Wind Engineering Issues for the South Pacific Island Countries

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ABSTRACT

This paper discusses the vulnerability of the South Pacific island nations to the tropical cyclone hazard, and highlights wind engineering issues and challenges that need be addressed towards a safer built environment and reduced risk during the passage of the deadly storms. The paper concludes by emphasising the importance of tropical cyclone specific wind engineering research, and the development and enforcement of building design and construction standards by stakeholders.

Introduction

The South Pacific island nations are especially vulnerable to hazards of five main types. These are wind hazards due to regular passage of tropical cyclones, earthquake hazards due to seismic activity in the region, tsunamis due again to offshore seismic activity, and hazards due to droughts and floods. Historical records show that the most important of these are undoubtedly hazards from tropical cyclones, which visit the South West Pacific on a regular basis. Consequently, the island nations suffer significant losses on a regular basis through damage and destruction caused to buildings and structures, the infrastructure, crops and land, and loss of life. A primary cause of losses to the built environment has been the structural failure due to the extreme winds generated in such storms. The wind engineering community thus has a significant role to play in order to mitigate such damage from tropical cyclone winds and thus improve the life of the islanders. The purpose of this paper is to examine the windstorm vulnerability of the nations of the South Pacific, and to highlight wind engineering issues and challenges that face these communities towards a safer built environment and reduced risk during the passage of the deadly tropical cyclones.

Occurrence of Tropical Cyclones in the South-West Pacific

Figure 1 shows the frequency of tropical cyclone occurrences in the South-West Pacific region, based on data from 1958 to 1988 [1]. It is abundantly clear that the South Pacific island nations, all of which are developing, are perhaps more, if not as, vulnerable to tropical cyclones than the affected coastal regions of Australia. In the 30 years between 1958 and 1988, as many as 119 tropical cyclones visited the regions of Vanuatu and New Caledonia, while approximately 40 such storms affected the islands of Fiji, Samoa and Tonga. In comparison, the upper coastal regions of Australia were affected by between 20 and 40 such storms, and perhaps as many as 60 in its North-West coast. The vulnerability of the region to the windstorm risk is further evidenced from a plot of the average annual number of tropical cyclones between 1970 and 2005 in Figure 2. This again shows highest occurrences of tropical cyclones in the Vanuatu and New Caledonia regions, with somewhat reduced but nevertheless high occurrence rates for the Fiji, Tonga and Samoa areas.

A recent NIWA media release of 6 October 2005 [2] projects that for most tropical South Pacific countries, the chances of tropical cyclone activity are near normal for the current season, which runs between November 2005 and May 2006. About half of the tropical cyclones that develop in the South-West Pacific are known to reach hurricane force (having) mean wind speeds of at least 64 knots (118 km/h). Table 1 taken from reference [2] shows the average number of tropical cyclones passing within 5° (550 km circle) of the main island groups of the Southwest Pacific over the full November through May period. This is based on 35 years of data, and for tropical cyclones having mean wind speeds over 34 knots. This shows that the islands of Vanuatu and New Caledonia are at highest risk in the

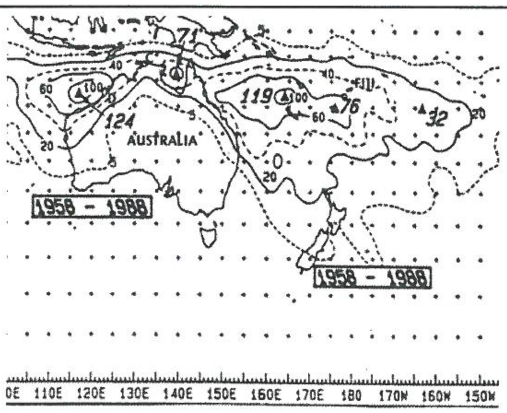

Figure 1: Tropical cyclone occurrences in the South- Pacific region between 1958 and 1988 [1].

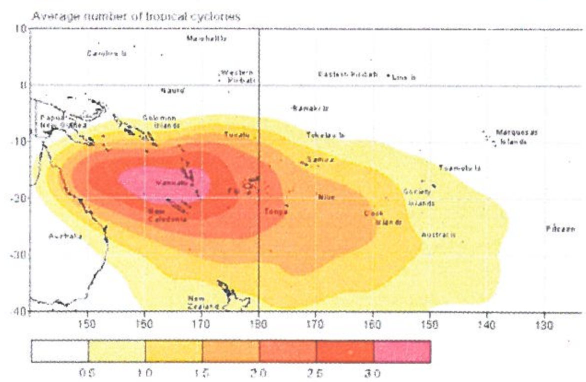

Figure 2: Average annual number of tropical cyclones in the South-West Pacific between 1970 and 2005 [2].

Table 1: Average annual number of tropical cyclones passing within 5° (550 km circle) of the main island groups of SW Pacific over the Nov - May period [2]

Area	Average over all years	Comment
Fiji	2.3	Average risk
Tonga	2.1	Average risk
Niue	1.9	Average risk
Vanuatu	3.0	Average risk
New Caledonia	2.8	Average risk
Wallis and Futuna	1.7	Average risk
Southern Cook Islands	1.4	Average risk
Samoa	1.4	Average risk
Tuvalu	1.1	Average risk
Northern New Zealand	1.0	Average risk
Southern PNG	0.6	Average risk
Tokelau	0.7	Average risk
Society Islands/Tahiti	0.8	Average risk
Austral Islands	0.8	Average risk
Solomon Islands	1.4	Possible

Table 2: Estimated costs of weather events in the Pacific Island Region during the 1990s (millions of US$) [5]

Event	Year	Country	Est'd losses
Cyclone Ofa	1990	Samoa	140
Cyclone Val	1991	Samoa	300
Typhoon Omar	1992	Guam	300
Cyclone Nina	1993	Solomon Islands	-
Cyclone Prema	1993	Vanuatu	-
Cyclone Kina	1993	Fiji	140
Cyclone Martin	1997	Cook Island	7.5
Cyclone Hina	1997	Tonga	14.5
Drought	1997	Regional	>175[a]
Cyclone Cora	1998	Tonga	56
Cyclone Alan	1998	French Polynesia	-
Cyclone Dani	1999	Fiji	3.5

- Not available.
[a] includes US$160million in Fiji alone
Note: Costs are not adjusted for inflation.

region, with approximately 3 tropical cyclones expected in any given season. Fiji, Tonga and Niue also have high risk at over 2 tropical cyclones per season. The level of risk is even more severe in view of recent evidence for global warming and its effects, including increased sea surface temperatures resulting in tropical cyclones being spawned with greater intensity [3]. Not surprisingly then, two category 5 tropical cyclones of Zoe and Heta recently smashed through the Solomons and Niue respectively, causing widespread damage and flattening many buildings. Having established that the occurrence rate of tropical cyclones is high for the South-West Pacific and their intensity might be on the increase, we examine the nature and extent of losses sustained by the island communities next.

Damage due to Tropical Cyclones

The damage accompanying tropical cyclones range from flooding of coastal areas and contamination of water supplies through devastation of agricultural land and crops to destruction of buildings, engineering structures and the infrastructure. In addition many lives may be lost. The major cause of damage and destruction are the strong winds, storm surge and heavy rainfall. As in other hurricane prone regions of the world, tropical cyclones in the South Pacific regularly inflict serious and often lasting damage. For example, the 1992-1993 visit of tropical cyclone Kina in the Fiji Islands saw some US$140 million of losses to the economy [4, 5], while cyclones Ofa and Val, which hit Samoa in 1990-1991, caused losses of US$440 million, well in excess of the countrys annual gross domestic product (GDP) [5]. In the 1990s alone, the cost of extreme events in the Pacific Island region exceeded US$1 billion (Table 2), much of it as a direct result of tropical cyclones. More recently, a number of intense tropical cyclones including Zoe, Ami and Heta have incurred large losses. In the 2002-2003 season, category 5 cyclone Zoe caused havoc in the Solomon Islands with estimated gust wind speeds of 350km/h [6, 7]. This was followed by category 3 cyclone Ami [8] causing widespread wind and flood damage in the Fiji group, and later in Tonga. In early 2004, another category 5 cyclone Heta devastated the island of Niue with gust winds of up to 300km/h [9]. The importance of the tropical cyclone hazard in the South-West Pacific can thus never be over-emphasised.

The very high winds of the tropical cyclone are its most striking feature, and together with the quality of construction, is the primary cause of property damage by the wind alone [10]. Two surveys in the aftermath of hurricanes

Figure 3: Damage caused by category 3 tropical cyclone Ami in Fiji, in 2003.

Figure 4: Buildings flattened during the passage of category 5 tropical cyclone Heta in Niue, in 2004.

in the USA and the Caribbean [11, 12] indicated that damage to buildings, particularly of the low-rise type, can be extensive. The main form of damage is consistently found to be partial or complete loss of roof sheathing and or the entire roof structure. In many cases roof damage/loss was also widespread with a large proportion of such buildings having at least one window broken. It is believed that roof damage was preceded by window failure so that the effect of building internal pressure may have been additionally responsible. A significant proportion of the buildings damaged were built to the then wind loading standards, believed to be enforced through insurance [11, 12]. In the South Pacific, damage reports also suggest that buildings sustain widespread destruction. Figures 3 and 4 taken after the visit of Ami and Heta in Fiji and Niue respectively provide some evidence of this. Ami caused direct damage to buildings amounting to 25% of total losses in Fiji [13], while Heta damaged 75% of the houses and completely destroyed most government buildings and the only hospital on Niue [14]. The authors own first-hand experiences also suggest that while a large proportion of damage is due to the lack of engineering and quality of construction, many engineered buildings can also perform poorly. Most damage suffered is to the envelope and roof in particular. It is also apparent that in addition to the external loads, building internal pressures induced through broken windows can contribute to further failure of the envelope.

Wind Resistant Design in the South Pacific

Building codes establish minimum standards of design, construction and materials in order to avoid structural collapse. The author is aware of only one island nation in the South Pacific, namely Fiji, where there exists a National Building Code – 1990 and a Home Building Manual – 1990 with provisions for wind resistant design [15, 16]. This is not to imply that buildings in other island nations are not designed for wind resistance. In the assessment of wind loads, the Fiji code refers directly to the AS1170.2 for the most part, with its own provisions with regards design gust wind speeds and terrain categorisation. Whilst the code was developed over 15 years ago in direct response to the disastrous cyclones of the 1980's, to this day however, it has not been adopted formally. In spite of this, appropriate sections of the engineering community nevertheless have been using the code. In the capital city Suva, the council has a well established structural engineering division employing professional engineers who amongst other things, criticise all building plans relative to the code. Enforcement of the code goes further than the capital however, through the insurance industry, who require an Engineers Certificate for insurance. This certificate is an assessment of the building design and construction by a registered engineer against the code. Through these mechanisms, many urban and suburban buildings in Fiji comply with the building code and are thus designed for wind resistance. However there still remain many buildings within suburbia and beyond that are not engineered for cyclone resistance. Beyond suburbia, strict building regulations are unrealistic and almost always unenforceable for the majority of homes that typically receive no engineering input and are made from locally available, inexpensive materials, and at low budget. In spite of the design for wind resistance, insurance losses relating to building damage in Fiji continue to remain at significant levels [4, 13]. Furthermore, each time a tropical cyclone strikes, the government is burdened with providing assistance for the re-building of a large number of dwellings and schools. The latter usually includes buildings that would normally not have been engineered for wind resistance, and thus do not carry insurance cover. The evidence therefore suggests that both engineered as well as non-engineered buildings in the South Pacific continue to suffer damage, a situation similar to that in other developed parts of the world [11, 12].

While building codes might be absent in other island nations, there is however no reason to believe that wind resistant design and construction is not being practised there. The UK Building Research Establishment (BRE) conducted a study of cyclone-resistant housing around the world including in the Pacific, and published a manual called Cyclone-Resistant Houses for Developing Countries [17]. Similarly, the Australian Overseas Disaster Response Organisation published a document entitled Disaster-Resistant Construction for Traditional Bush Houses [18], which is aimed at bush houses that are prevalent in the islands. Whilst the success of these efforts is difficult to determine, as mechanisms have not existed in the islands to ensure dwellings adhere to such guidelines, these might all the same be useful towards development of workable and flexible alternatives to rigid building codes. Establishment of these policies and standards should be based on the degree to which a certain level of performance is desired. For example, it is probably neither cost-effective nor technically feasible to build every house so that it is completely disaster-proof; yet it is possible to ensure that all houses have an increased level of safety. A primary objective of the standards, therefore, would be to encourage the development of more disaster-resistant houses (i.e. with a substantially increased level of safety) rather than to require that all houses be built to a very high engineering standard.

Wind Engineering Issues

It is clear that widespread wind damage to both engineered and non-engineered buildings can occur under the extreme wind conditions of tropical cyclones in the South Pacific. To mitigate such damage in the future with an ever increasing risk of intense tropical cyclones, not only wind resistant design and construction of buildings but also tropical cyclone specific wind engineering research must take high priority. Wind engineers and scientists can play a significant role in this and in particular towards research in order to fill gaps in knowledge. To be able to address these, one must consider all the links in the wind loading chain, and then identify the weak links for buildings in a tropical cyclone affected region.

Without doubt, the weakest link would be the characteristics of the tropical cyclone wind. Some authors [19, 20] have reasoned that the tropical cyclone wind is more turbulent than the neutrally stratified atmosphere assumed in wind engineering design and laboratory research. Others [21, 22] have suggested some of this increase is due to topographical features, and also that current near surface meteorological wind instrumentation and measurement methods may not be suitable for wind engineers. Furthermore, convective activity in tropical cyclones is believed to transport gusts vertically leading to a flat gust velocity profile. It is common for wind instrumentation to fail or be blown over during cyclones. Clearly then, there is an urgent need for developing robust instrumentation systems that will survive the extreme conditions of the tropical cyclone and not fail. Such instrumentation will need to be deployed in the region, perhaps at one or more centres in each island group. There is also the need for improving extreme value analysis methods to determine realistic design gust wind speeds [23], especially for the South Pacific countries where the dataset is relatively short. Perhaps, new methods employing not only past wind records, but also past hurricane intensities, frequencies and paths may need to be incorporated.

While the full-scale sites, particularly those at Silsoe UK and at the Texas Tech University USA, have served to increase our knowledge of wind effects on low-rise buildings, neither of these facilities are located in a tropical cyclone or hurricane affected area. There is thus a strong case for a fully instrumented full-scale facility within a tropical cyclone region, such as in the South Pacific. With the wide ranging resources, relatively advanced infrastructure, and the presence of the University of the South Pacific as well as the Fiji Meteorological Service – which is one of five Tropical Cyclone Regional Specialised Meteorological Centres (RSMCs) in the world, the Fiji Islands would naturally be the choice for efforts in this regard as well as for the siting of new wind instrumentation. Efforts are already underway with Fijian and regional authorities for projects in the broader wind engineering areas under the framework of disaster mitigation, which is a matter of priority for the UN. Furthermore, some effort could perhaps also be directed at model-scale wind tunnel simulation or even computational fluid dynamics modelling of the tropical cyclone boundary layer, at least as we understand it today, and its effects on the built environment.

Conclusions

The South Pacific island nations are vulnerable to the tropical cyclone hazard, especially in view of evidence for cyclones of increasing intensity linked to global warming effects. There is evidence that together with non-engineered buildings, those that are engineered are also being damaged during the regular passage of tropical cyclones. Gaps in tropical cyclone related wind engineering knowledge have been highlighted. In view of these, a case is made for tropical cyclone specific wind engineering research, and areas needing immediate attention have been highlighted. In particular, it is argued that robust wind instrumentation needs to be developed and deployed in the South Pacific region, to gain a better understanding of the characteristics of tropical cyclones winds. It is emphasised that there is also a need to develop new extreme value analysis methods to deal with tropical cyclone areas and scarcity of data, towards the derivation of design gust wind speeds for the region, and elsewhere. The idea of a full-scale instrumented facility for wind effects studies within the region is proposed.

References

[1] Neumann, C.J., 1993, *Global Guide To TC Forecasting: Global Overview*, WMO Tech. Doc. No. 560

[2] NZ National institute of Water and Atmospheric Research (NIWA), 2005, *Average Risk of Tropical Cyclones in SW Pacific*, Media release, Retrieved 16/01/2005, http://www.scoop.co.nz/stories/SC0510/S00012.htm (6 October 2005)

[3] Emanuel, K., 2005, *Increasing destructiveness of tropical cyclones over the past 30 years*, Nature, Volume 436/4, pp 686-688

[4] Ministry of Fijian Affairs and Rural Development, 1993, *A Preliminary Report on Cyclone Kina and Severe Flooding in Fiji 1993*, 51pp

[5] Worldbank report, 2000, Retrieved 16/01/2005, http://siteresources.worldbank.org/INTPACIFICISLANDS/Resources/4-Chapter+1.pdf

[6] CBC report, 2003, Retrieved 16/01/2005, http://www.cbc.ca/stories/2003/01/02/zoe_damage030102

[7] AUSAID, 2003, Retrieved 16/01/2005, http://www.ausaid.gov.au/publications/focus/focuspdfs/autumn03/focus_autumn_03_20.pdf

[8] Terry, J. P., McGree, S. and Raju, R., 2004, *The Exceptional Flooding on Vanua Levu Island, Fiji, during Tropical Cyclone Ami in January 2003*, Journal of Natural Disaster Science, Volume 26, Number 1, 2004, pp27-36

[9] Floor, A., 2004, *Cyclone Heta wreaks havoc on Niue Island*, Retrieved 18/01/2005, http://www.seafriends.org.nz/indepth/nd010.htm

[10] Anthes, R. A., 1982, *Tropical Cyclone : Their Evolution, Structure And Effects*, Meteorological Monographs, Vol 19, No. 41, 208pp

[11] Sparks, P. R., Schiff, S. D. and Reinhold, T. A., 1994, *Wind Damage to Envelopes of Houses and Consequent Insurance Losses*, Jour. of Wind Eng'g and Ind. Aero., Vol 53, pp 145-155

[12] Davenport, A. G., 1995, *The Role of Wind Engineering in the Reduction of Natural Disasters*, Keynote Paper - The 9th Int. Conf. on Wind Eng'g., 9-13 January 1995, New Delhi, India

[13] McKenzie, E., Prasad, B. and Kaloumaira, A., 2005, *Economic Impact Of Natural Disasters On Development In The Pacific Volume 1: Research Report*, USP Solutions-SOPAC-AusAID, 48pp

[14] Red Cross, 2004, *Pacific: Cyclone Heta*, Info. Bulletin N° 2/2004, Retrieved 18/01/2005, http://www.ifrc.org/docs/appeals/rpts04/cy0204.pdf

[15] Fiji Building Standards Committee, 1990, *National Building Code for Fiji – 1990*

[16] Fiji Building Standards Committee, 1990, *Home Building Manual for Fiji – 1990*

[17] Mayo, A., 1988, *Cyclone-Resistant Houses for Developing Countries*, UK Department of Environment Report commissioned by Building Research Establishment, Overseas Division, Garston, Watford WD2 7JR, 33pp

[18] Australian Overseas Disaster Response Organisation, 1980's, *Disaster-Resistant Construction for Traditional Bush Houses* (full details unavailable)

[19] Sharma, R.N. and Richards, P.J., 1999, A Re-Examination of the Characteristics of Tropical Cyclone Winds, Jour. of Wind Eng'g and Ind. Aero., 83, pp 21-33

[20] Tamura, Y., Shimada, K. and Hibi, K., 1993, *Wind Response Of A Tower (Typhoon Observation At The Nagasaki Huis Ten Bosch Domtoren)*, Jour. of Wind Eng'g. & Ind. Aero., Vol 50, pp 309-318

[21] Powell, M.D. and Houston, S.H., 1998, *Surface Wind Fields of 1995 Hurricanes Erin, Opal, Marilyn, and Roxanne at Landfall*, Monthly Weather Review, Vol 126, No 5, pp 1259-1273

[22] Kepert, J.D., 2002, Paper 4: *Coastal and Inland Structure Changes*, Topic 2: TROPICAL CYCLONE LANDFALL PROCESS, WMO Fifth International Workshop on Tropical Cyclones, Cairns Australia, 2-12 December 2002

[23] Rattan, S.S.P. and Sharma, R.N., 2005, *Extreme value analysis of Fiji's wind records*, South Pacific Journal of Natural Sciences, Vol 24