

COMPUTER-AIDED DESIGN AND STRUCTURAL ANALYSIS OF A SPONGE IRON (DRI) PLANT USING AUTOCAD AND STAAD.PRO

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ABSTRACT

Sponge iron, also called Direct Reduced Iron (DRI), is produced by reducing iron oxide below its melting point and has become an important feedstock for electric arc and induction furnace steelmaking, particularly in regions without access to large-scale coking coal reserves [1], [2]. The engineering of a DRI plant involves two distinct but interconnected design disciplines: process and layout drafting, typically performed using AutoCAD, and structural analysis and design of supporting steel and concrete members, typically performed using STAAD-Pro [3], [4]. This paper presents a meta-analytical review of existing literature on the application of these two software tools to industrial plant design, with specific emphasis on sponge iron plants. The methodology section outlines a structured approach for comparing published case studies on STAAD-Pro based structural design and AutoCAD based plant layout, the load combinations and design codes typically referenced, and the integration points between drafting and analysis workflows. A critical analysis identifies recurring gaps in the literature, including limited documentation of kiln-support and conveyor-gallery design, insufficient treatment of thermal and dynamic loading unique to rotary-kiln based DRI plants, and a general scarcity of dedicated DRI-plant case studies compared to the abundance of generic building and bridge studies. The discussion synthesises these findings into a proposed integrated design workflow, and the conclusion highlights directions for future research, including parametric BIM-linked structural optimisation for sponge iron plants.

Keywords: Sponge Iron Plant¹, Direct Reduced Iron (DRI)², AutoCAD³, STAAD.Pro⁴, Structural Analysis⁵, Plant Layout Design⁶, Industrial Structures⁷, Rotary Kiln⁸, BIM Integration⁹.

1. INTRODUCTION

The sponge iron industry occupies a significant position within the global and Indian iron and steel value chain. Direct Reduced Iron is obtained when iron ore, in the form of lumps, pellets or fines, is subjected to a reducing atmosphere generated from coal or natural gas at temperatures well below the melting point of iron, yielding a porous, metallic product with high metallisation that can later be charged into an electric arc furnace, induction

furnace, or basic oxygen furnace [1], [2]. Coal-based rotary kiln technology dominates DRI production in countries such as India, where natural gas is comparatively scarce, while gas-based shaft furnace technology is more common in regions with abundant natural gas, including parts of the Middle East and increasingly in emerging hydrogen-based reduction routes [1]. Regardless of the reduction route chosen, a DRI plant is a heavy industrial facility comprising a raw-material handling and storage yard, a kiln or shaft furnace with associated refractory lining, a cooler, a product separation and screening section, dust-collection and waste-heat-recovery systems, and an extensive network of conveyor galleries, transfer towers, and support structures.

The civil and structural engineering of such a facility is demanding because the layout must accommodate continuous material flow while the supporting structure must resist a combination of static, dynamic, thermal and accidental loads that are considerably more complex than those found in typical residential or commercial buildings. Kiln support structures must accommodate thrust and torque from kiln rotation, conveyor galleries must be designed for belt tension, vibration and impact loading from falling material, and dust-collection ductwork and bag-house structures must be designed against both wind and equipment-induced vibration. The drafting of equipment layout, piping, and structural general arrangement drawings is conventionally carried out using AutoCAD, including its specialised plant-design toolsets that provide parametric libraries for structural steel sections, piping specifications, and equipment templates, allowing designers to build coordinated two- and three-dimensional plant models [3]. Once the general arrangement and equipment loads are established, the structural skeleton, comprising columns, trusses, bracings, platforms and foundations, is typically modelled and analysed in STAAD-Pro, a structural analysis and design package capable of applying more than ninety international steel, concrete, timber and aluminium design codes and of performing both static and advanced dynamic analyses [4]. Given the centrality of these two tools to industrial plant engineering, a substantial body of literature exists on their individual application to buildings, bridges, and select industrial structures, yet dedicated treatment of sponge iron or DRI plants specifically remains comparatively limited. This paper therefore undertakes a structured survey and critical meta-analysis of available literature relevant to the design and analysis of DRI plants using AutoCAD and STAAD-Pro, with the objective of mapping the current state of knowledge, identifying methodological gaps, and proposing an integrated design approach suited to the unique demands of sponge iron plant engineering. The remainder of the paper is organised as follows: Section 2 surveys existing literature across three streams, namely DRI process engineering, STAAD-Pro based structural studies, and AutoCAD based plant layout studies; Section 3 describes the methodology adopted for the meta-analysis; Section 4 critically analyses the strengths and limitations of the surveyed work; Section 5 discusses the synthesis of findings into a coherent design methodology; and Section 6 concludes with recommendations for future research.

2. SURVEY OF EXISTING LITERATURE

2.1 LITERATURE ON THE DRI/SPONGE IRON PROCESS

A considerable volume of research addresses the metallurgical and process-engineering aspects of sponge iron production rather than its structural engineering. Studies describing the coal-based rotary kiln process emphasise that iron ore lumps, coal, and dolomite are charged into a rotating kiln where reduction occurs through gaseous reductants generated from partial oxidation of coal, with the resulting sponge iron typically exhibiting a total

iron content in the range of eighty-five to ninety-five percent and a metallisation level between roughly ninety-two and ninety-six percent [2]. Comparative studies of gas-based and emerging hydrogen-based direct reduction routes describe integrated mill configurations in which hot DRI is transferred directly into an electric arc furnace without intermediate cooling, and note that hydrogen-based plants eliminate the need for a reformer but require substantial pre-heating of the reducing gas because the ore-reduction reaction with hydrogen is strongly endothermic [1]. This process literature, while indispensable for understanding equipment selection, mass and energy balances, and the layout logic of a DRI plant, generally does not extend into the structural design domain, leaving a gap between metallurgical process design and the civil and structural engineering required to support that process physically.

2.2 LITERATURE ON STAAD-PRO BASED STRUCTURAL ANALYSIS

A separate and more extensive literature stream addresses structural analysis and design using STAAD-Pro, predominantly in the context of buildings, but with some extension to special structures. Comparative studies combining STAAD-Pro for structural analysis with other computational tools for detailed member design report that the software is widely used because of its strong analytical capability, and describe workflows in which a building frame is analysed for seismic behaviour in STAAD-Pro, with shear force, bending moment and storey deflection outputs subsequently used for reinforcement detailing in complementary programming environments [5]. Other studies on multi-storey residential buildings describe a typical STAAD-Pro workflow in which a structure is idealised as a two- or three-dimensional frame subjected to dead load, live load and wind load combinations derived from the Indian wind-loading code, with bending moments and shear forces obtained through iterative or automated analysis and cross-checked against allowable limits prescribed in the Indian concrete design code [9]. Studies on residential and commercial buildings designed for seismic zones additionally report that the CONNECT edition of STAAD-Pro incorporates dedicated seismic-analysis features that allow practitioners to perform detailed dynamic calculations in accordance with the Indian earthquake-resistant design code and the ductile detailing provisions for reinforced concrete structures subjected to seismic forces [8]. Industry-oriented descriptions of STAAD-Pro applications extend its use to industrial plants, bridges and offshore platforms, noting that the software's finite-element analysis capability allows designers to simulate multiple loading scenarios, evaluate structural behaviour for safety and stability, and iteratively optimise designs for material efficiency and cost [7]. While these studies collectively demonstrate the versatility and analytical depth of STAAD-Pro, very few of them address the specific load cases that distinguish a sponge-iron plant structure from a conventional building, namely kiln-thrust and torque loading, conveyor-gallery dynamic loading, and the thermal effects associated with high-temperature process equipment.

2.3 LITERATURE ON AUTOCAD BASED INDUSTRIAL PLANT LAYOUT

A third stream of literature concerns the use of AutoCAD and its specialised toolsets for industrial plant layout and drafting. Descriptions of AutoCAD's plant-design toolset indicate that it provides parametric equipment templates, industry-standard structural steel section libraries conforming to recognised steel design standards, and customisable piping specifications, enabling designers to build coordinated piping and instrumentation diagrams alongside three-dimensional structural and piping models on a single familiar drafting platform [3]. Documentation on the use of AutoCAD together with factory-design utilities describes workflows for creating

two-dimensional facility layouts using parametric equipment and material-handling assets, which can subsequently be coordinated with three-dimensional modelling tools for simulation of material flow [10]. Historical academic work on industrial plant layout and material-flow analysis using AutoCAD demonstrates that drafting software has long been used not merely for documentation but as an active tool for evaluating alternative equipment arrangements and material-handling routes prior to construction [10]. Industry guidance on steel structure drawing further emphasises that such drawings, once drafted, undergo a structured review process to verify dimensional accuracy and compliance with applicable building codes before release for fabrication and construction [13]. Taken together, this literature establishes AutoCAD as the conventional medium for translating process and structural design outputs into constructible drawings, but it generally treats drafting as a downstream documentation activity rather than as part of an integrated structural design loop with STAAD-Pro.

3. METHODOLOGY FOR META-ANALYSIS

The meta-analysis underpinning this paper followed a structured, three-stage methodology. In the first stage, literature was identified across three thematic categories corresponding to the survey presented in Section 2: process-engineering studies of sponge iron and direct reduced iron production, structural-engineering studies employing STAAD-Pro, and drafting or layout studies employing AutoCAD and its plant-design extensions. Sources were drawn from peer-reviewed journal articles, conference papers, technical reports, and professional engineering documentation, with preference given to sources that explicitly described software workflows, load assumptions, or design codes rather than purely qualitative descriptions of software capability.

In the second stage, each identified source was screened against four criteria: whether it addressed an industrial, as opposed to purely residential or commercial, structure; whether it specified the load combinations and design codes used; whether it described an integration or hand-off point between drafting and structural analysis; and whether it presented quantitative results such as bending moments, shear forces, deflections or section sizes that could be compared across studies. Sources meeting at least two of these four criteria were retained for detailed analysis, while purely promotional or vendor-oriented material was used only to corroborate factual claims about software capability and not as a basis for design recommendations.

In the third stage, the retained literature was synthesised along two parallel design tracks reflecting actual industrial practice. The first track concerns the AutoCAD-based plant layout process, in which the overall plot plan, equipment spacing, conveyor routing, and structural general arrangement are established based on process requirements, statutory clearances, and material-handling logic, drawing on the parametric structural and piping libraries described in plant-design toolset documentation [3]. The second track concerns the STAAD-Pro based structural analysis process, in which the structural skeleton derived from the general arrangement, comprising columns, trusses, platforms, kiln-support frames, and conveyor-gallery trestles, is modelled as a space frame and analysed for dead load, imposed or live load, wind load determined in accordance with the relevant wind-loading code, and, where applicable, seismic load determined in accordance with the relevant earthquake-resistant design code, following the same general modelling logic reported for multi-storey buildings in the reviewed literature [8], [9]. Because dedicated DRI-plant case studies are scarce, the meta-analysis necessarily extrapolates structural modelling principles from general industrial and building studies, while drawing on

process literature to define the specific equipment loads, such as kiln dead weight, kiln thrust, cooler loads and conveyor loads, that must be superimposed on the conventional load cases. This extrapolation is explicitly flagged as a limitation in Section 4.

4. CRITICAL ANALYSIS OF PAST WORK

The surveyed literature demonstrates clear strengths in each of its three constituent streams but also reveals important limitations when the streams are considered together in the specific context of sponge iron plant engineering. The process-engineering literature is methodologically strong in its treatment of mass and energy balances, reduction kinetics, and comparative evaluation of coal-based, gas-based and hydrogen-based reduction routes, with recent studies extending the analysis to cost and sustainability considerations for hydrogen-based direct reduction [1]. However, this literature treats the plant largely as a thermodynamic and chemical system, with structural and civil engineering aspects, such as the foundation design for a rotating kiln or the support framing for a bucket elevator, mentioned only in passing if at all. This represents a significant gap, since the structural design of a DRI plant cannot be performed in isolation from the process equipment it supports; the geometry, weight, dynamic behaviour and thermal output of kilns, coolers and dust-collection equipment directly determine the load cases that the structural engineer must apply in STAAD-Pro.

The STAAD-Pro literature, conversely, is methodologically strong in demonstrating the software's capacity to model complex three-dimensional frames and to apply a wide range of design codes, and several studies usefully document the iterative process of analysis, code-check and redesign that characterises professional structural practice [5], [7], [8], [9]. A clear limitation, however, is the near-total concentration of published case studies on residential and commercial buildings, with only general, non-quantified references to bridges, industrial plants and offshore platforms appearing in industry-oriented sources [7]. None of the reviewed sources presented a fully worked structural model of a rotary-kiln DRI plant, meaning that load cases specific to such facilities, including kiln thrust and torque transferred through support rollers, dynamic amplification from conveyor belt operation, and thermal expansion effects from refractory-lined equipment operating in the eight-hundred to twelve-hundred degree Celsius range, are not directly addressed in the available literature and must instead be inferred from first principles and from general industrial design practice. The AutoCAD literature is methodologically strong in documenting the parametric and library-based features that make plant layout drafting efficient, and in establishing that drafting can serve an active design-evaluation function rather than a purely documentary one [3], [10], [18]. Its principal limitation, from the perspective of this paper's subject, is that the reviewed sources rarely describe a formal, bidirectional data exchange between the AutoCAD layout model and the STAAD-Pro structural model; in most documented workflows, the structural general arrangement is transferred from drafting to analysis software manually, with member sizes determined in STAAD-Pro then redrawn in AutoCAD for final documentation, rather than through an integrated or automated interoperability pipeline. Several promotional sources describing steel structure drawing review processes confirm that a manual coordination and checking step, rather than automated synchronisation, remains the norm in current industrial practice [13]. Taken together, the critical analysis indicates that while each individual discipline, process engineering, structural analysis, and drafting, is well served by its own specialised literature, the integration of

all three for the specific case of a sponge iron plant remains an under-researched area, and this paper's discussion in Section 5 attempts to bridge that gap conceptually.

5. DISCUSSION

Synthesising the findings of Sections 2 through 4 suggests that a coherent design and analysis methodology for a sponge iron plant should proceed through four linked stages, each grounded in the literature reviewed but adapted specifically to the demands of DRI plant engineering. The first stage is process-driven layout planning, in which the plot plan, equipment spacing, conveyor routing and elevation differences required for gravity-fed material flow are established in AutoCAD using the parametric equipment and structural-steel libraries provided by its plant-design toolsets, ensuring that statutory clearances, fire-fighting access and maintenance corridors are respected from the outset [3]. The second stage is load definition, in which equipment data sheets for the kiln, cooler, dust-collection system, bucket elevators and conveyors are used to derive dead loads, equipment-operating loads, kiln thrust and torque, and dynamic or impact loads from material handling; these are combined with environmental loads, namely wind load and, where the site lies in a seismic zone, earthquake load, determined in accordance with the relevant national codes in the same manner documented for conventional buildings in the reviewed STAAD-Pro literature [8], [9].

The third stage is structural modelling and analysis in STAAD-Pro, in which the structural skeleton, including kiln-support frames, conveyor-gallery trestles, transfer-tower platforms, bag-house support structures and pipe racks, is idealised as a three-dimensional space frame and subjected to the load combinations defined in the previous stage. Consistent with the analytical approach reported across the surveyed building studies, this stage would typically involve linear static analysis for the majority of load combinations, supplemented by dynamic or seismic analysis where the facility is located in a zone of significant seismicity, with the software's extensive code library allowing the same model to be checked against multiple national steel and concrete design standards if the project requires compliance with more than one regulatory regime [4], [7], [8]. A distinguishing feature of DRI plant structures relative to the buildings emphasised in most of the reviewed literature is the need to model rotating-equipment support frames with explicit attention to bearing reactions and torque transfer, and to model conveyor-gallery trestles for both static belt tension and dynamic loading from intermittent material flow; because the literature does not document worked examples of these specific cases, engineers must currently rely on adapting general industrial-loading principles and manufacturer-supplied equipment data rather than on published precedent.

The fourth stage is design finalisation and documentation, in which member sizes, connection details and foundation requirements derived from the STAAD-Pro analysis are transferred back into AutoCAD for the production of general arrangement drawings, fabrication drawings and as-built documentation, following the structured drawing-review process described in the drafting literature to verify dimensional accuracy and code compliance before release for construction [13]. The discussion highlights that, although this four-stage methodology is consistent with established practice for industrial structures in general, its explicit application to sponge iron plants has not been extensively documented in the academic literature, representing both a limitation of the present meta-analysis and an opportunity for future case-study-based research. A further point arising from the discussion concerns sustainability: contemporary process literature increasingly emphasises the

environmental footprint of DRI production, including the comparative carbon intensity of coal-based, gas-based and hydrogen-based reduction routes [1], and this growing emphasis on sustainable process design suggests that future structural studies of DRI plants might usefully extend beyond conventional strength and serviceability checks to consider material-efficient structural optimisation as a complementary contribution to the overall sustainability of the facility.

6. CONCLUSION

This paper has undertaken a structured meta-analysis of the literature relevant to the design and analysis of sponge iron, or direct reduced iron, plants using AutoCAD and STAAD-Pro. The survey identified three largely separate streams of literature, addressing the metallurgical process of direct reduction, the structural analysis capabilities of STAAD-Pro as applied predominantly to buildings, and the drafting and layout capabilities of AutoCAD as applied to industrial facilities. The critical analysis found that each stream is individually well developed but that integrated, DRI-plant-specific treatment combining process loads, structural analysis and coordinated drafting is largely absent from the published literature, leaving practitioners to adapt general industrial design principles rather than draw on dedicated precedent. The discussion proposed a four-stage methodology, comprising process-driven layout planning, load definition, structural modelling and analysis, and design finalisation and documentation, intended to bridge this gap by combining established AutoCAD and STAAD-Pro workflows with the specific equipment and process loads characteristic of rotary-kiln based sponge iron production. Future research would benefit from the publication of fully worked structural case studies of operating DRI plants, including documented kiln-support and conveyor-gallery designs, as well as from investigation of more direct software interoperability between plant-layout and structural-analysis platforms, which would reduce the manual coordination effort that current literature suggests remains the norm in industrial structural practice.

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