بسم الله الرحمن الرحيم

KINGDOM OF SAUDI ARABIA
MINISTRY OF HIGHER EDUCATION
AL-BAHA UNIVERSITY
COLLEGE OF ENGINEERING

المملكة العربية السعودية
وزارة التعليم العالي
جامعة الباحة
كلية الهندسة

Compressive Strength of Concerete-filled Thin Steel Stubs: Theoretical and Experimental Study

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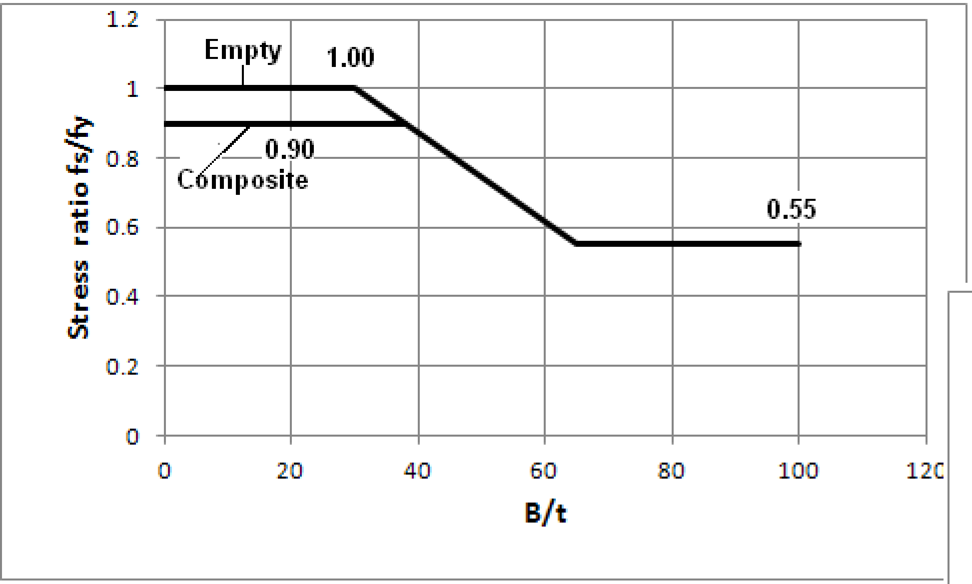
1. Introduction:

The use of thin steel hollow sections filled with concrete is an attractive method used in construction. However, many difficulties are encountered during the design phase as most codes of practice limit their use to a certain cross section slenderness B/t ratio. The latter is a major parameter that dictates the behaviour of the section and hence the structural element and consequently the whole structure.

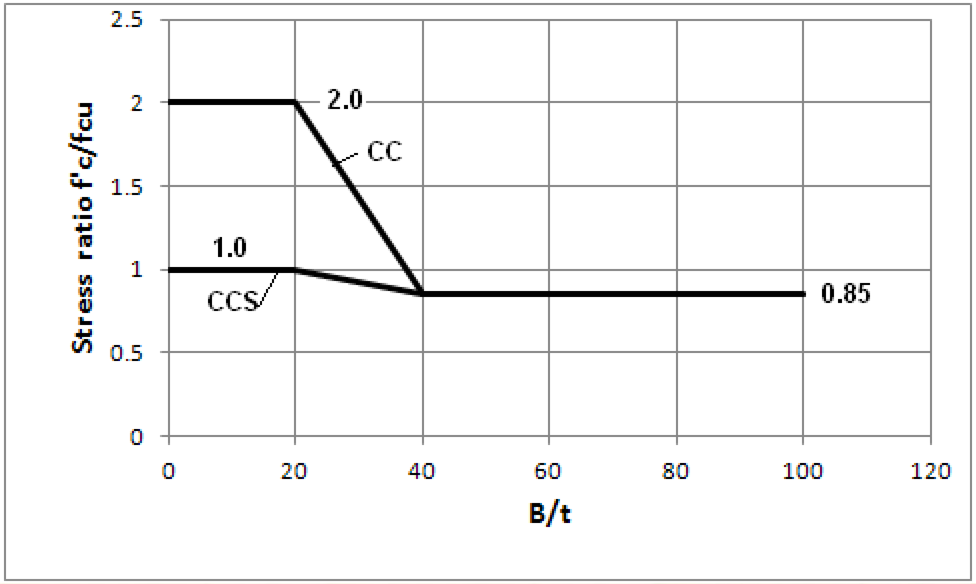
For the design purpose, there is a need to develop a method that could help predicting the strength of the studied composite section. More information could be given for the designer as far as local buckling is concerned. In advance we can predict the effect of the local buckling and consider its effect on the strength of the composite section and the column. This method could be used as guidance by considering the performance of the chosen section and decide whether the chosen section is appropriate or not. This will be the aim of the present study.

2. Theoretical analysis



Steel model

Concrete model



2. Theoretical analysis

$Nsq = fy.As + 0.67.fcu.Ac$ → Referential squash load

$N = fs.As + f'c.Ac$ → Theoretical load

$Ns = fs.As$ → Steel load

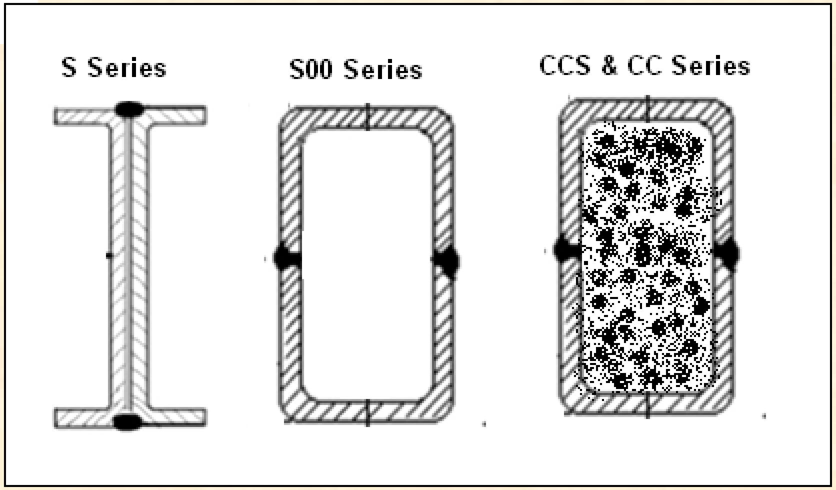
$Nc = f'c.Ac$ → Concrete load

$Ig = N/Nsq$ → Global strength index

$Is = Ns/Nsq$ → Steel strength index

$Ic = Nc/Nsq$ → Concrete strength index

3. Experimental program



Main studied parameters:

- The steel cross section **shape**
- The B/t ratio range: **20-100**
- The loading mode:

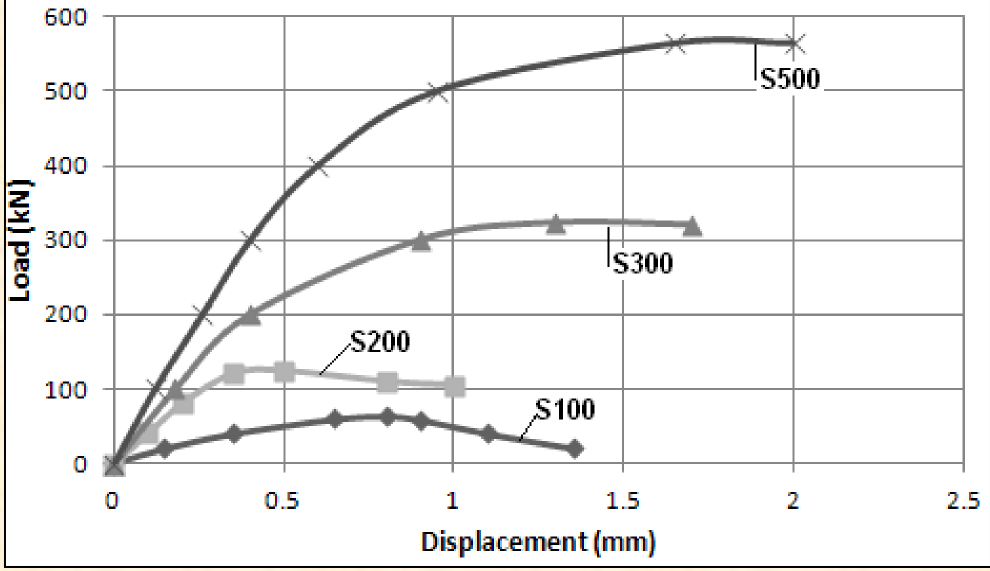
  CCS mode : steel &concrete loaded

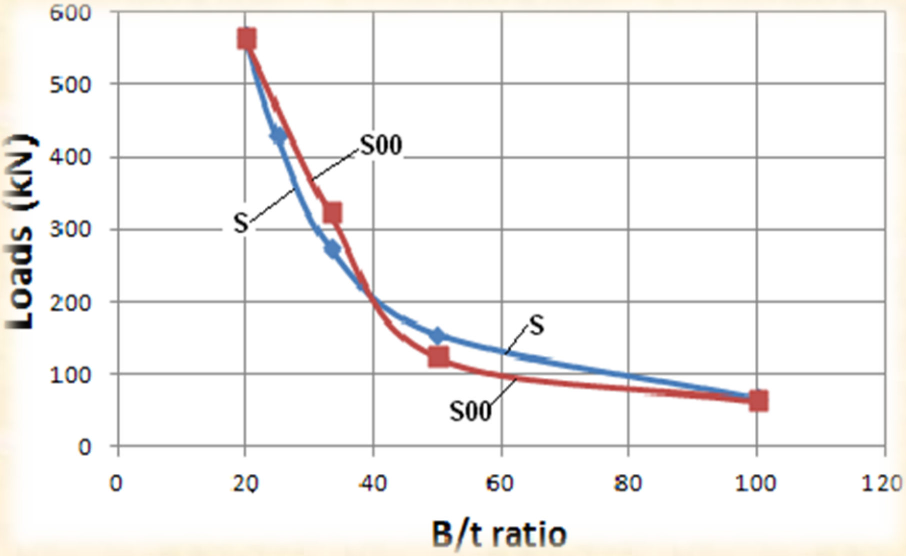
  CC mode: Only concrete loaded

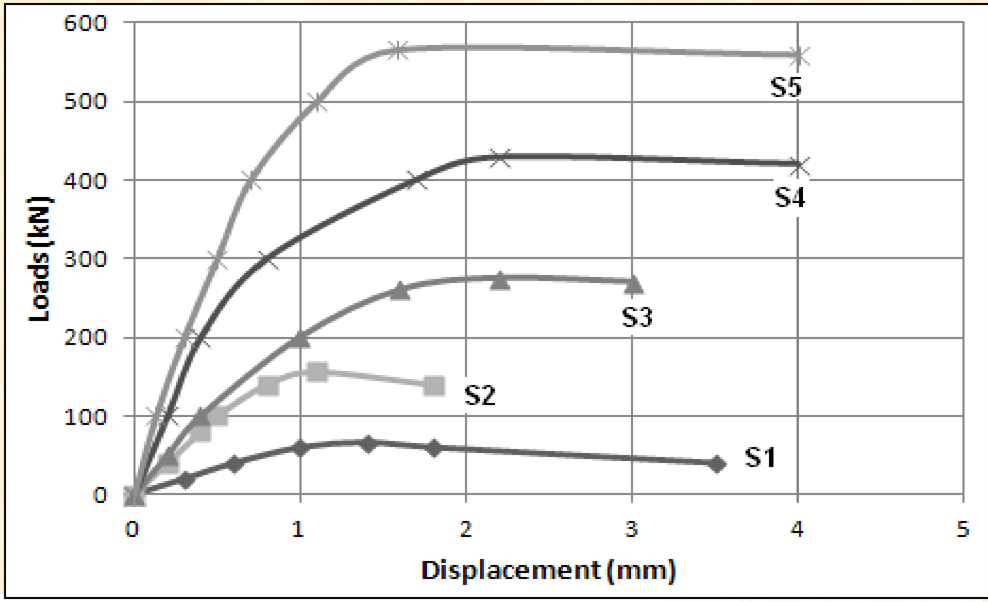
Steel: f_y= 300. MPa
Concerete: f_{cu}= 30. MPa
Steel cross section: 100x100 mm

3. Experimental program

Test Results for empty steel stubs







3. Experimental program

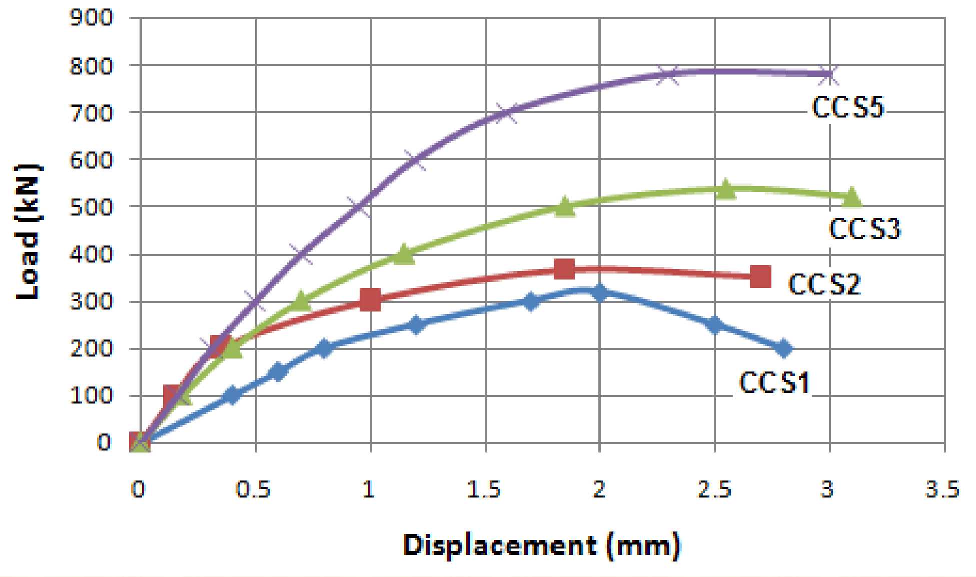
Theoretical and experimental results for empty steel stubs.

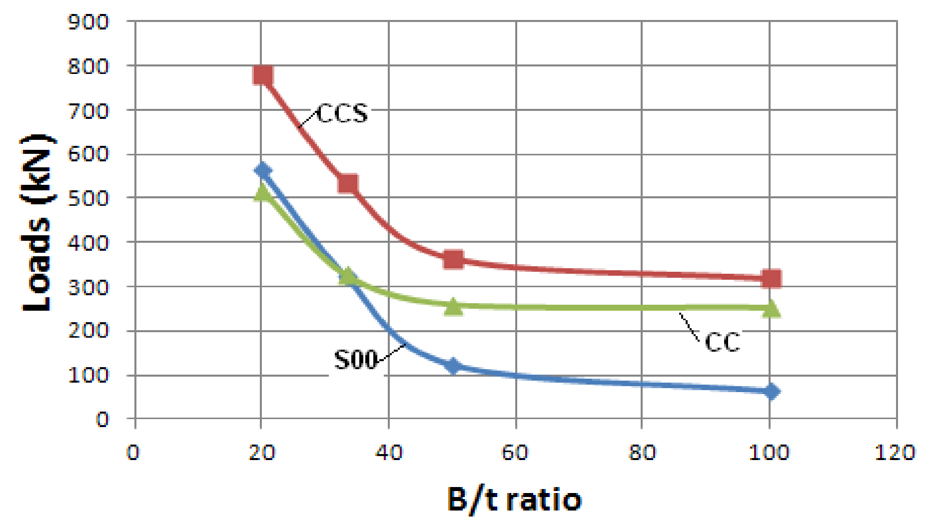
Sp.	B (mm)	T (mm)	B/T	As (mm²)	Test (kN)	f_s (MPa)	N (kN)	N_{sq} (kN)	I_s (kN)	N/Test
S100	100	1	100	396	**63.8**	165	65.3	118.8	0.537	1.023
S200	100	2	50	784	**124**	225	176	235.2	0.527	1.419*
S300	100	3	33.3	1164	**323**	269	314	349.2	0.972	0.972
S500	100	5	20	1900	**564**	300	570	570	0.989	1.010
S1	100	1	100	396	**66.3**	165	65.3	118.8	0.558	0.985
S2	100	2	50	784	**156**	225	176	235.2	0.663	1.128
S3	100	3	33.3	1164	**275**	269	314	349.2	0.787	1.141
S4	100	4	25	1536	**428.7**	270	414.7	460.8	0.93	0.967
S5	100	5	20	1900	**566**	300	570	570	0.992	1.007
									Mean:	**1.072**

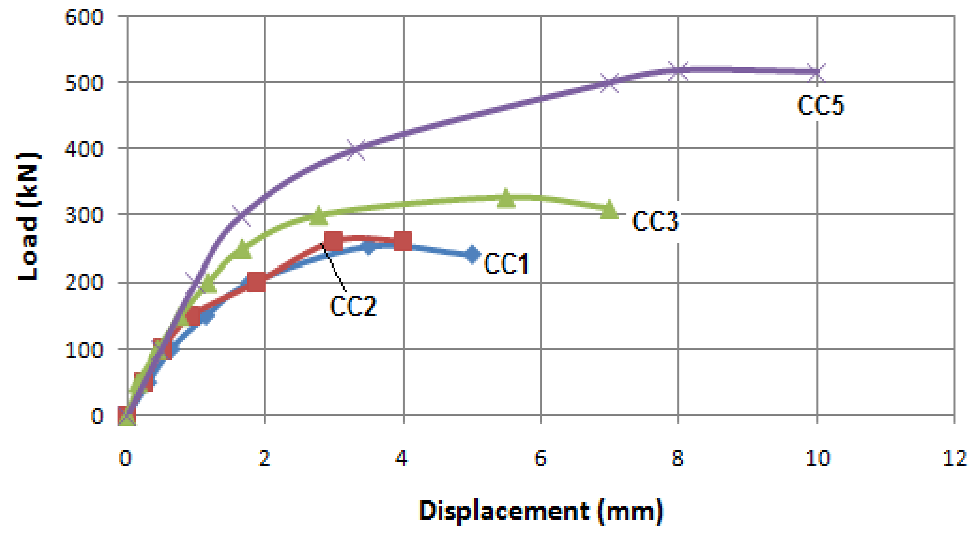
*When excluding odd result S_{200} Mean=1.029

3. Experimental program

Test Results for composite stubs







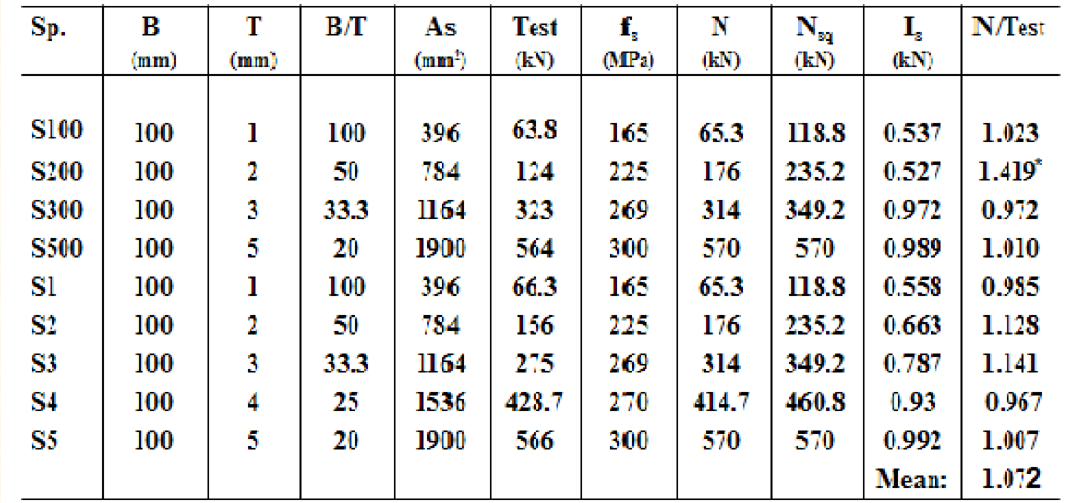
3. Experimental program

Theoretical & experimental results for composite stubs

Sp.	B (mm)	T (mm)	B/T	A_s (mm^2)	A_c (mm^2)	Test (kN)	N_{sq} (kN)	f_s (MPa)	f_c' (MPa)	N (kN)	I_g	N/Test
CCS1	100	1	100	396	9604	**316.6**	311.8	165	25.5	310.2	1.015	0.979
CCS2	100	2	50	784	9216	**365.**	420.4	219	25.5	406.6	0.868	1.113
CCS3	100	3	33.3	1164	8836	**536.7**	532.8	270	27.6	558.1	1.039	1.039
CCS5	100	5	20	1900	8100	**780.**	732.8	270	30.	756.	1.064	0.969
CC1	100	1	100	396	9604	**250.**	311.8	98.8	25.5	244.9	0.801	0.979
CC2	100	2	50	784	9216	**260.**	420.4	48.8	25.5	235.	0.618	0.903
CC3	100	3	33.3	1164	8836	**326.7**	532.8	32.3	36.	318.	0.613	0.973
CC5	100	5	20	1900	8100	**518.3**	732.8	18.9	60.	486.	0.707	0.937
											Mean:	**0.986**

4 Validation of suggested method

Comparison of experimental and theoretical results



Sp.	B (mm)	T (mm)	B/T	As (mm^2)	Test (kN)	f_s (MPa)	N (kN)	N_{sq} (kN)	I_s (kN)	N/Test
S100	100	1	100	396	63.8	165	65.3	118.8	0.537	1.023
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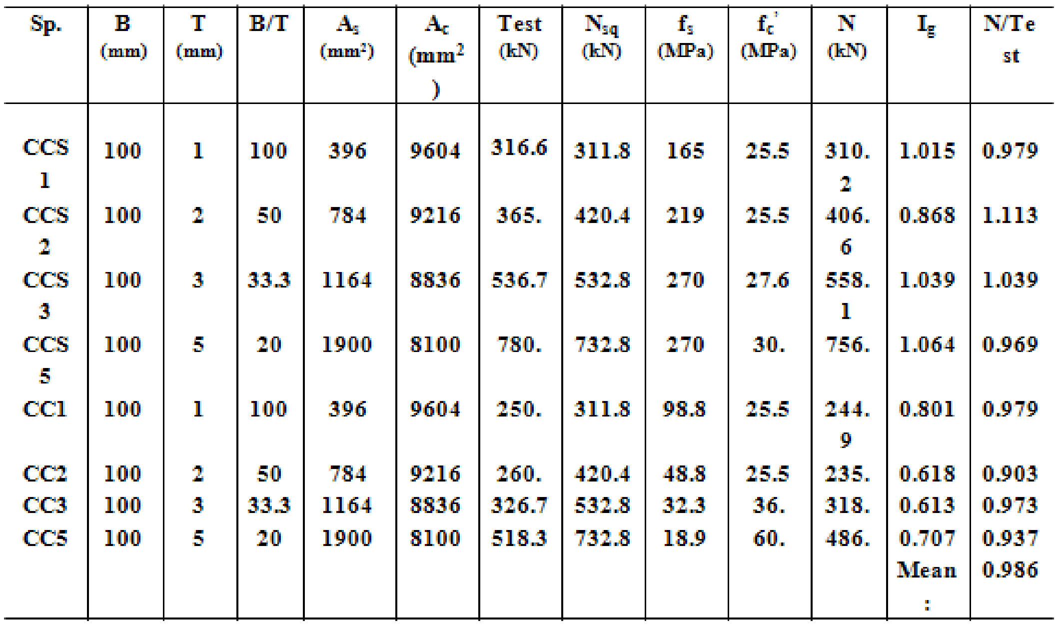
									Mean:	1.072



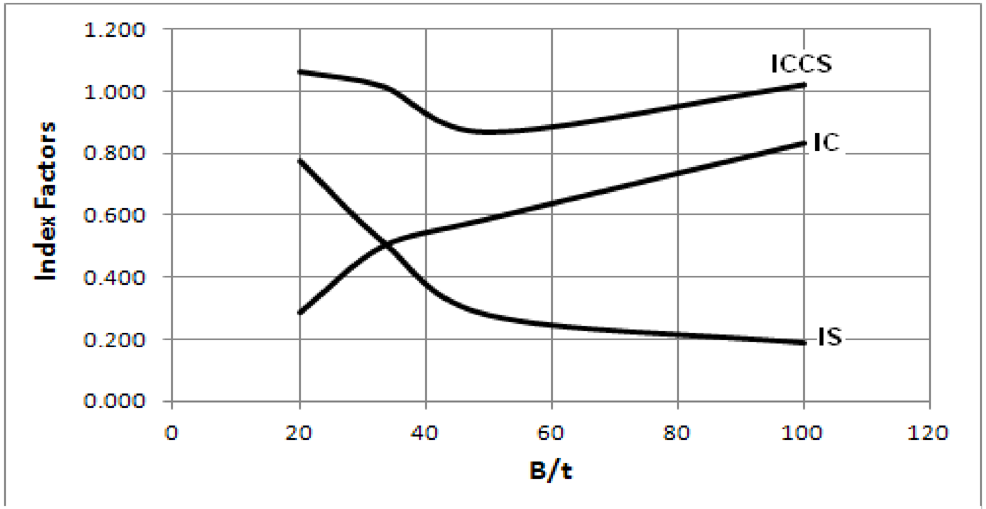
Sp.	B (mm)	T (mm)	B/T	A_s (mm^2)	A_c (mm^2)	Test (kN)	N_{sq} (kN)	f_s (MPa)	f_c' (MPa)	N (kN)	I_g	N/Test
CCS 1	100	1	100	396	9604	316.6	311.8	165	25.5	310.2	1.015	0.979
CCS 2	100	2	50	784	9216	365.	420.4	219	25.5	406.6	0.868	1.113
CCS 3	100	3	33.3	1164	8836	536.7	532.8	270	27.6	558.1	1.039	1.039
CCS 5	100	5	20	1900	8100	780.	732.8	270	30.	756.	1.064	0.969
CC1	100	1	100	396	9604	250.	311.8	98.8	25.5	244.9	0.801	0.979
CC2	100	2	50	784	9216	260.	420.4	48.8	25.5	235.	0.618	0.903
CC3	100	3	33.3	1164	8836	326.7	532.8	32.3	36.	318.	0.613	0.973
CC5	100	5	20	1900	8100	518.3	732.8	18.9	60.	486.	0.707	0.937
											Mean:	0.986

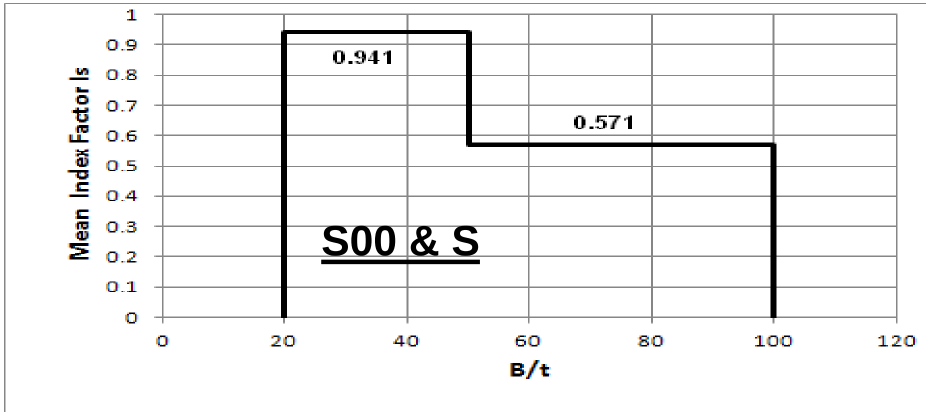
4 Validation of suggested method

Comparison of experimental and theoretical results from literature

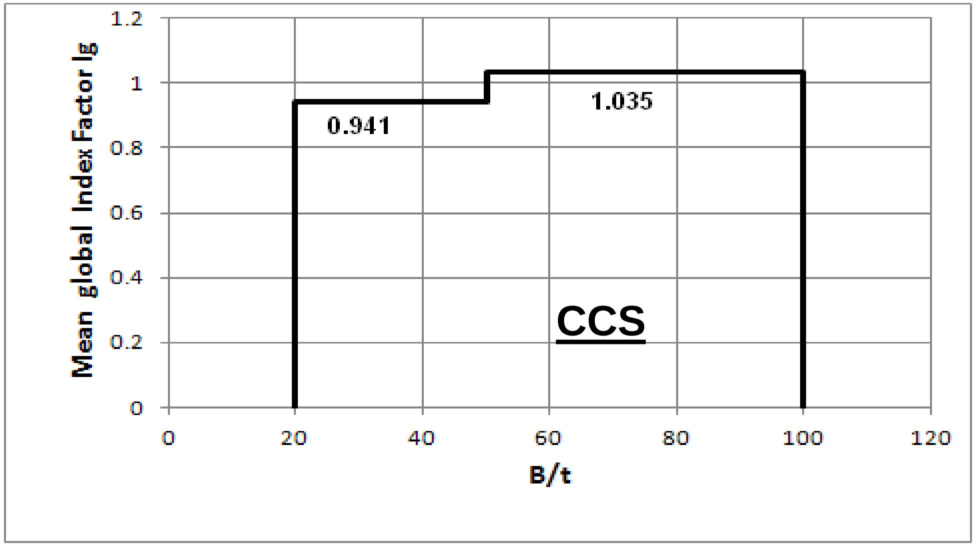
Sp.& Ref.	H (mm)	B (mm)	T (mm)	A_s (mm^2)	A_c (mm^2)	f_y (MPa)	f_{cu} (MPa)	Test (kN)	N (kN)	I_g	N/Test
Lin Hai Han & Guo Hang Yao(2004)	200	200	3	2364	37636	303.5	58.5	**2306**	**2266**	1.051	0.982
	200	200	3	2364	37636	303.5	58.5	**2284**	**2266**	1.046	0.992
										Mean:	**0.987**
M. Mouli (2007)	120	80	5	1845	7280	350	44.8	**985**	**897.5**	1.139	0.911
	150	100	5	2260	12080	346	44.8	**1340**	**1201.6**	1.170	0.896
	120	80	5	1845	7265	350	36.7	**947**	**840**	1.096	0.887
	150	100	5	2260	12070	346	36.7	**1306**	**1115.7**	1.210	0.854
										Mean:	**0.887**
N. Ferhoune & J. Zeghiche (2012)	102	68	2	664	-	300	-	**159**	**144.4**	0.798	0.908
	102	68	2	664	6272	300	20	**290**	**299.3**	1.024	1.032
	102	70	2.1	704.7	6465.2	300	20	**280**	**263.1**	0.939	0.939
										Mean:	**0.959**
J. Zeghiche (2013)	98	74	2	672	-	300	-	**180**	**145.1**	0892	0.806
	102	68	2	664	-	300	-	**159**	**143.4**	0.798	0.901
	99.9	69	1.95	643.5	-	300	-	**168**	**135.1**	0.870	0.804
	98	74	2	672	6580	300	20	**310**	**263.**	1.070	0.848
	102	68	2	664	6272	300	20	**290**	**250.**	1.024	0.862
	100	69	2	660	6240	300	20	**298**	**249.6**	1.058	0.837
										Mean:	**0.843**

5. Discussion

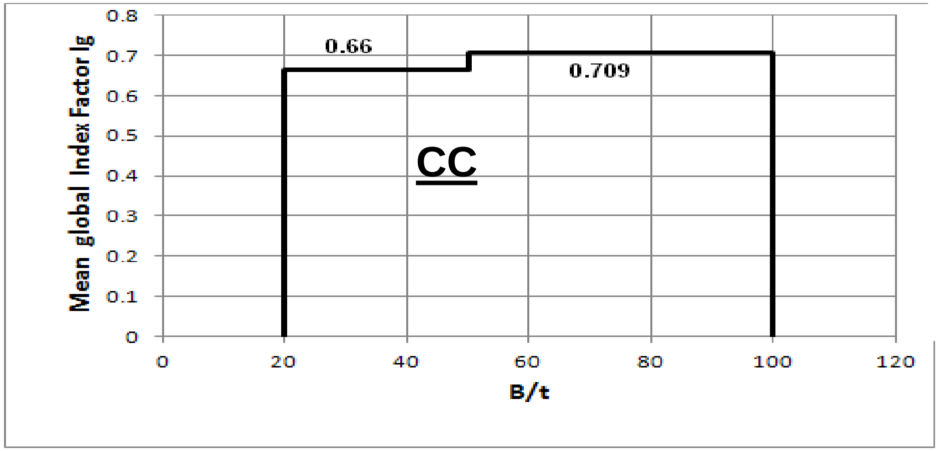




S00 & S

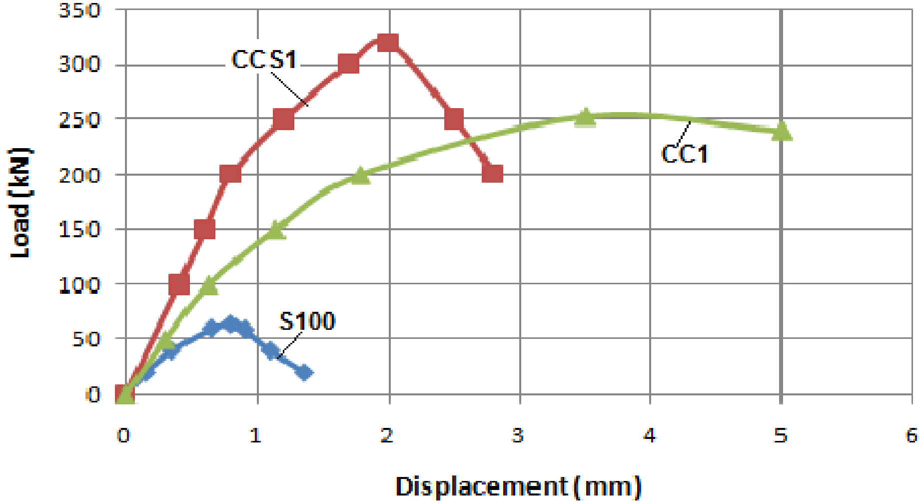


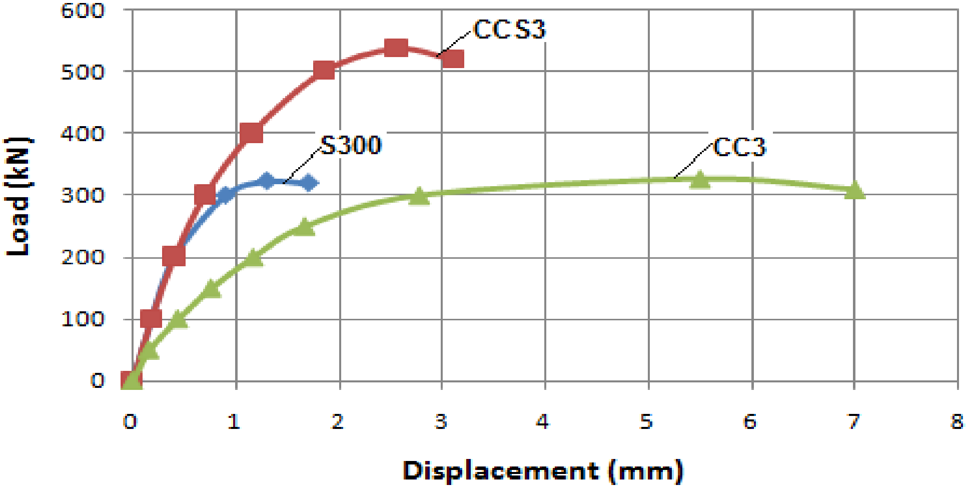
CCS

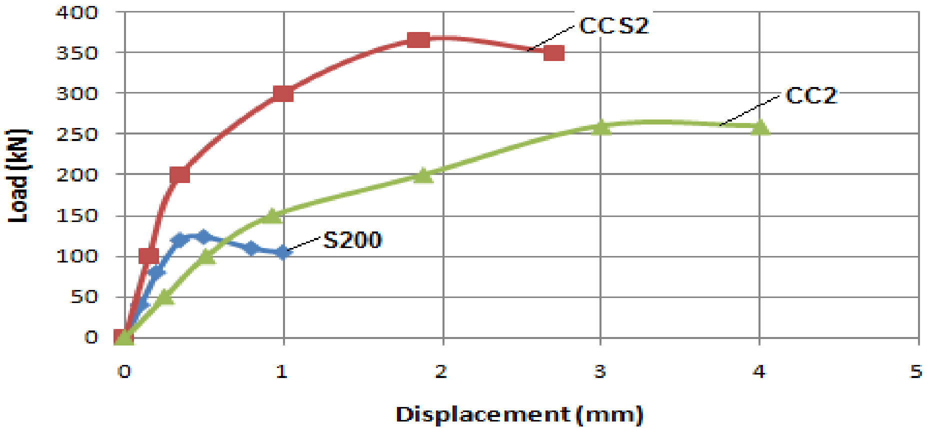


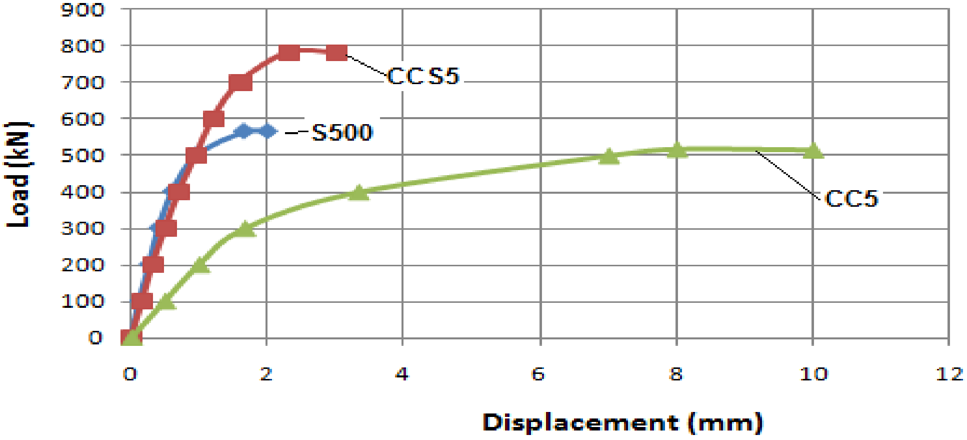
CC

5. Discussion

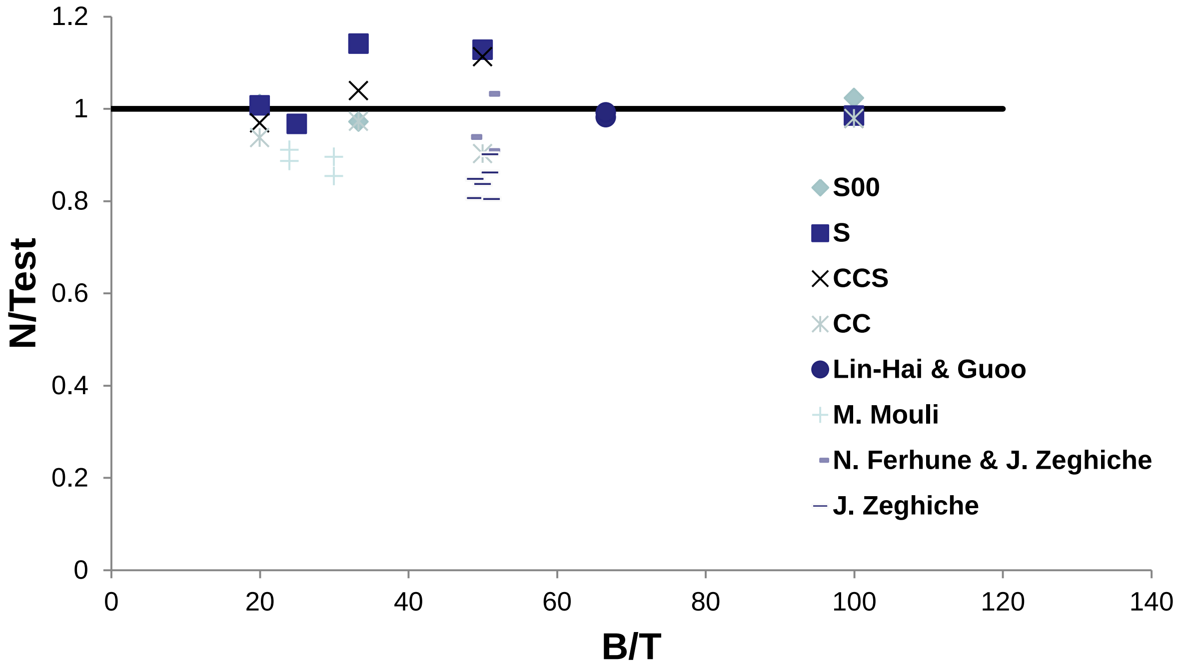






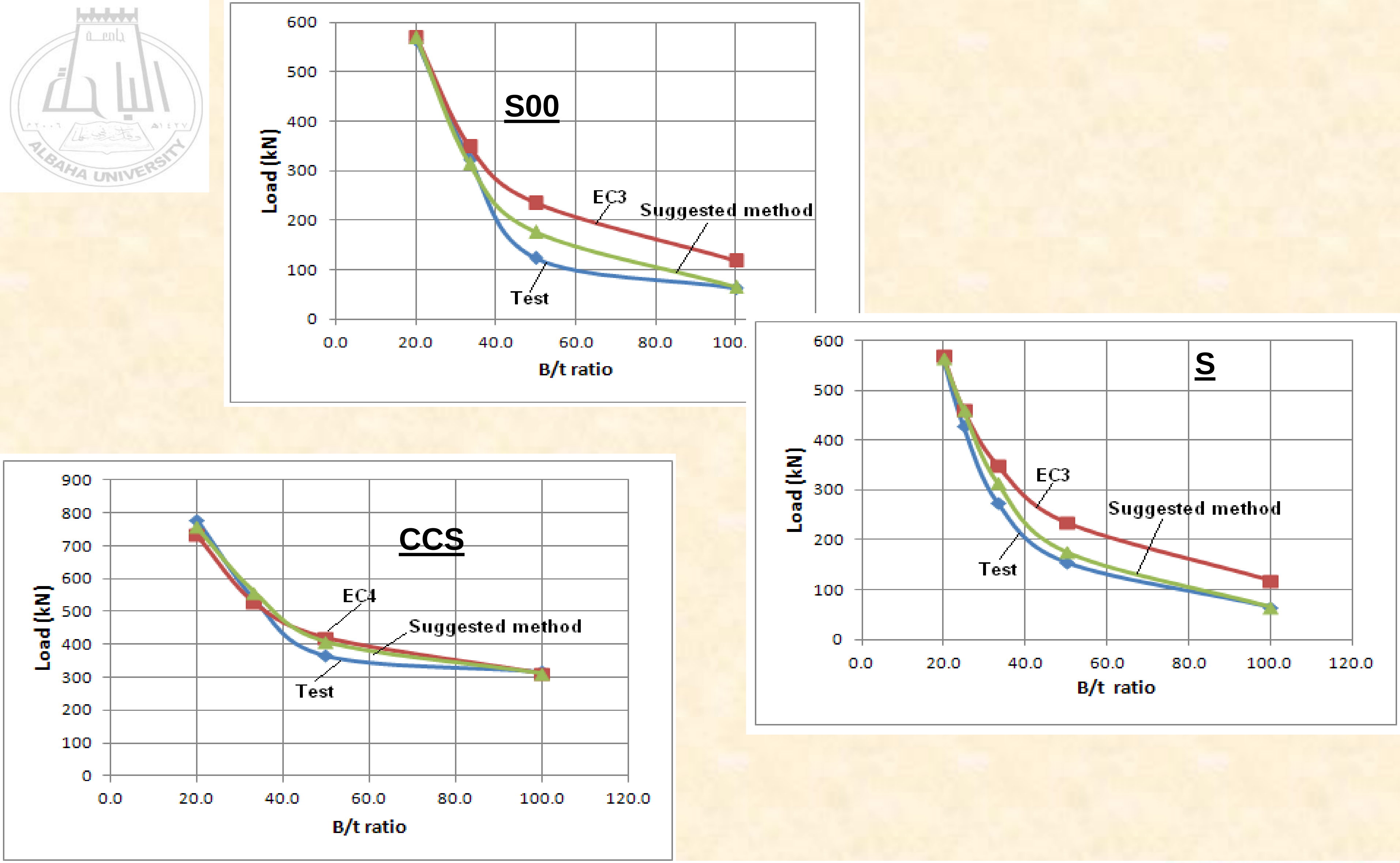


Steel : fs= 300-350 MPa
Concrete : fcu=20-58.5 Mpa
Section: B/t= 20-100



Empty steel stubs, S00 & S series

Composite stubs from CCS & CC series


S00
Load (kN)
600
500
400
300
200
100
0
0.0
20.0
40.0
60.0
80.0
100.
B/t ratio
EC3
Suggested method
Test
S
Load (kN)
600
500
400
300
200
100
0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
B/t ratio
EC3
Suggested method
Test
CCS
Load (kN)
900
800
700
600
500
400
300
200
100
0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
B/t ratio
EC4
Suggested method
Test

Conclusion:

Within the limits of the present research the following conclusion could be made:
1- A theoretical method was suggested to evaluate the strength of thin steel and concrete-filled steel stubs under compressive loading. By assuming for both **steel and concrete a model** that takes into account the **section slenderness**, the **steel local buckling** and the **concrete confinement** a reasonable prediction was obtained for empty steel and composite stubs.

2- **Experiments were conducted** on a large range of steel section **slenderness B/t (20-100)** . The **presence of concrete core for hollow steel stubs increased the section strength and delayed the steel local buckling** that was noticed to occur in most **empty steel stubs**.

3- **By loading both steel and concrete, higher strength was reached** for the studied sections. By loading only the concrete the response was **more ductile but less strength was reached** compared to the composite loading mode.

4- The global strength index Ig was monitored for both loading modes. It was found that **steel and concrete had active complementary role** in the case of CCS loading mode as indicated by steel and concrete indexes Is, Ic respectively.

5- By comparing experimental, theoretical and EC3 prediction it was found that the **EC3 ceases to predict at a B/t ratio of 33 for empty steel hollow stubs and 25 for empty I shaped steel stubs**. For composite stubs, **EC4 prediction was in good agreement with theoretical and test up to a B/t ratio of 100.** Future work will be focusing on the strength of concrete-filled steel stubs using high strength steel and concrete to validate the suggested theoretical method described in this paper.

Thank you for your attention

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