Module
5

Flanged I

Beams – Theory
and Numerical
Problems

Lesson
1 1

Flanged I3eams –
Numerical Problems

Instructional Objectives:
At the end of this lesson, the student should be able to:

o identify the two types of numerical problems – analysis and design types,
apply the formulations to analyse the capacity of a flanged beam,
determine the limiting moment of resistance quickly with the help of tables of SP–16.

5.11.1 Introduction

Lesson 10 illustrates the governing equations of flanged beams. It is now necessary to apply them for the solution of numerical problems. Two types of numerical problems are possible: (i) Analysis and (ii) Design types. This lesson explains the application of the theory of flanged beams for the analysis type of problems. Moreover, use of tables of SP–16 has been illustrated to determine the limiting moment of resistance of sections quickly for the three grades of steel. Besides mentioning the different steps of the solution, numerical examples are also taken up to explain their step–by-step solutions.

5.11.2 Analysis Type of Problems

The dimensions of the beam bf, bw, Df, d, D, grades of concrete and steel and the amount of steel A5; are given. It is required to determine the moment of resistance of the beam.

Step 1: To determine the depth of the neutral axis X"

The depth of the neutral axis is determined from the equation of equilibrium C = T. However, the expression of C depends on the location of neutral axis, Df/d and Df/Xu parameters. Therefore, it is required to assume first
that the xu is in the flange. If this is not the case, the next step is to assume xu in
the web and the computed value of xu will indicate if the beam is under-reinforced, balanced or over–reinforced.

Other steps:
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ml

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Ilyres. I:letenTIIne G. T 8: l'I."|,, if h -f D
from Equations of Lessons 4. 5 E; 3 ml C Eu: lfixéh ' assuming
as rectangular beam with tI=|::. “ '
tease i]
1f
-[ease Ii]-. balanoed ‘ { ease Iii]. under-relnforoed {ease iv}. over-relnforoed
Ifxu=’:u||u-: ; Ilxflxu... ifx.=*x.m
1r
1' ..
; ease ii .=..~,. if D.iD~==r.‘l.2. {case -i bl. -I we > 0.2. Egg” ffajg "i
use Eqs. 5.5.3 3. ‘r for use Eqs.5.8.9.1G 9 H W
r'_:_‘T3,r.,i|u__ 3:11for;-.-'.,C.T em, _
ir

|[case iil b]|, if D,i'x,, 1* 0.43,
use Eqs. 5.15.1E,1T &1B
for ;-.r.. C, T 3: l'I."|,,

{ ease Iii a]. if D..":t,, <=CI.43.
use Eqs.12,13 3; 14 for
C. T 3. M,

Fig. 5.11.1: Steps of solution ofanalysis type of problems

After knowing if the section is under-reinforced, balanced or over-reinforced, the respective parameter D;/d or D;/Xu is computed for the under-reinforced, balanced or over–reinforced beam. The respective expressions of C, Tand Mu, as established in Lesson 10, are then employed to determine their values. Figure 5.11.1 illustrates the steps to be followed.

5.11.3 Numerical Problems (Analysis Type)

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X_:9IS-fig-4
J-t.,. ,,=21|E3
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350
4-2E:T
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' J.

300
l‘ *i
Fig. 5.11.2: Example 1, case {I}

Ex.1: Determine the moment of resistance of the T–beam of Fig. 5.11.2. Given data: bf = 1000 mm, Df = 100 mm, bw = 300 mm, cover = 50 mm, d = 450 mm and As, = 1963 mm2 (4- 25 T). Use M 20 and Fe 415.

Step 1: To determine the depth of the neutral axis X"
Assuming xu in the flange and equating total compressive and tensile

forces from the expressions of C and T (Eq. 3.16 of Lesson 5) as the T–beam can be treated as rectangular beam of width bf and effective depth d, we get:

x _ 0.87 f, A., _ 0.87 (415)(1963)
” 0.36 bf f,, 0.36(1000) (20)

= 98.44 mm < 100mm

So, the assumption of xu in the flange is correct.

xffmax for the balanced rectangular beam = 0.48 d = 0.48 (450) = 216 mm.

It is under–reinforced since xu < xugmax.
Step 2: To determine C, T and Mu

From Eqs. 3.9 (using b = bf) and 3.14 of Lesson 4 for C and Tand Eq. 3.23 of Lesson 5 for Mu, we have:

c = 0.36 bf X.) fck
= 0.36 (1000) (93.44) (20) = 703.77 kN
T = 0.37 r,A,,
(3.14)
= 0.37 (415) (1963) = 703.74 kN

A
fly) (323)

M = 0.87f AS,d(l -
y fckbfd

u

i }= 290,06 W...

= 0.87 415 1963 450 l-
( )( )( ){ (20)(l000)(450)

This problem belongs to the case (i) and is explained in sec. 5.10.4.1 of Lesson 10.

1030 J
"I

_ 3:34 100
_ _ _ _ NE;
350
.$– 4-2-ET + 3-1E3T
$6 [= 3065 rrirn"} l
...fl...

Fig. 5.11.3: Example 2, case [ii 111]

Ex.2: Determine Ast,/im and Mu,/im of the flanged beam of Fig. 5.11.3. Given data are: bf = 1000 mm, Df = 100 mm, bw = 300 mm, cover = 50 mm and d

= 450 mm. Use M 20 and Fe 415.
Step 1: To determine Df/d ratio

For the limiting case Xu = Xffmax = 0.48 (450) = 216 mm > Df. The ratio Df/d is computed.

D,/d = 100/450 = 0.222 > 0.2

Hence, it is a problem of case (ii b) and discussed in sec. 5.10.4.2 b of Lesson 10.

Step 2: Computations of yf, Cand T

First, we have to compute yf from Eq.5.8 of Lesson 10 and then employ Eqs. 5.9, 10 and 11 of Lesson 10 to determine C, T and Mu, respectively.

yf = 0.15 Xffmax + 0.65 Df = 0.15 (216) + 0.65 (100) = 97.4 mm. (from Eq. 5.8)

C
(5.9)

0.36 fck bw Xugmax + 0.45 fck (bf - bw) yf

= 0.36 (20) (300) (216) + 0.45 (20) (1000-300) (97.4): 1,030.13 kN.

T = 0.37 r,As, = 0.37 (415) As,
(5.10)

Equating C and T, we have

2 (1080.18) (1000) N

= 2,991.77 2
3’ 0.87(415)N/rnmz mm

Provide 4–28T(2463 mm2) + 3-16T(603 mm2) = 3,066 mm2

Step 3: Computation of Mu
‘xumux 2
Mu, lim d bw d
+ 0-45f;k(bf -bW)yf (d-yf /2) (5.11)

= 0.36 (0.48) {1 - 0.42 (0.48)} (20) (300) (450)2
+ 0.45 (20) (1000 - 300) (97.4) (450 - 97.4/2) = 413.87 kNrn

= 0.36()C“7"“") {1–0.42(

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_____ _____fl!"~_ _ _ _ _ __' _ _ _ _ __r_
3.50
,g.—— 4-2sT + 2-2rJT
f."-l"~::,...fi 1:23.91 mm’)
2.11,} 1'50
1
l EEI-III

Fig. 5.11.4: Example 3. case {iii In)

Ex.3: Determine the moment of resistance of the beam of Fig. 5.11.4 when As,

= 2,591 mm2 (4— 25 T and 2- 20 T). Other parameters are the same as those of Ex.1: bf = 1,000 mm, Df = 100 mm, bw = 300 mm, cover = 50 mm and d = 450 mm. Use M 20 and Fe 415.

Step 1: To determine xu

Assuming xu to be in the flange and the beam is under-reinforced, we have from Eq. 3.16 of Lesson 5:

_ 0.87 f,A,, _ 0.87(415)(2591) _

xu — 129.93 mm > 100 mm
0.36 bf ft, 0.36 (1000) (20)

Since xu > Df, the neutral axis is in web. Here, Df/d = 100/450 = 0.222 > 0.2. So, we have to substitute the term yf from Eq. 5.15 of Lesson 10, assuming Df/ Xu > 0.43 in the equation of C = T from Eqs. 5.16 and 17 of sec. 5.10.4.3 b of Lesson 10. Accordingly, we get:
0.36 fa), bw xu + 0.45 fa), (bf — bw) yf = 0.87 fyAsf
or 0.36 (20) (300) (xu) + 0.45 (20) (1000 — 300) {0.15 xu + 0.65 (100)}
= 0.87 (415) (2591)

or Xu = 169.398 mm < 216 mm (Xu,maX= 0.48 Xu = 216 mm)

So, the section is under—reinforced.
Step 2: To determine Mu

Df/Xu = 100/169.398 = 0.590 > 0.43
This is the problem of case (ill b) of sec. 5.10.4.3 b. The corresponding equations
are Eq. 5.15 of Lesson 10 for yf and Eqs. 5.16 to 18 of Lesson 10 for C, Tand M), respectively. From Eq. 5.15 of Lesson 10, we have:

yf = 0.15 xu+ 0.65 Df = 0.15 (169.398) + 0.65 (100) = 90.409 mm
From Eq. 5.18 of Lesson 10, we have

Mu = 0.36(x,, /d){1 — 0.42(xu/d)} fa), bw d2 + 0.45 fCk(bf — bw) yf(d— yf/2)
or Mu = 0.36 (169.398/450) {1 — 0.42 (169.398/450)} (20) (300) (450) (450)

+ 0.45 (20) (1000 — 300) (90.409) (450 — 90.409/2)

= 138.62+230.56 = 369.18 kNm.

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Fig. 5.11.5: Example 4.1:asei{i~.r ti}

Ex.4: Determine the moment of resistance of the flanged beam of Fig. 5.11.5 with As, = 4,825 mm2 (6— 32 T). Other parameters and data are the same as those of Ex.1: bf = 1000 mm, Df = 100 mm, bw = 300 mm, cover = 50 mm and d = 450 mm. Use M 20 and Fe 415.

Step 1: To determine xu

Assuming xu in the flange of under—reinforced rectangular beam we have
from Eq. 3.16 of Lesson 5:

x _ 0-87 f, A., _ 0.37(415)(4325)
“ 0.36 bf f,, 0.36(1000) (20)

= 241.95 mm > Df

Here, Df/d = 100/450 = 0.222 > 0.2. So, we have to determine yf from Eq. 5.15 and equating Cand Tfrom Eqs. 5.16 and 17 of Lesson 10.

yf = 0.15x,,+ 0.65 D, (5.15)
0.36 fck bw x,, + 0.45 fck (bf - bw)yf = 0.37 1, As, (5.16 and 5.17)

or 0.36 (20) (300) (xu) + 0.45 (20) (1000 — 300) {0.15 xu + 0.65 (100)} = 0.37 (415) (4325)

or 2160 xu + 945 xu = — 409500 + 1742066
or xu = 1332566/3105 = 429.17 mm

Xu,max = 0.48 (450) = 216 mm
Since xu > xffmax, the beam is over—reinforced. Accordingly.

Xu = Xmmax = 216mm.
Step 2: To determine Mu

This problem belongs to case (iv b), explained in sec.5.10.4.4 b of Lesson 10. So, we can determine Mu from Eq. 5.11 of Lesson 10.

M, = 0.36(x,,, ma,/d){1 - 0.42(x,,, ma, /d)} 10,, 5,, d2 + 0.45 fCk(bf - bw) yf(d— yf
/2)
(5.11)

where yf = 0.15Xu,maX + 0.65 Df = 97.4 mm
(5.8)

From Eq. 5.11, employing the value of yf = 97.4 mm, we get:

Mu = 0.36 (0.48) {1 — 0.42 (0.48)} (20) (300) (450) (450)

+ 0.45 (20) (1000 — 300) (97.4) (450 — 97.4/2)
= 167.63 + 246.24 = 413.87 kNm

It is seen that this over—reinforced beam has the same Mu as that of the balanced beam of Example 2.

5.11.4 Summary of Results of Examples 1-4

The results of four problems (Exs. 1-4) are given in Table 5.1 below. All the examples are having the common data except As[.

Table 5.1 Results of Examples 1-4 (Figs. 5.11.2 — 5.11.5)

Ex. No.	Asf (mm2)	Case No.	Section	Mu (kNm)	Remarks

1 1,963 (i) 5.10.4.1 290.06 X), = 98.44 mm < Xu, max (= 216 mm),

Xu < Df(=100 mm),
Under-reinforced, (NA in the

flange).
2 3,066 (ii b) 5.10.4.2 413.87 x.) = xu, max = 216 mm,
(b) Df/d= 0.222 > 0.2,

Balanced, (NA in web).

3 2,591 (ill b) 5.10.4.3 369.18 Xu =169.398 mm < Xu,max(= 216 ('0) mm).

Df/Xu = 0.59 > 0.43,
Under-reinforced, (NA in the

web).
4 4,825 (iv b) 5.10.4.4 413.87 Xu = 241.95 mm > Xu, max (= 216 ('0) mm).

Df/d = 0.222 > 0.2,
Over-reinforced, (NA in web).

It is clear from the above table (Table 5.1), that Ex.4 is an over—reinforced flanged beam. The moment of resistance of this beam is the same as that of balanced beam of Ex.2. Additional reinforcement of 1,759 mm2 (= 4,825 mm2 — 3,066 mm2) does not improve the Mu of the over—reinforced beam. It rather prevents the beam from tension failure. That is why over—reinforced beams are to be avoided. However, if the Mu has to be increased beyond 413.87 kNm, the flanged beam may be doubly reinforced.

5.11.5 Use of SP—16 for the Analysis Type of Problems

Using the two governing parameters (bf /bw) and (Df/d), the Mu./im of balanced flanged beams can be determined from Tables 57-59 of SP-1 6 for the

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three grades of steel (250, 415 and 500). The value of the moment coefficient Mu),-m /bwdzfax of Ex.2, as obtained from SP—16, is presented in Table 5.2 making
linear interpolation for both the parameters, wherever needed. Mu),-m is then calculated from the moment coefficient.

Table 5.2 Mu,/im of Example 2 using Table 58 of SP-1 6

Parameters: (i) bf/bw = 1000/300 = 3.33
(ii) Df/d = 100/450 = 0.222

(Mu)-m/bwdzfax) in N/mm2

Df/d bf/bw
3 4 3.33
0.22 0.309 0.395
0.23 0.314 0.402
0.222 0.31 * 0.3964* 0.339*
* by linear interpolation
Mu lim
So, from Table 5.2, j’, = 0.339
bw d fck

Mu,/im = 0.339 bw dz fck = 0.339 (300) (450) (450) (20) 106 = 411.88

kNm

Mu,lim as obtained from SP—16 is close to the earlier computed value of Mu),-m = 413.87 kNm (see Table 5.1).

5.11.6 Practice Questions and Problems with Answers

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" £3-SET + 2-161'
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300

Fig. 5.11.5-_ o. 1

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Q.1: Determine the moment of resistance of the simply supported doubly reinforced flanged beam (isolated) of span 9 m as shown in Fig. 5.11.6. Assume M 30 concrete and Fe 500 steel.

A.1: Solution of Q.1:

9000

T" = T 300 = 1200
(1,,/b)+4 + W (9000/1500)+4 + m

Effective width bf =

Step 1: To determine the depth of the neutral axis

Assuming neutral axis to be in the flange and writing the equation C = T, we have:
fy A51 = f-Ck bfxu '1' (fsc Asc — f-CC Asa)

Here, d’/d = 65/600 = 0.108 = 0.1 (say). We, therefore, have faa = 353 N/mm2.

From the above equation, we have:

x Z 0.87 (500) (6509) - {(353) (1030) - 0.446 (30) (1030)}
” 0.36 (30) (1200)
So, the neutral axis is in web.

= 191.48 mm>120 rnrn

Df/d = 120/600 = 0.2
Assuming Df/Xu < 0.43, and Equating C= T
fy A51 = f-Ck bw Xu '1' Df '1' (fsc — f-CC) Ago

0.87 (500) (6509) - 1030{353 - 0.446 (30)}- 0.446 (30) (1200 - 300) (120)
0.36 (30) (300)
= 319.92 > 276 mm (xwm = 276 mm)

So, xu = xamax = 276 mm (over—reinforced beam).

$Df/Xu = 120/276 = 0.4347 > 0.43$

Let us assume $Df/Xu > 0.43$. Now, equating C = Twith yf as the depth of flange having constant stress of 0.446 fax. So, we have:

$yf = 0.15Xu+0.65\ Df = 0.15Xu+78$

f-Ck bw Xu '1' f-Ck — bw) yf '1' Age (fsc — f-CC) = fy A51

0.36 (30) (300) xu + 0.446 (30) (900) (0.15 xu + 78)

= 0.87 (500) (6509) — 1030 {353 — 0.446 (30)}
or X.) = 305.63 mm > Xamax. (Xamax = 276 mm)
The beam is over—reinforced. Hence, X.) = Xu,max = 276 mm. This is a problem of case (iv), and we, therefore, consider the case (ii) to find out the moment of resistance in two parts: first for the balanced singly reinforced beam and then for
the additional moment due to compression steel.

Step 2: Determination of xmf,-m for singly reinforced flanged beam

Here, Df/d = 120/600 = 0.2, so yf is not needed. This is aproblem of case (ii a) of sec. 5.10.4.2 of Lesson 10. Employing Eq. 5.7 of Lesson 10, we have:

Mu),-m = 0.36 (x,,,,,,ax/d) {1 — 0.42 (xumax/d)} rsx 5., d2

+ 0.45 fax (bf— bw) Df (d— Df/2)

0.36(0.46) {1 — 0.42(0.46)} (30) (300) (600) (600)
+ 0.45(30) (900) (120) (540)

1,220.20 kNm

M ,.
M,lTn

A . =
W“ 0.87fy d {1 — 0.42 (xm,
(1220.20) (106)

= = 5,794.6152 rnrnz
(0.87)(500)(600)(0.8068)

/d)}

Step 3: Determination of Mug

Total As, = 6,509 mm2, Ast,/im = 5,794.62 mm2

Asfa = 714.33 mm2 and Ass = 1,030 mm2
It is important to find out how much of the total Ass and Asfg are required effectively. From the equilibrium of C and T forces due to additional steel

(compressive and tensile), we have:

(A312) (0-87) (fy) = (Asa) (fsc)

If we assume Ass = 1,030 mm2

= T = 335.34 mm2 > 714.33 rnm2, (714.33 mm2 is the total

0.37(500)

Asfg provided). So, this is not possible.

st2

Now, using Asfg = 714.38 mm2 , we get Ass from the above equation.

A = m(714'38)(0‘87)(500) = 330.326 < 1,030 rnrnz, (1,030 mm2 is

S‘ 353
the total Ass provided).

114,, = 4,, f,, (d-d’) = (330.326) (353) (600-60) = 167.307 kNm

Total moment of resistance = Mu),-m + Mug = 1,220.20 + 167.81 = 1,388.01 kNm

Total As, required = As,,,,-m+As,a = 5,794.62+ 714.33 = 6,509.00 mm2, (provided Asf = 6,509 mm2)

Ass required = 880.326 mm2 (provided 1,030 mm2).

5.11.7 References

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5.11.8 Test 11 with Solutions

Maximum Marks = 50, Maximum Time = 30 minutes
Answer all questions.

TQ.1: Determine Mu,lim of the flanged beam of Ex. 2 (Fig. 5.11.3) with the help of SP—16 using (a) M 20 and Fe 250, (b) M 20 and Fe 500 and (c) compare the results with the Mu),-m of Ex. 2 from Table 5.2 when grades of concrete and steel are M 20 and Fe 415, respectively. Other data are: bf = 1000 mm, Df = 100 mm, bw = 300 mm, cover = 50 mm and d = 450 mm.

(10 X 3 = 30 marks)
A.TQ.1: From the results of Ex. 2 of sec. 5.11.5 (Table 5.2), we have:

Parameters: (i) bf/bw = 1000/300 = 3.33
(ii) Df/d = 100/450 = 0.222

For part (a): When Fe 250 is used, the corresponding table is Table 57 of SP-16. The computations are presented in Table 5.3 below:

Table 5.3 (M..,r.-n./b.. dz rsx) in N/mmz Of TO.1 (PART a for M 20 and Fe 250)

(Mam/bwdzrsx) in N/mmz

Df/d bf/bw
3 4 3.33
0.22 0.324 0.411
0.23 0.330 0.421
0.222 0.3252* 0413* 0.354174*

0 by linear interpolation

Mam,/bf, dz rsx = 0.354174 = 0.354 (say)

80, Mu),-m = (0.354) (300) (450) (450) (20) N mm = 430.11 kNm

For part (b): When Fe 500 is used, the corresponding table is Table 59 of SP-16. The computations are presented in Table 5.4 below:

Table 5.4 (M..,r.-n./b.. dz rsx) in N/mmz Of To.1 (PART b for M 20 and Fe 500)

(Mam/bwdzrsx) in N/mmz

Df/d bf/bw
3 4 3.33
0.22 0.302 0.386

0.23 0.306 0.393
0.222 0.3028* 0.3874* 0.330718*

* by linear interpolation
Mu,/im/bw dz fax = 0.330718 = 0.3307 (say)
So, Mu),-m = (0.3307) (300) (450) (450) (20) mm = 401.8 kNm
For part Comparison of results of this problem with that of Table 5.2 (M 20
an e

415) is given below in Table 5.5.

Table 5.5 Comparison of results of Mu),-m

Sl. No.	Grade of Steel	Mu),-m (kNm)
1	Fe 250	430.11
2	Fe 415	411.88
3	Fe 500	401.80

It is seen that Mu),-m of the beam decreases with higher grade of steel for a particular grade of concrete.

TQ.2: With the aid of SP—16, determine separately the limiting moments of resistance and the limiting areas of steel of the simply supported isolated, singly reinforced and balanced flanged beam of Q.1 as shown in Fig. 5.11.6 if the span = 9 m. Use M 30 concrete and three grades of steel, Fe 250, Fe 415 and Fe 500, respectively. Compare the results obtained above with that of Q.1 of sec. 5.11.6, when balanced.

(15 + 5 = 20 marks)
A.TQ.2: From the results of O.1 sec. 5.11.6, we have:

Parameters: (i) bf/bw = 1200/300 = 4.0
(ii)Df/d = 120/600 = 0.2

For Fe 250, Fe 415 and Fe 500, corresponding tables are Table 57, 58 and 59, respectively of SP—16. The computations are done accordingly. After computing the limiting moments of resistance, the limiting areas of steel are determined as
explained below. Finally, the results are presented in Table 5.6 below:

M
A . =
W“ 0.87fy d {1 — 0.42 (xm, /d)}

u Jim

Table 5.6 Values of Mu),-m in N/mmz Of To.2

Grade of Fe / o.1 of sec. 5.11.6	(Mu),-m/bw dz rsx) (N/mmz)	Mu),-m(kNm)	Asff,-m(mm2)
Fe 250	0.39	1, 263.60	12,455.32
Fe 415	0.379	1,227.96	7,099.73
Fe 500	0.372	1, 205.23	5,723.76
o.1 of sec. 5.11.6 (Fe 415)		1,220.20	5,794.62

The maximum area of steel allowed is .04 b D = (.04) (300) (660) = 7,920

mm^2 . Hence, Fe 250 is not possible in this case.

5.11.9 Summary of this Lesson

This lesson mentions about the two types of numerical problems (i) analysis and (ii) design types. In addition to explaining the steps involved in solving the analysis type of numerical problems, several examples of analysis type of problems are illustrated explaining all steps of the solutions both by direct computation method and employing SP—16. Solutions of practice and test problems will give readers the confidence in applying the theory explained in Lesson 10 in solving the numerical problems.