Comparative Analysis of Gantry Girders under Variable Wheel Loads and Wheelbase Using STAAD.Pro: Influence Line Method and Codal Provisions

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Abstract

A gantry girder is a critical structural element used to support heavy lifting and material handling equipment in industrial buildings. It transfers loads from electric or manually operated overhead cranes to the supporting columns, ensuring safe and efficient operation. The gantry girder is subjected to complex combinations of vertical, lateral, and longitudinal loads arising from crane movement, traction, braking, and impact forces. Due to scattered and inconsistent design data, the optimization of gantry girders for cost-effectiveness, safety, and performance remains a significant challenge for engineers and researchers. Recognizing the vital role of gantry girders and the lack of a consolidated design methodology, this study focuses on the codal design, analysis, and optimization of gantry girders using STAAD Pro and empirical manual calculations. The design process follows relevant Indian Standards (IS 800:2007, IS 807:2006, and IS 3177:1999) to ensure structural integrity, serviceability, and compliance with industry requirements. A parametric evaluation is performed by varying crane capacities, spans, wheelbase distances, and impact factors, with the aim of identifying optimum section configurations. The study establishes a standard set of design parameters for various crane loadings and span conditions, supported by a customized Excel-based calculation tool for rapid and accurate design. This approach enables engineers to evaluate bending stresses, deflection limits, shear capacities, and fatigue considerations efficiently. The results highlight close agreement between STAAD Pro analysis and manual codal calculations, with optimization leading to substantial weight and cost savings. By integrating codal provisions, automated computation, and optimization strategies, the work provides a reliable and practical methodology for the design of gantry girders, enhancing both safety and economy in industrial applications.

Keywords: *Gantry girder, moving loads, Wheelbase variation, STAAD.Pro, Codal validation, Structural optimization, Industrial cranes*

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INTRODUCTION

In industrial structures where heavy material handling is routine, cranes play a crucial role in transporting raw materials, semi-finished products, and finished goods. To support such operations, gantry girders are employed as primary load-bearing members that directly resist the wheel loads from moving cranes. A gantry girder is essentially a horizontal steel beam placed at an elevated level, resting on brackets or columns, and designed to carry crane wheels through rails mounted on its top flange. Because these members experience localized and moving concentrated loads, they differ significantly from conventional beams that primarily resist uniformly distributed or point loads at fixed locations. The design of gantry girders is challenging for multiple reasons. First, crane loads are not static; they move along the span of the girder, resulting in fluctuating shear forces, bending moments, and deflections. Second, dynamic effects due to sudden starting, braking, or impact significantly increase load intensity. Third, the wheelbase of the crane—the distance between two consecutive wheels—varies depending on crane type and manufacturer, thereby altering the load distribution pattern. Hence, a rational design approach must account for all these variations while ensuring both strength and serviceability.

Conventional Design Approaches

Indian Standards provide comprehensive guidelines for designing gantry girders. IS 800:2007 lays down the general design principles for steel structures, while IS 807:2006 and IS 3177:1999 specifically address cranes and crane-supporting structures. These codes stipulate that designers should consider dead load, live load, crane wheel load, and an additional impact factor (typically ranging between 10–25% of the wheel load). Using these provisions, engineers often compute equivalent static loads and analyze gantry girders through simple bending and shear equations. Although codal design procedures ensure structural safety, they are often conservative in nature. By assuming worst-case load positioning and applying high impact factors, the codes tend to overestimate the design forces. This results in the selection of heavier rolled or built-up sections, which increases material cost and construction effort. In today's context of sustainable construction and resource optimization, such overdesign is not always desirable.

Codal validation involves verifying that standard provisions adequately represent the actual structural response of gantry girders under crane loads. Indian Standards (IS 800, IS 807, IS 3177) and international codes (AISC, Eurocode) provide guidelines for bending, shear, deflection, and dynamic impact factors.

Role of Computational Methods

With the advent of advanced computational tools, structural engineers are now equipped with methods that go beyond simplified codal assumptions. One such approach is the influence line method, which directly evaluates the structural response due to moving loads. An influence line for a given response quantity (e.g., bending moment or shear at a specific section) shows how that response varies as a unit load moves across the span. By superimposing actual crane wheel loads onto the influence line, the exact maximum effect can be determined.

The influence line method is particularly well-suited for gantry girder analysis because:

- The governing loads are concentrated and moving, not distributed.
- The wheelbase arrangement changes the location of maximum stress.
- The effect of impact can be realistically superimposed.

STAAD.Pro, a widely used structural analysis software, provides features for influence line generation. By using this approach, engineers can determine bending moment and shear variations across the girder span under actual wheel load configurations. This is far more accurate than assuming codal load placements.

Objectives of the Study

a. To design gantry girders for heavy-duty cranes using STAAD.Pro, considering load capacity, structural stability, material economy, and serviceability requirements.
b. To establish clear design criteria for gantry girders in accordance with IS 800:2007, IS 875, IS 3177, IS807, and other relevant Indian Standards.
c. To develop Excel-based calculation sheets for accurate, repeatable, and time-efficient validation of gantry girder designs.
d. To cross-verify analytical results with theoretical formulations prescribed in IS codes.
e. To Identify gaps in current design practices and provide practical recommendations for optimized gantry girder design in industrial applications.
f. To provide simple design guidelines for engineers, enabling safe, economical, and code-compliant gantry girder designs without sole reliance on advanced software.

Scope of Work

The scope of this study includes:

a. Analysis of a 12-meter-span gantry girder subjected to three different crane load cases.
b. Consideration of wheel load variations corresponding to different crane capacities.
c. Evaluation of influence line diagrams for bending moment and shear in STAAD.Pro.
d. Comparison of maximum stress, deflection, and girder weight obtained from codal and influence line approaches.

LITERATURE REVIEW

The design of gantry girders has been the subject of extensive research due to their critical role in crane-supported industrial buildings. Researchers have investigated gantry girder behavior through codal approaches, experimental studies, numerical simulations, and optimization techniques. While codes of practice such as IS 800:2007, IS 807:2006, and IS 3177:1999 provide simplified yet safe guidelines, advanced computational methods have been increasingly applied to improve accuracy and optimize material usage.

This review organizes past studies into four thematic areas:

a. Structural behavior investigations – studies focusing on response under crane loads.
b. Codal and empirical approaches – highlighting the role and limitations of design codes.
c. Computational and analytical methods – including influence lines, finite element analysis, and optimization.
d. Critical design considerations – addressing load assessment, geometry, and serviceability.

Research Gap and Relevance

While past studies have extensively examined gantry girders using codal and computational methods, two key gaps persist:

a. Underutilization of the Influence Line Method – Although recognized for moving load analysis, its application in gantry girder design practice remains limited compared to FEA or codal design.
b. Variable Wheelbase and Impact Loads – Few studies have explicitly explored the combined effect of variable wheelbase configurations and impact factors using influence line analysis.

This research directly addresses these gaps by employing STAAD.Pro influence line method to analyze a 12-meter gantry girder under different crane wheelbase scenarios with impact loads. The results are compared with codal design outcomes to evaluate accuracy, safety, and economy.

METHODOLOGY

General Approach

The study adopts a dual-method framework to analyze and optimize gantry girders subjected to heavy-duty crane loads. The first approach involves codal design procedures as per IS 800:2007, IS 807:2006, and IS 3177:1999. This establishes the baseline safety and serviceability checks. The second approach utilizes the Influence Line Method implemented in STAAD.Pro, which enables more accurate determination of maximum structural effects under moving wheel loads. By comparing the two approaches, the study seeks to highlight areas where codal methods may be overly conservative and where computational analysis can lead to material and cost optimization.

Input Data for Analysis

To ensure a consistent basis for comparison, the same set of input parameters was used for both codal and computational approaches.

- Span of gantry girder: 12.0 m (fixed for all cases).
- Crane capacities considered: Three capacities were selected to represent light, medium, and heavy-duty industrial applications.
- Wheel load per wheel: Varied according to crane capacity, ranging from 125 kN to 557 kN.
- Wheelbase configurations: Multiple arrangements were studied, including short, medium, and long wheelbases (e.g., 2.5 m, 3.5 m, and 4.5 m spacing).
- Impact factor: An additional dynamic load percentage, as prescribed in IS 3177 (typically 10–25%), was applied to account for sudden braking, starting, or accidental impacts.
- Sections analyzed: A range of rolled I-sections (P1, P2) and built-up plate girders (P3) were selected to study the balance between strength and weight.

These inputs were selected to reflect realistic industrial crane operations while maintaining a manageable scope for analysis.

Codal Design Procedure

The codal approach was carried out in line with IS 800:2007 (general design provisions) and IS 807:2006/IS 3177:1999 (crane-specific loading guidelines).

Load Considerations

Dead load (DL): Self-weight of the girder, including rail section.

Live load (LL): Crane wheel load, distributed across the number of wheels.

Impact load (IL): Additional percentage increase in crane load, varying between 10 and 25% depending on crane class.

Load Positioning

Codes typically assume worst-case load placement, i.e., wheel loads positioned at locations that maximize bending moment or shear force at critical sections. For a simply supported beam, this usually occurs at mid-span (for bending) and near supports (for shear).

Structural Checks

Bending Stress Check

- Maximum bending moment computed from worst-case wheel load placement.
- Stress = M / Z, where M is bending moment and Z is section modulus.

Shear Stress Check

- Maximum shear at supports determined by total wheel load within influence zone.
- Stress = *V / A_w*, where *V* is shearing force and *A_w* is web area.

Deflection Check

- Mid-span deflection computed using elastic beam theory under equivalent loads.
- Checked against permissible limits (span/750 or as per IS 800).

Weight Estimation

- Self-weight of selected section estimated in kg/m for economic comparison.

Limitations of Codal Procedure

- Load placement is based on assumptions rather than actual moving load simulation.
- Conservatism in impact factors inflates design loads.
- Deflection and stress estimations do not account for variable wheelbase effects.

STAAD.Pro Influence Line Method

The computational approach relied on the influence line method in STAAD.Pro to directly simulate the response of the girder under moving crane loads.

Influence Lines in Theory

An influence line represents the variation of a structural response function (e.g., shear force, bending moment, or reaction) at a specific location on a structure as a unit load moves across the span. For gantry girders, influence lines were generated for:

- Shear at supports.
- Bending moment at mid-span and quarter-span sections.
- Deflection at mid-span.

The ordinates of the influence line indicate the magnitude of response due to a unit load. By multiplying these ordinates by actual crane wheel loads, the maximum effect for different load positions can be computed.

Implementation in STAAD.Pro

a. Modeling
   - The girder was modeled as a simply supported beam of 12 m span.
   - Cross-sections (P1, P2, P3) were assigned material and geometric properties.
   - Rails and self-weight were included in dead load.

b. Load Application
   - Crane wheel loads were defined as moving loads.
   - Variable wheelbases were modeled to simulate different crane types.
   - Impact factor was applied as an additional multiplier to wheel loads.

c. Generation of Influence Lines
   - Influence line diagrams for shear, bending moment, and deflection were generated at critical points.
   - Ordinates were recorded for each load position.

d. Superposition of Loads
   - Actual wheel loads were superimposed onto the influence lines.
   - This provided maximum bending moment and shear directly, corresponding to realistic wheel positions.

e. Serviceability Check
   - Mid-span deflection values obtained from STAAD.Pro were compared against codal limits.

f. Optimization Assessment
   - Self-weight of sections was compared to determine economy.

Advantages of the Influence Line Method

- Captures the true effect of moving loads instead of assumed positions.
- Accounts for variable wheelbase configurations explicitly.
- Provides realistic results for deflection and stresses, avoiding overdesign.
- Integrates seamlessly with STAAD.Pro workflow, reducing manual effort.

RESULT & DISCUSSION

Overview of Results

The analysis of the 12 m span gantry girder was conducted under three crane capacities; each associated with specific wheel load magnitudes and wheelbase configurations. For each case, three different sections (rolled and built-up) were evaluated. Both codal and influence line methods were used to compute bending stresses, shear forces, and deflections. Additionally, the self-weight of each section was recorded to assess material efficiency.

The results consistently revealed differences between codal provisions and STAAD.Pro outcomes. While codal calculations provided safe designs, they tende d to overestimate stresses and deflections, thereby recommending heavier girder sections. In contrast, the influence line method more accurately reflected actual load effects, suggesting that lighter sections could safely be adopted in several cases.

Representative Data Set

A simplified summary of key results is shown below

Span (m)	*Wheel Load (kN)*	*Wheelbase (m)*	*Section*	*Max Deflection (mm)*	*Max Bending Stress (MPa)*	*Self-Weight (kg/m)*
12.0	125	3.5	P1	15.70	87.04	219.23
12.0	225	3.0 + 3.5 + 3.0	P2	14.88	101.08	328.93
12.0	557	3.0 + 4.0 + 3.0	P3	13.45	119.32	412.50

Note: Values represent STAAD influence line analysis. Codal results were generally 10–20% higher for deflection and bending stress due to conservative assumptions.

Bending Stress Comparison

Bending stress is the primary design parameter for gantry girders.

Codal Method:

The maximum bending moment was derived by assuming the worst-case positioning of crane wheels. For example, in the 125 kN case, the codal method predicted bending stresses nearly 10% higher than STAAD. For the 557 kN case, codal stresses were about 15% higher.

STAAD Influence Line Method:

By generating actual influence lines, STAAD.Pro captured the precise positions of maximum effect. The results showed that the codal assumption of worst-case load placement does not always coincide with the true critical location. This discrepancy explains why codal stresses are consistently higher.

Discussion:

While codal conservatism ensures safety, it leads to oversized sections. The influence line method demonstrated that lighter sections can achieve the same safety margins, particularly for moderate wheel loads. For heavy-duty cranes, both methods converged more closely, reflecting the dominant effect of high load magnitude.

Deflection Comparison

Serviceability in gantry girders is governed by deflection limits. Excessive deflection can impair crane operation and cause misalignment of rails.

Codal Method:

Codal deflections were calculated using elastic beam theory under equivalent static loads. In the 125 kN case, the codal method predicted ~17 mm mid-span deflection, whereas STAAD gave ~15.7 mm. For heavier loads, codal estimates remained 8–12% higher.

STAAD Influence Line Method:

STAAD considered the actual moving wheel load positions, resulting in lower deflection values. These results remained well within codal limits (span/750 ≈ 16 mm for a 12 m girder).

Discussion:

The difference in deflection estimation further highlights codal conservatism. In practice, this may lead designers to adopt sections with greater stiffness (and weight) than necessary. STAAD's influence line approach suggests that serviceability can be achieved with more economical sections.

Shear Force Comparison

Shear forces were critical near supports.

Codal Method:

Codal guidelines assume all wheel loads adjacent to supports contribute to maximum shear. This often overestimates shear force, especially for longer wheelbases where not all wheels align simultaneously near the support.

STAAD Influence Line Method:

The influence line directly reflected actual shear contributions from each wheel as it passed near supports. This yielded slightly lower shear values than codal estimates.

Discussion:

Although the difference in shear values was less significant compared to bending and deflection, STAAD results were more precise. Codal overestimation again favors safety at the expense of material economy.

Effect of Variable Wheelbase

The study revealed that wheelbase variation strongly influences the location and magnitude of maximum responses.

Short Wheelbase:

Concentrated loads positioned closer together produced higher localized bending moments and deflections. Codal design, which assumes worst-case conditions, matched these outcomes reasonably well.

Long Wheelbase:

Load effects were more distributed, and STAAD results were significantly lower than codal predictions. This confirms that codal assumptions fail to exploit the reduced criticality of longer wheelbases.

Discussion:

Variable wheelbase consideration is essential for accurate design. Influence line analysis offers a clear advantage by capturing this effect directly.

Impact Load Effects

Impact factors amplify crane loads to account for dynamic effects.

Codal Method:

A fixed percentage (10–25%) was applied across all cases. While simple, this method ignores differences in crane speed, stiffness, and operational characteristics.

STAAD Influence Line Method:

The dynamic amplification was applied directly to moving loads. The results showed that the actual increase in stresses and deflections was slightly lower than codal estimates, particularly for moderate impact percentages.

Discussion:

Codal provisions ensure safe overestimation, but influence line analysis provides a more realistic assessment. Designers can balance safety and economy by adopting influence line results with codal-mandated safety margins.

CONCLUSION AND FUTURE SCOPE

This research focused on the codal validation and optimization of gantry girders subjected to variable wheelbase and impact loads using the STAAD.Pro Influence Line Method. A 12 m span gantry girder was analyzed for three different crane capacities (10T, 35T, and 100T), with corresponding wheel loads and wheelbases. Both codal methods (IS 800:2007, IS 875, IS 3177, IS 807) and influence line analysis were employed to evaluate bending stresses, deflections, and shear forces.

The comparative study highlighted that codal methods are inherently conservative, often leading to heavier girder designs. STAAD.Pro, by contrast, provided a more realistic simulation of moving crane wheel loads, enabling optimized girder sections with significant material savings.

Key Findings

Bending Stress Evaluation

- Codal methods predicted stresses 10–15% higher than STAAD.
- Influence line analysis captured the actual critical positions of wheel loads, which codal provisions generalized conservatively.
- This difference translated into lighter optimized girder sections under STAAD.

Deflection Control

- Codal deflections were consistently 8–12% higher than STAAD outcomes.
- Both methods satisfied span/750 deflection limits, but STAAD results revealed that smaller sections could remain serviceable.

Shear Force Predictions

- Codal provisions slightly overestimated shear near supports by assuming simultaneous wheel loading.
- Influence line analysis gave more accurate shear profiles, avoiding unnecessary strengthening.

Impact Load Considerations

- Codal methods apply a uniform percentage (10–25%) across cases.
- STAAD incorporated impact amplification more realistically, producing slightly lower increases in stresses and deflections.

Material Economy

- Codal design tended to recommend heavier sections, such as P2 (~329 kg/m), while STAAD validated the adequacy of lighter P1 (~219 kg/m).
- Savings of up to 25–30% in self-weight were achieved through influence line analysis.
- Considering multiple girders in an industrial plant, such optimization leads to substantial cost reductions.

Effect of Wheelbase Variation

- Shorter wheelbases caused more severe localized effects, while longer wheelbases distributed loads more evenly.
- Codal design could not exploit the reduced criticality of longer wheelbases, whereas STAAD did so effectively.

Practical Implications

The study demonstrates that adopting STAAD influence line analysis in gantry girder design can strike a balance between safety and economy. Engineers can use codal guidelines as a baseline while refining their designs using computational tools to minimize excess material usage. This has direct implications in:

- Industrial Plants: Optimized girders reduce overall steel tonnage.
- Construction Cost: Savings in material also reduce foundation requirements, welding, and erection costs.

- Sustainability: Lighter sections lower embodied energy and carbon footprint, aligning with green construction practices.

Limitations

Despite the advantages, the present research has certain lim itations:

- Only a 12 m span was considered; longer spans may exhibit more pronounced differences.
- The study used STAAD.Pro Influence Line Method, but did not incorporate dynamic time-history analysis.
- Impact loads were applied as per codal percentages; actual crane operation may produce more complex dynamic effects.
- The analysis was limited to simply supported conditions; fixed or partially restrained supports could alter results.

Future Scope

To advance this research, the following areas are recommended:

- Dynamic Analysis: Future studies can employ time-history or modal analysis to capture crane acceleration, braking, and resonance effects.
- Experimental Validation: Full-scale testing of gantry girders under moving crane loads would strengthen computational findings.
- Alternative Materials: Use of high-strength steels, composite girders, or hybrid sections can be explored for further weight reduction.
- Long-Span Girders: Investigating spans beyond 20 m can reveal the scalability of influence line optimization.
- 3D Structural Modeling: Incorporating the entire gantry system (columns, rails, and bracing) may yield more integrated and realistic results.
- Fatigue Analysis: Since cranes impose repetitive cyclic loads, fatigue performance should be examined for long-term service life.
- AI-Based Optimization: Machine learning tools can be applied to generate optimized girder cross-sections considering multiple parameters.

Final Conclusion

The research conclusively demonstrates that STAAD.Pro Influence Line Method provides a more accurate and economical approach for gantry girder design compared to conventional codal methods. While codal provisions ensure safety through conservatism, they often impose heavier and costlier sections. The influence line approach enables engineers to leverage computational precision without compromising safety, thus achieving a practical balance of strength, serviceability, and economy.

The study thus contributes to the broader objective of developing optimized, sustainable, and cost-effective structural solutions for heavy-duty crane applications in industrial settings.

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