Structural Systems in Architecture

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Module 1
Lecture – 5
Structural Loading and Support Reaction

Welcome to the NPTEL online certification course on Structural Systems in Architecture. So today we will go to the lecture number 5 of first week that is the Module-1. The topic of the lecture 5 is Structural Loading and Reactions.

The concepts covered will be:

- Understanding the unit of force
- Concept of concentrated load
- Concept of Uniform Distributed Load (UDL)

So, let us first discuss some of the concepts that we will be covering in this lecture. Initially, we will try to understand the unit of force and then two of the typical load components. They are very popular or very important in our structural engineering, so, the concepts of those will be discussed. One is concentrated load and another one is uniform distributed load or UDL.

The intended learning objectives are:

- Understanding the Structural Loading.
- Evaluating support reactions due to concentrated and uniform distributed load.

So, our learning objective of today's discussion on this lecture will be, we will try to understand what is the structural loading and try to translate the physical parameters of any particular building or any building element to structural loading. The second one is that, we will try to evaluate the support reactions due to concentrated and the uniform distributed load.

In our previous lecture, that is the lecture number 4, what we have covered is the different type of the structural supports and their redundancy and their unknown equations, unknown reactions etc. In this particular lecture also, we will try to evaluate the support reaction. So, first let us go to the concept 'understanding the unit of force'.

Now, what is force? It is well known to all that, force is the product of mass and acceleration. Suppose 1 kg of mass is under 1 meter per second acceleration, then I may say that, it is equivalent to 1 Newton force; and 1 Newton is the unit of force in SI, the international standard unit. Now let us see how much is this1 Newton means? The 1 kg in 1 meter per second may not give us the real picture of 1 Newton. Then 1 Newton is how much in kg, if it is having an acceleration due to gravity, that is g? That means how much is the weight component of the 1 Newton? I am going to find out that. So, as I know that the acceleration due to gravity is more or less 9.8 meter per second, then I multiply it by 10, instead of the acceleration due to gravity as 9.8, because 9.8 is very close to 10.

Force = Mass x Acceleration

1 Newton = 1 kg x 1m/s

1 Newton = (?) kg x acceleration due to gravity (g)

1 Newton = (?) kg x 9.8 m/s

1 Newton = (?) kg x 10 m/s

Weight of 0.1 kg (=100 gram) =1 Newton

Weight of 100 gram =1 Newton

Density of Water = 1000 Kg /m^3

Density of Water = 1 Kg /Lit = 1 gm/ml

100 ml of water = 100 gm = 1 Newton

So, the 0.1 kg if I put over there instead of the kg and the question mark, then that 0.1 x10 will be give you almost 1 Newton, which is equivalent to 100 grams. So, that means a weight of 0.1 kg, remember that, weight means it is the due to the gravity, is equivalent to 1 Newton. Now what is 0.1 kg, 0.1 kg is nothing but 100 grams. The 100 gram of weight is equivalent to your almost of your 1 Newton.

Now, if you take 100 milliliters of water, say one Bisleri water bottle of 100 milliliters, that means the smaller version of the Bisleri. Here, as 100 milliliter of the water is equivalent to 100 grams, because the density of water is 1000 kg /m^3 or 1 kg/liter or 1 gram /milliliter. So, it means that 100 grams of that particular one small Bisleri, the weight is equivalent to 1 Newton. So, please remember that, one small Bisleri water bottle with 100 grams of water is equivalent 1 Newton. So, from here we can understand how much is 1 Newton.

Now, let us discuss how much is 1 kilo-Newton, 1 kilo-Newton is 1000 Newton and from that point of view again I do the recalculation and finally I find it is almost about the 100 kg. Here, again I am taking the g, and the 9.8 is converted to 10 m/s. So, I am finding out how much is the kg?

1 kilo-Newton = 1000 Newton = 1000 Kg x 1 m/s

1 KN = 1000 Newton = (?)Kg X Acceleration due to Gravity (g)

1 KN = 1000 Newton = (?)Kg X 9.8 m/s

1 KN = 1000 Newton = (?)Kg X 10 m/s

Weight of 100 Kg = = 1000 Newton =1 KN

Weight of 100 Kg = 1 kilo Newton

Here, if I put 100 kg, then this will be 1000 Newton, which is equal to 1 kilo Newton
So, I may say that it is a weight of 100 kg, 100 kg is 1 kilo-Newton because kilo-Newton is very much used in our structural engineering for converting loads. Now, 100 kg is how much? 100 kg is almost the weight of two person, assuming a person to be of 40 to 60 kg. Hence, total of two persons is almost 100 kg and that will be equivalent to 1 kilo-Newton. So, that way initially we covered the unit of force.

Figure 1: concept of concentrated load

Now, let us discuss about concentrated load. How a concentrated load can be conceived in practice. In Figure 1, you can see that, this is a stand, where the cloth can be hanged with some hangers. So, in top beam or the top most metallic rod, it is under some concentrated pointed load. due to the hangers with hooks, which are hanged on the metallic rod, it gives you exactly pointed load on that particular point.
Suppose, this is a small truck, small very mini truck which is loaded, as shown in Figure 2. Now, what I have written here is, suppose the self-weight of the truck is 1200 kg and this truck is carrying some LPG cylinder which is having almost about total weight of almost 3.4 tones, where 1 tone is almost equal to 1000 kg that is the British ton, not the American ton.
So, I may say that the total weight of this vehicle including its self-weight and the LPG or cylinder weight is 4600 kg. Then the load on the 4 wheels is almost about 46 kilo-Newton. Why 46 kilo-Newton? Because as you know that 100 kg is equivalent to 1 kilo-Newton.
So, if I just remove two zeros from the 4600 kg, it will be equivalent to 46 kilo Newton. Now, that is the total load on the 4 wheels. Then, assuming that everything is uniform, then 1 wheel must take almost, 11.5 kilo-Newton. So, each tire or each wheel will take care of 11.5 kilonewton load and this is also a pointed load.

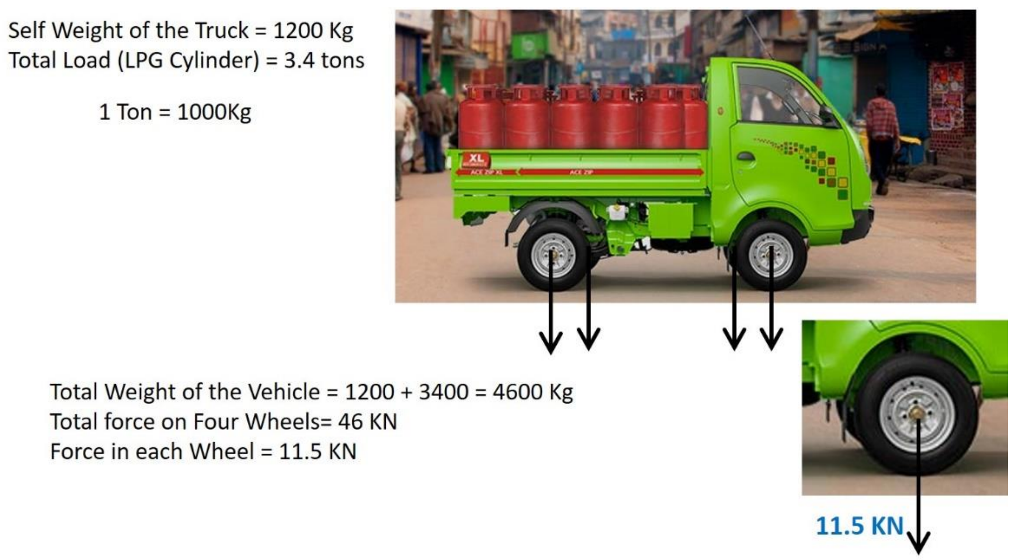

Figure 2: pointed load and its calculation

Why this is a pointed load? Because see, finally the load transmits to the road by virtue of the point on the tire touching the road, which is tangential to the wheel or the tire. So, this way we can find out what is the total amount of load in kilo-Newton by virtue of some real-life examples. So, we will translate these things to our building exercises also.

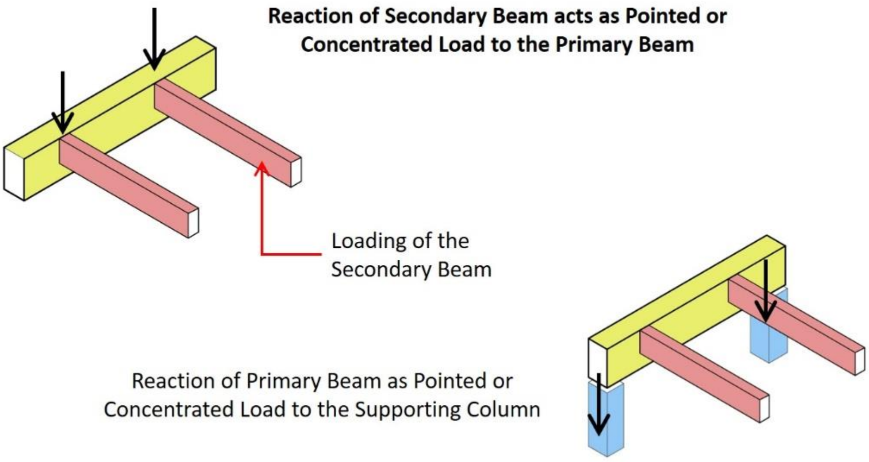

Figure 3: reaction of beams

You can see in the Figure 3 that it is a 3-dimensional image of beams. Here the two red color beams are called as secondary beam, and the yellow color one is the primary beam. The dimensions of the secondary beam are little less as compared to the other, the big one or the yellow color beam. So, those secondary beams will transfer the load to the primary beam that is from red color beam to the yellow color beam. Therefore, the reaction of the secondary beam will act as a pointed load or a concentrated load to the primary beam. Then, reaction will be generated at the primary beam, as shown in the top image of Figure 3. There are other loads as well in the primary beam, so, after the transferring of load from secondary to the primary beam, the total reaction of the primary beam will act as a pointed load to the supporting column, which is shown in blue color, in bottom image of Figure 3. Hence, in this way the load will be transferred from the secondary beam to the primary beam and from the primary beam to the supporting columns.

We will bring the discussion into much more detail, when we will go to the fourth week of our lecture, where we will discuss about the loading and the grid pattern for the building and how the loading is going to be analyzed in that.

Now, we will try to see an example.

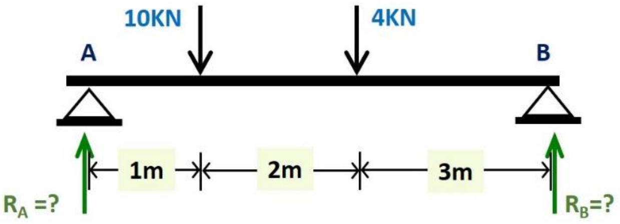

Figure 4: reactions due to applied load on a simply supported beam

So, this is a simply supported beam as shown in Figure 4, and I have put two pointed loads, one is 10 kilo-Newton and another is 4 kilo-Newton, and they are at a distance of 1m and 3m from point A. Your 10 kilo-newton is almost about 1000 kg. Now, my question is, how can I find out the reaction at A and reaction at B.

Here, all the applied forces are downward in nature that is towards the negative Y axis; and the reactions are in positive Y axis. So, I my first write down the equation:

$\sum F_Y = 0$

where

$R_A + R_B = 10 + 4 = 14$ k N.

Otherwise, the beam will be unstable, beam will translate in other, the upward or downward direction. Now, the second criteria is to find out the exact amount of the R_B.

If I take the moment about R_A and put it equal to 0, because as it is a hinged support, as you know this is a hinge support and we have discussed in the fourth lecture in this particular week that the hinged support cannot take any kind of moments. So, I will put this M_A at A = 0 and that gives me so $M_A = 0$, so this force R_B is having a distance of 6 meters from A. So, it will be

$\sum M_A = 0$

$6 R_B = (10 \times 1) + (4 \times 3) = 10 + 12 = 22$

$R_B = 22/6 = 3.67$ k N

R_A = (14 - 3.67) = 10.33 k N

So, in this way I can find out both the reactions.

There may be some other loads also. So, if I know the value, and if I know the distances, I can again put those particular change in the equations, so if I put two more loads, then two more load will increase and those equation will going to change and finally we can have some different values of R_A and R_B. So, this is the way we can find out, and this is one of the examples.

Now, let us conceptualize the uniform distributed load or UDL.

Before we conceptualize that one, let us have a brick work or a brick wall and assume that this brick wall is having 4 meters of length, thickness is of 250 mm or 0.25m, and height is 2 meters, as shown in Figure 5. As you may know that the density of the brick masonry is 1900 kg/m^3, and if I put all together, I can easily find out what is the total volume.

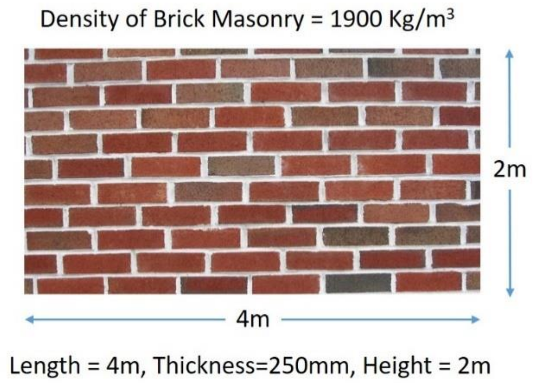

Figure 5: understanding load on a brick wall

So,

Volume = 4 x 2 x 0.25 = 2 m^3

Weight = 2 x 1900 = 3800 Kg

Force = 3800 Kg = 38 kN

So, I can say that instead of two zeros if I convert them to kilo Newton then it is almost 38 kilo-Newton is the total weight of the masonry.

Similarly, I can compute for RCC.

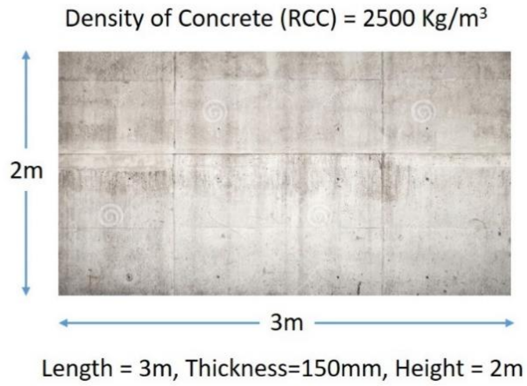

Figure 6: understanding load on RCC wall

Let us assume an RCC work of 3-meter length, 2-meter height and thickness of 150 mm. So, the volume is

$$\text{Volume} = 3 \times 2 \times 0.15 = 0.9\ m^3$$

$$\text{Weight} = 0.9 \times 2500 = 2250\ \text{Kg}$$

$$\text{Force} = 2250\ \text{Kg} = 22.5\ \text{k N}$$

So, like that we can actually compute if we know the density of the material, dimension of the material, and the total weight; and that cab be changed to total force.

Now we will try to understand the uniform distributed load on a structural element.

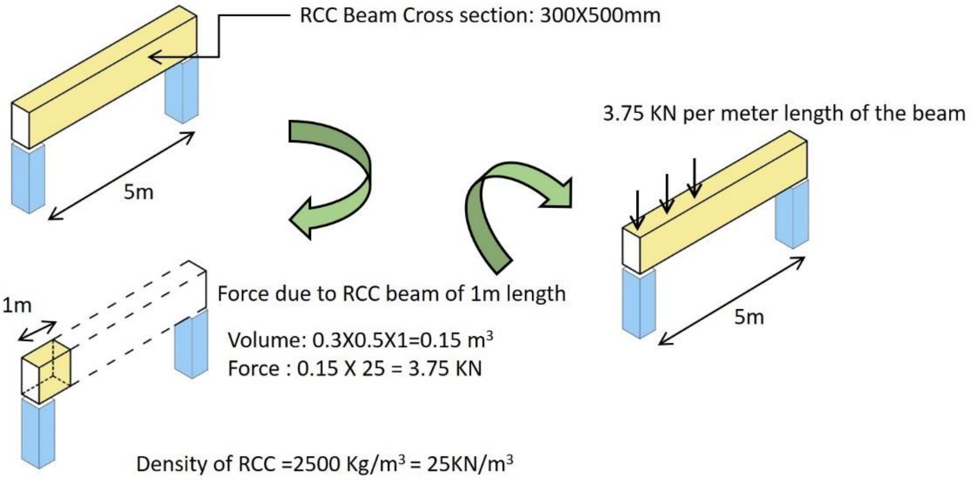

Figure 7: distribution of load on a beam

Now, as shown in top left image of Figure 7, we have a beam of cross section 300 x 500 mm, shown in yellow color, which is supported on two columns, shown in blue color; and it is having a span of 5 meters. So now, what I am going to do is that, I am going to find out what is the uniform distributed load (UDL) because of that beam which is placed over the two columns. So, what I will do?

I will take 1 meter of the length, 1 meter, please remember this 1 meter of the length of the beam, as shown in bottom image of Figure 7; and I will try to find out the volume and the weight. So, the force due to the RCC beam of 1 meter of the length is, the volume is 0.3, why 0.3; because 300 is the cross section, one dimension into 0.5, why 0.5 because 500 mm is the another dimension of the cross section, so those two gives me the area of the cross section and 1, why 1; because the length of unit considered. So, volume will be;

Volume = 0.3 x 0.5 x 1 = 0.15 m^3 (of beam of 1m)

Force = 0.15 x 25 = 3.75 k N

Density = 2500 Kg/ m^3

This volume is uniform throughout each 1 meter running length of the beam. Now, I multiply that with 25, why 25. The density of the RCC is 2500 kg/ m^3, which is equivalent to 25 kilo-Newton/ m^3. So, if I just multiply them, I get the force to be 3.75 k N. So that means, this particular beam is having a load intensity 3.75 kilo Newton per meter length.

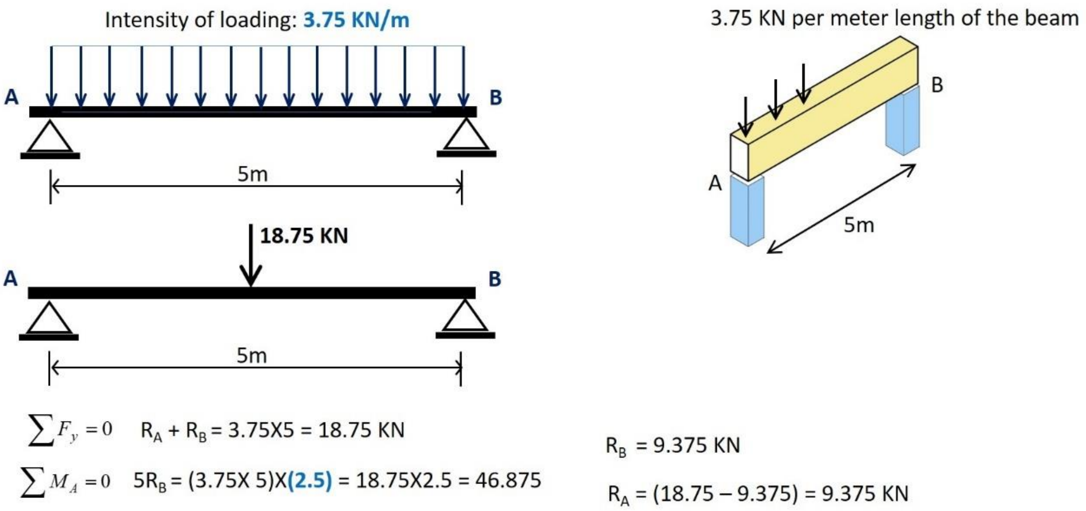

Figure 8: distribution of load and its reactions

Now, the beam has a length of 5 meters, I have to multiply this uniform load by five times. Intensity of load per meter length is 3.75kN. So, I can also write that this is under a uniform distributed load. Hence, the load is uniformly distributed from point A to point B over the span of 5 meter with the intensity of 3.75 kilo-Newton per meter. Now, from that point of view how can I find out this R_A and R_B.

So, I can say that instead of putting all over, I can imagine in this particular beam is having no load but a concentrated load of 18.75 kilo-Newton, which is acted at the middle, as shown in left side bottom image of Figure 8. Why 18.75 suddenly, because 18.75 comes from the total $R_A + R_B$, total load of this, that comes from:

3.75 x 5 = 18.75 k N; (meter-meter gets cancelled).

So, finally, I will get 18.75 kilo-Newton as the total load and that is acting over here at a distance 2.5 meter from A. So, I may now say that

$\sum F_Y = 0$, then

$R_A + R_B = 18.75$ (total load) and

$\sum M_A = 0$; because it is a hinged end.

So, now the at R_B, this R_B x 5 is moving upward in anti-clockwise direction, must be equal to the moment downward, in clockwise direction at the load point, this is 18.75 x 2.5. This 2.5 is nothing but the 5 /2, that is half of the total length. Because, if it is uniform distributed load, we can assume that this 18.75 which is total load is acting at the center of gravity of the total loading that is the center point of the total span.

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$\sum M_A = 0$;

$5R_B = (3.75X\ 5) \times (2.5) = 18.75X2.5 = 46.875$

$R_B = 46.875/5 = 9.375$ kN

$R_A = (18.75 – 9.375) = 9.375$ kN

So, by virtue of this understanding, we can now find out the reaction R_B as 9.375 kilo-Newton and R_A is also 9.375 kilo-Newton.

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Now we will consider another example, where there is a RCC beam of similar nature to the last example 300 by 500 mm, but in this case, there is a red colored brick wall also, whose dimension is 4500 millimeter in height and 250 mm in thickness and density of the RCC is 2500 kg/m^3 and of brick is1900 kg/m^3 , see Figure 9. So, I can easily find out how much is the total weight of the 1-meter length of this particular brick wall. So, that is

Force due to Brick Work of 1m length = (4.5 x 0.25 x 1) x 19 = **21.375KN**

I will explain this, 4500 mm gives me the 4.5 meter, that is the length in one dimension, 250 mm thickness is 0.25m and 1 is the considered unit length. So, I have taken all the 3 dimensions for this, so I found out the volume. After found out the volume, I have multiplied that with the density, so I got 21.375 k N. So, the total weight, the total UDL. UDL stands for uniform distributed load. Similarly, for the beam

Force due to RCC beam of 1m length = (0.3 x 0.5 x 1) x 25 = **3.75 KN**

So, the UDL is now 3.75 is for the beam and 21.375 is for the wall.

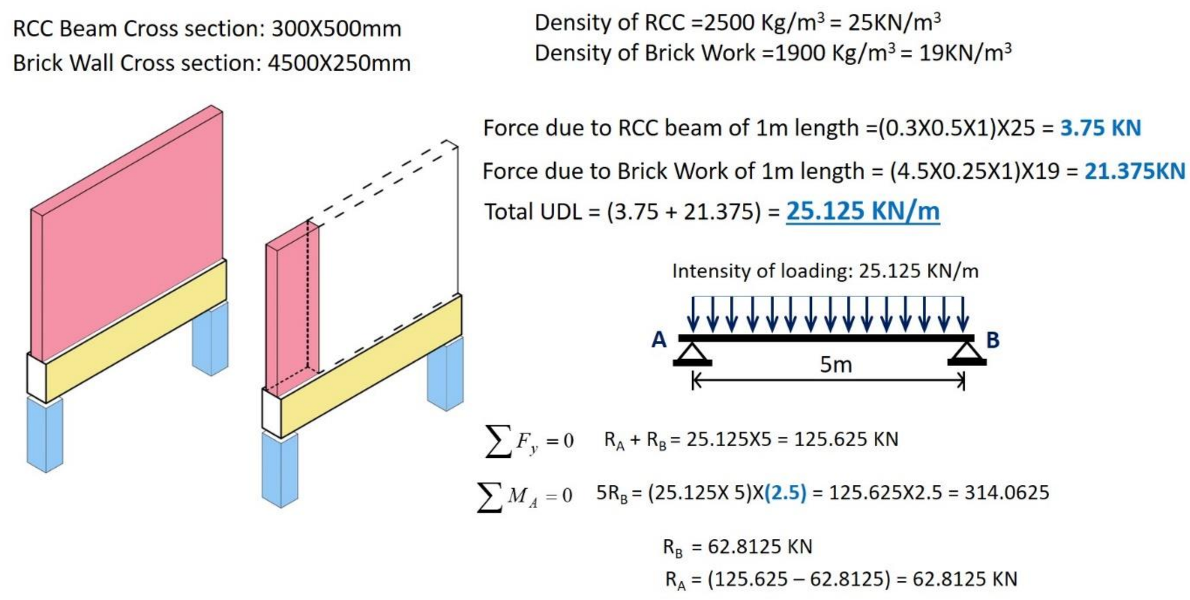

Figure 9: load distribution in RCC and Brick work

So, the total weight of this will be:

Total UDL = (3.75 + 21.375) = **25.125 KN/m**

The next is again, see right-hand side image of Figure 9. This is having a span of 5 meters, and total uniform distributed load intensity is 25.125, and again I can compute this. So, the total load on this 5-meter span will be:

25.125 x 5 = 125.625

Assuming the total loads acting at the centre, and I found out the moment at A = 0; like previous example.

$\sum M_A = 0$;

$5R_B$ = (25.125X 5)X**(2.5)** = 125.625X2.5 = 314.0625

R_B = 62.8125 KN

R_A = (125.625 – 62.8125) = 62.8125 KN

Finally, I come down to that, 314.0625 is the total moment or balancing moment and the reaction force at B, R_B = 62.8 kilo-Newton; and R_A = 62.8125. So, like that we can find out what is the intensity of the UDL from the nature of the building element multiplying the density, with a unit length of the particular element volume and the UDL can be calculated. Now we will the next example.

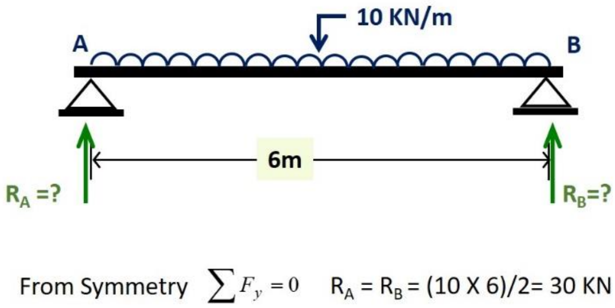

Figure 10: reactions in UDL

So, this is now very easy. If we see, we have shown the UDL half circles, or series of circles. So, total 10 kilo-Newton per meter is the intensity of the UDL from A to B, it is a simply supported beam and $R_A = R_B = 30$ kilo-Newton. It is very easy, because it is a simply supported beam at a symmetrical kind of beam, so the R_A must be equal to R_B and total intensity of the load is 10 x 6 that is 60 kilo-Newton. So, 30-30 will be the share of this beam.

Another example, I put a particular load, UDL which is 24 kilo-Newton per meter, at a smaller distance of about 2 meter, almost at the centre, 1 meter from the left and 3 meter from the right support. So, here you see the total load is 24 x 2 = 48 kilo-Newton is the total load. So, R_A and R_B must be equal to 48. R_A and R_B = 48. Now again I take the moment at A

$\sum M_A = 0$;

$6R_B = (24 \text{ X } 2)\text{X}(1+1) = 48\text{X}2 = 96$

$R_B = 16$ KN

$R_A = (48 – 16) = 32$ KN

That means, if I am taking the moment, the first R_B, R_B gives me like this moment, the anti clockwise kind of a moment which is RB into 6, why 6, because 3+2+1 = 6, must be equal to the moment due to this load and the total load is 48, acting at the center point. So, suppose, 48 acting at the centre, transfer that particular UDL to a pointed load at the center point.

So, this is 48, and this is why it is 1+1, because the acting perceive the point, you see the point of acting of 48, this is 1 meter and half of 2 meters, so this is another 1 meter, so 1+1 = 2. So 48 x 2 is 96. So, R_B = 96 /6 = 16 kilo-Newton and RA = 32 kilo-Newton that is 48 – 16. So, like that we can easily find out the reactions for the UDL, any kind of UDL placing anywhere in the particular beam.

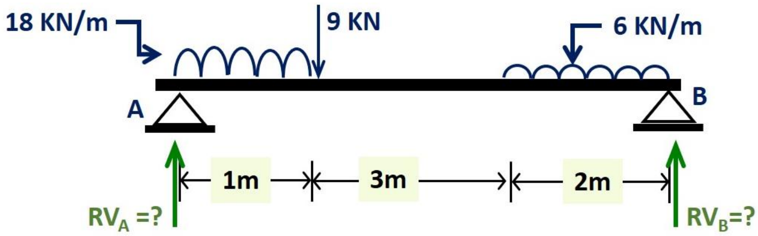

Figure 11: distribution of loads and computation of reactions in simply supported beam

So, this is another example where I have put two different types of UDL, left side UDL of 1 meter from A, it is little heavy, it is 18 kilo-Newton/m, on the right side 2 meter span of UDL with B, is the lighter one, of UDL 6 kilo-Newton; and 9 is the concentrated load at the particular point, 1m from A. So, let us first find the first equation of this

$\sum F_Y = 0$, then R_A and R_B must be equal to total downward loads.

$R_A + R_B = (18 \times 1) + 9 + (6 \times 2) = 18+9+12 = 39$

The total download load, we can get from the sum of load into respective distances. So it gives, 18 into 1, why 18 into 1, 18 kilo-Newton is the intensity over a length of 1 meter, now 9, this is straightforward, and this is 6 into 2, why 6 into 2, six 6 is the intensity of the load over a distance of 2 meters, so that is why 6 into 2. So that is 18+9+12, which is equal to your 39 kilo-Newton is the total downward load.

So, R_A and R_B, here I have written RV_A and RV_B, both should be equal to 39 kilo-Newton. Now, again I will take the moment from the A. So, if I take the moment from the A, this force will not create any kind of a moment. Moment will be created only by R_B which is:

$\sum M_A = 0$;

$6R_B = (18 \times 1) \times \mathbf{0.5} + 9 \times \mathbf{1} + (6 \times 2) \times \mathbf{5} = 9+9+60 = 78$

$R_B = 78/6 = 13$ KN

$R_A = (39 – 13) = 26$ KN

6 into R_B will give upward, clockwise reaction. So, this 18 into 1 is acting at a distance of 0.5 meters, and then the 9 into 1, 6 into 2 is your 12, total load and it is at a distance of 5 meters because 1+3+1 = 5 meters. So, 78 and finally we come down to the RV_A and RV_B as 13 and 26 kilo-Newton.

So, like that we have some other examples also.

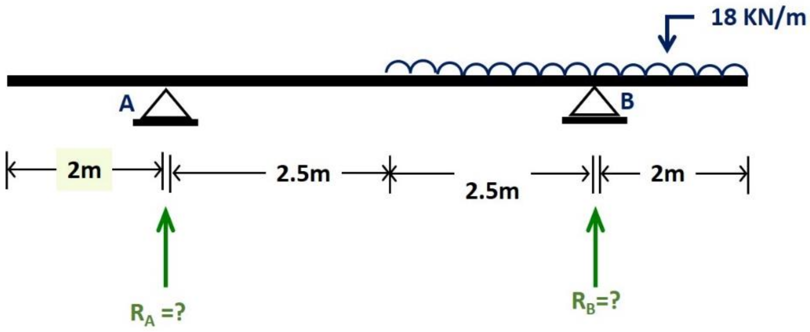

Figure 12: reactions due to UDL in overhanging beam

As shown in Figure 12, from that plate we can have some UDL which is overhanging kind of a scenario, where our $R_A + R_B$ is given, the total load is also come out to be the 81; and again I am taking the moment about A which gives me, moment about A means from point A it is 5 into RB is equal to 18 into 4.5, why 18 into 4.5? The load is 18 and distance is 4.5. Because 2.5 + 2 and the other distance, if you please read from point A then this is 2.5 + half of 4.5.

$\sum M_A = 0$;

$R_A + R_B = 18 \text{ X } 4.5 = 81$

$5R_B = (18 \text{ X } 4.5) \text{ X } \mathbf{(2.5 + 0.5 \text{ X } 4.5)} = 81 \text{ X } \mathbf{4.75} = 384.75$

$R_B = 384.75/5 = 76.95$ KN

$R_A = (81 – 76.95) = 4.05$ KN

So, that gives me the equation and finally I come down to the R_B and the R_A.

Now going to the next example.

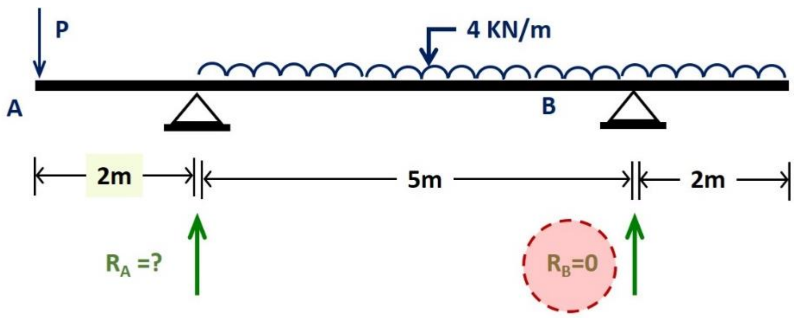

Figure 13: UDL, concentrated load and reactions in simply supported beam

Here, I have put it little another way around, what should be the value of this P? Towards the left end, there is a force P that gives the reaction at B = 0. So, reaction at B = 0 means if I take the moment at about the point of left hinge, that is 2m from the left end, then R_B becomes 0. So, the moment because of the 4 kilo-Newton per meter must be equal to the moment at A. So, if I equate these two 4 into 7 (because 5+2 = 7) and from here the center point of this load is your 3.5 meter. So, that must be equal to P into 2. Hence, I can find out P and R_A, this R_A in that case will be 77 kilo-Newton and the value of P is 49 kilo-Newton.

$\sum M_A = 0$;

$(4 \times 7) \times 3.5 = P \times 2$

$P = 98/2 = 49$ KN

$R_A = (49 + 4 \times 7) = 77$ KN

So, like that we can do for the simply supported beams.

Now, we will look some examples of cantilever beams

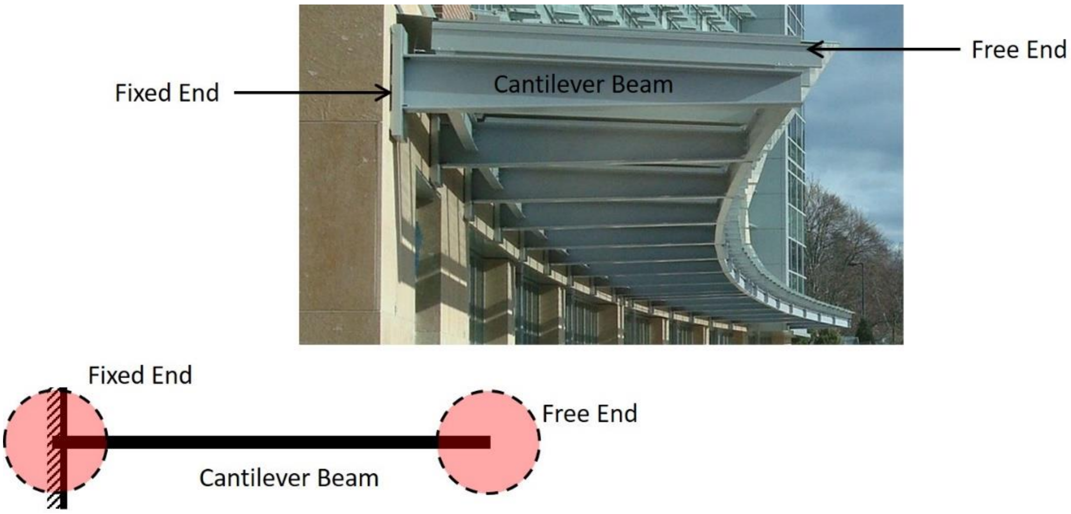

Figure 14: cantilever beam

So, in the cantilever beam, I have put some photographs where you see the fixed end and the free end.

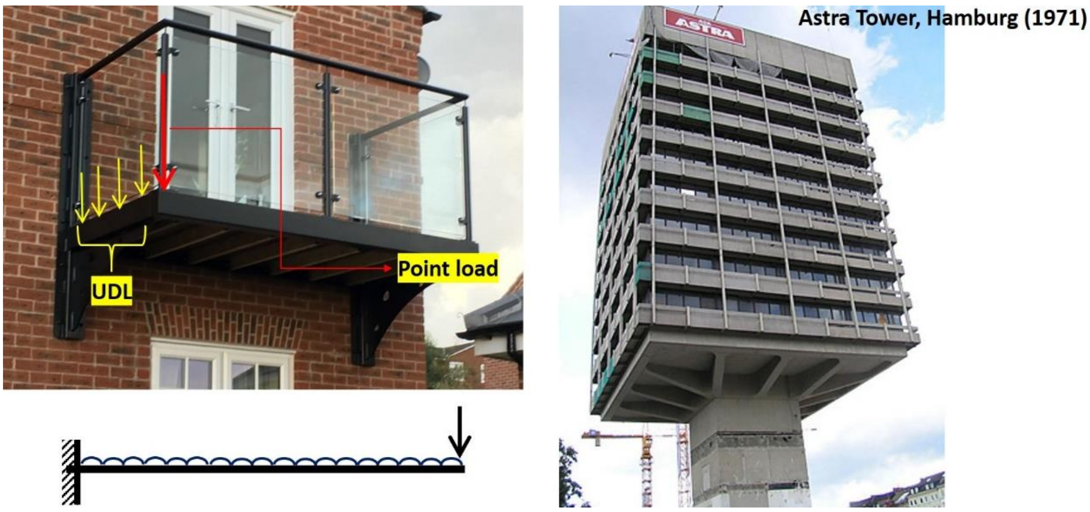

Figure 15: examples of cantilever beam

Source: http://content.time.com:

So, on the left-hand side image of Figure 15, you can see a balcony, which is an example of cantilever beam. In the cantilever beam also, there are some loading we can see. The yellow arrows represent the UDL and the Red line represents the pointed. The bottom image in left-hand side is the schematic representation of cantilever beam. The right-hand side image is the

Astra tower, Hamburg. It was constructed in 1971, where the cantilever beams can be visualized.

So, we can have those cantilever beam equations also where we can find out the RA and RB.

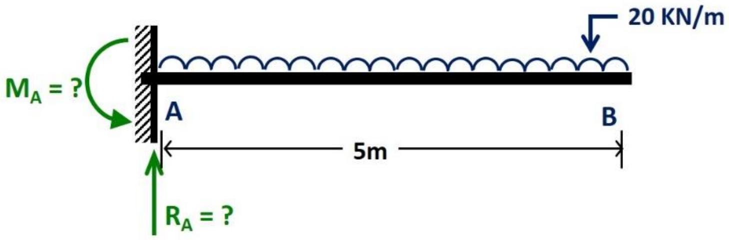

Figure 16: moment and reaction in a cantilever beam

Here, there is only one reactions R_A, so

$\sum F_Y = 0$; that gives me

$R_A = 20 \times 5 = 100$ KN (20 is the UDL and 5 is the distance)

$M_A = (20 \times 5) \times (0.5 \times 5) = 100 \times 2.5 = 250$ KN-m

So, that means the movement at A is your 250 Newton meter because as you know the cantilever beam, there are 2 unknowns, one is the reaction at A and another one is the movement at A or the fixed end.

Similarly, I can find out for thus too.

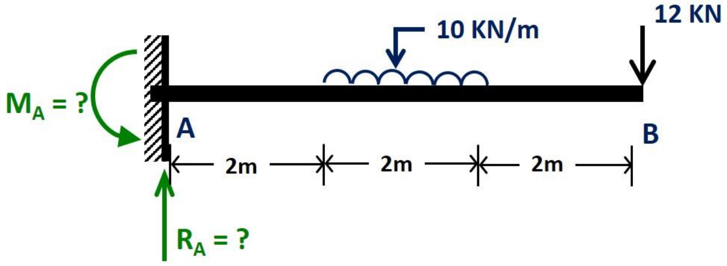

Figure 17: moment and reactions in a cantilever beam

$\sum M_A = 0$;

$R_A = 12 + (10 \times 2) = 32$ KN

$M_A = [12 \times \mathbf{6}] + (10 \times 2) \times \mathbf{(2 + 1)} = 72 + 60 = 132$ KN-m

This is also very simple, R_A is just adding up the forces 12 + 10 into 2 that is 32, and MA similarly I can find out 10 into 2 multiplied by this 2 into 1 because 2 + half of the 2 is 1 and this 12 into 6 six, why 12 and this acting as a distance 6, which is 132 kilo-Newton meter.

So, I have taken the reference for this particular discussion on these particular 2 books. You can go through these 2 books.

- **Basic Structures for Engineers and Architects** by Philip Garrison, Blackwell Publisher

- **Understanding Structures:** ***An Introduction to Structural Analysis*** by Meta A. Sozen & T. Ichinose, CRC Press

Now, let me conclude the lecture today. As we have estimated the exact loading on the structure and how it is essential for the structure. The type of structural loading also depends upon the material, the dimension and density of the parameter that also has been understood. The support reaction depends upon the type and the placement of the loading that is also we understood from our lecture.

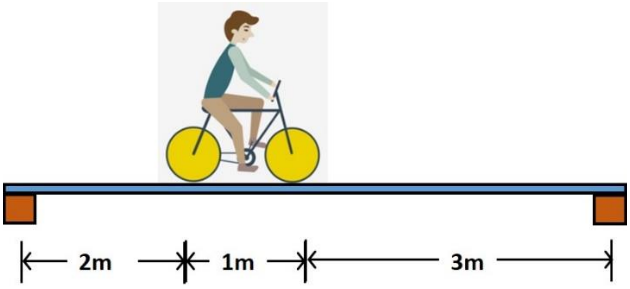

Figure 18: application of load and its reactions

Now next is, let us go to some homework. The homework 1 is suppose a particular boy is going with a bicycle, and this in a 6-meter span on a bridge, or wooden plank kind of a thing. So, I have given the weight of the boy, I have also given the weight of the bicycle. The distance between the wheels of the bicycle is almost about 1 meter. So, you have to find out what is the reaction at 2 supports when this boy is 1 meter away from the left-hand support.

Also, you have to plot a graph, to show the changes of the left and right support reactions. Suppose the boy is moving from the left support to the right support; so, how the changes of the reaction at A and reaction at B, reaction at A (left end) and B(right end), and how is it going to change you have to plot it through a graph.

The next homework is;

I have some typical profile, profile of 2 walls. So, there is a cut in the left -hand side profile and on right-hand side, it is triangular kind of a wall; and all the wall dimensions are given. The thickness of the wall is 250 and density of the wall material is 200 kg per meter cube. So, you have to finally find out what are the reaction in A and what will be the reaction in B?

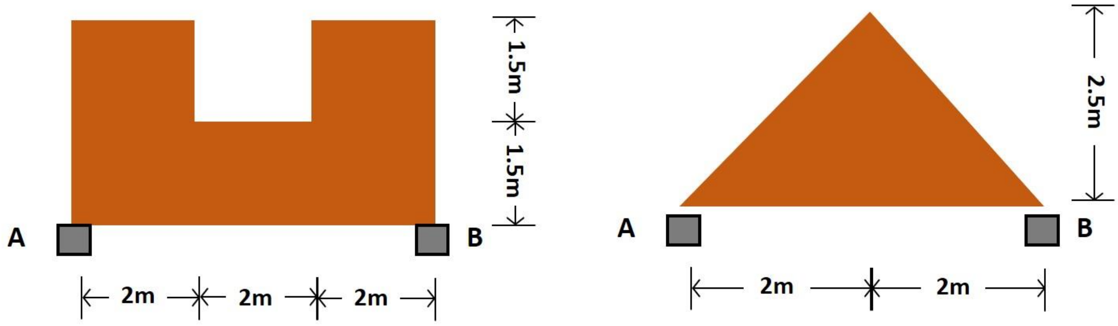

Figure 19: profiles of two walls

Finally, the third one is another small problem; the beam and the loading is given, in Figure 20. Find the reaction at A and B; and what should be the intensity of the additional UDL within BC. Suppose what should be the additional UDL I should put in between B and C, so that the reaction at B will be 40 kilo Newton. So you also have to find out that. So, those are the three homework. That is the end of this lecture number 5.

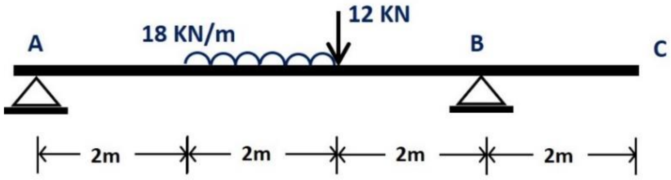

Figure 20: distribution of load and reactions