Design of Structures – II

Lecture – 38

In the previous lecture we have started discussing about the staircase, different components of staircase, type of staircases and also we have started finding the width of the components of the staircase by start designing with the help of first problem. In this lecture we are going to design the dog legged staircase by using the component which is predicted in the previous lecture.

Design of a Dog Legged Staircase

The service stair of an office building is to be located in a staircase hall measuring 3000mm x 5000mm. The vertical height of floor is 3500mm and thickness of slab is 125mm. The stair is supported on 230mm thickness walls. Use M20 and Fe415 as materials. Live load on slab is 3kN/m^2. Draw the cross section of staircase showing reinforcement details.

Section:

Here also we are going to find the fixing of dimensions of components, effective span of slab, loads on waist slab, loads on landing slab, loading diagram, bending moment and the effective thickness of slab from the bending moment and also we are going to find out the main steel as well as the distribution reinforcement of the bending moment. We are going to check the distribution of reinforcement detailing. So in the previous lecture by using these components we are going to start designing the dog legged staircase. Here the size of room which is given was 3000mm x 5000mm which was supported on 230mm wall so the effective size of the room is 5230mm x 3230mm. So here if you assume the thickness of the staircase is 150mm. Then we have found the number of steps as 12 numbers. And using 12 numbers we have found the exact thickness of the riser and also we have assumed the thickness of tread as 275mm. Using the tread thickness as well as the number of steps we have calculated the horizontal length of the waist slab as 3300mm. That is within 5000 we need to accommodate the width of passage as well as the landing. So here we have found the horizontal length of bases is 3300mm and the remaining length has to be adopted for the passage and to the mid-landing. And we have fixed the width of mid-landing as 900mm and the remaining width has been fixed to the passage that is 800mm. So we have calculated the horizontal as well as the vertical components of the staircase as well as the distance. Now we need to calculate the load.

Load Calculation:

Before the load calculation first we need to calculate the load calculation. The center to center of support here it is 5230mm and we have left some space for the waist slab that is 3300mm. And the remaining 900 and the half of the support is 1015mm and here it is 915mm. For loading diagram in meter here it is 0.915m and 3.3m and 1.015m. So here the effective length is 5.230m. Now we need to find out what is the loading on waist slab which must be normally greater than the loading on the other portion that is such as passage as well as the mid-landing.

Loading on waist slab:

Dead load:

$$= \frac{5230}{20} = 261.5mm$$

But I have assumed the overall slab as 230mm. So self weight of waist slab in slope form is 0.23 x 25 that is equal to 5.75kN/m^2 and here I need to find out what is the self weight of slab in horizontal position that is,

$$= 5.75 \frac{\sqrt{R^2 + T^2}}{T}$$

For horizontal component I need to find out,

$$Cos\theta = \frac{T}{\sqrt{R^2 + T^2}} = 5.75$$

$$= \frac{5.75 \times \sqrt{R^2 + T^2}}{T}$$

$$= 6.56kN/m^2$$

So for load calculation we need to take the self weight of the slab in horizontal position. Next one is self weight of the steps normally above the one we start constructing the steps. Normally the riser is 151.1mm this is the thing we have calculated so here the average thickness is,

$$= \frac{0.151}{2} \times 20 = 1.51kN/m^2$$

Now the thickness of the floor finish is normally o.025 x 24 which is equal to 0.60kN/m^2. Next assume the weight of handrail here I have used 0.6kN/m^2.

These are all the dead loads which are acting on the slab that is self weight of the waist slab in horizontal that is both the waist slab we are constructing and above the steps we are constructing floor finishing after floor finishing we are fixing the handrail. These are all the dead load which is acting on the waist slab. So total dead load on waist slab that is equal to 9.27kN/m^2.

Live load on the slab:

The live load of the slab which is given in the problem is

$$w_l = 3.0kN/m^2$$

Total load acting on waist slab that is $w_d = 12.27kN/m^2$. Now we are going to find out the load on the landing and the passage.

Load on landing and passage:

Dead loads:

The self weight of the slab normally we have assume is 0.23 x 25 which is equal to 5.75kN/m^2. This is the self weight of the slab. And self weight of floor finish is which is normally 0.02 x 24 which is equal to 0.60kN/m^2. These are all the dead load acting on the landing and passage.

Live load:

Live load on slab is 3kN/m^2. And now the total load on landing is equal to 9.35kN/m^2. Using this I am going to draw the loading diagram, here it is 0.915m and here it is 1.015m and at the center it is 3.3m. Totally the value is 5.23m. Now we need to calculate the maximum bending moment at this slab.

__Bending moment calculation:__

To find the bending moment first we need to find R_A & R_B. For that I am taking moment about A.

$$R_B \times 5.23 = 9.35 \times 0.915/2 + 3.3 \times 12.27(0.915 + 3.3/2)$$
$$+ 9.35 \times 1.015 \times (0.915 + 3.3 + 1.015/2)$$

$$R_A = 9.35 \times 0.915 + 12.27 \times 3.3 + 9.35 \times 1.015 - 29.18$$

$$= 29.36 kNm$$

Maximum Bending Moment

Now we need to calculate the maximum bending moment normally in the case of maximum bending moment occurs where the shear-force is zero. We need to first find out what is the distance of point of zeros here from the left end or the right end. So the distance of point of zero-shear from left end will be,

$$R_A - 9.35x - (12.27 - 9.35)(x - 0.915) = 0$$

$$x = 2.60m$$

Using x I am going to find out the bending moment. So the maximum bending moment that occurs at a distance 2.60m from the left side of the section.

__Maximum bending moment:__

The maximum bending moment is equal to,

$$= R_A \times 2.60 - 9.35 \times 0.915(2.60 - 0.915/2) - 12.27(2.60 - 0.915)$$
$$(2.60 - 0.915/2)$$

$= 40.12 kNm$

This is the maximum way of calculating the bending moment at the waist slab at the loading diagram. Next the ultimate moment will be,

$M_u = 1.5 \times 40.12 = 60.18 kNm$

Using this bending moment I am going to find out the effective thickness of the slab or effective depth of the slab.

Effective depth of the slab:

Consider one meter width of the slab and by equating the maximum bending moment to the bending moment limit.

$M_u = M_{u\lim} = 0.138 f_{ck} bd^3$

It means that we are assuming our section as the balanced section.

$$d = \sqrt{\frac{M_u}{0.138 f_{ck} b}} = \sqrt{\frac{60.18 \times 106}{0.138 \times 20 \times 1000}}$$

$= 147.66 mm < 202 mm$

Hence this is safe against flexure. So I am going to keep D is equal to 230mm and d is equal to 202mm.

Area of reinforcement:

Main steel:

$$M_u = 0.87 f_y A_{st} (d - 0.416 x_u)$$

$$x_u = \frac{0.87 f_y A_{st}}{0.36 f_{ck} b}$$

$$= 0.05 A_{st}$$

$$60.18 \times 10^6 = 0.87 f_y A_{st} (d - 0.416 x_u)$$

$$= 0.87 \times 415 \times A_{st} (202 - 0.416 \times 0.05 A_{st})$$

$$A_{st}^2 - 9711.33 A_{st} - 8.01 \times 10^6 = 0$$

$$A_{st}(req) = 910.10 mm^2$$

So here we have found the area of reinforcement then I am using 16mm diameter and number of bars that is,

$$= \frac{910.10}{\pi/4 \times (16)^2} = 4.53 \cong 5 Nos$$

Here I am providing 6 numbers that is (n+1) of 16mm diameter bars.

$$A_{st}(pro) = 6 \times \frac{\pi}{4} \times 16^2 = 1206.36 mm^2$$

Now we need to find the distribution steel.

$$A_{st} = \frac{0.12}{100} \times 1000 \times 202 = 242.4 mm^2$$

Here I am providing the 8mm diameter bar and the spacing of the section as,

$$= \frac{\pi/_4 (8)^2 \times 1000}{242.4} = 207.37mm$$

Here provide 8mm diameter bar at 175mm c/c.

Check for deflection:

The l/d ratio here it is 20.

$$\frac{l}{d} = 20 \times M.F$$

$$p_t = 0.60\%$$

$$f_s = 0.58 f_y \frac{A_{st}(req)}{A_{st}(pro)}$$

$$= 0.58 \times 415 \times \frac{910.10}{1206.36}$$

$$= 131.60 N/mm^2$$

Here the modification factor is 1.8 and it is found from the figure 4 of IS 456:2000.

$$d = \frac{l}{20 \times MF} = \frac{5230}{20 \times 1.8} = 145.28mm < 202mm$$

So it is safe and need to uneconomical hence we need to redesign the slab by reducing the thickness of the slab. But it is safe against the flexure and the serviceability. Here the main reinforcement which is provided at the bottom. So this length is equal to development length of the reinforcement.

$$L_{\phi} = \frac{\phi \sigma_{rt}}{4\tau_{bd}}$$

So the distribution reinforcement has been provided as 8mm diameter at 175mm c/c. So thickness of the slab we have design here it is 230mm. And the main reinforcement is 6 numbers of 16mm diameter bar and the distribution reinforcement is 8mm diameter bar at 175mm c/c.

Summary:

In this lecture we have seen the design of dog legged staircase used for any type of building. And in this case we are discussed the dimensions of the components of the staircase and we have started designing the effective span of the slab. And load acting on the slab and by drawing the loading diagram we have found the bending moment by using the bending moment we have found the thickness of the slab and the reinforcement required for it. In the case of dog legged staircase we have found the different reinforcement one is main steel and other one is distribution steel. Finally we have seen the thickness of the slab which is found against the bending moment against the serviceability condition also under deflection.

Questions:

Design a dog legged staircase for a residential building having staircase room of size 1200mm x 4500mm subjected to a live load of 3kN/m^2. Consider other dead loads also. Draw the cross section of staircase showing reinforcement detail.

References:

- IS 456:2000 Plain and reinforcement concrete – Code of practice.
- IS 875 (1-5):1987 Code of practice for design loads (other than earthquake) for buildings and structures.
- SP34:1987 Handbook of concrete reinforcement and detailing.
- S.N. Sinha, “Reinforced concrete Design”, Tata McGraw hill publishing Co. Ltd, New Delhii, 1998.
- Ashok Kk. Jain, “Reinforced concrete: Limit State Design” Nem Chand & Bros., Roorkee (Vol 6th Ed) year: 2006.