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Lifting pressure

Continuing the theme of pressure, this month MARCO VAN DAAL explains ground pressure as exerted by a crane

Pressure remains an interesting phenomenon, whether it is hydraulic pressure inside a cylinder or ground pressure resulting from a transporter tyre or crane outrigger.

Irrespective of whether it is an hydraulic crane or a lattice boom truck mounted crane, the weight of the crane and the load it is lifting is transmitted to the ground via the outriggers or stabilisers. How much of the total load each carries depends on the combined centre of gravity (CoG).

For a crane on outriggers to remain stable, the combined CoG must remain with the area formed by the four outriggers. This is the crane's stability area and can be square or rectangular depending on the crane but the CoG must remain within these four tipping lines. As soon as the combined CoG passes over one of these lines, you have lost control of the crane and it will fall over. Figure 1 shows a telescopic boom crane with the stability area marked with blue lines.

As the crane works, lifting, lowering, slewing, boom (or jib) up and down, the CoG moves about in the stability area. If you stay within the maximum load as indicated by the crane's capacity chart, you will make a safe lift. Provided that the crane is set up on level ground and that the wind does not exceed the maximum permissible speeds.

What most capacity charts do not tell you is the ground pressure under any one of the outriggers given a certain lift condition. At the most, a capacity chart or operating manual gives a maximum value for a worst case. There may be situations where one wants more detailed information.

Calculation

A crane basically consists of two parts. The fixed lower and the rotating upper. The lower has a fixed CoG and does not move throughout the lift. The rotating upper is slightly more complicated. It consists of everything that moves when the crane slews or lowers and lifts or booms up or down. It includes; upper carbody counterweights, superlift counterweights (if used), winches, hoist rope, pendant ropes, hydraulic boom cylinder, boom sections, jib sections (including stow away jib), hook block, rigging (wire rope, shackles, spreaders, lift beams, etc) and, of course, the load.

To calculate the combined CoG of all these components at a varying boom angle is a task for a spreadsheet. You may still need help from the manufacturer as not many crane manuals are this well documented.

Once the GoC of all components have been taken into account we end up with two CoGs. One for the fixed lower part and one for the rotating upper part with the lifted load. Let's assume that for this example the entire crane weight (plus load and rigging) is W_{total} = 320 tons. The fixed lower part weighs W_{fixed} = 85 tons and the rotating upper part with load weighs $W_{rotating}$ = 235 tons and that the CoGs are located as indicated in Figure 2.

There are now two methods to proceed:

METHOD 1: Determine the weight distribution of each of the two CoGs (fixed and rotating part) and add up the results to arrive at the total weight per outrigger. This is the method used in this article.

FIGURE 1

METHOD 2: Determine the combined CoG of the two CoGs (fixed and rotating part) before calculating the weight distribution onto the outriggers. This method is explained in more detail next month but with crawler cranes.

Weight distribution of the fixed lower part.

The CoG of the fixed lower part lies on the centreline of the vehicle and, therefore, the two North outriggers carry half of this weight: (W_{North} = W_{fixed} / 2 = 85 tons / 2 = 42.5 tons) and the two South outriggers carry the other half: (W_{South} = W_{fixed} / 85 tons / 2 = 42.5 tons).

The North/East outrigger carries: $W_{North/East}$ = 4,500/10,000 * 42.5 tons = 19.1 tons, as does the South/East outrigger. The North/West outrigger carries: $W_{North/West}$ = (10,000-4,500)/10,000 * 42.5 tons = 23.4 tons, as does the South/West outrigger. In summary:

$W_{North/West}$ = 23.4 tons
$W_{North/East}$ = 19.1 tons
$W_{South/Wes}$ = 23.4 tons
$W_{South/East}$ = 19.1 tons
W_{Total} = 85.0 tons

The CoG of the rotating upper part lies on the centreline of the upper part. As the upper part is allowed to slew we need to take into account the angle of the rotating upper part compared to the fixed lower part. The rotating upper part in Figure 2 is rotated at 90 degrees compared to the fixed lower part and this angle is called α.

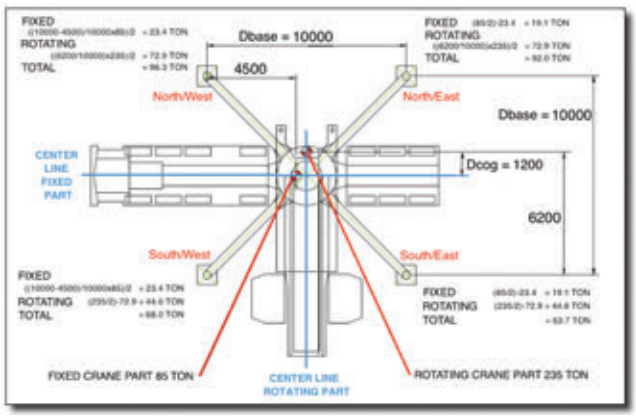

FIGURE 2

ABOUT THE AUTHOR

MARCO VAN DAAL has been in the heavy lift and transport industry since 1993. He started at Mammoet and later with Fagioli from Italy, both leading companies in the industry. His 20-year-plus experience extends to five continents and more than 55 countries. His book *The Art of Heavy Transport*, available at: www.khl-infostore.com/books Van Daal has a real passion for sharing knowledge and experience and holds training seminars around the world.

Weight distribution of the rotating upper part at 90 degrees

The North outriggers carry:

$W_{North} = (W_{rotating} / 2) + (W_{rotating} * D_{CoG} * \sin\alpha / D_{base})$
$= (235 / 2) + (235 * 1{,}200 * \sin 90 / 10{,}000)$
$= 117.5 + 28.2 = 145.7$ tons

The North/East outrigger carries:

$W_{North/East} = W_{North} * (D_{base} / 2 + D_{CoG} * \cos\alpha) / D_{base}$
$= 145.7 * (10{,}000/2 + 1{,}200 * \cos 90) / 10{,}000$
$= 145.7 * 0.5 = 72.9$ tons

The North/West outrigger carries:

$W_{North/West} = W_{North} * (D_{base} / 2 - D_{CoG} * \cos\alpha) / D_{base}$
$= 145.7 * (10{,}000/2 - 1{,}200 * \cos 90) / 10{,}000$
$= 145.7 * 0.5 = 72.9$ tons

The South outriggers carry:

$W_{South} = (W_{rotating} / 2) + (W_{rotating} * D_{CoG} * \sin(\alpha+180) / D_{base})$
$= (235 / 2) + (235 * 1{,}200 * \sin(90+180) / 10{,}000)$
$= 117.5 - 28.2 = 89.3$ tons

The South/East outrigger carries:

$W_{South/East} = W_{South} * (D_{base} / 2 + D_{CoG} * \cos\alpha) / D_{base}$
$= 89.3 * (10{,}000/2 + 1{,}200 * \cos 90) / 10{,}000$
$= 89.3 * 0.5 = 44.6$ tons

The South/West outrigger carries:

$W_{South/West} = W_{South} * (D_{base} / 2 - D_{CoG} * \cos\alpha) / D_{base}$
$= 89.3 * (10{,}000/2 - 1{,}200 * \cos 90) / 10{,}000$
$= 89.3 * 0.5 = 44.6$ tons

Note: a=0 when rotating upper part is in line with fixed lower part.

In summary:

$W_{North/West}$	= 72.9 tons
$W_{North/East}$	= 72.9 tons
$W_{South/West}$	= 44.6 tons
$W_{South/East}$	= 44.6 tons
W_{Total}	= 235.0 tons

Weight distribution of the total crane with upper part at 90 degrees

$W_{North/West}$	= 23.4 tons + 72.9 tons	= 96.3 tons
$W_{North/East}$	= 19.1 tons + 72.9 tons	= 92.0 tons
$W_{South/West}$	= 23.4 tons + 44.6 tons	= 68.0 tons
$W_{South/East}$	= 19.1 tons + 44.6 tons	= 63.7 tons
W_{Total}		= 320 tons

If the rotating upper part is rotated at a different angle from the 90 degrees as calculated above then (obviously) the load per outrigger changes.

Assuming that the rotating upper part only rotated 45 degrees, this would be exactly over the North/East outrigger. Below is the result of this lift while maintaining the same radius.

Weight distribution of the rotating upper part at 45 degrees

The North outriggers carry:

$W_{North} = (W_{rotating} / 2) + (W_{rotating} * D_{CoG} * \sin\alpha / D_{base})$
$= (235 / 2) + (235 * 1{,}200 * \sin 45 / 10{,}000)$
$= 117.5 + 19.9 = 137.4$ tons

The North/East outrigger carries:

$W_{North/East} = W_{North} * (D_{base} / 2 + D_{CoG} * \cos\alpha) / D_{base}$
$= 137.4 * (10{,}000/2 + 1{,}200 * \cos 45) / 10{,}000$
$= 137.4 * 0.585 = 80.4$ tons

The North/West outrigger carries:

$W_{North/West} = W_{North} * (D_{base} / 2 - DCoG * \cos\alpha) / D_{base}$
$= 137.4 * (10{,}000/2 - 1{,}200 * \cos 45) / 10{,}000$
$= 137.4 * 0.415 = 57.0$ tons

The South outriggers carry:

$W_{South} = (Wr_{otating} / 2) + (W_{rotating} * D_{CoG} * \sin(\alpha+180) / D_{base})$
$= (235 / 2) + (235 * 1{,}200 * \sin(45+180) / 10{,}000)$
$= 117.5 - 19.9 = 97.6$ tons

The South/East outrigger carries:

$W_{South/East} = W_{South} * (D_{base} / 2 + D_{CoG} * \cos\alpha) / D_{base}$
$= 97.6 * (10{,}000/2 + 1{,}200 * \cos 45) / 10{,}000$
$= 97.6 * 0.585 = 57.1$ tons

The South/West outrigger carries:

$W_{South/West} = W_{Sout}h * (D_{base} / 2 - D_{CoG} * \cos\alpha) / D_{base}$
$= 97.6 * (10{,}000/2 - 1{,}200 * \cos 45) / 10{,}000$
$= 97.6 * 0.415 = 40.5$ tons

In Summary:

$W_{North/West}$	= 57.0 tons
$W_{North/East}$	= 80.4 tons
$W_{South/West}$	= 40.5 tons
$W_{South/East}$	= 57.1 tons
W_{Total}	= 235.0 tons

Weight distribution of the total crane with upper part at 45 degrees

$W_{North/West}$	= 23.4 tons + 57.0 tons	= 80.4 tons
$WN_{orth/East}$	= 19.1 tons + 80.4 tons	= 99.5 tons
$W_{South/West}$	= 23.4 tons + 40.5 tons	= 63.9 tons
$W_{South/East}$	= 19.1 tons + 57.1 tons	= 76.2 tons
W_{Total}		= 320 tons

With this new weight distribution we can see that because the lift now takes place over the North/East outrigger, the load under this outrigger has increased from 92.0 to 99.5 tons. The load under each of the other outriggers has decreased. The increase in load under the North/East outrigger is relatively small (only 99.5 - 92.0 = 7.5 tons) because the CoG of the rotating upper part is only 1.2 metres from the crane's centre of rotation. The CoG shifts another 3.8 m by booming down before it reaches the tipping lines of the stability area. When the CoG of the rotating upper part is at exactly DCoG = 5.0 m the loads under each of the outriggers is as determined below. As you can see, a huge increase in load (190.4 - 99.5 = 90.9 tons) under the North/East outrigger that requires serious attention when preparing ground and setting up the crane.

Weight distribution of the total crane with upper part at 45 degrees and D_{CoG} = 5,000 mm

The North outriggers carry:

$W_{North} = (W_{rotating} / 2) + (W_{rotating} * D_{CoG} * \sin\alpha / D_{base})$
$= (235 / 2) + (235 * 5{,}000 * \sin 45 / 10{,}000)$
$= 117.5 + 83.1 = 200.6$ tons

The North/East outrigger carries:

$W_{North/East} = W_{North} * (D_{base} / 2 + D_{CoG} * \cos\alpha) / D_{base}$
$= 200.6 * (10{,}000/2 + 5{,}000 * \cos 45) / 10{,}000$
$= 200.6 * 0.854 = 171.3$ tons

The North/West outrigger carries:

$W_{North/West} = W_{North} * (D_{base} / 2 - D_{CoG} * \cos\alpha) / D_{base}$
$= 200.6 * (10{,}000/2 - 5{,}000 * \cos 45) / 10{,}000$
$= 200.6 * 0.146 = 29.3$ tons

The South outriggers carry:

$W_{South} = (W_{rotating} / 2) + (W_{rotating} * D_{CoG} * \sin(\alpha+180) / D_{base})$
$= (235 / 2) + (235 * 5{,}000 * \sin(45+180) / 10{,}000)$
$= 117.5 - 83.1 = 34.4$ tons

The South/East outrigger carries:

$W_{South/East} = W_{South} * (D_{base} / 2 + D_{CoG} * \cos\alpha) / D_{base}$
$= 34.4 * (10{,}000/2 + 5{,}000 * \cos 45) / 10{,}000$
$= 34.4 * 0.854 = 29.4$ tons

The South/West outrigger carries:

$W_{South/West} = W_{South} * (D_{base} / 2 - D_{CoG} * \cos\alpha) / D_{base}$
$= 34.4 * (10{,}000/2 - 5{,}000 * \cos 45) / 10{,}000$
$= 34.4 * 0.146 = 5.0$ tons

In summary:

$W_{North/West}$	= 29.3 tons
$W_{North/East}$	= 171.3 tons
$W_{South/West}$	= 5.0 tons
$W_{South/East}$	= 29.4 tons
W_{Total}	= 235.0 tons

Weight distribution of the total crane with upper part at 45 degrees and D_{CoG} = 5,000 mm

$W_{North/West}$	= 23.4 tons + 29.3 tons	= 52.7 tons
$W_{North/East}$	= 19.1 tons + 171.3 tons	= 190.4 tons
$W_{South/West}$	= 23.4 tons + 5.0 tons	= 28.4 tons
$W_{South/East}$	= 19.1 tons + 29.4 tons	= 48.5 tons
W_{Total}		= 320 tons

Disaster is inevitable when the calculated numbers per outrigger are inadequately distributed to the underground by means of sufficient load spreading. ■

■ Note that the calculated outrigger loads in this article do not include dynamic loading as a result of abrupt slewing or boom up or down operations. The experienced operator should minimise these dynamic impacts.