No 3 TWISTING and BENDING

Gerald Foley Given at CTC 3 March 2008

1. Last time, I was talking about tension and compression forces. Tension is a pull and can be resisted by long thin strong things like string, and muscle tendons.
2. Compression is a push or a squeeze and the shape of the thing resisting it is quite important. You cannot push with a piece of string and even a piece of steel will buckle under quite a small compression load if it is too narrow in relation to its length.
3. So the lateral dimensions are important when we are considering struts or compression members. We saw that if you spread out the material of which the strut is made it can carry a bigger compression load.
4. We saw how this helps explain certain features of how the musculo-skeletal system works and why it is the way it is. Muscles are attached to their insertion points by thin strong tendons. This means that contrary to what we sometimes feel, muscles do not push; they only pull.
5. The bones, which resist compression forces, especially the longer ones in the legs and arms, have relatively large lateral dimensions so they won't buckle.
6. Today, I want to look at another way in which forces act. So I am going to talk about twisting and bending.
7. First, twisting. Or as engineers like to call it torsion. It comes from the same Latin root as torture.
8. If I am undoing a tight bolt, on a lawnmower or something, I will normally use a spanner or a wrench. I fit the jaws over the nut and I apply a force to the handle of the spanner. We can show this diagrammatically like this.
9. It is obvious that the effect on the nut is neither a push nor a pull but a twisting or torsion tendency. The force is going round in a circle. And if we do a variety of experiments we find that the longer the handle, the less force we have to apply to get the nut to turn.
10. And if we are scientists, we can develop a very simple formula $T = F \times d$ to express this. The amount of twist is the product of the force by the distance.
11. This shows mathematically that if we want to increase the amount of twist on a particular bolt, we can do so by moving our

hand out along the handle or using a longer handle. Or we can increase the force. Or we can increase both.

12. The technical term for this twisting tendency is called the twisting moment. You might well ask why is the word moment used for something like this. It has absolutely nothing to with time – it comes from the Latin word movere to move – and according to one dictionary it is probably related to momentum. If there were an alternative I would use it. But moment is the word that is used.

13. Next, let’s look at a screw-top bottle. Here again, I am using a circular or twisting force to undo the cap.

14. If we look carefully at how this is being done, we see that we producing this twisting force by using two forces acting in opposite directions, a push in this direction and pull in this direction on either side of the screw top.

15. Once we become aware of this twisting tendency being produced by two forces separated by a distance and acting on a body, we see it at work in all kinds of ways.

16. When the men are closing off the water supply valve in the street, they use a tee-shaped tool with a cap which they fit over the valve in the pipe and they twist it around, pushing with one hand and pulling with the other.

17. When the sailors used to haul up the anchor in a sailing ship, they used a big horizontal wheel with spokes sticking out of it – called a capstan. While some of the sailors were pushing the spokes in this direction, the others were pushing the in the opposite direction.

18. If we carry out a variety of experiments, we will find that the amount of twist we apply is the product of the force on either side multiplied by the distance between them – the twisting tendency, the turning moment, is F x d – exactly the same formula as we had for the wrench.

19. And it has the same implications, we can increase the twist by increasing the force, or the distance, or both.

20. A very familiar example of this is when you are trying to undo a stiff cap on a bottle, it can sometimes help to wrap a cloth around it. Apart from giving you a better grip, one of the effects of this is to widen the distance between the push and the pull which increases the turning moment of the cap.

21. Because the diameter of the cap is quite small, the thickness of the cloth makes a significant difference.

22. Here is another technical term. When we have two forces, separated by a distance, acting in opposite directions on an object, as in when we are undoing a bottle cap, we refer to them as a couple.

23. One is pushing, the other is pulling, and the whole thing is going round in a circle – people in long-term relationships, who are also referred to as couples, often notice the same thing happening.

24. Now let's look at a see-saw – a board balanced on a pivot which is also called the fulcrum. If I put a weight, a child, on one end, it goes down. But this is no mystery to us. There is a twisting moment made up of the downward weight of the child by the distance from the support which is causing the seesaw to twist in a clockwise direction around its support.

25. If I now put another child of exactly the same weight at exactly the same distance from the support, on the other side of the seesaw, the two turning moments balance each other and the seesaw is evenly poised.

26. It is interesting how, quite instinctively, children find out how to work a seesaw and get it moving. What you see, if you look closely, is that one child leans inwards and the other leans outwards. The one leaning in is shifting its weight inwards – F x d goes down a little. and the other is shifting its weight outwards – F x d goes up a little.

27. The seesaw is then out of balance and rotates on the support. One end may come down and hit the ground, or the before it hits, the children may simply sway in the opposite directions to create the opposite effect.

28. If we have two children of quite different weights who want to use a seesaw, they deal with this by sitting at different distances from the centre. In this case they are changing both the F and d in the F x d formula – because F is higher in the case of the bigger child, the d has to reduce to get into balance with the other side of the seesaw.

29. Next, I want to look at the question of bending. As one might say, there's an awful lot of it about. Trees bend in the wind; diving boards bend when someone stands on the end of them; the pole used by athletes bends alarming in the pole-vault; if I

rest a plank of wood on two bricks and stand in the middle, it bends downwards – and so on.

30. For the engineer, bending is obviously very important. We normally refer to a bit of a building that is resisting bending as a “beam”.

31. The two most common forms of beam are those which span between two supports which we call simply-supported beams and those which are only supported at one end and stick straight up like a tree or a flagpole and or straight out like a diving board or a balcony. This kind of beam which is supported only at one end is called a cantilever.

32. How does a beam bend. This piece of ridged vacuum-cleaner tube illustrates it well.

33. It I support it at its two ends and gently bend it what do we notice about the ridges at the top and the bottom? Those at the top come closer together – the top is being squeezed or compressed. Those at the bottom move further apart – the bottom is being stretched or as we say is being put into a state of tension.

34. Now lets look at it as a cantilever sticking straight out with a weight on the end. Unlike the simply-supported beam, we get tension on the top and compression on the bottom. And if it is sticking straight up, we get compression on one side and tension on the other.

35. Because concrete is strong in compression but weak in tension, and steel is strong in tension, when engineers are designing concrete buildings, they use steel reinforcement, those iron bars that you see, in the part of the beam that is in tension.

36. So if we are designing a beam – this is a sideways-on view – which we know is going to crack on the underside, we put the main in the lower part of the beam.

37. But if we are designing a balcony – again a sideways-on view – which we know is going to crack at the top, we need to put the main reinforcement in the top.

38. In the 1960s and 1970s, quite a few balconies collapsed in cheap speculative hotels and apartment blocks when there was a boom in package tourism and buildings are put up without proper design and supervision. The workmen put the steel in

the bottom to start with or didn't support the bars enough when they are putting in the concrete so they sank to the bottom.

39. In practical terms, if a concrete balcony is going to collapse, you'll see cracks in the top near the inner edge. If a bridge is going to collapse, you'll notice cracks on the underside of the beams supporting it. In both cases, you take evasive action by getting in off the balcony or getting out from under the beam – these talks have their practical value.

40. But the process of bending also applies to human bodies and this is what I want to discuss now. The body is different from the beams and cantilevers I have been discussing which are bent by having loads or forces applied to them.

41. The human body actively bends itself using its own muscles. I don't mean bending at the joints which we will look at in the next lecture when we are discussing levers, but the process by which we curve the torso forward or backward or to either side.

42. If I want to curve my torso forward, and then backward, to one side and then to the other, I tighten the muscles on the concave side and, if I have a well-developed kinaesthetic sense, I let go on the convex side.

43. We can see this tightening very obviously when I lie on the floor and lift my upper body by tightening my stomach muscles. I do the reverse when I tighten my back muscles to arch myself backward.

44. Another example is when I tighten the muscles of my chest to pull myself down and inwards into what is sometimes called the near-work postural configuration – for working at a computer.

45. When we think about it in this way, we can see why we often say to people, if you want to straighten yourself up, it makes a lot of sense to stop pulling yourself down first.

46. We ask them to release and lengthen in the front. This enables the automatic postural systems of the body to bring them into a more natural and un-pulled-down state.

47. But you would be surprised at how many people who completely fail to see it.

48. The big mistake many school-teachers, and mothers, make is when they see children and young people pulled down in the front, they make them tighten their back muscles in order to straighten them out. "Pull your shoulders back," they say.

49. But if we have not released in the front before we start tightening in the result is that the front remains pulled in and down and the unfortunate person tightens up their back as well.

50. I think that’s probably enough for today. We covered undoing bottle-tops, using a seesaw, making sure the steel reinforcement is in the right place in a building, knowing when it would be prudent to get off the balcony or get out from under the beam, and remembering to release the front when straightening up from bending forwards and inwards.