Stiffening Effects on the Shear Behaviour of Single Perforated Lean Duplex Stainless Steel Rectangular Hollow Beams

Sonu J.K *and* Konjengbam Darunkumar Singh

Indian Institute of Technology Guwahati, India

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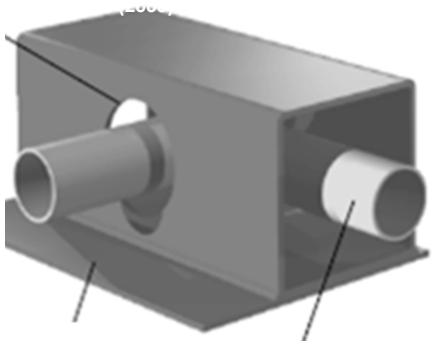
Introduction: Perforations, Stiffened Perforations ~ *examples*



~ Perforations can result in adverse effect on the structural performance

Stiffeners ~ to compensate reduced strength

Introduction: Lean Duplex Stainless Steel (LDSS) ~ *Constructions*

***LDSS ~ Less expensive (due to low nickel content), good corrosion resistance, high temperature properties, adequate weldability and fracture toughness** (e.g. Theofanous and Gardner, Saliba & Gardner, 2013).*


http://img.guidebook-sweden.com/soelvesborgs-kommun/soelvesborgsbron.jpg
Sölvesborg Bridge


https://upload.wikimedia.org/wikipedia/commons/7/7d/Sant_Fruit%C3%B3s_1.JPG
Sant Fruitos Bridge


http://www.diariovasco.com/multimedia/201511/27/media/anorga-bulevarizacion/A1-48341596_xoptimizadax.jpg
Añorga railway Bridge


https://spiral.imperial.ac.uk/bitstream/10044/1/15271/2/Engineering%20Structures_31_12_2009.pdf
Footbridge of Ruffolo


http://2.bp.blogspot.com/-W0DGCNwyaf8/TkOk3Ldl0N I/AAAAAAAAF9U/Lzs-gGPUr9M/s640/HBL_Norway6.jpg
Likholefossen Bridge

LDSS ~ a promising construction material

Introduction: Lean Duplex Stainless Steel (LDSS) ~ *Material properties*

METALCOR

1.4162

Trade name

LDX 2101®, Lean Duplex

Standards

Material No.	EN Designation	UNS
1.4162	X2CrMnNiN22-5-2	S32101

Description

1.4162 is a LEAN-DUPLEX chromium stainless steel with additional manganese, nickel, molybdenum and copper.

Special properties

Very good corrosion resistance. Good mechanical characteristics. Good endurance strength. Good weldability.

Chemical Composition

C %	Si ≤ %	Mn ≤ %	P ≤ %	S ≤ %
≤ 0.04	1.00	4.00-6.00	0.04	0.015
Cr %	**Mo %**	**Ni %**	**N %**	**Cu %**
21.0-22.0	0.10-0.80	1.35-1.70	0.20-0.25	0.10-0.80

Mechanical Properties 20°C

Hardness HB 30 ≤ HB	0.2% Yield strength R_p ≥ N/mm²	Tensile strength R_m N/mm²	Elongation A_5 ≥ %	Modulus of elasticity kN/mm²
290	450	> 650	30	200

Physical Properties 20°C

Density g/cm³	Specific heat capacity J/kg K	Thermal conductivity W/m K	Electrical resistivity Ω mm²/m
7.7	500	15	0.8

Suitable welding filler materials

CN 24/9 LDX PW-FD

Application

Chemical, pulp and cellulose industry, oil and gas industry

Available forms for 1.4162 /

Sheets/Plates	Bars	Tubes/Pipes	Fittings
			

http://www.metalcor.de/en/datenblatt/4/

Introduction: Lean Duplex Stainless Steel (LDSS) ~ *EN 1993-1-4:2006+A1*

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1993-1-4:2006+A1

June 2015

Type of stainless steel	Grade	Product form							
		Cold rolled strip		Hot rolled strip		Hot rolled plate		Bars, rods and sections	
		Nominal thickness t							
		$t \leq 8$ mm		$t \leq 13{,}5$ mm		$t \leq 75$ mm		$t \leq 250$ mm	
		f_y	f_u	f_y	f_u	f_y	f_u	f_y	f_u
		N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
	1.4547	320	650	300	650	300	650	300	650
	1.4318	350	650	330	650	330	630	-	-
Austenitic-ferritic steels	1.4062	530 [e]	700 [e]	480 [f]	680 [f]	450 [g]	650 [g]	380 [b]	650 [b]
	1.4162	530 [e]	700 [e]	480 [f]	680 [f]	450	650	450 [b]	650 [b]
	1.4482	500 [e]	700 [e]	480 [f]	660 [f]	450	650	400 [b]	650 [b]
	1.4662	550 [e]	750 [e]	550	750	480	680	450 [b]	650 [b]
	1.4362	450	650	400	650	400	630	400 [b]	600 [b]
	1.4462	500	700	460	700	460	640	450 [b]	650 [b]

[a] The nominal values of f_y and f_u given in this table may be used in design without taking special account of anisotropy or strain hardening effects.

[b] $t \leq 160$ mm

[c] $t \leq 25$ mm

[d] $t \leq 100$ mm

[e] $t \leq 6{,}4$ mm

[f] $t \leq 10$ mm

[g] $t \leq 50$ mm ($f_y = 430$ N/mm² and $f_u = 625$ N/mm² for 50 mm $< t \leq 75$ mm)

Introduction: Hollow steel members

Hollow steel beams ~ Better torsional rigidity, usable interior space, aesthetically pleasing

Objectives: Stiffened perforated hollow steel beams ~ *shear capacity*

Hollow steel beams

Lean Duplex Stainless Steel

Web perforation

Inclined stiffeners

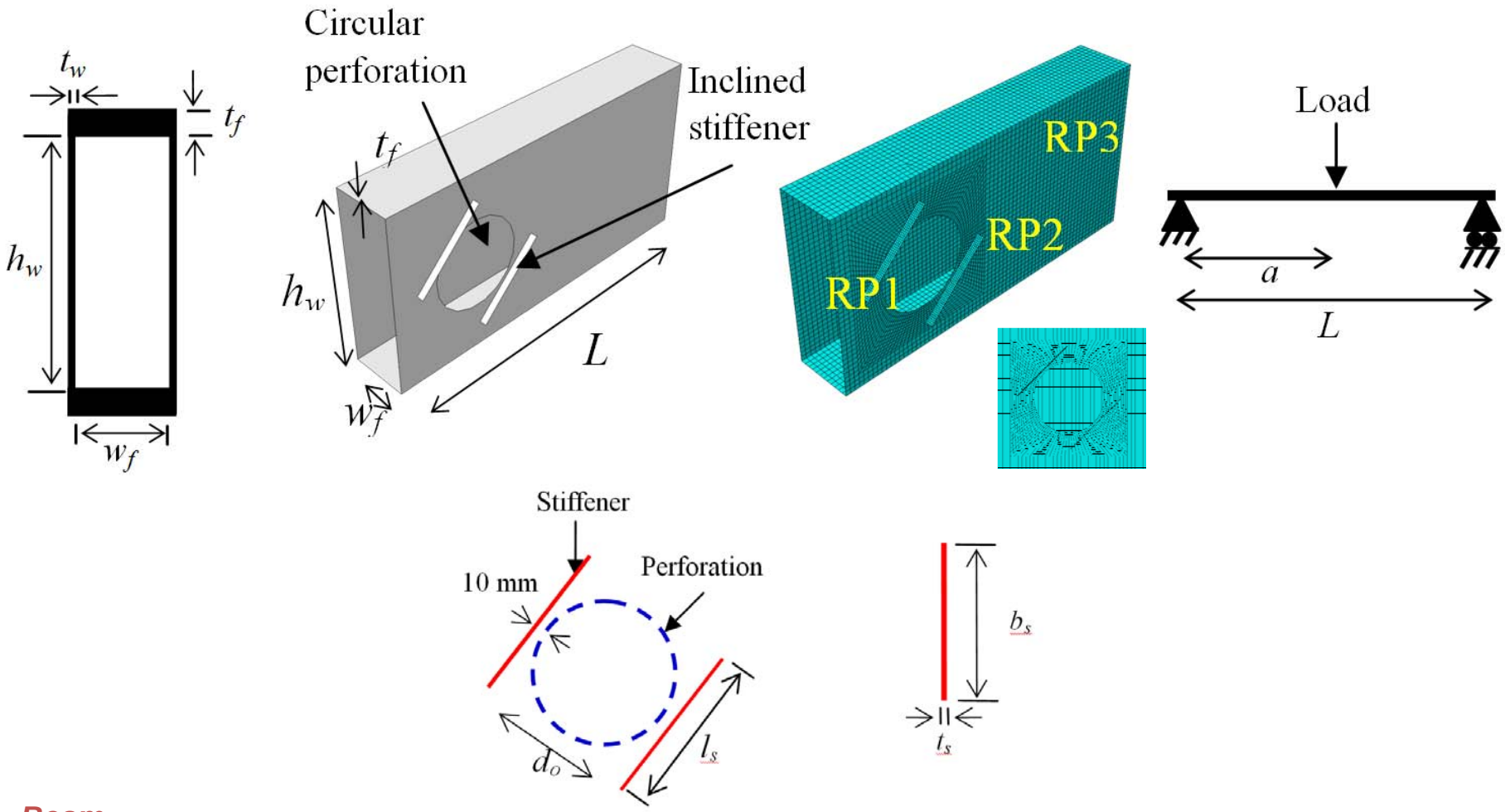
Shear capacity

Objective

❑To assess the shear behaviour of stiffened single perforated LDSS rectangular hollow beam, considering diagonal / inclined pattern.

➢More specifically, the effect of variation in cross-sectional dimensions (or slenderness) e.g. width (b_s), thickness (t_s) and length (l_s) of inclined (or diagonal) stiffener pattern is investigated.

FE Modelling: Geometry, mesh, boundary conditions, loading…



Beam

h_w/t_w = 300 (h_w = 600 mm, t_w = 2mm) , t_f/t_w = 5 (t_f = 10 mm), w_f/h_w = 0.33 (w_f = 200 mm), a/h_w = 1.00 (a = 600 mm)

Stiffener

l_s/h_w = 1.00 - 1.75 (***l_s = 300-515 mm***), b_s/h_w = 0.04 - 0.10 (***b_s = 24 – 60 mm***), t_s/t_w = 1-7 (***t_s = 2-14 mm***)

FE Modelling: FE Validation ~ *Material properties*

Theofanous and Gardner (2010)

SHS 60 × 60 × 3 – B2 specimen					
a) Tension flat material properties					
E_o (MPa)	$\sigma_{0.2}$ (MPa)	$\sigma_{1.0}$ (MPa)	σ_u(MPa)	Compound R-O coefficients	
209797	755	819	839	6.0	4.3
b) Compression flat material properties					
206430	711	845	-	5.0	2.7
c) Tensile corner material properties					
212400	885	1024	1026	6.3	4.0

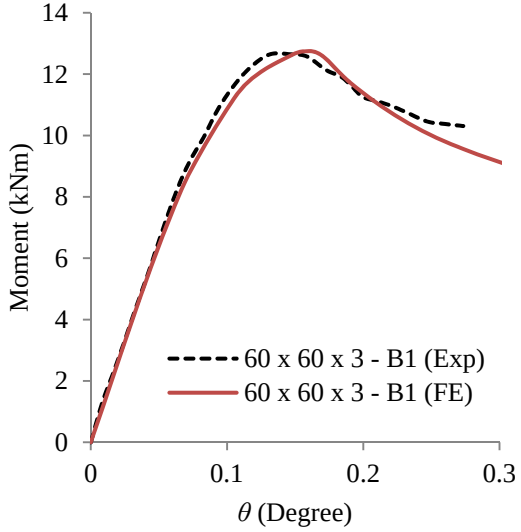
Specimen	L (mm)	B (mm)	D (mm)	t (mm)	r_i(mm)
SHS 60x60x3-B2	1100	60	60	3.10	2.3

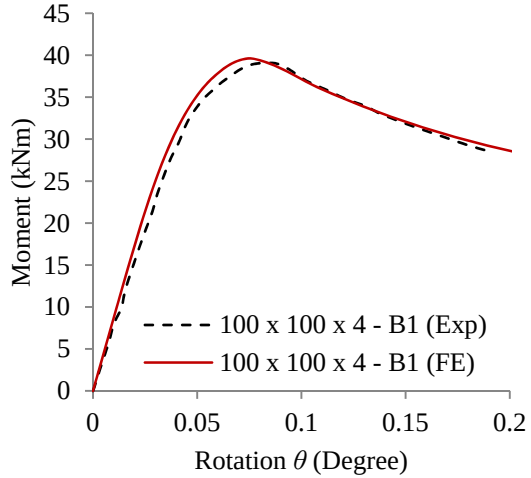
Saliba and Gardner (2013)

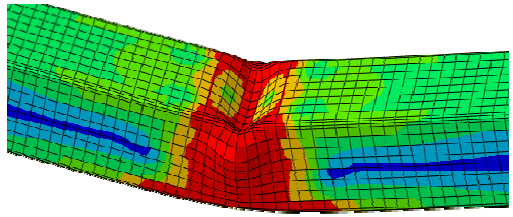
Plate girder	L (mm)	a (mm)	e (mm)	h_w (mm)	b (mm)	t_f (mm)	t_w (mm)	t_s (mm)	b_s (mm)	a/h_w
I - 600 x 200 x 12 x 4 - 1	1360	600	80	598.8	200.1	12.4	4.1	20.9	98	1
I - 600 x 200 x 12 x 8 - 1	1360	600	80	600.3	200.1	12.5	8.2	20.6	96	1

FE Modelling: Validation ~ *Square beam, Plate girder*

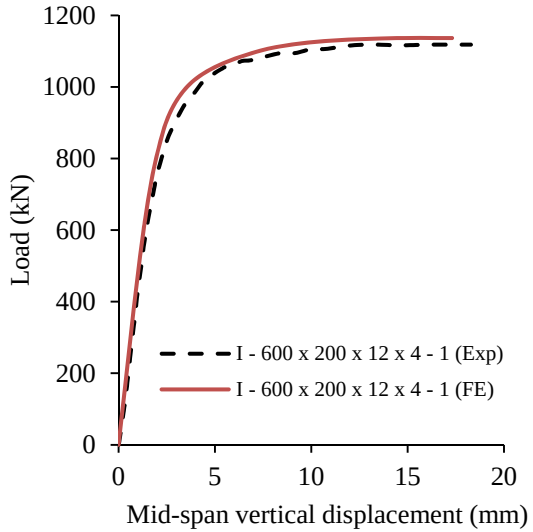
*A) **LDSS square hollow beam*** (Theofanous and Gardner, 2010)

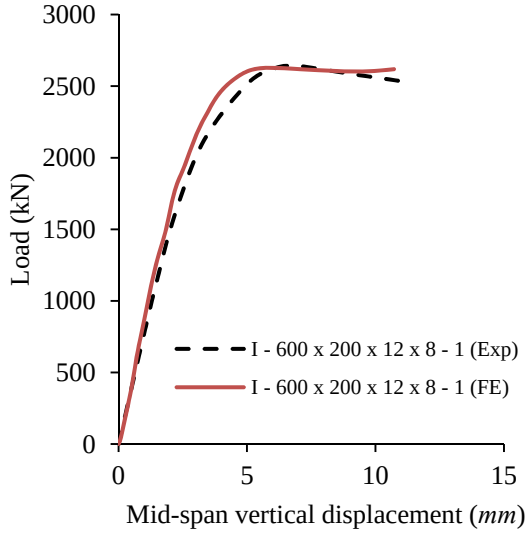


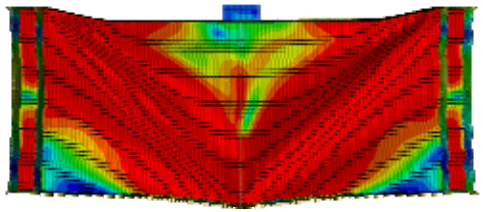




*B) **LDSS steel plate girder*** (Saliba and Gardner, 2013)



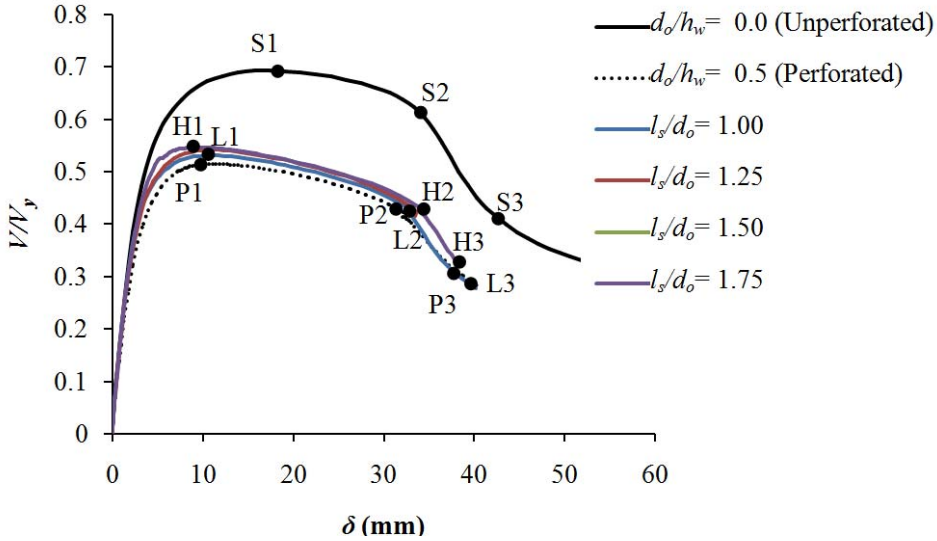


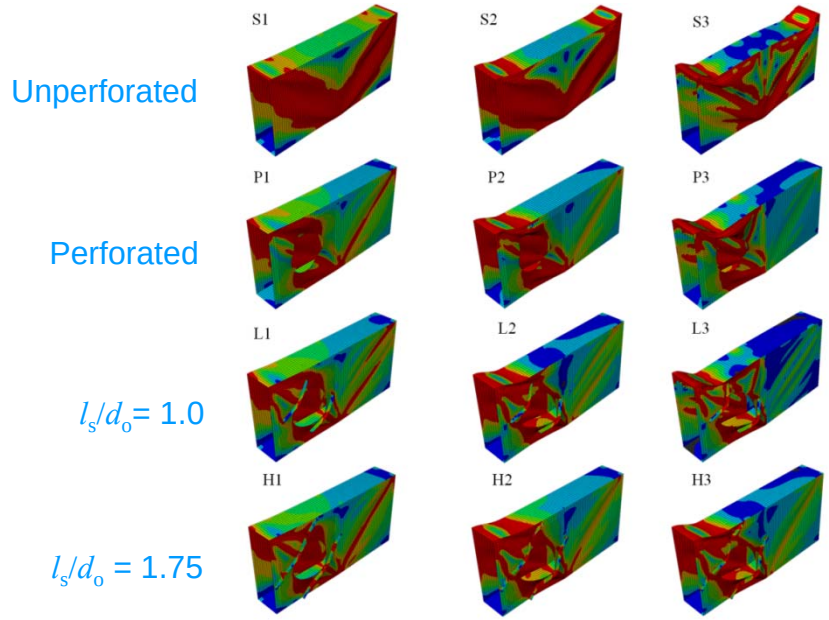


❖ ***Good agreement with experimental results***

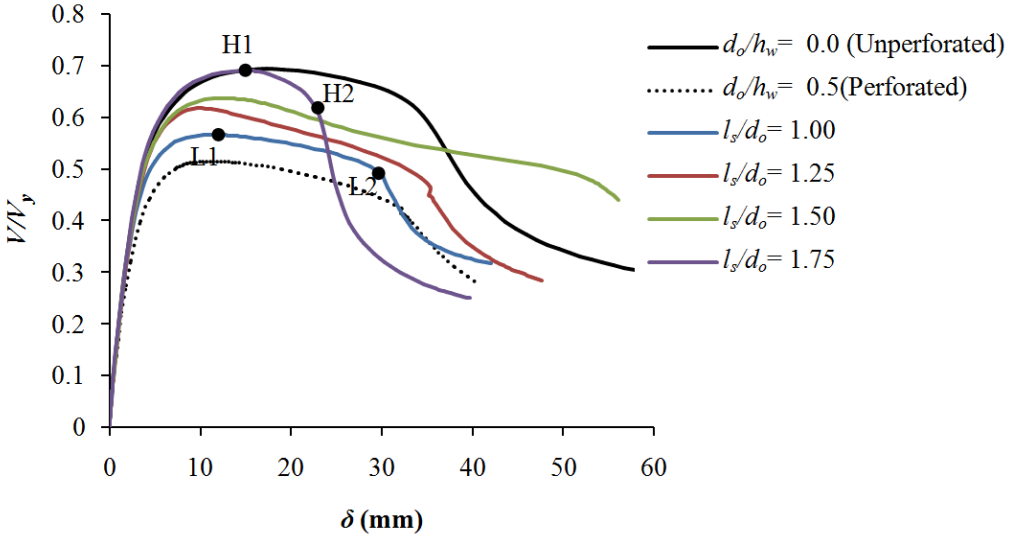
Results: Effect of stiffener length (l_s) ~ b_s/h_w = 0.04 (b_s = 24 mm)

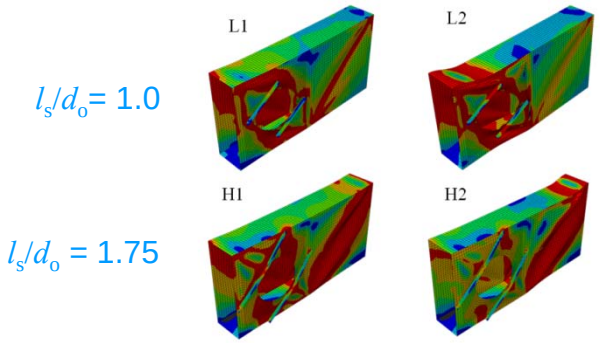
A) Slender section (t_s/t_w = 1.0 (t_s = 2 mm; t_w = 2 mm)





B) Stocky section (t_s/t_w = 7.0 (t_s = 14 mm; t_w = 2 mm)

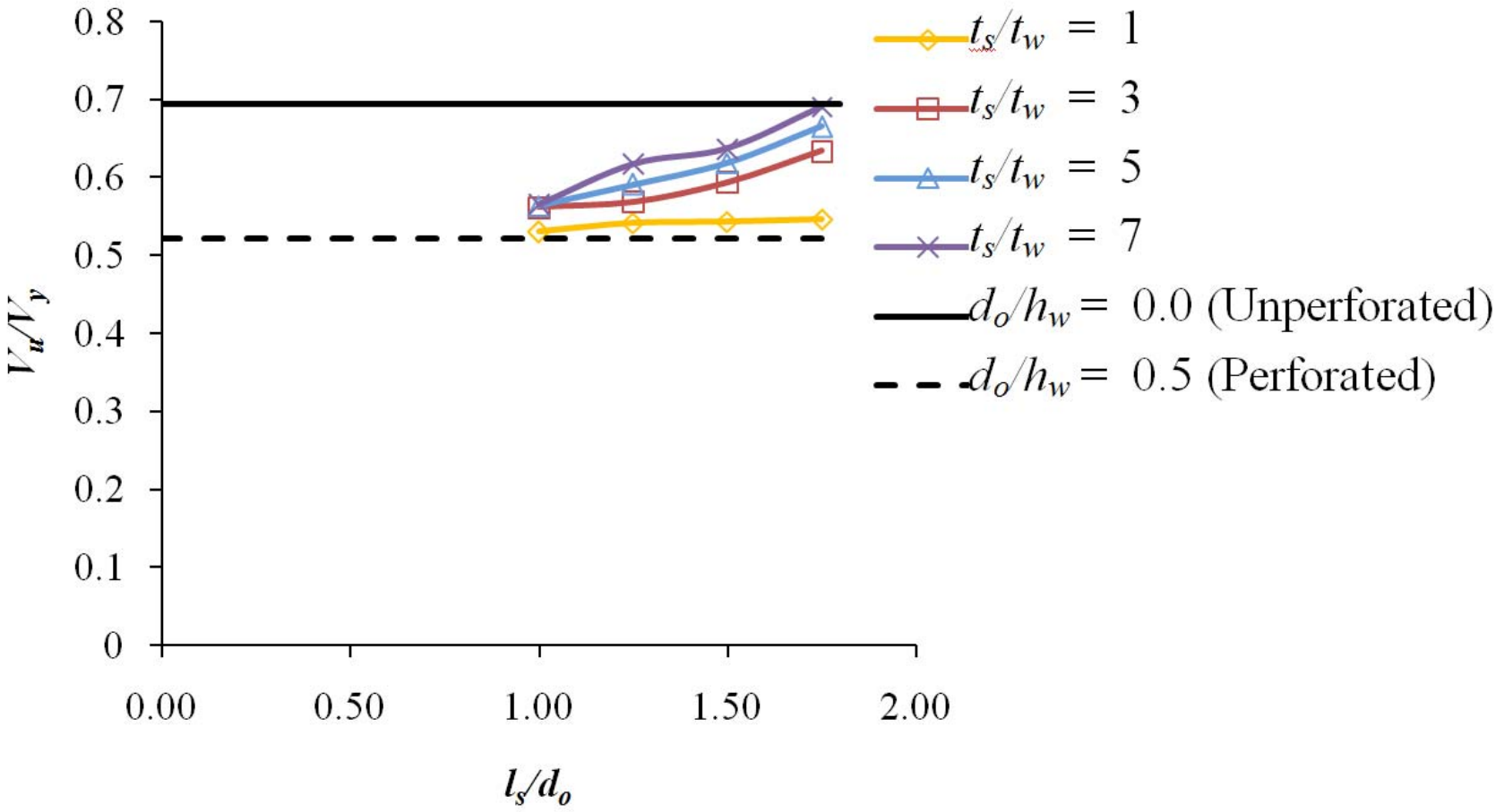




$$V_y = \left(\frac{f_y}{\sqrt{3}}\right)(2t_w h_w)$$

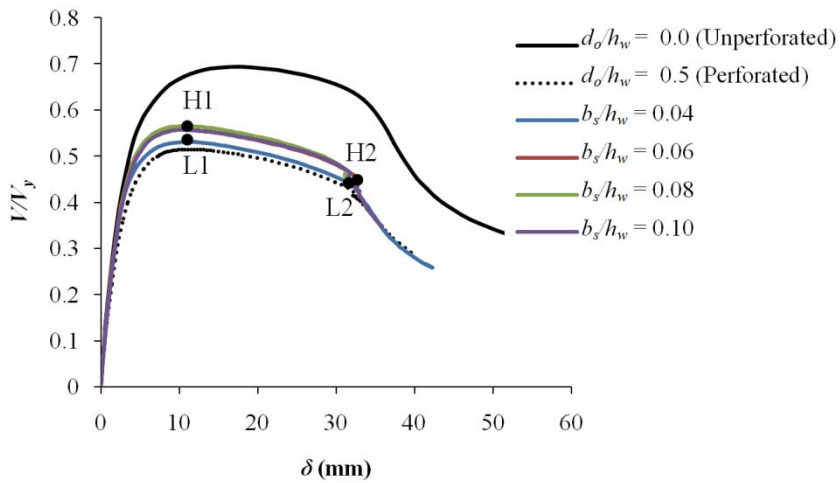
V_y= Shear yield capacity

Results: Effect of stiffener thickness (t_s) ~ $b_s/h_w = 0.04$ ($b_s = 24$ mm)



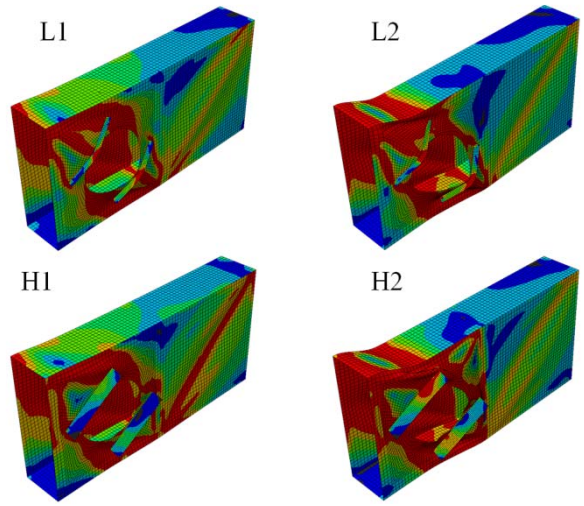
Results: Effect of stiffener breadth (b_s) ~ short stiffener (l_s/d_o = 1.0)

A) Slender section (t_s/t_w = 1.0)

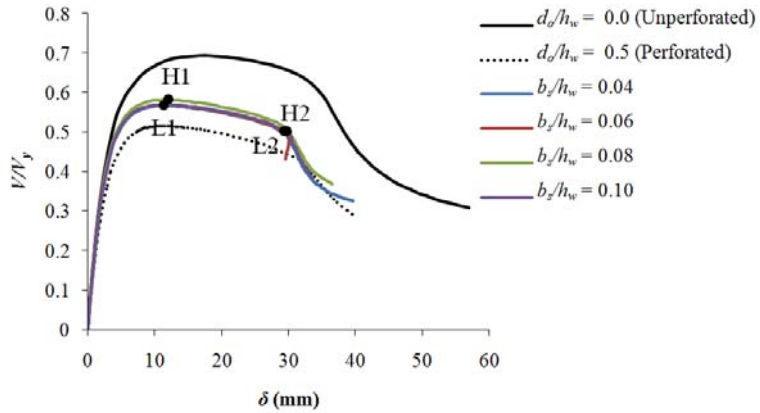


b_s/h_w= 0.04

b_s/h_w = 0.10

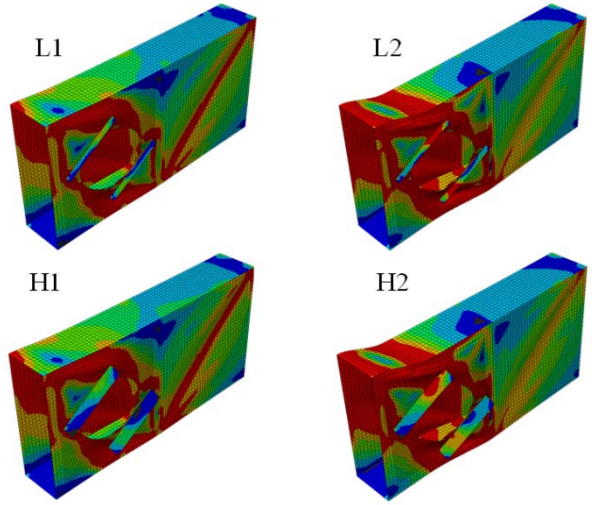


B) Stocky section (t_s/t_w = 7.0)

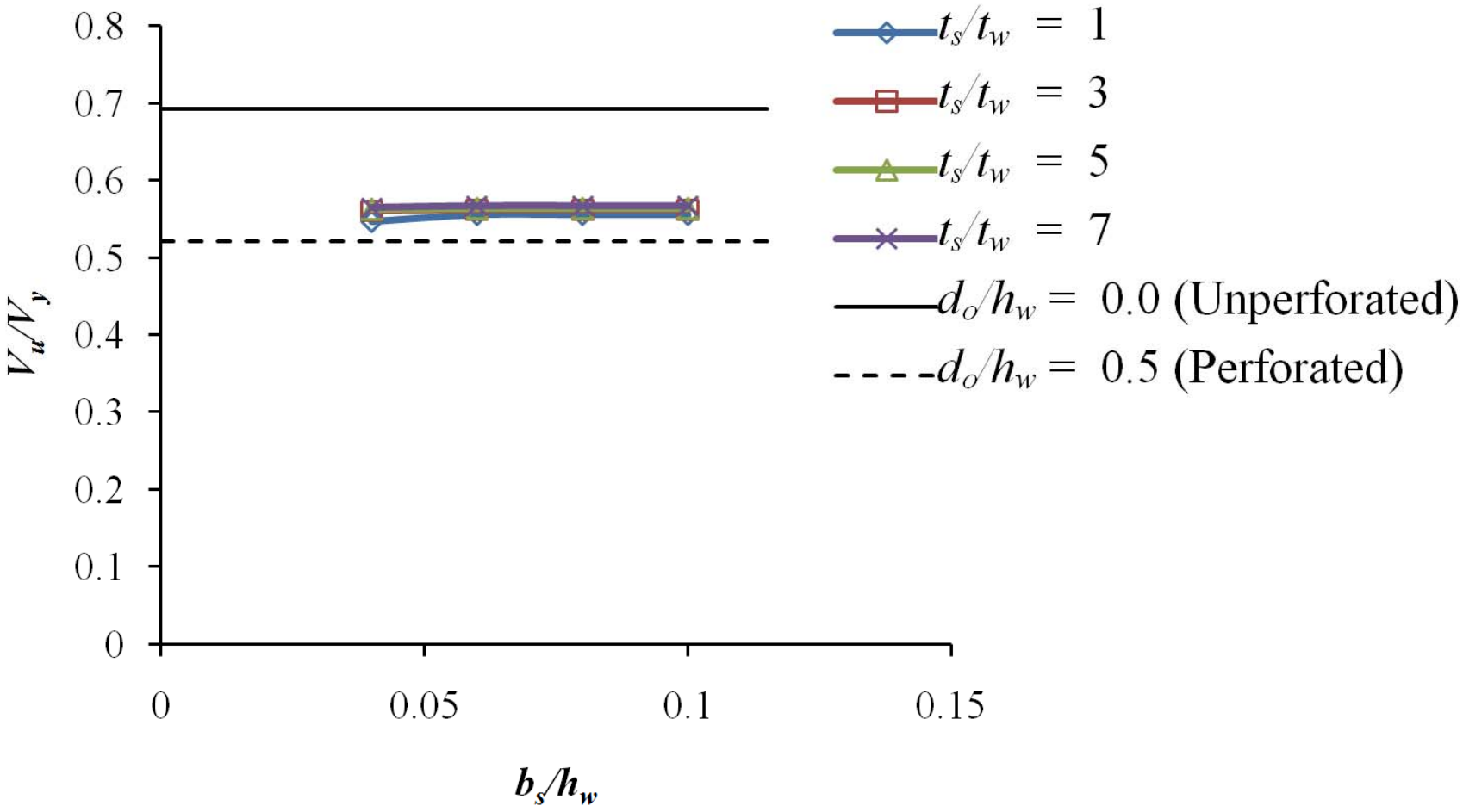


b_s/h_w= 0.04

b_s/h_w = 0.10

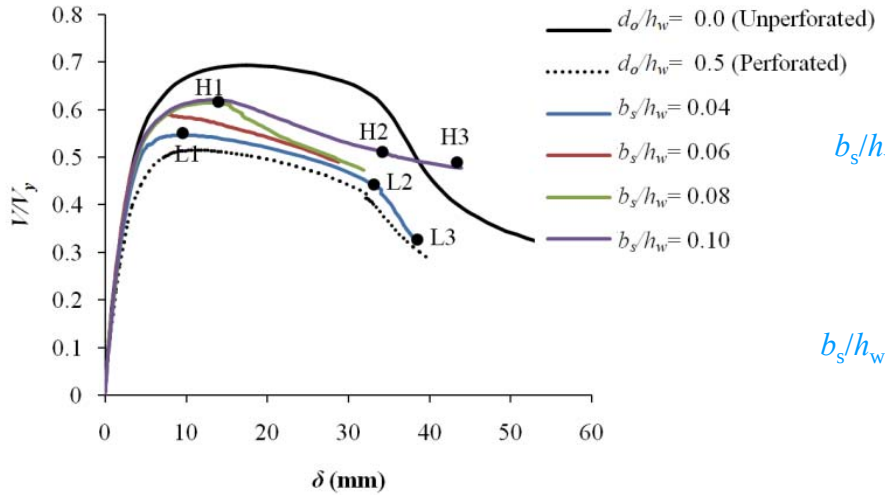


Results: Effect of stiffener breadth (b_s) ~ short stiffener (l_s/d_o = 1.0)



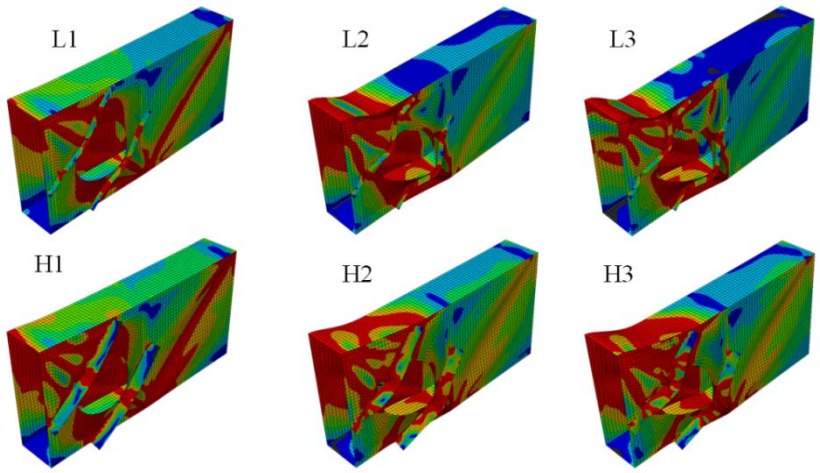
Results: Effect of stiffener breadth (b_s) ~ long stiffener (l_s/d_o = 1.75)

A) Slender section (t_s/t_w = 1.0)

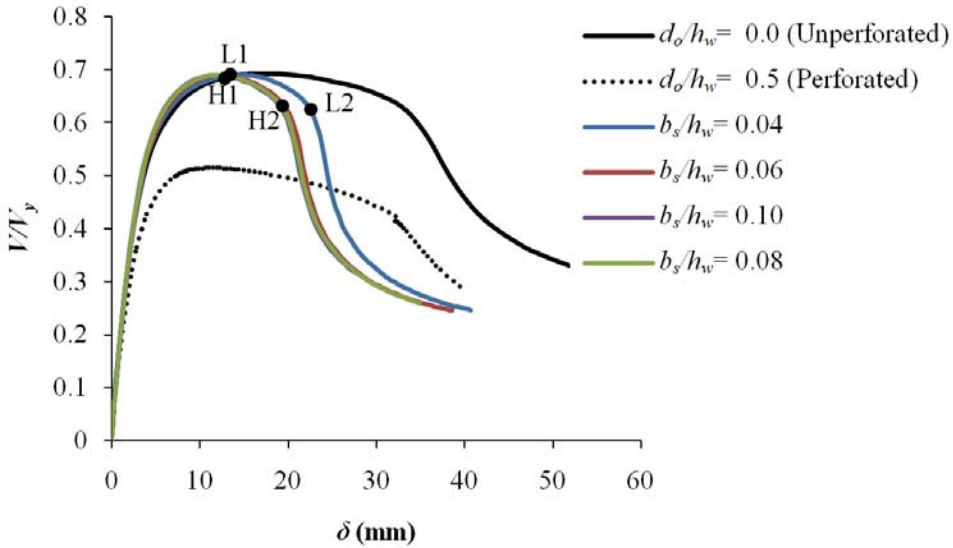


b_s/h_w= 0.04

b_s/h_w = 0.10

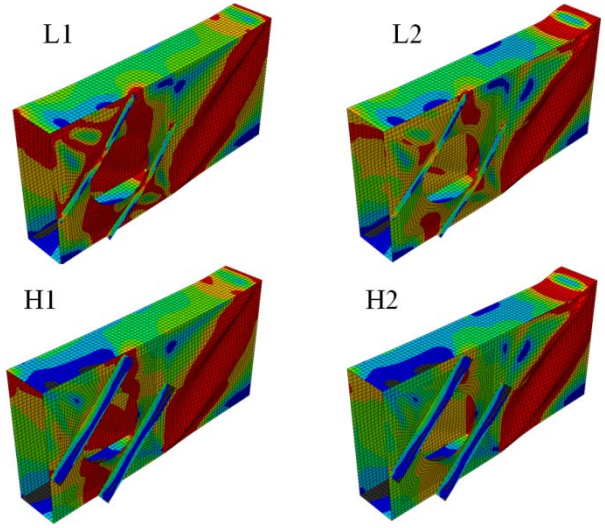


B) Stocky section (t_s/t_w = 7.0)

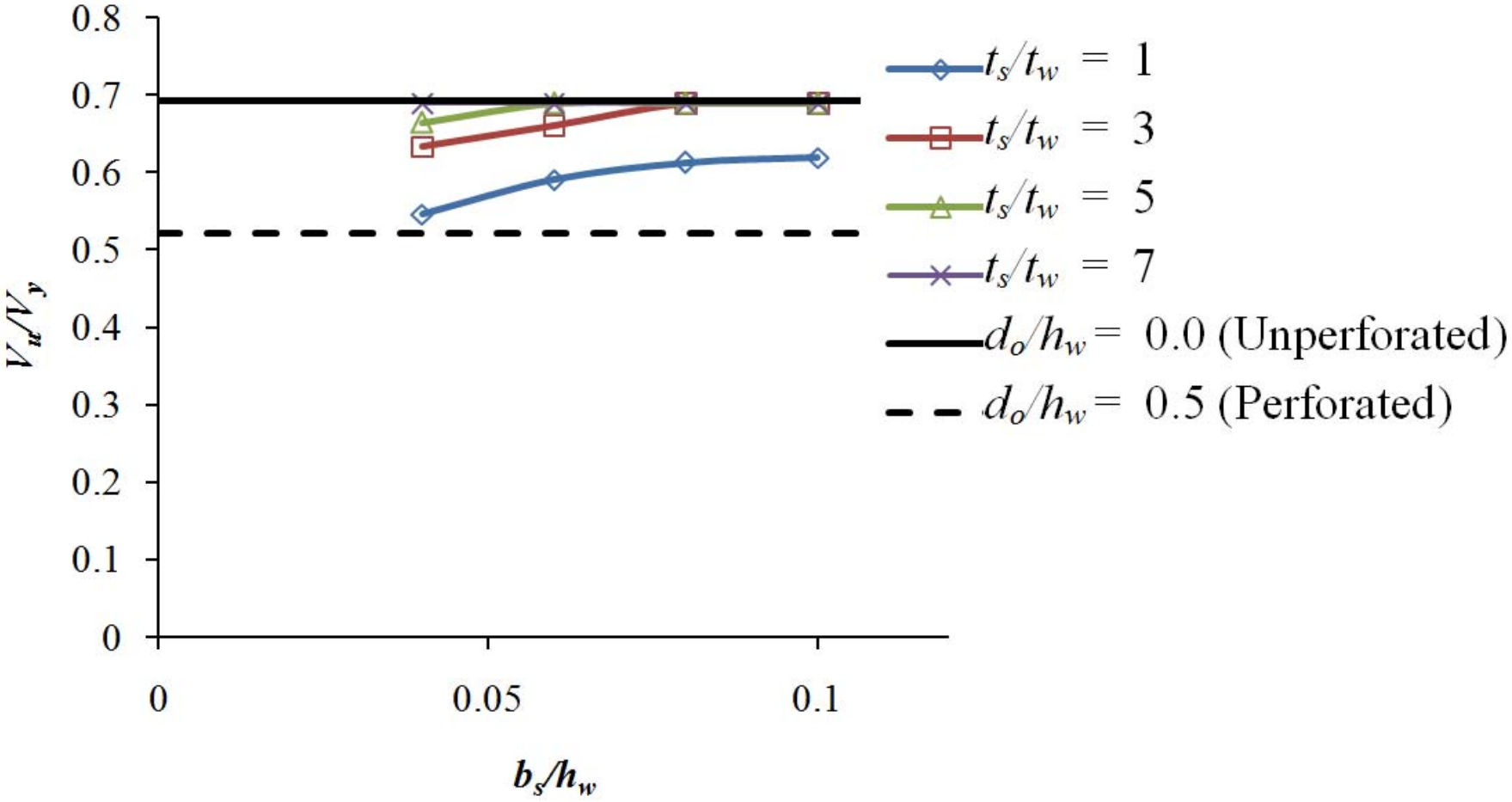


b_s/h_w= 0.04

b_s/h_w = 0.10



Results: Effect of stiffener breadth (b_s) ~ long stiffener (l_s/d_o = 1.75)



Conclusions:

FE studies on the shear behaviour of single perforated LDSS rectangular hollow beam, stiffened with inclined stiffeners have been presented considering cross-sectional dimensions (or slenderness) e.g. length (l_s), width (b_s) and thickness (t_s) as parameters. Based on the investigation, the following conclusions have been drawn:

- ❑ The rate of increase in shear capacity (V_u/V_y) increases with increasing stiffener length.
  It is also seen that it is possible to achieve the strength of unperforated beam, with larger stiffener length and thickness, e.g. for the longest and thickest stiffener (l_s/d_o = 1.75 & t_s/t_w = 7) considered, the stiffened perforated beam has achieved the shear capacity of unperforated beam.

- ❑ There is no significant change in the value of shear capacity for increase in stiffener width, suggesting that there is not much benefit in increasing the cross-sectional dimension (in terms of b_s and t_s) for short length stiffeners (l_s/d_o = 1.0).

- ❑In the case of long stiffeners, an improved enhancement in shear capacity can be seen even for thin stiffeners e.g. an increase of ~19% in V_u/V_y as compared to non stiffened case, can be observed for b_s/h_w = 0.10 (or b_s = 60 mm).

Whereas for thick stiffeners (e.g. t_s/t_w = 7), almost full strength of the unperforated beam could be achieved at lower b_s (e.g. b_s = 0.04).

Thank you very much for your patience