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Application of High Tensile (E-550 Grade) Structural Plates for Built-up Columns and Beams in Boiler Structure

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Abstract: In the past Boiler Structure has been designed using mainly carbon steel plates of Grade E250 or E350. This paper presents and analyses the application of High Tensile steel (E550 Grade as per IS: 2062) in Heavy structure like Boiler Supporting Steel Structure. Boiler supporting Structure consists of major weight contribution in Columns and Beams which are stress governed, the objective is to optimize the structural quantity through application of High Tensile Steel with higher yield stress. This paper describes the complete analytical approach adopted in analysis & design, conclusion and recommendation. Latest structural plate rolling technology provides excellent combination of high strength, Toughness and weldability for High Tensile Steel, these properties of steel plate are most critical mechanical properties for steel structure design. The key microstructural control is obtained in the plate rolling mills through on-line heat treatment immediately after accelerated cooling during Thermo-Mechanical Controlled Processing (TMCP). Thermo-Mechanical Controlled Processing technology is recent development applied in latest steel structural plate rolling mills for rolling with thickness up to 120mm. Niobium (Nb) as a micro alloy in the steel enables to achieve a substantial grain refinement, very fine-grained microstructure improves toughness and increases the yield strength. The TMCP process enables the required tensile properties in structural plates with leaner chemical composition. Leaner chemical composition, especially lower carbon content and lower carbon equivalents improves weldability. Improved weldability benefits the fabricator for fabrication of plate fabricated built-up profiles which is the main requirement in Heavy Structure like Boiler Supporting Steel Structure. Detailed analysis and design of typical 660 MW coal fired Boiler structure has resulted in 25% structural weight saving in case of High Tensile steel application (E550 Grade) as compared with commonly used carbon steel (E250/E350 Grade). Also, this analysis concludes that use of high tensile steel should be limited to Columns and Beams only which are stress governed and where yield strength is the main design criteria.

Keywords: E-550 Grade Steel, Boiler Supporting Structure, Thermo-Mechanical Controlled Processing (TMCP), Martensite-Austenite (M-A)

1. Introduction

In a Thermal Power Plant, Boiler Main supporting structure weight is about 20% of Boiler, Ducts, Piping and Auxiliaries weight. Columns and Beams weight contributes about 75% of Boiler Main supporting structure.

Boiler supporting structure is one of the steel structures with heavy loadings in power plant. For a typical 660 MW, Boiler structure height is about 90 meters with total vertical loading in the tune of 66,000 Metric tons to 74,000 Metric Tons which is non-uniformly distributed at various levels from 18 meter to 90meter. The boiler structure is subjected to the hung load of Boiler (about 16,000 Metric tons to 18,000 metric tons), thus the Boiler structure acts as inverted pendulum and non-linear structure for lateral loads during seismic condition.

Boiler Structure is being designed using built-up “H” profiles for Columns and Beams with varying depth up to 2.0 m and varying flange width up to 1.4 m consisting of structural plates with thickness varying from 20mm to 80mm. Such built-up structures are very expensive in regard with material cost and fabrication.

In view of optimizing the steel structure weight and to develop efficient structural design from layout point of view also, this study for application of high tensile plates with higher yield strength has been performed. Typical Boiler structure is modeled, analyzed, and designed using E-350 Grade and E-550 Grade steel Columns/Beams for one fixed set of Boiler loads including Wind and Seismic loads for specific site.

This paper describes the complete analytical approach adopted in analysis & design, conclusion, and recommendation.

Boiler main supporting structure safely transfers the Boiler Pressure Parts loads, Non-pressure parts loads, High Pressure /Low pressure piping loads, auxiliary Equipment loads, seismic and wind loads to the foundation system through a structural framing system consisting of Columns, Tie Beams, Top Girders, Vertical Bracing and Lateral Bracing.

Boiler Columns are subjected to axial compressive loads in the range of 2500 Metric tons to 3000 Metric Tons and huge Bending moments. Girders and Beams are subjected to vertical load in the range of 100 Metric tons to 500 Metric Tons.

Columns and Beams are Built-up “H” profiles made of structural plates. Yield strength of structural plates plays vital role in designing the profile of Columns/Beams.

In the present study, a Typical Boiler supporting structure has been designed for two different cases for fixed set of Boiler Loadings. In these two cases only plate material for Columns and Beams are changed i.e., Case-1 with columns /Beams of E-350 Grade plate and Case-2 with columns /Beams of E-550 Grade plate [8-11, 14, 17] per recent development in steel plate rolling.

For Structural analysis of Boiler Support Main steel structure STAAD-Pro software is used. In both the cases working stress Design Approach as per Indian Coded IS-800: 2007 has been followed.

Dynamic analysis of Boiler Supporting Structure has been conducted and comparative study of structural weight for Columns and Beams is carried out for both the cases,

From the comparative weight analysis of these two cases, it is found that Column/Beams weight could be optimized by 25% for Case-2.

Also, the reduced Column and beam Depth provides more space between two floors which is an advantage in layout planning of Ducting, Boiler Piping and Auxiliaries.

2. High Tensile TMCP Structural Plates

In recent years, the thermo-mechanical controlled process (TMCP) has been deployed by Steel Rolling Mills for rolling Structural plates up to 120mm thickness [9, 12, 14]. Heavy structures design requires higher thickness plates for built-up profiles of Columns and Beams.

Niobium (Nb) as micro- alloy in the steel making enables to achieve a significant grain refinement. Fine-grained microstructure improves toughness and increases the Yield strength which is advantageous for Columns and Beams in Heavy structure.

TMCP process enables the enhancement of tensile properties with a leaner chemical composition. The effect of leaner chemical composition mainly of lower carbon content and lower carbon equivalents, provides improved weldability which is essential for structural plate fabrication. TMCP steel permit a wide range of welding conditions producing quality welds and acceptable HAZ properties which benefit the fabricator in terms of fabrication cost [14].

Also, TMCP steel allows reduction in pre-heat temperature for thicker plate welding.

TMCP developed high tensile steel exhibits microstructure of fine M-A (Martensite-Austenite) constituent in the bainitic ferrite matrix. The key technology to obtain excellent combination in mechanical properties is the microstructural control of M-A constituent and bainitic ferrite dual- phase structure through on-line heat treatment immediately after accelerated cooling during Thermo-Mechanical Controlled Processing (TMCP). Through the On-line heating immediately after accelerated cooling results in structural plates having microstructure of fine M-A particles dispersed in the bainitic ferrite matrix [13, 15, 16, 18].

3. Loadings and Structural Design data

3.1. Dead Loads

D: Dead Loads.
Dead Load consists of following loads.
Self- weight of Boiler pressure part including water.
Non pressure part.
Air and Gas duct.
Self- weight of Piping with insulation.
Equipment weights.
Gallery/platform RCC Floor self-weight.
Cable trays.
Insulation and cladding.

3.2. Live Loads

L: Live Load.
Live Load consists of following loads.
Gallery /platform live loads.
Ash loads in furnace hopper.
Ash load in roof penthouse.
Live load on roof.
Live load on RCC floor /roof.

3.3. Equipment Loads

Q1: Equipment operating loads.
Q2: Equipment test loads.

3.4. T: Temperature Loads

As stipulated in the design code.

3.5. E: Seismic Loads

As stipulated in the design code IS: 1893.

3.6. W: Wind Loads

As stipulated in the design code IS: 875.

3.7. Load Combination for Design

S. no.	Load Combination
1.0	(D+Q1)
2.0	(D+Q1) +(L)
3.0	(D+Q2)
4.0	(D+Q1) ± T
5.0	(D+Q1) +L±T
6.0	(D+Q1) ±W
7.0	(D+Q1) ±E
8.0	0.90 (D+Q1) ±W
9.0	0.90 (D+Q1) ±E
10.0	(D+Q1) +L±W
11.0	(D+Q1) +L±E
12.0	(D+Q1) ±W±T
13.0	(D+Q1) ±E±T
14.0	(D+Q1) +L±W±T
15.0	(D+Q1) +L±E±T
16.0	0.90 D + W

3.8. Boiler Structural Plan (At Base Level)

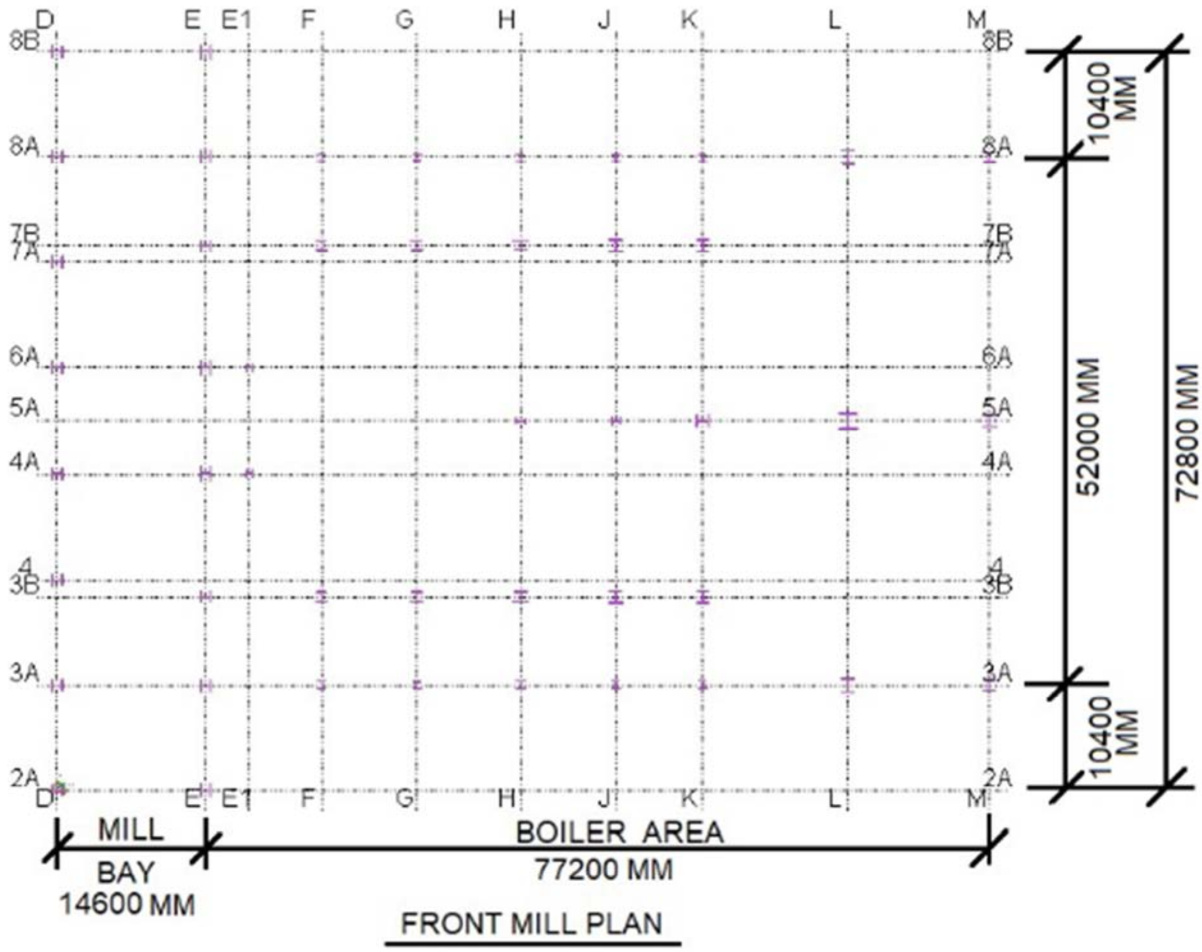

Figure 1. *Typical Plan Dimension of Boiler Structure at Base Level.*

Typical plan dimension for Boiler mill bay composite structure shall be 72.8- meter width and 91.8- meter length. Height of the Boiler Structure shall be about 90-meter.

3.9. Typical Boiler Structure 3D Model

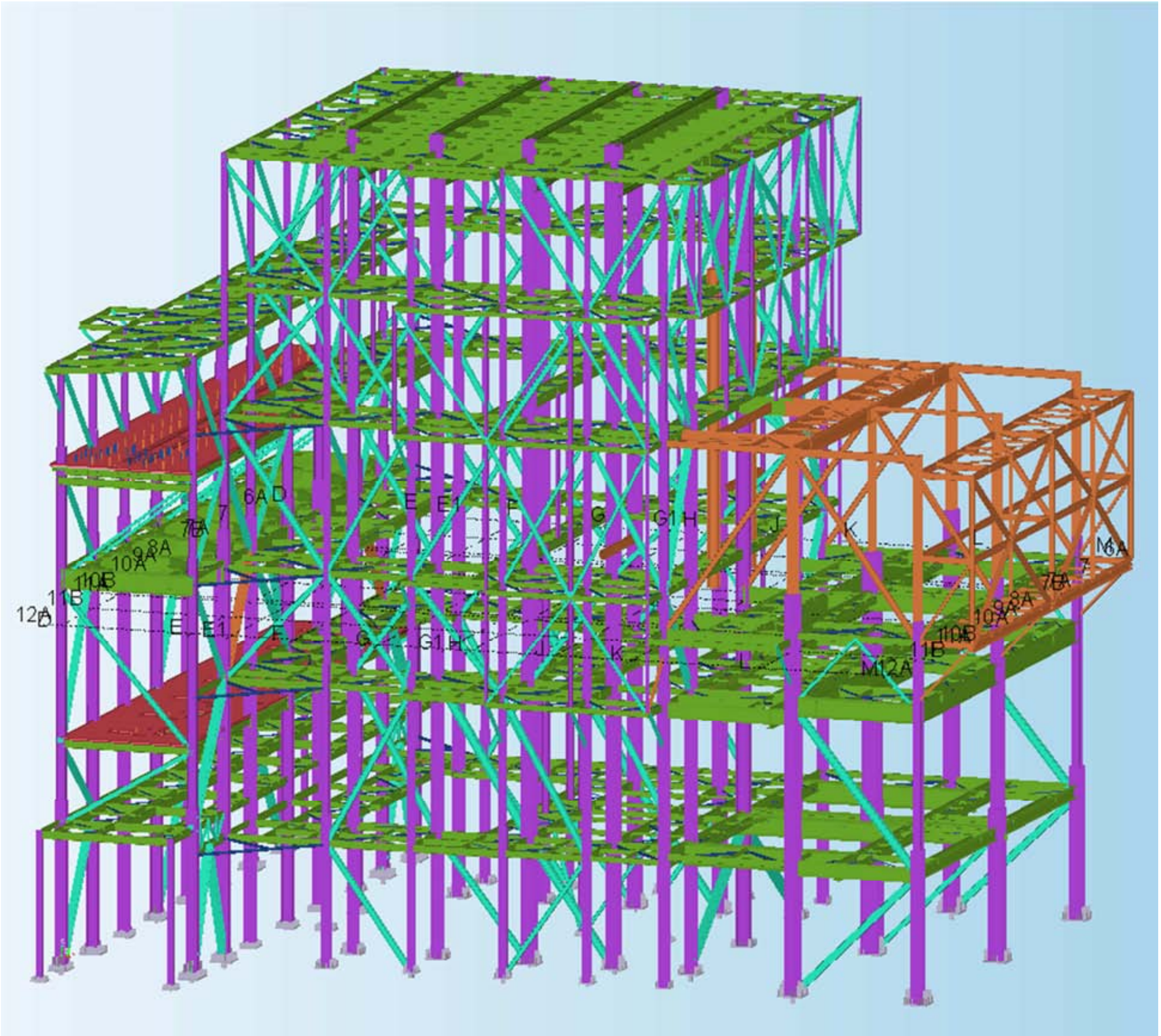

Figure 2. *Typical 3D Framing of Boiler Steel Structure.*

4. Design Approach

Boiler support structure is analyzed in Staad Pro for static and dynamic cases. Major Equipment loads of boiler are applied in analysis model and support reactions of gallery/platforms and roof structure are also applied in analysis model [1−7].

Time period of the structure for seismic load calculation is calculated based on the dynamic analysis and number of modes to be considered in the analysis should be such that sum of total masses of all modes considered is at least 90 percent of the total seismic mass.

Beams, columns, vertical bracings and horizontal bracings are designed for the load combination which will result maximum stress in the members.

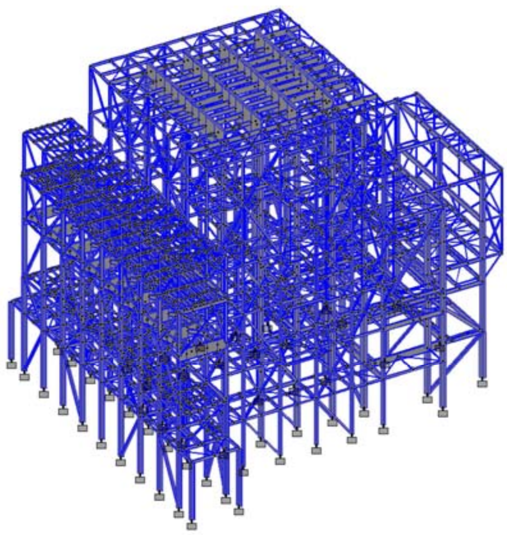

Figure 3. *3D STAAD Model used for Analysis.*

5. Mechanical Properties of Structural Plates

Grade	Quality	YS Min, MPa	UTS Min, MPa	% El Min Std. GL	Internal Bend Dia, min	Charpy Test °C	Charpy Test Jmin
E 250	A	250	410	23	2t	-	-
	BR					RT	27
	B0					0	27
	C					-20	27
E 275	A	275	430	22	2t	-	-
	BR					RT	27
	B0					0	27
	C					-20	27
E 300	A	300	440	22	2t	-	-
	BR					RT	27
	B0					0	27
	C					-20	27
E 350	A	350	490	22	2t	-	-
	BR					RT	27
	B0					0	27
	C					-20	27
E 410	A	410	540	20	2t	-	-
	BR					RT	25
	B0					0	25
	C					-20	25
E 450	A	450	570	20	2.5t	-	-
	BR					RT	20
E 550	A	550	650	12	3t	-	-
	BR					RT	15
E 600	A	600	730	12	3.5t	-	-
	BR					RT	15
E 650	A	650	780	12	4t	-	-
	BR					RT	15

1) t = thickness
2) For quality BR, impact is optional, if required at Room temperature

Figure 4. Mechanical properties of E350 and E410 Grade Steel.

6. Comparative Analysis of Columns and Beams Cost and Weight in Boiler Structure

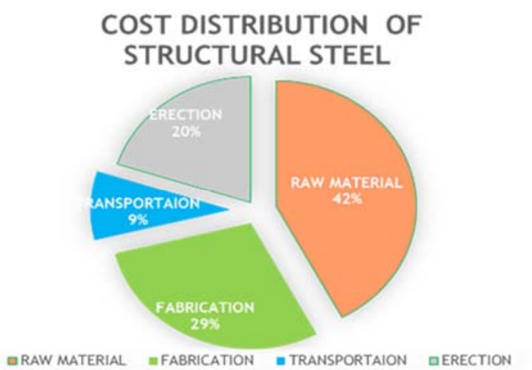

Figure 5. Cost Distribution of Boiler Steel Structure.

7. Conclusion and Recommendations

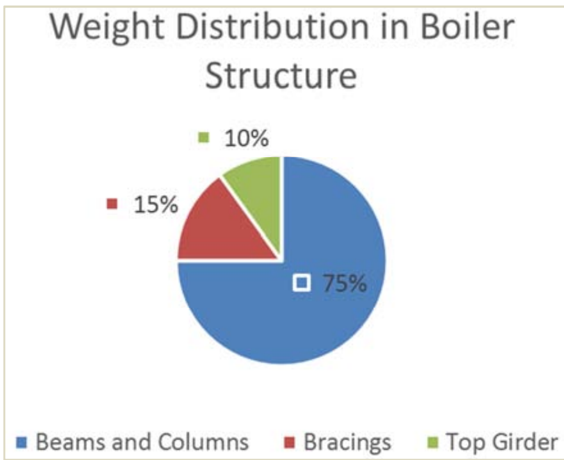

Figure 6. Weight Distribution of Members in Boiler Structure.

Column and Beams weight could be reduced by 25% when E-550 Grade steel is chosen in place of E-350 Grade Steel.

Weight reduction shall further contribute reduction of fabrication cost, transportation and erection cost.

Application of High Tensile steel require stringent Welding Process Specification (WPS) and Procedure Qualification Record (PQR) procedure establishment.

E- 550 Grade Structural steel has limited ductility of 12% as compared with 22% for E-350 Grade Structural Steel, hence ductility requirement of structure under consideration to be critically examined prior to application of high tensile steel.

Heat treatment for welding of plate thickness >=15mm shall be required.

Impact test and Hardness test is mandatory.

Availability and rolling of structural plates of varying thickness for E-550 grade steel have to be ensured by Structural Steel Plate rolling mills to enable structural design Engineer to achieve the optimized structural design.

Application of High Strength steel is economical only in Heavy structure where total tonnage is very significant.

Light weight or medium weight structure or wind governing structure may not be cost effective for High Tensile steel application.

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