Gantry Girders in India

Aamod Garg

Undergraduate Student, Department of Civil Engineering, MNNIT, Allahabad, India-211004

***Abstract*—*In India, industries usually have quality range of gantry girders for industrial sheds. Assisted by skilled workers in India, companies have been able to successfully grow towards the zenith, but there is still minor margin remaining which can be achieved by optimally designing the gantry girder in an economic as well as efficient manner. For this purpose, it is essential to implement the procedure for model, design, analyze and validate the girder efficiently.*

Keywords*—*Automated Beam, Built-Up Section,Crane Girder, Gantry Girder, Lateral Load, Vertical Load.

I. INTRODUCTION

Majority of the industrial buildings in India have built-in overhead cranes for handling heavy equipment or goods. With the help of the overhead cranes, heavy equipment or goods can be lifted and moved from one point of work place to another. The cranes may be hand operated (generally they have a capacity of up to 2 tonnes) and electrically operated (EOT). A typical EOT crane system is shown in Fig. 1 and Fig. 2.

Since India has an expanding construction potential, there is rising need for gantry girders with higher capacity. For this purpose, the paper contributes towards the modelling, analysis, design and checking of a gantry girder with capacity of 300 kilonewtons.

1.1. Design Element of Girders

The complete design of a gantry girder consists of the following elements:

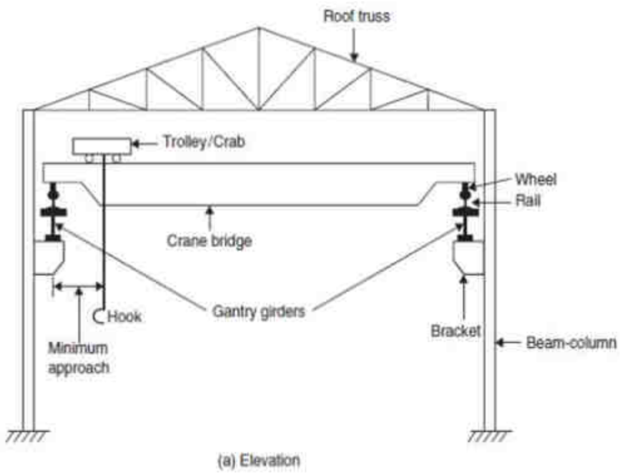


Fig. 1: Elevation of EOT crane

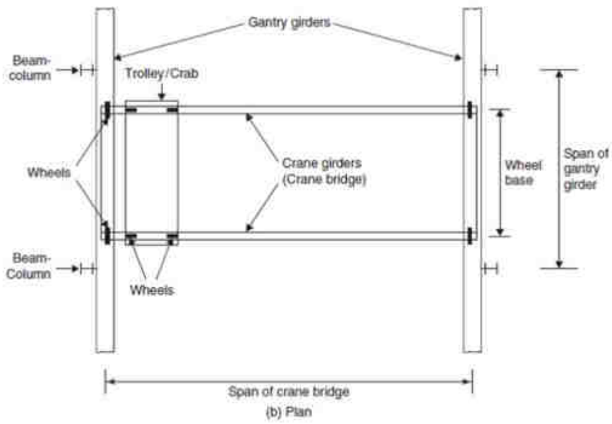


Fig. 2: Plan of EOT crane

i) Calculation of external loads and estimation of self-weight.
ii) Calculation of shear force and bending moment.
iii) Selection of girder section by trial and error.
iv) Design of girder section.
v) Design of web and flange.
vi) Design of connection.

High quality range of composite-steel gantry girder can be fabricated with the assistance of various IS codes present in India. Superior quality material and latest techniques are used to ensure that fabrication done is accurate and up-to-the-mark. Fabrication process is carried out in accordance with the prescribed quality guidelines and norms. Besides, ensuring completion of projects within the minimum possible time-period should be targeted.

Composite girders manufactured are demanded in ROBs and railway bridges. They are generally manufactured in following sizes: Flange from 140mm to 1200mm, thickness 6mm to 80mm, web 180mm to 3000mm, thickness 6mm to 60mm and maximum length 20meters.

Composite steel gantry girders have following advantages:

1) High capacity in shear, tension and compression,
2) Light weight,
3) Members are visible and thinner, factory made, which helps us to predict the girder's behavior in reasonable manner.

II. NUMERICAL PROBLEM

Design a Gantry Girder to be used in an industrial building carrying a Manually Operated Overhead Travelling Crane, for the following data in Table 1:

Table.1: Data for Numerical Problem

Sr. No.	Crane Property	Magnitude
1	Crane Capacity	300 kN
2	Self-Weight of Crane Girder excluding Trolley	200 kN
3	Self-Weight of Trolley, Electric Motor, Hook, etc.	40 kN
4	Approximate Minimum Approach of Crane Hook to the Gantry Girder	1.20 m
5	Wheel Base	3.5 m
6	Centre-to-Centre Distance between Gantry Rails	18 m
7	Centre-to-Centre Distance between Columns (Span of Gantry Girder)	10 m
8	Self-Weight of Rail Section	300 N/m
9	Diameter of Crane Wheels	150 mm

Steel is of Grade Fe 410. Design also the field welded connection if required.

III. SOLUTION

For Fe 410 grade of steel: f_u= 410 MPa,

$f_y = f_{yw} = f_{yf}$ = 250 MPa

For hand-operated OT crane

Lateral loads = 5% of maximum static wheel load

Longitudinal loads = 5% of weight of crab and weight lifted.

Maximum permissible deflection = L/500

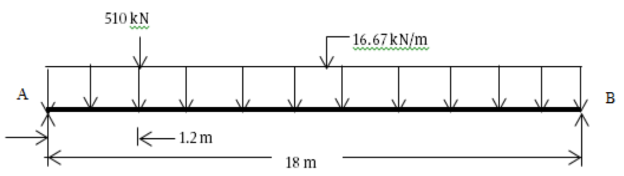


Fig. 3: Maximum reaction on gantry girder

1.2. Partial safety factors

γ_{m0} = 1.10

γ_{mw} = 1.50 (for site welds)

Load factor γ_{m1} = 1.50

$$\varepsilon = \varepsilon_w = \varepsilon_y = \sqrt{\frac{250}{fy}} = \sqrt{\frac{250}{250}} = 1.0$$

3.2. Design forces

Maximum wheel load:

Maximum concentrated load on crane=300 + 40 = 340 kN

Maximum factored load on crane = 1.5 × 340 = 510 kN

The crane will carry the self-weight as a uniformly distributed load $= \frac{200}{18}$ = 11.11 kN/m

Factored uniform load = 1.5 × 11.11 = 16.67 kN/m

For maximum reaction on the gantry girder the loads are placed on the crane girder as shown in Fig. 2.

Taking moment about B,

$$R_A \times 18 = 510 \times (18\text{-}1.2) + \frac{16.67 \times 18^2}{2}$$

or, R_A = 626 kN

Similarly, R_B = 184 kN

The reaction from the crane girder is distributed equally on the two wheels at the end of the crane girder.

Therefore, maximum wheel load on each wheel of the crane $= \frac{626}{2}$ = 313 kN

3.3 Maximum bending moment

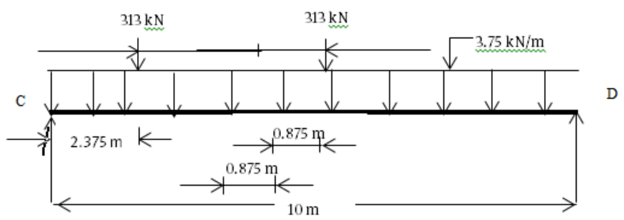


Fig. 4.Wheel configuration for max.bending moment

Assume self weight of gantry girder as 2.2 kN/m.

For maximum bending moment, the wheel loads shall be placed as shown in Fig. 4.

Total dead load = 2200 + 300 = 2500 N/m = 2.5 kN/m

Factored dead load = 1.5 × 2.5 = 3.75 kN/m

The position of one wheel load from the midpoint of span

$$= \frac{\text{wheel base}}{4} = \frac{3.5}{4} = 0.875 \text{ m}$$

Bending moment due to live load only:

Taking moment about D,

R_C × 10 = 313 × (10-2.375) + 313 × 4.125

R_C = 367.78 kN

Taking moment about C,

R_D × 10 = 313 × 2.375 + 313 × 5.875

R_C = 258.22 kN

Maximum bending moment

due to live load = 258.22 × 4.125
= 1065.16 kNm

Bending moment due to impact = 0.1 × 1065.16
= 106.52 kNm

Total bending moment due to live and impact loads
= 1065.16 + 106.52 = 1171.68 kNm

Bending moment due to dead load = $\frac{wL^2}{8} = \frac{3.75\times10\times10}{8}$
= 46.88 kNm

Therefore, maximum bending moment = 1171.68 + 46.88
= 1224.56 kNm
=1224.56 × 10^6 Nmm

3.4 Maximum shear force

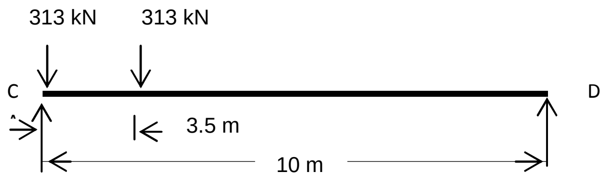


Fig. 5: Wheel configuration for maximum shear force

For maximum shear force, wheels are placed as shown in Fig. 5.

Taking moment about *D*,

R_C × 10 = 313 × 10 + 313 × 6.5

R_C = 516.45 kN

Hence maximum shear force due to wheel loads = 516.45 kNm

3.5 Lateral forces

Lateral force transverse to the rails = 5% of the weight of crab and weight lifted = 0.05 × 340 = 17 kN

Factored lateral force = 1.5 × 17 = 25.5 kN

Lateral force on each wheel = $\frac{25.5}{2}$ = 12.75 kN

Maximum reaction due to lateral forces at D by proportion at C

= $\frac{\text{Lateral force} \times \text{Reaction at C due tovertical load}}{\text{Maximum wheel load due vertical load}}$ = $\frac{9 \times 367.78}{313}$ = 10.58 kN

Horizontal reaction due to lateral force at D
= 25.50 – 10.58 = 14.92 kN

Maximum bending due to lateral load by proportion
= $\frac{12.75}{313}$× 1065.16 = 43.39 kNm

Maximum shear force due to lateral load by proportion
= $\frac{516.45}{313}$ × 12.25 = 20.21 kN

3.6 Preliminary trial section

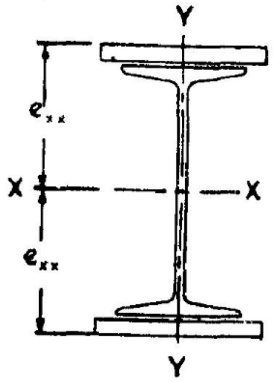
Approximate depth of section = $\frac{L}{12} = \frac{10 \times 1000}{12}$
= 833.33 mm ≈ 800 mm

Approximate width of flange = $\frac{L}{30} = \frac{10 \times 1000}{30}$
= 333.33 mm ≈ 300 mm

Approximate section modulus required,

$Z_{pz} = 1.4\frac{M_z}{f_y} = \frac{1.4 \times 1224.56 \times 10^6}{250}$
= 6857.5 × 10^3 mm^3

We use ISMB 600 with additional plates (thickness = 20 mm and width = 320 mm) on both flanges as shown in Fig. 6.



The relevant properties from Steel Table are as follows:

Weight per metre (w) = 248.2 kg = 2434.8 N

Sectional Area (A) = 316.21 cm^2

Mean thickness of flange (t_w) = 38.6 mm

Extreme fibre Distance (e_{xx}) = 32.50 mm

I_{xx} = 248146.3 cm^4

I_{yy} = 16304.3 cm^4

Least radius of Gyration = 7.18 cm

Modulus of section = 7635.3 cm^3

3.7 Classification of Section

Outstand of flange of I-section (b) = b_f / 2
= 210/2 = 105 mm

b/t_f of flange of I-section = 105/20.8 = 5.05 < 8.64

The entire section is plastic. (β_b = 1.0)

3.8 Check for moment capacity

Local moment capacity:

$M_{dz} = \beta_b Z_{pz} f_y / \gamma_{m0} \leq 1.2 Z_e f_y / \gamma_{m0}$

M_{dz} = 1.0 × 8793.618 × 10^3 × $\frac{250}{1.10}$ × 10^{-6}
= 1998.55 kNm

M_{dz}< 1.2 × 7635.27 × 10^3 × $\frac{250}{1.10}$ × 10^{-6}
< 2082.346 kNm

Hence, moment capacity of the section,

M_{dz} = 1998.55 kNm > 1224.56 kNm

Therefore, the trial section is safe by sufficient margin in the moment capacity and can be checked for combination of loads as laterally supported beam.

Moment capacity compression flange about y-axis,

$M_{dy} = \beta_b Z_{py} f_y / \gamma_{m0} \leq 1.2 Z_{ey} f_y / \gamma_{m0}$
= 1.0 × 1759.491 × 10^3 × $\frac{250}{1.10}$ × 10^{-6}
= 439.87 kNm

$< 1.2 \times 101946 \times 10^3 \times \frac{250}{1.10} \times 10^{-6} = 277.9$ kNm

Hence, moment capacity of flange, $M_{dy} = 277.9$ kNm

3.9 Combined check for local moment capacity

$$\frac{M_z}{M_{dz}} + \frac{M_y}{M_{dy}} \leq 1.0$$

$$\frac{1224.56}{1998.55} + \frac{43.39}{277.9} = 0.7688 < 1.0$$

which is safe. Therefore, the gantry girder is safe.

3.10 Check for buckling resistance in bending

The elastic lateral-torsional buckling moment,

$$M_{cr} = c_1 \frac{\pi^2 \times E \times I_y \times h_f}{2 \times L_{LT}^2}\left[1 + \frac{1}{20}\left(\frac{L_{LT} \times t_f}{r_y \times h_f}\right)^2\right]^{0.5} \quad (1)$$

Overall depth of the section, $h_f = h = 600+50 = 650$ mm

Effective length, $L_{LT} = 10 \times 10^3$ mm

Radius of gyration, $r_y = \sqrt{\frac{fy}{A}} = \sqrt{\frac{16304.3 \times 10^4}{316.21 \times 10^2}} = 71.81$ mm

Thickness of flange, $t_t = 38.6$ mm

Coefficient from codes, $c_1 = 1.046$

Elastic modulus of steel, $E = 2 \times 10^5$

Therefore using Formula 1: $M_{cr} = 2299.96 \times 10^6$ Nmm

Non-dimensional slenderness ratio,

$$\lambda_{LTz} = \sqrt{\frac{\beta b \times Z_{pz} \times f_y}{M_{cr}}} = \sqrt{\frac{1.0 \times 8793.618 \times 250}{2300 \times 10^6}} = 0.97766$$

$\phi_{LTz} = 0.5[1 + \alpha_{LT}(\lambda_{LTz} - 0.2) + \lambda^2_{LTz}] = 1.05956$

$\alpha_{LT} = 0.21$

$$\chi_{LTz} = \frac{1}{\phi_{LT_z} + (\phi_{LT_z}{}^2 - \lambda_{LT_z}{}^2)^{0.5}} = 0.81539$$

Design bending compressive stress,

$f_{bd} = \phi_{LT_z} f_y / \gamma_{m0} = 0.81539 \times 250 / 1.10$

$f_{bd} = 185.318$ N/mm^2

The design bending strength,

$M_{dz} = \beta_b Z_{pz} f_{bd} = 1.0 \times 8793.618 \times 10^3 \times 185.315 \times 10^{-6}$

$= 1629.596$ kNm > 1224.56 kNm

which is alright.

Therefore, the gantry girder is safe under vertical loads.

3.11 Check for shear capacity

Maximum shear force due to wheel load = 516.45 kN

Impact load = $0.1 \times 516.45 = 51.645$ kN (10% of wheel load)

Design shear force = 516.45 + 51.645 = 568.10 kN

Shear capacity = $\frac{A_v \times f_{yw}}{\sqrt{3} \times \gamma_{m0}} = \frac{(600 \times 12) \times 250}{\sqrt{3} \times 1.10} = 944.754$ kN > 568.10 kN

which is safe.

Maximum shear, V = 568.10 kN

< 576.85 kN ($0.6V_d = 0.6 \times 944.75 = 576.85$ kN)

Since V is less than V_d, the case obtained is of low shear and hence no reduction will be required in the moment capacity.

3.12 Web-buckling check

Web should be checked for buckling under the wheel load.

Buckling resistance = $(b_1 + n_1)\, t_w\, f_{cd}$

b_1 = bearing length = mm (wheel diameter)

$n_1 = 600/2 + 2\times25 = 350$ mm

Slenderness ratio of the web, $\lambda_w = 2.45\, d_1 / t_w = 107.065$

For $\lambda_w = 107.065$, $f_y = 250$ N/mm^2 and buckling curve c, the design compressive strength from Table 9(c) of IS 800:2007 = 98.32 N/mm^2

Buckling resistance = $(150+350)\times18\times98.32\times10^{-3}$

= 884.88kN > 313kN

which is safe.Therefore, the gantry girder is safe.

3.13 Deflection check

$$\delta = WL^3 \times \frac{\frac{3a}{4L} - \frac{a^3}{L^3}}{6EI}$$

W = maximum static wheel load = 313 / 1.5 = 208.67 kN

$a = (L-c)/2 = (10\times10^3 - 3.5\times10^3)/2 = 3250$ mm

Vertical deflection $= 208.67 \times 10^3\,(10\times10^3)^3$

= 14.67 mm

Permissible maximum deflection = L/500 = 20 mm

> 14.67 mm

which is safe.Therefore, the gantry girder is safe.

3.14 Design of connections

The required shear capacity of the weld, $q = \frac{V \times A \times y_1}{I_z}$

V = 516.45 kN

A = 8000 mm^2 (area above the section)

$y_1 = 325 - 25 = 300$ mm

$I_z = 248146.3 \times 10^4$ mm^4

$$q = \frac{516.45 \times 10^3 \times 8000 \times 300}{248146.3 \times 10^4} = 500 \text{ N/mm}$$

Let us provide a 5 mm weld size to connect plates with flange of I-section.

Strength of weld provided = $\frac{0.7 \times 5 \times 410}{\sqrt{3} \times 1.5} = 552.33$ N/mm

which is greater than 500 N/mm

Hence, provide 5 mm size fillet weld for making the connection.

IV. RESULT

Therefore, the gantry girder with crane capacity of 300-kN has been designed and has been checked as per the codal provisions. Similar gantry girders can also be designed with much higher capacities, with only change in the selection of the girder cross section. Higher load capacities can be achieved in India by selecting more efficient girders. Such practices would lead to more efficient operations in warehouses, industrial sheds, shipyards and rail yards.

As a result of this, it was understood how a complex steel structure is designed after expansive planning. The usage of Indian Standard codes, other codes and appropriate software was also understood.

V. CONCLUSION

Generally, it is argued as to how much load comes on each bracket plate. If each plate was independent of its neighbour, then either plate would, in turn, have to support the entire reaction due to the crane and its load. By using a diaphragm one side plate cannot deflect without taking its neighbour with it. There is another factor which is sometimes considered, and that is the frequency of case of loading. It will be seldom that the crane wheels will be called upon to carry the maximum load with the crab drawn in tightly against the bracket. The gantry girder is designed for the worst possible cases if loading without consideration as to the laws of chance, and to be consistent the vertical brackets should be designed to meet the requirements of the maximum load. Also, it is desirable to make the girders entirely self-supporting in the adjacent aisles.

Currently research is being carried out to ameliorate the vigor structure of overhead crane girder. These incipient efforts avail to surmount overhead crane girder failure. The girder is fortified on a felicitously composed seat and it is withal connected to the column near the top flange in each case in order to restrain it from lateral bending and convoluting at the fortification point. Material handling is a consequential practical consideration in the design of incipient manufacturing and distribution systems and research into better material handling systems and practices is paramount. Material handling uses different equipment and mechanisms. The structure is designed as per Indian standard codes

Thus, gantry girders should be utilized in India on a larger scale in order to maximize the output of industrial operations.

REFERENCES

[1] S K Duggal, Limit State Design of Steel Structures, 2nd ed., McGraw Gill Education, 2015, pp. 652-675.

[2] IS 800: 2007, Indian Standard General Construction In Steel – Code of Practice, 3rd ed., 2007.

[3] Birla Publications Pvt. Ltd., Steel Table,ISBN: 81-256-0011-6, 17th ed., 2010.

[4] Chen X, Wu S and Zhou J, “Compressive Strength of Concrete Cores with Different Lengths,” in Journals Materials and Civil Engineering, 2014.

[5] Song W, Ma Z, Vadivelu J, Burdette E, “Transfer Length and Splitting Force Calculation for Pretension Concrete Girders with High-Capacity Strands,” in Journal of Bridge Engineering, 2014.

[6] Hirol, Isami, Plate-Girder Construction, ISBN 978-0-554-88802-6., 2008.

[7] Venkatesh, A., Vignesh, S., Iyappan, S., Vignesh Kumar, P., Tamilvanan, G. and VijayaSarathy, R.,“Design of an overhead plate gantry girder” in International Journal of Development Research, 2016. CameliaBretoteanPinca, GeluOvidiuTirian, Ana Josan, Application of Finite Element Method to an Overhead Crane Bridge, Issue 2, Volume 4, 2009.

[8] Dr. Pumnia, B.C. and Ashok Kumar Jain,. “design of steel structures”, 1st September,1998.

[9] Euler, M. and Kuhlmann, U,.“Crane runways – Fatigueevaluation of crane rail welds using local concepts", in International Journal of Fatigue, 2011.

[10] OzdenCaglayan, KadirOzakgul, OvuncTezer, Erdogan Uzgider, 2010. “Fatigue life prediction of existing crane runway girders", in Journal of Constructional Steel Research, 2010.

[11] Ismail Gerdemeli, Serpil Kurt, HasanOnurAlkan, "Main girder beam design and finite element analysis of 2/160 gantry crane", in 14th International Research/Expert Conference, Trends In The Development Of Machinery and Associated Technology, 2010.