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EXPERIENCES WITH A CYCLIC WALL BRACING TEST AND EVALUATION PROCEDURE

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Synopsis

A cyclic wall bracing test and evaluation procedure has been developed primarily for use with the New Zealand Code of Practice for light timber frame construction, but it can also be used for buildings which are the subject of specific structural engineering design.

This procedure enables the wall bracing performance of various forms of light timber frame wall construction, or similar constructions of other materials, to be determined with respect to both wind and earthquake racking loads.

Both the procedure and the revised light timber frame code were available early in 1979 and since then a number of wall constructions have been tested in accordance with the procedure and some of the experiences of this testing are reported in this paper.

This is an amended version of a paper first presented to New Zealand Institution of Engineers Annual Conference, Auckland, February 1981

1. INTRODUCTION

NZS 3604[1] details a number of methods of light timber framed wall constructions which can serve as bracing elements to resist lateral wind and earthquake loadings applied to the walls. Other methods of constructing walls may be used provided their bracing performance is determined using a specified wall bracing test and evaluation procedure[2] (hereafter referred to as "P21").

"P21" can also be used to determine the design racking resistance applicable to a particular wall construction which is to be used in a specifically designed building, where such a racking resistance cannot be readily obtained by rational structural calculation.

Since early in 1979 more than 120 specimens representing a wide range of wall bracing element constructions have been tested. This testing has confirmed the suitability of the testing and evaluation procedures, but it has shown some problems related to the simulation of actual constructions and has also indicated where minor amendments to the procedures may be required.

2. EXPERIENCES

2.1 Bracing element constructions

The following lists in general terms those types of wall constructions which have been tested and on which the reported experiences are based. It is not possible for reasons of confidentiality to be specific about the particular wall bracing elements which have been tested. In a number of instances the testing has been conducted on only a single specimen during the development of a new product, and have been reported only to the client concerned.

- Timber framing clad with profiled sheet steel, with and without diagonal metal angle braces.

- Timber framing lined with gypsum based sheets, with and without diagonal braces.

- Timber framing sheathed or clad with plywood, wood based sheets or asbestos cement based sheets.

- Timber framing lined with gypsum based sheets, having a metal angle brace and clad with weatherboards.

- Timber framing lined with gypsum based sheets and having double diagonals of flat metal strap.

- Composite panels for both exterior and interior walls with various combinations of cladding and lining principally utilising wood-based, gypsum-based, and asbestos cement sheets. (Panels invariably between 900mm and 1200mm wide).

2.2 Test facilities

Most of the testing has been conducted at the following testing laboratories:

- Building Research Association of New Zealand, Wellington.

- Auckland Industrial Development Division, DSIR.

- Henderson & Pollard Ltd, Auckland.

- Winstone Wallboards Ltd, Auckland.

- Applied Research Office, University of Auckland.

- Australasian Research & Development Ltd, Napier.

The remainder of the testing has been conducted 'in-house' by Building Contractors and Consulting Engineers.

2.3 Application of "P21"

Experiences with the interpretation and application of "P21" are now discussed in relation to the enumerated items in that document:

2.3.1 P21 Item 2 *"Test and evaluation objectives"*

"P21" is based on design loads determined by the "alternative method" of design according to NZS 4203[3] but the test method does in fact require that the equivalent "strength method" design loads be achieved. Hence the determined bracing rating in kilonewtons (obtained directly or converted from BRACING UNITS) can be multiplied by the factors 1.25 and 1.3 to determine the equivalent "strength method" design loads for earthquake and wind respectively.

2.3.2 P21 Item 3 "Features of test method"

The recommended H/300 horizontal deflection limitation is based on the performance characteristics of traditional light frame constructions, and on criteria adopted by some other countries. There does not appear to be any documented reasons for this limit but rather it is "about right from experience".

The racking performance of walls must satisfy the requirements of NZS 1900 : Chapter 8[4] that the building achieves the following:

"(a) All loads likely to be sustained during the life of the building will be sustained with an adequate margin of safety.

(b) Deformations of the building will not exceed acceptable levels.

(c) In events that occur occasionally, such as moderate earthquakes and severe winds, structural damage will be avoided and other damage will be minimised.

(d) In events that occur very seldom, such as major earthquakes and extreme winds, collapse and irreparable damage will be avoided, and the probability of injury to or loss of life of people in and around the building will be minimised."

The strength requirements are straightforward, but the stiffness and non-structural damage ones are subjective. These latter essentially relate to sound (as it relates to movement), vibration, perceived movement and cracking of surface finishes and because of the extremely variable nature of the constructions being tested and evaluated there is scope for variation of the H/300 limit. Such variation, though, can only result from the subjective assessment of the performance of a particular type of construction over a period of time.

Some prototype bracing elements under test have proved to be comparatively flexible having bracing ratings equivalent to as little as 10 bracing units per metre length of wall. This low result has meant that they have not achieved the minimum rating of 50 bracing units that NZS 3604 specifies, although some have met the strength criteria. Most of these bracing elements have been either 900mm or 1200m wide and the flexibility has largely been a function of the stiffness of the panel to floor connection which controls the rotation of the element. These connections have often been subsequently modified to stiffen them to achieve the 50 bracing units minimum rating.

The relative flexibility of some constructions and hence their inability to achieve the specified 50 bracing unit rating has raised the questions: why the need to achieve 50? So long as a building has the minimum total amount of bracing distributed in the required manner, does it matter how it is achieved? It could be argued that a pair of bracing panels each having a rating of 25 bracing units, could comprise a single bracing element for the purposes of satisfying the minimum 50 bracing unit requirement in NZS 3604.

For wall bracing elements intended for use in non-inhabited buildings, many of the performance criteria applicable to inhabited buildings do not apply and hence the recommended H/300 limitation can be relaxed. Currently a value of H/150 is being recommended in such instances in order to gain experience on this subject since no other recommendations are available.

2.3.3 P21 Item 4.2.1 "Number"

The requirement for a minimum of three specimens has on occasions been considered by clients to be unduly expensive, particularly since up to three different specimens are often required during the development phase. On the other hand, the variability of timber framed constructions, as again evidenced by the wall bracing testing to date, indicates that the average of only three specimens can result in a particular construction being over-rated. Timber engineering design principles would require that a rating obtained from three specimens would be reduced to take account of this variability. "P21" recognises that any such over-rating which may occur in practice is usually compensated for in complete buildings by the bracing effectiveness of non-structural claddings, linings, windows, non-bracing walls and the like.

One approach recommended in Australia by Reardon[5] for similar testing is to factor the derived rating depending upon how many specimens are tested. For "P21" this would mean that, on a similar basis as used for determining the sampling factor (K_{19}) for the testing section of NZS 3603[6], then factors such as the following would be applied to the derived bracing values:

No of Specimens	Factor
1	0.8
2	0.9
3	1.0

"P21" could be amended along these lines if there is a demand for this to be done.

2.3.4 P21 Item 4.2.2 "Construction"

Simulation: The question of what is "representative" presents a number of problems and for some constructions, particularly the narrower bracing elements, can greatly influence the bracing rating.

Apart from testing a complete building, the most representative specimen is a complete wall, either internal or external. Two bracing tests of this type have been conducted but usually such tests are restricted for use with a fixed building plan design. In most instances building designers wish to retain the greatest possible flexibility in terms of wall length and opening sizes and locations. This means that wall bracing elements are usually designed as portions of wall 900mm or wider and located between windows, doors and corners. With internal wall bracing elements the lengths usually tested are in the range 1.8m to 3.0m.

Vertical restraint: In practice the sections of wall each side of a bracing element, including framing etc. around openings, offer restraint, and in particular vertical restraint, to the panels. It is the representation of this restraint which has proved the most difficult.

One method of providing this restraint for traditionally framed walls is illustrated in Appendix I of "P21" with two studs being added at each end of the bracing element to simulate the continuation of a wall frame or an adjoining wall at right angles. On a number of occasions this "example of a means" given in "P21" has been taken out of context and used on specimens where it is not applicable.

The most important aspect of providing vertical restraint is the assessment of both the stiffness and the strength of such restraint. This is particularly true of the narrower panels where the majority of the horizontal movement of the top plate has shown to be due to rotation of the total element, including the boundary framing members, rather than shear and rotation of the individual sheet panels.

In general the representation of this vertical restraint is considered to have been less than realistic resulting in the bracing elements being under-rated to varying degrees. As previously mentioned, this also in part helps balance the over-rating which may be obtained by averaging the performance of only three quite variable specimens.

The effort and expense relating to this restraint must obviously be assessed relative to the rating required for the particular application. In most instances ratings equivalent to approximately 40 to 50 bracing units per metre length of wall will be adequate for the majority of home designs and hence higher ratings have not been sought.

2.3.5 P21 Item 4.2.3 "Condition"

Experiences with this aspect of "P21" have already resulted in an addendum to "P21" as follows:

> "(Note: The stiffness and strength of fastenings, in particular metal strap fasteners which may be used between studs and plates or joists, are markedly affected by timber shrinkage such as occurs when framing is assembled when 'wet' but is 'dry' in service. The test specimen design and construction must ensure that such effects are adequately accounted for.)"

Most timber framed bracing elements tested to date have, because of the time factor, been constructed using dry (16-20% moisture content) framing timber whereas in most buildings wet (greater than 30% moisture content) timber is used, with the claddings and linings being fixed during the drying out of that timber. During this drying out the bottom plates and floor joists shrink transverse to the direction of the grain leaving gaps between studs, bottom plates, floor decking and floor joists. Recent work carried out by the Building Research Association of New Zealand on 800mm wide bracing elements[10] has shown that the total amount of such gaps between studs and joists is typically around 2mm.

The narrower the bracing elements, the greater the relative effect of element rotation. This rotation is not only a result of the lifting of one side of the element but can also be a result of depression of the other side, depression which can result from the closing of the gaps at the stud/bottom plate, bottom plate/floor decking, floor decking/floor joist joints.

Where flat metal straps are used to connect studs to floor joists for sheet bracing elements, as detailed in NZS 3604, then these straps buckle when the studs are in compression and the gaps close. For the panels recently tested by the Building Research Association using such straps the bracing rating was only 30 bracing units. If, however, these same panels had been constructed using dry framing timber then ratings in excess of 50 bracing units would have been achieved.

2.3.6 P21 Item 4.3.2 "Fixing"

Floor structure simulation: "P21" does not specify whether the movement of the floor framing should be allowed for in the test or not, or whether it is only the stiffness and strength of the bracing element and its connections which are required. This has resulted in some varied results due to the flexibility of the floor joists to which elements have been fixed. This effect has been most pronounced when a narrow panel is fixed in the middle of the span of 100mm deep joists.

It is now considered impracticable and unrealistic to model and allow for floor structure movement. Floor framing members, to which the bracing element is attached, should be fixed as rigidly as is possible to the testing frame. The present recommendation in "P21" in this respect will require modification.

Top edge support: Testing has shown that it is essential to support the top edge of the element at two points to prevent twisting. This can be achieved by using rollers on each side of the top edge adjacent to each corner, or by using horizontal pivoted members fixed to the top plate.

2.3.7 P21 Item 4.3.3 "Vertical dead load"

In the testing to date, dead load has seldom been applied. Because most constructions have been designed for use in either loadbearing or non-loadbearing situations and the latter will always have the lowest bracing rating, then it has to be the one simulated in the tests.

The more significant factor in this respect is the vertical restraint discussed earlier, which occurs in practice when an element rotates and the side which is lifting is restrained by a roof truss, rafter, upper storey floor joist and the like. Representation of these restraints has shown to be of far greater importance than providing the relatively small amount of dead load which is applied by these framing members.

2.3.8 P21 Item 4.3.4 "Racking load"

Connection to loading mechanism: A few problems have been experienced with the connection of the loading mechanism to the bracing element. Care is required to ensure that the method of load transfer is in fact representative of the actual situation.

One example in practice is where a ceiling is connected to an internal wall bracing element by way of ceiling battens connected to ceiling joists or trusses. The test load should then also be applied through framing representing this situation. This correct simulation will then enable the performance of the fixings between the element and ceiling framing to be included in the overall performance. On some occasions where the simulation has in fact been correct, these fixings have failed through lack of stiffness or strength.

Rate of loading: The use of gravity loads (e.g. bags of cement) to apply racking loads, and the use of other slow-acting devices, does lead to low bracing values. Because in most instances nails, bolts or screws in timber are used as part of the fixings of the bracing elements, and these fixings are invariably very highly loaded, then a large amount of creep occurs and the increased deflection (as a result of slow rates of loading) reduces the measured bracing value.

Since both wind and earthquake loads are applied at a fast rate and are transitory in nature, any testing involving a long duration of loading or a slow rate of loading will produce a conservative result. Testing conducted by the Building Research Association for example is done at the recommended maximum uniform rate of 1.5mm of top plate deflection per second with continuous recording of load and deflection. The use of such elaborate equipment is not always possible or necessary, but on the other hand the limitations of using non-uniform and/or slow loading rates on bracing elements which exhibit plastic deformation must be recognised. Where manual methods are used the application of loads and recording of deflections should be done as quickly as possible.

2.3.9 P21 Item 4.3.5 "Measurement"

Experiences with most testing rigs has shown that horizontal slip of the element being tested, relative to the reaction frame, does not occur with the bolting and clamp-down systems usually employed and hence after initial checking of a testing system this measurement requirement is no longer carried out.

"P21" refers to "slip of the bottom of the wall relative to the reaction frame". This should be interpreted as the slip of the total specimen including floor framing.

2.3.10 P21 Item 5.1 "Determination of test loads and deflection limits"

The option of determining unequal ratings for wind and earthquake loads has occasionally been used for single storey building systems which have light roofs where the design wind load exceeds that for earthquake. This option has also been usefully employed where excessive degradation under cycle loading occurs if the maximum deflection limits for earthquake loads are used, but where the degradation is acceptable at lower deflection limits. The rating achieved for earthquake loads in such instances is less than that for wind loads, but nonetheless it can be acceptable for design purposes.

2.3.11 P21 Item 5.2 "Test procedure"

Some difficulty has been experienced in initial applications of this section and it has been suggested that a typical load/deflection figure with the recording points marked, similar to that in the original bracing test[11], should be included for reference. An example of such a figure is shown in Appendix 1.

2.3.12 P21 Item 6 "Presentation of test data"

The sample data sheet in Appendix 4 of "P21" is designed to be used with any one of the different testing procedures, and hence is relatively complex. The majority of the testing to date has been done on 2.4m high walls with the earthquake and wind ratings being equal and occurring at deflections of $\pm$ 8mm thus leaving some portions of the data sheet blank. In some instances testing agencies have drawn up data sheets to suit this common type of test.

2.3.13 P21 Item 7.1.1 "Symmetry of performance"

The provisions of item 7.1.1(b) have been overlooked in a number of instances to date.

Asymmetry in performance usually occurs with bracing elements which incorporate a single diagonal brace, or which have differing end restraint conditions such as occur with an internal wall which at one end abuts an external wall. Where this asymmetry occurs then the data from each loading cycle must be assessed with respect to the provisions of this item of "P21" before amalgamating the data.

Significant assymetry has also occasionally occurred with apparently symmetrically constructed panels where the workmanship of the end fixings and the restraint details has been quite variable. Usually this situation can be rectified by improved workmanship, however if it is considered that the assymetry is indicative of actual constructions then the test specimens should be regarded as if they were assymetrically constructed.

2.3.14 P21 Item 7.1.4 "Recovery after loading"

Very few constructions have failed to satisfy this criteria. Since the residual deflection is a measure of the degree of "yielding" of the specimen, those specimens which have failed in this respect have invariably had insufficient diameter nails or number of nail fastenings which are loaded in shear. An increase in number and/or diameter of nails has resulted not only in a reduction in the residual deflection but also an increased overall performance.

One other cause of this type of failure has occurred where nails were loaded in withdrawal, such as a stud-to-plate joint, and had partially withdrawn when loaded and remained that way when the load was removed. In such instances it is usually necessary to redesign the method of jointing.

For bracing elements to be used in uninhabited buildings the recommended alternative to the value of X (H/300) previously discussed automatically provides for increased residual deflections for such buildings.

2.3.15 P21 Item 7.1.5 "Resistance to repeated loading"

For most constructions tested "yielding" has occurred during the first of the eight cycles to "Ymm". This yielding has been the result of, or a combination of, the following:

(a) Fracture of material around a fastening, as can occur for example in nail fixed gypsum based sheets.

(b) Withdrawal of fastenings such as nails and screws.

(c) Compression of material adjacent to a fastening, commonly of wood adjacent to nails, screws or bolts.

(d) Plastic bending of metal fastenings such as nails, bolts or brackets.

"Yielding" as a result of (a) and/or (b) is most likely to result in degradation under repeated loading whereas yielding of types (c) and/or (d) seldom does to any significant degree.

No lack of reserve in strength has been apparent in testing to date, but some prototype constructions have had difficulty in achieving the required ductility, as given by the deflection limit Y.

3. NZS 3604 RATINGS

Much of the testing has confirmed bracing ratings assigned by Table 20 of NZS 3604 to various types of construction. But the testing has thrown doubt on the validity of the ratings of some of the sheet bracing elements.

Because of the effects of timber shrinkage discussed earlier, it is apparent that the ratings for sheet bracing elements are only applicable where dry framing timber is used. When wet framing is used the ratings would have to be reduced, the reduction being variable and being greatest (up to 50%) for the narrowest (900mm) panels.

The effect of boundary framing member joint movements, as highlighted by using wet framing, also indicates that the ratings for type 10 sheet bracing elements, which have sheet panel materials on both faces, may be over-rated for the narrower panels.

The significance of element rotation compared with shear in narrow panels has also, in part, indicated another significant anomaly in NZS 3604. Walls can be up to 4.8m high whereas the ratings for wall bracing elements, as given in Table 20 of NZS 3604, are based on the testing of 2.4m high walls. They are only applicable to walls of other heights if the racking is solely a result of shear effects and not element rotation or panel rotation. Since for most wall bracing elements less than approximately 2.4m wide the racking deflection has a significant portion resulting from these rotations (as discussed previously), then some of the bracing ratings assigned by Table 20 should be modified with respect to bracing element height. As an example, it is estimated that sheet bracing elements 900mm to 1200mm wide and 4.8m high should have their ratings reduced by approximately 40%.

These matters require further investigation in order that NZS 3604 can be amended accordingly.

4. SUMMARY

The suitability of "P21" for its intended purpose has been confirmed by its use for testing a variety of wall bracing element constructions.

Should a reduction in the cost of testing be considered desirable in future, then consideration could be given to testing only one or two specimens and applying a suitable factor to the derived ratings. The economics of such testing would need to be evaluated relative to the reduced rating that would be obtained.

The test simulation of the actual construction and restraint of a wall bracing element in a building significantly affects its performance. The lack of simulated element edge restraint results in the element's performance being dominated by overall rotatation, particularly the narrower elements. The restraint simulation used in the tests has usually resulted in the constructions being under-rated.

Simulating in the test specimen the actual construction sequence with respect to moisture content, and hence allowing for the effects of timber shrinkage, can be very important.

The testing to date has confirmed that analytical methods developed overseas for determining bracing performance where sheet panels are used cannot be used in New Zealand because they do not take into account boundary framing joint movements which occur with most of our constructions.

Slow and/or non-uniform rates of loading on constructions where highly stressed mechanical joints in timber are used, produce unnecessarily low ratings as a result of creep. In such instances it is recommended that the loading rate be as fast as is practicable.

The relative flexibility of some types of constructions has meant that the minimum bracing element rating of 50 bracing units, required by NZS 3604, cannot be achieved. The need for such a criteria should be reviewed, but in the meantime pairs of elements could be used to satisfy this requirement.

The effects of timber shrinkage on the boundary framing member joints and also the movements of these joints indicates that a number of the sheet bracing element constructions specified in NZS 3604 are significantly over-rated because of lack of stiffness. Further work is required to investigate this matter.

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