Status of Design and Research & Development for ITER Sector Sub-assembly Tools

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Abstract. The International Thermonuclear Experimental Reactor (ITER) tokamak assembly tools are purpose-built tools to complete the ITER tokamak machine which includes the cryostat and the components contained therein. The sector sub-assembly tools descried in this paper are main assembly tools to assemble vacuum vessel, thermal shield and toroidal filed coils into a complete 40° sector. The 40° sector sub-assembly tools are composed of upending tool, lifting tool, sector sub-assembly tool and mid-plane brace tools. These tools should be designed to meet technical and functional requirements. These, also, shall have sufficient strength to transport and handle heavy dead weight of the ITER Tokamak machines up to some 1200 tonnes. The process of the ITER sector assembly and status of research and development of sector sub-assembly tools mentioned above are described in this paper. Also, results of the structural analysis using ANSYS code to verify structural stabilities are introduced.

1. Introduction

The sector sub-assembly tools described in this paper are purpose-built assembly tools to assemble vacuum vessel (VV), vacuum vessel thermal shield (VVTS) and toroidal filed coils (TFCs) into a complete 40° sector at assembly building. These tools should be designed to secure their structural strength due to heavy duty weight of ITER machine components. The ITER assembly tools are purpose-built tools to complete the ITER tokamak machine. Based on the design description document prepared by the ITER organization [1,2], Korea has carried out the conceptual design of assembly tools [3-7].
Procurement arrangement (PA) on the providing ITER assembly tools has been signed between Korea domestic agency (KODA) and IO on August 2009. Korea is responsible for design activities including preliminary and final design, and manufacturing including delivery and engineering support to install assembly tools at ITER site. Currently, KODA is carrying out the preliminary design of ITER assembly tools and mock-up fabrication to verify the design of tools.
The ITER tokamak main device is composed of 9 VV/VVTS/TFCs 40° sectors. Each VV/VVTS/TFCs 40° sector is made up of one 40° VV, two 20° TFCs and associated VVTS segments. The 40° sectors are sub-assembled at assembly building respectively using 2 sector sub-assembly tools and then 9 sectors which sub-assembled at assembly building are finally assembled at tokamak pit. The 40° sector assembly tools are classified into 2 groups. One group, to complete nine 40° sector, is the sub-assembly tools including upending tool, lifting tool, sub-assembly tool, VV supports and brace tools used at assembly building and the other group, to complete ITER tokamak machine with torus configuration, is the in-pit assembly tools that include radial beams, central column and supports. The process of the ITER sector assembly and status of research and development of sector sub-assembly tools are described in this paper.

2. Sector Assembly Process

Fundamentally, the ITER tokamak machine is assembled from nine VV/VVTS/TFCs 40° sectors. Each VV/VVTS/TFCs 40° sector is made up of one 40° VV sector, two 20° TFCs and associated VVTS 40° segment composed of one 40° inboard segment and two 20° outboard segments connected by bolting. The components of VV/VVTS/TFCs 40° sector are respectively delivered to ITER site from country that is in charge of manufacturing and delivery responsibility. The 40° sector components, delivered to the ITER tokamak assembly site, are sub-assembled into a sector at assembly building (95 m x 45 m).
Before the sectors are installed, components which cannot be installed after the final sector assembly such as the lower poloidal field (PF) coils, the lower correction coils (CC), the lower and side correction coil feeders and the lower pre-compression rings (PCRs) should be placed in their proper places on the cryostat base. The sub-assembled 40° sectors in assembly building are transported to tokamak pit by lifting tool operated by ITER main cranes in sequential order starting from sector 6. After the final sector has been installed, the VVs are welded toroidally, aligned with the TFCs and placed onto its permanent supports. The lower PCRs are then installed and the preload is applied to each of the TFCs.
The VV, TFCs and VVTS which are supported from and protected by VVTS inboard (IB)/outboard (OB) frames are upended using the upending tool operated by tokamak main crane (maximum lifting capacity: 1500 tons). The components upended in vertical position are transferred to the sector sub-assembly tool using the lifting tool and associated lifting attachments including radial beam and VV supports. The sector sub-assembly tool is capable of integrating sector components into VV/VVTS/TFCs 40° sector. Before transfer of the 40° sector into tokamak pit, the vertical support and brace tools are assembled to keep the gap between TF coils and VV against dynamic loads during the handling and transportation. The completed VV/VVTS/TFCs 40° sector with vertical support and mid-plane brace tools is transferred using the lifting tool into tokamak pit and positioned sequentially. VV/VVTS/TFCs 40° sectors with radial beam are placed on central column and radial beam supports. The inboard end of radial beam is supported on the upper plate of central column and the outboard end of radial beam is supported on the radial beam support which is connected with support brackets installed to bio-shield wall via anchor bolts. TFCs are supported from their permanent supports installed already. The overall sector assembly scheme is as shown in FIG. 1.

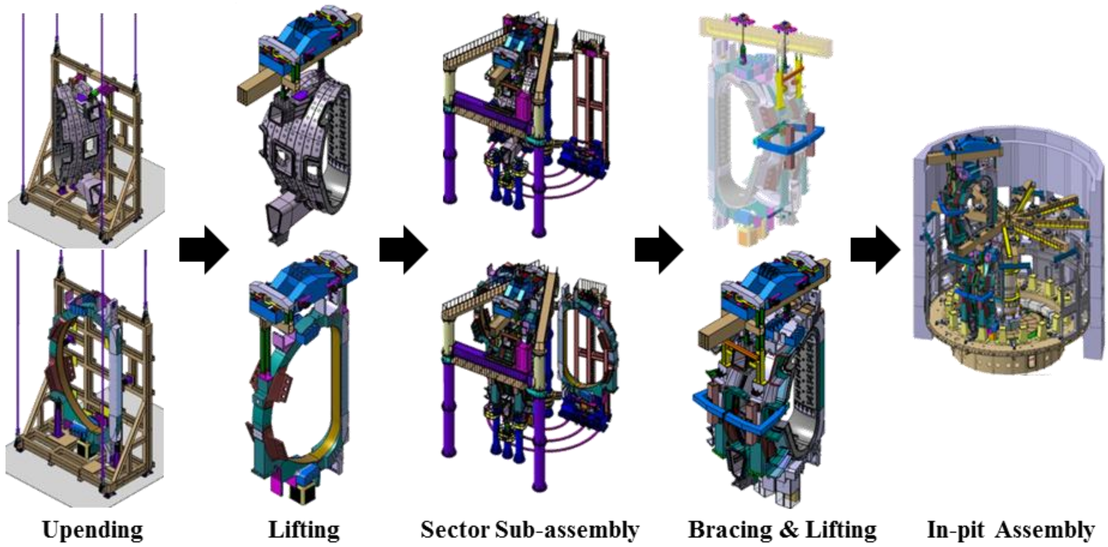


FIG. 1. Overall 40° sector sub-assembly and final assembly process.

3. Design of Sector Sub-assembly Tools

3.1 Upending Tool

The function of the upending tool is to raise nine 40° VV sectors, 18 toroidal field coils and vacuum vessel thermal shield sectors with frames from a horizontal position to the vertical position, which is required for subsequent sector sub-assembly operations. The basic structure of the upending tool has been developed with the assumption that lifting will be performed with 4 ITER main cranes which will be installed in the tokamak building. The upending tool, as shown in FIG. 2, is mainly composed of a rotating frame (main frame), mechanical locking devices, lifting crane lugs and component supports which are temporary supports to secure components during operation and in vertical position. Overall size of this tool is 15.9 m(L) x 13.8 m(W) x 6.9 m(H) and weight is about 120 tons.
Lugs and pins are sized considering shear and tensile stress under the applied maximal load. Component supports are considered for supports and clamps. Mechanical locking device secure the upending tool in its vertical orientation to withstand the assumed external force of 15% of dead weight of components at the upper end of frame. Interface surface contacting components will be manufactured from vacuum-compatible materials such as stainless steel or aluminum alloy. In the tool size design, it was considered available minimum distance of the rotating platform linked at 4 points of the crane lug. FIG. 3 shows the configurations of the upending tool loading VV and TFC ready to transfer in its vertical orientation.

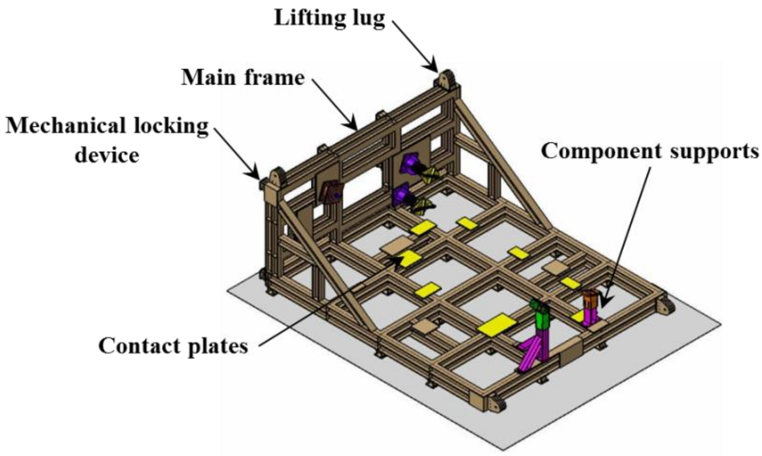


FIG. 2. Structure of upending tool.

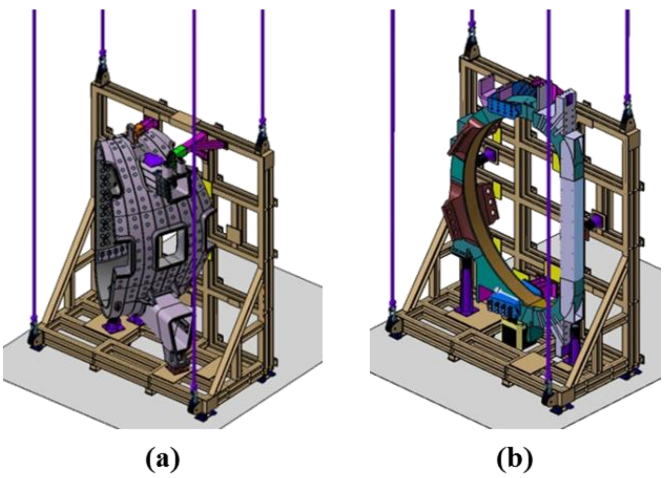


FIG. 3. Configuration of upending tool loading (a) VV, (b) TFC in vertical position.

3.2 Sector Lifting Tool

The sector lifting tool, as shown in FIG. 4, is composed of balancing beam, inboard cross beam, outboard cross beam and driving systems including longitudinal and transverse driving system. Lifting crane lug is placed on the upper centre of balancing beam. Overall size of this tool is 8.5 m(L) x 4.0 m(W) x 2.7 m(H) and weight is about 62 tons.
The function of the sector lifting tool, as shown in FIG. 5, is to transfer sector components and the completely assembled VV/VVTS/TFCs 40° sector from the lay-down area in assembly building to the upending tool, and from the upending tool to the sector sub-assembly tool, and from the sector sub-assembly tool to the cryostat base installed in the tokamak pit. This tool is to be compatible with dual crane heavy lifting beam (DCHLB) of the tokamak building crane so that it is able to accommodate the dead weight of each sector (about 1200 tons) and install each sector in a particular direction within the tokamak pit. This tool is designed to adjust the position of a sector to minimize the difference between the centre of the crane installed in tokamak building and the centre of gravity of the sector. Outboard cross beam and inboard cross beam hanging the sector adjust the sector by using screw jacks and electrical motors to match the centre of balancing beam and the sector. To facilitate moving of the IB/OB cross beams, very lower friction plates will be adopted between balancing beam and cross beam.

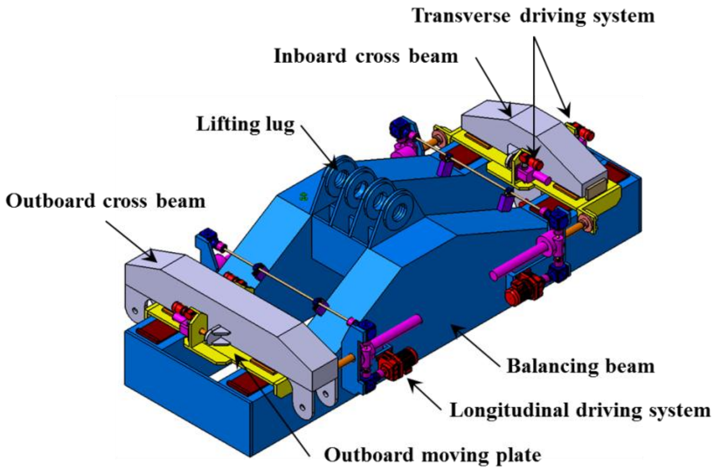


FIG. 4. Structure of lifting tool.

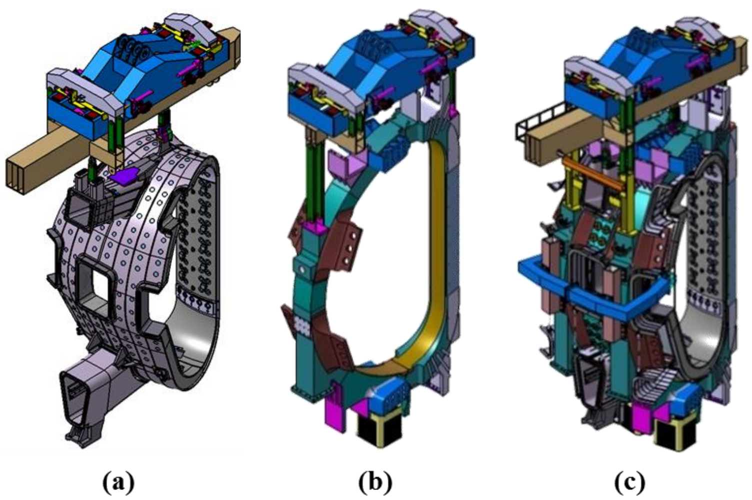


FIG. 5. Configuration of lifting tool loading (a) VV, (b) TFC, (c) 40° sector.

3.3 Sector Sub-assembly Tool

The sub-assembly of the 40° sectors is carried out in the assembly building, with the components in their final, vertical orientation. The sector sub-assembly tool on which the in-pit sector assembly procedures of the tokamak are based, integrates the VV sector, the VVTS sector, the VVTS port shrouds and TFCs into the 40° sector. This tool, as shown in FIG. 6, is composed of main structure, two rotating frames, lower components supports and aligning units. Overall size of this tool is 14.5 m(L) x 18.0 m(W) x 22.0 m(H) and weight is about 700 tons.

The main structure of this tool comprises 1 inboard column and 2 outboard columns which are connected with horizontal beams and the support beam. The axis of the inboard column, which is parallel to the machine center, is the reference for aligning the components in this tool. The VVTS sectors and TFCs rotate along the axis of inboard column, so that they can be assembled with the VV sector. The base of the rotating frame is equipped with the commercially available rollers, and moves along the circular rails. Aligning system with 6 degrees of freedom should be applied to this tool for accurate assembly with 3 mm assembly resolution. Slide block is designed to be traveled along support beam to secure sufficient moving height.

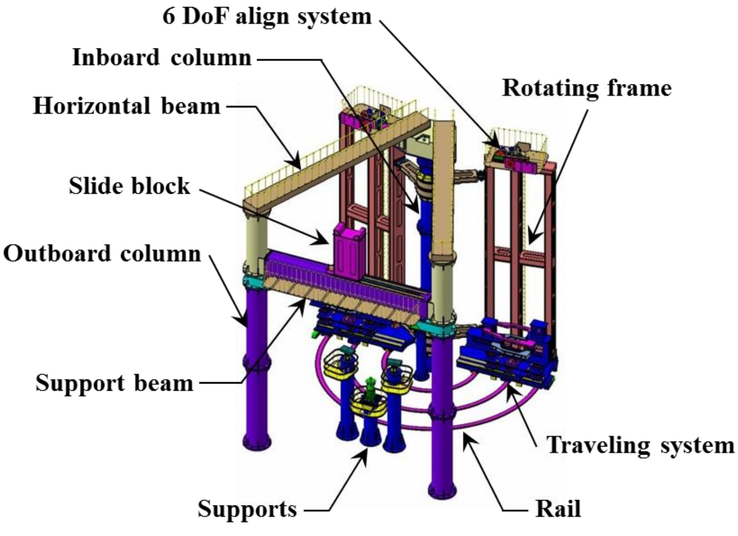
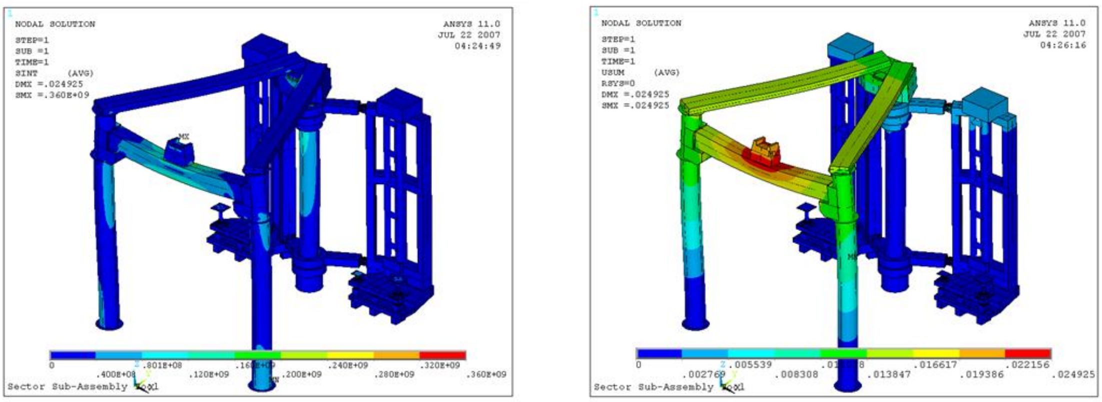


FIG. 6. Structure of sector sub-assembly tool.



(a) (b)

FIG. 7. Structural analysis results of sector sub-assembly tool using ANSYS classic; (a) distribution of stress intensity, (b) distribution of displacement summation.

TABLE I: Structural analysis results of sector sub-assembly tools

Items	Max. stress intensity (MPa)		Allowable values (MPa)	
	P_m	P_L+P_b	1.0Sm (P_m)	1.5Sm (P_L+P_b)
Support beam	207	350	276	414
Slide block	206	360		
Horizontal beam	53.9	60.6		
Inboard column	144	168		
Outboard column	105	173		
Rotating frame	49.4	97.6		
Rotating frame base	22.7	25.6		
Lower adjust transfer	<149	149		
Component support	<172	172		
Roller	<17.9	17.9		

To verify structural stabilities of this tool, structural analysis was carried out under applied load of dead weight x 4/3 using ANSYS code and compared with allowable stress. The results of stress intensity are evaluated according to ASME Section VIII, Division II. The main material is AISI 1050. The properties of AISI 1050 are following: density 7850 kg/m3, modulus of elasticity 205 GPa, Poisson's ratio 0.29.

FIG. 7 shows stress intensity and displacement in analysis results. The detailed results of analysis are given in TABLE I. For applied load, the maximum displacement is 24.9 mm at the border points between the slide block and the support. The maximum stress intensity is 360 MPa at the slide block and is well below the allowable stress.

3.4 Mid-plane Brace Tools

The function of the mid-plane brace tool is to prevent the radial and toroidal clash of components due to dynamic loads (handling load) in the region of the mid-plane port. The mid-plane brace tool is linked to inner surface of VV and outboard of each TFC. These tools are surely necessary to secure the relative positions of VV, TFC and VVTS during transportation and handling. The mid-plane brace tools, as shown in FIG. 8 and FIG. 9, are large horizontal C-shaped frames which have four different types to be compatible with the four kinds of different types of the equatorial ports of VV. Overall size of this tool is 7.1 m(L) x 4.8 m(W) and weight is about 27 tons (A-type brace tool).

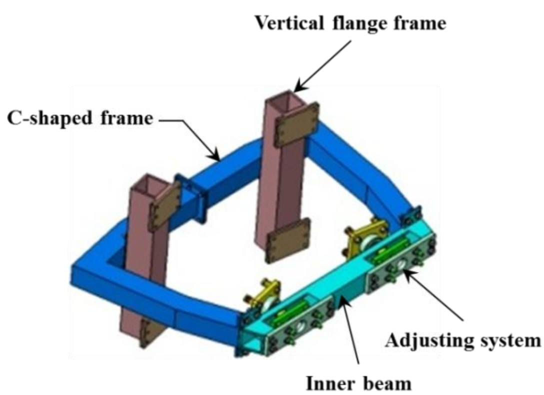
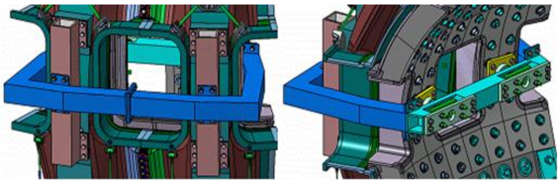
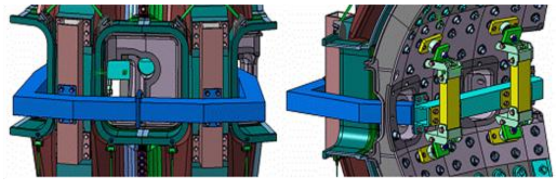
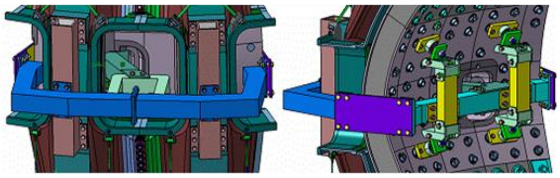


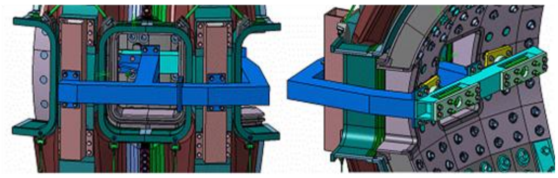
FIG. 8. Structure of mid-plane brace tool.





(a) (b)



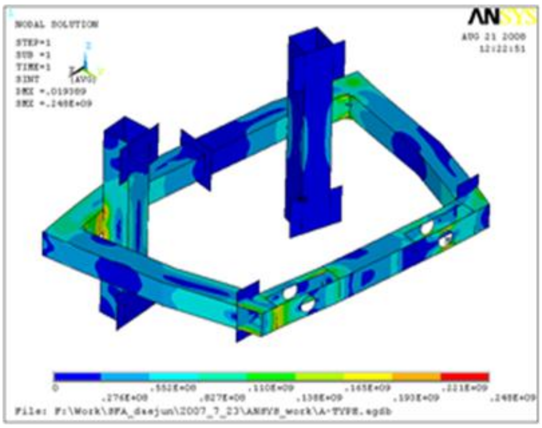


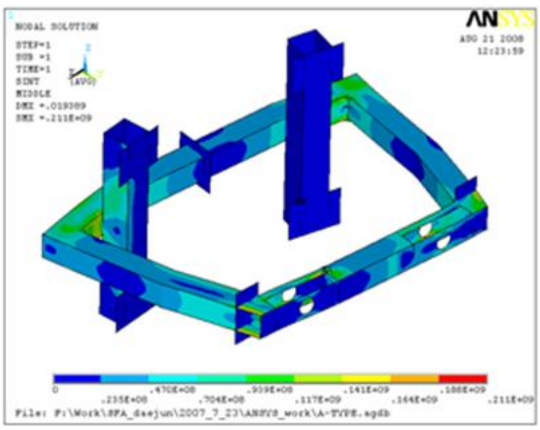
(c) (d)

FIG. 9. Classification of mid-plane brace tool according to configuration of VV equatorial port; (a) A-type (left/center/right opened), (b)B-type (left opened, center/right partly opened), (c) C-type (center opened, left/right closed), (d) D-type (center/right opened, left closed).

A-type is applied to the VV sector of which right and left equatorial ports are opened perfectly. B-type for the VV sector with middle and left port opened irregularly and narrowly. C-type for the sector with middle port opened irregularly and narrowly and right and left port closed perfectly. And D-type for the sector with middle and right port opened perfectly and left port closed perfectly. To avoid damages to VV blanket housings during installation or transportation, power locks and spacer will be applied between joint bracket of mid-plane brace and blanket housings.

The structural stabilities for the mid-plane brace tools have been studied and verified using ANSYS classic code. Equivalent static load, 1.25g (gravity), in vertical direction is applied to dead weight. And equivalent loads, 1.33g and 0.33g, in each radial and toroidal direction are applied to whole model. The same material, AISI 1050, is applied to mechanical properties. Stress intensity results of A-type mid-plane brace tool, as shown FIG. 10, show that this mid-plane brace tool maintains structural stability under dynamic condition due to transportation or handling. Shell elements are only used in this analysis. The maximum stress intensity is 248 MPa in A-type mid-plane brace tool and is below the allowable stress. The stress intensity results of others are within allowable limits also, as shown in TABLE II.





(a) (b)

FIG. 10. Structural analysis results of A-type mid-plane brace tool using ANSYS classic; (a) stress intensity P_L+P_b, (b) stress intensity P_m.

TABLE II: Structural analysis results of mi-plane brace tools

Items	Max. stress intensity (MPa)		Allowable values (MPa)	
	P_m	P_L+P_b	1.0Sm (P_m)	1.5Sm (P_L+P_b)
A-type	211	248	276	414
B-type	169	243		
C-type	177	243		
D-type	163	232		

4. Conclusion

Based on the design concept suggested by the IO, the conceptual designs of the sector sub-assembly tools including upending tool, lifting tool, sector sub-assembly tool and mid-pane brace tools have been developed to satisfy ITER assembly process, technical and functional requirements. And structural stabilities of assembly tools have been studied using ANSYS code for verifying structural strength of each assembly tools. In the results of the analysis for assessing structural stabilities of the tools, all stress intensities are less than allowable stress in each corresponding case. Consequently, it was verified that the sector sub-assembly tools ensure sufficient strength to transport and handle ITER tokamak components.
Since PA signature in August 2009, design work has been continued to develop the preliminary and detailed design of the ITER assembly tools by December 2011. Also, to verify operational and functional performance of sector sub-assembly tool, its mock-ups will be fabricated with 1/5 scale-down configuration by January 2011. To consider seismic effects, additional analysis will be carried out using ANSYS code too.

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