Centre of Mass

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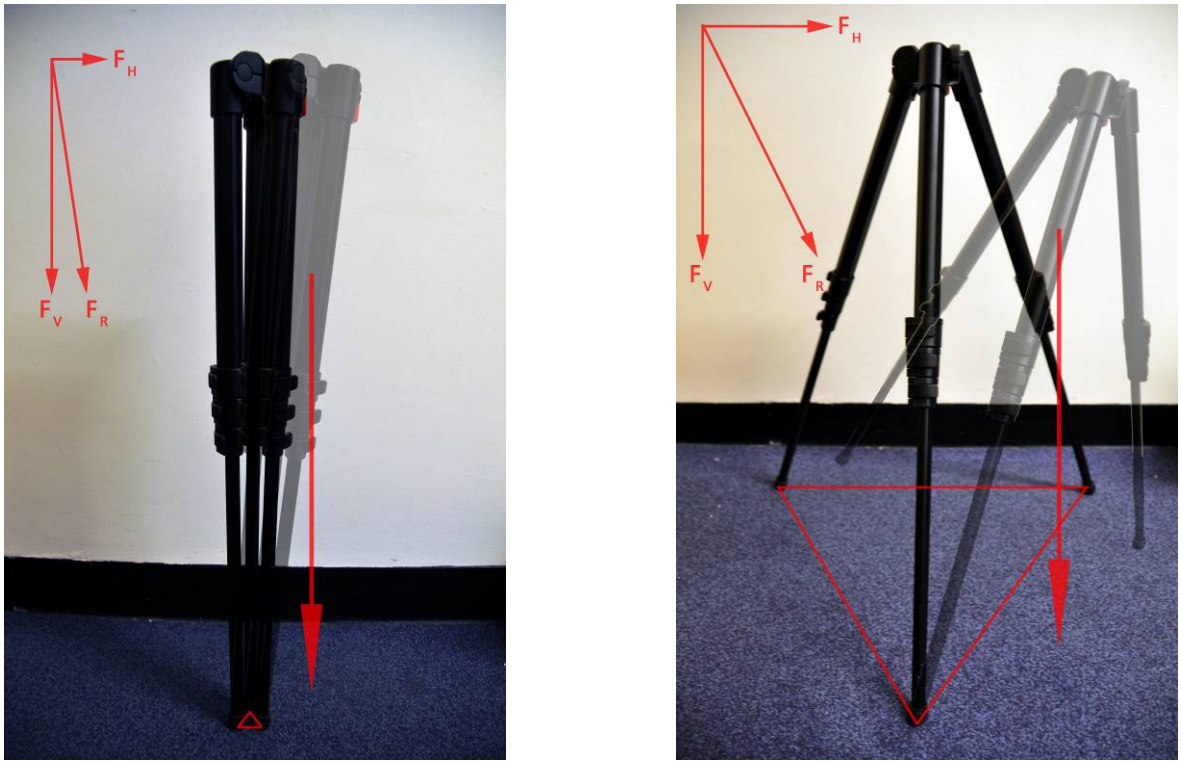
Concept: i. The wider the base of support, the more stable the structure.
ii. The lower the centre of mass of a structure, the more stable the structure.

This demonstration shows how the stability of a structure relates to the size of its base and the location of its centre of mass.



(a) (b)

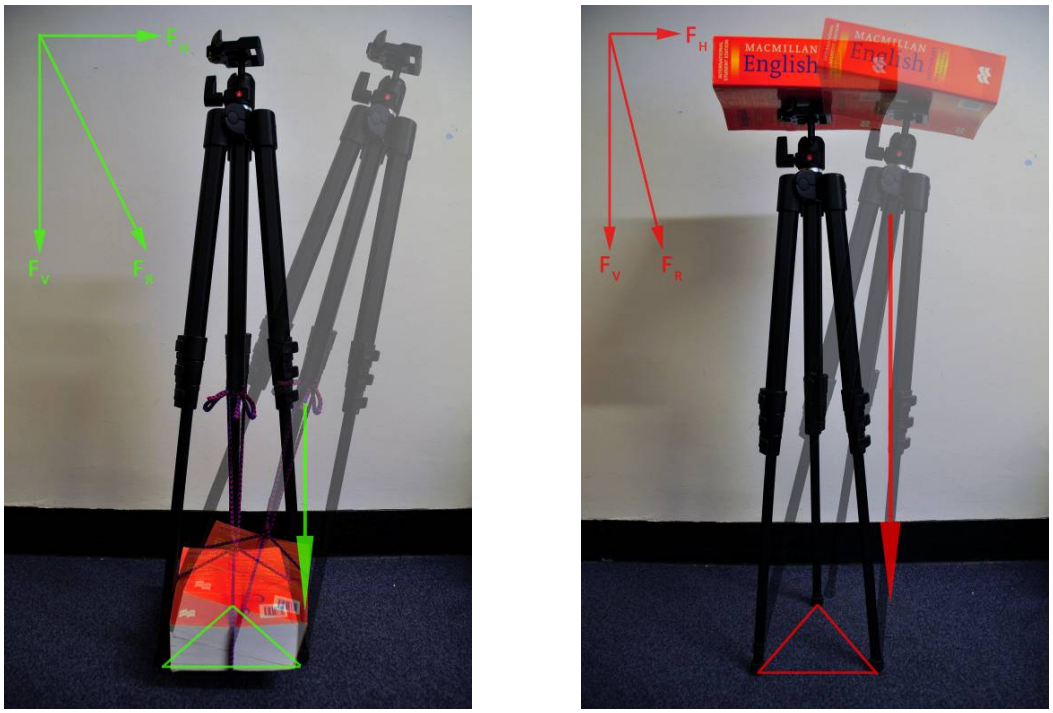
Figure 1: Tripods with different base area.

Figure 1 shows two tripods with the same height and weight. The tripod in Figure 1a has a small base area compared to the tripod in Figure 1b, which has a significantly larger base area. Theory predicts that the tripod with larger base area can sustain greater horizontal force before it topples over, hence more stable.

The demonstration is as follows:

1. The tripod is setup on a flat ground as shown in Figure 1.
2. A horizontal force is applied to the top of the tripod until it becomes unstable and topples over.
3. The horizontal force creates a moment at the base of the tripod. The combined vertical force (self weight of the tripod) and the horizontal force will produce a resultant force passing through the centroid of the two forces inclining at an angle to the vertical. The tripod topples over as the line of action of the resultant force passes outside the base of the tripod.

4. Despite having the same height of centre of mass, the tripod with smaller base area topples with small horizontal force. Conversely, the tripod with larger base area can sustain significantly greater horizontal force before it topples over. This can be clearly seen by the force diagrams in Fig 1a and Fig 1b. As the tripod base enlarges, in order to topple the tripod, the resultant force inclines more from vertical and the horizontal force increases.



(a) (b)

Figure 2: Tripods with different height of centre of mass.

Figure 2 shows two tripods with the same base area. However, the tripod in Figure 2a has a lower centre of mass due to a mass hanging at the lower part of the tripod, whereas the tripod in Figure 2b has a higher centre of mass due to a mass placed on top of the tripod. Theory predicts that the tripod with lower centre of mass can sustain greater horizontal force before it topples over, hence more stable.

This can be demonstrated by the force diagrams in Fig 2a and Fig 2b as before. The tripod with higher centre of mass in Fig 2b produce a resultant force which inclines closer to vertical as compared to the lower centre of mass in Fig 2a when the tripod topples. As the vertical force for both cases are the same, the former has a smaller horizontal force than that for the tripod with lower centre of mass.

To conclude, a structure is more stable if it has a larger base area compared to its upper part so that the distribution of the mass of the structure reduces with height, hence lower centre of mass. This reduces the tendency of the structure to topple when subjected to lateral loads, such as the wind. A good example of the structure which has successfully incorporated this concept into its design is the Eiffel Tower in Paris.

References:

- http://www.mace.manchester.ac.uk/project/teaching/civil/structuralconcepts/