

Analysis of Residual-Magnetization-Induced Electromagnetic Loads in the DEMO Breeding Blanket System

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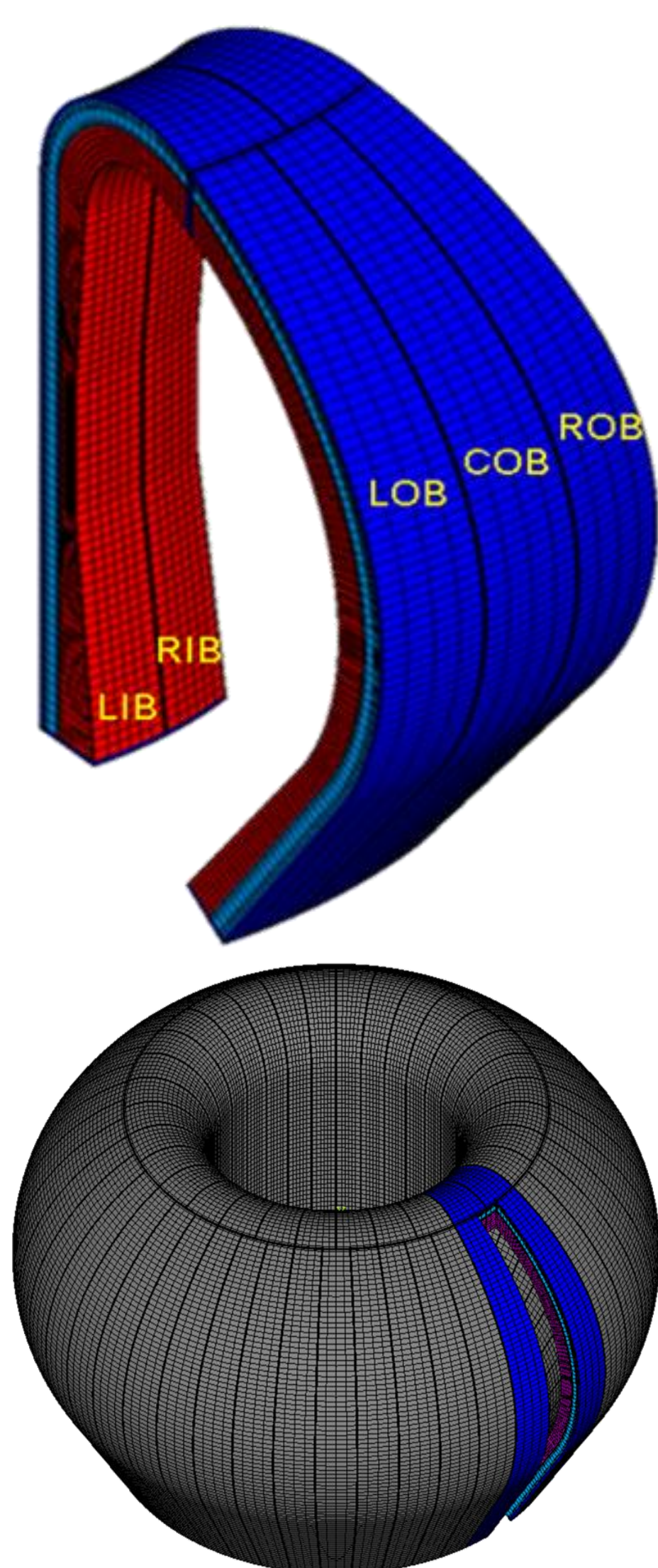
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EUROFER97, the main structural material of the DEMO breeding blanket, is a soft ferromagnetic steel that may retain remanent magnetization after plasma operation. During maintenance, with plasma and coils switched off, this residual magnetization can generate electromagnetic (EM) loads that may affect blanket handling. A full 360° ANSYS EMAG model was developed using homogenized WCLL-based blanket modules with 34% EUROFER97 and 2 cm toroidal gaps. The homogenized approach was validated against a heterogeneous material representation, showing very good agreement. Several non-axisymmetric maintenance configurations were analyzed, including removal of the Central Outboard Blanket (COB) and multiple modules within one sector. Residual-magnetization-induced loads were typically found to be of the order of 10² N and 10³ Nm, far below operational EM loads. A simplified model of COB vertical extraction predicted a recall force of about 52.5 N at 2.88 m displacement. These results suggest that, within the assumptions and maintenance scenarios considered, residual magnetization is not expected to represent a major limitation for DEMO blanket maintenance and disassembly.

Electromagnetic FEM models

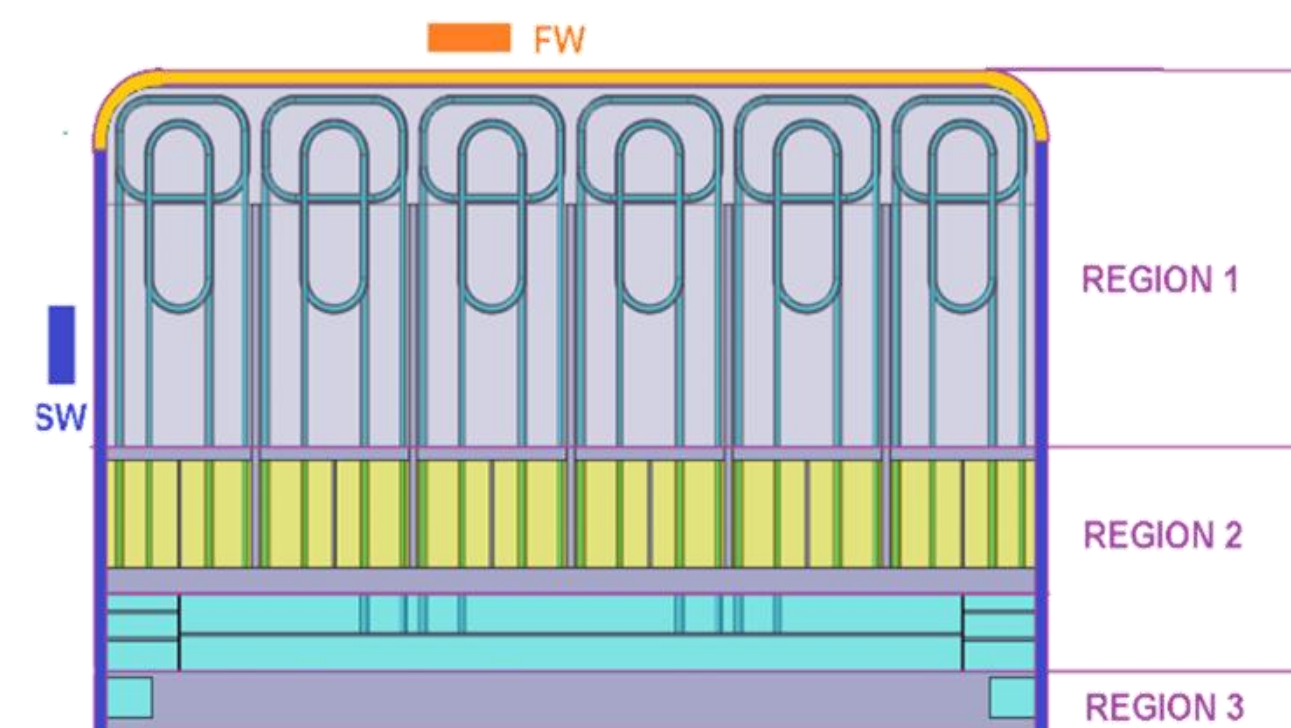


- 360° ANSYS EMAG model
- WCLL-based blanket geometry
- 2 cm toroidal gaps between adjacent modules
- All coils and plasma switched off
- Investigated cases:
 - all blankets in place
 - COB of one sector removed
 - LOB, COB, ROB, RIB removed in one sector

Item	Value / Setting
Element type	S236 (20-node edge element)
Intended use	Non-linear EM analyses
Formulation (KEYOPT(1))	Magnetic (A)
Matrix option (KEYOPT(2))	Strong Matrix
Activity (KEYOPT(5))	Active
Shape function (KEYOPT(7))	Corner only
Formulation (KEYOPT(8))	Maxwell

Limitation: residual magnetization assumed in the toroidal direction.

Materials and homogenization



EUROFER97 magnetic property	Symbol	Value at room temperature
Coercive field	Hc	0.81 kA/m
Remanent magnetization	Mr	4.04 A·m ² /kg
Remanent flux density	Br	≈ 0.04 T
Saturation magnetization	Ms	182.9 A·m ² /kg
Curie temperature	Tc	1030 K (≈757 °C)

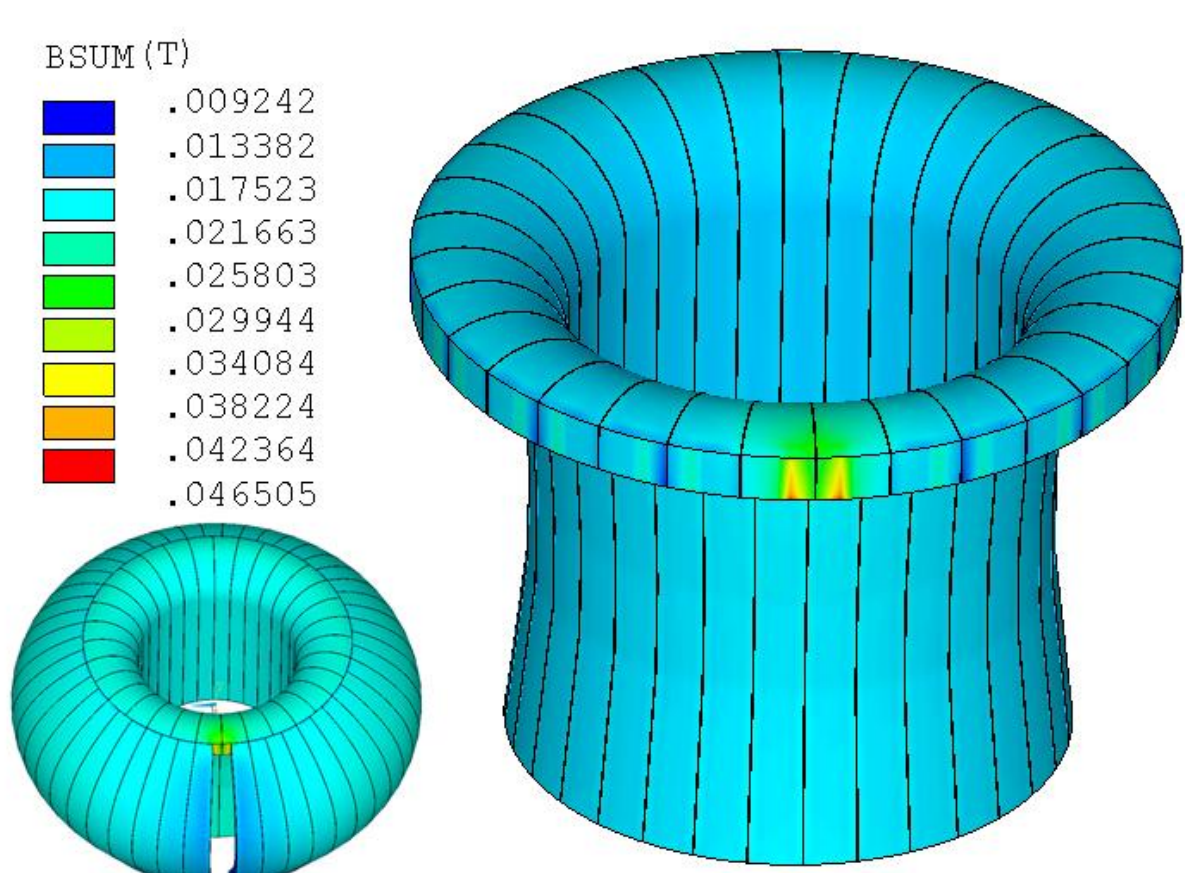
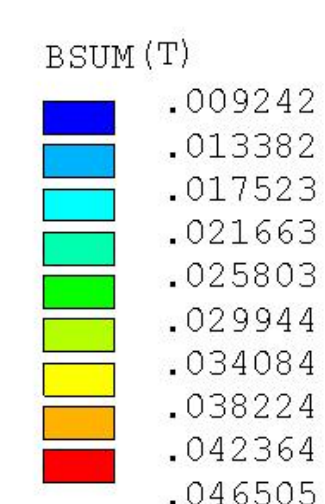
- A homogenized blanket material with 34% EUROFER97 content was adopted for all subsequent analyses.
- A verification study compared a 3-region heterogeneous material assignment with a fully homogenized model.
- The test case used the configuration with the COB removed.

Component	Case	Fy (N)	My (Nm)
LOB	3-zone model	-544	-377
LOB	Fully homogenized	-535	-426
ROB	3-zone model	543	-377
ROB	Fully homogenized	534	-426

The agreement is very good, supporting the use of the homogenized model.

Static EM loads due to residual magnetization

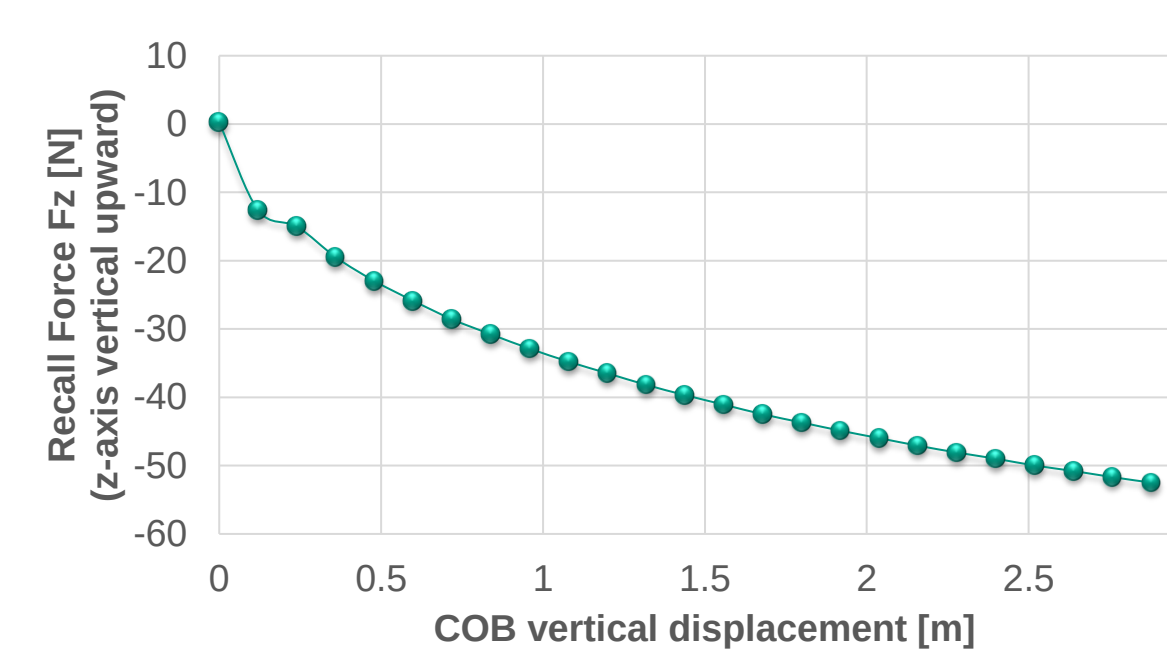
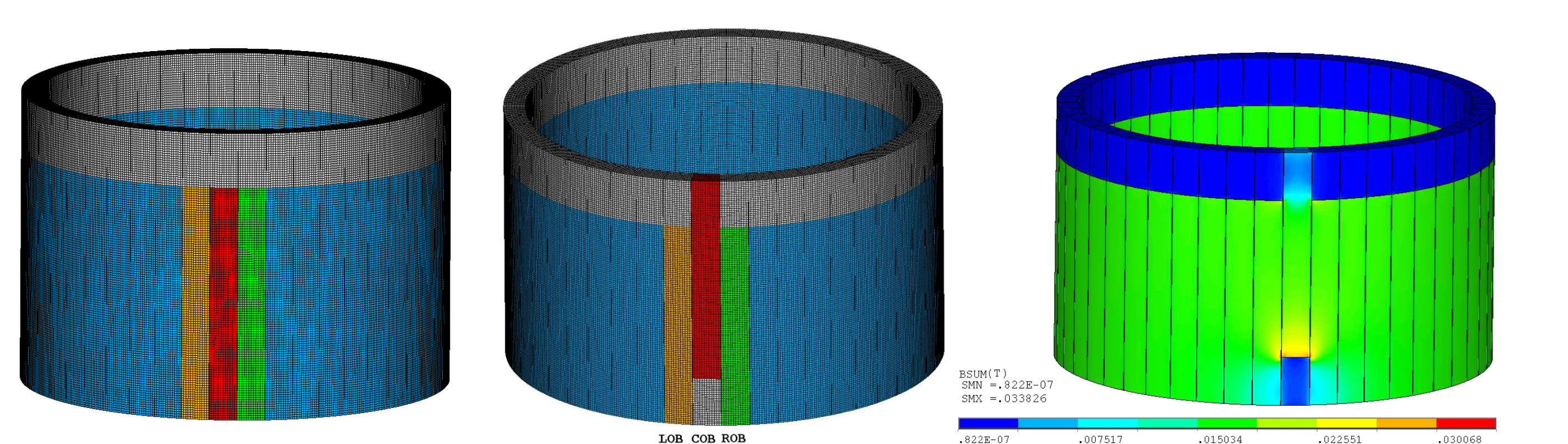
EM loads are reported in the local coordinate system of each blanket



Magnetic flux density perturbation after COB removal on the inboard segments.

All blankets in place	
LIB / RIB	Fx ≈ -240 N, all other components are negligible due to compensation
LOB, COB, ROB	Fx ≈ -200 N, all other components are negligible due to compensation
COB removed	
LIB	Fx ≈ -220 N, Fy ≈ -240 N, Mx ≈ -970 Nm
RIB	Fx ≈ -220 N, Fy ≈ +240 N, Mx ≈ +970 Nm
LOB	Fx ≈ -120 N, Fy ≈ -535 N, My ≈ -425 Nm
ROB	Fx ≈ -120 N, Fy ≈ +535 N, My ≈ -425 Nm
LOB, ROB, COB, and RIB removed	
LIB	Fy ≈ -527 N, Mx ≈ +130 Nm

Approximated COB vertical removal and recall force



- Rectangular shape for BB Segments
- Simplified removal kinematics
- 24 static analyses performed
- Vertical displacement step: 0.12 m
- Maximum simulated shift: 2.88 m

Residual Magnetization Management Strategies

Strategy	Suggested Role / Rationale	Feasibility
No demagnetization; RH designed to accommodate calculated forces	Baseline option, since predicted forces are negligible under the assumed conditions	Very high
Local, port-deployed low-frequency AC degaussing tool	Contingency if measured remanence exceeds the assumed value	Medium-high
Hot-cell demagnetization after extraction	Reduces of residual field for downstream handling	High
PF/CS-based machine degaussing	Limited effectiveness: PF/CS fields are poloidal, whereas the dominant remanence is toroidal	Low-medium
TF-coil-based degaussing	Potentially effective, but impractical due to TF-coil polarity reversal and machine-level operational constraints; not recommended.	Very low
Thermal demagnetization	Impractical due to the very high temperature required for demagnetization; not considered feasible.	Very low

Main conclusions

- Residual-magnetization loads are expected to be relevant only during the removal of the first few blanket modules, as the progressive increase in magnetic reluctance rapidly reduces these effects during disassembly.
- The recall force acting on the COB during vertical removal is negligible compared with the blanket self-weight and remains well within the expected capabilities of the remote-handling system.
- Overall, within the assumptions adopted in this study, residual magnetization does not represent a critical issue for DEMO breeding-blanket maintenance and disassembly operations.
- If additional mitigation is required, a dedicated local degaussing system integrated into the remote-maintenance or disassembly equipment appears more practical than using the tokamak main magnetic system, and its feasibility should be investigated in future work.