

## **CIVIL ENGINEERING DESIGN OF ITER NUCLEAR BUILDINGS – A PERSPECTIVE**

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### **ABSTRACT**

The safety of a nuclear facility is governed by the structural integrity and confinement capacity of nuclear components and buildings. Hence the design of nuclear buildings is dictated by the various safety functions the buildings needs to provide during the life cycle of such facilities. Safety functions of nuclear buildings vary depending on the nuclear inventory, process, method, postulated accidents and the site characteristics. The ITER Facility is a Basic Nuclear Installation in France. The risk associated with the design and operation of ITER machine and its implication on the design and assessment of nuclear buildings are defined in the Fundamental Safety Rules and other guidelines defined by the French Nuclear Regulator (ASN). This paper highlights the civil engineering design requirements of nuclear buildings accounting the safety, functional, operational and other fusion specific loads.

### **INTRODUCTION**

The ITER project is an international collaborative scientific project being undertaken by China, European Union, India, Japan, Korea, Russia and USA to demonstrate the technical feasibility of nuclear fusion. ITER has been declared as a basic nuclear installation (INB) by the French Nuclear Regulator and hence its design and construction shall meet the nuclear and other international safety standards.

The ITER facility has been designated as a Basic Nuclear Installation in France (French acronym INB) because of the tritium inventory in the overall facility. Tritium will be present in the vacuum vessel for fusion reactions, in the Tritium Plant, in the fuel cycle systems, the Hot Cell Facility and Radioactive Waste buildings. The licensing procedure of a Basic Nuclear Installation follows the French regulations. This defines a mostly non prescriptive approach based on a continuous dialogue between the nuclear installation owner (IO) and the Nuclear Safety Authority, "Autorité de Sûreté Nucléaire (ASN)". Hence the design, construction, commissioning and decommissioning of all the Systems, Structures and Components (SSC's) shall be commensurate with the quality order -1984[1].

The ITER facility will be built over an area of around 100 hectares at Cadarache, in the south of France. In all, the ITER facility will have 42 buildings and structures that deliver various operational and functional requirements of the Tokamak Machine and associated systems. The ITER platform is a leveled area of ground encompassing 32 buildings, 5 of which are classified as nuclear buildings. Fig.1 shows a bird's eye view of the ITER facility after construction. The Nuclear Buildings of ITER are being designed for 70 years service life consisting of 10 years for construction, 20 years of operation, 5 years for deactivation, 23 years of care & maintenance and 12 years for decommissioning. These buildings are designed to resist all the actions and combinations of events that may be generated during their design life. These include the self weight (gravitational), imposed, operational, environmental and accidental actions. Besides the traditional engineering challenges posed by the design of industrial buildings on this scale, satisfying all the Safety and Functional requirements further adds to the complexity of the design process.

### **NUCLEAR BUILDINGS**

The Nuclear Buildings of the ITER facility house all the systems and equipments required for the installation, commissioning, operation, deactivation and decommissioning of the Tokamak Machine. The ITER Nuclear Buildings comprise; Tokamak Complex, Hot Cell Facility Building, Radwaste Facility Building, Control Building and Personnel Access Control Building. These buildings contribute to the nuclear safety of the ITER facility and are hence termed as safety related buildings. Their design shall envelope the requirements of structural integrity, confinement and shielding during all postulated external and internal hazards during all phases of the

Tokamak machine operations. Applicable Codes and Standards for the design of these Nuclear Buildings have been developed based on French and European standards. These have considered in detail all postulated external events and incident and accident scenarios of the Tokamak machine. The functional requirements are described below.



Fig. 1: Birds Eye View of ITER Facility

### **Tokamak Complex**

The Tokamak Complex [2] is reinforced concrete, monolithic shear walled structure that consists of three buildings viz, Tokamak building, Tritium, building and Diagnostic building. The Tokamak building, located in the center of the complex, houses the cryostat, superconducting magnets and the vacuum vessel, together with all the related systems and equipment. The Tritium Building, located in the east of the complex, houses some of the systems related to pumping and fuel processing that are required for operation of the Tokamak machine (tritium fuelling management, vacuum, etc) as well as the air and water detritiation systems. The Diagnostic Building, located in the west of the complex, houses several systems, including diagnostic equipment, the switching networks for poloidal field (PF) and central solenoid (CS) coils.

Tokamak Complex is a base isolated structure. It is supported on anti-seismic bearings which are in turn supported from the concrete plinths that are part of the Seismic Isolation Pit structure. This is done to attenuate the seismic response of the structure and limit the seismic accelerations on the Tokamak machine and systems. Fig.2 shows a sectional view of Tokamak Complex and Seismic Isolation Pit. The Tokamak Complex is approximately 120m x 80 m x 72m (59 m above ground and 13m below ground), whereas the Seismic Isolation Pit is approximately 125m x 88m and 15m deep (all below ground).

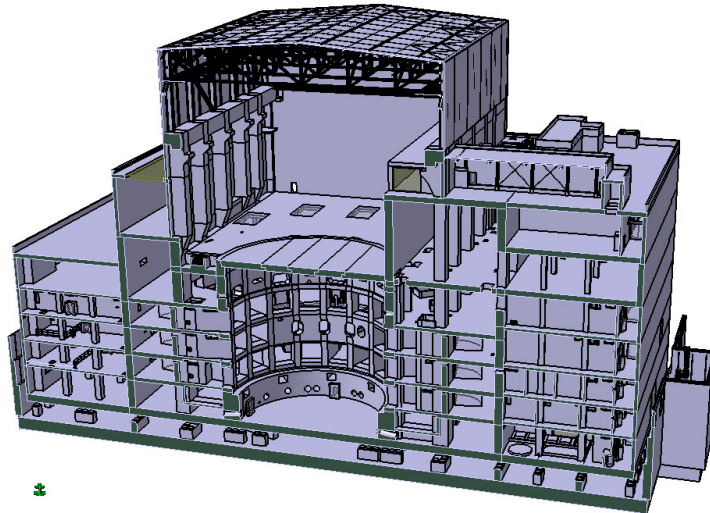


Fig. 2: Sectional view of Tokamak Complex and Seismic Isolation Pit

### Hot Cell Facility Building

The Hot Cell Facility building is a reinforced concrete, shear walled monolithic structure. It has a structural interface with Seismic Isolation Pit and functional interface with the Tokamak Complex. The Hot Cell Facility is designed to support ITER during Tokamak operations (nuclear and non-nuclear) de-activation and dismantling phases. The main functions carried out in the Hot Cell Facility include diagnosis, repair, cleaning, refurbishment, testing and storage of components, tools and equipment. These items may have become activated by neutron exposure and/or contaminated with tritium, beryllium or covered with activated dust. The structure is approximately 64m x 61m and 21m above ground and 12m below ground. In addition, there is an extension for the storage of radwaste located to the north of the Hot Cell Facility, which is approximately 60m x 25m x 12 m deep as shown in Fig.3.

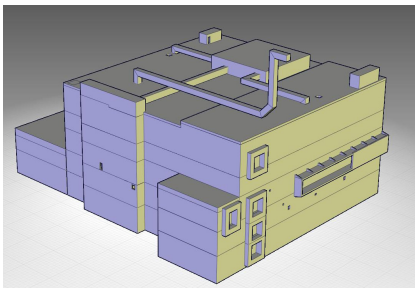


Fig. 3: Hot Cell Facility Building 3D model

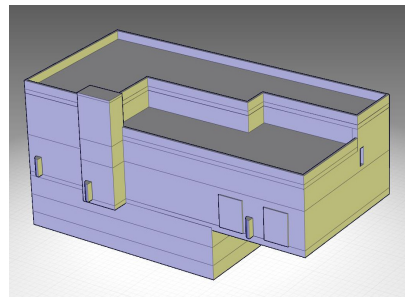


Fig. 4: Radwaste Facility Building 3D model

### Radwaste Facility Building

The Radwaste Facility building is standalone reinforced concrete shear wall monolithic structure with a functional interface with Tokamak Complex, Hot Cell Facility, Personnel Access Control buildings. The function of the Radwaste facility is to manage low and medium level solid radwaste and radioactive effluents generated by the ITER experimental systems. The structure is approximately 49m x 22m x 18m (12m above ground and 6m below ground). Fig.4 shows the 3D view of the Radwaste Facility Building.

### Personnel Access Control Building

The Personnel Access Control Building is a steel frame building that controls personnel access to the radiological controlled buildings. The building provides change, health and welfare facilities for personnel working within the Tokamak complex, Hot Cell Facility and Radwaste Facility. The PACB also houses the Backup Control Room, Hot Cell Facility operations control room and Remote Handling Operations control room. The building also

houses health physics laboratory and Beryllium laboratory. PACB is 36m x 24m and 8 m high. Fig .5 shows the 3D model of PACB building.

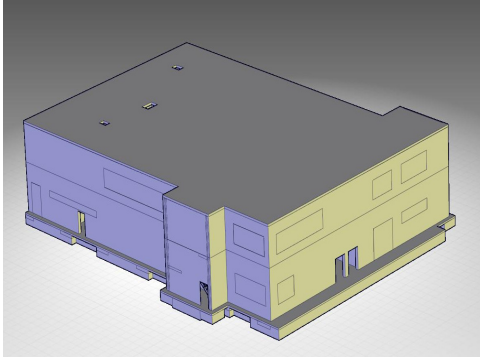


Fig. 5: Personnel Access Control Building

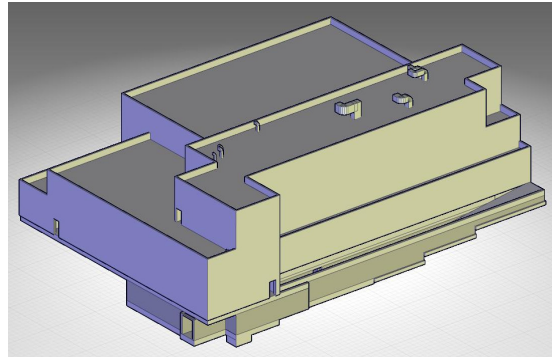


Fig. 6: Control Building 3D Model

### Control Building

The Control Building is a rectangular steel and concrete composite building. It houses the ITER facility Main Control Room; primarily centralized control systems such as ITER integrated Operations, Co-ordination of various plant systems, storage and retrieval of experimental data, Central Interlock System to assure the protection of investment and Central Safety Systems for the protection of workers and the environment. The building is approximately 76m x 44m and 15m height. Fig. 6 shows the 3D model of Control building.

Fig.7 shows the structural and functional interactions between Tokamak Complex and Hot Cell Facility building. The Hot Cell facility partially transfers its loads to the seismic isolation basemat structure.

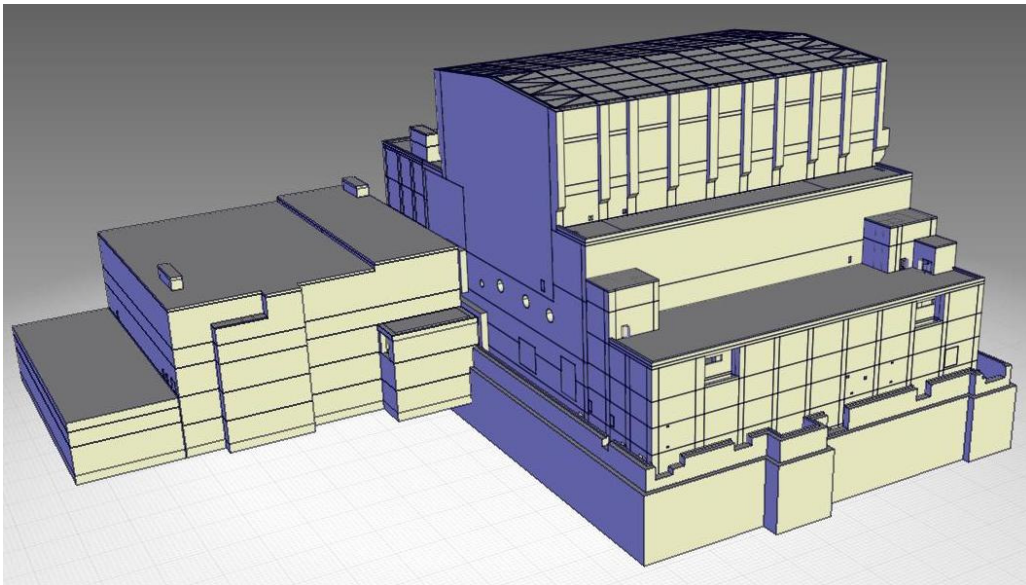


Fig. 7: Structural and Functional Interface among different ITER Nuclear buildings.

## **SAFETY REQUIREMENTS FOR BUILDINGS**

Safety requirements on building structures and associated systems were derived based on the safety analysis of ITER facility [2]. Building structures are designed to perform the following safety functions.

- Protection against Internal and External Hazards
- Control of radioactive material releases
- Biological shielding

### **Protection against Internal and External Hazards**

The ITER safety related building structures shall provide protection of all Safety Important Components and systems they house against the Internal and External hazards. These hazards include, but are not limited to, natural hazards, malevolent hazards, incident and accidental scenarios. Typically, they include site specific seismic hazard, external flooding, accidental load drops, internal and external explosions and Airplane crash.

Safety requirements on buildings have been categorized into 4 levels against the postulated site specific seismic hazard.

- Seismic Class 1-SF (SC1-SF): structural stability and required functional seismic safety performance required to be maintained in the event of an earthquake.
- Seismic Class 1-S (SC1-S): structural stability maintained in the event of an earthquake, i.e no rupture of piping, no collapse of structures or equipment, limited plastic strain, limited concrete cracking and supports function maintained.
- Seismic Class 2 (SC2): No damage to SC1 equipment: absence of damage to SC1 equipment, for buildings and structures housing and protecting safety important components or to buildings that can potentially damage such structures in the event of collapse, no other requirements regarding structural and functional performances in the event of an earthquake.
- Non Seismic Class (NSC): no seismic requirements for safety however will be designed to withstand the conventional earthquake, in accordance with Eurocode 8.

### **Control of radioactive material releases:**

Some nuclear buildings are designed and configured to control the release of radioactive materials in normal operations and accidental scenarios. The design criteria evaluated to control such postulated cases are as follows:

- Normal operations: 100% vol/day under  $\Delta P = 300$  Pa applicable for external walls and walls separating different confinement zones.
- Accidental Scenario: 100% vol/day under  $\Delta P = 0.1$  MPa, TCWS vault walls/slabs and  $\Delta P = 0.06$  MPa for Port cells.

### **Biological shielding**

The ITER safety related building structures shall provide biological shielding in various radiological zones depending on the process, inventory and operational needs. Shielding requirement in various buildings is achieved with minimum concrete or equivalent system thickness.

## **LOAD SPECIFICATIONS**

Loads are defined in terms of actions and each action is defined by the parts of the structures where it applies and its characteristic values. It may be a set of forces and moments (load) applied to the structure (direct action) or imposed deformations (indirect action). Actions are classified as follows:

- General actions basically applicable to all buildings, or to a specified group of them,
- Actions particular to each building or structure, in addition to or modification of the general actions,

In each of these groups, actions are classified as permanent, variable (quasi-permanent, frequent, rare or characteristic), seismic and accidental.

If the statistical distribution of the load is unknown, a nominal value defined in the European norm EN 1990 is applicable.

#### **Permanent Actions**

Permanent actions include, but are not limited to, the following:

- Gravity loads
- Soil reactions including the effects of soil settlements
- Lateral earth pressure
- Permanent water table effects
- Climatic conditions( Wind, temperature and snow)
- Prestressing loads
- Concrete Creep and shrinkage
- Service differential pressure and test actions.
- Permanent adjoint structural reactions.

#### **Variable actions**

Variable actions include, but are not limited to, the following:

- Actions applied during construction
- Variable loads due to equipment
- Loads from the Tokamak machine in case of VDE II
- Action of the magnetic field on buildings structures
- Dynamic loads due to equipment
- Variable loads due to carriages
- Normal variable loads due to occupancy and light equipment
- Normal overpressure or depression during operation or shut-down
- Test variable action
- Variation of actions due to lateral thrust of soil from their permanent values
- Variation of actions due to ground water table level from its permanent level
- Internal or external variation of temperature
- Wind
- Snow

#### **Seismic actions**

Design earthquake and specifications for floor response spectra, reactions from equipment, dynamic lateral earth pressure.

#### **Accidental actions**

- Accidental pressure due to LOCA and LOVA
- Thermal effect due to LOCA and LOVA
- Action from the Tokamak machine in case of VDE III
- Accidental action due to load drop
- Accidental internal flooding
- Accidental action due to external explosion
- Accidental action due to internal explosion
- Accidental action due to airplane crash
- Other accidental action due to equipment's
- Exceptional value of snow
- Extreme climatic temperatures
- Accidental level of water table

## DESIGN CRITERIA

Design criteria are described in ITER building code I-SDCB [3] and the principles are based on Eurocodes and French Nuclear Codes for civil work construction. The ITER building code encompasses the various Eurocodes and norms general requirements. Following is the list of various codes which forms the basis of design for ITER nuclear buildings.

- The basic principles for structural design are those of Eurocode EN1990 (EC0), particularly for the concept of limit states, the definition of partial safety factors and load combinations.
- Euronorm EN1991: Eurocode 1 gives basic requirements related to loads.
- Euronorm EN1992, EN 1993, EN199, EN195, EN1996: Material Eurocodes no's 2 to 6 (EC2 to EC6) for the design of structural elements.
- Euronorm EN1997-Eurocode 7(EC7) and Euronorm EN1998 – Eurocode 6-Part5 for geotechnical works referenced over the site specific geotechnical aspects.
- Euronorm EN1998- Eurocode 8 applicable principles and requirements. However specific analysis procedure and requirements are enforced by French Nuclear regulations.
- Euronorm EN15129 – 2009 Anti Seismic devices.

## CONCLUSIONS

The Preliminary design of the ITER nuclear buildings has been successfully completed after a series of technical reviews. Final design of some of these buildings is now in progress. The complex structural and functional interaction among various buildings will be completed over the course of the Final Design programme. Many of these buildings require state of art studies, considering that many of the systems that they interface with have never been built before; they will be the first of their kind. In parallel, within the frame work of RPrS review, the French Nuclear Authority is reviewing ITER civil structural designs. Construction of some of ITER nuclear buildings is scheduled to start in 2012.

## ACKNOWLEDGMENT

This paper was prepared as an account of work by or for the ITER Organization. Dissemination of the information in this paper is governed by the applicable terms of the ITER Joint Implementation Agreement.

## DISCLAIMER

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

## REFERENCES

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