Associate Professor Charles Clifton
Steel and Composites

THE UNIVERSITY OF AUCKLAND
FACULTY OF ENGINEERING
Department of Civil and Environmental Engineering

School of Engineering
20 Symonds St
Auckland, New Zealand
Telephone +64 9 923 8529
Facsimile +64 9 373 7462
Email: c.clifton@auckland.ac.nz

The University of Auckland
Department of Civil and Environmental Engineering
Private Bag 92019
Auckland 1142
New Zealand

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To: ramsetreid
RE: Summary of Revised Outcomes from ReidBrace Testing at the University of Auckland Structures Test Hall and Recommendation for Bearing Capacity of Ply Supporting the ReidBrace, plus the change from connector elements from bolts to pins.

This letter provides a summary of the revised key outcomes of experimental testing on the ReidBrace System undertaken during 2017/2018 at the University of Auckland Structures Test Labs and recommendations on the bearing capacity of the ply supporting the ReidBrace. This latter point was not part of the testing programme but incorporates recommendations proposed in 2005 and updated in February 2017 to be included in the next revision of NZS 3404. This letter also covers the change from bolts to pins, proposed for 2019, for connecting the ReidBrace to the end connectors. It includes development of design capacities based on the nominal yield strength for alignment with the force based seismic design methods of NZS 1170.5.

Scope and Purpose of Testing

The purpose of the programme was to test the ReidBrace System in accordance with AS/NZS 1170.0 Appendices A and B, involving the following tests:

- monotonic tensile testing of a 1.5m ReidBrace assembly to determine performance of the system through to final fracture,
- impact tensile testing on ReidBrace fittings at 0°C and below, to determine the performance through to fracture at ambient temperatures and temperatures down to – 10 Deg C and
- cyclic testing of a 4.5m ReidBrace assembly at ambient temperature, with testing applied through to the ductility demand associated with fully ductile design using two cycles of loading to each increased displacement ductility demand.

Summary of testing outcomes

The following design parameters have been derived from the testing programme.

Design Ductility Factors (μ)

Component	S. Cat. 4 max μ_{des}	S. Cat. 3 max μ_{des}	S. Cat. 2 max μ_{des}	S. Cat. 1 max μ_{des}
ReidBrace 12	1	1.25	3	5
ReidBrace 16	1	1.25	3	5
ReidBrace 20	1	1.25	3	5
ReidBrace 25	1	1.25	--------	--------

Tensile Capacities (kN)

Tested Capacity in kN, where N_u = Reduced Characteristic Capacity (UTS Tested) and $\phi = 0.9$

Component	N_{des}
ReidBrace 12	64
ReidBrace 16	112
ReidBrace 20	180
ReidBrace 25	255

Design Capacity, ϕN_t, in kN, incorporating $\phi = 0.9$ and Nominal Loads, N_{nom} for overstrength determination

Component	ϕN_t	N_{nom}
ReidBrace 12	51	57
ReidBrace 16	91	101
ReidBrace 20	141	157
ReidBrace 25	221	246

The Design Capacity (ϕN_t) is for use in design of the ReidBrace in a seismic resisting system to NZS 3404 and is based on the nominal yield strength of Grade 500E ReidBar, used as part of the ReidBrace System. The Tested Capacity (ϕN_u) exceeds the Design Capacity (ϕN_t), thus confirming that the recommended Design Capacity is suitable as per procedure of NZS3404 C17.5 & AS/NZS1170.0 Appendix B.

Overstrength Factors

This has been determined in accordance with the provisions of NZS 3404 and are to be used where the design capacity of the secondary members of the seismic resisting system is used to resist the capacity design derived design actions. The Nominal Capacity is multiplied by this factor to give the Overstrength Capacity for capacity design to NZS 3404.

	S. Cat. 4 max μ_{des}	S. Cat. 3 max μ_{des}	S. Cat. 2 max μ_{des}	S. Cat. 1 max μ_{des}
Overstrength Factor (ϕ_{oms})	1.0	1.25	1.30	1.35

Equivalent Elastic Modulus

Size	Equivalent Elastic Modulus (MPa)
12mm	160000
16mm	145000
20mm	140000
25mm	135000

Findings from impact tensile testing at 0°C and below
Component failures occasionally occurred when they were tested under impact tensile loading at -10°C, however improvement in performance was noted when tested at -5°C. It was therefore theorised that the ductile to brittle transition temperature of the product lies between -5°C and -10°C, and that the service temperature for the design of the ReidBrace System shall be limited to -5°C.

Ply in Bearing
The current (1997/2001/2007) provisions of NZS3404 for determination of the required thickness of the ply supporting the 8.8 Class Nut that connects the RBRACE and the RBRACE-END are very conservative. It has been proposed, in 2005 and revisited in 2017, to replace those provisions with the following:

$$V_b = \min(3.2 f_{yply} d_{pin} t_p k_p; 1.95 f_{uply} d_{pin} t_p k_p)$$

where: k_p = 1.0, unless the particular application must provide dependable in-service rotation, in which case k_p = 0.5 shall be used.

The recommended limit proposed to Standards New Zealand in 2005 give the first of the two limits only but it is written for the ply being of Grade 250 material, with $f_{y,nominal}$ = 250 MPa and $f_{u,nominal}$ = 410 MPa and is developed on the basis that appreciable ply hole elongation can be dependably developed at the ULS, which is the case for the Grade 250 plate around which the provisions were developed. However, as the ratio of fu/fy decreases with increasing plate strength, a limit around f_u based on the ratio for Grade 250 material needs to also be included to allow for higher strength plies. This is proposed in the above recommendations.

For a ReidBrace system which is not expected to undergo end rotation except during a significant earthquake, k_p = 1.0 is appropriate.

Changing Bolts to Pins for the ReidBrace to End Connectors.

The experimental testing undertaken at the University of Auckland used Property Class 8.8 Structural Bolts to AS/NZS 1252. It is proposed to replace these with pins machined from AISI 4340 material.

The change from a bolt to a pin will improve the performance under high cycle fatigue loading, as bolts have a much lower fatigue endurance limit than pins. Although performance in high cycle fatigue was not within the scope of the University of Auckland testing, it should be noted that this change will positively impact on the fatigue life.

In terms of monotonic static loading and severe seismic cyclic loading, the pin material will deliver comparable or better performance to a bolt provided the mechanical properties of the pin, fy and fu, are equal to or greater than those of the PC 8.8 structural bolt and that the cross sectional area of the pin ≥ the cross-sectional area of the shank of the bolt. The proposed pin sizes meet all these criteria, with $f_{y,0.2\%\ min}$ = 745 MPa and $f_{u,min}$ = 930 MPa, $f_{u,max}$ = 1080 MPa. This is for material supplied in Heat Treated Condition U which gives HRC from 28 to 36, which is the range specified in the Rbrace Pins Rev1 drawing. The Charpy Impact is 42 Joules at 0°C, which is above the minimum required of 27 Joules at 0°C.

Because these pins are to be galvanized and are being made from AISI 4340 material, then there is a potential for hydrogen embrittlement of the AISI 4340 pin from the galvanizing process, as the material has a tensile strength close to 1000 MPa, which is the minimum strength at which this may occur. The susceptibility for this should be determined by undertaking Charpy Impact Testing on the as galvanized material for the largest diameter pin proposed prior to producing these pins. A minimum of three tests should be undertaken, with all three specimens passing the 27J at 0°C limit. Alternatively, advice from an experienced metallurgist should be obtained to determine if this testing is necessary.

Summary and Recommendations.

On the basis of the above, the following tables consisting ply in bearing design capacities are derived for each ReidBrace size, where:

N_{nom} = ReidBrace Nominal Load = f_y*A_b
f_y = Yield stress
A_b = Stress area of bar
N_{ov} = ReidBrace Overstrength Loads = $N_{nom}\phi_{oms}$
ϕ_{oms} = Overstrength Factor

= Suitable for structures category 4 (μ = 1.0)
= Suitable for structural category 3 & 4 (μ ≤ 1.25)
= Suitable for structures of every category

Nominal Load (ReidBrace), kN

Component	N_{nom}
ReidBrace 12	57
ReidBrace 16	101
ReidBrace 20	157
ReidBrace 25	246

12mm ReidBrace

N_{nom} = 57kN
ϕ_{oms} (Cat. 1) = 1.35

N_{ov} (Cat. 1) = 76.95kN

ϕV_b Ply in Bearing (kN)			
Steel Grade	Thickness of steel plate (mm)		
	10	12	14
G 250	115.1	138.2	161.2
G 300	120.7	144.9	169.0
G 350	126.4	151.6	176.9

16mm ReidBrace

N_{nom} = 101kN
ϕ_{oms} (Cat. 1) = 1.35
ϕ_{oms} (Cat. 3) = 1.25
ϕ_{oms} (Cat. 4) = 1.0

N_{ov} (Cat. 1) = 136.35kN
N_{ov} (Cat. 3) = 126.25kN
N_{ov} (Cat. 4) = 101kN

ϕV_b Ply in Bearing (kN)				
Steel Grade	Thickness of steel plate (mm)			
	10	12	14	15
G 250	115.1	138.2	161.2	172.7
G 300	120.7	144.9	169.0	181.1
G 350	126.4	151.6	176.9*	189.5

20mm ReidBrace

N_{nom} = 157kN
ϕ_{oms} (Cat. 1) = 1.35

N_{ov} (Cat. 1) = 211.95kN

ϕV_b Ply in Bearing (kN)			
Steel Grade	Thickness of steel plate (mm)		
	16	18	20
G 250	230.3	259.0	287.8
G 300	241.5	271.7	301.9
G 350	252.7	284.3*	315.9

25mm ReidBrace

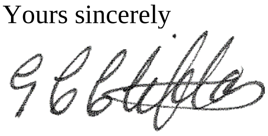
N_{nom} = 246kN
ϕ_{oms} (Cat. 3) = 1.25

N_{ov} (Cat. 3) = 307.5kN

ϕV_b Ply in Bearing (kN)			
Steel Grade	Thickness of steel plate (mm)		
	20	22	24
G 250	431.7	474.9	518.1
G 300	452.8	498.1	543.3
G 350	473.9	521.2	568.6

The testing programme concludes that the 12, 16, 20 & 25mm ReidBrace System meet the requirements of NZS1170.0:2002 Appendix A & B, and can be designed to NZS3404:1997/2001/2007 in accordance with the above design provisions.

Yours sincerely



Dr G Charles Clifton
Associate Professor of Civil Engineering