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Determining the Z

As shown last month a weighing can be used to determine the X and Y co-ordinates of a load. When it comes to the Z co-ordinate, however, it can be a different matter, as MARCO VAN DAAL explains

To determine an accurate weight of a load and the location of its centre of gravity (CoG) a weighing can be performed. Last month we saw how the X co-ordinate as well as the Y co-ordinate can be determined from the results of a weighing.

A logical question could be asked why the third co-ordinate, the Z co-ordinate, could not be determined in the same manner. This article (quite conceptual and theoretical in content) explains under which conditions the Z co-ordinate could be determined and why it is so difficult and often impossible.

Of equal importance is the question, why would the Z co-ordinate be so important to know? The latter question is fairly simple to answer. For every load or heavy lift that is to be transported, or shipped or lifted, the vertical CoG component (Z co-ordinate) is important as it has an effect on the equipment selection and/or its set-up. A high CoG may result in additional axles for transportation to warrant the needed stability.

The CoG of the load also has an influence on the KG value of a barge or ship. Explanation of the KG value is beyond the scope of this article but, for nautical readers, the statement makes sense. Last but not least the CoG may have an effect on the lift plan, depending on where the lifting lugs are located and if it is a single crane lift, a tandem lift or a multiple crane lift.

$$CoG_x = \frac{\Sigma D_x * W}{\Sigma W}$$

(principle of moment)

EXAMPLE: Wa = 6 tons and Wb = 4 tons and the distance between Wa and Wb is 5 feet.

With the above formula it can be calculated that X = 2 feet and Y = 3 feet. See Figure 1.

NOTE: *The units chosen are tons and feet but, in reality, can be any unit because the principle of moment formula is unit independent.*

To determine the X co-ordinate of a simple object, for example, a box, the weight is measured in at least two locations, say A on one side of the CoG and B on the other side of the CoG. With the distance between A and B known, the location of the CoG can be determined.

For the determination of the Z co-ordinate, the challenge lies in the direction of the Z co-ordinate and the direction in which gravity works. Both are in the same direction. The principle of moment cannot be applied as there is no "moment arm" or distance "D".

Thus, the conventional way to determine CoG cannot be applied to find the Z co-ordinate of the CoG. A different (unconventional) way may offer a solution.

Let us assume that the box is tilted by an angle of 5 degrees. The weight of the box remains the same – nothing is added and nothing is taken away. See Figure 2.

In this new situation, the weights of Wa' and Wb' have changed a bit as the CoG has slightly shifted. Wa' = 7 ton and Wb' = 3 ton. The distance between Wa' and Wb' is still 5 feet.

NOTE: *In reality the distance between Wa' and Wb' is smaller than 5 feet. It is actually 4.98 feet due to the 5 degree rotation. Because of this rotation Wa' and Wb' moved closer together. However, for this example 5 feet demonstrated an adequate result.*

Applying the above formula again, the distances X' and Y' can be determined. X' = 1.5 feet and Y' = 3.5 feet.

Let's have a look at what really happened with the box. Due to the rotation of 5 degrees, the CoG has shifted 0.5 feet closer to the left (difference between X = 2 feet and X' = 1.5 feet) and, as a result, Wa is now experiencing an increased load of 1 ton (difference between Wa = 6 ton and Wa' = 7 ton).

Figure 3 shows a graphical representation of the tilted box with the important dimensions and angles. The focus in now on the shift in CoG and how this shift can lead to the Z co-ordinate of

FIGURE 1

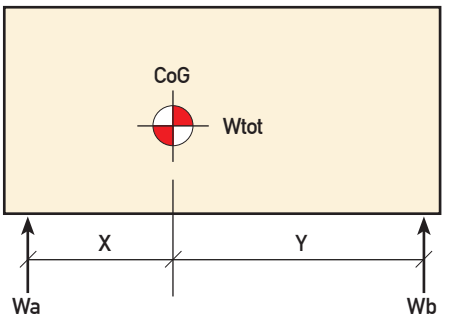
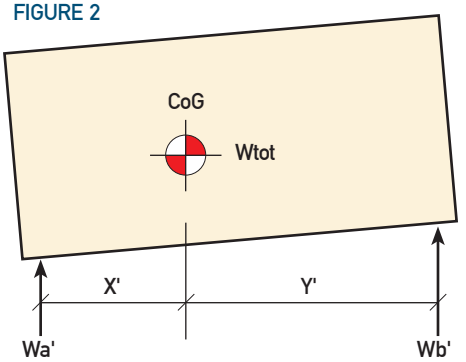


FIGURE 2



ABOUT THE AUTHOR

Marco van Daal has been in the heavy lift and transport industry since 1993. He started at Mammoet Transport from the Netherlands and later with Fagioli PSC from Italy, both esteemed companies and leading authorities in the industry. His 20-year plus experience extends to five continents and more than 55 countries. It resulted in a book *The Art of Heavy Transport*, available at: www.khl.com/books/the-art-of-heavy-transport/

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co-ordinate

this CoG. The box has been tilted by 5 degrees. This in turn means that the angle between the vertical line from the CoG and the original vertical line from the CoG (from before the box was tilted) is also 5 degrees. If the box tilts more, the angle between these two CoG line increases. If the box tilts less, the angle decreases. If the box is horizontal, thus no tilting (see Figure 1), there is no angle between these two lines as they then become one and the same line.

Calculations

With some trigonometric knowledge and the information available the height of the CoG (indicated as Hcog in Figure 3) can be determined. To make things easier to visualize, the CoG triangle has been extracted from Figure 3 and shown separately in Figure 4.

The top angle (alpha or α) can be recognised. This is the 5 degree tilting angle. The angle (beta or β) is a right angle and measures 90 degrees. The remaining angle, (gamma or γ) therefore, measures (180 – 90 – 5) = 85 degrees.

There is a trigonometric rule, called the sine rule:

$$\frac{a}{\sin\alpha} = \frac{b}{\sin\beta} = \frac{c}{\sin\gamma}$$

This sine rule can be converted to determine the CoG.

$$\frac{0.5}{\sin 5} = \frac{H_{COG}}{\sin 90}$$

If Hcog is isolated from the formula.

$$H_{COG} = \frac{0.5}{\sin 5} * \sin 90 = 5.736$$

The Z-co-ordinate of the CoG is 5.736, meaning that the CoG can be found at an elevation or height of 5.736 feet, measured from the base of the box.

In summary

By tilting the box a number of degrees, in this case 5 degrees, the CoG shifts an undetermined distance to one side. This shift of CoG results in a shift of load on the support points (or load cells). The loads on the support points before and after the CoG shift is known and that is why the load cells are used. With the application of trigonometry formulas the height of the CoG can be determined. It can therefore be stated that it is possible to determine the vertical component (Z co-ordinate) of the CoG.

Operational implications

Now that it is known that the Z co-ordinate is within reach and it was already known that this Z co-ordinate is important for equipment selection, lift plans and stability of transporters and ships or barges, then why is it not common practice to obtain a verifiable field reading as opposed to "only" an engineered value?

The answer to this question lies in the practicality of the above method.

The tilting of a box is one thing and the tilting of a box by exactly 5 degrees is another. Even when the box is tilted by exactly 5 degrees and the jacks raise the box (so the load cells can do their work), it could actually be tilted back or slightly further and the 5 degrees can end up being either less or more. By default the calculation will now produce an incorrect result.

In addition, the tilting method assumes that the box is infinitely stiff, meaning that torsional rigidity has no affect on the results. This, of course, is not the case in reality. Large structures, such as the example of last month (over 250 feet long) are often designed to flex under the influence of weather or, in this case, water. Such flex can cause the structure to be tilted at different angles at various locations along its length. Again, this will produce an incorrect result.

Moreover, for a whole array of reasons, designers or manufacturers may not allow their box to be tilted.

Last but not least, the location of the CoG plays a role in the accuracy of the results. It goes without saying that a high CoG shifts more under the influence of a 5 degree tilt than a low CoG. This means that high CoG boxes will yield a better result than low CoG boxes. For low CoG boxes the shift in CoG will be so small, and consequently also the shift in X versus X' and Wa versus Wa', that the accuracy of the difference in value will start to have an influence on the accuracy of the final result.

Conclusion

The purpose of this article is to indicate that there is a method to determine the Z co-ordinate of the CoG by weighing. There are, however, implications in this process and it may not always be practical to do so. ■

FIGURE 3

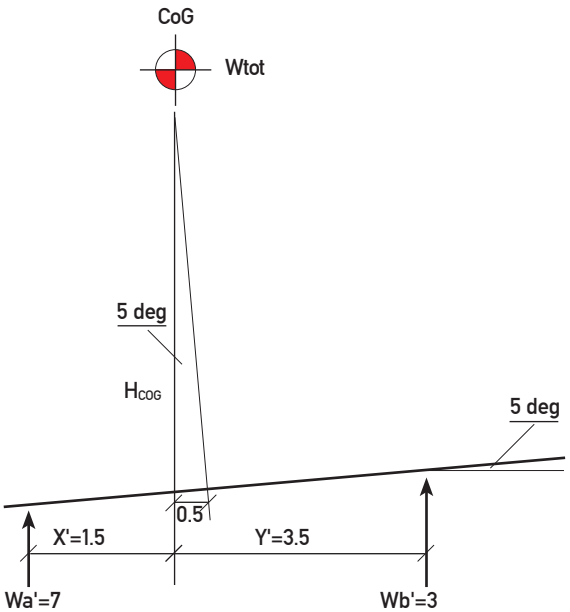
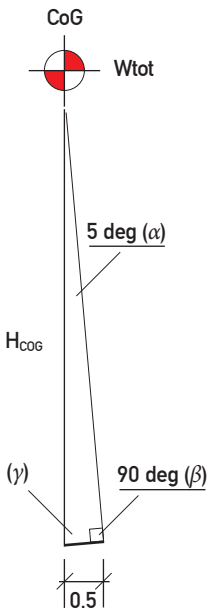


FIGURE 4



NOTE: Every effort is made to ensure the accuracy of the contents of these articles. If you find any mistakes, a brief notification and explanation would be appreciated.