Special Considerations for Structural design and Fabrication for tankers or similar vessels with Large Size (150m or more in length) in polar waters

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Abstract

Over the past decades the ice-infested sea route in has been steadily developed. Arctic shipping route, or Northern Sea Route, is becoming more and more a regular sea routing for commercial shipping. The trend of bigger size has never been stopped in merchant ships. The vessels in the Arctic shipping route are also following such trend. This paper will provide an overview of challenges on the vessels with larger size sailing in the polar waters and suggestion for the solutions based on the experience of the building two Arctic Module Carriers by Guangzhou Shipyard International, the writer's employer.

1 Introduction

Over the past decades the ice-infested sea route has been steadily developed. Arctic shipping route, or Northern Sea Route, is becoming more and more a regular sea routing for commercial shipping. The trend of bigger size has never been stopped in merchant ships. The vessels in the Arctic shipping route are also following such trend. Ships with length over 200m or beam over 40m are intended for navigation in the Arctic shipping route.

However, as the size is increased, the structural responses to the load cases will be different to those for vessels with smaller size. Main aspects are as follows:

1.1 For vessels up to an approximate displacement of 30 000 tons, Ice breaking bow load is in proportion to its displacement to the power of 0.64;

1.2 Longitudinal strength becomes a bigger factor in the consideration of structure design;

1.3 The loads for the Appendages, especially, for the rudder and its components are increased significantly as the dimensions are increased.

1.4 More critical structural should be verified in direct calculation as the dimensions increased.

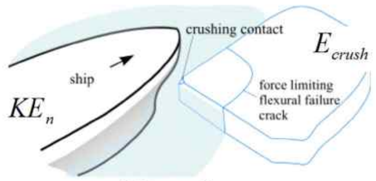
1.5 Fabrication of the structures will be more difficult when the grade, scantling, amount of steel works increased while the dimension of the ship increased.

2 For vessels up to an approximate displacement of 30 000 tons, Ice breaking bow load is in proportion to its displacement to the power of 0.64

2.1 Design ice load on bow for vessels with large size

For ships of all Polar Classes, a glancing impact on the bow is the design scenario for determining the scantlings required to resist ice loads. The dimensioning force is found from the minimum of the crushing limiting strength of the ice and the flexural limiting strength of the ice.

When colliding with the ice edge, the ship penetrates the ice. Force is found by equating the kinetic energy with energy used to crush the ice.

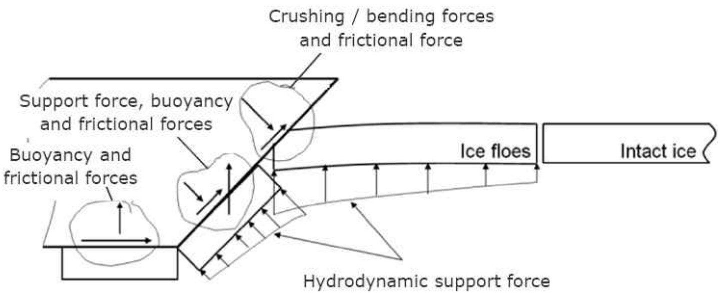


$$KE_n = E_{crush}$$

$$F_n = fa \cdot Po^{0.36} \cdot \Delta_{ship}^{0.64} \cdot V_{ship}^{1.28}$$

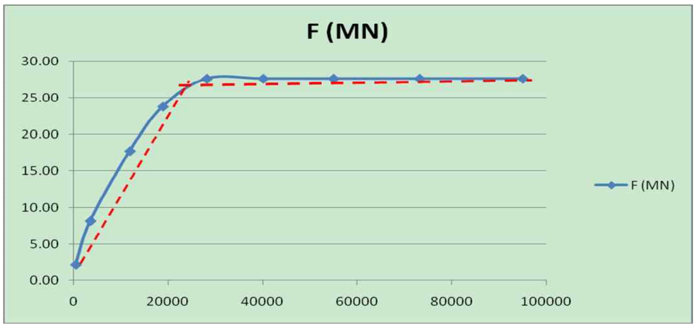
If flexural failure, the ice force will be limited. The vertical down force representing flexural failure of the ice is limited to

$$F_{n,\lim} = \frac{1.2 \cdot \sigma_f \cdot h_{ice}^2}{\sin(\beta')}$$



In order to make a comparison of ice load between a small vessel and a vessel with large size, calculations for different size of vessels with same hull form and ice classes (PC3) have been made and summarized as follows:

Displacement (t)	440	3520	11880	18865	28160	40095	55000	73205	95040
Lwl (m)	39.76	79.52	119.28	139.16	159.04	178.92	198.8	218.68	238.56
Failure mode	Crushing	Crushing	Crushing	Flexural bend	Flexural bend	Flexural bend	Flexural bend	Flexural bend	Flexural bend
F (MN)	2.15	8.14	17.72	23.83	27.67	27.67	27.67	27.67	27.67
Q (MN/m)	1.24	2.80	4.51	5.40	5.91	5.91	5.91	5.91	5.91
P (MPa)	5.02	6.72	7.92	8.43	8.69	8.70	8.71	8.71	8.71



For vessel with displacement less than 20,000 tons, the ice load is dominated by crushing strength limit and in proportion to displacement to power 0.64.
For vessel with displacement above 20,000 tons, the ice load is dominated by flexural limiting strength of the ice, somehow independent of the displacement.

Compared with ice breakers or scientific research vessels, whose average displacement are less than 15000 tons, the ice load for transportation vessels with same ice class will be bigger, as transportation vessels are normally have bigger displacement, especially the future transport vessels for polar waters which will be diverse and some of them will be even bigger.

It will be more critical for chemical tankers with displacement about 20000~30000tons due to their sizes are medium however their ice load reach the maximum of the ice load as for the bigger vessels.

2.2 Design of the bow structures for vessels with big size

When vessels collide with a block of ice the ice failure mode will change from crushing failure to ice flexural failure as the size of vessel increases. Meanwhile bigger normal frame angle will result in a smaller shape coefficient for the flexural bend mode and hence calculated ice force can be reduced. In order to take advantage of this behavior, the bow shape of big size vessels will be designed as a wedge raked stem which is helping a bigger normal frame angle.

The ice framing could be transversely arranged or longitudinally arranged. The bottom structure of mid part of the vessel is normally longitudinally framed. The structural continuity can be kept if the wedge part of the bow is also longitudinally framed. Transverse framing will require less plate thickness, however, the angle between the chord of the waterline and the line of the first level framing (Ω) is difficult to be kept 70 degree or above in all the bow area. Therefore, there is not a pure transverse frame system in the calculation. In the case of obliquely-framed plating ($70° > \Omega > 20°$), the scantling of the plate will be decided by linear interpolation between transverse framing and longitudinal framing. In practice, the thickness of the plate will be determined by longitudinal framing so as to maintain a uniform thickness in most of the bow area.

Normally, higher tensile material of yielding stress of 355 Mpa will be used for the bow shell and spacing between the ice frames are kept not less than 400mm for the necessary condition for the workmanship. Following table shows examples of required thickness on bow shell for vessel of different displacement; all cases are with same ship shape and PC-3 ice class.

Displacement (t)	440	3520	11880	18865	28160	40095	55000	73205	95040
t_long	32.3	36.8	39.7	40.8	41.4	41.4	41.4	41.4	41.4
t-trans	20.8	27.9	32.5	34.3	35.2	35.2	35.2	35.2	35.2

The table above suggests that the thickness of the bow shell is much thicker than normal vessels and as these plates are curved the fabrication process is more strenuous.

Meanwhile the stem shall be at least 20% thicker than the bow shell. The stem plate will be of thickness more than 50mm for large vessels. This is one outstanding characteristic for vessel of a large size in polar waters.

3 Special considerations on longitudinal strength aspects and direct calculation

Generally, Compared to the Design Vertical Ice Bending Moment derived from head on ramming scenario, wave bending moment and still water bending moment will govern the longitudinal strength requirements. Therefore, Vertical Ice Bending Moment is a smaller consideration in the global structural design. However, the Design Vertical Ice Shear Force will be greater than the wave vertical shear force and the still water shear force, especially on the fore part of the ship.

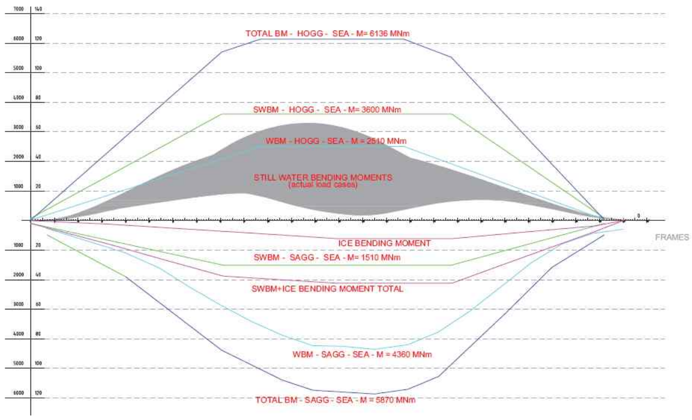
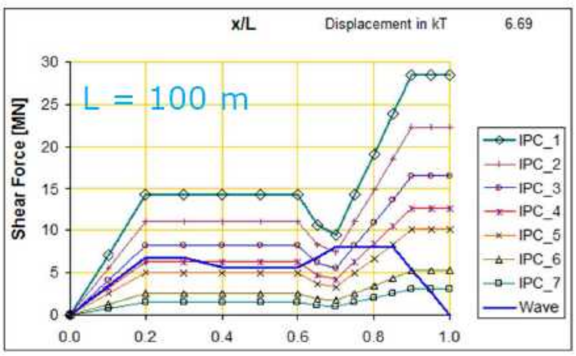
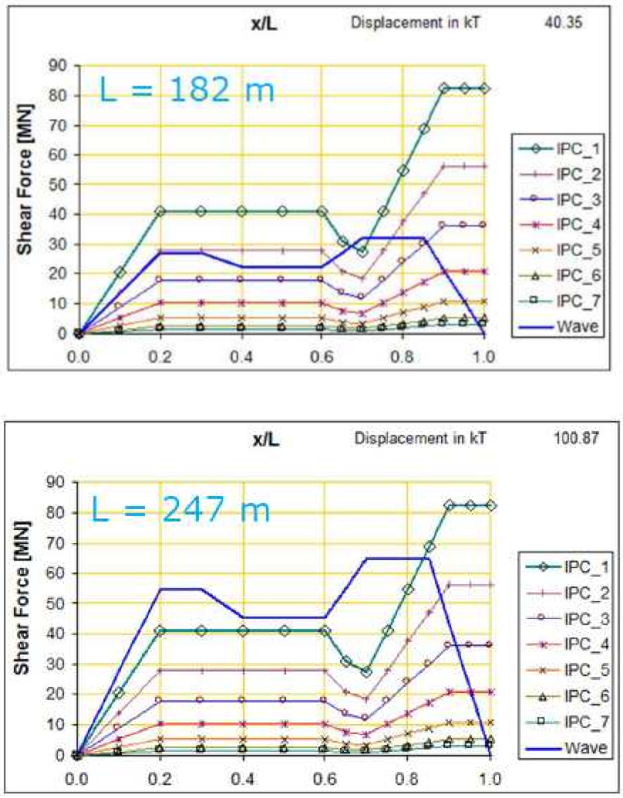


Fig.3.1 Bending moment envelop





Figs.3.2 Shear forces

As Design Vertical Ice Shear Force is much greater in bow area, the structure against such load case has to be assessed. The complex structures in bow area for larger vessel make a direct analysis necessary. The global strength analysis will check the hull girder strength in typical loading conditions. The model will constitute the whole vessel (except Deck House). The loading conditions will be discussed and agreed with Class Society. The loading conditions normally include the full load condition, ballast condition, docking condition and conditions when the vessel is loaded or discharged (aft load cases). The hull girder strength will be checked in yielding and buckling and the class rule requirements will be met along the hull girder.

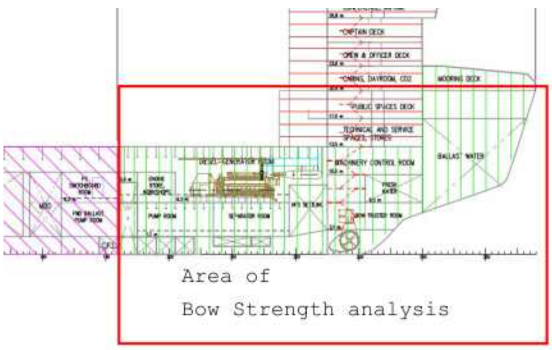


Fig.6.3.3 Area of Bow strength analysis

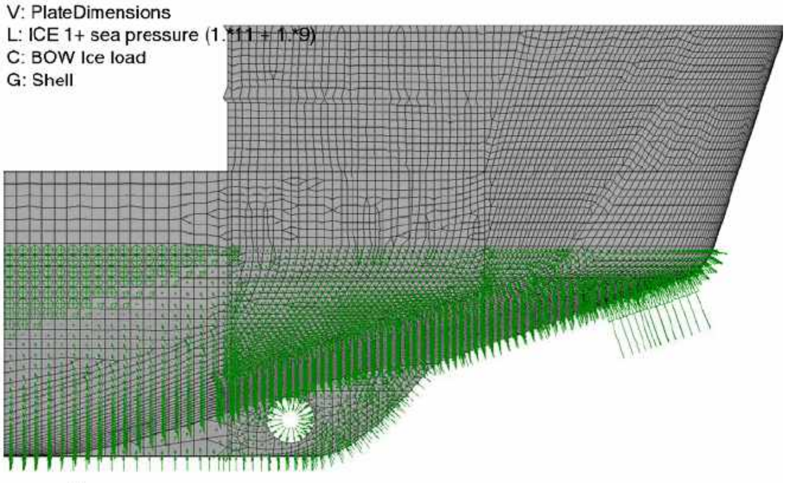


Fig.6.3.4 Sea pressure and ice patch load on the model

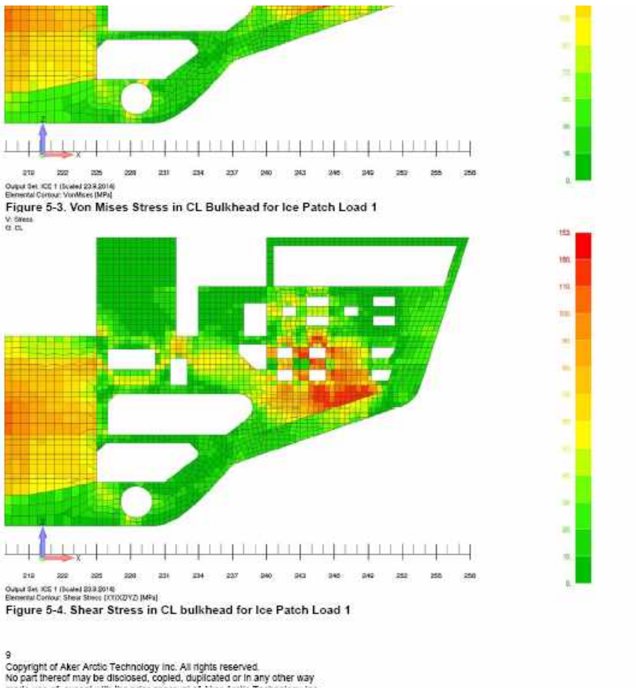


Fig.6.3.5 High shearing stress can normally be detected on the large longitudinal members

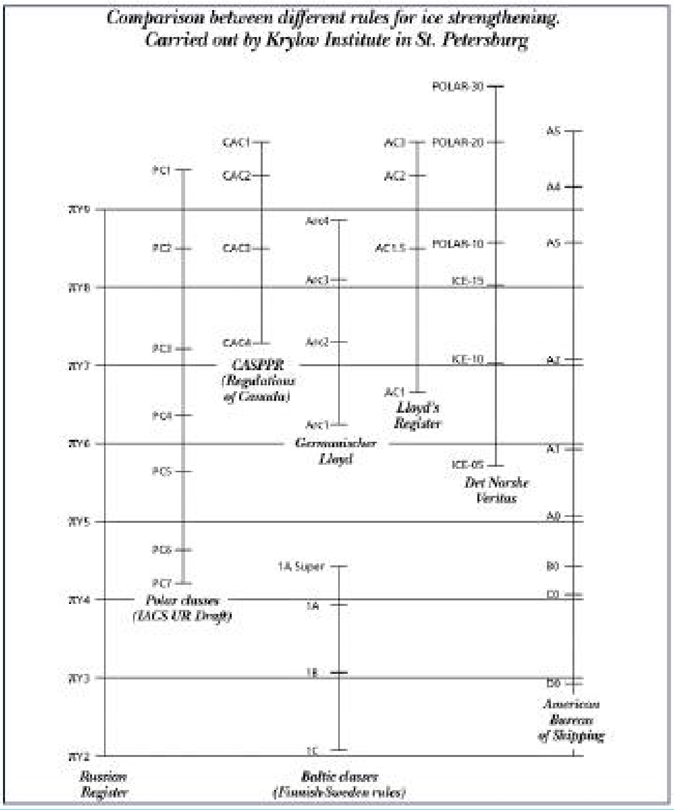
4. Proper design for Appendages structures for vessel with large size in polar waters

As the IACS Unified Requirements for Polar Ships (hereafter referred as PC class rule), all appendages shall be designed to withstand forces appropriate for the location of their attachment to the hull structure or their position within a hull area. However, the rule on how to determine the force is not clearly specified on the PC class rule. For example, the ice force, FU, acting on the uppermost part of the rudder, the ice horn included shall be assessed on a case by case basis based on the Society's current practice. The ice force, FR, acting on the rudder the distance zLIWL below LIWL shall be assessed on a case by case basis based on the Society's current practice.

For vessel with large size in polar waters, the ice force acting on the appendage and the bending moment will become a significant factor due the large size of the appendages. The method to determine the forces acting on the appendages shall be well discussed with Class in the beginning of the design. Direct analysis for evaluation of Appendage design may be necessary to determine the reaction loads on the appendages and fittings, e.g. rudder horns, horn pintles, rudder stock, etc.

5 Comparison between PC Class and Ice Class of Russian Maritime Register of Shipping (hereafter referred as RS ARC Class) in case of both compliances are required.

In some case, Both PC class and RS ARC class is necessary for a vessel. If a vessel plans to navigate northern sea route in Russian coast, admission to navigate in the Northern Sea Route Area shall be applied for and granted from Northern Sea Route Administration, which is established as a Russian federal government institution. The criterion of the admission of ships to the Northern Sea Route in compliance with the category of their ice strengthening is still based on RS ARC Ice Class. Therefore, in some case both PC class and RS ARC class is necessary for a vessel. Krylov institution made a study and comparison between the different ice class requirements from different class societies and PC class. However, this is for general comparison. Every individual ice class still has their own individual requirements. They can't be interchange or and are not simply equivalent with each other. Therefore, once ARC ice class is required for navigation, the evaluation of ice strengthening based on RMRS rule will be necessary, even though the vessel may have been granted Ice Class with PC class or other Class Societies.



6 Fabrication of the structures will be more difficult when the grade, scantling, amount of steel works increased while the dimension of the ship increased while the spacing for the structural members become narrow

6.1 Aiming at improving the weld ability of the hull structure, Suitable WPS and steel material for the high grade high tensile plate shall be considered.

For vessels with large size, in mid ship area, the steel in submerged and weather exposed shell plating will be 23mm~26mm, grade DH/EH; The steel in the bow area can be up to 42mm, grade EH; The thickness of the stem side plate shall further increased by not less than 20% of the net thickness of the plate in the bow area, i.e. the thickness of the plate in stem area can be up to 50mm. Depending on the purpose of the vessel, the plate for the main deck normally varies from 16mm, Grade DH (for tankers) to 35mm, Grade EH (for module carriers).

Such specifications of material will increase the difficulty for welding and fabrication of the hull structures.

Modern Shipyards are normally equipped with highly efficient automatic welding equipment and applying efficient welding processes, e.g. Fluxes-Cuprum Backing (FCB), Gas Electric Welding (GEW). These are high heat input welding processes which will normally increase the size of the Austenitic crystal in the Heat Affected Zone (HAZ), the material mechanical properties are therefore impaired. The chemical composition and proper temperature during milling rolling should be adjusted slightly to control the size of the Austenitic crystal. This together with WPS for such welding described above, shall be carefully selected and tested to enable the steels for the polar class vessels to be fabricated with the existing facilities in modern shipyards.

6.2 Attention shall be paid to the arrangement of outfitting and arrangement of structural members

For larger vessels, the capacity of their ballast system, stripping system or bilge system is normally bigger than those for small vessels. However, the spacing of the internal structural members will not increase due to its higher ice load. The outfitting of the marine systems, e.g. the bell mouths of the ballast system and the electrical anode of the ICCP will be bigger than the spacing of the structural members in ice strengthening area. Primary consideration shall be adjusting the design of the outfitting to enable the continuity of the structural members. Secondary consideration is to adjust the local ice strengthening member when such outfitting has to maintain its size or integrity.

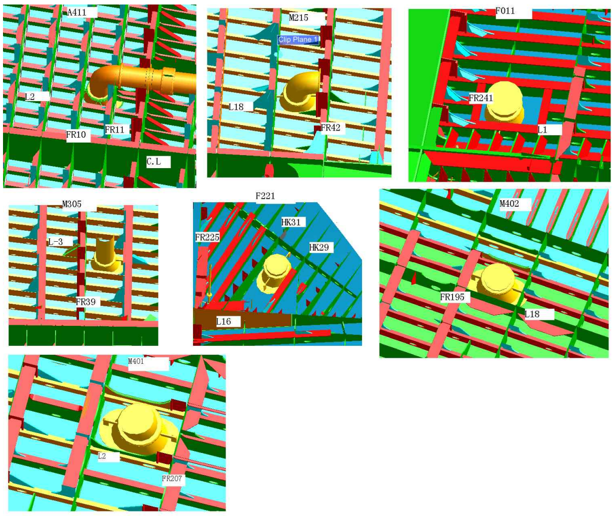


Fig.6.2.1 For normal vessels, the longitudinal is terminated due to the presence of the large bell mouth.

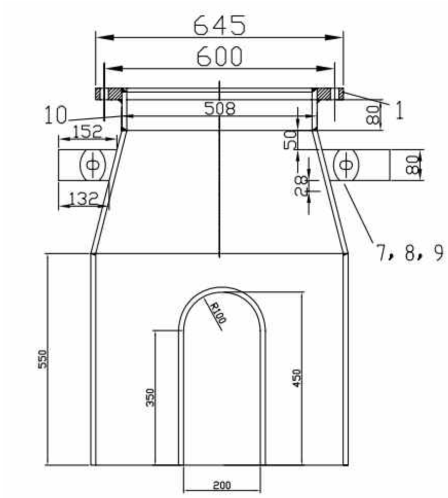


Fig.6.2.2 Re-designed bellmouth to ensure the continuity of the longitudinal stiffeners.

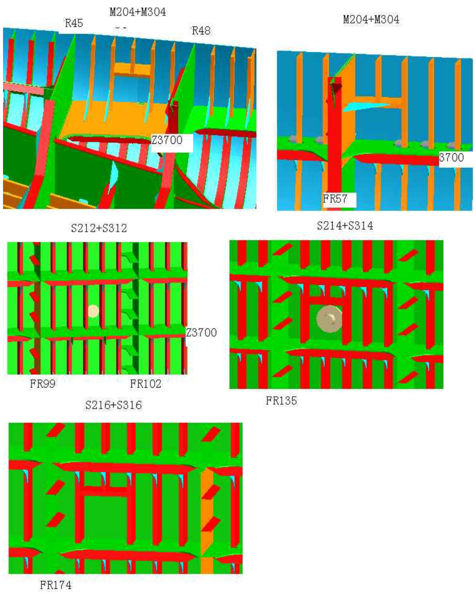


Fig.6.2.3 The longitudinal is terminated due to the presence of the electrial anode of ICCP

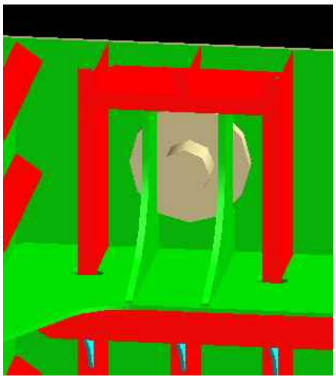
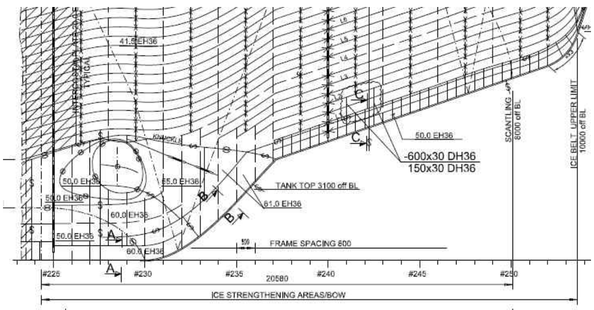


Fig.6.2.4 The reinforcement over the electrical anode

6.3 Detailed structural design for bow / Stern curved area.

Higher ice load on the bow /stern area than the other ice belt areas will require larger structural member scantlings or denser internal structural members. However, the narrow and curved space normally would not enable structural members that are too large of too tightly spaced. Proper selection of structural arrangement and adequate scantling shall be considered during design to ensure the adequate fabrication and welding quality of the structure.



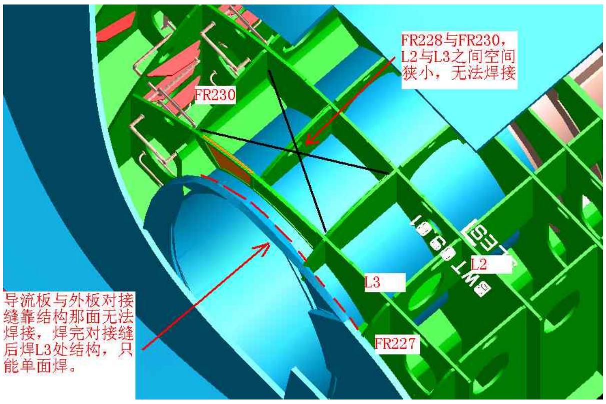
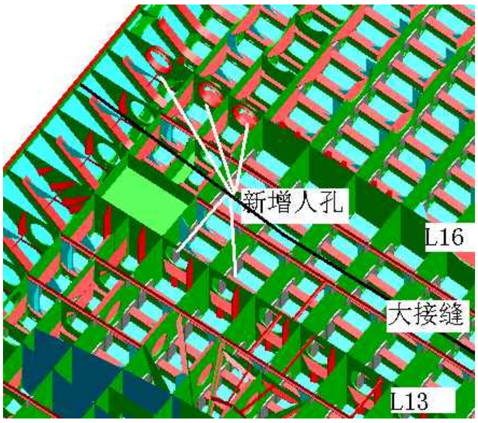


Fig. 6.3.1 large and dense structural members in bow area.

Meanwhile all the structural members shall be accessible for inspection. However the large and dense structural members with limitted cut outs will block such access. Twisted access routes may have to be considered to balance the structural arrangement and access arrangement.



7 Conclusions

As the size is increased, the structural responses to the load cases will be different than those in vessels of a smaller size. Due consideration shall be paid to these issues before the design and deployment of a vessel of large size for the navigation in Arctic Shipping Route. The success of delivery of two PC-3 / Arc7 Module Carriers by Guangzhou Shipyard international Company attested such due consideration and will guarantee the safety of the structures for the vessel with large size sailing in the polar water.