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FIRE RESISTANCE OF LOADBEARING TIMBER WALLS

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FIRE RESISTANCE OF LOADBEARING TIMBER WALLS

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ABSTRACT

Since 1978, Amendment 12 to NZS 1900 Chapter 5, Fire Resisting Construction and Means of Egress, has permitted the construction of commercial buildings up to four storeys. Most of the buildings constructed under this provision have used substantial timber members whose fire resistance is well established by the rate of char method. However, four storey buildings could also be designed using light timber frame construction, but the rate of char method is not appropriate to calculate the fire resistance of such structures. At present the only approvals for loadbearing timber stud walls in the Standards Association of New Zealand, (SANZ) Miscellaneous Publication MP9:1980, Fire Properties of Building Materials and Elements of Structure, are notional ones based on data from non-loaded tests. This paper describes the development of a facility to test loadbearing fire-rated stud walls and also discusses the correlation of the results obtained using the "onset of char" method suggested in MP9:1980.

1. BACKGROUND

In New Zealand the use of fire resistance rated, non-loadbearing partitions in commercial and industrial buildings is commonplace. Many systems have been tested and approved for such use. However, in 1978 the changes contained in Amendment 12 to the NZS 1900 Model Building Bylaw Chapter 5, Fire Resisting Construction and Means of Egress, [1] allowed timber structures to be constructed up to four storeys in height. Such buildings are presently only permitted in certain fire risk groups and also must be fully fitted with sprinklers.

To date such wooden buildings have mainly been constructed using heavy timber sections as discrete members as in the Odlins building in Petone, but there is no reason why loadbearing light timber framing should not be used. At the time of writing a further amendment (No. 16) to the bylaw is under consideration and this proposes reduction of the fire ratings of many walls by up to 50% of the present requirement. The changes envisaged in this amendment will make the use of loadbearing timber frame structures far more attractive, and therefore there is a need to have tested and approved fire resistance rated systems available for use by designers.

This paper looks at the work conducted by BRANZ on developing methods of assessing the fire resistance of loadbearing timber walls using the "onset of char" method as well as the development of a wall loading test frame to directly test the fire resistance of such constructions.

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2. DEFINITIONS

It is important to understand that by definition [2] the term "fire resistance" applies to "that property by virtue of which an element of a structure as a whole, functions satisfactorily for a specified period whilst subjected to a prescribed heat influence and load". In practice this requires that an element of structure have certain insulation properties (insulation), retain its integrity to the passage of flames or hot gases (flaming) and, if loadbearing, continue to support the load it was intended to carry (collapse). This definition precludes the application of the term fire resistance to individual members of which an element is constructed and only refers to complete elements such as floors, walls, and columns.

Although it has been customary for a loadbearing element of structure which is tested for fire resistance to be subjected to the maximum design load to induce the normally expected stresses there have been some developments in an alternataive method using the time taken for the structural member to reach a critical temperature. When testing fire protection systems for steel members, as an alternative to testing with a load applied the time taken for the average temperature of members to reach 500 or 550°C is taken as the time to failure. At this temperature research has shown that the steel will begin to yield and hence will not be able to perform its loadbearing function.

For heavy timber members the concept of char rate is well known and used; the figure usually accepted being a rate of 0.6 mm per minute. However, in the Standards Association of New Zealand (SANZ) Miscellaneous Publication MP9:1980 Fire Properties of Building Materials and Elements of Structure. Part 8, Fire Resistance Rating of Load Bearing Timber Elements, [3] an alternative method is proposed for use with constructions using light timber elements such as timber stud walls and timber joist floors. The "onset of char" method assumes that up to the time that charring begins in the supporting timber member, collapse would not occur even if the element had been fully loaded.

3. DEVELOPMENT OF "ONSET OF CHAR" METHOD

As mentioned earlier this concept was introduced as an alternative to conducting fire resistance tests on "loaded" specimens. However, only the concept was advanced, and the Fire Ratings Committee of SANZ which, at present, gives approvals of fire ratings, needs advice on how to apply it in practice.

The first problem was to decide how to measure the onset of char in a timber framed structure fully lined on both sides. A number of small scale tests were conducted to evaluate different types of thermocouples as well as their placement. The results from these tests indicated that the best method to indicate the onset of char was to use a 1 mm diameter sheathed thermocouple placed in a hole drilled 5 mm back and parallel to the face of the stud nearest the furnace. This ensured the thermocouple followed an isotherm and hence did not gain or lose heat. From other small scale tests a temperature of 300°C was chosen to indicate onset of char. This relates well to published data [5,6] for temperature of pyrolysis of around 290°C. Some further pilot scale furnace tests were performed and when the temperature of the buried thermocouples reached 300°C the tests were stopped and the specimens removed, extinguished and thoroughly dowsed with water to prevent further charring. Inspection showed that the visible charring had just reached the location of the thermocouple. Hence it was felt this method could be used in a manner analogous to that for steel temperatures as detailed earlier.

4. WALL LOADING TEST FRAME

To check the results from the "onset of char" method with actual tests conducted on loadbearing specimens, a frame was designed and constructed to function as a self contained specimen holder and wall loading frame.

The outline of the 4 m high x 3 m wall loading test frame is shown in Figure 1 with the load being applied via three jacks each with a capacity of 100 kN. Hence the total load capacity is almost 300 kN which was calculated to be sufficient to model the maximum expected load on a four storey timber frame structure [7]. Ideally the specimen should be in a similar structural environment to that expected in practice. The support frame however needed to be capable of accepting a range of wall thicknesses and stud spacings for reasons of economy.

In practice, loads would be applied at discrete points on the top plate by floor joists etc, but due to the requirements of frame adaptability it was considered impractical to model this aspect.

The top and bottom beams were therefore designed to minimise the differential deflection in the plane of the wall at full load to less than one millimetre. Initially the moving platen was restrained by lubricated steel guides at either end. However this allowed a limited amount of rotation of the platen to occur at any time during the test. This was considered unrepresentative of actual restraint of walls in practice. A restraint mechanism was therefore devised which fixes the bottom plate throughout the test but at the same time allows vertical movement of the platen with very little friction.

The implications of the expected structural behaviour in fire need to be considered when designing a specimen for test. Edge details are the most troublesome since the specimen is usually a short length (3 m) of a much longer wall which is to be fire rated. The detail must seal the hot gases in the furnace but as edge members are protected on one side by the frame they should not provide any structural restraint throughout the period of the test. The solution adopted for edge studs is to cut them short of the top and bottom plates and loosely bolt the remainder through slotted holes to the specimen holder. At least one overseas laboratory has been known to neglect this aspect which resulted in an extremely long test duration since the load was eventually taken by the edge studs which were bolted to the specimen holder and were also restrained from buckling.

5. TEST SPECIMEN DETAILS

Various specimens have been built and tested at BRANZ to gain experience and obtain information on the behaviour of timber frame structures under load when subjected to a standard fire resistance test.

Specimen No. 1: a 3 m square specimen, constructed from nominal 100 x 50 mm timber with five loadbearing studs at 600 mm centres and no dwangs. The frame was lined with one layer of 14.5 "Fyrestop" grade Gibraltar board on each side. The joints and nail heads were stopped. For a nonloaded test comparison, the Winstone Wallboards Ltd GB-6 system is identical in construction except that it requires three rows of dwangs for a 3 m high specimen.

Specimen No. 2: a 3 m x 4 m high specimen, constructed from nominal 150 x 50 mm timber with five studs at 600 mm centres and three rows of dwangs. Lining was applied to each side and consisted of one plaster stopped layer of 19 mm "Fyrwall" grade "Plasterglass".

Specimen No. 3: identical to No. 2.

Specimen No. 4: a 3 m square specimen, constructed from nominal 150 x 50 mm timber with five studs at 600 mm centres and no dwangs. On the fire side it was lined with two layers of 14.5 mm "Fyrestop" grade Gibraltar board, the non-fire side being lined with one layer of 6 mm "Hardiflex" asbestos cellulose/cement board.

Specimens Nos 5 and 6: both identical to No. 4. For comparison Winstone Wallboards Ltd GB-7 system is similar to these except it is based on 100 x 50 mm framing with three rows of dwangs and has two layers of 14.5 mm "Fyrestop" Gibraltar Board on both sides.

6. RESULTS AND DISCUSSION

TABLE 1 SUMMARY OF TEST RESULTS

Specimen number	Stud sizes Fire face protection	Load per stud (kN)	Failure mode and time (in minutes)	Time to reach onset of char criterion and range in minutes
1	100 x 50 14.5 "Fyrestop"	16.75	flaming at 44	42 38-48
*GB6		N/L	not known 60	Not known
2	150 x 50 19 "Fyrwall"	N/L	insulation at 140	74 62-85
3		32.85	flaming at 96	77 69-90
4	150 x 50 2x14.5 "Fyrestop"	N/L	insulation at 88 flaming at 95	78 68-90
5		11.3	insulation at 85 flaming at 89 collapse at 95	77 66-91
6		22.6	insulation at 75 flaming at 84 collapse at 95	75 71-86
*GB-7	100 x 50 2x14.5 "Fyrestop"	N/L	Not known 120	Not known

Note: The load levels [9] for specimen numbers 1 and 3 were calculated using a load sharing factor = 1.26 (K4) F'c = 7.1 MPa and load duration factor = 1.35 (K1). For test 6 the values were K4 = 1.26, F'p = 3.0 MPa and K1 = 1.35 and the load in test 5 was 50% of test 6.

* Not tested by BRANZ - results from published trade literature [8].

Early flaming failures of loaded walls were associated with bowing of the wall away from the fire causing splits in the non-fire exposed wall face through which flaming occurred. Tests 1 to 4 were stopped at this point to avoid damage to equipment through collapse of the specimens.

The results from Specimen 1 and GB6 show clearly the effect of load on a fire resistance rating. In this case the rating has been reduced by more than 25%. The "onset of char" method as applied in Specimen 1 has closely predicted the performance obtained from conducting a loaded test. The difference between loadbearing and non-loadbearing tests is again clearly shown for Specimens 2 and 3 with a reduction of approximately 30%. For this construction the onset of char criterion is rather more conservative when compared to the result for Specimen 3 by approximately 20%.

The tests conducted on specimens 4-6 represent the value of the concept of "one way" fire resistance ratings. It is becoming more evident that fire codes should require each building owner to have constructions that will prevent fire breaking out and endangering a neighbouring property. It can be seen that the results for this series of tests show how the protection on the fire side is very important in protecting a loadbearing timber frame. Hence if such constructions are permitted considerable cost savings could be made.

It may be expected that the constructions in specimens 5 and 6 would have achieved only a slightly greater fire resistance had the construction been symmetrical. From the results of GB-7 it may be expected that the insulation and possibly flaming failures would have been delayed. However, the fire resistance rating would not be expected to have been greater than one and a half hours for the loads used in these tests since collapse would govern the time to failure (at approximately 95 minutes).

One of the problems with using the "onset of char" method is the variation in times for thermocouples to reach 300^{o}C. The range of times from specimens 2-6 are quite similar, but no correlation has been found between time to onset of char and location of thermocouples in the specimens. Further study is required to determine the most appropriate number and location of thermocouples.

The "onset of char" method currently specified in MP9 [3] is undoubtedly conservative. But to develop it further requires a knowledge of the position and type of timber defect in the loadbearing members of the structure and a knowledge of the strength of the timber at elevated temperature. After charring begins the loadbearing members reduce in section size at a rate of approximately 0.6 mm per minute, from each fire exposed face. If the material were completely homogenous, the time to reach a critical section size could be calculated and hence there would be some chance of predicting failure times. The presence of timber defects unfortunately complicates matters. For a particular grade of timber certain maximum sized defects are allowable, or conversely a minimum net section is required. When structural failure occurs in fire this net section has been decreased below a critical value. The time at which this occurs depends on where the defect is in relation to the charring direction. For different strength grades it should be possible to determine critical defect locations for fire and hence predict charring times to reach a limiting section size. This has not yet been attempted but it is worthy of further examination in developing fire resistance design methods.

7. CONCLUSIONS

The results indicate that the relationship between load level and fire resistance is not a simple one and may depend on many factors which as yet have not been investigated.

The "onset of char" method generally gives a conservative measure of fire resistance rating for loadbearing timber framed walls. However, the times to char show wide variation and hence many thermocouples are required to assess performance.

The present system of establishing fire resistance ratings requires a series of tests on each lining system with various supporting frame details and load levels. A modified "onset of char" method has the potential for allowing all these ratings to be calculated from a single non-loaded fire resistance test providing the failure criterion is structural collapse and not integrity or insulation failure.

For loadbearing constructions the frame is protected mainly by the linings on the fire side. For external walls (assuming the fire to be from within) the fire rating can be identical for one-way or two way construction. Hence if codes permitted "one-way" fire resistance ratings, significant cost savings for timber framed construction are possible.

8. REFERENCES

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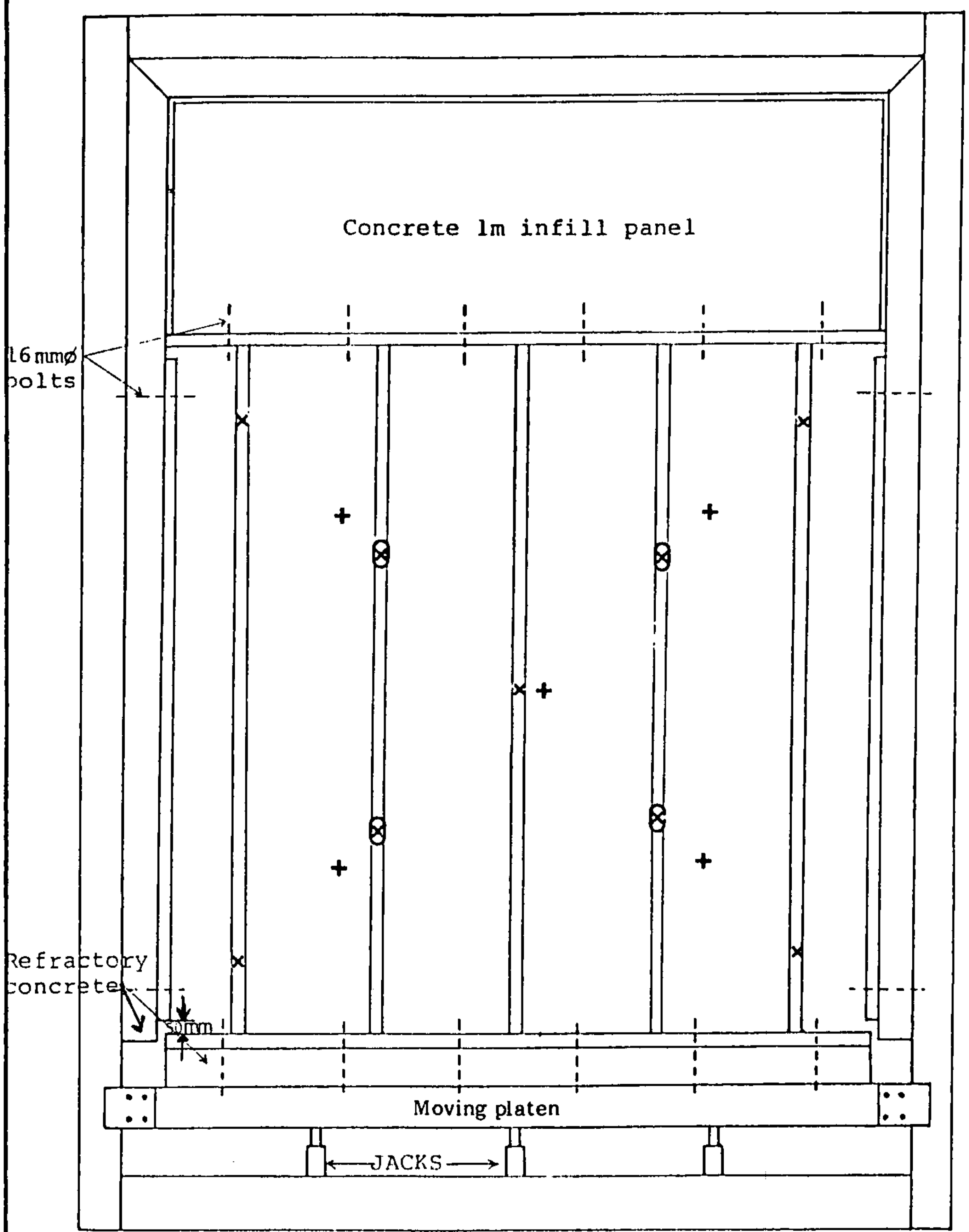
[9] Standards Association of New Zealand. 1981. NZS 3603. Code of practice for Timber Design

FIG 1 FRAME AND THERMOCOUPLE DETAILS



Notes:

1) Edge studs: nonload-bearing, 50mm gap top & bottom to plates, bolts only fingertight, slotted holes in studs.

2) Kaowool packing under plates and edge studs.

3) Wall nominally 3.0m x 3.0m.

4) Thermocouple legend:
   - +: ISO type on unexposed face.
   - x: 5mm internal, in stud.
   - ⊗: 10mm internal, in stud.

LOADED TEST	branz	SCALE 1:25	DRAWN VdH
		DATE 13-4-82	APPROVED HLB
SPECIMENS 5 AND 6	BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND	DRAWING NUMBER PTEC	AMENDMENT —