For updated version, please click on http://ocw.ump.edu.my

REINFORCED CONCRETE DESIGN 1

Design of Staircase (Examples and Tutorials)

by

Dr. Sharifah Maszura Syed Mohsin
Faculty of Civil Engineering and Earth Resources
maszura@ump.edu.my

Example 1: Straight staircase design

A reinforced concrete staircase for office use is shown in **Figure 1**. It is connected to a landing at upper part and supported by a beam at the end of the landing. At the end lower the stair supported by a beam and continuous with the floor slab. Design the staircase by using concrete grade 25 and strength of reinforcement of 500 N/mm^2. The imposed load is 2.5 kN/m^2 and finishes is 0.5 N/m^2. Nominal cover, c_{nom} is 25 mm. The width of staircase is 1500 mm, the thickness of landing is 150 mm and the waist thickness (h) is 150 mm. Design the reinforcement for the stairs. Use diameter bar = 10 mm.

Example 1: Straight staircase design

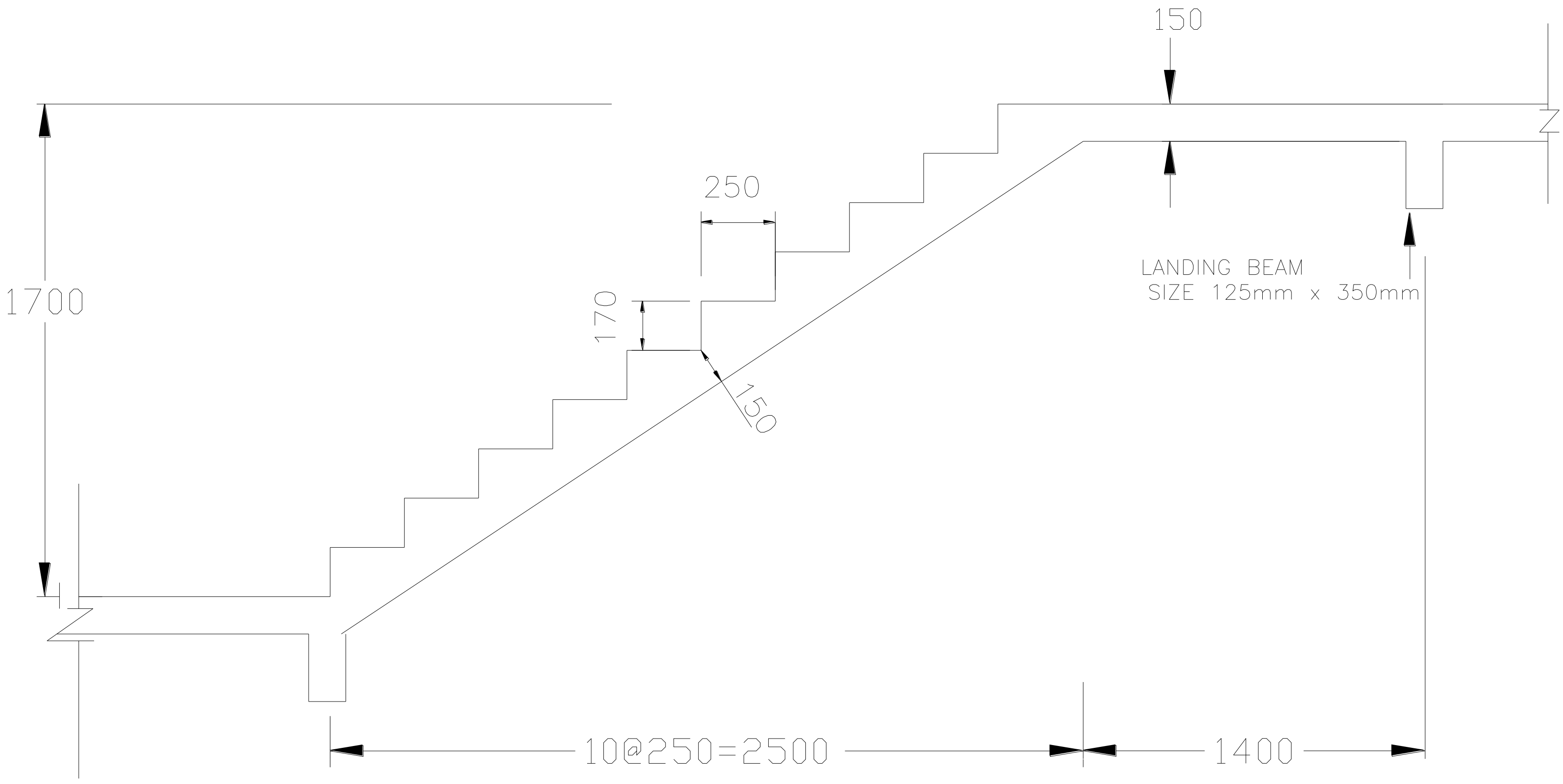


Figure 1

Example 1: Straight staircase design

<u>Load Analysis</u>

Average thickness of flight , y $= h(G^2 + R^2)^{1/2}/G$

$= 150\ (250^2 + 170^2)^{1/2}/250$

= 181.4 mm

Average thickness, t = y + (R/2) = 181.4 + (170/2)

= 266.4 mm

<u>Actions</u>

Landing permanent action,

Self-weight staircase = 0.15 x 25

= 3.75 kN/m^2

Finishes = 0.5 kN/m^2

Total g_k = 4.25 kN/m^2

Variable action, q_k = 2.5 kN/m^2

Example 1: Straight staircase design

Design Action, w = 1.35gk + 1.5qk

= 9.49 kN/m^2

Flight permanent action,

Self-weight staircase = 0.266 x 25

= 6.65 kN/m^2

Finishes = 0.5 kN/m^2

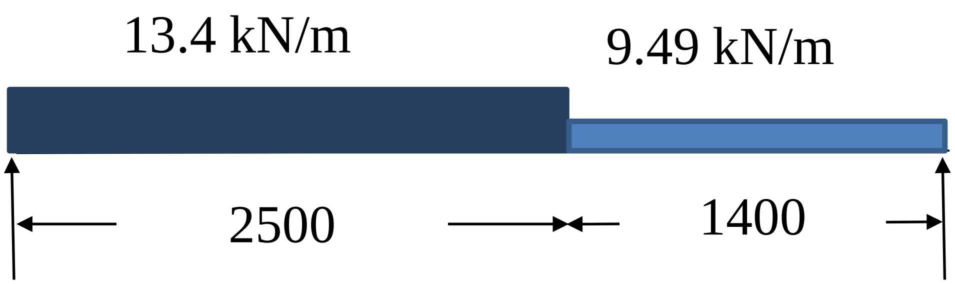
Total g_k = 7.15 kN/m^2

Variable action, q_k = 2.5 kN/m^2

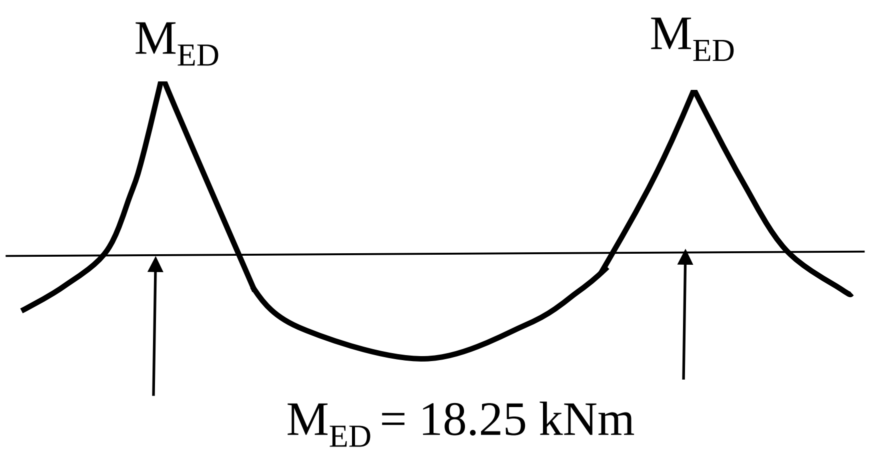
Design Action, w = 1.35gk + 1.5qk

= 13.4 kN/m^2

Example 1: Straight staircase design



Total load, F = 13.4(2.5) + 9.49(1.4) = 46.79 kN



$M_{ED} = wL/10$

$= 46.79\,(3.9)/10$

$= 18.25$ kNm

Example 1: Straight staircase design

Effective depth,

$d \quad = h - c_{nom} - 0.5\phi_{bar} \quad = 150 - 25 - 10/2 = 120$ mm

$M_{ED} = 18.25$ kNm

$K \quad = M/bd^2f_{ck}$

$= 18.25 \times 10^6/(1000 \times 120^2 \times 25)$

$= 0.052 < k_{bal} = 0.167$ no. compression reinforcement required

$z \quad = d[0.5 + (0.25 - K/1.134)^{1/2}]$

$= 0.98d > 0.95d$ use 0.95d

$A_s \quad = M/0.87f_{yk}z$

$= 18.25 \times 10^6/(0.87*500*0.95*120)$

$= 368$ mm^2

Provide H10-200
(A_s = 393 mm^2)

Example 1: Straight staircase design

Minimum and maximum reinforcement area,

$A_{s,min}$ $= 0.26(f_{ctm}/f_{yk})bd$

$= 0.0151\ bd > 0.013bd$

$= 179.45\ mm^2$

$A_{s,max}$ $= 0.04\ Ac$

$= 0.04(1000)(150)$

$= 6000\ mm^2$

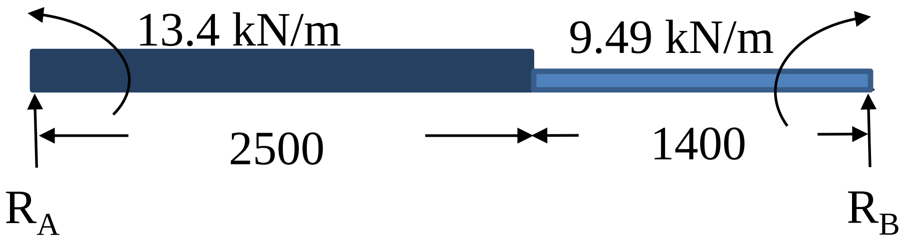
Secondary Reinforcement $= 20\%\ A_s$

$A_s = 20\%\ (As) = 0.2\ (503) = 100.6\ mm^2$

Provide H10-400 ($A_s = 196.5\ mm^2$)

Example 1: Straight staircase design

SHEAR



R_A = 29.56 kN R_B = 17.22 kN
Shear force, V_{ED} = 29.54 kN

V_{Rdc}= [0.12 k (100ρ1f_{ck})1/3] bd

k $= 1 + (200/d)^{1/2} \leq 2.0$

$= 2.29 >$ **2.0**

ρ1 $= (A_{sl} / b_w d)$ = 503/(1000x120) = 0.0033 $\leq$ 0.02

= 0.0033 > 0.002

V_{Rdc}= 34.03 kN

V_{min}= [0.035k $^{3/2}$ f_{ck} ½] bd = 59.4 kN

Thus, V_{Rdc} = 54.9 kN > V_{ED} = 29.56 kN, OK!

Example 1: Straight staircase design

<u>Deflection</u>

$\rho = A_{s,req}/bd = 368/(1000x120) = 0.0031$

$\rho_o = \sqrt{f_{ck}}^{(10\text{-}3)} = \sqrt{25}^{(10\text{-}3)} = 0.005 \text{ x } 10^{-3}$

$\rho_o > \rho$, structural system, K = 1.5

$L/d = k\,(11 + 1.5\sqrt{f_{ck}}\,(\rho_o / \rho) + 3.2\sqrt{f_{ck}}\,((\rho_o / \rho\,)\text{-}1)^{3/2})$

$L/d = 1.5\,(11 + 12.1 + 7.68)$

$(L/d)_{basic} = 46.17$

Modification factor, $A_{s,prov}/ A_{s,req} = 393/368 = 1.07 < 1.5$

$(L/d)_{allow} = 46.17 \text{ x } 1.07 = 49.4$

$(L/d)_{actual} = 3900/120 = 32.5 < (L/d)_{allow}$, OK!

Example 1: Straight staircase design

Check Crack

Slab thickness, h = 150 mm < 200 mm

Main bar:

$S_{v,max}$, slab = 3h ≤ 400 mm

= 3(150) ≤ 400 mm , 450 mm ≥ 400 mm, Use 400

Actual bar spacing = 200 mm < 400 mm OK

Secondary bar:

$S_{max,\ slab}$ = 3.5h ≤ 450 mm

= 450 mm , use 450 mm

Actual bar spacing = 400 < 450 mm**, OK**

Example 2: Open-well staircase design

A staircase of 1.5 m width for an office building with slab supported on a beam at the top and and on the landing of the flight at right angles at the bottom is shown in **Figure 2**. The riser and goings of the stairs are 160 mm and 250 mm, respectively. The variable load is 3.0 kN/m^2 and the permenant action from finishes, baluster and railing about 1.0 kN/m^2. Materials used in this construction consist of concrete with characteristic strength, f_{ck} = 30 N/mm^2 and steel strength, f_{yk} = 500 N/mm^2. The thickness of the landing is 150 mm and waist thickness (h) is 150 mm. Design the stairs if the concrete cover = 25 mm and the main bar diameter, ϕ_{main} = 10 mm.

Example 2: Open-well staircase design

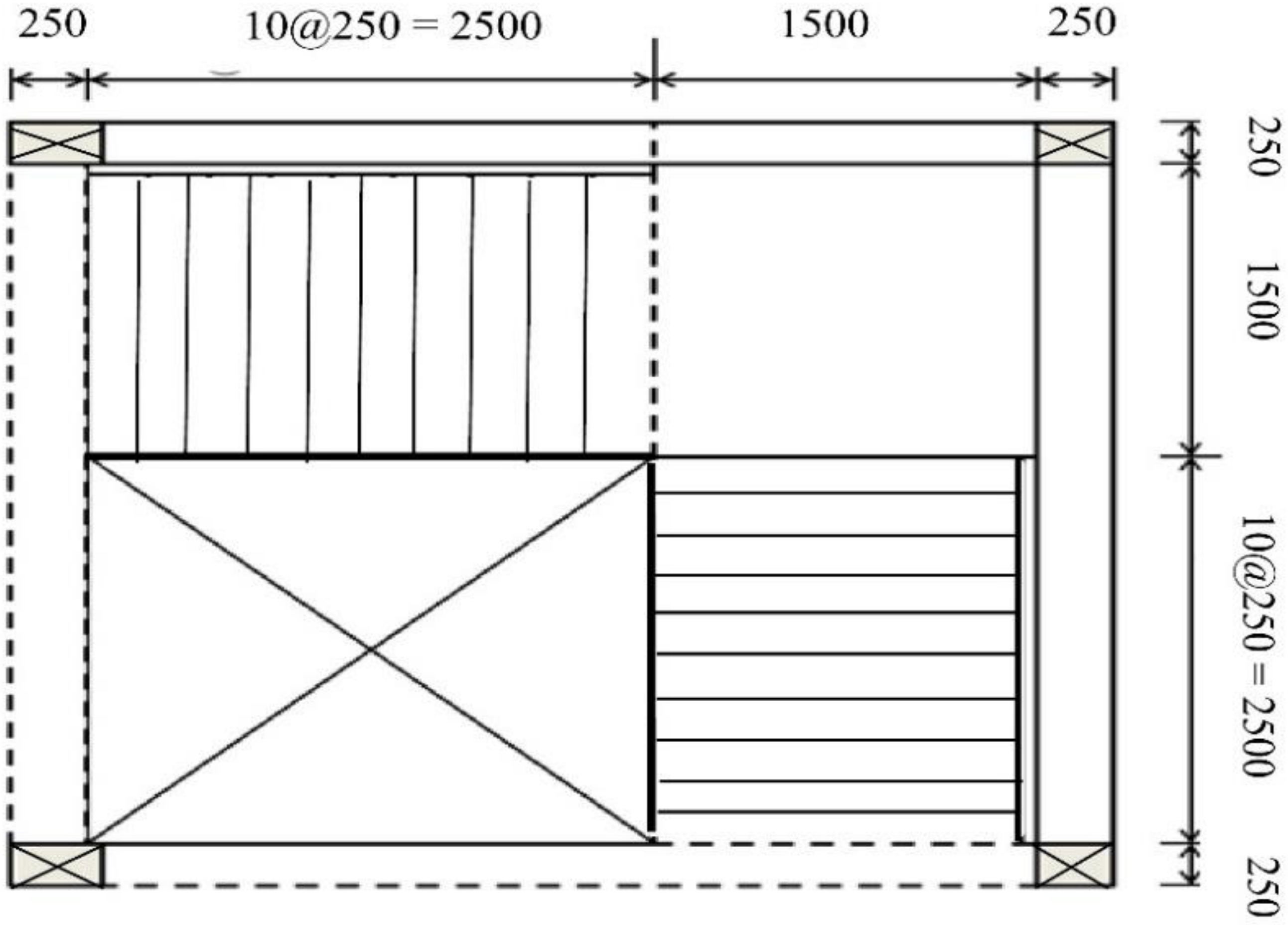


Figure 2

Example 2: Open-well staircase design

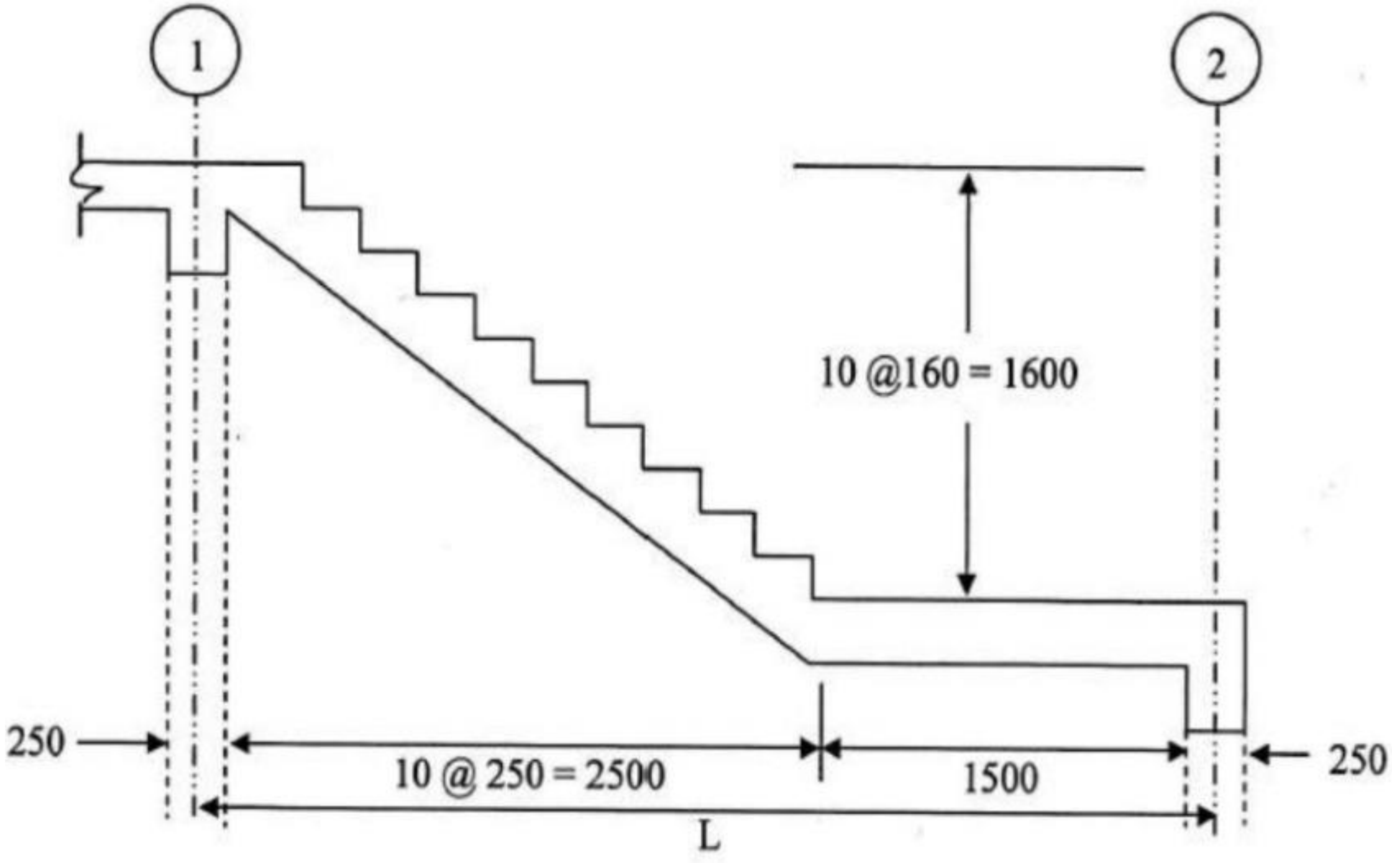


Figure 2 (continue)

Example 2: Open-well staircase design

Load Analysis

Average thickness, y $= h(G^2 + R^2)^{1/2}/G$

$= 150\ (250^2 + 160^2)^{1/2}/250$

= 178 mm

Average thickness, $t = [y + (y + R)]/2 = 258$ mm

Actions

Landing

Slab self-weight $= 0.15 \times 25 = 3.75$ kN/m^2

Permanent load excluding self-weight $= 1.00$ kN/m^2

Characteristic permanent action $= 4.75$ kN/m^2

Characteristic variable action $= 3.00$ kN/m^2

Example 2: Open-well staircase design

Design action n_d = 1.35 (4.75) + 1.5 (3.0) = 10.91 kN/m^2

Flight

Slab self-weight = 0.258 x 25 = 6.45 kN/m^2

Permanent load excluding self-weight = 1.00 kN/m^2

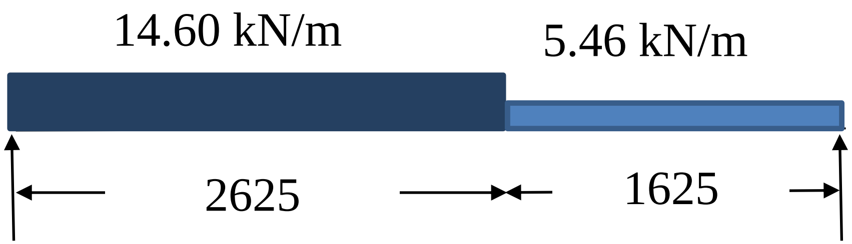
Characteristic permanent action = 7.45 kN/m^2

Characteristic variable action = 3.00 kN/m^2

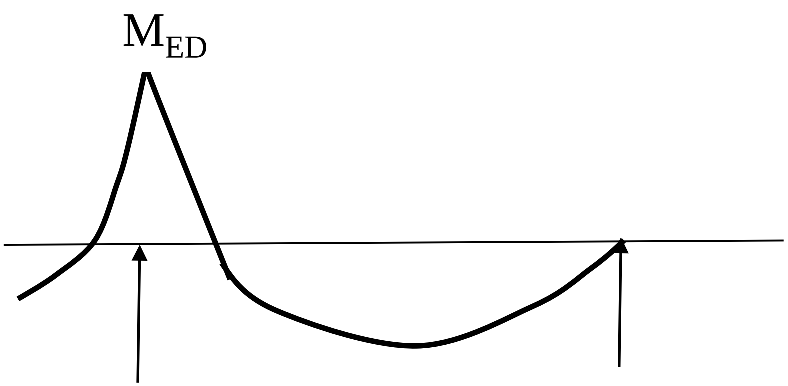
Design action n_d = 1.35 (7.45) + 1.5 (3.0) = 14.60 kN/m^2

Example 2: Open-well staircase design

Analysis



Total action = (5.46 x 1.625) + (14.6 x 2.625) = 47.2 kN/m



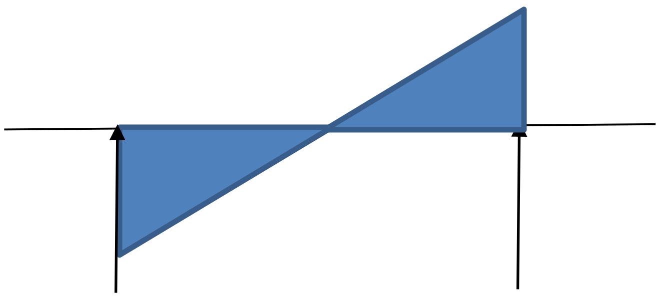
M_{ED} = 20.06 kNm

M_{ED} = FL/10

= 47.2 (4.25)/10

= 20.06 kNm

Example 2: Open-well staircase design



Shear force,

V_A = [(14.6 x 2.625 x 2.94) + (5.46 x 1.625 x 0.81) – 20.06]/4.25 = 23.48 kN/m

V_B = [(14.6 x 2.625) + (5.46 x 1.625) – 23.48 = 23.72 kN/m

Example 2: Open-well staircase design

MAIN REINFORCEMENT

Effective depth,

$d \quad = h - c_{nom} - 0.5\phi_{bar} = 150 - 25 - 10/2 = 120$ mm

$K \quad = M/bd^2f_{ck}$

$= 20.1 \times 10^6/(1000*120^2*25)$

$= 0.056 < k_{bal} = 0.167$, no. compression reinforcement required

$z \quad = d[0.5 + (0.25 - K/1.134)^{1/2}]$

$= 0.95d \leq 0.95d$ use 0.95d

$A_s \quad = M/0.87f_{yk}z$

$= 20.1 \times 10^6/(0.87 \times 500 \times 0.95 \times 120)$

$= 405.3$ mm^2

Example 2: Open-well staircase design

Minimum and maximum reinforcement area,

$A_{s,min}$ $= 0.26(f_{ctm}/f_{yk})bd$
$= 0.0145\ bd > 0.013bd$
$= 181\ mm^2$

$A_{s,max}$ $= 0.04\ Ac$
$= 0.04(1000)(150)$
$= 6000\ mm^2$

Secondary bar = 0.2 x 405.3= 81.1 mm^2/m

Main Reinforcement ➔Provide: H10-175 (449 mm^2)

Secondary Reinforcement ➔ Use: H10 – 400 (196 mm^2)

Example 2: Open-well staircase design

SHEAR

Shear force, V_{ED} = 23.72 kN

V_{Rdc}= [0.12 k (100ρ1f_{ck})1/3] bd

k = $1 + (200/120)^{1/2} \leq 2.0$

= 2.29 ≤ **2.0**

ρ1 = (A_{sl} / b_wd) = 449/(1000x120) ≤ 0.02

= 0.0037 ≤ 0.002

V_{Rdc}= 64.2 kN

V_{min}= [0.035$k^{3/2}$ f_{ck} ½] bd = 65.1 kN

So, V_{Rdc} = 65.1 kN > V_{ED} = 23.72 kN, OK! . No shear reinforcement required

Example 2: Open-well staircase design

Deflection

$\rho = A_{s,req}/bd = 405.3/(1000x120) = 0.0034$

$\rho_o = \sqrt{f_{ck}}^{(10\text{-}3)} = \sqrt{25}^{(10\text{-}3)} = 0.005$

$\rho < \rho_o$, structural system, K = 1.3

$L/d = k\,(11 + 1.5\sqrt{f_{ck}}\,(\rho_o / \rho) + 3.2\sqrt{f_{ck}}\,((\rho_o / \rho)\text{-}1)^{3/2})$

$L/d = 1.3\,(11 + 11.03 + 5.17)$

$(L/d)_{basic} = 35.35$

Modification factor, $A_{s,prov}/ A_{s,req} = 449/405.3 = 1.11 < 1.5$

$(L/d)_{allow} = 35.35 \times 1.11 = 39.24$

$(L/d)_{actual} = 4250/120 =$ **$35.42 < (L/d)_{allow}$, OK!**

Example 2: Open-well staircase design

Check Crack

Slab thickness, h = 150 mm < 200 mm

Main bar:

S_{max}, slab = 3h ≤ 400 mm

= 3(150) = 450 mm , use 400 mm

Max. bar spacing = 175 mm < 400 mm OK.

Secondary bar:

$S_{max,\ slab}$ = 3.5h < 450 mm

= 3.5(150) = 525 mm , use 450 mm

Max. bar spacing = 400 < 450 mm, OK

Tutorial 1: Staircase design

Design a straight reinforced concrete stairs supported by reinforced concrete beams at both ends. Landing slabs at both ends of the stairs are cast together connecting the stairs. Using the following information, design the staircase.

Concrete grade: C30/C37

Steel grade: 500

Perm. load from finishes, baluster and railing: 1.5 kN/m^2

Variable load: 3.5 kN/m^2

C_{nom} = 25 mm

Bar size = 10 mm

R = 180 mm

G = 250 mm

h = 120 mm

Tutorial 2: Staircase design

Figure 3 shows the plan view of open well stair support by beam at the end of its landing. The risers are 160 mm, goings are 250 mm as shown in Figure 4, and story height is 3.5 m. Goings are provided with 3 cm thick marble finish on cement mortar that weights 1.0 kN/m^2. The landings are surface finished with terrazzo tiles on sand filling that weighs 1.2 kN/m^2. The stair is to be designed for a variable action of 3.0 kN/m^2. Design the staircase by providing the reinforcement. Check the shear, deflection, and crack and illustrate the curtailments of the staircase.

Use of concrete strength, f_{ck} = 30 N/mm^2, steel strength, f_{yk} = 500 N/mm^2 and diameter of bar, ϕ^{main} = 12 mm. Nominal cover, c_{nom} for this stairs, is 25 mm.

Tutorial 2: Staircase design

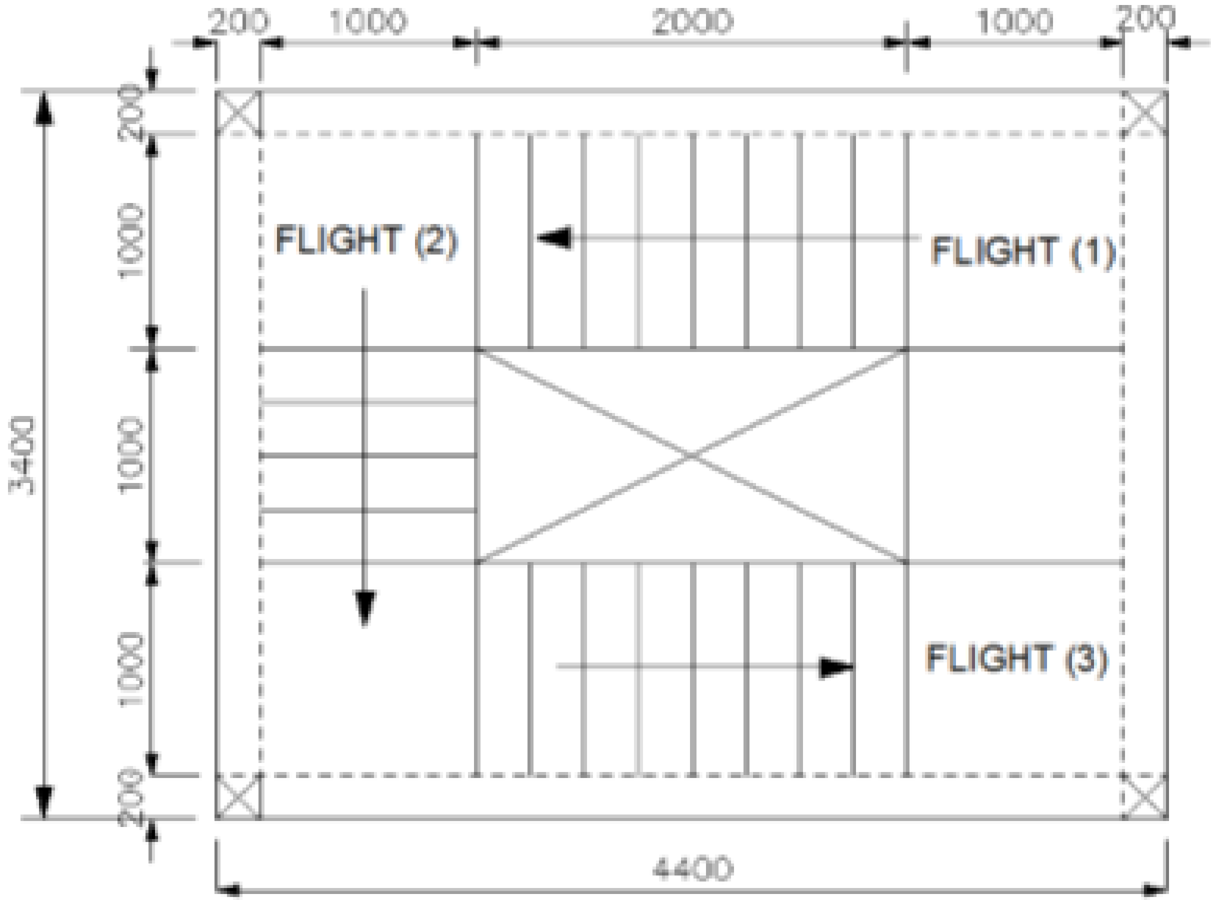


Figure 3

Tutorial 2: Staircase design

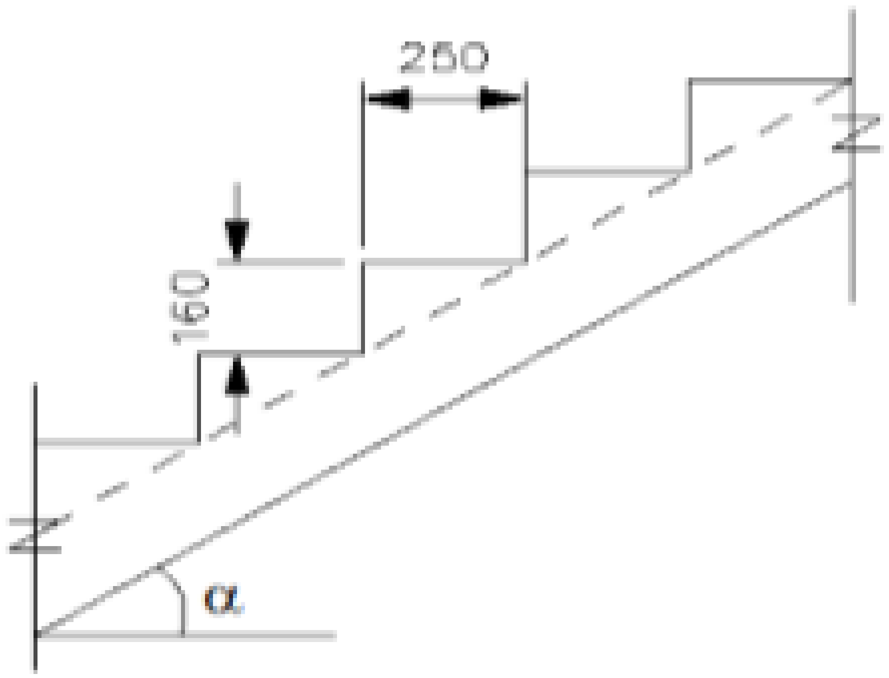


Figure 4

End of Examples and Tutorials