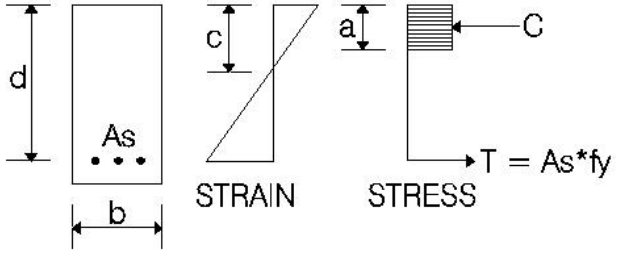
STRUCTWARE®

Program Documentation

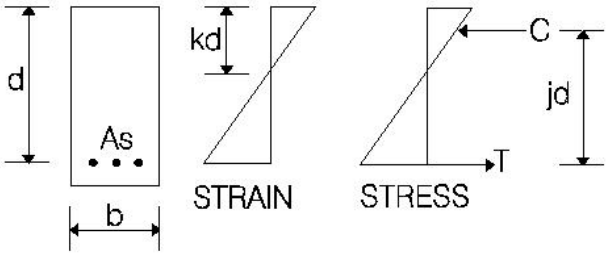
for

REBEAM®

Reinforced Concrete Beam Design Program



STRENGTH DESIGN



WORKING STRESS DESIGN

CONTENTS

INTRODUCTION

REBEAM may be used to design or review a reinforced concrete beam section in accordance with any American or Canadian concrete code. Design criteria include ACI-318, AASHTO, AREMA, AASHTO LRFD, CSA A23.3, CAN/CSA-S6 or OHBDC (Note: OHBDC was removed in REBEAM version 5.00). The program has built in default values for material strength, stress block, strength reduction factors and resistance factors which are set based on the selected design criteria. These factors may be modified as needed by the user. Review options include checks for ultimate strength, service load stresses, fatigue and crack control.

The online help file and graphical interface is shown in Section B. Verification problems are included in Section C. Additional information is contained in the following files installed in the program directory.

License.txt - The license agreement contains the terms and conditions for use of this program and documentation.

Readme.txt – The installation instructions, copyright and trademark notices and version history is contained in this file.

The following steps are recommended for users new to the program or specific features.

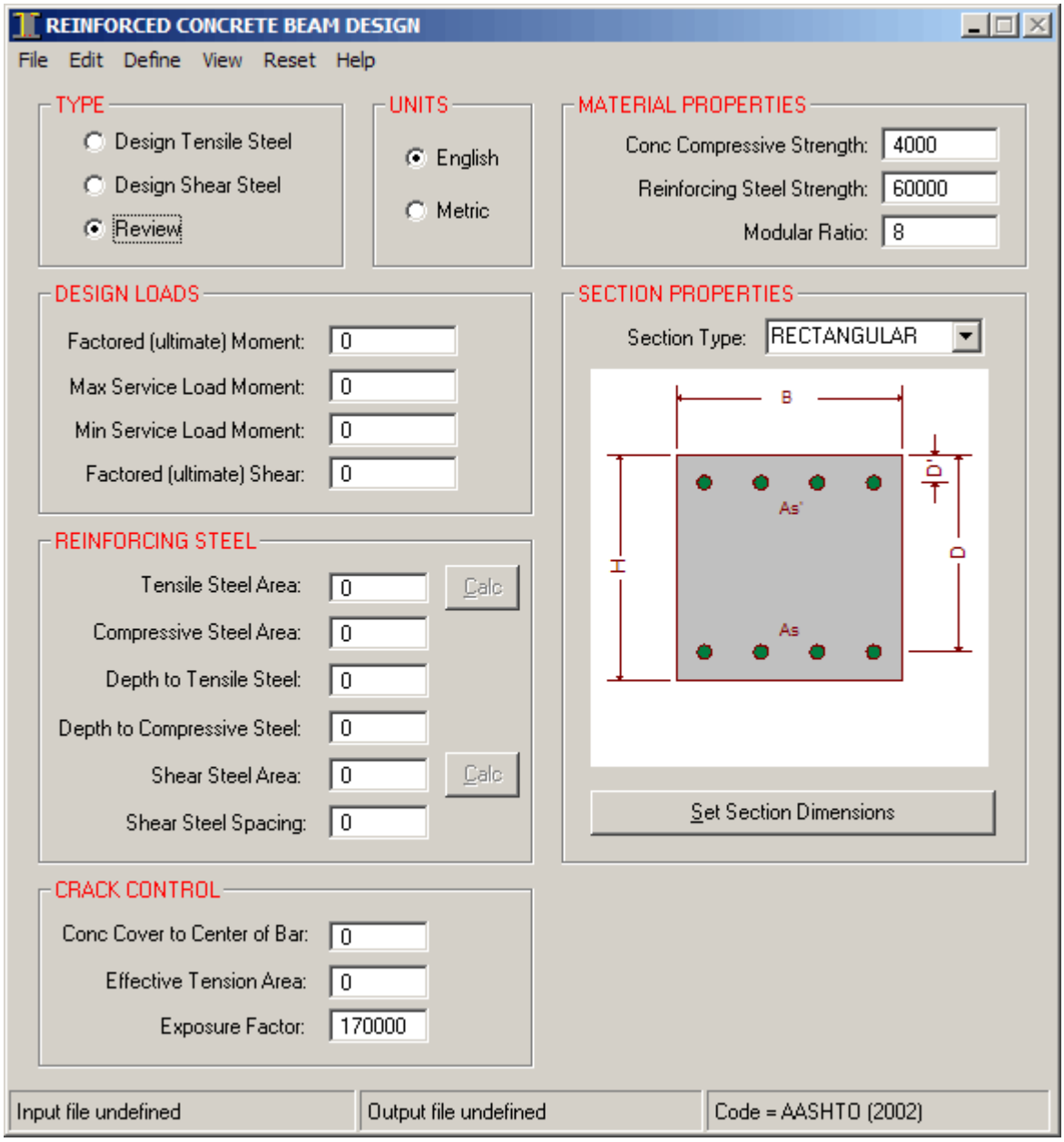
1. To learn how to use the program, view the Flash Demonstration Movie that is installed along with the program and read the "Instructions" section of the help file.

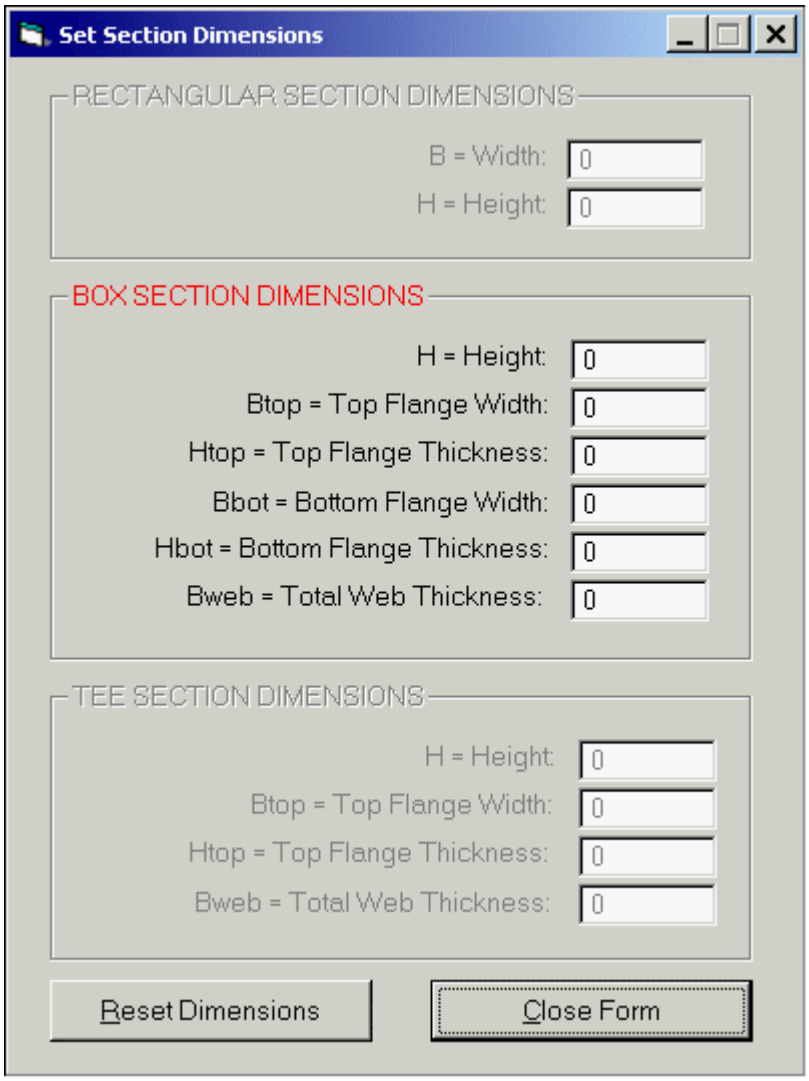
2. To apply this program to a specific problem, find a similar case in the Verification Problems section of this document. Run the program to see if you can reproduce the results. If your problem varies significantly from the Verification Problem, you should perform manual calculations for verification.

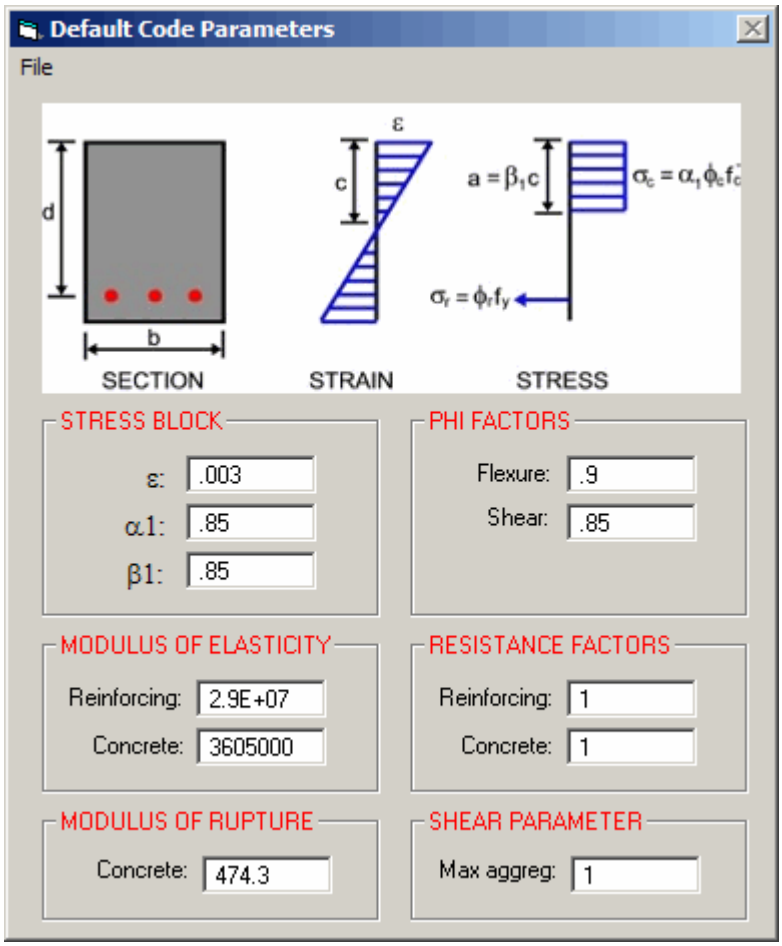
ONLINE HELP FILE

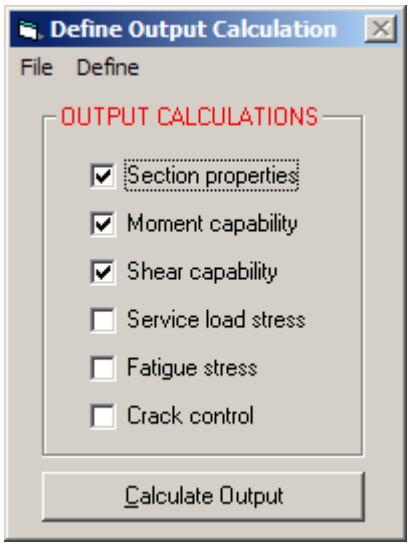
Rebeam help

GRAPHICAL INTERFACE




Set Section Dimensions
RECTANGULAR SECTION DIMENSIONS
B = Width:
0
H = Height:
0
BOX SECTION DIMENSIONS
H = Height:
0
Btop = Top Flange Width:
0
Htop = Top Flange Thickness:
0
Bbot = Bottom Flange Width:
0
Hbot = Bottom Flange Thickness:
0
Bweb = Total Web Thickness:
0
TEE SECTION DIMENSIONS
H = Height:
0
Btop = Top Flange Width:
0
Htop = Top Flange Thickness:
0
Bweb = Total Web Thickness:
0
Reset Dimensions
Close Form


Default Code Parameters
File
d
b
c
ε
a = β1c
σc = α1ϕcf'c
σr = ϕrfy
SECTION
STRAIN
STRESS
STRESS BLOCK
ε: .003
α1: .85
β1: .85
PHI FACTORS
Flexure: .9
Shear: .85
MODULUS OF ELASTICITY
Reinforcing: 2.9E+07
Concrete: 3605000
RESISTANCE FACTORS
Reinforcing: 1
Concrete: 1
MODULUS OF RUPTURE
Concrete: 474.3
SHEAR PARAMETER
Max aggreg: 1


Define Output Calculation
File
Define
OUTPUT CALCULATIONS
Section properties
Moment capability
Shear capability
Service load stress
Fatigue stress
Crack control
Calculate Output

VERIFICATION PROBLEMS

1. Rectangular section (AASHTO)
   - A. Review problem
   - B. Tension steel
   - C. Moment capability

2. Rectangular section (AASHTO)
   - A. Review problem
   - B. Tension and compression steel
   - C. Moment capability

3. Tee section (AASHTO)
   - A. Review problem
   - B. Tension steel
   - C. Service load stresses

4. Rectangular section (AASHTO)
   - A. Review problem
   - B. Tension and compression steel
   - C. Service load stresses

5. Rectangular section (AASHTO)
   - A. Design problem
   - B. Required tension steel

6. Tee section (AASHTO)
   - A. Design and review problem
   - B. Required tension steel
   - C. Moment capability
   - D. Service load stresses
   - E. Fatigue stresses
   - F. Crack control stresses

7. Tee section (CSA A23.3)
   - A. Design and review problem
   - B. Required tension steel
   - C. Moment capability
   - D. Service load stresses
   - E. Crack control stresses

8. Tee section (ACI 318)
   - A. Design and review problem
   - B. Required tension steel
   - C. Moment capability
   - D. Crack control calculations

9. Rectangular section (OHBDC) (Removed in version 5.00)
   - A. Review problem
   - B. Tension steel
   - C. Moment capability
   - D. Service load stresses
   - E. Crack control calculations

10. Box section (AASHTO LRFD)
    - A. Design and review problem
    - B. Required tension steel
    - C. Moment capability
    - D. Service load stresses
    - E. Fatigue stresses
    - F. Crack control stresses

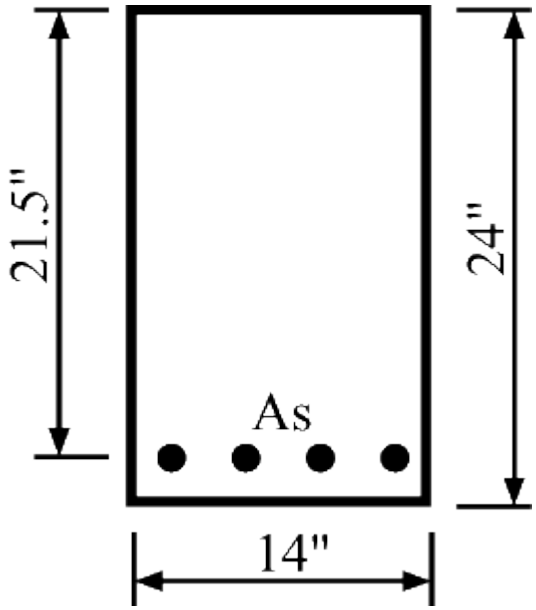
11. Shear calculations (Added in version 5.00)

12. LRFD shear calculation with stress less than table minimum

13. Tee section (CAN/CSA S-6)
    - A. Review problem
    - B. Moment capability
    - C. Service load stresses
    - D. Crack control

VERIFICATION PROBLEM NO. 1

AASHTO code
Ref. Wang and Salmon, "Reinforced Concrete Design", 5th edition, Example 3.4.1



f'_c = 5000 psi (34.5 MPa)
f_y = 50 ksi (345 MPa)

(4) #10 bars
A_s = 5.08 in^2 (3277 mm^2)

Results to check:

a = 4.27" (108 mm)
M_n = 410 k-ft (556 kN-m)

Perform calculations to verify other results:

$E_c = 57000(5000)^{1/2}$ = 4.0305E+06 psi
$E_c = 4700(34.5)^{1/2}$ = 27606 MPa

α_1 = 0.85
β_1 = 0.85 - (5000 - 4000) x 0.05 / 1000 = 0.800

$I_g = 14(24)^3/12 = 16128$ in^4 (6.713E+9 mm^4)
$14y^2/2 = 7 \times 5.08(21.5 - y)$
$7y^2 + 35.56y - 764.54 = 0$
$y = 8.215$ in
$I_{cr} = 14(8.215)^3/3 + 7 \times 5.08(21.5 - 8.215)^2 = 8863$ in^4 (3.689E+9 mm^4)

$\rho_b = (0.85 \times 0.80 \times 5 / 50)[29000 \times 0.003 / (29000 \times 0.003 + 50)] = 0.0432$
$A_{smax} = 0.75 \times 0.0432 \times 14 \times 21.5 = 9.75$ in^2 (6290 mm^2)

$1.2M_{cr} = 1.2 \times 16128 \times 7.5(5000)^{1/2} / (12 \times 12000) = 71.28$ k-ft (96.6 kN-m)

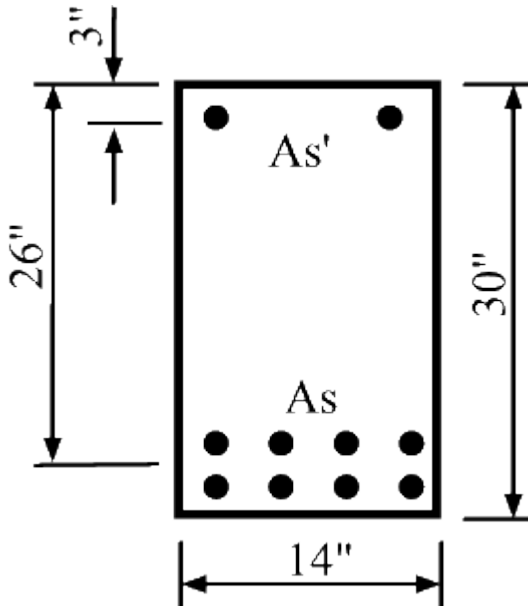
```
Verification problem 1

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                       10/28/06, 7:41 pm

Output file = v1.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 0.85
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8000
     Maximum concrete strain             = 0.0030
```

```
M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 5000
     Concrete modulus of elasticity      = 4.0305E+06
     Concrete modulus of rupture         = 530.3
     Reinforcing yield strength          = 50000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 7
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5.08
     Depth to tensile reinf     = 21.5
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
=====================================================

     Factored (ultimate) moment  = 0
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
=====================================================

RECTANGULAR SECTION:

     Width  = 14
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.6128E+04
     Gross section modulus       = 1.3440E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.8632E+03

M O M E N T   R E V I E W   C A L C U L A T I O N S
=====================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 7.1272E+01
```

```
MAXIMUM REINFORCING:

     Maximum tensile reinf area = 9.7484E+00

MOMENT CAPABILITY:

     Ultimate moment capability  = 4.0990E+02
     Stress block depth          = 4.2689E+00
```

VERIFICATION PROBLEM NO. 2

AASHTO code
Ref. Wang and Salmon, "Reinforced Concrete Design", 5th edition, Example 3.10.1



f'_c = 5000 psi (34.5 MPa)
f_y = 60 ksi (414 MPa)

(8) #10 bars
A_s = 10.16 in^2 (6555 mm^2)

(2) #8 bars
A_s' = 1.58 in^2 (1019 mm^2)

Results to check:

a = 8.77" (223 mm)
M_n = 1110 k-ft (1505 kN-m)

Perform calculations to verify other results:

$I_g = 14(30)^3/12 = 31500\ in^4$ (1.311E+10 mm^4)
$14y^2/2 + 6 \times 1.58(y - 3) = 7 \times 10.16(26 - y)$
$7y^2 + 80.6y - 1878 = 0$
y = 11.60 in
$I_{cr} = 14(11.6)^3/3 + 7 \times 10.16(26 - 11.6)^2 + 6 \times 1.58(11.6 - 3)^2 = 22733\ in^4$ (9.462E+9 mm^4)

ρ_b = (0.85 x 0.80 x 5 / 60)[29000 x 0.003 / (29000 x 0.003 + 60)] = 0.0335
A_{smax} = 0.75 x 0.0335 x 14 x 26 + 1.58 = 10.74 in^2 (6929 mm^2)

$1.2M_{cr}$ = 1.2 x 31500 x 7.5(5000)$^{1/2}$ / (15 x 12000) = 111.4 k-ft (151.0 kN-m)

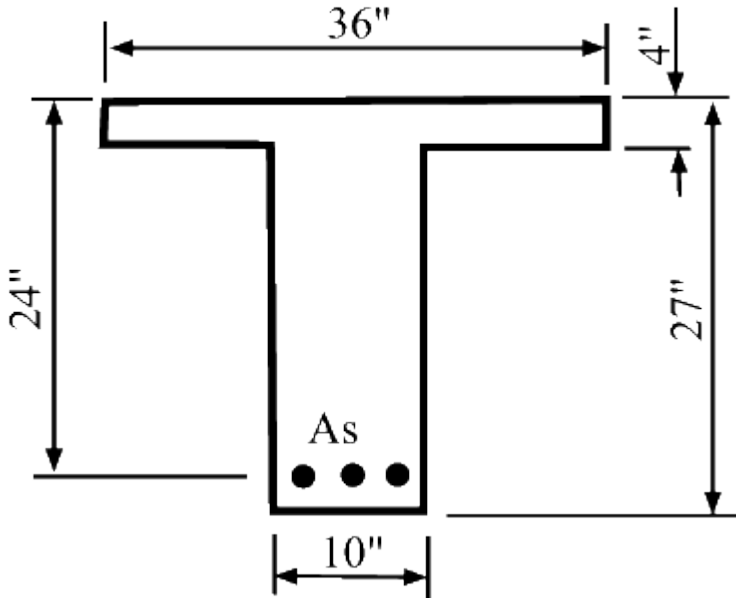
c = 8.77 / 0.8 = 11.0 in
Stress in compression steel = 29000(11.0 - 3)(.003) / 11.0 = 63.3 > 60 ksi

```
Verification problem 2

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                       10/28/06, 7:45 pm

Output file = v2.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor           = 1.00
     Shear reduction factor             = 0.85
     Concrete resistance factor         = 1.00
     Reinforcing resistance factor      = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8000
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength      = 5000
     Concrete modulus of elasticity     = 4.0305E+06
     Concrete modulus of rupture        = 530.3
     Reinforcing yield strength         = 60000
     Reinforcing modulus of elasticity  = 2.9000E+07
     Modular ratio                      = 7
     Maximum aggregate size             = 1.000
```

```
R E I N F O R C I N G   S T E E L
==================================================

     Tensile reinf area         = 10.16
     Depth to tensile reinf     = 26
     Compressive reinf area     = 1.58
     Depth to compressive reinf = 3
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 0
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 14
     Height = 30

PROPERTIES:

     Gross moment of inertia     = 3.1500E+04
     Gross section modulus       = 2.1000E+03
     Distance to neutral axis    = 1.5000E+01
     Cracked moment of inertia   = 2.2733E+04

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 1.1136E+02

MAXIMUM REINFORCING:

     Maximum tensile reinf area = 1.0736E+01

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.1091E+03
     Stress block depth          = 8.7650E+00
     Stress in compression steel = 6.0000E+04
```

VERIFICATION PROBLEM NO. 3

AASHTO code
Ref. McCormac, "Design of Reinforced Concrete", Example 2.5



f'_c = 3000 psi (20.7 MPa)
f_y = 60 ksi (414 MPa)

(3) #9 bars
A_s = 3.00 in^2 (1935 mm^2)

M_s = 110 k-ft (149 kN-m)

Results to check:

f_c = 638 psi (4.40 MPa)
f_s = 19696 psi (136 MPa)

Perform calculations to verify other results:

$E_c = 57000(3000)^{1/2}$ = 3.122E+06 psi
$E_c = 4700(20.7)^{1/2}$ = 21384 MPa

α_1 = 0.85
β_1 = 0.85

y_{cg} = (26 x 4 x 2 + 10 x 27 x 13.5) / 374 = 10.3
I_g = 26(4)^3/12 + 10(27)^3/12 + 104(10.3 - 2)^2 + 270(13.5 - 10.3)^2 = 26470 in^4 (1.102E+10 mm^4)
10y^2/2 + 36 x 4(y - 2) = 9 x 3.0(24 - y)
5y^2 + 171y - 936 = 0
y = 4.8 in
I_{cr} = 10(4.8)^3 / 3 + 26(4)^3 / 12 + 104(4.8 - 2)^2 + 9 x 3.0(24 - 4.8)^2 = 11276 in^4 (4.693E+9 mm^4)

c_b = 24 x 0.003 / (0.003 + 60 / 29000)] = 14.2 in
a_b = 14.2 x 0.85 = 12.07 in
$A_{sflange}$ = 26 x 4 x 0.85 x 3 / 60 = 4.42 in^2
A_{sweb} = 10 x 12.07 x 0.85 x 3 / 60 = 5.13 in^2
A_{smax} = 0.75(4.42 + 5.13) = 7.16 in^2 (4619 mm^2)

1.2M_{cr} = 1.2 x 26470 x 7.5(3000)$^{1/2}$ / (16.7 x 12000) = 65.1 k-ft (88.3 kN-m)
I_e = (54.25 / 110)^3(26470) + [1 - (54.25 / 110)^3](11276) = 13099 in4
(5.452E+9 mm^4)

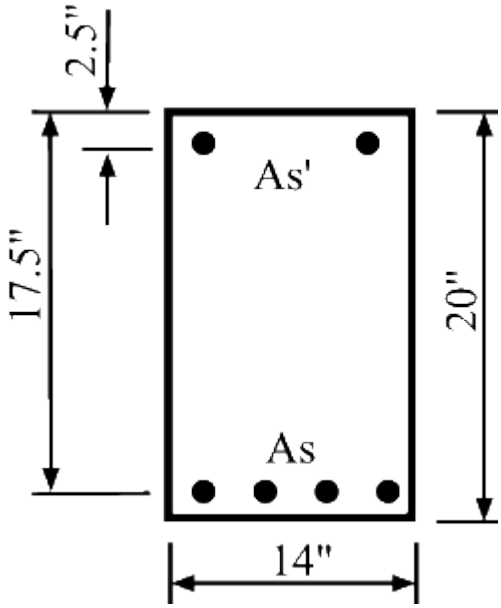
```
Verification problem 3

* * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 6:19 pm

Output file = v3.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor           = 0.90
     Shear reduction factor             = 0.85
     Concrete resistance factor         = 1.00
     Reinforcing resistance factor      = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030
```

```
M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 3000
     Concrete modulus of elasticity      = 3.1220E+06
     Concrete modulus of rupture         = 410.8
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 9
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 3
     Depth to tensile reinf     = 24
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
=====================================================

     Factored (ultimate) moment  = 0
     Maximum service load moment = 110
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
=====================================================

TEE SECTION:

     Height               = 27
     Top flange width     = 36
     Top flange thickness = 4
     Total web thickness  = 10

PROPERTIES:

     Gross moment of inertia     = 2.6471E+04
     Gross section modulus       = 1.5853E+03
     Distance to neutral axis    = 1.0302E+01
     Cracked moment of inertia   = 1.1207E+04
     Effective moment of inertia = 1.3040E+04

M O M E N T   R E V I E W   C A L C U L A T I O N S
=====================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 6.5123E+01
```

```
MAXIMUM REINFORCING:

     Maximum tensile reinf area = 7.1634E+00

MOMENT CAPABILITY:

     Ultimate moment capability  = 3.1076E+02
     Stress block depth          = 1.9608E+00

SERVICE LOAD STRESS:

     Maximum steel stress    = 1.9702E+04
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 6.3783E+02
     Minimum concrete stress = 0.0000E+00
```

VERIFICATION PROBLEM NO. 4

AASHTO code
Ref. McCormac, "Design of Reinforced Concrete", Example 2.6



f'_c = 2500 psi (17.2 MPa)
f_y = 60 ksi (414 MPa)

(4) #9 bars
A_s = 4.00 in^2 (2581 mm^2)

(2) #9 bars
A_s = 2.00 in^2 (1290 mm^2)

M_s = 118 k-ft (160 kN-m)

Results to check:

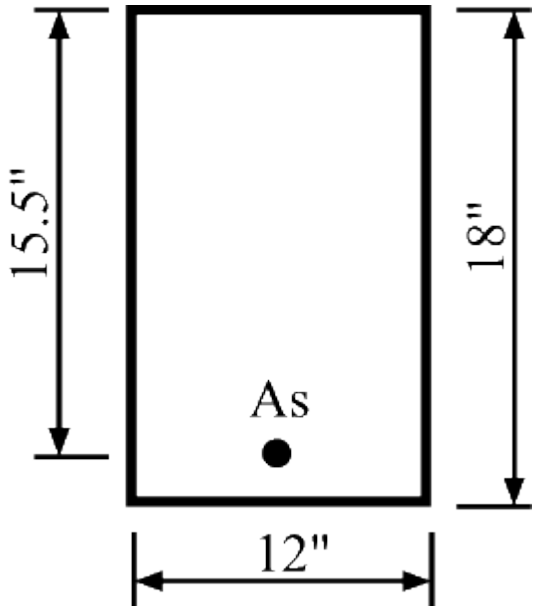
f_c = 1357 psi (9.36 MPa)
f_s = 23253 psi (160 MPa)

```
Verification problem 4

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 6:20 pm

Output file = v4.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor           = 0.90
     Shear reduction factor             = 0.85
     Concrete resistance factor         = 1.00
     Reinforcing resistance factor      = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 2500
     Concrete modulus of elasticity      = 2.8500E+06
     Concrete modulus of rupture         = 375
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 10
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 4
     Depth to tensile reinf     = 17.5
     Compressive reinf area     = 2
```

```
     Depth to compressive reinf = 2.5
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 0
     Maximum service load moment = 118
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 14
     Height = 20

PROPERTIES:

     Gross moment of inertia     = 9.3333E+03
     Gross section modulus       = 9.3333E+02
     Distance to neutral axis    = 1.0000E+01
     Cracked moment of inertia   = 6.3751E+03
     Effective moment of inertia = 6.4197E+03

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 3.5000E+01

MAXIMUM REINFORCING:

     Maximum tensile reinf area = 5.2738E+00

MOMENT CAPABILITY:

     Ultimate moment capability  = 2.7054E+02
     Stress block depth          = 4.8985E+00
     Stress in compression steel = 4.9259E+04

SERVICE LOAD STRESS:

     Maximum steel stress    = 2.3243E+04
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 1.3581E+03
     Minimum concrete stress = 0.0000E+00
```

VERIFICATION PROBLEM NO. 5

AASHTO code
Ref. McCormac, "Design of Reinforced Concrete", Example 4.4



f'_c = 3000 psi (20.7 MPa)
f_y = 40 ksi (276 MPa)

M_u = 100 k-ft (136 kN-m)

Results to check:

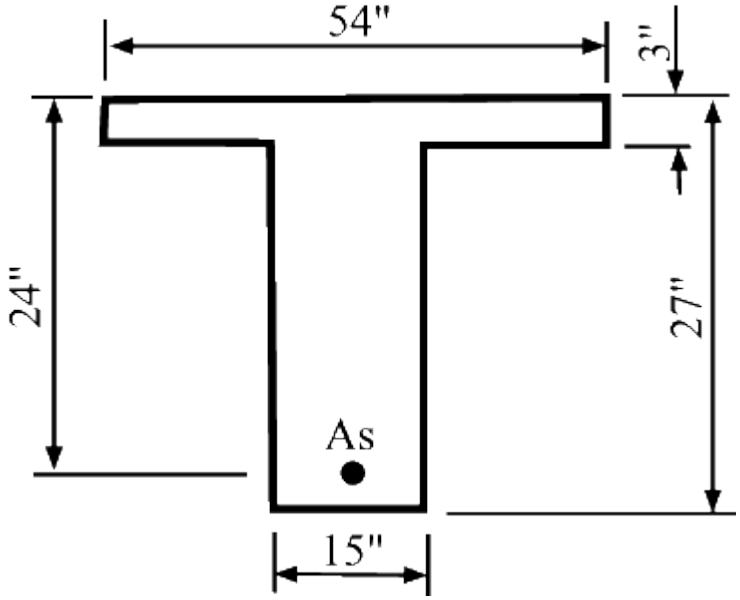
Required A_s = 2.39 in^2 (1542 mm^2)

```
Verification problem 5

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 6:20 pm

Output file = v5.out

Moment design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.85
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 3000
     Concrete modulus of elasticity      = 3.1220E+06
     Concrete modulus of rupture         = 410.8
     Reinforcing yield strength          = 40000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 9
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Depth to tensile reinf     = 15.5
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 18

PROPERTIES:

     Gross moment of inertia     = 5.8320E+03
     Gross section modulus       = 6.4800E+02
     Distance to neutral axis    = 9.0000E+00
     Cracked moment of inertia   = 2.8055E+03

M O M E N T   D E S I G N   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 2.6620E+01
     Design moment              = 1.0000E+02

MAXIMUM REINFORCING:

     Maximum tensile reinf area  = 5.1783E+00

COMPUTED REINFORCING:

     Stress block depth          = 3.1265E+00
     Required tensile reinf area = 2.3920E+00
```

VERIFICATION PROBLEM NO. 6

AASHTO code
Ref. McCormac, "Design of Reinforced Concrete", Example 5.4



f'_c = 3000 psi (20.7 MPa)
f_y = 50 ksi (345 MPa)

M_u = 858 k-ft (1163 kN-m)

Results to check:

Required A_s = 10.41 in^2 (6716 mm^2)

```
Verification problem 6

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                       10/28/06, 7:53 pm

Output file = v6.out

Moment design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.85
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 3000
     Concrete modulus of elasticity      = 3.1220E+06
     Concrete modulus of rupture         = 410.8
     Reinforcing yield strength          = 50000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 9
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Depth to tensile reinf     = 24
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 858
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

TEE SECTION:

     Height               = 27
     Top flange width     = 54
     Top flange thickness = 3
     Total web thickness  = 15

PROPERTIES:

     Gross moment of inertia     = 3.7763E+04
     Gross section modulus       = 2.3326E+03
     Distance to neutral axis    = 1.0810E+01
     Cracked moment of inertia   = 3.1470E+04

M O M E N T   D E S I G N   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 9.5821E+01
     Design moment              = 8.5800E+02

MAXIMUM REINFORCING:

     Maximum tensile reinf area  = 1.1908E+01

COMPUTED REINFORCING:

     Stress block depth          = 5.8663E+00
     Required tensile reinf area = 1.0455E+01
```

Perform design review to verify remaining REBEAM calculations:

A_s = 10.16 in^2 (6555 mm^2)
M_{max} = 200 + 340 = 540 k-ft (732 kN-m)
M_{min} = 200 k-ft (271 kN-m)

Verify A_{smax} = 11.9 in^2 (7677 mm^2) per original example.

Verify other output with the following calculations:

$\rho = A_s / (B_{top} * d) = 0.00784$
$k = [(\rho * n)^2 + 2 * \rho * n]^{1/2} - \rho * n = 0.312$
k * d = 7.5" > 3" Therefore neutral axis in web

$C1 = B_{web} / 2 = 7.5$
$C2 = (B_{top} - B_{web}) * H_{top} + n * A_s = 208.44$
$C3 = -(B_{top} - B_{web}) * H_{top} \text{ ^ } 2 / 2 - n * A_s * d = -2370$

$x = (-C2 + Sqr(C2^2 - 4 * C1 * C3)) / (2 * C1) = 8.67$

$XI = (B_{top} - B_{web}) * H_{top} \text{ ^ } 3 / 12 + B_{web} * x^3 / 12 + (B_{top} - B_{web}) * H_{top} * (x - H_{top} / 2)^2 + B_{web} * x * (x / 2)^2 + n * A_s * (d - x)^2$

XI = 30792

Sc = XI / x = 3552
Ss = XI / ((d - x) * n) = 223.2

fcmax = Mmax * 12000 / Sc = 1824 psi (12.58 MPa)
fsmax = Mmax * 12000 / Ss = 29032 psi (200.2 MPa)
fcmin = Mmin * 12000 / Sc = 676 psi (4.661 MPa)
fsmin = Mmin * 12000 / Ss = 10753 psi (74.14 MPa)

Fatigue stress range = 29032 - 10753 = 18279 psi (126 MPa)
Allow stress = 23400 - 0.33 x 10753 = 19852 psi (137 MPa)

Allow crack stress = $170*1000/(3 * 90)^{1/3}$ = 26351 psi (182 MPa)
Maximum stress at crack = 29032 psi (200.2 MPa)

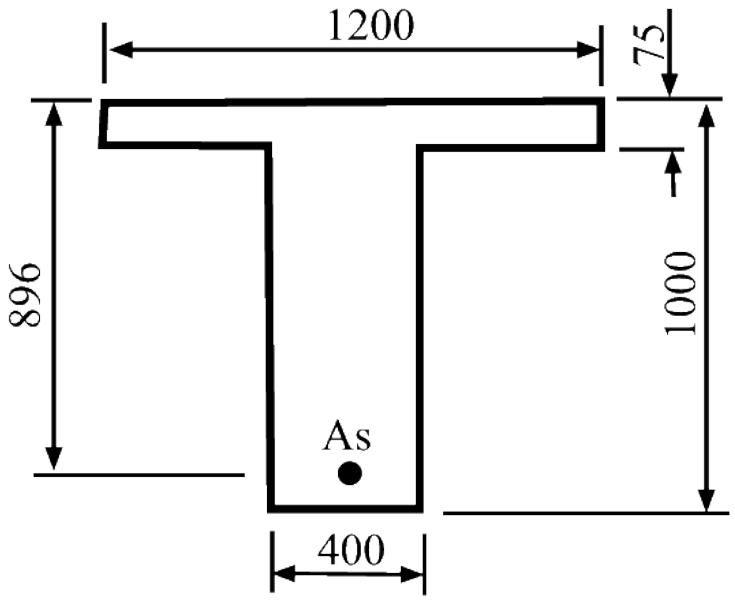
```
Verification problem 6 review

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                         *
*           P R O G R A M   R E B E A M                   *
*                                                         *
*                    OUTPUT DATA                          *
*                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                       10/28/06, 9:08 pm

Output file = v6r.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor           = 0.90
     Shear reduction factor             = 0.85
     Concrete resistance factor         = 1.00
     Reinforcing resistance factor      = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 3000
     Concrete modulus of elasticity      = 3.1220E+06
     Concrete modulus of rupture         = 410.8
     Reinforcing yield strength          = 50000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 9
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 10.16
     Depth to tensile reinf     = 24
     Compressive reinf area     = 0
```

```
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 858
     Maximum service load moment = 540
     Minimum service load moment = 200
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

TEE SECTION:

     Height               = 27
     Top flange width     = 54
     Top flange thickness = 3
     Total web thickness  = 15

PROPERTIES:

     Gross moment of inertia     = 3.7763E+04
     Gross section modulus       = 2.3326E+03
     Distance to neutral axis    = 1.0810E+01
     Cracked moment of inertia   = 3.0850E+04
     Effective moment of inertia = 3.0873E+04

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 9.5821E+01
     Design moment              = 8.5800E+02

MAXIMUM REINFORCING:

     Maximum tensile reinf area = 1.1908E+01

MOMENT CAPABILITY:

     Ultimate moment capability  = 8.3774E+02
     Stress block depth          = 5.4810E+00

     *** Design moment exceeds capacity ***
```

```
SERVICE LOAD STRESS:

     Maximum steel stress    = 2.8985E+04
     Minimum steel stress    = 1.0735E+04
     Maximum concrete stress = 1.8206E+03
     Minimum concrete stress = 6.7428E+02

FATIGUE:

     Steel stress range             = 1.8250E+04
     Allowable fatigue stress range = 1.9857E+04

CRACK CONTROL:

     Concrete cover            = 3
     Effective tension area    = 90
     Exposure factor           = 170000
     Maximum steel stress      = 2.8985E+04
     Allowable cracking stress = 2.6351E+04
```

VERIFICATION PROBLEM NO. 7

CSA A23.3 code
Ref. CPCA, "Concrete Design Handbook", 2nd edition, Example 2.7



f'_c = 30 MPa
f_y = 400 MPa

M_f = 1500 kN-m

d_c = 66 mm
A = 240 MPa
z = 30000 N/mm

The design calculation determined the required steel area A_s = 5221 mm^2
Perform review calculations with: A_s = 5600 mm^2 and M_{max} = 1000 kN-m.

α_1 = 0.85 - 0.0015 x 30 = 0.805
β_1 = 0.97 - 0.0025 x 30 = 0.895

$E_c = 4500(30)^{1/2}$ = 24648 MPa

y_{cg} = (800 x 75 x 37.5 + 400 x 1000 x 500) / 460000 = 440 mm
$I_g = 800(75)^3/12 + 400(1000)^3/12 + 60000(402.5)^2 + 400000(60)^2$
I_g = 4.452E+10 mm^4
$1.2Mcr = 1.2 \times 0.6(30)^{1/2} \times 4.452E+10 / [(1000 - 440) \times 1000000]$ = 314 kN-m

$400y^2/2 + 60000(y - 37.5) = 8 \times 5600(896 - y)$
$200y^2 + 104800y - 42390800 = 0$
y = 268 mm
$I_{cr} = 400(268)^3 / 3 + 800(75)^3 / 12 + 60000(230.5)^2 + 8 \times 5600(628)^2$
I_{cr} = 2.345E+10 mm^4

$S_c = I_{cr} / y$ = 87500000
$S_s = I_{cr} / ((896 - 268) * 8)$ = 4667596

f_{cmax} = 1000 * 1000000 / 87500000 = 11.43 MPa
f_{smax} = 1000 * 1000000 / 4667596 = 214 MPa

$f_{cr} = 30000 / (66 \times 10400)^{1/3}$ = 342 MPa > 0.6 x 400 = 240 MPa

Tension steel is assumed to yield.
with a = 153.2 mm
c = 153.2 / 0.895 = 171 mm
c/d = 171 / 896 = 0.191
Max c/d = 700 / (700 + 400) = 0.636
T = 0.85 x 400 x 5600 = 1904000 N
C_{web} = 0.65 x 0.805 x 30 x 153.2 x 400 = 961943 N
C_{flange} = 0.65 x 0.805 x 30 x 800 x 75 = 941850 N
M_r = 961.943 x (0.896 - 0.1532 / 2) + 941.85 x (0.896 - 0.075 / 2) = 1597 kN-m

```
Verification problem 7

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 6:22 pm

Output file = v7.out

Moment design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CSA A23.3 (2004)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor           = 1.00
     Shear reduction factor             = 1.00
     Concrete resistance factor         = 0.65
     Reinforcing resistance factor      = 0.85

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8050
     Ratio of depth of compression block = 0.8950
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 30
     Concrete modulus of elasticity      = 2.4648E+04
     Concrete modulus of rupture         = 3.286
     Reinforcing yield strength          = 400
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Depth to tensile reinf     = 896
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 1500
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

TEE SECTION:

     Height               = 1000
     Top flange width     = 1200
     Top flange thickness = 75
     Total web thickness  = 400

PROPERTIES:

     Gross moment of inertia     = 4.4522E+10
     Gross section modulus       = 7.9457E+07
     Distance to neutral axis    = 4.3967E+02
     Cracked moment of inertia   = 2.2237E+10

M O M E N T   D E S I G N   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 3.1331E+02
     Design moment              = 1.5000E+03

MAXIMUM REINFORCING:

     c/d                         = 1.6551E-01
     Maximum c/d                 = 6.3636E-01

COMPUTED REINFORCING:

     Stress block depth          = 1.3273E+02
     Required tensile reinf area = 5.2210E+03
```

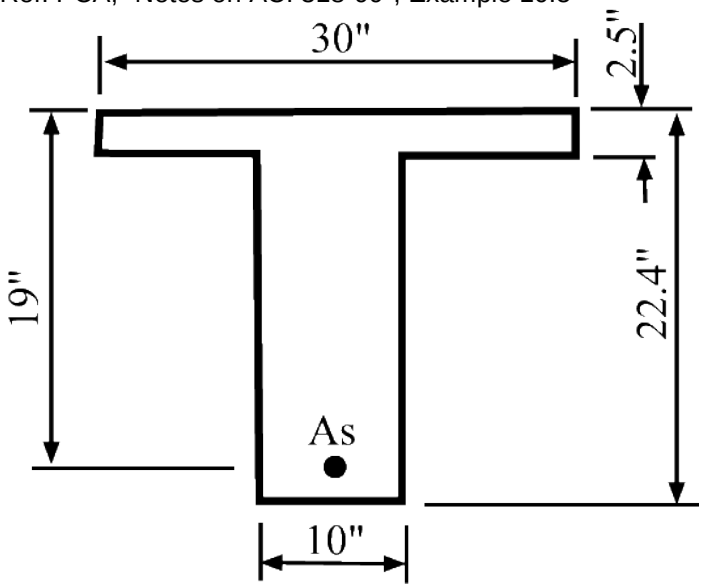
```
Verification problem 7 review

* * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                       10/28/06, 9:02 pm

Output file = v7r.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CSA A23.3 (2004)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor           = 1.00
     Shear reduction factor             = 1.00
     Concrete resistance factor         = 0.65
     Reinforcing resistance factor      = 0.85

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8050
     Ratio of depth of compression block = 0.8950
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength      = 30
     Concrete modulus of elasticity     = 2.4648E+04
     Concrete modulus of rupture        = 3.286
     Reinforcing yield strength         = 400
     Reinforcing modulus of elasticity  = 2.0000E+05
     Modular ratio                      = 8
     Maximum aggregate size             = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5600
     Depth to tensile reinf     = 896
     Compressive reinf area     = 0
```

```
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 1500
     Maximum service load moment = 1000
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

TEE SECTION:

     Height               = 1000
     Top flange width     = 1200
     Top flange thickness = 75
     Total web thickness  = 400

PROPERTIES:

     Gross moment of inertia     = 4.4522E+10
     Gross section modulus       = 7.9457E+07
     Distance to neutral axis    = 4.3967E+02
     Cracked moment of inertia   = 2.3451E+10
     Effective moment of inertia = 2.3826E+10

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 3.1331E+02
     Design moment              = 1.5000E+03

MAXIMUM REINFORCING:

     c/d                        = 1.9108E-01
     Maximum c/d                = 6.3636E-01

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.5969E+03
     Stress block depth          = 1.5323E+02

SERVICE LOAD STRESS:

     Maximum steel stress    = 2.1433E+02
     Minimum steel stress    = 0.0000E+00
```

```
        Maximum concrete stress = 1.1416E+01
        Minimum concrete stress = 0.0000E+00

    CRACK CONTROL:

        Concrete cover            = 66
        Effective tension area    = 10400
        Exposure factor           = 30000
        Maximum steel stress      = 2.1433E+02
        Allowable cracking stress = 2.4000E+02
```

VERIFICATION PROBLEM NO. 8

ACI 318 code
Ref. PCA, "Notes on ACI 318-99", Example 10.5



f'_c = 4000 psi
f_y = 60000 psi

M_u = 400 k-ft

Results to check:

Required A_s = 5.11 in^2
a = 4.02 in

The design calculation determined the required steel area A_s = 5.10 in^2. Perform review calculations with: M_{max} = 265 k-ft and A_s = 5.00 in^2

α_1 = 0.85
β_1 = 0.85

$E_c = 57000(4000)^{1/2}$ = 3605000 psi

Tension steel is assumed to yield.

Minimum tensile steel =>
$3(4000)^{1/2} / 60000 = 0.00316 < 200 / 60000 = 0.00333$
Asmin = 0.00333 x 10 x 19 = 0.633 in

with a = 3.824 in
c = 3.824 / 0.85 = 4.499 in
ε_r = (19 - 4.499)(0.003) / 4.499 = 0.00967
Minimum strain = 0.004 < 0.00967 OK

T = 60000 x 5.0 = 300000 lbs
C_{web} = 0.85 x 4000 x 3.824 x 10 = 130016 lbs
C_{flange} = 0.85 x 4000 x 20 x 2.5 = 170000 lbs
M_n = [130.016 x (19 - 3.824 / 2) + 170 x (19 - 2.5 / 2)] / 12 = 437 k-ft
ϕM_n = 0.9 x 437 = 393 k-ft

Crack control =>
c_c = 2.0 in
f_s = 36627 psi
s = 600000 / 36627 - 2.5 x 2.0 = 11.38 in < 480000 / 36627 = 13.11 in

```
Verification Problem 8

* * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                        10/28/06, 2:57 pm

Output file = v8.out

Moment design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = ACI-318 (2005)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.75
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030
```

```
M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Depth to tensile reinf     = 19
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
=====================================================

     Factored (ultimate) moment  = 400
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
=====================================================

TEE SECTION:

     Height               = 22.4
     Top flange width     = 30
     Top flange thickness = 2.5
     Total web thickness  = 10

PROPERTIES:

     Gross moment of inertia     = 1.3439E+04
     Gross section modulus       = 1.0325E+03
     Distance to neutral axis    = 9.3843E+00
     Cracked moment of inertia   = 0.0000E+00

M O M E N T   D E S I G N   C A L C U L A T I O N S
=====================================================

MINIMUM REINFORCING:

     Minimum tensile reinf area = 5.1040E+00
```

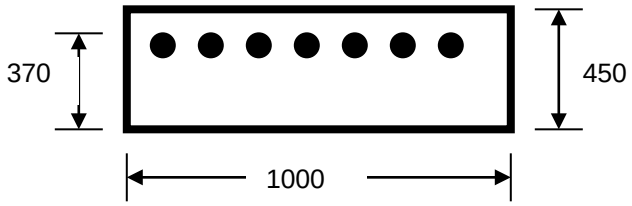
```
MAXIMUM REINFORCING:

     Strain in tensile reinf     = 9.0898E-03
     Minimum strain              = 4.0000E-03

COMPUTED REINFORCING:

     Stress block depth          = 4.0075E+00
     Required tensile reinf area = 5.1043E+00



Verification Problem 8 review

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                      10/28/06, 3:00 pm

Output file = v8r.out

Shear and moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = ACI-318 (2005)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor           = 0.90
     Shear reduction factor             = 0.75
     Concrete resistance factor         = 1.00
     Reinforcing resistance factor      = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
```

```
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
==================================================

     Tensile reinf area         = 5.104
     Depth to tensile reinf     = 19
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 400
     Maximum service load moment = 265
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

TEE SECTION:

     Height               = 22.4
     Top flange width     = 30
     Top flange thickness = 2.5
     Total web thickness  = 10

PROPERTIES:

     Gross moment of inertia     = 1.3439E+04
     Gross section modulus       = 1.0325E+03
     Distance to neutral axis    = 9.3843E+00
     Cracked moment of inertia   = 8.6910E+03
     Effective moment of inertia = 8.7083E+03

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     Minimum tensile reinf area = 6.3333E-01

MAXIMUM REINFORCING:

     Strain in tensile reinf    = 9.0912E-03
     Minimum strain             = 4.0000E-03
```

```
MOMENT CAPABILITY:

     Ultimate moment capability  = 3.9998E+02
     Stress block depth          = 4.0071E+00

     *** Design moment exceeds capacity ***

SERVICE LOAD STRESS:

     Maximum steel stress    = 3.5906E+04
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 2.4637E+03
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Clear concrete cover      = 2
     Maximum rebar spacing     = 1.1710E+01
```

VERIFICATION PROBLEM NO. 9

OHBDC code
Ref. MTO, "A Practical Guide to the Design of Post-Tensioned Decks", Section 7.1



f'_c = 35 MPa
f_y = 400 MPa

A_s = 1200 mm^2
s_c = 105 mm
c_c = 70 mm

M_{uls} = 139.41 kN-m
M_{sls} = 87.23 kN-m

Results to check:

$1.2M_{cr}$ = 1.2 x 99.8 kN-m = 119.76 kN-m
f_s = 206.8 MPa
M_w = 27.0 kN-m
β_2 = 26566 N/mm

Perform calculations to check results:

α_1 = 0.85
β_1 = 0.85 - (35 - 30) x 0.08 / 10 = 0.81

$E_c = 5000(35)^{1/2}$ = 29580 MPa

$I_g = 1000(450)^3/12$ = 7.594E+09 mm^4
$1000y^2/2 = 7 \times 1200(370 - y)$
$500y^2 + 8400y - 3108000 = 0$
y = 70.89 mm
$I_{cr} = 1000(70.89)^3/3 + 7 \times 1200(370 - 70.89)^2$ = 8.703E+08 mm^4

f_s = 87.23 x 299 x 7 x 1.0E+6 / 8.703E+08 = 209.8 MPa

Tension steel is assumed to yield.

with a = 19.36 mm
c = 19.36 / 0.81 = 23.9 mm
c / d = 23.9 / 370 = 0.0646 < 0.5 OK

T = 0.9 x 400 x 1200 = 432000 N
C = 0.75 x 0.85 x 35 x 19.36 x 1000 = 431970 N
M_r = 432 x (0.370 - 0.0239 / 2) = 155 kN-m

Crack control =>

$1.2M_{cr}$ =1.2 x 0.5(35)$^{1/2}$ x 7.594E+09 / (225 x 1.0E+06) = 119.8 kN-m
M_w = 0.4 x 119.8 / 1.2 = 39.9 kN-m (Note value in reference is erroneous)
β_2 = 1.0(0.9 x 105 + 2 x 70) x 209.8 x [1 - (39.9 / 87.23)^2] = 38905 N/mm

FILE = VER9.OUT (REVIEW PROBLEM)

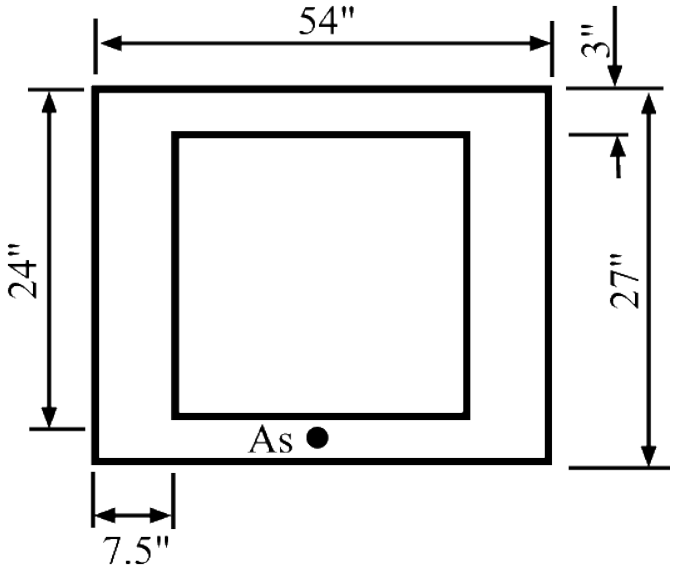
```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
6/26/02, 5:24 pm

D E S I G N   C R I T E R I A
=====================================================

Code  = OHBDC (1991)
Units = Metric (Newtons, millimeters - moments in kN-m)

MATERIAL PROPERTIES:

     Concrete compressive strength       = 35
     Concrete modulus of elasticity      = 2.9580E+04
     Reinforcing yield strength          = 400
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 7

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8100
     Maximum concrete strain             = 0.0030
```

```
S E C T I O N   P R O P E R T I E S:
==================================================

RECTANGULAR SECTION:

     Width  = 1000
     Height = 450

PROPERTIES:

     Gross moment of inertia     = 7.5938E+09
     Gross section modulus       = 3.3750E+07
     Distance to neutral axis    = 2.2500E+02
     Cracked moment of inertia   = 8.7027E+08
     Effective moment of inertia = 7.5938E+09

R E V I E W   C A L C U L A T I O N S:
==================================================

REINFORCING STEEL:

     Tensile steel area         = 1200
     Compressive steel area     = 0
     Depth to tensile steel     = 370
     Depth to Compressive steel = 0

     c/d                        = 6.4602E-02
     Maximum c/d                = 5.0000E-01

DESIGN MOMENTS:

     Factored ultimate moment    = 139.41
     Maximum service load moment = 87.23
     Minimum service load moment = 0

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.5566E+02
     1.2 * Cracking moment       = 1.1980E+02
     Design moment               = 1.3941E+02
     Stress block depth          = 1.9361E+01

SERVICE LOAD STRESS:

     Maximum steel stress    = 2.0987E+02
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 7.1053E+00
     Minimum concrete stress = 0.0000E+00
```

```
CRACK CONTROL:

     Clear concrete cover      = 70
     Clear rebar spacing       = 105
     Moment at 40% fcrack      = 3.9934E+01
     Computed exposure factor  = 3.8900E+04
     Allowable exposure factor = 5.0000E+04
```

VERIFICATION PROBLEM NO. 10

Design and review box using AASHTO LRFD code. Use dimensions similar to Tee section used in Verification problem 6.



f'_c = 3000 psi (20.7 MPa)
f_y = 50 ksi (345 MPa)

M_u = 858 k-ft (1163 kN-m)

Results to check:

Required A_s = 10.41 in^2 (6716 mm^2)

```
Verification Problem 10

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                       10/28/06, 3:09 pm

Output file = v10.out

Moment design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD (2004)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 3000
     Concrete modulus of elasticity      = 3.1523E+06
     Concrete modulus of rupture         = 415.7
     Reinforcing yield strength          = 50000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 9
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Depth to tensile reinf     = 24
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 858
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

BOX or I SECTION:

     Height                  = 27
     Top flange width        = 54
     Top flange thickness    = 3
     Bottom flange width     = 54
     Bottom flange thickness = 3
     Total web thickness     = 15

PROPERTIES:

     Gross moment of inertia     = 5.8475E+04
     Gross section modulus       = 4.3315E+03
     Distance to neutral axis    = 1.3500E+01
     Cracked moment of inertia   = 0.0000E+00

M O M E N T   D E S I G N   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 1.8006E+02
     Design moment              = 8.5800E+02

MAXIMUM REINFORCING:

     c/d                         = 2.8757E-01
     Maximum c/d                 = 4.2000E-01

COMPUTED REINFORCING:

     Stress block depth          = 5.8663E+00
     Required tensile reinf area = 1.0455E+01
```

Perform design review to verify remaining REBEAM calculations:

Most of the output for this problem can be compared to Verification problem number 6 to check the results. Verify other output with the following calculations:

$I_g = 15(27)^3 / 12 + 2 \times 39 \times (3)^3 / 12 + 2 \times 3 \times 39 \times (12)^2 = 58475 \text{ in}^4$
$1.2M_{cr} = 1.2 \times 7.5(3000)1/2 \times 58475 / (13.5 \times 12000) = 178$ k-ft

Fatigue:

Maximum steel stress = 2.8985E+04
Minimum steel stress = 1.0735E+04
Stress range = 18250 psi
Allow range = (24000 – 0.33 x 10735) / 1.5 = 13638 psi

Crack control:

$\beta = 1 + 3 / (0.7(27-3)) = 1.18$
$S < 700000 \times 1.0 / (1.18 \times 28985) – 2 \times 3 = 14.5$”

Maximum reinforcing:

a = 5.48 in
c = 5.48 / 0.85 = 6.447 in
$\varepsilon_r = (24 – 6.447)(0.003) / 6.447 = 0.00817$
Minimum strain = 0.005 < 0.00817 OK

Verification Problem 10 review

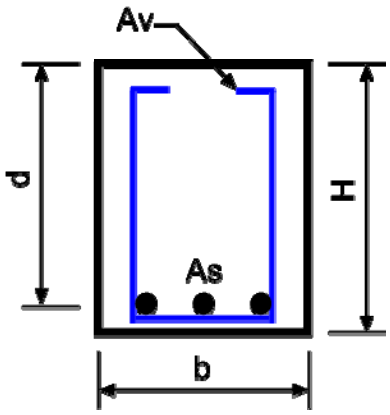
```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                         *
*           P R O G R A M   R E B E A M                   *
*                                                         *
*                    OUTPUT DATA                          *
*                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    6/03/17, 3:15 pm

Output file = v10r.out

Shear and moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
```

```
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
====================================================

     Concrete compressive strength       = 3000
     Concrete modulus of elasticity      = 3.1523E+06
     Concrete modulus of rupture         = 415.7
     Reinforcing yield strength          = 50000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 9
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
====================================================

     Tensile reinf area         = 10.16
     Depth to tensile reinf     = 24
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
     Shear reinf area           = 0
     Shear reinf spacing        = 0

D E S I G N   L O A D S
====================================================

     Factored (ultimate) moment  = 858
     Maximum service load moment = 540
     Minimum service load moment = 200
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
====================================================

BOX or I SECTION:

     Height                  = 27
     Top flange width        = 54
     Top flange thickness    = 3
     Bottom flange width     = 54
     Bottom flange thickness = 3
     Total web thickness     = 15

PROPERTIES:

     Gross moment of inertia     = 5.8475E+04
     Gross section modulus       = 4.3315E+03
```

```
     Distance to neutral axis    = 1.3500E+01
     Cracked moment of inertia   = 3.0850E+04
     Effective moment of inertia = 3.1443E+04

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 1.8006E+02
     Design moment              = 8.5800E+02

MAXIMUM REINFORCING:

     Strain in tensile reinf    = 8.1658E-03
     Minimum strain             = 5.0000E-03

MOMENT CAPABILITY:

     Ultimate moment capability  = 8.3774E+02
     Stress block depth          = 5.4810E+00

     *** Design moment exceeds capacity ***

SERVICE LOAD STRESS:

     Maximum steel stress    = 2.8985E+04
     Minimum steel stress    = 1.0735E+04
     Maximum concrete stress = 1.8206E+03
     Minimum concrete stress = 6.7428E+02

FATIGUE:

     Steel stress range             = 1.8250E+04
     Allowable fatigue stress range = 1.3638E+04

CRACK CONTROL:

     Concrete cover            = 3
     Exposure factor           = 1
     Maximum rebar spacing     = 1.4491E+01
```

VERIFICATION PROBLEM NO. 11

Design and review reinforced concrete beam for shear using all supported codes. The capability was added in version 5.00.



f'c = 4000 psi (27.6 MPa)
fy = 60000 psi (414 MPa)

b = 12" (305 mm)
H = 24" (610 mm)
D = 21" (533 mm)

As = 5 in2 (3226 mm2)
Av = 0.4 in2 (258 mm2) – for review
s = 5" (127 mm) – for review

Mu = 100 k-ft (136 kN-m)
Vu = 100 kips (445 kN)
Use Vu = 50 kips (222 kN) for checking w/no reinf

Minimum area of shear reinforcement

AASHTO (2002) 8.19.1.2

$$A_{v\min} = \frac{50bs}{f_y}$$

Avmin = 50 x 12 x 5 / 60000 = 0.05 in2 (32 mm2)

AASHTO LRFD (2004) 5.8.2.5

$$A_{v\min} = 0.0316\sqrt{f_c'}\,\frac{bs}{f_y}$$

Avmin = $0.0316(4)^{1/2}$ x 12 x 5 / 60 = 0.063 in^2 (41 mm^2)

AREMA (2006) 8-2.10.1b

$$A_{v\min} = \frac{60bs}{f_y}$$

Avmin = 60 x 12 x 5 / 60000 = 0.06 in^2 (39 mm^2)

ACI 318 (2005) 11.5.6.3

$$A_{v\min} = 0.75\sqrt{f_c'}\,\frac{bs}{f_y} \geq \frac{50bs}{f_y}$$

Avmin = $0.75(4000)^{1/2}$ x 12 x 5 / 60000 = 0.047 in^2
Avmin = 50 x 12 x 5 / 60000 = 0.05 in^2 (32 mm^2)

CSA-A23.3 (2004) 11.2.8.2

$$A_{v\min} = 0.06\sqrt{f_c'}\,\frac{bs}{f_y}$$

Avmin = $0.06(27.6)^{1/2}$ X 305 X 127 / 414 = 29 mm^2

CAN/CSA-S6 (2006) 8.9.1.3

$$A_{v\min} = 0.15 f_r \left(\frac{bs}{f_y} \right)$$

fr = 0.4(27.6)$^{1/2}$ = 2.1 MPa
Avmin = 0.15 x 2.1 x 305 x 127 / 414 = 29 mm^2

Maximum spacing of shear reinforcement

AASHTO (2002) 8.19.3
AREMA (2006) 8-2.10.3
ACI 318 (2005) 11.5.5.1

$$s \le \frac{d}{2} \le 24"$$

$$\text{If } \phi_v V_s > \phi_v 4\sqrt{f_c'} bd \text{ Then } s \le \frac{d}{4} \le 12"$$

Vs = 0.85 x 4(4000)$^{1/2}$ x 12 x 21 = 54.2 < 100 – 36.3 = 63.7 See strength of concrete section
Vs = 0.75 x 4(4000)$^{1/2}$ x 12 x 21 = 47.8 < 100 – 32 = 68 (ACI)
s = 21 / 4 = 5.25" (133 mm)

AASHTO LRFD (2004) 5.8.2.7

$$s \le 0.8 d_v \le 24 \text{ in}$$

$$\text{If } V_f > 0.125 \phi_v f_c' b d_v \text{ Then } s \le 0.4 d_v \le 12"$$

dv = 0.9 x 21 = 18.9" (480 mm)
Vf = 100 < 0.125 x 0.9 x 4 x 12 x 18.9 =102 kips
s = 0.8 x 18.9 = 15.1" (384 mm)

CSA-A23.3 (2004) 11.3.8.1

$$s \le 0.7 d_v \le 600 \text{ mm}$$

$$\text{If } V_f > 0.125 \phi_c f_c' b d_v \text{ Then } s \le 0.35 d_v \le 300 \text{ mm}$$

Vf = 445 > 0.125 x 0.65 x 27.6 x 305 x 480 / 1000 = 328 kN
s = 0.35 x 480 = 168 mm

CAN/CSA-S6 (2006) 8.14.6

$$s \le 0.75 d_v \le 600 \text{ mm}$$

$$\text{If } V_f \ge 0.10 \phi_c f_c' b d_v \text{ Then } s \le 0.33 d_v \le 300 \text{ mm}$$

Vf = 445 > 0.1 x 0.75 x 27.6 x 305 x 480 / 1000 = 303 kN
s = 0.33 x 480 = 158 mm

Maximum shear strength

AASHTO (2002) 8.16.6.3.9
AREMA (2006) 8-2.35.3e
ACI 318 (2005) 11.5.7.9

$$V_{\max} = \phi_v \left[8\sqrt{f_c'} bd + V_c \right]$$

Vmax = 0.85[8(4000)$^{1/2}$ x 12 x 21]/1000 + 36.3 = 145 kips (644 kN)
Vmax = 0.75[8(4000)$^{1/2}$ x 12 x 21]/1000 + 32 = 128 kips (568 kN)(ACI)

AASHTO LRFD (2004) 5.8.3.3

$$V_{\max} = \phi_v \left[0.25 f_c' b d_v \right]$$

Vmax = 0.9 x 0.25 x 4 x 12 x 18.9 = 204 kips (907 kN)

CSA-A23.3 (2004) 11.3.3
CAN/CSA-S6 (2006) 8.9.3.3

$$V_{\max} = 0.25 \phi_c f_c' b d_v$$

Vmax = 0.25 x .65 x 27.6 x 305 x 480 / 1000 = 657 kN (A23.3)
Vmax = 0.25 x .75 x 27.6 x 305 x 480 / 1000 = 758 kN (S6)

Shear strength of concrete

$$\phi_v V_c = \phi_v \left[1.9\sqrt{f_c'} + 2500\rho \frac{V_f d}{M_f} \right] bd \le \phi_v 3.5\sqrt{f_c'}\, bd$$

AASHTO (2002) 8.16.6.2.1
AREMA (2006) 8-2.35.2b
ACI 318 (2005) 11.3.2.1

$$\text{but } \frac{V_f d}{M_f} \le 1.0$$

ρ = 5 / (12 x 21) = 0.0198
Vc = 0.85 x 3.5(4000)$^{1/2}$ x 12 x 21 / 1000 = 47.4 kips
Vc = 0.75 x 3.5(4000)$^{1/2}$ x 12 x 21 / 1000 = 41.8 kips (ACI)
Vd/M = 100 x 21 / (100 x 12) = 1.75
Vc = 0.85[1.9(4000)$^{1/2}$ x 2500 x 0.0198] x 12 x 21 / 1000 = 36.3 kips (161 kN)
Vc = 0.75[1.9(4000)$^{1/2}$ x 2500 x 0.0198] x 12 x 21 / 1000 = 32.0 kips (142 kN) (ACI)

$$\phi_v V_c = \phi_v 0.0316\beta\sqrt{f_c'}\, bd_v$$

AASHTO LRFD (2004) 5.8.3.3

$$\beta = f\left(\frac{v_f}{f_c'}, \varepsilon_x \right)$$

$$\varepsilon_x = \frac{\left[\frac{|M_f|}{d_v} + 0.5|V_f| \cot\theta \right]}{2E_s A_s} \le 0.001$$

Mf > 100 x 18.9 / 12 = 157.5
vf/f'c = 100 / (12 x 18.9 x 0.9 x 4) = 0.122
For vf/f'c < 0.125, try 8th column theta = 34.4
ε = $\frac{157.5 \times 12/18.9 + 0.5 \times 100 \times \cot(34.4)}{2 \times 29000 \times 5}$ = 0.000597
Since 0.000597 falls in assumed range, then theta = 34.4, beta = 2.26.
Vc = 0.9 x 0.0316 x 2.26(4)$^{1/2}$ x 12 x 18.9 = 29.2 kips (130 kN)

$$V_c = \phi_c \beta\sqrt{f_c'}\, bd_v$$

CSA-A23.3 (2004) 11.3.4

$$\beta = \frac{0.40}{(1+1500\varepsilon_x)} \times \frac{1300}{(1000+s_{xe})}$$

$$\theta = 29 + 7000\varepsilon_x$$

$$s_{xe} = 300 \text{ mm}$$

$$\varepsilon_x = \frac{\left[\frac{|M_f|}{d_v} + |V_f| \right]}{2E_s A_s} \le 0.003$$

Mf > 445 x 480 / 1000 = 213.6

ε = 213.6 x 1000/480 + 445 / 2 x 200 x 3226 = 0.000690
θ = 29 + 7000 x 0.000690 = 33.8
β = 0.4/(1+1500x0.000690) x 1300/(1000+300) = 0.197
Vc = 0.65 x 0.197(27.6)$^{1/2}$ x 305 x 480 / 1000 = 98.8 kN

$$V_c = 2.5\beta\phi_c f_r b d_v$$

CAN/CSA-S6 (2006) 8.9.3.4

$$\varepsilon_x = \frac{\left[\frac{|M_f|}{d_v} + |V_f|\right]}{2E_s A_s} \le 0.003$$

$$\beta = \frac{0.40}{(1+1500\varepsilon_x)} \times \frac{1300}{(1000+s_{xe})}$$

$$\theta = (29+7000\varepsilon_x) \times \left(0.88 + \frac{s_{xe}}{2500}\right)$$

$$s_{xe} = 300 \text{ mm}$$

Mf > 213.6
ε = 213.6 x 1000/480 + 445 / 200 x 3226 = 0.000690
β = 0.4/(1+1500x0.000690) x 1300/(1000+300) = 0.197
θ = (29 + 7000 x 0.000690) (0.88+300/2500)= 33.8
Vc = 2.5 x 0.197 x 0.75 x 2.1 x 305 x 480 / 1000 = 114 kN

Shear strength of concrete with no shear reinforcement

$$\phi_v V_c = \phi_v 0.0316\beta\sqrt{f_c'} b d_v$$

AASHTO LRFD (2004) 5.8.3.3

$$\beta = f(s_{xe}, \varepsilon_x)$$

$$s_{xe} = s_x \frac{1.38}{a_g + 0.63} \le 80 \text{ inches}$$

$$\varepsilon_x = \frac{\left[\frac{|M_f|}{d_v} + 0.5|V_f|\cot\theta\right]}{E_s A_s} \le 0.002$$

sxe = 18.9 x 1.38 / (1 + 0.63) = 16.0 in
For sxe < 20, try 8th column theta = 45.5
Mf > 50 x 18.9 / 12 = 78.75 < 100
ε = 100 x 12/18.9 + 0.5 x 50 x cot(45.5) / 29000 x 5 = 0.000607
Since 0.000607 falls in assumed range, then beta = 2.09
Vc = 0.9 x 0.0316 x 2.09(4)$^{1/2}$ x 12 x 18.9 = 27.0 kips (120 kN)

CSA-A23.3 (2004) 11.3.4

$$V_c = \phi_c \beta \sqrt{f_c'} b d_v$$

$$\beta = \frac{0.40}{(1+1500\varepsilon_x)} \times \frac{1300}{(1000+s_{xe})}$$

$$\theta = 29 + 7000\varepsilon_x$$

$$s_{xe} = \frac{35 s_x}{15 + a_g} \geq 0.85 s_x$$

$$\varepsilon_x = \frac{\left[\frac{|M_f|}{d_v} + |V_f|\right]}{2E_s A_s} \leq 0.003$$

Mf > 222 x 480 / 1000 = 106.6 < 136

ε = $\frac{136 \times 1000/480 + 222}{2 \times 200 \times 3226}$ = 0.000392

θ = 29 + 7000 x 0.000392 = 31.7

Sxe = 35 x 480 / (15 + 20) = 480

β = 0.4/(1+1500x0.000392) x 1300/(1000+480) = 0.221

Vc = 0.65 x 0.221(27.6)$^{1/2}$ x 305 x 480 / 1000 = 110 kN

CAN/CSA-S6 (2006) 8.9.3.4

$$V_c = 2.5 \beta \phi_c f_r b d_v$$

$$\beta = \frac{0.40}{(1+1500\varepsilon_x)} \times \frac{1300}{(1000+s_{xe})}$$

$$\theta = (29 + 7000\varepsilon_x) \times \left(0.88 + \frac{s_{xe}}{2500}\right)$$

$$s_{xe} = \frac{35 s_x}{15 + a_g} \geq 0.85 s_x$$

$$\varepsilon_x = \frac{\left[\frac{|M_f|}{d_v} + |V_f|\right]}{2E_s A_s} \leq 0.003$$

Mf > 106.6 < 136

ε = $\frac{136 \times 1000/480 + 222}{2 \times 200 \times 3226}$ = 0.000392

θ = (29 + 7000 x 0.000392)(0.88 + 480/2500) = 34.0

Sxe = 35 x 480 / (15 + 20) = 480

β = 0.4/(1+1500x0.000392) x 1300/(1000+480) = 0.221

Vc = 2.5 x 0.221 x 0.75 x 2.1 x 305 x 480 / 1000 = 127 kN

Strength of shear reinforcement

$$\phi_v V_s = \phi_v \frac{A_v f_y d}{s}$$

AASHTO (2002) 8.16.6.3.2
AREMA (2006) 8-2.35.3a
ACI 318 (2005) 11.5.7.2

Vs = 0.85 x 0.4 x 60 x 21 / 5 = 85.7 kips (381 kN)
Av/s > (100 – 36.3)/(0.85 x 60 x 21) = 0.0595" (1.51 mm)
Vs = 0.75 x 0.4 x 60 x 21 / 5 = 75.6 kips (336 kN)(ACI)
Av/s > (100 – 32)/(0.75 x 60 x 21) = 0.072" (1.83 mm)(ACI)

$$\phi_v V_s = \phi_v \frac{A_v f_y d_v \cot\theta}{s}$$

AASHTO LRFD (2004) 5.8.3.3

Vs = 0.9 x 60 x 0.4 x 18.9 x cot(34.4) / 5 =119 kips (529 kN)
Av/s > (100 – 29.2)/(0.9 x 60 x 18.9 x cot(34.4)) = 0.0475" (1.21 mm)

$$V_s = \frac{\phi_s f_y A_v d_v \cot\theta}{s}$$

CSA-A23.3 (2004) 11.3.5
CAN/CSA-S6 (2006) 8.9.3.5

Vs = 0.85 x 414 x 258 x 480 x cot(33.8) / 127000 =512 kN (A23.3)
Av/s > (445 – 98.8) x 1000 / (0.85 x 414 x 480 x cot(33.8)) = 1.37 mm (A23.3)
Vs = 0.9 x 414 x 258 x 480 x cot(33.8) / 127000 =543 kN (S6)
Av/s > (445 – 114) x 1000 / (0.9 x 414 x 480 x cot(33.8)) = 1.24 mm (S6)

Minimum longitudinal tension reinforcement

$$A_s \geq \frac{\frac{|M_f|}{\phi d_v} + \left(\frac{|V_f|}{\phi_v} - 0.5V_s\right)\cot\theta}{f_y}$$

$$\phi V_s \leq V_f$$

AASHTO LRFD (2004) 5.8.3.5

119 > 100 kips, therefore use ϕVs = Vf
As = $\frac{100x12/(0.9x18.9) + (100/0.9 - 0.5x100/0.9)\cot(34.4)}{60}$ = 2.53 in^2 (1631 mm^2)

As = $\frac{100x12/(0.9x18.9) + (50/0.9)\cot(45.5)}{60}$ = 2.09 in^2 (1346 mm^2) (No shear reinforcement)

$$A_s \geq \frac{\frac{|M_f|}{d_v} + \left(V_f - 0.5V_s\right)\cot\theta}{\phi_s f_y}$$

$$V_s \leq V_f$$

CSA-A23.3 (2004) 11.3.9.2
CAN/CSA-S6 (2006) 8.9.3.11

512 and 543 > 445 kips, therefore use Vs = Vf
As = $\frac{136000/480 + (445 - 0.5x445)\cot(33.8)}{0.85 \times 0.414}$ = 1750 mm^2 (A23.3)
As = $\frac{136000/480 + (445 - 0.5x445)\cot(33.8)}{0.9 \times 0.414}$ = 1652 mm^2 (S6)

As = 136000/480 + (222)cot(31.7) = 1827 mm^2 (A23.3) (No shear reinforcement)
0.85 x 0.414

As = 136000/480 + (222)cot(34) = 1644 mm^2 (S6) (No shear reinforcement)
0.9 x 0.414

REBEAM Output Files

The following output files are included below for the calculations performed in this section.

FILE	DESCRIPTION
Aashto-vde.out	AASHTO Shear design English units
Aashto-vre.out	AASHTO Shear review English units
Aci-vde.out	ACI-318 Shear design English units
Aci-vre.out	ACI-318 Shear review English units
Arema-vde.out	AREMA Shear design English units
Arema-vre.out	AREMA Shear review English units
Csa-uvrm.out	CSA-A23.3 Unreinforced concrete shear review metric units
Csa-vdm.out	CSA-A23.3 Shear design metric units
Csa-vrm.out	CSA-A23.3 Shear review metric units
Lrfd-uvre.out	AASHTO LRFD Unreinforced concrete shear review English units
Lrfd-vde.out	AASHTO LRFD Shear design English units
Lrfd-vre.out	AASHTO LRFD Shear review English units
S6-uvrm.out	CAN/CSA-S6 Unreinforced concrete shear review metric units
S6-vdm.out	CAN/CSA-S6 Shear design metric units
S6-vrm.out	CAN/CSA-S6 Shear review metric units

```
AASHTO Shear design english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                      10/29/06, 12:21 pm

Output file = aashto-vde.out

Shear design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.85
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   D E S I G N   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth    = 2.1000E+01
     Concrete shear strength  = 3.6365E+01
     Maximum shear strength   = 1.4474E+02

COMPUTED REINFORCING:

     Required Av / s      = 5.9400E-02
     Minimum Av / s       = 1.0000E-02
     Max reinf spacing    = 5.2500E+00
```

```
AASHTO Shear review english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                      10/29/06, 12:30 pm

Output file = aashto-vre.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO (2002)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.85
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0.4
     Shear reinf spacing       = 5

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 2.1000E+01
     Concrete shear strength    = 3.6365E+01

SHEAR REINFORCING:

     Min shear reinf area       = 5.0000E-02
     Max shear reinf spacing    = 5.2500E+00

     Shear reinf strength       = 8.5680E+01
     Ultimate shear capability  = 1.2204E+02
     Maximum shear capability   = 1.4474E+02
```

```
ACI-318 Shear design english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                      10/29/06, 12:23 pm

Output file = aci-vde.out

Shear design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = ACI-318 (2005)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.75
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   D E S I G N   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth    = 2.1000E+01
     Concrete shear strength  = 3.2086E+01
     Maximum shear strength   = 1.2771E+02

COMPUTED REINFORCING:

     Required Av / s      = 7.1900E-02
     Minimum Av / s       = 1.0000E-02
     Max reinf spacing    = 5.2500E+00
```

```
ACI-318 Shear review english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                      10/29/06, 12:28 pm

Output file = aci-vre.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = ACI-318 (2005)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.75
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0.4
     Shear reinf spacing       = 5

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 2.1000E+01
     Concrete shear strength    = 3.2086E+01

SHEAR REINFORCING:

     Min shear reinf area       = 5.0000E-02
     Max shear reinf spacing    = 5.2500E+00

     Shear reinf strength       = 7.5600E+01
     Ultimate shear capability  = 1.0769E+02
     Maximum shear capability   = 1.2771E+02
```

```
AREMA Shear design english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                         *
*           P R O G R A M   R E B E A M                   *
*                                                         *
*                    OUTPUT DATA                          *
*                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                      10/29/06, 12:23 pm

Output file = arema-vde.out

Shear design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AREMA (2006)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.85
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   D E S I G N   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth    = 2.1000E+01
     Concrete shear strength  = 3.6365E+01
     Maximum shear strength   = 1.4474E+02

COMPUTED REINFORCING:

     Required Av / s      = 5.9400E-02
     Minimum Av / s       = 1.2000E-02
     Max reinf spacing    = 5.2500E+00
```

```
AREMA Shear review english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5)                      10/29/06, 12:29 pm

Output file = arema-vre.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AREMA (2006)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.85
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6050E+06
     Concrete modulus of rupture         = 474.3
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0.4
     Shear reinf spacing       = 5

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 2.1000E+01
     Concrete shear strength    = 3.6365E+01

SHEAR REINFORCING:

     Min shear reinf area       = 6.0000E-02
     Max shear reinf spacing    = 5.2500E+00

     Shear reinf strength       = 8.5680E+01
     Ultimate shear capability  = 1.2204E+02
     Maximum shear capability   = 1.4474E+02
```

```
CSA-A23.3 Unreinforced shear review metric

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 6:02 pm

Output file = csa-uvrm.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CSA A23.3 (2004)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 1.00
     Concrete resistance factor          = 0.65
     Reinforcing resistance factor       = 0.85

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8090
     Ratio of depth of compression block = 0.9010
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 27.6
     Concrete modulus of elasticity      = 2.3641E+04
     Concrete modulus of rupture         = 3.152
     Reinforcing yield strength          = 414
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 3226
     Depth to tensile reinf     = 533
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0
     Shear reinf spacing       = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 136
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 222

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 305
     Height = 610

PROPERTIES:

     Gross moment of inertia     = 5.7691E+09
     Gross section modulus       = 1.8915E+07
     Distance to neutral axis    = 3.0500E+02
     Cracked moment of inertia   = 3.6057E+09

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 4.7970E+02
     Concrete shear strength    = 1.1059E+02
        Crack spacing parameter = 4.7970E+02
        Longitudinal strain     = 3.9175E-04
        Theta                   = 3.1742E+01
        Beta                    = 2.2135E-01

     *** Design shear exceeds capacity ***

MINIMUM LONGITUDINAL TENSILE REINFORCING:

     Minimum reinf area         = 1.8254E+03
```

```
CSA-A23.3 Shear design metric

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 6:03 pm

Output file = csa-vdm.out

Shear design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CSA A23.3 (2004)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 1.00
     Concrete resistance factor          = 0.65
     Reinforcing resistance factor       = 0.85

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8090
     Ratio of depth of compression block = 0.9010
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 27.6
     Concrete modulus of elasticity      = 2.3641E+04
     Concrete modulus of rupture         = 3.152
     Reinforcing yield strength          = 414
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 3226
     Depth to tensile reinf     = 533
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 136
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 445

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 305
     Height = 610

PROPERTIES:

     Gross moment of inertia     = 5.7691E+09
     Gross section modulus       = 1.8915E+07
     Distance to neutral axis    = 3.0500E+02
     Cracked moment of inertia   = 3.6057E+09

S H E A R   D E S I G N   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth    = 4.7970E+02
     Concrete shear strength  = 9.8226E+01
     Maximum shear strength   = 6.5619E+02

COMPUTED REINFORCING:

     Required Av / s      = 1.3800E+00
     Minimum Av / s       = 2.3222E-01
     Max reinf spacing    = 1.6790E+02
```

```
CSA-A23.3 Shear review metric

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 6:02 pm

Output file = csa-vrm.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CSA A23.3 (2004)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 1.00
     Concrete resistance factor          = 0.65
     Reinforcing resistance factor       = 0.85

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8090
     Ratio of depth of compression block = 0.9010
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 27.6
     Concrete modulus of elasticity      = 2.3641E+04
     Concrete modulus of rupture         = 3.152
     Reinforcing yield strength          = 414
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 3226
     Depth to tensile reinf     = 533
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 258
     Shear reinf spacing       = 127

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 136
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 445

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 305
     Height = 610

PROPERTIES:

     Gross moment of inertia     = 5.7691E+09
     Gross section modulus       = 1.8915E+07
     Distance to neutral axis    = 3.0500E+02
     Cracked moment of inertia   = 3.6057E+09

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 4.7970E+02
     Concrete shear strength    = 9.8226E+01
        Crack spacing parameter = 3.0000E+02
        Minimum moment          = 2.1347E+02
        Longitudinal strain     = 6.8971E-04
        Theta                   = 3.3828E+01
        Beta                    = 1.9660E-01

SHEAR REINFORCING:

     Min shear reinf area       = 2.9492E+01
     Max shear reinf spacing    = 1.6790E+02

     Shear reinf strength       = 5.1172E+02
     Ultimate shear capability  = 6.0995E+02
     Maximum shear capability   = 6.5619E+02

MINIMUM LONGITUDINAL TENSILE REINFORCING:

     Minimum reinf area         = 1.7491E+03
```

```
AASHTO LRFD Unreinforced shear review english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/22/07, 4:46 pm

Output file = lrfd-uvre.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD (2004)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6400E+06
     Concrete modulus of rupture         = 480
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0
     Shear reinf spacing       = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 50

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 1.8900E+01
     Concrete shear strength    = 2.6981E+01
        Crack spacing parameter = 1.6001E+01
        Longitudinal strain     = 6.0731E-04
        Theta                   = 4.5500E+01
        Beta                    = 2.0900E+00

     *** Design shear exceeds capacity ***

MINIMUM LONGITUDINAL TENSILE REINFORCING:

     Minimum reinf area         = 2.0857E+00
```

```
AASHTO LRFD Shear design english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/22/07, 4:46 pm

Output file = lrfd-vde.out

Shear design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD (2004)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6400E+06
     Concrete modulus of rupture         = 480
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   D E S I G N   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth    = 1.8900E+01
     Concrete shear strength  = 2.9176E+01
     Maximum shear strength   = 2.0412E+02

COMPUTED REINFORCING:

     Required Av / s      = 4.7500E-02
     Minimum Av / s       = 1.2649E-02
     Max reinf spacing    = 1.5120E+01
```

```
AASHTO LRFD Shear review english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 5:23 pm

Output file = lrfd-vre.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD (2004)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6400E+06
     Concrete modulus of rupture         = 480
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0.4
     Shear reinf spacing       = 5

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 100

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 1.8900E+01
     Concrete shear strength    = 2.9176E+01
        Minimum moment          = 1.5750E+02
        Longitudinal strain     = 5.9663E-04
        Theta                   = 3.4400E+01
        Beta                    = 2.2600E+00

SHEAR REINFORCING:

     Min shear reinf area       = 6.3246E-02
     Max shear reinf spacing    = 1.5120E+01

     Shear reinf strength       = 1.1924E+02
     Ultimate shear capability  = 1.4842E+02
     Maximum shear capability   = 2.0412E+02

MINIMUM LONGITUDINAL TENSILE REINFORCING:

     Minimum reinf area         = 2.5281E+00
```

```
CSA-S6 Unreinforced shear review metric

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    11/01/07, 8:22 pm

Output file = s6-uvrm.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CAN/CSA-S6 (2006)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8090
     Ratio of depth of compression block = 0.9010
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 27.6
     Concrete modulus of elasticity      = 2.4913E+04
     Concrete modulus of rupture         = 2.101
     Reinforcing yield strength          = 414
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 3226
     Depth to tensile reinf     = 533
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0
     Shear reinf spacing       = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 136
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 222

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 305
     Height = 610

PROPERTIES:

     Gross moment of inertia     = 5.7691E+09
     Gross section modulus       = 1.8915E+07
     Distance to neutral axis    = 3.0500E+02
     Cracked moment of inertia   = 3.6057E+09

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 4.7970E+02
     Concrete shear strength    = 1.2758E+02
        Crack spacing parameter = 4.7970E+02
        Longitudinal strain     = 3.9175E-04
        Theta                   = 3.4024E+01
        Beta                    = 2.2135E-01

     *** Design shear exceeds capacity ***

MINIMUM LONGITUDINAL TENSILE REINFORCING:

     Minimum reinf area         = 1.6434E+03
```

```
CSA-S6 Shear design metric

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 5:21 pm

Output file = s6-vdm.out

Shear design problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CAN/CSA-S6 (2006)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8090
     Ratio of depth of compression block = 0.9010
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 27.6
     Concrete modulus of elasticity      = 2.4913E+04
     Concrete modulus of rupture         = 2.101
     Reinforcing yield strength          = 414
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 3226
     Depth to tensile reinf     = 533
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

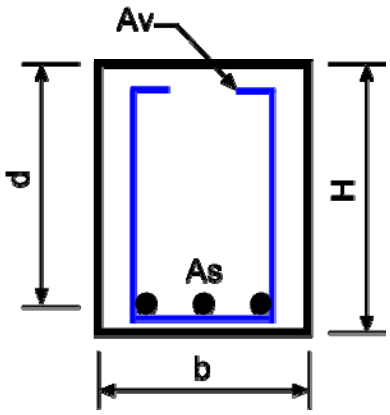
```
D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 136
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 445

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 305
     Height = 610

PROPERTIES:

     Gross moment of inertia     = 5.7691E+09
     Gross section modulus       = 1.8915E+07
     Distance to neutral axis    = 3.0500E+02
     Cracked moment of inertia   = 3.6057E+09

S H E A R   D E S I G N   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth    = 4.7970E+02
     Concrete shear strength  = 1.1331E+02
     Maximum shear strength   = 7.5715E+02

COMPUTED REINFORCING:

     Required Av / s      = 1.2400E+00
     Minimum Av / s       = 2.3218E-01
     Max reinf spacing    = 1.5830E+02
```

```
CSA-S6 Shear review metric

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    10/31/07, 5:18 pm

Output file = s6-vrm.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CAN/CSA-S6 (2006)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8090
     Ratio of depth of compression block = 0.9010
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 27.6
     Concrete modulus of elasticity      = 2.4913E+04
     Concrete modulus of rupture         = 2.101
     Reinforcing yield strength          = 414
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 3226
     Depth to tensile reinf     = 533
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 258
     Shear reinf spacing       = 127

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 136
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 445

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 305
     Height = 610

PROPERTIES:

     Gross moment of inertia     = 5.7691E+09
     Gross section modulus       = 1.8915E+07
     Distance to neutral axis    = 3.0500E+02
     Cracked moment of inertia   = 3.6057E+09

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 4.7970E+02
     Concrete shear strength    = 1.1331E+02
        Crack spacing parameter = 3.0000E+02
        Minimum moment          = 2.1347E+02
        Longitudinal strain     = 6.8971E-04
        Theta                   = 3.3828E+01
        Beta                    = 1.9660E-01

SHEAR REINFORCING:

     Min shear reinf area       = 2.9486E+01
     Max shear reinf spacing    = 1.5830E+02

     Shear reinf strength       = 5.4182E+02
     Ultimate shear capability  = 6.5514E+02
     Maximum shear capability   = 7.5715E+02

MINIMUM LONGITUDINAL TENSILE REINFORCING:

     Minimum reinf area         = 1.6520E+03
```

VERIFICATION PROBLEM NO. 12

Determine concrete shear strength using AASHTO LRFD code with shear stress less than minimum table values. This capability was added in version 5.10.



f'c = 4000 psi (27.6 MPa)
fy = 60000 psi (414 MPa)

b = 12" (305 mm)
H = 24" (610 mm)
D = 21" (533 mm)

As = 5 in2 (3226 mm2)
Av = 0.4 in2 (258 mm2) – for review
s = 5" (127 mm) – for review

Mu = 100 k-ft (136 kN-m)
Vu = 50 kips (222 kN)

Shear strength of concrete

AASHTO LRFD (2004) 5.8.3.3

$$\phi_v V_c = \phi_v 0.0316 \beta \sqrt{f_c'} b d_v$$

$$\beta = f\left(\frac{v_f}{f_c'}, \varepsilon_x\right)$$

$$\varepsilon_x = \frac{\left[\frac{|M_f|}{d_v} + 0.5|V_f|\cot\theta\right]}{2E_s A_s} \le 0.001$$

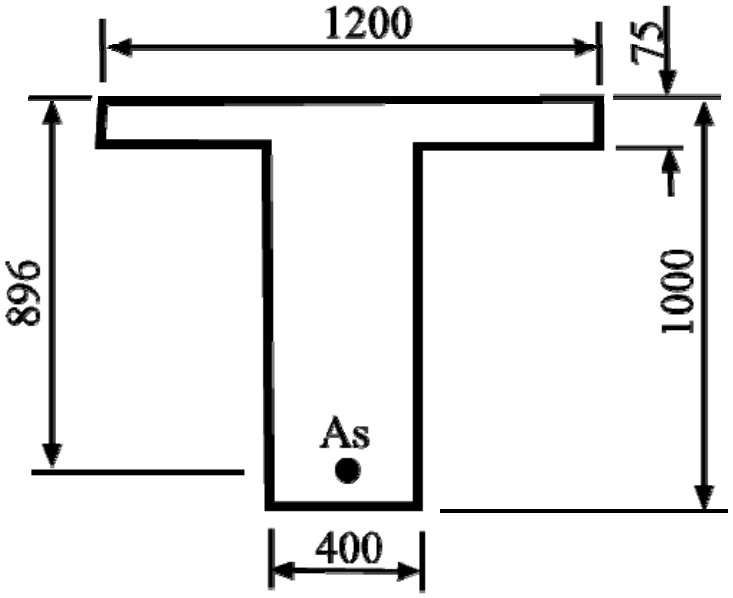
Mf > 100 x 18.9 / 12 = 157.5
vf/f'c = 50 / (12 x 18.9 x 0.9 x 4) = 0.061 < minimum table value of 0.075
For vf/f'c < 0.075, try 7th column theta = 30.5
ε = 157.5 x 12/18.9 + 0.5 x 50 x cot(30.5) = 0.000491
2 x 29000 x 5
Since 0.00025 < 0.000491 < 0.0005 falls in assumed range, then theta = 30.5, beta = 2.59.
Vc = 0.9 x 0.0316 x 2.59(4)$^{1/2}$ x 12 x 18.9 = 33.4 kips (149 kN)

```
AASHTO LRFD Shear review english

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                         *
*           P R O G R A M   R E B E A M                   *
*                                                         *
*                    OUTPUT DATA                          *
*                                                         *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    11/02/07, 3:08 pm

Output file = lrfd-vre-min.out

Shear review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = AASHTO LRFD (2004)
Units = English (pounds, inches - shear and moments in kip-ft)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 0.90
     Shear reduction factor              = 0.90
     Concrete resistance factor          = 1.00
     Reinforcing resistance factor       = 1.00

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8500
     Ratio of depth of compression block = 0.8500
     Maximum concrete strain             = 0.0030

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 4000
     Concrete modulus of elasticity      = 3.6400E+06
     Concrete modulus of rupture         = 480
     Reinforcing yield strength          = 60000
     Reinforcing modulus of elasticity   = 2.9000E+07
     Modular ratio                       = 8
     Maximum aggregate size              = 1.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5
     Depth to tensile reinf     = 21
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0.4
     Shear reinf spacing       = 5

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 100
     Maximum service load moment = 0
     Minimum service load moment = 0
     Factored (ultimate) shear   = 50

S E C T I O N   P R O P E R T I E S
==================================================

RECTANGULAR SECTION:

     Width  = 12
     Height = 24

PROPERTIES:

     Gross moment of inertia     = 1.3824E+04
     Gross section modulus       = 1.1520E+03
     Distance to neutral axis    = 1.2000E+01
     Cracked moment of inertia   = 8.6758E+03

S H E A R   R E V I E W   C A L C U L A T I O N S
==================================================

CONCRETE SHEAR CAPABILITY:

     Effective shear depth      = 1.8900E+01
     Concrete shear strength    = 3.3436E+01
        Longitudinal strain     = 3.6529E-04
        Theta                   = 3.0500E+01
        Beta                    = 2.5900E+00

SHEAR REINFORCING:

     Min shear reinf area       = 6.3246E-02
     Max shear reinf spacing    = 1.5120E+01

     Shear reinf strength       = 1.3861E+02
     Ultimate shear capability  = 1.7205E+02
     Maximum shear capability   = 2.0412E+02

MINIMUM LONGITUDINAL TENSILE REINFORCING:

     Minimum reinf area         = 1.9617E+00
```

VERIFICATION PROBLEM NO. 13

CAN/CSA S6 code
Ref. CPCA, "Concrete Design Handbook", 2nd edition, Example 2.7



Same beam as used in verification problem no. 7

f'_c = 30 MPa
f_y = 400 MPa

A_s = 5600 mm^2 => (8) 30M bars
M_f = 1500 kN-m
M_{max} = 1000 kN-m

$\alpha_1 = 0.85 - 0.0015 \times 30 = 0.805$
$\beta_1 = 0.97 - 0.0025 \times 30 = 0.895$

$E_c = (3000(30)^{1/2} + 6900)(2450/2300)^{1.5} = 25650$ MPa

$y_{cg} = (800 \times 75 \times 37.5 + 400 \times 1000 \times 500) / 460000 = 440$ mm
$I_g = 800(75)^3/12 + 400(1000)^3/12 + 60000(402.5)^2 + 400000(60)^2$
$I_g = 4.452E+10$ mm^4
$1.2Mcr = 1.2 \times 0.4(30)^{1/2} \times 4.452E+10 / [(1000 - 440) \times 1000000] = 209$ kN-m

$400y^2/2 + 60000(y - 37.5) = 8 \times 5600(896 - y)$
$200y^2 + 104800y - 42390800 = 0$
$y = 268$ mm
$I_{cr} = 400(268)^3 / 3 + 800(75)^3 / 12 + 60000(230.5)^2 + 8 \times 5600(628)^2$
$I_{cr} = 2.345E+10$ mm^4

$S_c = I_{cr} / y = 87500000$
$S_s = I_{cr} / ((896 - 268) * 8) = 4667596$

$f_{cmax} = 1000 * 1000000 / 87500000 = 11.43$ MPa
$f_{smax} = 1000 * 1000000 / 4667596 = 214$ MPa

Crack width = w

$w = 1.0 \times 1.7 \times s_{rm} \times \varepsilon_{sm}$

Bar diameter $d_b = 30$
$A_{ct} = 400 \times (1000 - 268) / 3 = 97600$
$\rho_c = 5600 / 97600 = 0.0574$
$s_{rm} = 50 + 0.25 \times 0.5 \times 30 / 0.0574 = 115$
$M_w = 209 / 1.2 = 174$ kN-m
$f_w = 174 \times 1000000 / 4667596 = 37.3$ MPa
$\varepsilon_{sm} = (214 / 200000) \times [1 - (37.3/214)^2] = 0.00104$

$w = 1.0 \times 1.7 \times 115 \times 0.00104 = 0.20$ mm < 0.35 mm Okay

Tension steel is assumed to yield.
with a = 128.3 mm
$T = 0.9 \times 400 \times 5600 = 2016000$ N
$C_{web} = 0.75 \times 0.805 \times 30 \times 128.3 \times 400 = 929534$ N
$C_{flange} = 0.75 \times 0.805 \times 30 \times 800 \times 75 = 1086750$ N
$M_r = 929.534 \times (0.896 - 0.1283 / 2) + 1086.75 \times (0.896 - 0.075 / 2) = 1706$ kN-m

```
Verification problem 13 review

* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                       *
*           P R O G R A M   R E B E A M                 *
*                                                       *
*                    OUTPUT DATA                        *
*                                                       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * *
(Version  5.1)                    11/02/07, 7:49 pm

Output file = v13.out

Moment review problem

D E S I G N   C R I T E R I A
=====================================================

Code  = CAN/CSA-S6 (2006)
Units = Metric (Newtons, millimeters - shear and moments in kN-m)

STRENGTH REDUCTION AND RESISTANCE FACTORS:

     Flexure reduction factor            = 1.00
     Shear reduction factor              = 1.00
     Concrete resistance factor          = 0.75
     Reinforcing resistance factor       = 0.90

STRESS BLOCK:

     Ratio of average concrete strength  = 0.8050
     Ratio of depth of compression block = 0.8950
     Maximum concrete strain             = 0.0035

M A T E R I A L   P R O P E R T I E S
=====================================================

     Concrete compressive strength       = 30
     Concrete modulus of elasticity      = 2.5650E+04
     Concrete modulus of rupture         = 2.191
     Reinforcing yield strength          = 400
     Reinforcing modulus of elasticity   = 2.0000E+05
     Modular ratio                       = 8
     Maximum aggregate size              = 20.000

R E I N F O R C I N G   S T E E L
=====================================================

     Tensile reinf area         = 5600
     Depth to tensile reinf     = 896
     Compressive reinf area     = 0
     Depth to compressive reinf = 0
```

```
     Shear reinf area          = 0
     Shear reinf spacing       = 0

D E S I G N   L O A D S
==================================================

     Factored (ultimate) moment  = 1500
     Maximum service load moment = 1000
     Minimum service load moment = 0
     Factored (ultimate) shear   = 0

S E C T I O N   P R O P E R T I E S
==================================================

TEE SECTION:

     Height               = 1000
     Top flange width     = 1200
     Top flange thickness = 75
     Total web thickness  = 400

PROPERTIES:

     Gross moment of inertia     = 4.4522E+10
     Gross section modulus       = 7.9457E+07
     Distance to neutral axis    = 4.3967E+02
     Cracked moment of inertia   = 2.3451E+10
     Effective moment of inertia = 2.3562E+10

M O M E N T   R E V I E W   C A L C U L A T I O N S
==================================================

MINIMUM REINFORCING:

     1.2 * Cracking moment      = 2.0891E+02
     Design moment              = 1.5000E+03

MAXIMUM REINFORCING:

     c/d                        = 1.5994E-01
     Maximum c/d                = 5.0000E-01

MOMENT CAPABILITY:

     Ultimate moment capability  = 1.7060E+03
     Stress block depth          = 1.2826E+02
```

```
SERVICE LOAD STRESS:

     Maximum steel stress    = 2.1433E+02
     Minimum steel stress    = 0.0000E+00
     Maximum concrete stress = 1.1416E+01
     Minimum concrete stress = 0.0000E+00

CRACK CONTROL:

     Rebar x load type factor  = 1.7
     Rebar diameter            = 30
     Average crack spacing     = 1.1538E+02
     Average rebar strain      = 1.0392E-03
     Computed crack width      = 2.0384E-01
     Maximum crack width       = 3.5000E-01
```