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Lecture Notes on Design of Stair cases

DESIGN OF RCC STRUCTURAL ELEMENTS - 10CV52

(PART – B, UNIT – 8)

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DESIGN OF STAIR CASES

Syllabus

UNIT – 8

General features, types of stair case, loads on stair cases, effective span as per IS code provisions, distribution of loading on stairs, Design of stair cases with waist slabs.

Stairs

Stairs consist of steps arranged in a series for purpose of giving access to different floors of a building. Since a stair is often the only means of communication between the various floors of a building, the location of the stair requires good and careful consideration.

In a residential house, the staircase may be provided near the main entrance. In a public building, the stairs must be from the main entrance itself and located centrally, to provide quick accessibility to the principal apartments. All staircases should be adequately lighted and properly ventilated.

The staircase is an important component of a building, and often the only means of access between the various floors in the building. It consists of a flight of steps, usually with one or more intermediate landings provided between the floor levels. The horizontal top portion of a step is termed tread and the vertical projection of the step is called riser. Generally tread of 300 mm and Riser of 150 mm are ideally suited for public buildings. For residential and factory buildings lower values of tread up to 250 mm combined with higher values of riser up to 190 mm are preferred. The width of the stair is generally around 1.1 – 1.5m, and in any case, should normally not be less than 850 mm. The horizontal projection (plan) of an inclined flight of steps, between the first and last risers, is termed going of flight. Generally, risers in a flight should not exceed about 12 in number.

Types of stair cases

Geometric classification

1. straight stairs (with or without intermediate landing)
2. quarter-turn stairs
3. dog-legged stairs
4. open well stairs
5. spiral stairs
6. helicoidal stairs
7. slabless stair case
8. free standing stair case

Structural Classification

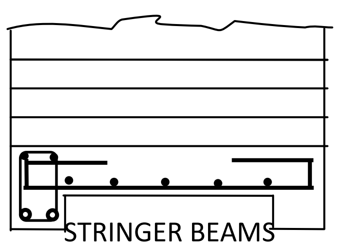
1. Stairs with cantilever steps
2. Stair slab spanning transversely
   (or horizontally between stringer beams or walls)
3. Stair slab spanning longitudinally
4. Slabless or raiser and tread type
5. Spiral stair case
6. Helicoidal slab stair case
7. 3D or free standing stair slab

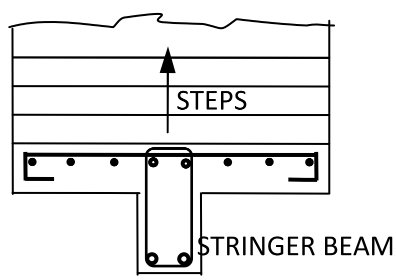
- **Classification based on span**

Based on type of span, following are the two types of stair cases;

- ❖ Horizontally spanning or transversely spanning stairs. Figure 1
- ❖ Longitudinally spanning stairs. For details refer IS: 456-2000 and SP (34).

Transversely spanning stair cases can be seen in figure 1. Here the main steel is provided transversely and the distribution steel is in the longitudinal direction.





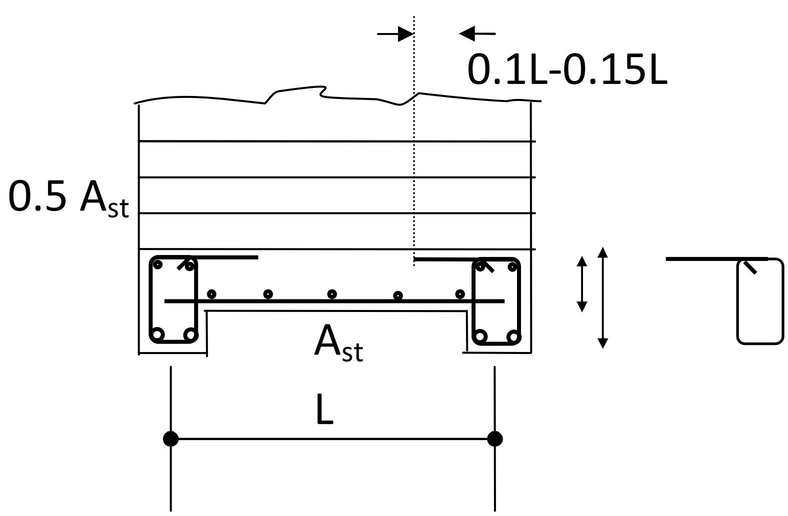


Figure 1. Transversely spanning stair cases

Longitudinally spanning stair cases:

Here the main steel in provided longitudinally and the distribution steel is in the transverse direction. Refer problem.

Effective span

The effective span is defined as follows based on the type of support.

Where flight supported at the ends of the landings in such a way that both landing and flight spans in the same direction, the effective span is the distance between the center to center of the supporting beams or wall. Refer Figure 2.

Where spanning on the edge of a landing slab which spans parallel with the riser, the effective span is the distance equal to the going of the stairs plus at each end either half the width of the landing or one meter, whichever is smaller. Refer Figure 3.

Where supported at top and bottom riser by beams spanning parallel with the riser, the distance center to center of the beams is the effective span. Refer Figure 4.

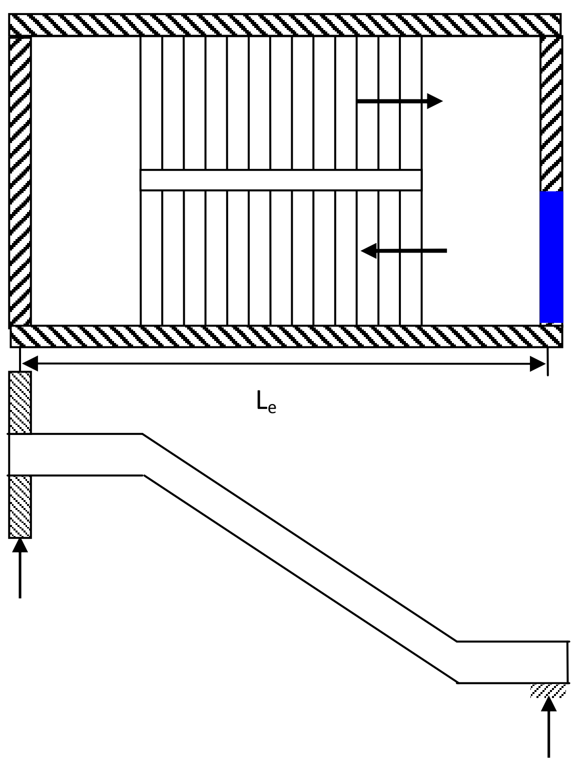


Figure 2. Flight supported at the ends of the landings on walls

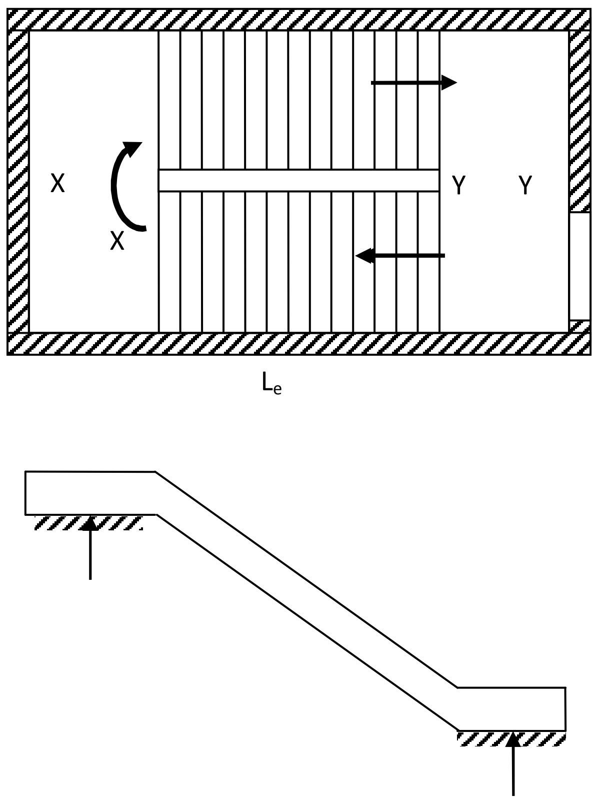


Figure 3. Flight supported at the sides of the landings on walls

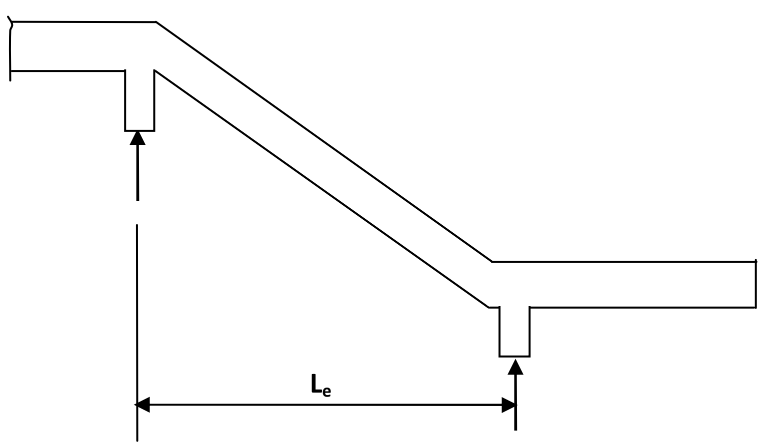


Figure 4. Flight supported on landing beams

- **Guide lines**

Guide lines to be followed for fixing the dimensions of component parts of stair.

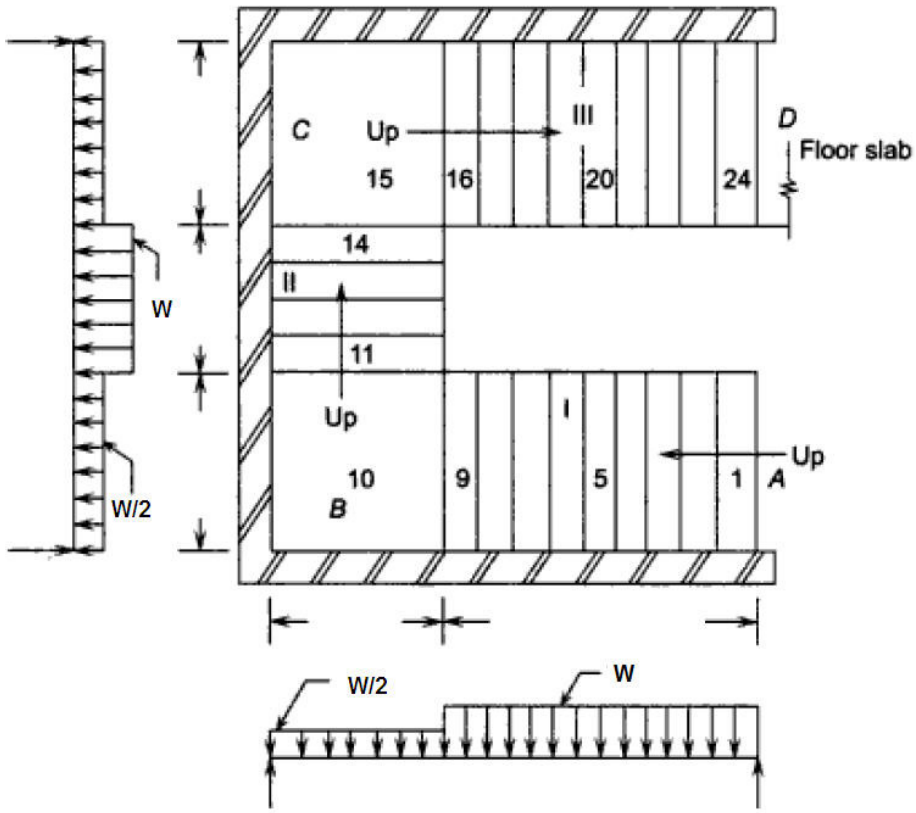
1. Rise (R) is 150mm to 180mm and tread (T) is 220 mm to 250 mm for a residential building.
2. For public building rise is kept between 120 to 150 mm and tread between 250 to 300 mm
3. Sum of tread (T) and twice the rise (2R) should be between 500 mm to 650 mm
4. The width of the stair is dependent on the usage and is between 0.8 m to 1 m for residential building and 1.8 m to 2 m for public building.
5. The width of the landing is equal to the width of stairs.
6. The number of steps in each flight should not be greater than 12
7. The pitch of the stair should not be more than 38 degrees.
8. The head room measured vertically above any step or below the mid landing shall not be less than 2.1 m.

Distribution of Loading on Stairs

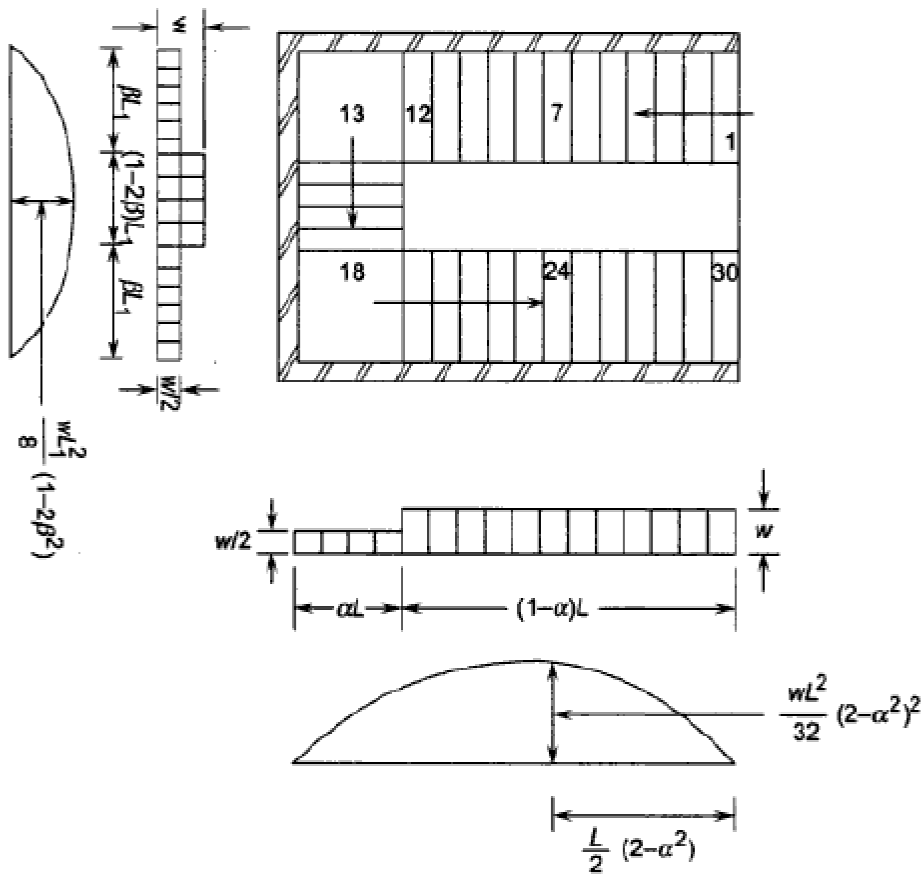
In the case of stairs with open wells, where spans partly crossing at right angles occur, the load on areas common to any two such spans may be taken as one half in each direction as shown in Fig. 5. Where flights or landings are embedded into walls for a length of not less than 110 mm and are designed to span in the direction of the flight, a 150 mm strip may be deducted from the loaded area and the effective breadth of the section increased by 75 mm for purposes of design (see Fig. 6).

Depth of Section

The depth of section shall be taken as the minimum thickness perpendicular to the soffit of the staircase.



βL_1, $(1-2\beta)L_1$



Load distribution and bending moments

RCC design of a Dog-legged staircase

In this type of staircase, the succeeding flights rise in opposite directions. The two flights in plan are not separated by a well. A landing is provided corresponding to the level at which the direction of the flight changes.

Design of Dog-legged Stairs

Based on the direction along which a stair slab span, the stairs maybe classified into the following two types.

1. Stairs spanning horizontally
2. Stairs spanning vertically

Stairs spanning horizontally

These stairs are supported at each side by walls. Stringer beams or at one side by wall or at the other side by a beam.

Loads

- Dead load of a step = ½ x T x R x 25
- Dead load of waist slab = b x t x 25
- Live load = LL (KN/m^2)
- Floor finish = assume 0.5 kN/m

Stairs spanning Longitudinally

In this, stairs spanning longitudinally, the beam is supported ay top and at the bottom of flights.

Loads

- Self weight of a step = 1 x R/2 x 25
- Self weight of waist slab = 1 x t x 25
- Self weight of plan = 1 x t x 25[$(R^2 + T^2)/T$]
- Live load = LL (KN/m^2)
- Floor finish = assume 0.5 KN/m

For the efficient design of an RCC stair, we have to first analyse the various loads to be imposed on the stair.

The load calculations will help us determine, how much strength is required to carry the load. The strength bearing capacity of a staircase is determined on the amount of steel and concrete used.

The ratio of steel to concrete has to be as per standards. Steel in the staircase will take the tension imposed on it and the concrete takes up the compression

Design of RCC Stair case

Ex. 1 Design a dog legged stair case for a residential building hall measuring 2.2 m x 4.7 m. The width of the landing is 1m. The distance between floor to floor is 3.3 m. The rise and tread may be taken as 150mm and 270mm respectively. The weight of floor finish is 1 kN/m^2. The materials used are M20 grade concrete and Fe415 grade steel. Sketch the details of steel. Here flight and the landing slabs spans in the same direction i.e, Flight spans longitudinally.

Data:
f_{ck} = 20 MPa, f_y = 415MPa, Landing = 1m, H = 3.3m,
Size of stair case hall = 2.2m x 3.7 m.

Assume the wall thickness as 200 mm.

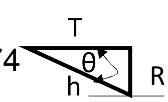
Proportioning of stair:
R = 150 mm, T= 270 mm. H = 3.3m. Height of each flight = H1= H/2 =3.3 /2 = 1.65m

Number of risers in each flight = H1/R = 1650 /150 = 11.
Thus Number of steps = 11-1 =10
Width of flight horizontally = 10 x 270 = 2700mm
Width of hall = 4700mm. Thus the each landing width = 1m
Let the width of step = 1m. Gap between the flights = 0.2 m

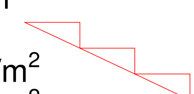
To fix the depth of waist slab:
l/d = 26, assuming partial fixity

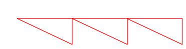
l_e = 4700 + 200 = 4900 mm. d= 4900/26= 188mm.
Assume effective cover = 20 mm NC (mild exposure) + 10/2 = 25 mm,
D= d + d_e = 213 mm say 215mm. Thus, d= 190mm

Calculation of loads:
Tanθ = R/T = 0.56. Hypotenuse, h = 309mm. Cosθ = T/h= 270/309= 0.874



Deal load of waist slab in plan = (0.215x1x1x25) 1/Cosθ = 6.14 kN/m^2
Weight of all floor finish horizontally, assumed as = 1kN/m^2
Weight of steps = R/2 x1 x1 x 24 = 1.80 kN/m^2
Imposed load = 3 kN/m^2
Total load = w = 11.94 kN/m^2
Ultimate load= 1.5x11.94 = w_u = 17.91 kN/m^2





Design of second flight:
Factored bending moment for second flight taking partial fixity effect
BM = $w_u l^2/10$ = 17.91 x 4.9^2/10 = 43.0 kNm
$M_{u,\,lim}$ of the given waist slab as balanced section = Qbd^2
= 2.76 x 1000 x 190^2=99.63 kNm> 43kNm. Under reinforced section. The depth provided is ok.

To find area of steel: Main steel

By calculation (Use this approach in exam)
For URS, Area of steel: $M_u = 0.87\, f_y\, A_{st}\, (d - f_y A_{st}/f_{ck}\, b) = 43 \times 10^6$
$68599 A_{st} - 7.49\, A^2_{st} = 43 \times 10^6$. Thus, $7.49\, A^2_{st} - 68599 A_{st} + 43 \times 10^6 = 0$
Solving $A_{st} = 676\ mm^2$, $p = 100A_{st}/bd = 0.356\% < p_{t,\ lim} = 0.96\%$, URS
Provide 10 mm @ s= 78.6/676 x 1000 =116.2, say 110mm c/c. Provide #10@110.
Here spacing is <300mm, <3d. Thus ok from serviceability requirements for cracking.

Use of SP 16 flexure table
$M_u/bd^2 = 43 \times 10^6/1000 \times 190 \times 190 = 1.191$. From SP-16,Table 2, page 48, p =0.359% , $p_{t,\ lim} = 0.96\%$
$A_{st} = 0.359 \times 1000 \times 190/100 = 682\ mm^2$. Provide #10@110.

Use of SP 16 design table for slabs
Also from SP-16, Table 23, page 64 for slab design, for a moment of 43 kNm, the steel can be obtained directly for M20, f_y=415 and **D=225 mm** as #10@120. As D = 215mm, provide #10@110.
$A_{st} = 79/110 \times 1000 = 718\ mm^2$, $p = 100A_{st}/bd = 0.38\%$

Use of SP 16 design charts for slabs and beams:
Chart 13, page 33 for M20, Fe415, d=190mm, Mu =43 kNm, percentage of steel p = 0.355%. Provide #10@110. These tables are valid for flexure members having 50mm to 800 mm depth which covers both slabs and beams.

Distribution steel:

Area of steel = 0.12% of $A_g = 0.12\, bD/100 = 0.12 \times 1000 \times 215/100 = 258\ mm^2$. Provide #8@ 50/258 x1000 = 190 mm c/c. The spacing is less than 450mm and also 5d. Thus safe in cracking.

Design for shear:
$V_u = w_u l_e/2 = 17.91 \times 4.9/2 = 43.88$ kN. $\tau_v = V_u/bd = 43.88 \times 1000/(1000 \times 190) = 0.23$MPa
P_t =0.35%, From IS:456-2000, $\tau_{c,\ slab} = k_s \tau_v = 1.18 \times 0.41$. Thus, $\tau_v < k_s\, \tau_c < \tau_{c,\ max.}$ ok
Hence the slab is safe in shear.

Check for development length:
Provide enough development length at the junction of flight and landing and also necessary anchorage over the support as shown in figure. $L_d = 47\varphi = 470$ mm and $l_d/3$ =160mm.

Check for deflection:
As the effective depth provided is more than that required for controlling the deflection, the slab is safe in shear. $(L_e/d)_{available} < (l/d)_{basic\ value} \times k_1\, k_2\, k_3$. 4700/190 = 24.7 <

26x1x1.3x1. ok. Here k_2 is 1.3 from IS:456-2000, Fig. 4, page 38, for p=0.35% and f_s = 240MPa of Fe415 steel.

Check for cracking:
As the detailing requirements with regard to diameter, spacing for main and dist. steel and cover for slab are satisfied as per the requirements of IS:456-2000, the cracking is prevented indirectly. Thus slab is safe in serviceability requirements.

Detailing: As shown in figure 1.

Design of First flight which starts from foundation

The same steel can be provided for first flight also. However the effective span for this flight is less (l_e= 3.9 m) and hence the steel required is also less. Thus, ground flight is safe in shear, deflection and cracking as well.

If the support conditions are different, then the effective span will be different. All other design calculations remain same. In this problem, if the flight is supported at its ends by means of landing slab (i.e. at the junction of flight and landing), then l_e = 2700 mm (distance b/n first and last risers) for both flights. Here the flight and the landing spans in opposite directions. Flight spans longitudinally and landing spans transversely). Landing is to be designed separately depending on its edge conditions. Similarly for the other support condition, i.e. when the flight is supported at all edges of the landing, then $l_e = l_g$ +x +y as per IS;456-2000.

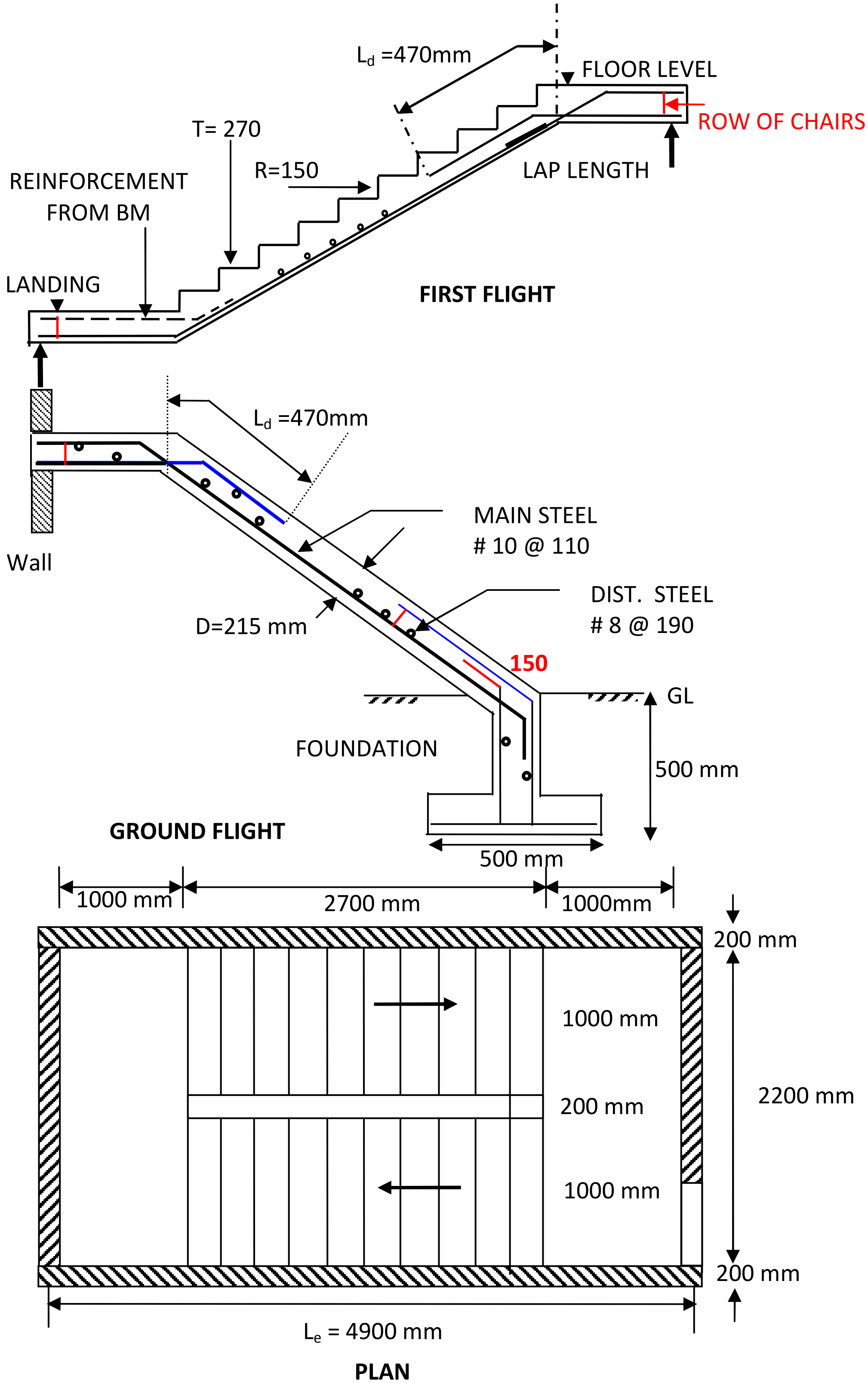


Figure 1. Detailing for stair case when supported at the ends on landing on walls. Ex.1

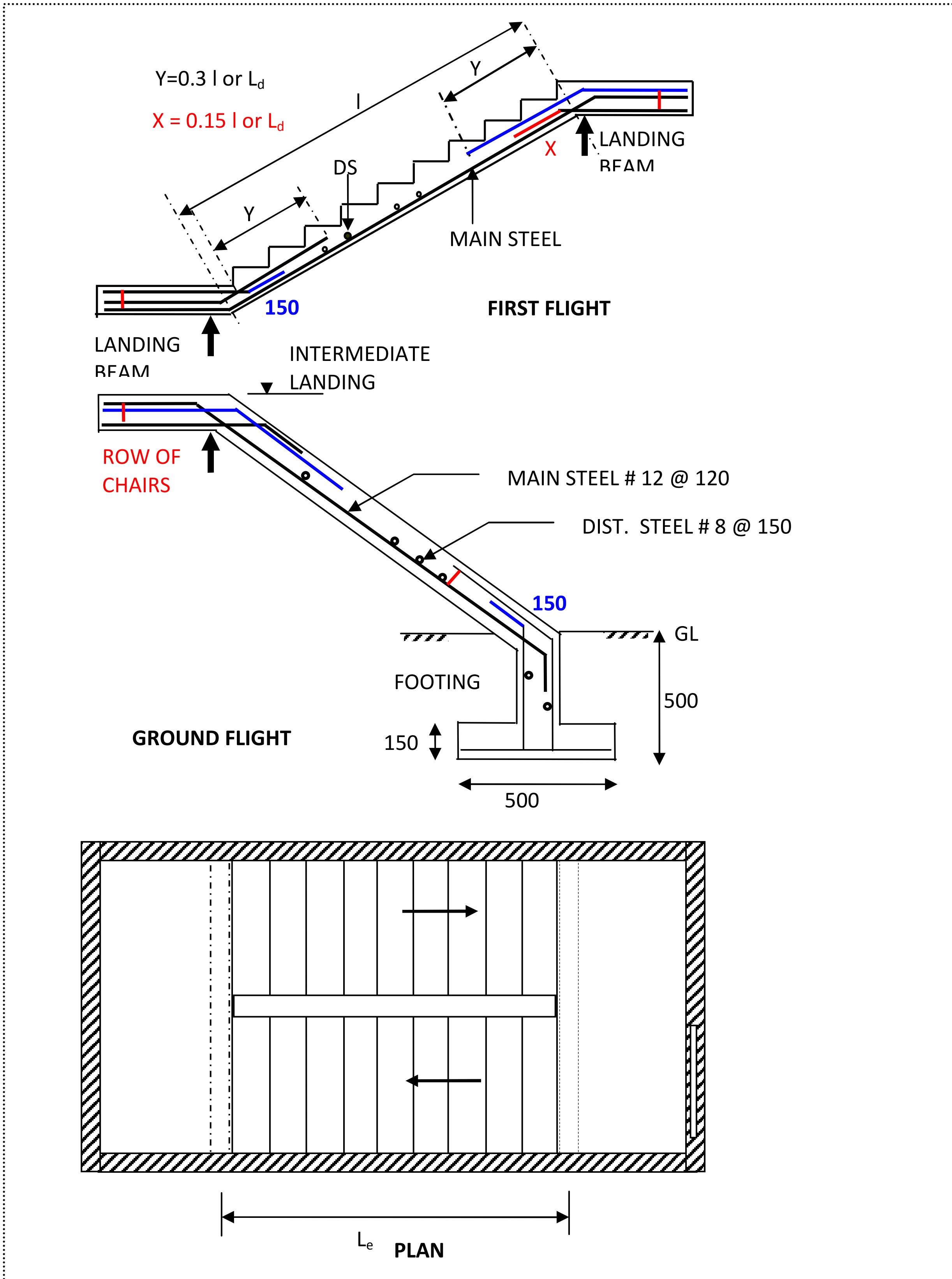


Figure 2. Detailing for stair case when supported on landing beams.