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Fourteenth International Specialty Conference on Cold-Formed Steel Structures
St. Louis, Missouri U.S.A., October 15-16, 1998

COLD-FORMED SHEAR CONNECTORS FOR COMPOSITE CONSTRUCTIONS

Maximiliano Malite[1], Walter Abrahão Nimir[1], José Jairo de Sáles[1]
and Roberto Martins Gonçalves[1]

SUMMARY

Construction employing composite steel-concrete structures has been increasingly applied in building and bridge structures, and solutions involving cold-formed profiles have recently appeared which, in many cases, have resulted in reduced costs. Because constructions using composite steel-concrete structures, involving cold-formed profiles, are not covered by current Brazilian Codes, it is necessary to investigate the issue.

This paper, therefore, presents the results of an experimental analysis (24 push-out tests) made for two types of connectors: U-profile and angle, with two plate thicknesses: 2.65 mm and 4.76 mm, evaluating their strength and their load-slip behavior. The tests were performed on test specimens adapted to those proposed by the British Standard BS 5400 - part 5 and by EUROCODE 3.

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INTRODUCTION

The use of cold-formed steel structures in Brazil has increased considerably, mainly due to the fact that hot-rolled shapes are less available on the market and that welded shapes have a relatively high cost. In Brazil, cold-formed shapes that had previously been used mainly in light roof structures are now being employed in increasingly diversified applications, notably in association with concrete slabs in floor or roof structures, as well as in small industrial buildings and homes.

The codes in Brazil for the design of steel structures using cold-formed shapes do not include requirements for the design of composite structures. Thus, two tendencies have lately been observed in design: a disregard of the behavior of composite steel-concrete, which leads to a higher consumption of steel and, therefore, to higher costs, or the adoption of the procedure and expressions destined for hot-rolled elements, which may lead to unsafe conditions.

The main purpose of this study was to make an experimental analysis of the structural behavior and strength of cold-formed shear connectors (U-shapes and angle plates) commonly employed in Brazil. The results of this analysis were compared to those obtained from the expression of the American code AISC-LRFD/94 for hot-rolled channel connectors, evaluating the feasibility of extending the use of this classic expression to cold-formed shapes.

SHEAR CONNECTORS - STRUCTURAL BEHAVIOR

Shear connectors are mechanical devices that are employed to unite steel beams to concrete slabs, absorbing the shear flow at the beam-slab interface and preventing a vertical separation between the two elements (uplift). Connectors are classified as flexible and stiff. Generally speaking, the flexibility of connectors can be associated with their response in relation to the shear flow generated between the steel beam and the concrete slab when they function as composite beams. This response corresponds to a relation of strength vs. relative displacement (slip) of the type shown in figure 1, in other words, it corresponds to “ductile” behavior.

This characteristic does not strongly affect the behavior of the composite beam in a serviceability or “elastic” state, but it conditions the response of the connector in the ultimate state by allowing the shear flow to be redistributed among all the connectors. Thus, under increasing loads, a flexible connector approaching its maximum capacity presents sufficient strain to allow the shear flow to be passed on to the adjacent connectors, which leads to uniformity. This characteristic allows for uniformly spaced connectors along the length of the beam, without reducing the capacity of the connection in the strength limit state.

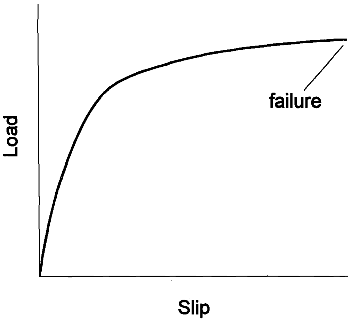

Fig. 1 - Typical load-slip curve for flexible connectors

NOMINAL STRENGTH OF COMMON CONNECTORS

Some types of connectors have already been analyzed exhaustively from the experimental point of view, as for example, the headed stud and the hot-rolled channel. Based on the results of these tests, analytical expressions have been proposed to evaluate the nominal strength of these connectors, such as the one presented by the American code AISC-LRFD/94 (eq.1), applicable to hot-rolled connectors. The Brazilian code NBR 8800/86 adopts the same expression as the AISC-LRFD.

$$Q_n = 0.0003(t_f + 0.5t_w)L_c\sqrt{f_c E_c} \qquad (1)$$

where

t_f = flange thickness of channel shear connector, mm
t_w = web thickness of channel shear connector, mm
L_c = lenght of channel shear connector, mm
f_c = specified compressive strength of concrete, MPa
E_c = modulus of elasticity of concrete, MPa. For normal-weight concrete ($\gamma = 2{,}300$ Kgf/m^3),

$$E_c = 4{,}600\sqrt{f_c} \qquad (2)$$

Equation 1 was applied to the case of cold-formed connectors (U-shape and angle plate) and the results then compared with those obtained in "push-out" type tests. In the case of cold-formed shapes, the thickness is constant and, therefore, expression 1 results in:

$$Q_n = 0.00045\ tL\sqrt{f_c E_c} \qquad (3)$$

where

L = lenght of cold-formed connector, mm
t = thickness of cold-formed connector, mm

SHEAR CONNECTORS - RESULTS OF PUSH-OUT TESTS

The evaluation of load-slip strength and behavior of cold-formed channel connectors (fig. 2) and angle plates was carried out through standard push-out tests (fig. 3) on specimens similar to those presented in the British code BS 5400/79 - part 5. Two thicknesses – 2.65 mm and 4.76 mm – that are commonly used in Brazil were tested. Six tests were carried out for each connector type and thickness – three in position I and three in position II (inverted), totaling 24 tests, as shown in fig.4.

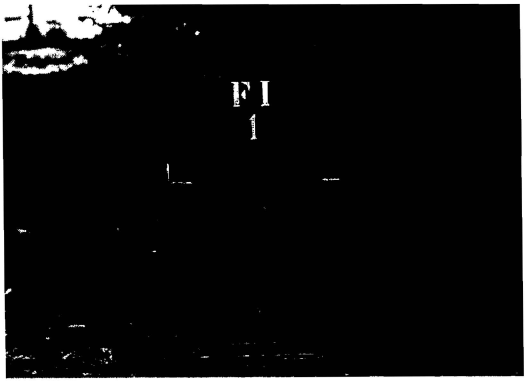

Fig. 2 - Channel connector

Fig. 3 - General view of the push-out test

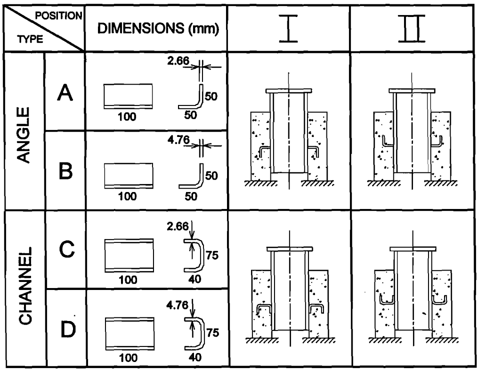

Fig. 4 - Specimens for the push-out tests

The mechanical properties of the steel of the connectors were evaluated through tension tests, according to the code ASTM A370, and the results are summarized on table 1.

Table 1 - Tensile properties of virgin steel (ASTM A370/92)

SPECIMEN	THICKNESS (mm)	f_y (MPa)	f_u (MPa)	A (%)
1	2.65	246.4	341.0	41.4
2	2.65	258.5	357.7	38.4
3	2.65	245.3	345.3	40.0
4	2.65	250.0	345.3	40.4
5	2.65	254.2	350.3	40.6
6	2.65	243.7	343.7	39.0
average	**2.65**	**249.7**	**347.2**	**40.0**
7	4.76	247.7	362.2	38.8
8	4.76	245.4	360.3	40.6
9	4.76	248.3	360.2	38.0
10	4.76	249.1	360.1	38.2
11	4.76	244.6	359.3	40.6
12	4.76	240.8	358.7	42.4
average	**4.76**	**246.0**	**360.0**	**39.8**

where
f_y = yield strenght; f_u = tensile strenght; A = elongation (in 50mm)

The mechanical properties of the concrete were evaluated through compression tests, on 15x30 (cm) cylindrical specimens, and the results are summarized on table 2.

Table 2 - Compression properties of concrete (average values)

TYPE	CONNECTOR	f_c (MPa)	E_c (MPa)
A	angle - 2.65 thickness	30.4	41,850
B	angel - 4.76 thickness	24.8	33,322
C	channel - 2.65 thickness	25.9	36,092
D	channel - 4.76 thickness	26.7	no considered (high variability)

where
f_c = compressive strength of concrete (28 days)
E_c = modulus of elasticity of concrete (measured by strain gages)

Fig. 5 shows the dimensions of the specimens for the push-out tests. These tests were carried out until collapse of the specimens occurred, with load steps equal to 20 kN (10 kN per connector) and, in each step, the relative displacements between the steel and the concrete (slip) at four symmetrically placed points were recorded.

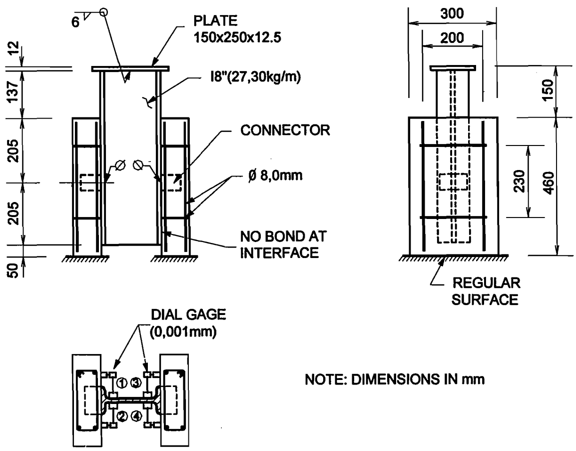

Fig. 5 - Dimensions of the specimen for the push-out test

Fig. 6 shows a typical result of the push-out tests, while table 3 summarizes the results of the 24 tests carried out. Figures 7 to 10, below, show the load-slip curves for all the tests, corresponding to the average slip values evaluated at the four measured points.

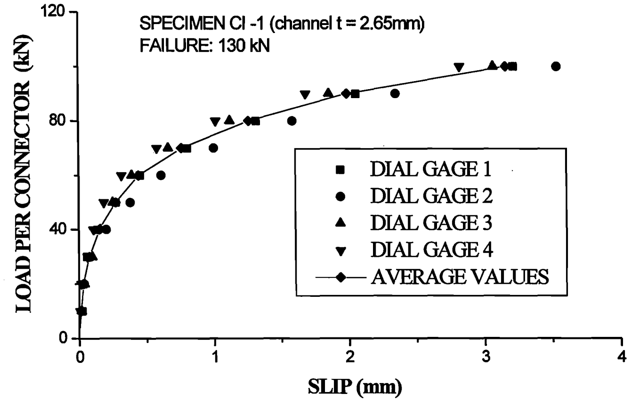

Fig. 6 - Typical results of the push-out test

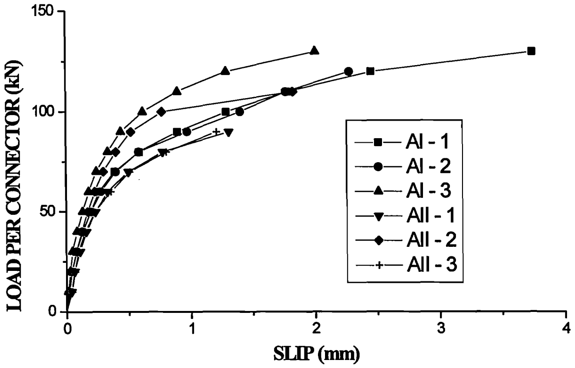

Fig. 7 - Load-slip curves of the type A connector (angle t = 2.65mm)

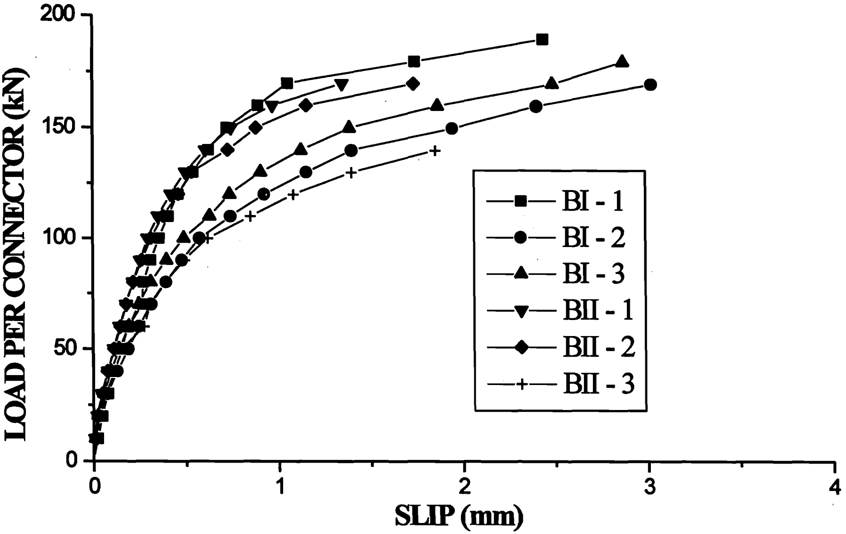

Fig. 8 - Load-slip curves of the type B connector (angle t = 4.76mm)

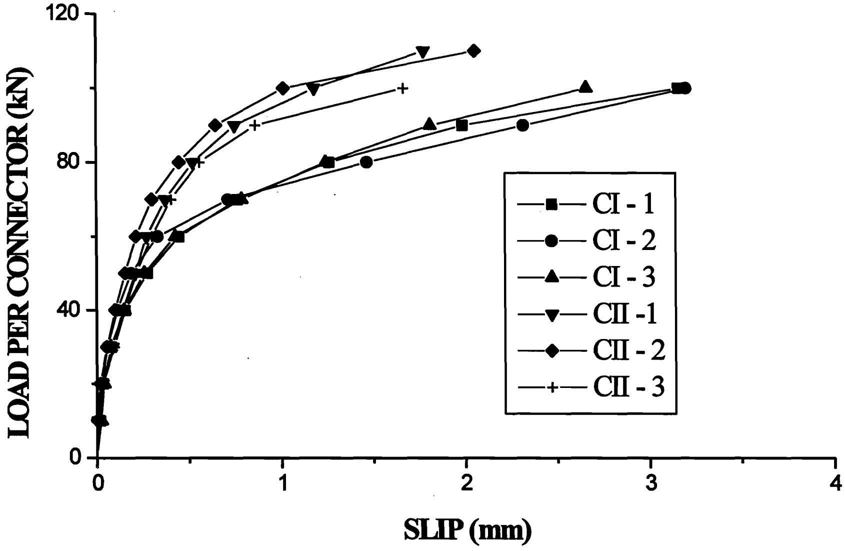

Fig. 9 - Load-slip curves of the type C connector (channel t = 2.65mm)

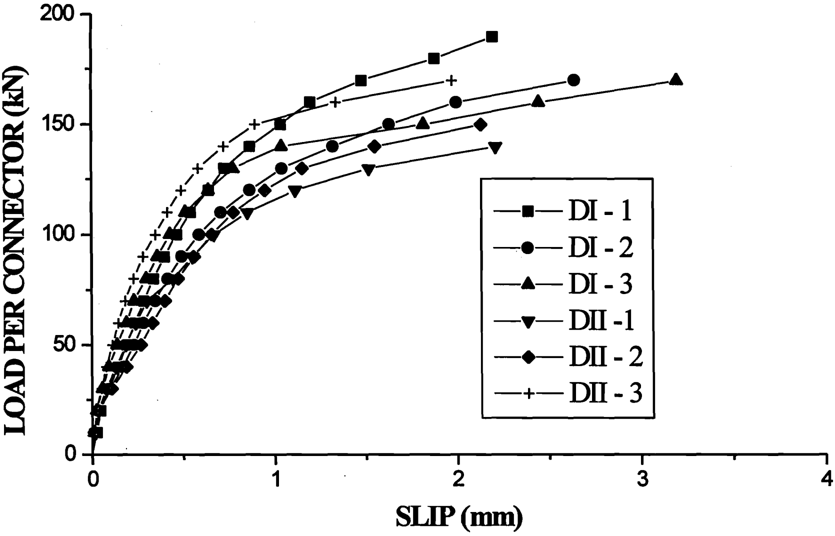

Fig. 10 - Load-slip curves of the type D connector (channel t = 4.76mm)

Table 3 - Results of the push-out tests

SPECIMEN	P_u (kN)	s_{max} (mm)	FAILURE MODE
AI-1	135.0	3.7	connector/concrete
AI-2	132.5	2.3	connector/concrete
AI-3	135.0	2.0	connector/concrete
AII-1	105.0	1.3	connector/concrete
AII-2	117.5	1.8	connector/concrete
AII-3	120.0	1.2	connector/concrete
average	**124.2**	-	
BI-1	195.0	2.4	concrete
BI-2	175.0	3.0	concrete
BI-3	187.5	2.9	concrete
BII-1	175.0	1.4	concrete
BII-2	177.5	1.7	concrete
BII-3	157.5	1.8	concrete
average	**178.0**	-	
CI-1	130.0	3.2	connector/concrete
CI-2	120.0	3.2	concrete
CI-3	122.5	2.7	connector/concrete
CII-1	125.0	1.8	connector/concrete
CII-2	115.0	2.1	connector/concrete
CII-3	125.0	1.7	connector/concrete
average	**122.9**	-	
DI-1	215.0	2.2	concrete
DI-2	200.0	2.6	concrete
DI-3	195.0	3.2	concrete
DII-1	155.0	2.2	concrete
DII-2	175.0	2.1	concrete
DII-3	175.0	2.0	concrete
average	**185.8**	-	

where
P_u = load per connector at failure
s_{max} = maximum slip measured in push-out test

Two failure modes were observed in the push-out tests. In the case of the connectors with 2.65 mm thickness, rupture of the connector occurred at the connection weld associated with rupture of the concrete (except CI-2), while in the case of the connectors with 4.76 mm thickness, there was rupture of the concrete resulting from excessive rotation of the connector (figs. 11 and 12, respectively).

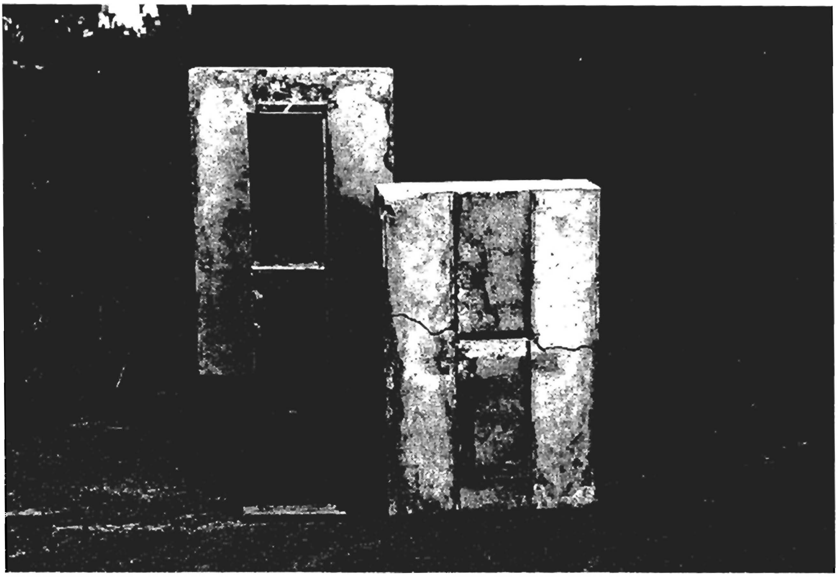

Fig. 11 - Failure of the connector

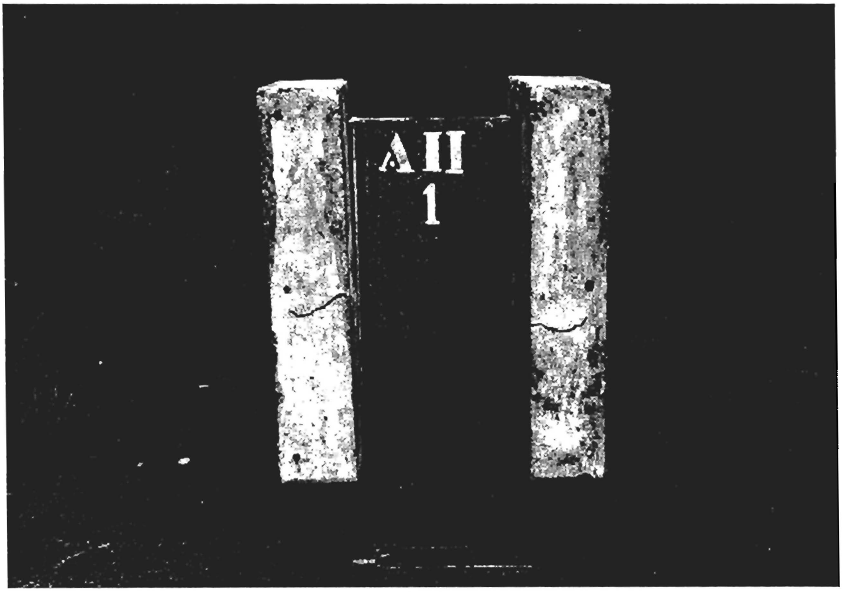

Fig. 12 - Failure of the concrete

CONCLUSIONS

The load-slip behavior obtained from the push-out tests indicated the flexibility of the analyzed connectors, which was characterized by the occurrence of relatively high slip until rupture was reached (see figs. 6 to 10).

The slip values indicated by the four dial gages presented strongly divergent values in some tests, which results from several factors such as, for instance: eccentricity in the application of force, irregular bases, imperfections in the production of the concrete slabs, etc.

For the two types of connectors analyzed, the positions in relation to shear flow (positions I and II indicated in fig. 4) showed a slight influence on connector strength, however, the connectors placed in position I presented higher ductility than those in position II did.

The experimental results were compared with the theoretical values evaluated by expression (3), considering the modulus of elasticity (E_c) calculated by expression (2) and that obtained experimentally from the compression tests carried out on concrete specimens (see table 2). Table 4, below, contains a summary of the results.

From table 4 it can be seen that the experimental values of connector strength (P_u) were only slightly above the theoretical values obtained from the theoretical modulus of elasticity of the concrete (calculated by equation 2), and slightly below the theoretical values obtained from the modulus of elasticity determined experimentally.

To conclude, it can be stated that in the absence of experimental results, the expression presented by the AISC-LRFD/94 code for hot-rolled channel connectors proved to be adequate to evaluate the nominal strength of cold-formed channel or angle plate connectors, admitting the modulus of elasticity for concrete obtained by expression (2). It must be pointed out, however, that this equation should be used with caution, since there is need for a more detailed study on other connector sizes and concrete strengths.

Table 4 - Theoretical and experimental results

TYPE	(1) Q_n (kN) (E_c by eq. 2)	(2) Q_n (kN) (E_c experimental)	(3) P_u (kN) (experimental)	(3)/(1)	(3)/(2)
A	104.7	134.5	124.2	1.19	0.92
B	161.5	194.7	178.0	1.10	0.91
C	92.8	115.3	122.9	1.32	1.07
D	170.6	-	185.8	1.09	-

where
Q_n = nominal resistance of connector, eq. 3
P_u = experimental load per connector at failure (average value)

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APPENDIX A - REFERENCES

AMERICAN INSTITUTE OF STEEL CONSTRUCTION (1994). *Load and resistance factor design (LRFD)*. Chicago.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (1992). *ASTM A370 - Standard test methods and definitions for mechanical testing of steel products.* Philadelphia.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (1986). *NBR 8800 - Projeto e execução de estruturas de aço de edificios.* Rio de Janeiro.

BRITISH STANDARDS INSTITUTION (1979). *BS 5400 - Steel, concrete and composite bridges: part 5 - code of practice for design of composite bridges.* London.

JOHNSON, R.P. (1975). *Composite structures of steel and concrete.* London, Constrado Monographs, Granada Publishing, v.1.

MALITE, M. (1990). *Composite steel-concrete beams of buildings* (in portuguese). MsC thesis, University of São Paulo at São Carlos campus, São Carlos, SP, Brazil.

MALITE, M. (1993). *Structural behavior of composite steel-concrete cold-formed beams* (in portuguese). PhD thesis, University of São Paulo at São Carlos campus, São Carlos, SP, Brazil.

SALMON, C.G.; JOHNSON, J.E. (1996). *Steel strucutres: design and behavior.* New York, Harper & Row.

YU, W.W. (1985). *Cold-formed steel design.* New York, John Wiley & Sons.

APPENDIX B - NOTATION

A = elongation (in 50mm)
E_c = modulus of elasticity of concrete
f_c = specified compressive strength of concrete (28 days)
f_y = yield strenght of virgin steel
f_u = tensile strenght of virgin steel
L = lenght of cold-formed connector, mm
L_c = lenght of channel shear connector
P_u = load per connector at failure
Q_n = nominal strenght of connector
s_{max} = maximum slip measured in push-out test
t = thickness of cold-formed connector
t_f = flange thickness of channel shear connector
t_w = web thickness of channel shear connector