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# STATUS ON SEISMIC DESIGN AND VERIFICATION FOR ITER IN JAPAN

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**ABSTRACT**: This paper outlines the latest status on seismic design for ITER in Japan, considering uniqueness in structure and safety features, and describes the associated on-going research for evaluation on tokamak dynamic response and verification tests using scaled tokamak model.

**Key Words**: ITER, fusion experimental device, tokamak

## INTRODUCTION

ITER is a tokamak facility using Deutium and Tritium for fusion reaction, developed under the international collaboration of Japan, the European Union, the Russian Federation, the United States of America, the People's Republic of China and the Republic of Korea, aiming at scientific and technological demonstration of fusion energy. Overall layout of the ITER tokamak is shown in Fig. 1. The engineering design of the ITER facility has been successfully accomplished to establish the sound technical basis for construction, involving the detailed plant design, the technology development through prototypes fabrication and testing, and the safety evaluation characterizing the ITER safety attractiveness. Based on this achievement, preparation has been initiated for Negotiations toward

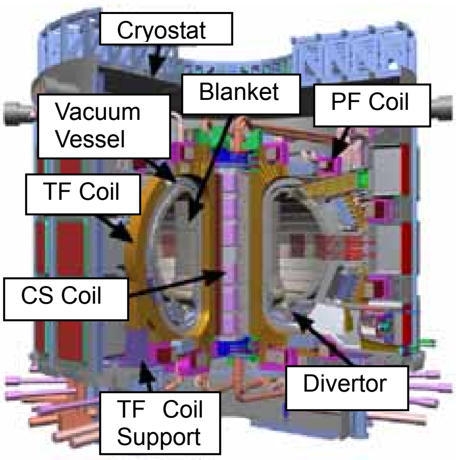



Fig. 1 Overall layout of ITER

construction agreement among the ITER participants.

The main structure of the ITER tokamak is composed of three types of superconducting coils (poloidal field coil, toroidal field coil and central solenoid coil), a vacuum vessel and in-vessel components, which are operated at quite wide temperatures ranging from 4 K (-269 degree C) to 200 degree C. For this, multiple plates shown in Fig. 2 have been chosen as the machine supports so as to provide flexibility in the radial direction for accommodating the temperature differences, while keeping high rigidity vertically for sustaining the whole dead weight and loads. This results in a low natural frequency of around 4Hz in the horizontal direction. Since those tokamak structures and supports are designed in accordance with the IAEA SL-2 seismic acceleration of 0.2 g as a reference, extensive efforts have been made, for siting ITER in Japan, to apply a seismic isolation to the tokamak building so as to enhance earthquake-proof for large seismic loads over 0.2 g.

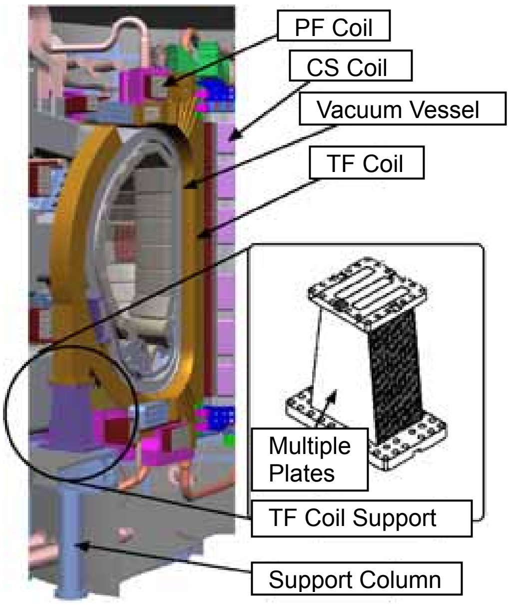
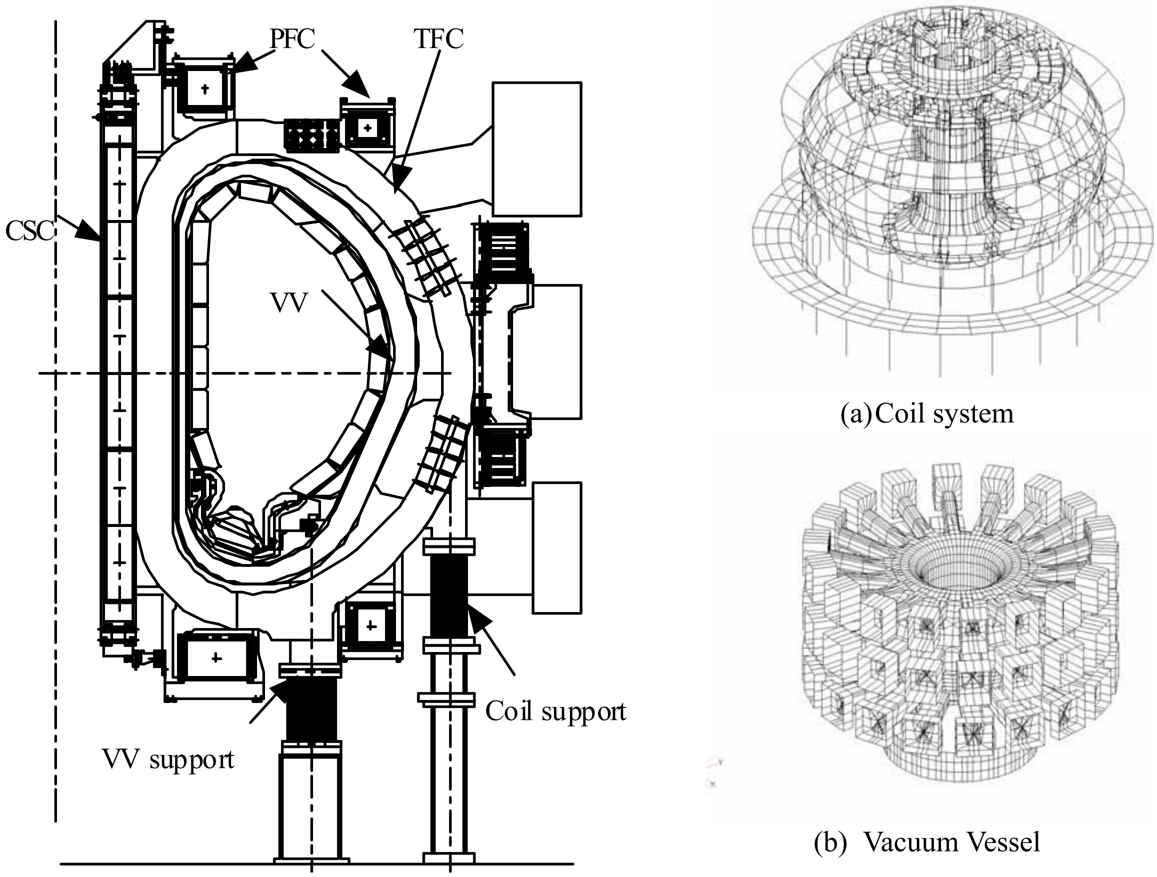


Fig. 2 Gravity support of ITER

Analytical and experimental studies have been conducted to characterize the ITER dynamic response. Parameter studies on seismic isolation using a simple mass-spring model of tokamak structures and building with interfaces to the ground have shown that the laminated rubber bearings with an oscillation period of around 3 sec are adequate to reduce the response acceleration acting on the tokamak components. Dynamic response of the ITER tokamak seismically isolated was also evaluated using 3-D FEM tokamak models as a parameter of the level of ground acceleration. In addition, verification tests have being conducted on tokamak structures/supports using a scaled-tokamak model.

## DYNAMIC RESPONSE ANALYSIS OF ITER TOKAMAK

The tokamak building of ITER is seismically isolated in the horizontal direction and it is important to verify earthquake-proof in the vertical direction. On the other hand, the electromagnetic force due to the plasma disruption is severe and hence ITER is designed stiffly in the vertical direction. In view of this, the response analysis has been focused to evaluate how strong earthquakes the ITER tokamak can accept and to clarify applicability of the current seismic isolation technique. For this, a parameter study was performed and the design margin has been confirmed for the ITER tokamak. In the analysis, an independent-support model as shown in Fig. 3 was chosen as a reference. In this model, the vacuum vessel (VV) is supported by multiple plate springs independently from the toroidal field coil (TFC). The poloidal field coil (PFC) and center solenoid coil (CSC) are connected to TFC supported by multiple plate springs. The natural frequencies calculated are listed in Table 1.




(a) Coil system

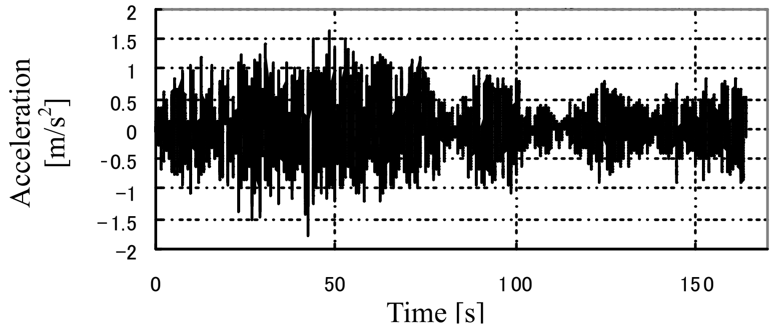
(b) Vacuum Vessel

Fig. 3 Concept of independent support and analysis model

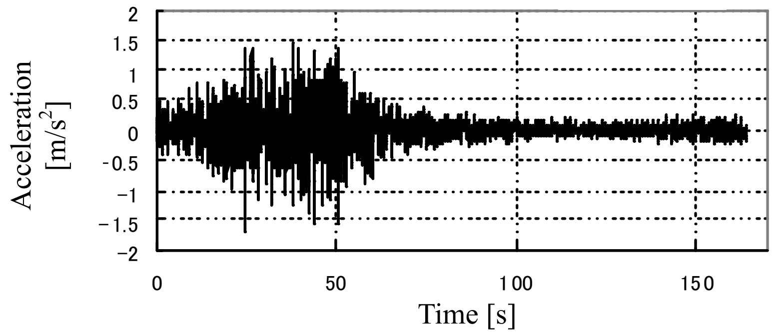
Table 1 Natural frequency

| Mode No. | Coil system | | Vacuum Vessel | |
|---|---|---|---|---|
| | Frequency [Hz] | Mode | Frequency [Hz] | Mode |
| 1 | 4.08 | Sway | 3.22 | Sway |
| 2 | 4.08 | Sway | 3.22 | Sway |
| 3 | 8.49 | Rotation | 4.11 | Rotation |
| 4 | 9.33 | Vertical | 8.97 | Rocking |
| 5 | 9.44 | CS Sway | 8.97 | Rocking |
| 6 | 9.44 | CS Sway | 12.56 | Vertical |
| 7 | 11.20 | Rocking | 13.14 | Port Vertical |

In the analysis, an earthquake motion is input to the base stratum (free surface) and its velocity is about 45 kine: this is almost same as the design maximum seismic wave used for nuclear facility in Rokkasho area, with modification of magnification on long period contents. Figure 4 shows the calculated floor response to the input earthquake and this response was used for the dynamic response analysis of the ITER tokamak, assuming damping factor of 1 %. Figure 5 shows typical assessment points to evaluate the response of the tokamak components during earthquake motion.




(A) Horizontal acceleration (Max : 1.77m/s$^2$)




(B) Vertical acceleration (Max: 1.71m/s$^2$)

Fig. 4 Floor response used for Tokamak dynamic analysis

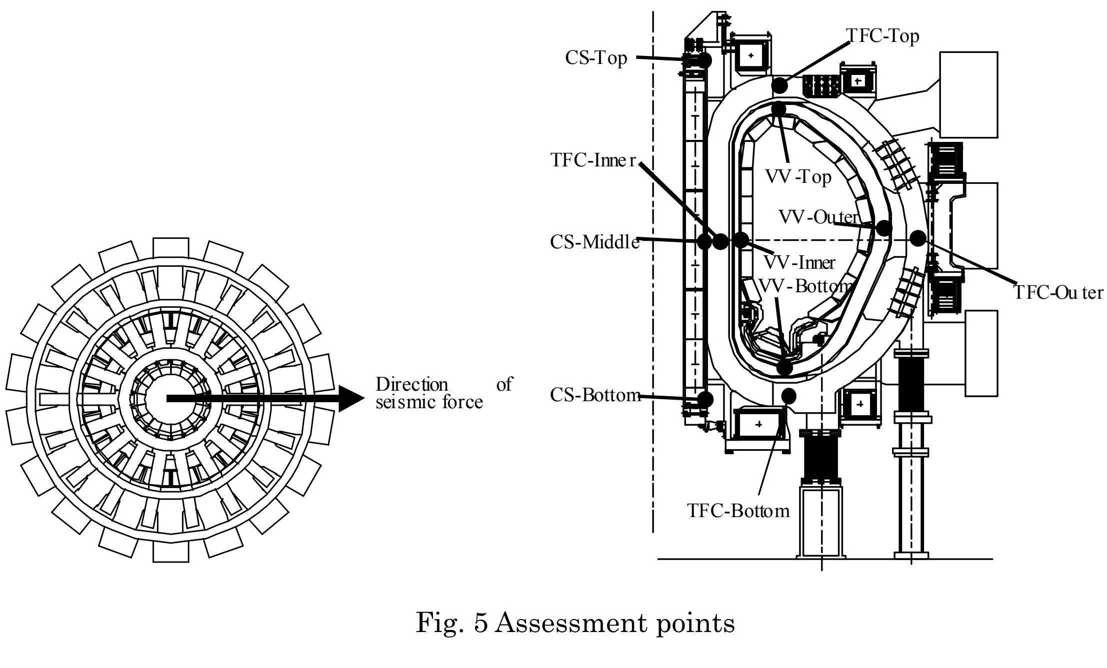



Fig. 5 Assessment points

The maximum response displacement and acceleration calculated at assessment points are summarized in Table 2. From these results, the maximum mutual displacement between TFC and VV is evaluated by summation of the maximum value of each displacement. This results in the maximum mutual displacement of 11.4 mm at the top of the machine, which is below the allowable value of 16.5 mm. The maximum displacement of the port tip is evaluated to be 6.63mm and is under the allowable value of 14.8mm. The maximum stress of the VV and coil supports is also evaluated to be about 180 MPa and 130 MPa, respectively: these are also below the allowance.

In addition, as a parameter study, large earthquake motion with a velocity of 100 kine has been analyzed. The results show that the maximum mutual displacement and the maximum stress are increased but they are still below the allowances.

Table 2 Summary of maximum response displacement and acceleration

| | Maximum response displacement [mm] | | | | Maximum response acceleration [$m/s^2$] | | | | Max. mutual disp. of VV and TFC [mm] |
|---|---|---|---|---|---|---|---|---|---|
| | TFC | CS | VV | Port | TFC | CS | VV | Port | |
| Horizontal | 5.26 Top | 6.52 Top | 6.12 Top | 6.63 Upper | 3.93 Bottom | 6.46 Top | 2.53 Top | 2.85 Upper | 11.4 Top |
| Vertical | 0.77 Inner | 1.31 Bottom | 1.06 Outer | 1.87 Equa. | 2.88 Inner | 4.15 Bottom | 2.70 Inner | 2.80 Upper | 1.59 Outer |

Lower line shows position

## SCALED MODEL OF TOKAMAK

The vibration characteristics, such as the low eigen frequency, affect on the seismic design of the tokamak device. Currently the vibration mode and the dynamic response are analyzed using numerical calculation codes and the numerical model needs to be verified by the experiment. Therefore, the vibration test using a sub-scaled tokamak model had been planned in order to validate the numerical analysis. The model referred to the 1998 ITER design (ITER, 1998) but the result can be applied also to the other tokamak fusion devices which use flexible supports such as plate springs.

The dimensional scale of the model was chosen as 1/8 considering the capacity of vibration test facility. The stress of the scaled model should be equivalent to that of the real machine to verify the fracture mode. Steel was selected for material so the Young's modulus and the density are almost same as the real machine. The scaling ratios of other parameters, as listed in Table 3, are calculated from the ratios mentioned above. The main components and support structures were designed so as to simulate weight and stiffness, respectively. Figure 6 shows the design of the 1/8-scaled tokamak model and the current appearance of the model after the preliminary assembly. The gravity supports, the inter-coil structures and the toroidal field (TF) coils have been fabricated by now.

Concerning with single TF coil model, the eigen vibration modes were measured using the tapping method. The measured frequency was 58.4 Hz while the result of the numerical calculation was 52.2 Hz. The discrepancy between these results was about 10% and was caused by bolted joints applied to the TF coil model while the actual coil case is fabricated only with welding.

In addition, the machine supports composed of spring plates were preliminary tested to obtain stiffness and damping ratio. The obtained stiffness in flexible and rigid direction was about 4.7 MN/m and 500 MN/m, respectively. In both cases, the stiffness values obtained by static and dynamic tests were agreed well. The damping ratio was calculated from the logarithmic decrement of the free vibration test. The obtained damping ratio in flexible and rigid direction was about 0.15 and 2, respectively. These values will be used in the dynamic response analysis of the scaled model.

Table 3 Scaling ratio for the tokamak model

| Dimension | Stress | Young's Modulus | Density | Weight | Frequency | Acceleration |
|---|---|---|---|---|---|---|
| 1/8 | 1 | 1 | 1 | 1/512 | 8 | 8 |

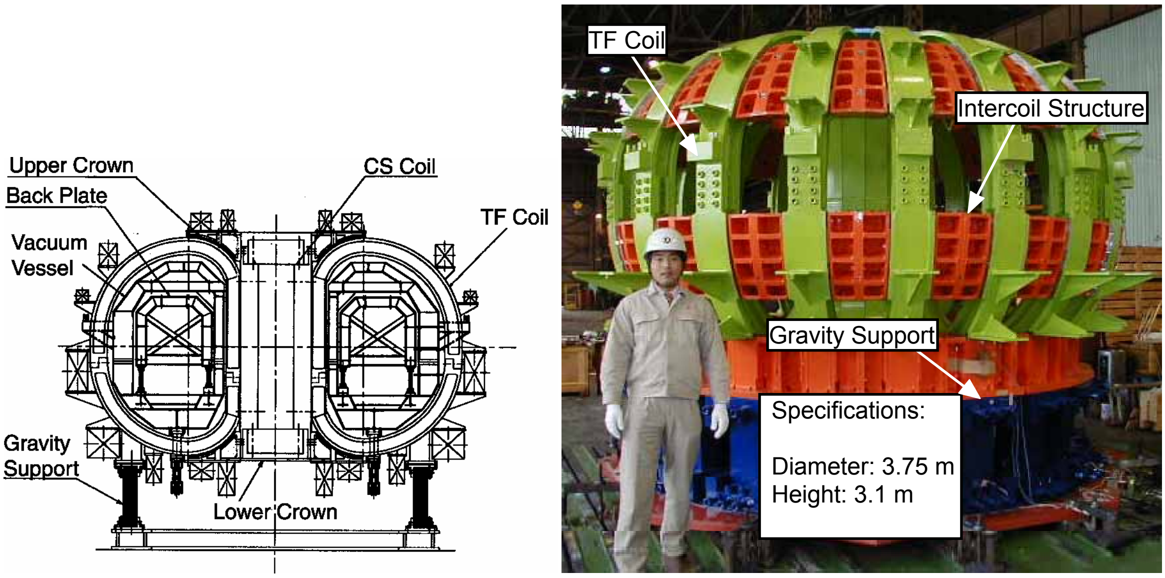



Fig. 6 Sub-scale tokamak model

## CONCLUSIONS

ITER seismic/isolation design has been outlined, including special structural feature. According to the design, the parameter study to evaluate dynamic response was performed on the ITER tokamak and its response behavior had been quantitatively clarified. In this study, seismic response analyses were performed based on the maximum design seismic wave in Rokkasho area and larger earthquakes as a parameter study. The results show that mutual displacement and stress of the machine supports blow allowable values.

Regarding the sub-scaled tokamak model, it is also in progress to validate analytical model of the tokamak components that behave in low frequency of about 4Hz due to flexible machine supports. Based on basic performance tests of spring supports and TF coil , the integrated vibration test using the whole tokamak assembly is scheduled.

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