JR - DM/425

AUSTRALIAN ACHIEVEMENTS IN THE MITIGATION OF WIND DAMAGE TO HOUSING FROM TROPICAL CYCLONES

George R. Walker ME,PhD,FIEAust,FAIB
Assistant Chief of Division, North Ryde
CSIRO Division of Building, Construction & Engineering

Paper for presentation at International Decade for Natural Disaster Reduction Seminar, Canberra, 17 October 1991.

SYNOPSIS

Current knowledge of maximum likely wind loads on houses during tropical cyclones, while not complete, is sufficient to provide a basis for reliable design of houses to resist their effects. The essential details of this knowledge have been known for many years, and have been widely published in wind loading codes for at least fifteen years. Despite this, in most parts of the world housing continues to suffer disproportionately large losses relative to larger buildings in severe tropical cyclones.

This paper looks at some of the reasons for this anomaly, and at the progress that has been made in correcting it in Australia during the last fifteen years. The current measures adopted in Australia to mitigate damage to housing from extreme winds, and the research and development which underlies these measures, has resulted in Australia becoming a world leader in this aspect of building construction.

1 INTRODUCTION

High levels of wind damage to housing have been a recurring feature of reports of damage from tropical cyclones for as long as records are available. An analysis of these records through to the present day would show that there does not appear to have been any significant reduction in the level of this damage with time. Indeed there is considerable evidence that the level of damage in economic terms has significantly increased in most tropical cyclone prone areas. This is in sharp contrast to a very real decrease in deaths from tropical cyclones in most areas, and the very large increase in knowledge of wind effects on buildings which has occurred during this century.

In Australia the problem was brought to the fore by the destruction of Darwin by Cyclone Tracy in 1974. The magnitude of the resulting disaster in Darwin was almost entirely due to the poor performance of the housing under the extreme winds which occurred in Cyclone Tracy (Ref.1). Almost sixty percent of the houses in Darwin were destroyed and only about five percent of the houses remained sufficiently undamaged to be continuously inhabitable. Although loss of life was surprisingly small - about 50 in a population of 45,000 - the economic loss was large, and the scale of the damage to housing necessitated the evacuation of the majority the population. Because of Darwin's isolation from the rest of Australia, the evacuation was a major exercise and a traumatic experience for those involved on top of the loss they had already suffered.

By contrast, of the larger industrial, commercial and government buildings, less than five percent were destroyed and over seventy five percent suffered only minor damage or no damage at all. If the housing had performed as well as the larger buildings the magnitude of the disaster would have been at least an order of magnitude less, no evacuation of the population would have been necessary, and for most people life would have continued on without major disruption.

The reason that the larger buildings performed so well was that they had been specifically structurally engineered to resist the anticipated wind forces of severe tropical cyclones. The housing on the other hand had not. Had the housing been structurally designed to the same criteria and with the same rigour as the larger buildings its performance would have been just as good.

The poor performance of the housing in Darwin was not a unique event. Most of the tropical cyclone disasters around the world in which wind damage is a significant factor show a similar pattern. In both well developed and lesser developed countries society has tended to regard housing construction as a traditional art for which sufficient experience exists to build structures which are safe enough without resort to modern technology. Unfortunately, as Cyclone Tracy showed only too well, experience can be a poor guide, especially where severe events are relatively rare, as is usually the case with tropical cyclones, and when building practices are changing relatively rapidly, which has been a world wide characteristic of housing construction over the past thirty to forty years in both well developed and lesser developed countries.

2 REASONS FOR POOR CONSTRUCTION

Why is it that the standard of design and construction of small buildings such as houses has lagged so far behind that of larger buildings?

The most common answer given to this question is that the cost of small buildings does not warrant significant expenditure on ensuring structural adequacy against rare extreme events, whereas the cost of large buildings does.

This argument certainly has validity where the risks to buildings are small and independent from one building to another. Under these conditions damage to small buildings can be expected to occur relatively frequently in the community, but because it is spread in time and place, occurring regularly, and in small amounts at a time, it can be coped with by insurance and other forms of community assistance.

A good example of this type of risk is that from fires originating in buildings, assuming the presence of building requirements to prevent the spread of fire from one building to another. Failure under ordinary selfweight and occupancy loads arising from errors in design or construction due to inadequate quality control of these activities can also be considered in this class. Under these conditions of independence of risk from one building to another it is the magnitude of the individual risk which determines the appropriate level of design and construction, since the greater the magnitude of the loss in an individual event and the more infrequent it is, the less able is society to cope with it, and hence the greater is its social and economic consequences. In such circumstances larger buildings do warrant much more concern than small buildings in their design and construction.

However if a large number of small buildings are all at risk from the one rare event then it is not their individual value which is important but their combined value. A community can cope much better with one house a month being burnt down over a period of fifty years than it can cope with 600 houses being burnt down at the same time once in fifty years (which is the bushfire problem), just as it can cope with road accidents occurring every day of the year but could not cope if they all occurred on just one day in the year.

In most communities the aggregate value of small buildings exceeds that of larger buildings, and hence the performance of the smaller buildings is just as important as that of the larger buildings in determining the overall magnitude of the disaster arising from a single event. When social factors are taken into account it can even be argued that under such conditions the performance of the housing is more important than that of most larger buildings in view of its role in providing one of the basic human needs, that of shelter. This is particularly so in regard to tropical cyclones when, because of the warning period, people are more likely to be in their homes than elsewhere, unless well organised evacuation procedures are implemented.

So when communities are subjected to large scale natural hazards such as tropical cyclones, earthquakes and bushfires, the assumption of structural independence of buildings is no longer valid.

It is the failure historically to recognise this greater importance of housing under these conditions which is the real cause of the poor performance of housing in tropical cyclones. It has occurred in the well developed countries because their building regulations, and more importantly the basic design philosophies of the structural engineering and architechural professions which underlie them, have been largely developed in temperate locations where extreme events affecting the whole community at one time have not been a consideration. It has occurred in lesser developed countries because their building policies have been largely influenced by architects and structural engineers from well developed countries in whom the philosophy of the lesser importance of small buildings has been an ingrained axiom.

The consequences of this attitude towards small buildings, which is endemic in the architectural and structural engineering professions world wide, are to be seen in many well meaning publications and reports on the construction of small buildings in tropical cyclone areas which are strong on generalised empirical advice but extremely weak on actual details of construction and the level of wind resistance which they provide. The technical content of this advice is often very low and under no circumstances would the authors, generally professional architects or structural engineers, suggest a similar approach to larger buildings. Such buildings they would aver should be designed by professionals because of their greater importance!

A change in this attitude underlies the developments in wind resistant housing construction that have occurred in Australia.

3 THE SOLUTION

The reason that the larger buildings performed better than the small buildings in Cyclone Tracy was that the larger buildings had been fully structurally engineered to resist extreme wind loads. Australian structural design codes have long recognised the greater risk of extreme winds in the tropical cyclone prone region of Australia - a coastal strip several thousand miles long stretching roughly from Brisbane on the east coast to Perth on the west coast - but building regulations historically had only called up these codes for larger construction, with housing being covered by presciptive details based on traditional practice. The major conclusion reached in the aftermath of Cyclone Tracy was that if houses are to perform well in tropical cyclones then they must also be fully structurally engineered to resist the anticipated extreme wind loads (Ref.1).

The implementation of the principle that all buildings in tropical cyclone prone areas should be structurally engineered to resist wind loads was not a simple matter. Although there were significant technical problems to overcome (Ref.2), the two primary obstacles were the high cost of the associated design process relative to the cost of individual houses, and the conservative nature of the building industry. These are basic obstacles world wide. In Australia they were overcome by the incorporation of two basic principles into the approach to the problem - standardisation to spread the design costs over many houses, and evolutionary change rather than revolutionary change as far as forms of construction were concerned (Ref.3).

Although many empirical guidelines put great emphasis on the relative adequacy of different forms of construction, much of this is misleading. Nearly all forms of construction can be made wind resistant by suitable modification. Most of the damage in Cyclone Tracy was due to inadequate connections. Many of the new houses built to the new provisions are identical in form to those which failed miserably. The differences are in how they are put together - the size, type and number of nails, the use of tested straps and nail plate connections instead of skew nails, the size and spacing of bolts, etc. It is the actual details of these that is the most important aspect of the construction in regard to wind resistance, not the general form, but it is this very detail that is usually lacking in empirical guidelines - lacking because it needs a high level of structural engineering input to establish them, and because the details must be consistent with local building practices and forms of construction if the principle of evolutionary change is to be maintained, thus limiting the generality of their application.

The outcome of this approach are `deemed to comply' publications of standardised details of the common forms of construction in the community for which they are intended. The Queensland Home Building Code (Ref.4) and the TRADAC timber framing manuals (Ref.5) are good examples of these. These, in conjunction with design manuals such as the Domestic Construction Manual (Ref.6) have become the basic textbooks for educating building tradesmen and owner builders on how to make local common forms of construction resistant to extreme winds, as well as becoming source documents for house designers, and reference standards for building inspectors. If novel forms of construction not covered by these documents are to be undertaken then the services of a structural engineer must be sought.

This approach is now well established in Australia. Its success was demonstrated in the much better performance of new houses in Cyclone Winifred in early 1986 (Ref.7). During this tropical cyclone maximum wind speeds of the order of 180 kilometres per hour - peak 3 second gust at a height of 10 metres in flat clear terrain - were experienced by the small coastal community of Kurramine Beach. The community had developed in a progressive manner along a strip of beach front with housing becoming progressively more recent with distance along the beach front. Of houses built before 1975 about 30 percent suffered significant structural damage. Of those built after 1980 none suffered significant structural damage. Similar observations were made in the small towns of Ayr and Home Hill after they were hit by Cyclone Aivu in 1989.

4 IMPORTANT FACTORS

The experience gained in Australia in developing wind resistant housing has shown several factors to be important.

A very necessary first step is the acceptance of appropriate criteria in respect of design wind loads. Most of the development of wind loading codes around the world has been undertaken in the context of communities not at risk from tropical cyclones, and thus the resulting codes do not take into account the special problems that are created by them (Refs.8,9). These include the inappropriateness of regarding the 50 year return period event as the design event, the need to take into account the high probability of dominant openings being created by debris impact, and the need to take wind induced fatigue into account in the design of light metal elements.

Most wind codes around the world specify design wind speeds equivalent to the 50 year return period event. These are used in conjunction with other design criteria such as allowable stresses which incorporate factors of safety. The combined effect can be shown to provide protection against failure from an event with a return period of the order of a thousand years for normal winds such as those arising from gales and thunderstorms. However it can also be shown that for tropical cyclone winds this approach results in protection against failure for events with a return period of only two hundred to three hundred years. This weakness was recognised in Australia twenty years ago and a special tropical cyclone factor introduced into the design process in tropical cyclone areas to account for it. In recent years Australia has made its structural engineering codes more transparent by presenting them in limit state format. Consistent with this approach the most recent edition of the Australian wind code (Ref.10) has abandoned the 50 year return period wind speed as its basis, and for strength design specified design wind speeds based on the estimated thousand year return period event. In recognition of the uncertainties surrounding the magnitude of these extreme events a zoning system has been developed for the tropical cyclone prone areas with the specified design wind speeds for strength in each zone being closely related to the expected extreme event in terms of the international Saffir-Simpson intensity scale (Ref.11)

It was clearly demonstrated in the investigation of Cyclone Tracy (Refs.1,2) that the two major factors contibuting to the widescale damage to housing were internal pressurisation of buildings following failure of windward windows, generally due to windborne debris, and fatigue failure of cladding and metal connections under the fluctuating pressures. The current code specifies appropriate criteria to account for both of these effects in tropical cyclone areas. It remains the only national wind code in the world that recognises these particular problems in tropical cyclones which are a consequence of both the magnitude and duration of the extreme wind speeds that can occur, as well as recognising the limitation of basing design wind speeds on the 50 year return period event.

Another problem with many current wind loading codes is their increasing complexity. This has been particularly true in Australia where the wind loading code, reflecting the high level of wind engineering expertise in Australia, has kept abreast of latest knowledge on the complexities of wind loading. This increasing complexity has made the codes less suitable for application to small buildings. The economics of small building design and construction often cannot justify a high degree of sophistication in the design of individual buildings, and the level of expertise required to interpret the codes is higher than that often available in the design and construction of small buildings.

To overcome this, simplified forms of wind loading criteria, based on the official more complex code, have tended to be used in Australia for a number of years. The first of these appeared in guidelines on testing building components for use in tropical cyclone prone regions published in 1977 (Ref.12), but these proved to be too simplified for general use. A more detailed set of criteria was published in the Domestic Construction Manual (Ref.6) which has been widely used. In recognition of the need for such a document a simplified set of wind loads for the design of small buildings has been incorporated in the current edition of the Australian wind loading code. An international simplified code based on the Australian experience has been proposed (Ref.13).

The search for an acceptable simplified wind code for small buildings has proved to be a difficult exercise as simplification inevitably leads to increased conservatism in many situations and this is often unacceptable in the highly competitive and cost conscious housing industry. Although Australia has probably progressed further than most countries in this area, it remains an area of continuing investigation which is raising many fundamental questions related to acceptable risk and the built environment. Mitigation of damage to housing from large scale events such as tropical cyclones does not mean ensuring that every building of every conceivable geometry in every conceivable location will be designed to have the same uniform level of safety against damage - an implicit assumption behind most modern wind codes. Nor do simplified codes for housing have to be such that they will never produce lower design loads than the detailed codes from which they are derived, as the objective is not protection of individual buildings but protection of a community of buildings from significant damage (Ref.11). Unfortunately this concept appears to be difficult to accept by the structural engineering profession with its traditional concern for the design of individual structures. This issue is currently being addressed in Australia in relation to the development of a national performance based design code for housing.

A key aspect of the structural engineering approach to the design of wind resistant houses is the testing of building components and assemblies to determine their resistance to wind induced forces. This is necessary because the structural behaviour of houses is far less understood than that of larger buildings, since most structural engineering research has been directed at the latter. Consequently analytical methods of design such as those normally used for larger structures do not exist and resort must be made to testing to prove the adequacy of many of the construction details. This testing has not only included basic building components and assemblies such as wall panels, roof cladding systems, etc, but has also included testing of full scale houses under simulated wind loads (Ref.14). The centre for much of this testing activity in Australia has been the Cyclone Testing Station at James Cook University of North Queensland in Townsville, but many other structural testing facilities in tertiary institutions and research organisations have contributed to it. It is important that these testing facilities be readily available as without them evolutionary change through innovation is stifled.

Essential to the general acceptability of the results of this testing activity is the development of standard methods of testing building components under simulated wind forces. The TR440 guidelines published in 1977 (Ref.12) have played a major role in this respect. The testing of standard details of construction and commercial products based on this document, together with the deemed to comply documents and product manufacturer's design literature which have resulted from it (e.g. Refs. 15-22), has been one of the cornerstones of the development of wind resistant housing in Australia.

A major factor in the Australian success has been the involvement of a wide range of people from all levels of the building industry in the development of the standardised details of construction. The major initial focus for this activity was Committee BD/57 established by the Standards Association of Australia in the aftermath of Cyclone Tracy to develop a national set of guidelines on details of construction of houses in high wind areas. The task eventually proved to be too ambitious for its time and was abandoned, but not before the Committee had involved a very wide section of the building industry at a national level in its deliberations, and made it aware of both the need and the difficulties of achieving it. It provided the ground work for the subsequent developments of deemed to comply details of construction which eventually fulfilled the need. Many view the BD/57 project as a failure, but many of the subsequent successes had their origins in its activities.

Activities such as the BD/57 project led to a high level of interaction between researchers, designers, manufacturers, builders and building surveyors. This not only ensured that the details developed were soundly based but that they were also practical and compatible with local and traditional building skills. It also gave a wide ranging group of members of the building industry a vested interest in the results, and made a major contribution to the diffusion of information on wind resistant building construction through the industry.

A strong and continuing education programme for all levels of the building industry and even the general public, backed up by continuing academic research, has been another characteristic feature of the Australian developments.

The existence of a civil engineering department at James Cook University of North Queensland in the tropical cyclone prone area of Australia was a major factor. The University has had a major influence on the development of wind resistant housing in providing leadership in technical matters at the front line, as well as facilitating information transfer and enhancing the interaction between the various levels of the building industry at the local level. It became involved when Townsville was hit by Cyclone Althea in 1971, accepted the challenge in respect of housing, and consequently found itself playing a leading role following the destruction in Darwin from Cyclone Tracy. In 1977 in collaboration with the building industry it established the James Cook Cyclone Structural Testing Station which has become a major focus for involvement of the building industry at large.

The contributions of James Cook University and other academic institutions has been another cornerstone of the development of wind resistant housing in Australia.

Academic institutions such as James Cook University have been significant contributors to the associated educational activities but they have not been the only ones. In North Queensland at the tradesman level the most significant educational activity was probably that undertaken by the Townsville based Cyclone Building Research Committee. This was a local group of builders, architects and engineers, formed following Cyclone Althea, who dedicated themselves, in a voluntary capacity, to improving housing construction through involvement in the development of acceptable details of construction, and in the presentation of seminars on wind resistant construction at tradesman level (Ref.23). Their activities ensured that much of the housing construction in North Queensland complied with the deemed to comply regulations well before they came into force. The commitment of such individuals at all levels has been another of the cornerstones of Australian developments of wind resistant housing.

Government, both Federal in Darwin, and State in Queensland, have played a significant educational role in relation to the implementation of their building regulations. Industry has also played its role through product promotion seminars incorporating wind resistance educational material, as have other tertiary institutions, CSIRO, and professional bodies.

Without the weight of the law behind it, or some other strong incentive such as conditions of insurance (which is the case in Fiji), implementation on a community wide basis is unlikely. Legal requirements require the support of the relevant governments in enacting appropriate legislation and enforcing it. Australia has been well served in this respect.

Following Cyclone Tracy the Federal Government through its then Department of Housing and Construction played a major role in setting and enforcing the requirement for the reconstruction to be based on details of construction engineered to resist wind forces. The Northern Territory Government has maintained this commitment since taking over reponsibility for building regulations.

In Queensland the Department of Local Government was reponsible for the development of the Home Building Code Queensland (Ref.4) which was incorporated in the State's building regulations. The development of this document and its implementation took approximately six years. Most of the delays were political rather than technical, but the long time period, and the continuing development and education that took place during it, ensured a high technical quality and a high degree of public acceptance of the final product. An important aspect of the introduction of the Home Building Code Queensland was its publication a year ahead of its date of implementation to give the building industry time to become familiar with it. Currently a major revision is underway to bring it into line with the latest edition of the wind code and to reflect developments since 1981.

The support by government in providing the necessary legal backing by developing the necessary building regulations, particularly those of the deemed to comply nature, has been the other cornerstone of the development of wind resistant housing construction in Australia.

5 INTERNATIONAL SIGNIFICANCE

The development of wind resistant housing in Australia has placed it in the forefront of such activities at the international level at a time when international concern at the damage from tropical cyclone winds, particularly in relation to reinsurance (Ref.24), has been increasing. This has a number of consequences.

Firstly the Australian experience can be used as a model by other countries. This has already been happening. In 1979 Australia, as a form of technical aid, prepared a manual for the design of low rise buildings to resist tropical cyclones for Sri Lanka, following a severe tropical cyclone there in 1978 (Ref.25). Since 1985 UNESCO has been utilising Australian expertise in the development of guidelines for the design and construction of wind resistant school buildings in tropical cyclone prone areas of Asia and the Pacific (Refs.26-28). Following Cyclones Eric and Nigel in Fiji early in 1985 Australian expertise, funded in part by Australian aid, has been utilised in improving the wind resistance of housing (Ref.29).

In applying the Australian model overseas there are some lessons to be learnt from the experience to date. The manual prepared for Sri Lanka was probably the best of its type in the world when it was produced. From all accounts it has however found little use. The reason for this appears to be that it was prepared externally and presented as a final document with none of the detailed local involvement in its preparation that has marked the development of similar documents in Australia. Consequently no one in Sri Lanka had a vested interest in seeing it implemented. In the subsequent exercise in Fiji this lesson was taken to heart with the emphasis being on Australia assisting the Fijians in developing their own requirements (Ref.30). The benefits of this approach can already be seen in current house construction in Fiji. Since then the Australian Government has followed this approach in assisting in the development of model building codes and home building manuals for the Pacific Island nations of Fiji, Niue, Tuvalu, Solomon Islands, Cook Islands and Vanuatu (e.g. Refs.31,32).

Secondly Australian expertise can be exported to these countries in the provision of design and testing services, and in the supply of wind resistant building products and the construction of wind resistant housing. A limited amount of this activity has also occurred - e.g. the testing of a Tongan house by the Cyclone Testing Station (Ref.33) - but there is scope for a much greater involvement in this type of activity by the Australian building industry.

Finally it has significant implications for the international reinsurance market. The increasing level of insurance losses from tropical cyclone winds due to increasing concentrations of wealth in the form of housing and contents in tropical cyclone prone areas has raised questions about the insurability of these items against wind damage from tropical cyclones. The Australian experience has demonstrated that practical measures can be undertaken to mitigate wind damage from tropical cyclones to a level that is insurable (Ref.34). The barriers to the wider acceptance of these measures will not be technical. They will be political, as was evidenced in South Carolina when in the aftermath of Hurricane Hugo the Legislature voted against implementing such measures. Unfortunately through reinsurance it is the rest of the world that pays the price of these attitudes.

6 CONCLUSIONS

During the past two decades Australia has made major advances in the application of wind engineering technology to the design of low rise housing construction to resist extreme winds. These advances have put Australia in the international forefront in this aspect of building design and construction.

The underlying cornerstones of Australia's success in this field have been:

- a sound academic base of research, scholarship and education;

- a ready commitment by industry to testing building products to ensure their adequacy;

- the strong support of government agencies in enacting relevant legislation and encouraging its enforcement;

- a dedicated commitment by many individuals at all levels to achieving success.

As a result of these advances, in tropical cyclone prone areas the damage risk of current housing construction is believed to be an order of magnitude less than that of housing constructed prior to 1975. It is an achievement worthy of emulation by other countries at risk from tropical cyclones .

7 REFERENCES

1. Walker,G.R., *Report on Cyclone Tracy - Effect on Buildings - December 1974*, 3 Vols., Department of Housing and Construction, Australian Government, Melbourne, 1975.

2. Walker,G.R., A review of the impact of Cyclone Tracy on Australian building codes and practice, *Civil Engineering Transactions, Institution of Engineers Australia*, Vol.CE22, No.2, pp.100-107, 1980.

3. Walker,G.R. and Eaton,K.J., Application of wind engineering to low rise housing, *J. of Wind Engineering and Industrial Aerodynamics*, Vol.14, pp.91-102, 1983.

4. *Home Building Code Queensland*, Appendix 4, Standard Building By-Laws 1975, Queensland Government Printer, Brisbane, 1981.

5. *Queensland Timber Framing Manuals - W33, W42, W59, and W65*, Timber Research and Development Advisory Council (TRADAC), Brisbane, 1986.

6. Smith,P.R. and Adams,R.H.T., *Domestic Construction Manual*, Queensland Master Builders Association and Queensland Institute of Technology, Brisbane, 1980.

7. Reardon,G.F., Walker,G.R., and Jancauskas, E.D., *Effects of Cyclone Winifred on Buildings*, Technical Report No.27, James Cook Cyclone Structural Testing Station, Townsville, 1986.

8. Walker,G.R., Cyclonic storms and related design criteria, *Proceedings, 1st Asia Pacific Symposium on Wind Engineering*, University of Roorkee, pp.lxv-lxxvi, 1985.

9. Walker,G.R., Codification of design for tropical cyclones, *Proceedings, Seminar on Building Standards*, Fiji Building Standards Committee, Commissioner of

Insurance, Fiji, 1987.

10. *SAA Loading Code, Part 2 - Wind Forces*, AS1170, Pt.2 - 1989, Standards Association of Australia, Sydney, 1989.

11. Holmes, J.D., Melbourne, W.H. and Walker, G.R., *Commentary on the Australian Standard for Wind Loads*, Australian Wind Engineering Society, Melbourne, 1990.

12. *Guidelines for Cyclone Product Testing and Evaluation*, Technical Record 440, Experimental Building Centre (now CSIRO Division of Building, Construction and Engineering), Sydney, 1977.

13. Walker,G.R., A simplified wind loading code for small buildings in tropical cyclone prone areas, *J. of Wind Engineering & Industrial Aerodynamics*, Vol.30, pp 163-171, 1988.

14. Boughton,G.N., Testing a full scale house with simulated wind loads, *J. of Wind Engineering & Industrial Aerodynamics*, Vol.14, pp 103-112, 1983.

15. *Masonite Readyfix Structural Wall Bracing in High Wind Areas*, Hardboards Australia Ltd., Sydney, 1978.

16. *Structural Wall Bracing in High Wind and Cyclone Areas with Hardiflex / Villaboard Flat Sheeting*, James Hardy and Co. Pty. Ltd., Sydney, 1982.

17. *Structural Plywood Wall Bracing Design Manual*, Plywood Association of Australia, Brisbane, 1982.

18. *Gyprock Structural Wall Bracing System*, Gypsum Products Group, CSR Ltd., Sydney, 1982.

19. *Roof and Cladding Systems for Industrial and Commercial Applications*, Comalco, Sydney, 1982.

20. *Victorboard Structural Wall Bracing*, Australian Gypsum Ltd., Melbourne, 1985.

21. *Particleboard Structural Wall Bracing Design Manual*, Australian Particleboard Research Institute, Sydney, 1986.

22. *Cyclonic Area Design Manual - Steel Roofing and Walling*, Lysaght Building Industries, Sydney, 1987.

23. Macks,K.J.(Ed.), *Cyclone Building Construction*, Seminar Proc., Cyclone Building Research Committee, Townsville, 1980.

24. Walker,G.R., Wind Engineering and Insurance, *Proceedings, 5th U.S.*

National Conference on Wind Engineering, pp.1-14, 1985.

25. *Design of Buildings for High Winds - Sri Lanka*, Sri Lanka Ministry of Local Government, Housing and Construction, Columbo, 1980.

26. Macks,K.J., *Design of School Buildings in Cyclone Regions*, UNESCO Subregional Training School, Suva,1985.

27. Macks,K.J., *Design of Educational Buildings in Typhoon Regions*, UNESCO Subregional Training School, Manila, 1986.

28. Macks,K.J., *Typhoon Resistant School Buildings for Viet Nam*, UNESCO, Bangkok, 1987.

29. *Seminar to Introduce the Proposed Building Code*, Fiji Building Standards Committee, Suva, 1987.

30. *Our War Against Cyclones*, Guidance to homeowners on how to upgrade existing homes, Fifi Building Standards Committee, Commissioner for Insurance, Suva, 1985.

31. *Fiji National Building Code,* Pacific Building Standards Project, Australian International Development Assistance Bureau, Suva, 1990.

32. *Fiji Home Building Manual*, Pacific Building Standards Project, Australian International Development Assistance Bureau, Suva, 1990.

33. Boughton,G.N. and Reardon,G.F., *Simulated Wind Load Tests on the Tongan Hurricane House*, Technical Report No.23, James Cook Cyclone Structural Testing Station, 1984.

34. Walker, G.R., Losses due to the effect of wind and rain on structures during tropical cyclones, *Natural Hazards and Reinsurance* (Ed.J.Oliver & N.R.Britton), pp 1-17, Sterling Offices (Australia) Ltd, Sydney, 1989.