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Report

DNB Vessel manufacturing feasibility assessment

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1. Introduction

DNB Vacuum vessel is a rectangular vessel with detachable top lid configuration. The detailed design of the vessel is presented in (Ref. of DDD). Top lid and Vessel are to be manufactured separately. Material of construction for both are SS304L. Manufacturing of vessel and top lid consists of the welding of plates / forgings, welding of stiffeners and welding of nozzles. Extensive welding activities are involved in manufacturing of both sub-assemblies. The typical raw material product form considered are plates, forgings, bars, pipes and tubes depending on the final configuration requirements, market availability and overall manufacturing feasibility. Austenitic Stainless Steel (ASS), having the high thermal coefficient of expansion, is prone to significant weld induced distortion, especially for high thickness welds. Therefore, the important consideration while fabricating heavy structures of ASS, is the prediction of the distortion based on various variables like joint configurations, heat input, welding sequence and clamping conditions. These predictions enable the selection of the optimized variable and designing the necessary fixturing accordingly. Simulation methodology through computational assessment has been is adopted for the prediction of welding distortion for various options of the different process variables. Based on the outcome of the results, the recommendations have been concluded and shall be used as guidelines during manufacturing like post-weld machining specifically for the areas of sealing surface and bolting. This assessment has also provided the information on the need of post welding machining and the necessary machining allowance required.

Applicable manufacturing specification for the DNB Vessel are as follows:

- Annexure 2_QA, QC, Inspection and testing
- Annexure 3_Vacuum Quality Assurance
- Annexure 4_Materials_General requirements
- Annexure 4_Materials_Section 1_Forgings
- Annexure 4_Materials_Section 2_Rolled or forged bars
- Annexure 4_Materials_Section 3_Plates
- Annexure 4_Materials_Section 4_Pipes
- Annexure 5_Fabrication
- Annexure 6_Welding_General Requirements
- Annexure 6_Welding_Section 1_Acc. and Qual. of Filler mat.

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- Annexure 6_Welding_Section 1_Acc. and Qual. of Filler mat.
- Annexure 6_Welding_Section 2_Welding Procedure Qualification
- Annexure 6_Welding_Section 3_Qual. of welder and operators
- Annexure 6_Welding_Section 4_Tech. qual. of prod. workshops
- Annexure 6_Welding_Section 5_Production welds
- Annexure 7_Cleaning and Cleanliness
- Annexure 8_Pickling and passivation
- Annexure 9_Baking
- Annexure 10_Leak Testing
- Annexure 11_Dimensional Inspection
- Annexure 12_engineering Analysis

2. Simulation Work Plan

Shrinkage based analysis approach has been considered for the welding analysis. Main shell and top lid have been divided into subassemblies for carrying out the welding distortion analysis.

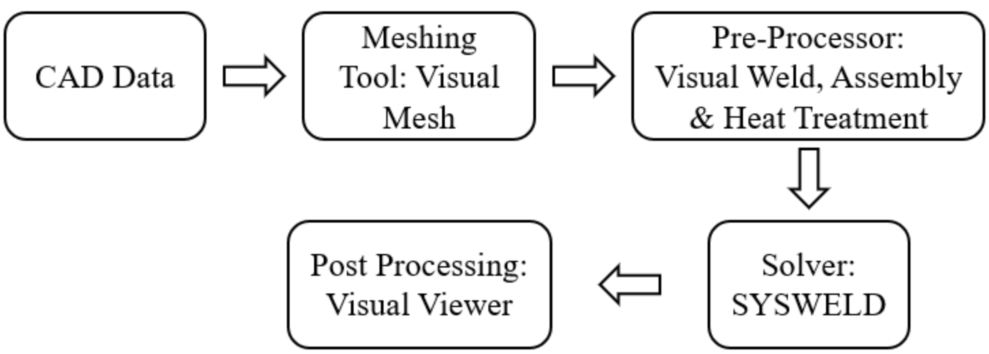


Figure 1: Simulation work plan

Simulation results provides the distortion results as function of welding sequence and clamping conditions in each of the directions i.e. x, y and z for clamped and released condition. The sequence of the simulation work plane is shown in the fig 1.

3. Material

Material considered for the analysis is SS304L. The temperature dependent material data for the shrinkage-based distortion assessment considered as follows:

Table 1: Material Properties for SS304L

Modulus of Elasticity	Poisson's ratio	Thermal Expansion coefficient	Melting Point
N/mm^2		**1/K**	**^{o}C**
195000	0.3	0.00001992	1400

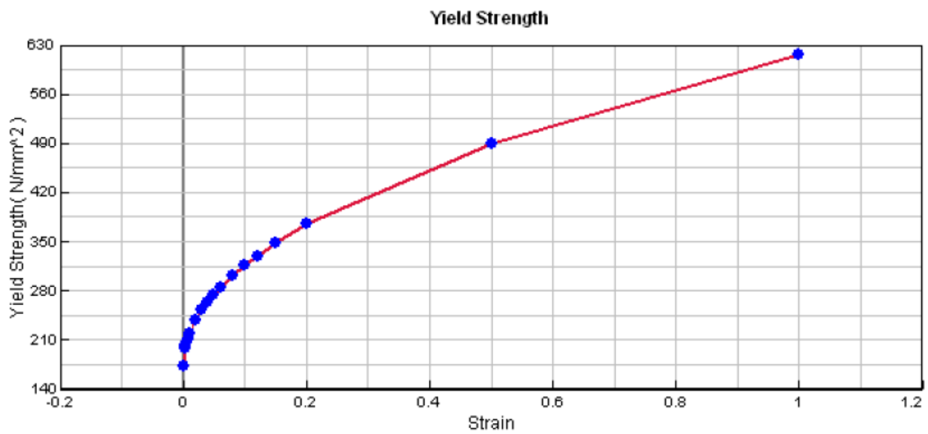


Figure 2: Stress-strain curve

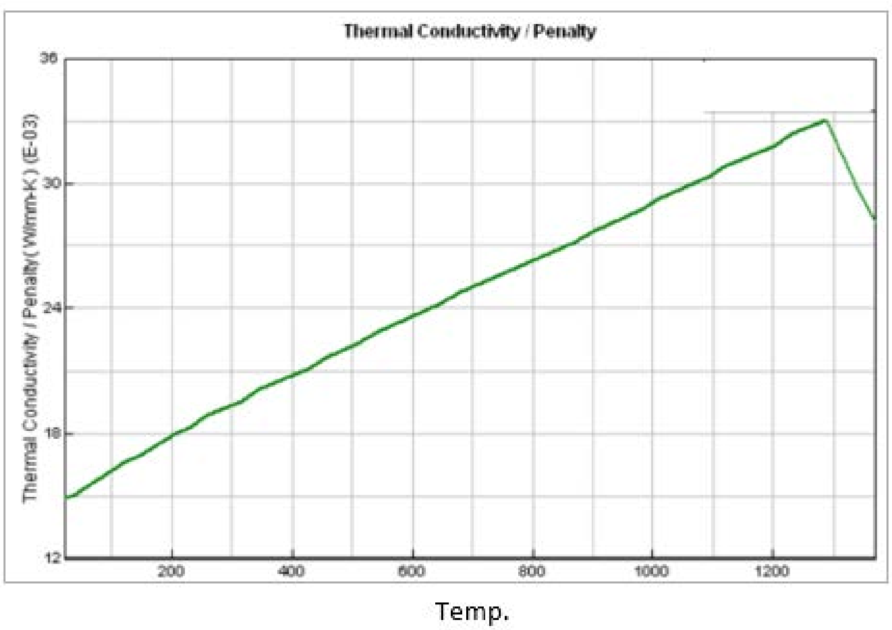
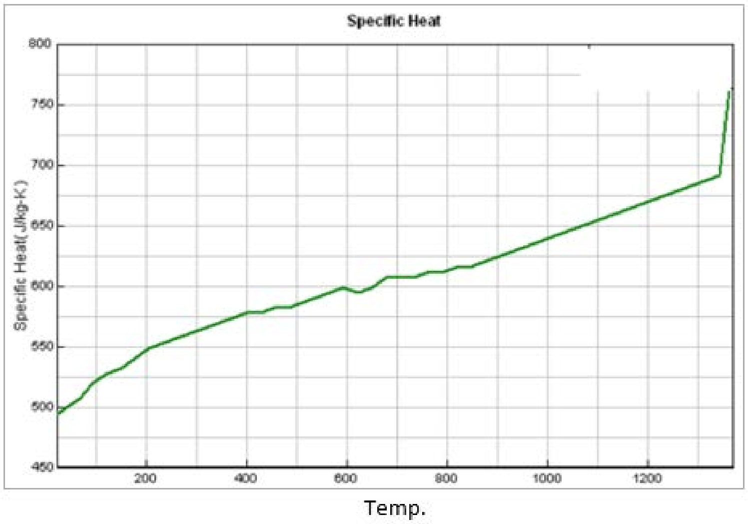
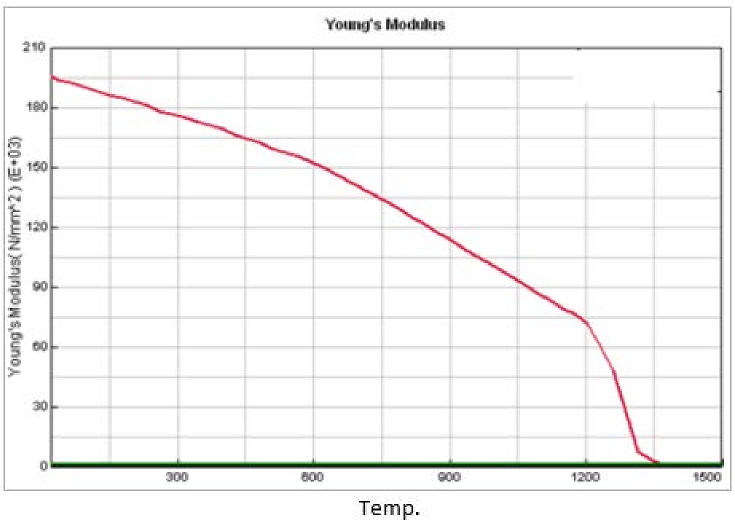


Figure 3: Thermal conductivity





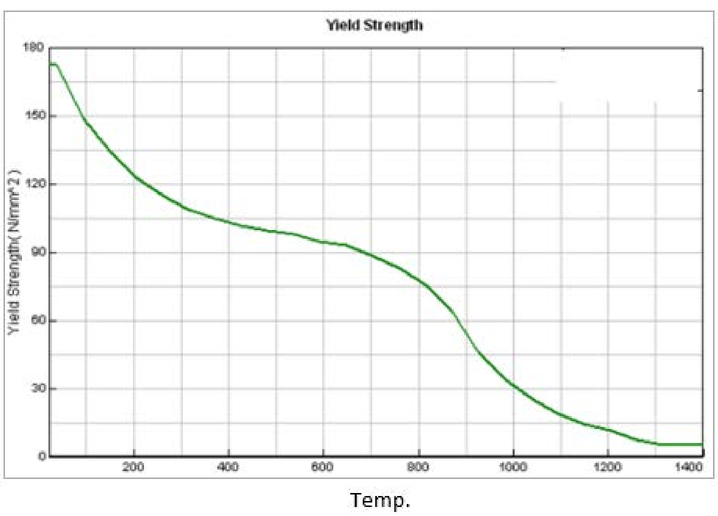


Figure 4: Specific heat, Young's modulus and Yield strength

4. Manufacturing of Main Shell Plate Assembly

The size of plate and number of welds has been optimized based on the supplier's feedback available as of now, and shown in fig 5. There could be some variation in the number of welds depending on the size of the welds.

Two different approaches are envisaged for the fabrication of main shell. One, approach 1, would involve the fabrication of all the five sides of plates of main shell separately followed by corner welds as shown in fig 5. Another approach, approach 2 could be the forming of the segments as shown in fig 6. The three segments will be welded together to obtain the main shell.

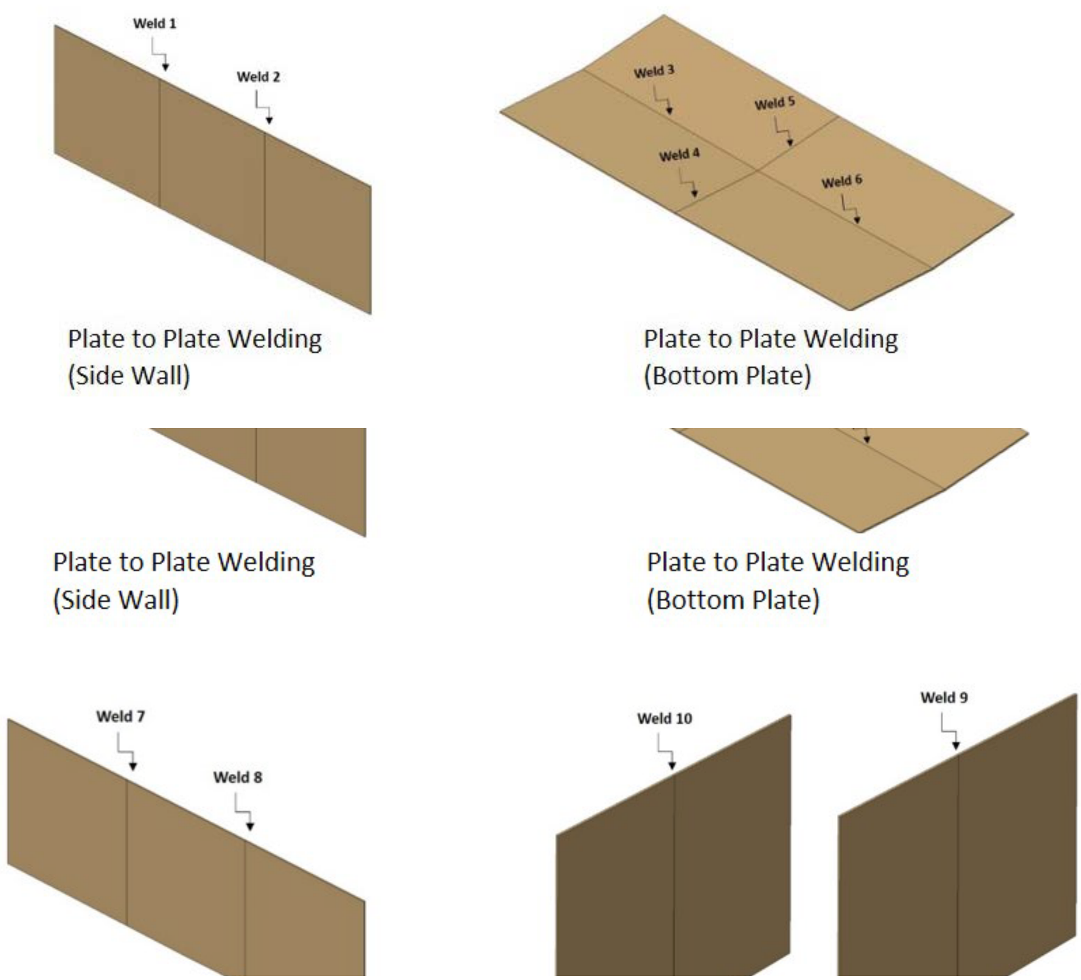


Figure 5: Welding of main shell plate assembly – Approach – 1

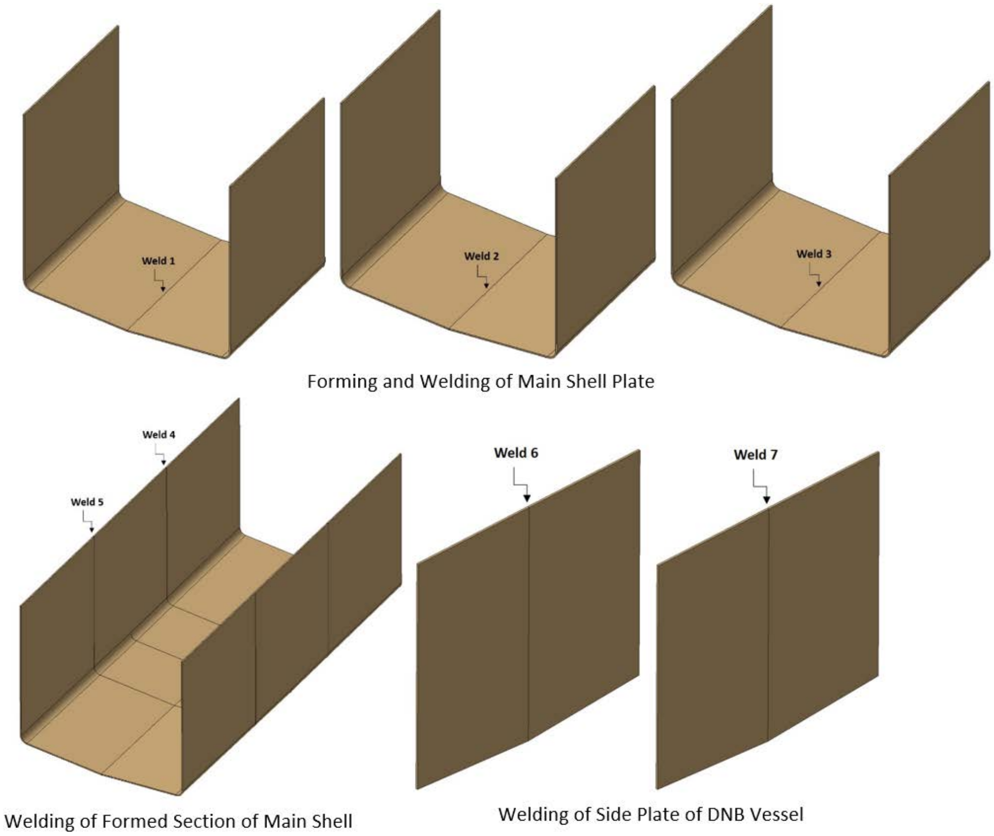


Figure 6: Welding of main shell plate assembly – Approach – 2

The corners of the vessel shall be in form of cold / hot rolled condition. Necessary heat treatment after forming shall be carried out (if applicable) with respect to code requirements. Number of weld requirements for both the approaches have been decided based on the supplier's feedbacks.

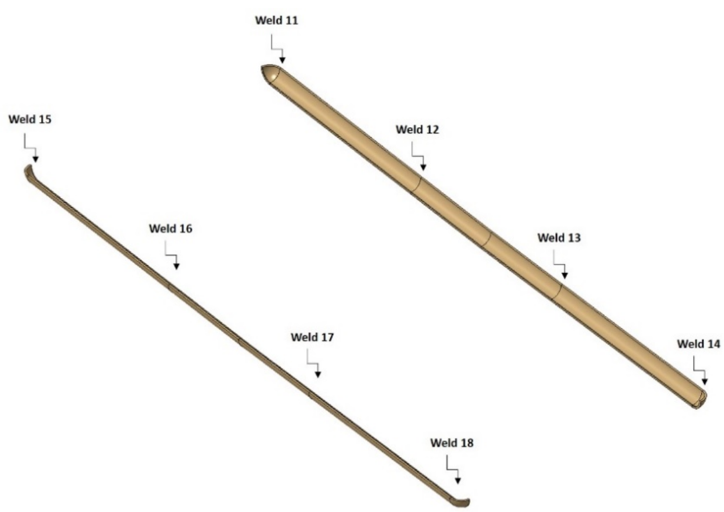


Figure 7: Corner welding of main shell assembly

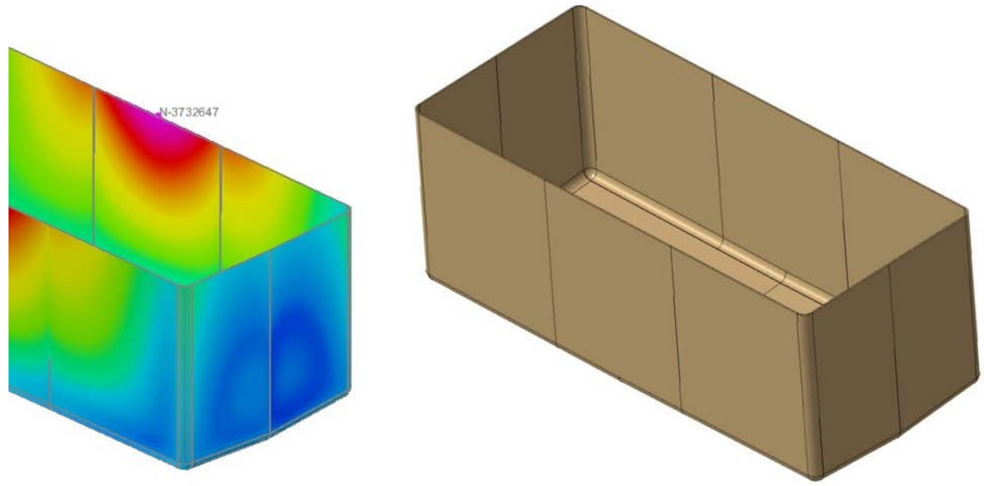


Figure 8: Main shell assembly

For the draining requirement, the angle on bottom plate can be achieved by forming, machining or by pre-angled weld joints so that after welding the plate achieves the desired angle. This can be based on the manufacturer experiences and industrial practices. Fig 9 shows the angle bottom plate of the DNB Vessel for both the approaches discussed above. Port opening and welding of drain pipe is shown in section 10 of this report.

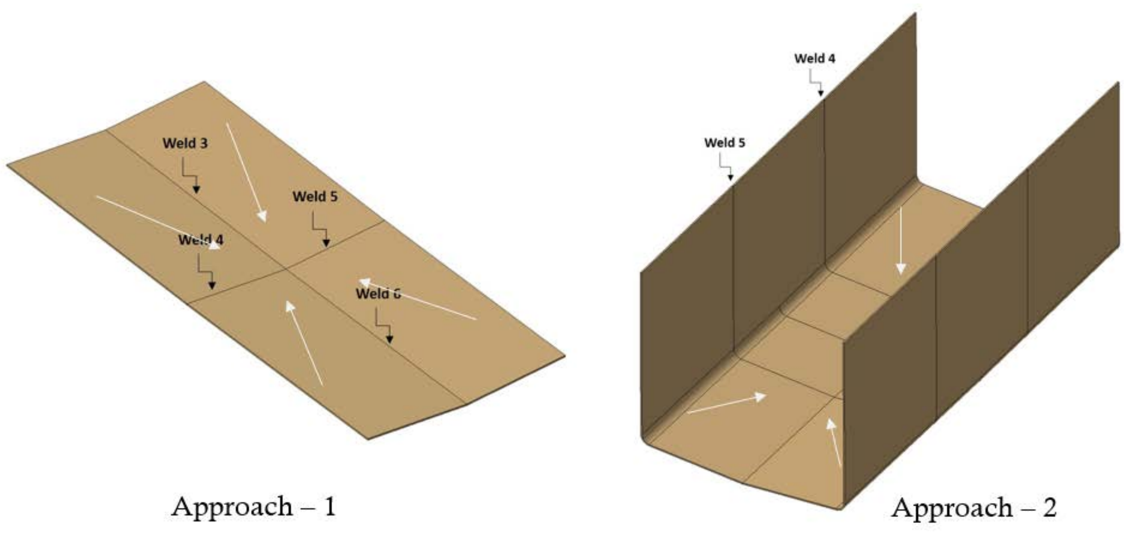


Figure 9: Angled plate configuration

Note: Welding is accessible from both side and volumetric examination (RT and UT) is possible. At present one side welding is considered and the details of the same are provided in the drawings. Fig 10 shows the drawings considered for main shell welding. For detailed drawing set refer (#IDM).

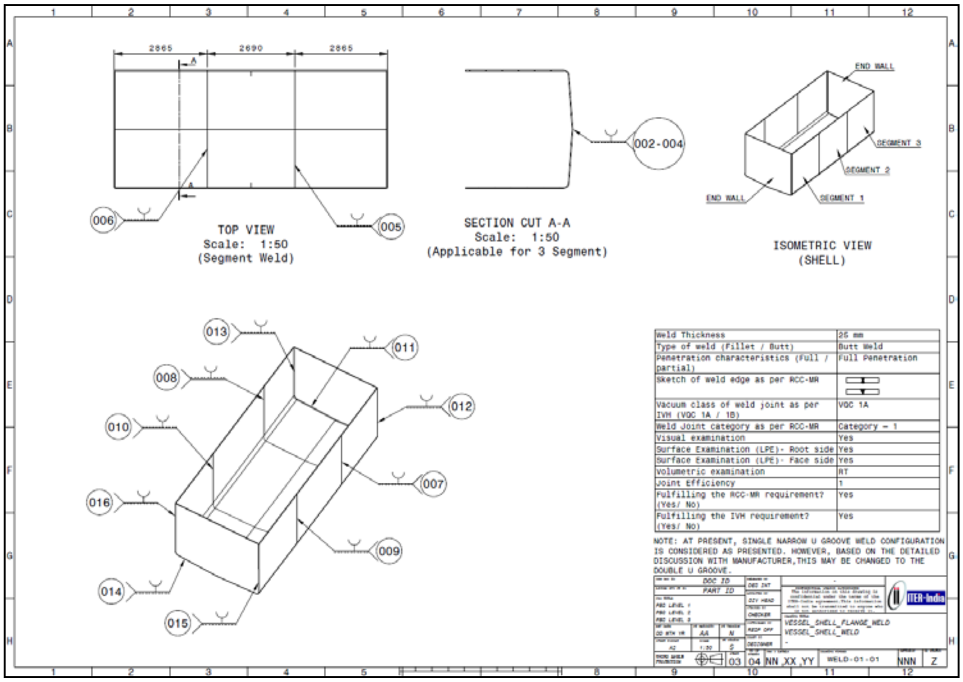
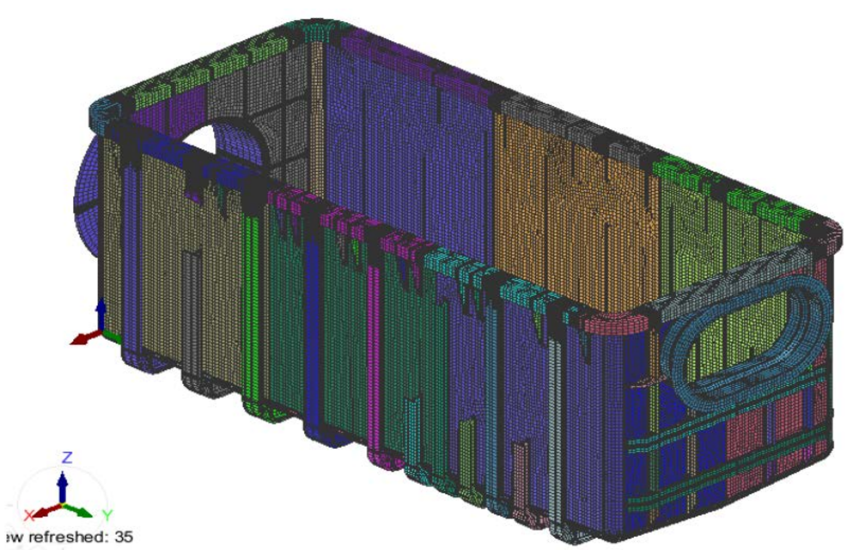


Figure 10: Welding details for main shell fabrication – approach 2 (for information)

5. Welding Analysis for the Main Shell Plate Assembly

To enable the study related to estimating distortions during post welding, detailed studies have been performed. Meshing of the CAD model is done in the Visual Mesh 15.5 module. Hexagonal elements have been considered for the meshing with fine mesh in specific areas around the weldment to capture the proper shrinkage in the assembly.



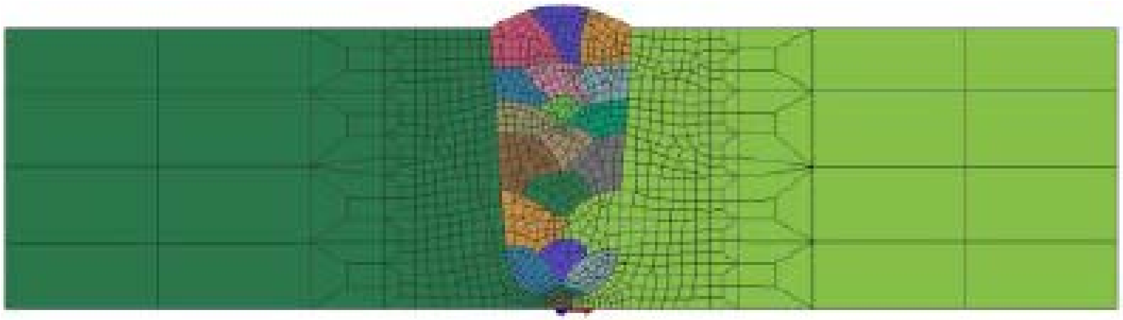


Figure 11: Meshed model of main shell assembly

Different manufacturing sequences have been studied for the main shell fabrication. Based on the outcome of welding distortion analysis, approach 2 has been considered for the vessel fabrication. Optimized manufacturing sequence in terms of the distortion control is being presented in this report. Typical weld configuration for the 25 mm thick plate to plate welding of main shell is shown below and table 2 shows the typical weld parameters for the same based on previous experiences.

Typical Welding Configuration

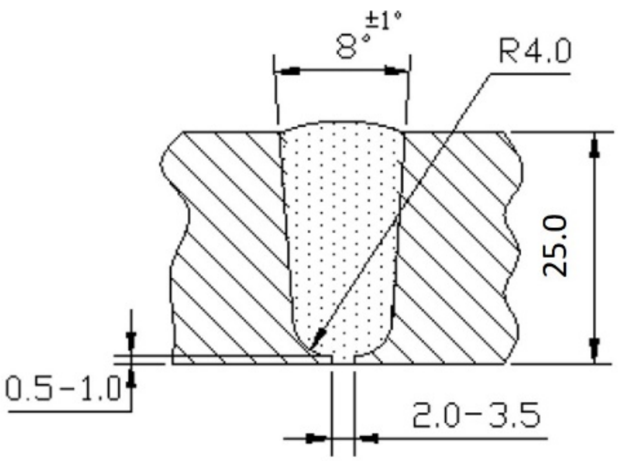


Table -2: Typical Welding Parameters

No of weld pass: 20

Polarity	Current (Amp range)	Voltage	Travel Speed
DCEN	60 – 300 A	10 – 14 V	55 mm/min

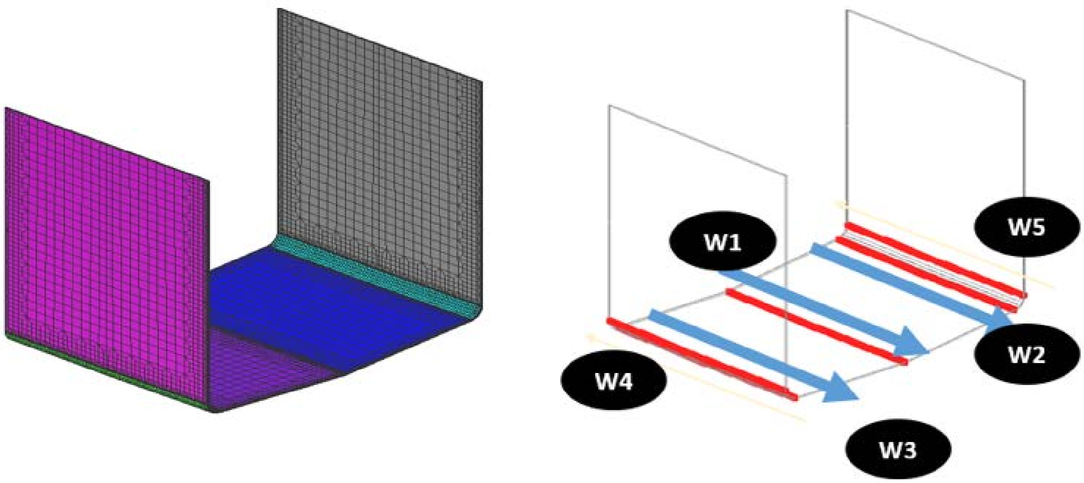


Figure 12: Meshed model and welding sequence for single U segment

The main shell shall be manufactured by welding of three U shaped segments, as shown in fig 13.

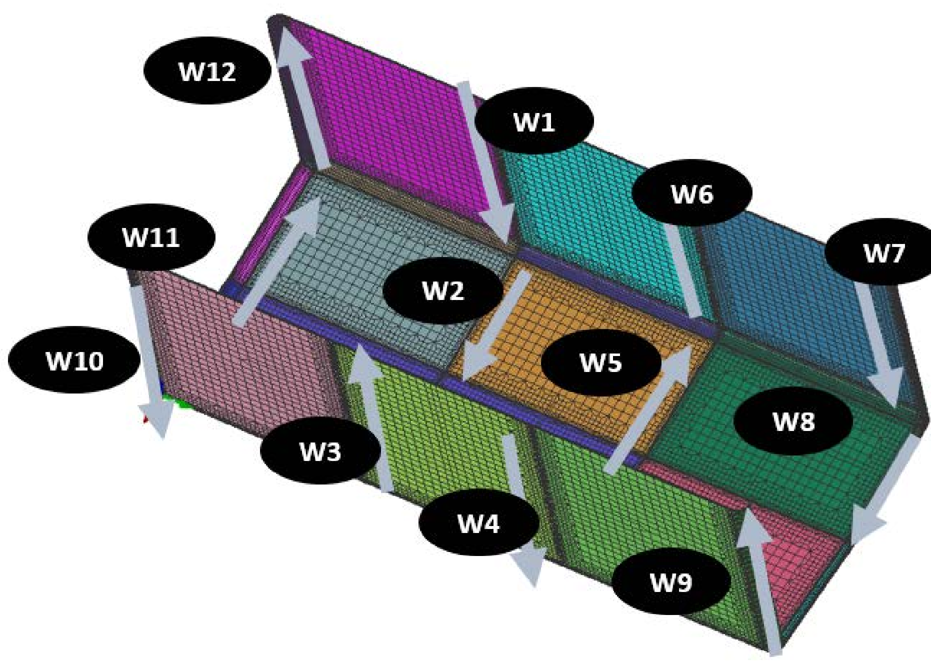


Figure 13: Welding sequence for combined U segment

Each of the U shaped segment consists of two vertical plates, two corners and two bottom plates. The clamp details for welding of the single U shaped segment is shown in fig 14 and for the combined weld assembly, to be manufactured from these U shaped segments is shown in fig 13. The clamping details for combined U segment is shown in fig 14,

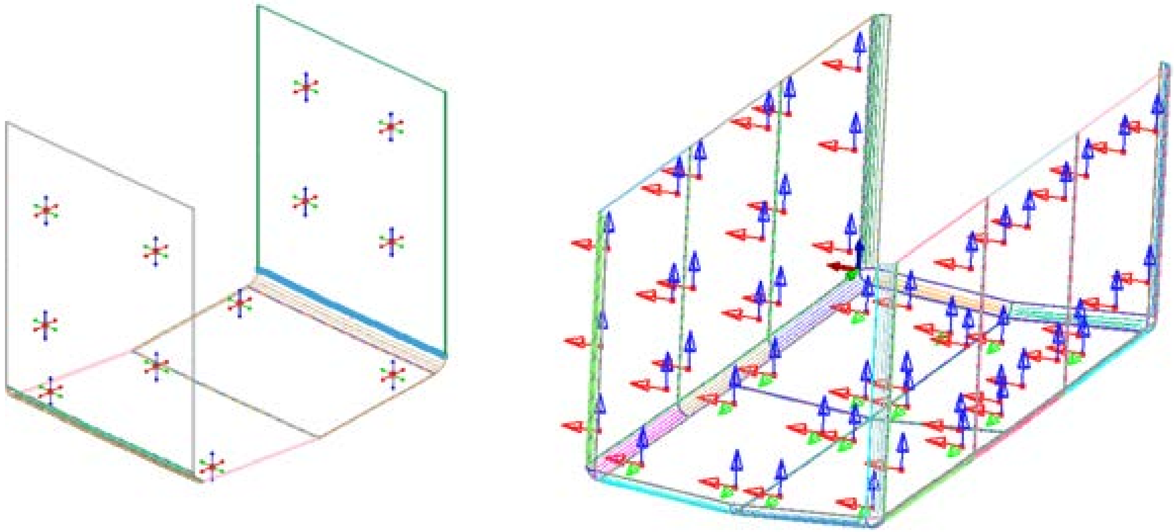


Figure 14: Clamping details of single and combined U segment

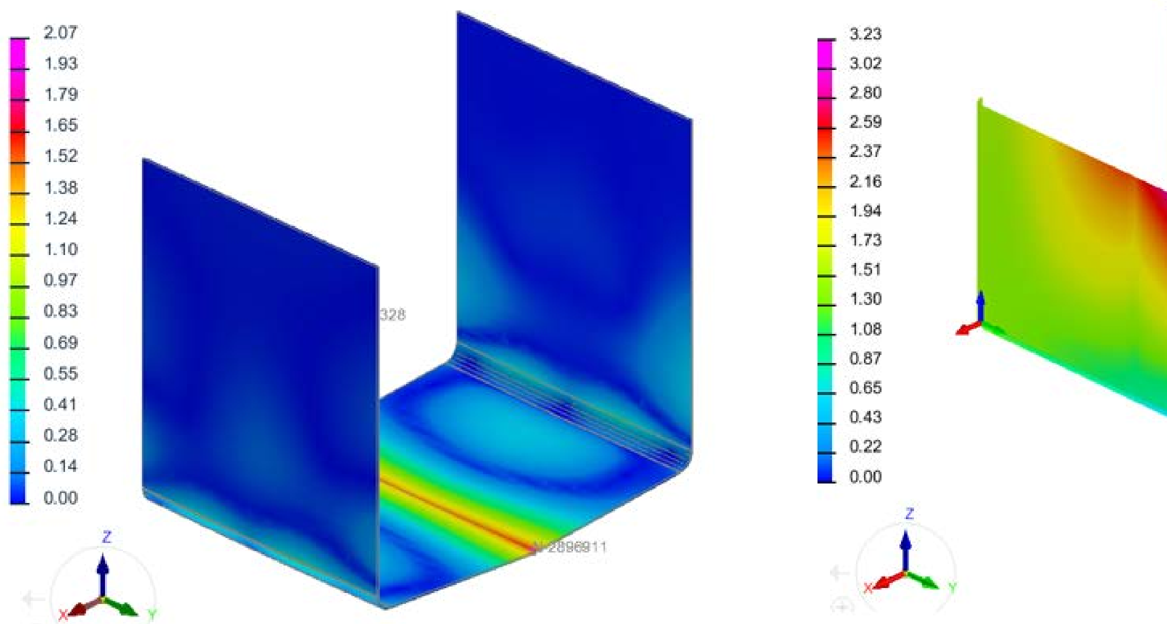


Figure 15: Welding distortion of single U segments

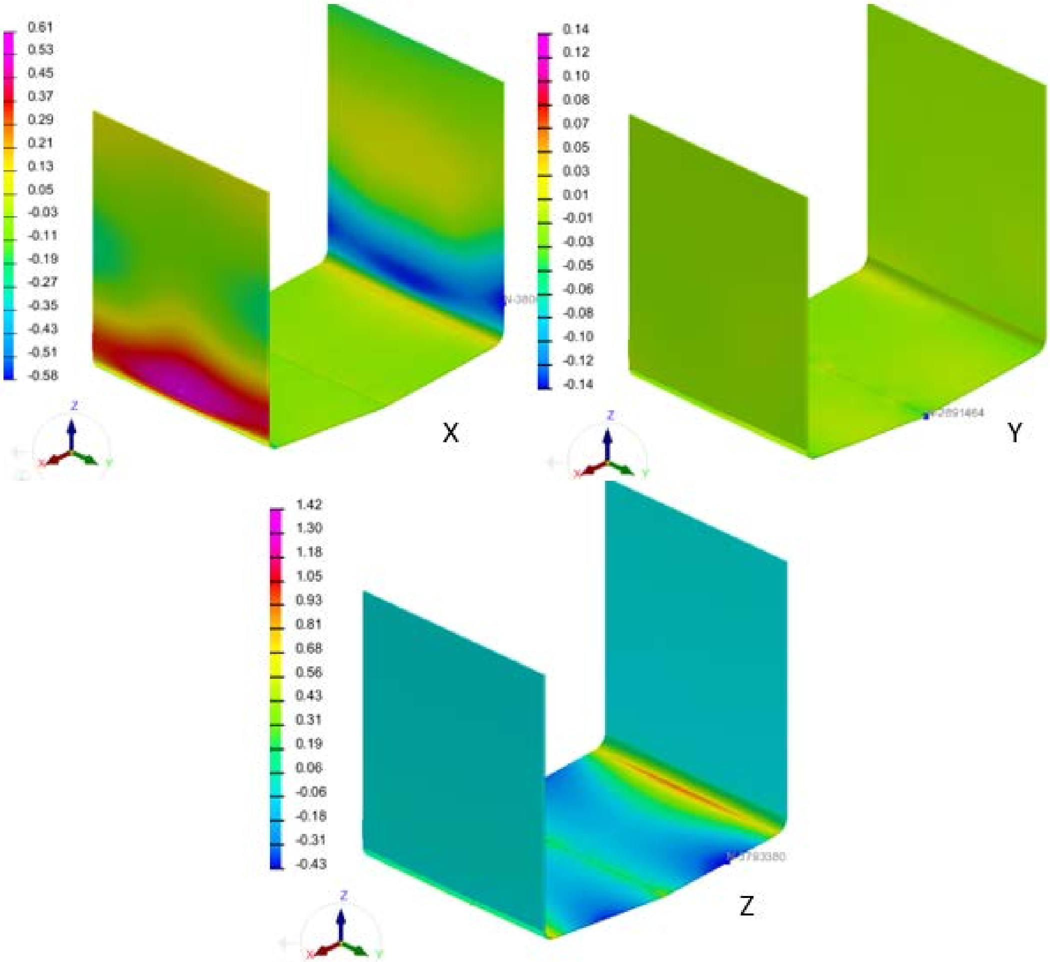


Figure 16: Direction welding distortion of single U segment

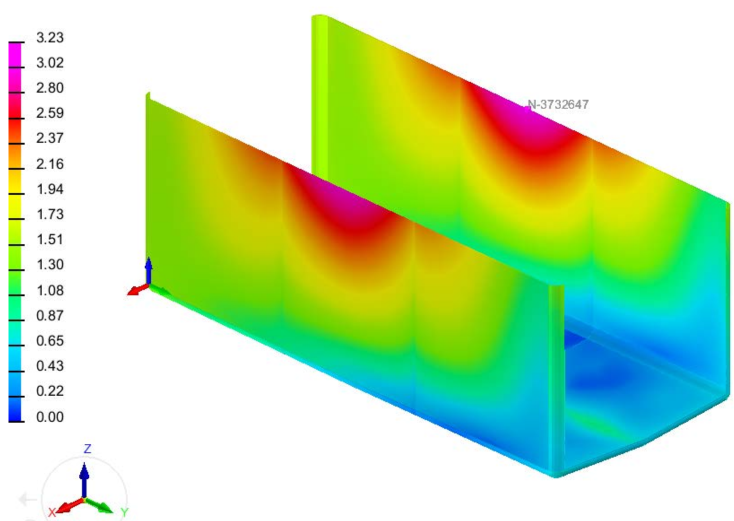


Figure 17: Welding distortion of combined U segment

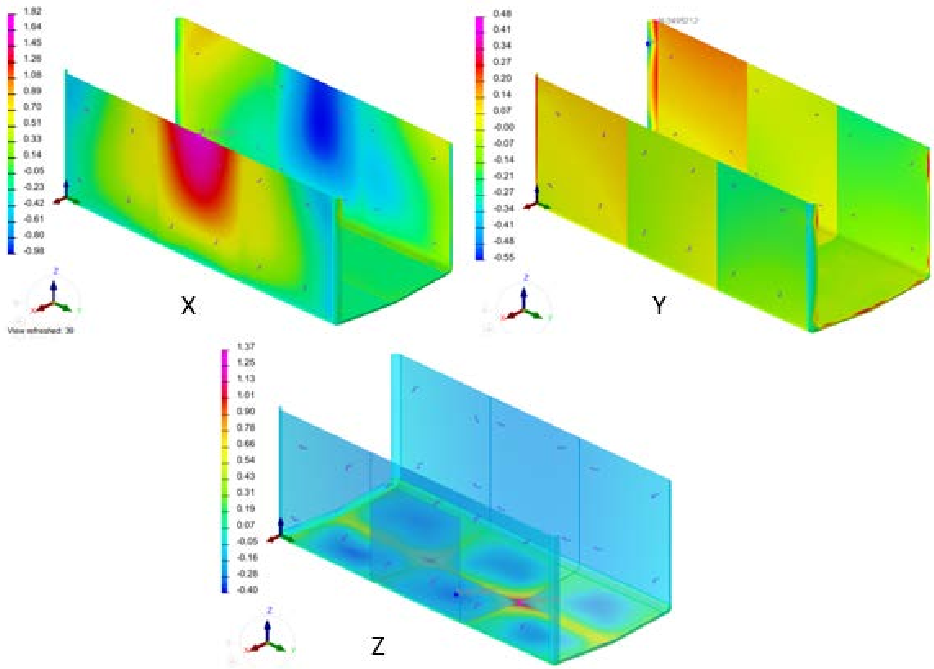


Figure 18: Direction welding distortion of combined U segment

Fig 15 shows the maximum distortion of 2.07 mm during welding of the single U shaped segments. Directional deformation of the same are shown in fig 16. The combined assembly welding of three U shaped segment has the maximum distortion of 3.23 mm in the clamped conditions, as shown in fig 17. The weld distortion of single U segment and clamping details has been considered for the welding analysis of the combined assembly. Fig 18 shows the directional deformation of the welded combined U shaped segment. The necessary matching of the weld edge preparation has to be performed through the additional fixturing while weld set up. Further, the assembly shall be kept in the clamped condition for the next level welding with the end plates as shown in the below fig 19.

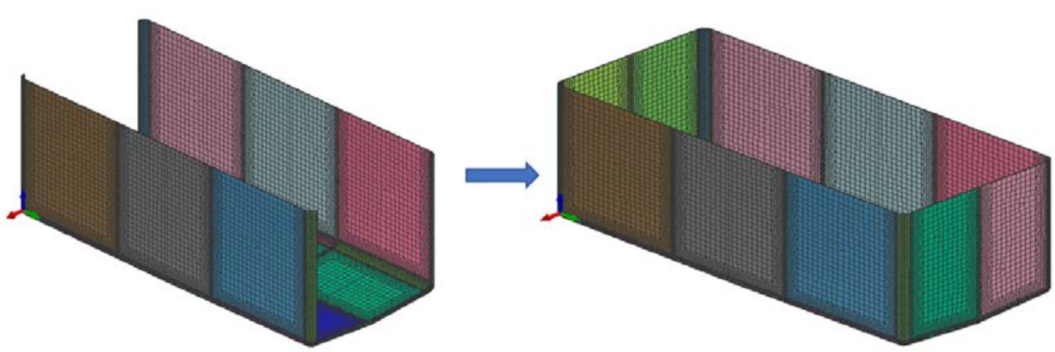


Figure 19: Meshed model for end plates

End plate for the both the sides are to be fabricated separately from plates and then to be brought together with U shaped segment assembly for the welding. Fig 20 shows the clamping condition and welding distortion of end plate for the optimized condition. Maximum distortion of 6.020 mm in the positive X and 7.041 in the negative X direction is observed. This distortion value is in the clamped condition. This plate shall be aligned with the U shape assembly to enable the desired welding. Assembly clamping have to be introduced to match the weld edge with the main shell fabricated in the previous assembly.

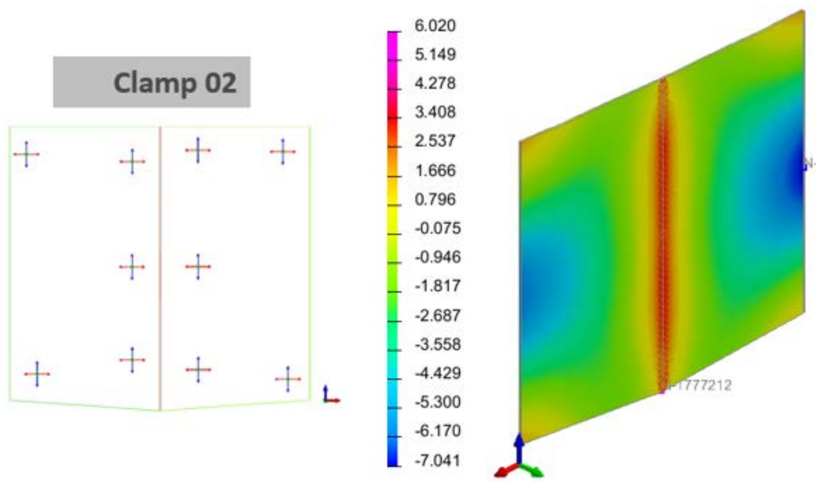


Figure 20: Clamping details and welding distortion of end plate

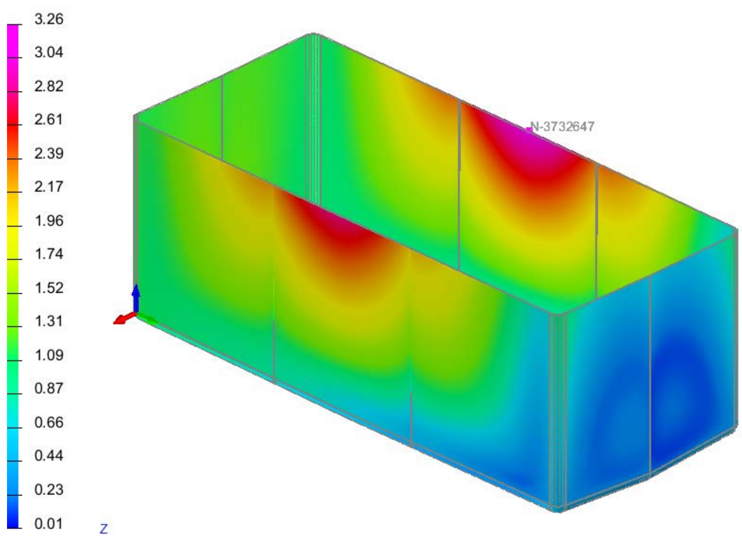


Figure 21: Combined weld distortion of main shell plate to plate welding

Fig 21 shows the maximum distortion of 3.26 mm at the center of the side plate after the final welding of main shell assembly. Fig 22 shows the directional (X, Y and Z) distortion in the main shell welding. Major distortion is in the direction of X and Z (3.08 mm and 1.23 mm resp.), whereas the Y has the minimal distortion of 0.64 mm. The reported distortion behaviour is in the clamped condition.

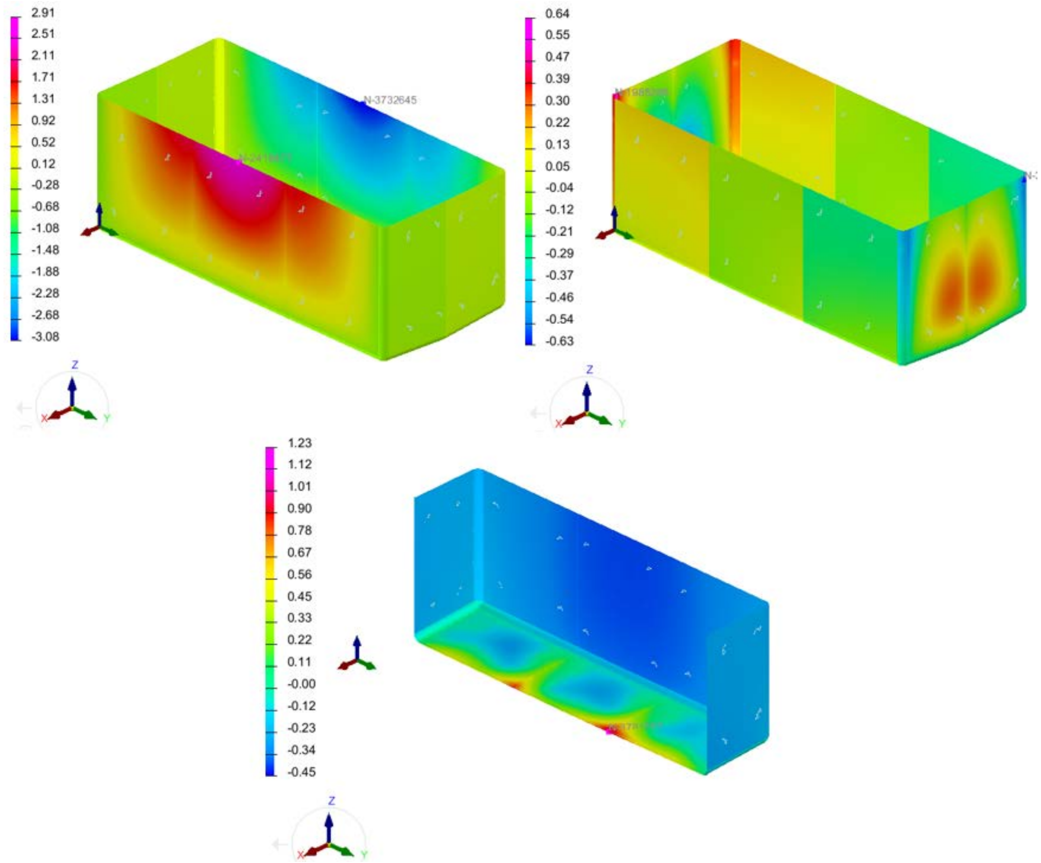


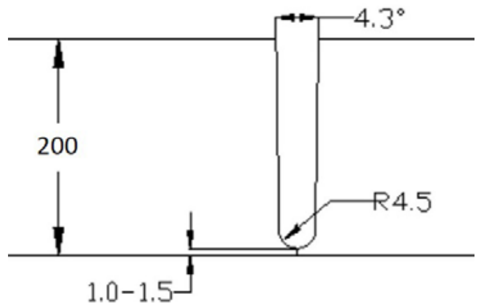
Figure 22: Directional weld distortion of main shell plate to plate welding

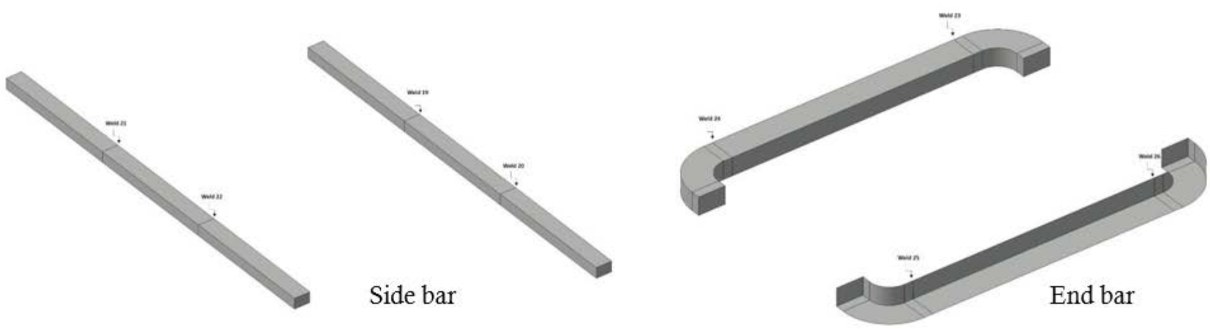
6. Manufacturing of Main Shell Flange Assembly

The manufacturing of flange assembly can be done by either considering the high thickness plates or the forge bars of 200 mm thickness. Based on the supplier's feedback on the available size of plate/forging, the fabrication sequence has been decided as show in fig 23.

The typical weld plan for the full penetration butt welding configuration of different segments of flange assembly is shown below.

Typical WEP for flange welding





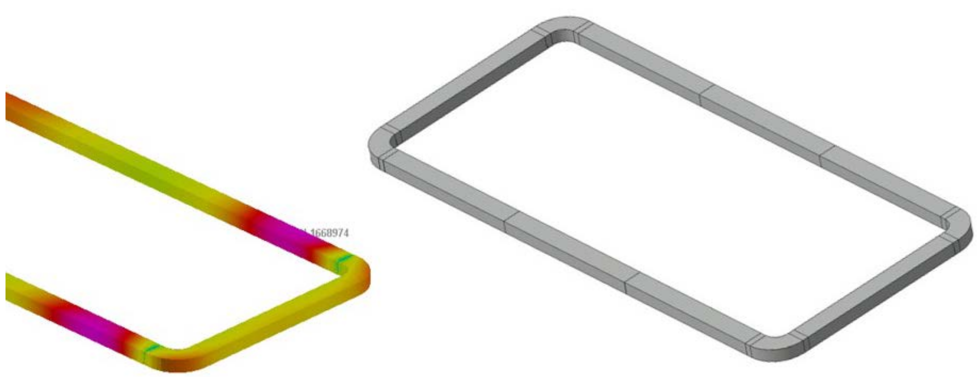


Figure 23: Welding of top flange of main shell assembly

7. Welding of Main Shell Flange Assembly

Meshing of the CAD model is done in the Visual Mesh 15.5 module. Hexagonal elements have been considered for the meshing with fine mesh around the weldment to capture the proper shrinkage in the assembly.

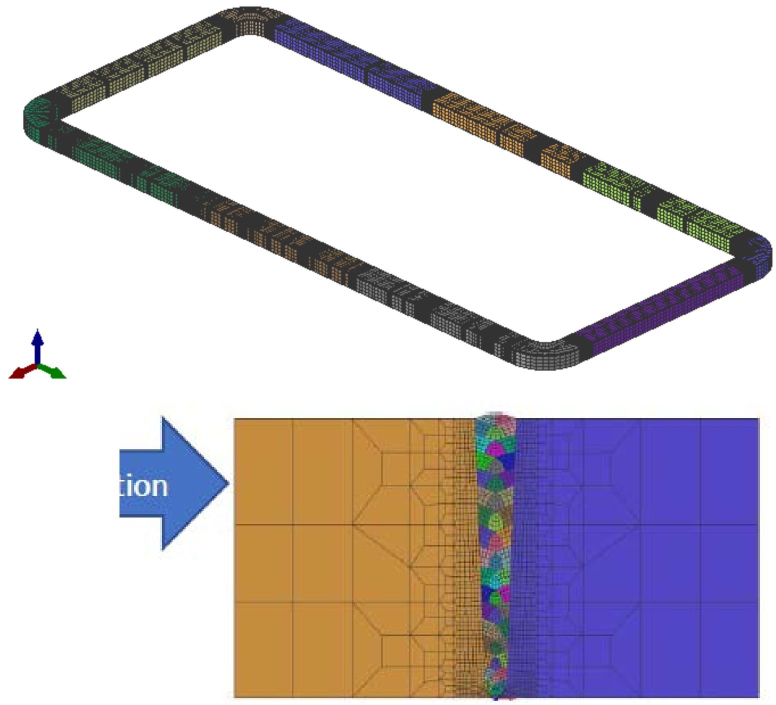
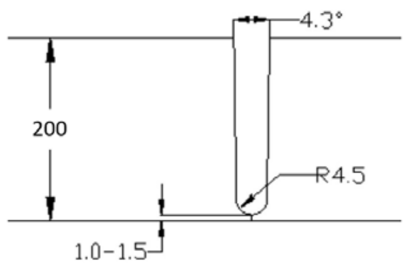


Figure 24: Meshed model for top flange of main shell

Typical Welding Configuration (Narrow U groove):



Typical Welding Parameters

No of weld pass: 100

Polarity	Current (Amp range)	Voltage	Travel Speed
DCEN	250 – 300 A	09 – 11 V	80 mm/min

7.1. Sub-Assembly 1: Side Bar

Two clamping conditions and one welding sequence are assessed for fabricating the side bar. Optimized results in terms of the clamping condition and weld distortion are shown here.

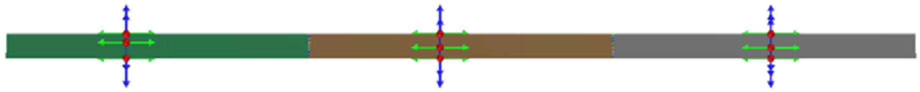


Figure 25: Clamping of side bar

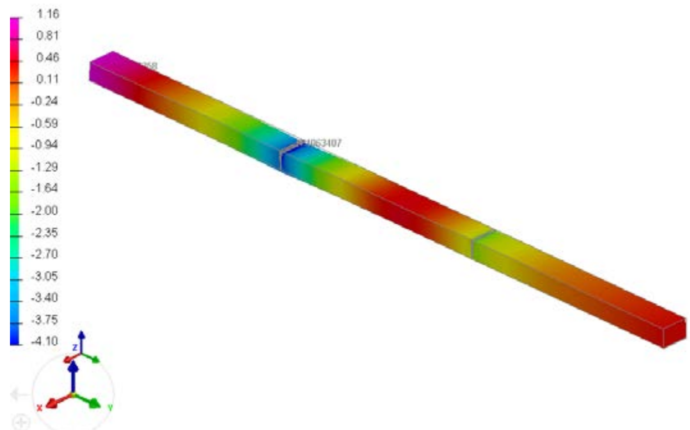


Figure 26: Welding distortion of side bar

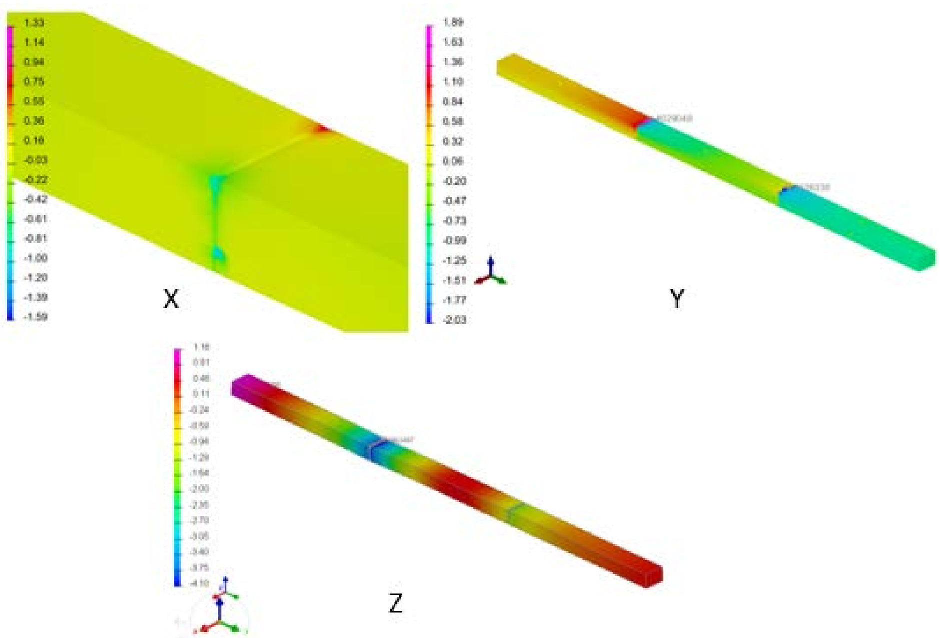


Figure 27: Directional weld distortion of side bar

Under the clamped condition, maximum distortion of 1.16 mm in the positive Z direction and 4.10 mm in the negative Z direction is observed in the clamped condition at the ends of the side bars, as shown in fig 26. Fig 27 shows the directional deformation of the side bar. This sub-assembly will be taken for further welding in the clamped condition only.

7.2. Sub-Assembly 2: End Bar

Figure 28: Clamping of end bar

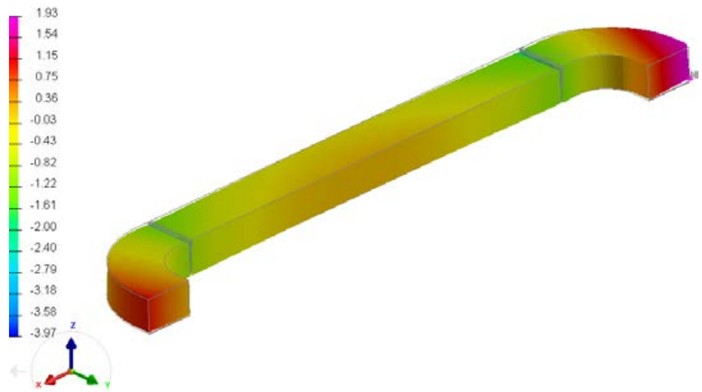


Figure 29: Welding distortion of end bar

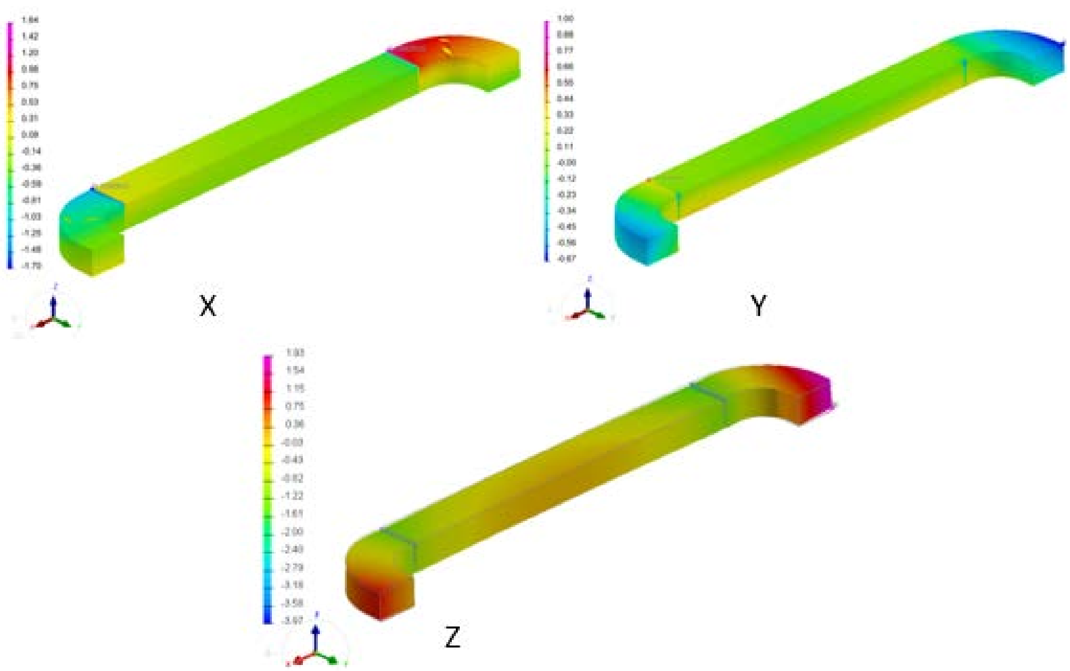


Figure 30: Directional weld distortion of end bar

As shown in fig 29 maximum distortion of 1.93 mm in the positive Z direction and 3.97 mm in the negative Z direction is observed in the clamped condition. Fig 30 shows the directional deformation of the end bar.

7.3. Final Top Flange Assembly (Welding of sub-assembly 1 and sub-assembly 2)

For final assembly welding, four clamping conditions and three welding sequences have been assessed. With a common clamping condition (minimum clamps), best welding sequence was finalized, and the same welding sequence was then used to optimize the clamping condition. Results of the optimized clamping condition and the welding sequence, which provides the minimum distortion are shown here.

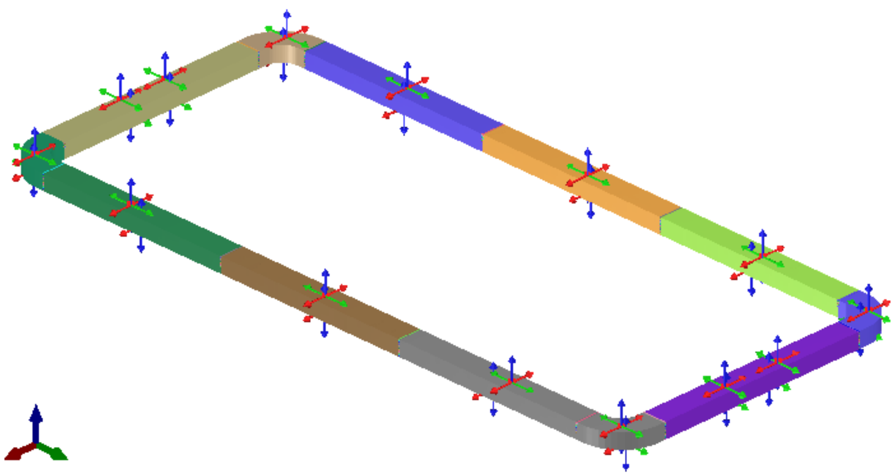


Figure 31: Clamping details of top flange assembly

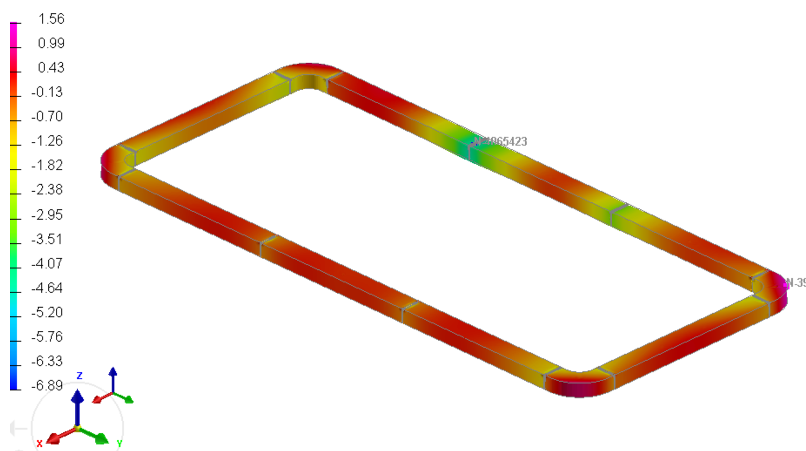


Figure 32: Welding distortion of top flange assembly

As shown in fig 32, In the optimized condition, the maximum distortion of 1.56 mm in positive Z direction and 6.89 mm in the negative Z direction of the top flange in the clamped condition.

As seen in fig 32, maximum distortion values are mainly in the unsupported location of the top flange. During welding of top flange with the main shell assembly, top flange shall be kept in the clamped condition. The necessary distortion removal followed by the weld edge preparation shall be done through the machining.

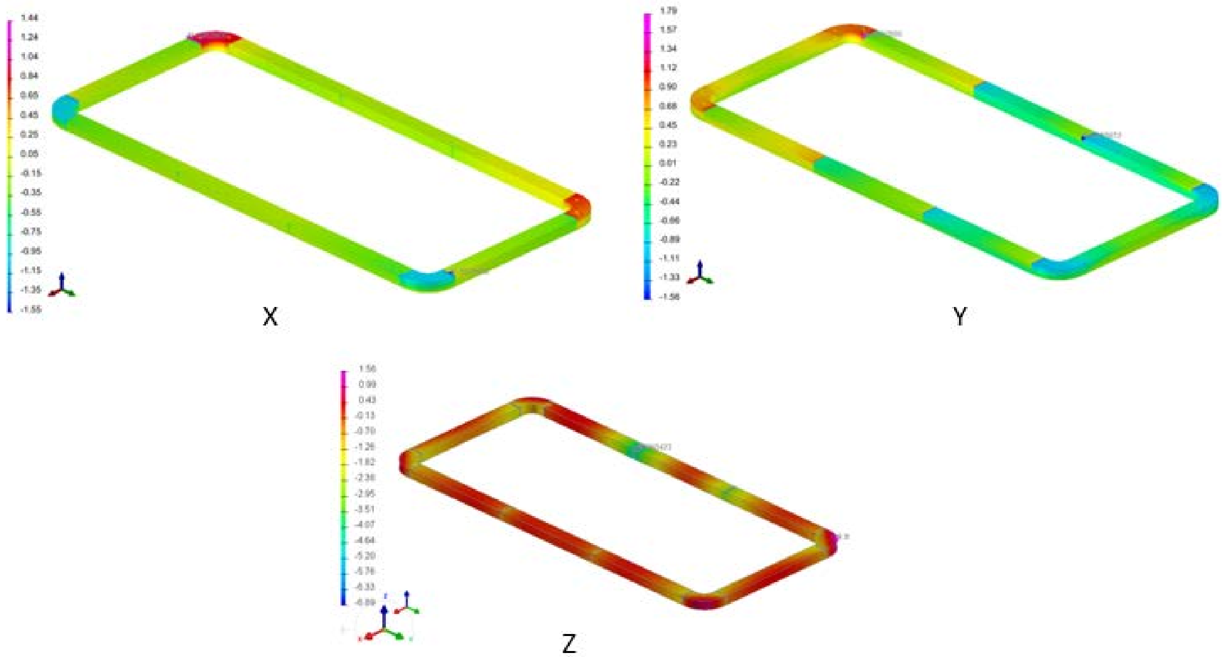


Figure 33: Directional distortion results for top flange assembly

To estimate the machining allowance in different location, the welding distortion pattern were examined in X, Y and Z direction and they are as presented in fig 33. In X and Y direction, the maximum distortion is 1.5 mm, whereas the maximum distortion in Z direction is 6.89 mm. Machining of the sub-assemblies are also considered before the final welding of top flange assembly. Considering the machining of the subassemblies, the maximum distortion of the top flange assembly has been reduced to 1.58 mm in the positive Z direction and 2.89 mm in the negative Z direction.

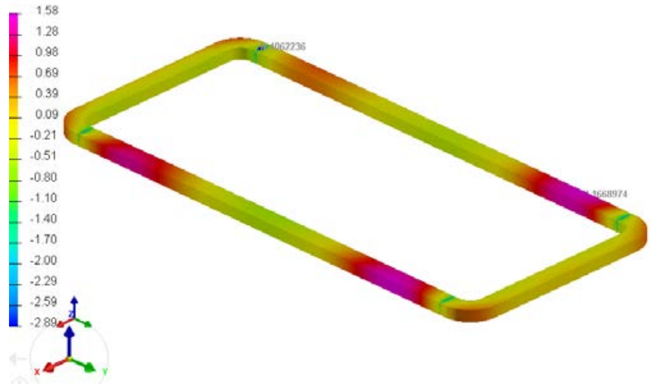


Figure 34: Welding distortion considering sub assembly machining

8. Welding of Main shell and flange assembly

Main shell and flange welding shall conform to full penetration butt weld with 100 % volumetric examination. After final welding of flange, machining will be done to form a step at the bottom of flange with the thickness of 25 mm (equal to the plate thickness) (see fig. 35). Weld map of this shall be exactly similar to the main shell welding for plate to plate of 25 mm thickness.

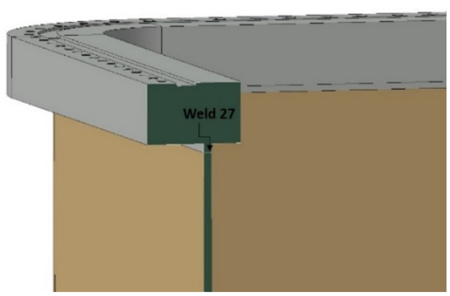


Figure 35: Welding of top flange with main shell

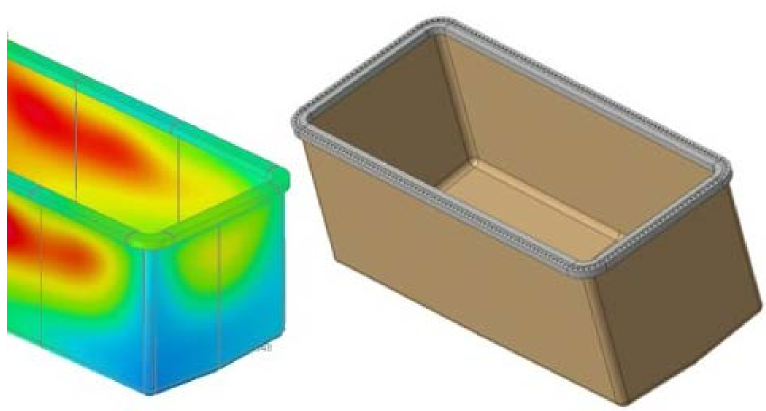


Figure 36: Welded assembly of top flange and main shell

Fig 37 shows the clamping details and optimized welding sequence of the top flange to main shell welding. This shall be the full penetration welding of 25 mm thickness main shell plate and a lip of 25 mm thickness machined from the top flange. Profile matching of the weld edge defined in the fig 35 shall be one of the critical activities in the vessel fabrication. Additional clamps shall be employed around the weld edge to match them and perform the welding.

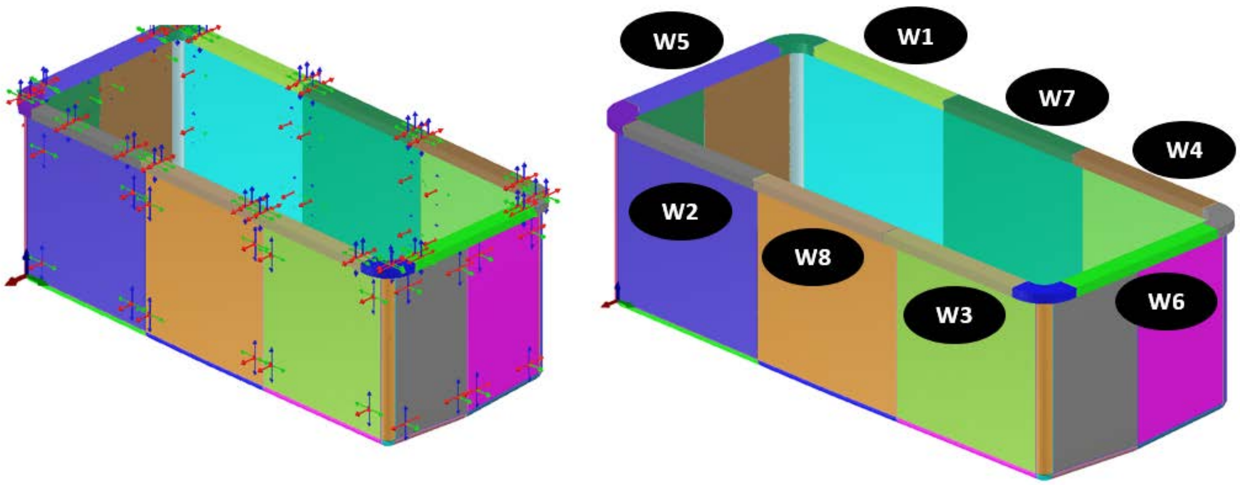


Figure 37: Clamping and weld sequence for main shell to flange welding

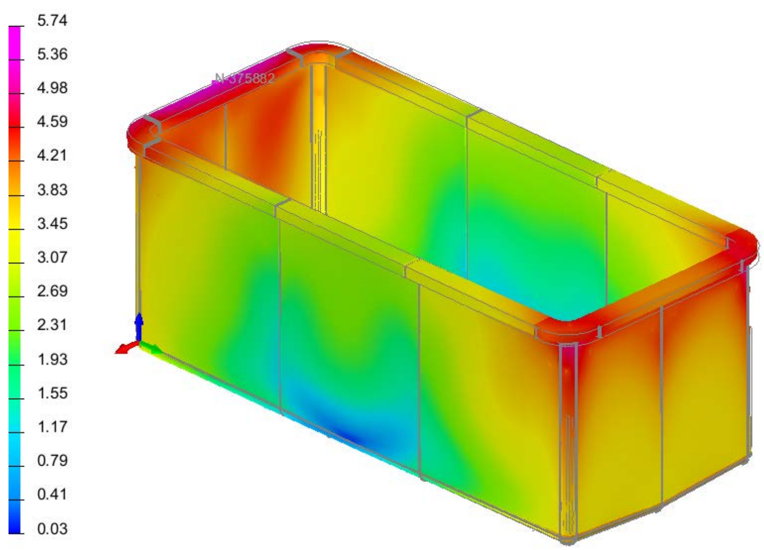


Figure 38: Welding distortion for main shell to flange welding

Fig 38 shows the maximum distortion of 5.74 mm in the top lid to main shell welded assembly. These distortions are mainly at the end portion of the main shell.

To reduce the overall distortion, another methodology was adopted, wherein the top flange was machined to the nominal dimensions (to nullify the distortion) before its welding to the main shell. This approach has reduced the final distortion to less than 1 mm (0.95 mm). Fig 39 shows the distortion results from this approach.

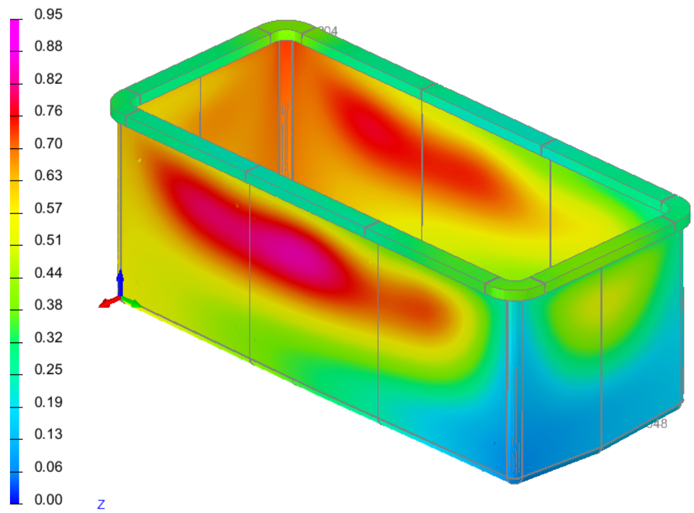


Figure 39: Welding distortion for machined subassembly welding

9. Stiffeners and support welding for the Main shell

T-stiffener can be manufactured from drawing operation from a mill ingot. Also, there is option available to fabricate them from plate by welding or even they can be a forged section also. The selection of the manufacturing process shall be in optimised way based on the supplier's recommendations.

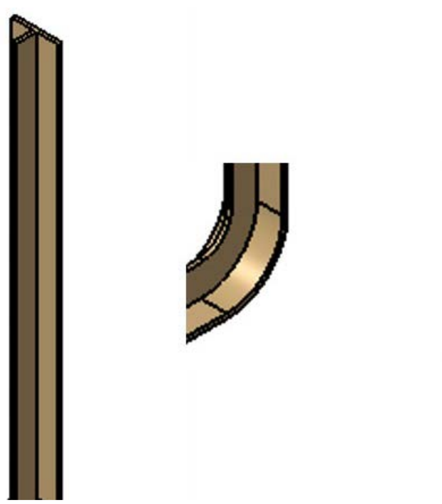


Figure 40: Stiffeners

The Welding of the stiffeners shall be done on the main shell. Welding sequence has been optimized in order to get the least welding distortion. Supports are not considered for the welding distortion analysis, however, continuous stiffeners are considered at the bottom support location as shown fig 41.

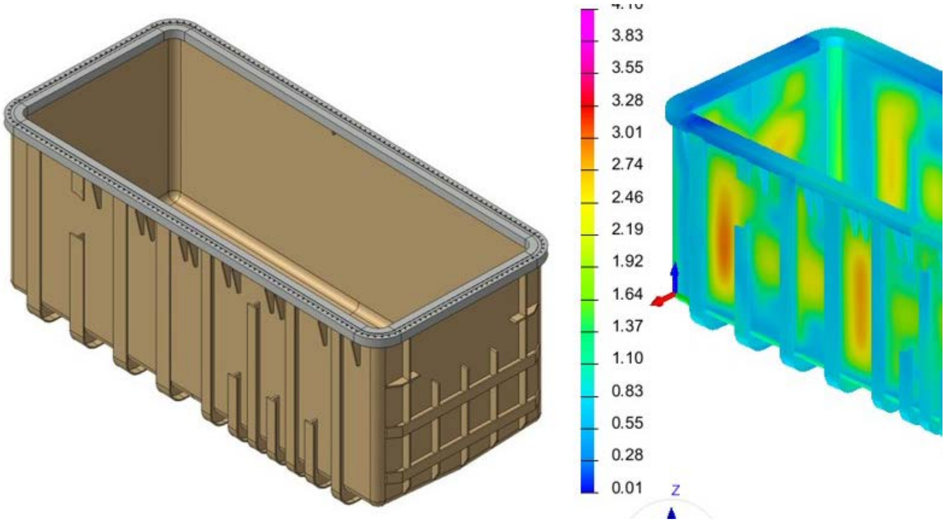


Figure 41: Stiffeners welded with the main shell

Fig 42 shows the clamped condition of stiffeners during stiffeners welding to the main shell. Welding sequence are also staggered as shown in fig 43 to control the weld distortion. The small stiffeners near the top flange shall be welded at the end.

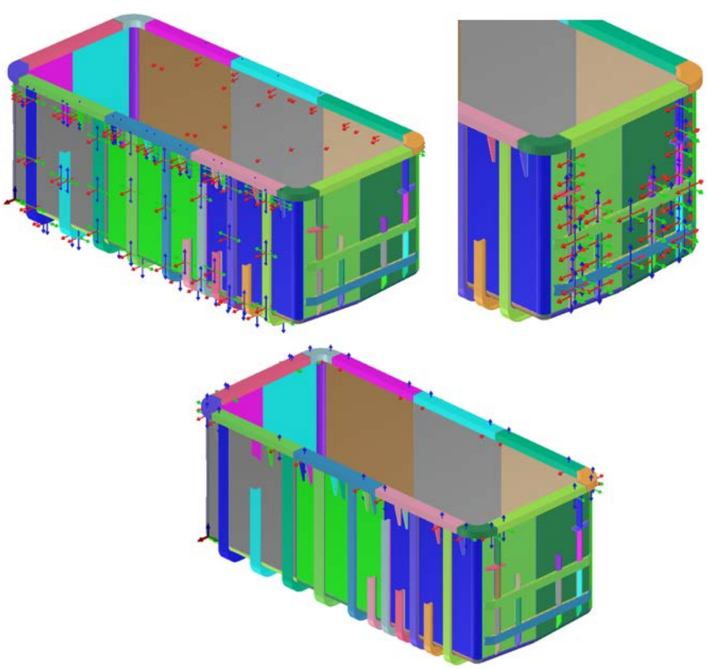


Figure 42: Clamps for stiffener welding

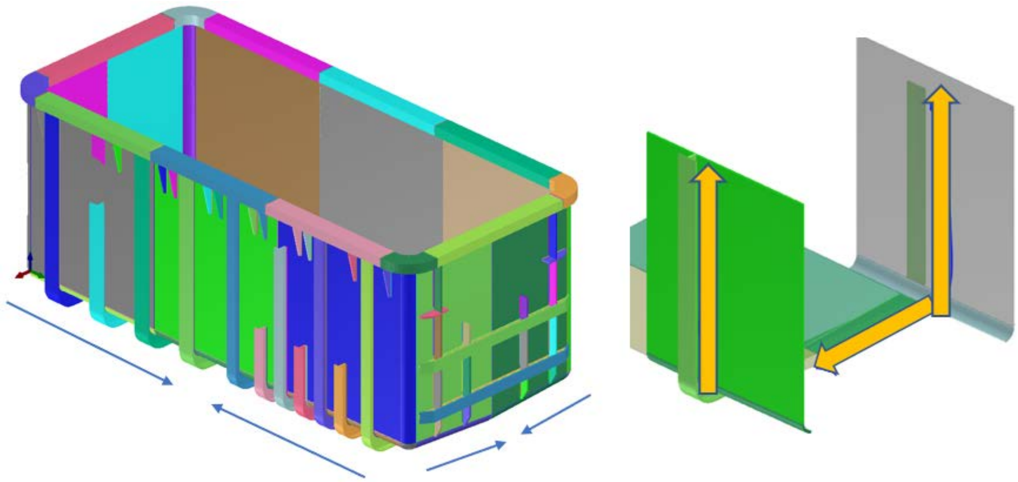


Figure 43: Welding sequence for stiffener welding

For the stiffener welding, there are two strategies has been adopted. Weld distortion assessment has been done for the full penetration (groove + fillet) and fillet weld configuration. It may be noted that the use of fillet weld configuration will considerably reduce the weld heat input and thus reduce the overall distortion. Firstly, results of the full penetration groove + fillet case are presented and discussed.

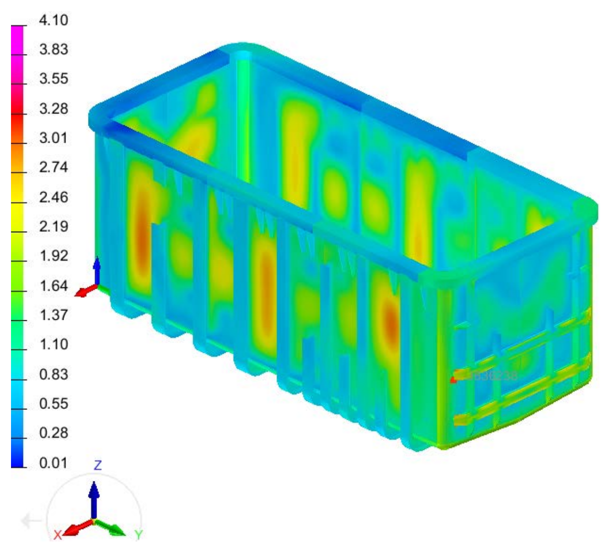


Figure 44: Welding distortion after stiffener welding

Fig 44 shows the distortion behaviour of the DNB vessel with welded stiffeners. Maximum distortion of 4.10 mm is observed on the side plates. Fig 45 shows the direction distortion pattern, which shows the distortion is distributed in the all the directions and that too in the unsupported portions (in between the stiffeners) of the shell.

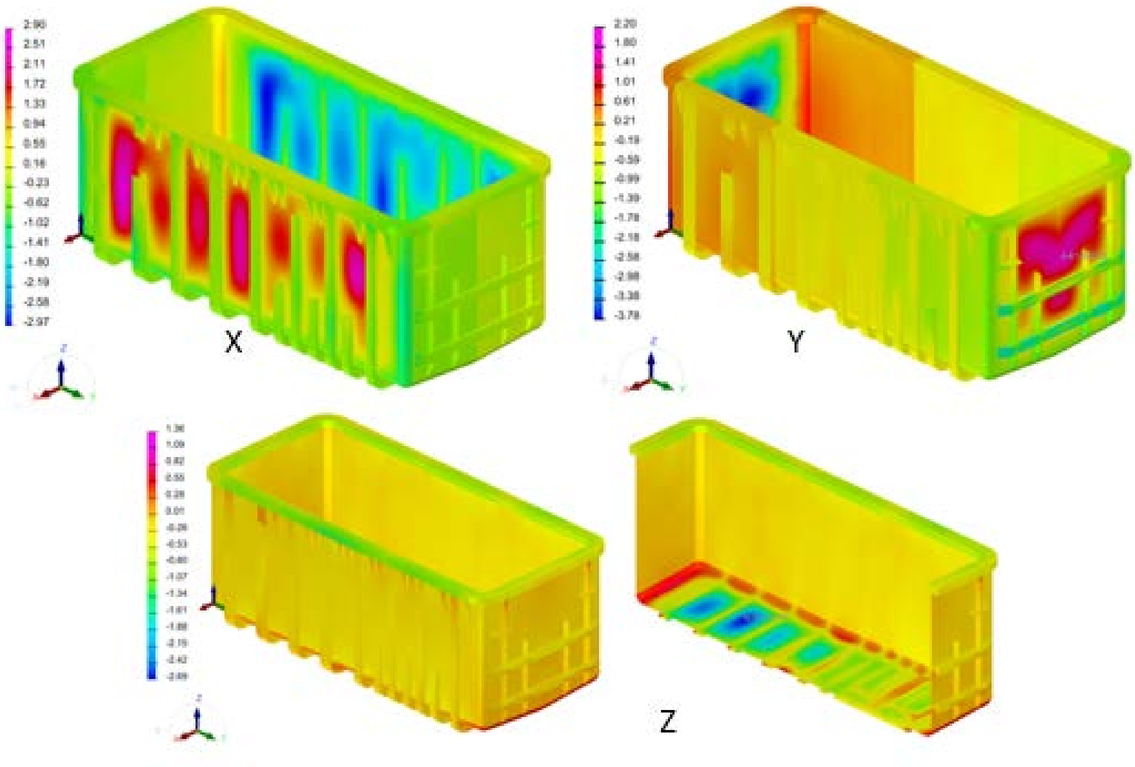


Figure 45: Directional weld distortion pattern for stiffener welding

10. Manufacturing of Feedthroughs

After the welding of stiffeners, port marking and opening on the main shell shall be done as shown in fig 46. Port opening can be done by the gas or plasma cutting and finally grinding and machining to match the dimensions and profiles. The final selection of the process shall be based on the manufacturer experiences and industrial practices. Opening shall be provided on the main shell for the following connections:

- BLCs Hydraulic (PHTS) connection – 10 openings
- Neutralizer Gas connection – 1 opening
- RID HV connection – 1 opening
- Beam Source actuators connections – 3 openings
- Calorimeter actuator connection – 1 opening
- Feedthrough box connection – 1 opening
- Foreline connection – 1 opening

- Vacuum Instrumentation – 4 openings
- Drain line – 1 opening
- Cryolines – 1 opening
- High voltage bushing – 1 Opening
- Fast shutter – 1 Opening

Details in terms of size, location and configuration for all the feedthroughs and corresponding interface are provided in the Design description document.

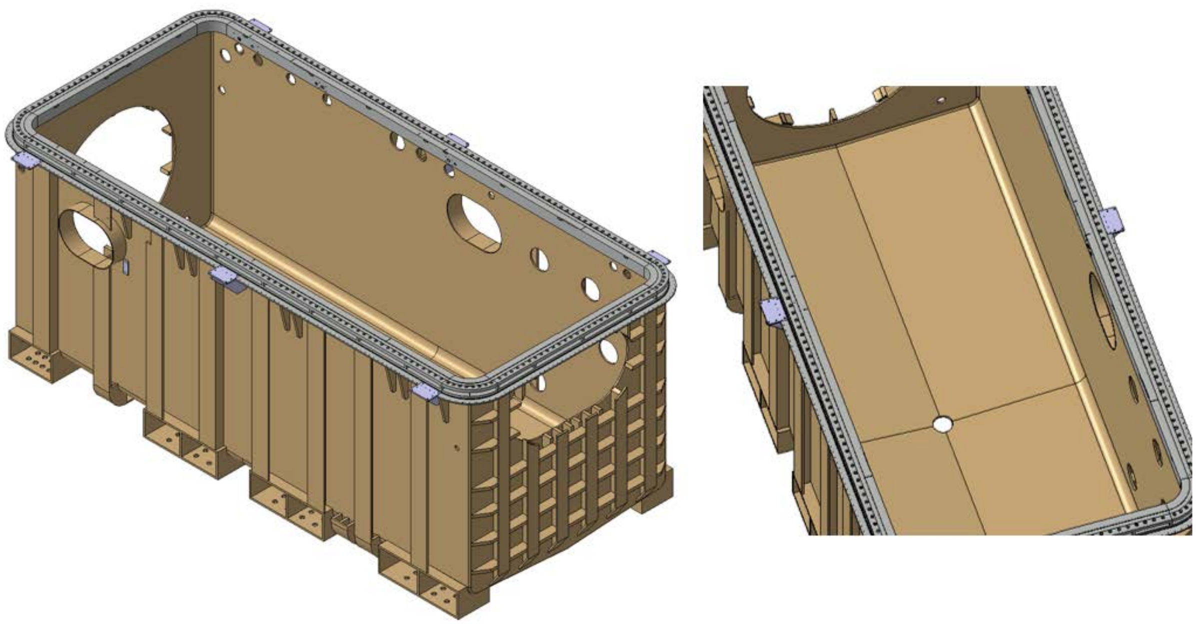


Figure 46: Opening for the feedthrough's connection with DNB Vessel

After the port marking and opening, all the feedthroughs shall be welded with the vessel. In order to meet the requirement of Full penetration butt weld with the 100% volumetric examination, Configuration is designed for the feedthrough welding, as shown in fig 47. This can be manufactured from forging and shall be machined out to get the desired dimensions. The forging shall meet the additional requirements on the inclusion content imposed by IVH. The welding details for the feedthrough joining with the vessel wall is shown in fig 48.

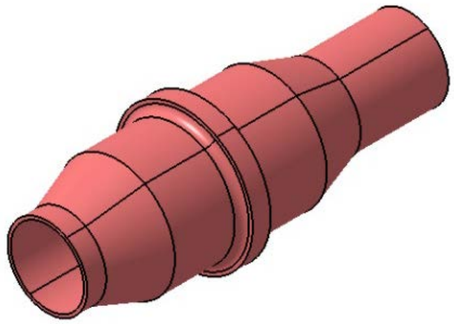


Figure 47: Feedthrough configuration

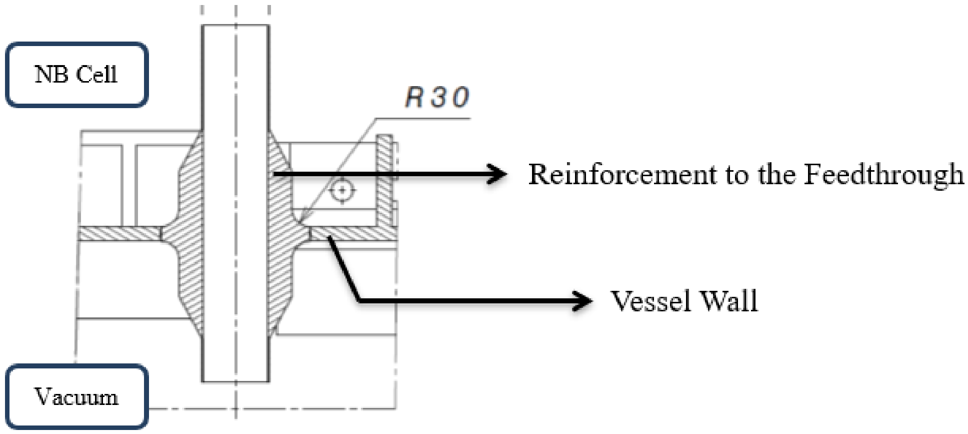


Figure 48: Welding configuration for feedthrough connection with the vessel

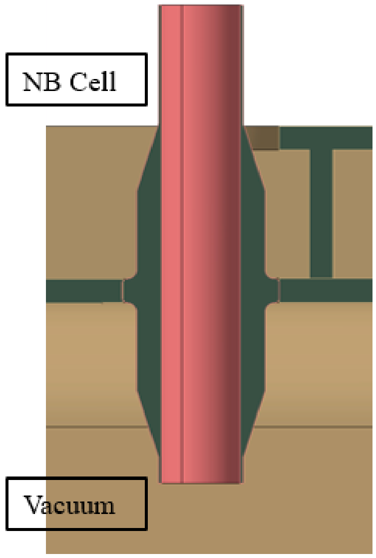


Figure 49: Welded connection of feedthroughs

Fig 50 shows the finally welded feedthroughs on the vessel wall. All the feedthrough welds are the vacuum boundary welds and shall be welded with full penetration butt weld configuration as show in fig 49.

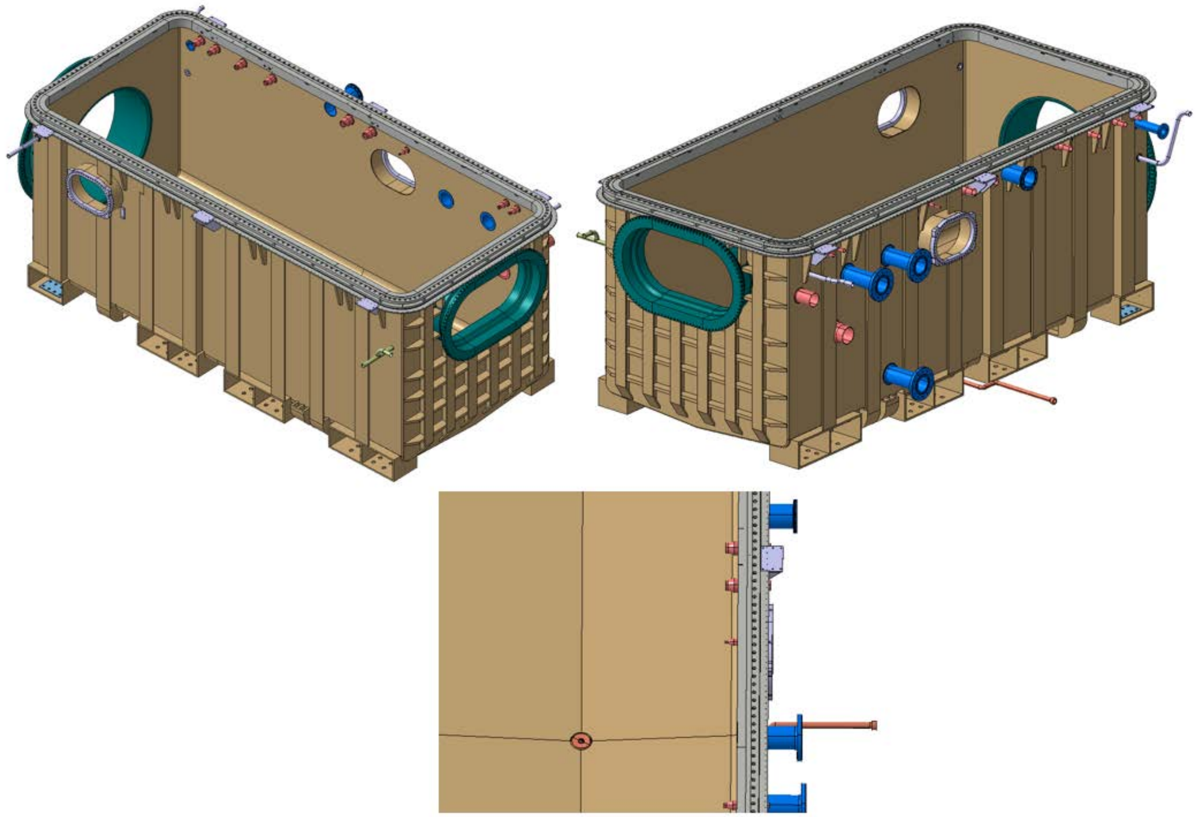


Figure 50: Welded feedthrough connection with DNB Vessel

In case of manufacturing of large size flanges for Front (FS side), rear (HVB side) and cryo, it is preferable to manufacture this as a single forged component. As an option this can be manufactured from forged ring (or rolled plate with longitudinal seam welded is the dimensional tolerances can be achieved) and forged flange. The welding involved shall be as per the requirements of VQC 1A. Fig 20 shows the individual flanges of front, rear and cryo. These flanges will be welded on the main shell, front flange shall be provided for attaching the fast shutter and rear end will connect the high voltage bushing. Cryo flange will be used for giving the cryolines connection to the DNB cryopump. Fig 52 shows the welding configuration considered for the welding of front, rear and cryo flanges.

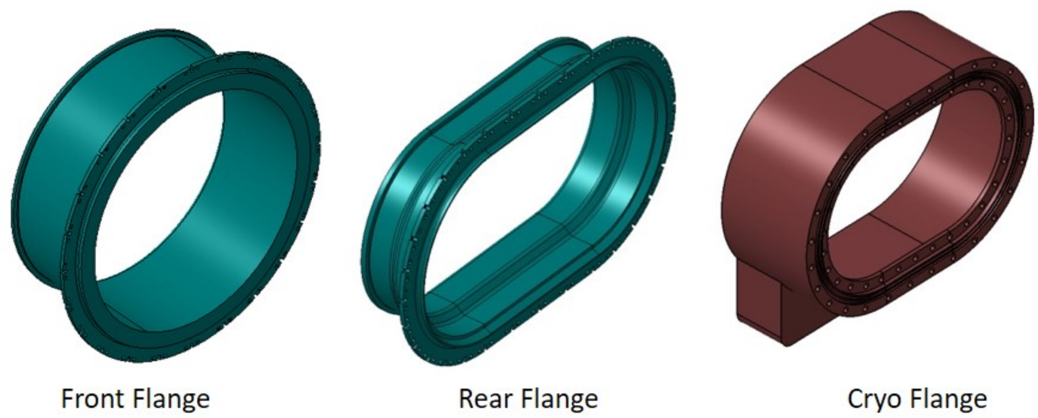


Fig:

Figure 51: Front flange (Fast shutter FS)), rear flange (HVB) and Cryoflange

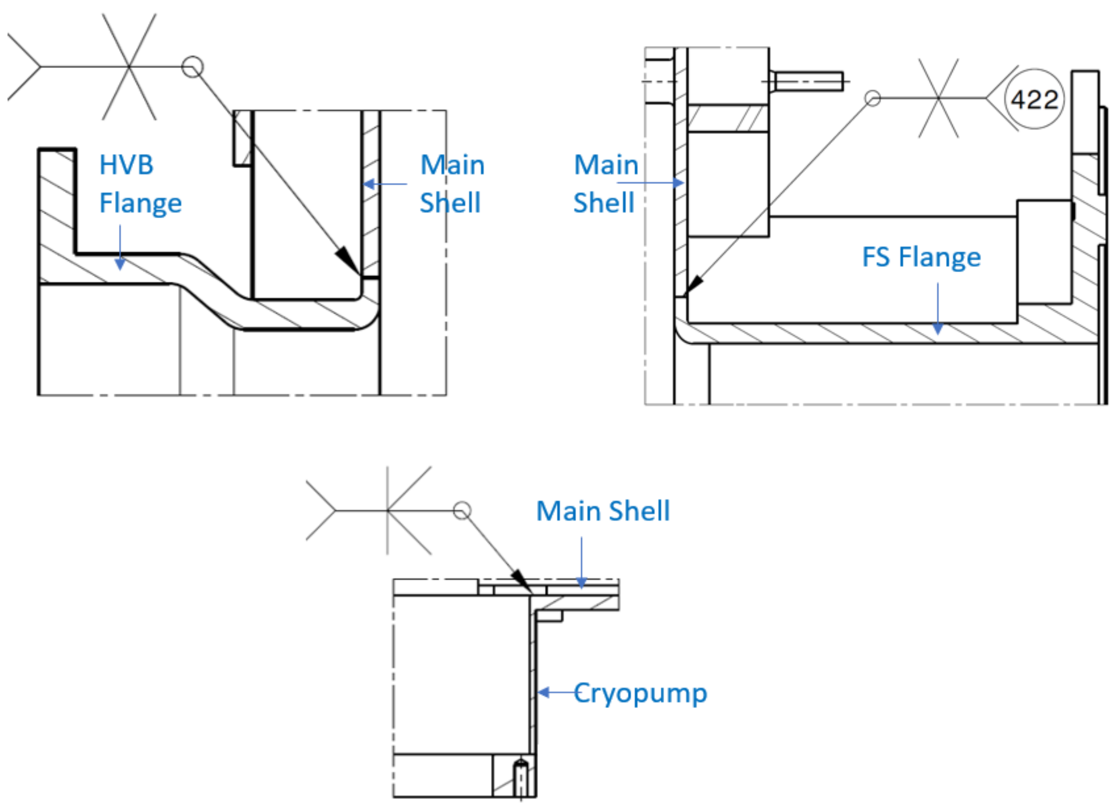


Figure 52: Welding configuration for HVB, FS and cryo flange

In the distortion analysis, only HVB and Fast shutter nozzle welding has been considered while other feedthrough connection nozzles are not considered as they shall have very small weld length and have negligible effect on the overall vessel distortion. Fig 53 shows the welding sequence considered for the Fast shutter flange welding and HVB flange welding. The estimated distortion pattern arising out of these welding is shown in fig 54.

Note: The fast shutter flange (including the neck) and HVB flange (including the neck) are prefabricated using the forging and plate and they are considered as ready to match with the vessel main shell in full penetration butt welding configuration.

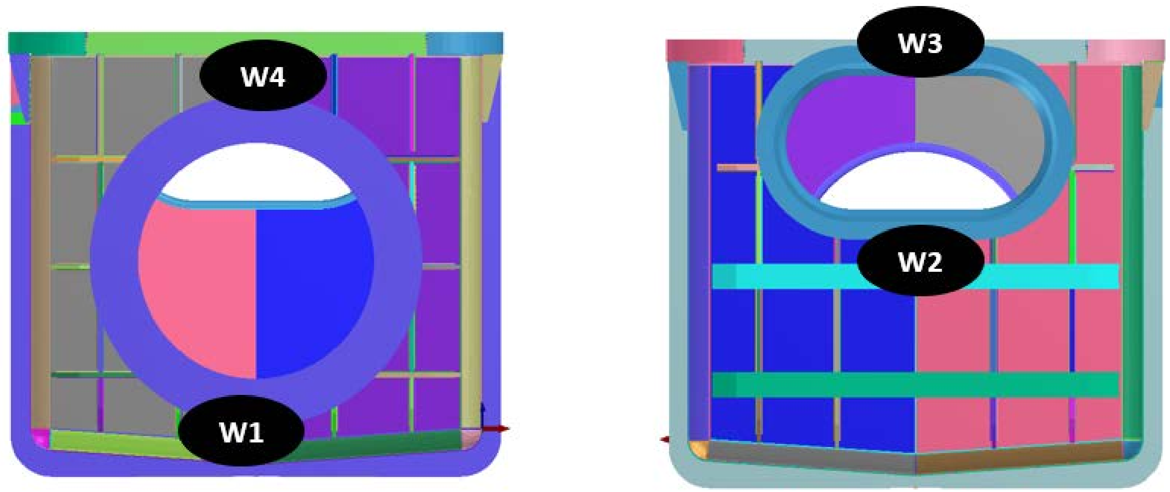


Figure 53: Welding sequence for ES and HVB flange

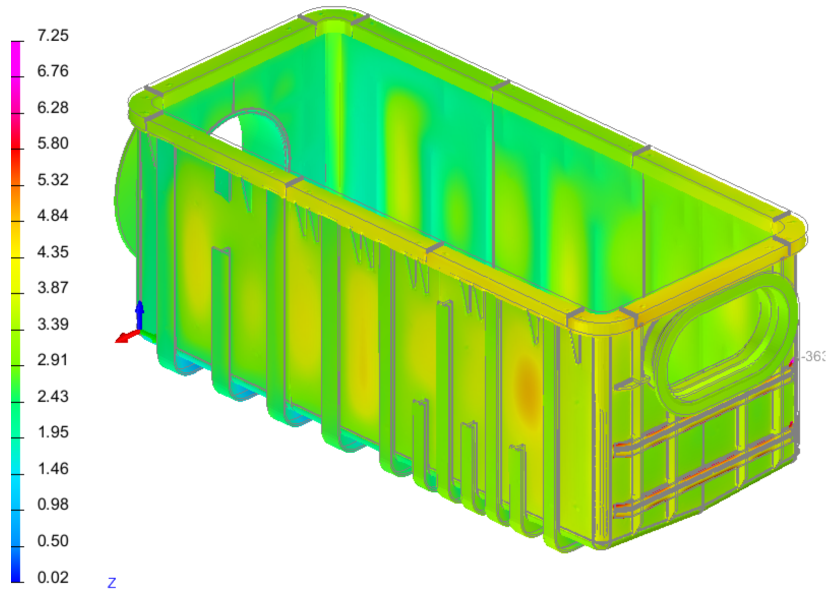


Figure 54: Welding distortion after FS and HVB flange welding

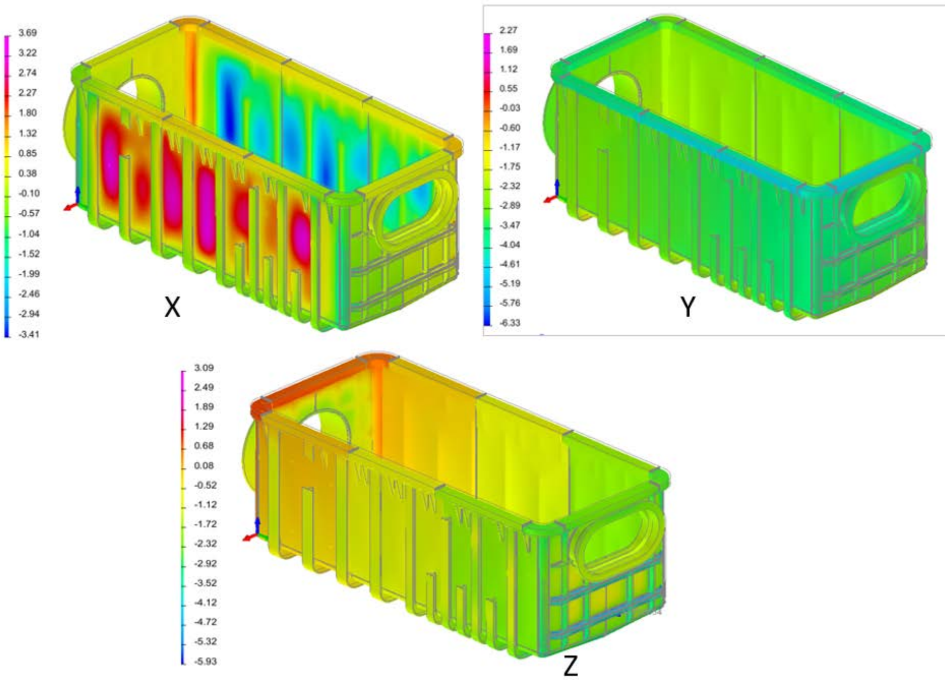


Figure 55: Directional weld distortion after stiffener welding

Maximum distortion of 7.25 mm is observed on the main shell after all the welding considered for the main shell fabrication, as shown in fig 54. Directional weld distortion results are presented in fig 55.

Distortion estimate with the fillet weld configuration for stiffeners:

A similar analysis was carried out for the fillet weld configuration. Fig 56 shows the final results after considering all the fillet weld stiffener joints and the maximum distortion has been reduced to 3.27 mm from 7.25 mm.

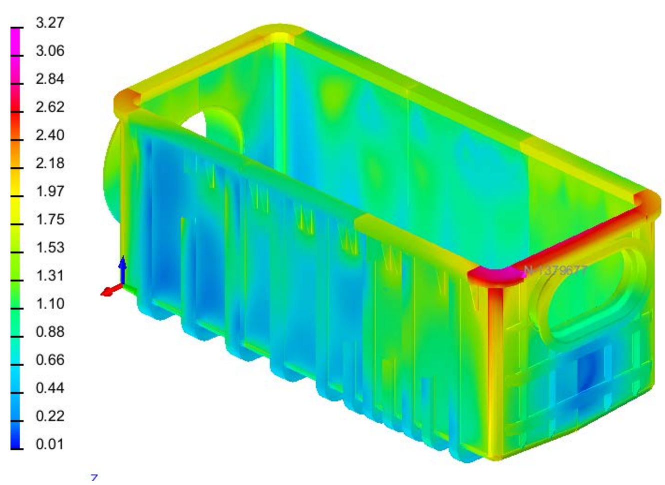


Figure 56: Welding distortion considering fillet weld configuration

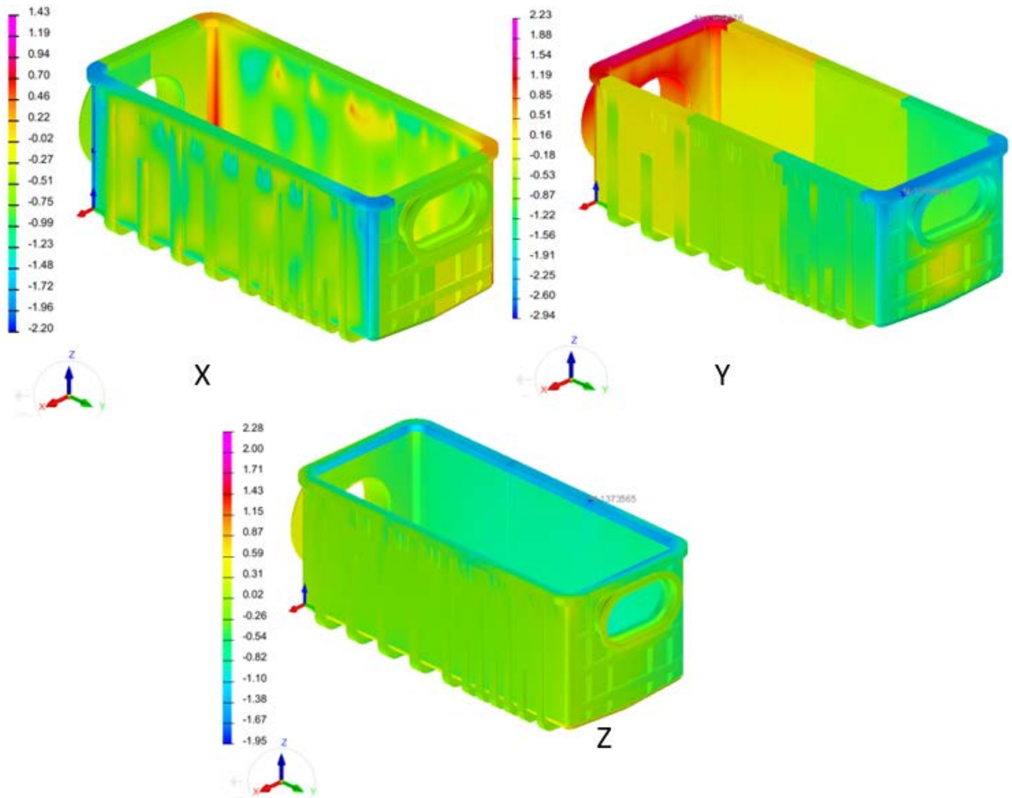


Figure 57: Directional weld distortion considering fillet weld configuration

Further, as shown in fig 58, due to stiffener welding, the vessel is tending to distort inward along the long side of the vessel. This is given by distortion in X direction as presented below.

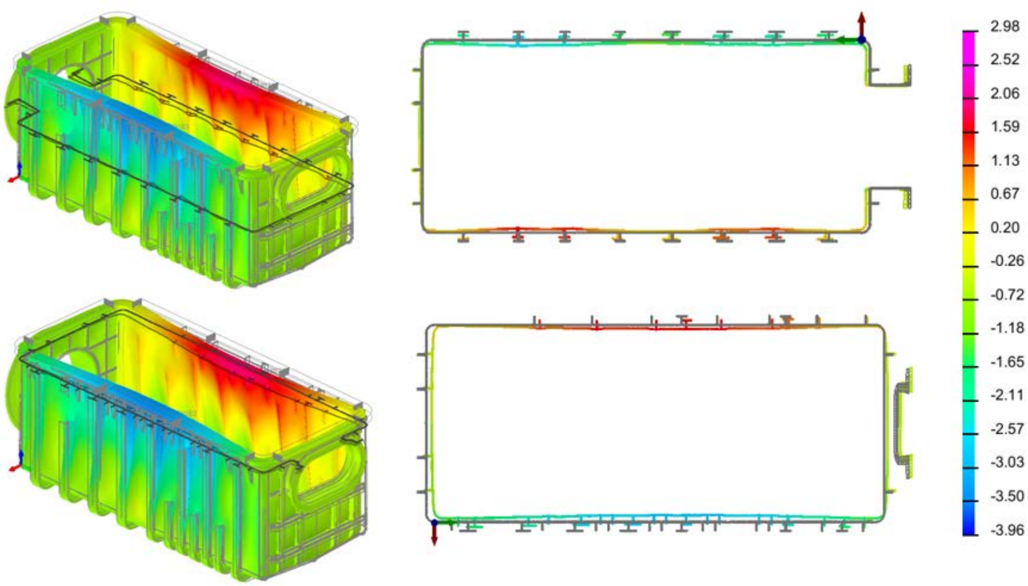


Figure 58: Welding distortion (X-direction)

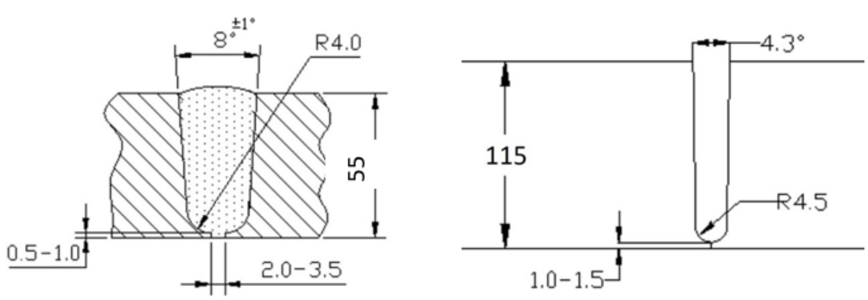
Distortion results has been analyzed by taken cross section at two different location, one at the center line of the vessel (indicated by black line in upper photograph of fig 58) and other at the top flange location (indicated by black line in lower photograph of the fig 58). The maximum distortion in the assessment is at the top flange location, of ~3.96 mm inward along the long side of the vessel.

As per the discussion with manufacturer, this distortion can be nullified by machining after welding. However, machining at the sub-assembly level is also expected to reduce the distortion level.

11. Manufacturing of Top Lid

Top lid of the DNB vessel is an enclosure for the main shell and forms a vacuum boundary. The top lid will be attached with the main shell with 220 no. of bolts and metallic seal shall be used for the vacuum sealing requirement. The top lid design of the DNB vessel consists of the flange and formed plate. The flange having a thickness of 115 mm will be in contact with the main shell flange and the central formed plate (55 mm thickness) will be welded with the flange to form a top lid as shown in fig 59.

Typical WEP for top lid welding



The transition of the 115 mm flange thickness has been given to form a butt weld configuration with the plate of 55 mm thickness, as shown in fig 60

The typical weld plan for the full penetration butt welding configuration of flange to formed plate welding is shown above.

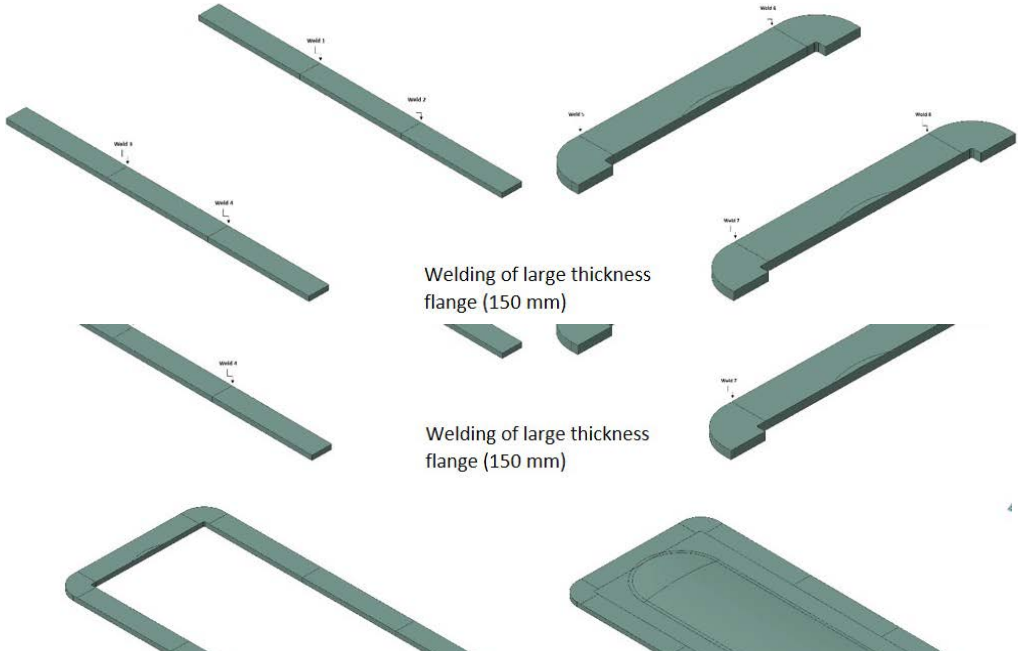


Figure 59: Welding of top lid assembly

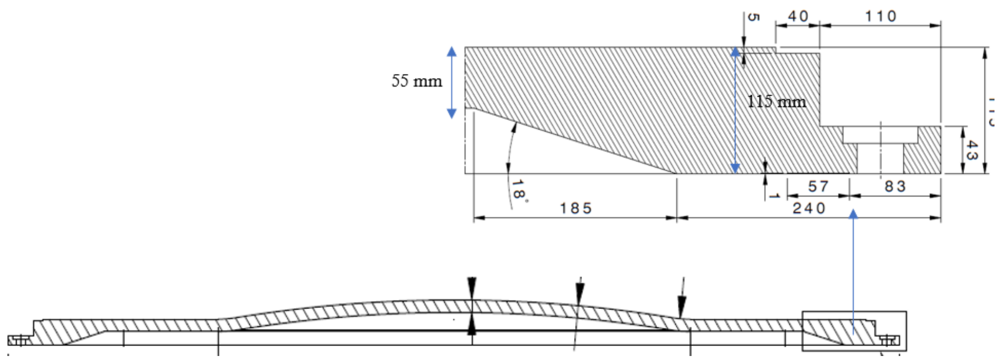


Figure 60: Transition welding of top lid flange and plate

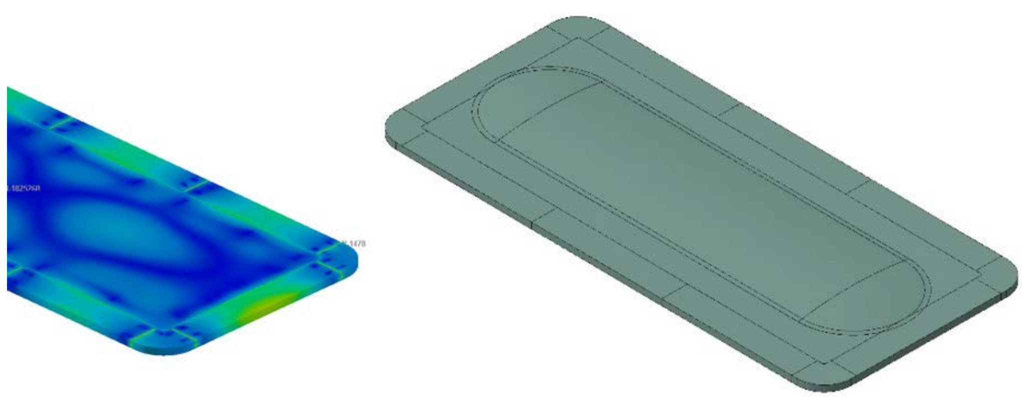


Figure 61: Welded assembly of top lid

12. Welding of Top Lid Flange

Meshing of the top lid CAD model is done in the Visual Mesh 15.5 module. Hexagonal elements have been considered for the meshing, fine mesh around the weldment is done to capture the proper shrinkage in the assembly. In similar to vessel flange, as per the manufacturing sequence, top flange is also divided in to different subassemblies for the welding distortion analysis. Fig 62 shows the meshed model of the top lid used for the welding distortion analysis.

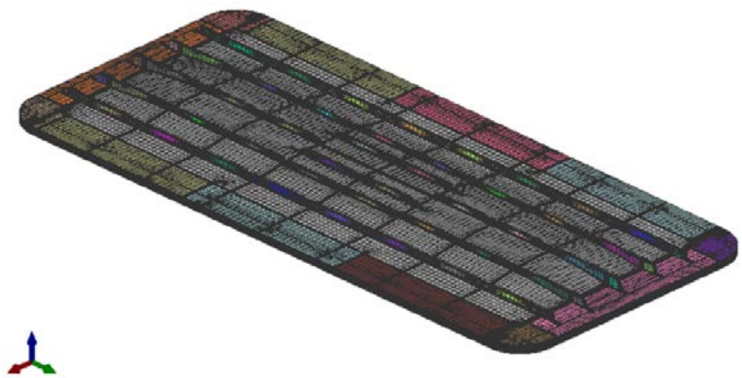


Figure 62: Meshed model of top lid

12.1. Sub Assembly 1 – Side bar

Two clamping conditions and one welding sequence are assessed for fabricating the side bar. Optimized results in terms of the clamping condition and weld distortion are shown here.

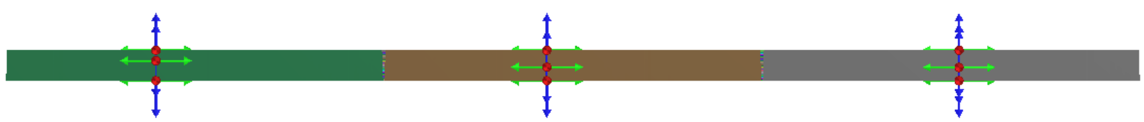


Figure 63: Clamping of side bar

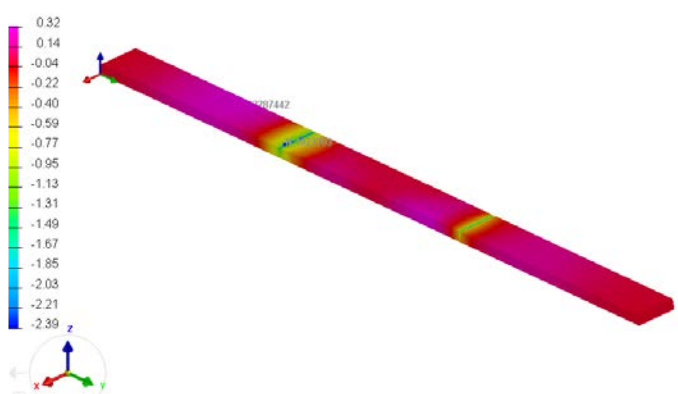


Figure 64: Welding distortion of side bar

Maximum distortion of 0.32 mm in the positive Z direction and 2.39 mm in the negative Z direction is observed in the clamped condition at the ends of the side bars. As these subassemblies will be welded in the clamped condition, so these distortion values shall be considered for the final welding of the top flange assembly.

12.2. Sub-Assembly 2: End Bar

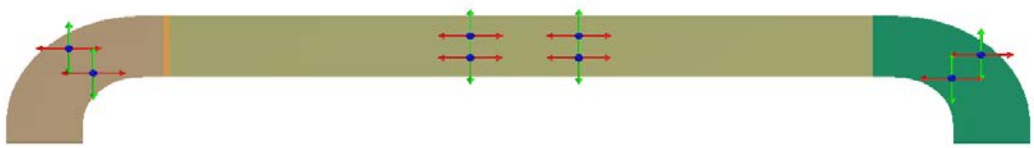


Figure 65: Clamping of end bar

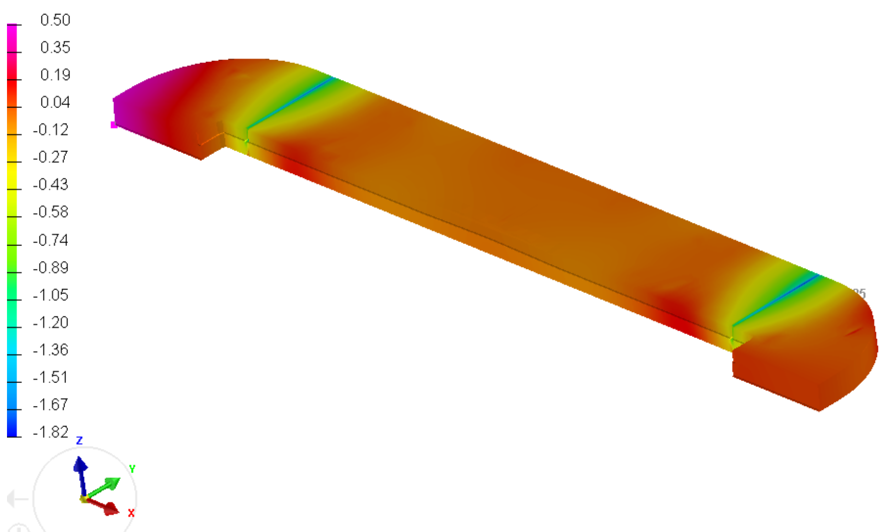


Figure 66: Welding distortion of end bar

Maximum distortion of 0.50 mm in the positive Z direction and 1.82 mm in the negative Z direction is observed in the clamped condition at the ends of the end bars.

12.3. Final Top lid Flange Assembly

For final assembly, four clamping condition and three welding sequence has been considered for the analysis. With a common clamping condition (minimum clamps), best welding sequence was finalized, and the same welding sequence was used to optimize the clamping condition. Optimized results in terms of the clamping condition and weld distortion are shown here.

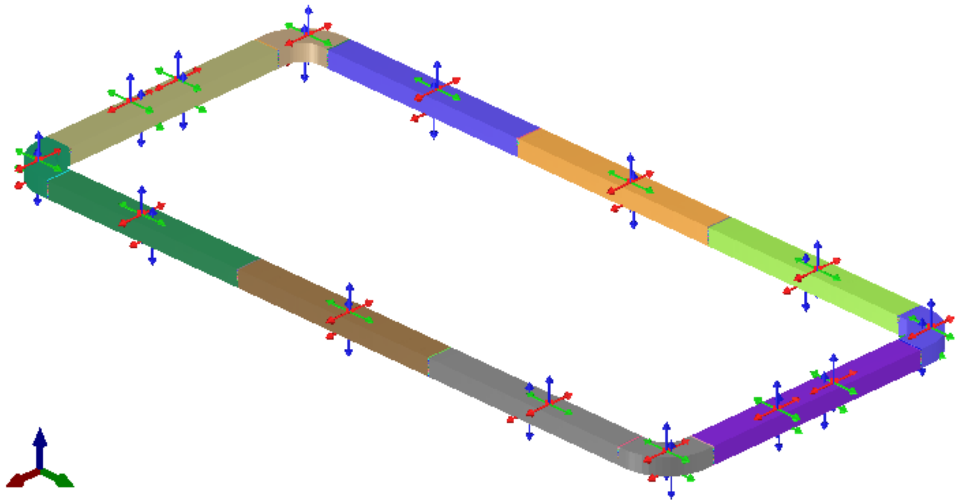


Figure 67: Clamping of top flange

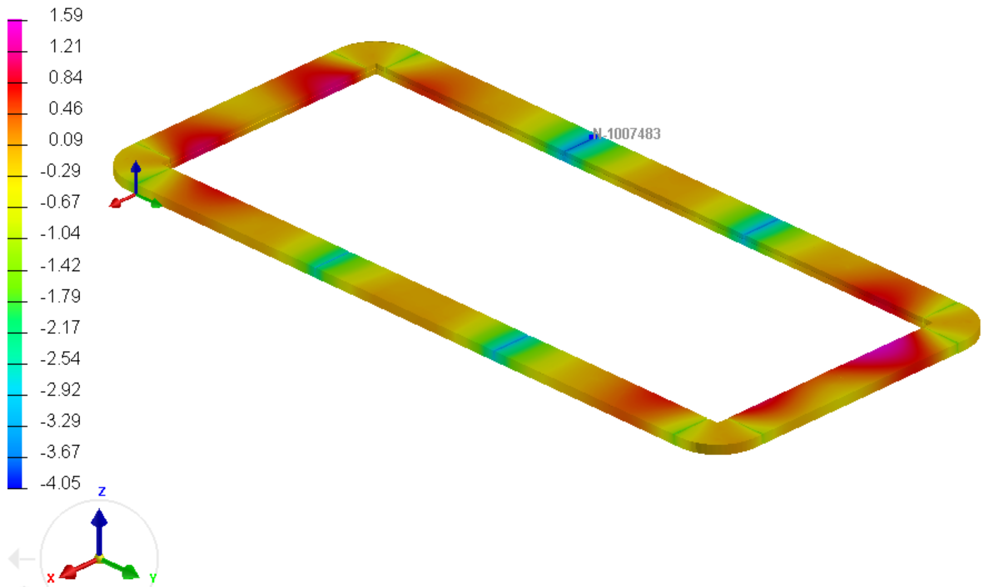


Figure 68: Welding distortion of top lid flange

Fig 67 shows the optimized clamping condition of top flange welding and fig 68 shows the maximum distortion of 1.59 mm in positive Z direction and 4.05 mm in the negative Z direction of the top flange in the clamped condition. Maximum distortion values are mainly in the unsupported location of the top lid flange as shown in fig 68. As the top flange shall be welded to the main shell assembly, this shall be kept in the clamped condition.

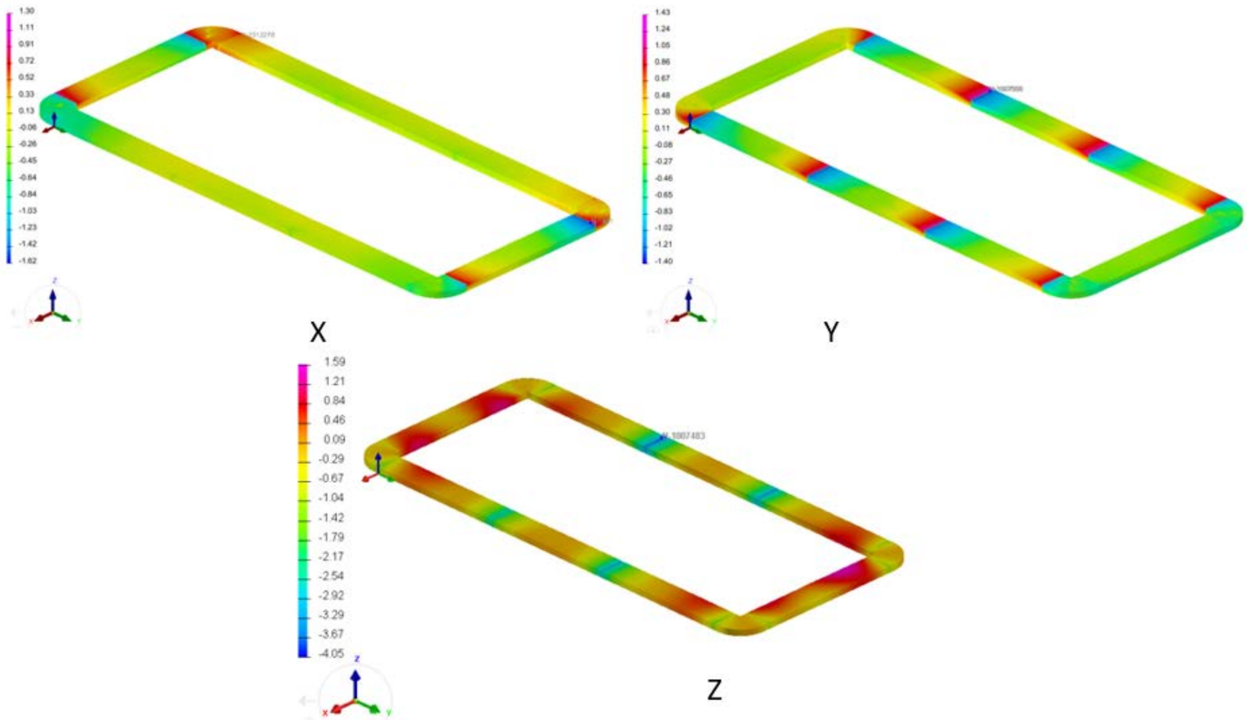


Figure 69: Directional welding distortion of top lid flange

Fig 69 shows the welding distortion pattern of the top flange in X, Y and Z direction. In X and Y direction, the maximum distortion is 1.5 mm, whereas the maximum distortion in Z direction is 4.05 mm.

13. Welding of Top lid flange with formed plate

In this section, welding of the top lid flange of 115 mm shall be welded with the formed plate of 55 mm. Transition shall be given between 115 to 55 mm to make the butt weld configuration as shown in fig. Full penetration weld has been considered for this weld joints also.

Three different clamping condition and welding sequence has been studied for this welding. Optimized clamping and welding sequence results are discussed here.

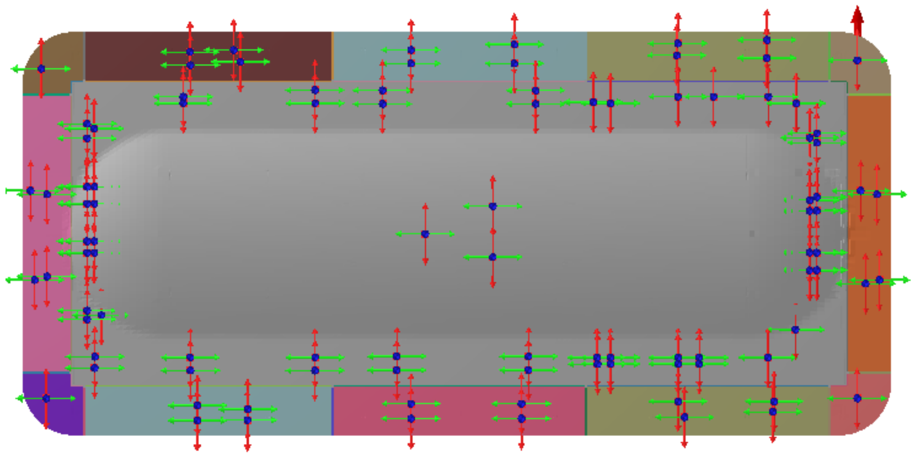


Figure 70: Clamping of top lid welding

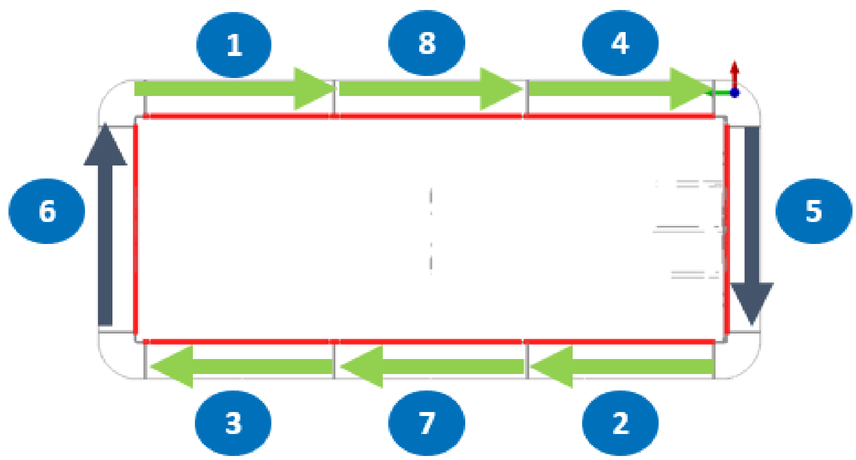


Figure 71: Welding sequence for top lid welding

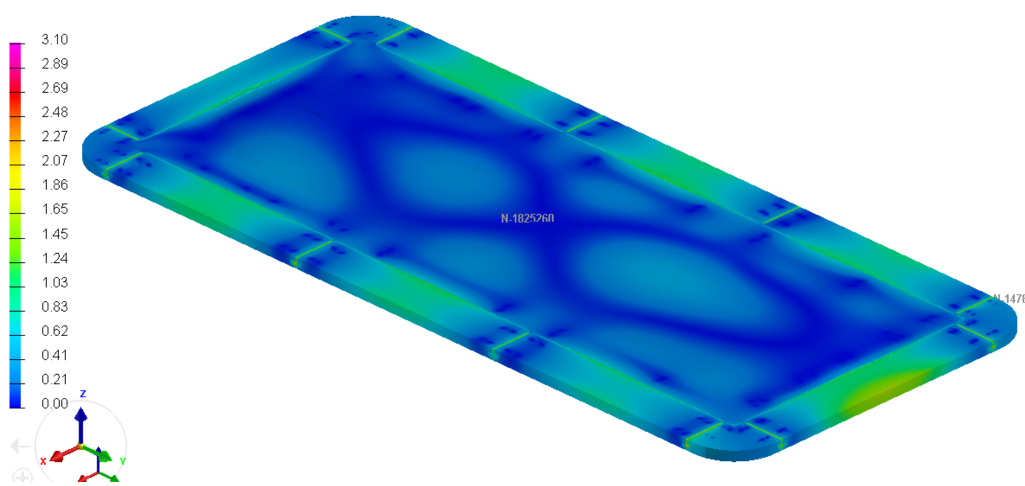


Figure 72: Welding distortion of top lid

Fig 72 shows the maximum distortion of 3.10 mm after the welding of top flange and formed center plate. The maximum distortion value is very localized and average distortion value is mainly in the range of 1 – 2 mm. Direction distortion pattern are also plotted and shown in fig 73.

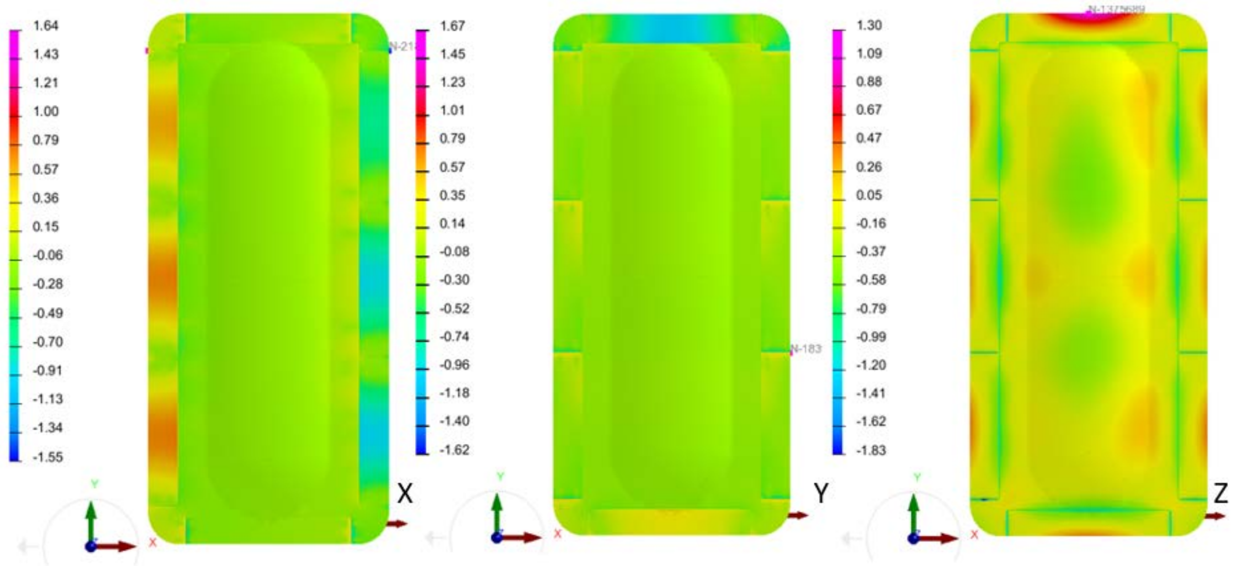


Figure 73: Directional welding distortion pattern

14. Welding of top lid stiffeners

In the next step, stiffeners shall be welded. There are two different orientations (along the length and width) of stiffeners mounted on the top lid. In similar to the main shell stiffener welding, full penetration weld and fillet weld are studied. Fillet weld configuration has reduced the overall distortion of the top lid and results of the same are discussed here.

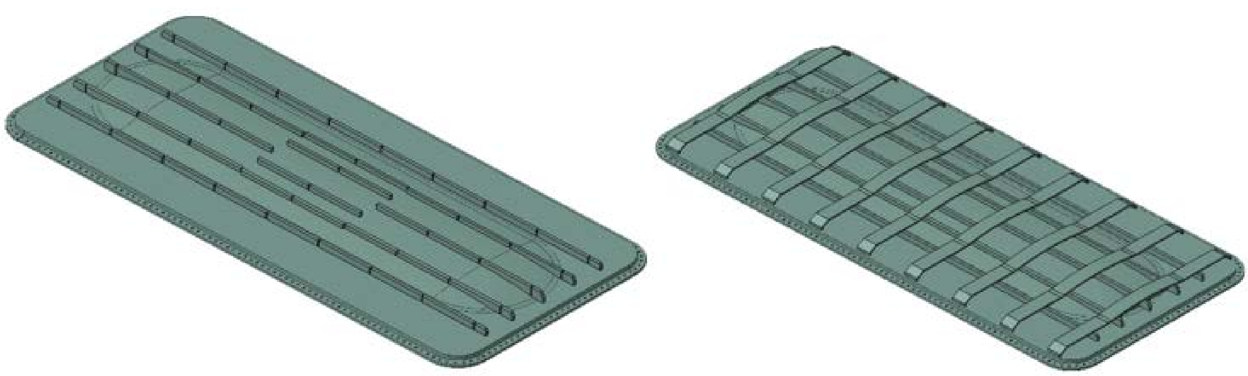


Figure 74: Top lid stiffeners

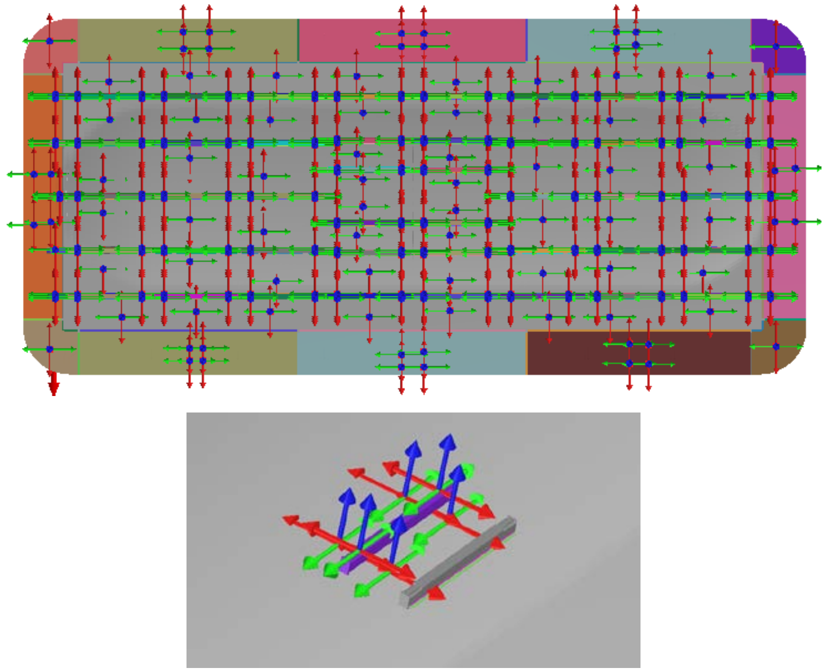


Figure 75: Clamping details for stiffener welding

For the first step, stiffeners along the length shall be welded and the fig 75 shows the clamps distributions considered for the welding. These clamps shall be used for constraining the motion of global assembly in all direction. In addition to these, local clamps are also provided for controlling the local distortions for the specific stiffeners as shown in fig 75 (below image). Local clamp is to be shifted as the stiffener welding progresses to allow the welding accessibility. Five different welding sequences are studied for arriving at an optimal stiffener welding sequence shown in fig 76 and the results of the same are discussed here.

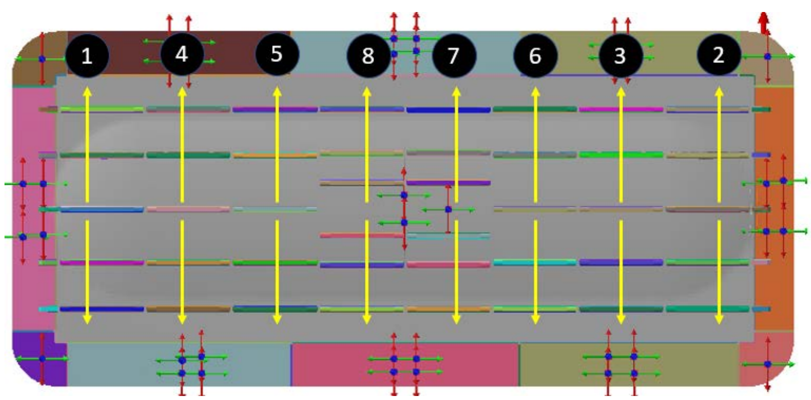


Figure 76: Welding sequence for stiffener welding

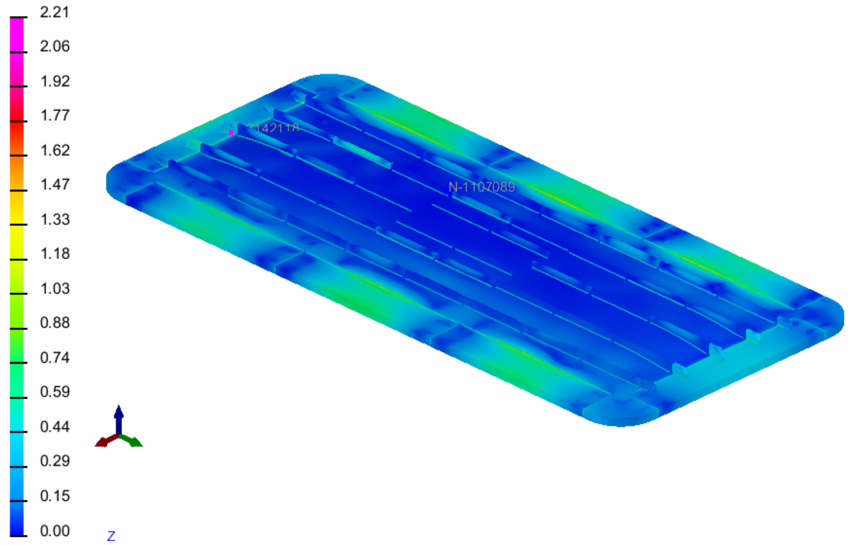


Figure 77: Welding distortion after stiffener welding

Fig 77 shows the maximum weld distortion of 2.21 mm for the stiffener welding along the length of the top lid. Directional distortion results are also presented in fig 78, which shows that the major distortion is in the Z direction.

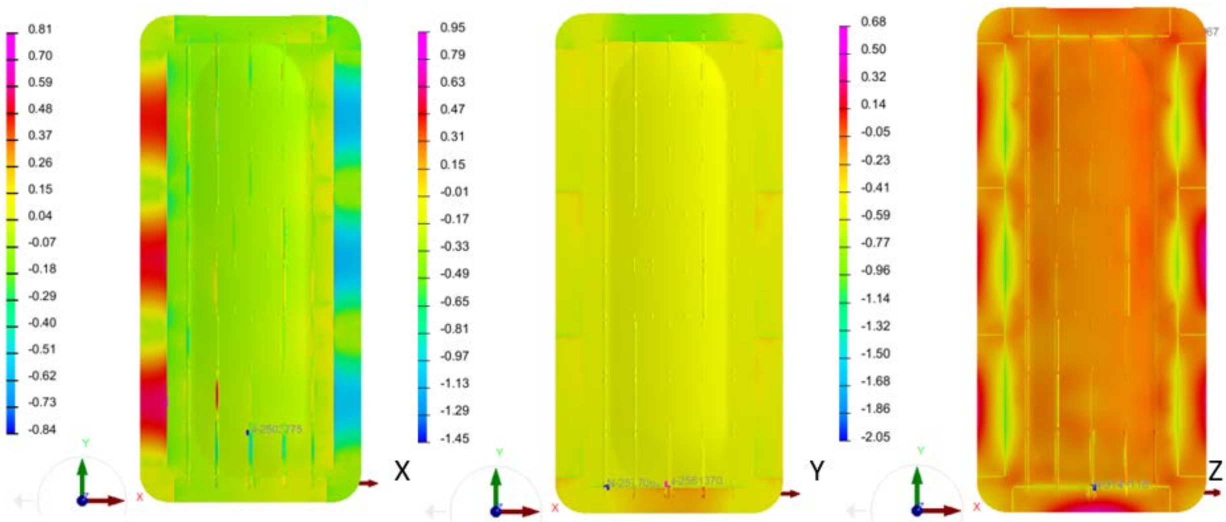


Figure 78: Directional distortion after stiffener welding

In the next step, horizontal (along the width) stiffeners shall be welded. This is the final welded subassembly for the top lid manufacturing. Clamping used for the vertical (along the length) stiffener welding on the top lid plate will be remain intact for this case as well. Additional clamps shall be used for the horizontal stiffeners. Sequence used for the clamping is shown in fig 79, after the welding of each stiffener, clamps shall be shifted to the next horizontal stiffener. Three different welding sequence were considered for welding the horizontal stiffeners, fig 80 shows the optimized weld sequence.

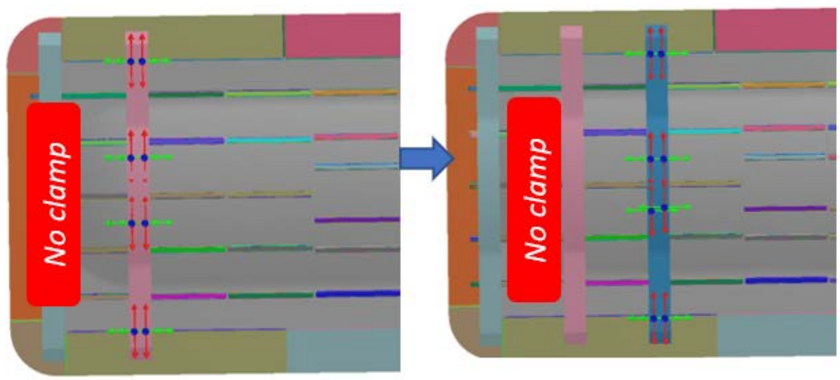


Figure 79: Clamping for the stiffener welding

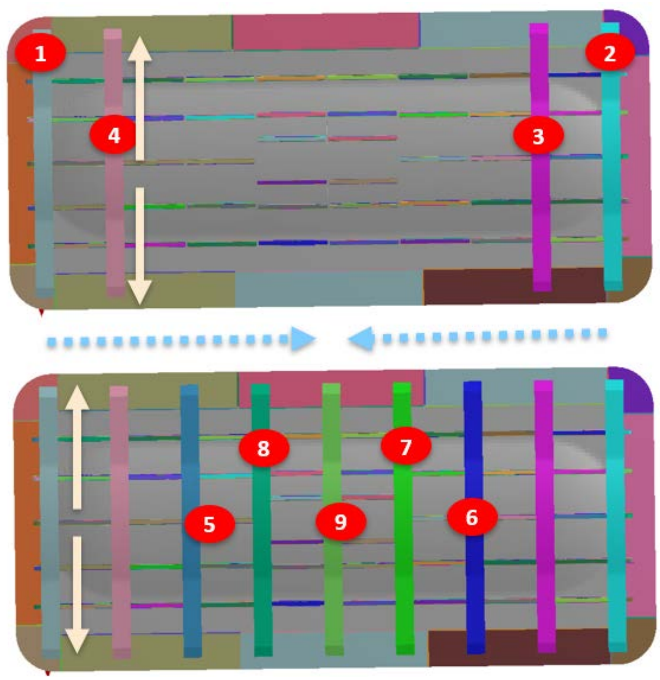


Figure 80: Welding sequence for the stiffener welding

To control the deformation in the Z direction, stiffeners were welded end to center one and similarly for the controlling the deformation in Y direction, each stiffener were welded from inside to outside. Considering the above defined welding sequence and clamping conditions, analysis was carried out and the results are shown in fig 81. Maximum distortion of 1.90 mm has been observed.

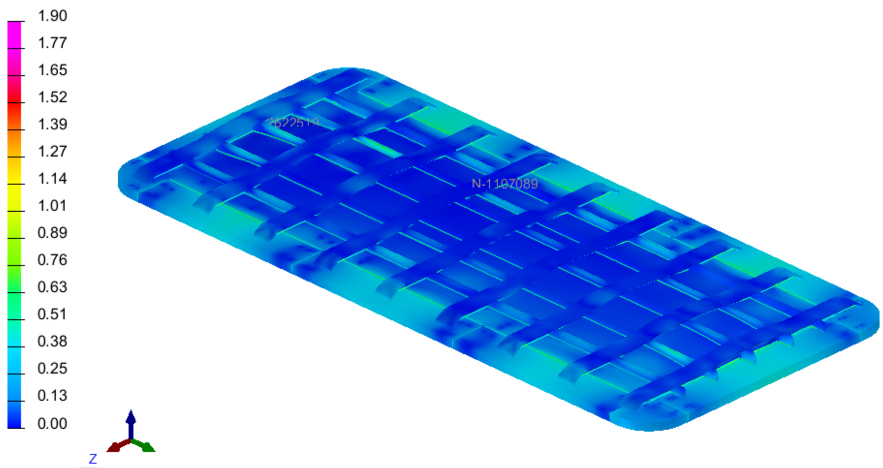


Figure 81: Welding distortion of top lid after final welding of stiffeners

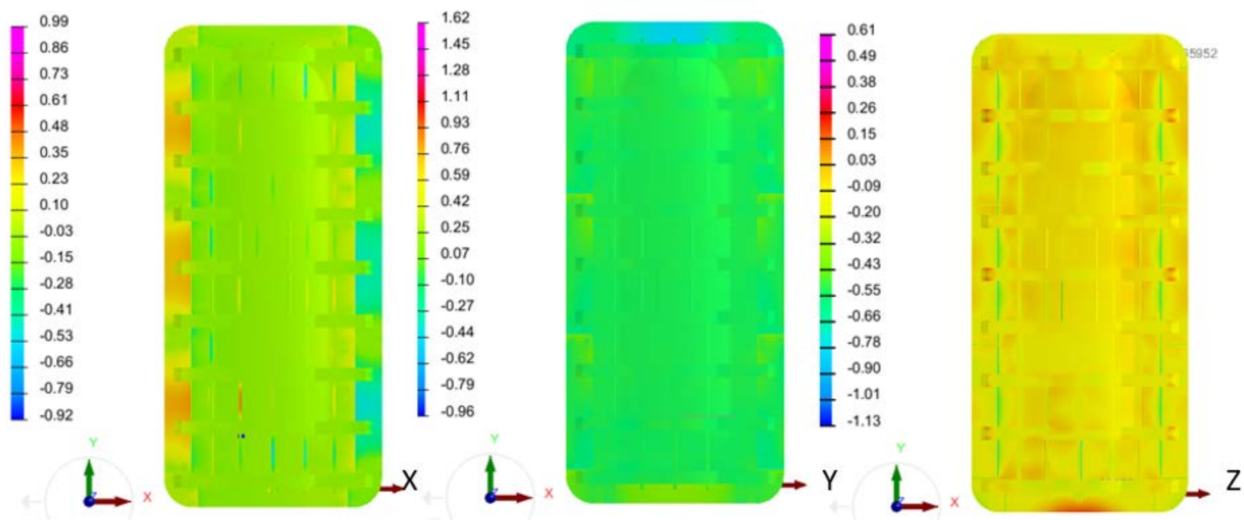


Figure 82: Directional welding distortion of top lid after final welding of stiffeners

As per the discussion with manufacturer, this distortion can be nullified in the machining. However, practice of machining at the sub-assembly level will also reduce the distortion level.

15. Attachments on the DNB Vessel for Internal components

Attachments are provided in the main shell for supporting the internal components. The cryopump and beam source are supported on the side wall of the DNB vessel, welded attachments for supports and alignment are provided as shown in fig 83.

To support the exit scraper, bracket shall be welded on the front opening of the shell, see fig 84. Neutralizer, RID and calorimeter shall be mounted on the combined alignment bed, and the alignment bed has the interface with the vessel. To support the alignment bed, support pads are provided on the vessel, as shown in fig 85.

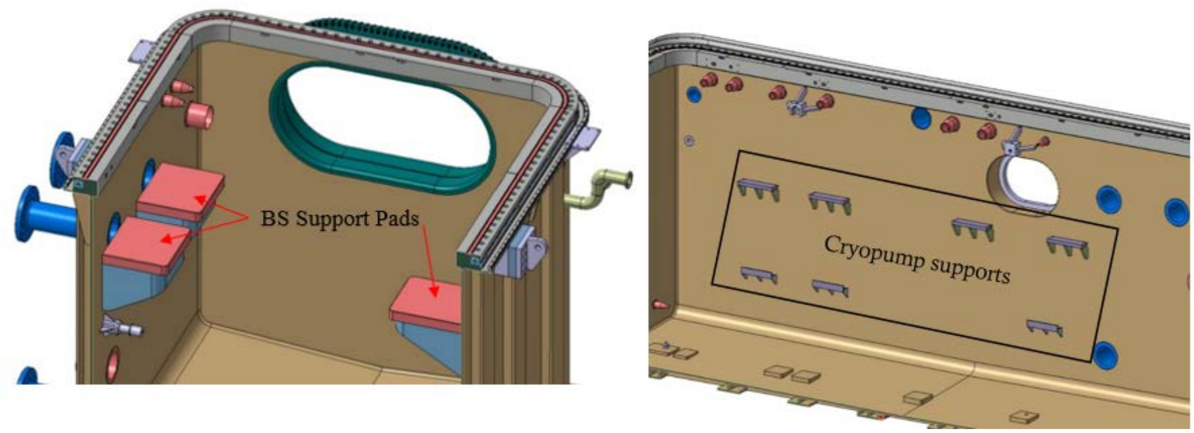


Figure 83: Welding of beam source and cryopump supports

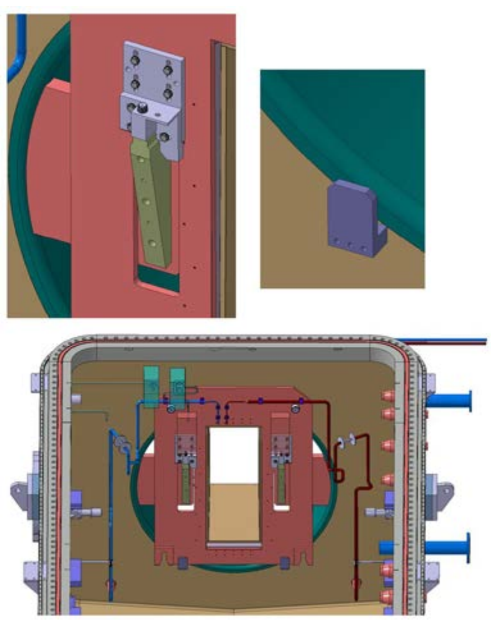


Figure 84: Welding of brackets for exit scraper mounting

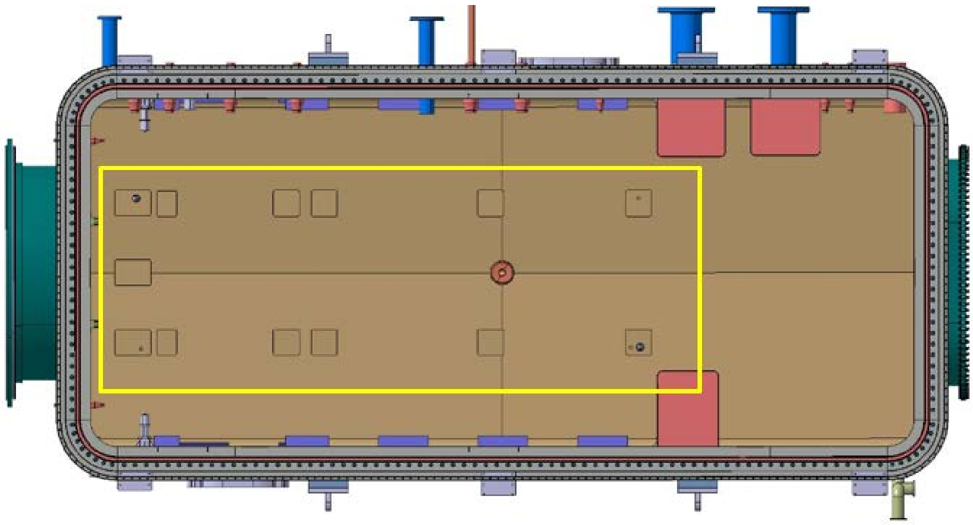


Figure 85: Welding of supports pads for alignment bed

In addition to these, additional features have been provided on the vessel for mounting the guiding mechanism and bagging tools. These features shall be provided by machining as shown in fig 86.

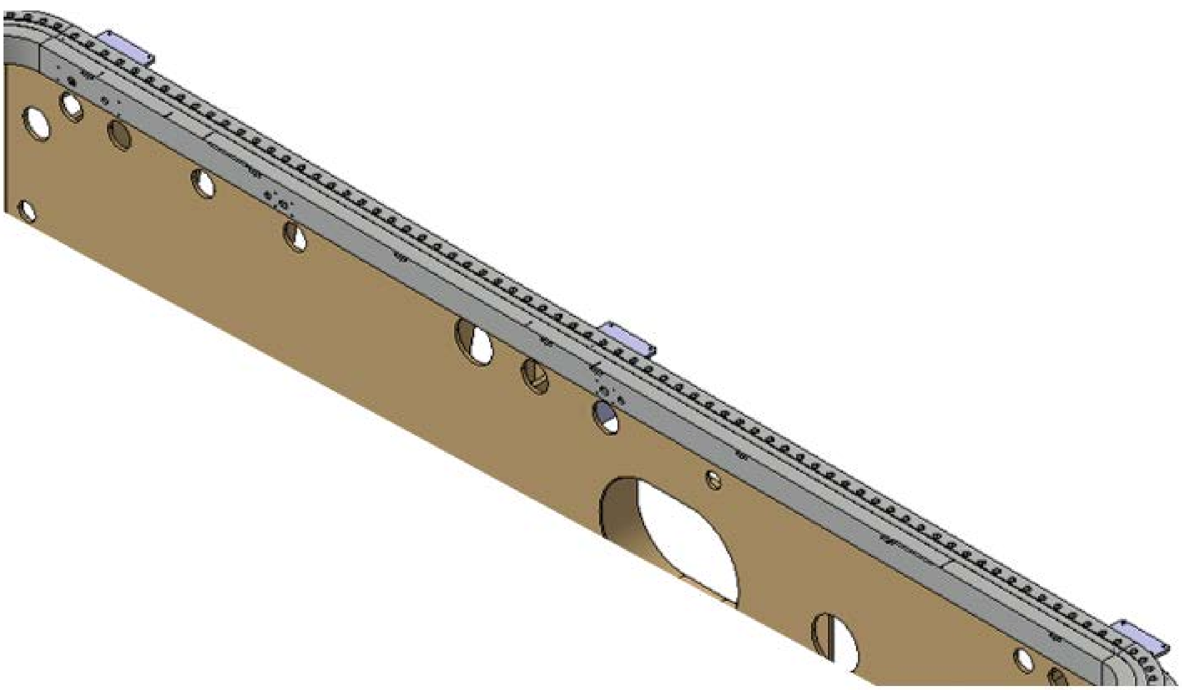


Figure 86: Machined features for guiding and bagging mechanism tools

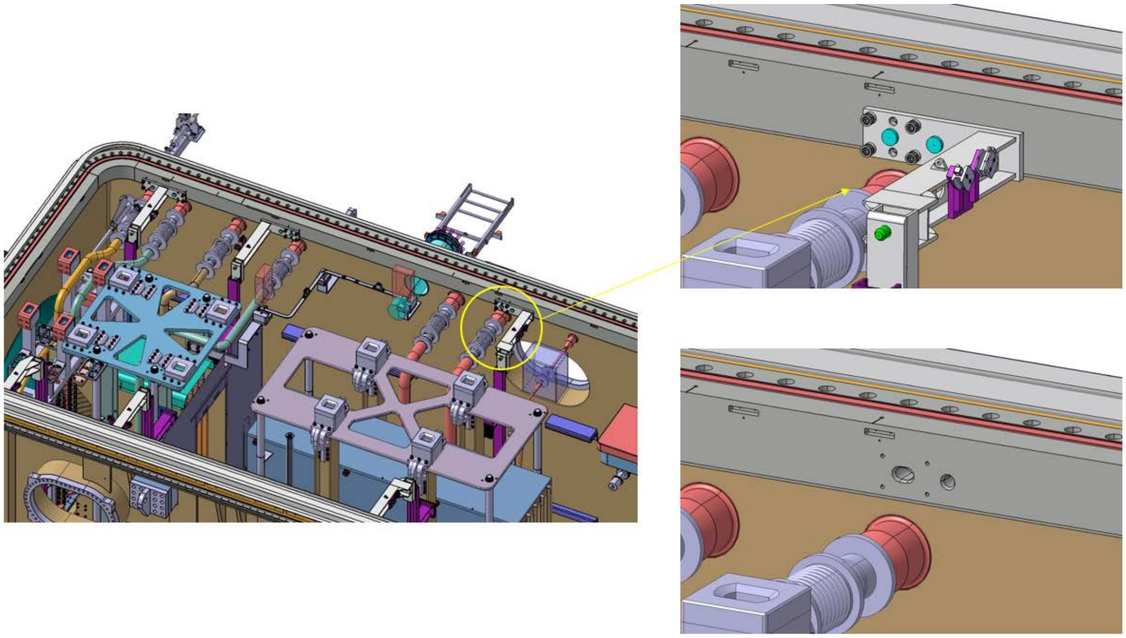


Figure 87: Guiding mechanism

16. Welding Consideration

- The requirements related to the joint configurations, joint category and joint efficiency defined in Annexure (FEA verification report) shall be considered.
- All the vacuum boundary joint shall be carried out in compliance with Attachment 1 of IVH.
- Welding shall be done on the job, strictly following the approved welding procedures using approved welding consumables and qualified welders.
- Suitable sequencing of welds shall be carried out to avoid build-up of residual stresses and distortion.
- All welding equipment's, shall be suitably calibrated and shall be checked on a regular basis during production.
- Welds shall normally be made in such a way that they can be leak tested at the time of completion. Welds that cannot be inspected are not permitted for use.

16.1. Qualification of cross welds:

Following are the vacuum boundary welds identified to having the cross welds during DNB vessel manufacturing.

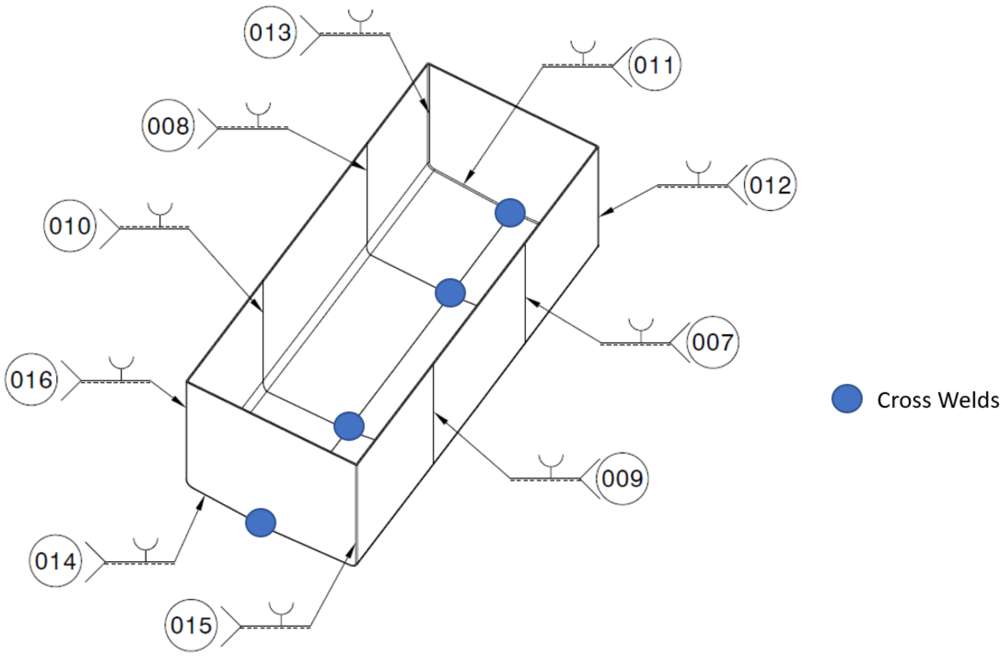


Figure 88: Cross weld details of main shell

As per the RCC-MR, RC 3833.2, no welds assembling the various parts of main shell are allowed to cross each other except the weld joint of stiffeners. In case such a condition is difficult to meet and when these requirements cannot be met, the following complementary examinations are prescribed by the code to verify the welds:

- Ultrasonic examination (for e > 10 mm) of each branch of the weld cross on a minimum length equal to 3e from the theoretical of the cross (e being the greater thickness of the parts to be joined).

In the main shell welding, thickness of 25 mm plate shall be welded (>10 mm). Cross welds could be qualified in such a case following either of the two approaches:

- Providing the biscuits (round about) to avoid the cross welds.
- Ultrasonic examination of 75 mm length of weld at each branch.

However, staggering of the bottom line welds shall also be explored during manufacturing, to avoid the cross welds.

In addition to the cross welds, similar strategy shall be followed for the T joints (as shown in fig 89) coming in the top lid welding.

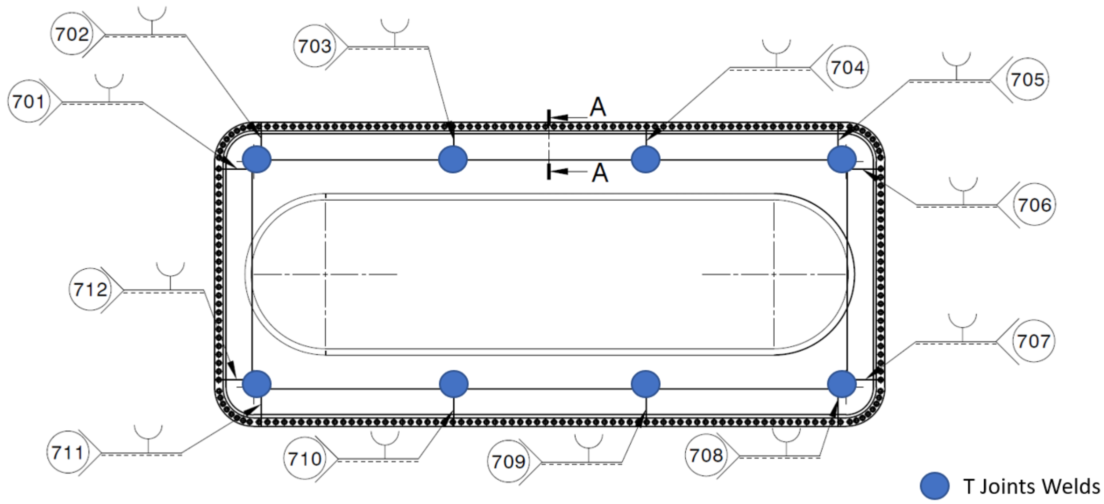


Figure 89: T joints on the top lid

For detailed requirements refer the following annexures of technical specification

Refer Annexure 6_Welding # IDM

Refer Annexure 5_Fabrication # IDM

17. Qualification of Welding Procedure Specification

- The qualification of the WPS is intended to provide proof that the welding process, using the specified processes consumables, materials etc, will achieve a weld of acceptable quality in accordance with the applicable code.
- The Qualification of the WPS shall be performed in accordance with the requirements of RCC-MR and Attachment 1 of IVH. All welding data and results from the required non - destructive and destructive testing shall be documented using a Procedure Qualification Record (PQR).
- Selection, manufacturing, procurement and testing of welding consumable shall be as per the requirements of RCC-MR

- Welder / welding operator Performance Qualification: Welder / Welding Operator Performance Qualification is intended to show the competence of the welder / welding operator to deposit sound weld material when following a qualified WPS.
- Welder Qualification shall be in accordance with EN287-1, ISO 9606 or equivalent standard. For welding operators ISO 1418 shall be used.

For detailed requirements refer the following annexures of technical specification

Refer Annexure 6_Welding # IDM and Refer Annexure 5_Fabrication # IDM

18. Inspection and Testing Consideration

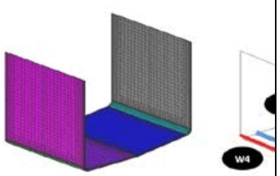
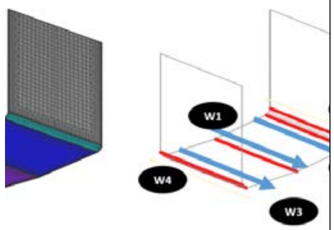
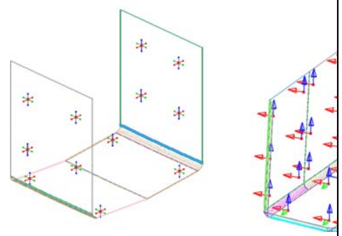
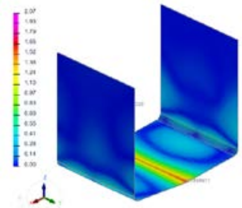
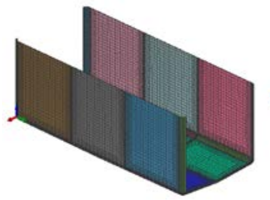
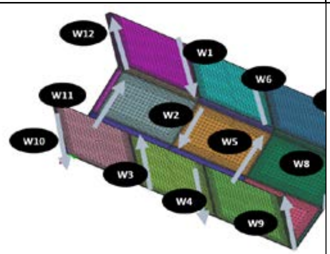
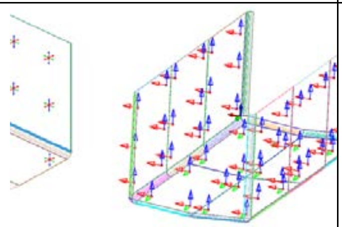
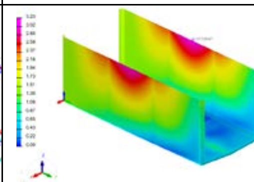
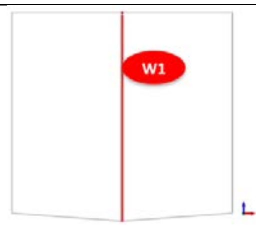
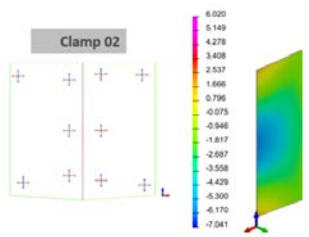
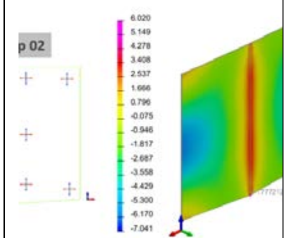
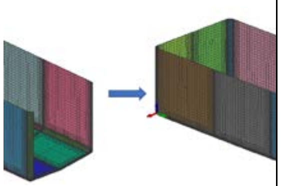
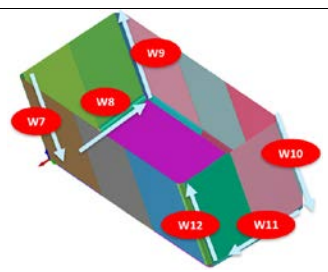
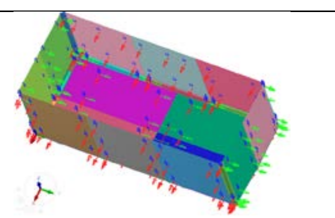
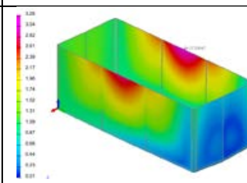
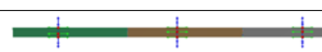
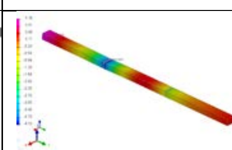
- The requirements related to Quality assurance, Manufacturing and inspection Plan, QRA shall be in accordance with Annexure 1, Annexure 2 and Annexure 3.
- Selection of NDE, its Procedure and acceptance criteria for the non-destructive examination shall be as per RCC-MR / Attachment 1 of IVH requirements.
- Personnel Qualification: The NDE operators, inspectors and engineers shall be trained and qualified to the appropriate level to meet the requirements of ISO 9712 or ASNT Level 2 or EN 473 prior to performing or evaluating examinations.
- The NDE personal shall also be qualified for any special technique or procedures to be followed as per the need of specification or drawing.

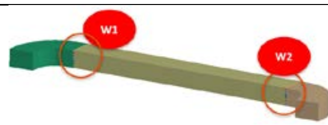
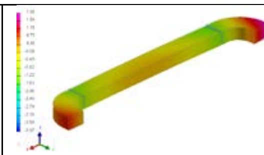
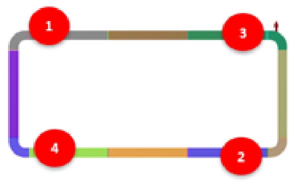
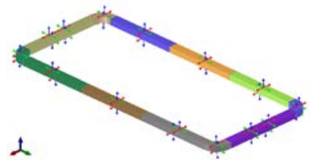
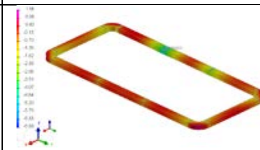
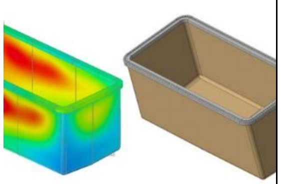
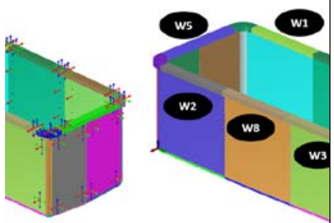
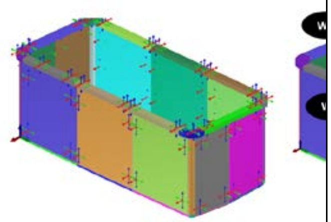
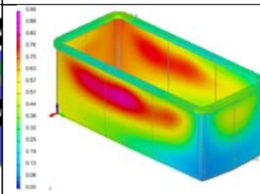
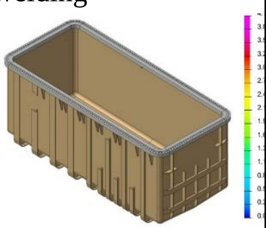
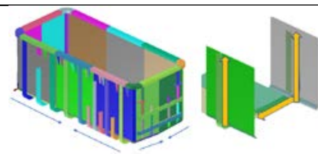
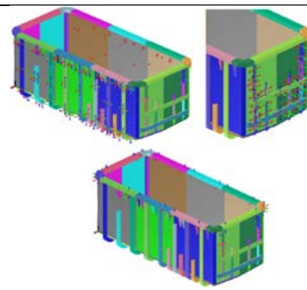
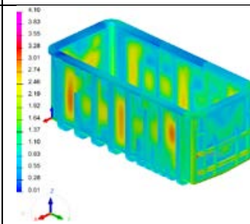
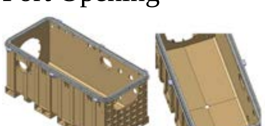
For detailed requirements refer the following annexures of technical specification

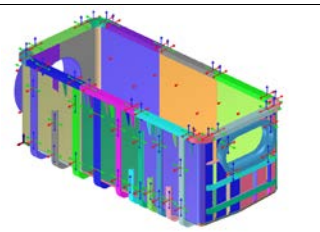
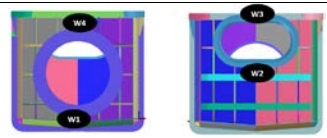
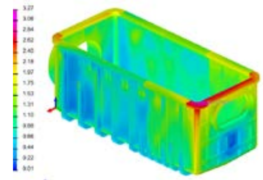
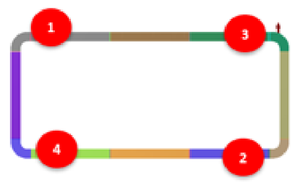
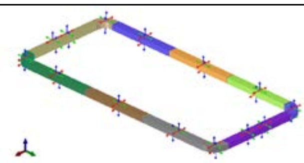
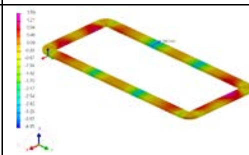
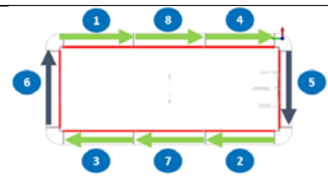
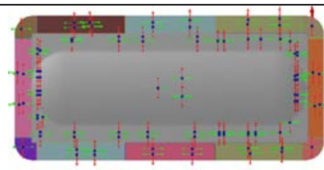
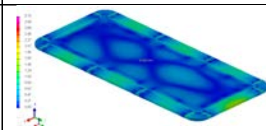
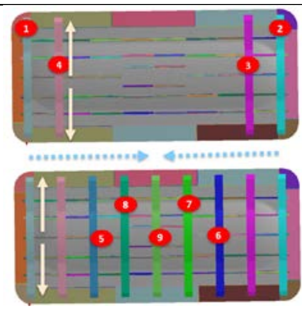
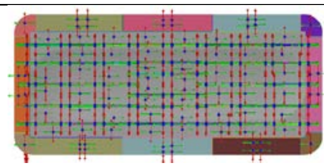
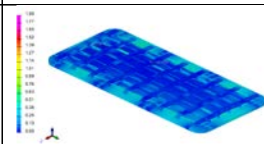
Refer Annexure 2_QA_QC_Inspection & Testing # IDM

19. Summary

Manufacturing sequence for the DNB Vessel main shell and top lid are finalized based on the market survey and manufacturer’s feedback and the results of the welding distortion analysis studies. The welding distortion analysis studies carried out for both the assemblies (Main shell and top lid) have helped to optimize the welding sequence and clamping conditions. The outcome of these studies and mentioned in the sections above is summarized in table given below.

Assembly/ Subassembly	**Welding Sequence**	**Clamping Condition**	**Distortion Pattern**
Main Shell			
Single U-shaped segment 			 Distortion: 2.07 mm (total)
Combined U-shaped segment 			 Distortion: 3.23 mm (total)
End Plate			 Distortion: 7.04 mm (total)
Main Shell 			 **Distortion: 3.28 mm (total)**
Main Shell Flange Side bar			 Distortion: 4.10 mm (total)

End bar			 Distortion: 3.97 mm (total)
Main shell flange assembly			 **Distortion: 1.56 mm (total)**
Welding of main shell and flange 			 **Distortion: 0.95 mm (total)**
Main Shell Stiffener welding 			 Distortion: 4.10 mm (total)
Port Opening 			
Feedthroughs welding 			

Main Shell opening nozzle welding for HVB and FS			 **Distortion: 3.27 mm (total)**
Top Lid Top Lid flange			 Distortion: 4.05 mm (total)
Top lid plate to flange welding			 Distortion: 3.10 mm (total)
Top Lid Stiffener welding			 **Distortion: 1.90 mm (total)**

#Directional distortion values are placed in the specific sections

Note:

At present the distortion assessment has been considered with the basic weld design and the conventional practices and it is expected that the observed distortion can be handled as per the mentioned clamping condition, weld joint configuration and weld sequences.

Further improvements are also possible (and those have been discussed with manufacturer and assessed to be feasible) by implementing the practical solutions, based on the experiences, are as listed below:

- Pre-cambering the weld edge at the time of set-up by the amount equivalent to the expected distortion

- Double sided weld and welding up-side down in a sequential manner
- Selection of welding process with lower heat inputs (like HWT, SAW etc.)
- Providing the external cooling
- Dual Operator technique

All of these techniques have already been practiced by INDA during the execution of other PAs and have thorough understanding and confidence about the effectiveness of the same.