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Software for the Design of Light Timber Frame Construction For Fire Resistance - A User's Guide - Version 2.0

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**SOFTWARE FOR THE DESIGN OF LIGHT TIMBER FRAME
CONSTRUCTION FOR FIRE RESISTANCE - A USER'S GUIDE Version 2.0**

Acknowledgements

Keywords

Charring; Design; Eccentricity; Failure; Fire Endurance; Fire Resistance; Fire Testing; Failure; Gypsum Plasterboard; Insulation; Linings; Loading; Model; Structural; Studs; Test; Timber.

Contents

1. GENERAL

This Windows™ based software package has been developed from the version 1.0 software (Collier 1996) which originated from the findings of a research project, "Design of loadbearing light timber framed wall for fire resistance" (Collier, 1991a, 1991b and 1992), conducted by BRANZ.

The minimum requirements for hardware and software required to install and run this programme are:
- Microsoft Windows™ 95 or later.
- 486 or higher microprocessor.
- VGA display.
- 8 MB of memory.
- 7 MB of disk space.

2. SCOPE OF APPLICATION

Subject to the availability of suitable fire resistance test results, this programme can be used as a tool in the design of timber buildings which are required to have fire separations, such as fire-rated walls and floors.

Starting with a building design where the firecells and fire separations have been identified, the loads on the various elements providing the fire separations are calculated, using the guidelines of Clause 2.4.3.4(a) of NZS 4203:1992 (SNZ, 1992). This requires dead and live loads to be factored according to $G + Q_u$.

where Q_u = $\psi_u \cdot \psi_a \cdot Q_b$

and ψ_u = live load combination factor

ψ_a = area reduction factor

Q_b = basic live load

G = dead load

Using the wall or floor/ceiling file menu item, the result of a tested prototype (a library is provided of tested systems) can be extrapolated so that the fire resistance of modified constructions can be assessed.

It is assumed that the lining used and its method of fixing in an extrapolated (or modified) design will be the same as that which was tested and is in the manufacturer's specification.

A new design may differ from a tested prototype by variations in the applied load, the height of the wall or the span of the floor. These changes may be accommodated by increasing the stud or joist dimensions. This design method is not intended to be used for increasing the fire resistance period beyond that achieved by the test prototype.

3. BACKGROUND

The supporting research on which this software is based is published in Collier (1991a, 1991b and 1992).

3.1 Walls

Figure 1 shows the type of construction and loading conditions for walls to which this software applies.

The studs in a light timber framed wall, when subjected to fire, are modelled as axially loaded columns. The effect of fire is simulated by the loss of timber cross-section in the studs and a calculation of the residual loadbearing capacity. The "Secant Formula" is applied to what is assumed to be eccentrically loaded studs (in a wall) and has been modified to include the effects of charring of the studs and face loading due to lateral forces.

The equation describing the stresses in the studs is a modified version of the "Secant formula" as used in Collier (1991a) and is as follows:

$$\sigma_{max} = \frac{P}{A}[1 + \frac{ec}{r^2}\sec(\frac{\alpha L}{2})] + \frac{M(D - C)}{2I}$$

where :

σ_{max} = maximum permissible stress, N/m^2

P = axial load per stud, N

$A = (D - C)(B - C)$, residual cross-section area of stud, m^2

D = depth of stud, m

C = char depth in stud (or charfactor, see definitions below), m

B = breadth of stud, m

$e = \dfrac{C}{2} + X$ actual eccentricity of loading, m

X = initial eccentricity of loading, m

$c = \dfrac{D - C}{2}$,

$r = 0.289(D - C)$, radius of gyration, m

$\alpha = \sqrt{\dfrac{P}{EI}}$

$I = \dfrac{(B - C)(D - C)^3}{12}$, second moment of area, m^4

E = modulus of elasticity of the timber, N/m^2

L = height of stud, m
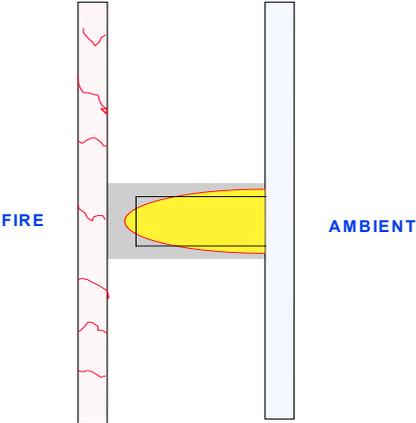
M = bending moment due to face pressure, Nm

A prototype fire resistance test on a loaded wall is required to establish the performance of the lining system and timber frame in terms of the criteria of **stability, integrity** and **insulation.** The test result will also enable the **charfactor** (degree of damage to the wall) to be assessed.

The charfactor, as the measure of fire damage, is applied to the new design, which may be required to be a different height and/or loadbearing capacity. A new stud size is selected to support the applied load at the required height, thus meeting the stability criterion. If the wall remains intact the integrity criterion is also likely to be satisfied, as the curvature of the

FIREWALL FRAMING

P P P P

L
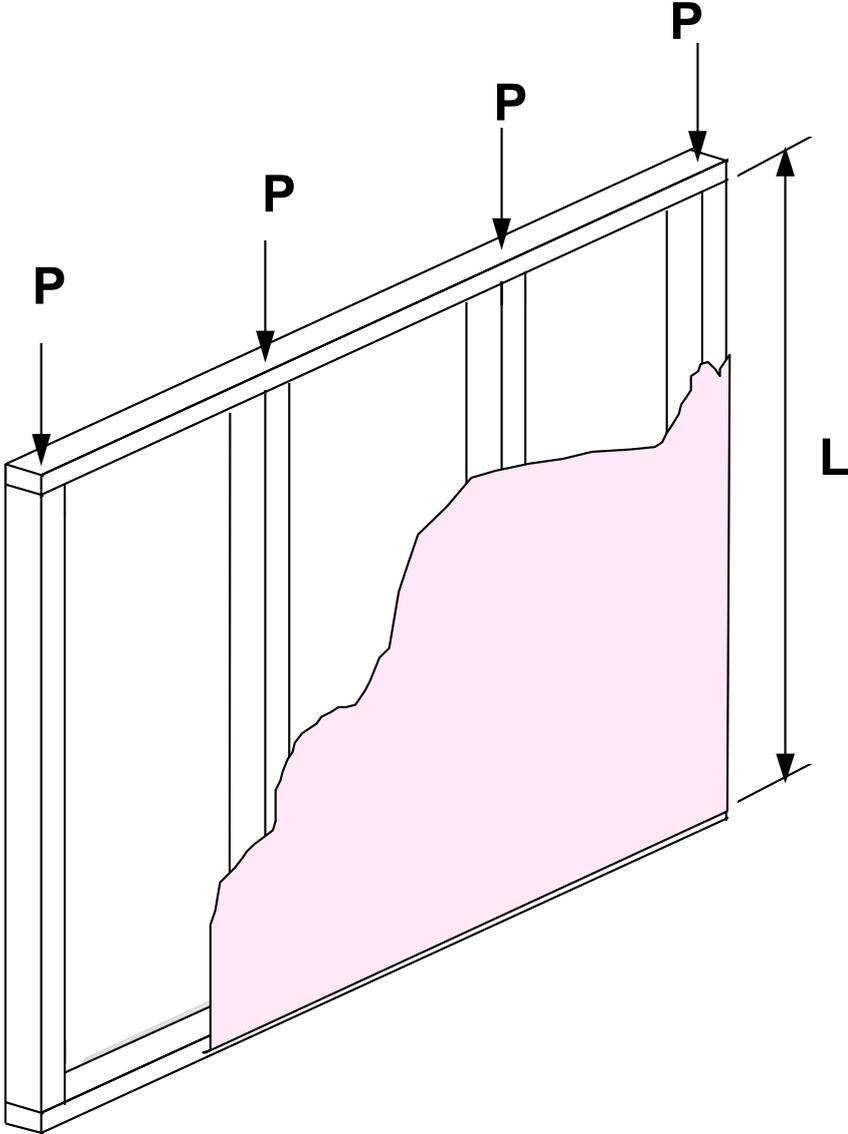
Cavity Wall Construction

FIRE AMBIENT

Stud Cross-section

B

C/2 C/2

C

D

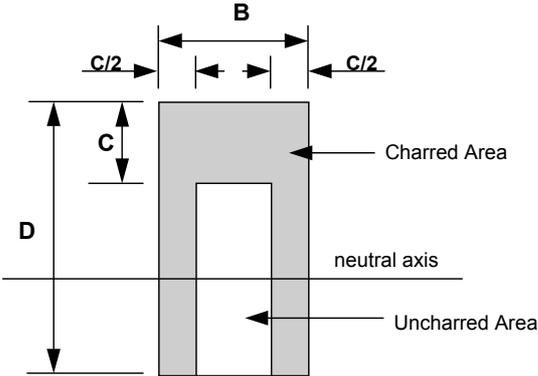Charred Area

neutral axis

Uncharred Area

Figure 1 : Loadbearing wall

new wall cannot exceed that of the tested wall due to the imposed limitations (Collier, 1991b) preventing reduction of either stud dimension. The insulation criterion as established in the prototype test will also be met, provided the space between linings is not reduced.

The assumptions on which this model is based are as follows:

1.   Once the temperature on the cold side of the exposed lining(s) reaches 300 $^{\circ}$C, the studs will commence charring on three surfaces - the stud surface against the exposed lining, and the two sides of the stud. The side against the exposed lining chars at twice the rate of the other two sides.

All charring proceeds in parallel planes with respect to the original surface of the stud. The reducing cross-section continues to carry the applied load until the stress exceeds the maximum permissible stress of the timber.

2.   The applied axial loads act eccentrically to the stud centreline.

For the prototype tests the initial eccentricity of loading is 5% of the stud depth.

For the extrapolated design the initial eccentricity of loading is 10% of the stud depth.

The difference between the two eccentricities is intended to differentiate between the strictly controlled laboratory conditions under which a prototype will be prepared and the on-site construction of an extrapolated design.

3.   The maximum permissible stress in the studs is set at 24 MPa.

4.   The Modulus of Elasticity of the timber is set at 8 GPa.

Since the above material properties apply to the prototype test and the extrapolated design, the end result will be relatively insensitive to any moderate variation in material properties.

The above material properties are default values as assessed for No.1 Framing grade timber, as defined in NZS 3603 (SNZ, 1993) and determined by testing the samples used in the validation tests (Collier, 1991a). They cannot be altered to accommodate different timber grades, but this feature may be included in a later version of this software.

3.2   Floor/ceilings

Figure 2 shows the type of construction and loading condition for floor/ceilings to which this software applies.

The result of a fire resistance test on a loadbearing floor system may be applied to a floor of similar construction. The basis for comparison is that the calculated stress induced in critical areas of the extrapolated design is not greater than that in the test specimen. The span of the floor may be increased if required, and the structural adequacy of the joists is subject to the critical stress in the prototype test not being exceeded. The load on the extrapolated floor may not be increased above the load applied to the prototype, as there is a danger of the flooring membrane being penetrated, causing an integrity failure.

FLOOR FRAMING

Area of critical stress

Particleboard or Plywood flooring
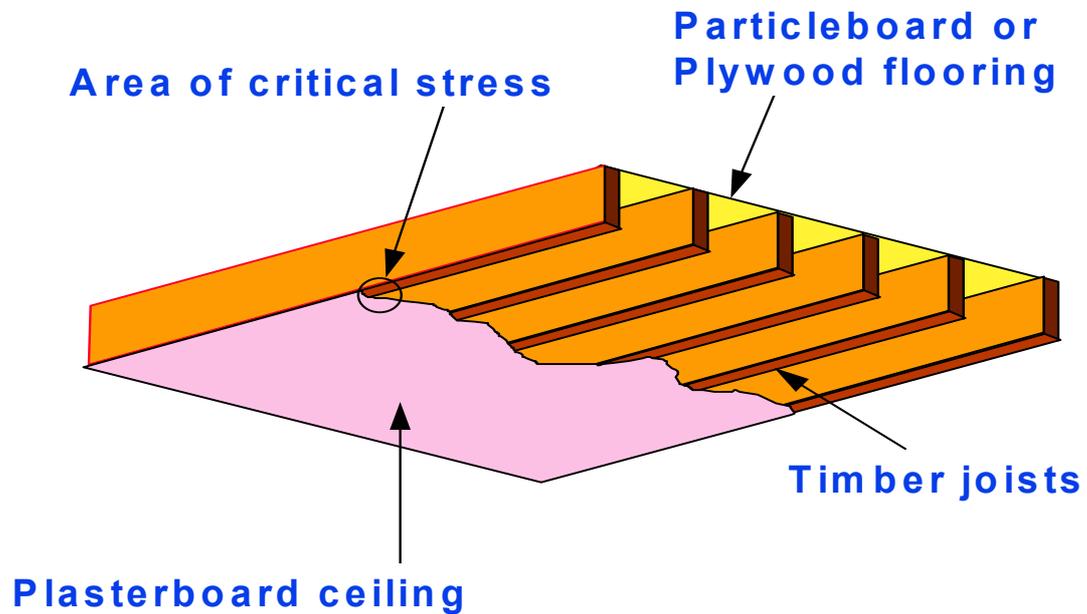
Timber joists

Plasterboard ceiling

Figure 2 : Floor / Ceiling

A simply supported beam is modelled by the software. The parameters for the prototype test are entered and the stress at the bottom of the beam (joist) at mid span is calculated. The required parameters for the extrapolated floor are entered, and for the same induced stress the minimum depth of joist is calculated.

The equations, based on beam theory, describing the induced stress in a joist are:

$$M = \frac{wl^2}{8} \quad and \quad \sigma = \frac{M}{Z}$$

where :

l = the span of the floor joists, m

M = moment acting on centre of floor joists due to floor loading, Nm

w = uniformly distributed load per metre span, N/m

Z = section modulus, m^3

σ = the induced stress in the joists, N/m^3

from which :

$$\sigma = \frac{3Psl^2}{4bd^2} \quad \text{is derived}$$

where :

P = load on the floor, pressure, Pa

s = the spacing between joists, m

b = the breadth of the joist, m

d = the depth of the joist., m

4.0   LIMITATIONS

The model is subject to the following provisos, for both walls and floor/ceilings:

1. A fire resistance test on a prototype is required to prove the fire performance of the lining system when attached to timber framing, and to show that the fire-damaged timber is capable of performing its structural function for that fire resistance period.

2. The fire resistance time established in the prototype test must not be exceeded in any future extrapolations. In the case of timber framed walls the fire resistance time may be reduced, if less resistance is required, to take advantage of any conservatism in the test specimen. However, this is not permitted for floor/ceilings.

3. If the prototype test is on a non-loadbearing wall then extrapolations may only be performed if the fire resistance period is for 1 hour or less.

4. The dimensions of studs or joists may not be reduced in either cross-section direction from the tested prototype.

5. Fire-resisting closures or penetrations may only be included in extrapolated designs if their respective performances were proven in the prototype test.

Warning messages (in messages boxes) when the software is being used indicate when the above limitations have been breached. More than one warning message may occur, but only one will be displayed on the screen. It is therefore essential that each message is cleared so that all messages may be viewed and the respective error conditions eliminated.

5.0   OPERATION

This software will operate on IBM PC's and compatibles running Windows™ 3.1 or above. The software is installed from the 3 disks or CD by running "setup.exe" and following the instructions

Once the programme is installed it can be opened by clicking on the icon in the Start Menu, for Windows™ 95 and later versions.

5.1   Introduction

From the **File** menu the options are **Wall, Proprietary Walls, Floors, Printer** and **Exit**. A **Help** menu is also included with options **Contents** and **About.**

5.1.1   Saving A Calculation

Calculations may be saved by clicking the **Save** button at the bottom of the form and following the instructions for filename etc.

5.1.2   Exiting From Programme

Clicking the **Close** button returns to the main page and selecting **Exit** from the **File** menu exits from the programme.

5.1.3   Printing

Printing of the screen output can be accomplished by clicking the **Print** button. The printer used is as selected in the Windows™ print manager.

If a copy of the output is required for pasting into a report this is performed by the keyboard combination **Alt+PrintScrn** which copies the image to the clipboard, which in turn can be pasted into a document by **Edit- Paste.**

5.2   File Menu Item - Wall

Loads a wall with default values, which can then be edited as required.

The following screen output (Figure 3) is displayed, the outputs (on the screen) are highlighted in red type.

When **Proprietary Walls** is selected then a manufacturers system is entered, but the actual test result is hidden for reasons of confidentiality.

Figure 3: Screen output, Firewall.

The initial values displayed on screen are either the default values written into the program, or those from the file loaded.

INPUT OF DATA

The user may edit the following input information as required and the outputs are updated whenever "**Solve**" is pressed.

5.2.1   Prototype Test Result

INPUTS

ACTUAL STUD DEPTH

This is the actual measured depth in mm of the studs used in the prototype test.

ACTUAL STUD BREADTH

This is the actual measured breadth in mm of the studs used in the prototype test.

STUD SPACING

This is the 'between centres' horizontal spacing in mm of the studs as used in the prototype test.

NOG SPACING

This is the 'between centres' vertical spacing in mm of the nogs as used in the prototype test.

WALL HEIGHT

This is the height in m of the wall in the prototype test.

TEST LOAD

This is the external load applied axially to the wall in kN per stud.

TIME TO FAILURE

This is time in minutes to the condition in which the wall can no longer support the applied load. If the mode of failure is other than structural or the test was simply terminated, then that time can be used as the failure time, and any design based on such a test result will be conservative.

TIME TO ONSET OF CHAR

This is time at which the studs, protected by the lining, begin charring. This can be determined from the test data and is the time that the stud/lining interface or the inner side of the exposed lining reaches a temperature of 300° C. If this data was not recorded then it may be estimated from similar test data or taken as zero.

OUTPUT

CHARFACTOR

The charfactor is an output calculated from the performance of the prototype test and is related to the load-carrying capacity of (or the depth of charring in) the studs at time of failure. Its prime function is as a means of linking the fire damage occurring in a tested specimen, to an equivalently lined untested wall.

5.2.2 Extrapolated Design

The requirements for the extrapolated wall are entered and the maximum load that it would be expected to sustain is calculated. Top plate requirements can also be assessed if required.

INPUTS

NEW WALL HEIGHT

This is height of the wall in m, of the new design under consideration.

FIRE RESISTANCE TIME
This is the fire resistance time in minutes required of the new wall.

NEW STUD DEPTH
This is the actual measured depth in mm of the studs required in the extrapolated design.

NEW STUD BREADTH
This is the actual measured breadth in mm of the studs used in the extrapolated design.

FACE LOAD ON WALL

A superimposed load in kPa can be applied horizontally to the extrapolated wall in accordance with the requirements of NZS 4203 (SNZ, 1992), clause 2.4.3.4(b). A uniformly distributed face load of 0.5 kPa is recommended.

<u>OUTPUTS</u>

MAX STUD SPACING

This is the maximum 'between centres' spacing in mm of the studs that is permitted in an extrapolated design and is limited by that tested in the prototype.

MAX NOG SPACING

This is the maximum 'between centres' spacing in mm of the nogs that is permitted in an extrapolated design and is limited by that tested in the prototype.

NEW CHARFACTOR

A new charfactor is determined by conservatively regressing the charfactor obtained in the prototype test, at failure time, back to what it would have been at the FIRE RESISTANCE TIME required.

MAX LOAD

This is the maximum load in kN per stud that the proposed wall design would be expected to carry. Loads less than 2 kN per stud are shown as zero, and a warning is given indicating that the design is unsatisfactory.

This maximum load refers to the fire limit state and must satisfy or exceed the requirements of NZS 4203 (SNZ, 1992). NZS 4203 requires that members, in this case studs, shall be designed for the following combination of factored loads, $G + Q_u$ where: G is the dead load and Q_u is the live load.

TOP PLATE DESIGN

In situations where the top plate of a wall supports the joists of a floor above, and the stud spacing and joist spacing differ, then loads on the top plate need to be considered.

<u>INPUT</u>

ACTUAL LOAD

This is the actual load in kN per stud that will be applied to the extrapolated wall. It may be considerably less than the studs can actually sustain. It is required for sizing the top plates.

<u>OUTPUT</u>

SINGLE OR DOUBLE TOP PLATE

The dimensions of the top plate are determined initially by the depth of the stud, as the two must match each other. The minimum required thickness of the top plate is determined by the load applied.

5.2.3   **Results**

The output is in the form of the maximum load that the proposed wall can be expected to sustain at the end of the fire resistance time required. If the load is excessive for the requirements then modifications can be tried, such as reducing the stud dimensions.

The suggested dimensions for the top plates apply where the stud and joist spacings differ or the joists bear down between the studs, and are based on the actual load to be applied. The option of a double top plate is included if the supply of timber stock is limited such that the dimensions suggested for a single top plate are not available.

NON-LOADBEARING WALLS

The application of this method is better served if the prototype test result is based on a loaded test, otherwise excessive conservatism will result. Where a non-loadbearing prototype test result is used the load is simply entered as zero. An allowance for the self weight of the wall (based on stud size) has been included. The maximum fire resistance time permitted, when extrapolations on a non-loadbearing wall are required, is 60 minutes.

If the extrapolated design calls for a non-loadbearing wall, then the required wall parameters such as height and stud size are entered. The maximum load is then checked to see whether the wall can support its own weight. Provided the maximum load permitted is 2 kN per stud or greater then the design is satisfactory. If the maximum load is shown as zero a warning will flash, indicating that the design is not satisfactory.

5.3   Floor/ceiling

Loads a floor with default values, which can then be edited as required.

The following screen output (Figure 4) is displayed, the outputs (on the screen) are highlighted in red type.

Figure 4: Screen output, Fire Floor

INPUT OF DATA

The user may edit the following input information as required and the outputs are updated whenever **"Solve"** is pressed.

5.3.1 PROTOTYPE TEST RESULT

INPUTS

ACTUAL JOIST DEPTH

This is the actual measured depth in mm of the joists used in the prototype test.

ACTUAL JOIST BREADTH

This is the actual measured breadth in mm of the joists used in the prototype test.

JOIST SPACING

This is the 'between centres' horizontal spacing in mm of the joists as used in the prototype test.

NOG SPACING

This is the 'between centres' horizontal spacing in mm of the nogs as used in the prototype test.

FLOOR SPAN

This is the span in m of the floor/ceiling in the prototype test.

FLOOR TEST LOAD

This is the load in kPa applied to the floor/ceiling joists in the prototype test.

TIME TO FAILURE

This is time in minutes after which the floor/ceiling can no longer support the applied load. If, however, the mode of failure is other than structural, or the test was simply terminated, then that time can be used as the failure time, and any design based on such a test result will be conservative.

OUTPUT

MAXIMUM STRESS IN JOIST

The maximum stress in MPa induced in critical areas of the tested specimen is calculated.

5.3.2 Extrapolated Design

The requirements for the extrapolated floor/ceiling are entered and the minimum depth of joist that can be used is calculated. The basis for this is that the maximum induced stress in critical areas of the joists must not be greater than that in the tested specimen.

INPUTS

NEW FLOOR SPAN

This is the span in m of the floor/ceiling joists in the extrapolated design.

NEW LOAD ON FLOOR

This is the load in kPa applied to the floor/ceiling, based on the fire limit state, which must satisfy or exceed the requirements of NZS 4203 (SNZ, 1992), clause2.4.3.4(a). This requires that members, in this case joists, shall be designed for the combination of factored loads, $G + Q_u$, where G is the dead load and Q_u is the live load.

NEW JOIST SPACING

This is the maximum 'between centres' spacing in mm of the joists that is permitted in an extrapolated design.

MAXIMUM NOG SPACING

This is the maximum 'between centres' spacing in mm of the nogs that is permitted in an extrapolated design.

ACTUAL WIDTH OF JOIST

This is actual width in mm of the joist in the extrapolated design. This must be equal to or greater than the joist width which was tested.

OUTPUT

MINIMUM DEPTH OF JOIST

This is the minimum depth in mm of the joists in the extrapolated design. This is determined by the equivalence of stress in critical areas between the prototype test and the extrapolated design. Also the minimum depth of the joists may not be less than that tested.

6.0 EXAMPLES

Example 1.

The following example shows how a prototype test, in this case BRANZ research test FR1515 on a 60-minute loadbearing wall with a single sheet of 14.5 mm gypsum plasterboard lining on each side, can be regressed to a lower fire resistance (30 minutes) if required. The advantage in doing this may be a saving in timber, providing the marginal cost of the additional thickness of lining is not greater than that of the timber saved.

The following screen output (Figure 5) is displayed. The outputs are in red type.
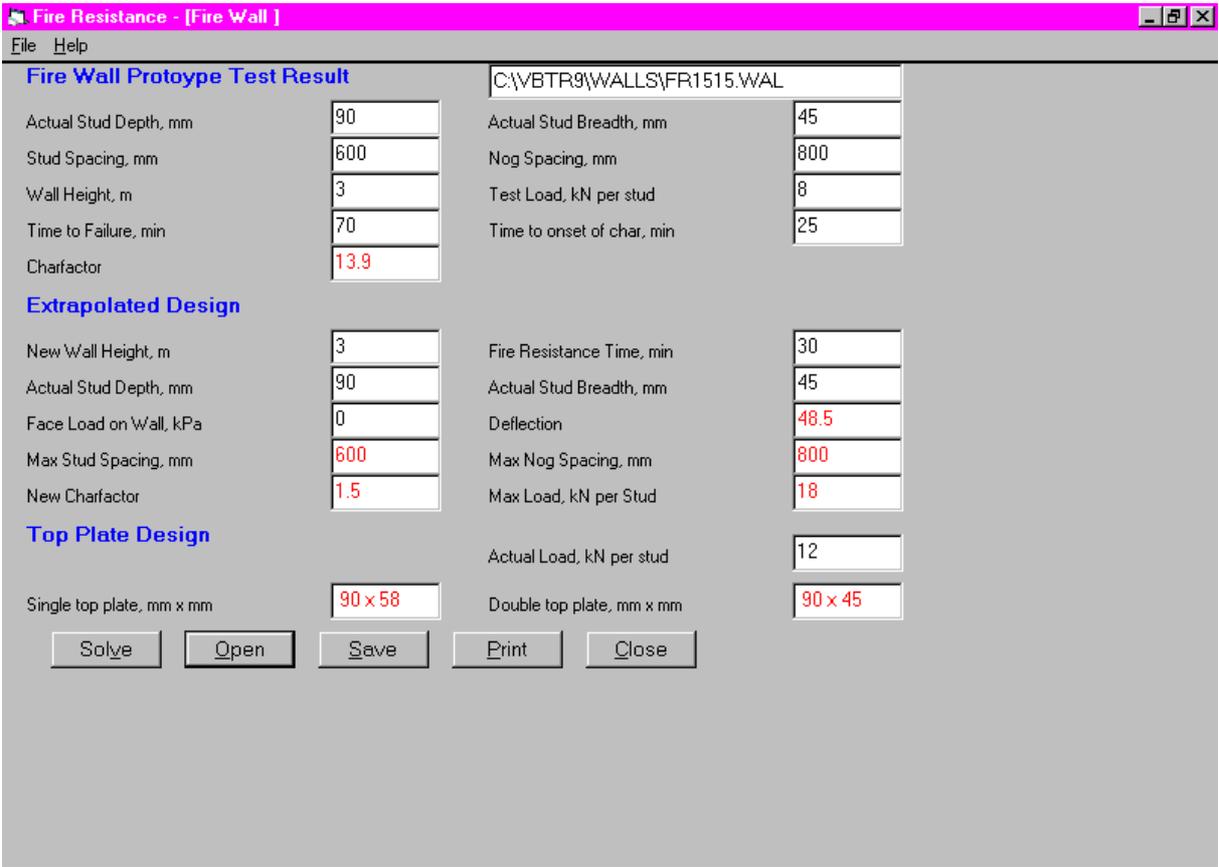
Figure 5: Example 1

The maximum load of 18 kN per stud is the load which may be applied to the new wall. For the design of the top plate the actual load that the wall is subjected to (in this example 12 kN per stud) is entered. This may be equal to the maximum load but is more likely to be less. The dimensions of the top plate(s) are determined from this actual load.

Example 2

This was a commercial test whose results are confidential, but extrapolation may still be made from it.

The following screen output (Figure 6) is displayed. The outputs are in red type.

Figure 6: Example 2

Example 3

The following example shows how the span of a tested floor/ceiling may be increased from 4 to 6 m if the floor load is reduced from 3 kPa to 1.5 kPa.

The following screen output (Figure 7) is displayed. The outputs are in red type.

Figure 7: Example 3

7.0   REFERENCES

Collier, P.C.R. 1991a. Design of loadbearing light timber framed walls for fire resistance: Part 1. Building Research Association of New Zealand Study Report No. 36. Judgeford, Wellington.

Collier, P.C.R. 1991b. Design of light timber framed walls and floors for fire resistance. Building Research Association of New Zealand Technical Recommendation No.9. Judgeford. Wellington.

Collier, P.C.R. 1992. Design of loadbearing light timber framed walls for fire resistance:Part 2. Building Research Association of New Zealand Study Report No. 42. Judgeford. Wellington.

Collier, P.C.R. 1996 Software for the design of light timber frame construction for fire resistance - a user's guide version 1.0 Building Research Association of New Zealand Judgeford. Wellington

Standards New Zealand. 1992. General structural design and design loadings for buildings.NZS 4203, Wellington, New Zealand.

Standards New Zealand. 1993. Code of practice for timber design. NZS 3603, Wellington, New Zealand.