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Halifax Class – Defect Assessment

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SIGNATURE PAGE

HALIFAX CLASS – DEFECT ASSESSMENT

Technical Report # TR-17-79, Rev 02
14 November 2017

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EXECUTIVE SUMMARY

In a previous task, Lloyds Register – Advanced Technology Group (LR ATG) produced a defect database for the HALIFAX Class to support DNPS-2 enhancing the survey procedure for Canadian Forces Naval Ships. From the information provided in the present task, an attempt was made to develop a list of recurring structural defects, along with potential repairs and/or modifications.

Due to limitations in the information available in the database, it was determined that prevalent structural defects could be better determined from the experience of the hull inspectors and the Naval Architecture section of FMFCS.

Two locations were chosen from the identified list of re-occurring defects, namely (i) the FAMR forward bulkhead intersection with the No. 1 deck centerline girder, and (ii) the FER uptake with No. 1 deck.

For the FAMR location, the observed fatigue life was between 5 and 10 years. The modified connection developed through this analysis resulted in a fatigue life of 57 years.

The FER connection detail is quite complex, and its susceptibility to fatigue may be difficult to correct. The fatigue life observed during operation was approximately 5 years. The modified connection detail produced an estimated fatigue life of 12.4 years. It is predicted that a larger bracket than that considered for this analysis should improve the resulting fatigue life. However, other considerations would need to be taken into account, such as the possibility of creating a tripping hazard for ship personnel. This is be a topic for discussion with the ship's crew. Based on the complexity of stresses in this location, monitoring of the proposed modification is recommended to ensure that the addition of the bracket does not simply move the cracking problem to a new location. Much more detailed analysis would be necessary to ensure improved structural performance at this location.

A similar approach could be used on other areas of the vessel experiencing recurring defects. Further development of the existing FDA2 model of the HALIFAX Class could assist in providing valuable information for the development of future inspection plans. It is therefore recommended that consideration be given to expanding the current FDA2 model to capture a larger portion of the vessel.

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1.0 INTRODUCTION

In a previous task, Lloyds Register – Advanced Technology Group (LR ATG) was requested to produce a defect database for the HALIFAX Class based on historical inspection data. The intent of the Database was to support Director Naval Platform Systems (DNPS-2) in enhancing the survey procedure for Canadian Forces Naval Ships. The database consists of a collection of historical survey data from both the East and West coast that can potentially be used to identify possible defect trends across the HALIFAX Class.

The original intent of this task was to use the information contained within the Halifax Class Defect Database to compile a list of structural defects common across the Class; identify reoccurring structural defects; and develop potential repairs and/or modifications that would improve long-term structural performance.

2.0 REVIEW OF DEFECT DATABASE

A detailed review of the Halifax Class Defect Database identified that it contained insufficient information to compile a reasonable list of prevalent structural defects. The document contained limited information related to the exact type of defect and its location. In order to establish a list of prevalent defects, a meeting was arranged with the Hull Inspectors from Fleet Maintenance Facility Cape Scott (FMFCS) [1]. FMFCS Hull Inspectors confirmed that the observation regarding the lack of information in the database was correct. They also indicated that the database only contains defect information prior to 2010, and does not include more serious structural issues found during recent inspections; specifically, those related to HMCS Montreal. From this meeting and follow up teleconferences [2], it was determined that a more appropriate means of establishing the reoccurring structural defects would be to draw directly from the experience provided by the Hull inspectors and Naval Architecture Group in FMFCS.

An additional challenge was establishing quantitative information (loading) associated with the defect and ensuring the proposed repair would improve structural performance. A pre-existing partially-complete fatigue (FDA2) model of the Halifax Class developed by LR ATG through a separate internal research project provided the required analytical input. This FDA2 model contained the historical mission profile data and the hydrodynamic loading data for the vessel. The FDA2 model also provided the stress range and number of cycles for selected structural connections that could be used to in performing a fatigue assessment.

3.0 LOCATION OF STRUCTURAL DEFECTS

Based on a discussion with the FMFCS hull inspectors and Naval Architecture department, the locations below have been identified as areas of repeated structural cracking. Figure 3-1 identifies these locations on the GA of No. 1 deck.

- FAMR Casing - Fwd and Aft
- FER Casing Corners – Port and Stbd

- GT Uptake Steadies - Port and Stbd
- AAMR Casing Corners – Port and Stbd
- AER Casing Corners – Port and Stbd

For the purposes of this task, the FAMR and FER locations have been considered for detailed analysis.

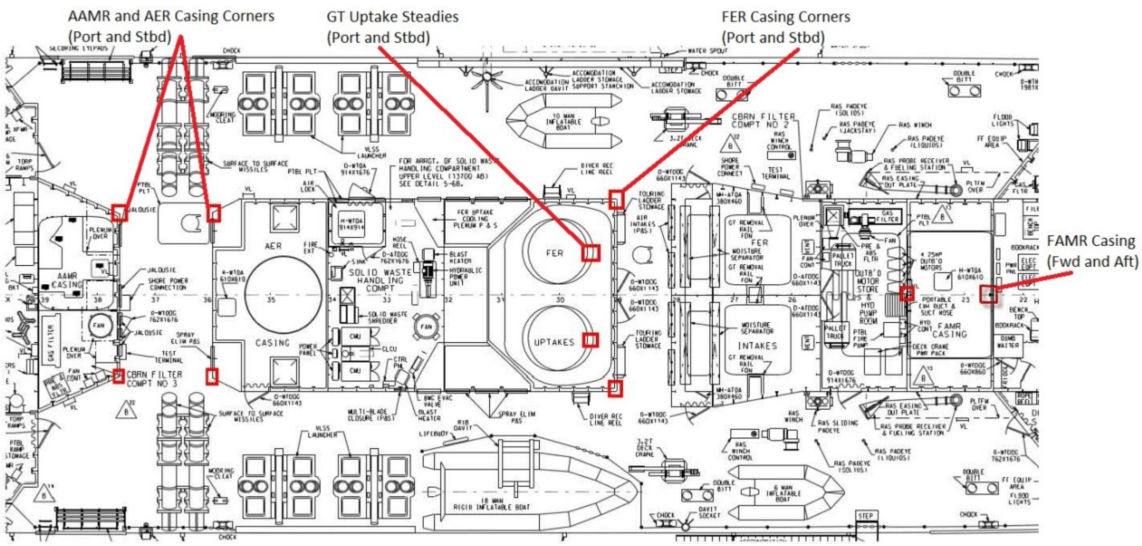

Figure 3-1: Locations of Repeated Structural Cracking

4.0 ANALYSIS METHODOLOGY

As indicated in Section 3.0 above, the two locations chosen for detailed analysis are the FAMR and AER casings. One challenge associated with this task was the lack of available quantitative data that would allow a detailed analysis to confirm that the proposed modifications would improve the structural performance of the connection detail. In both of these locations, fatigue is considered to be the cause of repeated cracking.

Through the use of the partially-complete FDA2 model, stress range ($\Delta\sigma$) and number-of-cycles (N_i) data were developed for the two locations under consideration. Since the historical mission profile for the vessel was incorporated into the FDA2 analysis, the stress range and cycles data is representative of the vessel history.

The FDA2 software uses a library of common structural connection types to determine representative stress concentration factors (SCF). The structural connections for the FAMR and AER locations are not considered common; hence, no representative detail was available within the FDA2 library of details. Therefore, in order to determine representative SCFs, two FE models were developed for each detail under consideration. One model would determine the SCF for the existing detail, while a second model would be used for the proposed modification. The FE-estimated SCFs, along with the nominal stress and cycle data extracted from the FDA2 analysis, could then be used to determine the representative fatigue lives for the as-built and modified details.

The input from the FMCS hull inspectors provided an accurate timeline for the development of the fatigue cracks. Using this information, the representative SCF value for the existing structural detail could be modified to produce a more appropriate value. The modified value resulted in an FDA2-estimated fatigue life that matched more closely with the life-to-cracking time observed from the ship surveys. On the basis of stresses predicted via the FE models, a ratio of stress between the existing detail and the proposed modification was then used to estimate a representative SCF for the modified detail and establish the fatigue life prediction.

5.0 FDA2 ANALYSIS PROCEDURE

The FDA2 direct calculation assessment utilises a simplified (first principles) spectral fatigue analysis procedure. The structural detail fatigue life characteristics are assigned using a parametric formulation of the geometric SCF, derived from systematic finite element analyses of the ship structural details. Unfortunately, as indicated above, the parametric formulations for the SCFs in this case were not representative of the details under consideration, and alternate methods were adopted to establish the SCFs.

The wave-induced loads and motions in regular waves were determined using the first principle ship loads and motions software Waveload-FD, which is a frequency domain linear code, developed by LR ATG.

The short-term total stress response in irregular waves was computed from the structural response influence coefficients, the regular wave load amplitudes and phase angles, and the wave energy spectrum.

For every sea state under consideration, the fatigue damage rate and stress-reversal frequency were calculated from the short-term stress response statistics and the fatigue strength characteristics of the structural detail.

The accumulated long-term fatigue damage was computed from each individual sea state contribution using the probability matrix of sea state occurrence. This was defined by the computed fatigue wave environment and the associated short-term fatigue damage rate and stress-reversal frequency.

The FDA2 analysis was performed in three steps. The initial data input, including structural properties, operational profile, and fatigue parameters, was carried out using the Naval FDA2 spreadsheet[3]. The input and hydrodynamic results were imported into the ShipRight software [4] to perform the analysis. Finally, once the analysis was complete, the FDA2 spreadsheet was used to retrieve the ShipRight fatigue results. Finally, the stress range and cycle data were exported to a custom spreadsheet, where the modified SCF was used to calculate the fatigue life of the connection.

6.0 FDA2 MODEL

The following sections describe aspects of the FDA2 model considered for the analysis.

6.1 SHIP PARTICULARS

Displacement:	4956.8 tonnes
Length Between Perpendiculars:	124.5 m
Mean Draft:	5.161 m

6.2 LOADING CONDITION

The loading condition considered for the development of the hydrodynamic loading and the FDA2 analysis was the Deep Departure condition. The vessel displacement in that loading condition, as stated above, was 4956.8 metric tonnes.

6.3 SPEED PROFILE

Table 6-1 identifies the 5 representative vessel speeds considered for fatigue analysis of the Halifax Class, along with the relative percentage of time at each speed assumed for this analysis.

Table 6-1: Speed Profile Used for FDA2 Analysis

Speed Index	Speed (knots)	Proportion of time at speed
	Total	1
1	4	0.2
2	10	0.5
3	16	0.27
4	22	0.02
5	28	0.01

6.4 OPERATIONAL PROFILE

The operational profile for the vessel is specified as a function of the relative percentage of time operating in various Marsden Zones. The values used for this analysis were provided by Defence Research and Development Canada (DRDC-Atlantic). These are based on the operation of a single Halifax Class vessel that was exposed to the highest waves, on average, which is expected to be the most pessimistic among the fleet for fatigue life. Table 6-2 provides the breakdown of time in each zone. These values were used directly in the analysis. The operational zones for this analysis are highlighted in blue in Figure 6-1.

Based on discussions with DRDC, the percentage of time the vessel will spend at sea (utilization factor) has been specified as 26% (or 6.5 years for a 25-year service life). This value was also incorporated into the analysis.

Table 6-2: Proportion of Time in Region

Marsden Zone	Percentage of operating time
15	50
23	14
26	10
33	4
47	3
59	3
24	3
27	2
30	2
4	2
20	2
8	1
16	1
25	1
11	1
37	1

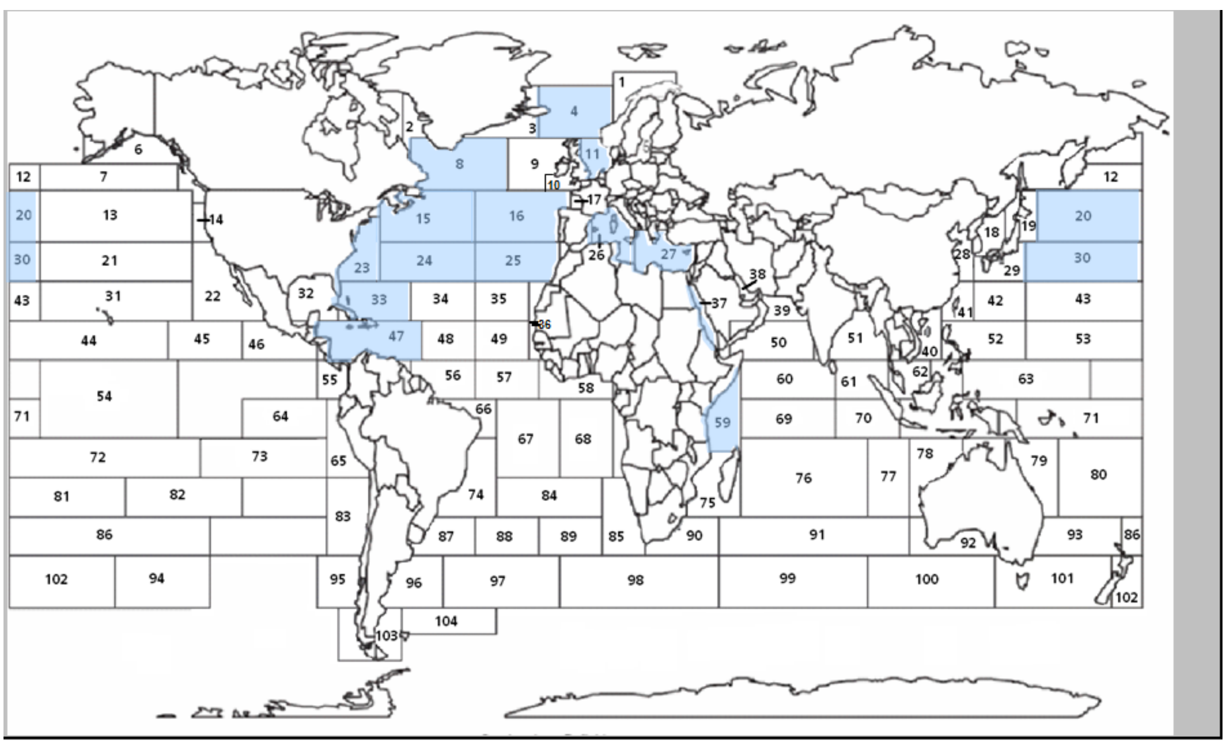

Figure 6-1: Map of Operating Marsden Zones

6.4.1 Still Water Bending Moment

Figure 6-2 shows the still water bending moment considered for the analysis. This moment distribution was determined from the mass distribution and draft provided for the Deep departure condition. This data is used for the mean stress correction when the mean stress is in compression.

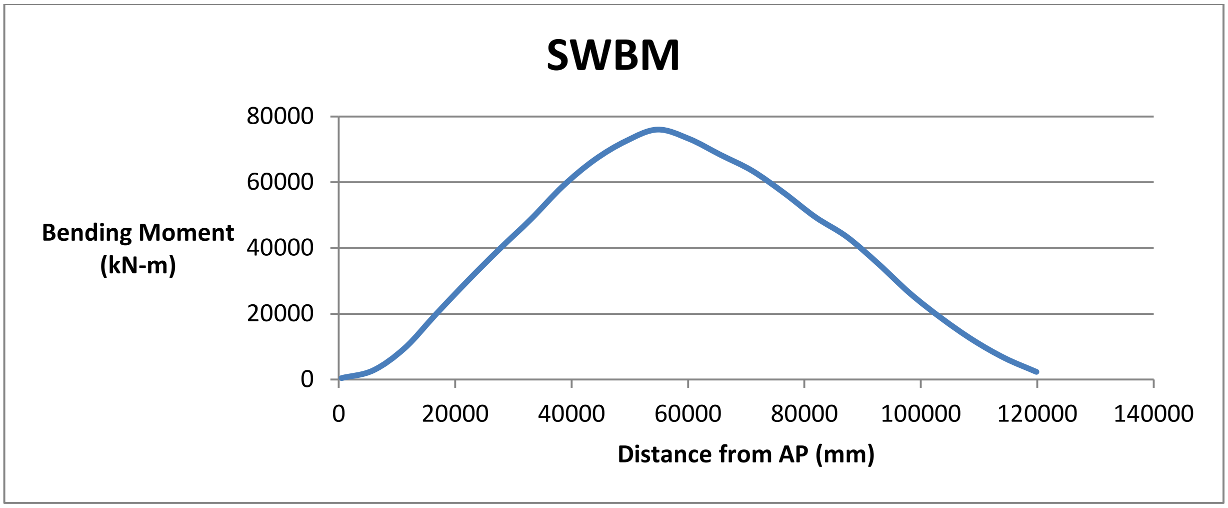

Figure 6-2: Still Water Bending Moment for Deep Departure Condition

6.4.2 S-N Curve

The FDA2 software default S-N curve was used for this analysis. Table 6-3 below provides the details defining the S-N curve.

Table 6-3: S/N Curve Used for Fatigue Assessment

Name	Sr (N/mm^2)	N (Sr)	m1	Log10 (K)	m2	SD Log10 (N)
SN1	75.625	1.00E+07	3	12.636	5	0.221839

Sr (N/mm^2)	Stress range where the gradient of the S-N Curve changes.
N (Sr)	Number of cycles to failure at Sr.
m1	Inverse slope of the S-N Curve for N <= N(Sr).
Log10 (K)	Intercept of the hot spot stress S-N Curve with the log N axis.
m2	Inverse slope of the S-N Curve for N > N(Sr).
SD Log10 (N)	Standard deviation.

6.5 FDA2 Analysis Results

Typically, the results of the FDA2 analysis are extracted directly from the software in the form of fatigue lives and/or damage. In this case, since the SCFs were derived from FE analysis, only the nominal stress ranges and number of cycles were taken from the software. A custom spreadsheet was developed, and used to derive the predicted fatigue lives. The spreadsheet was validated using unaltered baseline FDA2 predictions.

7.0 FE ANALYSIS

Local FE models were created for both the FAMR and AER locations. For each location, a model of both the existing structural arrangement and the proposed structural modification were developed. Below is a description of the models developed and analysis carried out.

7.1 FAMR Location – As-Built Connection

The connection between the centerline girder and the FAMR bulkhead was identified as an area of repetitive cracking. Figure 7-1 shows the structure and location of cracking for this position. Figure 7-2 shows the representative FE model developed for this connection.

Figure 7-1: Cracks at Centerline Girder to FAMR Casing Connection

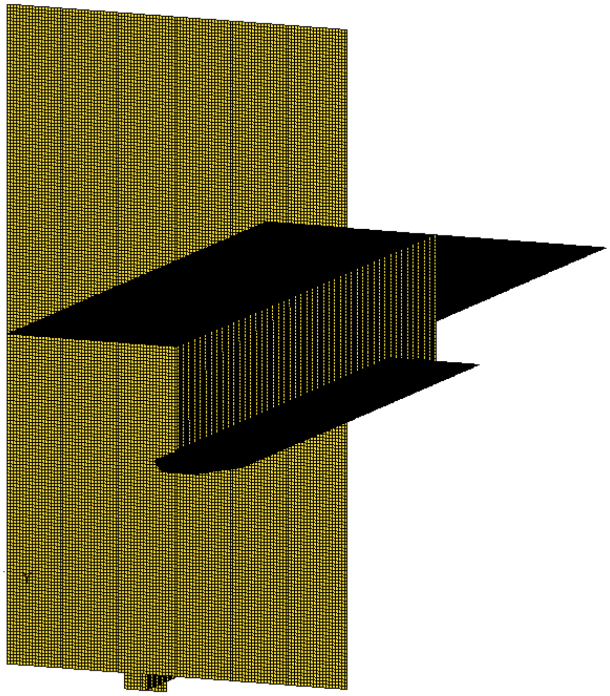

Figure 7-2: FE Model of FAMR Casing Connection

A unit load was applied in the ship longitudinal direction (+x). Figure 7-3 shows the load application.

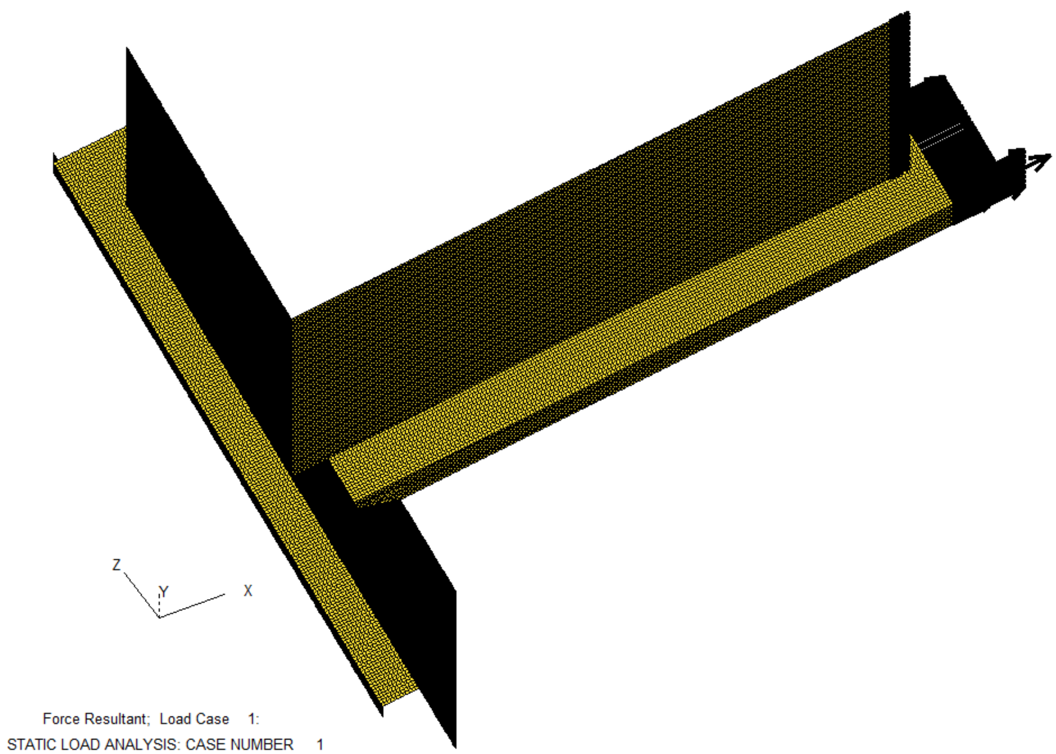

Figure 7-3: Applied Load for FAMR Connection

The boundary conditions were applied to the top and bottom of the FAMR bulkhead to produce a simply-supported connection. The bottom was pinned in the x-, y-, and z-directions, while the top was pinned in the x- and y-directions only. Figure 7-4 shows a plot of the boundary conditions.

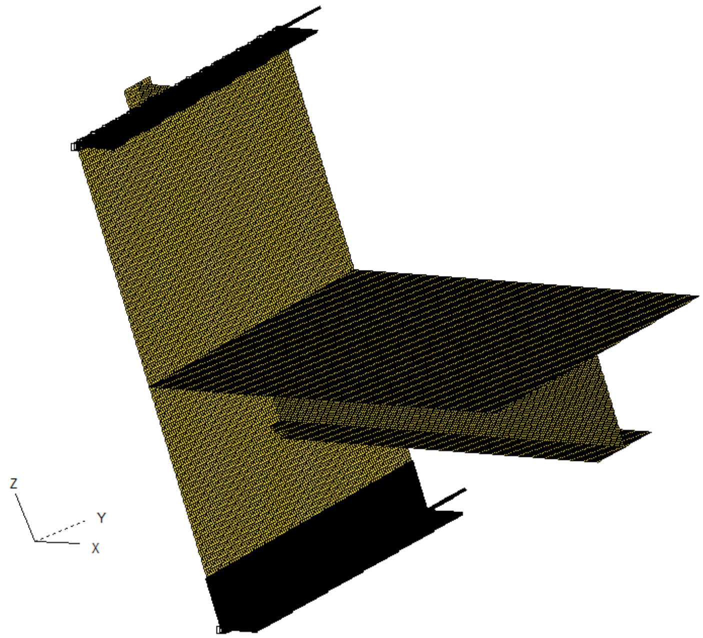

Figure 7-4: Boundary Conditions for FAMR Connection

The maximum stresses associated with the applied loading are plotted below. The maximum stresses are identified as first principal stress in the direction of loading. Figure 7-5, Figure 7-6, and Figure 7-7 show the resulting stress distributions.

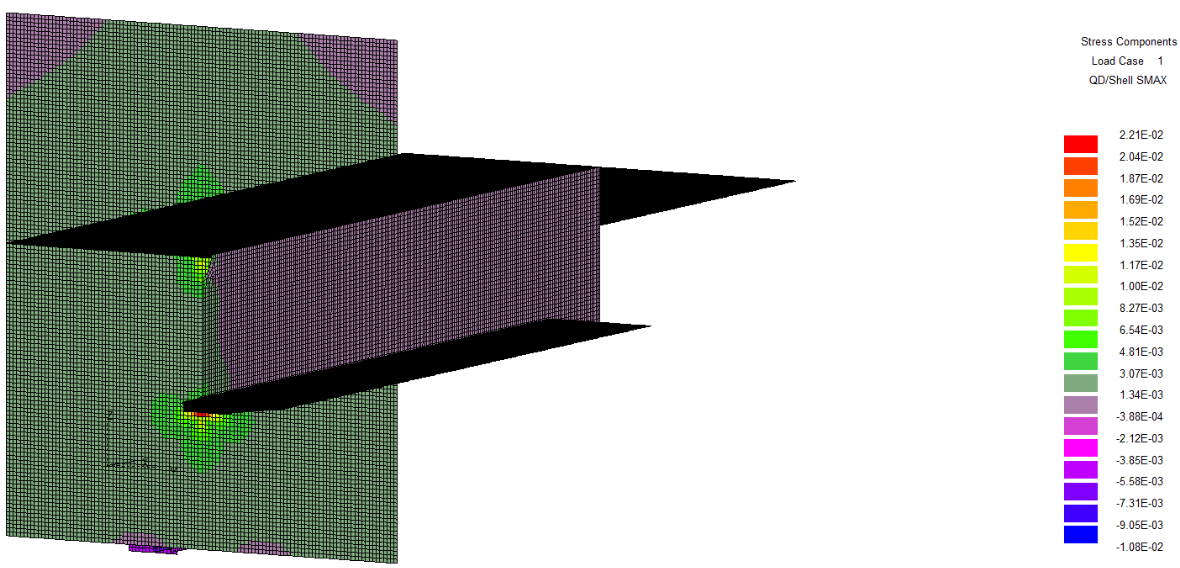

Figure 7-5: Maximum Stresses for FAMR Connection – View 1

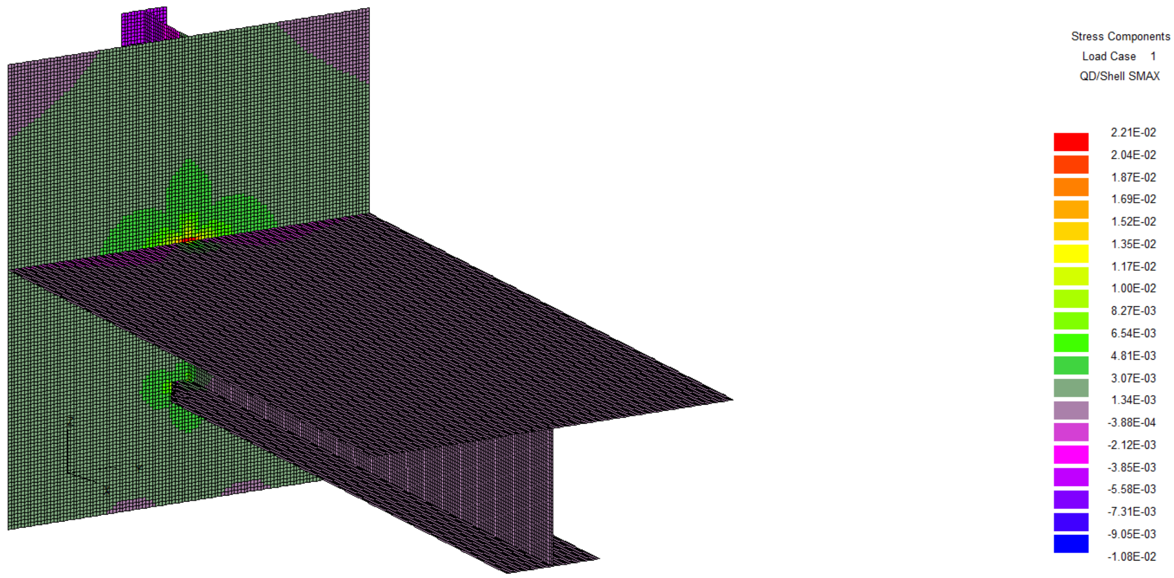

Figure 7-6: Maximum Stresses for FAMR Connection – View 2

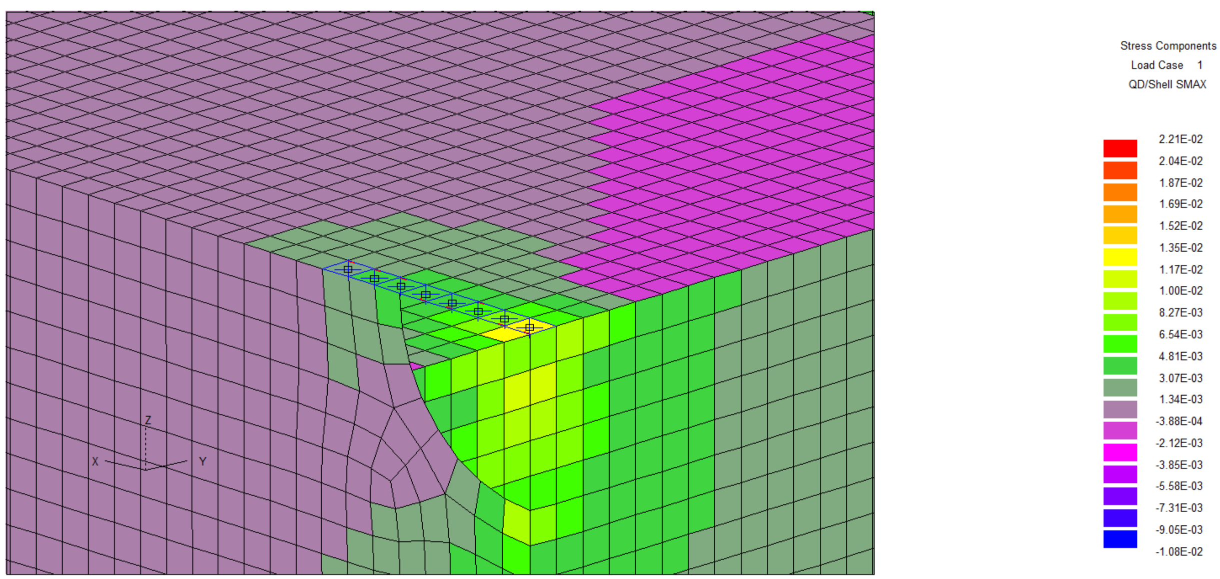

Figure 7-7: Local Stresses for FAMR Connection

7.2 FAMR LOCATION – RECOMMENDED MODIFICATION

The connection between the centerline girder and the FAMR bulkhead was also identified as an area of repetitive cracking. The proposed modification for this connection includes the installation of gussets between the vertical bulkhead stiffener and No. 1 deck. It was proposed that the rat-hole at this location be closed-off to reduce the stress concentration caused by the cruciform associated with the intersection of No.1 deck and the vertical bulkhead stiffener.

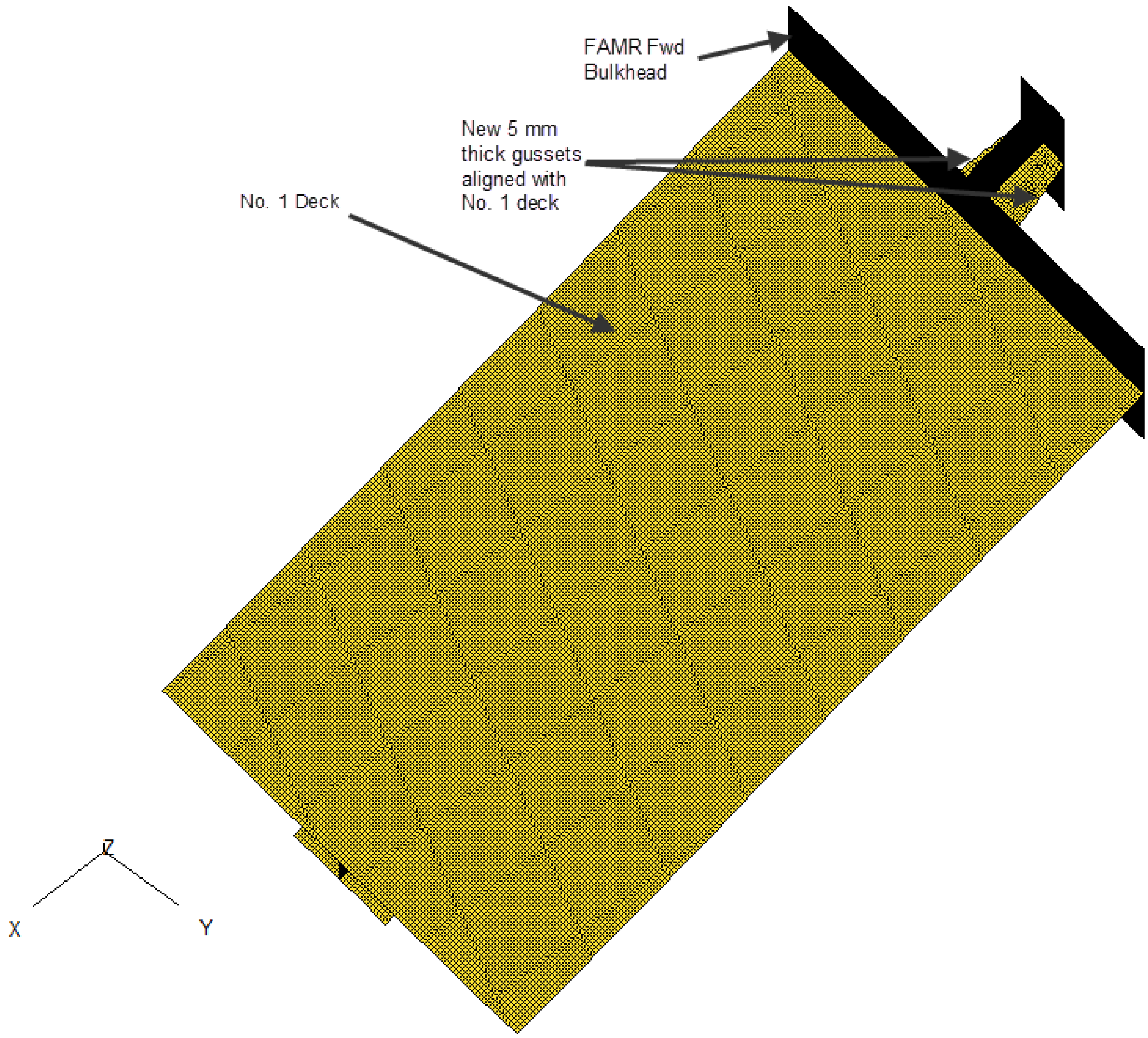

Figure 7-8: FAMR Connection – Proposed Modification

The approach adopted for application of loads and boundary conditions was identical to that adopted for the un-modified detail presented Section 7.1. The stresses associated with the proposed modification are plotted in Figure 7-9 and Figure 7-10 below. Figure 7-11 shows a comparison of the stresses with and without the structural modification.

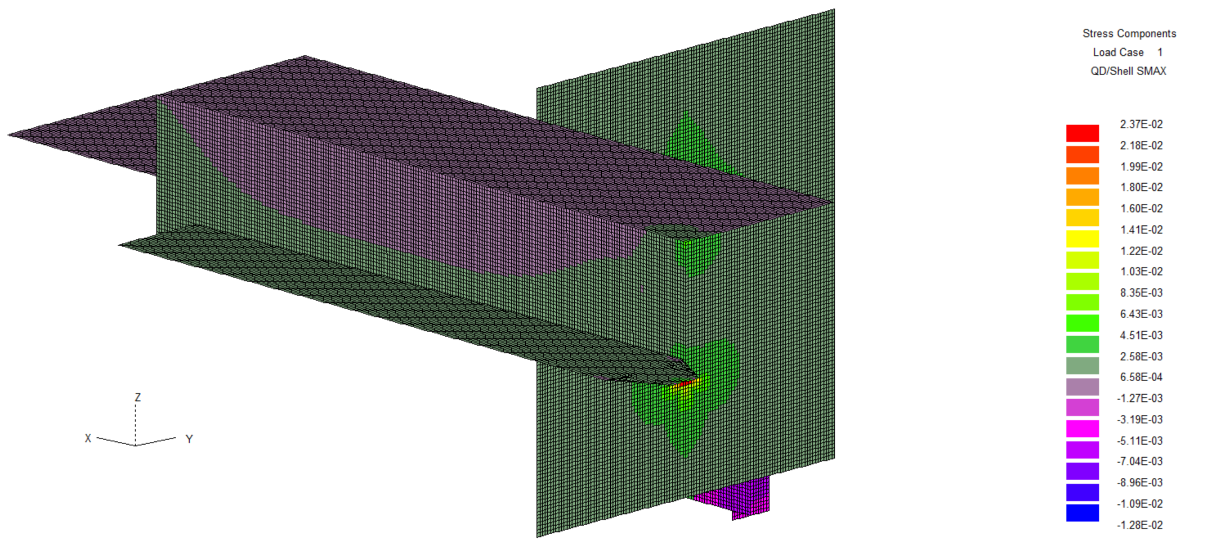

Figure 7-9: Stresses Near the Rat-hole for FAMR Connection

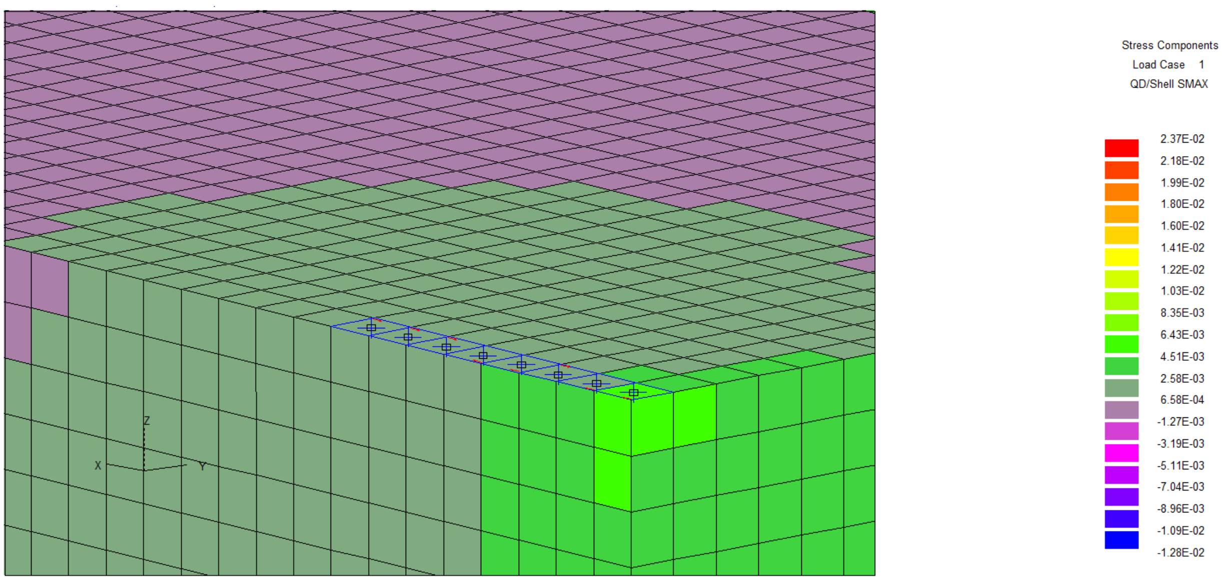

Figure 7-10: Stresses Near the Peak Stress for FAMR Connection

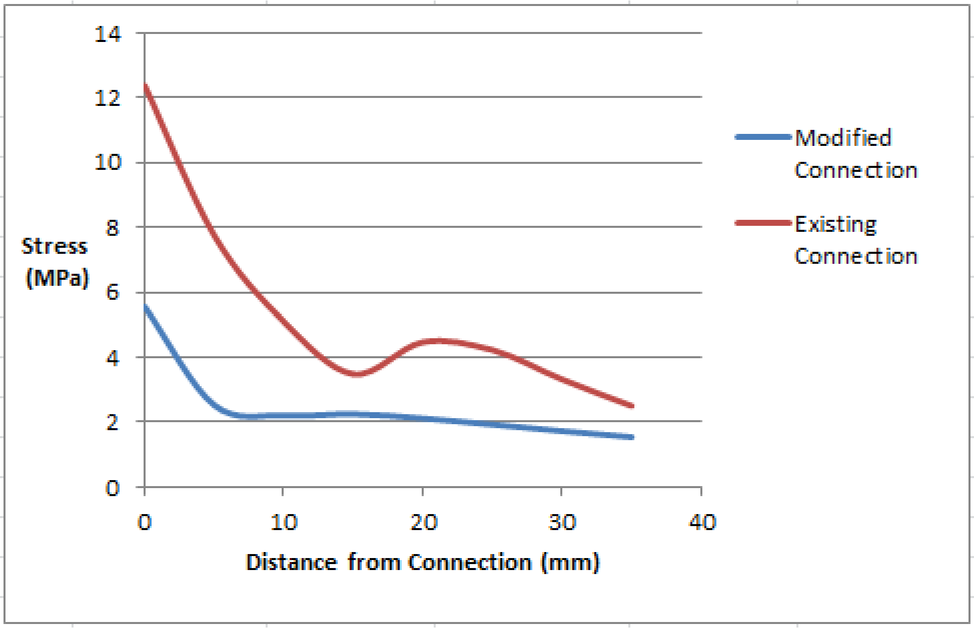

Figure 7-11: Stress vs. Distance from Connection - Before and After Modification

Table 7-1 shows the ratio of stress reduction between the original detail and the modified detail. Considering a number of elements within a 35mm radius of the peak stress location, an average stress reduction ratio SRR=2.124 was estimated. This ratio was then used to establish the reduced SCF associated with the modified detail. The SCF was then used to determine the corresponding increase in fatigue life. The stress contours indicate that a significant stress concentration also exists at the bottom flange of the centerline girder/bulkhead intersection. Although no cracking was observed in this location, a similar detail as that used for the modified upper connection could be considered for future repairs.

Table 7-1: Ratio of Stress Before and After Structural Modification (FAMR)

Location	Modified Detail		Original Detail		Ratio of Stress Reduction
	Distance (mm)	Stress (Mpa)	Distance (mm)	Stress (Mpa)	
Peak Stress	0	5.56	0	12.38	2.227
Element 2	5	2.531	5	7.756	3.064
Element 3	10	2.212	10	5.108	2.309
Element 4	15	2.256	15	3.49	1.547
Element 5	20	2.122	20	4.474	2.108
Element 6	25	1.931	25	4.233	2.192
Element 7	30	1.731	30	3.321	1.919
Element 8	35	1.545	35	2.507	1.623
				Average	2.124

Figure 7-12 shows a plot of the stress range vs. number of cycles for the FAMR connection detail, as determined by the FDA2 analysis. The SCF was not included in these stress range values. This stress range and cycle data were used in the custom spreadsheet to calculate the resulting fatigue life for both the existing and modified FAMR connections. The raw stress range and cycle data for this location is provided in Appendix A.

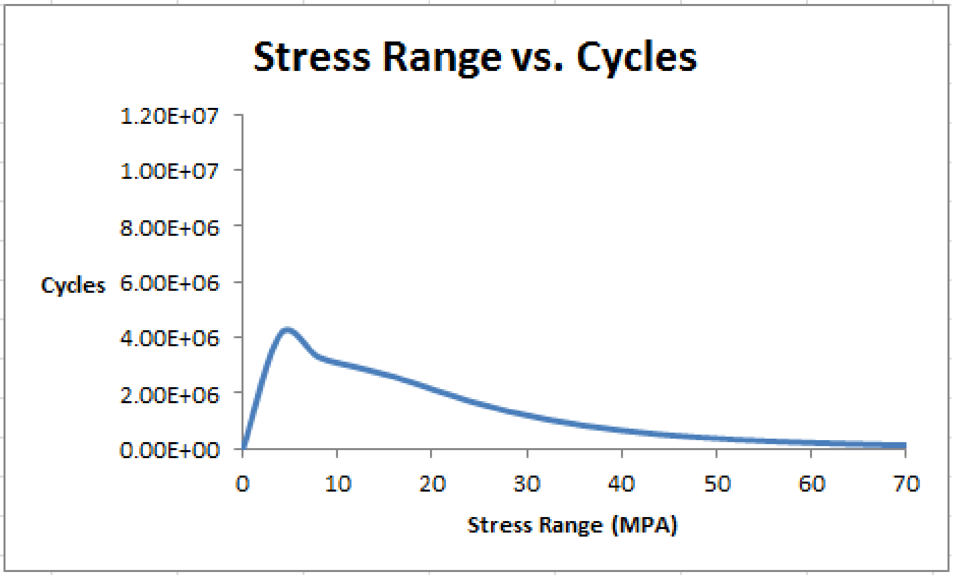

Figure 7-12: Plot of Stress Range vs. Cycles for FAMR Connection Detail

Table 7-2: Sample of Fatigue Life Calculation Spreadsheet

SCF	2.62					Total Damage	5.009			
Log A1	12.636		Log A2	16.393		Fatigue Life	4.991	years		
m1	3		m2	5						
Sr	75.625								Allowable	
Element_I	Surface	Angle	Stress_Range	PDF	CDP	Total_Cycle	Cycles at Range	Stress+SCF	Cycles	Damage
677	N/A	0	0	0.00E+00	1.00E+00	2.83E+07	0.00E+00	0	#DIV/0!	#DIV/0!
677	N/A	0	4	4.25E-02	8.82E-01	2.83E+07	4.13E+06	10.48	1.955E+11	2.11E-05
677	N/A	0	8	3.39E-02	7.28E-01	2.83E+07	3.30E+06	20.96	6.110E+09	0.00054
677	N/A	0	12	3.02E-02	6.01E-01	2.83E+07	2.94E+06	31.44	8.046E+08	0.003652
677	N/A	0	16	2.66E-02	4.87E-01	2.83E+07	2.59E+06	41.92	1.909E+08	0.01356
677	N/A	0	20	2.20E-02	3.89E-01	2.83E+07	2.15E+06	52.4	6.257E+07	0.034288
677	N/A	0	24	1.76E-02	3.10E-01	2.83E+07	1.72E+06	62.88	2.514E+07	0.068288
677	N/A	0	28	1.39E-02	2.48E-01	2.83E+07	1.36E+06	73.36	1.163E+07	0.116678
677	N/A	0	32	1.10E-02	1.98E-01	2.83E+07	1.07E+06	83.84	7.339E+06	0.145895
677	N/A	0	36	8.66E-03	1.59E-01	2.83E+07	8.46E+05	94.32	5.155E+06	0.164139
677	N/A	0	40	6.86E-03	1.28E-01	2.83E+07	6.71E+05	104.8	3.758E+06	0.178456
677	N/A	0	44	5.46E-03	1.04E-01	2.83E+07	5.33E+05	115.28	2.823E+06	0.188957
677	N/A	0	48	4.36E-03	8.40E-02	2.83E+07	4.26E+05	125.76	2.175E+06	0.195911
677	N/A	0	52	3.49E-03	6.84E-02	2.83E+07	3.41E+05	136.24	1.710E+06	0.199645
677	N/A	0	56	2.81E-03	5.58E-02	2.83E+07	2.75E+05	146.72	1.369E+06	0.200524
677	N/A	0	60	2.26E-03	4.57E-02	2.83E+07	2.22E+05	157.2	1.113E+06	0.198946
677	N/A	0	64	1.83E-03	3.76E-02	2.83E+07	1.79E+05	167.68	9.174E+05	0.195333
677	N/A	0	68	1.48E-03	3.10E-02	2.83E+07	1.45E+05	178.16	7.648E+05	0.190109
677	N/A	0	72	1.21E-03	2.56E-02	2.83E+07	1.18E+05	188.64	6.443E+05	0.183673
677	N/A	0	76	9.85E-04	2.13E-02	2.83E+07	9.66E+04	199.12	5.478E+05	0.176375
677	N/A	0	80	8.07E-04	1.77E-02	2.83E+07	7.91E+04	209.6	4.697E+05	0.168505
677	N/A	0	84	6.63E-04	1.48E-02	2.83E+07	6.50E+04	220.08	4.057E+05	0.160295
677	N/A	0	88	5.46E-04	1.24E-02	2.83E+07	5.36E+04	230.56	3.529E+05	0.151926
677	N/A	0	92	4.52E-04	1.04E-02	2.83E+07	4.43E+04	241.04	3.088E+05	0.143538
677	N/A	0	96	3.75E-04	8.72E-03	2.83E+07	3.68E+04	251.52	2.718E+05	0.135236
677	N/A	0	100	3.11E-04	7.35E-03	2.83E+07	3.06E+04	262	2.405E+05	0.127104
677	N/A	0	104	2.60E-04	6.21E-03	2.83E+07	2.55E+04	272.48	2.138E+05	0.119203

Based on the FE modelling/analysis of the original connection, a stress concentration factor SCF=2.62 was determined for the original connection. Considering the ratio of stress reduction between the original detail and the proposed modification, coupled with the SCF estimated for the original connection, a representative stress concentration factor for the modified detail was estimated as 2.620/2.124 = 1.230. This new SCF, used for the fatigue calculation, results in a fatigue life of 57 years; a significant improvement from the 5 years estimated for the original detail.

7.3 FER UPTAKE LOCATION – AS BUILT CONNECTION

The location of the FER uptake intersection with No. 1 deck (Figure 7-13) was also identified as an area of repetitive cracking. As indicated by the FMFCS Hull Surveyors, this cracking recurs approximately every 5 years. An analysis approach similar to that presented earlier for the FAMR location was adopted.

The representative FE model of the connection is shown in Figure 7-14. Applied loading shown in Figure 7-15 consists of unit concentrated loads on the forward end of the model, representing the axial load associated with hull vertical bending. Representative boundary conditions for the FER connection model consist of pinned nodes (x, y, and z) along the aft end of the local structure. This restrains the structure from movement in the longitudinal direction. Applied boundary conditions are shown in Figure 7-16.

Figure 7-17 and Figure 7-18 indicate the resulting stresses; used for the estimation of a representative SCF associated with the FER connection.

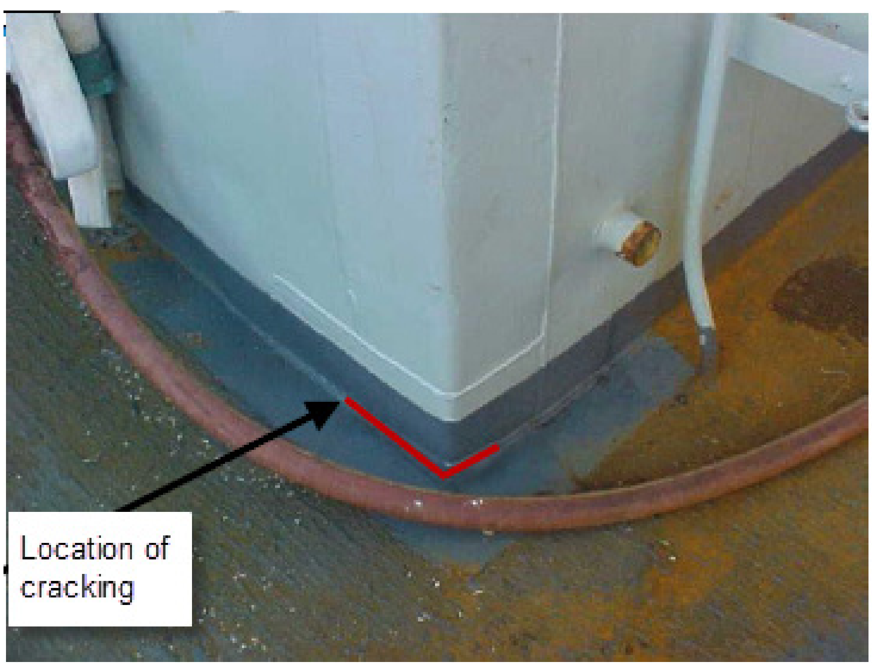

Figure 7-13: FER Uptake Location of Repetitive Cracking

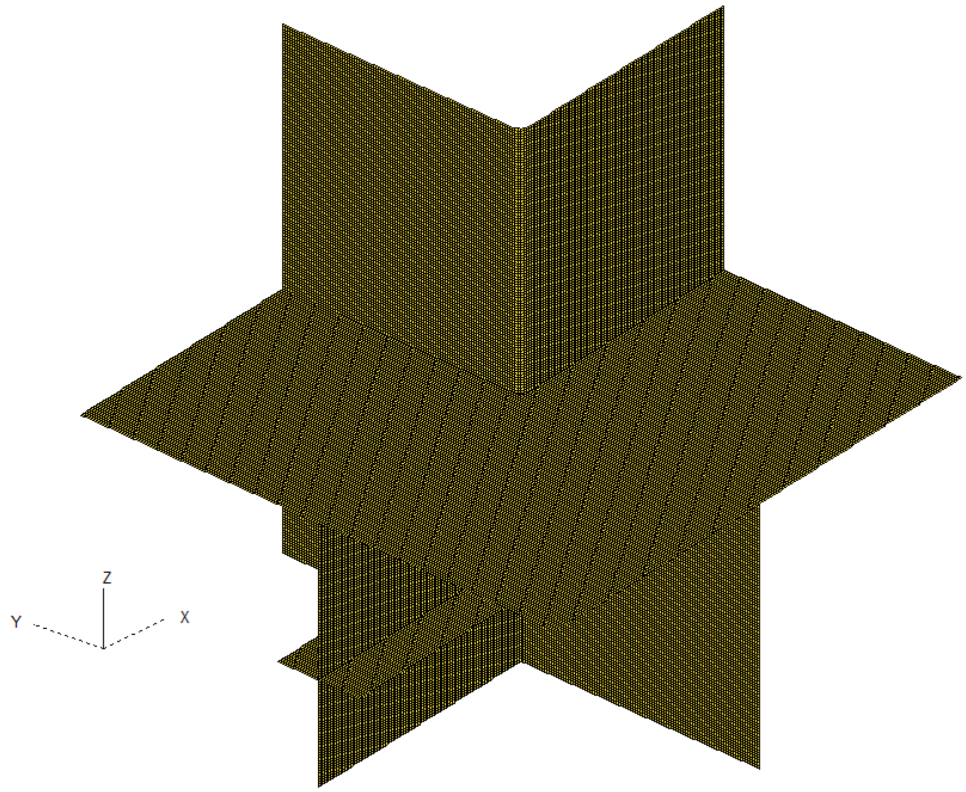

Figure 7-14: FE Model of the FER Uptake Connection to No. 1 Deck

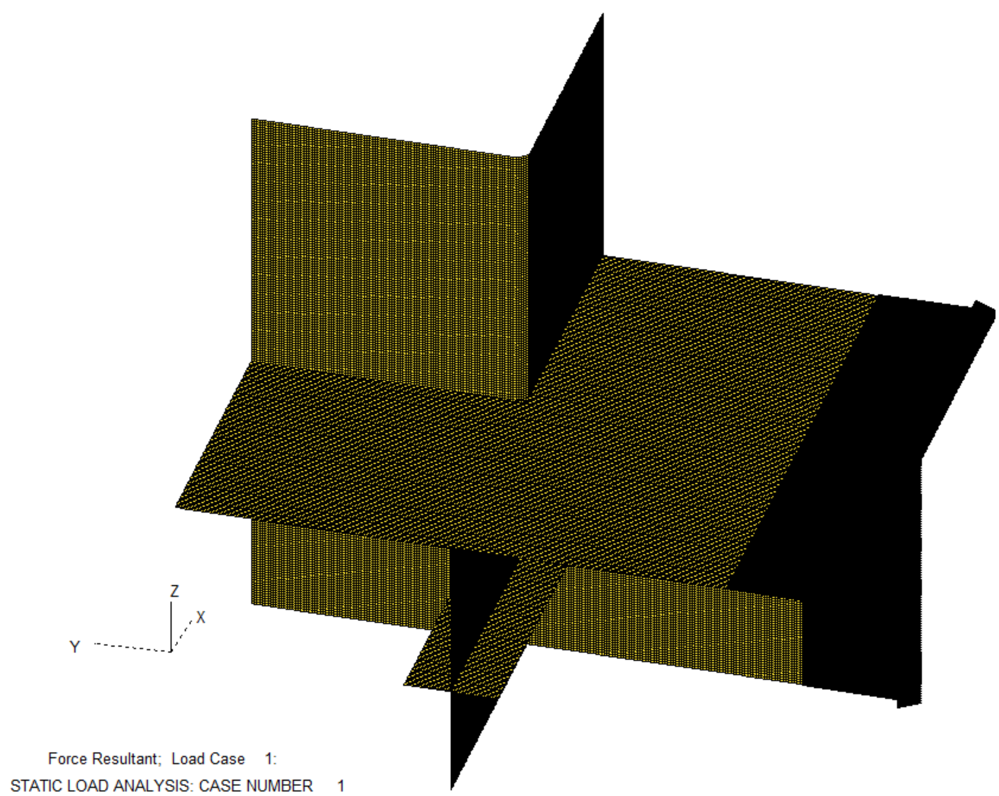

Figure 7-15: Forces Applied to the FER Uptake Model

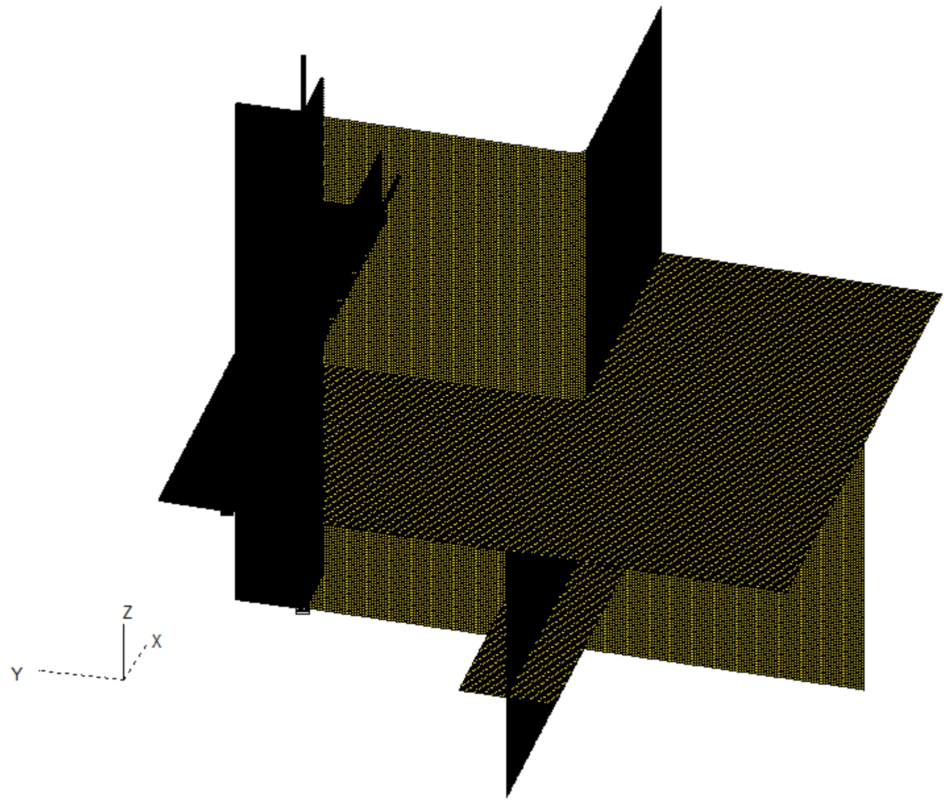

Figure 7-16: Boundary Conditions for the FER Uptake Model

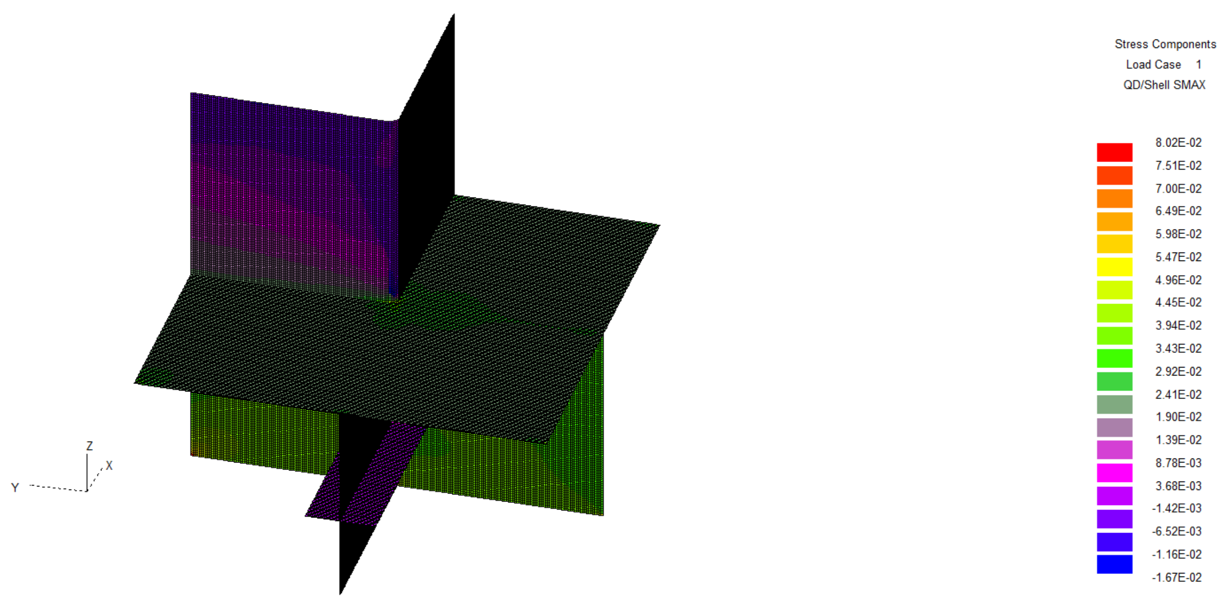

Figure 7-17: Stresses at FER Connection

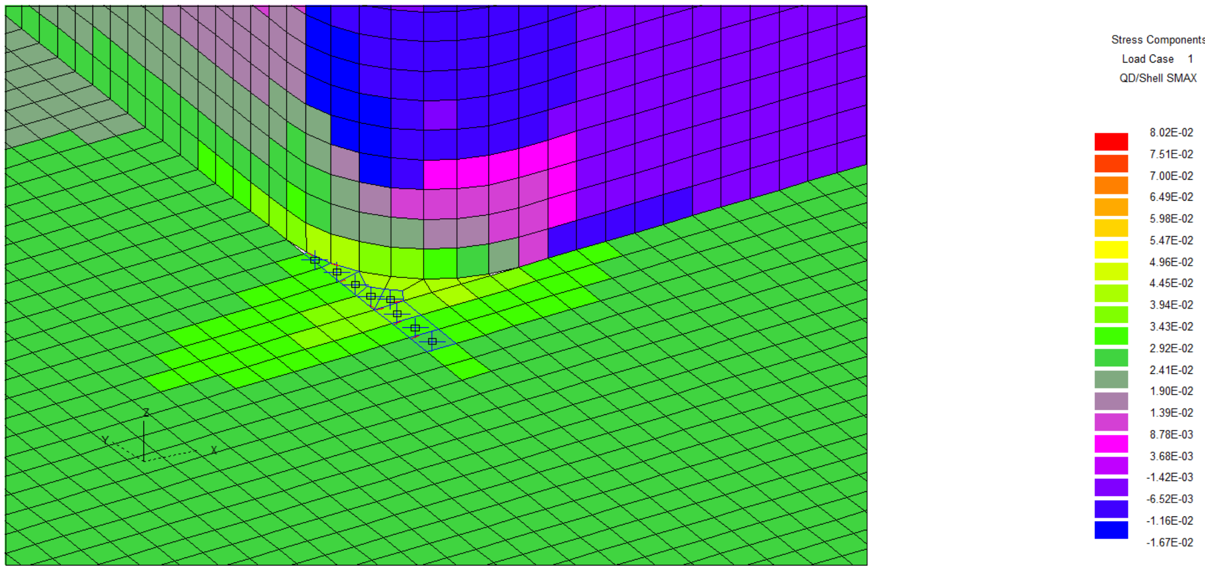

Figure 7-18: Local Stresses at Corner of FER Connection

7.4 FER LOCATION – RECOMMENDED MODIFICATION

The connection between the corner of the FER uptake and No. 1 deck creates a hard point that is susceptible to fatigue, as shown by the 5-year repair cycle currently observed in-service. It is proposed that a soft-toe bracket be added between the vertical corner of the FER uptake and No. 1 deck in the longitudinal direction. Figure 7-19 and Figure 7-20 illustrate the proposed modification. For the purposes of visual enhancement, the bracket has been manually highlighted in Figure 7-20.

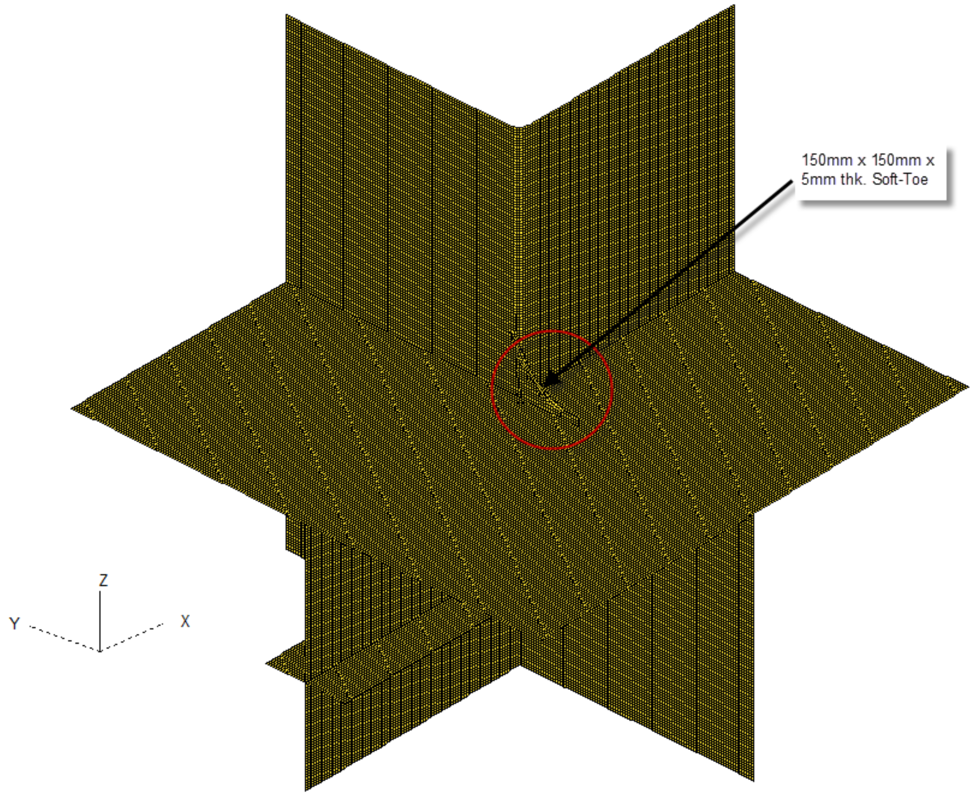

Figure 7-19: Proposed Repair for FER Uptake Connection

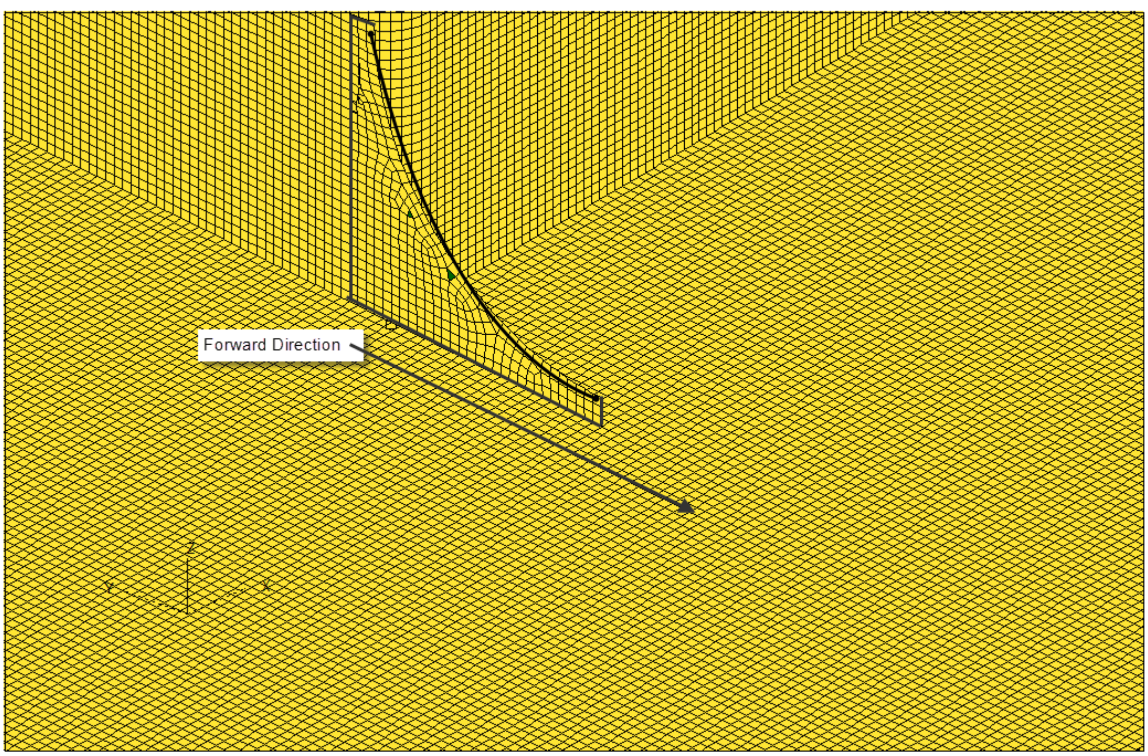

Figure 7-20: Zoomed View of Proposed Repair for FER Uptake Connection

The stresses associated with the proposed modification are plotted below. Load and boundary conditions are identical to the un-modified detail. Table 7-3 shows the ratio of stress reduction (SRR = 1.337) between the original detail and the modified detail. This ratio was used to establish the reduced SCF associated with the modified detail, which was then used to determine the increase in fatigue life.

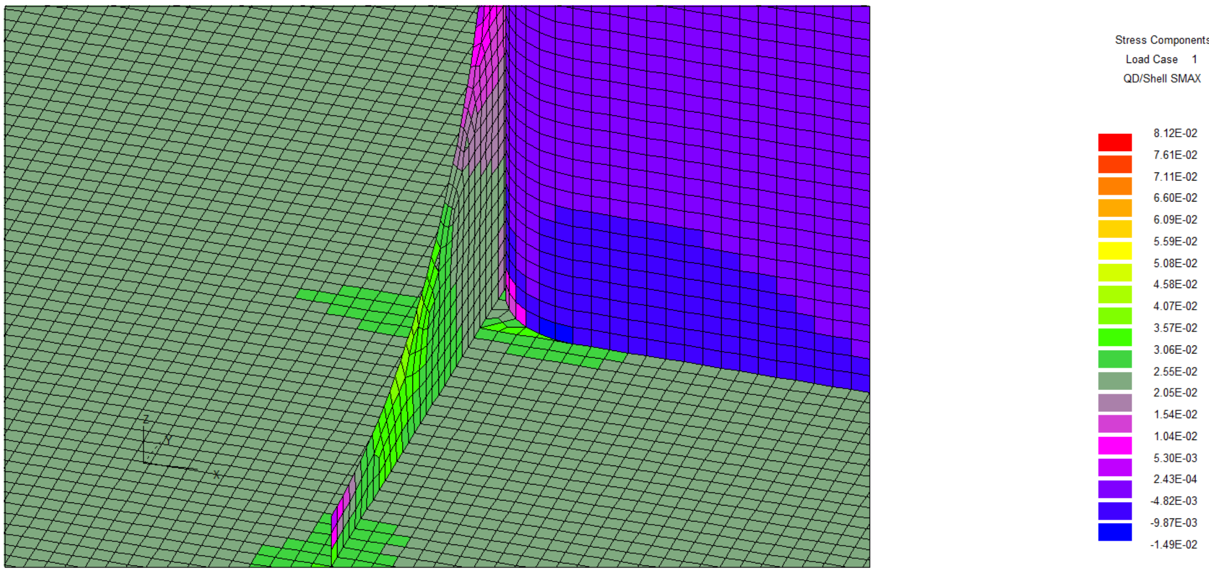

Figure 7-21: Zoomed View of Stresses at Modified FER Uptake Connection

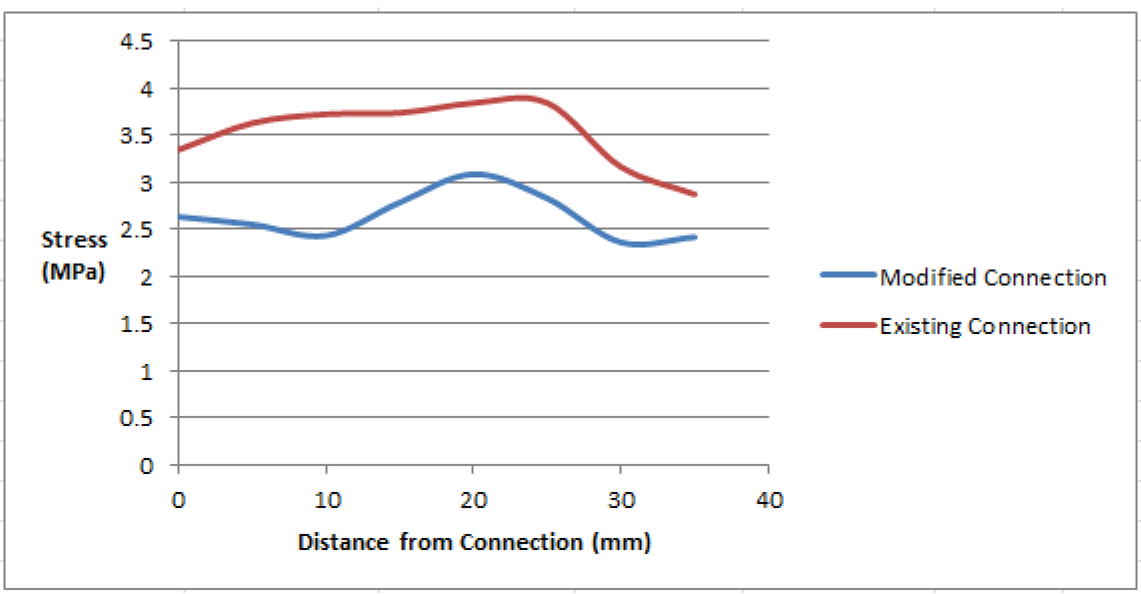

Figure 7-22: Stress vs. Distance from Connection - Before and After Modification

Figure 7-23 is a plot of the stress range vs. number of cycles for the FER connection detail, as determined by the FDA2 analysis. The SCF is not included in these stress range values. This stress range and cycle data is used in the custom spreadsheet to calculate the resulting fatigue life for both the existing and modified FER connections. The raw stress range and cycle data for this location is provided in Appendix B.

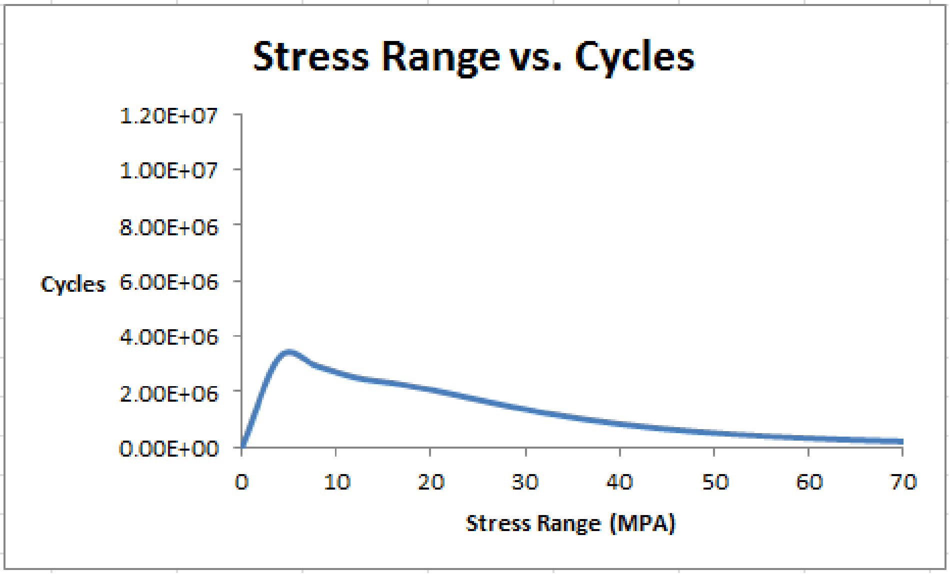

Figure 7-23: Plot of Stress Range vs. Cycles for FER Connection Detail

Table 7-3 shows the ratio of stress reduction between the original detail and the modified detail. Considering a number of elements within a 35mm radius of the peak stress location, an average stress reduction ratio SRR=1.337 was estimated. This stress reduction ratio was used to establish the reduced SCF associated with the modified detail, which was then used to determine the corresponding increase in fatigue life.

Table 7-3: Ratio of Stress Before and After Structural Modification (FER)

Location	Modified Detail		Original Detail		Ratio of Stress Reduction
	Distance (mm)	Stress (Mpa)	Distance (mm)	Stress (Mpa)	
Peak Stress	0	2.634	0	3.347	1.271
Next Element	5	2.552	5	3.631	1.423
3 elements	10	2.434	10	3.725	1.530
4 elements	15	2.787	15	3.739	1.342
5 elements	20	3.087	20	3.844	1.245
6 elements	25	2.83	25	3.845	1.359
7 elements	30	2.362	30	3.165	1.340
8 elements	35	2.417	35	2.873	1.189
				Average	1.337

Based on FE modelling/analysis of the original connection a stress concentration factor SCF= 2.14 was determined for the original connection. Considering the ratio of stress reduction between the original detail and the proposed modification, coupled with the SCF estimated for the original connection, a representative stress concentration for the modified detail was estimated as 2.140/1.337 = 1.600. The new SCF used for the fatigue calculation resulted in a fatigue life of 12.4 years. This is not as significant an improvement as that reported for the proposed modification at the FAMR location. A larger bracket should improve fatigue performance. However, other considerations would need to be taken into account, such as possible creation of a tripping hazard. This is something to be discussed with the ship's crew. A small (50mm x 50mm x 5mm) doubler pad should be placed on No. 1 deck at the toe of the bracket to reduce stress concentrations at the end of the bracket.

The existing connection detail at the FER location is quite complex; its susceptibility to fatigue may be difficult to correct. Since this location is clearly visible, it provides the opportunity to monitor the structual modification regularly for signs of fatigue. In cases such as this, where complex stress distributions exist, the introduction of such a bracket could move the hot spot to a new location. Monitoring is needed to confirm whether the modification does improve structural performance. Much more detailed analysis would be required to ensure improved structural performance at this location.

8.0 CONCLUSIONS AND RECOMMENDATIONS

In a previous task, Lloyds Register – Advanced Technology Group (LR ATG) was requested to produce a defect database for the HALIFAX Class to support DNPS-2 in enhancing the survey procedure for Canadian Forces Naval Ships. The database consists of a collection of survey data that could potentially be used to identify possible defect trends across the HALIFAX Class. From this task, a list of recurring structural defects was developed, along with potential repairs/modifications.

A detailed review of the defect database identified that it contained insufficient information to compile a reasonable list of prevalent structural defects.

As an alternative to establishing the list of prevalent defects from the database, it was decided that problematic structural defects could be identified based on the experience of the hull inspectors and Naval Architecture section of FMFCS, and this information could be used as the baseline for the task.

Two locations were chosen from the list of recurring defects, namely (i) the FAMR forward bulkhead intersection with the No. 1 deck centerline girder, and (ii) the FER uptake with No. 1 deck.

Through the use of FDA2 and FE modelling, analysis was performed in an attempt to provide guidance in developing modified details that improved the fatigue performance of these two locations.

For the FAMR location the observed fatigue life was between 5 and 10 years. The modified connection developed through this analysis resulted in a fatigue life of 57 years.

The FER connection detail is rather complex, and its fatigue performance may therefore be difficult to correct. The commonly-observed fatigue life in-service was approximately 5 years. The modified connection detail proposed here has an estimated fatigue life of 12.4 years. It was predicted that a larger bracket than that considered for the analysis should improve the resulting fatigue life. However, other considerations would need to be taken into account, such as potentially creating a tripping hazard. This is something to be discussed with the ship's crew. Based on the complexity of stresses in this location, regular monitoring is recommended to ensure that the addition of the bracket does not move the cracking problem to a new location. Much more detailed analysis would be necessary to ensure improved structural performance at this location.

A similar approach to this analysis method could be used on other areas of the vessel experiencing recurring defects. Further development of the existing FDA2 model of the HALIFAX Class ships could assist in providing valuable information for the development of future inspection plans. It is therefore recommended that consideration be given to expanding the current FDA2 model to capture a larger portion of the vessel.

This approach is intended to provide a simplified check on various structural connections. In order to achieve a more accurate assessment, a significant increase in the level of effort is required (e.g., FDA3 or similar methods). Such a detailed approach is considered outside of the scope of this task.

9.0 REFERENCES

[1] Meeting: Mike MacIsaac, Hugh Lancaster, Cindy Hawkins (FMFCS)/ATG, 6 Jul, 2017.
[2] Teleconference: Mathew Robbins/ATG, 17 Aug, 2017.
[3] Naval FDA2 Spreadsheet, version 1.1.171, 17 March 2016.
[4] ShipRight 2014.02, 14.2.0.3

APPENDIX A

RAW STRESS RANGE AND CYCLE DATA FOR FAMR LOCATION

FAMR Location					
Element_ID	Stress_Range	PDF	CDP	Total_Cycle	Cycles at Range
677	0	0.00E+00	1.00E+00	2.43E+07	0.00E+00
677	4	4.25E-02	8.82E-01	2.43E+07	4.13E+06
677	8	3.39E-02	7.28E-01	2.43E+07	3.30E+06
677	12	3.02E-02	6.01E-01	2.43E+07	2.94E+06
677	16	2.66E-02	4.87E-01	2.43E+07	2.59E+06
677	20	2.20E-02	3.89E-01	2.43E+07	2.15E+06
677	24	1.76E-02	3.10E-01	2.43E+07	1.72E+06
677	28	1.39E-02	2.48E-01	2.43E+07	1.36E+06
677	32	1.10E-02	1.98E-01	2.43E+07	1.07E+06
677	36	8.66E-03	1.59E-01	2.43E+07	8.46E+05
677	40	6.86E-03	1.28E-01	2.43E+07	6.71E+05
677	44	5.46E-03	1.04E-01	2.43E+07	5.33E+05
677	48	4.36E-03	8.40E-02	2.43E+07	4.26E+05
677	52	3.49E-03	6.84E-02	2.43E+07	3.41E+05
677	56	2.81E-03	5.58E-02	2.43E+07	2.75E+05
677	60	2.26E-03	4.57E-02	2.43E+07	2.22E+05
677	64	1.83E-03	3.76E-02	2.43E+07	1.79E+05
677	68	1.48E-03	3.10E-02	2.43E+07	1.45E+05
677	72	1.21E-03	2.56E-02	2.43E+07	1.18E+05
677	76	9.85E-04	2.13E-02	2.43E+07	9.66E+04
677	80	8.07E-04	1.77E-02	2.43E+07	7.91E+04
677	84	6.63E-04	1.48E-02	2.43E+07	6.50E+04
677	88	5.46E-04	1.24E-02	2.43E+07	5.36E+04
677	92	4.52E-04	1.04E-02	2.43E+07	4.43E+04
677	96	3.75E-04	8.72E-03	2.43E+07	3.68E+04
677	100	3.11E-04	7.35E-03	2.43E+07	3.06E+04
677	104	2.60E-04	6.21E-03	2.43E+07	2.55E+04
677	108	2.17E-04	5.26E-03	2.43E+07	2.13E+04
677	112	1.82E-04	4.47E-03	2.43E+07	1.78E+04
677	116	1.53E-04	3.80E-03	2.43E+07	1.50E+04
677	120	1.28E-04	3.24E-03	2.43E+07	1.26E+04
677	124	1.08E-04	2.77E-03	2.43E+07	1.06E+04
677	128	9.17E-05	2.37E-03	2.43E+07	9.00E+03
677	132	7.77E-05	2.03E-03	2.43E+07	7.63E+03
677	136	6.59E-05	1.74E-03	2.43E+07	6.48E+03
677	140	5.61E-05	1.50E-03	2.43E+07	5.51E+03
677	144	4.78E-05	1.29E-03	2.43E+07	4.70E+03
677	148	4.08E-05	1.11E-03	2.43E+07	4.01E+03
677	152	3.49E-05	9.63E-04	2.43E+07	3.43E+03

FAMR Location					
Element_ID	Stress_Range	PDF	CDP	Total_Cycle	Cycles at Range
677	156	2.99E-05	8.34E-04	2.43E+07	2.94E+03
677	160	2.57E-05	7.23E-04	2.43E+07	2.53E+03
677	164	2.21E-05	6.27E-04	2.43E+07	2.17E+03
677	168	1.90E-05	5.45E-04	2.43E+07	1.87E+03
677	172	1.64E-05	4.75E-04	2.43E+07	1.61E+03
677	176	1.42E-05	4.14E-04	2.43E+07	1.39E+03
677	180	1.23E-05	3.61E-04	2.43E+07	1.21E+03
677	184	1.06E-05	3.15E-04	2.43E+07	1.04E+03
677	188	9.22E-06	2.75E-04	2.43E+07	9.06E+02
677	192	8.00E-06	2.41E-04	2.43E+07	7.87E+02
677	196	6.96E-06	2.11E-04	2.43E+07	6.84E+02
677	200	6.06E-06	1.85E-04	2.43E+07	5.96E+02
677	204	5.28E-06	1.63E-04	2.43E+07	5.19E+02
677	208	4.61E-06	1.43E-04	2.43E+07	4.53E+02
677	212	4.03E-06	1.26E-04	2.43E+07	3.96E+02
677	216	3.52E-06	1.10E-04	2.43E+07	3.46E+02
677	220	3.08E-06	9.73E-05	2.43E+07	3.03E+02
677	224	2.70E-06	8.58E-05	2.43E+07	2.66E+02
677	228	2.37E-06	7.56E-05	2.43E+07	2.33E+02
677	232	2.08E-06	6.67E-05	2.43E+07	2.05E+02
677	236	1.83E-06	5.89E-05	2.43E+07	1.80E+02
677	240	1.61E-06	5.21E-05	2.43E+07	1.58E+02
677	244	1.41E-06	4.60E-05	2.43E+07	1.39E+02
677	248	1.25E-06	4.07E-05	2.43E+07	1.23E+02
677	252	1.10E-06	3.60E-05	2.43E+07	1.08E+02
677	256	9.69E-07	3.19E-05	2.43E+07	9.53E+01
677	260	8.55E-07	2.83E-05	2.43E+07	8.41E+01
677	264	7.55E-07	2.51E-05	2.43E+07	7.43E+01
677	268	6.67E-07	2.22E-05	2.43E+07	6.56E+01
677	272	5.90E-07	1.97E-05	2.43E+07	5.80E+01
677	276	5.22E-07	1.75E-05	2.43E+07	5.13E+01
677	280	4.62E-07	1.55E-05	2.43E+07	4.55E+01
677	284	4.09E-07	1.38E-05	2.43E+07	4.03E+01
677	288	3.63E-07	1.22E-05	2.43E+07	3.57E+01
677	292	3.22E-07	1.09E-05	2.43E+07	3.16E+01
677	296	2.85E-07	9.66E-06	2.43E+07	2.80E+01
677	300	2.53E-07	8.58E-06	2.43E+07	2.49E+01
677	304	2.25E-07	7.63E-06	2.43E+07	2.21E+01
677	308	1.99E-07	6.78E-06	2.43E+07	1.96E+01

FAMR Location					
Element_ID	Stress_Range	PDF	CDP	Total_Cycle	Cycles at Range
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677	316	1.57E-07	5.36E-06	2.43E+07	1.55E+01
677	320	1.40E-07	4.77E-06	2.43E+07	1.37E+01
677	324	1.24E-07	4.24E-06	2.43E+07	1.22E+01
677	328	1.10E-07	3.77E-06	2.43E+07	1.09E+01
677	332	9.82E-08	3.36E-06	2.43E+07	9.66E+00
677	336	8.73E-08	2.99E-06	2.43E+07	8.59E+00
677	340	7.77E-08	2.66E-06	2.43E+07	7.64E+00
677	344	6.91E-08	2.36E-06	2.43E+07	6.80E+00
677	348	6.15E-08	2.10E-06	2.43E+07	6.05E+00
677	352	5.47E-08	1.87E-06	2.43E+07	5.38E+00
677	356	4.87E-08	1.66E-06	2.43E+07	4.79E+00
677	360	4.33E-08	1.48E-06	2.43E+07	4.26E+00
677	364	3.86E-08	1.32E-06	2.43E+07	3.79E+00
677	368	3.43E-08	1.17E-06	2.43E+07	3.38E+00
677	372	3.06E-08	1.04E-06	2.43E+07	3.00E+00
677	376	2.72E-08	9.26E-07	2.43E+07	2.67E+00
677	380	2.42E-08	8.24E-07	2.43E+07	2.38E+00
677	384	2.15E-08	7.32E-07	2.43E+07	2.12E+00
677	388	1.92E-08	6.51E-07	2.43E+07	1.89E+00
677	392	1.71E-08	5.78E-07	2.43E+07	1.68E+00
677	396	1.52E-08	5.14E-07	2.43E+07	1.49E+00

APPENDIX B

RAW STRESS RANGE AND CYCLE DATA FOR FER LOCATION

FER Location					
Element_ID	Stress_Range	PDF	CDP	Total_Cycle	Cycles at Range
679	0	0.00E+00	1.00E+00	2.43E+07	0.00E+00
679	4	3.37E-02	9.13E-01	2.43E+07	3.27E+06
679	8	3.01E-02	7.82E-01	2.43E+07	2.92E+06
679	12	2.59E-02	6.72E-01	2.43E+07	2.52E+06
679	16	2.39E-02	5.72E-01	2.43E+07	2.32E+06
679	20	2.14E-02	4.81E-01	2.43E+07	2.08E+06
679	24	1.84E-02	4.02E-01	2.43E+07	1.79E+06
679	28	1.54E-02	3.34E-01	2.43E+07	1.50E+06
679	32	1.28E-02	2.78E-01	2.43E+07	1.25E+06
679	36	1.05E-02	2.31E-01	2.43E+07	1.03E+06
679	40	8.69E-03	1.93E-01	2.43E+07	8.48E+05
679	44	7.17E-03	1.61E-01	2.43E+07	7.00E+05
679	48	5.93E-03	1.35E-01	2.43E+07	5.79E+05
679	52	4.92E-03	1.13E-01	2.43E+07	4.80E+05
679	56	4.09E-03	9.53E-02	2.43E+07	4.00E+05
679	60	3.41E-03	8.04E-02	2.43E+07	3.33E+05
679	64	2.84E-03	6.79E-02	2.43E+07	2.78E+05
679	68	2.38E-03	5.75E-02	2.43E+07	2.33E+05
679	72	1.99E-03	4.88E-02	2.43E+07	1.95E+05
679	76	1.67E-03	4.15E-02	2.43E+07	1.64E+05
679	80	1.41E-03	3.53E-02	2.43E+07	1.38E+05
679	84	1.19E-03	3.02E-02	2.43E+07	1.16E+05
679	88	1.00E-03	2.58E-02	2.43E+07	9.81E+04
679	92	8.47E-04	2.21E-02	2.43E+07	8.30E+04
679	96	7.18E-04	1.90E-02	2.43E+07	7.04E+04
679	100	6.10E-04	1.63E-02	2.43E+07	5.98E+04
679	104	5.20E-04	1.41E-02	2.43E+07	5.09E+04
679	108	4.43E-04	1.22E-02	2.43E+07	4.35E+04
679	112	3.79E-04	1.05E-02	2.43E+07	3.72E+04
679	116	3.25E-04	9.12E-03	2.43E+07	3.18E+04
679	120	2.79E-04	7.91E-03	2.43E+07	2.73E+04
679	124	2.39E-04	6.88E-03	2.43E+07	2.35E+04
679	128	2.06E-04	5.99E-03	2.43E+07	2.02E+04
679	132	1.78E-04	5.22E-03	2.43E+07	1.75E+04
679	136	1.54E-04	4.56E-03	2.43E+07	1.51E+04
679	140	1.33E-04	3.99E-03	2.43E+07	1.31E+04
679	144	1.15E-04	3.49E-03	2.43E+07	1.13E+04
679	148	1.00E-04	3.06E-03	2.43E+07	9.83E+03
679	152	8.70E-05	2.69E-03	2.43E+07	8.55E+03

FER Location					
Element_ID	Stress_Range	PDF	CDP	Total_Cycle	Cycles at Range
679	156	7.58E-05	2.36E-03	2.43E+07	7.44E+03
679	160	6.61E-05	2.08E-03	2.43E+07	6.49E+03
679	164	5.77E-05	1.83E-03	2.43E+07	5.67E+03
679	168	5.04E-05	1.62E-03	2.43E+07	4.95E+03
679	172	4.41E-05	1.43E-03	2.43E+07	4.34E+03
679	176	3.87E-05	1.26E-03	2.43E+07	3.80E+03
679	180	3.40E-05	1.12E-03	2.43E+07	3.34E+03
679	184	2.98E-05	9.91E-04	2.43E+07	2.93E+03
679	188	2.63E-05	8.79E-04	2.43E+07	2.58E+03
679	192	2.31E-05	7.81E-04	2.43E+07	2.27E+03
679	196	2.04E-05	6.94E-04	2.43E+07	2.00E+03
679	200	1.80E-05	6.17E-04	2.43E+07	1.77E+03
679	204	1.59E-05	5.49E-04	2.43E+07	1.56E+03
679	208	1.41E-05	4.90E-04	2.43E+07	1.38E+03
679	212	1.25E-05	4.37E-04	2.43E+07	1.22E+03
679	216	1.10E-05	3.90E-04	2.43E+07	1.09E+03
679	220	9.80E-06	3.48E-04	2.43E+07	9.63E+02
679	224	8.70E-06	3.11E-04	2.43E+07	8.55E+02
679	228	7.73E-06	2.78E-04	2.43E+07	7.60E+02
679	232	6.88E-06	2.49E-04	2.43E+07	6.76E+02
679	236	6.12E-06	2.23E-04	2.43E+07	6.02E+02
679	240	5.46E-06	2.00E-04	2.43E+07	5.37E+02
679	244	4.87E-06	1.79E-04	2.43E+07	4.79E+02
679	248	4.34E-06	1.61E-04	2.43E+07	4.27E+02
679	252	3.88E-06	1.45E-04	2.43E+07	3.82E+02
679	256	3.47E-06	1.30E-04	2.43E+07	3.41E+02
679	260	3.10E-06	1.17E-04	2.43E+07	3.05E+02
679	264	2.78E-06	1.05E-04	2.43E+07	2.73E+02
679	268	2.49E-06	9.45E-05	2.43E+07	2.45E+02
679	272	2.23E-06	8.51E-05	2.43E+07	2.19E+02
679	276	2.00E-06	7.66E-05	2.43E+07	1.97E+02
679	280	1.79E-06	6.90E-05	2.43E+07	1.76E+02
679	284	1.61E-06	6.22E-05	2.43E+07	1.58E+02
679	288	1.45E-06	5.61E-05	2.43E+07	1.42E+02
679	292	1.30E-06	5.06E-05	2.43E+07	1.28E+02
679	296	1.17E-06	4.57E-05	2.43E+07	1.15E+02
679	300	1.05E-06	4.13E-05	2.43E+07	1.04E+02
679	304	9.47E-07	3.73E-05	2.43E+07	9.32E+01
679	308	8.53E-07	3.37E-05	2.43E+07	8.40E+01

FER Location					
Element_ID	Stress_Range	PDF	CDP	Total_Cycle	Cycles at Range
679	312	7.69E-07	3.04E-05	2.43E+07	7.57E+01
679	316	6.93E-07	2.75E-05	2.43E+07	6.82E+01
679	320	6.25E-07	2.49E-05	2.43E+07	6.15E+01
679	324	5.64E-07	2.25E-05	2.43E+07	5.55E+01
679	328	5.09E-07	2.04E-05	2.43E+07	5.01E+01
679	332	4.60E-07	1.84E-05	2.43E+07	4.52E+01
679	336	4.15E-07	1.67E-05	2.43E+07	4.09E+01
679	340	3.75E-07	1.51E-05	2.43E+07	3.69E+01
679	344	3.39E-07	1.37E-05	2.43E+07	3.34E+01
679	348	3.06E-07	1.24E-05	2.43E+07	3.02E+01
679	352	2.77E-07	1.12E-05	2.43E+07	2.73E+01
679	356	2.51E-07	1.02E-05	2.43E+07	2.47E+01
679	360	2.27E-07	9.21E-06	2.43E+07	2.23E+01
679	364	2.05E-07	8.35E-06	2.43E+07	2.02E+01
679	368	1.86E-07	7.56E-06	2.43E+07	1.83E+01
679	372	1.68E-07	6.86E-06	2.43E+07	1.66E+01
679	376	1.52E-07	6.21E-06	2.43E+07	1.50E+01
679	380	1.38E-07	5.63E-06	2.43E+07	1.36E+01
679	384	1.25E-07	5.11E-06	2.43E+07	1.23E+01
679	388	1.13E-07	4.63E-06	2.43E+07	1.12E+01
679	392	1.03E-07	4.20E-06	2.43E+07	1.01E+01
679	396	9.31E-08	3.81E-06	2.43E+07	9.17E+00

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