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Challenges for the Application of Earthquake Engineering in the Pacific Islands

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ABSTRACT: Experience has shown that successful application of earthquake engineering in the Pacific, particularly the understanding of earthquake risk as applied in the high-risk urban areas, is fundamentally dependent on continuing studies of seismicity and neotectonics; research on foundation problems; the institution of building standards; and seismic microzonation studies of urban population centres. The whole needs to be carried forward by a comprehensive risk-management approach that takes scientific and engineering advances towards social outcomes by defining the people, buildings and infrastructure at risk, and engages the relevant communities in planning for ways to treat risk, including risk-financing for catastrophes. The challenges inhibiting that successful application in the Pacific Islands are manifold, and include problems imposed from outside the region as well as those inherent from within. The focus of activities related to earthquake engineering should now be on the solutions to those challenges, including improvements in education, organisational approaches and research on the local risk, as well as providing for an immediate technical response capacity to disasters and a regional network facility. Overwhelmingly, a more efficient coordination of the services provided by the international community is called for, because a concerted effort is required if there is to be any chance of successfully overcoming the challenges to sustainable development in the Pacific.

1 PREAMBLE

As this paper was being written, Port Vila was still recovering from its worst shock at least since 1927, and perhaps in more than a century – the shallow, M_w 7.1 earthquake of 2nd January, 2002, located less than 50 km west of the capital. Damage was relatively light considering the size and proximity of the event. An accompanying tsunami struck 15 minutes later – near the bottom of a low spring tide – so the potential for almost 2 metres of flooding through the central business district was narrowly averted. UK DFID reacted quickly to fund a rapid technical response to the event, and followed through with further funding for programs to reduce community risk, while AusAID and NZAID, amongst others, provided infrastructural aid. However, funds were still being sought to repair major school buildings while students worked under canvas, and while a project to develop a risk-financing scheme for catastrophes (by coincidence using Port Vila as a pilot study) was faltering in the too-hard basket. What should have been a major wake-up call for Vanuatu and the aid donor community was treated seriously initially, but now is in danger of being forgotten in many quarters.

Several 3-storey classroom and dormitory blocks in a prestigious high-school college, together with other public buildings, were damaged beyond repair, highlighting the arguably inappropriate construction techniques applied to at least some public buildings over the past several decades. At the time, early January, the boarding students were still on summer vacation and thus escaped falling block-work. Structural columns in a major 3-storey supermarket failed, short of collapse; luckily shoppers were still in their beds at 4:22 am local time when the earthquake struck. Port Vila was cut off in all directions by road as several major bridge abutments and structures failed. The major shipping port was isolated for weeks by massive landslides on the difficult access road, and stretches of the waterfront fill slumped seaward, taking inappropriately-founded buildings with them. Visible cracks at the column-beam connections of buildings around the city were plastered over within the week. A 200-tonne limestone boulder crushed a resort bungalow that was fortunately unoccupied.

That same night, a M_w 6.4 earthquake shook the city again, throwing over shelves, cabinets and TV sets in the British High Commission and other places throughout the city. Foreign High Commissions and Embassies were desperate for answers on what would happen next but the local scientific and disaster management community were struggling with their own immediate problems. A rumour flew around that a massive tsunami was hovering offshore, hours after the real tsunami had already struck. As the aftershocks began to abate a fortnight later, a local paper gave far more column space than it had given earlier to scientific reports, to an expatriate water-diviner who had foreseen "…energy readings in time and space…" that foretold Vanuatu would be hit by another major earthquake on the 23rd January. This story threw the population again into a minor panic of anticipation. The fact that the date eventually passed without incident was not remarked upon further by the newspaper. Community perceptions had been reinforced!

Fate was kind in January, 2002: the epicentral distance was just far enough from Port Vila; the tide low enough; the day and the time were right; the duration of shaking just short enough; and the reinforcing steel barely thick enough, so that no life was lost. Port Vila is just one of a dozen such Pacific cities that teeter on the edge of destruction, relying on such vagaries of fate for their survival. The people living on a 25 km strip of beach stretching from Sissano to Malol village on the northern coast of PNG were not so lucky three years earlier on 17th July 1998 (Chung et al. 1998) when a magnitude 7 earthquake triggered a 10 m tsunami from 35 km offshore – almost as many people died on the PNG coast that evening as in the New York World Trade Center tragedy of 11th September, 2001.

There are certainly plenty of challenges in applying what we already know about earthquake engineering in the Pacific Islands.

2 INTRODUCTION

Thirty years ago – around the time of the infamous Peru earthquake that killed 50,000 people – many of the countries of the Pacific were just emerging from a form of colonialism towards the bright light of national independence: Fiji in 1970, PNG in 1975, the Solomon Islands in 1978, and Vanuatu in 1980. A lot has changed since that time – and a lot has stayed the same. Now, a quarter of a century on, it seems that the shining edifice is crumbling more than just a little at the edges and, with civil strife on the rise, earthquakes often take a back seat to riots.

When one now looks to a single, small aspect of the history of these countries – the application of earthquake engineering in the Pacific and the challenges facing that endeavour – there appears to have been plenty of activity; players moving in and out of the wings and strutting the Pacific stage; each searching their own truth and working and playing hard, but the props remain standing largely unmoved by these flurries: Bending only where necessary – enough to accommodate the winds of change – but returning with heavy inertia, slowly, to the old positions.

Earthquake engineering has been a major consideration for many years now in terms of protecting the vital infrastructure of the Pacific, but in the growth-spurt since independence, it has become an even more pressing concern. Increasing urbanisation throughout the Pacific Islands has taken us now to a situation where one in every four (and soon, one in every two) people in the Pacific lives in an urban centre. For illustration, according to the 1999 Vanuatu National Population and Housing Census, the population of Port Vila in 1999 (29,356 inhabitants) was almost six times larger than the 1967 population of 5,208. With the urbanisation has come increasing numbers of high-rise buildings, generally built in high-hazard harbour reclamations on sites that would normally require considerable effort to be put into foundation design and construction, increasingly complex public building and housing structures, many of which are constructed without the benefit of engineering design, certainly at least without official building standards, and often in the absence of effective urban planning. Infrastructure development has always proceeded at the very limit of available funding, leaving little room for engineering over-design. In the harsh marine-tropical climate, and in the absence of an effective maintenance program, many structures are already at the limit of their performance. There are, too, indications coming to light of cases where cumulative damage from a combination of low-level earthquake activity and inadequate design has weakened some major public structures, markedly reducing margins of safety.

With two of every three dollars in the Pacific being generated by the urban power-houses, entire national economies (and perhaps the very survival of some nations) are extremely dependent on what fate should befall the very small areas encompassing the capital cities, placing an even heavier burden on the shoulders of the earthquake engineer and urban planner. Risk-loss studies of Port Vila show that even the 100-year cyclone will cause a direct loss of almost 30% of the AUD$1 billion value buildings and infrastructure, while the 100-year earthquake will cause a loss of almost 15%. For earthquake risk alone, this translates to a 50:50 chance in a given three-score and ten lifetime that an amount of half of the current Gross Domestic Product (GDP: AUD$320 M) will be lost in a single event. There is a smaller, yet significant, 10% chance that an amount equal to the GDP will be lost during a single earthquake in any 50-year period. The costs of loss of income and the effects of investor and tourism insecurity are yet to be calculated. This projection should be viewed in the light of the reality of the aftermath of the AUD$10.5 M loss arising from the 2nd January, 2002 Port Vila earthquake – aid donors and Government seem hard-pressed to meet even these relatively small costs, so that the redevelopment of damaged schools is still incomplete at the time of writing some nine months after the event.

While all players concerned are obviously trying to do the very best for their own organisation (or country) and career, unfortunately the sum of these individual efforts does not always produce the best outcome for the people most at risk. A concerted effort always produces more than the sum of its individual parts. In a climate of relatively diminishing public funds, increasing urban poverty, questionable governance practices, degraded building stock, and fragile infrastructure where high levels of hazard are a way of life, the need for professionals to work closely together to manage the risk of earthquake – especially in this particularly multi-disciplinary field – is more apparent than ever before in the history of the Pacific Islands.

3 APPLICATIONS OF EARTHQUAKE ENGINEERING

The background to and applications of earthquake engineering in the Pacific are many and varied but there are a number of immediate areas from which the region benefits from advances in the field. Studies of seismicity and neotectonics (1) that have been carried out for several decades now in the Pacific are fundamental to any understanding of earthquake risk, particularly as applied in the high-risk capital cities. Research on foundation problems (2) in these cities has received a boost in the past decade, while at the same time the institution of building standards (3) has been receiving more cross-sectoral attention. In recent years, the specific risk to urban population centres has been defined more completely through seismic microzonation studies (4). A risk-management approach (5) that has been introduced to the region even more recently has moved the focus onwards from scientific and engineering outcomes to one of social outcomes and, in conjunction with this, the need to more closely define and quantify the elements at risk – including building and infrastructure asset assessment (6) – has become more apparent. Risk financing for catastrophes (7) is a necessary outgrowth of the past decades of earthquake studies; having recognised the risk, it is now incumbent on the communities involved to deal with it in an appropriate fashion.

3.1 *Seismicity and Neotectonics*

The global earthquake research carried out over the past several decades by the institutes and universities of the United States has defined the seismological framework for the Pacific and continues to underpin research today through the USGS NEIS earthquake catalogue. The work by Hamburger et al. (1990), including results from the Fiji seismographic network, helped to better define the seismicity of Fiji. However, the detailed local work carried out by various researchers has probably done the most to develop the basis for earthquake engineering in the Pacific.

Trevor Jones' seminal work on the probabilistic earthquake hazard assessment of Fiji examined all significant earthquake data, incorporating Ian Everingham's largely unpublished works with the Fiji Department of Mineral Resources. The reader is referred to Jones (1998) as an excellent source of information on the Fiji Islands and one that forms a basis for the development of earthquake loadings in the building code for that country. Jones defined the 450-year acceleration response spectral value for the capital city Suva as 0.68 *g* at a period of 0.2 s, and estimated peak horizontal ground accelerations to be about 40% of the spectral acceleration values. Houtz (1962a, b) contributed greatly to the knowledge of local earthquake effects with his paper on the 1953 Suva earthquake and tsunami that caused extensive damage in the city.

Research sponsored by France though ORSTOM (now IRD) in Port Vila has defined the seismicity of Vanuatu over the past two decades (e.g., Prevot & Chatelain 1984) with Louat & Baldassari (1989) providing a chronology of felt earthquakes and tsunamis for the region. Prevot & Chatelain estimated the greatest possible earthquake for Vanuatu archipelago to be of magnitude 7.6 (although this has subsequently been modified upward by IRD to around 8.1), and predicted the maximum likely Modified Mercalli intensity for the main island of Efate (including the capital Port Vila) to be MM 8 and up to MM 9 (at least) in the area of poor ground conditions in the Mele region to the north of the city.

A comparison of the effects (averaging MM 7-8) of the recent M_w 7.1 (M_s 7.3) Port Vila earthquake of 2nd January 2002 (Shorten 2002; Garaebiti et al. 2002), with published New Zealand experience from Dowrick & Rhoades (1999), also suggests that the maximum likely effect in the capital city of Port Vila would be at least MM 9). However, in this highly active tectonic setting, it is not out of the question that higher intensities could occur in Port Vila due to a larger or closer earthquake than is likely under broader-scale seismo-tectonic models. More recently a research program by IRD has tracked the deformation of Efate through precise satellite monitoring of fixed survey points. The recent withdrawal of IRD from Port Vila to Noumea has left a skills vacuum in the area of seismology for Vanuatu that won't be easily filled.

Work carried out on the basic geology and neo-tectonics of the area around Port Vila by Howorth (1983; 1985) added to the understanding of the Quaternary history of the capital city including the identification of a mega-landslide involving fully one third of Efate, and including the Port Vila area. While Howorth's figures indicate fairly steady uplift rates of around 0.8 mm/year for the area around Port Vila for the past 4,000 years, there appears to have been a major and rapid uplift along the western edge of the mega-landslide around 5,000 years ago, perhaps representing the timing of the collapse of the island to the east of this line. Seismic reflection profiling carried out by SOPAC in 1996 indicated a young fault crossing the harbour and CBD, probably reflecting continuing adjustments within the collapsed mass. Although micro-seismic recordings (Marc Regnier pers. comm.) indicate that this faulting is not currently active, significant micro-seismic activity is present near the northern limits of the city.

The main Tongan island of Tongatapu lies to the west of the active Tonga Trench. In 1977, the capital Nuku'alofa, located on Tongatapu, was rocked by a magnitude 7.2 earthquake (Campbell et al. 1977) which destroyed wooden bungalows and caused extensive damage to the causeway structures of the main wharves. An 1853 earthquake (Sawkins 1856; Nunn & Finau 1995) tilted the northeast of the island down to the extent that the sea encroached several kilometres inland, while the southwest coast was uplifted by almost a metre.

In the Solomon Islands, Guadalcanal island is experiencing general uplift, but more rapidly on its southern side adjacent to the active trench than on the northern coast were the capital Honiara is located. Honiara also suffered a damaging earthquake in 1977 with MM 7 effects recorded (Thompson & Tuni 1977), while an M_s 7.5 shock in 1984 (Tuni 1986) caused major damage to city buildings. In both cases buildings founded on young coastal sediments and reclaimed land suffered the most damage (Hackman 1979; Tuni 1981).

So what are the common denominators? Given that these cities exist in one of the most active regions of the Earth's crust, why isn't there a long string of earthquake disasters? While conceding that every case is different, some generic points can be made for the Pacific situation:

- The relatively low strength of the crust in the vicinity of subduction zones limits the maximum earthquake magnitude in those areas. The maximum-recorded Fiji earthquake (Jones 1998) was M_w 7.1 and, while Prevot & Chatelain estimated the greatest possible earthquake for the Vanuatu archipelago to be of magnitude 7.6, Vasily Titov (pers. comm.) estimates a maximum M_w 8.1. Honiara and Nuku'alofa are both in very similar situations.
- The majority of urban centres are on an over-riding plate and are somewhat isolated from the focus of earthquakes within the subduction zones by a highly attenuating wedge of mantle and imbricated crustal material. Attenuation-distance curves in the case of both Fiji and Vanuatu are comparable to the curve for strike-slip/normal events in the main seismic region of New Zealand developed by Dowrick & Rhoades (1999).
- Taken together, the two points above result in estimates of a theoretical limit to the maximum MM effect that should be felt in each of the capitals. Given their distance from the active trench together with the intervening high-attenuation wedge effectively limits the likely felt intensities in these cities to between MM 7-9. The 1953 Suva earthquake, however, serves as a salutary warning that not all damaging earthquakes occur within active subduction zones or fracture zones, but sometimes within island-arc platform areas as well.
- Apart from damage to demonstrably weak and unsuitable building structures much of the damage recorded to date from earthquakes in the Pacific capitals is related to failure of various artificial fills, be they reclaimed foreshores, wharf causeways, bridge abutments, road embankments or building foundations.
- Historical written records are short and poorly maintained – it is even difficult to find any records of the 1977 earthquake in Tonga; the oral tradition of Pacific societies does not wholly assist the recording of long return-period, major earthquake events. In addition, the elements at risk; the modern indicators of earthquake damage – buildings and infrastructure – have existed for only a short time (generally less than 100 years) in the Pacific Island Countries.

3.2 *Foundation Problems*

By their nature, Pacific capitals are port cities, so that vital facilities and CBD developments are clustered on harbour-side land. Pressure for unencumbered land has led to extensive reclamation to the limit in the case of nearly all cities. At best, emergent young and weak limestones provide reasonable foundation conditions at the shoreline. Overlying this bedrock to seaward, carbonate (and in some cases terrigenous) muds, sands and gravels provide highly variable foundation conditions. More questionable conditions again are to be found in the deep and steep-sided channels or sink-holes cut during the last glacial episode about 15,000 years ago when sea levels were in the order of 100 m lower than today's levels. The channels, as a result, are anything from 40-100 m deep and backfilled with sand and gravel fluvial deposits only in their lowermost parts. Generally, weak fine-grained, organic sediment was deposited in their middle and upper parts as sea level rose to its current height about 4,000 years ago. These deep areas remained as protected tidal inlets to be slowly infilled over the next several thousand years. Arguably, the worst conditions arise where uncontrolled artificial fills have been placed over these weak sediments. Suva provides the classic case where fine organic material deposited in inshore areas gives rise to foundation conditions comparable to the San Francisco Bay muds, and approaching those of Mexico City on a scale of foundation unpredictability. The high void ratios and low permeability of the organic silts give rise to excessive settlement in the long term as a result of high primary and secondary consolidation, and early failure under rapid loading or earthquake shock due the development of high pore pressures (Shorten 1989; 1990; 1993a, b; 1995; Shorten & Carter 1994).

The SOPAC Pacific Cities program began in 1996 in parallel with similar initiatives by Geoscience Australia, and the RADIUS program. As well as acquiring and gathering together physiographic and bathymetric data, cadastral information, assets data, and hazard zonations on a common spatial Geographic Information System (GIS) database, the program also collated bedrock data and all available borehole records in the cities of Apia (Biukoto et al. 2001a), Nuku'alofa (Biukoto et al. 2001b), Port Vila (Biukoto et al. 2001c), Suva (Biukoto et al. 2001d), and Honiara (Swamy et al.

2001), presenting them in a 3-D spatial database within the GIS. The borehole records were gathered from various sources including government departments and geotechnical consulting firms but in no case had there been any previous serious attempt to develop a central or comprehensive register of what might be considered critical information in the development of any city.

3.3 *Building Standards*

An Australian-aid program in the late 1980s funded Kris Ayyar to write a prospective National Building Code (NBC) for each of Cook Islands, Fiji Islands, Samoa, Solomon Islands, Vanuatu, and Niue. Up to now, Fiji is the only Southwest Pacific Island Nation where building standards have gone into legislation, and then only less than a year before the preparation of this paper.

A review by Josefani Bola in 1999, 10 years after the program was initiated, found Samoa was the only country to incorporate NBC training into existing programs. While the other countries fully supported the need, Fiji, Solomon Islands and Vanuatu were the only ones to have existing technical training institutions capable of conducting full NBC training programs. Although the review found that the NBCs and Home Building Manuals were not formally being used 10 years later, in fact engineering groups in-country have been using them as an ad-hoc standard (along with a mix of other Australian, New Zealand and British standards) since their introduction. Recently Kris Ayyar undertook the same exercise for Tonga and that country is now also moving towards legislating building standards in the near future.

A workshop, jointly sponsored by SOPAC and UNOCHA in Suva in November 2001, reviewed the progress on legislation and enforcement of building standards in Pacific countries, and assessed the state of planning for urban infrastructure development, and the feasibility of the creation of local Urban Search and Rescue (USAR) capacity. '*Building Safer Urban Communities in the South Pacific: Regional Workshop*' (Barr 2001) brought together government urban planners, staff of public works departments, national disaster managers and the chief fire officers of Fiji, Papua New Guinea, Samoa, Tonga, and Vanuatu. From the host country, Fiji, a wider constituency of interested persons was invited, including representatives from within national and municipal government, particularly those concerned with urban development and building safety standards; the architectural and engineering professions; emergency services; donor community; and relevant commercial and non-governmental organisations.

3.4 *Seismic Microzonation*

Early work on the microzonation of Suva was carried out under UNDHA funding (Hull et al. 1997; Singh et al. 1997; Singh et al. 1998). Concurrently with this work, a comprehensive seismic microzonation project under USAID funding was instituted in four Pacific capital cites (Suva, Port Vila, Honiara and Nuku'alofa) between 1996-1999 (Shapira & van Eck 1993; Shapira 1999; Shorten et al. 1999; Regnier et al. 2000; Shorten et al. 2001). The project was implemented through the Geophysical Institute of Israel (GII) and supported by ORSTOM/IRD in the case of Port Vila and Nuku'alofa, and reviewed through NZIGNS. The work did much to stimulate the risk mapping of the cities involved. As part of the microzonation research, frequency-magnitude relationships were determined for the four areas of concern (Hofstetter et al. 2000). A further, 3-D seismic microzonation of Suva was carried out by Monge et al. (2000) with funding from France, and a qualitative microzonation of Apia (Teakle & Swamy 2001) was undertaken at a later date.

In the case of the GII-SOPAC-IRD study of Port Vila and Nuku'alofa, the predicted spectral accelerations at the 1:450-year return level are so high (>1 *g*) that there is little practical likelihood of designing buildings to withstand the forces generated. It is also evident from the models that foundation ground failure would take place before the building structure, as the material is too weak to sustain an elastic response to the predicted forces. In retrospect, and in the light of the recent 2nd January earthquake experience, the predicted accelerations determined for Port Vila are apparently too high because of the inclusion of Efate itself within the zone of earthquake generation.

3.5 *Risk Management Approach*

Whereas in the past, researchers in the Pacific might have had the luxury of concentrating on the subject at hand – *viz*. the science of earthquake engineering – today there is a broader approach, as in much of the world, that widens the early narrow focus on scientific effort to now also include the impact on communities. The scientific and engineering advances will increasingly come from rich countries to be applied in the Pacific. There will always be a place, however, for defining the specific problems of the developing countries in which context the technologies will be applied. For people to believe that all the knowledge needed can be imported like so much tinned fish, so that the entire funding effort can then be applied immediately to the end-users is unrealistic – there is a growing danger that inappropriate technologies will be transferred to the Pacific communities to provide inadequate solutions to their problems.

Notwithstanding this, the adoption of the approach of the Australian and New Zealand Risk Management Standard (SAA 1999) is hopefully leading to a better cohesion in risk programs, and a structuring of the risk management effort that has up until recently been lacking. In particular, the ultimate focus of the approach is to treat the risks that afflict the people of the Pacific Island Countries. No longer is the Holy Grail for earthquake engineering the solving of engineering problems, but rather, how those solutions will be applied to treat the impact of that problem on the wider community. The SOPAC Community Risk Program has adopted the risk management standard with vigour, and the activities now being developed throughout the Pacific are demonstrated in a new SOPAC publication entitled '*Comprehensive Hazard and Risk Management (CHARM)*'.

3.6 *Building and Infrastructure Asset Assessment*

Along with the developing risk-management approach comes the need to evaluate the risk and, to do so, requires that the elements at risk be quantitatively assessed. As well as conducting sociological surveys to assess the demography and characteristics of the communities at risk, the building stock in the capitals of the SOPAC Pacific Cities program have been assessed. A survey in each of the capital cities has attempted to assess every individual building, defining a raft of characteristics pertinent to the response of the buildings to a range of hazards. The surveys used GPS location for each building and the database is stored in GIS format. In addition to the survey database that includes building floor area, structural damage classes and pertinent insurance values were also added. For example, using insurance industry valuations for over 6,000 buildings and contents, and city infrastructure, the total assets value of Port Vila city and its peri-urban settlements is assessed at almost AUD$1 billion. Within the Pacific region, and including district towns and rural villages, it is estimated that some 1.6 million people and over 300,000 buildings with a combined buildings, contents and infrastructure asset value of AUD$40 billion are at risk in Fiji, Solomon Islands, Samoa, Tonga and Vanuatu alone.

3.7 *Risk Financing for Catastrophes*

A pilot project undertaken in Port Vila has now put dollar figures on earthquake risk. It runs only second to cyclone risk in the region, but nevertheless is of sufficient magnitude to potentially wreck any of the fragile developing country economies.

A report to the 6th Forum Economic Ministers Meeting held in Port Vila in July, 2002 summarised the outcomes of research on the efficacy of a Catastrophe Insurance Scheme, including a report on the conclusions of the Port Vila pilot study on hazard and disaster events, and a review of the feasibility of risk financing for catastrophes as part of a broader risk-management strategy in that part of the Pacific region most at risk. For the purposes of the exercise, the 'region' was defined as Fiji, Solomon Islands, Samoa, Tonga and Vanuatu.

The greater Port Vila urban area stands to lose assets worth AUD$120 M in the 100-year earthquake with around AUD$300 M loss expected from the 500-year (maximum probable) earthquake. As well, a special survey of infrastructure for Port Vila (Stewart 2002) indicated that full and permanent reinstatement of damaged works and infrastructure following the maximum earthquake would cost at least AUD$32 M. Up to an additional AUD$50 M loss is expected in the event of a significant tsunami event. The maximum tsunami expected could lead to a flooding of 6.5 m above ground level, with the whole of Port Vila CBD and petroleum storage facilities, and much of Mele and Blacksands settlements inundated, resulting in potentially heavy casualties. Extrapolation of the research for Port Vila indicates a combined 100-year loss for the regional grouping of Pacific countries at AUD$350 M, with an expected maximum probable earthquake loss figure of around AUD$800 M.

4 CHALLENGES

The challenges impeding the application of earthquake engineering are broad and formidable, ranging from an increasing and worrying disconnect between the Pacific Island governments and their own peoples, so blocking the effective application of technology to the grass roots, to an inability of the many professionals and professional groupings inside and outside the countries to agree on a concerted approach to applying technology for the good of the populace. Little wonder that the aid donors also act often in confusion, not knowing whether to apply their efforts though Pacific governments often unable to meet the expectations of aid programs, or through external organisations competing intensely for the aid dollar. It is easy to construct a list of problems or challenges that inhibit the application of earthquake engineering in the Pacific. Such a list (not exhaustive) is proffered below in Table 1.

What appears as a problem to one group, of course, always has a cultural bias or flavouring, and may not be seen as such to another. The list is divided into intrinsic challenges that essentially exist in the Pacific countries themselves, and extrinsic problems that have their origin outside the region. It's important to realise that some of the challenges are of the making of those who focus on the many intrinsic problems. In particular, the fragmented approach from the outside world introduces a major inefficiency into the system.

Table 1: Challenges to the application of earthquake engineering in the Pacific

INTRINSIC CHALLENGES	Solutions
Cultural	
More pressing problems than earthquakes eg. health services	Promote all-risks approach linked to broader issues
Land ownership issues restrict relocation, effective risk treatment	Improve public/community awareness
Traditional responsibilities overwhelm scientific responsibilities	Improve public/community awareness
Apparently poor communication	Improve public/community awareness
Organisational	
No rapid response capability	Organise rapid response teams
Too many tasks to perform and calls on time	Improve priority-setting and raise profile
Projects collapse when champion departs	Move from supply to demand-management
Promotion of specialists out of field of expertise	Support training programs
Fragmented response by local organisations	Instil CHARM approach
Governance	
Government instability and poor governance practices	Promote good governance
Disconnect between governments and people	Promote greater accountability and transparency
Educational	
Ignorance of earthquake hazard and anti-scientific mind-set	Improve education and awareness
Lack of building codes	Improve education and awareness
Unprepared for disaster response	Improve education and awareness
Technical	
Basic information scattered and scarce	Adopt Pacific Cities/CHARM approach
Not enough known about building foundations and structures	Adopt Pacific Cities/CHARM approach
Not enough known about earthquake hazard	Encourage University researchers
Not enough known about the effects of earthquakes	Risk-loss assessment, Risk-financing studies
Structural	
Ageing buildings and infrastructure	Assess and warn population
Shortage of skilled builders	Improve education and awareness
Poor quality building materials	Address issues of affordability and access

EXTRINSIC CHALLENGES	Solutions
International	
Perennial under-resourcing of the Pacific region	Promote strategic and sustainable development
Fragmentation of professional approach through competition	Improve coordination
International scientists not sharing knowledge with countries	Ensure client ownership
Aid donors uncoordinated in response	Promote donor harmonisation
Regional organisations uncoordinated	Improve coordination and strengthen CROP
Exploitation	
Brain-drain of trained and experienced local workers	Promote donor harmonisation
Greed by ex ternal organisations	Develop suitable filters
Misuse of aid funds	Improve accountability and transparency
Foreign aid tied to donor benefits	Move from supply to demand-management

Without trudging through the challenges one by one, it is also critical to come to terms with the fact that many of the problems are not readily reconcilable in this context – that is, a group of people whose main aim is to improve the application of earthquake engineering. There are, however, many challenges for which a solution is at least within grasp, and within these solutions there are many commonalities. It's probably most constructive to focus on these common solutions, and so summarise them into a brief series of actions that can be taken to clear the way forward to the effective application of earthquake engineering in Pacific Island Countries.

The type of concerted actions the New Zealand and Australian earthquake engineering societies might undertake, or contribute to, could include:

1. Improving the **coordination** of earthquake engineering services by the international scientific community and the international aid donor community
2. Developing opportunities for **education** and awareness-raising in Pacific Island Countries, particularly on issues pertinent to earthquake risk management
3. Supporting and expanding initiatives such as Pacific Cities and CHARM to help in structuring international and local **organisational approaches** to earthquake engineering
4. Instituting an externally-funded and regionally coordinated **rapid reaction** team structure to provide immediate technical response to earthquake disasters and assessments of building stock in conjunction with local authorities and organisations
5. Encouraging **research** on local earthquake risk, including the hazard, social impacts and response in Pacific Island Countries
6. Supporting solutions to higher profile concerns particularly those related to governance and **poverty alleviation**, towards the ultimate goal of sustainable development
7. Developing a **regional nodal centre** or network of seis mographs that could equally service the Pacific Islands while contributing to better resolution on the fringes of the Australian and New Zealand networks

The World Summit on Sustainable Development in Johannesburg drew to a close in September 2002 with calls from the leaders for concrete action on ways to promote sustainable development for the world's poor. Without that positive and concrete action, the Pacific region will be sentenced to lingering degradation and donor funds will forever remain locked into rehabilitation and restoration following earthquakes and other disasters, rather than building a safer, more enlightened Pacific. A solution is only possible through a completely integrated, demand-driven approach: The New Zealand and Australian earthquake engineering societies may indeed see themselves as playing an important role. Now is the time to be pro-active; to lead by example and set the requisite standards, and here is the place and opportunity to influence the foreign policy of two major donor countries in the Pacific.

One more impediment to applying more effort is the perception that people in the Pacific (and elsewhere in the developing world) are used to picking themselves up after disasters. It is true that the people themselves may have almost become inured to the traumas. We need to work at raising expectations on acceptable levels of security, particularly in relation to earthquake risk in the Pacific.

If the challenges 'over there' in the Pacific seem to be too overwhelming, then it's incumbent on the developed countries to first look after their home-grown problems and, after that, to show the wisdom to know what they are able to change in the developing countries, and the will to go about changing it.

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