CYCLONE TESTING STATION

A DISCUSSION OF CRITERIA FOR THE STRUCTURAL DESIGN OF BUILDINGS TO RESIST TROPICAL CYCLONES

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PREFACE

This Technical Report is different from previous ones in that it is not a report of research findings but a discussion of structural design and testing criteria. The report consists of two segments, the first being a discussion paper to be presented at the 1987 Engineering Conference of the Institution of Engineers, to be held in Darwin from May 11th to 15th. The second segment consists of a copy of the National Building Technology Centre (formerly the Experimental Building Station) Technical Record 440 "Guidelines for the Testing and Evaluation of Products for Cyclone-Prone Areas", which the discussion paper addresses.

As it is more than ten years since the guidelines in TR 440 were formulated and agreed to, and since there has been a significant amount of research and testing conducted in that time, the authors suggest that a review of the document should be made. In order to encourage meaningful discussion of the review paper the Cyclone Testing Station has undertaken to distribute it in this form prior to the conference in Darwin.

While it is most desirable that people or establishments with an interest in design criteria should attend the Darwin Conference and participate in the discussion, it is accepted that this may not always be feasible. The Cyclone Testing Station therefore invites written comments or proposals on the paper. They should be addressed to

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The Station gratefully acknowledges the co-operation of the Institution of Engineers and the National Building Technology Centre in agreeing to the publication of the two documents forming this Technical Report.

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SUMMARY

This paper has been prepared to stimulate discussion on design criteria for buildings constructed in tropical cyclone prone areas. A brief history of the criteria in current use, a survey of the degree to which it is used, a discussion of some of the problem areas, and recommendations aimed at developing a greater degree of uniformity of criteria used in the design of buildings in cyclone areas are presented.

1 INTRODUCTION

The damage caused by Cyclone Tracy resulted in significant changes to structural design practice being recommended in Australia in regard to buildings constructed in tropical cyclone prone regions [1,2]. Criteria related to these changes were quickly developed for incorporation in the Darwin Area Building Manual [3] on which the reconstruction was based. Two years later in the light of further research and experience revised criteria were developed and published by the then Experimental Building Station as Technical Record 440 [4]. The latter were only guidelines developed as a consensus at a workshop widely representative of the building industry. They have been widely used in Queensland, to a lesser extent in Western Australia, and hardly at all in the Northern Territory where the criteria originally incorporated in the Darwin Area Building Code continue to be used.

A great deal of research, development, design and construction has been undertaken since 1977 in respect of design for tropical cyclones. Significant changes in design codes, due to the change to limit state design format, and to building regulations, due to the development of a new Australian Uniform Building Code, can be expected during the next few years. It therefore seems timely to critically review the current criteria being used in cyclone areas and consider possible improvements including the adoption of more uniform criteria throughout the cyclone areas of Australia. This discussion paper has been prepared with the objective of initiating such a review.

2 HISTORICAL BACKGROUND

2.1 Interim 350

The first national wind loading code in Australia was published in 1952 as part of the Interim Code for Minimum Design Loads on Buildings which is more commonly known as SAA Interim 350. Prior to this date designers were dependent on an appendix in the 1939 version of SAA CA1, the steel structures code of the day. Interim 350 remained the SAA wind loading code until 1971.

Interim 350 recognised the special problems of designing for wind in the cyclone regions by specifying design wind speeds in coastal areas north of latitude 25 degrees approximately forty five percent higher than in other parts of Australia. This led to design wind forces in the cyclone areas being a little over twice those for otherwise similar buildings in non-cyclone areas.

2.2 AS CA34,Pt2-1971

In 1971 the Standards Association of Australia published a completely new wind loading code, the format of which has remained the basic format of the wind loading code until the present time.

In this new code design wind speeds were related directly to estimated 50 year return period maximum three second gust speeds at 10 m height in terrain category 2 which had been analysed separately for each major location from a Gumbel analysis of available records of annual maximum gust speeds. The limitations of basing strength design in cyclone prone areas on the 50 year return period were recognised by the introduction of the 1.15 cyclone factor. The tropical cyclone area was defined as the area within 30 miles of the coast north of latitude 27 degrees.

AS CA34 Part 2 was metricated in 1973 and republished as AS1170 Pt2. with some minor revisions.

2.3 AS 1170, Pt2-1975

In 1975 a major revision of the wind code was published which had a significant impact on design in cyclone areas. In the previous code, because design wind speeds for each major location were based on local wind records, major anomalies were present, particularly in the cyclone areas. For instance in the 1971 version the design wind speeds for Cairns were less than those for Sydney even after allowing for the cyclone factor, and Brisbane had a design wind speed approximately the same as that of most cyclone prone locations after allowance for the cyclone factor and higher than that for Port Hedland.

Cyclone Tracy at the end of 1974 highlighted the magnitude of the extreme wind speeds that could occur in tropical cyclones and the shortcomings of existing local records in predicting local extreme wind speeds for design purposes. Meanwhile new methods had been developed and applied for estimating extreme wind speeds in cyclone areas. These suggested much higher design wind speeds than were then being used and much more uniformity within the cyclone region. As a result a uniform 50 year return period wind speed of 55 m/s was specified for the entire cyclone region with the exception of Onslow and Willis Island where higher wind speeds were specified.

With some minor changes, as far as the special characteristics of design for tropical cyclones are concerned this has remained the situation as regards AS 1170 Pt 2 until the present time.

2.4 Darwin Area Building Manual

Following Cyclone Tracy it was recognised that there were a number of special aspects of design for cyclonic winds that needed to be incorporated into the design process. In particular there was a need to recognise the potential for fatigue failure of roof cladding under the sustained fluctuating wind pressures. and the potential for major structural damge due to internal pressures induced following window failures often as a result of debris damage. To ensure that the reconstruction incorporated these aspects relevant criteria were included in the Darwin Area Building Manual which was written after Tracy.

The fatigue problem was accounted for by requiring roof cladding systems to be fatigue tested by the application of 10 000 cycles of loading from zero to design load followed by a single loading to 1.8 times the design load. The internal pressure problem was accounted for by requiring buildings to be designed on the assumption that a dominant opening may exist as a result of a window or door failure unless approved debris protection of windows and glass doors was provided. Approved debris protection was defined as the ability to prevent a 4 kg piece of 100 mm x 50 mm timber travelling at 20 m/s from causing an opening failure.

2.5 TR 440

The adoption of the Darwin Area Building Manual for the reconstruction of Darwin led to the recognition that similar measures were needed in other cyclone areas of Australia, particularly in the relatively highly populated eastern coastline of Queensland. As they were not covered by existing building regulations except in a very general way it was left to each local authority and designer to determine its own interpretation of what was required and to each building product manufacturer to decide how he would comply. To add to the confused situation there was a widespread feeling that the criteria adopted in Darwin may have been unnecessarily conservative. In combination with the competitive nature of the building industry this led to a great deal of confusion and rancour.

In an attempt to resolve these problems the then Commonwealth Department of Construction agreed to host a workshop at its Experimental Building Station - now the National Building Technology Centre - in Sydney to formulate guidelines for the testing and evaluation of building products intended for use in tropical cyclone prone areas. It was attended by over 30 persons representing a wide cross-section of the building industry [4].

The guidelines endorsed the requirement of the Darwin Area Building Manual that internal pressures be based on the assumption of a dominant opening unless protective measures were taken. However it reduced the requirement for the protection by specifying a missile velocity of 15 m/s instead of 20 m/s. It also specified a modified fatigue criteria for roof cladding which retained the 10 000 cycles but reduced the loading level for most of them.

The guidelines, however went further than just dealing with these criteria. In an attempt to resolve problems caused by differences in interpretation of the wind code where standardisation was required a simplified set of wind loads for low rise buildings was presented together with standardised guidelines for the determination of terrain categories. Separate serviceability loading criteria distinct from that for strength were also introduced by specifying that serviceability loads could be based on the 25 year return period wind speed, ignoring the cyclone factor, and using normal internal pressures assuming the outer envelope of the building remained intact. Fatigue criteria were also introduced for structural elements as opposed to cladding. Lastly guidelines, including load factors, were given for the actual testing of cladding in fatigue and shear walls in racking.

3 CURRENT SITUATION

TR 440 was developed as a consensus document. Consequently its adoption was dependent on voluntary acceptance of the criteria by manufacturers and designers and the encouragement of its use by building authorities. Reference to it is made in the form of a note in the current version of the wind loading code but the roof cladding code AS 1562 did not include the fatigue loading requirement in its 1980 revision. In practice the use of TR 440 has varied from state to state.

3.1 Queensland

TR 440 has received its widest acceptance in Queensland, although it is not explicitly called up in building regulations. Deemed to comply documents such as the Home Building Code Queensland [5], which is incorporated into the Queensland building regulations as Appendix 4 of the Queensland Building By-Laws,embody its requirements and most manufacturers and designers abide by it. The James Cook Cyclone Structural Testing Station,used extensively by manufacturers of building components intended for use in cyclone areas in Queensland,bases all its testing on it. Both federal and state government departments have adopted its principles as the basis for sound design in tropical cyclone areas as have many of the major structural engineering consultants.

However there are exceptions to this general acceptance which are the cause of considerable concern and conflict within the building industry. In Queensland designs are accepted on the basis of a certificate of compliance by a qualified structural engineer. Since the regulations do not explicitly require compliance with the principles embodied in TR 440, and because many local authorities, including relatively large ones like Towsville, do not employ structural engineers in their building approvals section, it is relatively easy for designs to be accepted by local building authorities which do not comply with TR 440. This has been the cause of considerable concern to responsible designers, particularly in regard to 'design and construct' competitive tendering, where they have found themselves seriously disadvantaged by following what is regarded by the experts in this area of structural engineering as sound practice.

Some manufacturers have also steadfastly refused to use TR 440, despite in at least one case having having been a party involved in the preparation of TR440, to their commercial advantage. One major organisation in this category is the Plywood Association of Australia which uses a load factor of 1.75 in developing its safe load tables from the results of racking tests. This load factor is much lower than that recommended in TR 440, and certainly gives them an unfair commercial advantage in the eyes of their competitors. The Plywood Association of Australia argues that by specifying the load factor they use it is left to the professional judgement of designers as to how the tables are used but this overlooks the fact that many of those who use the tables do not have the expertise needed to make this judgement.

Another problem which occurs, primarily because TR 440 is a document of recommended practice not of required practice, is lack of implementation due to ignorance. This can be particularly a problem on large contracts involving designers and manufacturers not familiar with the special problems of tropical cyclone areas, or in large organisations such as government bodies where although it is policy to use TR 440 those involved in approving the use of products are unaware of all the implications. For instance there was a major roof cladding failure in a new school building Cairns during Cyclone Winifred involving a material which had not been tested for fatigue loading according to TR 440 due to a failure to check in detail the manufacturer's claims that the system had been tested - it had apparently been tested statically according to AS 1562 but not in fatigue according to TR 440. In another example a major federal government structure was designed for an internal pressure coefficient of 0.3 instead of 0.8 despite the latter being the policy of the particular department.

3.2 Northern Territory

Northern Territory building authorities did not accept the reccomendations of TR 440 choosing to continue using the more severe requirements of the Darwin Area Building Manual in addition to prescribing Category 2 1/2 as a minimum design level. However a maximum internal pressure coefficient of 0.6 is specified rather than 0.8 as required by TR 440 lessening the relative conservatism slightly for category 3 structures but introducing an unconservative element for buildings designed for terrain categories 1 and 2. These requirements have been maintained in the new Northern Territory Building Code introduced in 1984 [6].

The inclusion of the special provisions within the building regulations overcomes the Queensland problem of some manufacturers and some designers choosing to ignore them. However the rigour of their implementation by the building authorities in conjunction with their relative conservativeness in general in comparison with TR 440 does cause some problems for designers, manufacturers, and builders. The Northern Territory is much more insistent on the need for structural engineering justification of construction details than other States which have tended to accept some traditional forms of construction for which the necessary structural information is lacking but which in the opinion of the building authorities is believed to be satisfactory.

An example of the latter is the attitude towards brick veneer construction. In Queensland brick veneer is accepted without question by the building authorities providing the internal frame is constructed to withstand the total wind forces and specified ties are used to connect the brick veneer to the internal frame. However very little research has been undertaken on the interaction between the brick veneer and the internal frame and questions have been raised about the effects of incompatibility of stiffness between the relatively rigid brickwork and the relatively flexible internal structure. Northern Territory building authorities will not accept brick veneer without a structural engineer's certificate certifying the performance of the overall structure, including the brick veneer. Lack of knowledge precludes structural engineers from giving such a certificate, in effect precluding brick veneer as a form of construction in cyclone prone areas of the Northern Territory.

Another example is the insistence on the use of 'cyclone washers' in connecting roof cladding as a result of concern about the role played by roof cladding in transmitting horizontal roof loads from the tops of walls to the cross-walls. Reseach has shown that without cyclone washers the fatigue strength of roof cladding can be significantly reduced. This effect is not taken into account in the standard fatigue test to which roof cladding systems are subjected. Again there is little structural engineering knowledge of the relative role played by the roof cladding and the other elements of horizontal roof bracing such as the ceilings. In Queensland it is assumed that providing the ceiling has the strength to resist the horizontal forces on its own then the cladding can be designed on the assumption that it will only be subjected to uplift forces. But this overlooks again the all important problem of compatibility and fatigue has no respect for such assumptions. So again in view of the lack of necessary knowledge the Northern Territory has opted for the more conservative approach of assuming that the cladding will be subjected to in-plane shear forces and that cyclone washers therefore need to be used.

Building designs and building products are subjected to rigorous checking by structural engineers employed by the Building Branch of the Department of Lands before approval is given. In submitting plans designers must specify on a special form the basic wind criteria used such as external and internal pressure coefficients, terrain categories, design wind speeds etc. thus quickly drawing attention to designs undertaken in ignorance of the special requirements of the Northern Territory. In the case of building products once approval is given for their use they are included in the Northern Territory Deemed to Comply Manual. Only products included in this manual are permitted to be generally used thus making mistakes such as that exposed by Cyclone Winifred in Cairns much more unlikely.

3.3 Western Australia

Like Queensland the building regulations in Western Australia simply require structural design for wind loads to be in accordance with the Australian wind loading code, with no special requirements for cyclone areas being incorporated as legal requirements. In practice it falls to the local council building inspectors to enforce this requirement. Many councils rely on the services of consultants for checking designs. The use of TR 440 does not appear to be as widespread in the cyclone areas as it is in Queensland with considerable variation occurring in the means of compliance with specified code criteria.

However awareness of tropical cyclones and their potential effect on buildings is relatively high, particularly in the region between Port Hedland and Onslow, due to their relatively high frequency of occurrence. Consequently there is considerable experience available regarding the performance of local common forms of construction in moderate to severe cyclones which tends to ensure that damage is minimal in such events. This is helped by the way in which communities clean up potential debris at the beginning of each cyclone season.

The character of the towns in North West Australia is also quite different from those in North East Queensland. The total population is very much less as is the size of the major communities, reducing considerably the potential magnitude of disasters arising from tropical cyclones. Furthermore there are few privately owned dwellings, with most homes being owned by either the State Government through Homeswest (formerly the State Housing Commission), mining companies, or large service organisations such as banks, all of which tend to make extensive use of Perth based structural engineers for their structural design. Where private buildings are constructed, they frequently incorporate the structural details used by Homeswest. As a result the level of individual structural engineering input is relatively high. Supervision of the construction of the buildings is often left to the local building inspector.

4 NEED FOR NEW GUIDELINES

4.1 Change To Limit State Codes

As part of a major revision of the structural engineering codes to limit state format the wind loading code is being rewritten. It is proposed that in the new code ultimate wind speeds and wind loads will be specified for strength design, with serviceability wind speeds and wind loads being separately specified.It is also proposed to include a section specifying simplified wind loads for small buildings (currently defined as those not greater than 15 m in height and not greater than 1000 sq m in area) and to include fatigue loading criteria for cyclone areas. Thus a number of functions currently served by TR 440 will be included in the code. The changes will make TR 440 in its present form of little value. Any new guidelines will need to be consistent with the new code, and will not need to cover the aspects covered by it.

4.2 Uniformity

The failure of TR 440 in being adopted as a uniform requirement throughout the cyclone prone areas of Australia is a handicap to manufacturers of building products and a problem for the structural design profession at the national level. It is illogical that different criteria be used for the same phenomenon in different parts of the country. In addition to the problems it causes within Australia it also has international ramifications. Australia is looked upon internationally as a leader in the development of appropriate criteria for the wind resistant design of buildings in tropical cyclone prone areas and the lack of uniformity within Australia certainly creates some confusion in this regard.

A primary objective in any development of new guidelines should be to ensure that the revised document will be accepted throughout all the cyclone areas of Australia, leading to a more uniform application of design criteria and enabling greater standardisation of building product specification and deemed to comply information.

Hopefully the full scale house testing being undertaken by the James Cook Cyclone Structural Testing Station will help to resolve some of the problems arising from lack of knowledge of the detailed structural behaviour of houses, epecially in regard to brick veneer construction and shear forces in roof cladding.

4.3 Fatigue Testing Criteria

Currently two different fatigue criteria are in use for testing roof cladding systems - that used in the Northern Territory and that specified in TR 440. One of the major reasons for the lack of acceptance of the TR 440 criteria by the Northern Territory authorities is scepticism of its effectiveness. This arises from their observations that some of the systems passing the test seem little different to systems that failed in Cyclone Tracy, and that it is a 'sensitive' test in that many systems seem to just pass or just fail. The fear is that if the test is unsatisfactory widespread failures could again occur if a very severe cyclone of Tracy's intensity was to strike a major community. The possible influence of shear forces has already been discussed but there are other unknowns as well.

Unfortunately the research base on which the fatigue tests are based is relatively small compared with that on which most structural engineering criteria are based - a limited investigation by the Experimental Building Station immediately following Cyclone Tracy and one Masters project - and it is not sufficient to resolve the conflict. One concern that has been raised is that the TR 440 fatigue test relates to working strength design loadings rather than to ultimate loadings to which it should be related. Currently a major wind tunnel study is being undertaken at James Cook University of North Queensland which it is hoped will answer some of these questions. However the loading characteristics are only one part of the problem and much more research is required on the basic nature of the fatigue failure of the components themselves before all the questions can be resolved.

TR 440 specifies two sets of fatigue criteria, one set for roof structures and roof and wall claddings, and one set for wall structures. Only in respect of roof cladding has it tended to be regarded as an essential requirement with application to other elements being left to the designer or testing authority. Full scale testing of houses using the fatigue criteria has resulted in fatigue failures of straps and other tie down elements which have generally been used without fatigue testing. Any new guidelines will need to address this problem and make recommendations on the types of components for which fatigue testing should be regarded as essential in addition to roof cladding systems.

4.4 Internal Pressures

Probably none of the special criteria recommended for cyclone areas has been more questioned and caused more contentious problems within the building industry and the structural engineering profession than that relating to the appropriate level of internal pressures for design. This specifies that buildings in cyclone areas should be designed to resist full internal pressures, positive and negative, to allow for the possibility of a window in a critical location being broken in a severe event if no measures have been taken to reduce internal pressures by venting or to reduce the probability of window failure by adequate protection.

The need to protect against internal pressures due to window or door failures continues to be demonstrated every time there is serious building damage in a cyclone. Internal pressures arising from dominant openings, usually arising from failed windows or doors, are a primary factor in most major structural damage to roofs arising from the severe winds. Hopefully the conflicts arising from the lack of application of this requirement in competitive situations will be overcome by its specification in the new wind code.

However a major question remains about the amount of venting and its location for it to be effective in reducing internal pressures in the event of window or door failure and whether natural leakage in many industrial buildings is sufficient to significantly reduce internal pressure build up. Another question commonly raised is whether this requirement is applicable to all buildings or only to small buildings or only low rise buildings etc. It is another area of structural engineering where the research base is insufficient to resolve many of these questions. There is certainly a strong need for full scale information on the natural leakiness of industrial buildings where the cost penalties of this measure are probably most keenly felt. However considerable research on internal pressures has been undertaken since this requirement was introduced and any new guidelines should reflect the results of this.

4.5 Debris Impact Test

A number of misunderstandings have occurred in relation to the debris impact test used for the approval of window and glass door protection. Most of these concern the purpose of the test. The test was devised solely to provide a standard performance level for debris resistance which it was felt would reduce the risk of failure of glass panes in windows and doors in a very severe cyclone to a similar level as the risk of failure of other elements of the structure when the ultimate limit loads due to wind on the structure are being approached. It is an empirical test and intended to reduce the risk of damage from debris only. It is assumed that the windows themselves will be designed to resist the design wind pressures and that debris will therefore be the major cause of window failures.

Since the purpose of the test is to prevent dominant openings being caused by debris impact, where the window itself is to provide impact resistance it must be capable of continuing to resist the wind pressures after impact. Its use is primarily directed at reducing the risk of occurrence of high internal pressures within the structure, thus allowing lower internal pressures to be used in design. If protection of occupants and contents is required, then this level of window protection would need to be specified irrespective of the internal pressures used in design, or other tests prescribed with the specific purpose of reducing the danger of glass injury in the event of glass breakage.

Any new guidelines produced will need to address these misunderstandings. If criteria are required for occupancy protection in addition to building protection then this will need to be a separate consideration.

4.6 Test Procedures

When TR 440 was developed testing building components and elements for resistance to wind induced forces was still in its infancy. Consequently the number of tests is small and the degree of sophistication in their description is low.

In effect TR 440 deals with only three types of test - cladding systems to resist uplift pressures, walls in racking, and the debris test. Since TR 440 was written these tests have been improved and many more tests have been developed. A major objective of any new guidelines should be the documentation of current test methods for standardisation purposes and the development of guidelines for establishing new test procedures as the need arises.

A major issue that needs to be looked at is that of load factors. The development of limit state design has led to a much greater understanding of load factors and the rationale of their determination. There is a need to apply this knowledge to the test procedures to ensure that the load factors being used in the design of buiding components by means of these tests are compatible with those being used in other areas of structural engineering. This is particularly true of the current fatigue test specified in TR 440 in which it appears load factors are only applied to the final ultimate static load and not to the fatigue loads.

4.7 Non-Structural Elements

It is common in building design to refer to the different elements of construction as either structural or non-structural elements. The distinction between the two classes has largely depended upon whether or not the element required structural design - in other words whether structural engineers had any responsibility for the design of the element. Historically only the major structural elements such as the roof structure, floors and principal load supporting elements such as the columns or walls supporting dead and live load were considered as structural elements. However in extreme winds nearly all elements are subjected to significant loadings and require structural engineering design if the overall damage to buildings in extreme winds is to be minimised. Apart from the professional questions, particularly in regard to liability and fees, raised by the added responsibility, questions also arise regarding criteria. Should the same criteria be used or can a lower performance level be accepted?

Again historically it has been generally accepted that the principal reason for the relatively low probabilities of failure associated with structural design criteria is the protection of occupants from death and injury arising from building failure. But in respect of wind damage it is clear that in addition to protection of occupants society expects economic protection as well from properly engineered construction. Even the structural designer in certifying or approving a particular roof cladding system is likely to be more concerned about the liability that might arise due to subsequent damage to contents, internal non- structural components, and building services, than that which might arise from injury or death to persons from the failure.

It is clear that the full consequences of failure, both human and economic, must be considered in the establishment of design criteria for both structural and so called non-structural elements. In the case of roof cladding there does not seem to have been any real objections to requiring the same level of performance as for the main structural elements. However there have been considerable differences of opinion regarding the design of wall claddings, particularly in respect of glazing.

In the design of glazing some designers are content to use the pressures specified in the glazing code AS 1266 which are based on a nett pressure coefficient of 1.1. Others use pressures based on pressure coefficients derived from the wind loading code with 'normal' internal pressures which often leads to more severe loadings than those given in AS 1266, especially in corner regions. Others again believe that in cyclone areas full internal pressures should be used based on the assumption of a dominant opening. The minimum requirement in the Northern Territory is based on an internal pressure coefficient of 0.6. Consensus is needed on the appropriate criteria. In reaching this consensus, account needs to be also taken of some research results that suggest that internal pressures in air-conditioned buildings may be strongly influenced by the location of the air-conditioning vents and the external pressures in their vicinity, which may be considerably greater than are commonly assumed in so called sealed buildings.

A 'non-structural' aspect to which very little consideration is currently given is the design of internal walls and partitions and ceilings to resist differential internal pressures. That these differential pressures occur is well known. But little is known of their magnitude. This uncertainty combined with the fact that the elements are 'non-structural' - i.e. not the concern of structural engineers - and that historically they do not seem to have been the cause of serious problems in respect of wind damage appears to be the reason for the current neglect of this aspect of building design. However historically internal walls and ceilings were of similar construction to external walls. The move to lighter construction of these elements in recent years may have serious implications for wind damage in the future if nothing is done about this.

4.8 Serviceability

Considerable differences exist in the approach to design for serviceability conditions. Those unaware of the TR 440 guidelines in this respect may well be overdesigning if they are using the same loads derived from AS 1170 Pt 2 for strength design. On the other hand there are others who believe that in cyclonic areas serviceability considerations in respect of wind loads are unimportant and can therefore be neglected. There is also evidence that considerable differences also arise in respect of the other serviceability criteria such as allowable deflections, though this is not restricted to cyclone areas. Serviceability criteria has proven to be a difficult area to standardise. The new wind loading code will prescribe the loading levels but any guidelines developed should give some guidance on the choice of appropriate perfomance criteria under these loadings.

In addition to the structural aspects of serviceability such as deflections and cracking an aspect of cyclone damage that appears to be causing increasing concern is rain water entry around windows, airconditioners, etc. Current requirements for resistance against rain penetration embodied in window standards do not cover cyclonic conditions. The increasing value of building contents vulnerable to rain water damage relative to the capital value of the buildings themselves is becoming an increasingly important factor in this respect. Related to this are high values of 'loss of profit' which can arise from disruption of business in some types of buildings. Perhaps there needs to be some guidelines as to when these factors need to be taken into account.

4.9 Other Factors

New guidelines may also need to address a number of other factors which experience suggests are or may become important. These include importance factors, upgrading criteria, corrosion, skin friction, porous external claddings and screens, and porous structures.

AS 1170 Pt 2 requires increased design loads for certain important structures. Concern has been expressed about the adequacy of the increases in respect of cyclone regions in view of the much higher degree of uncertainty implicit in the prediction of extreme wind forces from tropical cyclones. Additionally there may be a need to prescribe in more detail what is meant by an important building. Clearly buildings intended for use as public refuge centres during tropical cyclones, and those which have a major public role in an emergency situation following a disaster should be classified as important. But damage in recent years has shown that there is a case for also rating as important those buildings for which the potential damage value to contents or from loss of business is many times the maximum possible value of structural damage.

Changes in the insurance industry originally introduced in Darwin following Cyclone Tracy, and currently being implemented in Fiji, are likely to be introduced more widely in Australia in the near future. A major feature of these changes is the introduction of differential insurance depending on the degree of compliance with current criteria. As has already happened in Fiji this could lead to the need to prescribe minimum criteria for upgrading recognising that full upgrading may be quite uneconomic on overall cost-benefit considerations.

In Darwin concern about corrosion and durability in general has been advanced as one reason for taking a relatively conservative approach to design against cyclones. This concern has been shown by Cyclone Winifred to have some foundation with a number of cases being reported of failures of relatively recent construction due to corrosion. There appears to be an urgent need to address this problem and to include relevant information in any new guidelines.

Skin friction is a factor which is probably rarely taken into account by designers and for which little guidance is available in the current wind loading code. For long buildings with the wind blowing parallel to their length calculations suggest that the skin friction effect can dominate the horizontal loading in the longitudinal direction and in cyclone areas is large enough to influence design. Skin friction in the longitudinal direction will be a function of the cladding profile and more guidance on appropriate values is needed than is currently available.

In recent years there has been an increasing use of porous screens on the external faces of buildings for sunshading, debris protection and security purposes. The determination of the wind loads on these systems is a difficult problem as they are not directly related to the wind loads on the building itself. They will be a function of the local wind speeds around the building in the vicinity of the screens, on which little published information seems to be currently available, and the geometry of the screens themselves. The question also arises as to whether or not the presence of the screens affects the wind loads on the building itself, particularly in respect of local cladding pressures. Porous claddings such as tiled roofs could be considered a special case of this problem.

Cyclone Winifred drew attention to the special problem of the wind resistance of shade cloth structures which are widely used in the nursery and horticultural industries. Because of their porosity nett pressure coefficients will in general be less than for non-porous structures, but the flexibility of these structures raises the question of possible dynamic excitation. Little information is currently available to structural engineers engaged to design such structures.

5 RECOMMENDATIONS

Although the new wind loading code will include more special criteria for design in cyclone areas than the current code there will still be many special problems associated with the structural design of buildings to withstand cyclonic wind forces for which guidelines will be required if a uniform sound standard of design is to be achieved.

It is recommended that:

1. Following the publication of the new wind loading code a new set of guidelines on the design of buildings in tropical cyclone prone areas be produced.

2. These guidelines be produced as a consensus document having the support of the building authorities in Western Australia, the Northern Territory, and Queensland, Commonwealth building authorities, building product manufacturers, industry associations, and professional structural engineers, architects and builders.

3. The development of these guidelines not be regarded as just a revision of TR440 but rather as the development of a new document intended to serve designers as well as product manufacturers.

4. The procedure used in the development of these guidelines be modelled on that used in the development of TR 440 with a workshop attended by all interested parties being the focal activity.

5. The National Building Technology Centre and the James Cook Cyclone Structural Testing Station be jointly approached to sponsor the development of the guidelines.

6 REFERENCES

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APPENDIX A

TECHNICAL RECORD 440

GUIDELINES FOR THE TESTING AND EVALUATION OF PRODUCTS FOR CYCLONE-PRONE AREAS

Recommendations of a Workshop
held during July 1977
at the Experimental Building Station
of the Department of Construction

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PREFACE

Field research following the occurrence in recent years of major cyclones in populated areas of Australia has provided much data on the nature of such winds and their effects on buildings and building components. Notable among the discoveries has been the importance of the influence on structural performance of the dynamic response of building components to strong winds of long duration and of the generation of debris.

Immediately following the occurrence of cyclone Tracy in Darwin in 1974 criteria were formulated to provide a basis for the development of products to be used in the reconstruction of Darwin and although the assessment of such products was a major activity in research and development laboratories during the period of reconstruction, research continued in two main areas:

1. The nature of winds and the response of buildings and building components to them; and

2. The development of valid methods of performance testing.

As the demand for product assessment eased, the opportunity was taken to conduct a workshop among representatives of research and development organisations active in these two areas in order to reformulate design criteria and to draw up guidelines for laboratory test procedures that would

1. ensure the validity and relevance of test results;

2. optimise economy in testing; and

3. ensure reproducibility of results between laboratories.

The workshop was held at the Experimental Building Station of the Department of Construction from 11th to 13th July 1977. It was attended by representatives of industry, design consultants, universities, governmental research organisations, and local, State and Commonwealth governments. Consensus was reached on loads to be applied during testing and the procedures to be adopted when testing and evaluating the performance of products to be used in cyclone-prone areas.

This document was produced following the circulation among workshop participants of draft guidelines drawn up at the workshop. It comprises recommendations on loading criteria for design purposes and on test methods and evaluation criteria for the assessment of the performance of roof claddings, wall systems and windows.

G.W. Anderson, Chairman
V.R. Beck, Technical Secretary
December 1977

A1. INTRODUCTION

Damage caused by tropical cyclones that have struck the northern Australian coast in recent years has revealed a number of weaknesses in practices commonly adopted for domestic construction. Studies of the damage caused by cyclone Althea which hit Townsville in December 1971 and cyclone Tracy which hit Darwin in December 1974 highlighted the need to have houses structurally engineered.

In general, the introduction of structural engineering principles into the design and construction of houses will be a gradual process. Following cyclone Tracy the Darwin Area Building Manual was introduced. An initial requirement was that all house construction be structurally engineered; in addition a number of novel loading criteria were introduced. But there was little or no advice available on the test procedures, test specimens and evaluation criteria to be adopted when assessing the performance of the building product to be used in cyclone-prone areas. Paucity of advice on evaluation procedures and design criteria to be adopted wastes time and effort and can lead to inappropriate recommendations being produced.

In recognition of the need to have available more comprehensive advisory information on product assessment and evaluation, to reassess existing design criteria, and to facilitate the introduction of structurally engineered components and systems into houses located in cyclone-prone areas, it was decided to conduct a workshop on 'Guidelines for Cyclone product Testing and Evaluation'. The workshop was held at the Experimental Building Station, Department of Construction, Sydney, from 11th to 13th July 1977.

It was intended that the workshop would be a forum where representatives of industry, consultants, universities, CSIRO, and local, State and Commonwealth governments could discuss and reach some consensus on guidelines for the testing and evaluation of products intended for use in cyclone-prone areas. A list of the participants who attended the workshop is given in Appendix 1.

During the first two days of the workshop, papers were presented and discussed; a list is given in Appendix 2. On the third day, the workshop divided into three groups, each under the guidance of a chairman-secretary. The groups developed draft guidelines for loading criteria, roof testing, and wall, impact and window testing. Towards the end of the third day the workshop reconvened and the recommendations from each of the three groups were presented and discussed.

Following the workshop, draft guidelines which had been developed by the three drafting session groups were circulated to workshop participants for comment. Comments received were taken into account and revised draft sections were then directed to the appropriate chairman-secretary of the drafting session groups for final comment prior to the production of the report: 'Guidelines for Cyclone Product Testing and Evaluation'. As the title indicates these are guidelines; mandatory status could be conferred only by their adoption by a statutory authority.

A2. LOADING CRITERIA

A2.1 General

In testing and evaluating structural components and assemblies that are intended for use in low-rise domestic construction of one and two storeys in tropical cyclone-prone areas, the simplified loading criteria given in this chapter are recommended.

A2.2 Exposure

Exposure of domestic housing to wind loads will be classified according to the terrain categories defined in AS 1170, Part 2. In assessing these the following guidelines may be followed:

(a) Houses in suburban areas shielded by at least two rows of houses from open spaces - Category 3. The majority of houses would be expected to be in this category.

(b) For houses on the edge of open areas the terrain category may be determined from Figure 1 and Table 1. In applying these rules the following should be taken into account:

- Spaces narrower than 10 m in the cross-wind direction can be ignored.

- If the building of interest is in an area that is in the process of being built up, then the anticipated exposure conditions after 5 years may be used in the assessment of terrain category.

- If the space S occurs on a slope of more than 1 in 5, then it should be taken as equivalent to a space of twice its size in applying these rules.

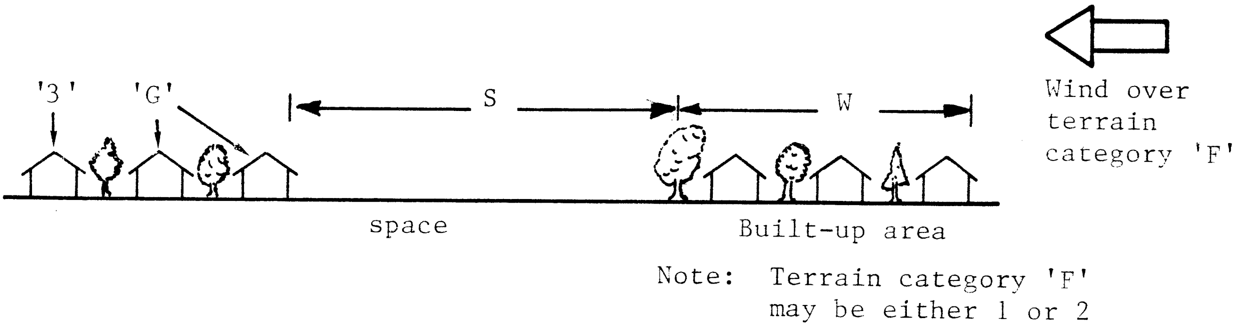

Fig. 1. Definition of S and W

Table 1. SPECIFICATION OF CATEGORY G

Space	Category G		
S	W Greater than 1500 m	W 1500 m to 100 m	W Less than 100 m
Greater than 150 m	2	2	F
50 m to 150 m	3 (2-1/2)*	2	F
Less than 50 m	3 (2-1/2)*	3 (2-1/2)*	F

* Category 2-1/2 to be used if space W consists of bush land only

A2.3 Design Wind Loads - Magnitude

Category 3	:	Loadings as prescribed in Table 2.
Category 2-1/2	:	One-and-a-half times the loadings prescribed for Category 3.
Category 2	:	Twice the loadings prescribed for Category 3.
Category 1	:	Two-and-a-half times the loadings prescribed for Category 3.

In using Table 2 the following should be noted:

(a) The prescribed strength design loads are for normal working strength design. In calculating the required ultimate strengths for performance testing they must be multiplied by appropriate load factors.

(b) The prescribed serviceability loads may be used for evaluating performance in respect of normal deflection, cracking (of masonry, concrete and internal linings) and other serviceability criteria.

(c) Edge areas for cladding loads are the local pressure areas as defined in AS 1170, Part 2. These edge areas, having a width of 10 per cent of the plan width of the building, include the outside edges of the building, hip and ridge lines. For roofs the roof plan width should be used, while for walls the wall plan width may be used.

(d) Structural elements supporting an area of cladding less than 1.5 m^2, over a single span of the supporting element, should be designed to support the local cladding loads as specified. This is mainly directed at roof battens and their connections in edge regions. For structural elements supporting an area of cladding greater than 1.5 m^2 over a single span of the supporting element, the design loading can be taken as the prescribed loads for the structure.

(e) The strength design loads have been derived from AS 1170, Part 2 by:

- assuming the 50-year return period velocity (55 m/s),
- adopting the specified cyclone factor of 1.15,
- assuming a height of 6 m, and
- employing specified pressure coefficients.

The strength design loads are based on the following coefficients:

(i) Structure:

- Full internal pressurisation, C_{pi} = 0.8, combined with
- external pressure coefficients (C_{pe}) on the roof of - 0.9 and on the walls of + 0.8, - 0.6; except for cantilevered eaves where a net C_p of 2.15 has been used which assumes a local C_{pe} of - 1.35 on top of the roof and of + 0.8 on the underside.

(ii) Claddings:

- For loading in general areas and away from edges the same pressure coefficients have been assumed as for the structure.
- For edge loading, local external negative pressure coefficients of - 1.8 on the roof and - 0.9 on the walls have been assumed.
- Full internal pressurisation (C_{pi} = + 0.8 for roofs and + 0.8 or - 0.6 for walls) has been assumed. The exception is for external wall claddings, on walls with an internally clad wall and the cavity between the claddings sealed, when only the external pressures have been assumed to be acting.

(f) The serviceability design loads have been derived from AS 1170, Part 2, assuming the 25-year return period wind velocity (50 m/s), a height of 6 m and normal internal pressurisation with no dominant openings (C_{pi} = - 0.3, + 0.2). It should be noted that the 1.15 cyclone factor has not been employed for the determination of serviceability design loads. The external pressure coefficients have been selected from those used for strength. These criteria are approximately the same as the serviceability criteria used in non-cyclonic areas and this recognises the principle that severe cyclones, for which high strength design loads are required, are very infrequent events to which normal serviceability criteria are not applicable.

Table 2. DESIGN WIND LOADING FOR DOMESTIC CONSTRUCTION IN CATEGORY 3 (UNEXPOSED SUBURBAN) TERRAIN IN TROPICAL CYCLONE-PRONE AREAS

Item	Design Loading, kPa	
	Strength	Serviceability
STRUCTURE:		
Roof - general	1.8	0.8
- cantilevered eaves	2.7*	1.7*
Walls -	1.5	0.9
CLADDING:		
Roof - general	1.8	0.8
- edges	2.7	1.3
Walls generally including windows and doors		
- general	1.5	0.8
- edges	2.1*	0.9*
Walls with external cladding over internally clad wall		
- general	0.9*	0.5
- edges	1.3*	0.8*

NOTE: (1) The prescribed strength loads are for normal working strength design. In calculating the required ultimate strengths they must be multiplied by appropriate load factors.

(2) The design loading on the roof is suction loading.

(3) The loading on walls can be either suction or pressure and the design loading is to be taken as acting in either direction.

* Amended to comply with AS 1170, Part 2-1983.

A2.4 Repeated Loading Criteria

Where repeated load testing is specified to ensure that there is no unacceptable reduction in strength or performance due to the dynamic nature of wind loading, the loading program shown in Table 3 is recommended.

Table 3. RECOMMENDED REPEATED LOADING CRITERIA

Sequence	Loading Range (D = Strength Design Load)	Number of Cycles: Type I (Wall Structures)	Number of Cycles: Type II (Roof Structures Roof and Wall Claddings)
A	0 - 0.625D - 0	800	8000
B	0 - 0.75D - 0	200	2000
C	0 - D - 0	20	200
D	0 - Ultimate Load	1	1

In using Table 3 the following should be noted:

(a) The sequence of the loading cycles should be as indicated in Table 3 or A through to D except as noted in (d) and (e) below.

(b) Repeated loading criteria Type I given in Table 3 are applicable to wall structures. For roof structures, repeated loading criteria Type II are appropriate.

(c) Repeated loading criteria Type II are also appropriate to roof and wall claddings, their fixings and their supporting structural elements where the wind loading is suction and is normal to the plane of the cladding.

(d) It may be necessary to assess the behaviour of wall claddings and wall structures under both suction and positive pressure loadings, applied perpendicular to the plane of the element, to represent the case when there is reversal of the wind loading direction. In this case the repeated loading criteria Type I (applicable for positive pressure loadings) should be applied first followed by repeated loading criteria Type II (applicable for suction loadings) and finally the ultimate load is applied.

(e) For walls in racking, where loads can also be applied in either direction, half the total number of the Type I specified load cycles should be applied in one direction and half applied in the other direction.

This may be achieved by carrying out the specified loading program sequence of A through to C with half the total number of specified cycles applied at each load level in one direction, followed by a repeat of this program in the opposite direction and then the ultimate load test.

Alternatively for each load level, after loading from zero-maximum-zero in one direction, the loading direction is reversed and the next loading cycle is applied in the opposite direction. The loading sequence A through to C is followed and then the ultimate load is applied.

(f) Loading cycles should be not less than 3 seconds in duration for Type I tests or 0.3 seconds for Type II tests.

(g) Recommendations which have been based on repeated load testing at the design load for 10 000 cycles for roof claddings and 1000 cycles for shear panels are considered to satisfy the repeated loading criteria given in Table 3.

A2.5 Impact Testing

In tropical cyclone-prone areas where it is desired to assess the impact resistance of residential buildings or parts of them, the following performance criterion is recommended for rating purposes:

A 4-kg mass having a timber impacting head of nominal 100 mm x 50 mm dimensions shall be used striking with an impact velocity of 15 m/s.

Where testing limitations make it desirable to use an increased mass at lower velocities, this may be done provided the missile has the same energy at impact, the velocity is not decreased by more than 25 per cent, and the specified impacting head is used.

A2.6 Commentary - Loading Criteria

As was noted in the introduction, studies following damage caused by recent tropical cyclones have revealed the need to have houses structurally engineered in cyclone-prone areas. However, the introduction of structural engineering principles into the design of houses will be a gradual process. In a large section of the housing industry, the control and supervision of housing design and construction is not in the hands of people with engineering training and consequently sophisticated codes of practice prepared by engineers for engineers are often not appropriate. The wind-loading code is a good example of this. Its use requires a considerable degree of engineering judgment particularly in relation to the choice of terrain category and internal pressure coefficients. In addition the degree of sophistication of the wind code is far greater than that exercised in the design and construction of housing.

The simplified criteria outlined in these recommendations are considered to be more in keeping with the state of the art of the housing industry and require a much lower degree of engineering skill in their application.

In particular it has been found that the method of specifying the terrain category in AS 1170 is difficult to apply in practice, the occurrence of large open spaces making it difficult to classify terrain categories for specific houses. The basic method included in these recommendations has been tried with a few building surveyors in Melbourne, and found to be easy to apply. It is based on wind tunnel studies which have indicated that for a group of houses subjected to Category 2 wind only the first two rows at the most are subjected to the full velocity.

The loading criteria are presented in terms of design pressures with strength being differentiated from serviceability. Resistance to extreme events, when local damage or severe distortion may be tolerated, is provided for by specifying an ultimate strength equal to the design strength multiplied by a suitable load factor (see subsequent chapters on roof and wall testing). Design pressures are thus based on applying the cyclone factor of 1.15 to the 50-year return period wind velocity and assuming full internal pressurisation (i.e. C_{pi} = + 0.8, - 0.6). The assumption of full internal pressurisation has been adopted since it is considered most likely that a dominant opening will be created at loads in the vicinity of the ultimate load during a tropical cyclone. It should be noted the loading criteria are in terms of design pressures and not ultimate pressures.

On the other hand design pressures for deflection calculations are based on the 25-year return period velocity and on the assumption that windows and doors will be undamaged, which would be reasonable for this event (C_{pi} = + 0.2, - 0.3).

It is inevitable that this approach will lead to some individual houses being overdesigned and perhaps others being underdesigned. The primary object, however, is to limit the impact of tropical cyclones on the community as a whole by reducing the total potential for damage, rather than guaranteeing the absolute security of every individual dwelling. This is not considered to be a serious objection, particularly as the variables and uncertainties inherent in the current design and construction of dwellings are probably of a greater magnitude.

In regard to roof loads it has been assumed that the full internal pressure may be transmitted to the cladding because few ceiling spaces are sealed completely - deliberate ventilation and unbolted trapdoor access being common place. It was also recognised that tiles, because of their leakiness, are subjected to lesser loads than sheet roofing, but lack of technical information precluded any recommendation for lesser design loads in this respect.

After cyclone Tracy it was established that dynamic wind loading effects had been a significant factor in the failure of metal roof claddings. As a consequence the Darwin Area Building Manual adopted a repeated loading requirement for roof claddings of 10 000 cycles at design load followed by an ultimate load test. Subsequent investigations, based on wind tunnel and field observations have shown that these requirements were somewhat conservative. The recommendations in this report are based on the results of these new studies. The repeated loading criteria reflect the fact that the whole structure is subjected to dynamic loading by wind, although those parts of the structure subjected to suction loading tend to be exposed to a much higher frequency of loading. This is shown in the larger number of loading cycles specified for elements subjected to suction loading.

The recommended debris loading criteria also represent a revision of the Darwin criteria in the light of experience and further information both from Darwin and elsewhere. Because of the variety of debris and the lack of detailed knowledge in high winds, the prescribed criteria should not be regarded as providing guaranteed resistance against debris in a cyclone but rather as providing a performance standard for rating purposes which it is believed will provide reasonable protection against penetration. With present knowledge it is not possible to be any more specific.

In conclusion it should be emphasised that these recommendations should not be regarded as superseding AS 1170, Part 2 or the results of detailed research and investigations. They are put forward as a simplified set of criteria which may be used where recourse to a more sophisticated approach is not deemed necessary. For this reason they may well be conservative in some respects, and where a manufacturer believes this to be the case for his particular product he may well consider seeking further technical advice.

A3. TESTING OF ROOF CLADDINGS

A3.1 General

After cyclone Tracy it was established that dynamic wind loading effects had been a significant factor in the failure of metal roof claddings. Consequently it is the intent of these guidelines that all roof cladding systems proposed for cyclone-prone areas be assessed for any degradation in their strength which may result from dynamic wind loading. Accordingly, a repeated-load test procedure is required.

The test methods outlined in this chapter are designed to check the performance of roof claddings for strength under suction load conditions only. Serviceability requirements are considered to be covered in relevant existing standards for the installation of roof claddings.

The test methods do not apply to flashing systems. The fixing of flashing systems should be specified by the manufacturer and the specification should include detailed requirements for fastener type and spacing.

A3.2 Modelling and Test Specimens

The objective of the modelling is to ensure that the region of roofing that is under consideration in the prorotype should be so modelled that the behaviour of cladding and fixings in the test specimen will correspond as closely as possible to their behaviour in the prototype.

It is considered a basic requirement that the magnitude of the maximum load per fastener or fixing in the prototype must be modelled exactly, and that the test specimen be so constructed that these loads are transmitted to the fasteners or fixings in a realistic fashion.

Repeated-load test results are peculiar to the complete test system and so it is impossible to apply test results beyond the conditions modelled in the test specimen (i.e. to similar systems, to increased spans or to increased modelling parameters such as load per fastener and, if appropriate, bending moment or ratio of deflection-to-span). This determines that the most heavily loaded part of the roof cladding in any roof must always be tested.

The fabrication of test specimens should be controlled to avoid conservative results being obtained. In particular, it has been found that the tightness of cladding fasteners has a significant effect on the performance of test specimens, and that the test performance improves with the tightness of the fastener. Accordingly, fasteners in test specimens should not be unrealistically tight.

1. Continuous Cladding Systems (Multi-span Systems). In the testing of multi-span sheet claddings the load per sheet fastener must be modelled exactly, and attention should be given to the modelling of sheet parameters such as bending moments or the ratio of deflection-to-span. Care must also be exercised to avoid undesirable 'side effects' in the modelling, such as over-rotation of purlins, any resonance in the system and, in the case of brittle sheets, unrealistically concentrated loading or impact loading.

Specimen Size. The specimen size necessary to model prototype conditions is considered to be a length equivalent to at least one sheeting span of the prototype and a width sufficient to include at least four sheet-fastening points subjected to maximum loading. The sheeting span used in the model may be different from the span of the prototype in order to achieve correct modelling conditions with the test arrangement used. For cladding systems in which the interlocking of the edges of adjoining sheets is essential to their fastening, the specimen should incorporate at least three interlocking sheets in its width.

2. Discrete Cladding Systems (Single-span Systems). The following recommendations which apply to single-span discrete cladding systems (for example, tiles) at present take no account of any possible venting effects in reducing load or the contribution of any sarking system in resisting wind loading.

In the case of roofing of concrete or terracotta tiles it should be remembered that some tiles in the roof rely solely on cappings and flashings for their fixing; no recommendations are given for the testing of these situations.

For discrete roofing systems involving small span elements it is advised that satisfactory modelling is achieved by applying distributed loads to the individual cladding elements in such a way that their movement is not unrealistically restricted.

Specimen Size: A sufficiently large test specimen must be used so that the behaviour of the test region is as representative of roof behaviour as is possible. This will normally require the loading of a number of adjoining cladding elements which are themselves supported in a realistic manner.

The joints or laps in the roof should be modelled so that all joint types are tested, and the loads are applied in a realistic fashion. For concrete or terracotta roofing tiles laid with staggered side laps, a minimum of six adjoining tiles should be loaded; tiles are to be arranged in two rows having three tiles per row. When tile side-laps are straight, a minimum of four adjoining tiles should be loaded; tiles are to be arranged in two rows having two tiles per row.

A3.3 Loading Criteria

The prototype roofing systems will be subjected to design loads which are defined in Section 2.3 as the strength design loads for roof claddings. The repeated loading criteria to be adopted for roof claddings is loading criteria Type II (for 'Claddings') given in Table 3, Section 2.4.

The required 'Ultimate Load' of the roof cladding assembly, as noted in Table 3 is to be taken as γ times the design load. The value of γ is defined in Table 4 (Section 4.3) and depends on the number of specimens tested.

A3.4 Test Procedure

Repeated load testing is undertaken using loading criteria Type II and the loading sequence given in Table 3, Section 2.4. The design load level employed in the test loading must model the strength design load applied to the prototype system. After repeated load testing the required ultimate load is applied to the test specimen.

A3.5 Evaluation of Test Results

In the final loading application to γ times the design load, no failure (as defined in Sections 3.5, items 1 and 2) can occur during this loading sequence if the cladding system is to be acceptable at the design load level employed in the test loading.

If no failure occurs in the test specimen under repeated loading but a failure occurs under the subsequent static load at a lesser load level than γ times the design load, an estimated value of design load can be obtained by dividing the minimum achieved ultimate load by the appropriate load factor γ. If desired, this reduced design load can then be accepted without retesting the cladding system.

After any failure has occurred in a system under repeated loading, that system should not be resubmitted for test without some modification.

1. Failure of Continuous Cladding Systems. Any disengagement of the sheeting from the purlin should be interpreted as failure. Disengagement may occur by failure of the sheeting-fastener fixing or the fastener-purlin fixing, or by fracture of the fastener.

2. Failure of Discrete Cladding Systems. Any disengagement of the cladding from the supporting structure should be considered a failure. This disengagement may occur by dislodgement or failure of the cladding-fastener fixing, the batten-fastener fixing, the fracture of the fastener, or dislodgment of a cladding element. The fracture of a concrete or terracotta roofing tile could only be neglected if on examination the failure is found to result from a manufacturing imperfection not normally acceptable in the tile.

   Another mode of failure of concrete or terracotta tiles is by disengagement of the batten lug. Test methods will often restrain tiles from sliding down the roof, as may occur in practice. It is therefore recommended that the test specimen be observed during the test to check if the batten lugs lift clear of their supporting battens, and any such behaviour be classed as failure.

A3.6 Reporting of Test Results

It is important to provide sufficient information in the test report to enable subsequent evaluation by others of the test results. It is therefore essential to record full details of the modelling and loading techniques employed, in addition to relevant details peculiar to the test specimen. Relevant details should include:

(a) a description of the cladding,

(b) a description of the fasteners and fixing technique,

(c) a description of the test procedure and loading arrangement,

(d) the simulated design loading,

(e) the applied ultimate load,

(f) the number of specimens tested,

(g) the date of test,

(h) the test performance of the specimens, and

(i) the names of the testing authority and testing officer.

A4. TESTING OF WALL SYSTEMS

A4.1 General

Investigations of damage to houses following cyclone Tracy in Darwin and cyclone Althea in Townsville indicated weaknesses which were present in the construction of walls, in respect of their capacity to transmit horizontal racking forces and uplift forces on the roof to the floor structure.

It is the intent of the following to provide guidance in evaluating the performance of walling systems under racking loads in cyclone-prone areas. Test methods outlined in this chapter can be used to evaluate the serviceability, design and ultimate load capacities of a walling system. In addition to the usual static racking-load tests, a repeated racking-load test procedure is specified for those walling systems whose strength may be degraded under dynamic wind loading.

Included also are notes on the possible degradation of strength of a walling system under the action of combined wind loading; see Section 4.7.

A4.2 Test Assembly

Test assemblies for evaluation purposes should be representative of those used in service. This is particularly important with respect to construction details, point of application of load, and use of any auxiliary methods of restraint including the use of anti-racking and cyclone bolts.

A typical wall assembly for testing purposes would include the wall itself plus a short section of any attached rafters (if any uplift load testing is to be conducted) and floor joists or slab. The wall assembly should be bolted to a reaction frame or floor via the wall assembly's floor joists (or floor slab sections) and can be stabilised by a bracing frame which does not inhibit vertical and horizontal movement in the plane of the wall being tested.

A4.3 Loading Criteria

1. Test Serviceability Load. The test serviceability racking load will be taken as the lowest load to cause a net horizontal displacement of the top edge of the wall assembly, with respect to its bottom edge, equal fo H/300, where H is the distance between the top and bottom edges of the wall assembly. Alternatively the test serviceability load can be taken as that load to cause cracking in the case of concrete or masonry walls.

2. Static Load Testing. For static load testing the smallest ratio between the ultimate static test failure load(s), see Section 4.4, item 1, and the nominated design load of the wall system will be at least equal to the appropriate value of α given in Table 4.

Table 4. MINIMUM RATIO BETWEEN ULTIMATE STATIC AND REPEATED TEST FAILURE LOAD AND NOMINATED DESIGN LOAD

Number of Specimens Tested	Minimum Ratio Between Ultimate Test Failure Loads and Nominated Design Load	
	α	γ
1	2.6	2.0
2	2.2	1.8
5	2.0	1.6

NOTE: (1) $\alpha = \dfrac{\text{Ultimate Static Test Failure Load}}{\text{Nominated Design Load}}$

(2) $\gamma = \dfrac{\text{Ultimate Repeated Test Failure Load}}{\text{Nominated Design Load}}$

3. Repeated Load Testing. It is possible that the racking strength of a wall assembly may be degraded under dynamic wind loading. To investigate the extent of any degradation, repeated racking-load testing should be undertaken. The repeated racking-load test criterion to be adopted for walls is loading criterion Type I (for 'wall structures') given in Table 3, Section 2.4.

   Following repeated load testing the wall assembly is then statically loaded to failure. The smallest ratio between the ultimate repeated test failure load(s), see Section 4.4, item 2, and the nominated design load of the wall system will be at least equal to the appropriate value of γ given in Table 4.

A4.4 Test Procedure

1. Static Load Testing. The racking load is gradually increased to a predetermined limit which may be defined in terms of a maximum allowable net horizontal deflection of H/300, or maximum permissible racking in the case of concrete or masonry walls.

   The racking load is removed and reapplied in the opposite direction to the same limit. The lesser of the two loads obtained at the serviceability limits is defined as the test serviceability load.

   The wall assembly is then loaded in racking to its ultimate load which is taken as the maximum load resisted by the assembly irrespective of distortion or local failures. This load is defined as the ultimate static test failure load.

2. Repeated Load Testing. When repeated racking-load testing is undertaken, use the loading criteria and the sequence of loads to be applied to the wall assembly as given in Table 3, Section 2.4. After repeated load testing the wall assembly is loaded in racking to its ultimate load which is taken as the maximum load resisted by the assembly irrespective of distortion or local failures. This load is defined as the ultimate repeated test failure load.

   The repeated loading criteria in Table 3 of Section 2.4 is given in terms of the design load of the wall system. A preliminary estimate of the design load of the wall assembly may be made by equating this to the smallest load obtained by dividing each of the ultimate static test failure load(s) by the appropriate value of α; see Table 4.

A4.5 Evaluation of Test Results

The test serviceability load can be determined by reference to sub-sections 4.3 item 1 and 4.4 item 1.

The nominated design load of the wall system will be taken as the smallest load obtained by:

(a) dividing each of the ultimate static test failure load(s) by the appropriate value of α, and

(b) if repeated load testing is undertaken dividing each of the ultimate repeated test failure load(s) by the appropriate value of γ.

The values of α and γ are given in Table 4. If an assembly fails prior to the completion of repeated load testing, this system should not be resubmitted for test without some modification.

The recommended serviceability and design loads for a given wall system should not exceed the test serviceability load and the nominated design load of the system respectively. The required serviceability and strength design loads of a walling system are given in Section 2.3.

A4.6 Reporting of Test Results

It is important to provide sufficient information in the test report to enable subsequent evaluation by others of the test results. Relevant details should include:

(a) A description of the wall assembly including dimensions of the assembly.

(b) A description of the test procedure, loading arrangement and mounting details.

(c) Static load testing data stating:

- number of assemblies tested
- test serviceability load and criteria used
- ultimate static test failure load(s)
- type of failure mode and sequence

(d) Repeated load testing data stating:

- number of assemblies tested
- details of repeated loading program
- ultimate repeated test failure load(s)
- type of failure mode and sequence

(e) Recommended serviceability and design loads.

A4.7 Note on Combined Loading

Under the action of the wind loading, a wall assembly which is subjected to racking loads can also be subjected to wind loading normal to the plane of the wall. This may be either suction or pressure loading. Depending on the type of construction the wall assembly may also be subjected to simultaneous uplift loading imposed from the roof structure. While no detailed recommendations are currently available it may be necessary to consider what effects, if any, load interaction and debris attack have on degrading the racking strength of a wall assembly which has been evaluated under racking loads only.

A5. IMPACT TESTING

A5.1 General

It is the intent of the following to provide guidance in assessing the performance against impact of those external parts of the dwelling structure where impact resistance is deemed necessary.

Testing to the prescribed impact criteria, while not guaranteeing resistance against impact, will provide reasonable protection against the penetration of debris to those parts of the dwelling envelope which meet the prescribed criteria.

A5.2 Test Assembly

The test specimen, which should be typical of production units proposed for use, should be mounted in a manner that closely simulates the proposed method of attachment to the building. Doors, shutters, windows, wall sections or other parts of the structure intended to be subjected to impact testing should be complete with all fittings and connections. Each test specimen should then be fixed to a rigid supporting frame with the attachments proposed for use.

A5.3 Loading Criteria

The loading criteria to be adopted for impact testing are given in Section 2.5.

A5.4 Test Procedure

It is permissible that a new test specimen be used for each specified impact test, but only one specimen need be used. At least two impact tests should be conducted.

The test specimen must be mounted in such a position that the projectile will strike the specimen normal to its surface and within the zone specified below:

(a) One test will be conducted such that the point of impact is within 300 mm of the centre of the test specimen.

(b) Further impact testing will be conducted such that in the case of:

(i) opening doors, windows, screens and shutters, the point of impact will be within 300 mm of typical sliding, hinging or opening and locking attachments;

(ii) non-opening components or parts of the structure, the point of impact will be within 300 mm of a supporting frame member.

A5.5 Evaluation of Test Results

Where resistance to penetration is the evaluation criterion, then a building component or assembly is considered acceptable provided that under each of the specified impact tests the specimen completely resists penetration.

Should the missile partly or fully penetrate the test specimen then it is permissible to conduct two subsequent impact tests using new test specimens; both impact tests will be conducted according to Section 5.4. Should the new test specimens completely resist penetration from the subsequent impact tests, the original prototype component or assembly can be considered as acceptable.

A5.6 Reporting Test Results

It is important to provide sufficient information in the test report to enable subsequent evaluation by others of the test results. Relevant details should include:

(a) A description of the test specimen together with manufacturer's model number if appropriate or any other identification.

(b) A description of the mounting details for the test specimen(s).

(c) A description of the loading arrangement adopted for testing.

(d) Cross-sectional area, mass and strike velocity of the projectile.

(e) Location of impacts on the test specimen(s).

(f) A description of the condition of the test specimen(s) after testing, including details of any damage, penetration of the projectile, residual deflection and any other pertinent observations.

(g) Comments as to whether the test specimen(s) meets the intent of the guidelines.

A6. WINDOW PERFORMANCE

A6.1 General

The Standards Association of Australia has published two standards relating to aluminium windows. These are:

(a) AS2047-1977: Australian Standard Specification for Aluminium Windows. This specification details materials, construction, corrosion protection and performance test standards for aluminium windows and sliding doors installed in external walls of buildings.

(b) AS 2048-1977: Australian Standard Code of Practice for Installation and Maintenance of Aluminium Windows in Buildings. This code sets out requirements for the installation and maintenance of aluminium windows in buildings.

A6.2 Performance Test Requirements

AS 2047 details test procedures that a window manufacturer shall employ when establishing that a window complies with the specified requirements for the nominated rating of the window. This standard also requires that each window have stamped on the frame the following information:

(a) The manufacturer's identification mark.

(b) The window rating (in Pascals).

A6.3 Evaluation of Test Results

The window rating, as determined by the manufacturer according to AS 2047, should not be less than the specified pressures for windows, appropriate to strength requirements, as given in Section 2.3.

A6.4 Installation

The window frame should be attached to the building structure according to the manufacturer's recommendations.

APPENDIX 1

PARTICIPANTS

UNIVERSITIES

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Professor W.H. Melbourne	Monash University
Professor L.K. Stevens	Melbourne University
Professor G.R. Walker	James Cook University

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Mr. L.R. Harding	Public Works Department, W.A.
Mr. P. Johnson	Department of Productivity
Mr. D. Mitchell	Darwin Reconstruction Commission
Mr. G.W. Anderson	Department of Construction
Mr. V.R. Beck	Department of Construction
Mr. C.T.J. Bubb	Department of Construction
Mr. N. Law	Department of Construction
Mr. J. Morgan	Department of Construction

Formulation Guidelines

Workshop participants formed three groups to formulate guidelines on:

1. Loading Requirements
   Chairman/Secretary: G.R. Walker

2. Roof Testing
   Chairman: D. Mitchell
   Secretary: J. Morgan

3. Wall, Window, Impact Testing
   Chairman/Secretary: R.L. Andrews

APPENDIX 2

PAPERS PRESENTED AT THE WORKSHOP

Wind Loading Criteria

Wind Terrain Categories	R.H. Leicester and G.F. Reardon
The Nature of Wind Loading on Low-Rise Buildings	J.D. Holmes
Total Wind Loads on Low-Rise Buildings	G.F. Reardon and R.H. Leicester
Simplified Wind Loading Criteria for the Design of Houses	G.R. Walker
Recommended Interim Design Criteria for Cyclone-Prone Areas	G.F. Reardon
Loading Cycles for Simulation of Wind Loading	W.H. Melbourne
Random Wind Loading of Metal Cladding	V.R. Beck
Wind Driven Missiles	R.H. Leicester and G.F. Reardon

General Test Requirements

Basic Requirements of Standard Performance Tests	G.R. Walker
Effect of Sample Size	R.H. Leicester

Roof Testing

Roof Sheet Testing	N.H. Best
Roof Testing for Cyclonic Winds	C.J. Curtis
Concrete Roof Tile Testing	R. Aarons
Dynamic Load Testing of Roof Sheeting	J. Morgan

Wall Testing

Investigation into Wall Framing	J.C. Emmerig
Report on Shear Panel Testing - Darwin	H. Jhamb*
The James Cook University Wall Testing Machine	G.R. Walker

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*Mr. H. Jhamb is a Principal Engineer, Structural, with Northern Territory Region, Department of Construction. The paper was presented by Mr. D. Mitchell.

Brickwork in Cyclones	P.H. Denton
The Need for Repeated Suction Loading on Walls	V.R. Beck

<u>Impact Testing</u>

Testing of Light-Weight Wall Cladding Systems - Impact Test Methods	P.U.A. Grossman
Procedure for Impact Testing Used by the Division of Building Research, CSIRO	P.U.A. Grossman
Impact Testing of Building Products for Cyclone-Prone Areas	P.I. Johnson
Wall Performance-Impact Test Methods	N.H. Best

<u>Window Testing</u>

Aluminium Windows	F.J. Sloggett
Testing Windows	N. Law

<u>Background Paper</u>

Derivation of Repeated Loading Criteria and Load Factors	V.R. Beck

This paper was prepared after the workshop to provide some background on the recommended repeated-loading criteria and load factors appearing in the report 'Guidelines on Cyclone Product Testing and Evaluation'.