Simplified Fatigue Guideline for Deck Opening and Outfitting Supports

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Abstract

In the shipbuilding industry, the concern of the fatigue problem has been a very important item for the ship owner, shipbuilder and classification society etc. The evaluation method for fatigue strength is very complex and a time consuming job, but for the maintenance purposes it is a very critical item.
However, for the opening and hull outfitting, pipes and control units installed on the main deck, the fatigue problems are not considered / evaluated like hull structure. Those are installed and constructed according to yard’s experience and practice without the reasonable verification procedure for fatigue strength, and some casualties due to the crack occurring on the outfitting and around holes on the main deck.
From these reasons, the fatigue strength in way of outfitting and openings installed on the main deck are evaluated and verified with the simplified method developed through the JDP between DSME and DnV. In addition, the effectiveness of the double plate underneath the various supports on the upper deck has been evaluated using the method to be introduced in this paper.

1 Introduction

Recently, the importance of the fatigue strength verification has been continuously increasing in the ship building industry and so on. Especially, for hull structures of the ship, the verification of the fatigue strength should be performed at the welded joints and structural discontinuities etc, from the initial design stage. And the evaluation methods for fatigue strength have been very complex and a time consuming job, but for the maintenance purposes it is a very critical item for ship owners. As the important structural items to be evaluated the fatigue strength are considered as follows.

1. Connection points of longitudinal stiffener/web plate (especially around drift line)
2. Connection points of Transverse Bulkhead/Longitudinal Bulkhead and Stringer/Longitudinal stiffeners
3. Hopper Knuckle Points, etc.

Through the many evaluations of the fatigue strength of the hull structure, some structural members have been confirmed that they are governed only by hull girder dynamic stresses and not by local dynamic stresses which are directly affected to the fatigue strength. Those structures are considered as located on the main deck like as followings,

1. Supports and piping holes installed on the main deck
2. Various access holes on the main deck
3. Ladder supports for access inside of tanks

Using the above concept, in case of applying DnV fatigue evaluation method (Classification Notes 30.7 of DnV), the fatigue strength could be evaluated easily with some additional assumptions because the concerned structures are not affected with any local dynamic stress from the cargo/ballast water and so on.

So based on the DnV guideline and the above mentioned concept, the simplified fatigue strength evaluation method has been developed, and will be introduced in this paper.

2 Strength Evaluation

As abovementioned, the deck structures are not directly affected with the local dynamic stresses which are considered as the main important factors for the fatigue strength, but governed by hull girder dynamic stresses which are caused by vertical/horizontal wave bending moment. Additionally, outfitting and piping holes have been installed and constructed on the deck according to the Yard's experience and practice without the reasonable verification procedure for fatigue strength and reported casualties due to the crack which occurred on the outfitting and around holes.
So to avoid any damages and for easy maintenance purposes, fatigue strength verification is requested to be performed to the relative structures and details.

2.1 Objective

To evaluate the fatigue strength using the simplified evaluation method, the mainly considered items on the main deck are piping holes, access holes, coaming and outfitting supports and so on. In addition, pipe support and ladder supports etc are included in cargo and ballast tanks as described in Figure A1 ~ A6 in Appendix. And for the installed locations, 2 different cases are selected as on deck and in water ballast tank. In ballast tank, ladder end connection will be evaluated with the comparison method.

2.2 Evaluation Procedure

Based on DnV Classification Notes 30.7, the simplified fatigue evaluation method has been developed as described in the flow chart as shown in Figure 1 below.
Fatigue evaluation is performed using maximum allowable stress range calculated from vertical/horizontal wave bending moments of full load and ballast condition which will cause maximum hogging and sagging condition. Wave bending moments can be simply calculated using the equations (Eq. 1) given in the Classification Rule. From this, maximum stress ranges of the concerned position can be calculated easily.

$$M_{WO} = -0.11\alpha C_W L^2 B(C_B + 0.7) \text{ (kNm) in sagging} \qquad \text{-------- (Eq. 1)}$$

$$= 0.19\alpha C_W L^2 B C_B \text{ (kNm) in hogging}$$

And then, to calculate and/or evaluate the fatigue strength, two methods can be considered as show in the Figure.
Alterative 1 is that with the rule length of the ship, Weibull shape parameter can be calculated as indicated in Figure 1. Using the shape parameter, the maximum allowable stress range for fatigue strength evaluation can be simply obtained in Table 2.7 & 2.8 of DnV Classification Notes 30.7. And then through the comparison with maximum allowable stress range and calculated dynamic stress range, the fatigue strength can be evaluated. It can be expressed to the maximum allowable SCF for the easy comparison and decision.
Alternative 2 is a procedure to consider the long term stress range for many different loading conditions, in which the procedure is very difficult and complex comparing with Alternative 1. Also Alternative 2 is a very time consuming job, but the accuracy is better than Alternative 1.
However, considering the purpose of the evaluation and the location of the objects, to apply Alternative 2

is not reasonable for fatigue strength evaluation to Alternative 1. So for easy evaluation of the fatigue strength, Alternative 1 procedure has been selected for the simplification.

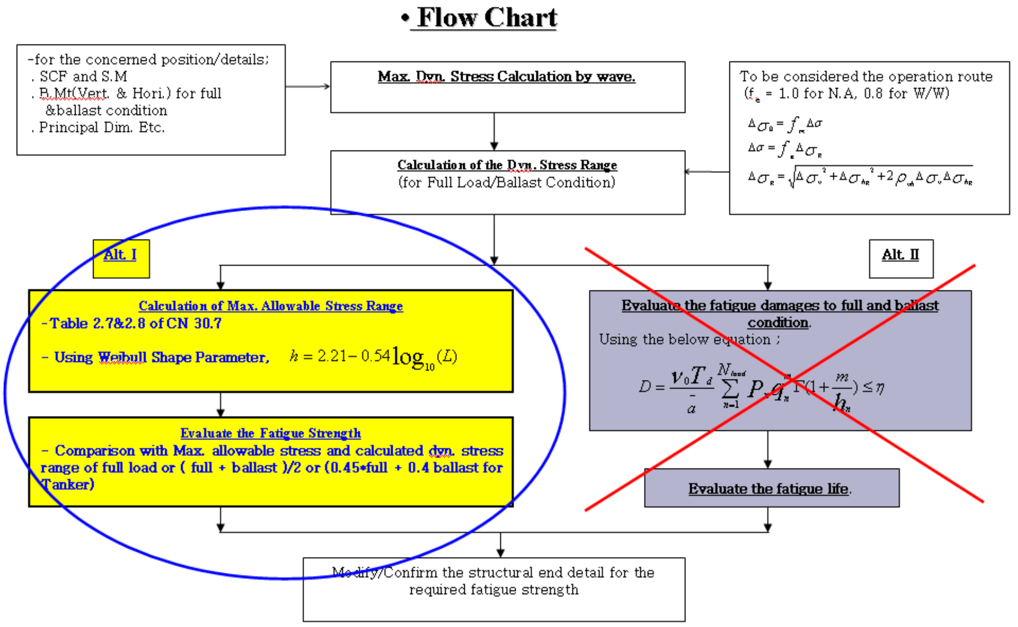


Figure 1 Flow Chart for the Simplified Fatigue Strength Evaluation

2.3 Application

To simplify the fatigue evaluation, considered sea states are world wide and North Atlantic operation, and 4 different levels of S-N curve are applied as described in the Classification Notes: for welded joint(in air or with cathodic protection and corrosive environment) and base material (in air or with cathodic protection and corrosive environment).
For the evaluation and the verification of the fatigue strength, 3 vessel types have been selected as a typical vessel based on Yard's experience as follows.

1. VLCC (Very Large Crude-oil Carrier),
2. Aframax Tanker
3. Conventional LNGC (140K M^3 Class).

Using the developed simplified evaluation tool mentioned in the above, the fatigue evaluation has been performed to 3 locations which are 1) on deck, 2) in ballast tank and 3) for outfitting support pad to be described in details. In addition, for the easy estimation, the maximum allowable SCF are calculated for 20, 30 and 40 years of the fatigue life.

2.3.1 On Deck

For every outfitting and holes installed/constructed on deck, evaluating the fatigue strength is very difficult and a time consuming job. So to screen and evaluate the fatigue strength, simplified fatigue evaluation sheet has been developed as shown in Figure 2. Using this excel sheet, maximum allowable SCF to the allowable fatigue strength can be easily found and calculated.
For example, Figure 2 is a fatigue strength evaluation sheet for LNGC Carrier, and the calculated maximum allowable SCF is 4.13 which are higher than the actual SCF given in Figure A1 to A6. It can be, therefore, easily supposed that for all installed outfitting and holes on deck this vessel has sufficient

fatigue strength for the design fatigue life of 20 years under the corrosive environment.

Simplified Fatigue Evaluation Sheet iwo Hole & Outfitting on Deck (for LNGC of 145K)

Ship characteristics

Length:	269.40	[m]	
Breadth:	43.40	[m]	
T-loaded:	12.35	[m]	
T-ballast:	9.71	[m]	
Depth:	26.00	[m]	
Block:	0.769	[-]	Full
	0.734	[-]	Ballast
Weibull(h_0):	0.90	[-]	
Max.A.Stress Range :			
(for W.J. Air/Ca.)	239.0	Mpa	(Level 1)
(for W.J. Cor.)	182.4	Mpa	(Level 2)
(for B.M. Air/Ca.)	286.8	Mpa	(Level 3)
(for B.M. Cor.)	219.2	Mpa	(Level 4)

Wave bending moments(at 10^{-4} P.L.)

Hogging:	2.25E+06	[kNm]	Full
Sagging:	-2.49E+06	[kNm]	Full
Hogging:	2.15E+06	[kNm]	Ballast
Sagging:	-2.43E+06	[kNm]	Ballast
Horizont:	7.22E+05	[kNm]	Full
Horizont:	6.17E+05	[kNm]	Ballast
$W_{D(ACT.)}$:	66.39	[m^3]	
$I_{y(ACT.)}$:	1109.70	[m^3]	
$\Delta\sigma_v$:	294.70	Mpa	Full
	284.65	Mpa	Ballast
$\Delta\sigma_{hg}$:	116.62	Mpa	Full
	99.73	Mpa	Ballast
$\Delta\sigma_g$:	327.60	Mpa	Full
	310.88	Mpa	Ballast
$\Delta\sigma$:	262.08	Mpa	Full
	248.70	Mpa	Ballast
$\Delta\sigma_{0L}$:	183.46	Mpa	Full
	248.70	Mpa	Ballast
$\Delta\sigma_0$:	182.04	Mpa	

Results : O.K for all details

Reduction factor

f_e :	0.8	[-]
f_m :	1.0 Ballast	
	0.7 Full	
a		
b		

Parameters

C_w :	10.58	[-]	
k_{wm} :	1.00	[-]	at m/s
f_r :	0.462	[-]	
x :	135	m	(at m/s)
K :	4.13	[-]	
y :	21.7	m	

For all details iwo hole & outfitting on deck structure,

Max. SCF to the details iwo Hole & Outfitting on deck
(refer to the attached sheets for the hole and outfitting details);
- 3.3 for welded joints except 2 cases which are needed to evaluate using more comprehensive tool.
- 3.3 (2.8 for row material) for cut out with coaming.
  3.45 for doubler iwo cut-out.

Conclusion :
Considering the above actual SCF's, the calcuated Max. allowable SCF of **4.13** is higher than those of the actual. Therefore it can be considered that this vessel has a sufficient fatigue strength for design fatigue life of 20 years under the corrosive envirnoment.
In addition to the above, for the details under air/cathodic envirnoment, Max. allowable SCF is possible to **5.42**.

Figure 2 Fatigue Calculation Sheet for LNG Carrier

In addition, using the excel sheet, maximum allowable SCFs have been calculated and summarized as shown in Table 1. In which, the calculated maximum allowable SCFs are listed for 3 types of vessels LNGC, Aframax Tanker and VLCC, in case of the design fatigue life of 20, 30 and 40 years.

Table 1 Summary for Maximum Allowable Stress Concentration Factors (S.C.F)

Vessel Type	Env.		World-Wide			North Atlantic			Remarks
			20 yrs	30 yrs	40 yrs	20 yrs	30 yrs	40 yrs	
LNGC (140K)	Weld Joint, Non-Corr.	Level 1	5.42	4.73	4.30	4.33	3.78	3.44	
	Weld Joint, Corr.	Level 2	4.13	3.61	3.28	3.34	2.92	2.65	
	Base Metal, Non-Corr.	Level 3	6.50	5.68	5.16	5.20	4.54	4.13	
	Base Metal, Corr.	Level 4	4.97	4.34	3.94	3.97	3.47	3.15	
Aframax Tanker	Weld Joint, Non-Corr.	Level 1	3.61	3.15	2.87	2.89	2.52	2.29	
	Weld Joint, Corr.	Level 2	2.65	2.31	2.10	2.20	1.92	1.75	
	Base Metal, Non-Corr.	Level 3	4.33	3.78	3.44	3.46	3.02	2.75	
	Base Metal, Corr.	Level 4	3.30	2.88	2.62	2.64	2.31	2.10	
VLCC (320K)	Weld Joint, Non-Corr.	Level 1	3.31	2.89	2.63	2.65	2.31	2.10	
	Weld Joint, Corr.	Level 2	2.53	2.21	2.01	2.03	1.77	1.61	
	Base Metal, Non-Corr.	Level 3	3.97	3.47	3.15	3.18	2.78	2.52	
	Base Metal, Corr.	Level 4	3.05	2.66	2.42	2.44	2.13	1.94	

2.3.2 In Ballast Tank

In the construction stage of the vessels, many arguments regarding the end connection of the ladder for access purposes have been raised between Owner's/Classification's surveyors and designers. The problem is the location of the installation of ladder supports which is considered as a sensitive point for any possible damage like a crack due to the lack of fatigue strength.
So to verify the adequacy of the structural strength, especially for the fatigue strength, an assumption has been given as longitudinal top stiffener is satisfied with the design fatigue life.

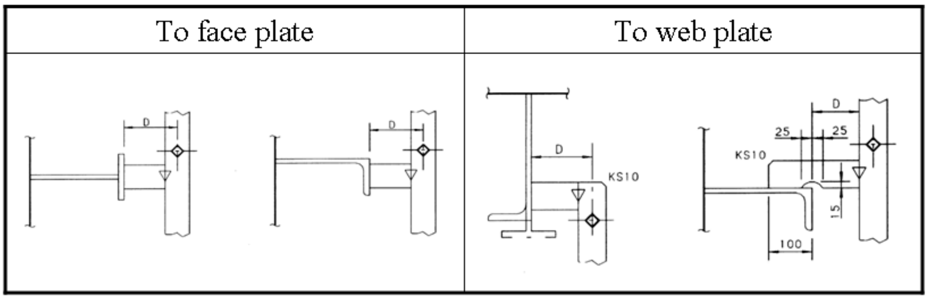


Figure 3 Detail of Vertical Ladder End Connection in Water Ballast Tank

On the above Figure 3, two (2) types of end connections are given as a Yard's practice. First is a case connected to face plate of the stiffener, second is a case of the attached to web plate of the stiffener. Gererally, between the above 2 types, considering the fatigue strength and Yard's workability, the first case is preferable, but there are some limitations for the fatigue strength.
So for the verification, based on the assumption, in the compressive stress range the fatigue strength shall not make any problems and iwo mid span of the stiffener the bending stress is lower than both ends of the stiffener considering boundary condition(generally, regarded as fixed condition at both ends of the longitudinal stiffeners) etc. Also comparing the load condition, the ballast condition is a severe condition because the bending stress at both ends on the stiffener top is tension, but in full load condition the bending strses is compression as described in Figure 4 below. Therefore, the ballast condition is the main consideration for the fatigue strength evaluation here.
Also considering the magnitude of the bending stress, tenssion range is 0.2L from both ends, and the half length of tension area to mid span can be considered with sufficient fatigue strength as a reasonable location to be attached the ladder support based on the explained theoretical background mentioned above.

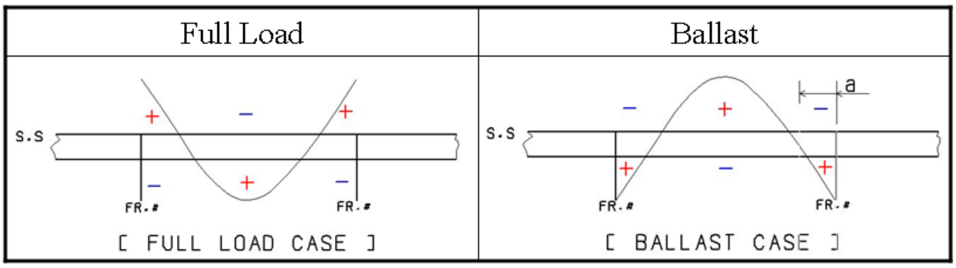


Figure 4 Bending Stress Distribution at the Span of Longitudinal Stiffener

So as a summary for the allowable installation range for two (2) end connection types of vertical ladder are proposed with sufficient strength margin as indicated in Table 2 below.

Table 2 Recommended Position of the Ladder End Connection

Location	End Connection Type	
	To Face Plate	To Web Plate
Full Load governing area **(S.S., draft line 2*Zwl area)**	$a > 0.1l$	$0 < a < l$
Other Space **(Ballast Load, governing factor)**	$a > 0.2l$	$0 < a < l$

(Where, Z_{wl} means distance in m from actual water line)

2.3.3 For Outfitting Support Pad

In detail design stage, there are many requests to verify the strength adequacy, the engineering background and the Yard's standard for the doublers of the supports to install the outfitting from internal and external engineers/surveyors. To give and set up a reasonable background and practice to install the doublers, two (2) evaluation methods are involved, those are allowable strength evaluation based on the classification rule and fatigue strength evaluation using the developed simplified methods mentioned above.

First, to evaluate the yield strength of the deck plate to be attached to the outfitting support, DnV rule(Pt.6 Ch.1 Sec. 2, Eq. 2) has been used, which is rule scantling equation for the helicopter deck. Except this, no requirements are applied to evaluate the yielding strength. And for this regard, major classifications, ABS, DnV, LR, BV and GL, do not have any different opinion.

$$t = k \times (1+s) \times (P_w)^{0.5} / (f_1)^{0.5} + 2.0 \text{ (mm)} \quad \text{--------------} \quad \text{(Eq. 2)}$$

Based on this, the required plate thickness are calculated as shown in the Table 3 and comparing with the actual plate thickness, it is thought that the concerned plate thickness is sufficient strength margin without any additional consideration.

Table 3 Rule Requirement for Plate Thickness iwo the Outfitting Support

Location	k	s(m)	Pw (kN/)	f_1 (AH32)	t_{req}	t_{act}	Remarks
Upper Deck	0.7	0.95	40.0	1.28	9.63AH	18.0 "AH" 20.0 "AH"	OK

Secondly, the fatigue strength has been evaluated with the same procedure developed simplified fatigue evaluation method. The allowable SCF has been calculated if SCF is lower than 3.57 in case of with/without pad, then fatigue strength problems shall not occur.

Comparing with the actual SCF of the pad types shown in Appendix A3 & A4, maximum SCF is confirmed with 2.2 to 2.4 according to the types. This means that the pad detail has sufficient strength margin with about 3.5 times and a fatigue life of about 70 years.

Also, for a more detailed and reasonable definition of SCF, FE analysis has been carried out to two (2) types of the pad with triangular and circular shape. From the results, the detail without the pad has been confirmed with lower SCF than one with the pad as described in Figure A7.

Therefore, in view point of structural strength, the pad for outfitting supports is not necessary to be attached on the deck plate. But for the maintenance purpose of the vessel, if ship Owner wants to attach the pad on deck plate, that will be another story.

3 Conclusion

Through this paper, it has been introduced the progress to develop the simplified fatigue evaluation method and the compatibility of the tool has been verified through the comparison with rule requirement and FE analysis and so on. With this tool, fatigue strength evaluations and structural adequacy for three (3) practical items for design and engineering purposes have been performed and confirmed with sufficient strength margin based on the theoretical background.

And applying this simplified tool in the design and the engineering stage, there are many advantages to reduce the engineering time and so on, if sufficient strength margin is confirmed, and to find out the weak points of the hull structures through the screening.

Appendix.

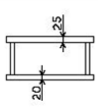
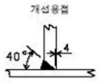
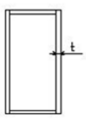
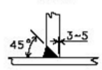
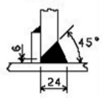
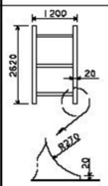
No.	Group Name	Details							Dep.	SCF
		형상	Size	방향	위치	Loading	Welding	선종		
1	Machinery (Closed Chock)		1) 1000*500 2) 830*470	PORT / FWD	Sheer Strake		개선용접 	COT	선장철의	To be evaluated by FEM.
2	Machinery (Bollard)		1) 2510*820 (t=22) 2) 2040*690 (t=18)	PORT / FWD	Deck OutSide		개선용접 	COT	선장철의	
3	Machinery (Cross Bitt)		Ø300		Deck OutSide		개선용접 	COT	선장철의	Max. 3.3
4	Machinery (Pipe Heavy Support)			PORT / FWD	Deck Center	있음	Fillet	COT	선장배관	Max. 2.2

Figure A1. Summary of the Actual SCF for Each Outfitting Supports

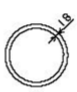
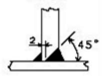
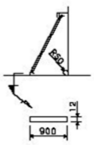
No.	Group Name	Details							Dep.	SCF
		형상	Size	방향	위치	Loading	Welding	선종		
5	Machinery (Hose Handling Crane)		Ø2035		Deck OutSide	있음	개선용접 	LNG COT	선장철의	Max. 3.3
6	Machinery (Water Braker)			Longitudinal	Deck OutSide		Fillet	COT	선장철의	Max. 2.2

Figure A2. Summary of the Actual SCF for Each Outfitting Supports

No.	Group Name	Details							Dep.	SCF
		형상	Size	방향	위치	Loading	Welding	선종		
	SUPPORT		10.0, Ø160, R50, 30, 500	FWD	I.W.O C.L	HEAVY LOAD'G	FILLET	TANKER	선장 배관	Max. 2.2
	SUPPORT		t, D; D / t: 55≤D≤135 / 8; 165≤D≤350 / 10		ALL	HEAVY LOAD'G (IF PIPE SUP'T) LIGHT LOAD'G (OTHERS)	FILLET	ALL	선장 철의 선장 배관	Max. 2.2
	SUPPORT		R15, t, A, A; A / t: 50≤A≤100 / 8; 130≤D≤180 / 10	LONGI & TRANS	ALL	LIGHT LOAD'G	FILLET	ALL	선장 철의	Max. 2.2
	SUPPORT		8.0, L, 30, 55≤A≤130	LONGI & TRANS	ALL	LIGHT LOAD'G	FILLET	ALL	선장 철의	Max. 2.2

Figure A3 Summary of the Actual SCF for Each Outfitting Supports

No.	Group Name	Details							Dep.	SCF
		형상	Size	방향	위치	Loading	Welding	선종		
	SUPPORT (ACC.LAD.)		R30, 200, 660	LONGI & TRANS	SHIP SIDE (I.W.D SHEER STRAKE)	LIGHT LOAD'G	FILLET	ALL	선장 철의	Max. 2.2
	SUPPORT (STANCHION)		25A PIPE		ALL	NO LOAD'G	FILLET	ALL	선장 철의	Max. 2.4
	SUPPORT (STANCHION)		65X16F.B	LONGI & TRANS	ALL	NO LOAD'G	FILLET	ALL	선장 철의	Max. 1.8
	MAST		10.0, 260		I.W.D C.L	NO LOAD'G	FILLET	ALL	선장 철의	Max. 2.2

Figure A4. Summary of the Actual SCF for Each Outfitting Supports

No.	Group Name	Details: 형상	Size	방향	위치	Loading	Welding	선종	Dep.	SCF
1	CUTOUT (Pipe Hole)		~ 100 101 ~ 300 301 ~ 500 501 ~ 1000 1001 ~	PORT FWD	All Position		Open Type	All	선장배관 기장배관	Max. 3.0 (2.38)
							Ring Type			Max. 3.3
							Double Pl.			Max. 3.45 (doubler) Max. 3.0 (cut_out)
							Coaming			
			365*365*R83		T-BDH					
			230*430*R60	PORT FWD	T-BDH					Max. 3.3 (Welding) Max. 2.8 (cut_out)

Notes;

The value in ( ) means SCF of base metal.

Reason : The fatigue life of base metal is about 2 times of welded joints. Therefore SCF of 3.0 for base metal can be reduced to 2.38.

Figure A5. Summary of the Actual SCF for Each Cutout

No.	Group Name	Details: 형상	Size	방향	위치	Loading	Welding	선종	Dep.	SCF
2	CUTOUT (Tank Access Hatch)	700 / 1070	1070*700	PORT FWD	SHEAR STRAKE		Coaming 11t	COT	선장철의	Welded : Max. 3.3 Cut out : Max. 3.0 (2.38)
	CUTOUT (Access Hatch)		800*600*R120 800*650*R135	PORT FWD	SHEAR STRAKE		Coaming 11t	ALL	선장철의	
			650*600*R130 650*600*R100	PORT FWD	SHEAR STRAKE		Double PL 20t	ALL	선장철의	Doubler : Max. 3.45 Cut out : Max. 3.0 (2.38)
	CUTOUT (Rescue & Maint. Hatch)		900*900*R180 1000*800*R160	PORT FWD	Deck Mid.		Coaming 11t	COT	선장철의	
	CUTOUT (Gas Freeing Fan Seat)		D320 D650		Deck Mid.		Double PL 22t	LNG	선장철의	

Figure A6. Summary of the Actual SCF for Each Cutout

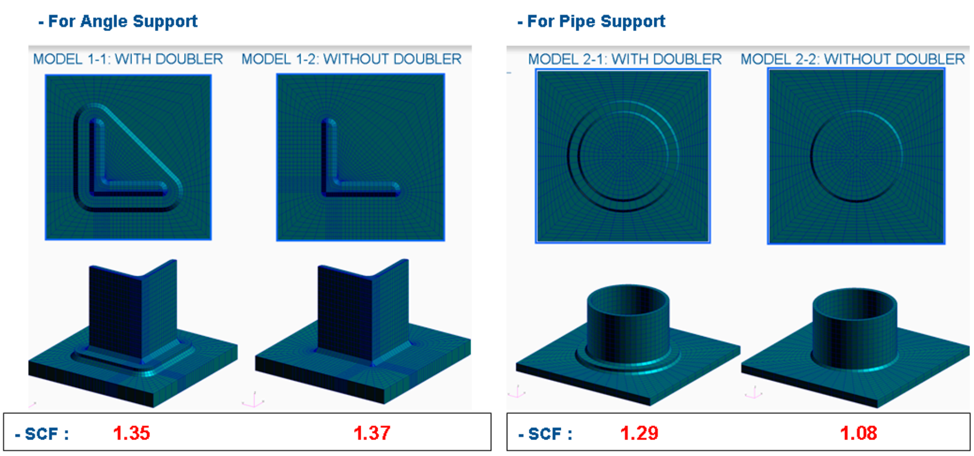


Figure A7. SCF Comparison for the with/without Pad under the supports