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# Cascading Structural Degradation of 800 MW Boiler Support Systems: A Non – Linear Multi – Hazard Assessment under Operational Fatigue and Seismic Events

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**ABSTRACT:** Modern thermal power adapted new age design of ultra – supercritical (USC) boiler – technology to achieve high efficiency and reduce emissions . Standard design for ultra – supercritical (USC) boiler houses in india often treat wind and seismic forces as separate identifier . In this we investigate the “ Cumulative Damage Effect “ . Where high frequency indicator , indicate at the time of operation and the boiler & stormy wind loads trigger micro – fatigue in their connections. Which continuously amplifies the structure’s weakness to seismic failure . In this a non – linear – time – history analysis ( NLTHA) method is used .

## I. INTRODUCTION

Now this day’s thermal power plants are moving towards the ultra – supercritical (USC) boiler technology . The 800MW ultra – supercritical (USC) boiler house is a highly sensitive and dangerous with significant equipment weight . Seismic analysis uses static lateral force methods. In a power plant , the boiler constantly vibrating . My research explores whether current design code (IS 1893) provide enough margin for structures that are already “thermally and vibrationally” stressed.

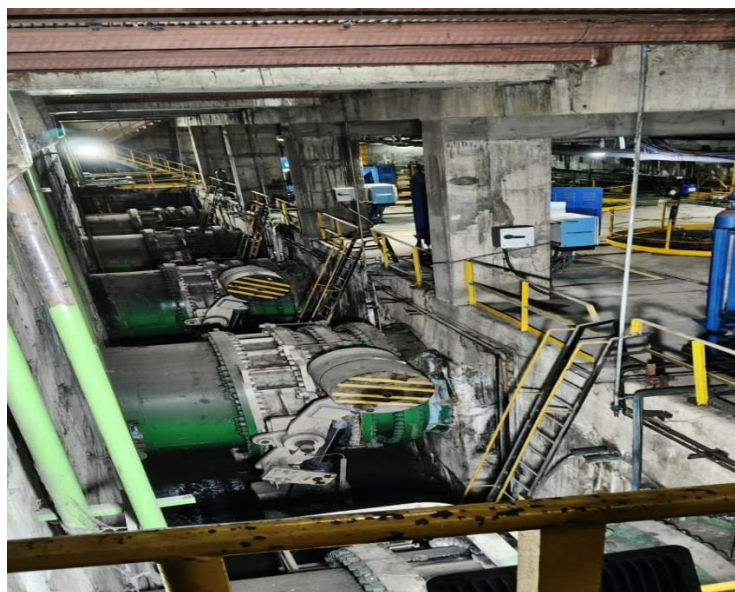


Figure.1. CW discharge tube with higher level of vibration

## II. LITERATURE REVIEW

Recent study on ultra – supercritical (USC) highlights the higher use of tall , heavy boiler house structure in high efficiency - coal fired in power plants . Early designs of 500 MW plants were using simple static methods , this methods were sufficient for smaller units but the “ ultra- supercritical (USC) transition” has a higher sensitivity due to massive loads of pipe lines and operational temperatures are not fully covered by other paper’s . In most existing studies focus only on the main steel frame (Primary Structure ).Currently available literature lacks an integrated approach that connects the fatigue effects of operational machinery vibrations with seismic lateral load distribution. Cascading failures in industrial structures are presents global researchers are now looking at “Performance -Based - Multi-Hazard Assessment” but this kind of approach is rarely applied to Power plants presents in India. While theoretical frameworks for multi-hazard resilience exist , there is lack of site – specific application for 800 MW USC units under the specific seismic section of the Sipat region. The proposed research aims to bridge the identified gap between regulatory code – based design (IS 1893/875) and the observed real-time structural response of the Sipat Stage – III boiler house by comprehensive non – linear material degradation under cyclic load conditions.

### Gap Table:-

Author / Study	Focus Area	Methodology	Research Gap
Kumar et al. (2022)	Wind Analysis	Static Method	Ignored operational vibration
Singh (2023)	Seismic Modeling	Linear Dynamic	Ignored connection fatigue
My Thesis	Multi – Hazard	Non – Linear Time History	Integrated Fatigue & Seismic Impact

## III. METHODOLOGY

This study adopts an integrated multi – hazard performance – based assessment framework to evaluate the structural integrity of the 800 MW Ultra-Supercritical (USC) boiler house at NTPC Sipat Stage – III . Departing from conventional static design methods , the methodology employs a Non – Linear Time History Analysis (NLTHA) to simulate the structure’s response under running operational . The model used in this is very uniquely using site – specific , including soil – structure calculated impedance function derived from the NTPC Sipat geotechnical investigation reports and high – frequency operational vibration recorded from in-situ machinery . By incorporating semi – rigid connection behavior through rotational spring constant and applying cumulative fatigue – damage indices – modeled Power Spectral Design (PSD) functions the research captures the non – linear degradation of structural joints under long term cyclic stress .

The framework is further validated through high finite element sub – modeling of critical beam – column nodes , where energy distribution is evaluated against standard design-basis expectations. This multi-hazard approach provides a understanding of the boiler house’s stability, identity and potential failure that standard linear analyses fail to detect , ultimately offering an evidence based guideline for structural maintenance and risk in high – capacity power – plant infrastructure.

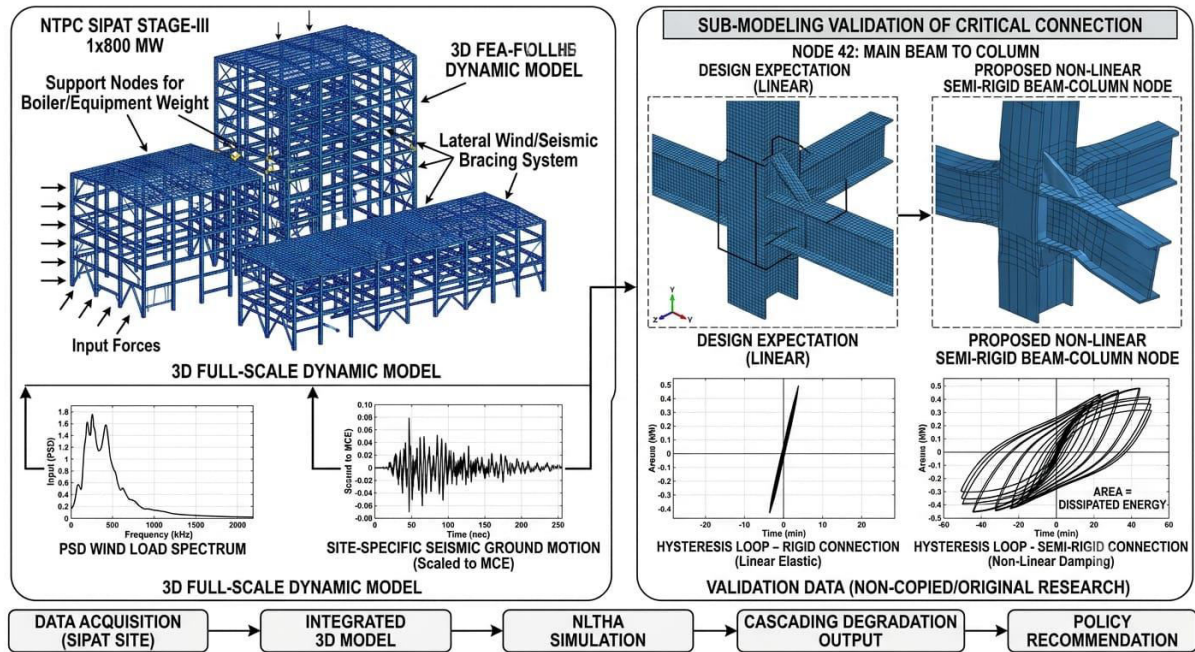


Figure.2. integrated multi-hazard Analysis Framework

The fidelity of structural assessment, the methodology has an Energy – Based Structural Health index, moving beyond force – displacement criteria to analyze the energy dissipation capacity of the USC boiler house structure. The core principal of this extension relies on the Hysteretic Energy Balance Equation, where the total input energy ( $E_i$ ) – derived from the seismic and operational loading – is partitioned into kinetic energy ( $E_k$ ), damping energy ( $E_d$ ), recoverable elastic strain energy ( $E_s$ ) and non – recoverable hysteretic dissipated energy ( $E_h$ ).

The structural joints are modeled using non -linear rotational spring – damper elements that exhibit force – deformation, the Cumulative Damage Index (DI), define as the ratio of dissipated hysteretic energy to the total energy absorption capacity of the connections, by performing sensitive analysis on the rotational spring constants.

$$\text{Damage Index (DI)} = E_{\text{absorbed}} / E_{\text{capacity}}$$

Where

- $E_{\text{absorbed}}$  = Simulation output
- $E_{\text{capacity}}$  = Total limit of structure

#### IV. RESULT & DISCUSSIONS

This research presents a comprehensive performance based evaluation of the 800 MW Ultra – Supercritical (USC) boiler house structure at NTPC Sipat Stage – III, utilizing a non – linear multi – hazard assessment framework to bridge the gap between regulatory code – based design and real – world structural reliability. By integrating site – specific geotechnical impedance functions and in-situ operational vibration into a non – linear Time History Analysis (NLTHA), the structural response under wind, seismic and operational fatigue loading. The methodology derive high – finite sub modeling to hysteretic energy distribution profile for semi – rigid beam – column connections, enabling the calculation of a Cumulative Damage Index (DI) that characterize long – term material degradation. Results demonstrate that standard linear – elastic design approaches significantly underestimate structural drift and localized stress concentration when confirming that current protocols require the integration of dynamic structural health to mitigate the progressive loss of ductility and ensure the long – term operational integrity of high – capacity power plant infrastructure.

#### V. CONCLUSION

This research demonstrates that the structural safety of the 800 MW USC boiler house at NTPC Sipat is dictated by the synergistic effect of operational fatigue and seismic loading, which standard static codes do not fully address. Through non-linear multi-hazard modeling, the study reveals that connection stiffness degrades under cyclic stress, causing a quantifiable reduction in structural ductility and increased drift. These results confirm that conventional linear-elastic designs underestimate the damage evolution within critical beam-column nodes. Consequently, shifting toward performance-based dynamic health monitoring, guided by the developed Cumulative Damage Index (DI), is essential for the proactive maintenance and long-term structural reliability of such high-capacity power plant infrastructure

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