KC#425

Steel coil loading on hopper plate

According to Ch. 6 Sec. 1 [2.7.3] Hopper sloping plate and inner hull plating thickness

The net thickness of plating of longitudinally framed hopper sloping plate and inner hull is to be not less than the value obtained, in mm, from the following formula:

$$t = K_1 \sqrt{\frac{\left[g\cos(\theta_1 - \theta_2) + a_Y \sin\theta_1\right]F'}{\lambda_P R_Y}}$$

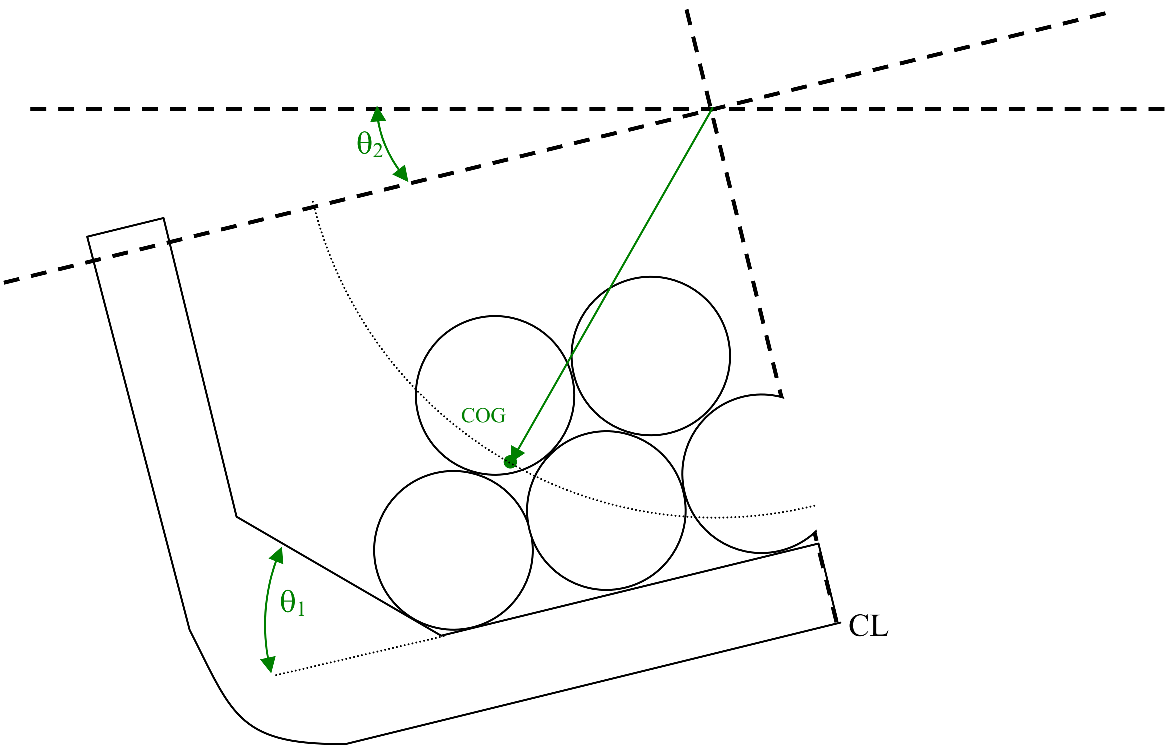
where:

a_Y : Transverse acceleration, in m/s2, defined in Ch 4, Sec2, [3.2]

According to Ch. 4 Sec2 [3.2]

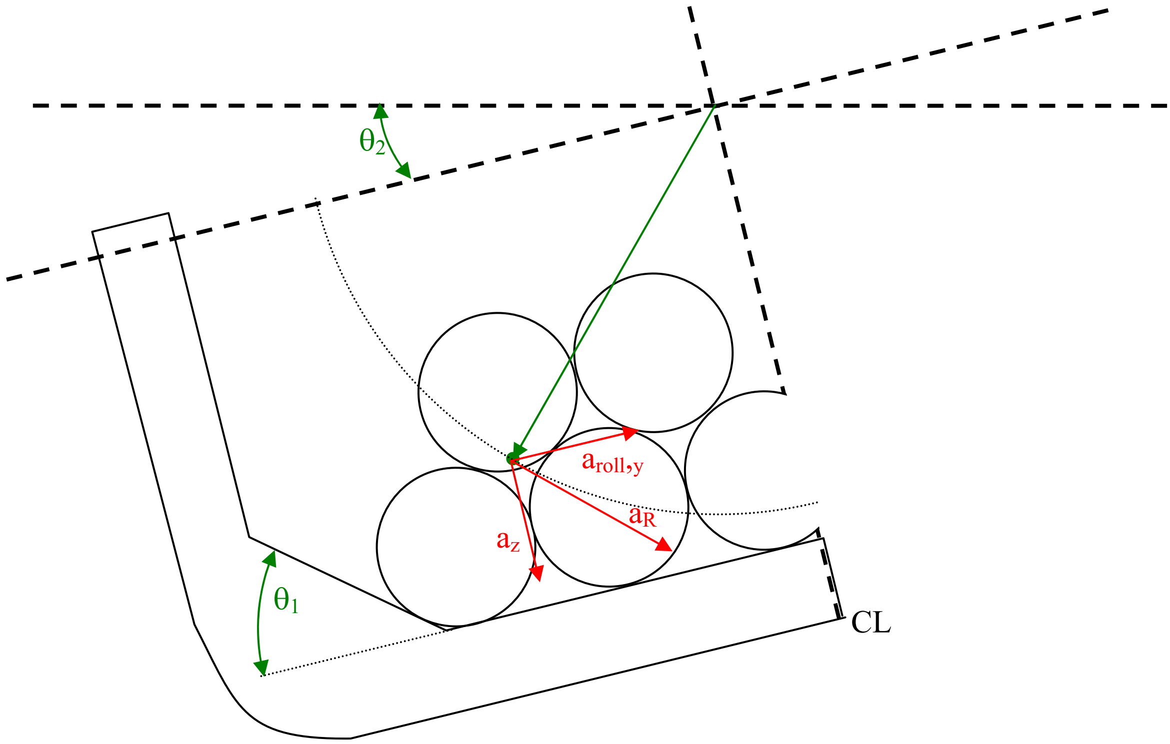
$$a_Y = C_{YG} g \sin\theta + C_{YS} a_{sway} + C_{YR} a_{roll\,y}$$

A typical steel coil loading pattern is shown in the figure below. The θ_2 is denoting the roll angle and COG is indicating the centre of gravity of the coils towards the hopper tank. Please see below calculation of the acceleraton term in the eq. [2.7.3], $a_\perp = g\cos(\theta_1 - \theta_2) + a_Y \sin\theta_1$

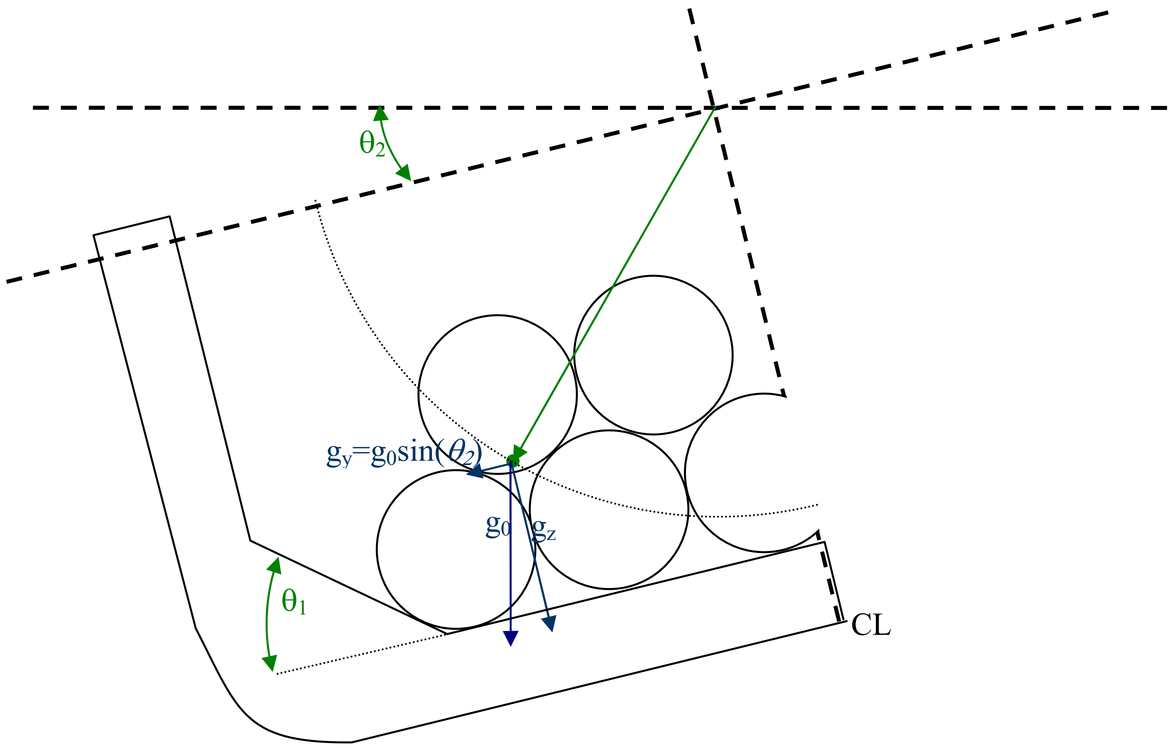


The rule formulation for acceleration according to Ch.4 Sec2 [3.2]:

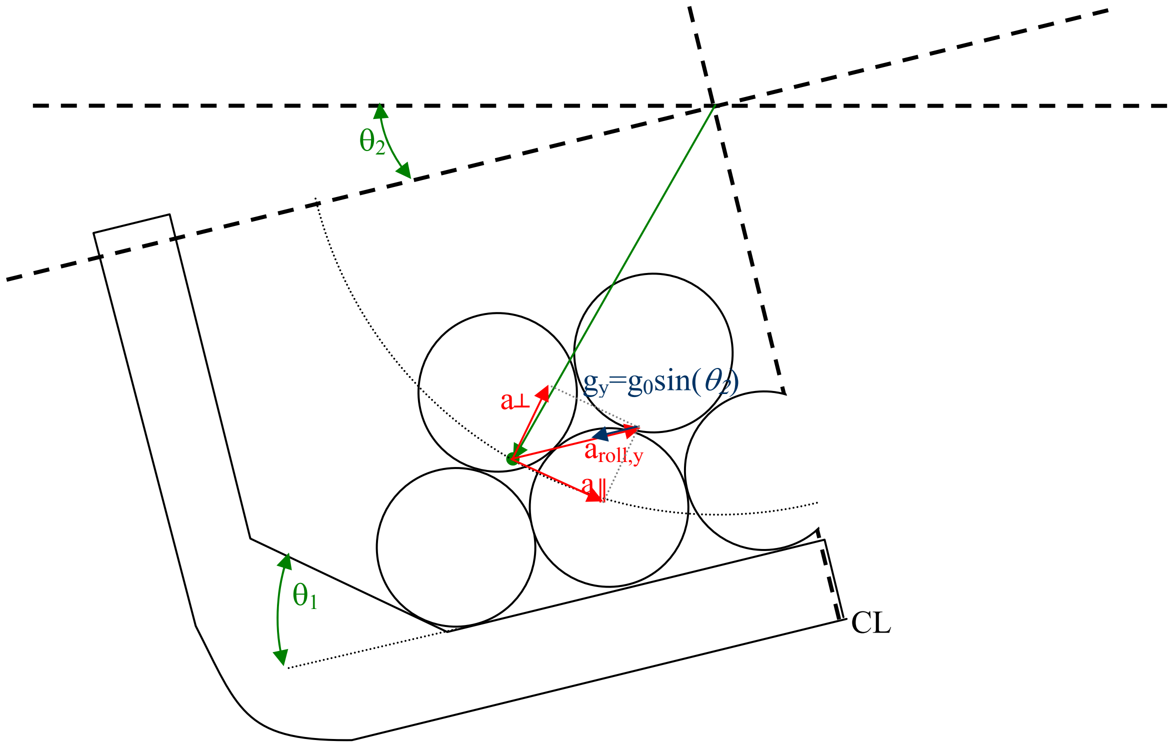
The component originating from the roll motion $C_{YR}a_{roll\ y}$ is shown in the figure below.



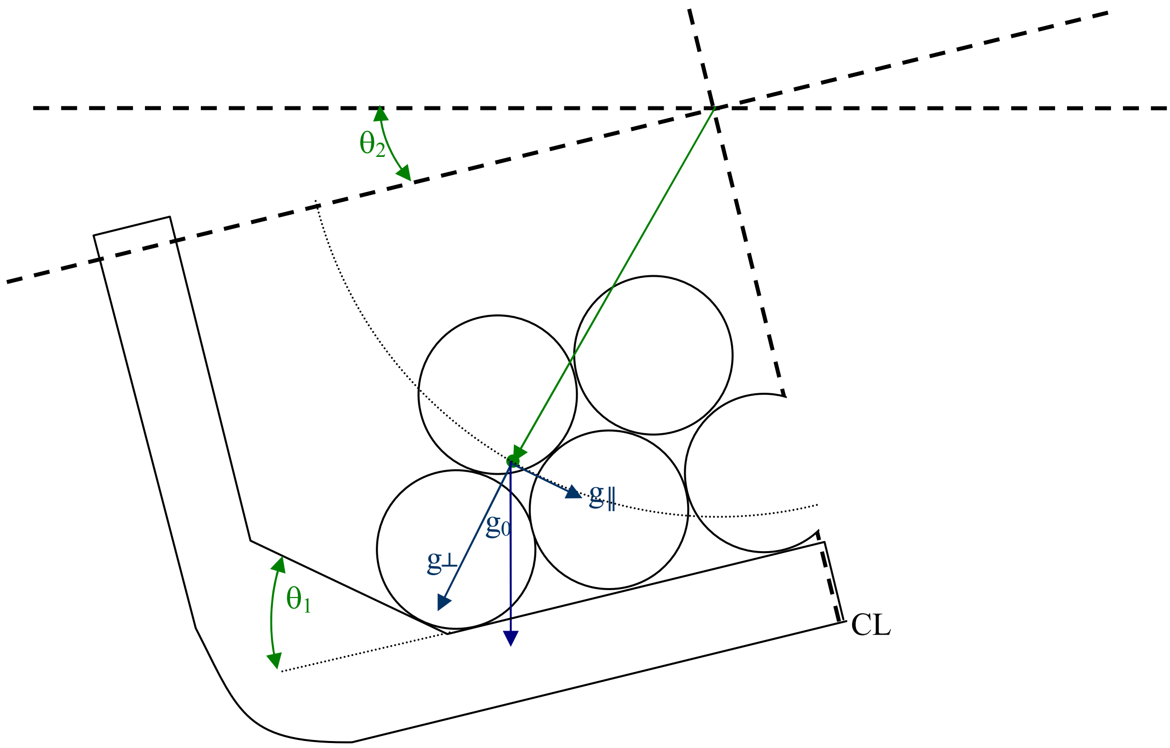
The component $C_{YG}g_0 \sin\theta_2$ is given in the following figure:



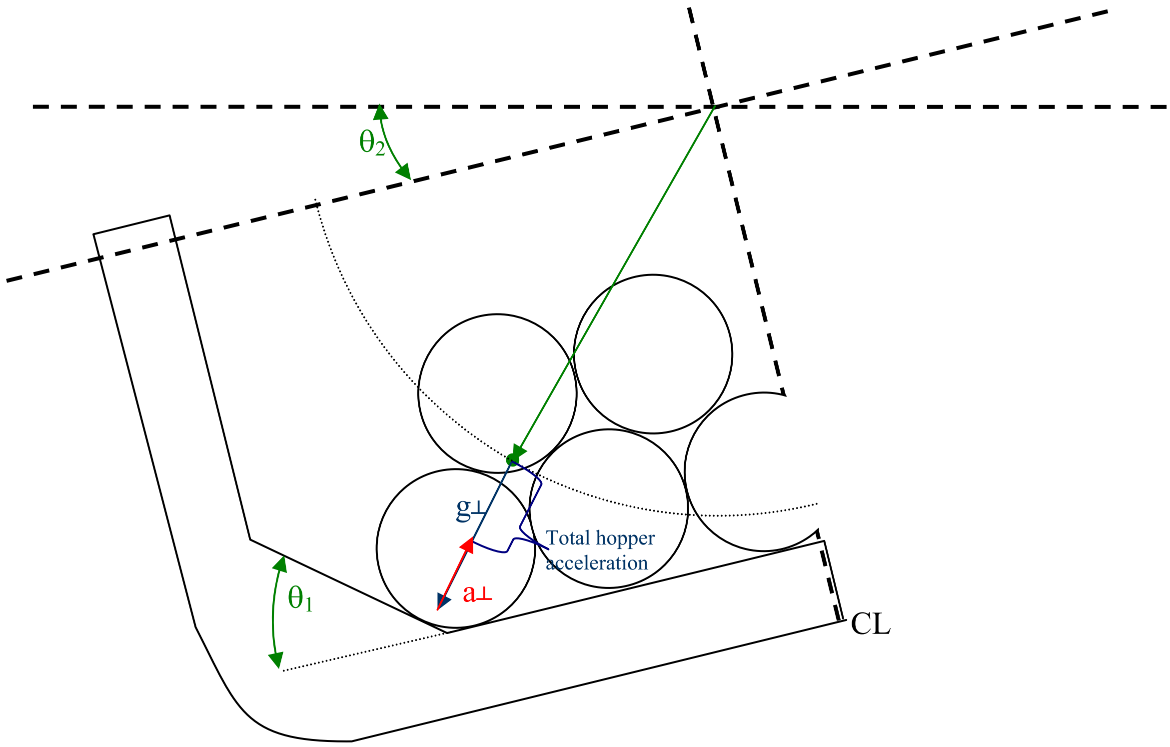
The total component $a_Y = C_{YG} g \sin\theta + C_{YR} a_{roll\ y}$, when neglecting the a_{sway} component, is illustrated in the figure below. The component normal to the hopper, $a_{\perp} = a_y \sin\theta_1$, is also indicated in the drawing.



The second term, $g_{\perp} = g_0 \cos(\theta_1 - \theta_2)$, is shown in the figure below:



Total rule acceleration $a_{\perp} = g\cos(\theta_1 - \theta_2) + a_Y \sin\theta_1$ is shown below:



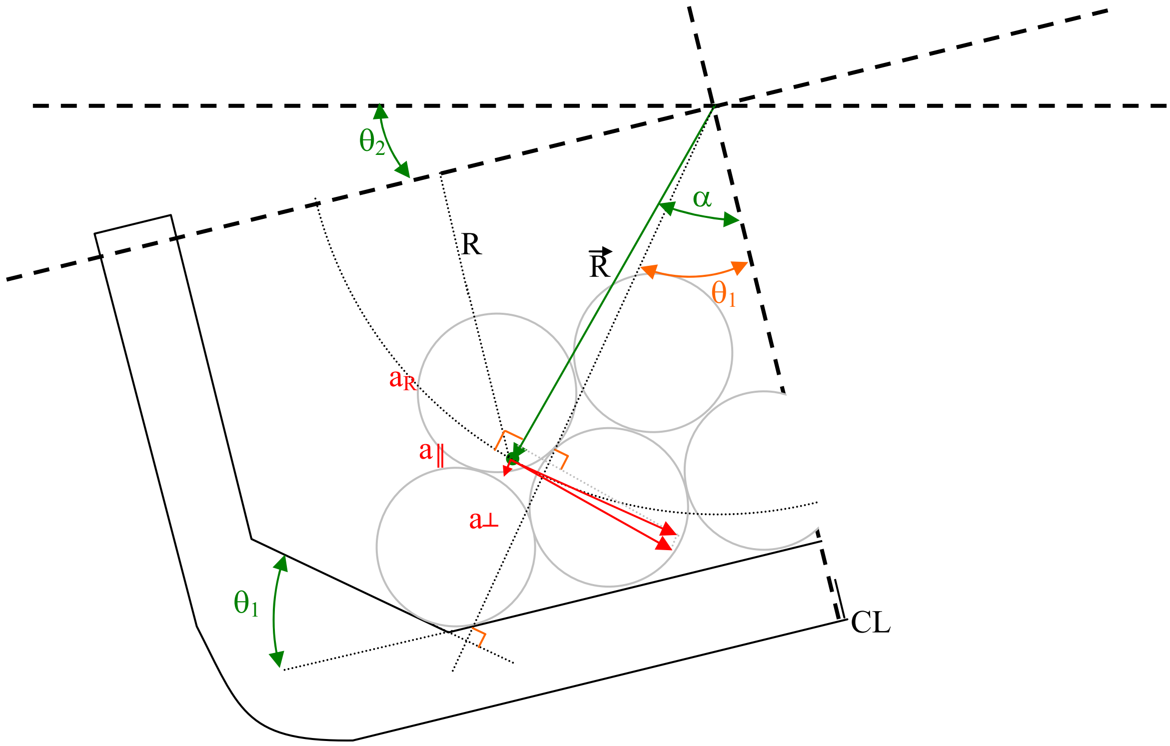
Please note following:

1. Gravity component in the equation is accounted for twice.
2. The roll component is decomposed twice. That is, the component normal to (⊥) the hopper tank is decomposed from the transverse acceleration a_y.
3. The rule formulation is in some cases summing the vectors without sign. This depend on the ratio between the hopper angle and the angle of the vector R. Please see below sketches.

Please consider below alternative calculation. The calculation is based on the two fundamental acceleration components gravity,g_0, and roll acceleration a_{roll}.

The coil closest to the hopper is resting on the hopper only. That is, the force on the inner bottom is neglected.

The acceleration component normal to (⊥) the hopper from roll acceleration may be described as shown in the figure below:



The angle α is expressed as:

$$\sin\alpha = \frac{y_{COG}}{\left|\vec{R}\right|}$$

Further more the vector $\vec{R}$ is the vector from the ship roll centre to the coil COG:

$$\vec{R} = \left[y_{COG}, R\right]$$

Consequently the angle α may be expressed as:

$$\sin\alpha = \frac{y_{COG}}{\sqrt{y_{COG}{}^2 + R^2}}$$

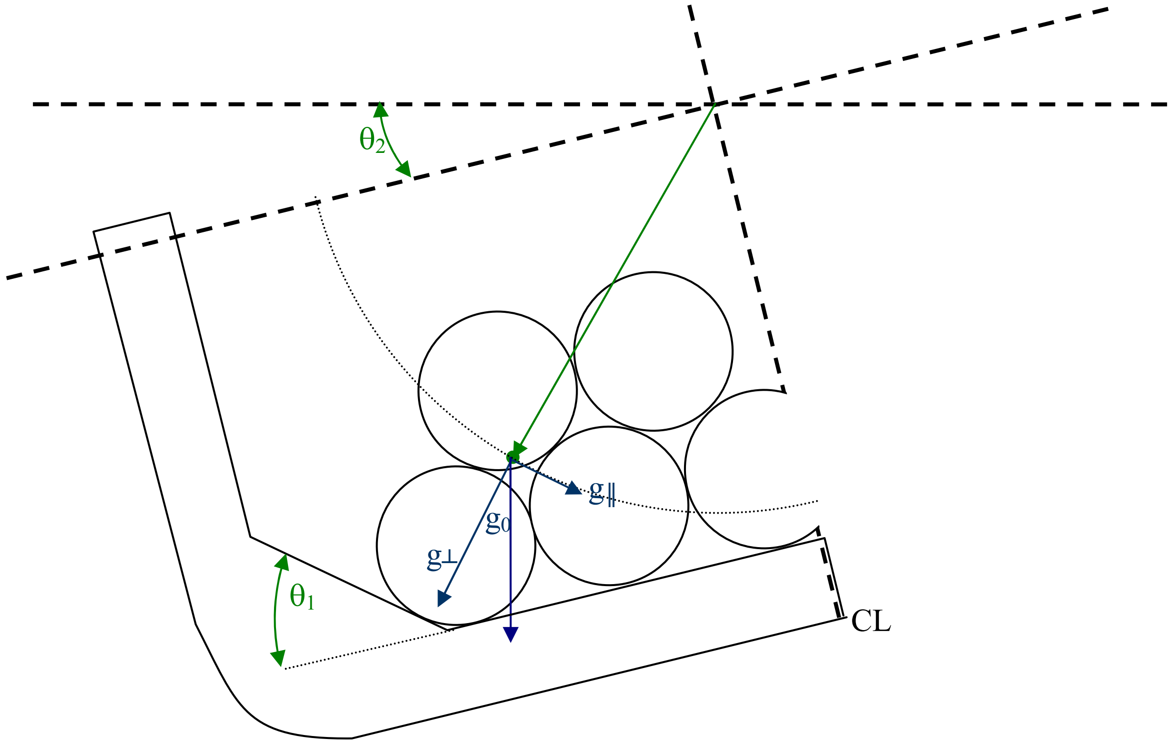
The normal acceleration can be expressed as:

$$a_{\perp} = a_R \sin(\alpha - \theta_1)$$

$$a_R = \theta_2 \frac{\pi}{180}\left(\frac{2\pi}{T_R}\right)^2 \left|\vec{R}\right| = \theta_2 \frac{\pi}{180}\left(\frac{2\pi}{T_R}\right)^2 \sqrt{y_{COG}{}^2 + R^2}$$

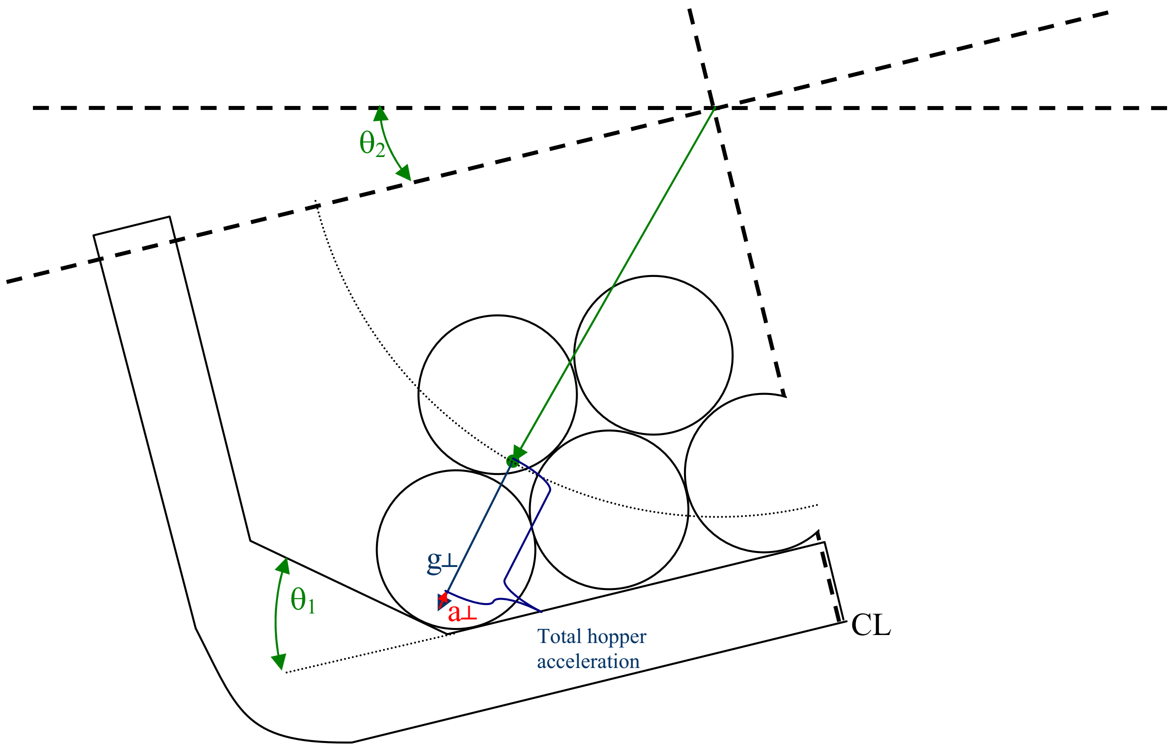
The gravity component is expressed in the same way as the rule formulation- $g_{\perp} = g\cos(\theta_1 - \theta_2)$.

Ref. below figure.



The total acceleration is the sum of the contribution from the roll and the gravity component.

$$a_{\perp} = a_R \sin(\alpha - \theta_1) + g\cos(\theta_1 - \theta_2)$$



If we include the sway component and introduce the load combination factors, the acceleration can be written as:

$$a_{\perp} = C_{YR} a_R \sin(\alpha - \theta_1) + g\cos(\theta_1 - C_{YG}\theta_2) + C_{YS} a_{Sway} Sin(\theta_1)$$

Example for straight inner side (no hopper) configuration θ_I = 90. The EDW R1 is choosen as the condition is normally decisive for inner side/hopper structure.

Acceleration term according to the rules (EDW R1):

$$a_\perp = g\cos(\theta_1 - \theta_2) + a_Y \sin\theta_1 = g\cos(90 - \theta_2) + a_Y \sin 90 = g\sin(\theta_2) + a_Y$$

$$a_Y = C_{YG} g \sin\theta_2 + C_{YS} a_{sway} + C_{YR} a_{roll\,y} = g\sin\theta_2 + a_{roll\,y}$$

$$\Updownarrow$$

$$a_\perp = g\sin(\theta_2) + g\sin\theta_2 + a_{roll\,y} = 2g\sin\theta_2 + a_{roll\,y}$$

Acceleration term according to DNV above assumption (EDW R1)

$$a_\perp = C_{YR} a_R \sin(\alpha - \theta_1) + g\cos(\theta_1 - C_{YG}\theta_2) + C_{YS} a_{Sway} Sin(\theta_1) = a_R \sin(\alpha - 90) + g\cos(90 - \theta_2)$$

$$a_\perp = -a_R \cos(\alpha) + g\sin(\theta_2) = -\theta_2 \frac{\pi}{180}\left(\frac{2\pi}{T_R}\right)^2 \sqrt{{y_{COG}}^2 + R^2}\cos(\alpha) + g\sin(\theta_2), \cos(\alpha) = \frac{|R|}{\sqrt{{y_{COG}}^2 + R^2}}$$

$$a_\perp = -a_R \cos(\alpha) + g\sin(\theta_2) = -\theta_2 \frac{\pi}{180}\left(\frac{2\pi}{T_R}\right)^2 \frac{\sqrt{{y_{COG}}^2 + R^2}\,|R|}{\sqrt{{y_{COG}}^2 + R^2}} + g\sin(\theta_2)$$

$$a_\perp = -a_{roll\,y} + g\sin(\theta_2)$$

Please note that the $a_{roll,y}$ term is negative in the CSR. Except the 2 x factor the two terms are identical.

For a small handy the trem $a_{roll,y}$ is about 0.5 m/s^2 and gsin θ_2 = 4.1m/s^2 (typical θ_2=25 deg)

CSR acceleration $a_\perp$=7.8m/s2

DNV interpretation $a_\perp$ = 3.6m/s2

Q1: Please note that the hopper normal acceleration calculated directly based on the fundamental accelerations is smaller than the rule accelerations. Dependent on the term $\sin(\alpha - \theta_1)$, the roll acceleration will work towards the gravity acceleration. Please note that the acceleration is sensitive to the definition of COG. The procedure to define COG should be clearly defined in the rules. With reference to IACS KC #380 please consider above acceleration calculations.

Q2: DNV have noted that the results of eq. [2.7.3] give very strict results for the hopper sloping plate. The thickness of the hopper sloping plate is in many cases in excess of the requirement of the inner bottom.

The force on the hopper is larger than the force for the inner bottom. This is caused by the Ck factor which is 4 for 2 tiers stowage. Could you please give details regarding the background of this term. According to our steel coil experts the stowage is, even though it is shored, quite flexible. Have there been attempted any test to account for the amount of force taken by the hopper plating?