Q2. In Fig. 12-15, a rigid beam is attached to two posts that are fastened to a floor. A small but heavy safe is placed at the six positions indicated, in turn. Assume that the mass of the beam is negligible compared to that of the safe. (a) Rank the positions according to the force on post A due to the safe, greatest compression first, greatest tension last, and indicate where, if anywhere, the force is zero. (b) Rank them according to the force on post B.

(a) 1 > 2 > 3 = zero force > 4 > 5 > 6. Under tension: 4, 5, 6.
(b) 6 > 5 > 4 > 3 > 2 > 1 = zero force. Post B is always under compression, except for position 1.

Q4. A ladder leans against a frictionless wall but is prevented from falling because of friction between it and the ground. Suppose you shift the base of the ladder toward the wall. Determine whether the following become larger, smaller, or stay the same (in magnitude): (a) the normal force on the ladder from the ground, (b) the force on the ladder from the wall, (c) the static frictional force on the ladder from the ground, and (d) the maximum value $f_{s,max}$ of the static frictional force.

(a) Same. Has to equal weight of ladder.
(b) Decreases. Has to balance torque the weight of the ladder, which has a moment arm of half the distance from base to wall.
(c) Decreases. Has to balance the normal from the frictionless wall.
(d) Stays the same. The $f_{s,max}$ is set by $\theta_s$ and $n_{ground}$, both of which are fixed. The safety factor $f_{s,max}/f_{s,actual}$ goes up.

P3. In Fig. 12-24, a uniform sphere of mass $m = 0.85$ kg and radius $r = 4.2$ cm is held in place by a massless rope attached to a frictionless wall a distance $L = 8.0$ cm above the center of the sphere. Find (a) the tension in the rope and (b) the force on the sphere from the wall.

XFBD for sphere: Draw a circle. $mg$ down, from center; $T$ up/left, from point on perimeter directly between center and suspension point; $n$, to right, at contact point. $\vec{a} = 0$. $+x$ to right, $+y$ upward. Designate the angle the string makes with the vertical as $\theta$, where $\theta = \text{Tan}^{-1}(r/L) = \text{Tan}^{-1}(4.2/8.0) = 27.7^\circ$ is served on a brass platter.

(a) $y$-eq: $T \cos \theta - mg = 0 \implies T = mg/\cos \theta = (0.85 \text{ kg})(9.8 \text{ m/s}^2)/0.8854 = 9.41 \text{ N}$.
(b) $x$-eq: $n - T \sin \theta = 0 \implies n = T \sin \theta = (9.41 \text{ N})(.4648) = 4.37 \text{ N}$

Torque eq: Taking the ref as the center of the sphere, all forces have zero moment arm, so $0 = 0$. Not very useful - good thing we already got the answers.

P7. A 75 kg window cleaner uses a 10 kg ladder that is 5.0 m long. He places one end on the ground 2.5 m from a wall, rests the upper end against a cracked window, and climbs the ladder. He is 3.0 m up along the ladder when the window breaks. Neglect friction between the ladder and window and assume that the base of the ladder does not slip. When the window is on the verge of breaking, what are (a) the magnitude of the force on the window from the ladder, (b) the magnitude of the force on the ladder from the ground, and (c) the angle (relative to the horizontal) of that force on the ladder?

Sketch ladder pointed up and right.

XFBD: Line angled up/right. $n_w$ (normal from wall) leftward, at top; $W_L$ (weight of ladder) down, at center; $W_p$ (weight of person) downward, at 3/5 the way up the ladder; $n_G$ (normal from ground) upward, at base of ladder; and $f_s$ rightward, at base of ladder. $\vec{a} = 0$, of course. $+X$ rightward and $+y$ upward.

$x$-eq: $f_s - n_w = 0 \implies n_w = f_s$.
$y$-eq: $G - W_L - W_p = 0 \implies n_G = W_p + W_L$. 

Take torque about the base. Use $L$ for the length of the ladder (5 m), and $a$ for the distance from the wall (2.5 m). Note that the height (call it $H$) on the wall is given by

$$H = \sqrt{L^2 - a^2} = 4.33 \text{ m}.$$ 

(a) For torque, use the moment arm to take the $\sin \theta$ factor into account. Also select the base of the ladder as the reference point.

Torque eq: $n_w L - W_A (1/2) - W_B (3/5) = 0 \Rightarrow n_w = (W_A (1/2) + W_B (3/5)) / H = [(98 \text{ N})(2.5 \text{ m})(0.5) + (735 \text{ N})(2.5 \text{ m})(0.6)] / (4.33 \text{ m}) = 282.9 \text{ N}$

(b) The force from the ground is the vector sum of $f_1$ and $n_w$. We have from the $x$-eq that $f_1 = n_w = 282.9 \text{ N}$. From the $y$-eq, we have that $n_G = 98 \text{ N} + 735 \text{ N} = 836 \text{ N}$. The magnitude is obtained by Pythagoras

$$|\vec{F}_{\text{ground}}| = \sqrt{282.9^2 + 836^2} = 882.6 \text{ N}.$$ 

(c) Use $\theta$ for the angle from horizontal: $\theta = \tan^{-1}(836/282.9) = 71.3^\circ$.

Incidentally, the angle of the ladder is $\tan^{-1}(H/a) = \tan^{-1}(4.33/2.5) = 60.0^\circ$. One rule is that the ground force has to point above the ladder for stability. To see this, remember that this “force by ground” is the vector sum of $f_1$ and $\vec{n}_g$, and consider using the wall contact as the reference point.

**P10.** The system in Fig. 12-26 is in equilibrium, with the string in the center exactly horizontal. Block $A$ weighs 40 N, block $B$ weighs 50 N, and angle $\phi$ is $35^\circ$. Find (a) tension $T_1$, (b) tension $T_2$, (c) tension $T_3$, and (d) angle $\theta$.

Recognize a statics problem. Further recognize that the objects of interest are the knots above the blocks.

FBD for Block $A$: $T_A$ up (tension in the vertical string tied to $A$); $W_A$ down. Hence $T_A = W_A = 40 \text{ N}$. Similarly, $T_B = 50 \text{ N}$. These should be trivial for you by now.

Call the knots $A$ and $B$ according to which block they support.

Start with Knot $A$, since more is known about it.

FBD for Knot $A$: $T_1$ up/left at $\phi = 35^\circ$ from vertical; $T_2$ to right; $W_A = 40 \text{ N}$ down. $\vec{a} = 0$. Conventional $x$ and $y$.

(a) $y$-eq: $T_1 \cos 35^\circ - 40 \text{ N} = 0 \Rightarrow T_1 = (40 \text{ N})/\cos 35^\circ = 48.83 \text{ N}$.

(b) $x$-eq: $T_2 - T_1 \sin \phi = 0 \Rightarrow T_2 = T_1 \sin \phi = (48.83 \text{ N})(0.5736) = 28.01 \text{ N}$.

FBD for Knot $B$: $T_2 = 28.01 \text{ N}$ to left; $W_B = 50 \text{ N}$ down; $T_3$ up/right at angle $\theta$ to vertical.

$x$-eq: $T_3 \sin \theta - 28.01 \text{ N} = 0 \Rightarrow T_3 \sin \theta = 28.01 \text{ N}$

$y$-eq: $T_3 \cos \theta - 50 \text{ N} = 0 \Rightarrow T_3 \cos \theta = 50 \text{ N}$.

Square these equations and add:

$$T_3^2 \sin^2 \theta + T_3^2 \cos^2 \theta = (28.01 \text{ N})^2 + (50 \text{ N})^2 \Rightarrow T_3^2 = 3285 \text{ N}^2 \Rightarrow T_3 = 57.3 \text{ N}.$$ 

(d) Divide the $x$-eq by the $y$ eq to eliminate $T_3$ and get

$$\tan \theta = (28.01 \text{ N})/(50 \text{ N}) = 0.5602 \Rightarrow \theta = 29.26^\circ.$$ 

We never actually needed the mass, which is generally true in statics: if given masses, you need to calculate weights; but if given the weights, you don’t need the masses. Also note that by starting from the best-known side, it was possible to calculate $T_1$ and $T_2$ before we even looked at the FBD for Block $B$. When you can do this, it makes the solution easier. Sometimes, you need to write out all 4 (or however many) equations and then figure out how to solve them.