Assessment of Dynamic Collapse of Container Ship Subjected to Whipping

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Motivation

- Most of the accidents due to whipping load
  - Container ships
  - *MOL Comfort, Napoli, MSC Carla*
- Recent accident of MOL Comfort
  - more interest of whipping effect on the hull girder loadings

MOL Comfort Accident
[https://goo.gl//velqiC]

Objectives

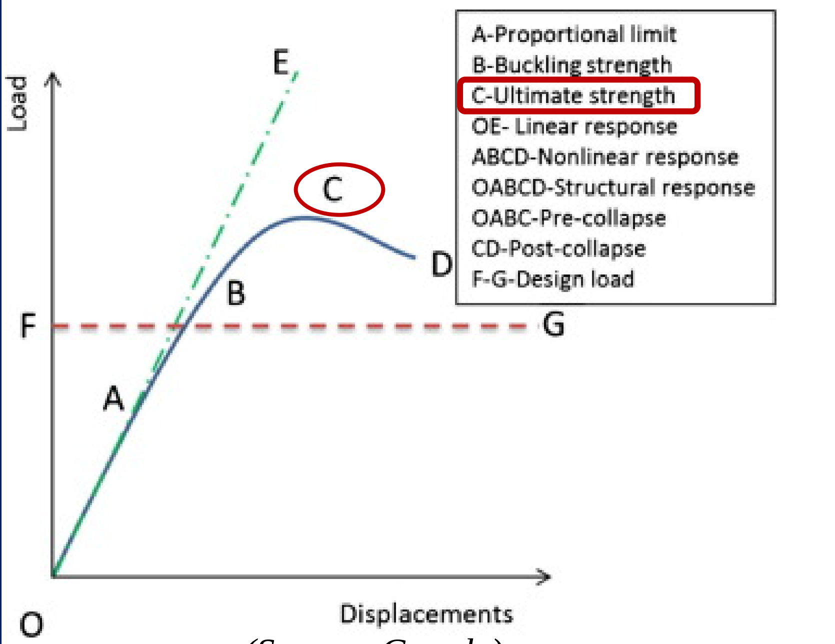
- To access the ultimate strength of 14000 TEU container ship
- To investigate the influence of material strain rate
- To investigate the effect of whipping load on hull girder capacity strength

Introduction

Ultimate strength check ⟶ DNV GL class guideline (code-0153)

$$\Upsilon_S M_{SW} + M_{WV}\,(\Upsilon_W + (\Upsilon_{WH} - \Upsilon_W)\,\boxed{\Upsilon_{dU}}\,) \le M_U/\Upsilon_R$$

?



(Source: Google)

Υ_{dU} = partial safety factor reducing the whipping effect during collapse

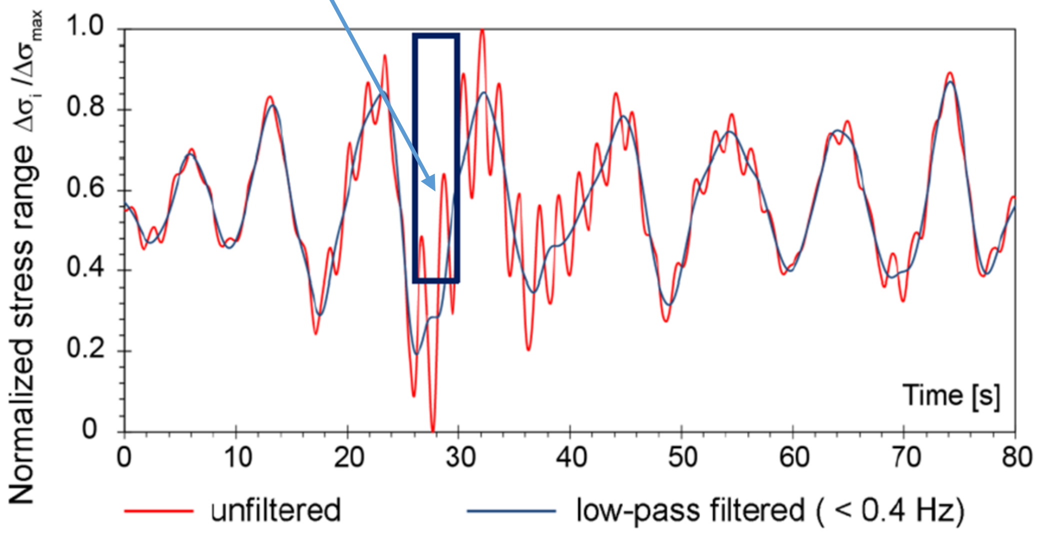
Whipping ⟶ transient hydro elastic ship structural response due to impulsive loading

⟶ by Large bow flare angle, high ship speed, low draft with flat bottom

⟶ structural failure of hull girder

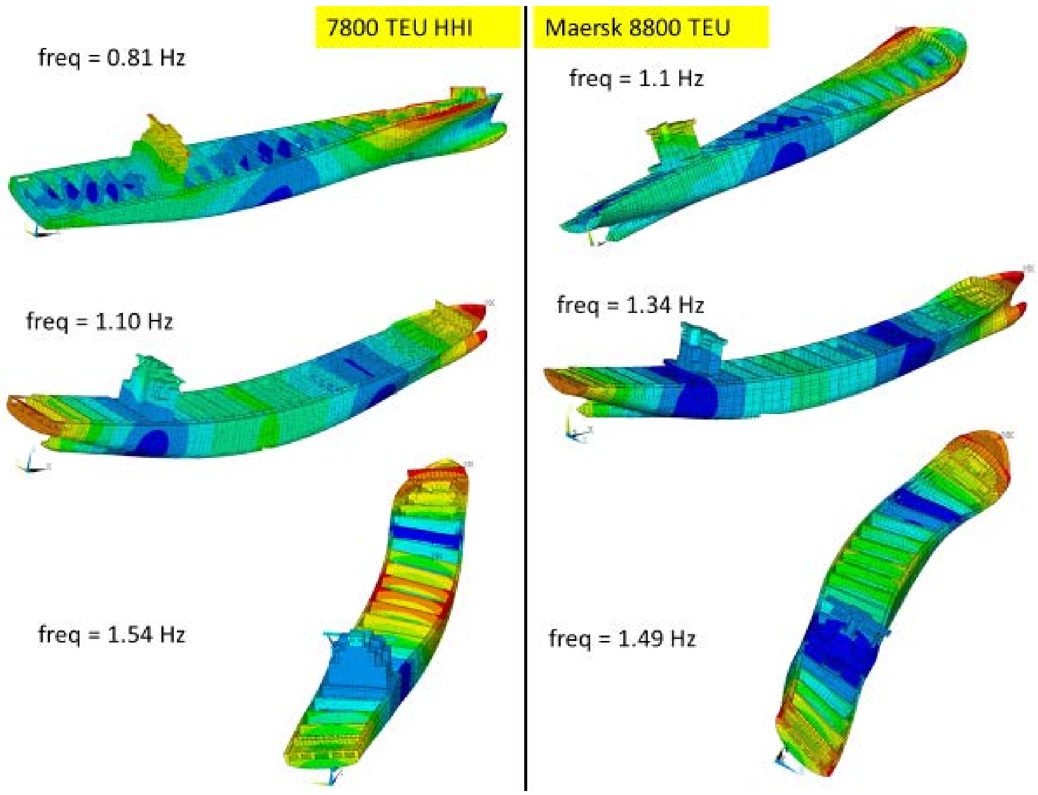
Collapse Modes of Container Ships

Frequency of 14000 TEU Container Ship
0.54 Hz (1.85 sec)



Normalized Stress Range in Time Domain
(Full Scale Measurement, DNV GL)

Frequency Modes of Container Ships



Solvers

Static Analysis → Implicit Solver [LS-DYNA]

$$\boldsymbol{K\,u(t) = F_{ext}(t) - F_{int}(t)}$$

Dynamic Analysis → Explicit Solver [LS-DYNA]

$$\boldsymbol{M\,\ddot{u}\,(t) = F_{ext}(t) - F_{int}(t) - C\,\dot{u}\,(t)}$$

Dynamic Analysis → Different times [0.1 sec, 1 sec, 2 sec, 5 sec, 10 sec]

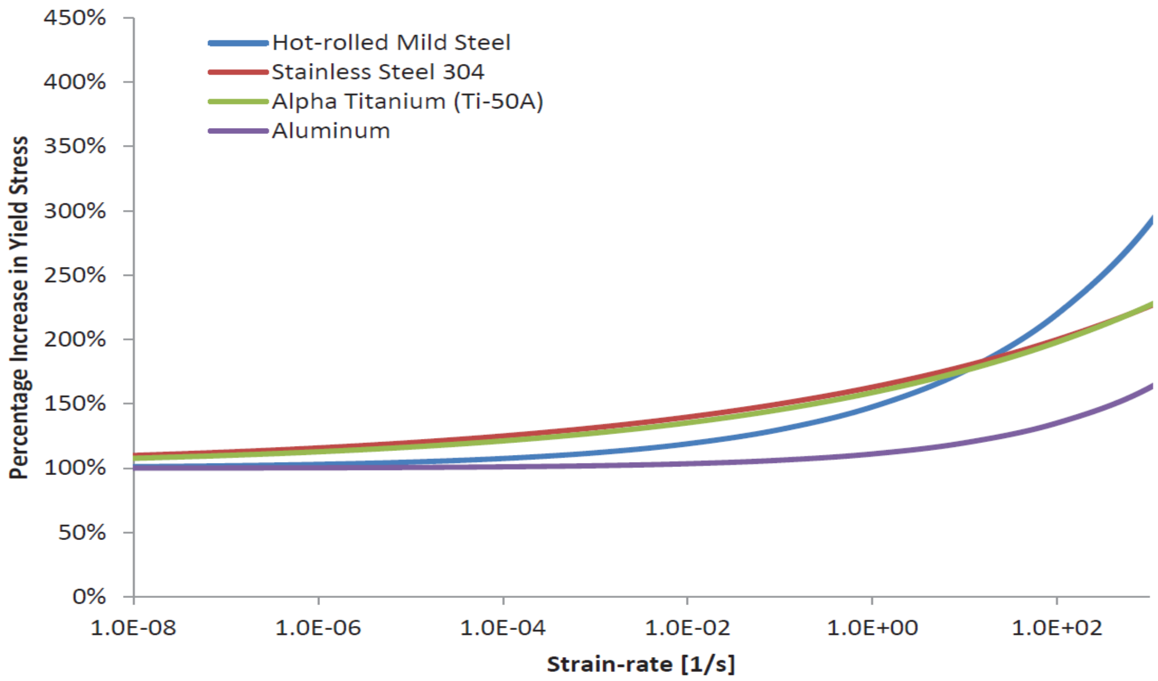
- Without strain rate imposed by Cowper-Symonds constants
- With strain rate imposed by Cowper-Symonds constants

Cowper-Symonds Relation

Cowper-Symonds Equation:

$$\sigma' = \sigma_y \left[1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{p}}\right]$$

σ'_y = *dynamic yield stress,*
σ_o, σ_y = *initial yield stress,*
$\dot{\varepsilon}$ = *material strain rate,*
C and p = *Cowper-Symonds Constants*



Behavior of Strain Rate(Experiments)

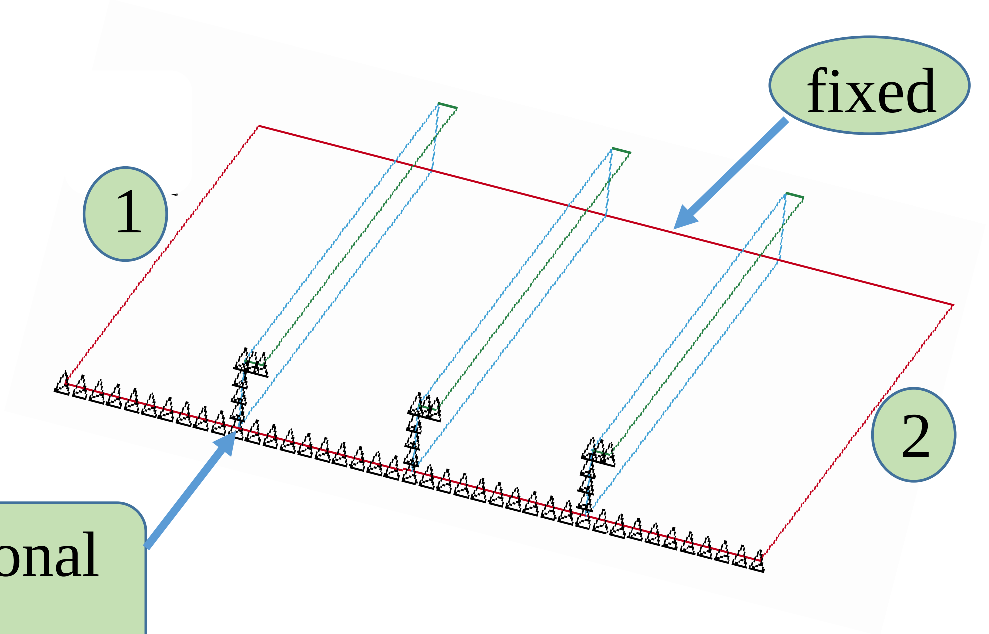
	Value of C		Value of p	
Researchers' Name	**Mild steel**	**High Tensile Steel**	**Mild steel**	High Tensile Steel
Paik	**40.4**	**3200**	**5**	
Lim(2005)	**40**	**24086**	**5**	
Lim(2005) [for different steels]	**$92000\times\exp(\frac{\sigma o}{364})$-193779 for σ_o >271MPa** **40 for $\sigma_o \leq$271MPa**		**5**	

Analyzed Models and Conditions

Analyzed Model	**Type of Steels Used in Model**	**Initial Yield Strength of Steel [MPa]**	**Analyzed Conditions**		
			Static	Dynamic Condition without Strain Rate	Dynamic Condition with Strain Rate
Stiffened Panel	Mild Steel	245	Yes	Yes	Yes
	High Tensile Steel	315	Yes	Yes	Yes
Double bottom	High Tensile Steel	315	Yes	Yes	Yes
	Mixture of Steels	235,315,355	Yes	Yes	Yes
Cargo Hold	Mixture of Steels	235,315,355, 390 & 460	Yes	Yes	Yes

Analysis of Stiffened Panel

Symmetric boundary condition at 1 & 2



imposed translational displacement

Stiffened Panel with Mild Steel

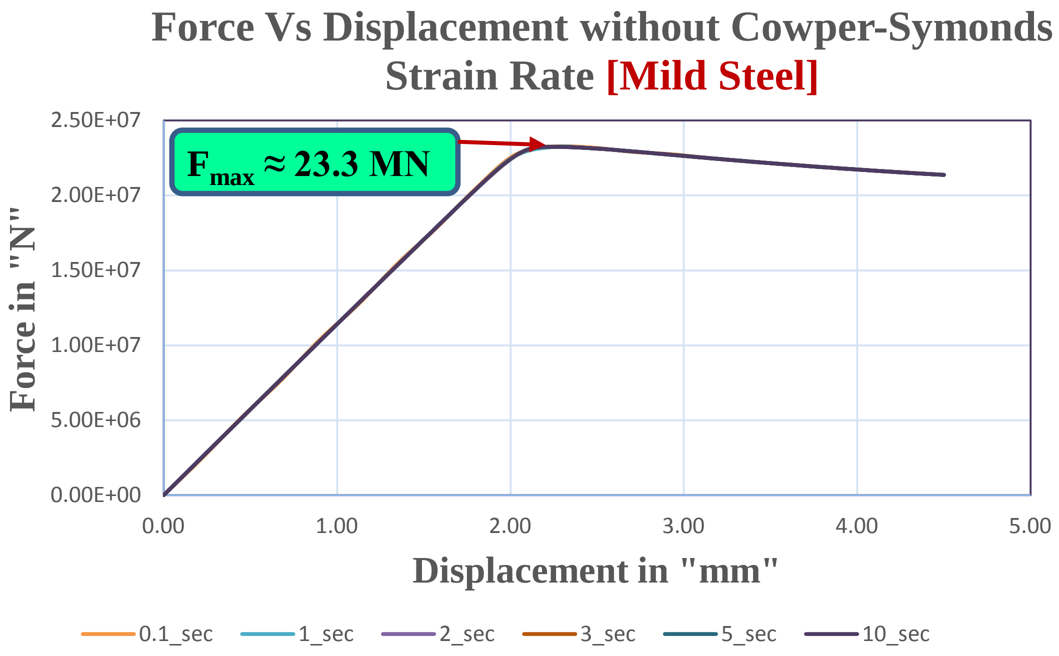
Stiffened Panel with High Tensile Steel

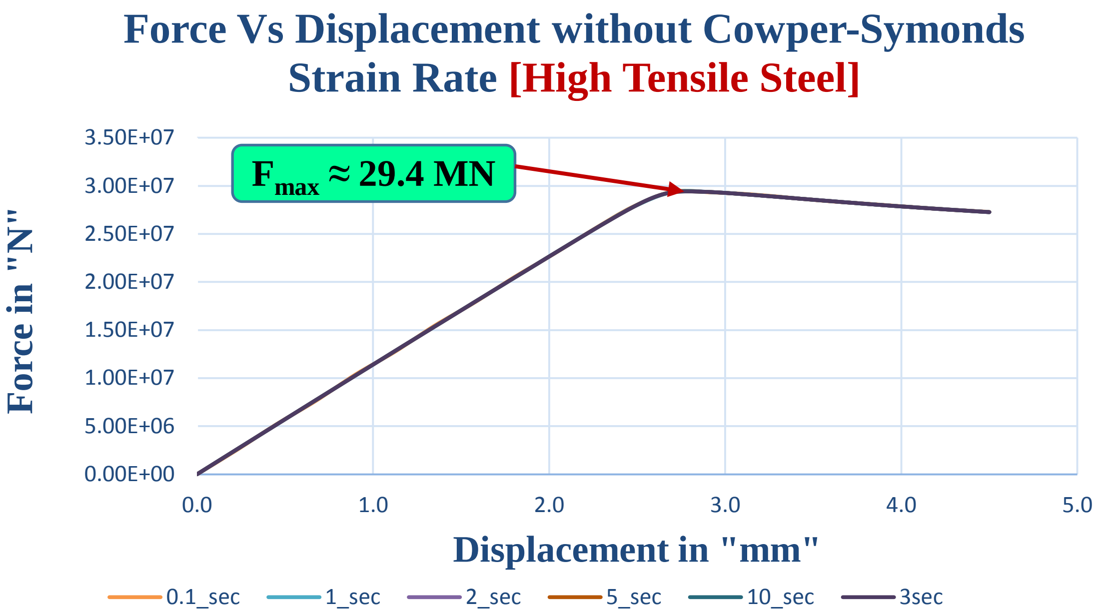
Impose the Strain Rate with Cowper-Symonds Constants recommended by Lim & Paik

Dynamic Analysis without Cowper-Symonds Strain rate

Static Collapse Force = 23.3 MN

Static Collapse Force = 29.38 MN



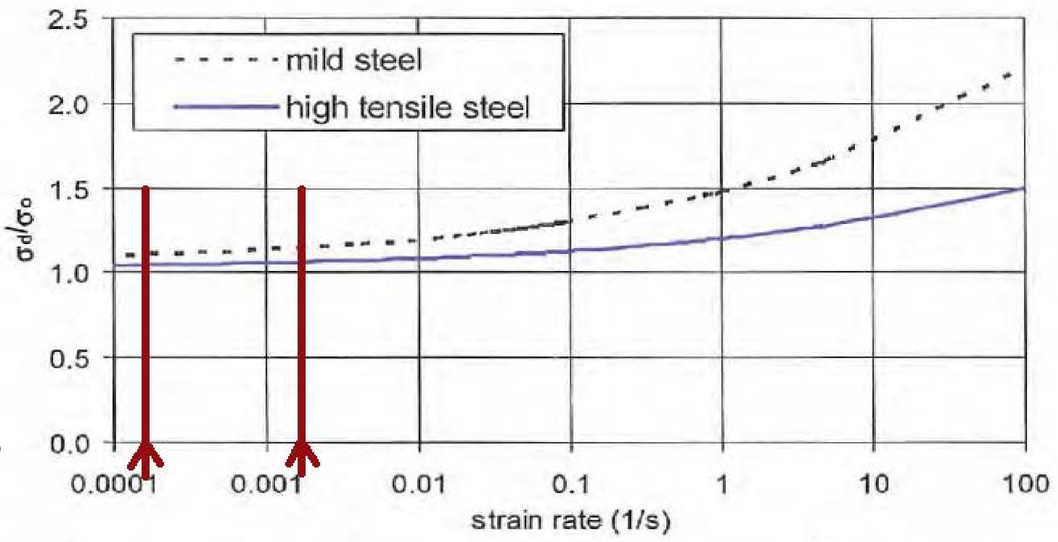


No significant changes in dynamic collapse compared to static collapse force

Dynamic Analysis with Cowper-Symonds Strain rate

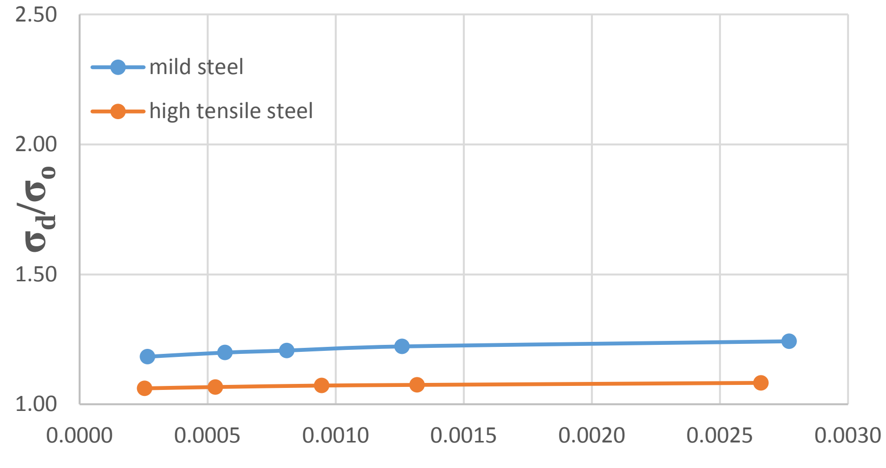
	Results with Mild Steel			Results with High Tensile Steel					
Static Collapse Force	23.26 MN			29.38 MN					
Researchers' Name	Lim & Paik			Lim			Paik		
Simulation Time	Collapse Frequency [Hz]	Force Ratio	Strain Rate	Collapse Frequency [Hz]	Force Ratio	Strain Rate	Collapse Frequency [Hz]	Force Ratio	Strain Rate
0.1sec	15.38	1.29	2,46E-02	14.29	1.08	3.75E-02	14.29	1.12	2.66E-02
1sec	1.67	1.21	2.77E-03	1.54	1.06	2.61E-03	1.43	1.09	2.66E-03
2sec	0.80	1.19	1.26E-03	0.77	1.05	1.36E-03	0.74	1.08	1.32E-03
3.1sec,2.8 sec,2.8 sec	0.54	1.17	8.10E-04	0.54	1.05	9.22E-04	0.54	1.07	9.45E-04
5sec	0.33	1.16	5.68E-04	0.31	1.04	5.80E-04	0.30	1.07	5.10E-04
10sec	0.17	1.14	2.66E-04	0.15	1.04	2.57E-04	0.15	1.06	2.54E-04

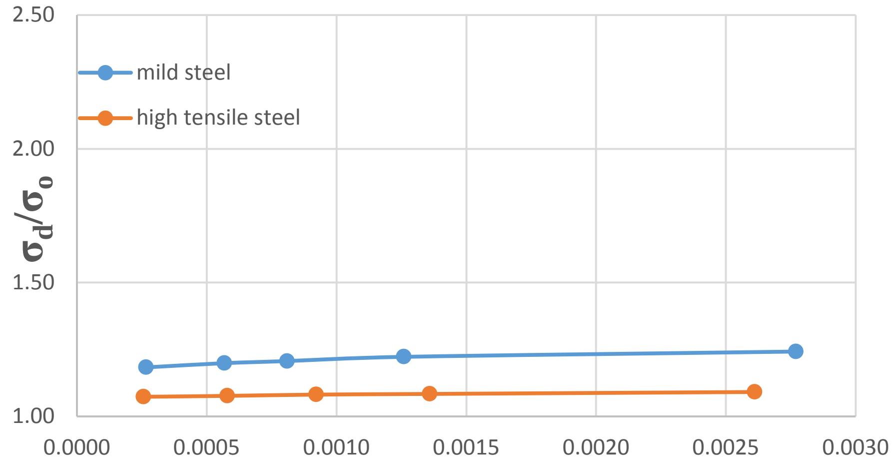
Validation of Strain Rate



Select C & P values recommended by Lim

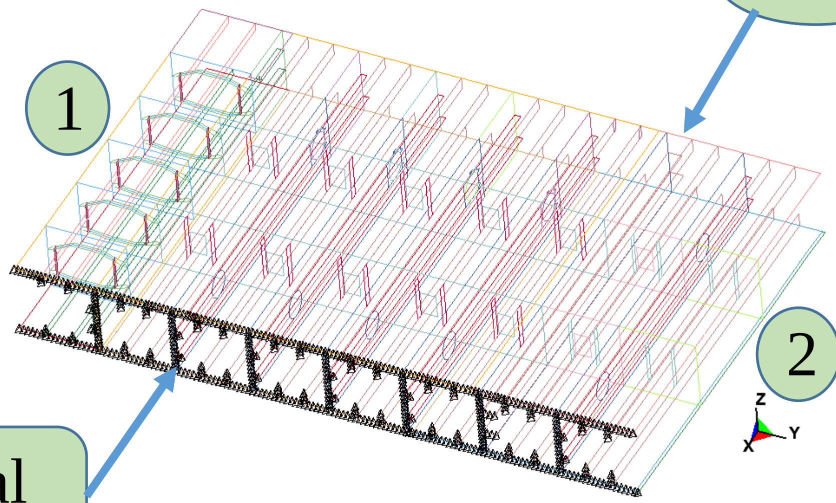
- ❑ Detail formulation for all type of ship structural steel
- ❑ Force increment ratio is less than that using Paik's constants
- ❑ Strain rate is also valid with the measurement values





Analysis of Double Bottom Model

Symmetric boundary condition at 1 & 2



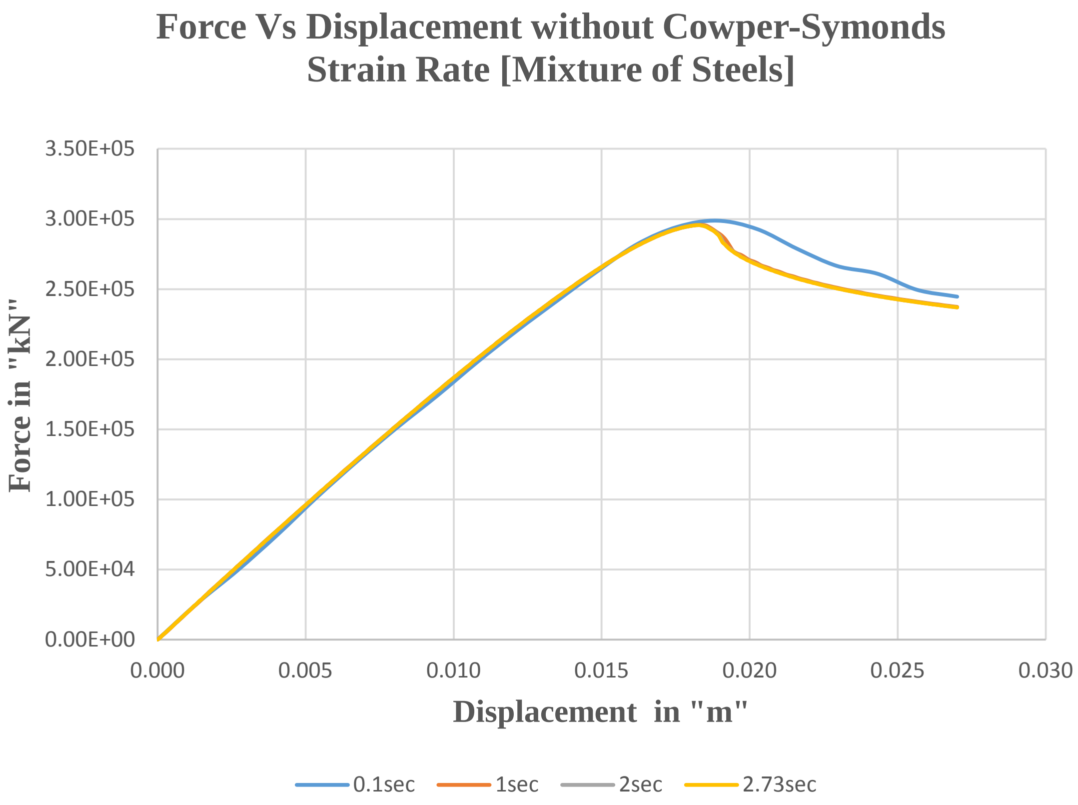
Imposed translational displacement

Double Bottom Model with High Tensile Steel

Double Bottom Model with Mixture of Steels (235MPa, 315MPa and 355MPa)

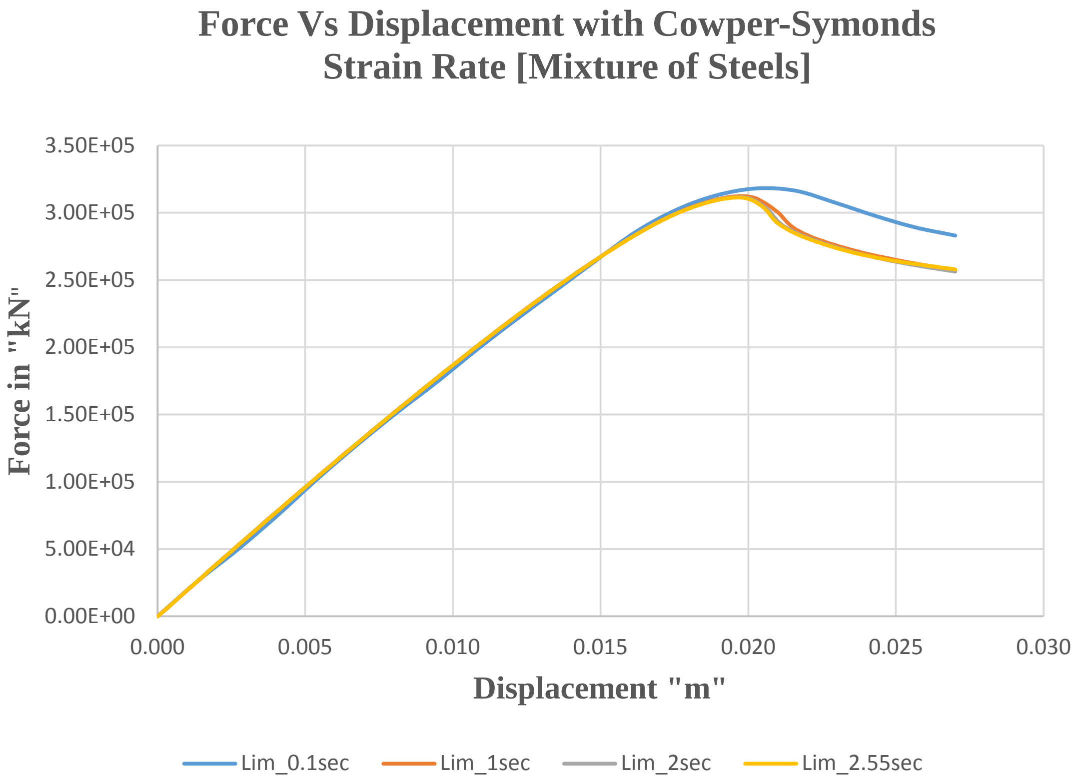
Impose the Strain Rate with Cowper-Symonds Constants recommended by Lim

Dynamic Analysis without Cowper-Symonds Strain rate



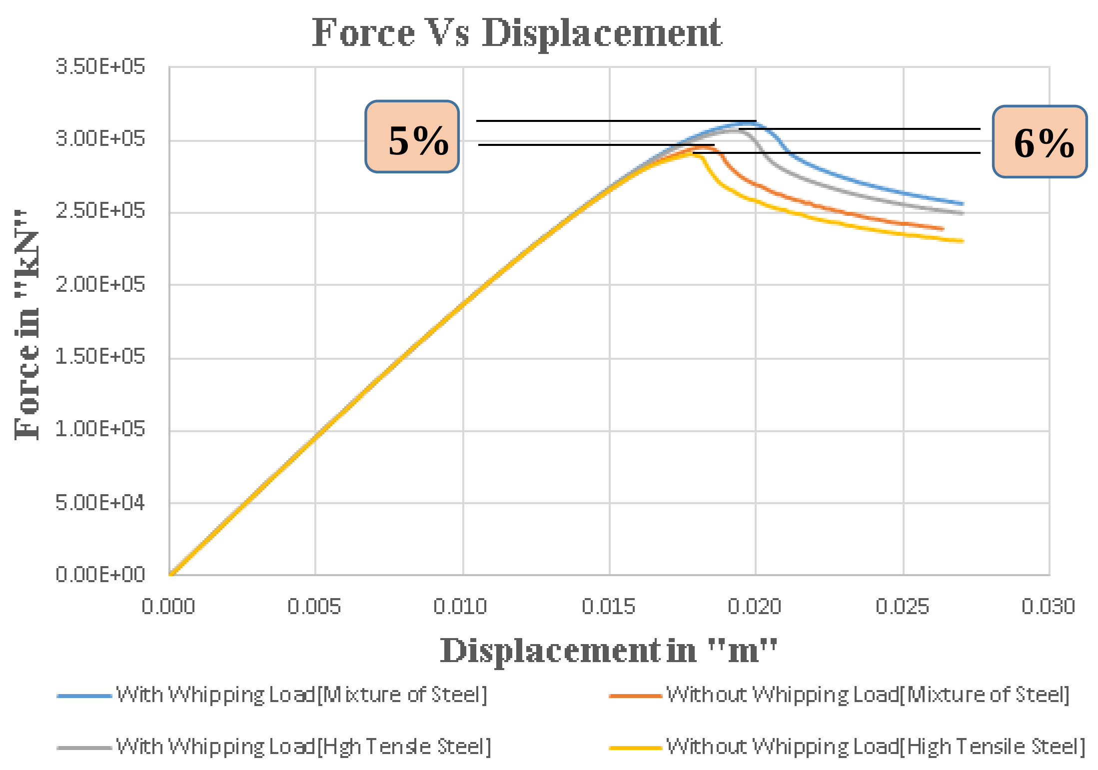
	Results with High Tensile Steel		Results with Mixture of Steels	
Static Collapse Force	290.506 MN		295.40 MN	
Simulation Time	Collapse Frequency [Hz]	Force Ratio	Collapse Frequency [Hz]	Force Ratio
0.1sec	14.29	1.01	14.29	1.01
1sec	1.52	1.00	1.47	1.00
2sec	0.75	1.00	0.74	1.00
2.8sec, 2.73sec	0.54	1.00	0.54	1.00
5sec	0.30	1.00	-	-

Dynamic Analysis with Cowper-Symonds Strain rate



	Results with High Tensile Steel		Results with Mixture of Steels	
Static Collapse Force	290.51 MN		295.41 MN	
Simulation Time	Collapse Frequency [Hz]	Force Ratio	Collapse Frequency [Hz]	Force Ratio
0.1sec	13.33	1.08	13.33	1.08
1sec	1.39	1.06	1.37	1.06
2sec	0.70	1.06	0.69	1.05
2.59sec, 2.55sec	0.54	1.06	0.54	1.05
5sec	0.28	1.05	-	-

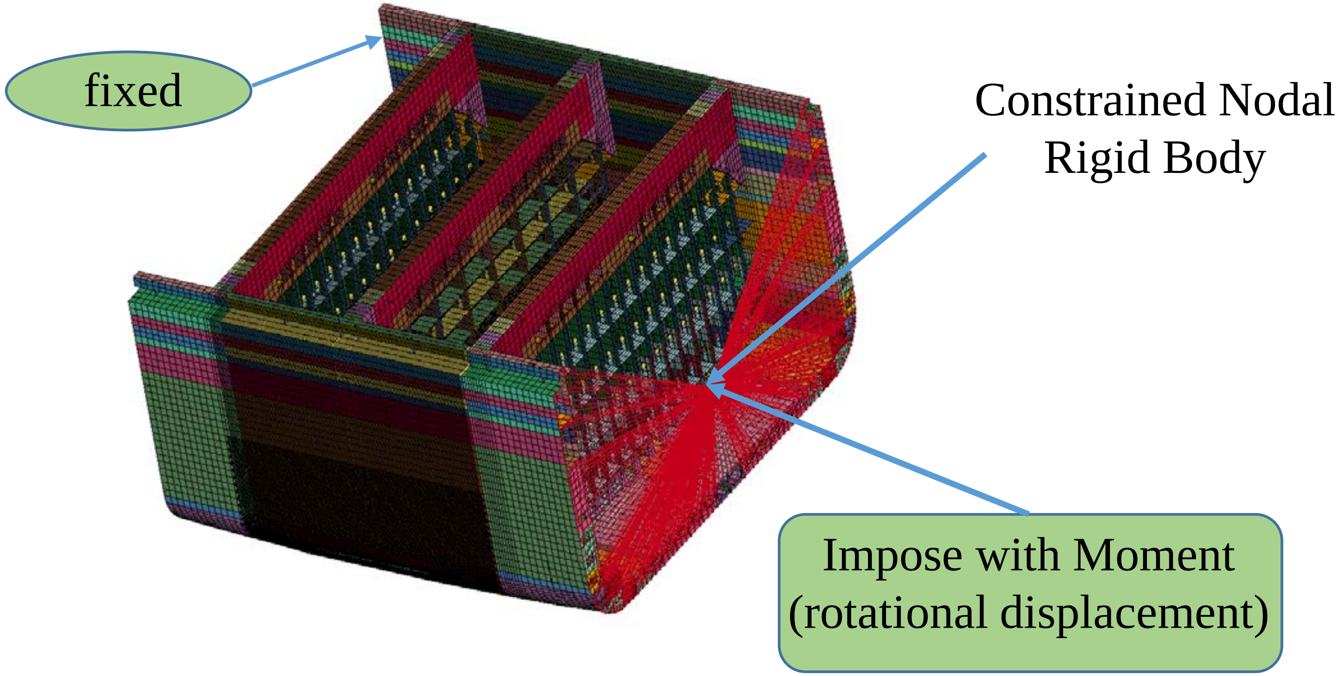
Comparison of the results of Double Bottom Model at 0.54 Hz



- **Without Whipping**
  Mixture of Steels 2% greater than High Tensile Steel
- **With Whipping**
  Mixture of Steels 2% greater than High Tensile Steel
- **Mixture of Steels**
  With whipping 5% greater than without whipping
- **High Tensile Steel**
  With whipping 6% greater than without whipping

Analysis of Cargo Hold Model

- Static Analysis
- Dynamic Analysis with Cowper-Symonds Strain Rate
    - Used Cowper-Symonds Constants recommended by Lim



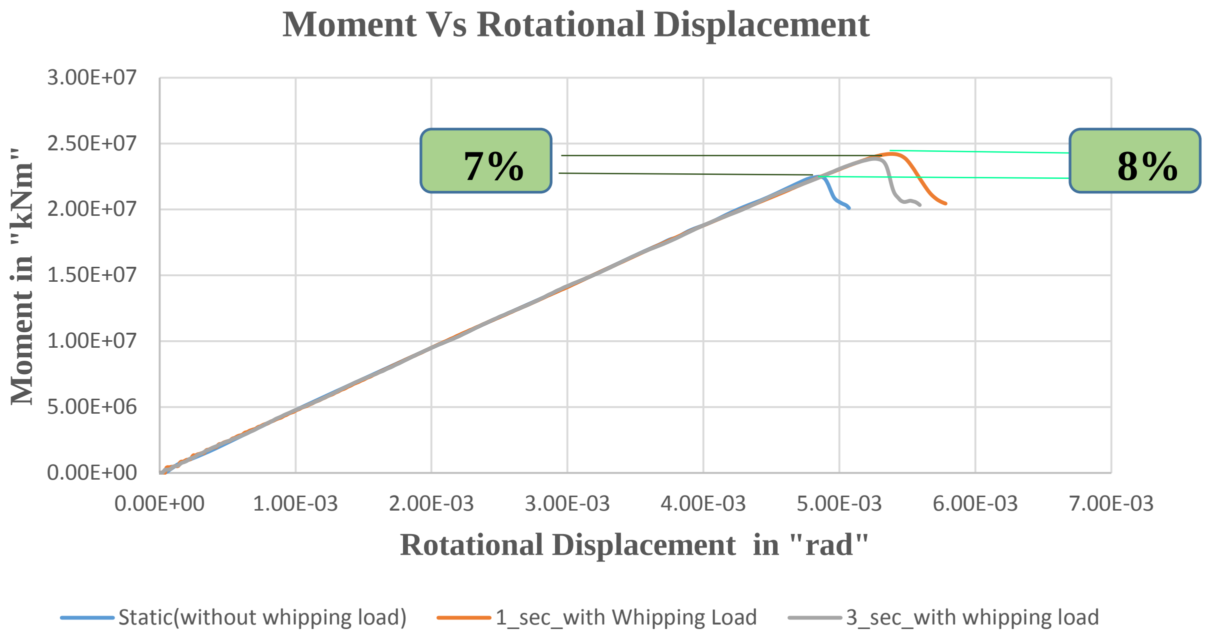
Materials in Model	Cowper-Symonds Constants	
Initial Yield Strength of Steel[MPa]	C	p
235	40	5
315	24806	5
355	50195	5
390	74819	5
460	131774	5

Dynamic Analysis of Cargo Hold Model

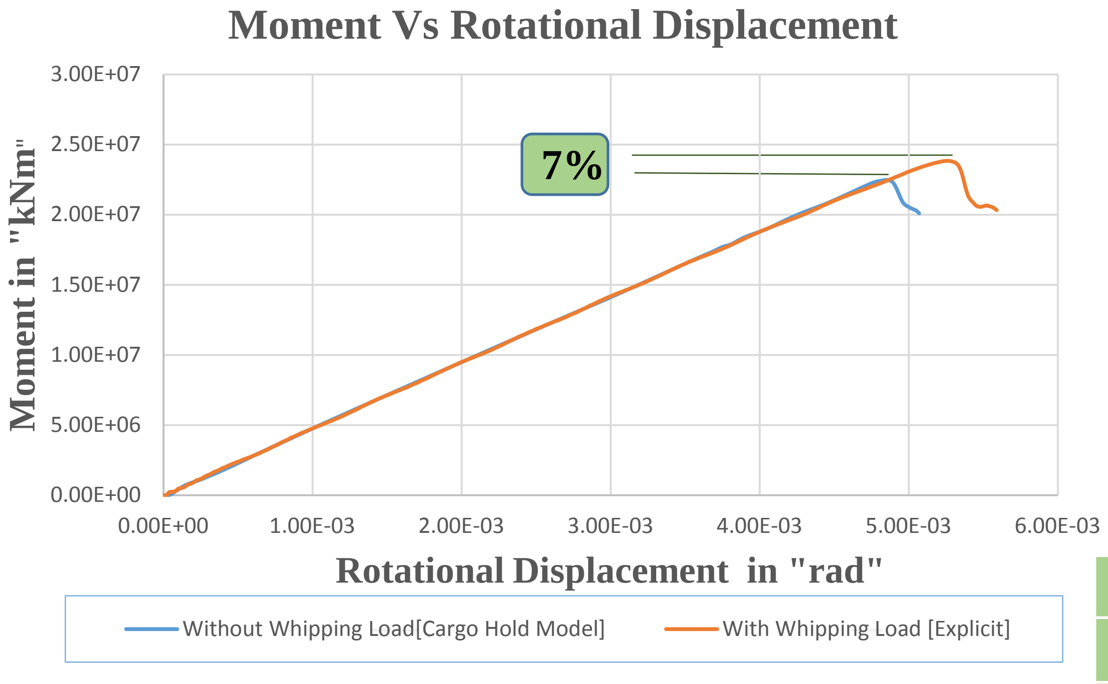
Simulation Time	Collapse Time [sec]	Collapse Frequency [Hz]	Dynamic Collapse Moment [GNm]	Moment Ratio	Strain Rate	Rotational Displacement [radian]
1 sec	0.54	1.86	24.21	1.08	1.83E-02	0.0054
3 sec	1.68	$\boxed{0.59}$	23.84	$\boxed{1.07}$	5.03E-03	0.0053

Static Collapse Moment = 22.38 GNm

Desired Collapse Frequency of 0.54 Hz



Hull Girder Ultimate Strength Check(14000 TEU Container Ship)



Υ_{dU} = 0.9 (DNV GL) **Υ_{dU} = 0.93 (Analysis)**

e.g. M_{sw} = 8.5 GNm and M_{wv} = 8 GNm

	DNV GL	Analysis	Unit
Load (with whipping)	19.54	19.59	GNm
Strength(with whipping)	19.74	19.74	GNm
UF (with whipping)[UF=load/strength]	0.990	0.992	-
Load(Static)	18.10	-	GNm
Strength(Static)	18.53	-	GNm
UF (Static)[UF=load/strength][w/o whipping]	0.977	-	-

Conclusion and Recommendation

At Collapse Frequency of 0.54 Hz

Analysed Model	Increment of Ultimate Strength Capacity due to whipping load including Strain Rate Effect		
	Mild steel	High Tensile Steel	Mixture of Steels
Stiffened Panel	**17%**	**5%**	**-**
Double Bottom	**-**	**6%**	**5%**
Cargo Hold	**-**	**-**	**7%**

- Ultimate Strength Capacity increases up to **7 %** (**10 %** by DNV GL)
- Simulation Time in LS-DYNA ⟹ a few days (sometimes, a few weeks)
- Need some implementation of FE Model

Thank You For Your Attention