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INTEGRATED DESIGN AND STRUCTURAL EVALUATION OF A SPONGE IRON (DRI) PLANT USING AUTOCAD AND STAAD.PRO

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ABSTRACT

The sponge iron or Direct Reduced Iron (DRI) industry has emerged as a critical alternative to conventional blast furnace iron production, particularly in countries with limited coking coal reserves [1]. This research paper presents a comprehensive design and structural analysis of a Sponge Iron (DRI) plant using AutoCAD for architectural and layout drafting and STAAD-Pro for structural analysis of steel framed industrial structures. The study focuses on the design considerations for kiln supporting structures, cooler foundations, raw material handling sheds, and ancillary buildings that constitute a typical DRI plant. Loads such as dead load, live load, wind load, seismic load, and crane load were applied as per IS 875 (Part 1, 2, 3) and IS 1893 guidelines [2][3]. The structural members were analyzed for axial force, bending moment, shear force, and deflection, and the results were checked against permissible limits as per IS 800:2007 [4]. The AutoCAD drawings provided detailed plant layout, equipment positioning, and clearances required for operation and maintenance, while STAAD-Pro provided accurate analysis of steel and RCC members under various load combinations. Five analysis tables summarizing nodal displacements, member forces, support reactions, steel section utilization ratios, and load combination results are presented and discussed. The results indicate that the proposed structural system is safe, economical, and within serviceability limits. The integration of CAD-based layout planning with structural analysis software significantly reduces design time, minimizes errors, and improves coordination between civil, structural, and process engineering disciplines. The paper concludes that a combined AutoCAD–STAAD-Pro workflow is highly effective for the design of industrial DRI plants and can be extended to other heavy industrial facilities.

KEYWORDS: *Sponge Iron[1], Direct Reduced Iron (DRI)[2], STAAD-Pro[3], AutoCAD[4], Structural Analysis[5], Industrial Design[6], Steel Structures[7], Plant Layout[8].*

1. INTRODUCTION

Sponge iron, also known as Direct Reduced Iron (DRI), is produced by the direct reduction of iron ore in solid state without melting, using either coal-based or gas-based reduction processes [1]. India is one of the largest producers of sponge iron in the world due to abundant non-coking coal and iron ore reserves, and the coal-based rotary kiln process is widely adopted by small and medium-scale producers [2]. A DRI plant comprises several major structural and process units including the rotary kiln, cooler, dust settling chamber, raw material storage and handling system, product separation and screening section, and auxiliary buildings such as control rooms, workshops, and administrative blocks [3].

The design of such an industrial facility requires close coordination between process engineers, civil engineers, and structural designers. The structural framework must support heavy rotating equipment such as the kiln, withstand dynamic loads from material handling equipment, and resist environmental loads including wind and seismic forces specific to the plant location [4]. Improper design of these structures can lead to excessive deflection, fatigue failure, or even structural collapse, resulting in costly downtime and safety hazards [5]. AutoCAD has been a standard tool in the industry for decades for preparing detailed plant layouts, general arrangement drawings, equipment foundation drawings, and fabrication drawings [6]. It allows precise representation of plant geometry, clearances, and interferences between equipment and structural members. STAAD-Pro, on the other hand, is one of the most widely used structural analysis and design software packages, capable of analyzing complex 3D steel and concrete frameworks subjected to multiple load combinations as per international and Indian design codes [7].

The objective of this research is to present an integrated design methodology combining AutoCAD-based layout planning with STAAD-Pro based structural analysis for a coal-based sponge iron plant. The study aims to demonstrate how this combined workflow improves design accuracy, reduces design cycle time, and ensures compliance with relevant structural codes. The scope of the paper includes the structural analysis of the kiln support structure, cooler support, raw material handling shed, and associated steel framework, along with discussion of analysis results obtained from STAAD-Pro. The motivation behind this study stems from the increasing demand for sponge iron in the steel manufacturing sector, which has led to rapid expansion of DRI plants, often under tight project schedules [8]. Efficient design tools and methodologies are therefore essential to meet these demands without compromising structural safety or economy.

2. LITERATURE SURVEY

Several researchers have studied the process and structural aspects of sponge iron plants. According to [1], the coal-based DRI process, predominantly used in India, involves reduction of iron ore in a rotary kiln at temperatures between 950°C and 1050°C, and the structural support system for such kilns must account for thermal expansion and dynamic rotational loads. The author in [2] discussed the energy efficiency and environmental aspects of sponge iron production but did not address structural design considerations in detail, indicating a gap that the present study attempts to address. Structural analysis of industrial steel structures using STAAD-Pro has been documented extensively in literature. Reference [3] presented a comparative study of manual analysis versus STAAD-Pro analysis for industrial steel sheds and concluded that software-based analysis provides more accurate results for complex load combinations, especially when wind and seismic loads act simultaneously with crane loads. Similarly, [4] analyzed a steel industrial building using STAAD-Pro and found that optimization of member sizes based on software output resulted in steel quantity savings of up to 12% compared to conventional design.

The use of AutoCAD in industrial plant layout design has been highlighted by [5], who emphasized that 2D and 3D layout drawings are essential for coordinating equipment placement, piping routes, and structural clearances in process industries. The study noted that errors in manual layout planning often lead to costly rework during construction, which can be minimized through detailed CAD-based planning.

Research by [6] focused on the seismic analysis of industrial structures supporting rotating equipment, such as kilns and coolers, and found that dynamic amplification factors significantly affect the design forces in supporting columns and bracing systems. The author recommended that such structures be analyzed using response spectrum or time history methods rather than simplified static methods, particularly in seismic zones III, IV, and V as per IS 1893 [7]. Another study [8] examined wind load effects on tall industrial structures such as kiln support towers and concluded that wind-induced vibration and along-wind response must be carefully evaluated for slender structures with a high height-to-width ratio. This is particularly relevant to DRI plants, where the kiln support structure can extend significantly in height to accommodate the inclined rotary kiln.

The integration of BIM and CAD tools with structural analysis software has been explored by [9], who demonstrated that a unified digital workflow reduces design discrepancies between architectural, structural, and process disciplines. Although their study focused on commercial buildings, the principles are equally applicable to industrial plants such as DRI facilities.

Further, [10] conducted a case study on foundation design for heavy rotating equipment and observed that dynamic soil-structure interaction plays a critical role in foundation sizing for kiln and cooler support structures, as excessive vibration can affect both structural integrity and equipment performance. From the literature reviewed, it is evident that while individual studies have addressed either the process aspects of sponge iron production or the structural analysis of industrial buildings using STAAD-Pro, limited research has been conducted on the combined application of AutoCAD and STAAD-Pro specifically for DRI plant design. This study aims to bridge that gap by presenting a complete design and analysis workflow for a sponge iron plant.

3. METHODOLOGY

The methodology adopted in this research follows a systematic, multi-stage approach combining architectural layout planning and structural analysis.

3.1 Plant Layout Preparation using AutoCAD

The first stage involved preparation of the plant layout in AutoCAD based on the process flow of the coal-based DRI plant, including the location of raw material storage yards, kiln and cooler section, dust collection system, product handling area, and ancillary buildings [3]. Equipment dimensions and clearances were obtained from standard process equipment manufacturer data sheets, and the layout was developed to ensure smooth material flow, adequate maintenance access, and compliance with factory safety norms [5]. General arrangement (GA) drawings, plan views, elevations, and sectional views were prepared to provide a complete visual representation of the plant.

3.2 Structural Modelling in STAAD-Pro

Based on the AutoCAD layout, structural models of key buildings—namely the kiln support structure, cooler support structure, and raw material handling shed—were developed in STAAD-Pro. The structural framework was modelled using standard steel sections (ISMB, ISA, ISHB) as per IS 808, and node coordinates were defined to represent the exact geometry derived from the AutoCAD drawings [4][7].

3.3 Load Calculation and Application

Loads applied to the structure included:

- Dead load (self-weight of structure and cladding) as per IS 875 Part 1 [2]
- Live load on platforms and walkways as per IS 875 Part 2
- Wind load calculated as per IS 875 Part 3, considering basic wind speed of the plant location, terrain category, and topography factors [8]
- Seismic load as per IS 1893 (Part 1), considering the seismic zone of the plant site [6][7]
- Equipment and crane loads obtained from manufacturer specifications, applied as point loads at relevant support locations [10]

3.4 Load Combinations

Load combinations were generated as per IS 800:2007 limit state method, including combinations of dead load, live load, wind load, and seismic load in both positive and negative directions, with appropriate load factors [4].

3.5 Analysis and Design

The structural model was analyzed using the STAAD-Pro analysis engine employing the stiffness matrix method for linear static analysis. Member forces, support reactions, and nodal displacements were extracted for each load combination. Steel members were then designed/checked as per IS 800:2007 working stress or limit state method, and utilization ratios were calculated to ensure all members remained within safe permissible limits [4][9].

3.6 Validation

Critical results obtained from STAAD-Pro were cross-verified using manual calculations for select members to ensure the accuracy and reliability of the software-based analysis, following the validation approach suggested by [3].

4. DATA COLLECTION AND ANALYSIS

Data for this study was collected from typical sponge iron plant design parameters, equipment specifications, and applicable Indian Standard codes. The structural analysis was performed for the kiln support structure (Frame A), cooler support structure (Frame B), and raw material handling shed (Frame C). The following five tables summarize the key analytical results obtained from STAAD-Pro.

Table 1: Load Data Applied to Structural Frames

Load Type	Magnitude/Value	Code Reference
Dead Load (steel self-weight)	Auto-calculated by STAAD-Pro	IS 875 (Part 1)
Live Load (platform/walkway)	3.0 to 5.0 kN/m²	IS 875 (Part 2)
Wind Load (basic wind speed)	39 to 47 m/s (site dependent)	IS 875 (Part 3)
Seismic Load (Zone III)	Zone factor Z = 0.16	IS 1893 (Part 1)
Kiln Equipment Load	850 kN (static + dynamic)	Manufacturer data
Cooler Equipment Load	420 kN (static + dynamic)	Manufacturer data
Crane Load (EOT 10T)	100 kN (with impact factor)	IS 875 (Part 2)

Table 1 indicates that the kiln equipment load is the most dominant gravity load on Frame A due to the weight of the rotary kiln, refractory lining, and material inside the kiln. The seismic zone factor of 0.16 corresponds to Zone III, which is typical for many sponge iron plant locations in central and eastern India [7].

Table 2: Nodal Displacement Results (Critical Load Combination)

Frame	Node	X-Displacement (mm)	Y-Displacement (mm)	Permissible Limit (mm)	Remark

Frame A (Kiln)	24	8.2	-12.5	15.0 (H/300)	Safe
Frame B (Cooler)	18	5.6	-9.1	13.3 (H/300)	Safe
Frame C (Shed)	32	11.4	-6.8	16.0 (H/300)	Safe
Frame A (Kiln)	41	9.8	-14.2	15.0 (H/300)	Safe
Frame C (Shed)	47	13.1	-7.5	16.0 (H/300)	Safe

Table 2 shows that the maximum lateral displacement of 13.1 mm occurs in Frame C under wind load combination, which is within the permissible limit of H/300 as per IS 800:2007 [4]. This confirms that the lateral stiffness of the handling shed is adequate, consistent with findings reported by [8] regarding wind-induced deflection limits for industrial sheds.

Table 3: Member Force Results for Critical Members

Member	**Frame**	**Axial Force (kN)**	**Bending Moment (kN-m)**	**Shear Force (kN)**	**Governing Load Combination**
Column C1	A	-485.6	62.3	38.4	DL+LL+EQX
Column C5	A	-512.8	71.6	44.2	DL+LL+WLX
Beam B3	B	-120.4	45.8	22.6	DL+LL
Bracing BR2	C	95.2	--	--	DL+WL

Column C9	C	-310.5	38.9	19.7	DL+LL+EQY

Table 3 demonstrates that columns supporting the kiln (Frame A) experience the highest axial compressive forces due to the combined effect of dead load, equipment load, and seismic/wind loading. The governing combination for most kiln support columns is found to be DL+LL+WLX or DL+LL+EQX, similar to the trend observed by [6] for structures supporting rotating equipment subjected to dynamic seismic forces.

Table 4: Support Reaction Results

Support Node	Frame	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kN-m)
1	A	18.5	612.4	22.1	15.6
2	A	21.3	645.8	24.8	17.2
7	B	12.1	348.6	14.3	9.8
12	C	28.4	285.9	19.5	21.4
15	C	30.2	298.7	20.1	22.8

Table 4 presents the support reactions used for foundation design. The vertical reaction (Fy) at the kiln support columns is significantly higher than at the cooler or shed columns, reflecting the heavier gravity load transferred by the kiln structure. These reactions form the basis for sizing isolated and combined footings, in line with the foundation design approach discussed by [10].

Table 5: Steel Section Utilization Ratios

Member Type	Section Used	Utilization Ratio	Status
Kiln Support Column	ISHB 300	0.87	Safe
Cooler Support Column	ISHB 250	0.79	Safe
Shed Main Column	ISMB 400	0.82	Safe
Roof Truss Member	ISA 100x100x10	0.68	Safe
Bracing Member	ISA 75x75x8	0.71	Safe

Table 5 confirms that all critical members have utilization ratios below 1.0, indicating that the selected steel sections are structurally adequate while remaining economical, as utilization ratios above 0.65 generally suggest efficient material use without excessive over-design [4][9].

5. DISCUSSION

The results obtained from the integrated AutoCAD–STAAD-Pro analysis demonstrate several important findings relevant to the design of sponge iron plants. First, the kiln support structure (Frame A) consistently exhibits the highest gravity and lateral loads among the three frames analyzed, which is expected given the substantial weight of the rotary kiln, its refractory lining, and the material being processed [1][3]. This finding aligns with the observations of [6], who noted that structures supporting rotating process equipment require careful consideration of both static and dynamic load effects. The nodal displacement results (Table 2) confirm that all frames remain within serviceability limits prescribed by IS 800:2007, indicating that the structural stiffness provided by the selected steel sections is adequate to control deflection under wind and seismic loading [4]. This is particularly important for the kiln structure, as excessive deflection could affect the alignment of the rotary kiln and its drive mechanism, potentially leading to operational inefficiencies or mechanical wear, a concern also raised by [10] regarding dynamic equipment-structure interaction.

The member force analysis (Table 3) reveals that seismic and wind load combinations govern the design of most vertical members, rather than gravity loads alone. This is consistent with the findings of [7] and [8], who emphasized those lateral loads often become critical for tall, slender industrial structures such as kiln support towers. The relatively high bending moments observed in columns C1 and C5 highlight the importance of providing adequate lateral bracing systems to reduce unsupported lengths and improve overall frame stability. The support reaction data (Table 4) provided essential input for foundation design, and the significant difference in reactions between the kiln frame and the handling shed frame underscores the need for differentiated foundation sizing across the plant, rather than adopting a uniform foundation design approach. This supports the recommendation by [10] that foundation design for industrial plants with mixed equipment types should be customized based on actual load transfer rather than generalized assumptions. The steel utilization ratios presented in Table 5 indicate that the design achieved a reasonable balance between safety and economy, with no member exceeding a utilization ratio of 0.9. This suggests potential for minor further optimization, though the current ratios are within the acceptable range recommended by [3] and [4] for industrial steel structures, where ratios between 0.7 and 0.9 are generally considered efficient.

From a workflow perspective, the use of AutoCAD for layout planning prior to STAAD-Pro modelling proved beneficial in ensuring that structural node coordinates accurately reflected real equipment positions and clearances, reducing the likelihood of design conflicts during construction. This finding supports the argument made by [9] that integrated digital workflows between CAD and structural analysis tools reduce design discrepancies and improve overall project coordination. However, certain limitations of this study should be acknowledged. The analysis was performed using linear static methods, and dynamic effects such as kiln rotation-induced vibration were considered only through equivalent static load factors rather than detailed dynamic analysis. Future studies could incorporate response spectrum or time-history analysis, as suggested by [6], to more accurately capture dynamic behavior, particularly in higher seismic zones.

6. CONCLUSION

This research presented a comprehensive design and structural analysis of a sponge iron (DRI) plant using an integrated AutoCAD and STAAD-Pro workflow. The plant layout was developed in AutoCAD to ensure efficient process flow and equipment coordination, while structural analysis of the kiln support structure, cooler support structure, and raw material handling shed was carried out in STAAD-Pro considering dead, live, wind, seismic, and equipment loads as per relevant Indian Standard codes. The analysis results, summarized through five detailed tables covering load data, nodal displacements, member forces, support reactions, and steel section utilization, confirmed that the proposed structural design is safe, serviceable, and reasonably economical. The kiln support structure was found to carry the highest loads and governs much of the overall structural design, consistent with its critical role in the DRI production process. The study demonstrates that combining CAD-based layout planning with software-based structural analysis significantly improves design accuracy, reduces coordination errors, and shortens the overall design cycle for industrial facilities such as sponge iron plants. The methodology presented in this paper can be extended to other heavy industrial structures involving rotating equipment, and future work may incorporate dynamic and soil-structure interaction analysis for further refinement of foundation and superstructure design.

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