Comparative Study of Requirements for High Speed Crafts

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Background and Motivation

Factors forcing DNVGL to improve HSLC Rules

- Design of HSC primarily relying on Class Rules (High costs and time consumption to perform experiments and numerical simulations)
- Rapid development of HSC design and construction
- Introduction of new concepts and techniques
- Faster and larger HSCs being built
- Competition between different Classes

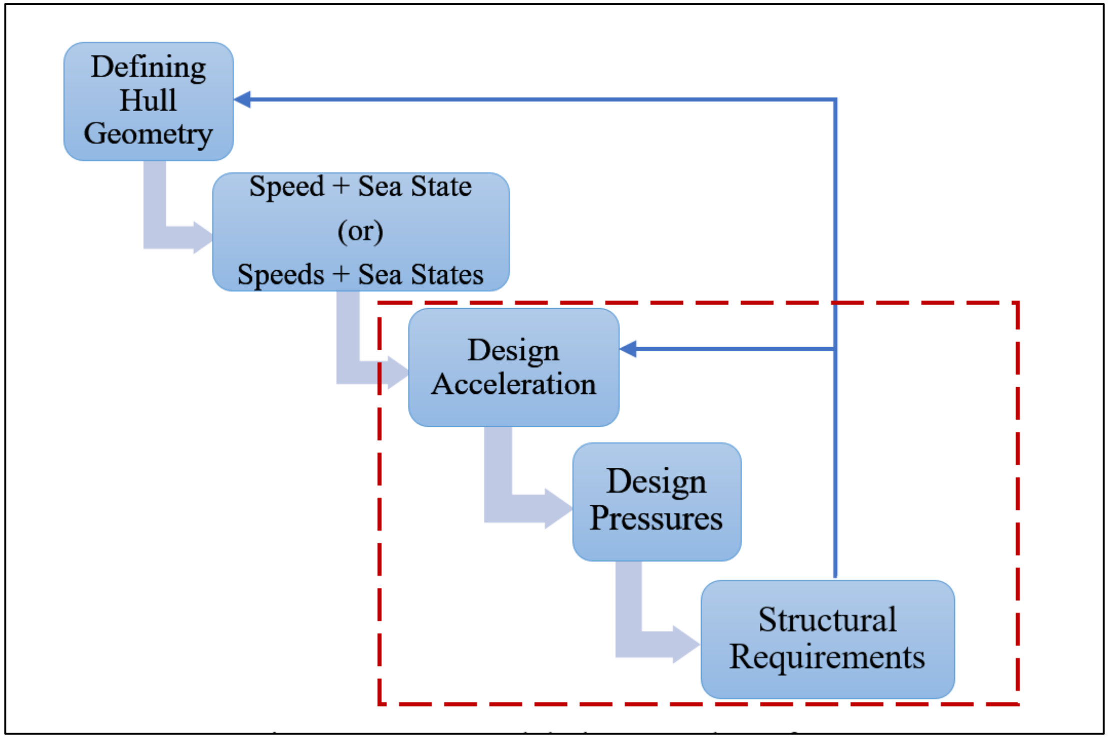
Objectives

- To study the background of formulations in HSLC rules
- To verify the results presented in SSC Report (to compare DNV-HSLC and DNVGL-HSLC Rules)
- To identify application range of DNVGL-HSLC Rules
- To evaluate possibility of merger of DNVGL-HSLC and DNVGL-Naval Rules
- To identify shortcomings in the current DNVGL-HSLC rules

Contents

Structural Design of High Speed Crafts

- Optimization of **Strength** (to resist loads) and **Weight** (for cost effectiveness and envionmental prospect)
- Involve several inter-steps and repititions
- Generally satisfy the procedures in figure.



Background of DNVGL-HSLC rules

Design acceleration – based on Savitsky & Brown (1976)

Design pressures – based on Allen & Jones (1978)

Structural requirements – application of beam theory

Design Acceleration

- **Savitsky & Brown (1976)**

Avg acceleration (g's) in:

$$\tilde{n}_{cg} = 0{,}0104\ \left(\frac{H_{1/3}}{b} + 0.084\right) \frac{\tau}{4} \left(\frac{5}{3} - \frac{\beta}{30}\right) \left(\frac{V_k}{\sqrt{L}}\right)^2 \frac{L/b}{C_\Delta}$$

$$C_\Delta = \frac{\Delta}{b^3}$$

1/Nth highest acceleration:

$$\tilde{n}_{1/N} = \tilde{n}_{cg}\,(1 + \ln N)$$

Range of Applicability

	Lower limit	Upper limit
$\Delta_{lt}/(0.01L_m)^3$	3531	8829
L/B	3	5
Deadrise, deg (β)	10	30
Trim angle, deg (τ)	3	7
H_s/B	0.2	0.7
$V_{kn}/\text{sqrt}(L_m)$	3.6	10.86

- **DNVGL-HSLC rules**

Highest 1/100th average acceleration (5.6 times $\tilde{n}_{cg}$) and Trim = 4 degree

$$a_{cg} = \frac{k_h\, g_0}{1650} \left(\frac{H_{si}}{B_{wl2}} + 0.084\right) (50 - \beta_{cg}) \left(\frac{V_i}{\sqrt{L}}\right)^2 \frac{L\, B_{wl2}^2}{\Delta}$$

Design Pressures

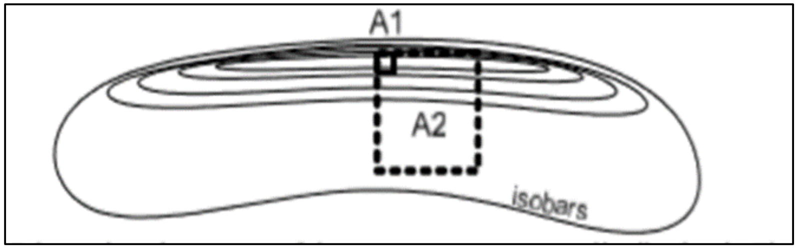
- **Allen & Jones (1978)**

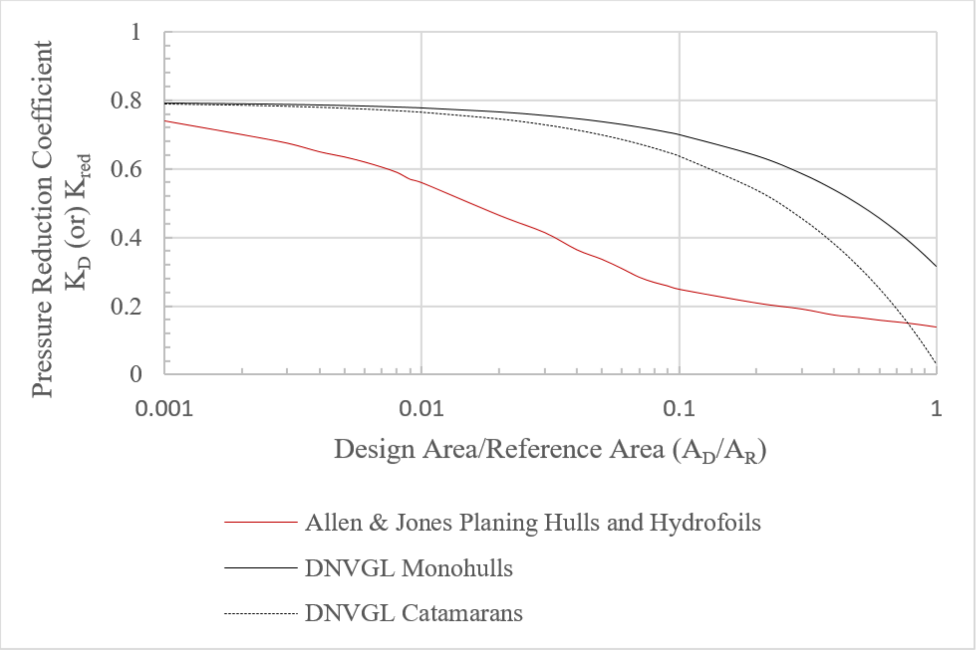
Key ideas

– formation of reference area ($A_R = 0.7\Delta/d$)

– momentary pressure distribution

$$P_D = \frac{\Delta N_z}{0.14 A_R} K_D F$$





- **DNVGL-HSLC rules**

$$p_{sl} = \frac{\Delta a_{cg}}{0.14 A_{ref}} K_{red} K_l K_\beta$$

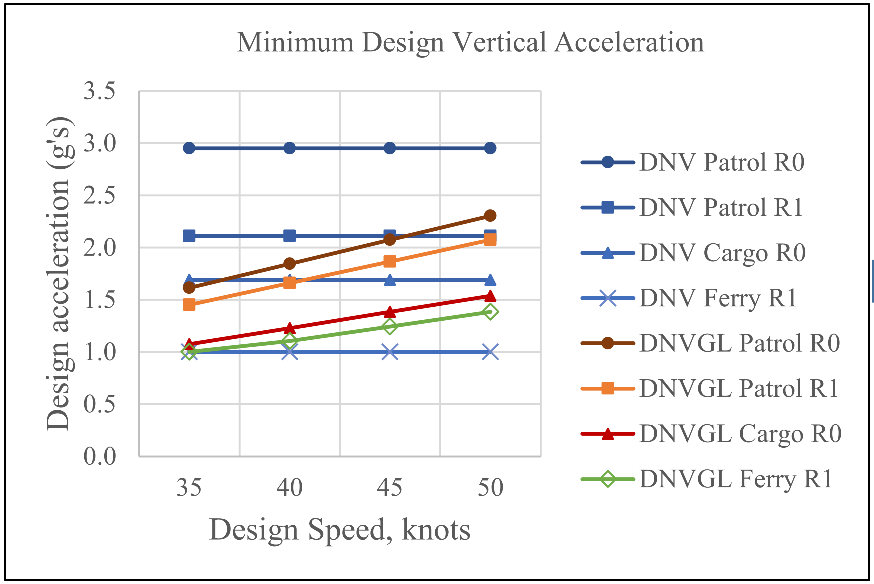
Verification of SSC Report-439
(Comparison of DNV-HSLC and DNVGL-HSLC Rules)

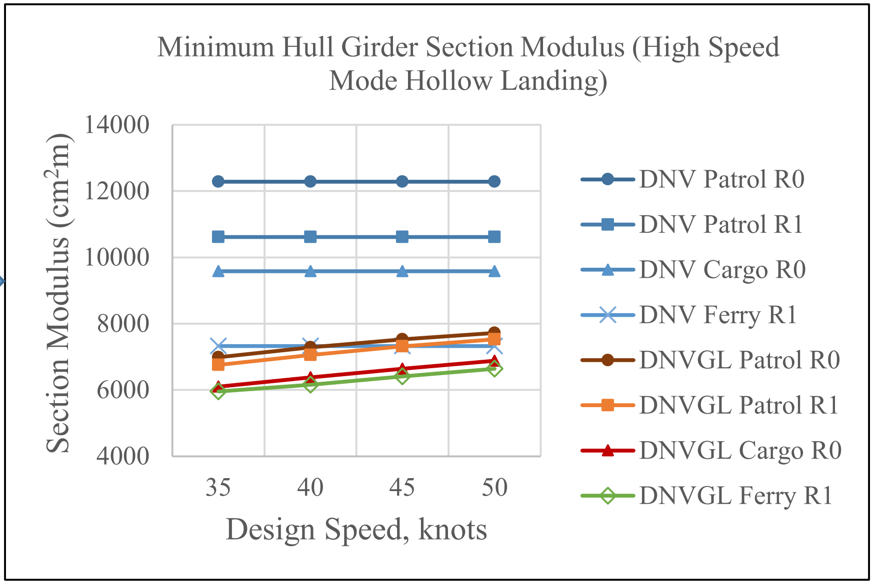
- 61m Aluminium Monohull
- Speed range 35-50 knots (V/sqrt(L) between 4.5 and 6.4)
- Four different ship type & service notations – Patrol R0, Patrol R1, Cargo R0, Ferry R1

Description	Symbol	Unit	Value
Rule length	L	m	61
Moulded breadth	B	m	12.9
Draught	T	m	2.7
Full load displacement	Δ	ton	950
Breadth at waterline	B_{WL}	m	11.7
Position of LCG		m	25.7
Dead rise angle at LCG	β_{cg}	degree	17

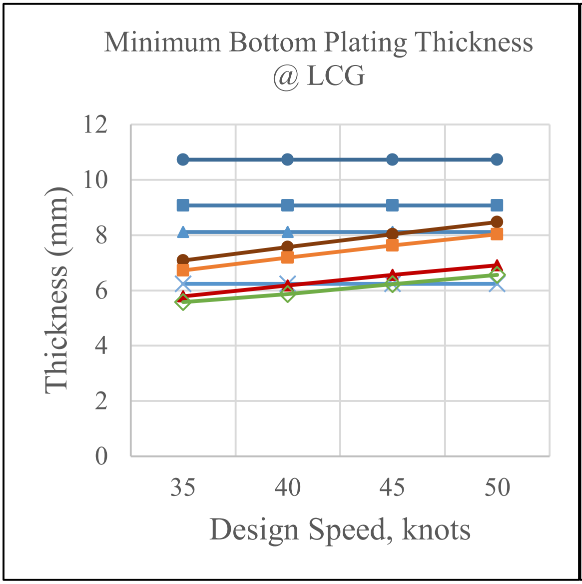
Comparison of Veritcal Design Acceleration and Hull Girder Section Modulus

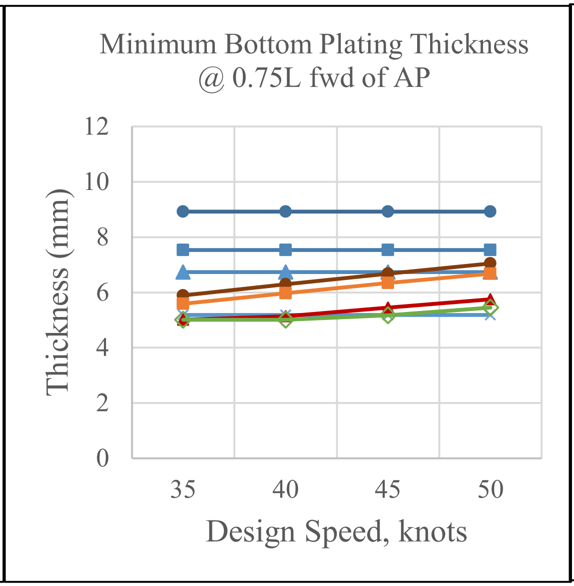
- Two kinds of hull bending moments
- Displacement Mode Cases (Still water + Sagging , Still water + Hogging) are F(ship parameters, wave coefficient)
- High Speed Mode Cases (Hollow landing , Crest landing) are F(ship parameters, vertical acceleration)

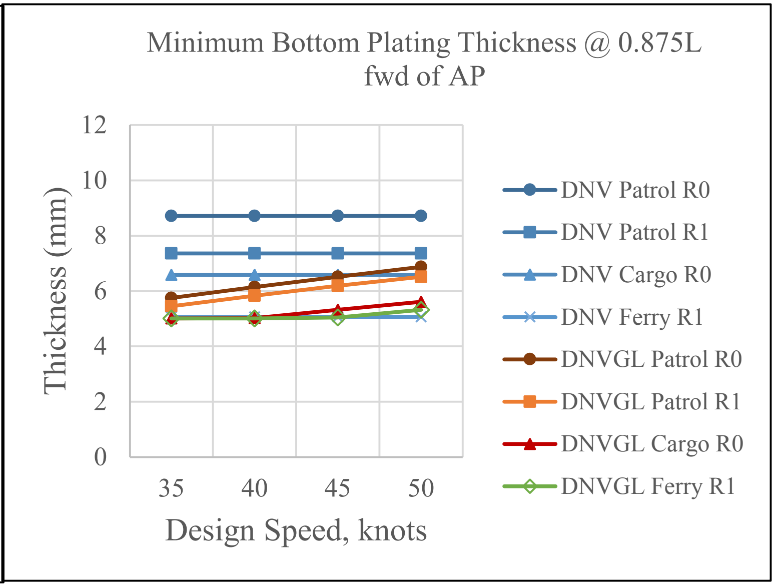




Comparison of Bottom Plating Thickness

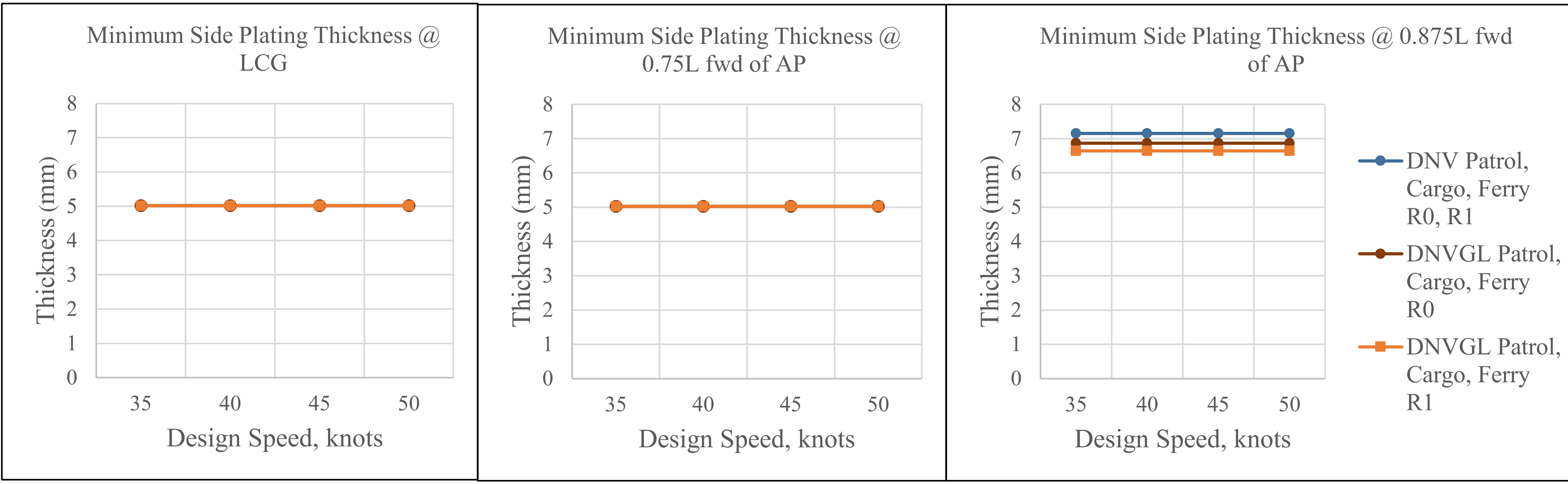






- ❑ **Heaviest scantlings near to LCG than forward parts due to**
  - **- vertical impact**
  - **- significant reduction in deadrise angle**
- ❑ **Reduction of scantlings in DNVGL except for Ferry R1**

Comparison of Side Plating Thickness



- ❑ **Heavier forward side elements subjecting to impact pressure**
- ❑ **Aft side elements subjecting to sea pressure only**
- ❑ **Similar scantlings between DNV and DNVGL**

Major Differences between DNV and DNVGL

DNV-HSLC	DNVGL -HSLC
• Distance from port + wave height = service area $$a_{cg} = \frac{V}{\sqrt{L}} \frac{3.2}{L^{0.76}} f_g g_0$$ • $\frac{V}{\sqrt{L}} \leq 3$ • a_{cg} depends only on service area and ship type (f_g) • Constant design acceleration,pressures, and scantlings over a range of speeds where $\frac{V}{\sqrt{L}} > 3$ • too conservative for lower speeds and less for higher speeds • Not fixing $\frac{V}{\sqrt{L}}$ may lead to more unrealistic values	• Distance from port defines service area. $$a_{cgi} = \frac{k_h\, g_0}{1650} \left(\frac{H_{si}}{B_{wl2}} + 0.084\right) (50 - \beta_{cg}) \left(\frac{V_i}{\sqrt{L}}\right)^2 \frac{L\, B_{wl2}^2}{\Delta}$$ $$a_{cgmin} = C_{HSLC}\, C_{RW} \frac{V_i}{\sqrt{L}}$$ • a_{cg} depends on wave height and ship parameters. • Acceleration increases as the speed increases. • Speed reduction needs to be considered in case of higher wave heights.

Comparison of DNVGL-HSLC and DNVGL-Naval Rules

- Three high speed crafts with lengths between 30m to 80m
- 1st – 37.5m Patrol Boat
  - Aluminium monohull
  - Deep-V, hard chine
- 2nd – 61.9m Fast Attack Craft
  - Steel monohull
  - round-bilge
- 3rd – 79.9m Offshore Patrol Boat
  - Steel monohull
  - round-bilge

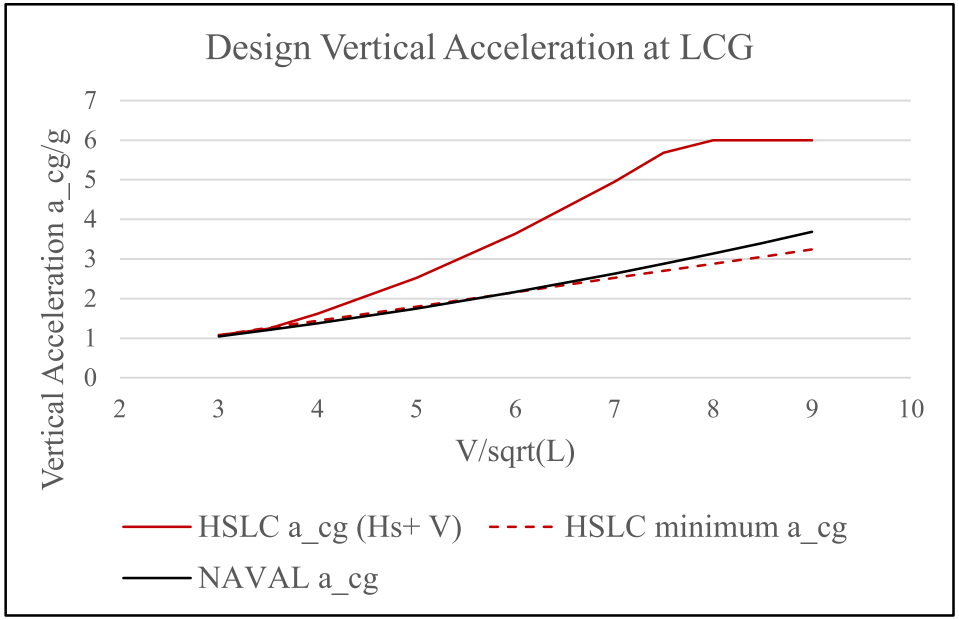
Description	Symbol	Unit	1st	2nd	3rd
Length over all	LOA	m	37.5	61.9	79.9
Rule length	L	m	31.19	56.3	71
Moulded breadth	B	m	7.2	9.5	11.52
Moulded depth	D	m	5	6	7
Height above baseline	H	m	9.935	10.8	14.9
Draught	T	m	1.85	2.6	4.2
Full load displacement	Δ	ton	148.5	580	1670
Breadth at waterline	B_{WL}	m	6.92	8.65	11.17
Dead rise angle at LCG	β_{cg}	degree	18	12	11
Significant wave height	H_s	m	3	4.6	6.5

Checking with Savitsky Limits

	Savitsky's Limit	37.5m	61.9m	79.9m
$\Delta_{lt} /(0.01L_m)^3$	3531 – 8829	4894 (Yes)	3250 (No)	4665 (Yes)
L/B	3 – 5	4.5 (Yes)	6.5 (No)	6.4 (No)
Deadrise, deg (β)	10 – 30	18 (Yes)	12 (Yes)	11 (Yes)
Trim angle, deg (τ)	3 – 7	4 (Yes)	4 (Yes)	4 (Yes)
H_s/B	0.2 – 0.7	0.4 (Yes)	0.5 (Yes)	0.6 (Yes)

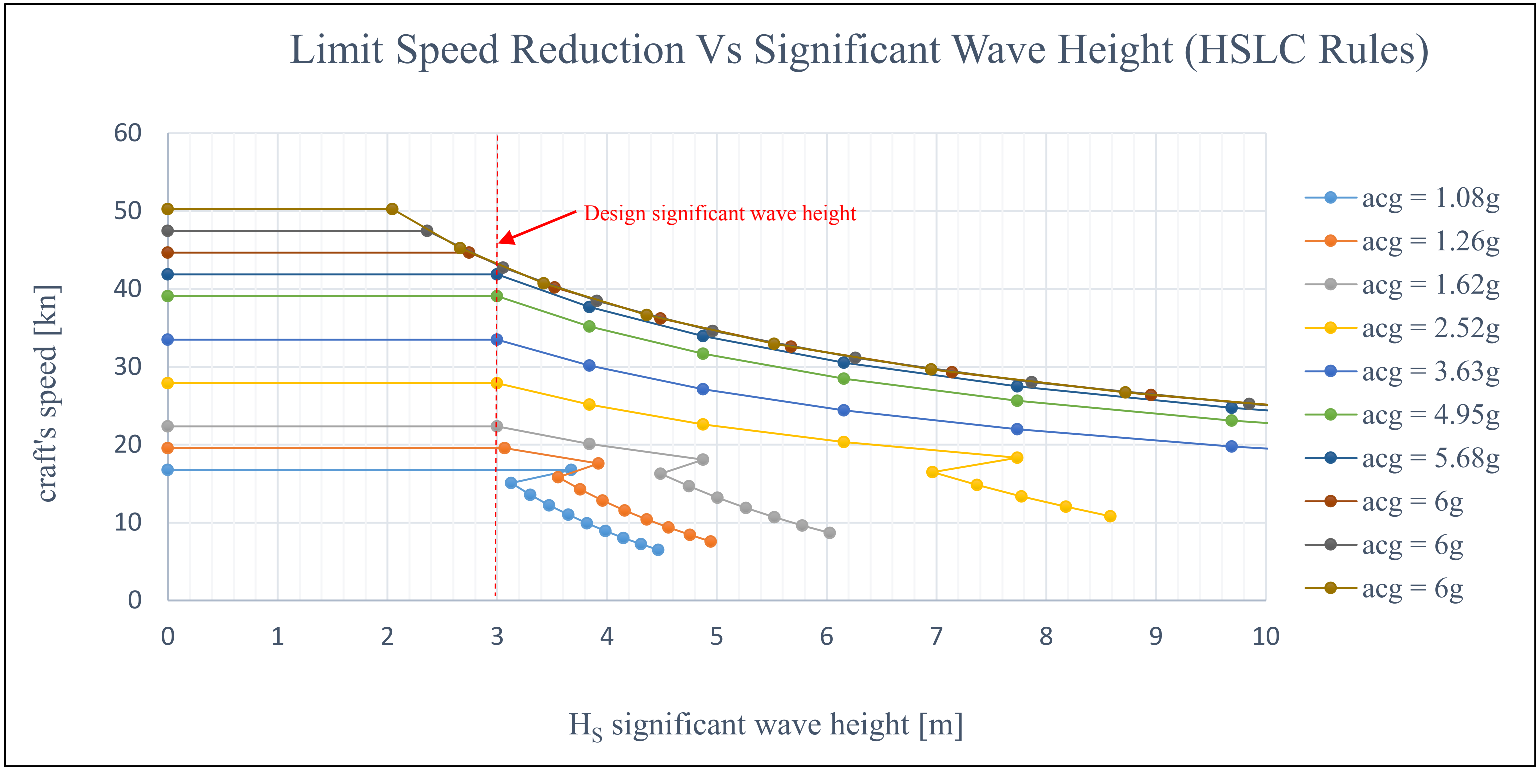
- ❑ Load calculations are done for a range of speeds (V/sqrt(L) between 3 and 9) to decide application limits.
- ❑ Scantling calculations are done only for design speeds (29 knots, 34 knots, 30 knots).
- ❑ Comparison are done for all vessels. Results for only 37.5m patrol boat are shown below.

Comparison of Design Acceleration



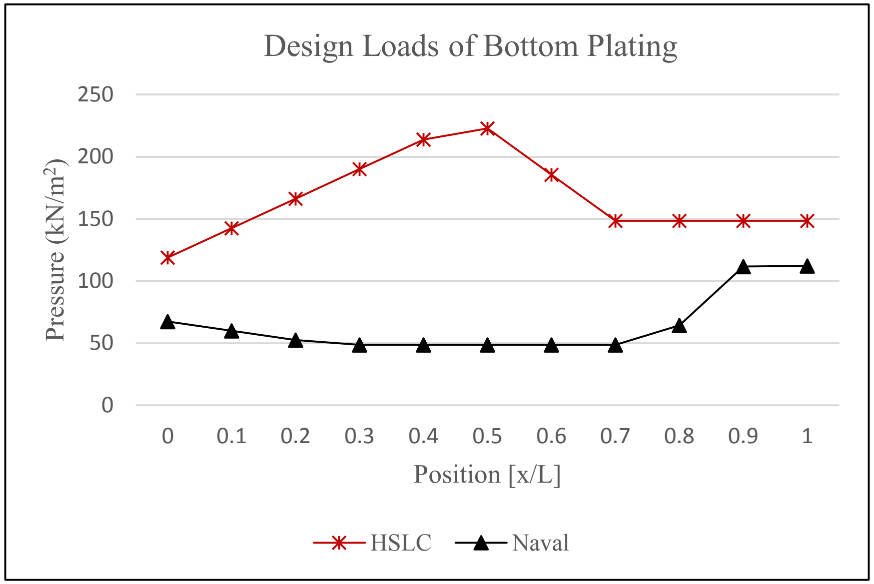
- ❑ Minimum acceleration values from HSLC rules are used for comparison with Naval rules.
- ❑ Wave height-dependent accelerations are used to find the application range of HSLC rules.
- ❑ Maximum acceleration is reached when the speed is between 42 and 45 knots.

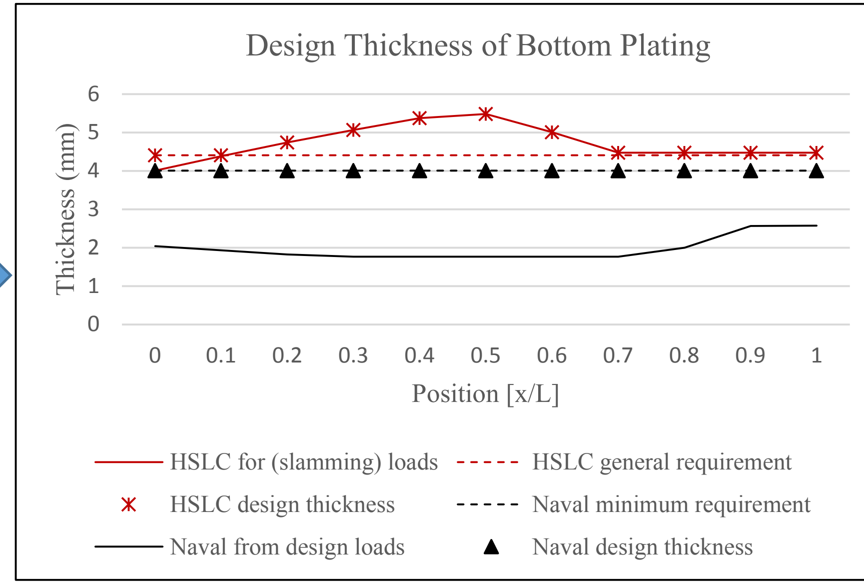
Limit Speed Reduction in Higher Significant Wave Heights



- Maximum possible design speed ~ 42 knots at 6g (for design waveheight)
- Formation of kinks around 17 knots (Switch of formulations at V/sqrt(L) = 3)
- Reduction of design speeds
- For acg=1.08g, 17 knots at 3m and 14 knots at 3.2m

Comparison of Bottom Design Loads and Scantlings





- **Different distribution and absolute values of load and scantlings**
- **HSLC Rules –** Reduction factor K_{red} increases as the element area decreases.

$$p_{sl} = \frac{\Delta\, a_{cg}}{0.14\, A_{ref}} K_{red}\, K_l\, K_\beta$$

- **Naval Rules –** C_A (max) = 2

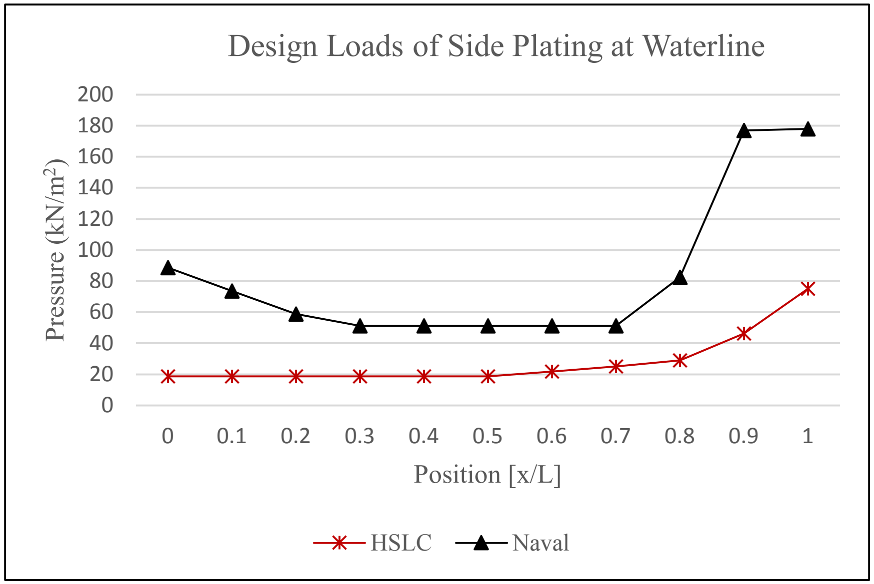
  – constant load for all element areas < $5 m^2$

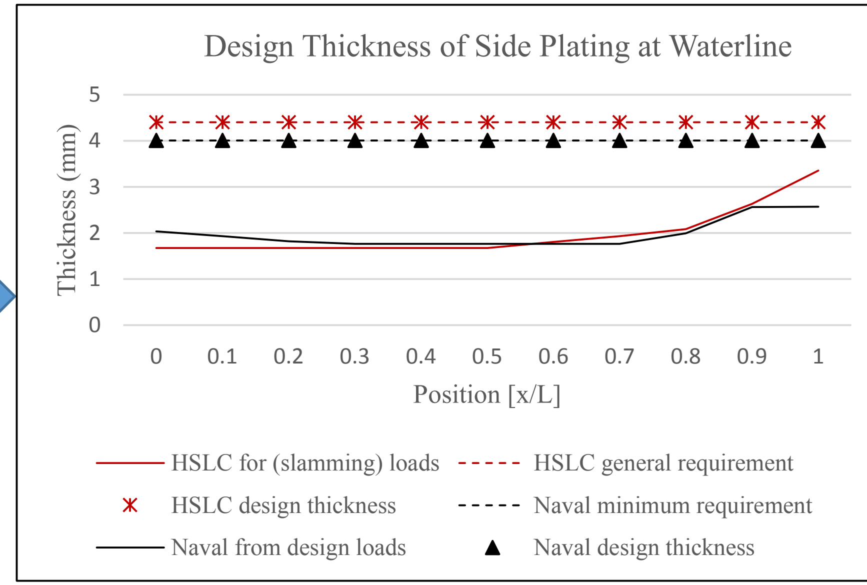
  – design element area of the ship = $0.264 m^2$

$$p_{SL} = C_A\, c_\alpha\, c_{SL}\, (0.2\, v_0 + 0.6\sqrt{L}\,)^2$$

$$C_A = 1 + \frac{5}{A}$$

Comparison of Side Design Loads and Scantlings

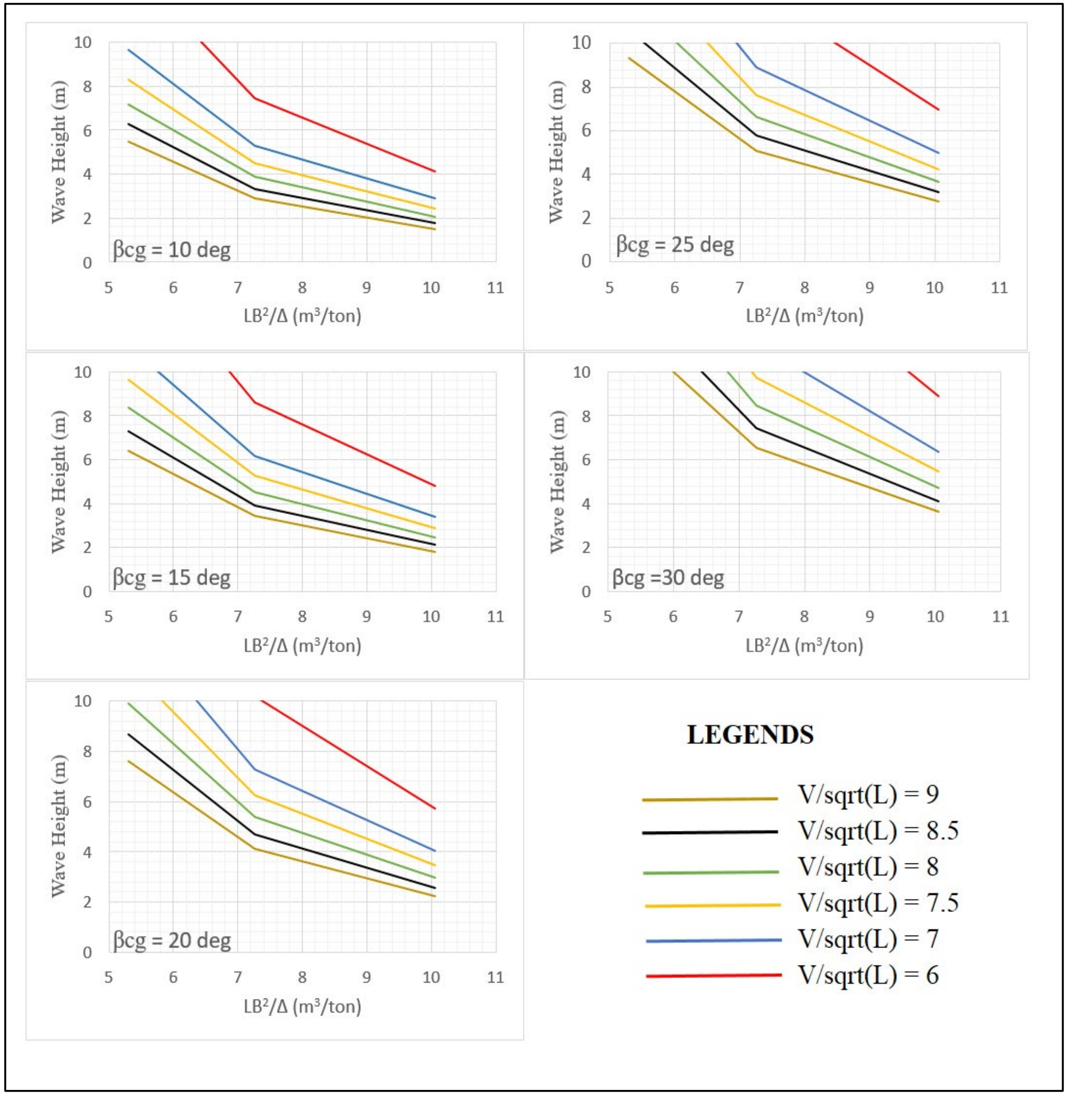




- **General thickness requirements in both rules are higher than thickness for design loads.**
- **Same thickness required for different design loads.**
- **Difference of permissible stresses** – 225. 37 N/mm² in Naval rules

  – 162 N/mm² in HSLC rules

Limit Speeds for Applicability of DNVGL HSLC Rules



- ❑ Smoother lines are expected if more data are available
- ❑ Generally decides maximum speed that can be designed by DNVGL HSLC rules
- ❑ Based on maximum acceleration 6g, practical design accelerations differ
- ❑ 2g-3g for smaller crafts, 1g-1.5g for larger crafts (in Koelbel, 2000)
- ❑ Only for structural design (crew safety and comfort to be exclusively considered)
- ❑ Strictly valid for monohull HSCs

Proposals for Improvements in DNVGL HSLC Rules

- ❑ Allowance for higher trim angles
  - Equilibrium trim angle = 4 degree
  - 2 degree increase in trim cause 50% higher acceleration
- ❑ Inclusion of Savitsky's Limits
  - applicability is decided only by the speed currently
  - $V > 7.16\ \Delta^{0.1667}$ knots
- ❑ Revisions of Allen & Jones done by Razola et al. (2014)
  - Comparison with experimental results, agreement observed only for panels with high aspect ratios near to the centerline
  - addition of transverse distribution to contribute light weight
  - correction factor for low aspect ratios (transversely framed hulls)

Possibility of Merger?

- ❑ Agreements in side design loads and scantlings
  - each set of rules being well tuned
  - adjust of permissible stress
- ❑ Disagreements in bottom design loads and scantlings
  - based on different background theories
  - different physics on load expectation
- ❑ DNVGL Naval Rules
  - Designated for longer vessels and larger stiffener spacings
  - Small bottom loads due to larger panel areas and less vertical motions
  - heavier scantlings close to waterline due to wave impact
- ❑ DNVGL HSLC Rules
  - more suitable for small crafts
  - shorter crafts subjected to more vertical motions
  - heavier bottom elements to resist high peak pressures from vertical impact

No Merger

Choice of Appropriate Rules

- Both DNVGL Naval Rules and DNVGL HSLC rules should be kept to cover a whole range of ships.
- Not easy to choose appropriate class rules only by ship type and speed
- Should consider the followings:
  - size of the ship
  - expected behavior (high speed displacement mode or planning mode)
  - Savitsky's Limits
  - stiffening arrangement
  - etc

Three Main Points of Master Thesis

- ❑ Differences and improvements between DNV and DNVGL HSLC rules are studied.
- ❑ Applicability limits of DNVGL HSLC rules are developed for monohulls and possible improvements are proposed.
- ❑ Merger of HSLC rules and Naval rules is not recommended and it is important to choose the right design method to design specific ships.