2001–10 as a result of extreme weather and climate conditions[3], such as extreme cold, heat, storms, floods and drought.

The year 2010 was particularly lethal, with the total recorded number of people killed by natural events reaching 268,818, much higher than the ten-year average[2]. The two most lethal disasters – the 12 January earthquake in Haiti, which killed over 222,500 people, and the Russian summer heat wave which caused about 56,000 deaths – made 2010 the deadliest year in at least two decades[4]. After the events in Haiti and Russia, there were several other high-profile deadly natural events including (with number of deaths): earthquakes in China (2,968), Chile (562) and Indonesia (530); floods in Pakistan (1,985) and China (1,691); landslides in China (1,765) and Uganda (388); and a cold wave in Peru (409)[2]. To give some perspective on the impact of natural disasters that year, over 40% of the population of Haiti were affected or killed; nearly 16% in Chile; and about 11% of the population of China and Pakistan. Earthquakes and droughts remain the biggest killers, but floods, hurricanes, cyclones and storms are the events that affect most people worldwide.

Deaths are the most obviously negative aspect of such disasters, but the statistics on the number of people killed or affected is not the whole human story. In addition to killing nearly 300,000 people and affecting over 207 million others, the 373 natural disasters that were recorded in the International Disasters Database (EM-DAT) for 2010 caused more than US$109 billion of economic damage[4]. In fact a whole host of economic impacts can follow an event, from decreased tourism revenue, to damaged property, loss of cultivatable land area and increased vulnerability to future disasters, and the degree of impact can be related to a given country's stage of economic development. **Figure 1** shows economic loss as a consideration alongside loss of life and people affected within an economic development stage framing. The diagram illustrates that despite the fact that the actual number of disasters appears to be almost evenly distributed between areas of high (40%) and medium to low (60%) development, loss of life and number of people affected are skewed strongly towards the medium and low development areas (>90%).[5]; However, the opposite is true for the economic impact, where the loss emphasis is on highly developed areas (~70%) rather than the medium and low group. Hurricane or 'Superstorm' Sandy, which made landfall on the eastern seaboard of the United States in October 2012, provides a good case in point, with 43 people killed in New York City[6] and economic damages initially estimated at $60 billion[7].

Figure 1: Impact of natural disasters relative to economic development stage[8]

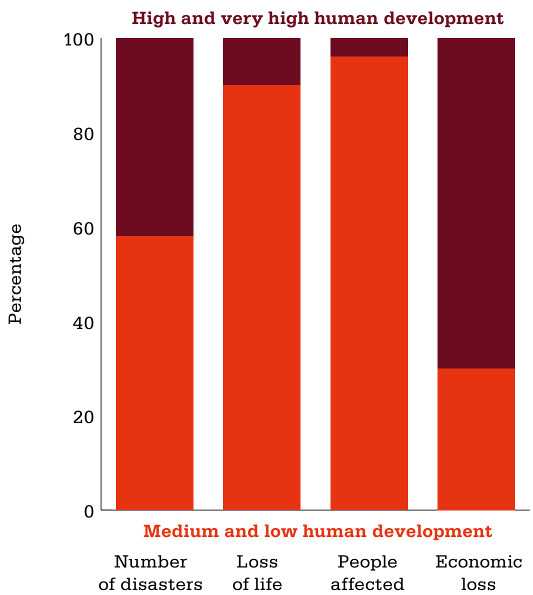


Table 1, which excludes data for Sandy, but includes provisional estimated information for the impact of the 2011 tsunami that struck the east coast of Japan[9], further illustrates this relationship between a nation's economic loss and its economic development stage. Including China – which is arguably a relatively highly developed country in this regard – of the top 20 national economic losses over the period 1965 to date, 18 are concentrated in the economically developed nations of the world. Indeed, the devastating Indian Ocean tsunami resulting from the Sumatra-Andaman earthquake of 2004[10], which killed more than 230,000 people over a wide area of Asia-Pacific does not appear in the table as its impact was on a large number of nations at the early stage of economic development.

In such countries, low property and land values, combined with low levels of economic activity, meant that although many local communities were impacted by the event suffered economic disaster, at the national level economic impacts were small; the overall combined economic loss across the impacted region of around $14 billion[2] is actually lower than the $30 billion loss sustained by Italy from the Friuli earthquake in 1976 (**Table 1**).

Table 1: Summary information on the world's costliest natural disasters since 1965 from data sources such as the IMF and World Bank[2,11]

Natural disaster	Year	Approximate economic loss ($ billion)	Approximate insured loss ($ billion)	% GDP loss in disaster year
Earthquake/tsunami, Japan (provisional)	2011	230	30	4.1
Kobe earthquake, Japan	1995	200	10	1.9
Hurricane Katrina, USA	2005	170	80	1.0
Northridge earthquake, USA	1994	90	30	0.6
Sichuan/Wenchuan earthquake, China	2008	90	0	1.9
Irpinia earthquake, Italy	1980	70	0	2.6
Hurricane Andrew, USA	1992	70	40	0.4
Yangtze River floods, China	1998	50	5	3.0
Great Floods, USA	1993	50	5	0.3
Tangshan earthquake, China	1976	50	Unavailable	3.7
Spitak earthquake, Armenia	1988	50	Unavailable	1.9*
River floods, China	1996	50	0	2.8
Drought, USA	1988	40	5	0.3
Kalimantan forest fires, Indonesia	1982–83	40	Unavailable	9.3
Hurricane Ike, USA & Caribbean	2008	40	20	0.3
Niigata earthquake, Japan	2004	40	5	0.6
Eastern floods, China	1991	40	5	3.6
River Arno floods, Italy	1966	40	0	2.7
Loma Prieta earthquake, USA	1989	30	5	0.2
Friuli earthquake, Italy	1976	30	0	1.7

A Haitian woman rests sitting on the rubbles of a destroyed building at a market in Port-au-Prince on 22 January 2010 following the massive 7.0-magnitude quake that shattered the country.

Beyond the absolute economic loss values themselves, it is also important to note from **Table 1** the impact on national Gross Domestic Product (GDP), which provides a broader perspective on the scale these losses can represent for a particular country. For example, the 9.3% loss in GDP to Indonesians in 1982–83 due to the Kalinmantan fires was a significant impact on their developing economy. Similarly, a review of **Table 1** reveals the repeated loss to China of about 3% of GDP from natural disasters in 1976 (Tangshan earthquake), 1991 (Eastern floods), 1996 (River floods) and 1998 (Yangtze River floods), which clearly represents an unwelcome repeated burden on the country's activity.

The Japanese earthquake and tsunami of 2011 could prove to be the costliest disaster since comparable records began in 1965[2]. Not including any knock-on effects resulting from the failure of the Fukushima nuclear power plant, provisional estimates released by the World Bank put the economic damage as a result of the disaster at anything from $122 billion to $235 billion, or about 2.5–4% of Japan's GDP[12]. The earthquake itself was the biggest in Japanese history, one of the five most powerful earthquakes since modern records began in 1900, triggering massive tsunami waves of up to 40.5m high that reached 10km (6 miles) inland[9].

However, the impact of the disaster reached far beyond Japan, with considerable disruptions to financial markets and to international supply chains that either pass through or originate in Japan, especially in the automotive and electronics industries. The World Bank predicts further trade and financial implications from the earthquake and tsunami[12], and the economic impact of the ongoing closure of Japan's fleet of nuclear power stations adds further to the disruption. Over the last five years, trade with Japan accounted for 9% of East Asia's total external trade. Thus impacts on Japan's GDP will affect other East Asian countries – particularly those trying to develop – and influence the regional economics. This is the region of the world which, overall, has suffered most in the past three decades, by the economic fall-out of natural disasters. In this regard, what **Table 1** does not show, is that 38% of disaster-related economic losses globally in the period 1980–2009 occurred in Asia-Pacific and that this region is more likely to be affected by natural disasters than Africa and Europe by a factor of 4 and 25, respectively[13]. Indeed, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) has found that a disproportionate number of people are affected in Asia-Pacific, with the region having accounted for 75% of disaster fatalities worldwide between 1970-2011[14].

The ongoing longer term consequences of natural disasters are often ignored by mainstream media, which generally focuses on breaking news. However, at any given time, there are thousands of people coming to terms with the consequences of natural disasters, which may have happened many years ago. Surprisingly this is the case for both rich and poor countries alike, with the stage of economic development appearing to have little bearing on the ability of shattered communities to rebuild. In the former, bureaucracy and politics act as a break on progress[15], whereas in the latter case the issue is largely a lack of indigenous financial resource and local capacity to rebuild[16].

The vulnerable Asia-Pacific economic powerhouse

With 55% of the world's GDP and 44% of trade, Asia-Pacific forms the powerhouse of today's globalised economy[17]. However, it is also one of the most exposed to natural disasters with, for example, 52% of China's industrial areas at risk of floods[18], leading potentially to global supply chain disruption. Seven of the ten countries most vulnerable to climate change related impacts are also located in the region[13].

Given that about 90% of goods transported internationally are moved by shipping[19], ports are a vital infrastructure component for world trade. It is therefore significant that eight of the top ten port cities in the world exposed to future coastal flooding risks and ranked by projections of future exposed asset values (in 2075), are in growing and industrialised Asian cities[20].

Natural disasters in this region both now and in the future clearly threaten global productivity, along with the stability of world trade and financial markets.

COMPARING POST DISASTER ACTIVITIES BETWEEN HAITI AND THE UNITED STATES

Haiti

Three years after the devastating earthquake of January 2010, rebuilding in Haiti had hardly begun, with over 350,000 people still located in 496 temporary camps at the start of 2013[16]. Despite receiving about US$7.5 billion of aid, very little had been achieved on the ground in terms of reconstruction and redevelopment. This was largely due to a combination of poor local engagement – with most of the money being channelled through non-profit organisations, private contractors from outside Haiti and government foreign agencies (and spent on temporary emergency food, water and tents) – and a lack of local capacity to know what infrastructure is located where, of what quality, and what needs to be done to restore it. Add to this the lack of continuity and the inconsistent decision-making that result from short-term temporary secondments of engineers and technicians from outside Haiti to the country (typically for three months), and the challenge of reconstructing and redeveloping becomes acute.

United States of America

In the United States, which has the financial resources and indigenous capacity to rebuild, the case of Hurricane Katrina and New Orleans highlights a different set of challenges. This natural disaster, which occurred in August 2005, killed at least 1,833 people, affected 500,000 more[2], damaged or destroyed 240,000 homes and resulted in economic losses estimated to be approximately $170 billion. Many of these losses were caused by storm surge waters overcoming inadequately engineered levees to flood 80% of the city. More than seven years and nearly $75 billion later, the levee system that protects the city has been substantially re-engineered[21], but the majority of the plans and ideas for creating a more sustainable, resilient, equitable community have not been implemented[22]. In many aspects the city is still trying to recover, with areas where housing and businesses have been demolished but not yet rebuilt. For example in the St Bernard parish, one of the worst hit, 14% of homes are empty lots and 8% stand gutted or derelict, while 20% of business properties are demolished or derelict[23]. Affordable housing is in short supply across the city, lost public schools and hospitals have still not been replaced and New Orleans' population has barely returned to three quarters of its former level[24,25]. Critics have attributed this situation to a mixture of government-related mismanagement and bureaucracy, lack of clear leadership, political agendas, inadequate planning, contractual focus on the easy and quick tasks and poor communication[22].

Disasters: impact on a globalised world

In the 21st century world of highly globalised trade in food, goods, finance and energy, the impacts of natural disasters in both the short and long term can have a profound effect on stability, supply chains and global, national and local economics. The World Economic Forum's *Global Risks Landscape 2011*[26], indicates that there are essentially three natural disaster types that most worry world leaders: storms and cyclones, which have the highest perceived likelihood of occurring in the next decade with an estimated impact of over $250 billion; floods, with a similar level of perceived probability and an equal economic impact forecasted; and earthquakes and volcanoes, also perceived to have a 'very likely' chance of occurring in the next ten years with a potential impact of nearly $250 billion. So what are the real trends and what should our response to them be?

A U.S. Coast Guard helicopter flies over flooded homes in the aftermath of Hurricane Katrina in New Orleans, 6 September 2005.

GLOBAL TRENDS IN NATURAL DISASTERS

CLASSIFICATION OF NATURAL DISASTERS

EM-DAT classifies natural disasters into five categories[27]:

Geophysical disasters are those that originate from solid earth events such as earthquakes, volcanoes and mass movements (dry).

Meteorological disasters are caused by short-lived (from minutes to days), small to medium-scale atmospheric events such as storms (including cyclones, hurricanes and tornadoes).

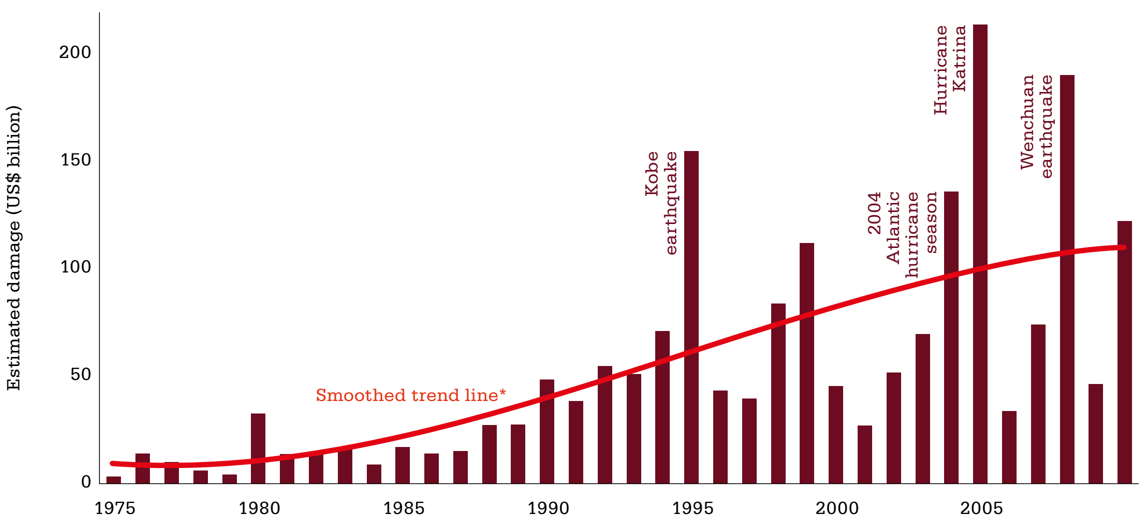
Hydrological disasters, such as flooding or wet-earth movements (for example mudslides), result from deviations in the normal water cycle or overflows of bodies of water, including coastal storm surges.

Climatological disasters are those caused by long-lived (from intra-seasonal to multi-decadal climate variability), medium to large-scale atmospheric processes and include drought, extreme temperatures, both high and low, and wildfire.

Biological disasters caused by exposure of living organisms to germs and toxic substances such as epidemics, insect infestations and animal stampedes.

This engineering based report is primarily concerned with the first four categories of disaster type, which are physical in character. Biological disasters are not considered specifically, though it is noted that epidemics can occur as 'secondary' disasters following a physical event, such as the emergence of waterborne disease after flooding. While climatological events are a response to long-lived climate variability, they are still considered in the context of having short/medium-duration impacts with engineering implications.

Figure 2: Estimated damage (US$ billion) caused by reported natural disasters 1975–2009. Source: EM-DAT: OFDA/CRED International Disaster Database. (*Polynomial Function)[2]



APPARENT TRENDS

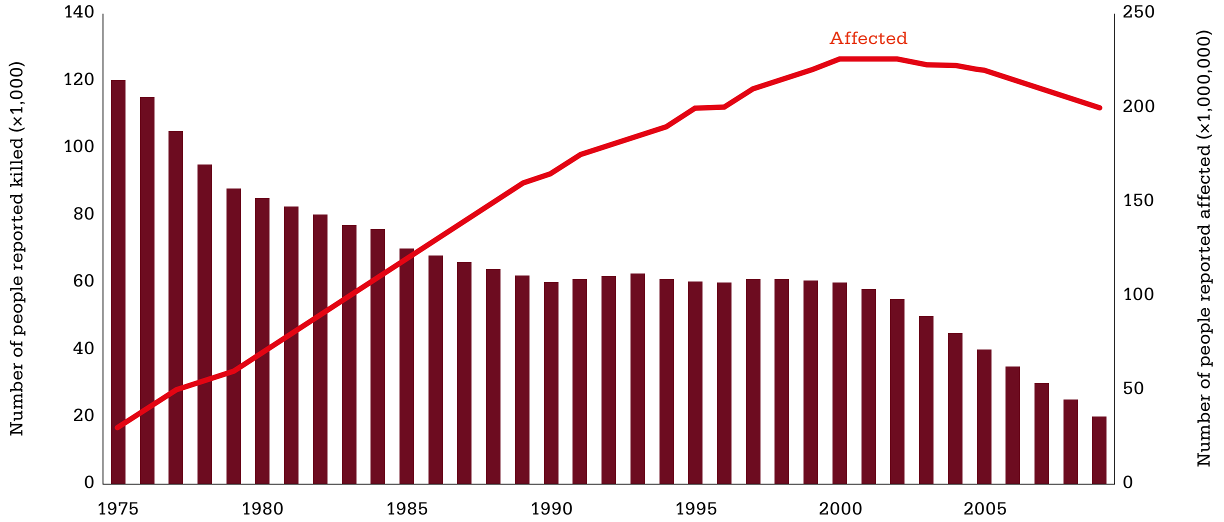
According to EM-DAT, natural disasters appear to have been occurring more frequently in recent decades and resulting in larger average yearly damages[2]. Indeed, **Figure 2** illustrates this trend of damage increasing in recent decades. Despite the 'spiky' nature of natural disaster impacts from year to year, which makes it difficult to initially identify any clear trends, smoothing of the data indicates that, overall, since comparable records began in the 1970s the average estimated yearly damage has been increasing, reaching on average $100 billion per year.

The number of country-level natural disasters reported has actually been growing for the last four decades. Since 1975, when about 60 disasters were reported, there has been a steady increase with about 440 disasters reported in 2000[2]. One key question in this regard is how much of this additional reporting is due to an increasing awareness of the reporting system globally, combined with improved communication methods, as opposed to an actual increase in the overall number of disasters occurring annually. Indeed, from 2000 to 2010 this increasing trend of reported disasters has flattened off[2], which might indicate a more complete global engagement with the reporting process.

In line with the overall trend in the number of disasters reported, the number of people reported to have been affected worldwide has increased each decade, from under 50 million per year in the 1970s, see **Figure 3,** to a levelling off at about 200 million per year for the last decade. **Figure 3** also shows that although the number of affected people has increased, deaths from natural disasters have been steadily decreasing, which suggests a possible improvement in a range of activities from disaster warning systems, emergency relief and recovery operations, to community preparedness. Since 1975, when about 120,000 people were reported killed, the number of fatalities has dropped to about 20,000 deaths in 2009[2]. In fact, this decreasing trend in yearly deaths goes back to the early 1900s, when on average approximately 500,000 people per year were killed due to natural disasters. However, against this overall trend it should be noted that in the case of natural disasters caused by weather and climate related extremes, there has been a recent increase in deaths, with deaths up 20% in the decade 2001–10 compared with 1991–2000 levels[3].

On the question of whether these trends indicate a genuine increase in the number of natural disasters or a more complete global engagement with the reporting process, three other trends suggest the former: that the number of natural disasters, and the people affected by them, are indeed rising.

Figure 3: Natural disasters 1975–2009.
Source: The EM-DAT: OFDA/CRED International Disaster Database[2].



Migration

Throughout the 20th century and into the 21st there has been a continuous demographic shift, characterised by a mass human migration to cities and urban landscapes, many of which are located on sites vulnerable to the impacts of natural events[28]. These include settlements susceptible to flooding from adjacent rivers, estuaries and lakes, or on coastlines exposed to storms, tsunamis and extreme tides, as well as those communities established in areas of seismic or volcanic activity. In the case of earthquakes, the United States Geological Survey (USGS) has noted the increasing number of humans exposed to earthquakes, highlighting that while the number of major events has remained fairly constant, population density in earthquake-prone areas is constantly increasing; the outcome being increasing numbers of casualties from the same-sized events.

Urbanisation and informal settlements

With the global average of urbanised population passing the 50% mark in 2010, as the first decade of the new Millennium reached its end, the majority of humans became urban dwellers in a trend that is projected to continue throughout the 21st century[29] and 95% of that expansion is anticipated in developing countries[30]. Indeed, by 2050 it is anticipated that an extra three billion people will be located in urban settings, much of this growth taking place in Asia and Sub-Saharan Africa, with about 75% of the global population predicted to be living in an urbanised landscape. At the moment, almost 180,000 people move to cities and urban areas every day[2]. As a result of such rapid growth, urban newcomers often encounter a lack of infrastructure, services, housing and property rights and are often obliged to live in unsafe, informal places. It is estimated that 18% of all urban housing units are currently non-permanent structures and one third of the world's population live in what the UN defines as slum conditions[31]. When earthquakes and other extreme natural events strike, unsafe buildings in urban sprawl are a primary killer and their widespread collapse affects homes and economic activity on a large scale. If urban development is not made more resilient, natural disasters are likely to grow as expanding cities place an increasing number of people in the path of extreme natural events of all forms, often in vulnerable accommodation reliant on poor infrastructure with little resilience to impacts.

Man-made changes to the environment

There have been considerable man-made alterations to the environment that have removed natural barriers to protect against natural disasters. These include human activities such as deforestation, swamp and marsh degradation, island development and sand dune removal. As barriers to the development of natural events such as heavy run-off, floods, storm surges and sea waves are removed, and the ability of natural systems to absorb their impacts in defence of human settlements is reduced, the outcome is likely to be observed as an increase in the severity and number of natural disasters. For example, a recent study concluded that since the 1950s, the number of annual reported fluvial flood related natural disasters has increased by a factor of nine, to more than 180 per year, and that deforestation played a key underlying role in this upward trend[32]. A case in point is the June 2013 flooding experienced in the Uttarakhand state of northern India, which resulted in at least 600 people dead and almost 40,000 stranded[33]. In the immediate wake of this natural disaster, expert opinion[34] has cited deforestation of Himalayan foothills, along with inadequate planning control of floodplain development, as the cause of the region's increased vulnerability to floods and landslides following heavy rain.

Removal of natural barriers

Human exposure to the impact of natural events is compounded by mankind's removal of natural barriers that both hinder the development of extreme events and mitigate against the impact of events once they have developed. In this regard, the Millennium Ecosystem Assessment noted that, globally, changes to ecosystems have contributed to a significant rise in the number of floods and major wildfires on all continents since the 1940s[35]. A century ago for example, the south-east parts of Staten Island in New York State, USA, were mainly uninhabited swamps, but continuous land development reduced the mitigation potential of the marshlands and in 2012 this area was one of the worst hit by the impact of Superstorm Sandy. By contrast, other parts of the Island remained relatively unscathed because they were protected by the massive Freshkills Park and its wetlands[22]. Similarly, since 1932, 29% of the wetlands that protect the metropolitan area of New Orleans from flooding, such as that caused by Hurricane Katrina, have also been lost[25].

Recognition of the part played by natural barriers in natural disaster mitigation is leading to a growing interest in the conservation and restoration of these types of structure. This has recently been reflected in Mayor Bloomberg's $19.5 billion initiative[36] following Superstorm Sandy, to improve the protection of New York City against natural events, which includes the re-introduction and regeneration of natural barriers as part of the resilience building mix. Examples of projects proposed for Coney Island and the Rockaways, as well as Staten Island, include widened beaches and the restoration of wetlands and dunes. Natural barriers have previously been used in Vietnam, in the form of mangroves planted to protect existing sea dykes by dissipating wave energy and stabilising the coast; and following the Indian Ocean tsunami of 2004, an extensive mangrove restoration project was undertaken in Banda Aceh[37]. However, these programmes, while natural, are still very complex, with a need to understand the hydrology, topology and tidal water flows. Increased consideration of this approach in the planning, architecture and engineering professions needs to be supported by more engineering, science and policy research that aims to better understand how and when these 'Green Infrastructure' initiatives should be used[22].

Climate Change

Recent analyses by both the Intergovernmental Panel on Climate Change (IPCC) and the World Meteorological Organization (WMO) indicate that the Earth's biosphere as a whole is warming[38,3]. In this regard, nearly 94% of the countries reporting to the WMO had their warmest decade in 2001–10[3] and the study found strong evidence of warming in the surface water of the oceans, with unprecedented warming in the deep ocean too. This was linked to melting ice in Greenland as well as in the Antarctic and glacial regions, sea-level rises and an unprecedented number of climate and meteorological related disasters in the decade to 2010; the latter reflecting that warmer, higher oceans increase the risk of frequent extreme weather events, damaging floods and storm surges. The Global Humanitarian Forum suggests that 40% of the increase in the number of weather related natural disasters since 1980 is a result of climate change[39]. Of the disaster types monitored by EM-DAT, flooding and storm disasters demonstrate a considerable increase in the number of reported occurrences from the middle of the 20th century onwards[2]; similarly a recent report by the Asian Development Bank (ADB) also noted that these are occurring with increased frequency and severity in the region[13]

Coastal Cities

River and coastal-based cities account for about 80% of global GDP[40] and three quarters of the world's largest cities are located on a coast. In the United States alone, 39% of the population live in areas directly on the shoreline and this is projected to grow from 122 million people today to 134 million in the second decade of this century[41]. With rising sea levels and an increase in extreme weather events leading to storm surges, many of these residents will be at risk from the impact of flooding. New York City provides a good example: the recent impact of Superstorm Sandy highlighted the fact that 83% more people than 30 years ago live on the city's 1 in 100 year floodplain[7], that two thirds of the city's major electricity substation infrastructure is also located there, as are 270,000 jobs[36]. However, many of these large coastal cities are in developing low and middle-income countries[20], with some such as Dhaka, Bangkok and Shanghai located on deltaic plains where land subsidence will exacerbate sea-level rise, and therefore be at high risk of disaster[2]. Indeed, the United Nations *Global Assessment Report on Disaster Risk Reduction*[42] identifies cities such as Dhaka in Bangladesh (the ninth-largest and one of the most densely populated cities in the world) as "disasters waiting to happen."

Indian Army members attempt to repair an embankment that was washed away alongside a sewage treatment plant due to heavy flooding of the Ganga river in Allahabad on 26 August 2013. The embankment helps to separate more than half the city from the Ganga.

ENGINEERING RESPONSE TO NATURAL DISASTERS

There are many definitions of the various discreet phases that make up the human response to natural disasters[8], each with their own focus. However, broadly speaking they fall into three aspects, two of which are reactionary and the third pre-emptive. Appropriate action in each of these aspects potentially results in less damage from a natural event and reduces the likelihood of a disaster taking place.

Emergency relief and recovery

The immediate humanitarian response of emergency relief, in the first few hours and days after a disaster occurs, is focused on reducing suffering and preventing further loss of life. The meeting of urgent short-term basic needs for clean water, sanitation, nutrition and protection from the elements is the priority at this time. As the days and weeks progress, this response transitions, and there is more focus on medium-term solutions to meeting these needs, such as the provision of transitional shelters and temporary relief infrastructure for water, food, waste and energy services.

Reconstruction and redevelopment

Once the immediate humanitarian crisis is under control and effectively managed, efforts turn to rebuilding the communities affected by the disaster. This phase involves putting in place longer-term infrastructure and provides the opportunity to learn from the disaster, redesign and re-engineer, and incorporate knowledge from around the world on how to build-in preparedness and resilience against future events (often termed 'building back better').

Preparedness and resilience

Action taken before a natural event occurs is the most effective way to prevent and minimise loss of life, damage to infrastructure and economic impact. Indeed, there is much work that can be done in advance that can significantly improve the ability of a community to continue to function at some level during an extreme event and minimise post-event relief, recovery and reconstruction costs. It has been estimated that for every $1 spent on making communities more resilient, as much as $4 can be saved in future relief and rehabilitation[43,44]. However, the balance of effort is still very much focused on the two phases that occur after the event. In 2009, the United Nations International Strategy for Disaster Reduction (UNISDR) made recommendations that 10% of humanitarian aid should be spent on disaster resilience. Currently, the global figure stands at only 4%[45]. Part of the challenge is that preparing for extreme natural events doesn't provide any immediate benefits to people's day-to-day lives. It is therefore much less likely to be perceived as an issue needing imminent attention, particularly when competing for attention with a wide range of other pressing issues that also need solutions.

Given that trends indicate the likelihood of more natural disasters in the coming decades, the shortfall in effort on preparedness and resilience is clearly not a sensible or prudent approach. There needs to be a much greater focus in preparedness and resilience. However, while increased attention and investment in this area would help communities avoid future natural disasters, the Institution of Mechanical Engineers recognises that, given the timescales required for many of the engineering, planning and policy interventions to be designed and deployed, efforts also need to be made to improve the work that is being done on the other two 'reactive' aspects. This report therefore aims to provide a clear vision for an engineering-based approach to meeting the challenges presented by shortcomings identified in each of the three aspects of natural disaster response. The work has particular focus on Asia-Pacific, reflecting its susceptibility to natural disasters as well as its global importance as the world's growing centre for trade, finance and economic development.

EMERGENCY RELIEF AND RECOVERY

The United Nations ReliefWeb website listed 31 natural disaster events that required intervention by the UN during the first three months of 2013, including a range of hazards from storms and cold weather to earthquakes, wildfires, disease epidemics and locust plagues in locations from South America, Africa, Europe to Asia and the Pacific region. There are variations in reporting, but the data broadly shows that 627 people died in the 31 events and about 292,000 people were made homeless, representing about 58,000 homes destroyed and a larger number damaged. For those caught in the aftermath of these events, surviving the disaster is an immediate challenge and the first priority for emergency relief is to provide shelter, followed by infrastructure including water supply, sanitation, and energy. At the same time it is critically important to clear debris and to bury the dead, both human and fallen livestock, as these represent potential infection hazards.

People affected by disasters deserve and increasingly expect high standards of response. Working with the state authorities of the affected country, co-ordination of the international elements of the response is organised by the UN Office for Coordination of Humanitarian Affairs (UNOCHA)[48]. This responsibility is cascaded to 11 sectoral ‘clusters’, of which five can benefit from engineering inputs: Emergency Shelter, Camp Management & Co-ordination; Water, Sanitation & Hygiene Promotion; Logistics; Emergency Telecommunication. Each cluster has a designated lead agency that undertakes immediate assessments of the requirements generated by the disaster and engineers should always be part of this planning activity; their knowledge of infrastructure and supply chains is critical to helping achieve a successful outcome, particularly in the longer term.

Engineers supporting emergency relief

Following a natural disaster, there are many organisations involved in emergency relief and recovery. In a large number of these organisations, which have significant influence in decision-making, engineers are under-represented or absent[46]. A considerable amount of planning, contract management, project management and infrastructure expertise can be provided by engineers who specialise in water, fuel, power, road, rail, airport and seaport infrastructure[47]. However, engineers are generally consulted on an individual basis, often on short-term contracts or secondments, with little focus on long-term relationships, capacity building and knowledge transfer[8].

Emergency shelter, camp management and co-ordination

Sites for temporary camps need rapid assessment by engineers and must be located well away from potential hazards, particularly from the impact of follow-on natural events, such as secondary earth tremors or tsunami, or sources of disease or other health risks. Ad hoc camps often spring up in any open space available, providing challenges to the introduction of infrastructure, fire-breaks and security. Successful camp planning requires skilled resources and knowledge that bodies such as the UN High Commissioner for Refugees and the Red Cross movement have been developing for decades. Broadly, camps need to cover about 40m^2 for each occupant, provide 3.5m^2 of roof cover per person and include medical provisions, education and infrastructure. The engineer's role is generally one of support to ensure that the necessary infrastructure for access, buildings, water supplies, sanitation and energy can be provided.

In the 2004 Indian Ocean tsunami, swathes of homes had been completely removed from a 1km strip of eastern Sri Lanka's shoreline, where many shacks had been occupied by low-income families living in vulnerable infrastructure. In total, more than 500,000 people were displaced[49]. This is typical of many rapid-onset disasters in developing countries and in these cases the more robust structures that survive – particularly those with potential as temporary community accommodation or medical facilities – have to be quickly assessed to determine whether they are safe for re-occupation. In Sri Lanka, rapid assessment of such structures was made by a range of engineering professionals to determine their load bearing capacity, structural condition and suitability for modifying into family units, and in many cases structural integrity issues arose from the undermining of foundations by the tsunami wave impact. Fire risk assessments and design of communal sanitation, including solid waste and disease vector management, were also needed.

Importance of planning

The first action of engineers is to determine the locations affected by the event, the impact on the population, the condition of the infrastructure, the critical points and interdependencies and the local ability and resources to make repairs. This is vital to understanding what needs to be done when, and the key issues involved, ensuring a strategic and integrated approach which meets the needs of the situation[50].

There are a number of electronic tools and data resources, both governmental and in the public domain that can be used to assist with this process, such as national Government records, mapping data, aerial and satellite photography and open source information from the web. In extreme cases, such as in the immediate aftermath of the 2010 Haiti earthquake, government records and data may have been completely destroyed in the event and informal sources accessed by internet[51]. Mobile technology therefore must be relied upon. The amount of data for even a modest-scale operation can be considerable and therefore a systematic approach is vital for the collation and evaluation of this data prior to any analysis. Indeed, in Haiti, one of the major challenges that emerged after the immediate response was the archiving and management of the data gathered[52].

Analysis and mapping of the information gathered highlight the critical points in the infrastructure systems together with the relationships between the various sectors. These findings provide engineers with an understanding of the sector interdependencies and inform the assessment of how critical, vulnerable and risky the situation is in order for an infrastructure development plan to be prepared. This plan details how the infrastructure should be developed, identifying resources, prioritisation and timescales. Critically, wherever possible the plan should be produced in collaboration with the national government of the country affected, the local community, international institutions (such as the UN) and the relevant NGOs that are active in the emergency relief effort. This is particularly important as it helps to ensure collaboration with the building of local capacity as well as national ownership of the recovery. In this regard the plan should consider local skills and seek to understand the need, based on national requirements and standards. The starting point is likely to be based on the infrastructure that was in place prior to the crisis, along with the support for any temporary accommodation.

The planning process is time-consuming, but it is vital that it is conducted correctly and comprehensively for the long-term success of the operation.

Water, sanitation and hygiene

The rapid provision of clean water and disposal of waste is generally more critical to human survival than the meeting of other basic human needs, such as food. In hot climates in particular, supplies of clean water are required immediately by survivors and medical support teams alike. Many recent disasters have been affected by waterborne disease outbreaks resulting from crowded and insanitary conditions that arise in temporary shelter.

The choice of water source varies depending on existing infrastructure, geography and topography. The engineer must, for example, balance using readily available river water (which needs energy-intensive and costly treatment to remove turbidity and infection) against groundwater sources that require minimal treatment but take time to develop. In the areas of Sri Lanka affected by the 2004 Indian Ocean tsunami, the public supply infrastructure had been ripped from the ground and all the private wells were tainted with salt water. Supplies had to be brought from inland areas to the temporary camps and the quickest solution was water delivery by truck. Although this was a flexible option in the short term, there was a challenge in sourcing tanks for local water storage and, ultimately, trucking is expensive and unsustainable. In Sri Lanka public supplies could be restored over time and the trucking abandoned, but in more remote places new, local sources must be developed for displaced people.

Simple solutions in high-tech wrappers

The interconnectedness of systems and the conditions in which they must operate means it is important for engineers to develop solutions that respond to and are robust within the local context. However, leading-edge techniques and technologies can be used to inform the implementation of often simple technologies to increase their effectiveness. One such approach is the United Nations Platform for Space-based Information for Disaster Management and Emergency Response, UN-SPIDER[53]. This has been formed to promote and enable the use of space-based technology such as Geospatial Information Systems (GIS) in disaster resilience and recovery work to ensure that 'simple' systems are implemented with strategies based on the latest technologies.

A practical example of how space-based information can assist on the ground in post-disaster recovery occurred in the summer of 2012, when relief agencies were overwhelmed by an influx of 120,000 people into refugee camps on the border between Sudan and South Sudan (Upper Nile State). This influx exacerbated a burgeoning humanitarian crisis caused by a desperate shortage of safe drinking water at a time when the floodplain on which the camps sat was being deluged by rivers fed from rainfall in the highlands of Ethiopia. Boreholes sunk by hydrologists on the ground had yielded little result, while heavy rainfall increasingly engulfed the sprawling refugee camps with toxic, stagnant water, compounding the crisis. Using a range of resources, ranging from satellite imagery to experience gained from operations in similar arid regions, a team of water engineers and a geologist conducted a desktop analysis that provided the relief teams with directions to where potable water might be located within the camps[54]. Ultimately, the information contributed towards the UN being able to locate other potable water sources and reduced the crisis to a manageable level.

Whatever is chosen, the new source must be isolated from, or upstream of, waste disposal processes, and the challenges of dealing with waste from large camps should never be underestimated. Sanitation practice is subject to strong cultural influences and engineers working in unfamiliar areas need to discover what is required. Simple pit latrines provide rapid basic sanitation but were, for example, not appropriate in Sri Lanka because of high groundwater tables. In earthquake-devastated Haiti in 2010, the ground was too hard to dig holes for pit latrines. In both these cases, lavatories with tanks had to be built and provisions made for emptying them. Emptying was more easily achieved than disposal in Haiti, where there were no treatment works or disposal sites for waste from about one million displaced people.

In addition to human waste, displaced people generate considerable amounts of waste materials such as food packaging and discarded clothing. Failure to consider access for collection vehicles and receptacles for household waste at strategic locations throughout a camp will soon result in breeding grounds for a range of insect and rodent vectors of disease.

Logistics – food and energy

Logistics is the art of getting the right thing to the right place at the right time and organising the operation. In natural disaster relief this covers sourcing, transporting, storing and distribution of relief goods. Engineering specialities are a fundamental part of this activity, as they are required in the assessment and maintenance of access routes and infrastructure, in establishing the warehousing of goods and in the deployment and maintenance of machinery used. Long supply routes may need the establishment of road and bridge maintenance gangs, if none already exists, and transport engineers must assess not only the present condition of the routes but also the likely impact of seasonal weather patterns, and mitigate those impacts in good time[55].

Warehousing includes the management of both hazardous and non-hazardous materials, such as water disinfectants, foodstuffs, bulk powders (flour, dried milk), fuel and a range of products that do not usually sit in the same store. All of this provides challenges for the materials handling specialist and for the maintenance engineer. Depending on the climate, warehousing may also have to be heated or ventilated and must be made secure against rodents, to avoid food losses, and thieving. The supply chain needs careful management to avoid goods going astray in the chaos that inevitably surrounds a disaster relief operation.

Emergency telecommunication

Telecommunications, both in disasters and more widely, has been transformed in the past 20 years by the advent of the mobile phone and to a lesser extent by the satellite phone. Very high frequency (VHF) radio networks still have a role to play, but this is diminishing as mobile networks spread. Consequently there is increasing demand for telecommunication engineers and expertise to help provide real-time information and data, both within the disaster area itself, and out to the principal co-ordination bodies in the USA, Europe, Bangkok and other regional centres.

The main disadvantages of mobile technology are that it is insecure, it operates over short ranges, it needs power provision and it can be easily damaged in the area of a disaster. In Haiti, however, mobile networks were operating very soon after the earthquake and provided most communications for thousands of relief workers in Port-au-Prince. VHF radios allow independence but may be difficult to get licensed for use. Some states also restrict the importation of satellite telephone technology.

The telecoms specialist has to weigh up all these issues in deciding what systems to use and how to provide effectively for the immediate needs for both voice and secure data transfer. Topography plays a part in this decision, as the installation of signal boosters might be needed in a mountainous region. In Sri Lanka, most incoming relief workers and almost all indigenous ones already had mobile phones that linked to the local network, which soon became overloaded.

Taking the longer-term view in the short term

In the immediate aftermath of a natural disaster, the priority of all concerned is the preservation of life and the provision of emergency water, sanitation, food, shelter and healthcare sufficient to meet a community's core basic needs. The immediate response consists largely of what engineers call 'tier 1' support: equipment-based and redeployable infrastructure such as tents and portable low voltage (LV) generators. As the situation improves and develops into recovery, support progresses from temporary equipment to the construction-based solutions of 'tier 2' and 'tier 3' developments. Typically, tier 2 is medium-term (normally up to five-year lifespan), semi-permanent cabin-type developments, and tier 3 longer term permanent construction.

Too often, the process from short-term through medium recovery to long-term reconstruction is depicted as a linear process of steps in series; ie a community cannot consider the next phase until the previous one is complete. This mind-set might account for why in the aftermath of Hurricane Katrina in 2005, a recovery plan was not developed until 18 months after the event[56]. As is unequivocally stated by the UN Development Group, "The foundation for sustainable recovery and a return to longer-term development should be planned from the outset of a humanitarian emergency."[57] The sooner the work on recovery and reconstruction planning begins, the quicker and more successful the overall outcome will be[58]. In many cases this may represent the best opportunity for decades for significant progress to be made in improving the provision of services within the affected areas. At an early stage, therefore, engineers should recognise and use opportunities to increase their effectiveness by developing a long-term post-disaster vision. This can take many forms, the applicability of which will depend on individual circumstances but may stretch from urban planning to the design and installation of core water, waste, communications and energy infrastructure, effectively laying the groundwork for future reconstruction.

RECONSTRUCTION AND REDEVELOPMENT

When an area or region is rendered temporarily uninhabitable by a natural disaster, in many cases a proportion of those displaced want to return 'home' and re-establish their 'normal' lives as soon as possible. Planning for this return is a complex process, with many social and political issues to address, such as ensuring equality, adequate tenure, safety and the reformation of a cohesive community[59,60]. In the midst of these issues, it is also important to ensure that the correct degree of engineering thought has gone into preparing the area prior to repopulation. Incorporating an adequate degree of co-ordination on engineering topics between the many parties involved in a resettlement programme can, in the long run, pay dividends.

Two of the most important engineering aspects to effective reconstruction are the early integration of long-term planning into the recovery phase and the incorporation of the principles of effective resilience in rebuilding efforts, often referred to as the 'Building Back Better' approach[61,62]. The latter incorporates many aspects of developing a resilience strategy prior to a natural disaster occurring. However, a disaster changes many things, from the effectiveness of infrastructure to the degree of attention on resilience issues and the associated political will for change. Therefore, 'Building Back Better' is focused on delivering a reconstruction with improved resilience under the special conditions that exist in the aftermath of a disaster.

What is resilience?

Many definitions of resilience have been considered since the concept emerged from the field of ecology in the 1970s, but perhaps the most relevant in the context of this report comes from the UNISDR, which defines resilience as:

"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."[63]

It is important to note that the role of resilience is not to remove risk completely. While hard physical infrastructure designed to keep nature at bay may be appropriate in some circumstances, an underlying principle of resilience is that we must accept that there are unknown potential situations that cannot be fully planned for. Therefore, the ability of a community to respond to and recover from unpredictable events, the exact character of which cannot be predicted, must be developed by incorporating uncertainty into preparation activities.

The suite of actions that are needed to translate these slightly abstract concepts into real resilient communities and cities must be informed by the context in which they are undertaken, resulting in a unique solution for every location.

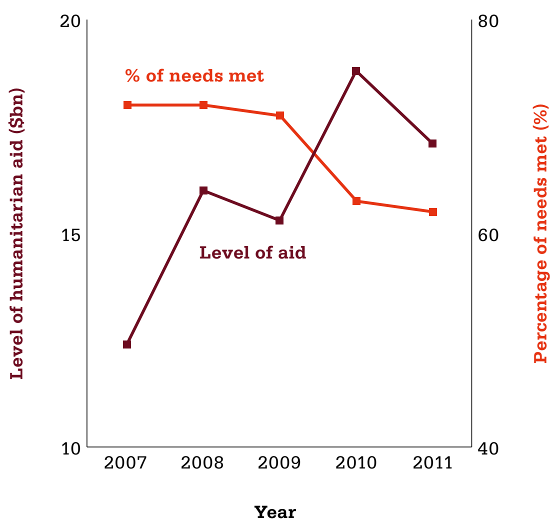
Resilient reconstruction

Levels of humanitarian aid are on an upward trend, see **Figure 4**, with a total of US$17.1 billion dollars spent in 2011, a 38% increase on 2007 levels. In the same period, the percentage of needs met fell from 72% to 62%[45].

Of the aid donated, the amount spent in countries with a history of natural disaster vulnerability was disproportionately high. While the situation is clearly complicated and requires detailed understanding to determine causal links, an obvious conclusion is that resilience needs to be integrated more effectively into the recovery process for those countries repeatedly at risk.

The over-riding principles of incorporating future resilience into a post-disaster reconstruction programme are similar to those used when considering preparedness for an event that has not yet occurred. However, cities and communities have many existing and competing drivers and challenges that inform their degree of engagement in resilience building during business-as-usual operation, the focus of which can be shifted significantly during a reconstruction effort. The post-disaster reconstruction phase can, in many cases, represent the most significant opportunity to incorporate resilience ahead of the next potential disaster. In this period, a new awareness of vulnerability causes multiple stakeholders to come together with common goals, political will is enhanced, previous development mistakes are evident and the level of resourcing is often unprecedented[64]. As a result, under such conditions engineers should become advocates for resilience, seeking to maximise on the opportunities that emerge to 'Build Back Better' and solve the significant challenges that exist in doing so, such as the co-ordination and compromise required between multiple stakeholders.

Figure 4: Effectiveness of aid



‘Building Back Better’ can mean not building at all

In areas of the world that are undergoing rapid development and urbanisation, issues related to the resilient reconstruction of informal settlements (slums) are complex, particularly with regard to the added fragility of the community and informal economic relationships that exist therein. Further, given that these tend to be sited on marginal land, the question needs to be asked whether reconstruction should be attempted or alternative arrangements made.

Following multiple floods, the administration of Surat, India, took the decision to relocate a number of communities from flood-prone land to purpose-built blocks, successfully reducing their physical vulnerability[65]. In addition, in an attempt to prevent resettlement in the hazardous areas vacated by the relocation, in the context of the city’s land being under constant pressure from increasing urbanisation of the state’s population, the city authorities re-zoned the places vacated by the relocation as public spaces[46]. However, it should be noted that care needs to be taken with such initiatives, as relocation of slum dwellers can impact detrimentally on the relationships and informal economies that can contribute significantly to the resilience of these communities[29].

The principle that, in some cases, ‘Building Back Better’ is best done by not building back at all is applicable not only to the developing world. Land rezoning following a disaster may be the best method to reduce future vulnerability and needs to be considered as an option in highly developed nations too[20]. However, this approach can face multiple barriers, not least of which is an individual’s and community’s sense of place leading to strong emotional ties to their devastated homes and neighbourhoods. Following Superstorm Sandy, a fund was approved by the US Federal Government that was to be used to purchase homeowners’ land, should they not want to rebuild their homes[6]. However, take-up has not been as high as expected as people have chosen to rebuild their homes[66,67], while complying with enhanced building controls, and risk future events rather than relocate[68].

Standards for buildings and infrastructure

One of the earliest engineering actions in the planning for long-term reconstruction, is the accurate assessment of damage to existing buildings and infrastructure systems, along with the collection of information on types of failure. The latter can be invaluable in the future engineering design of resilient systems. For example, a comprehensive study of buildings affected by the Christchurch earthquake of 2011 led to a series of recommendations ranging from research studies, to the amendment of structural codes for earthquake resistance[69]. Indeed, a post-disaster review of the construction regulations and building codes applicable to the affected area should take place during the early stages of recovery to ensure that reconstruction is done to appropriate standards. This must clearly focus on the technical content of the codes, but should also include consideration of the suitability of the measures for the location that sustained damage[70]. In this regard, account needs to be taken of the potential for enforceability of the codes, given the local administrative structures, resources and levels of technical understanding. The latter may lead to the conclusion that there is a need for more training of the local government employees.

It is a common misconception that an improvement in the standards of engineering design is the most important aspect of addressing the vulnerability of the building stock to the impact of natural events. While undoubtedly an important contributing factor, it must be appreciated that the mere existence of such codes will not have a significant effect without the political will or the technical engineering capacity to enforce them. In 2010, for instance, it was estimated that 70% of the housing stock in Istanbul was either illegal, or legalised and built with no consideration for earthquake building codes[71]. In this environment it is estimated that 5% of buildings would potentially collapse in an earthquake similar to the event that occurred in 1999. However, for the individual building owners, at 5% this level of risk might be perceived as acceptable; non-compliance would therefore take many years to address as there is little incentive for owners to retrofit for an ‘unlikely’ event[71]. Similarly, the loss of life, physical and economic damage resulting from the June 2013 floods in Uttarakhand state, northern India, has been attributed by some experts[34] to unauthorised and ‘mindless’ building activities on the river floodplains, in addition to the deforestation in the Himalayan foothills.

There are significant discrepancies between different nations and regions of the world with regard to building codes and standards. In many countries, Codes of Practice and standards for construction simply do not exist and a considerable effort needs to be made to rectify this deficit through the transfer of engineering knowledge and practice experience. Two of the earthquakes that struck in 2010 demonstrate this issue[2]. On 12 January 2010 about 70% of homes and buildings collapsed in Haiti when a magnitude 7.0 earthquake struck, killing over 200,000 people and causing economic damage about one and a quarter times the nation's annual GDP. Just over a month later, on 27 February 2010, a magnitude 8.8 earthquake struck Chile, releasing about 500 times the energy and destructive power of the earthquake in Haiti, but with significantly less impact in human and economic terms. Part of the reason for the different outcomes is that after a devastating magnitude 9.5 earthquake in 1960, strict building codes were enforced in Chile that ensured subsequent buildings were more resilient. Also, a concerted effort was made to educate the population about earthquake safety and ensure better preparedness to act appropriately when an earthquake struck. In Haiti, no such lessons had apparently been learned from the past (although the city of Port-au-Prince had been completely destroyed by earthquakes in 1751 and 1757). Geologists had picked up minor quakes in Haiti in September 2008 and alerted authorities to the likelihood of an earthquake of greater intensity, yet the population remained largely unprepared. Had similar initiatives been taken in Haiti as in Chile, it is conceivable that the disaster would have been much smaller in scale.

In addressing this apparent discrepancy, UNISDR's Hyogo Framework for Action[70], a ten-year plan to make the world safer from natural hazards by building the resilience of nations and communities to disasters, is a step in the right direction. The framework was adopted by 168 nations in 2005 following the 2004 Indian Ocean tsunami, and is the first international plan to explain, describe and detail the work that is required from the full range of sectors and individuals involved to reduce disaster losses. However, despite including a priority for action on standards to reduce the underlying risk factors, the mid-term review found that progress in this area was amongst the least made by the initiative[72]. Much can be achieved without the need to resort to expensive engineering, but to achieve adequate levels of resilience will need collaboration between governments, businesses and individuals to transfer knowledge and mitigate the impact of natural events.

Capacity-building training may also be needed within the local labour force to ensure that a shortage of skills does not hamper post-disaster rebuilding processes. This is particularly important where updated or more vigorously enforced building codes will require a change in construction methods over what has traditionally been employed.

Socio-economic recovery as a priority

Infrastructure and the physical environment are only two aspects of a more holistic reconstruction a region must go through following a natural disaster[61]. The reconstruction of the socio-economic fabric is also vital and engineers need to be mindful of the different possible approaches. This highlights the need for engineering solutions to be developed with respect to the local context and for engineers to look outside their technical specialisms for other drivers and influencing factors. It may also lead to reprioritising actions, such as focusing on the reinstatement of an area's agricultural output and food distribution, prior to tackling other infrastructure, in order to re-establish this sector, which is often critical to economic development.

Currently, in general, several development NGOs require the use of local labour as part of any major reconstruction work. This is partly to help the local community feel a sense of ownership, but it also provides income, which is critical to the rebuilding of families' lives and the local economy after a disaster[62]. This means that the method by which initial recovery and longer-term reconstruction work is physically delivered on the ground is ideally through regional and local civilian contractors, thereby building local capacity for future responses to natural events. However, the actual procurement strategy adopted will depend on a host of considerations, including:

1. **Time, cost and performance**
   Some contracting options are faster to deliver than others, but may be more expensive or take greater risk with the quality/performance of the finished product. A balance must be struck appropriate to the specific requirements of the work.
2. **Threat and the permissiveness of the environment**
   The freedom of movement may impact differently on locals, ethnic groups and personnel from overseas.

3. **Security**
Some work areas or projects may have sensitive security issues, such as the construction of penal detention centres or defence facilities, which may make the use of particular contractors unviable.

4. **Complexity and contractor capability**
If less technically competent contractors are used it may be necessary to avoid contracts framed around output-based specifications and instead use more traditional designs and bills of quantities/schedules of rates.

5. **Availability of materials and robustness of supply chains**
The availability of materials and the robustness of their supply will influence the contract strategy.

6. **Defects liability**
It is usual practice in construction projects to have a defects liability period of up to 12 months, with final payment withheld until the end of the period. This may be difficult to enforce, and socially unacceptable, especially during the early stages of responding to the disaster. In many cases a defects period of typically three to six months might be adopted.

7. **Maintenance**
The longer-term maintenance of the works must be considered, as the national government needs to be able to operate and maintain the infrastructure once the recovery teams have left. It is often prudent (although not always practical) to have the same contractor maintain the facility it builds after the project is completed. Not only is the contractor already familiar with the work, the responsibility for any defects is also more readily attributable. The importance of effective maintenance should not be underestimated. During the Bangladesh floods of 1999, poorly maintained flood defences became counter-productive as they trapped floodwater and prolonged flooding.

8. **Health and safety**
While it is critical to understand the importance of using local technology in the provision of infrastructure, and the need to apply overseas standards sparingly, the same is not true for safety. For example, UK engineers often apply UK standards where reasonably practicable and, in addition, comply with local national standards.

Engineers building local capacity

Disaster relief is becoming increasingly professionalised and technological. Several ‘second-tier’ organisations have been established over the past 30 years to support relief agencies with technical advice, standards and quality assurance procedures. One such is RedR[73], set up by the UK engineering professions in 1980 to maintain a roster of technical professionals available for relief work and to offer vital training to relief workers at all levels. Having learned the importance of supporting local skills from experience in Sri Lanka after the 2004 Indian Ocean tsunami, a team of RedR trainers arrived in Port-au-Prince within two weeks of the 2010 Haiti earthquake to join over 50 international RedR members, many of them engineers, already working with a range of aid organisations.

RedR training in Haiti was directed at newly recruited local staff working with the international agencies, building local capacity for the longer term. It provided basic skills in standards, logistics and security management, which are vital in the early days of a relief, and training was often provided ‘on the job’. Later the team delivered technical skills right at the heart of the response. Over 1,000 people were trained by RedR in six months, over 90% of them Haitians. There is a hugely important role for engineers in passing on their knowledge to those who can make immediate use of it to relieve suffering after disasters. RedR teams are currently working in Jordan, Sudan, South Sudan and Kenya.

Earthquake-Proof 'Coral Reef Island' for Haiti by Vincent Callebaut Architectures.

PREPAREDNESS AND RESILIENCE

Human activity can influence the occurrence of hydrological, meteorological and climatological events that can lead to natural disasters[32,3,38]. Working to reduce the human-driven event-magnifying effects in the areas of, for example, deforestation, water resource pressure, ecosystem degradation, natural barrier removal, global warming and climate change would be a good place to start in attempting to arrest the trend of increasing human exposure to flooding, storms, mudslides, drought, extreme temperatures and wildfires. However, given the reality of 21st-century population growth projections[29], the environmental degradation that has already taken place and increasing urbanisation around locations vulnerable to extreme events, including geophysical events such as earthquakes and volcanoes, it is critical for human well-being that communities exercise preparedness and build resilience.

Preparedness

Preparedness means ensuring individual citizens, families and communities are ready to take appropriate actions if an extreme natural event occurs[74]. This includes preparation such as being informed and making a plan to cope with interruptions, for example building and maintaining a store of important supplies including food and water and establishing a place of shelter. It can also extend to initiatives such as painting marks on items such as lampposts and fence posts, to indicate the height to which previous peak flood waters rose.

Resilience

Resilience is focused on building local awareness of hazards, reducing vulnerability and enhancing the capacities of communities and their assets to cope with a range of scenarios[75]. Inherent to this is the notion that while we can do little to control a natural event, we can take steps to prevent it from being or becoming a disaster by ensuring that critical services can recover and function, which enables citizens to continue with their lives and remain safe and healthy. Five characteristics feature strongly in resilience: redundancy; flexibility; safe failure; ability to recover; ability to learn and adapt behaviour[75].

Assessing the risk

One of the first steps in any resilience programme is to assess a community's exposure and vulnerability to natural hazards (see **Table 2**), be they flooding, tropical storms, earthquakes or other types, and identify the associated risks. Engineers have a significant role to play in both this assessment and the proposal of methods for mitigation of the identified characteristics. Tools and systems such as Hazard Analysis and Critical Control Points (risk matrices that consider both likelihood and magnitude of each risk), as well as failure analysis tools, can all be revised and applied by engineers to assess what risks may occur in the future and how to best manage them[30].

In this regard it is important to ensure that a full risk-map is developed that considers all the potential risks in a holistic approach[30]. As a result, synergies between the resilience required for each risk can be maximised and the likelihood of resilience measures against one type of hazard increasing vulnerability to another can be minimised[76]. With this approach, the potential of interconnected disasters such as, for example, flooding and health issues or drought and famine, can also be captured.

These risks and their implications need to be integrated into plans for the region. This is to ensure they are considered and taken into account when developing initiatives, thereby helping to avoid projects aimed at tackling other challenges affecting extreme event vulnerability. As an example, the widening of a coastal road in Da Nang, Vietnam, designed as the solution to a transport problem, removed dunes and vegetation which had previously afforded some protection from wave-strikes. Many houses were subsequently destroyed and inhabitants had to retreat inland[46].

Table 2: Definitions of terms[63]

Vulnerability	The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.
Exposure	People, property, systems or other elements present in hazard zones that are thereby subject to potential losses.
Risk	The combination of the probability of an event and its negative consequences.

Population density – rural to urban

Initiatives aimed at embedding resilience into communities vulnerable to extreme natural events need to respect the differences between urban and rural settings. However, it is too simplistic to assume that only two approaches are needed, one for each landscape, as in reality there is a broad spectrum of gradual variation between mega-cities and the most rural areas, including suburban and peri-urban areas along with smaller towns and cities. It should also be remembered that urban areas rely on rural areas, for example for food production and recreation and vice versa, for example municipal support, markets and employment. Urban and rural communities are inextricably linked.

Figure 5 defines the characteristics of resilient smaller-scale, largely rural, communities and **Figure 6** those of resilient urban centres; these illustrate a range of distinct and subtle differences.

Some of the most critical factors of resilience in rural communities relate to the characteristics of social cohesion, that is the ability and willingness of community members to support one another during difficult times – such as natural disasters. Hazards will affect some members of the community more than others, notably the elderly, the young and those with lowest incomes.

These groups tend also to be less able to make their plight known in times of emergency. In rural settings, an example of social cohesion is members of community response teams knowing where those most vulnerable in the community live, and ensuring that they receive prioritised help to evacuate, access to shelters and relief supplies. Engineering is still relevant in rural settings, but solutions must respect these relationship structures and fit within them.

The characteristics identified in **Figure 5** suggest that although it is important to be able to call upon a wider support network when required, resilience in smaller-scale communities places emphasis on self-sufficiency and local connectivity; the community being able to assess risk and cope with impacts within itself, not least when agriculture and food security are concerned. Conversely, the urban system's approach to resilience, as shown in **Figure 6**, highlights the fact that the well-being of city dwellers is more remote from the ecosystems that supports them. In the case of urban dwellers, there is a clear need for effective engineered infrastructure networks at various scales to allow human well-being to be sustained. The characteristics of urban areas: their density, levels of infrastructure, developed communication channels, complex supply channels and, in some developing nations, greater degree of administration when compared to more rural counterparts, pose both opportunities and increased risks when considering the impacts of natural events.

Figure 5: Characteristics of a safe and resilient community (based largely on rural communities). © Arup

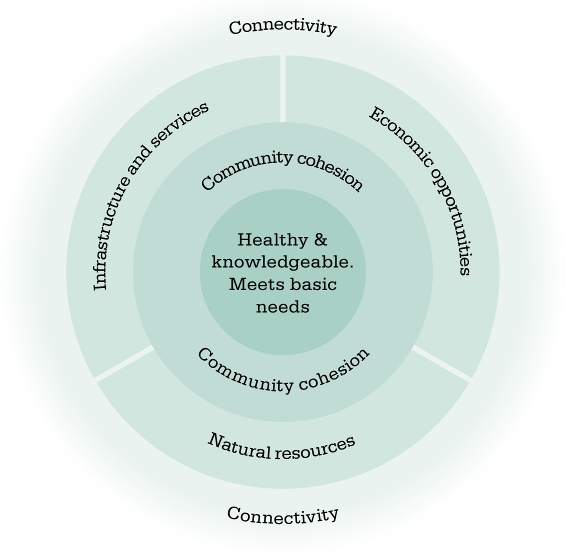
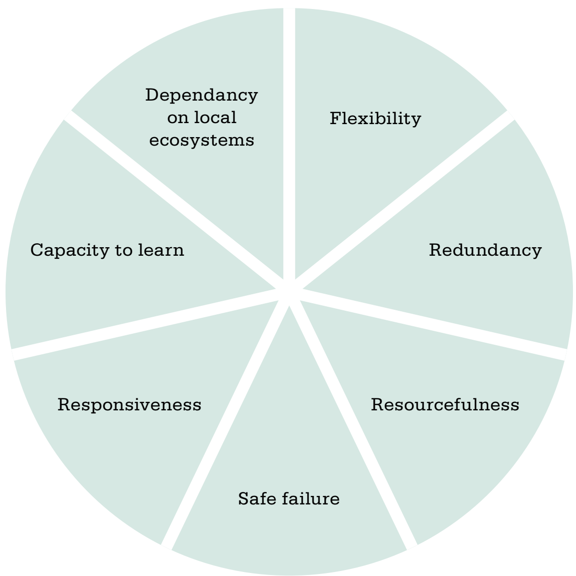


Figure 6: Characteristics of resilient urban systems. Source: da Silva, Kernaghan & Luque (2012) Available at http://dx.doi.org/10.1080/19463138.2012.718279



While urban resilience is more closely linked to physical and infrastructure-based resilience, the importance of a strong local government, that has the ability to organise a coherent, inclusive and co-ordinated plan, cannot be underestimated. Of the communities living in urban areas, the most vulnerable inhabitants are those living in the informal settlements, or 'slums', that are growing rapidly in those nations that are experiencing mass urbanisation[27,29]. These typically develop on marginalised land such as floodplains or landslide-prone steep inclines. These 'slums' suffer from low levels of basic engineered infrastructure for the provision of water, sanitation, food and energy. The characteristic for resilience in these settlements are therefore often closer to the rural setting of **Figure 5** than the urban of **Figure 6**, particularly with regard to community cohesion and self-sufficiency. One key aspect however, is that they are usually illegal settlements and thus homes and systems are not supported by recognised and enforceable codes, standards and land tenure systems[72]. A reluctance on the part of authorities to act to increase the physical resilience of these areas may therefore exist to avoid 'legitimising' their presence. However, the sheer density of the urban environment they create and the extremely high levels of vulnerability mean that it is essential that they are considered within the remit of an urban resilience plan[27].

Increasing the resilience of informal settlements

Increased physical resilience in informal urban settlements can often be achieved as a result of actions taken to increase the quality of life for those living in the areas, such as the provision of more robust housing, sanitation infrastructure, energy supply and clean water [27], along with improved accessibility to post-event emergency vehicles. However, increases in living standards will result in resilience only if they are based on resilient systems. For example, inhabitants may switch from individual kerosene lamps to electric lighting due to the availability of an electricity supply, but if the electricity supply system has no built-in redundancy, or is reliant on a small number of connections serving many people, then it will be susceptible to the effects of an extreme natural event. Where new infrastructure is created it must have redundancy built in[40] and this might, for example, in some cases include maintaining previous simpler technology (such as hand-pumps for water abstraction) embedded within the system to improve resilience.

Communications defining the 'community'

The advent of smart phones and social media has redefined the concept of 'communities'. People, particularly in urban areas, often aren't acquainted with their neighbours and may not feel part of a 'physical' community. Social media however has allowed people to develop virtual communities, which can function in much the same way as traditional communities – and sometimes even more effectively.

With the vast amount of up-to-date information available at people's fingertips, there has been a huge rise in people depending on tools like Twitter, Facebook, YouTube and Instagram to find out about events and news in their local area.

In response to Superstorm Sandy in New York City in 2012, members of the public took to social media en masse to share photographs, videos and information[77]. In one 24 hour period, social media analysts Topsy noted 3.5 million tweets using the hashtag #Sandy. This disaster also saw US Government agencies, such as the National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (US EPA) and Federal Emergency Management Agency (FEMA), more than ever before, turn to tools like Twitter to advise people and share information on, for example, the direction and development of the storm, environmental risks and where to find shelter or medical help, before, during and after the hurricane struck.

These new forms of communications present a huge opportunity for government agencies, nonprofit organisations and emergency services, not just to gather information quickly but also to disseminate it[51] and show leadership in preparedness and resilience building.

With these new opportunities however, come challenges. For example, if the public are depending on smart phones or computers for information, there has to be a reliable source of power (either batteries or electricity). Other potential challenges include the need to develop standards for information provided through updates and tweets, as well as potential barriers like Twitter bandwidth and update limits.

Vulnerability and system resilience

Vulnerability is in part related to the likelihood of failure and is an important influencing factor in overall resilience. In the 21st century, human activity is largely carried out within highly complex globalised systems (see **Figure 7**), whether for the production and distribution of food, water, sanitation, energy, healthcare, transport or other services, and the vulnerability of a system is often the key factor to how resilient a community is to a natural event.

Where efforts are made to create frameworks for resilience planning, in both rural and urban environments, systems thinking must be engaged and networks should be engineered to be resilient within themselves as well as in relation to each other (ie water systems often rely on electricity systems for pumping and electricity systems often rely on water for cooling, etc). In this regard the interdependencies between individual networks and sets of networks need to be understood, as the reliance one system has on another and the dynamic feedback loops that might arise in the case of an extreme external event, can be critical to the overall resilience.

Significant hazards may emerge as a result of a series of small failures that, individually, have little significance, but when combined have the potential to cascade and thereby add to the disaster. The importance of cascading failures in disaster scenarios, including both natural and man-made systems, has been recognised by the Global Science Forum of the OECD. Indeed, the forum found that there was an increased need for data to be gathered and models to be developed on vulnerability and risk at national and global levels[78]. Engineers need to be engaged in such initiatives as they are well positioned to be able to understand existing and planned systems and the steps necessary to increase resilience.

Figure 7: Risks affect capitals and systems in different ways and are event specific – a general relationship is illustrated. © Arup

Capital	**System**	**Risk**							
		Earthquake	Volcano	Landslide	Storm	Flooding	Heatwave	Drought	Wildfire
Social	Education	•	•	•	•	•	•	•	•
	Health	•	•	•	•	•	•	•	•
Human	Food	•	•	•	•	•	•	•	•
	Communications	•	•		•	•			
Economic	Business	•	•		•	•			•
Natural	Flood control	•		•	•	•			
	Habitat/biodiversity					•	•	•	•
Physical	Energy	•			•	•	•		•
	Water	•			•	•	•	•	•
	Transport	•	•	•	•	•			•
	Housing	•	•	•	•	•	•	•	•
	Sewerage	•	•		•	•			
Political	Waste management	•	•		•	•	•		
	Safety & security	•	•	•	•	•			•
	Government	•	•	•	•	•			•

Of the systems that contribute to an overall resilience, each will have specific considerations. A resilient water supply system, for example, is based on the fundamental issue of redundancy of supply sources and supply routes. There is little that can be cost-effectively implemented in terms of increasing the ability of the pipe network to withstand, for example, earthquake events, but if a system as a whole can lose part of the network and still provide a service to the remainder, then the impacts of failure will be lessened. The same thinking applies to electricity systems: multiple deployments of local generation and storage capability supported by micro-grids embedded within a larger national or regional grid network, provide a route to increased resilience[79]. The latter was evident on a small scale in New York City in the aftermath of Superstorm Sandy, where a localised 40MW Combined Heat and Power (CHP) plant based micro-grid in Co-op City maintained electricity supplies to the local area while 8.5 million New Yorkers suffered a blackout[80].

Resilience and system interdependencies

Water supply and sanitation systems coupled with electricity systems are particularly good examples of the interdependencies that arise in municipal utility networks. Very few water supply networks are able to distribute water to users entirely through harnessing gravity forces and therefore need the application of electric pumps. Interruptions to the power supply can thus have a critical effect on the flow of water, sometimes with catastrophic consequences, as for example in the case of the Fukushima nuclear accident, where failure of the diesel generators that should have driven the reactor cooling system led to a major nuclear incident for Japan[81]. Loss of power can impact severely on the availability and quality of potable water, as electricity is required for pumping and the treatment of waste streams. Following Cyclone Evan in 2012, a power outage in Samoa meant that the majority of rural people who relied on boreholes for their water could not access clean water and generators had to be flown in from New Zealand to restore supplies[82].

Timescales and resources

A plan to build resilience that looks only at short-term actions specifically centred around physical will not be robust. It will be vulnerable to changes in community leadership and to being overturned by shifts in public attention to other pressing priorities. Frameworks within which resilience planning is done must therefore include elements to encourage long-term changes to attitudes, policies and behaviour that lead to new processes being integrated into the broad range of actions a community needs to take[83]. Although these medium to long-term timescales are often alien to short-term orientated politicians, the increasing global focus on adapting to climate change is encouraging leaders to be more aware of the need to think in these terms.

A further difficulty associated with government thinking is that the quantitative outcome, in human and economic terms, of building community resilience is very difficult to measure with any degree of certainty and therefore ‘value for money’ is almost impossible to judge. Individual characteristics of resilience can be assessed for discreet physical systems in areas or regions, but to combine these assessments into an overall measure of resilience, risks missing the importance of more intangible elements such as relationships, culture and the interdependencies. Qualitative appraisals are possible, but these are hard to use to justify investment. The effects of Hurricane Katrina and ‘Superstorm’ Sandy on New Orleans and New York respectively suggest that the availability of financial resources is not a guarantee of action[15,83]. A lack of political will and the technical literacy of those in power to develop effective resilience strategies can often be the limiting factors.

There is a role for engineers as advocates for better thinking about pre-emptive resilience capacity building in developed and developing nations alike. Many studies of resilience and vulnerability in developing areas such as Asia, focus not on the need of funding for hard infrastructure but on the need to build capacity within the local and national administration to understand the complexity and multi-dimensional nature of resilience[84,85,86]. Of the 23 key obstacles to resilience identified by the ADB, the vast majority are related to information, leadership, understanding, political will, legislation, poor integration and the ability of proponents of resilience to have an effective platform for discussion[84].

The route required to overcome these obstacles is defined by UNISDR as "The process by which people, organizations and society systematically stimulate and develop their capacities over time to achieve social and economic goals, including through improvement of knowledge, skills, systems, and institutions."[63]

It is clear that engineers can play an instrumental part in improving local knowledge, skills and systems as well as make a contribution to the development of local institutions. There is, however, also a clear need to engage the private sector in the challenge of transferring technical ability and capacity to nations developing their resilience programmes[87]. With the increasingly global nature of business supply chains, measures aimed at increasing local resilience can have beneficial effects on maintaining business continuity across the world when extreme natural events occur. The Bangkok floods of 2011, for instance, led to significant disruption to many global industrial supply chains, slowing car production and tripling the price of some hard-drives[88]. Engineers involved in manufacturing, in particular, are well placed to understand these potential impacts and to reduce potential effects. Tackling these issues will undoubtedly require investment in time, money and intellectual effort, but would be worthwhile given how it could help provide stability in global trade.

A transitional shelter project led and financed by the International Committee of the Red Cross on January 2011 in Port-au-Prince, Haiti.

WHAT NEEDS TO CHANGE?

Historical trends show that ever-greater numbers of people are being affected by natural disasters and there is a growing economic impact, both locally and globally, the latter through the disruption of international supply chains for food, industrial goods and energy resources. A continuation of these trends appears likely in coming decades, particularly given the combination of population growth, rising urbanisation in vulnerable areas, environmental degradation and climate change. The risks faced by Asia-Pacific are of specific concern given the region's increasing role as the world's economic powerhouse. It is clear that, in light of these trends, a greater focus on how to respond effectively to extreme natural events and how to build resilience is critical.

The Institution of Mechanical Engineers recognises that governments around the world are, currently, poorly allocating their funds by focussing almost exclusively on immediate disaster relief and post disaster recovery efforts, while largely ignoring the obvious benefits of increased funding for preparedness and resilience building against future events[83,89]. Identifying areas where disasters are likely to happen and funding programmes to build in better local resilience will help reduce future deaths, the numbers of people affected and the economic damage. Additionally, the amount of funding needed in future for relief, after an extreme natural event has occurred would be reduced. Indeed, if investment of $1 today can help save as much as $4 in future relief, an expansion of this approach would allow organisations such as the UK's Department for International Development (DFID) to divert more of its funds to other activities such as education and health outreach.

While it is clear to the engineering profession that the response to natural disasters should be primarily focused at the human scale – in particular, behaviour, mind-sets, leadership and relationships – engineering is an important enabler, allowing more effective individual and community responses. To realise the full potential of the engineering-based approaches and solutions identified in this report, engineers should strive for a greater involvement with the main organisations involved in resilience building, emergency relief and recovery efforts. Engineers must also develop their input in collaboration with local practitioners and stakeholders, thereby promoting local ownership and independence. However, there also needs to be greater recognition by local, national and international governments, as well as organisations involved in disaster relief and recovery efforts, of the vitally important role for engineers. This will help to ensure that the physical solutions developed are culturally sensitive, sustainable and socially responsible. Having solutions based on the local context is often the difference between an effective rebuilding effort and a failed one.

Recognition of the contribution the engineering profession can make, together with a greater degree of collaboration between engineers and local communities that need to build capacity for resilience, provides a route for long-term knowledge-transfer partnerships. The current level of short-term resilience knowledge transfer is insufficient to tackle long term needs. In order to address this issue, the Institution advocates that DFID and its international counterparts consider introducing long-term contracts (2–3 years) for engineers across all disciplines, who are then embedded into developing nation governments and agencies to help advise, develop, build and transfer knowledge on resilience. By creating a sustainable knowledge transfer of engineering skills and expertise, agencies such as DFID would be more effective in assisting developing nations to become more self-sufficient and resourceful in future disaster planning and response.

This knowledge transfer approach is particularly important in the case of urban coastal settlements in developing countries in Asia-Pacific, where the combined effects of anticipated sea-level rise, increased storm activity, natural barrier degradation, and the widespread development of fragile informal communities, create the potential for an increased frequency of natural disasters in the future. Here, facilitating local engineering capability through international collaboration between governments, businesses and engineering bodies, together with identifying local technical training needs for both pre-emptive resilience decision-making and enforcement of appropriate building standards and codes, should be a priority for all with a stake in the resilience of global supply chains.

The engineering profession itself should be more vocal an advocate for resilience building in all areas of the world at risk of natural disasters, seeking to address the gaps and obstacles highlighted in this report; such as inadequate risk information, poor understanding of disaster risk management, a weak voice for resilience proponents and a lack of integration of thinking on resilience across sectors and within organisations. Engineers must work to strengthen indigenous engineering capacity in order to develop local, relevant risk reduction actions, and help communities to increase the level of attention on resilience issues that matter to them. Engineers can also play a part in counteracting the transient nature of short-term politics. Given the often lengthy timescales of construction and long lifespan of most engineered infrastructure, engineers intrinsically think in the long term and exhibit tenacity in the prolonged pursuit of solutions, a characteristic that is beneficial to work on reconstruction plans in the wake of natural disasters.

The involvement of engineers in the immediate response to an extreme natural event has the potential to facilitate early recovery and also increase the possibilities for incorporating resilience into the reconstruction effort through planning for long-term solutions. Decisions taken in the short term set the trend and often provide the physical foundations, and sometimes constraints, for longer-term infrastructure reconstruction. During the emergency relief stage there is much that can be done in this regard by engineers working in the background, so as not to affect the immediate focus on reducing suffering and meeting basic human needs. Early involvement will allow the concept of resilience to be embedded in the mind-set of those involved in the reconstruction process before significant investment is made. Those involved in co-ordinating these efforts should recognise the potential benefit of this engineering input and collaborate with the profession.

Some of the products of today's engineers will conceivably still have an influence in more than a 100 years' time and there can be no accurate predictions of environmental, societal or economic change over such a timeframe. Engineers should therefore seek solutions in collaboration with other professionals, such as architects, planners, lawyers, social scientists and economists, that embrace uncertainty and flexibility in the long term. These timescales can be particularly relevant in urban areas, where greater levels of engineering infrastructure are needed to support inhabitants. Rising urbanisation has also led to an increased focus on the complexities of resilience, particularly in the context of populations concentrated in urban settings vulnerable to extreme natural events.

Over recent years, the principle of taking a systems based approach to developing resilience in urban areas has emerged and this needs to be embraced widely both inside and outside the engineering profession. In the first instance, this approach allows a clearer understanding of the inter-relationships and interdependencies across engineering-based systems, maximising synergies and minimising mal-adaptations. It can also show the effects of different potential hazards along with the impact of existing local development plans. However, engineering exists in a complex world of social, political and economic relationships and examining the effect engineering solutions have on these other aspects of resilience, will allow engineers to indirectly improve areas that are outside their direct discipline. This systems approach suits the complexity of the activities needed to increase a city's resilience and is highly complementary to the collaborative multi-disciplinary nature of today's engineering.

Tokyo Sky Tree featuring seismic proofing.

RECOMMENDATIONS

It is crucial for the future of people's lives, their properties and communities, as well as local, national and global economic activity, that the third, pre-emptive aspect, resilience building, is incorporated more vigorously in the human response to extreme natural events. The Institution of Mechanical Engineers therefore makes the following key recommendations:

1. **To focus more international development funding on building future resilience.** Currently only 4% of all international humanitarian aid is channelled to helping build resilience in disaster hotspots, well below the UN's recommended 10%. As it is estimated that every $1 spent on making communities more resilient can save as much as $4 in disaster relief in the future, by spending now, donor nations such as that of the UK could maximise their development aid. Doing so would provide better living for residents, ensure more effective use of UK taxpayers' money and help ensure a more secure future for all.

2. **Build local capacity through knowledge transfer.** Governments, the private sector and all those with a stake in global supply chains need to prioritise the transfer of knowledge, information and skills for the building of local resilience capacity. Technical knowledge for embedding resilience thinking, improved building standards and codes, engineering practice know-how and appropriate relevant training builds local expertise and indigenous capability. To facilitate international knowledge transfer partnerships, the Hyogo Framework priority for action to reduce the underlying risk factors must be reinvigorated by the UN, and DFID and its international counterparts should create long-term engineering placements (three or more years) that enable effective transfer of relevant skills and know-how. By helping to ensure nations are able to cope more effectively with extreme natural events, the prospects for the future stability and continuity of worldwide supply chains are improved.

3. **Embed the long-term engineering view in the short-term response.** NGOs, national governments, the UN and others involved in co-ordinating the short-term response to natural disasters should seek the early involvement of engineers in their activities. Decisions made in the immediate recovery stage of a response set the engineering foundations and constraints for eventual reconstruction and redevelopment. The quicker engineers can begin infrastructure assessment and longer-term reconstruction planning, the better short-term decision-making will be and the more likely a successful overall outcome that increases a community's resilience.

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