Lecture 02

GANTRY GIRDER: CALCULATIONS

We will look the calculations involved in the design of gantry girder then conclude the specification of Bolted joints which is also a critical part of the design process.

Gantry girder design

Design a gantry girder for the following data:

Wt. of crane girder/truss =180kN

Crane capacity=200kN

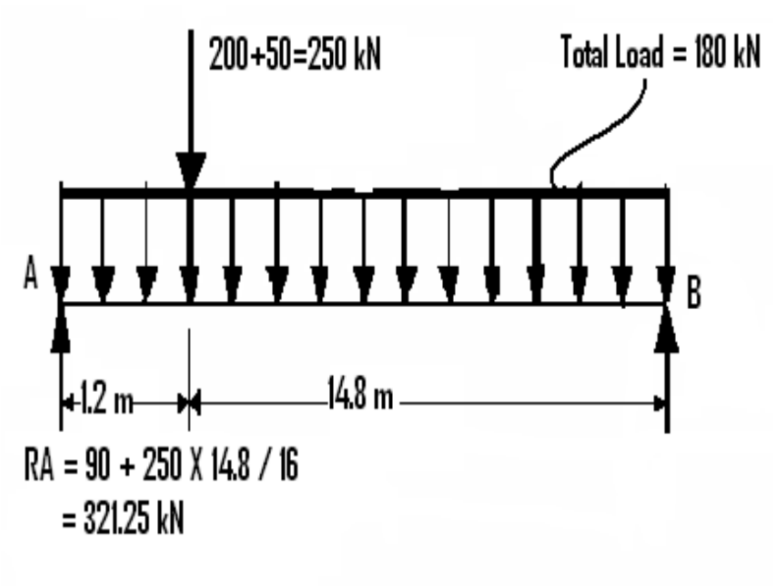
Wt. of crab + motor= 50kN

Span of crane girder/truss=16m

Min hook approach= 1.2m

c/c distance between gantry columns= 6m

Wt. of rail =0.25kN/m



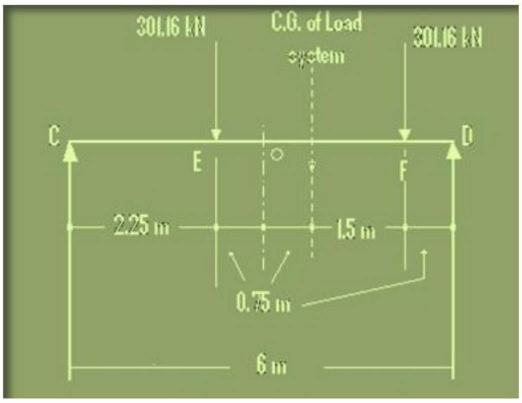
Maximum vertical static wheel load = $R_A/2$ =160.625 kN

Wheel load with impact = 1.25 x 160.625 = 200.775 kN

Factored load = 1.5 x 200.775 = 301.16 kN

Absolute max bending moment in Gantry Girder:

This will occur under any wheel load when distance between that load and C.G. of load system is equidistant from the centre of the Gantry Girder span.



Absolute max bending moment = 508.21 kNm

Md = Design moment for laterally unsupported beam

= $\beta_b \cdot Z_p \cdot f_{bd}$ *(Clause 8.2.2, p. no. 54)*

where β_b = 1.0 for plastic section (assumed)

Z_p = plastic modulus of section

f_{bd} = design bending compressive stress

Assuming f_{bd} = 200 Mpa

Z_p required = $(508.21 \times 10^6) / (1.0 \times 200)$

$= 2.54 \times 10^6\ mm^3$

Using I and channel section and assuming 80% of Z_p is contributed by I section

Z_p by I section = $2.032 \times 10^6\ mm^3$

using shape factor of I section = 1.14

Z_e required = 2032 / 1.14 = 1766.95 cm^3

select ISWB 500 @ 0.94 kN/m

Z_e provided = 2091.6 > 1766.95 cm^3 …. OK

Width of the flange of ISWB 500 = 250 mm

Select channel section having clear web depth more than 250 mm.

Select ISLC 350 @ 0.38 kN/m

having h_1 = 291.9 mm > 250 mm ….. OK

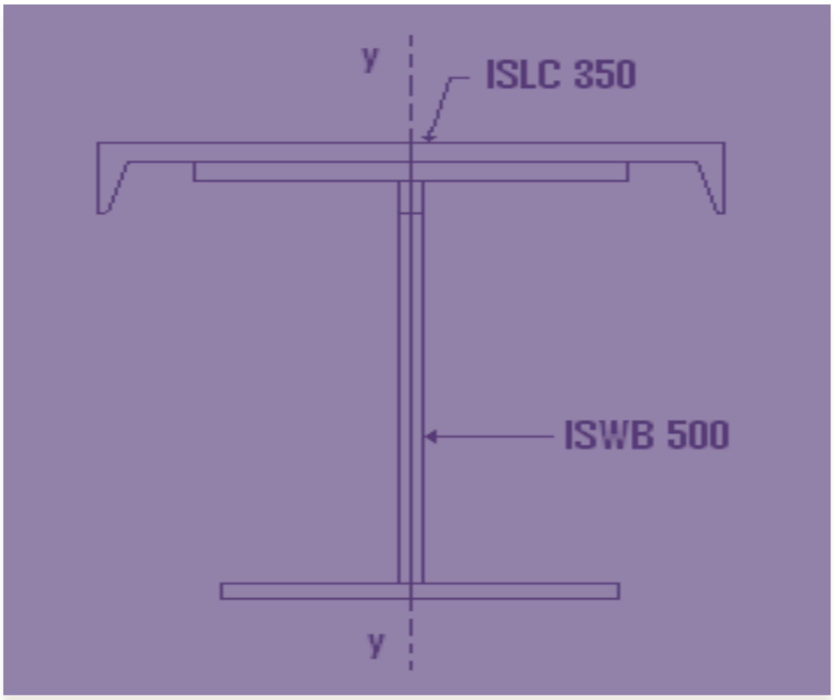
Total dead load intensity = 0.94 + 0.38 + 0.25

= 1.57 kN/m

Factored dead load intensity = 1.5 x 1.57 = 2.355 kN/m

Bending moment @ E = 9.93 kNm

Total bending moment due to DL + CL = 518.14 kNm



Refer Annexure E (p. no. 128) of IS800-2007

Elastic lateral torsional buckling moment

Elastic critical moment of a section symmetrical about minor axis yy is given by E-1.2 of Annexure E (p. no. 128) in which various factors and geometrical values of Gantry Girder section are involved.

These are as under c_1, c_2, c_3, = factors depending upon the loading and end restraint conditions, *Refer table 42* (p. no. 130)

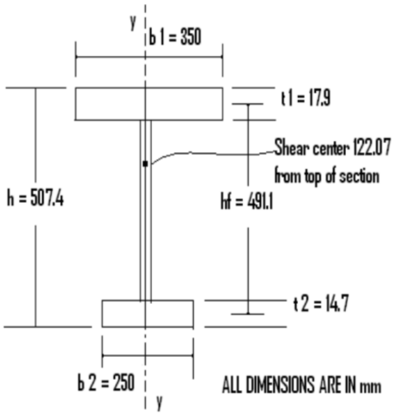
K = effective length factor = 0.8

Therefore c_1 = 1.03, c_2 = 0.422 & c_3 = 1.22

K_w = warping restraint factor = 1.0

y_g = y distance between the point of application of the load & shear centre of the cross section (+ve when load acts towards Shear centre)

= 122.07 mm



y_j for lipped flanges of channel section which depends on ratio of β_f

Where $\beta_f = I_{fc} / (I_{fc}+I_{ft}) = 0.7$

$y_j = 94.055$

Iyy = Iyy of ISWB 500 + Ixx of ISLC 350

$= 2987.8 + 9312.6 = 12300.4 \times 10^4\ mm^4$

$L_{LT} = K . L = 0.8 \times 6000 = 4800$ mm

I_w = warping constant

$= (1- \beta_f)\ \beta_f . I_y . (h_y)^2$

$= 6.23 \times 10^{12}\ mm^6$

I_t = Torsion constant

$= \sum bt^3/3 = 10.86 \times 10^5$

$G = 0.77 \times 10^5 \quad = 2950$ kNm

To find Z_p of Gantry Girder section we need to find equal area axis of the section.

This axis is at a depth of 48.74 mm from the top of the section.

Taking moments of areas about equal area axis.

$\sum A . y = Z_p = 29.334 \times 10^5\ mm^3$

$\lambda_{LT} = (\beta b Zpfy/Mcr)^{1/2} = 0.4984$

$\alpha_{LT} = 0.21$ for rolled section

$\varphi_{LT} = 0.5[1+\alpha_{LT}(\lambda_{LT}-0.2)+\lambda_{LT}^2]=0.655$

$\chi_{LT} = 1/(\varphi_{LT}+[\varphi_{LT}^2-\lambda_{LT}^2] \quad = 0.925$

Therefore $f_{bd} = \chi_{LT} . f_y / \gamma_{m0}$

$= 0.925 \times 250 / 1.1 = 210.22\ N/mm^2$

$M_{dZ} = \beta_b . Z_p . f_{bd} = 616.66$ kNm $> M_d = 508.21$ kNm

OK

<u>Horizontal Action</u>

Total horizontal force perpendicular to span of

Gantry Girder = 10 % (crane capacity + wt. of crab and motor)

= 10% (200+50) = 25 kN.

As wheels are having double flanges

Horizontal force / wheel = 25/4 = 6.25 kN

Therefore max horizontal BM in proportion to vertical bending moment

M_y = (6.25 /301.16) x 508.21 = 10.546 kNm

This is resisted by ISLC 350 with top flange of ISWB 500

$Z_{py1y1} = 100 \times 12.5 \times 337.5^2 + (1/4)\, 7.4 \times 325^2 + (1/4) \times 14.7 \times 250^2$

$= 8.47 \times 10^5\ mm^3$

Plastic moment capacity about y_1y_1 axis

$M_{dy} = \beta_b \cdot f_y \cdot Z_p / \gamma_{mo}$ = 192.5 kNm

Check for biaxial moment

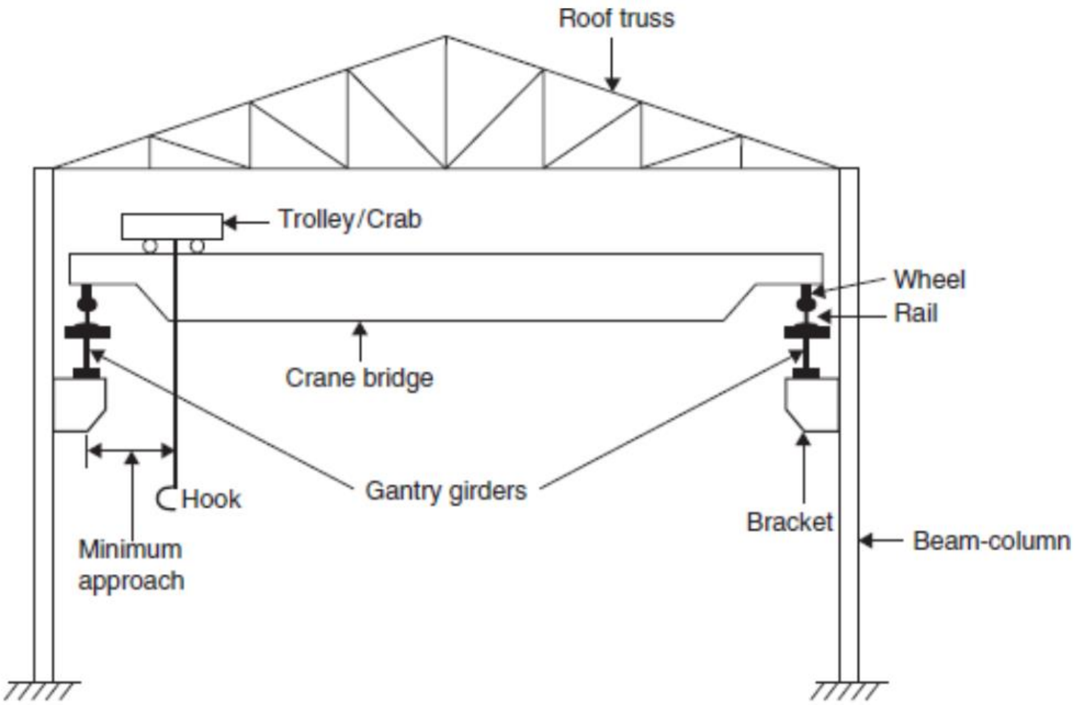
Reffering clause 9.3.1.1 (p. no. 70)

$(M_z/M_{dz}) + (M_y/M_{dy})$

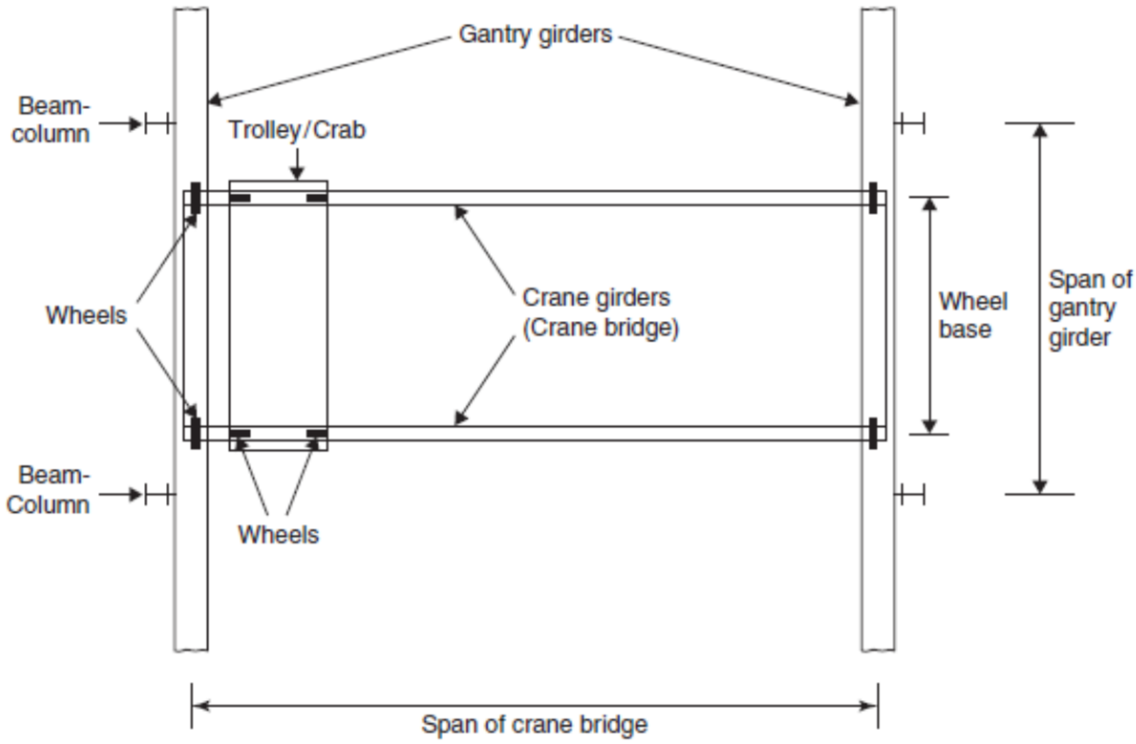
= (518.14 / 614.57) + (10.54 / 192.5)

= 0.897 < 1.0 …….. OK

Hence select section for the gantry Girder as ISWB 500 and ISLC 350 over it.



(a) Elevation



(b) Plan

SP ECIFICAT ION OF BO LTED JOI NTS

1. D iameter of t he bolts

In general, a connection with few larger diameter bolts are economical than a connection with smaller diameter bolts. This is basically because as the number of bolts increases, the work associated with drilling of holes and installations of bolts will also increases. Larger diameter bolts are particularly advantages in the case of connections where bolt shear governs the design because the shear strength of bolts varies as the square of bolt diameter.

2. Pitch

Spacing of bolt holes in ajoint is defined by three parameters namely; pitch, edge distance an end distance. Pitch is the distance between the centers of two consecutive bolts measured along a row of bolts. When the bolts are placed staggered, then the pitch is known as staggered pitch.

2.1. Minimum pitch

This is to prevent the bearing failure of the plate between the two bolts, to permit the efficiency in installation of bolts by providing sufficient space for tightening of bolts, to prevent overlapping of washers and to provide adequate resistance to tear out of bolts.

Minimum Spacing is specified by IS 800:2007 in cl. 10.2.2. The distance between centre of fasteners shall not be less than 2.5 times the nominal diameter of the fastener.

2.2. Maximum Spacing

This is to ensure a compact joint reducing the length of connection and to ensure uniform stress in bolts

Cl. 10.2.3.1 gives the maximum distance between the centres of any two adjacent fasteners which shall not exceed 32t or 300 mm, whichever is less, where t is the thickness of thinner connected plate. Cl.10.2.3.2 gives the distance between the centres of two adjacent fasteners (pitch) in a line lying in the direction of stress, which shall not exceed 16t or 200 mm, whichever is less, in tension members and 12t or 200 mm, whichever is less, in compression members; where t is the thickness of the thinner plate. In the case of compression members wherein forces are transferred through butting faces, this distance shall not exceed 4.5 times the diameter of the fasteners for a distance equal to 1.5 times the width of the member from the butting faces.

Cl. 10.2.3.3 specifies the distance between the centres of any two consecutive fasteners in a line adjacent and parallel to an edge of an outside plate shall not exceed 100 mm plus 4t or 200 mm, whichever is less, in compression and tension members; where t is the thickness of the thinner outside plate. Cl. 10.2.3.4 deals with the staggered fasteners. When fasteners are staggered at equal intervals and the gauge does not exceed 75 mm, the spacing specified in 10.2.3.2 and 10.2.3.3 between centres of fasteners may be increased by 50 percent, subject to the maximum spacing specified in 10.2.3.1.

2.3. Edge and End Distances

Cl. 10.2.4.1 specifies the way to compute the edge distances in various cases. The edge distance is the distance at right angles to the direction of stress from the centre of a hole to the adjacent edge. The end distance is the distance in the direction of stress from the centre of a hole to the end of the element. In slotted holes, the edge and end distances should be measured from the edge or end of the material to the centre of its end radius or the centre line of the slot, whichever is smaller. In oversize holes, the edge and end distances should be taken as the distance from the relevant edge/end plus half the diameter of the standard clearance hole corresponding to the fastener, less the nominal diameter of the oversize hole.

Cl. 10.2.4.2 gives the minimum edge distance. The minimum edge and end distances from the centre of any hole to the nearest edge of a plate shall not be less than 1.7 times the hole diameter in case of sheared or hand-flame cut edges; and 1.5 times the hole diameter in case of rolled, machineflame cut, sawn and planed edges.

Cl. 10.2.4.3 specifies the permissible maximum edge distance. The maximum edge distance to the nearest line of fasteners from an edge of any un-stiffened part should not exceed $12t\varepsilon$, where $\varepsilon = \sqrt{(250/f_y)}$ and t is the thickness of the thinner outer plate. This would not apply to fasteners interconnecting the components of back to back tension members. Where the members are exposed to corrosive influences, the maximum edge distance shall not exceed 40 mm plus 4t, where t is the thickness of thinner connected plate.

2.4. Tacking Fasteners

In case of members covered under 10.2.4.3, when the maximum distance between centres of two adjacent fasteners as specified in 10.2.4.3 is exceeded, tacking fasteners not subjected to calculated stress shall be used. Tacking fasteners shall have spacing in a line not exceeding 32 times the thickness of the thinner outside plate or 300 mm, whichever is less. Where the plates are exposed to the weather, the spacing in line shall not exceed 16 times the thickness of the thinner outside plate or 200 mm, whichever is less. In both cases, the distance between the lines of fasteners shall not be greater than the respective pitches. All the requirements specified in 10.2.5.2 shall generally apply to compression members, subject to the stipulations in Section 7 affecting the design and construction of compression members. In tension members (see Section 6) composed of two flats, angles, channels or tees in contact back to back or separated back to back by a distance not exceeding the aggregate thickness of the connected parts, tacking fasteners with solid distance pieces shall be provided at a spacing in line not exceeding 1000 mm. For compression members covered in Section 7, tacking fasteners in a line shall be spaced at a distance not exceeding 600 mm. These specifications are outlined in Cl. 10.2.5 of IS 800: 2007.

2.5. Combination of fasteners

When different fasteners are used to carry shear loads or when welding and other types of fasteners are c bined together, then one form of the fasteners should be designed to take up the total load. Nevertheless, if we use HSFG bolts along with welds and the bolts are tightened after welding is completed, then such bolts can be used to share the load with the welds.

SHEAR CONNECTIONS WITH BEARING TYPE BOLTS

In this section the force transfer mechanisms of bearing and friction type of bolted connections are described.

1. Force transfer of bearing type bolts

It is seen that tension in one plate is equilibrated by the bearing stress between the bolt and the hole in the plate. Since there is a clearance between the bolt and the hole in which it is fitted, the bearing stress is mobilised only after the plates slip relative to one another and start bearing on the bolt .The section x-x in the bolt is critical section for shear. Since it is a lap joint there is only one critical section in shear (single shear) in the bolt .In the case of butt splices there would be two critical sections in the bolt in shear (double shear), corresponding to the two cover plates.

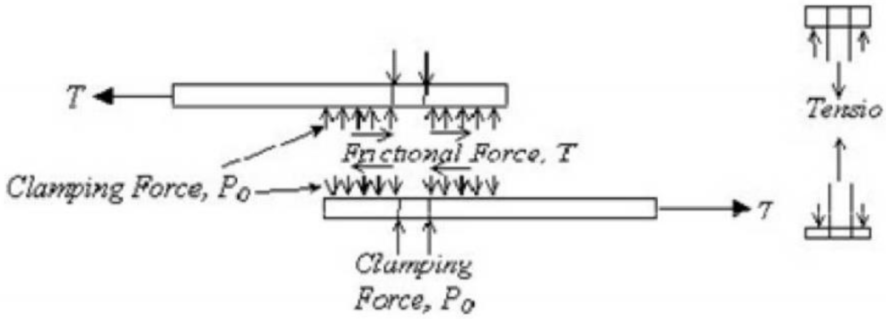
2. Design shear strength of bearing type bolts

The failure of connections with bearing bolts in shear involves either bolt failure or the failure of the connected plates. In this section, the failure modes are described along with the codal provisions for design and detailing shear connections. In connections made with bearing type of bolts,

the behaviour is linear until i) yielding takes place at the net section of the plate under combined tension and flexure or ii) shearing takes place at the bolt shear plane or iii) failure of bolt takes place in bearing, iv) failure of plate takes place in bearing and v) block shear failure occurs. Of these, i) and v) will be discussed in the chapter on tension members. The remaining three are described below.

2.1. Shearing of bolts

The shearing of bolts can take place in the threaded portion of the bolt and so the area at the root of the threads, also called the tensile stress area A_t, is taken as the shear area A_s. Since threads can occur in the shear plane, the area A_e for resisting shear should normally be taken as the net tensile stress area, A_n, of the bolts. The shear area is specified in the code and is usually about 0.8 times the shank area. However, if it is ensured that the threads will not lie in the shear plane then the full area can be taken as the shear area. A bolt subjected to a factored shear force (V_{sb}) shall satisfy $V_{sb} \leq V_{db}$ as per cl. 10.3.2 of IS 800:2007, where $V_{db} = V_{dsb} = V_{nsb}/\gamma_{mb}$ as given by cl. 10.3.3 of the code.



Here V_{nsb} = nominal shear capacity of a bolt, calculated by $V_{nsb} = \frac{f_u}{\sqrt{3}}(n_n A_{nb} + n_s A_{sb})$ in which f_u = ultimate tensile strength of a bolt; n_n = number of shear planes with threads intercepting the shear plane; n, = number of shear planes without threads intercepting the shear plane; A_{sb} = nominal plain shank area of the bolt; and A_{nb} = net shear area of the bolt at threads, may be taken as the area

corresponding to root diameter at the thread as given in Table 5 and γ_{mb} = 1.25. For bolts in single shear, either n_n or n_s is one and the other is zero. For bolts in double shear the sum of n_n and n_s is two.

Table 5 Tensile area of ordinary bolts (Grade 4.6)

Bolt size, d (mm)	12	16	20	22	24	27	30	36
Tensile stress area (mm^2)	84.3	157	245	303	353	459	561	817

2.2. Bearing failure

If the connected plates are made of high strength steel then failure of bolt can take place by bearing of the plates on the bolts. If the plate material is weaker than the bolt material, then failure will occur by bearing of the bolt on the plate and the hole will elongate. The beating area is given by the nominal diameter of the bolt times the combined thickness of the plates bearing in any direction. – A bolt bearing on any plate subjected to a factored shear force (V_{sb}) shall satisfy $V_{sb} \leq V_{db}$ as per cl. 10.3.2 of IS 800:2007, where $V_{db} = V_{dpb} = V_{npb}/\gamma_{mb}$ as given by cl. 10.3.4 of the code where, γ_{mb} = 1.25 and V_{npb} = bearing strength of a bolt, calculated as $V_{npb} = 2.5 k_b d t f_u$ where f_u = smaller of the ultimate tensile stress of the bolt and the ultimate tensile stress of the plate, d = nominal diameter of the bolt, t = summation of the thicknesses of the connected plates experiencing bearing stress in the same direction and k_b is smaller of $e/3d_0$, $p/3d_0$-0.25, f_{ub}/f_u, 1.0 where e, p = end and pitch distances of the fastener along bearing direction; d_0 = diameter of the hole; f_{ub}, f_u = Ultimate tensile stress of the bolt and the ultimate tensile stress of the plate, respectively.

The underlying assumption behind the design of bolted connections, namely that all bolts carry equal load is not true in some cases. In long joints, the bolts farther away from the centre of the joint will carry more load than the bolts located close to the centre. Therefore, for joints having more than two bolts on either side of the building connection with the distance between the first and the last bolt exceeding 15d in the direction of load, the nominal shear capacity Vns, shall be reduced by the factor, βlj, given by (Cl.10.3.2.1) $\beta_{lj} = 1.075 - l_j / (200\ d)$ but $0.75 < \beta_{lj} < 1.0$ where, d= nominal diameter of the bolt Similarly, if the grip length exceeds five times the nominal diameter, the strength is reduced as specified in IS 800. In multi-bolt connections, due to hole mismatch, all the bolts may not carry the same load. However, under ultimate load, due to high bearing ductility of the plates considerable redistribution of the load is possible and so the assumption that all bolts carry equal load may be considered valid.

SHEAR CONNECTIONS WITH HSFG BOLTS

1. Force transfer of HSFG bolts

The free body diagram of an HSFG connection is shown in Figure 14. It can be seen that the pretension in the bolt causes clamping forces between the plates even before the external load is applied. When the external load is applied, the tendency of two plates to slip against one another is resisted by the friction between the plates. The frictional resistance is equal to the coefficient of friction multiplied by the normal clamping force between the plates. Until the externally applied force exceeds this frictional resistance the relative slip between the plates is prevented. The HSFG connections are designed such that under service load the force does not exceed the frictional resistance so that the relative slip is avoided during service. When the external force exceeds the frictional resistance the plates slip until the bolts come into contact with the plate and start bearing against the hole. Beyond this point the external force is resisted by the combined action of the frictional resistance and the bearing resistance.

2. Design shear strength of HSFG bolts

HSFG bolts will come into bearing only after slip takes place. Therefore if slip is critical (i.e. if slip cannot be allowed) then one has to calculate the slip resistance, which will govern the design. However, if slip is not critical, and limit state method is used then bearing failure can occur at the Limit State of collapse and needs to be checked. Even in the Limit State method, since HSFG bolts are designed to withstand working loads without slipping, the slip resistance needs to be checked anyway as a Serviceability Limit State.

2.1. Slip Resistance

Design for friction type bolting in which slip is required to be limited, a bolt subjected only to a factored design shear force, V_{sf}, in the interface of connections shall satisfy the following (Cl.10.4.3): $V_{sf} \leq V_{dsf}$ where $V_{dsf} = V_{nsf} / \gamma_{mf}$ in which $\gamma_{mf} = 1.10$ if slip resistance is designed at service load and 1.25 if slip resistance is designed at ultimate load. V_{nsf} = nominal shear capacity of a bolt as governed by slip for friction type connection, calculated as follows: $V_{nsf} = \mu_f\, n_e\, K_h\, F_o$. where, μ_f = coefficient of friction (slip factor) as specified in Table 20 of the code ($\mu_f < 0.55$), n_e =number of effective interfaces offering frictional resistance to slip, K_h = 1.0 for fasteners in clearance holes = 0.85 for fasteners in oversized and short slotted holes, and for fasteners in long slotted holes loaded perpendicular to the slot and 0.7 for fasteners in long slotted holes loaded parallel to the slot, F_o= minimum bolt tension (proof load) at installation and may be taken as 0.8 A_{sb} f_o where A_{sb}= shank area of the bolt in tension and f_o= proof stress (= 0.70 f_{ub}).

V_{ns} may be evaluated at a service load or ultimate load using appropriate partial safety factors, depending upon whether slip resistance is required at service load or ultimate load.

2.2. Bearing strength

The design for friction type bolting, in which bearing stress in the ultimate limit state is required to be limited, (V_{ub} = factored load bearing force) shall satisfy $V_{bf} < V_{nbf} / \gamma_{mf}$ (Cl.10.4.4 of the code), where γ_{mf}= 1.25, V_{nbf} = bearing capacity of a bolt, for friction type connection, given by V_{nbf} = $2.2dtf_{up} \leq 3dtf_{yp}$ where f_{up}= ultimate tensile stress of the plate, f_{yp} = tensile yield stress of the plate, d = nominal diameter of the bolt t = summation of thicknesses of all the connected plates experiencing bearing stress in the same direction. The block shear resistance of the edge distance due to bearing force shall also be checked.

We will discuss Welded connections at a later stage of the lectures

Lecture 02

REFERENCE:

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