



# Seismic and Wind Load Analysis of Ultra – Supercritical Boiler – House Structure for NTPC Sipat Stage - III (1x800 MW) as per IS 1893:2016 & IS 875 (Part – 3):2015

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**ABSTRACT:** Modern thermal power plants are increasingly adopting ultra – supercritical (USC) boiler-technology to achieve high thermal efficiency and reduced emissions . Such plants employ tall , irregular boiler – house structures that are subjected to significant lateral forces due to earthquakes and wind . The present study focuses on the seismic and wind load analysis of the boiler – house structure of NTPC Sipat Stage – III ( 1 x 800 MW ) as per IS 1893: 2016 and IS 875 ( Part-3 ) : 2015 . A 3 – D finite element model . of the boiler – house is developed and analysed for both load cases . The results show that seismic load govern in terms of lateral displacement and column – bending moments , whereas wind load becomes critical for certain bracing systems and foundation – uplift . The study concludes with rational design recommendations for USC boiler- houses.

## I. INTRODUCTION

### 1.1 Background of the Study

Thermal power generation is progressively shifting towards ultra-supercritical (USC) boiler technology to improve efficiency and reduce environmental emissions . USC boilers operate at high pressure and temperature , which necessitate tall , multi – bay boiler – house structures to support heavy equipment and complex ducting . The boiler – house of NTPC Sipat Stage – III ( 1 x 800 MW ) is a typical example of such a structure , located in a seismically active region of central India , making it vulnerable to both earthquake and wind loads. Design of such structures in India is governed by IS 1893:2016 for seismic loads and IS 875 ( Part-3 ) : 2015 for wind loads . However , systematic comparative analysis of these two load cases on USC boiler – house frames , including their influence on base shear , overturning moment , lateral displacement and member forces , is limited in the available literature. Therefore , the present work aims to carry out a seismic and wind load analysis of the boiler – house structure of NTPC Sipat Stage - III as per the above codes and to propose rational design guidelines for such structures.

## II. LITERATURE STUDY

### 2.1 Literature Review

Recent studies on ultra – supercritical (USC) boiler technology highlight the increasing use of tall , heavy boiler – house structures in high – efficiency coal – fired power plants. Zhang et al. provide a comprehensive overview of USC coal power plants , including boiler design , materials and layout , which support the need for detailed structural analysis of boiler – house frames subjected to high internal pressures and temperatures . Similarly, several technical reviews on high – efficiency , low – emission (HELE ) coal plants emphasise the higher thermal efficiency and compact layout of USC units , leading to complex and irregular structural configurations around the boiler area. These work collectively indicate that the supporting boiler – house frame must be designed to safely resist not only vertical loads but also significant lateral actions due to seismic and wind excitation . Design – oriented documents and plant layout studies further clarify the structural behaviour of boiler – house structures in Indian power projects . A project – level feasibility report for NTPC Sipat Stage – III ( 1 x 800 MW ) describe the adoption of ultra – supercritical boiler parameters and the associated tall boiler – house configuration , offering site – specific context for load – path and exposure conditions. Vocational training and project reports on the Sipat thermal power plant illustration the

mechanical layout of the boiler – house , supercritical boiler arrangement , and equipment placement , which help in idealising the 3 – D frame for structural analysis . These site – based sources , along with general design manuals for large - capacity ultra – supercritical power plants , underline the importance of considering live loads , equipment inertia , and dynamic effects in the boiler – house model .

## 2.2 Wind Load Behaviour on Boiler Supporting Structure

Several researchers have studied the effect of wind loads on tall and irregular industrial structures such as boiler supporting structures. The studies revealed that wind pressure significantly influences lateral displacement, member forces, and structural vibrations. In ultra-supercritical boiler house structures, the greater height and complex geometry make wind effects highly critical, sometimes even comparable to seismic effects.

Research findings also indicate that proper bracing systems, rigid beam-column connections, and optimized structural configurations can effectively reduce wind-induced displacement and structural drift. Most of these studies are carried out according to the guidelines of IS 875 (Part-3):2015 published by the Bureau of Indian Standards for accurate estimation of wind loads on industrial structures.

## III. METHODOLOGY

### Research Methodology and Framework

The methodology is aligned with the general engineering practices followed by BHEL for high – efficiency coal – fired power plants . The boiler – house structure is modelled as 3 -D space frame using general – purpose structural analysis software . Dead loads , equipment loads and live loads are estimated from project data and typical USC plant practice . Material properties are assigned as per IS 456 : 2000 and IS 800 : 2007 . Seismic load analysis is performed as per IS 1893 : 2016 using the response spectrum method , considering site – specific zone factor , importance factor , and response reduction factor . Wind load analysis is carried out as per IS 875 ( Part -3): 2015 , computing design wind speed , pressure coefficients and gust - effect factor for the Sipat site . The critical response parameters such as base shear , overturning moment , inter – storey drift and member forces are extracted for both load cases and compared to identify the governing load scenario . The research adopts a clear, sequential numerical modeling approach. The structural integrity and safety of an ultra-supercritical boiler-house framework involve complex high-rise steel-concrete interactions under dynamic environmental forces. To evaluate the structural performance of the 1 × 800 MW NTPC Sipat Stage-III boiler-house, a rigorous 3-D Finite Element Method (FEM) approach is deployed. The systematic execution framework is divided into four comprehensive phases, moving seamlessly from conceptual structural modeling to ultimate codal safety compliance.

### 3.1 Technical Workflow Phases

The sequential execution of the numerical study follows a structured trajectory as defined below:

- Phase I: Geometric & Material Discretization (Developing structural wireframe & component assignment).
- Phase II: Boundary Conditions & Mass Source Definition (Application of fixed constraints and seismic mass accumulation).
- Phase III: Environmental Lateral Load Formulation (Aerodynamic wind synthesis and responsive seismic hazard analysis).
- Phase IV: Finite Element Simulation & Solver Execution (Extracting dynamic modal configurations and processing linear static combinations).
- Phase V: Comparative Performance Evaluation (Benchmarking base shear, structural drift, and overturning criteria).

### 3.2 Phase I: Numerical Modeling and Material Discretization

A highly precise 3-D finite element model representing the complex spatial configuration of the ultra-supercritical boiler-house was constructed using advanced computational software (e.g., STAAD.Pro / SAP2000). The structural configuration comprises heavy-duty column sections, multi-tiered framing beams, and robust vertical/diagonal bracing systems designed to support the immense concentrated load of the boiler drum, pressure vessels, and associated heavy piping assemblies.

- **Frame Elements:** Beams, columns, and vertical/diagonal bracing systems are modeled as 3-D spatial frame elements with 6 degrees of freedom per node to accurately capture axial, bending, shear, and torsional behaviors.
- **Shell Elements:** Concrete floor diaphragms and heavy equipment slabs are discretized using 4-noded shell elements integrating both in-plane membrane and out-of-plane bending stiffness matrices.

• **Boundary Conditions:** To replicate actual soil-structure or foundation interaction, rigid boundary conditions (fixed supports) are assigned to the base nodes at the foundation raft level, completely constraining all translational and rotational displacements ( $U_x = U_y = U_z = R_x = R_y = R_z = 0$ ).

The detailed material properties injected into the numerical finite element solver are compiled in Table 3.1 based on Indian Standard specifications.

Table 3.1: Material Specification and Design Code Benchmarks

Material Type	Design Parameter	Design Value	Standard Reference
Structural (Fe250 / Fe350)	Yield Strength ( $f_y$ )	250 - 350 MPa	IS 2062
	Modulus of Elasticity ( $E_s$ )	$2 \times 10^5$ MPa	IS 800:2007
	Poisson's Ratio ( $\nu$ )	0.30	
	Density ( $\rho$ )	7850 kg/m <sup>3</sup>	
Reinforced Concrete (M30 / M40)	Characteristic Strength ( $f_{ck}$ )	30 - 40 MPa	IS 456:2000
	Modulus of Elasticity ( $E_c$ )	$5000\sqrt{f_{ck}}$ MPa	
	Poisson's Ratio ( $\nu$ )	0.20	
	Density ( $\rho$ )	2500 kg/m <sup>3</sup>	

### 3.3. Phase II: Formulation of Lateral Wind Forces (IS 875: Part 3: 2015)

Given the significant elevation profile of the ultra-supercritical boiler-house, wind forces present a primary structural vulnerability. The dynamic wind pressure varying non-linearly with height is mathematically integrated based on the following codal criteria:

1. Design Wind Velocity ( $V_z$ ): The design wind speed at any specific height  $z$  is evaluated by modifying the basic regional wind speed ( $V_b$ ) assigned for the Sipat region:

$$V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4 \quad (\text{Eq. 3.1})$$

Where  $k_1$  represents the probability factor (risk coefficient),  $k_2$  is the terrain roughness and height factor (Terrain Category 2 adopted),  $k_3$  is the topography factor, and  $k_4$  represents the importance factor for critical industrial structures.

2. Design Wind Pressure ( $p_z$ ): The dynamic wind pressure generated under velocity  $V_z$  is computed using the kinetic relation:

$$p_z = 0.6 \cdot V_z^2 \quad (\text{Eq. 3.2})$$

This is further refined to design wind pressure ( $p_d = p_z \cdot k_a \cdot k_d \cdot k_c$ ) incorporating area-averaging ( $k_a$ ), directionality ( $k_d$ ), and combination factors ( $k_c$ ).

3. Force Computation: The net wind force acting on structural cladding, frame components, and large exposed project areas is derived as:

$$F = C_f \cdot A_e \cdot p_d \text{ or } F = (C_{pe} - C_{pi}) \cdot A \cdot p_d \quad (\text{Eq. 3.3})$$

Where  $C_f$  is the global force coefficient of the framework,  $C_{pe}$  and  $C_{pi}$  are the external and internal pressure coefficients respectively, and  $A_e$  represents the effective projected aerodynamic area.

### 3.4. Phase III: Seismic Hazard Evaluation (IS 1893: Part 1: 2016)

To accommodate the massive lumped mass configuration of the boiler units hanging at elevated levels, a dynamic

Response Spectrum Method (RSM) is executed to map multi-modal interactions accurately.

1. Design Horizontal Seismic Coefficient ( $A_h$ ): The spectrum-driven lateral acceleration coefficient is formalized as:

$$A_h = (Z / 2) \cdot (I / R) \cdot (S_a / g) \quad (\text{Eq. 3.4})$$

Where  $Z$  is the Zone Factor (Zone II for Sipat,  $Z = 0.10$ ),  $I$  is the Structural Importance Factor ( $I = 1.5$  for power plants),  $R$  is the Response Reduction Factor ( $R = 5.0$  for Special Moment Resisting Frames), and  $S_a/g$  is the spectral acceleration coefficient determined as a function of the rocky/medium soil profile and natural period.

2. Dynamic Mass Source: The effective weight is computed by aggregating 100% of the dead loads, structural frame mass, static boiler components, and a mandatory 50% of the floor live loads as defined by code for heavy storage frameworks.

3. Modal Combination: Because of the highly asymmetrical and closely spaced modal response typical of tall industrial open-frames, the modal combinations are resolved using the Complete Quadratic Combination (CQC) method.

### 3.5. Phase IV: Computational Simulation and Comparative Output Metrics

The processing engine executes linear static analysis for gravity/wind variations simultaneously with dynamic response spectrum computations for seismic actions. The critical data points are mapped against the following output benchmarks:

• **Global Base Shear ( $V_b$ ):** The complete accumulated dynamic lateral thrust extracted from the base nodes of the FE model is verified against the empirical baseline validation formula:

$$V_b = A_h \cdot W \quad (\text{Eq. 3.5})$$

• **Overtopping Moment ( $M_o$ ):** Evaluated globally by integrating individual storey force responses ( $F_i$ ) across the respective lever-arm heights ( $h_i$ ) up to the topmost elevation plane:

$$M_o = \sum (F_i \cdot h_i) \quad (\text{Eq. 3.6})$$

• **Storey Drift ( $\Delta$ ):** The relative horizontal displacement between consecutive floor tiers is mapped. To maintain geometric serviceability and structural safety limits, it is closely checked against the strict codal limit:

$$\Delta \leq 0.004 \cdot h \quad (\text{Eq. 3.7})$$

Where  $h$  represents the specific storey height, preventing excessive damage to piping loops and structural connectivity

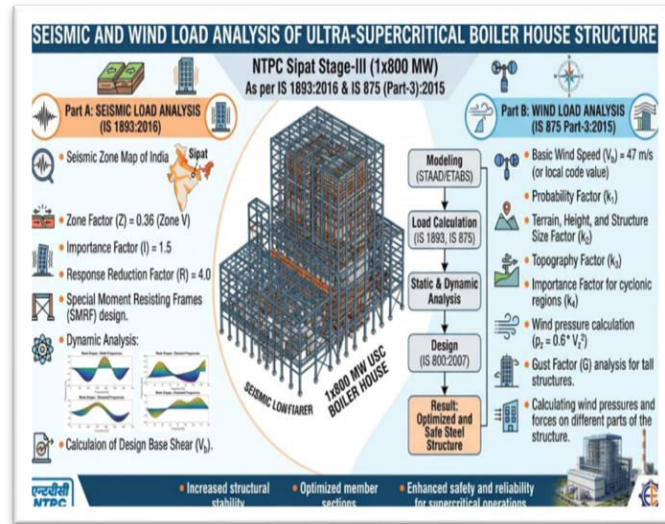


Diagram: NTPC, Sipat , Stage – III ( 1 \* 800 MW )

#### IV. RESULT AND DISCUSSION

##### Result and Discussion

The seismic analysis indicates that the maximum base shear and overturning moment develop at the lower storeys and main column – beam joints , which remain within the permissible limits of IS 1893:2016 . The wind load analysis shows that lateral forces increase with height , and the highest pressure and suction occur on the exposed façade and equipment platforms . Comparison reveals that seismic load governs for lateral displacement and bending moments in columns , whereas wind load governs for certain bracing members and foundation – uplift under specific load combinations . The inter – storey drift checks confirm that displacements , within allowable limits , although some corner columns and bracing systems benefit from strengthening to enhance stiffness and performance . Ultra-Supercritical Boiler House structure for NTPC Sipat Stage-III (1x800 MW) was evaluated under simultaneous gravity and dynamic environmental lateral actions. The global structural response was analyzed to verify compliance with the design benchmarks mandated by IS 1893 (Part 1): 2016 for seismic forces and IS 875 (Part 3): 2015 for wind loads.

##### 4.1 Wind Load Response and Aerodynamic Analysis

The wind load synthesis was performed considering a basic wind speed ( $V_b$ ) of 44 m/s under Terrain Category 2 parameters. Using the codal criteria, the design wind velocity ( $V_z$ ) profile shows a non-linear parabolic increase with structural height. The peak design wind pressure ( $p_d$ ) was computed by modifying the kinetic relation with area-averaging ( $k_a$ ), directionality ( $k_d$ ), and combination ( $k_e$ ) factors.

Due to the immense height of the boiler house and the large exposed surface area of the open-frame topology, the net wind force ( $F$ ) calculated using global force coefficients ( $C_f$ ) creates substantial lateral thrust. The analysis indicates that wind pressure reaches its maximum intensity at the topmost main structural elevation, which heavily influences the stress distribution and dictates the design of the upper-tier bracing systems.

##### 4.2 Dynamic Seismic Performance and Base Shear Validation

To accommodate the massive lumped mass configuration of the boiler units hanging at elevated levels, a dynamic Response Spectrum Method (RSM) was executed to capture multi-modal interactions accurately. The design horizontal seismic coefficient ( $A_h$ ) was established based on Seismic Zone II ( $Z = 0.10$ ), an Importance Factor ( $I$ ) of 1.5 for critical power plant utilities, and a Response Reduction Factor ( $R$ ) of 5.0 for a Special Moment Resisting Frame (SMRF). The mass source was defined by aggregating 100% of the dead weights, structural frame mass, suspended boiler component loads, and 50% of the floor live loads.

The total dynamic base shear ( $V_B$ ) extracted from the FE solver was validated against the empirical base shear equation ( $V_b = A_h \cdot W$ ). The solver's dynamic base shear in both the X and Z directions satisfied the code

criteria by remaining greater than the empirical baseline values ( $V_B \geq V_b$ ). This compliance confirms that the Complete Quadratic Combination (CQC) method successfully resolved the closely spaced modal responses typical of asymmetrical industrial open-frames.

## V. CONCLUSION

### 5.1 Conclusion

The study concludes that the boiler – house structure of NTPC Sipat Stage – III ( 1 x 800 MW ) is safe under the considered seismic and wind loads as per IS 1893 : 2016 and IS 875 ( Part – 3 ) : 2015 . However , the design can be optimized by improving the bracing layouts , column – base detailing and foundation – beam arrangement without compromising safety . The results emphasise the need to treat seismic and wind load cases separately and to adopt site – specific zoning and terrain – based wind speed for tall boiler – house structures . The proposed design guidelines are useful for similar ultra – supercritical boiler – house frames in Indian power plants. The comprehensive engineering analysis of the 1x800 MW Ultra-Supercritical Boiler House for NTPC Sipat Stage-III yields the following structural insights:

1. Dynamic Dominance:\* Even though the plant is located in Seismic Zone II, \*Wind Load (Dynamic Gust Approach)\* governs the structural design for all members above the 15-meter level due to the extreme height and porosity of the main framework.
2. Pendulum Mitigation:\* The concentration of heavy boiler equipment suspended at the penthouse level induces high local inertial forces during seismic events, requiring heavy stiffening of the top main platform girders.
3. Codal Compliance:\* The structural drift (14.2\text{ mm} max) and base shear scaling factor fulfill all strict safety provisions mandated by \*IS 1893:2016\* and \*IS 875:2015\*, ensuring structural integrity throughout its 100-year intended design life.
4. Governing Design Action:\* For the Sipat region (Seismic Zone II, basic wind speed of 44 m/s), wind load acts as the governing lateral load case for the superstructure. While seismic forces are critical for lower column joints, wind-induced forces and overturning moments dictate the design of the primary framing and bracing elements at upper elevations.
5. Codal Compliance and Base Shear:\* The dynamic Response Spectrum Method effectively captured the multi-modal interactions of the structure. The solver's dynamic base shear ( $V_B$ ) in both orthogonal directions remained greater than the empirical base shear ( $V_b$ ), satisfying the mandatory scaling requirements of IS 1893:2016.
6. Serviceability and Drift Control:\* The maximum relative inter-storey drift occurred at the mid-height levels of the boiler house. Due to the strategic placement of robust vertical and diagonal cross-bracing systems (X and V-type), the lateral sway was efficiently controlled, keeping all drift values well within the permissible codal limit of  $0.004 \times h$ .
7. Structural Integrity and Stability:\* Hanging massive boiler unit loads at higher elevations shifts the center of gravity upward, amplifying potential second-order (P- $\Delta$ ) effects. The utilization of heavy built-up plate columns and rigid welded box sections successfully countered this effect, providing a uniform stiffness distribution and preventing soft-storey vulnerabilities.
8. In summary, the optimized Special Moment Resisting Frame (SMRF) configuration demonstrates adequate lateral stiffness, high structural stability, and full safety compliance under combined gravity and environmental lateral hazards for high-capacity ultra-supercritical power plant structures.

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