ENR202 Mechanics of Materials Lecture 3A Slides and Notes

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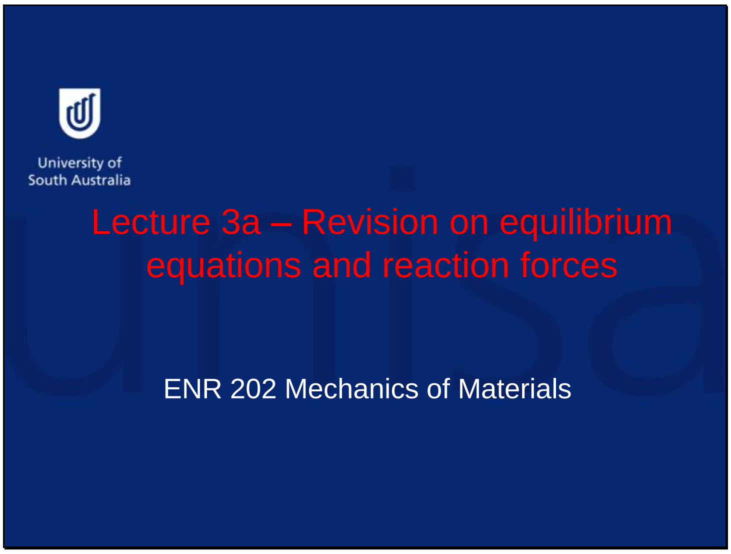

Welcome to Lecture Summary 3a, which revises equilibrium equations and reaction forces. First, we will go through a brief introduction, and a brief review of static mechanics.

Note that throughout all the lecture summaries for Mechanics of Materials, you will see live links, denoted by the letters W, P and V. These links point to web pages, presentations and videos which will enhance your understanding of the content. You can pause the presentation at any time to access these links, and then go back to the presentation when you have finished looking at them.

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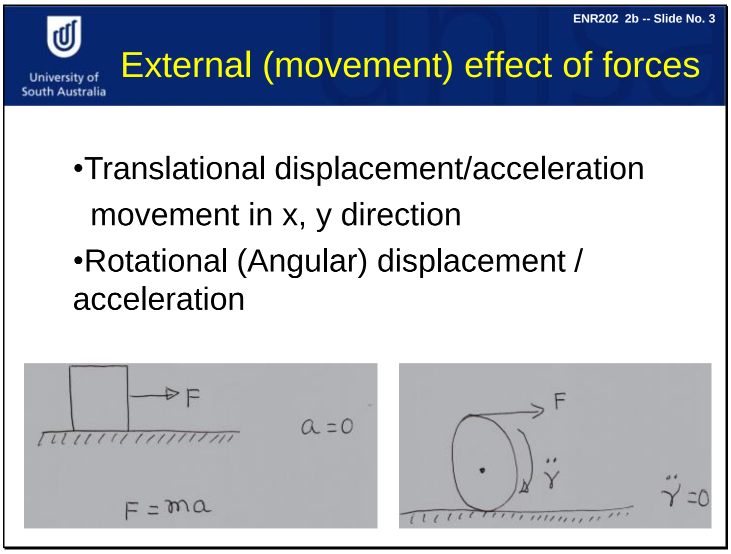

Firstly, let's have look at the external effects of forces. When we apply external forces on objects, we have movement. The first possible effect we can have is translational displacement or acceleration, calculated by Newtons law (Force equals mass times acceleration). This translational effect can be horizontal or vertical.

We can also have a rotational effect: for example, if we have a ball on a surface, and we apply a force, we know the ball will rotate around its axis. We have rotational acceleration, and this effect is rotational force. However, when we consider static analysis of objects of structure (that means the structure of an object in equilibrium) there is no moment or displacement, so we don't have translational acceleration or rotational acceleration.

As the rotational angular displacement is new to us, today we will concentrate on rotational or angular displacement.

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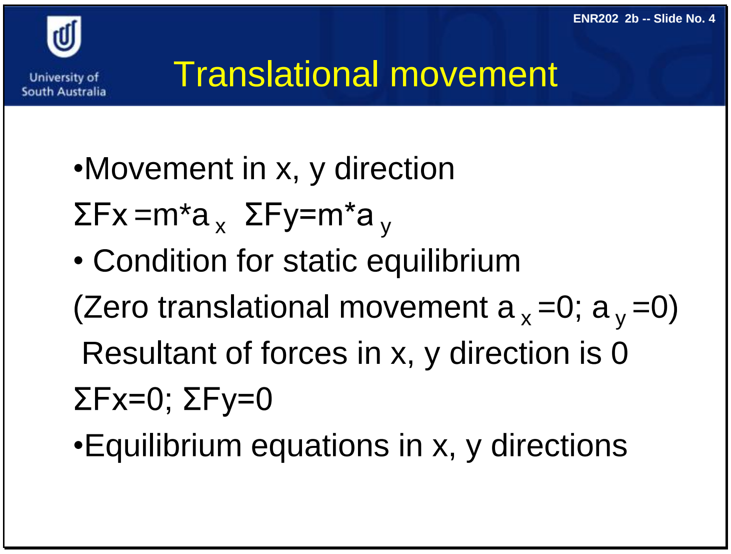

This slide shows information about translational movement or displacement. Suppose we have an unbalanced force and acceleration in an x-direction, and an unbalanced force and acceleration in a y-direction, and the condition of static equilibrium is zero movement or zero acceleration in both the x-direction and y-direction. Based on the above equation, the acceleration is zero, the total force should be zero. So the resultant forces in the x-direction or the y-direction should be zero. That is the meaning of equilibrium: sigma Fx is zero, and sigma Fy is zero. These are called equilibrium equations.

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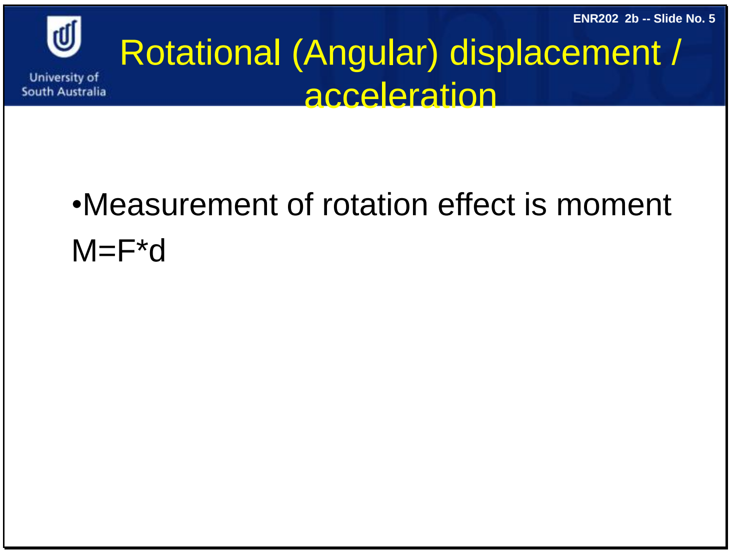

For rotational displacement, we first consider the measurement of rotation effect, and we use moment for rotational effect.

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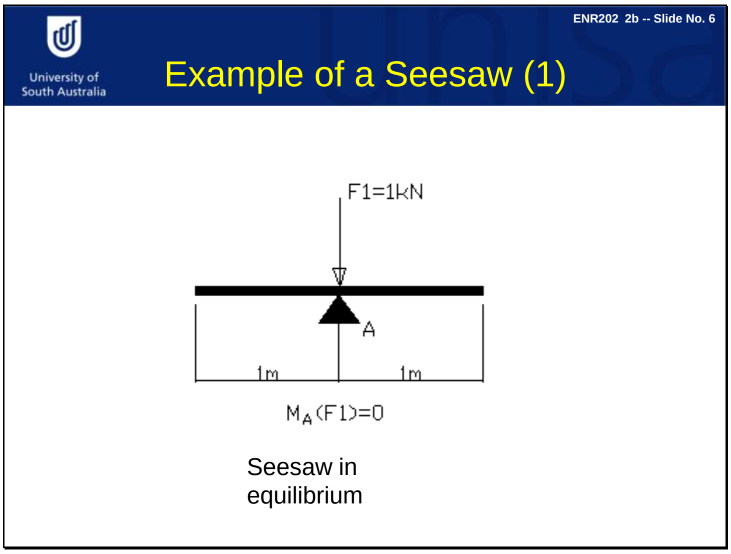

Let's look at a simple example: a seesaw. If Point A is the pivot of the seesaw, and we apply a 1 KN load vertically at A, the seesaw is still static. The equilibrium is not affected, even though we have an external loading on the seesaw.

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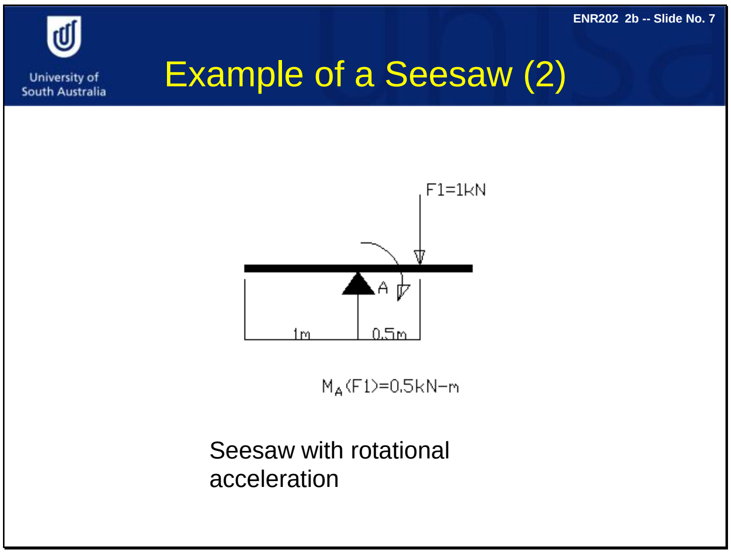

However, if you move this load (for example, move F1 from Point A to the right side of seesaw 0.5m from A), the seesaw is not static, it will rotate. Why will it rotate for this force and not for the previous force, even though it is the same amount of force? Because the force is acting in a different location. In this equation, this force has moment at pivot, and the moment is equal to force times distance of 0.5m. Therefore this force has moment about Point A of 0.5KNm, so we have a rotational effect on seesaw.

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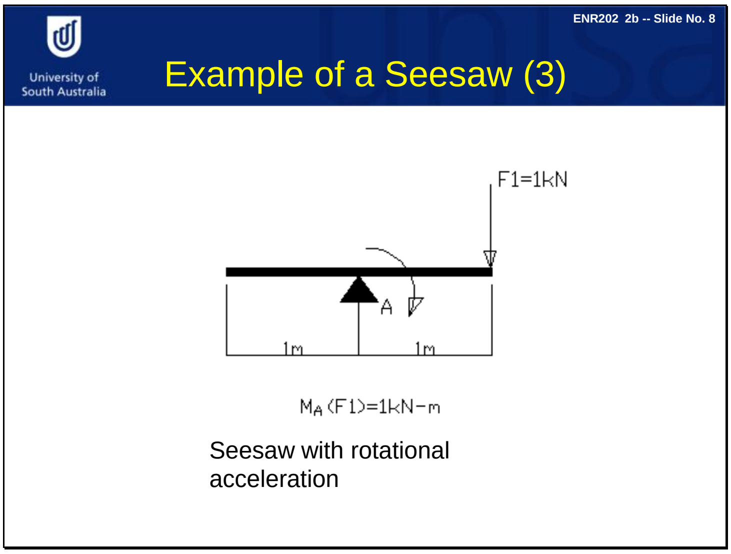

If we move the force further right (for example, to the right end), we know the seesaw will also rotate, but this time it will rotate faster … why?

The answer is because we have larger moment here. We now have a larger distance between the force and the pivot here of 1 meter, so the moment here is 1 Kilo Newton meter. 1 Kilo Newton meter means 1 Kilo Newton times 1 meter, so we have a moment of F1 about A point of 1 Kilo Newton meter, and the seesaw will not keep a static equilibrium.

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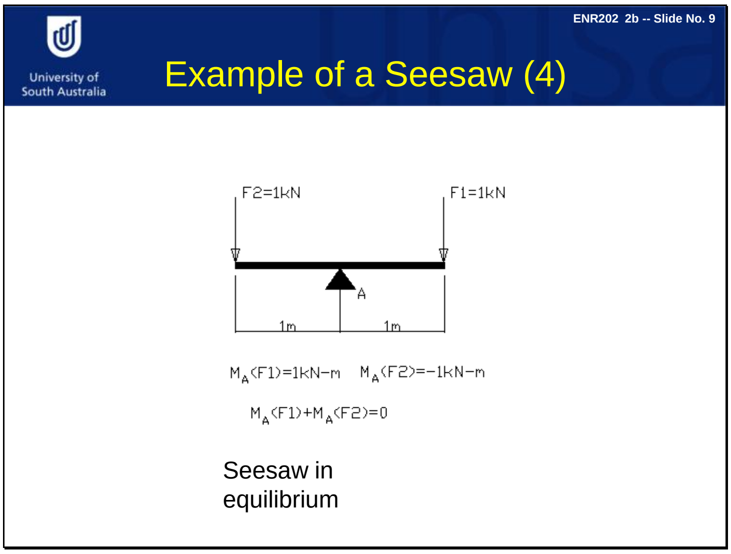

If we apply another force to the left side of seesaw (for example, if we apply F2 1KN on the seesaw), the seesaw will remain static, in equilibrium. Why?

Because although the F1 moment at Point A 1kNm will cause the seesaw to rotate clockwise, we have another force F2, which has a moment about Point A, and the F2 moment at Point A is equal to 1kNm as well, but in the opposite direction. F2 will cause the seesaw to rotate anti-clockwise, so the two forces counteract each other, and we have zero moment about Point A. That means this seesaw is in equilibrium, and the total moment is zero.

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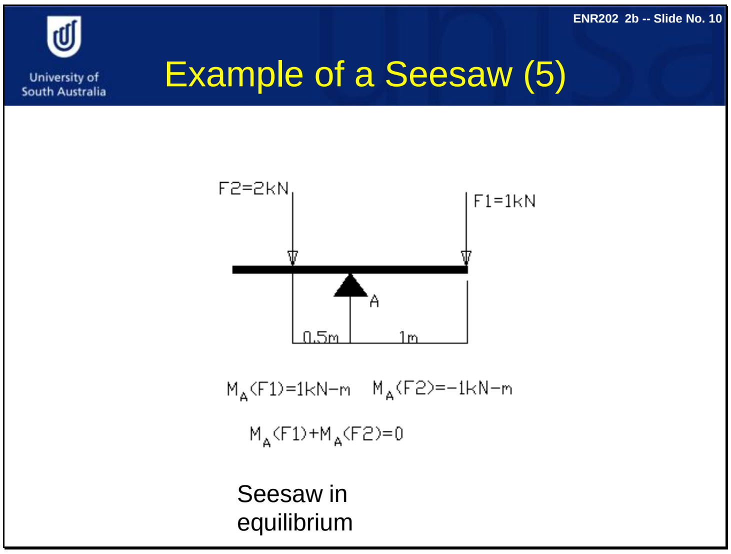

So, can we apply another force F2 of 2 kilo Newtons to make the seesaw stop rotating? This time F2 is acting at a distance of 0.5 meters from Point A (F2 moment is equal to 1 Kilo Newton meter, because 2 Kilo Newton by 0.5 meters equals 1 Kilo Newton meter). So F2 has another moment about Point A in anti-clockwise, and this anti-clockwise moment counteracts the F1 moment 1 Kilo Newton meter. Thus, again we have total moment at Point A is zero. We know the seesaw is in equilibrium because we have zero total moment.

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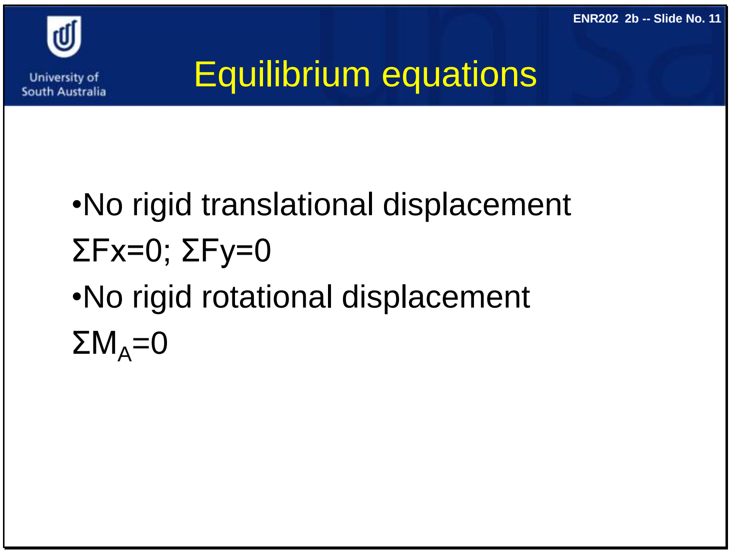

So the condition required for non-rotational displacement is that all moment together adds up to zero. This is the equilibrium equation of our object.

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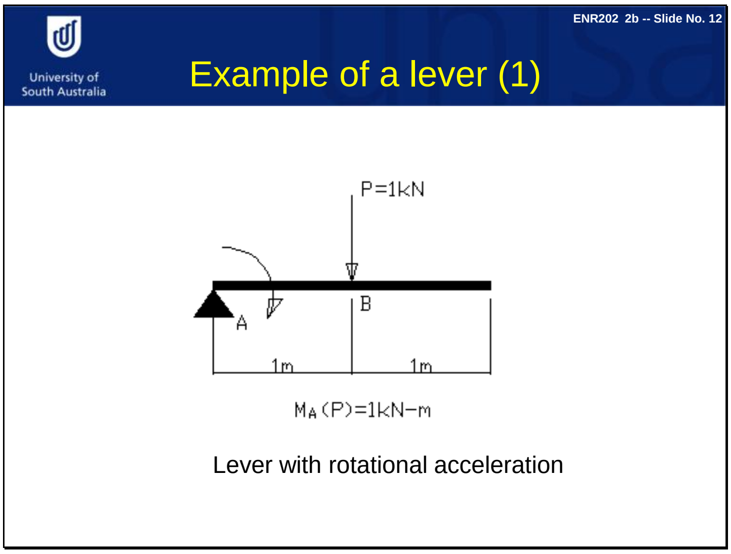

Let's look at another example … a lever. Suppose we have a lever, and Point A point is the pivot of the lever. We apply an external load of 1KN to P at Point B. The distance between Point A and Point B is 1m, and we know the P load has a moment about point A equal to 1KNm. Because we have an unbalanced moment acting on the lever, the lever rotates clock-wise.

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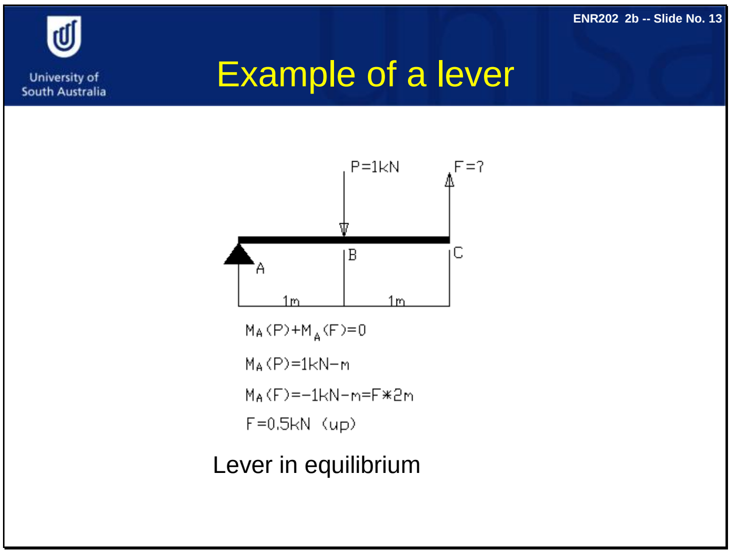

To stop the lever rotating clock-wisely, we have to apply another force on the lever. For example, if we apply a load at Point C, how much force do we need to stop the rotation of the lever? The answer is on the slide. To stop the rotation, the total moment acting on the lever must be zero.

We have two moments on this lever. The first is from external force P, the P moment about A point 1kNm (1KN times 1m equals 1kNm). The second is the F moment about A. The two moments together are equal to zero. We already have the P moment 1KNm. That means the F moment acting anti-clockwise should be equal to 1kNm. As we know, the F moment about A should be equal to F times 2m, which is the distance between Point A and F. Thus 2m x F equals 1kNm. So that F is equal to 0.5KN. If we apply a load at Point C with F equals 0.5KN, the F force stops the rotation of lever.

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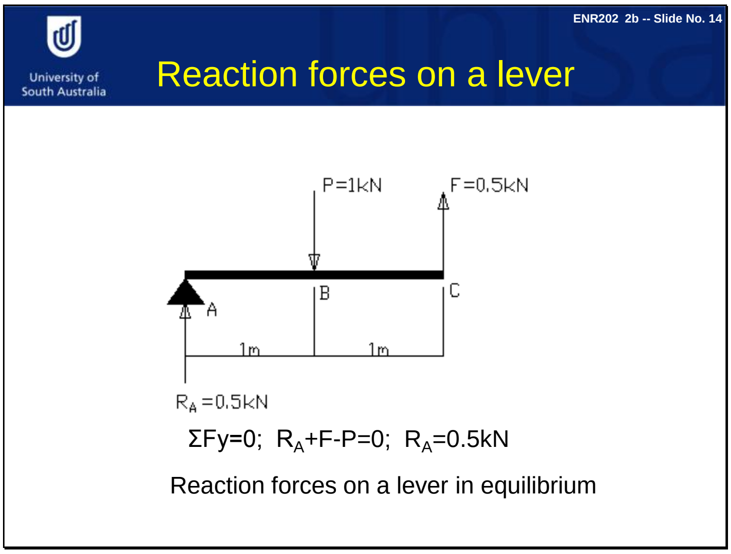

Lets look at the reaction forces on the lever. Some reaction forces are acting at Point A. Because the P load is acting down, and the F force is acting up, and these two forces together equal 0.5 kN down. But the lever is in equilibrium and will not move down. That means the total force acting on the lever should be equal to zero. That means RA is equal to 0.5kN. The forces acting on the lever here are RA (0.5kN up), P (1kN down), and F (0.5kN up).

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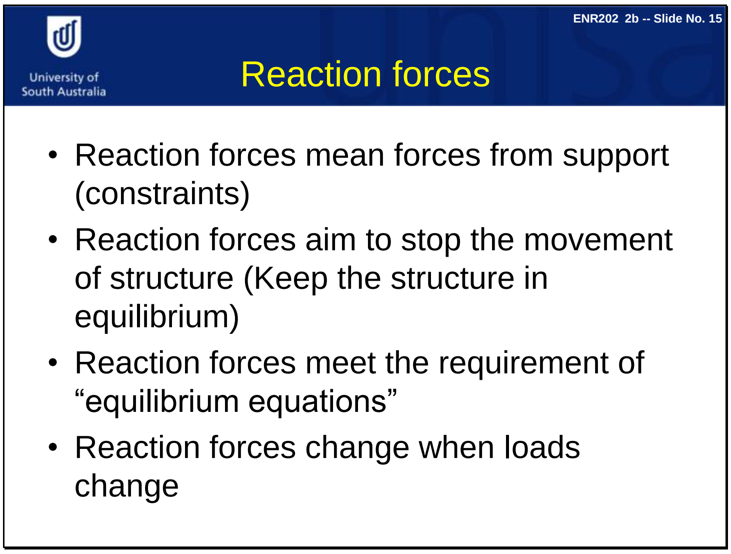

Reaction force is the force from support. For example, in the previous example we saw support A pivot forces acting on the lever, so RA was the reaction force. The reaction force aims to stop the movement of the structure.

We need reaction forces because structures or objects tend to move, and restraints or supports will stop that movement. The aim of reaction forces is to stop the object from moving or to keep the structure in equilibrium. Reaction forces should meet the requirement of equilibrium equations.

Reaction forces change if loads change. If we have a structure with external loadings on it, the support will produce reaction forces on the structure. If we change the loadings in the structure, the reaction forces also change.

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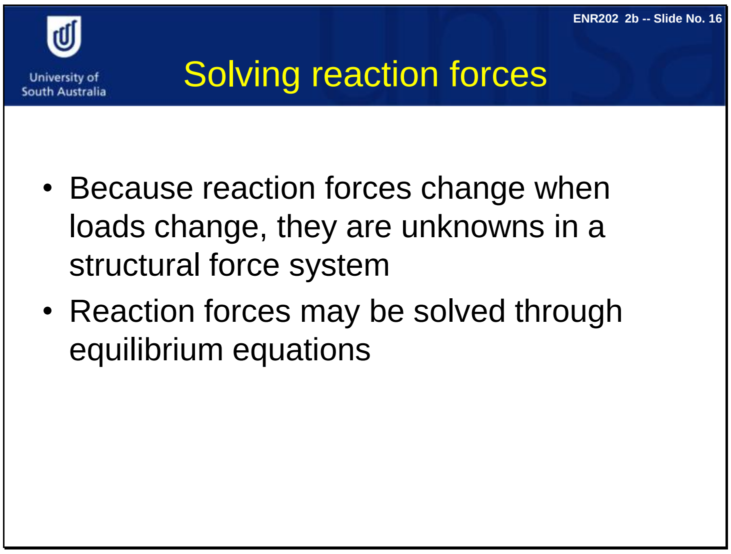

To solve reaction forces when loads change, we have to use equilibrium equations.

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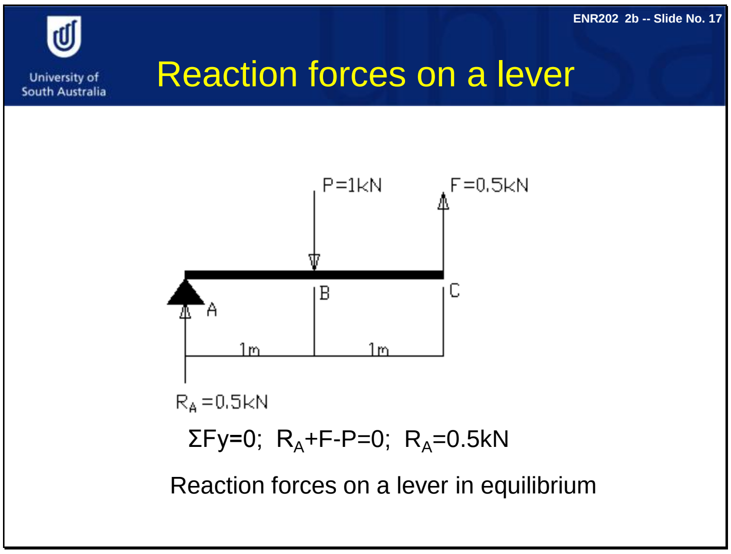

Let’s come back to the lever reaction forces. We already calculated that RA is acting at Point A. The force acting at Point A is 0.5KN, the force acting at Point B is 1kN down, and the force acting at Point C is 0.5kN upwards.

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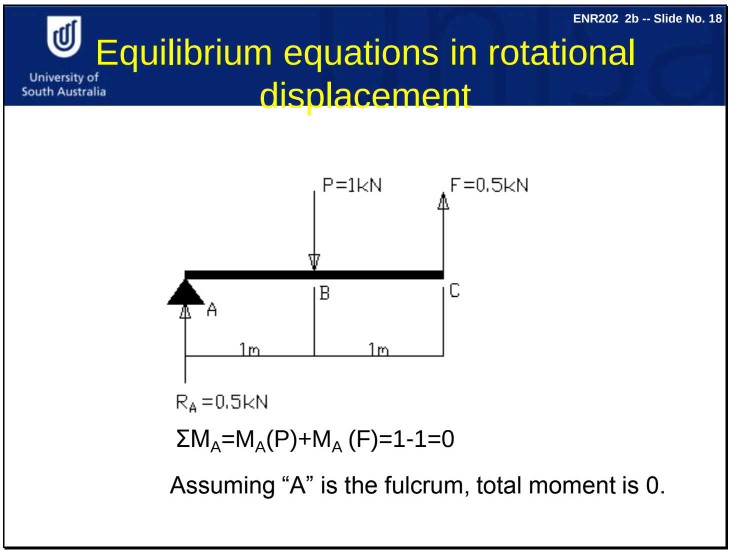

Let’s look at this picture. If we consider Point A as a pivot, the total moment about A is zero. We already know that there is a P moment about A of 1KNm, and the F moment about A is another 1kNm, but in different directions, so we have zero moment at the lever. These three forces acting on the lever produce zero bending moment at Point A.

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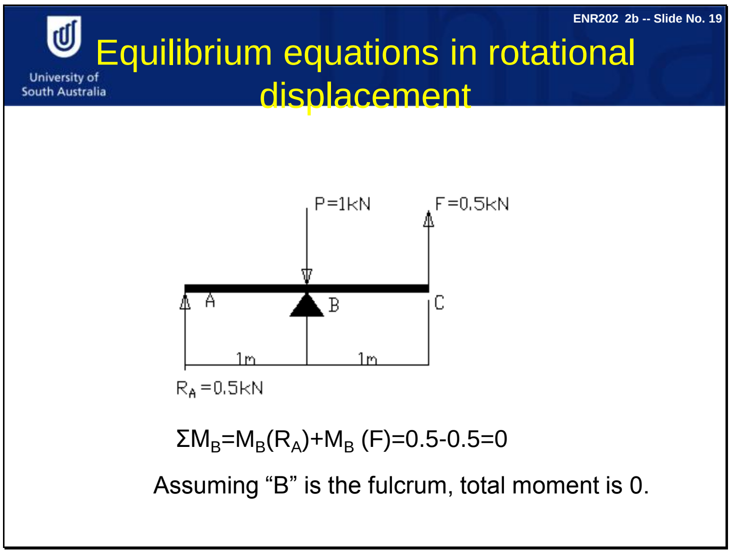

If we change the pivot to Point B, what will happen? We still have three forces acting on the lever, but now we have RA moment at Point B. How much is it? It is equal to 0.5KN times 1m, which equals 0.5kNm. The P load does not have any moment at Point B, because the distance is zero. The F load has moment at Point B and is also equal to 0.5KNm. The F force moment is acting anti-clockwise and the RA moment is acting clock-wise, altogether there is zero moment. The lever is in equilibrium; the three forces acting on the lever are producing zero moment.

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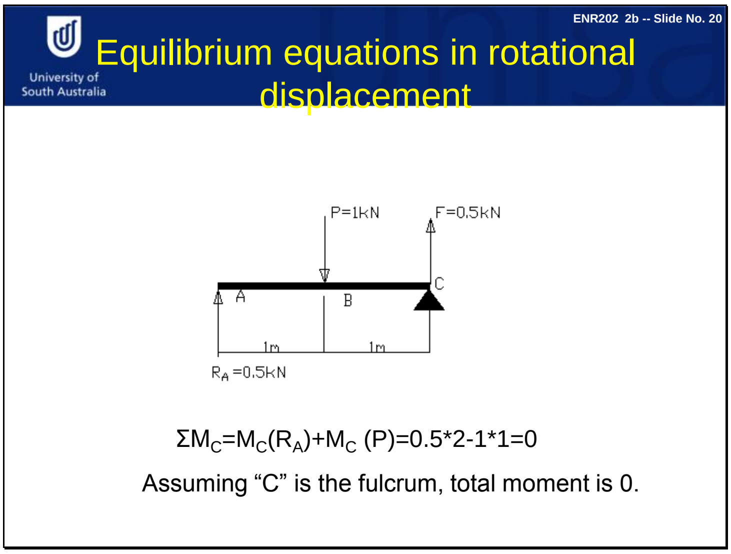

Now let’s consider Point C as the lever. In this case, the RA force has moment about Point C equal to 0.5KN times 2m, or 1kNm. The P load has moment about Point C equal to 1KN times 1m, or 1KNm anti-clockwise. Therefore, we still have zero total moment.

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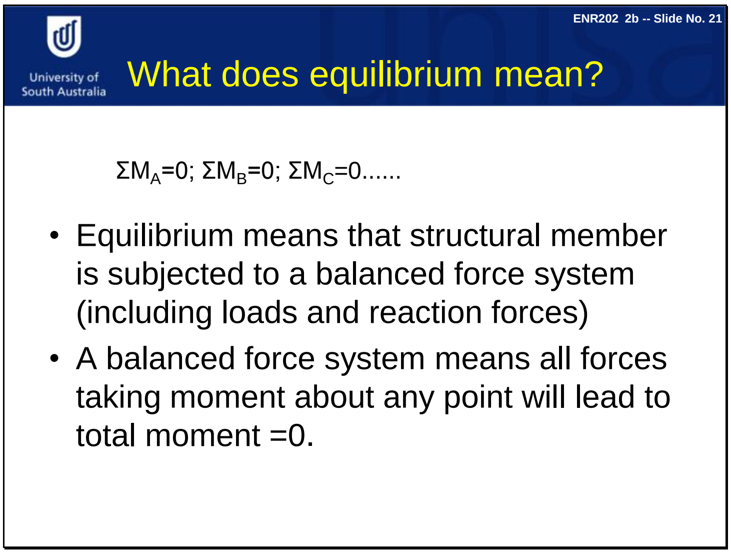

So, we have zero moment about A, and we have zero moment about B, and we have zero moment about C. The real meaning of equilibrium is that a structural member is subjected to a balanced system, and this balanced system will produce zero moment about any point.

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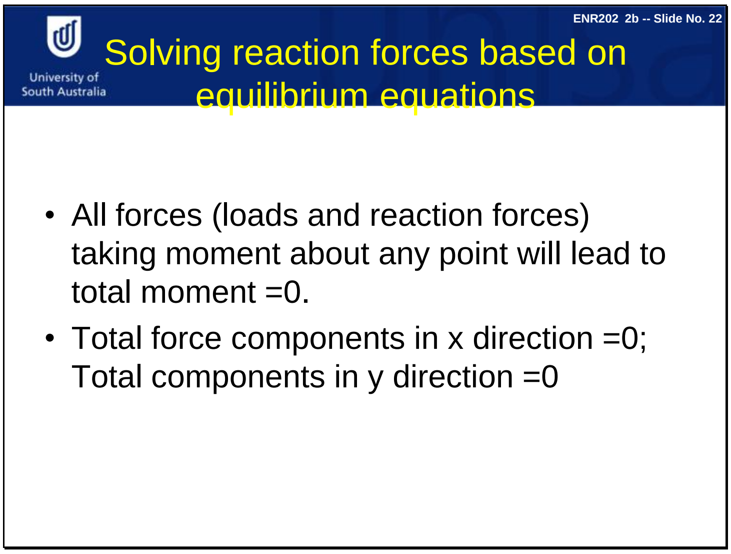

Now let's look at the general procedure. All forces, including loads and reaction forces, taking moment about any point will lead to a total moment of zero. All force components in x-direction together equal to zero, and total components in y-direction equal to zero. This is what equilibrium equations are all about.

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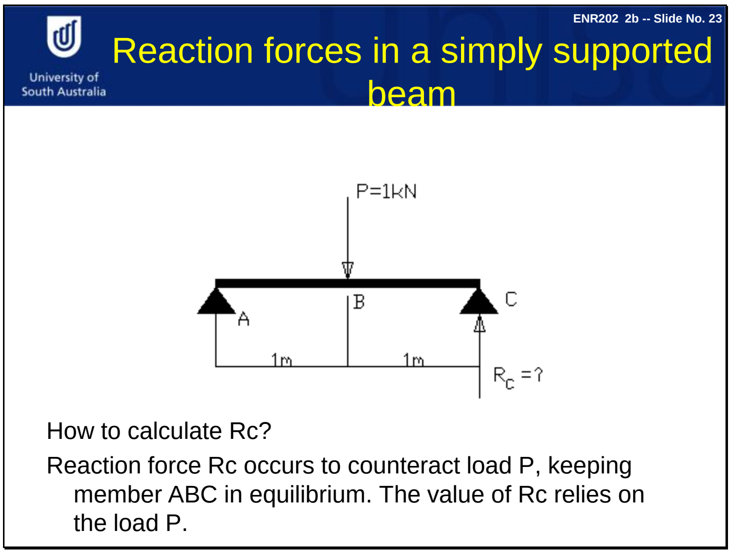

Let’s look at another example, If we have a simply supported beam, and a load acting on middle span of the beam, we know this beam is in equilibrium. How do we solve the reaction forces at Point C? The reaction forces at C, together with the P load, together with the A support, will keep the beam in equilibrium, and the value of RC depends on the load P.

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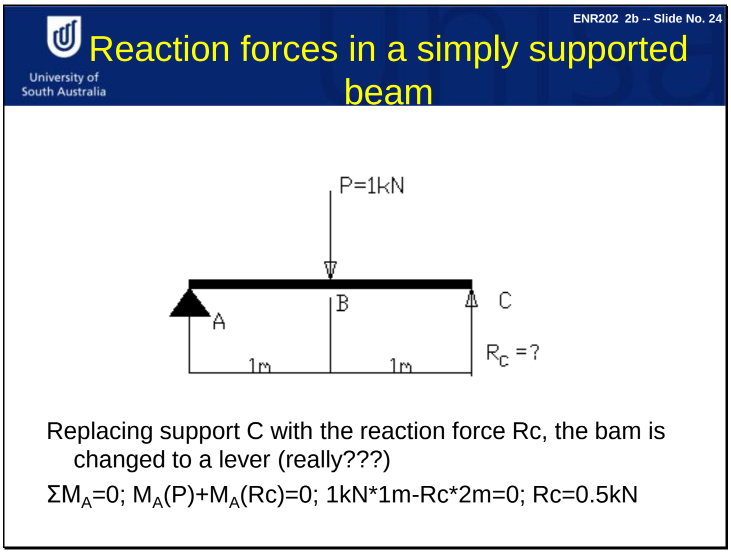

So, this is the way to calculate the reaction forces in the beam. We just replace the support C, with the reaction force RC, so the beam is changed to a lever. Having the beam in equilibrium that means the modified lever is also in equilibrium, so you can calculate RC here. Because this beam lever is in equilibrium, all moment about the pivot together should be zero. The total moment at A should be zero. We have two moments here: one moment from the P load (P times 1m, 1KNm) and other moment from RC (RC times 2m) and both moments together equal zero. Thus, RC = 0.5KN.

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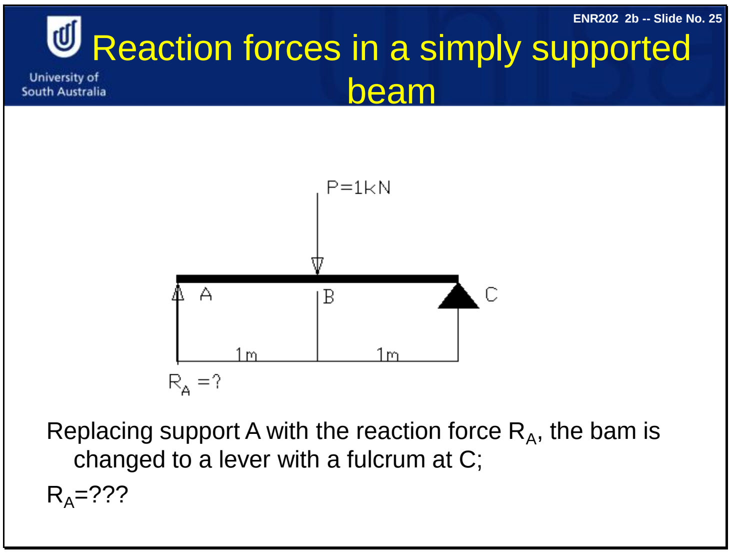

Right, let's replace the A support with a reaction force RA and a lever at Point C. What is RA? The answer is 0.5KN

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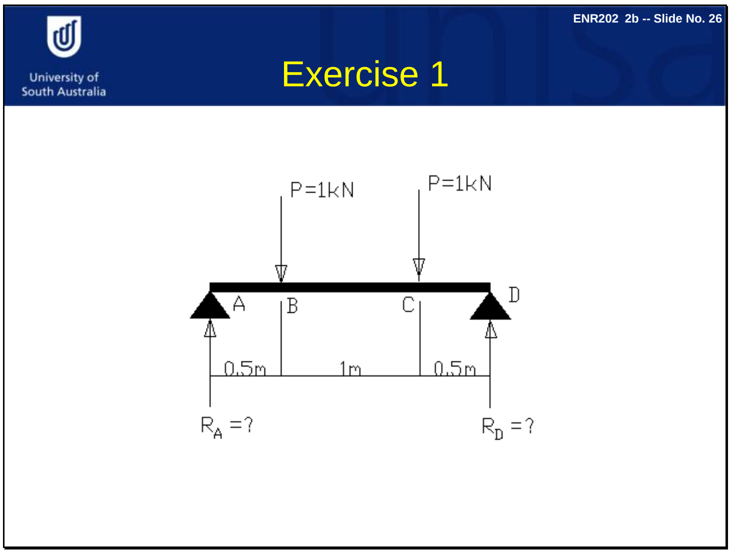

Here’s another example. How do you calculate the reaction forces RA and RD here? Pause the presentation and try to work this out. The solution is on the next slide.

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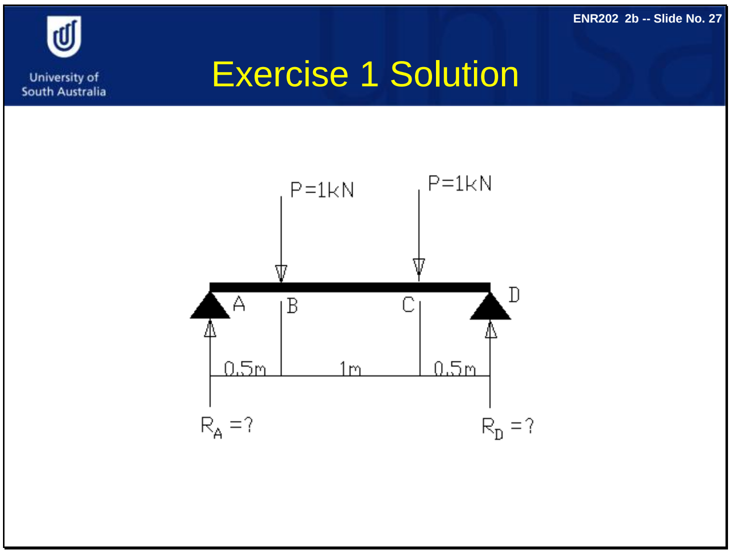

If we replace the support A by the RA, and we consider the Point D as a pivot, how many moments are acting on the pivot? The answer is 3 moments: one is 0.5KNm in anti-clockwise direction, another moment is 1.5KNm in anti-clockwise direction, and final moment is RA by 2 and this is in clockwise direction. The 3 moments together equal zero (0.5 plus 1.5 minus 2RA equals 0.) RA must be 1KN.

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Thank you for your attention.