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REPAIR AND REFURBISHMENT ■ INTERVIEW: STEVE FILIPOV ■ CONEXPO PREVIEW

Don't crack under pressure

Continuing the theme of pressure, this month MARCO VAN DAAL goes into more detail on the relationship between suspension design and the terrain

Last month we demonstrated that a load onto a hydraulic axle results in a certain force and pressure on the hydraulic cylinder of the axle. Due to the construction of the axle, a type 2 lever, this force and pressure multiplies by a factor equal to the mechanical advantage or M.A.

In addition, as the axle lowers and rises, the angle of the hydraulic cylinder changes and this also has an effect on the force and pressure.

FORMULA 1

$$F_{cyl} = \frac{F_L * M.A.}{\sin\alpha}$$

We saw that a 15 tonne load placed on a single axle (not axle line) causes a 268.5 kN force in the hydraulic cylinder, given a certain axle geometry. See formula below.

$$F_{cyl} = \frac{F_L * M.A.}{\sin\alpha} = \frac{147{,}000 * 1.776}{\sin(76.5)}$$

$$= 268{,}490\ N = 268.5\ kN$$

In this article we take this a step further. In the above formula the only variable is the sine of angle α, the other properties (F_L and M.A.) are fixed. Therefore, the conclusion can be drawn that during the execution of a transport only the angle of the hydraulic cylinder (angle α) has an influence on the force on the cylinder and, therefore, the pressure inside the cylinder.

The pressure being determined by;

FORMULA 2

$$F_{cyl} = p * A \quad \text{or} \quad p = \frac{F_{cyl}}{A}$$

NOTE: *The angle of the hydraulic cylinder in turn is determined by its stroke. The set deck height at the start of a transport (often near mid stroke) determines the initial angle. The unevenness in the road surface (bumps and holes) change the cylinder stroke and, therefore, the cylinder angle. Figure 5 shows a transport combination where virtually each axle has a different stroke and, therefore, a different cylinder angle.*

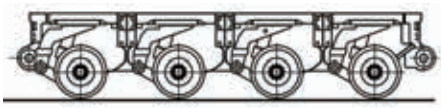

FIGURE 1

CASE 1

Let's review Figure 1, it shows 4 axles (again, not axle lines), these axles are all part of the same hydraulic group or pool. Assume that a total load of 60 tonnes is placed on the deck. Common sense tells us that in this case, where all axles are at an equal stroke and all hydraulic cylinder are at an 76.5 degree angle, each axle carries 15 tonnes and the force on each cylinder is 268.5 kN.

CASE 2

What happens, however, when one of the axles encounters unevenness in the road surface and the hydraulic cylinder angle

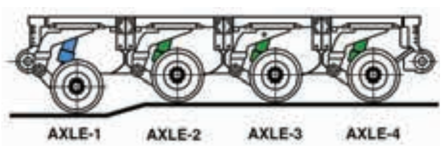

FIGURE 2

changes from 76.5 degrees to 60.0 degrees. See Figure 2.

Since we are now no longer faced with a single cylinder and a single angle α, we require a slightly different approach to determine the hydraulic pressure (p) and force (F_{cyl}) in each cylinder. We can no longer use Formula 1 in its current form.

NOTE: *Since all four axles are part of the same hydraulic group or pool, by definition, the hydraulic pressure is equal everywhere. The pressure in cylinder 1 is equal to the pressure in cylinder 2, etc.*

What we need to do is combine formulas 1 and 2

$$p = \frac{F_{cyl}}{A} \quad \text{where} \quad F_{cyl} = \frac{F_L * M.A.}{\sin\alpha}$$

therefore

$$p = \frac{F_L * M.A.}{A * \sin\alpha} \quad \text{or}$$

$$p = \frac{F_L * M.A.}{A * (\sin\alpha_1 + \sin\alpha_2 + \sin\alpha_3 + \sin\alpha_4)}$$

From last month's article we know that;

A = 132.7 cm^2 or 0.01327 m^2

M.A. = 1.776

From the above text we know that;

F_L = 60 tonnes (m) or 588,000 Newton (F_L) following F_L=m*g

α_1 = 60.0 degree

$\alpha_2 - \alpha_4$ = 76.5 degree

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.

$$p = \frac{F_L * M.A.}{A * (\sin\alpha_1 + \sin\alpha_2 + \sin\alpha_3 + \sin\alpha_4)}$$
$$= \frac{588{,}000 * 1.776}{0.01327 * (\sin 60.0 + 3 * \sin 76.5)}$$

$p = 20{,}801{,}636$ Pa = 208 bar

NOTE: *1 bar = 100,000 Pa*

This calculated pressure is the system pressure in each of the four (4) hydraulic cylinders.

The force on each cylinder F_{cyl} can now be determined with Formula 2;

$F_{cyl} = p * A = 20{,}801{,}636 * 0.01327 = 276{,}037$ N = 276 kN

So far we have not done much different from last month. The question now is, how does this force F_{cyl} translate into an axle force onto the ground.

$$F_{axle\text{-}1} = \frac{p * A * \sin\alpha_1}{M.A.} = \frac{20{,}801{,}636 * 0.01327 * \sin 60.0}{1.776} =$$

134,603 N = 134.6 kN

Following $F_{axle\text{-}1} = m * g$ this equals 13.74 tonnes

Note that this can only be calculated once the system pressure (p) is known, and this system pressure is determined by the angle of each of the hydraulic cylinders.
As the hydraulic cylinder for axles 2 and 3 and 4 all have the same angle α, these axles experience the same axle load.

$$F_{axle\text{-}2,3,4} = \frac{p * A * \sin\alpha_{2,3,4}}{M.A.} = \frac{20{,}801{,}636 * 0.01327 * \sin 76.5}{1.776} =$$

151,132 N = 151.1 kN

Following $F_{axle\text{-}2,3,4} = m*g$ this equals 15.42 tonnes

Check the math, to make sure no mistakes have slipped in.

$F_{axle\text{-}tot} = F_{axle\text{-}1} + F_{axle\text{-}2} + F_{axle\text{-}3} + F_{axle\text{-}4} =$
$134.6 + 3 * 151.1 = 587.9$ kN

Following $F_{axle\text{-}tot} = m * g$ this equals 60 tonnes

The load onto the ground is 60 tonnes, which makes sense as we placed a 60 tonne load onto the deck. Transporter self-weight is neglected here.

With a 60 tonne load placed onto four axles that are all connected to the same hydraulic group or pool, one would logically expect the axle load onto the ground to be 15 tonnes per axle (60 tonnes / 4 axles = 15 tonnes/axle).

The axle geometry resulting in an ever varying hydraulic cylinder angle causes this not to be true. See below overview.

$F_{axle\text{-}1}$	= 13.74 tonnes	(60.0 degrees)
$F_{axle\text{-}2}$	= 15.42 tonnes	(76.5 degrees)
$F_{axle\text{-}3}$	= 15.42 tonnes	(76.5 degrees)
$F_{axle\text{-}4}$	= 15.42 tonnes	(76.5 degrees)
$F_{axle\text{-}tot}$	= 60.00 tonnes	

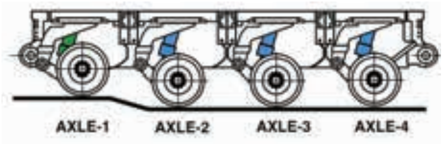

FIGURE 3

CASE 3

For arguments sake, let's also review the numbers when only the hydraulic cylinder of the first axle is at 76.5 degrees and of axle 2, 3 and 4 at 60.0 degrees. See Figure 3.

The following applies;

A	= 132.7 cm² or 0.01327 m²
M.A.	= 1.776
F_L	= 60 tonnes (m) or 588,000 Newton (F_L) following $F_L = m*g$
α_1	= 76.5 degree
$\alpha_2 - \alpha_4$	= 60.0 degree

$$p = \frac{F_L * M.A.}{A * (\sin\alpha_1 + \sin\alpha_2 + \sin\alpha_3 + \sin\alpha_4)}$$
$$= \frac{588{,}000 * 1.776}{0.01327 * (\sin 76.5 + 3 * \sin 60.0)}$$

$p = 22{,}040{,}775$ Pa = 220 bar

The force on each cylinder F_{cyl} can now be determined with Formula 2;

$F_{cyl} = p * A = 22{,}040{,}775 * 0.01327 = 292{,}481$ N = 292 kN

The load of each axle onto the ground becomes now;

$$F_{axle\text{-}1} = \frac{p * A * \sin\alpha_1}{M.A.} = \frac{22{,}040{,}775 * 0.01327 * \sin 76.5}{1.776} =$$

160,135 N = 160.1 kN

Following $F_{axle\text{-}1} = m*g$ this equals 16.34 tonne

$$F_{axle\text{-}2,3,4} = \frac{p * A * \sin\alpha_2}{M.A.} = \frac{22{,}040{,}775 * 0.01327 * \sin 60.0}{1.776} =$$

142,621 N = 142.6 kN

Following $F_{axle\text{-}2,3,4} = m * g$ this equals 14.55 tonnes

Check the math, to make sure no mistakes have slipped in.

$F_{axle\text{-}tot} = F_{axle\text{-}1} + F_{axle\text{-}2} + F_{axle\text{-}3} + F_{axle\text{-}4} =$
$160.1 + 3 * 142.6 = 587.9$ kN

Following $F_{axle\text{-}tot} = m * g$ this equals 60 tonnes

$F_{axle\text{-}1}$	= 16.34 tonnes	(76.5 degrees)
$F_{axle\text{-}2}$	= 14.55 tonnes	(60.0 degrees)
$F_{axle\text{-}3}$	= 14.55 tonnes	(60.0 degrees)
$F_{axle\text{-}4}$	= 14.55 tonnes	(60.0 degrees)
$F_{axle\text{-}tot}$	= 60.00 tonnes	

Axle-1 carries 8.9 % more load than what was expected when the load (FL) would be equally shared between the four axles.

CASE 4

The last exercise of this article is to determine the effect on axle loads if there are 8 axles in a hydraulic group or pool. This simulates a common 12-axle line transporter in a 3-point suspension set-up where each group consists of eight axles. Obviously we have to increase the load (F_L) from 60 tonnes to 120 tonnes. Figure 4 shows such a 12-axle line combination crossing a short span bridge using bridge jumper beams. It can be clearly seen that six of the 12 axles are close to their minimum stroke, the remainder of the axles are approximately at mid stroke. For the below calculation we assume that only one axle is at minimum stroke.

The following applies;

A	= 132.7 cm² or 0.01327 m²
M.A.	= 1.776
F_L	= 120 tonnes (m) or 1,176,000 Newton (F_L) following $F_L = m*g$

$\alpha_1 = 76.5$ degree
$\alpha_2 - \alpha_4 = 60.0$ degree

$$p = \frac{F_L * M.A.}{A * (\sin\alpha_1 + \sin\alpha_2 \ldots + \sin\alpha_7 + \sin\alpha_8)}$$

$$= \frac{1{,}176{,}000 * 1.776}{0.01327 * (\sin 76.5 + 7 * \sin 60.0)}$$

$p = 22{,}373{,}976 \text{ Pa} = 224 \text{ bar}$

The force on each cylinder F_{cyl} can now be determined with Formula 2;

$F_{cyl} = p * A = 22{,}373{,}976 * 0.01327 = 296{,}902 \text{ N} = 297 \text{ kN}$

The load of each axle onto the ground becomes now;

$$F_{axle\text{-}1} = \frac{p * A * \sin\alpha_1}{M.A.} = \frac{22{,}373{,}976 * 0.01327 * \sin 76.5}{1.776} =$$

$162{,}556 \text{ N} = 162.6 \text{ kN}$

Following $F_{axle\text{-}1} = m * g$ this equals 16.59 tonnes

$$F_{axle\text{-}2,3,4,5,6,7,8} = \frac{p * A * \sin\alpha_2}{M.A.} = \frac{22{,}373{,}976 * 0.01327 * \sin 60.0}{1.776} =$$

$144{,}778 \text{ N} = 144.8 \text{ kN}$

Following $F_{axle\text{-}2,3,4,5,6,7,8} = m*g$ this equals 14.77 tonnes

Check the math, to make sure no mistakes have slipped in.

$F_{axle\text{-}tot} = F_{axle\text{-}1} + F_{axle\text{-}2} + \ldots + F_{axle\text{-}7} + F_{axle\text{-}8} =$
$162.6 + 7 * 144.8 = 1{,}176.2 \text{ kN}$

Following $F_{axle\text{-}tot} = m*g$ this equals 120 tonnes

$F_{axle\text{-}1}$	= 16.59 tonnes	(76.5 degrees)
$F_{axle\text{-}2}$	= 14.77 tonnes	(60.0 degrees)
$F_{axle\text{-}3}$	= 14.77 tonnes	(60.0 degrees)
$F_{axle\text{-}4}$	= 14.77 tonnes	(60.0 degrees)
$F_{axle\text{-}5}$	= 14.77 tonnes	(60.0 degrees)
$F_{axle\text{-}6}$	= 14.77 tonnes	(60.0 degrees)
$F_{axle\text{-}7}$	= 14.77 tonnes	(60.0 degrees)
$F_{axle\text{-}8}$	= 14.77 tonnes	(60.0 degrees)
$F_{axle\text{-}tot}$	= 120.00 tonnes	

Note that the axle geometry in this article as well as in last month's article was arbitrarily chosen. To perform the calculations as shown in this article, the correct dimensions and angles have to be determined, these can differ per brand and per model.

From these four case studies we can draw a few important conclusions;

- Axles of which the hydraulic cylinders are at the same angle α carry the same load
- Axles closest to 90 degrees, compared to the other axles in the same group, carry the highest load
- Multiple axles closest to 90 degrees share the highest load, the highest load per axle then becomes less.