# Equipment Design: Mechanical Aspects
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## Lecture 15
## Design of Flanges

Welcome to the fifth lecture of week 3 where we will discuss design of flanges. If you remember lecture 2, 3 and 4, there we have discussed details of flanges and design procedure. In this particular lecture we will discuss, we will solve a few examples related to design of flanges. So let us focus on example 1.

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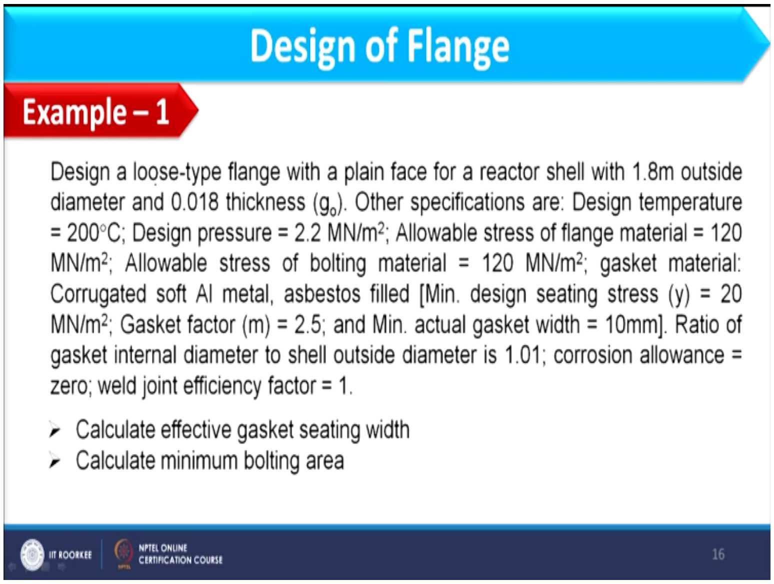

Design of Flange

Example – 1

Design a loose-type flange with a plain face for a reactor shell with 1.8m outside diameter and 0.018 thickness ($g_o$). Other specifications are: Design temperature = 200°C; Design pressure = 2.2 $MN/m^2$; Allowable stress of flange material = 120 $MN/m^2$; Allowable stress of bolting material = 120 $MN/m^2$; gasket material: Corrugated soft Al metal, asbestos filled [Min. design seating stress (y) = 20 $MN/m^2$; Gasket factor (m) = 2.5; and Min. actual gasket width = 10mm]. Ratio of gasket internal diameter to shell outside diameter is 1.01; corrosion allowance = zero; weld joint efficiency factor = 1.

- Calculate effective gasket seating width
- Calculate minimum bolting area

In this example, we need to design a loose-type flange with plain face. So loose-type flange that you must have understood that it is basically lying over the pipe and second point we have is the plain face. So that face we have discussed in lecture 3. And this flange is to be designed for reactor shell with 1.8 meter outside diameter. So D o is given as 1.8 and 0.018 thickness g o. Now what is g o, if you remember g o is basically width of upper section of welded-neck, okay. So if g o is given we should understand that it is the width of lower section of welded-neck.

Other specifications are design temperature is 200, design pressure 2.2 meganewton per meter square. Allowable stresses for flange material and bolting-up material are equal and which is 120 meganewton per meter square. Gasket material is given as corrugated soft aluminum metal asbestos filled where minimum design seating stress is 20 meganewton per meter square. Gasket factor is given as 2.5 and minimum actual gasket width is 10 mm.

Ratio of gasket internal diameter to shell outside diameter is 1.01, corrosion allowance is 0, weld joint deficiency factor is 1. What we need to find is effective gasket seating width, minimum bolting area and which amongst the following bolts will be used for bolting the flange. Here we are given four bolts M 36 x 3, 39 x 3, 42 x 3 and 45 x 3. And g 1 is given as 1.415 g o.

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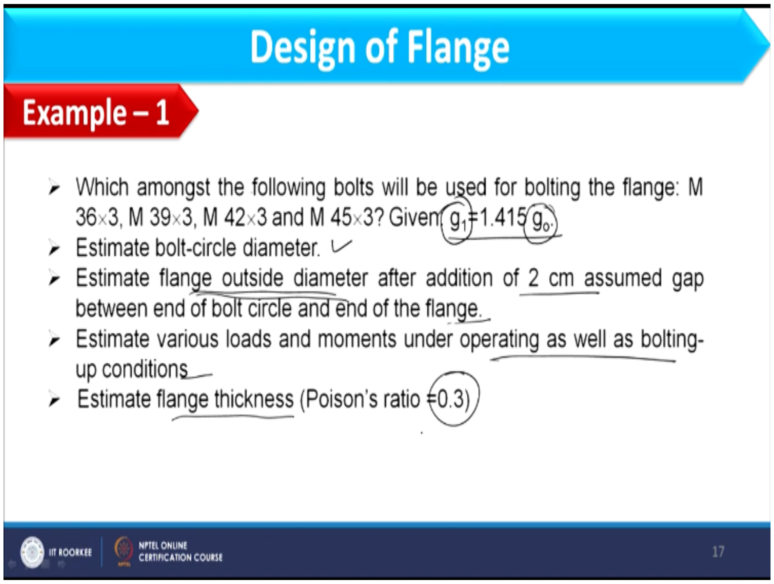

## Design of Flange

### Example – 1

- Which amongst the following bolts will be used for bolting the flange: M 36×3, M 39×3, M 42×3 and M 45×3? Given $g_1$=1.415 $g_o$.
- Estimate bolt-circle diameter.
- Estimate flange outside diameter after addition of 2 cm assumed gap between end of bolt circle and end of the flange.
- Estimate various loads and moments under operating as well as bolting-up conditions
- Estimate flange thickness (Poison's ratio =0.3)

So basically once I know g 1 it means the flange is welded-neck, only if g o value is given it may be welded-neck or it may be tapered neck, but g 1 will decide whether it is welded-neck or not. Next I need to compute is bolt circle diameter, then flange outside diameter after adding 2 cm assumed gap between end of bolt circle and end of flange. Estimate various loads and moments under operating as well as bolting-up condition and then calculate the flange thickness for Poisson's ratio given as 0.3.

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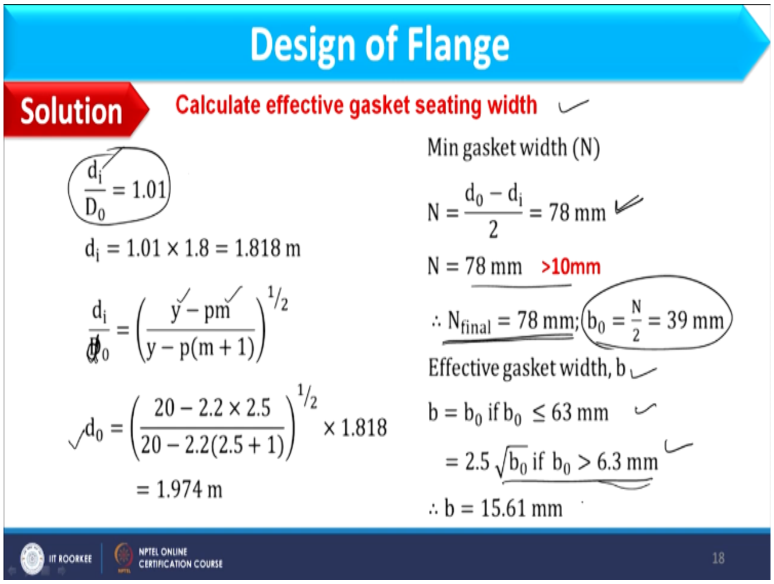

## Design of Flange

**Solution** Calculate effective gasket seating width

$$\frac{d_i}{D_0} = 1.01$$

$$d_i = 1.01 \times 1.8 = 1.818\ \text{m}$$

$$\frac{d_i}{d_0} = \left(\frac{y - pm}{y - p(m+1)}\right)^{1/2}$$

$$d_0 = \left(\frac{20 - 2.2 \times 2.5}{20 - 2.2(2.5+1)}\right)^{1/2} \times 1.818$$

$$= 1.974\ \text{m}$$

Min gasket width (N)

$$N = \frac{d_0 - d_i}{2} = 78\ \text{mm}$$

$N = 78$ mm >10mm

$\therefore N_{final} = 78\ \text{mm};\ b_0 = \frac{N}{2} = 39\ \text{mm}$

Effective gasket width, b

$b = b_0$ if $b_0 \leq 63$ mm

$= 2.5\sqrt{b_0}$ if $b_0 > 6.3$ mm

$\therefore b = 15.61$ mm

So in this example we are coving almost all parts related to design of flanges. So let us start to solve these parts one by one. First of all we have to find out effective gasket seating width and for this purpose I have to calculate the gasket dimension that is the width of the gasket. And for that purpose I will start with the given ratio d i/D o is 1.01, d i is the inner diameter of gasket. So d i would be 1.01 x 1.8, so 1.818 meter we can find as d i.

Further I am having d i/d o and here this d o is small d o not the D because this d o is the outer diameter of gasket, okay. So d i/d o both are related to the gasket and here y is given as 20 and m is given as 2.5, other value we can put and then we can calculate d o, so outer diameter of gasket is coming out as 1.974 meter, inner diameter is equal to 1.818. So considering these two values we will calculate minimum gasket width and which comes out as 78 mm.

Now if you remember the problem, there we are given minimum actual gasket width should be 10 mm and here I am getting 78 mm. So whatever would be higher that I need to take, but here the comparison of this value with the actual minimum gasket width given in the standard or given in the table that is required. Here I am having minimum gasket width which comes out as 78.

And if you remember the problem there we have seen that minimum actual gasket seating width is 10 mm. So higher value of calculated and given value I have to take as value of N, but here I need to compare the given value with the calculated value. So N final would be 78 mm and therefore b o value we can find as N/2 which is equal to 39 mm. This b o is basic gasket seating width, which is used to calculate effective gasket seating width.

And here I am having two conditions. In this case this condition will be applicable because b o is greater than 6.3 and therefore b we can find as 15.61 mm. So in this way we can calculate effective gasket seating width. Now this seating width we will use to calculate value of g, where g is the diameter of reaction of load in the gasket.

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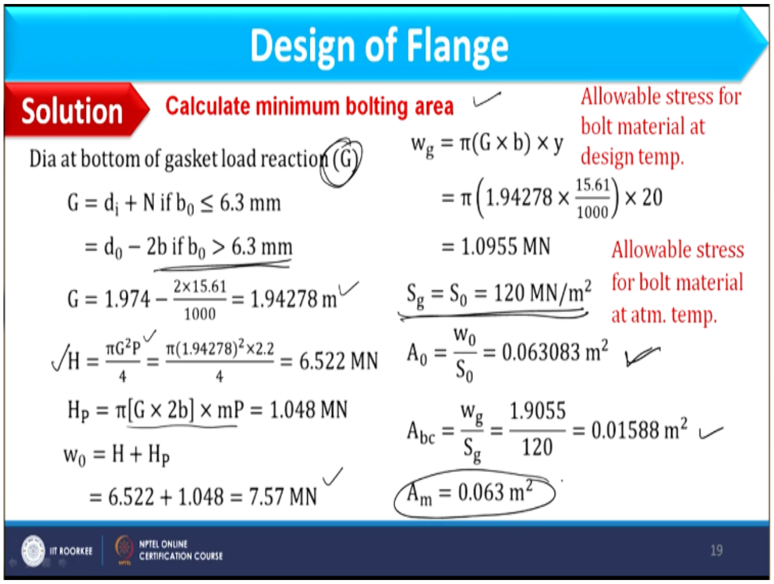

## Design of Flange

**Solution** Calculate minimum bolting area ✓

Dia at bottom of gasket load reaction (G)

$G = d_i + N \text{ if } b_0 \leq 6.3 \text{ mm}$

$= d_0 - 2b \text{ if } b_0 > 6.3 \text{ mm}$

$G = 1.974 - \frac{2 \times 15.61}{1000} = 1.94278 \text{ m}$ ✓

✓ $H = \frac{\pi G^2 P}{4} = \frac{\pi (1.94278)^2 \times 2.2}{4} = 6.522 \text{ MN}$

$H_P = \pi [G \times 2b] \times mP = 1.048 \text{ MN}$

$w_0 = H + H_P$

$= 6.522 + 1.048 = 7.57 \text{ MN}$ ✓

$w_g = \pi (G \times b) \times y$

$= \pi \left(1.94278 \times \frac{15.61}{1000}\right) \times 20$

$= 1.0955 \text{ MN}$

Allowable stress for bolt material at design temp.

$S_g = S_0 = 120 \text{ MN/m}^2$

Allowable stress for bolt material at atm. temp.

$A_0 = \frac{w_0}{S_0} = 0.063083 \text{ m}^2$ ✓

$A_{bc} = \frac{w_g}{S_g} = \frac{1.9055}{120} = 0.01588 \text{ m}^2$ ✓

$A_m = 0.063 \text{ m}^2$

Next part of the problem is to calculate minimum bolting area and whatever effective gasket width will be computed that we will used to calculate value of G and as this condition will be applicable G would be computed as g o – 2 b. So 1.974 – 2 x 15.61/1000 because that is given in mm. So G comes out as 1.94278. So once I know the G value I have to find out load at operating condition and bolting-up condition and then we will find out respective area and then we can calculate the bolting area.

So using value of G as well as design pressure I can calculate H by this expression which comes out as 6.522 meganewton. H p we can calculate by this expression Pi g x 2b x m P and that comes out as 1.048 meganewton. Total load in this case would be 7.57 meganewton. And then we have to focus on bolting-up condition where W g I need to find by this expression, where W g is equal to Pi (G x b) x y. Putting all these values over here we can have W g as 1.0955 meganewton.

So here we have to find out S g or S o, and So is basically allowable stress of bolt material at design temperature and considering that we can find out bolting area at operating condition and which is equal to W g x S o and which is equal to 0.06308 m 2. And further we have A bc which is equal to W g/S g which is equal to 1.9055/120 and that is equal to 0.01588, okay. Now what is the point you have to focus on is this point.

In this particular case I am taking S g and S o constant, which is equal to 120 meganewton per meter square, now why it is so because if you remember the design procedure there we have discussed that S o is the allowable stress of bolt material at operating condition or at design temperature, okay. And S g is the allowable stress of bolt material at atmospheric temperature. And here in this problem, allowable stress of bolt material is given as 120, okay.

So now why these two values I am taking equal because if you remember what is the design temperature, design temperature is 200, and if you remember allowable stress table, okay which we have discussed in terminologies and many previous lectures, there minimum value of allowable stress is available at 250 degrees Celsius and design temperature is less than 250. Therefore I have to take S o at 250 degrees Celsius.

And if I am considering atmospheric condition, atmospheric condition we can have 25 degrees or so, but because allowable stress value is not available for temperature less than 250 for atmospheric condition also I have to take value at 250. Therefore in this particular case both allowable stress values at operating condition as well as at bolting-up condition are equal because temperature is 250 in both case. I hope you are getting this.

For example, if design temperature is given as 300 or 350, so you have to take S o at 350 and S g at 250. I hope I am clear. So here I have computed A o as well as A bc and minimum bolting area will be considered maximum of this two and which is equal to 0.063. So that area we will use to calculate the optimum bolt and bolt circle diameter, okay. So let us start calculation of that.

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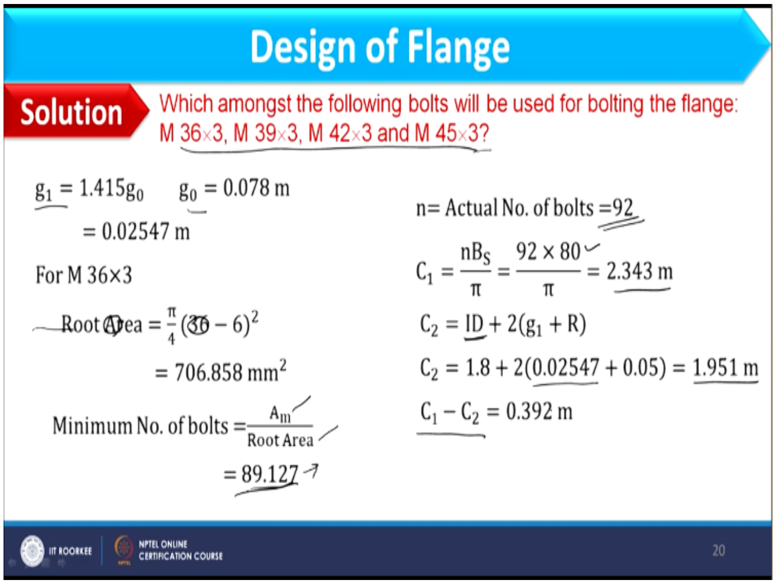

## Design of Flange

**Solution** Which amongst the following bolts will be used for bolting the flange: M 36×3, M 39×3, M 42×3 and M 45×3?

$g_1 = 1.415 g_0 \quad g_0 = 0.078$ m

$= 0.02547$ m

For M 36×3

Root Area $= \frac{\pi}{4}(36 - 6)^2$

$= 706.858\ \text{mm}^2$

Minimum No. of bolts $= \frac{A_m}{\text{Root Area}}$

$= 89.127$

n= Actual No. of bolts =92

$C_1 = \frac{nB_S}{\pi} = \frac{92 \times 80}{\pi} = 2.343$ m

$C_2 = ID + 2(g_1 + R)$

$C_2 = 1.8 + 2(0.02547 + 0.05) = 1.951$ m

$C_1 - C_2 = 0.392$ m

If you remember the problem it is given as we have four different bolts and I have to choose the optimum bolts among these, okay. So for that I know g 1 value, I know g o, so I can calculate g 1 as 0.02547. First bolt I am having is M 36 x 3, where root area I have to calculate as equal to Pi/4 (36-6) whole square and which comes out as 706.858 mm 2.

Now minimum number of bolts would be minimum bolting area divided by root area, so it comes out as 89.127 and then you have to take actual number of bolts, which should be multiple of 4 to this and then that value comes out as 92. Once I am having the actual number of bolts I will calculate C 1 and C 2. So C 1 would be equal to n B S/Pi which is equal to 92 x 80/Pi. Now from where that 80 comes, it is available in this table. I am having bolt 36 x 3, so B s value is given as 80, so that I have kept over here.

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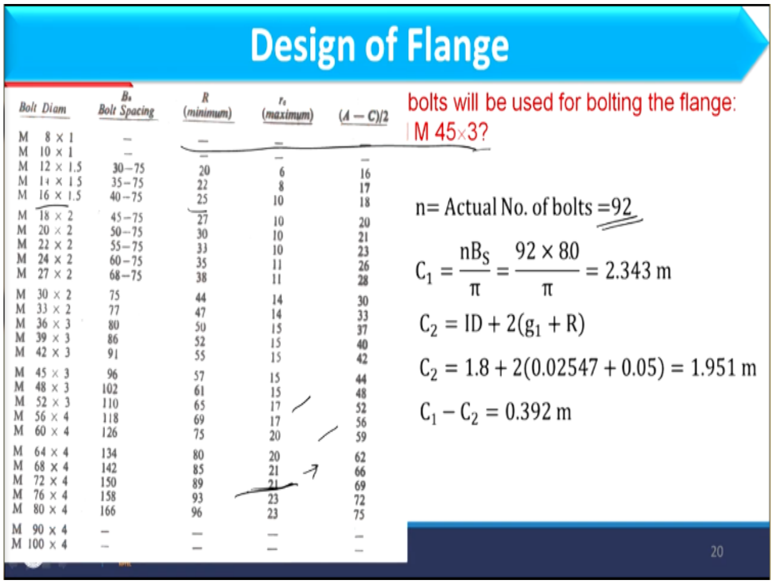

## Design of Flange

| Bolt Diam | $B_s$ Bolt Spacing | R (minimum) | $r_e$ (maximum) | (A − C)/2 |
|---|---|---|---|---|
| M 8 × 1 | – | – | – | – |
| M 10 × 1 | – | – | – | – |
| M 12 × 1.5 | 30–75 | 20 | 6 | 16 |
| M 14 × 1.5 | 35–75 | 22 | 8 | 17 |
| M 16 × 1.5 | 40–75 | 25 | 10 | 18 |
| M 18 × 2 | 45–75 | 27 | 10 | 20 |
| M 20 × 2 | 50–75 | 30 | 10 | 21 |
| M 22 × 2 | 55–75 | 33 | 10 | 23 |
| M 24 × 2 | 60–75 | 35 | 11 | 26 |
| M 27 × 2 | 68–75 | 38 | 11 | 28 |
| M 30 × 2 | 75 | 44 | 14 | 30 |
| M 33 × 2 | 77 | 47 | 14 | 33 |
| M 36 × 3 | 80 | 50 | 15 | 37 |
| M 39 × 3 | 86 | 52 | 15 | 40 |
| M 42 × 3 | 91 | 55 | 15 | 42 |
| M 45 × 3 | 96 | 57 | 15 | 44 |
| M 48 × 3 | 102 | 61 | 15 | 48 |
| M 52 × 3 | 110 | 65 | 17 | 52 |
| M 56 × 4 | 118 | 69 | 17 | 56 |
| M 60 × 4 | 126 | 75 | 20 | 59 |
| M 64 × 4 | 134 | 80 | 20 | 62 |
| M 68 × 4 | 142 | 85 | 21 | 66 |
| M 72 × 4 | 150 | 89 | 21 | 69 |
| M 76 × 4 | 158 | 93 | 23 | 72 |
| M 80 × 4 | 166 | 96 | 23 | 75 |
| M 90 × 4 | – | – | – | – |
| M 100 × 4 | – | – | – | – |

bolts will be used for bolting the flange:
M 45×3?

n= Actual No. of bolts =92

$$C_1 = \frac{nB_S}{\pi} = \frac{92 \times 80}{\pi} = 2.343 \text{ m}$$

$$C_2 = ID + 2(g_1 + R)$$

$$C_2 = 1.8 + 2(0.02547 + 0.05) = 1.951 \text{ m}$$

$$C_1 - C_2 = 0.392 \text{ m}$$

So C 1 comes out as 2.343. Further C 2 I have to calculate and which is equal to ID+ 2 (g 1 + R). So ID is basically inner diameter of flange and which is equal to outer diameter of Pi, so C 2 would be equal to 1.8 + 2 g 1, which we have already calculated, R we have taken as 0.05, which is given in this table corresponding to 36 x 3 bolt. So considering these values we can have C 2 as 1.951 meter and then I have to find out difference between C 1 and C 2 and it comes out as 0.392 meter.

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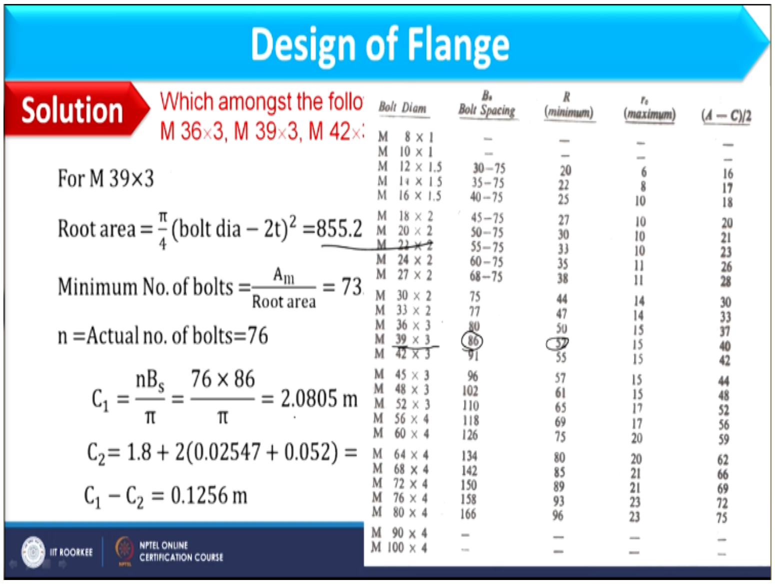

## Design of Flange

**Solution**

Which amongst the follo
M 36×3, M 39×3, M 42×

For M 39×3

Root area $= \frac{\pi}{4}(\text{bolt dia} - 2t)^2 = 855.2$

Minimum No. of bolts $= \frac{A_m}{\text{Root area}} = 73.$

n =Actual no. of bolts=76

$$C_1 = \frac{nB_s}{\pi} = \frac{76 \times 86}{\pi} = 2.0805 \text{ m}$$

$$C_2 = 1.8 + 2(0.02547 + 0.052) =$$

$$C_1 - C_2 = 0.1256 \text{ m}$$

| Bolt Diam | $B_s$ Bolt Spacing | R (minimum) | $r_e$ (maximum) | (A − C)/2 |
|---|---|---|---|---|
| M 8 × 1 | – | – | – | – |
| M 10 × 1 | – | – | – | – |
| M 12 × 1.5 | 30–75 | 20 | 6 | 16 |
| M 14 × 1.5 | 35–75 | 22 | 8 | 17 |
| M 16 × 1.5 | 40–75 | 25 | 10 | 18 |
| M 18 × 2 | 45–75 | 27 | 10 | 20 |
| M 20 × 2 | 50–75 | 30 | 10 | 21 |
| M 22 × 2 | 55–75 | 33 | 10 | 23 |
| M 24 × 2 | 60–75 | 35 | 11 | 26 |
| M 27 × 2 | 68–75 | 38 | 11 | 28 |
| M 30 × 2 | 75 | 44 | 14 | 30 |
| M 33 × 2 | 77 | 47 | 14 | 33 |
| M 36 × 3 | 80 | 50 | 15 | 37 |
| M 39 × 3 | 86 | 52 | 15 | 40 |
| M 42 × 3 | 91 | 55 | 15 | 42 |
| M 45 × 3 | 96 | 57 | 15 | 44 |
| M 48 × 3 | 102 | 61 | 15 | 48 |
| M 52 × 3 | 110 | 65 | 17 | 52 |
| M 56 × 4 | 118 | 69 | 17 | 56 |
| M 60 × 4 | 126 | 75 | 20 | 59 |
| M 64 × 4 | 134 | 80 | 20 | 62 |
| M 68 × 4 | 142 | 85 | 21 | 66 |
| M 72 × 4 | 150 | 89 | 21 | 69 |
| M 76 × 4 | 158 | 93 | 23 | 72 |
| M 80 × 4 | 166 | 96 | 23 | 75 |
| M 90 × 4 | – | – | – | – |
| M 100 × 4 | – | – | – | – |

In the similar line I will calculate for other bolts also. Like for M36 x 3 we can calculate root area as this, minimum number of bolt I can calculate as 73.658 and next multiple 4 is available as

76, so that we have taken as actual number of bolts. C 1 is n B S/Pi, so if you consider this 39 x 3 bolt, it has 86 as B s and 52 as R.

So B s as 86 we can consider in C 1, which comes out as 2.0805 and C 2 will be equal to 1.8 + 2 and this g 1 and this corresponding R which is 52 mm, okay. Now if you see this table, all values are given in mm, even these values, okay. All these values are given in mm. So C 1 – C 2 in this case is 0.1256.

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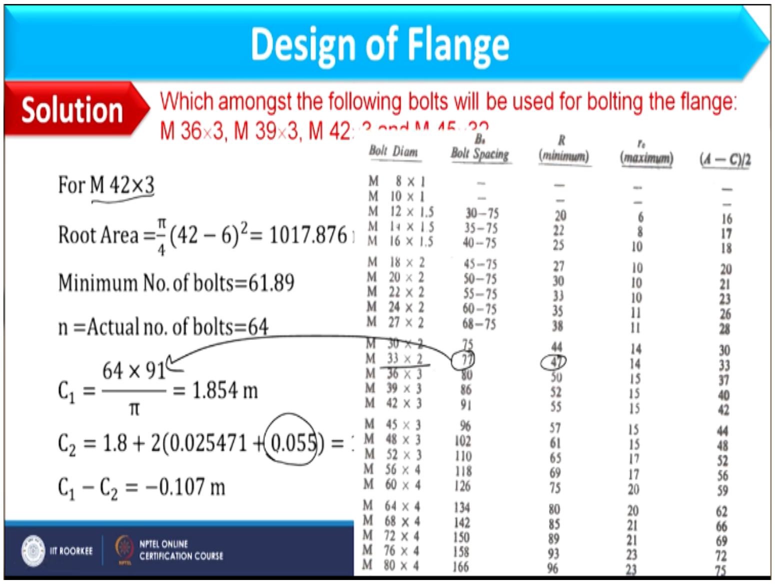

## Design of Flange

**Solution** Which amongst the following bolts will be used for bolting the flange:
M 36×3, M 39×3, M 42

For M 42×3

Root Area $=\frac{\pi}{4}(42-6)^2 = 1017.876$

Minimum No. of bolts=61.89

n =Actual no. of bolts=64

$$C_1 = \frac{64 \times 91}{\pi} = 1.854 \text{ m}$$

$$C_2 = 1.8 + 2(0.025471 + \boxed{0.055}) =$$

$$C_1 - C_2 = -0.107 \text{ m}$$

| Bolt Diam | $B_s$ Bolt Spacing | R (minimum) | $r_e$ (maximum) | (A − C)/2 |
|---|---|---|---|---|
| M 8 × 1 | – | – | – | – |
| M 10 × 1 | – | – | – | – |
| M 12 × 1.5 | 30–75 | 20 | 6 | 16 |
| M 14 × 1.5 | 35–75 | 22 | 8 | 17 |
| M 16 × 1.5 | 40–75 | 25 | 10 | 18 |
| M 18 × 2 | 45–75 | 27 | 10 | 20 |
| M 20 × 2 | 50–75 | 30 | 10 | 21 |
| M 22 × 2 | 55–75 | 33 | 10 | 23 |
| M 24 × 2 | 60–75 | 35 | 11 | 26 |
| M 27 × 2 | 68–75 | 38 | 11 | 28 |
| M 30 × 2 | 75 | 44 | 14 | 30 |
| M 33 × 2 | 77 | 47 | 14 | 33 |
| M 36 × 3 | 80 | 50 | 15 | 37 |
| M 39 × 3 | 86 | 52 | 15 | 40 |
| M 42 × 3 | 91 | 55 | 15 | 42 |
| M 45 × 3 | 96 | 57 | 15 | 44 |
| M 48 × 3 | 102 | 61 | 15 | 48 |
| M 52 × 3 | 110 | 65 | 17 | 52 |
| M 56 × 4 | 118 | 69 | 17 | 56 |
| M 60 × 4 | 126 | 75 | 20 | 59 |
| M 64 × 4 | 134 | 80 | 20 | 62 |
| M 68 × 4 | 142 | 85 | 21 | 66 |
| M 72 × 4 | 150 | 89 | 21 | 69 |
| M 76 × 4 | 158 | 93 | 23 | 72 |
| M 80 × 4 | 166 | 96 | 23 | 75 |

For next bolt, which is 42 x 3, we can find out root area which comes out as 1017.876 mm 2, minimum number of bolts 61.89, actual bolts would be 64. C 1 we can find as 64 x 91/Pi. So this is corresponding to 42 x 3, 91 would be the B s that we can use over here. And then C 1 comes out as 1.854 meter. Further I am having C 2, where I will use value of R and which is equal to 55 mm that we will use over here. And then we can find C 2 as 1.961 meter. So C 1 – C 2 will be equal to -0.107 meter.

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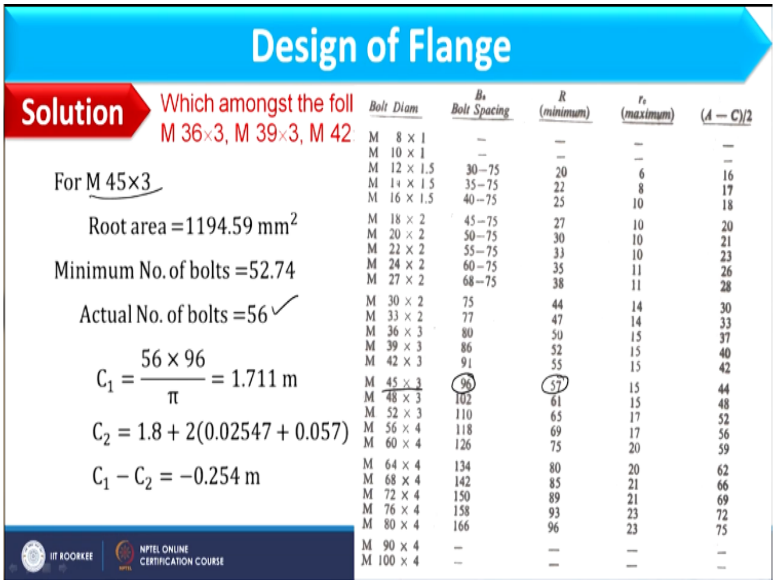

## Design of Flange

**Solution** Which amongst the foll
M 36×3, M 39×3, M 42

For M 45×3

Root area =1194.59 mm$^2$

Minimum No. of bolts =52.74

Actual No. of bolts =56 ✓

$$C_1 = \frac{56 \times 96}{\pi} = 1.711 \text{ m}$$

$$C_2 = 1.8 + 2(0.02547 + 0.057)$$

$$C_1 - C_2 = -0.254 \text{ m}$$

| *Bolt Diam* | $B_s$ *Bolt Spacing* | $R$ *(minimum)* | $r_c$ *(maximum)* | $(A-C)/2$ |
|---|---|---|---|---|
| M 8 × 1 | — | — | — | — |
| M 10 × 1 | — | — | — | — |
| M 12 × 1.5 | 30–75 | 20 | 6 | 16 |
| M 14 × 1.5 | 35–75 | 22 | 8 | 17 |
| M 16 × 1.5 | 40–75 | 25 | 10 | 18 |
| M 18 × 2 | 45–75 | 27 | 10 | 20 |
| M 20 × 2 | 50–75 | 30 | 10 | 21 |
| M 22 × 2 | 55–75 | 33 | 10 | 23 |
| M 24 × 2 | 60–75 | 35 | 11 | 26 |
| M 27 × 2 | 68–75 | 38 | 11 | 28 |
| M 30 × 2 | 75 | 44 | 14 | 30 |
| M 33 × 2 | 77 | 47 | 14 | 33 |
| M 36 × 3 | 80 | 50 | 15 | 37 |
| M 39 × 3 | 86 | 52 | 15 | 40 |
| M 42 × 3 | 91 | 55 | 15 | 42 |
| M 45 × 3 | 96 | 57 | 15 | 44 |
| M 48 × 3 | 102 | 61 | 15 | 48 |
| M 52 × 3 | 110 | 65 | 17 | 52 |
| M 56 × 4 | 118 | 69 | 17 | 56 |
| M 60 × 4 | 126 | 75 | 20 | 59 |
| M 64 × 4 | 134 | 80 | 20 | 62 |
| M 68 × 4 | 142 | 85 | 21 | 66 |
| M 72 × 4 | 150 | 89 | 21 | 69 |
| M 76 × 4 | 158 | 93 | 23 | 72 |
| M 80 × 4 | 166 | 96 | 23 | 75 |
| M 90 × 4 | — | — | — | — |
| M 100 × 4 | — | — | — | — |

In the similar line I can calculate for bolt 45 x 3, where actual number of bolts are 56 and in this case, it is 45 x 3 B s 96 and R is 57. So these values I can use over here to calculate C 1 and C 2 respectively. And then C 1 can be found as 1.711 meter and C 2 as 1.965 mm, difference of these two would be -0.254. So in this way we have calculated all parameters related to four bolts.

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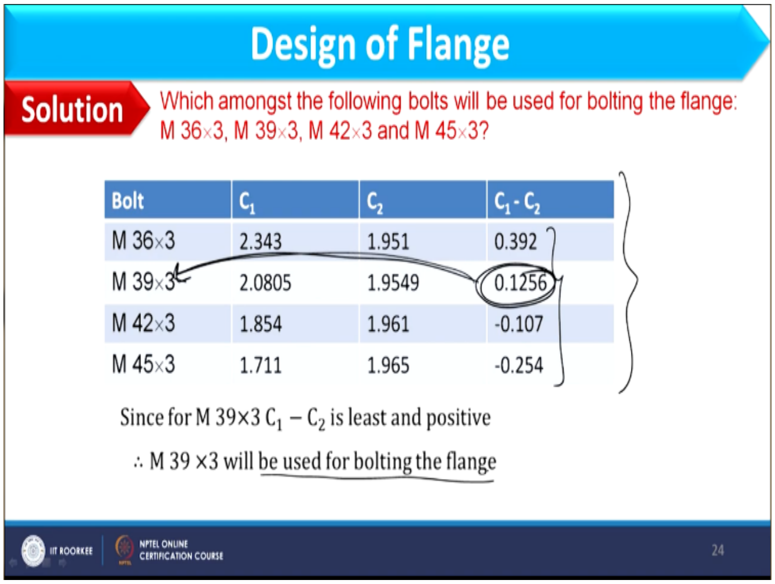

## Design of Flange

**Solution** Which amongst the following bolts will be used for bolting the flange:
M 36×3, M 39×3, M 42×3 and M 45×3?

| Bolt | $C_1$ | $C_2$ | $C_1 - C_2$ |
|---|---|---|---|
| M 36×3 | 2.343 | 1.951 | 0.392 |
| M 39×3 | 2.0805 | 1.9549 | 0.1256 |
| M 42×3 | 1.854 | 1.961 | -0.107 |
| M 45×3 | 1.711 | 1.965 | -0.254 |

Since for M 39×3 $C_1 - C_2$ is least and positive

∴ M 39 ×3 will be used for bolting the flange

Now we will summarize the results of these bolts. So summary is given in this table, where I am having the bolt C 1, C 2 and C1 – C2, okay. So you can see here that I have to choose the bolt which has C 1 – C 2 positive and least. So it will come out for this particular bolt and accordingly the bolt which I have to choose is 39 x 3, so 39 x 3 will be used for bolting the flange, okay.

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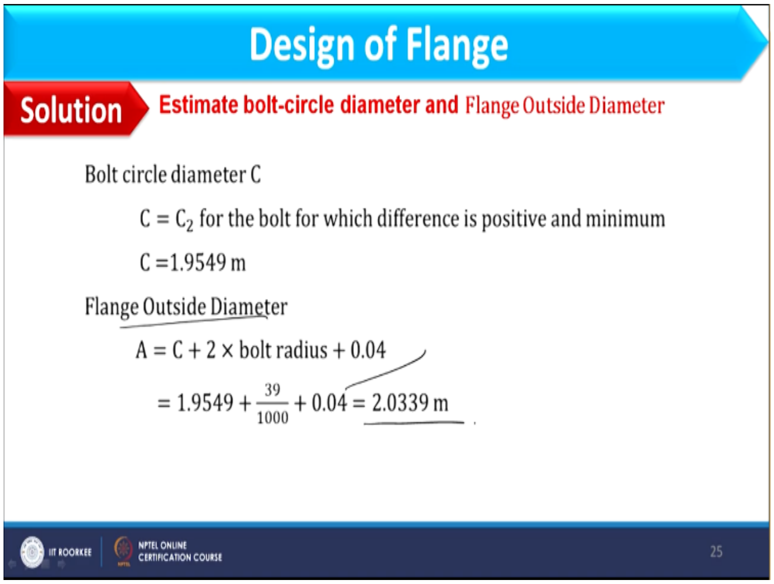

## Design of Flange

**Solution** Estimate bolt-circle diameter and Flange Outside Diameter

Bolt circle diameter C

$C = C_2$ for the bolt for which difference is positive and minimum

$C = 1.9549$ m

Flange Outside Diameter

$A = C + 2 \times \text{bolt radius} + 0.04$

$= 1.9549 + \frac{39}{1000} + 0.04 = 2.0339$ m

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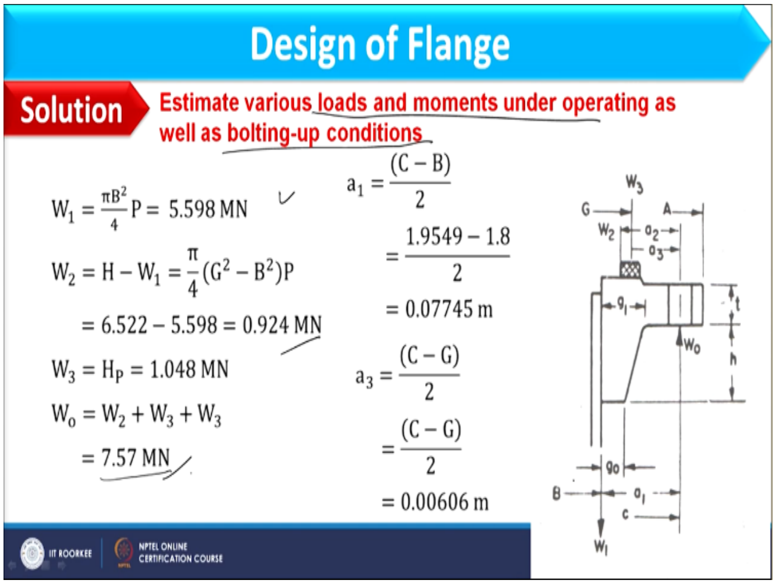
So once I have chosen the bolt, I can see the value of bolt circle diameter and if you consider this table bolt circle diameter would be C 2 of the respective bolt, okay. So now bolt circle diameter would be C 2 of that bolt, which comes out as 1.9549 meter and then we have to find out flange outside diameter, okay.

Flange outside diameter how I can calculate because C is there so that C + 2 x bolt radius + 0.04, so C is coming as 1.9549 x bolt diameter or you can use 2 x bolt radius, it is same. And then 0.04, why this is 0.04 because it is given that gap between the outer diameter of bolt circle to the outer edge of the flange is given as 20 mm. So in that case we are considering 40 mm because both sides I have to consider to calculate the diameter. So therefore 40 mm is added over. So total flange outside diameter comes as 2.0339 meter.

**(Refer Slide Time: 17:44)**



## Design of Flange

**Solution** Estimate various loads and moments under operating as well as bolting-up conditions

$$W_1 = \frac{\pi B^2}{4}P = 5.598\ \text{MN}$$

$$W_2 = H - W_1 = \frac{\pi}{4}(G^2 - B^2)P$$

$$= 6.522 - 5.598 = 0.924\ \text{MN}$$

$$W_3 = H_P = 1.048\ \text{MN}$$

$$W_o = W_2 + W_3 + W_3$$

$$= \underline{7.57\ \text{MN}}$$

$$a_1 = \frac{(C - B)}{2}$$

$$= \frac{1.9549 - 1.8}{2}$$

$$= 0.07745\ \text{m}$$

$$a_3 = \frac{(C - G)}{2}$$

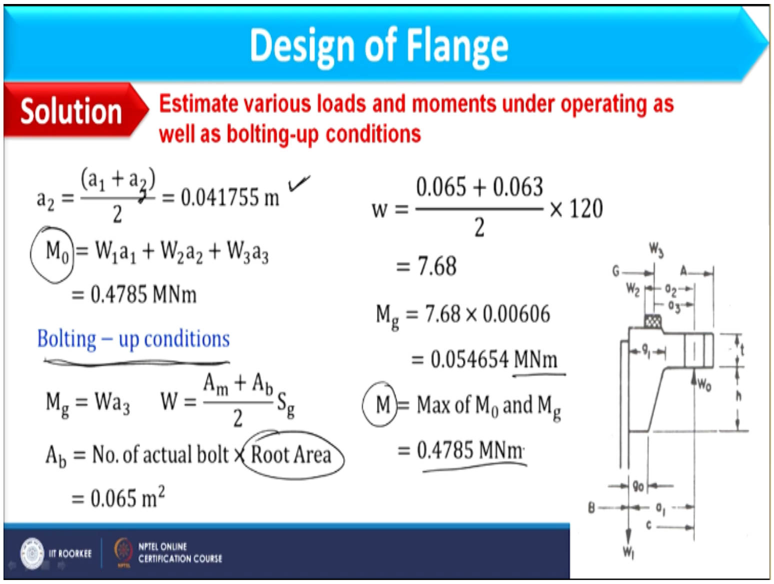
$$= \frac{(C - G)}{2}$$

$$= 0.00606\ \text{m}$$

And next I have to estimate the load and moment under operating as well as bolting-up condition because now I have to calculate the thickness of flange. Let us focus on operating condition and then we will move to bolting-up condition. For operating condition we have three load W 1, W 2, W 3 and you can find that W 1 as Pi B 2/4 x p which comes out as this. W 2 you can have as 0.924 and W 3 is 1.048. So considering all these loads we can have total load of 7.57 meganewton.

So this load you can also observe while computing the bolting area, okay. Now once I am having this bolt, I have to calculate the arms to find out the moment. So these arms are given as a 1, a 2 and a 3. So a 1 is equal to C – B/2, so here I can put the value C – B/2, which comes out as 0.07745 meter, a 3 I can consider as 0.00606 meter, which is nothing C – G.

**(Refer Slide Time: 19:02)**



# Design of Flange

**Solution** Estimate various loads and moments under operating as well as bolting-up conditions

$$a_2 = \frac{(a_1 + a_{\overset{3}{2}})}{2} = 0.041755 \text{ m} \checkmark$$

$$\boxed{M_0} = W_1 a_1 + W_2 a_2 + W_3 a_3$$

$$= 0.4785 \text{ MNm}$$

Bolting – up conditions

$$M_g = W a_3 \quad W = \frac{A_m + A_b}{2} S_g$$

$$A_b = \text{No. of actual bolt} \times \boxed{\text{Root Area}}$$

$$= 0.065 \text{ m}^2$$

$$W = \frac{0.065 + 0.063}{2} \times 120$$

$$= 7.68$$

$$M_g = 7.68 \times 0.00606$$

$$= 0.054654 \text{ MNm}$$

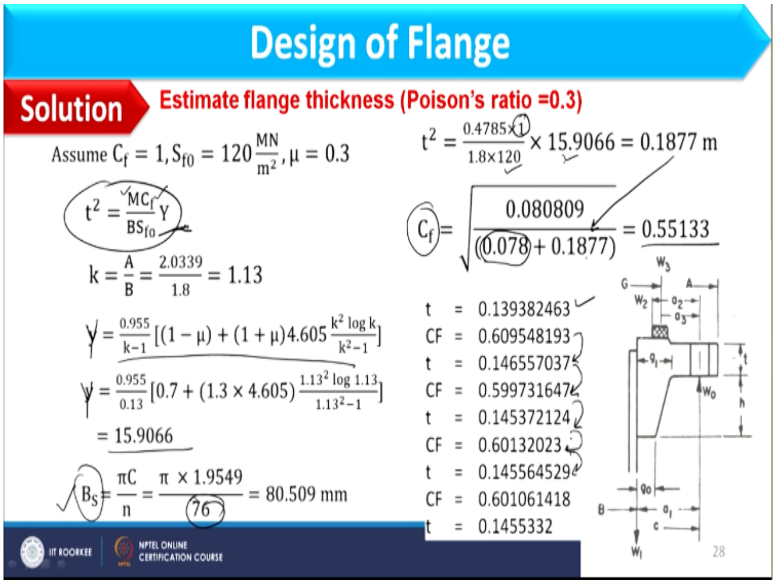
$$\boxed{M} = \text{Max of } M_0 \text{ and } M_g$$

$$= \underline{0.4785 \text{ MNm}}$$

And in the similar line I can calculate a 2 as a 1 and a 3. Here this is not a 2, this a 3/2 which is equal to 0.041755 meter and then considering all these arms as well as load I can calculate the moment at operating condition and which comes out as 0.4785 meganewton meter. Further I have to focus on bolting-up condition, where M g is equal to W x a 3, and W we can define as A m + A b/2 x S g. So S g is basically the allowable stress of bolt material and A b is given as number of actual bolt into root area, which comes out as 0.065.

So root area you will choose corresponding to 39 x 3 bolt, okay. So considering all these values we can have W as 7.68 meganewton and then you can find out M g as 0.054654 meganewton meter. Further I have to calculate M as maximum of M o as well as M g and which can be taken as 0.4785 meganewton meter which is corresponding to M o value.

**(Refer Slide Time: 20:38)**



## Design of Flange

**Solution** Estimate flange thickness (Poison's ratio =0.3)

Assume $C_f = 1, S_{f0} = 120\frac{MN}{m^2}, \mu = 0.3$

$$t^2 = \frac{MC_f}{BS_{f0}}Y$$

$$k = \frac{A}{B} = \frac{2.0339}{1.8} = 1.13$$

$$Y = \frac{0.955}{k-1}\left[(1-\mu) + (1+\mu)4.605\frac{k^2 \log k}{k^2-1}\right]$$

$$Y = \frac{0.955}{0.13}\left[0.7 + (1.3 \times 4.605)\frac{1.13^2 \log 1.13}{1.13^2-1}\right]$$

$$= 15.9066$$

$$B_S = \frac{\pi C}{n} = \frac{\pi \times 1.9549}{76} = 80.509 \text{ mm}$$

$$t^2 = \frac{0.4785 \times 1}{1.8 \times 120} \times 15.9066 = 0.1877 \text{ m}$$

$$C_f = \sqrt{\frac{0.080809}{(0.078 + 0.1877)}} = 0.55133$$

t = 0.139382463
CF = 0.609548193
t = 0.146557037
CF = 0.599731647
t = 0.145372124
CF = 0.60132023
t = 0.145564529
CF = 0.601061418
t = 0.1455332

Now once I am having the flange moment I will calculate the thickness of flange, where Poisson's ratio is given as 0.3, okay. So here this is the expression to calculate the thickness where M we have already computed in last slide. C f I have to take as 1 as a initial guess, B is basically bow diameter or inner diameter of flange or outer diameter of shell. S fo is the allowable stress of shell material and Y is the factor which we can compute through this.

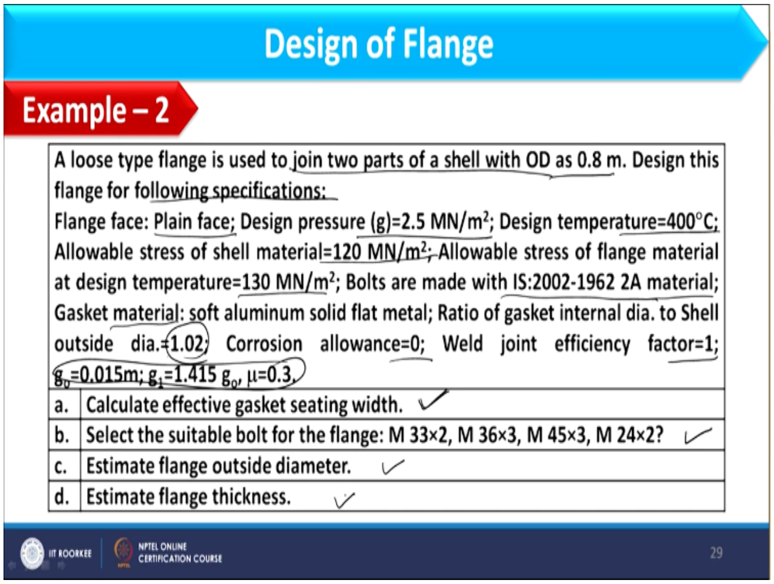
So to find out Y value I have to consider k as A/B, which comes out as 1.13 and then putting k value as well as Mue in this expression I can find Y as 15.9066 and then we can calculate thickness of thickness, that is t 2 = 0.4785 that is M x C f, which I have taken as 1 as initial guess divided by B x S fo x Y, so t comes out as 0.1877 meter. Considering this t we will find out revised value of C f which is given as B s/2d + t.

So B s we have to consider as revised value, which can be computed by this expression, where C is the bolt circle diameter which we have chosen. So B s is equal to Pi x 1.9546/n where n is the actual number of bolts corresponding to 39 x 3 bolt. And therefore B s is 80.509 mm. So that B s I have kept over here. Then this is nothing but 2 d because 39 is there, so 78 mm I can consider as 2 d.

And this thickness I have considered over here to calculate C f and corresponding value of C f is 0.5513, okay. Once I have calculated C f 0.5513 I will use this C f in this expression in place of 1. Then t I can find out and then further considering this t value at this place I can find revised value of C f, which comes out as 0.6095. Considering this C f I will calculate t, which is 0.1466 and then C f and then t and then C f and then t, like this we keep on moving till two consecutive values of t would be equal almost.

So here we have final value of thickness is 0.1455, which is almost equal to the previous value of t and therefore this we can consider as final thickness of flange. So in this way we have computed all parts for flange design and I hope the method is clear to you. Now we will consider another example for design of flange.

**(Refer Slide Time: 23:56)**



## Design of Flange

### Example – 2

A loose type flange is used to join two parts of a shell with OD as 0.8 m. Design this flange for following specifications:
Flange face: Plain face; Design pressure (g)=2.5 MN/$m^2$; Design temperature=400°C; Allowable stress of shell material=120 MN/$m^2$; Allowable stress of flange material at design temperature=130 MN/$m^2$; Bolts are made with IS:2002-1962 2A material; Gasket material: soft aluminum solid flat metal; Ratio of gasket internal dia. to Shell outside dia.=1.02; Corrosion allowance=0; Weld joint efficiency factor=1; $g_0$=0.015m; $g_1$=1.415 $g_0$, $\mu$=0.3.

| | |
|---|---|
| a. | Calculate effective gasket seating width. ✓ |
| b. | Select the suitable bolt for the flange: M 33×2, M 36×3, M 45×3, M 24×2? ✓ |
| c. | Estimate flange outside diameter. ✓ |
| d. | Estimate flange thickness. ✓ |

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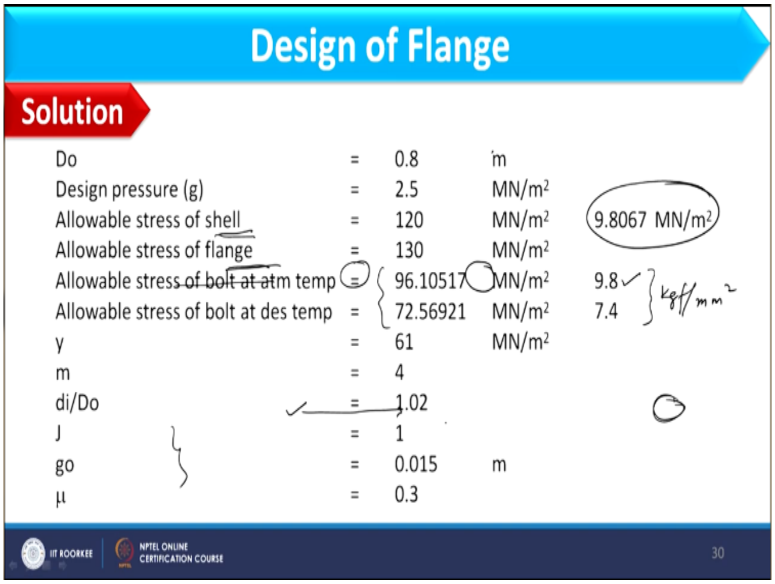
Now here we have example 2, in which we are designing again a loose-type flange, which is used to join two parts of shell with OD as 0.8 meter. Design this flange for following specification that is plain face, design pressure is given like this and design temperature here as 400. Allowable stress of shell material 120 meganewton per meter square. Allowable stress of flange material at design temperature is given as 130 meganewton per meter square.

And bolts are made with IS:2002-1962 2A material. Gasket material is soft aluminium solid flat metal. Ratio of gasket internal diameter to shell outside diameter is 1.02, corrosion allowance 0 and joint deficiency factor 1, and all these parameters we can use for designing. Now what I have to find is effective gasket seating width as we have computed in last example. We have to choose the optimum bolt or suitable bolt among these flange outside diameter and flange thickness.

**(Refer Slide Time: 25:12)**



## Design of Flange

**Solution**

Do = 0.8 m

Design pressure (g) = 2.5 MN/m²

Allowable stress of shell = 120 MN/m²

Allowable stress of flange = 130 MN/m²

Allowable stress ~~of bolt at atm~~ temp = 96.10517 MN/m²

Allowable stress of bolt at des temp = 72.56921 MN/m²

y = 61 MN/m²

m = 4

di/Do = 1.02

J = 1

go = 0.015 m

μ = 0.3

9.8067 MN/m²

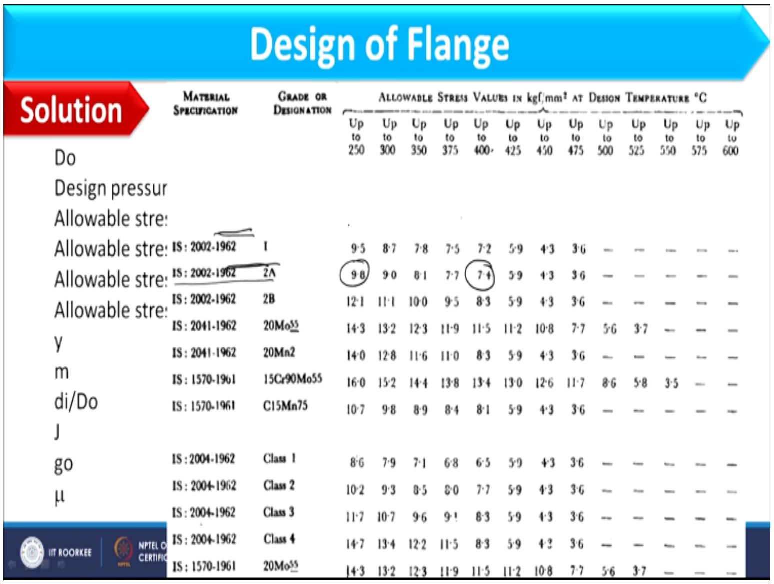
9.8 ✓

7.4

kgf/mm²

So let us start the part one of this. Before starting solution of this, we have summarized here a few parameters as outer diameter pointed, design pressure is given as 2.5 meganewton per meter square, allowable stress of shell and flange are given as 120 and 130 meganewton per meter square respectively. Now allowable stress of bolt at atmospheric temperature and that at design temperature.

**(Refer Slide Time: 25:43)**



## Design of Flange

**Solution**

Do

Design pressur

Allowable stre:

Allowable stre:

Allowable stre:

Allowable stre:

y

m

di/Do

J

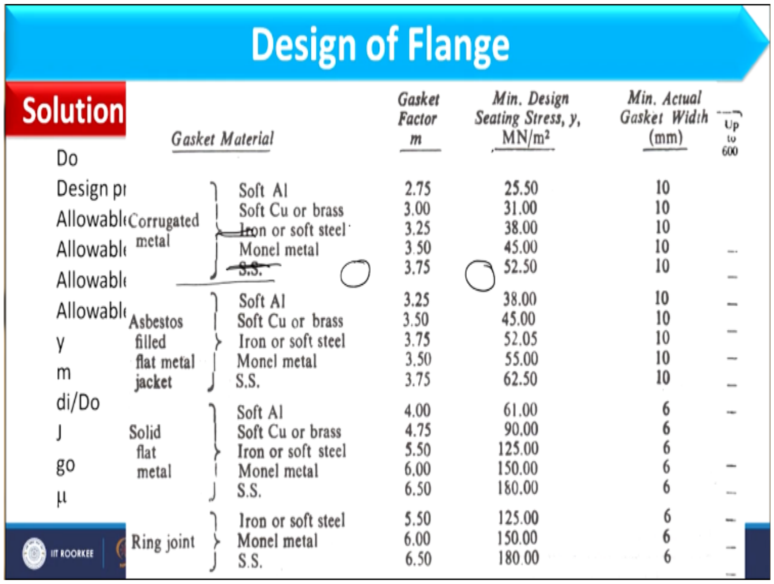
go

μ

| Material Specification | Grade or Designation | Allowable Stress Values in kgf/mm² at Design Temperature °C<br>Up to 250 | Up to 300 | Up to 350 | Up to 375 | Up to 400 | Up to 425 | Up to 450 | Up to 475 | Up to 500 | Up to 525 | Up to 550 | Up to 575 | Up to 600 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IS : 2002-1962 | 1 | 9·5 | 8·7 | 7·8 | 7·5 | 7·2 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 2002-1962 | 2A | 9·8 | 9·0 | 8·1 | 7·7 | 7·4 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 2002-1962 | 2B | 12·1 | 11·1 | 10·0 | 9·5 | 8·3 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 2041-1962 | 20Mo55 | 14·3 | 13·2 | 12·3 | 11·9 | 11·5 | 11·2 | 10·8 | 7·7 | 5·6 | 3·7 | — | — | — |
| IS : 2041-1962 | 20Mn2 | 14·0 | 12·8 | 11·6 | 11·0 | 8·3 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 1570-1961 | 15Cr90Mo55 | 16·0 | 15·2 | 14·4 | 13·8 | 13·4 | 13·0 | 12·6 | 11·7 | 8·6 | 5·8 | 3·5 | — | — |
| IS : 1570-1961 | C15Mn75 | 10·7 | 9·8 | 8·9 | 8·4 | 8·1 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 2004-1962 | Class 1 | 8·6 | 7·9 | 7·1 | 6·8 | 6·5 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 2004-1962 | Class 2 | 10·2 | 9·3 | 8·5 | 8·0 | 7·7 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 2004-1962 | Class 3 | 11·7 | 10·7 | 9·6 | 9·1 | 8·3 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 2004-1962 | Class 4 | 14·7 | 13·4 | 12·2 | 11·5 | 8·3 | 5·9 | 4·3 | 3·6 | — | — | — | — | — |
| IS : 1570-1961 | 20Mo55 | 14·3 | 13·2 | 12·3 | 11·9 | 11·5 | 11·2 | 10·8 | 7·7 | 5·6 | 3·7 | — | — | — |

So if you remember the problem we are given material for bolt, and that is IS:2002-1962 2A, okay. And in this case design temperature is 400, okay. So 7.4 would be the allowable stress of bolt material at design temperature. And here 9.6 will be considered as allowable stress of bolt material at atmospheric temperature because value at lesser temperature than 250 is not available in this table.

**(Refer Slide Time: 26:20)**



## Design of Flange

**Solution**

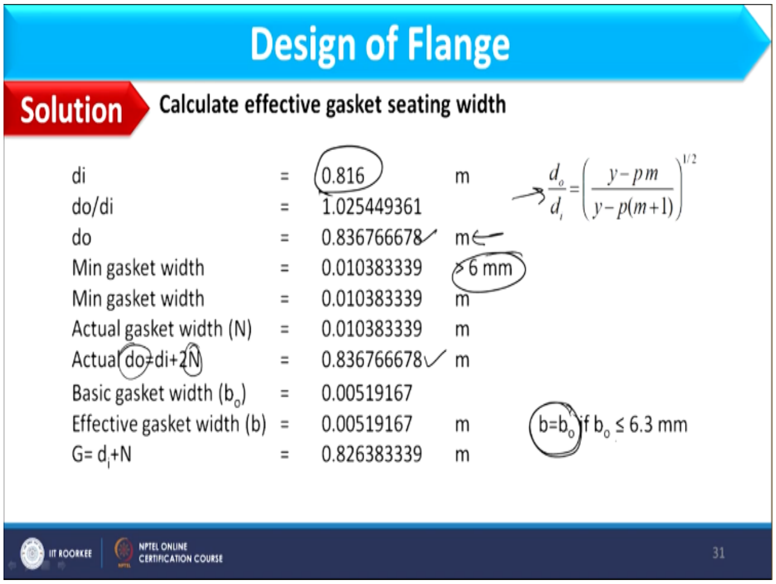
Do
Design p
Allowabl
Allowabl
Allowabl
Allowabl
y
m
di/Do
J
go
μ

| Gasket Material | | Gasket Factor m | Min. Design Seating Stress, y, MN/m² | Min. Actual Gasket Width (mm) | Up to 600 |
|---|---|---|---|---|---|
| Corrugated metal | Soft Al | 2.75 | 25.50 | 10 | |
| | Soft Cu or brass | 3.00 | 31.00 | 10 | |
| | Iron or soft steel | 3.25 | 38.00 | 10 | |
| | Monel metal | 3.50 | 45.00 | 10 | – |
| | ~~S.S.~~ | 3.75 | 52.50 | 10 | – |
| Asbestos filled flat metal jacket | Soft Al | 3.25 | 38.00 | 10 | – |
| | Soft Cu or brass | 3.50 | 45.00 | 10 | – |
| | Iron or soft steel | 3.75 | 52.05 | 10 | – |
| | Monel metal | 3.50 | 55.00 | 10 | – |
| | S.S. | 3.75 | 62.50 | 10 | – |
| Solid flat metal | Soft Al | 4.00 | 61.00 | 6 | – |
| | Soft Cu or brass | 4.75 | 90.00 | 6 | |
| | Iron or soft steel | 5.50 | 125.00 | 6 | |
| | Monel metal | 6.00 | 150.00 | 6 | – |
| | S.S. | 6.50 | 180.00 | 6 | – |
| Ring joint | Iron or soft steel | 5.50 | 125.00 | 6 | – |
| | Monel metal | 6.00 | 150.00 | 6 | – |
| | S.S. | 6.50 | 180.00 | 6 | – |

And further if you consider the gasket material we are given soft aluminum solid flat metal as gasket material and corresponding to this I am having 4 as value of m and 61 as seating stress and 6 is the actual minimum width of the gasket, okay. So all these values I have taken over here that is allowable stress at design temperature 7.4 at atmospheric pressure 9.8 and this is the conversion because if you remember these values are in kg force per mm 2.

So conversion of this 2 meganewton per meter square is 9.8067 and that value I have converted and respective value are given over here in meganewton per meter square, and y we have taken from gasket table, which is 61 and m we can consider as 4, so d i/D o is 1.02, other parameters are you can see from the example.

**(Refer Slide Time: 27:34)**



## Design of Flange

**Solution** Calculate effective gasket seating width

di = 0.816 m

do/di = 1.025449361

do = 0.836766678 m

Min gasket width = 0.010383339 >6 mm

Min gasket width = 0.010383339 m

Actual gasket width (N) = 0.010383339 m

Actual do=di+2N = 0.836766678 m

Basic gasket width ($b_o$) = 0.00519167

Effective gasket width (b) = 0.00519167 m

G= $d_i$+N = 0.826383339 m

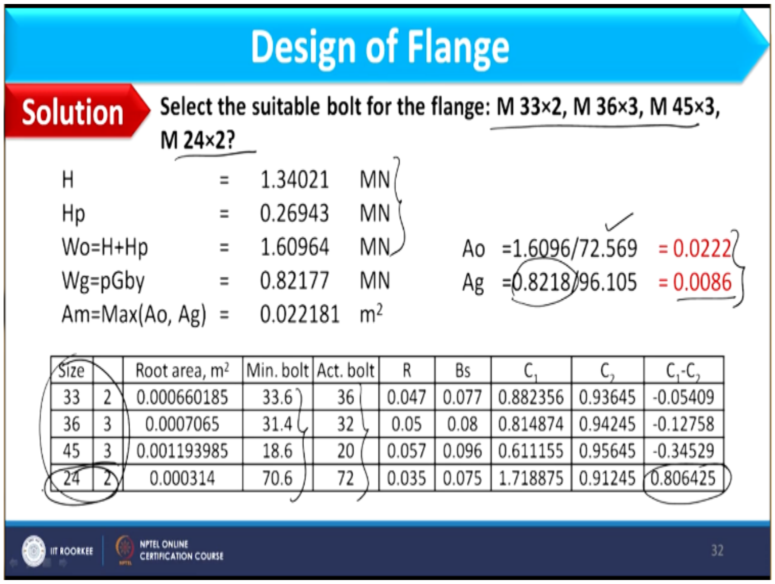
$$\frac{d_o}{d_i} = \left(\frac{y-pm}{y-p(m+1)}\right)^{1/2}$$

$b=b_o$ if $b_o \leq 6.3$ mm

So effective gasket width again I have to find d i because I know d i/D o as 1.02, so here this is the value of d i, d o/d i you can find by this expression and then d o I can find as 0.83677. Minimum gasket width is found as 0.01038, it means 10.38 mm and which has to compare with the value given in the table and that is 6 mm.Larger among these we can consider as minimum gasket width, which is 10.38 mm.

Now outer diameter of gasket will not be changed as whatever we have computed value of N that I have taken as it is. So it will be equal to the previous value. Basic gasket width I can find as B o and that should be N/2 if you remember because I have considered plain face. And further based on B o as it is coming less than 6.3 mm I can calculate effective gasket width equal to B o and which comes out as 0.00519, and further we can calculate G that is the diameter of reaction of load in gasket and which comes out as 0.82638.

**(Refer Slide Time: 29:09)**



## Design of Flange

**Solution** Select the suitable bolt for the flange: M 33×2, M 36×3, M 45×3, M 24×2?

H = 1.34021 MN
Hp = 0.26943 MN
Wo=H+Hp = 1.60964 MN
Wg=pGby = 0.82177 MN
Am=Max(Ao, Ag) = 0.022181 $m^2$

Ao =1.6096/72.569 = 0.0222
Ag =0.8218/96.105 = 0.0086

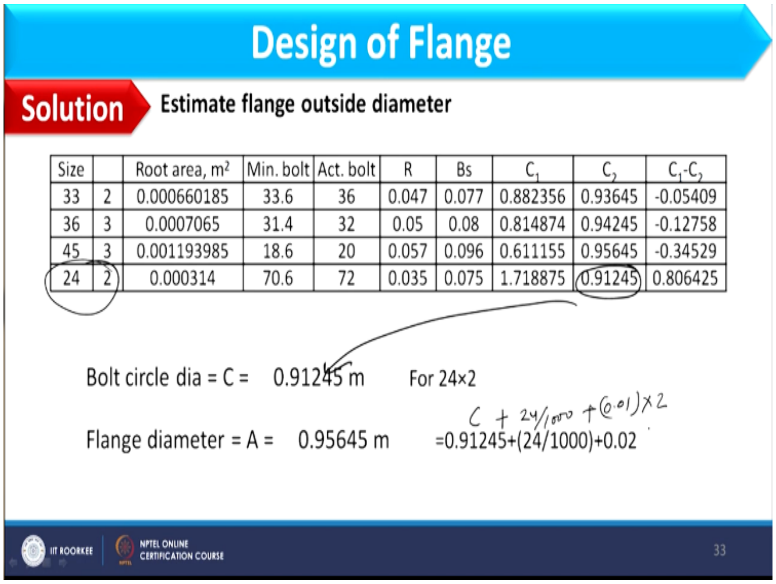
| Size | | Root area, $m^2$ | Min. bolt | Act. bolt | R | Bs | $C_1$ | $C_2$ | $C_1$-$C_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 33 | 2 | 0.000660185 | 33.6 | 36 | 0.047 | 0.077 | 0.882356 | 0.93645 | -0.05409 |
| 36 | 3 | 0.0007065 | 31.4 | 32 | 0.05 | 0.08 | 0.814874 | 0.94245 | -0.12758 |
| 45 | 3 | 0.001193985 | 18.6 | 20 | 0.057 | 0.096 | 0.611155 | 0.95645 | -0.34529 |
| 24 | 2 | 0.000314 | 70.6 | 72 | 0.035 | 0.075 | 1.718875 | 0.91245 | 0.806425 |

Now I have to choose the suitable bolt among these, okay. For that purpose I have to calculate the bolting area and that we can calculate by operating condition as well as bolting-up condition. So for operating condition this W o comes as 1.6094, H and H p we can find as we have discussed in the last example. W g we can consider as 0.8177. Based on that we can find out area for operating condition and area for bolting-up condition.

So based on these values I can find area at operating condition and bolting-up condition. So at operating condition it is equal to 1.6096/72.569, which is the conversion of 7.4 kg force per mm 2, which is the allowable stress at design temperature and the area comes out as 0.0222. In the similar line A g I am having as this 0.8218/96.108 and which comes out as 0.0086. Larger value among these I have to choose as bolting area and that I can take as 0.02218, okay. And then considering this bolting area and root area corresponding to these bolts, I can calculate minimum number of bolts as we did in last example.

Now next multiple of 4 of all these values are given here, okay. And then R and B s I can see from the bolt table and then considering these values we can calculate C 1 and C 2 and difference of C 1 and C 2 we can find and which is found positive and minimum for 24 x 2.

**(Refer Slide Time: 31:15)**



## Design of Flange

**Solution** Estimate flange outside diameter

| Size | | Root area, m² | Min. bolt | Act. bolt | R | Bs | $C_1$ | $C_2$ | $C_1$-$C_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 33 | 2 | 0.000660185 | 33.6 | 36 | 0.047 | 0.077 | 0.882356 | 0.93645 | -0.05409 |
| 36 | 3 | 0.0007065 | 31.4 | 32 | 0.05 | 0.08 | 0.814874 | 0.94245 | -0.12758 |
| 45 | 3 | 0.001193985 | 18.6 | 20 | 0.057 | 0.096 | 0.611155 | 0.95645 | -0.34529 |
| 24 | 2 | 0.000314 | 70.6 | 72 | 0.035 | 0.075 | 1.718875 | 0.91245 | 0.806425 |

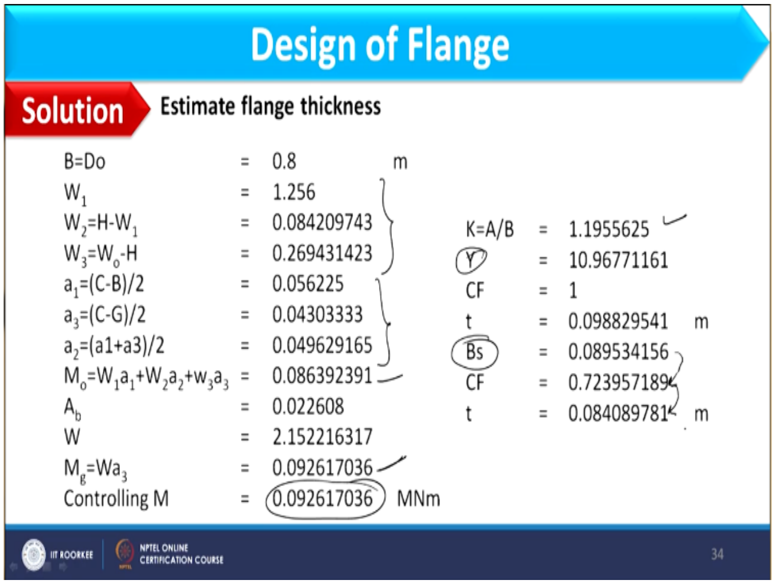
Bolt circle dia = C = 0.91245 m For 24×2

$C + 24/1000 + (0.01) \times 2$

Flange diameter = A = 0.95645 m =0.91245+(24/1000)+0.02

So 24 x 2 can be chosen as suitable bolt or optimum bolt and corresponding value of C 2 I can choose as bolt circle diameter, which comes out as 0.91245 for 24 x 2 bolt, okay. And then flange diameter I can calculate as 0.95645 meter which is basically C + bolt diameter, that is 24/1000, which is already written over here plus 0.02, so that should be 0.01 x 2 because in this case the value is not known to me so I will take 10 mm as minimum value which is basically recommended minimum value for design of flange.

**(Refer Slide Time: 32:11)**



## Design of Flange

**Solution** Estimate flange thickness

B=Do = 0.8 m
$W_1$ = 1.256
$W_2 = H - W_1$ = 0.084209743
$W_3 = W_o - H$ = 0.269431423
$a_1 = (C-B)/2$ = 0.056225
$a_3 = (C-G)/2$ = 0.04303333
$a_2 = (a1+a3)/2$ = 0.049629165
$M_o = W_1 a_1 + W_2 a_2 + w_3 a_3$ = 0.086392391
$A_b$ = 0.022608
W = 2.152216317
$M_g = W a_3$ = 0.092617036
Controlling M = 0.092617036 MNm

K=A/B = 1.1955625
Y = 10.96771161
CF = 1
t = 0.098829541 m
Bs = 0.089534156
CF = 0.723957189
t = 0.084089781 m

So considering all these values I can find out flange diameter as this. And then I have to find out flange thickness and for that purpose I have to calculate flange moment. So for that I have calculated W 1, W 2, W 3 and a 1, a 2, a 3 as we did in last example and then we can find out moment at operating condition and similar moment at bolting-up condition. So controlling M would be larger from these two and that is given for bolting-up condition, okay.

Now K I have taken as A/B, which is this and then Y I can calculate as 10.9677, Mue 0.3 I can take, further C f I will take as 1 and then we can calculate thickness of flange which comes out as 0.0988 meter. Revised value of B s I have to take as 0.089 and considering this B s value I will find out C f and then I can calculate revised value of t and in the similar line I keep on moving to calculate the thickness of t.

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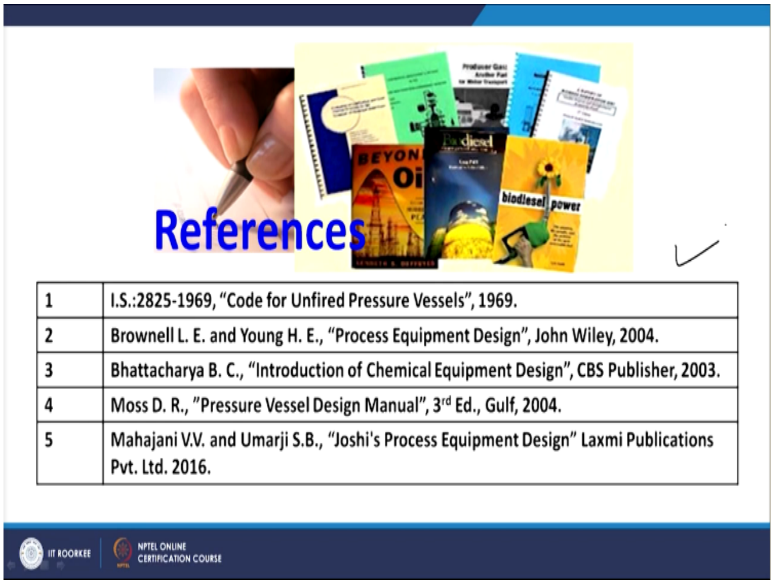

References

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So in that way we can calculate the thickness of flange and then we can complete the design of flanges. So here we have solved two examples for design of flanges and I hope the method is clear to you and here I am having some of the references to study about design of flanges and here we will summarize the video and in this video we will summarize for lecture 2, 3, 4 and 4 of week 3 because all these lectures were devoted to design of flanges, okay.

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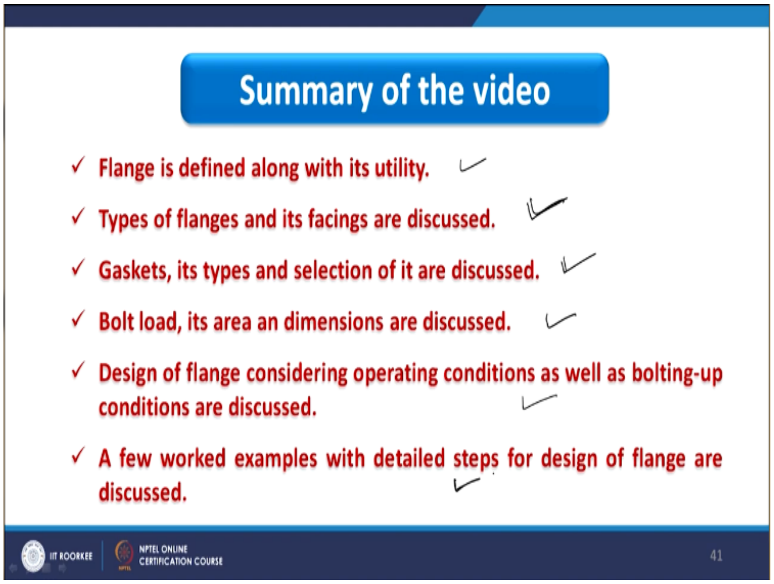

## Summary of the video

- ✓ Flange is defined along with its utility.
- ✓ Types of flanges and its facings are discussed.
- ✓ Gaskets, its types and selection of it are discussed.
- ✓ Bolt load, its area an dimensions are discussed.
- ✓ Design of flange considering operating conditions as well as bolting-up conditions are discussed.
- ✓ A few worked examples with detailed steps for design of flange are discussed.

So summary goes as flange is defined along with its utility. Types of flanges and its facings are discussed. Gaskets, its types and selection of it are discussed. Bolt load, its area and dimensions are discussed. Design of flange considering operating condition as well as bolting-up conditions are discussed. And then we have solved few examples with detail steps for design of flange. That is all for now, thank you.