CHAPTER 3

CODAL PROVISIONS

3.1 GENERAL

The aim of structural design is to ensure that a structure fulfills its intended purpose during its lifetime with adequate safety and serviceability performance. Increase in utilization of cold-formed steel members has been largely due to the sustained research. Considerable improvement in the knowledge gained through research in the intervening time has led to better design guidelines as reflected in literature and many recent international codes of practice. Comparison of the provisions of the British, American, Australian and New Zealand standards is carried out along with experimental results.

Allowable Stress Design (ASD) or the Limit state approach usually referred as Load and Resistance Factor Design (LRFD) are the basis for the determination of load carrying capacities of cold-formed steel members.

Most of the specifications AISI, AS/NZS, and BS have switched over from ASD to LRFD. AISI standard allows the use of both the ASD and LRFD, whereas IS follows the Allowable Stress Design approach.

3.1.1 Allowable Stress Design

Allowable stress design also known as the elastic design, is based on the elastic limit of the material. The elastic limit is nothing but the
maximum stress, which a material can withstand without being permanently deformed. The allowable stress is obtained by dividing either the yield stress or the ultimate tensile strength by a factor of safety. The factor of safety is the ratio of yield point of the material to its working stress. In ASD it is ensured that “the stresses in a structure under working or service loads do not exceed designated allowable values”.

The general format of the Allowable Stress Design is

\[ \frac{R_n}{FS} \geq \sum_{i=1}^{m} Q_{n,i} \]  \hspace{1cm} (3.1)

where

- \( R_n = \) Nominal resistance of the structural member
- \( Q_n = \) Nominal working or service stresses computed under working loads
- \( FS = \) Factor of safety
- \( i = \) type of load
- \( m = \) number of load types

The term \( R_n/FS \) represents the allowable stress of the structural member or component under a given loading condition. The term \( Q_n \) represents the combined stresses produced by various load conditions. In this method the factor of safety is applied only to the resistance term and safety is evaluated in the load term. Therefore, allowable stress design is characterized by the use of unfactored ‘working loads’ in conjunction with a single factor of safety applied to the resistance. Because of the greater variability and unpredictability of the live load and other loads in comparison with the dead load, a uniform reliability is not possible with Allowable Stress Design.
3.1.2 Limit State Design

Limit state means “those condition of a structure at which it ceases to fulfill its intended function”. It is divided into two category as strength and serviceability.

- The strength Limit State deals with behavioural phenomenon such as achieving ductile maximum strength, buckling, fatigue and fracture, overturning and sliding.
- The serviceability Limit State are those concerned with occupancy of the building such as deflection, vibration, permanent deformation and cracking.

The ultimate limit state is checked for strength consideration and the serviceability limit state is checked for actual service condition. The load acting and the resistance of the structure to load are variables that are considered in the Limit State Design.

For a safe structure it is required that

\[ Q < R \]  \hspace{1cm} (3.2)

where \( Q \) = load and \( R \) = resistance

The general format for Limit State Design is

\[ \varphi R_n \geq \sum_{i=1}^{m} \gamma_i Q_{n_i} \]  \hspace{1cm} (3.3)

where \( R_n \) = nominal strength
\( \varphi \) = resistance factor
\( \gamma_i \) = load factors
\( Q_{n_i} \) = load effects.
The term $\varphi R_n$ represents the resistance or strength of the component. The term $\gamma_i Q_{ni}$ represents the load expected. Normally $\gamma$ is larger than unity and $\varphi$ is less than unity.

### 3.1.3 Importance of Limit State Design

Ductile structural materials such as steel can withstand strains much larger than those encountered with in the elastic limit. Design methods, which are based on elastic limit, fail to take advantage of the ability of such material to carry stresses above the yield stresses (strain hardening). The ductile material will cause redistribution of stresses beyond the elastic limit. These redistribution of stresses carry often additional loads. From this view point elastic analysis is unduly conservative. The limit state design method offers alternative to the objections in the elastic design. It takes full advantage of ductility and the method is mathematically simple.

### 3.2 EFFECT OF COLD FORMING

The cold-formed steel members are produced either by press breaking or cold rolling. These production processes cause strain hardening in the cold-formed corners of the cross section. The strain hardening cause increase in the yield strength of the material in the corner for stresses in the longitudinal direction. All codes impose a limit on the maximum values of strain hardening and maximum radius to thickness ratio as well as the minimum bend angle.

To account for the effect of strain hardening due to cold working of the members the codes allow increase in the average yield stress ($F_{ya}$) of the member to be used in the design instead of $F_y$ as given in the following.

The design yield stress, $F_{ya}$, of the steel can be determined on the basis of one of the following methods.

- Full section tensile tests
- Stub column tests
- Computed as follows

$$F_{ya} = CF_{yc} + (1-C) F_{yf} \quad (3.4)$$

where

- $F_{yc}$ = weighted average of yield stress of corners is given by
  - when $F_{uv}/F_{yv} \geq 1.2$, $R/t \leq 7$ and minimum included angle $\leq 120^\circ$,
  - $F_{yc} = B_c F_{yv} / (R/t)^m$, tensile yield point of corners.

- $C$ = ratio of the total corner area to the total cross-sectional area of the full section.

- $B_c = 3.69 (F_{uv}/F_{yv}) - 0.819 (F_{uv}/F_{yv})^2 - 1.79$

- $m = 0.192 (F_{uv}/F_{yv}) - 0.068$

- $R$ = Inside bend radius

- $F_{yv}$ = tensile yield point of virgin steel

- $F_{uv}$ = ultimate tensile strength of virgin steel

- $F_{yf}$ = weighted average of yield stress of flat portions.

3.2.2 BS:5950 (Part 5)-1998

The increase in yield strength due to cold forming is obtained by replacing the material yield strength $Y_s$, by the average yield strength of the cold formed section $Y_{sa}$. The average yield strength $Y_{sa}$ may be calculated as
\[ Y_{sa} = Y_s + 5Nt^2 \frac{(U_s-Y_s)}{A} \] (3.5)

where 
- \( N \) = number of full 90° bends in the section with an internal radius \( \leq 5t \)
- \( t \) = net section thickness of the material
- \( U_s \) = minimum ultimate tensile strength
- \( A \) = gross area of the cross-section

The value of \( Y_{sa} \) used in calculations should not exceed 1.25 \( Y_s \) or \( U_s \). The full effect of cold forming on the yield strength may be used for calculating the tensile strength of the elements.

The increase in yield strength due to cold working is not allowed for members which undergo welding, annealing, galvanizing or any other heat treatment after forming which may produce softening.

**Summary**

- Considering the effect of cold forming the codes IS 801 - 1975, AISI, AS/NZS present similar expressions which are of the same format as derived by Karren (1967).
- BS:5950 provides a different expression which accounts for the number of bends and limits the increase in the strength to 1.25 times of the virgin yield strength.

### 3.3 LOAD CARRYING CAPACITY

The existing Indian Standard code of practice for cold-formed steel IS 801-1975 does not elaborately deal with the design of tension members.
The following codal provisions are used to predict member capacities of the single and double angle members of American Iron and Steel Institute, the Australian / New Zealand Standards, and British Standards.

3.3.1 **AISI Manual -2001**

The nominal tensile strength $P_n$ of the member,

$$P_n = A_e F_u$$  \hspace{1cm} (3.6)\)

where $A_e = UA_n$ and $U = 1.0 - 1.20 \frac{x}{L} < 0.9$ but shall not be less than 0.4

$A_e = $ effective net area of the section

$A_n = $ net area of the connected part.

$x = $ distance from shear plane to centroid of the cross section.

$L = $ length of the end connection i.e. distance between the outermost bolts in the joint along the length direction.

3.3.2 **AS/NZS 4600-2005**

The nominal section capacity of a member in tension shall be taken as the lesser of

$$N_t = 0.85 K_t A_n f_u$$  \hspace{1cm} (3.8)\)

where $A_g = $ gross cross sectional area of the member

$f_y = $ yield stress of the material

$K_t = $ correction factor for distribution of forces.

for eccentrically connected single angles and double angles connected to opposite side of the gusset plate, the value of $K_t = 0.85$
for double angles connected to the same side of the gusset plate the value of $K_t = 1.0$

$A_n =$ net area of the cross-section, obtained by deducting from the gross area of the cross-section, the sectional area of all penetrations and holes, including fastener holes.

$f_u =$ tensile strength used in the design.

### 3.3.3 BS:5950 (Part 5)-1998

The tensile capacity $P_t$, of a member

$$P_t = A_e \times p_y$$  \hspace{1cm} (3.9)

#### 3.3.3.1 Single angles

For single angles connected through one leg only, the effective area $A_e$ is computed as

$$A_e = a_1(3a_1+4a_2)/(3a_1+a_2)$$  \hspace{1cm} (3.10)

#### 3.3.3.2 Double angles

For double angles connected to opposite side of gusset plate, the effective area is determined as

$$A_e = a_1(5a_1+6a_2)/(5a_1+a_2)$$  \hspace{1cm} (3.11)

For double angles connected to the same side of gusset plate the effective area can be determined as that of single angles.
\[ A_e = \text{effective area of the section} \]
\[ a_1 = \text{the net sectional area of the connected leg} \]
\[ a_2 = \text{the gross sectional area of the unconnected leg} \]
\[ p_y = \text{the design strength}. \]

### 3.4 EDGE STIFFENER

In order to improve the strength of a wide unstiffened elements, stiffeners in the form of a simple edge plate element and secondary or intermediate stiffener between the main longitudinal stiffeners or webs are used, when the width to thickness ratio is large.

#### 3.4.1 IS 801-1975

In order that a flat element is to be considered as a stiffened element, IS recommends that the element should be stiffened along each longitudinal edge parallel to the direction of stress by a web, lip or other stiffening means and should have the following minimum moment of inertia \((I_{\text{min}})\)

\[
I_{\text{min}} = 1.84t^4 \sqrt{(w/t)^2 - 281200/F_y} \quad (3.12)
\]

but not less than \(9.2t^4\). The required overall depth \(d_{\text{min}}\) of edge stiffener is determined as follows.

\[
d_{\text{min}} = 2.8t^6 \sqrt{(w/t)^2 - 281200/F_y} \quad (3.13)
\]

but not less than \(4.8t\). A simple lip is not recommended to be used as an edge stiffener for any element having a flat width to thickness ratio greater than 60.
where \( I_{\text{min}} \) = minimum allowable moment of inertia of stiffener (of any shape) about its own centroidal axis parallel to the stiffened element

\( w/t \) = flat-width ratio of stiffened element.

3.5 BOLTED CONNECTION

Connection forms an important part in any structure and are designed more conservatively than members. The connections are required to transmit various type of loading and must be designed to carry these loads without failing.

3.5.1 Failure Modes of Bolted Connections

There are four type of failure mechanism that arises in bolted connections and is shown in Figure 3.1. They are

a. Longitudinal shearing of the sheets by the bolt (Figure 3.1(a)).

b. Bearing failure with materials shearing and piling up in front of the bolt (Figure 3.1(b)).

c. Transverse tension tearing of the sheet (Figure 3.1(c)).

d. Shearing of Bolts taking place in threaded portion of the bolt (Figure 3.1(d)).
3.5.1.1 Longitudinal shearing of the steel sheets

When the edge distance ‘e’ is relatively small, connections usually fail in longitudinal shearing of the sheet along two parallel lines.

3.5.1.2 Bearing or piling up of steel sheet

When the edge distance ‘e’ is sufficiently large the connection may fail by bearing or piling up of steel sheet in front of the bolt. The bearing strength of bolted connections depends on several parameters, including the tensile strength of the connected part, the thickness of the connected part, the type of joint, the $f_u/f_y$ ratio of the connected part, the use of washers and the rotation of fasteners.

3.5.1.3 Tearing of sheet at net section

In bolted connections the type of failure by tearing of sheets at the net section is related to stress concentrations caused by the presence of bolts and the concentrated localized force transmitted by the bolt to the sheets.
3.5.1.4 Shearing of bolt

When the bolt area provided is insufficient to carry the applied load shearing of the bolt occur. This type of failure is sudden and hence it should be avoided in all connections.

3.5.2 Design criteria for bolted connections

In the determination of the allowable load the following points should be considered.

a) Minimum spacing and edge distance in line of stress
b) Tensile capacity of steel sheets
c) Bearing capacity between bolts and steel sheets
d) Shear capacity of bolts.

3.5.2.1 IS 801-1975

Minimum spacing and edge distance in line of stress

The clear distance between bolts which are arranged in rows parallel to the directions of force, also the distance from center of any bolt to that end or other boundary of the connecting member towards which the pressure of the bolt is directed shall not be less than 1.5d nor less than

\[ \frac{P}{(0.6F_yt)}. \]  

(3.14)

where \( d \) = diameter of bolt
\( P \) = force transmitted to bolt
\( t \) = thickness of thinnest connected sheet
F\textsubscript{y} = yield point

**Tension stress on net section**

The tension stress on the net section of a bolted connection shall not exceed 0.6 \( F_y \) nor shall it exceed

\[
(1.0 - 0.9r + 3 \text{ rd/s}) 0.6F_y
\]

(3.15)

where \( r \) = the force transmitted by the bolt or bolts at the section considered divided by the tension force in the member at that section. If \( r \) is less than 0.2, it may be taken as equal to zero.

\( s \) = spacing of bolts perpendicular to line of stress. In the case of single bolt \( s \) is equal to the width of sheet

\( d \) = diameter of bolt

\( F_y \) = yield point

**Bearing stress in bolted connections**

The bearing stress on the area (\( d \) x \( t \)) shall not exceed 2.1\( F_y \).

**Shear stress on bolts**

Shear stress on the gross cross-sectional area of bolt under dead and live load, shall not exceed the following values.

- Precision and semi precision bolts : 970 kgf / cm\(^2\)
- Black bolts : 820 kgf / cm\(^2\)
- Steel conforming to property : 1060 kgf / cm\(^2\)
3.5.2.2  AISI Manual -2001

Shear, spacing and edge Distance

The nominal shear strength $P_n$ of the connected part as affected by spacing and edge distance in the direction of applied force shall be calculated as

a) when $F_u/F_{sy} \geq 1.08$

$$P_n = 0.70teF_u$$  \hspace{1cm} (3.16)

b) when $F_u/F_{sy} < 1.08$

$$P_n = 0.60teF_u$$  \hspace{1cm} (3.17)

where $e$ = distance measured in line of force from center of a standard hole to nearest edge of adjacent hole or to end of connected part.

t = thickness of thinnest connected part

$F_u$ = tensile strength of connected part

$F_{sy}$ = yield point of connected part.

In addition, to the above requirements the AISI specification also includes the following requirements concerning minimum spacing and edge distance in the line of stress.

a) The minimum distance between centres of bolt holes should not be less than 3 times the bolt diameter.

b) The distance from the centre of any standard hole to the end or other boundary of the connecting member should not be less than 1.5 times the diameter of the bolt.
c) The clear distance between edges of two adjacent holes should not be less than 2 times the diameter of the bolt.

d) The distance between the edge of the hole and the end of the member should not be less than diameter of the bolt.

**Fracture in net section (Shear Lag)**

The nominal tensile strength $P_n$ shall be determined as

1) For flat sheet connections not having staggered hole patterns

$$P_n = A_n F_t$$  \hspace{1cm} (3.18)

a) When washers are provided under both the bolt head and the nut

For single bolt, or a single row of bolts perpendicular to the force

$$F_t = (0.1 + 3d/s) 0.55F_u \leq 0.55F_u$$  \hspace{1cm} (3.19)

For multiple bolts in the line parallel to the force

$$F_t = 0.65F_u$$  \hspace{1cm} (3.20)

b) When either washers are not provided under the bolt head and the nut

For a single bolt, or a single row of bolts perpendicular to the force

$$F_t = (2.5d/s)0.65F_u \leq 0.65F_u$$  \hspace{1cm} (3.21)

For multiple bolts in the line parallel to the force

$$F_t = 0.65F_u$$  \hspace{1cm} (3.22)
where \( A_n \) = net area of connected part
\( s \) = sheet width divided by number of bolt holes in cross section
\( F_u \) = tensile strength of connected part

2) For flat sheet connections having staggered hole patterns
\[ P_n = 0.65 \, A_n F_t \] (3.23)

Bearing

The design bearing strength of bolted connections shall be determined as follows.

Case (i) Strength without consideration of bolt hole deformation

The nominal bearing strength \( P_n \),
\[ P_n = 0.60m_1CdtF_u \] (3.24)

where \( C \) = Bearing factor as in Table 3.1
\( d \) = Nominal bolt diameter
\( t \) = uncoated sheet thickness
\( F_u \) = tensile strength of sheet
\[ m_f = \text{modification factor for type of bearing connection as in Table 3.2} \]

**Table 3.1 Bearing factor, C**

<table>
<thead>
<tr>
<th>Thickness of connected part t in mm</th>
<th>Ratio of fastener diameter to member thickness d/t</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.024 ≤ t &lt; 0.1875 (0.61 ≤ t &lt; 4.76)</td>
<td>d/t &lt; 10</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>10 &lt; d/t ≤ 22</td>
<td>4 - 0.1 (d/t)</td>
</tr>
<tr>
<td></td>
<td>d/t &gt; 22</td>
<td>1.8</td>
</tr>
</tbody>
</table>

**Table 3.2 Modification factor \( m_f \) for type of bearing connection**

<table>
<thead>
<tr>
<th>Type of Bearing connection</th>
<th>( m_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single shear and outside sheets of double shear connection with washers under both bolt head and nut</td>
<td>1.00</td>
</tr>
<tr>
<td>Single shear and outside sheets of double shear connection without washers under both bolt head and nut, or with only one washer</td>
<td>0.75</td>
</tr>
<tr>
<td>Inside sheet of double shear connection with or without washers</td>
<td>1.33</td>
</tr>
</tbody>
</table>

Case (ii) Strength with consideration of bolt hole deformation

The nominal bearing strength \( P_n \),

\[
P_n = 0.65(4.64\alpha t + 1.53)dt F_u
\]

(3.25)

where \( \alpha = \) coefficient for conversion of units, for SI units \( \alpha = 0.0394. \)
Shear and tension in bolts

The nominal bolt strength $P_n$ resulting from shear, tension or a combination of shear and tension shall be calculated as

$$P_n = A_b F_n$$  \hspace{1cm} \text{(3.26)}

where $A_b =$ Gross cross-sectional area of bolt

$F_n =$ Nominal tensile stress as shown in Table 3.3

Table 3.3 Nominal tensile stress $F_n$ (MPa) for bolts subjected to the combination of shear and tension

<table>
<thead>
<tr>
<th>Description of bolts</th>
<th>Threads not excluded from shear planes</th>
<th>Threads excluded from shear planes</th>
<th>Resistance factor $\varphi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A325 bolts</td>
<td>779 – 2.4$f_v$ ≤ 621, $f_v = 621$</td>
<td>779 – 1.9$f_v$ ≤ 621, $f_v = 621$</td>
<td></td>
</tr>
<tr>
<td>A354 Grade BD bolts</td>
<td>876 – 2.4$f_v$ ≤ 696, $f_v = 696$</td>
<td>876 – 1.9$f_v$ ≤ 696, $f_v = 696$</td>
<td>0.75</td>
</tr>
<tr>
<td>A449 bolts</td>
<td>696 – 2.4$f_v$ ≤ 558, $f_v = 558$</td>
<td>696 – 1.9$f_v$ ≤ 558, $f_v = 558$</td>
<td></td>
</tr>
<tr>
<td>A490 bolts</td>
<td>972 – 2.4$f_v$ ≤ 776, $f_v = 776$</td>
<td>972 – 1.9$f_v$ ≤ 776, $f_v = 776$</td>
<td></td>
</tr>
<tr>
<td>A307 bolts, Grade A</td>
<td>324 – 2.4$f_v$ ≤ 279, $f_v = 279$</td>
<td>359 – 2.4$f_v$ ≤ 310, $f_v = 310$</td>
<td>0.75</td>
</tr>
</tbody>
</table>
### 3.5.2.3 AS/NZS-2005

**Tear out**

A connected part shall have a spacing between bolts and an edge distance from a bolt such that the design shear force $V_f^*$ satisfies

$$V_f^* \leq \phi V_f \quad (3.27)$$

where $\phi =$ capacity reduction factor of bolted connection subject to tear out $= 0.6$ for $f_u/f_y < 1.08$ and $0.70$ for $f_u/f_y \geq 1.08$

$V_f =$ nominal shear capacity of the connected part along two parallel lines in the direction of the applied force $= t e f_u$

$t =$ thickness of the connected part

ee = distance measured in the line of force from the centre of a standard hole to the nearest edge of an adjacent hole or to the end of the connected part.

In addition, to the above requirements the AS/NZS specification also includes the following requirements concerning minimum spacing and edge distance in the line of stress similar to that of AISI.

**Net section tension**

The design tensile force $N_f^*$ on the net section of the connected part shall satisfy

$$N_f^* \leq \phi N_f \quad (3.28)$$
where \( \phi \) = capacity reduction factor of bolted connection subject to net section

\( N_f = \) nominal tensile capacity of the net section of the connected part

The design tensile capacity \( \phi N_f \) of the connected part shall be determined as follows

a) where washers are provided under both the bolt head and the nut

\[
\phi = 0.65 \text{ for double shear connection} \\
\phi = 0.55 \text{ for single shear connection}
\]

for a single bolt, or a single row of bolts perpendicular to the force

\[
N_f = [0.1 + (3d_f / s_f)]A_{nf_u} \leq A_{nf_u} \tag{3.29}
\]

for multiple bolts in the line parallel to the force

\[
N_f = A_{nf_u} \tag{3.30}
\]

b) where either washers are not provided under the bolt head and nut or only one washer is provided under either the bolt head or nut

\[
\phi = 0.65
\]

for a single bolt, or a single row of bolts perpendicular to the force

\[
N_f = (2.5d_f / s_f)A_{nf_u} \leq A_{nf_u} \tag{3.31}
\]

For multiple bolts in the line parallel to the force

\[
N_f = A_{nf_u} \tag{3.32}
\]
where

\[ s_f = \text{spacing of bolts perpendicular to the line of force or width of sheet in case of a single bolt} \]
\[ A_n = \text{net area of the connected part} \]

**Bearing**

The design bearing capacity \( \varphi V_b \) shall be determined as follows

Case(i) Bearing capacity without considering bolt hole deformation

The nominal bearing capacity \( V_b \) is calculated as

\[ V_b = \alpha C d_f t f_u \]

(3.33)

where

\( \varphi = 0.60 \)

\( \alpha = \text{modification factor for type of bearing connection as in Table 3.2} \)

\( C = \text{bearing factor as in table 3.4} \)

\( d_f = \text{nominal bolt diameter} \)

\( t = \text{base metal thickness} \)

\( f_u = \text{tensile strength of sheet} \)

**Table 3.4 Bearing factor, C**

<table>
<thead>
<tr>
<th>Thickness of connected part t in mm</th>
<th>Ratio of fastener diameter to member thickness d/t</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.42 ( \leq ) t &lt; 4.7)</td>
<td>( d_f/t &lt; 10 )</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>10 &lt; ( d_f/t \leq 22 )</td>
<td>4-0.1 (( d_f/t ))</td>
</tr>
<tr>
<td></td>
<td>( d_f/t &gt; 22 )</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Case (ii) Bearing capacity at a bolt hole deformation of 6mm

The nominal bearing capacity $V_b$ is calculated as

$$V_b = (4.64\alpha t + 1.53)\phi dtF_u$$

where $\phi = 0.65$  \hspace{1cm} (3.34)

### Shear and tension in bolts

The design shear force $V_{fv}^*$ on a bolt shall satisfy

$$V_{fv}^* \leq \phi V_{fv}$$  \hspace{1cm} (3.35)

where $\phi =$ capacity reduction factor of a bolt subject to shear = 0.80

$V_{fv} =$ nominal shear capacity of a bolt

$$= 0.62f_{uf}(n_nA_c + n_xA_o)$$  \hspace{1cm} (3.36)

$f_{uf} =$ minimum tensile strength of a bolt

$= 400\text{MPa for Grade 4.6 bolt and 830 MPa for Grade 8.8 bolt}$

$n_n =$ number of shear planes with threads intercepting the shear plane

$A_c =$ minor diameter area of a bolt

$n_x =$ number of shear planes without threads intercepting the shear plane

$A_o =$ plain shank area of bolt

The design tensile force $N_{ft}^*$ on a bolt shall satisfy

$$N_{ft}^* \leq \phi N_{ft}$$  \hspace{1cm} (3.37)

where $\phi =$ capacity reduction factor of a bolt subject to shear = 0.80

$N_{ft} =$ nominal tensile capacity of bolt = $A_s f_{uf}$

$A_s =$ tensile stress area of a bolt

### 3.5.2.4 BS:5950 (Part 5)-1998

The following recommendations are applicable to bolts in nominally 2mm oversize clearance holes.
Bolt pitch and edge distance

Minimum pitch

- For material less than or equal to 4mm thick, the distance between the centres of adjacent bolts in the line of stress should not be less than 3d where d is the diameter of the bolt.
- For material greater than 4mm thick, the minimum pitch should not be less than 2.5d.

Minimum edge and end distances

The distance between the centre of a bolt and any edge of the connected member should not be less than 1.5d

Tensile stress on net section

The tensile stress on the net area of section in a bolted connection should not exceed either

\[ p_y \text{ or } (0.1 + \frac{3d}{s}) \cdot p_y \]  

(3.38)

where \( p_y \) = design strength in N/mm\(^2\)
\( d \) = diameter of the bolt in mm
\( s \) = distance between centres of bolts normal to the line of force

Bearing capacity

The bearing capacity \( P_{bs} \) for each bolt in the line of force when washers are used under both the bolt head and the nut, should be taken as
for $t \leq 1\text{mm}$

$$P_{bs} = 2.1dtp_y$$  \hspace{1cm} (3.39)

for $1\text{mm} < t \leq 3\text{mm}$

a) for $d_e/d \leq 3$,

$$P_{bs} = \{2.1 + (0.3d_e/d - 0.45) (t-1)\}dtp_y$$  \hspace{1cm} (3.40)

b) for $d_e/d > 3$, $P_{bs} = (1.65 + 0.45t)dtp_y$  \hspace{1cm} (3.41)

for $3\text{mm} < t \leq 8\text{mm}$

a) for $d_e/d \leq 3$,

$$P_{bs} = (1.2 + (0.6d_e/d)dtp_y$$  \hspace{1cm} (3.42)

b) for $d_e/d > 3$, $P_{bs} = 3.0dtp_y$  \hspace{1cm} (3.43)

where:

- $t$ = minimum thickness of the connected material in mm
- $d$ = nominal diameter in mm
- $p_y$ = design strength in N/mm$^2$.
- $d_e$ = distance from the centre of a bolt to the end of the connected element in the direction of the bolt force in mm

**Shear and Tension**

The shear capacity $P_s$ of a bolt should be taken as

$$P_s = p_sA_n$$  \hspace{1cm} (3.44)

where:

- $p_s$ = the shear strength obtained from table 3.5
- $A_n$ = shank area or area at the bottom of threads
Table 3.5 Strength of bolts in clearance holes

<table>
<thead>
<tr>
<th>Bolt property class</th>
<th>Other grades of fasteners</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.6</td>
<td>8.8</td>
</tr>
<tr>
<td>Shear strength $p_s$ N/mm²</td>
<td>160</td>
</tr>
<tr>
<td>Tensile strength $p_t$ N/mm²</td>
<td>195</td>
</tr>
</tbody>
</table>

$Y_f$ is the specified minimum yield strength of the fastener

$U_f$ is the specified minimum tensile strength of the fastener

The tension capacity $P_t$ of a bolt should be obtained from

$$P_t = p_t A_t$$  \hspace{1cm} (3.45)

where

- $p_t = \text{tension strength obtained from table 3.5}$
- $A_t = \text{tensile stress area}$