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NASH
TECHNICAL NOTE 4

Establishing Design Values by Testing

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NATIONAL ASSOCIATION OF STEEL-FRAMED HOUSING INC.

INTRODUCTION

This Technical Note explains how design capacities for cold-formed steel members and connections may be established from testing.

Testing of materials, sections and structures forms an important part of design and construction. Different forms of testing include:

CONFORMANCE TESTING

This is carried out to ensure that the product meets the required specification given in the appropriate Standard. Examples of conformance testing are:

- Testing cold formed steel strip in accordance with the requirements of AS 1397 to ascertain the properties of the steel such as yield stress, ultimate strength, minimum bend radii, coating thickness, etc.
- Testing of screws to ensure they conform to AS 3566 and manufacturer's specifications.

PROOF TESTING

This testing is carried out to determine whether the structure, sub-structure, member or connection complies with its strength or serviceability requirements. Pressure vessels and crane lifting devices are normally subject to proof tests prior to being put in service. Proof testing is occasionally used to check the capacity of existing structures when questions are raised about the design or where there is insufficient information to carry out an assessment by calculation. More information on proof testing can be found in AS 4100 Steel structures [1].

PROTOTYPE TESTING

This is where the capacity of a structure, element or connection is determined by testing as part of the design process.

The NASH Standard for Residential and Low-rise Steel Framing, Part 1: Design Criteria [2] allows assessment of structural adequacy to be carried out by:

- Calculation;
- Testing; or
- A combination of calculation and testing.

Calculation is typically used for one-off design situations and large assemblies where testing is uneconomical or impractical.

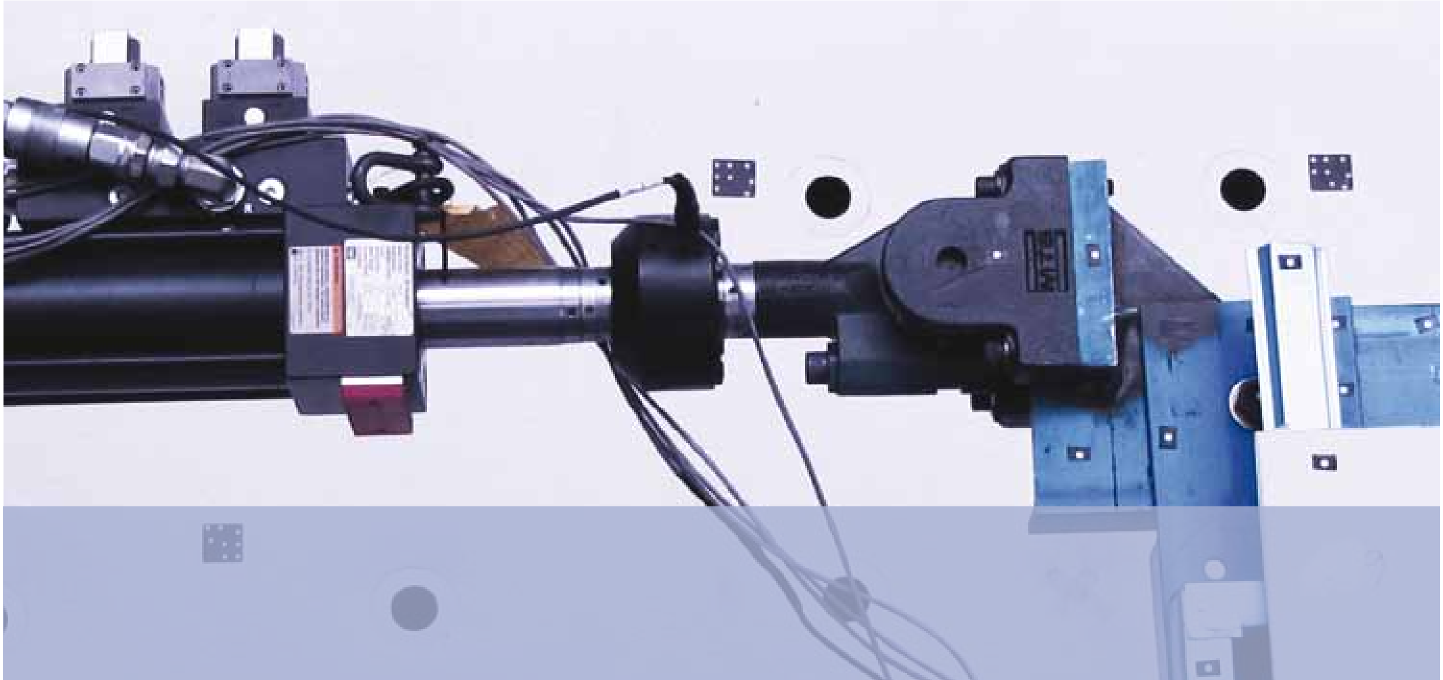
The assessment of cold-formed members and assemblies by prototype testing is often employed as it offers a quick and reliable method of determining the capacity of members and connections. It also allows failure mechanisms such as buckling mode, connection failure, crushing etc. to be observed.

Typical items that are often designed using the results of prototype testing include:

- Wall studs and plates
- Trusses
- Connector capacities
- Connections

The focus of this Technical Note is to explain the procedure by which design values are calculated directly from appropriate prototype test data.

The National Construction Code (NCC) sets the performance requirement that only 5% of materials or components are permitted to fall below the design resistance for the relevant property. Where testing is used to determine design resistance, the guidance in this Technical Note will enable this performance requirement to be met. More information on testing can be found in the NASH Handbook - Design of Residential and Low-rise Steel Framing [3] and NASH Standard Part 1.



DESIGN BY TESTING

The design capacity can be determined by testing a number of samples that fail by the same mechanism. It is important that the boundary conditions are correctly modelled in the test set up and no artificial restraints are imposed during the testing.

The assessment of test results is required to be carried out in accordance with NASH Standard Part 1 Section 7. The Standard gives minimum coefficients of variation (see Table 1) for various applications and appropriate values for sampling factors used to establish design values (see Tables 3 and 4). The coefficient of variation is defined as the ratio of the standard deviation to the average value and shows the extent of variability in relation to the mean of the population. Sampling factors are discussed further below.

The minimum coefficients of variation given in Table 1 are significantly greater than those calculated from test results as the prototypes do not cover all the variability that can be expected in practice. For example, prototypes are typically:

- components fabricated from a single coil;
- steel members rolled all at the one time;
- fasteners from one batch; or
- connections assembled by one technician.

Hence the range of values of the various properties of the components being tested will be relatively small and the resulting capacity variation will not generally represent the full range of variation expected in service.

TABLE 1: Minimum coefficients of variation k_{SC} (NASH Standard Part 1)

Measured property	Minimum coefficient of variation
Member strength	10%
Connection strength	20%
Assembly strength	20%
Member stiffness	5%
Assembly stiffness	10%

SAMPLING FACTOR

The sampling factor (k_t) accounts for the statistical uncertainties involved in prototype testing of a small number of samples. The design capacity is determined by dividing the minimum or average test value by the appropriate sampling factor. A larger number of samples gives a smaller sampling factor and therefore a larger design capacity.

NASH Standard Part 1 Section 7 contains tables to enable selection of the appropriate value of the sampling factor as a function of k_{sc} and the number of test units in the sample. Sampling factors have the symbol $k_{t\text{-}min}$ for minimum value and $k_{t\text{-}ave}$ for average value calculations.

Where possible, a minimum of 3 tests is recommended. Fewer tests will require quite high sampling factors to be applied and this should be avoided. For example, a single test value needs to be divided by 2.21 when an assembly such as a truss or wall panel is tested for strength (see Tables 3 and 4).

The design capacity R_d must satisfy one of the following:

FOR MINIMUM VALUE METHOD:

$R_d \leq R_{min} / k_{t\text{-}min}$

FOR AVERAGE VALUE METHOD:

$R_d \leq R_{ave} / k_{t\text{-}ave}$ where -

R_{min} is the minimum test value

R_{ave} is the average test value

The design capacity must exceed the limit state action combinations given in NASH Standard Part 1.

eg 1.2 G + 1.5 Q

The capacity reduction factor phi (Φ) is not applicable when applying design values derived from testing as it has already been accounted for in the derivation of the sampling factor.

The minimum value method depends almost entirely on a single selection, making it more sensitive to outlying values in the population.

The average value method reacts more slowly to outlying values, while still accounting for them in the determined value, and tends to produce more reliable values.

While both methods are statistically equivalent, they do not produce identical results when applied to real test cases. Wang and Pham [4] show that the use of average test values leads to more consistent estimates of the design capacity. The following examples illustrate the use of sampling factors in different testing situations.

EXAMPLE 1:
DETERMINATION OF DESIGN CAPACITY OF A SCREW CONNECTION IN SHEAR.

Following several prototype tests, it is established that the consistent mode of failure is by tilting and bearing of the screw. Two sets of samples were taken and Table 2 gives the test results obtained. Sample 2 had one low result and the impact of this is discussed below.

TABLE 2. SCREW CONNECTION – SHEAR TEST

Test Number	TEST VALUE – SHEAR (kN)		
	Sample 1	Sample 2	Combined Sample
1	4.8	4.5	
2	4.9	4.9	
3	5.0	5.0	
4	5.1	5.1	
5	5.2	5.2	
Minimum	4.8	4.5	4.5
Average	5.00	4.94	4.97
Standard deviation	0.16	0.27	0.21
Coefficient of variation	3.2%	5.5%	4.2%

In selecting the sampling factor, it is important to remember that although the coefficient of variation of these particular samples varies between 3.2% and 5.5%, a coefficient of variation of 20% in accordance with Table 1 must be assumed for connections in the absence of a comprehensive test program which covers the variability of all of the parameters.

SAMPLE 1 ANALYSIS

- Option A: Determination of shear capacity based on minimum test value

From Table 3, the sampling factor for minimum of test results is 1.67, giving a design capacity of 4.8/1.67 = 2.87 kN.

- Option B: Determination of shear capacity based on average test value

From Table 4, the sampling factor for average of test results is 1.85, giving a design capacity of 5.0/1.85 = 2.70 kN.

For this particular sample, the minimum value method produced a slightly higher result (6.3%) than the average value method. Either value can be used for the design capacity with a high degree of confidence.

SAMPLE 2 ANALYSIS

- Option A: Determination of shear capacity based on minimum test value

From Table 3, the sampling factor for minimum of test results is 1.67, giving a design capacity of 4.5/1.67 = 2.69 kN.

- Option B: Determination of shear capacity based on average test value

From Table 4, the sampling factor for average of test results is 1.85, giving a design capacity of 4.94/1.85 = 2.67 kN.

TABLE 3.	Sampling factor $k_{t\text{-}min}$ for use with the MINIMUM value of the test results (NASH Standard Part 1 Table 7.3(a))					
No. of test units	Coefficient of variation of structural characteristics (k_{sc})					
	5%	10%	15%	20%	25%	30%
1	1.20	1.46	1.79	2.21	2.75	3.45
2	1.17	1.38	1.64	1.96	2.36	2.86
3	1.15	1.33	1.56	1.83	2.16	2.56
4	1.15	1.30	1.50	1.74	2.03	2.37
5	1.13	1.28	1.46	**1.67**	1.93	2.23
7	1.11	1.23	1.38	1.56	1.76	1.99
10	1.10	1.21	1.34	1.49	1.66	1.85
20	1.06	1.13	1.21	1.29	1.39	1.50

TABLE 4.	Sampling factor $k_{t\text{-}ave}$ for use with the AVERAGE value of the test results (NASH Standard Part 1 Table 7.3(b))					
No. of test units	Coefficient of variation of structural characteristics (k_{sc})					
	5%	10%	15%	20%	25%	30%
1	1.20	1.46	1.79	2.21	2.75	3.45
2	1.18	1.39	1.67	2.01	2.44	2.98
3	1.17	1.37	1.62	1.93	2.33	2.80
4	1.16	1.35	1.59	1.88	2.25	2.69
5	1.15	1.34	1.57	**1.85**	2.20	2.62
7	1.15	1.32	1.54	1.81	2.14	2.53
10	1.14	1.31	1.51	1.77	2.07	2.45
20	1.13	1.29	1.47	1.70	1.98	2.32

The above comparative analysis demonstrates that while the method based on the minimum test value is very sensitive to the lowest test value, the average test value is not very sensitive to one lower test result. The average test method gives a greater benefit for carrying out additional tests.

COMBINED ANALYSIS OF SAMPLES 1 AND 2

Combination of the two samples gives a more reliable estimate and reduces the sampling factor as illustrated below.

OPTION A: Determination of shear capacity based on minimum test value:

From Table 3, the sampling factor for ten test results is 1.49, giving a design capacity of 4.5/1.49 = 3.02 kN.

Option B: Determination of shear capacity based on average test value:

From Table 4, the sampling factor for ten test results is 1.77, giving a design capacity of 4.97/1.77 = 2.81 kN.

EXAMPLE 2:
DETERMINATION OF STUD CAPACITY

The capacity envelope of a stud can be determined by testing the stud separately in axial compression and in bending.

As shown in Figure 1, it is also worthwhile to carry out some tests in combined compression and bending. In this series of tests the tension flange is restrained, which does not provide any benefit in the design rules of AS/NZS 4600.

The test capacity curve in Figure 1 is the average of three tests at each of three testing points. The design capacity curve derived from testing is obtained by dividing the test curve by 1.37 (see Table 4). The failure mechanism at each testing point was different so the sampling factor is based on the number of tests at each point and not the total number of tests. This is based on a coefficient of variation of 10% as given in Table 1 for Member strength.

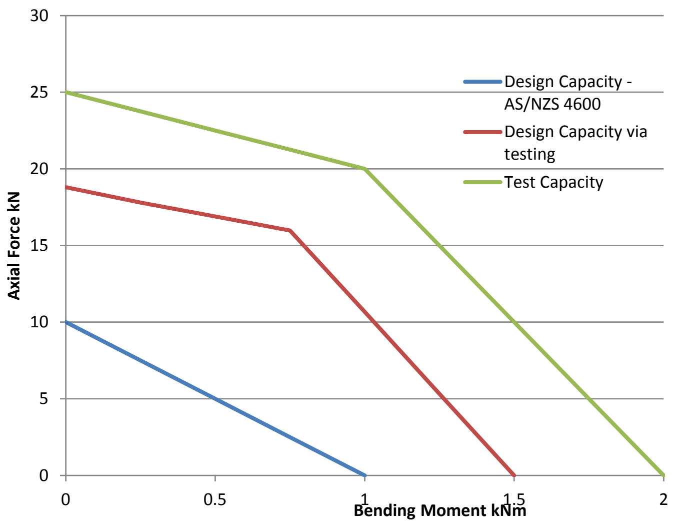


Fig 1. Stud Capacity Curve

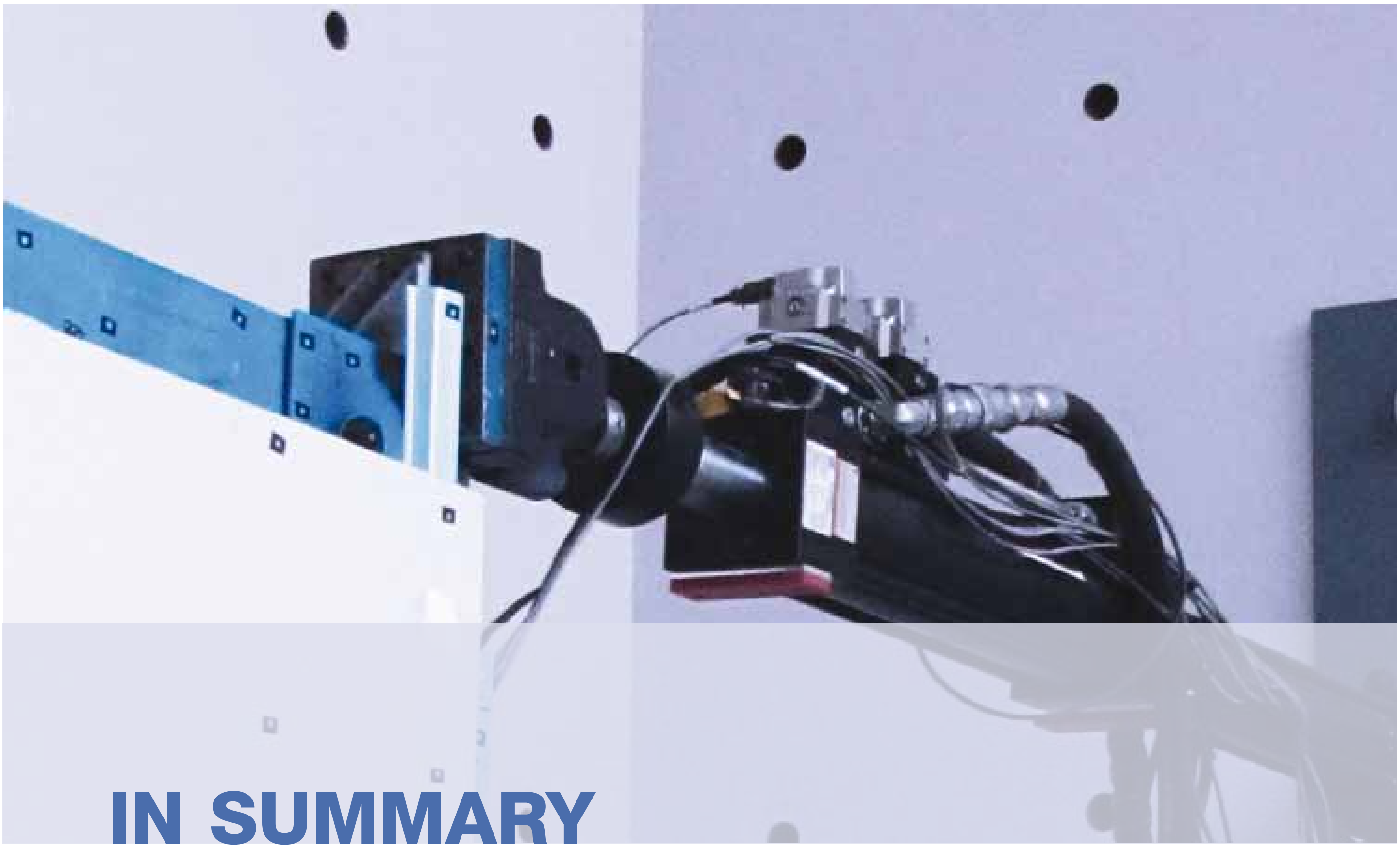
EXAMPLE 3:
POINT LOAD ON TRUSS

A test was carried out on a truss to check if it can be used to support a live load of 10 kN at midspan. The required design capacity is 15 kN (1.5 x 10 kN).

The single test result was 22.1 kN. The design capacity is:

- As a truss is an assembly of members, k_{SC} is 20% (Table 1).
- $K_{t\text{-}ave}$ = 2.21 (Table 4)
- Therefore the design capacity is 10 kN (22.1/2.21)

Therefore the truss cannot be used to support the required load.



IN SUMMARY

Design by testing is a powerful design tool, often used in practice for new and innovative products and for mass-produced components.

It enables direct calculation of a design capacity from the results of a small number of tests. Generally a minimum of 3 tests should be carried out, and more tests tend to give more reliable results. The design capacity can be calculated using either the minimum or average test result for a particular property. The coefficient of variation should be chosen as representative of the whole population and not the prototype test results.

References:

1. *NASH Standard – Residential and Low-rise Steel Framing, Part 1: Design Criteria, NASH 2005.*
2. *AS 4100 Steel Structures, Standards Australia, 1998.*
3. *NASH Handbook – Design of Residential and Low-rise Steel Framing, NASH Inc 2009.*
4. *CH Wang and L Pham, 2012 Sampling Factors for prototype testing of structures, Australian Journal of Structural Engineering, vol. 12, No 2, pp 119–126.*

NASH TECHNICAL NOTES

Note 1 – Structural Design of Buildings for Northern Australia

Note 2 – Six-Star Energy Efficiency Measures for Houses

Note 3 – Telecommunications Reception in Residential and Low-Rise Buildings

NASH STANDARDS

Residential and Low-rise Steel Framing:

- **Part 1 –** Design Criteria
- **Part 2 –** Design Solutions
- **Part 2.N –** Non Cyclonic Span Tables (N1 to N4)
- **Part 2.C –** Cyclonic Span Tables (C1 and C2)

Steel Framed Construction in Bushfire Areas

NASH HANDBOOK

Design of Residential and Low-rise Steel Framing

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