



a strong influence on the correct operation of industrial equipment is the precision in manufacturing, transportation and installation. Such possible weaknesses, occurred during the route from conception to putting into operation of mechanical structures should be avoided or known and their influence on the state of stress appreciated. It should not be neglected the fact that during transportation might appear the danger of explosion and / or fire with the most dangerous effects [5]. The present paper aims to present some elements concerning the assessment of longitudinal stability when transporting oversize industrial equipment such as to avoid any unexpected damage.

**2. HYPOTHESES STUDY**

Within the study are taken into consideration some acceptable simplifications, such as [6]:

- The assembly, platform for transportation – load is considered as an one piece system, without showing how to support it and anchorage it;
- The forces occurring during transportation are considered concentrated in their points of application (wind forces are positive if their direction is opposite to the movement of the convoy);
- The road surface is considered without bumps;
- The analyzed assembly is supported on wheels as a static beam with supports ( the wheel – suspension assembly) nondeformable or deformable. The platform is supported by constant stiffness along its length.
- The reactions expressions are established at the contact of the tires with the road, using the method of three moments [5 - 9]. In this context, it si taken into consideration both the tracting force and also the resistance force behind the platform (present or not).
- The stability of the movement provides that the overturning bending moment, relative to the center of mass of the system studied, multiplied by a safety factor should be less than the stability calculated on the same point.
- The condition that the lowest normal reaction si positive shall be checked:

$$Z_m = \min \{ Z_i \}_{i=1, n_0} \geq 0,$$

respectively that the largest to be below the bearing capacity of the axle:

$$Z_M = \max \{ Z_i \}_{i=1, n_0} \leq Z_{0a},$$

with  $n_0$  is noted the number of the platforms axles.

- Under the conditions specified above it can be calculated the force required to tow the convoy in question.

**3. CONDITIONS OF MOVEMENT STABILITY**

**3. 1. The deformation of the suspension and tires is neglected**

The unknown bending moments in the axles (considered as the platform supports) shall be obtained with the equality:

$$\{ M_{M(n_0-2)} \} = [ A_{M(n_0-2)} ]^{-1} \cdot \{ T_{TM(n_0-2)} \}, \quad (1)$$

where  $\{ M_{M(n_0-2)} \}$  represents the transposed vector of the bending moments  $M_j$  ( $j = \overline{2, n_0 - 2}$ );  $[ A_{M(n_0-2)} ]$  - the matrix of the influence factors, withc have the expressions:

$$\begin{aligned} a_{11} &= 4 \cdot d_1; \quad a_{12} = d_1; \quad \dots\dots\dots \\ a_{i(j-1)} &= a_{i(j+1)} = d_1; \quad i \neq j; \\ a_{ij} &= 4 \cdot d_1; \quad i \neq j; \quad i = \overline{2, n_0 - 3}; \quad j = \overline{2, n_0 - 3}; \\ &\dots\dots\dots \\ a_{n_0-2, n_0-3} &= d_1; \quad a_{n_0-2, n_0-2} = 4 \cdot d_1; \quad (3) \end{aligned}$$

$\{ T_{TM(n_0-2)} \}^T = \{ b_i \}_{i=1, n_0-2}$  is the transposed vector of the free terms, in wherein:

$$\begin{aligned} b_1 &= d_1 \cdot M_f; \quad \dots\dots b_{\frac{n_0}{2}-1} = 6 \cdot A_{\frac{n_0}{2}, (\frac{n_0}{2}+1)} / (\frac{n_0}{2}+1); \\ b_{\frac{n_0}{2}} &= 6 \cdot A_{\frac{n_0}{2}, (\frac{n_0}{2}+1)} / (\frac{n_0}{2}); \quad \dots\dots b_{n_0-2} = d_1 \cdot M_s. \quad (4) \end{aligned}$$

In previous equalities it was considered that the center of mass of the assembly is between the supports  $(n_0/2) - 1, n_0/2$ , wich is why the sizes are:

$$A_{\frac{n_0}{2}, (\frac{n_0}{2}+1)} / (\frac{n_0}{2}) = A_{23/3}^*; \quad A_{\frac{n_0}{2}, (\frac{n_0}{2})} / (\frac{n_0}{2}) = A_{12/3}^*, \quad (5)$$

where it is changed  $A_1$  with  $d_1$  [8].

Takeing into account the expressions of the bending moments of the supports, it results the normal reactions:

$$\begin{aligned} Z_1 &= -k_{crf} \cdot (F_{cr})_f \cdot \sin \gamma_f + (M_2 - M_f) / d_1; \\ Z_2 &= (M_f - 2 \cdot M_2 + M_3) / d_1; \quad \dots\dots\dots \\ Z_i &= (M_{i-1} - 2 \cdot M_i + M_{i+1}) / d_1; \quad i = \overline{3, (n_0/2)-1}; \\ &\dots\dots\dots \\ Z_{n_0/2} &= (1 - d/d_1) \cdot (M_i + M_v) \cdot g \cdot \cos \alpha_i + \end{aligned}$$

$$\begin{aligned}
 &+ \left( M_{n_0/2-1} - 2 \cdot M_{n_0/2} + M_{n_0/2+1} \right) / d_1; \\
 Z_{n_0/2+1} &= (d/d_1) \cdot (M_i + M_v) \cdot g \cdot \cos \alpha_i + \\
 &+ \left( M_{n_0/2} - 2 \cdot M_{n_0/2+1} + M_{n_0/2+2} \right) / d_1; \\
 &\dots\dots\dots \\
 Z_{n_0-1} &= \left( M_{n_0-2} - 2 \cdot M_{n_0-1} + M_s \right) / d_1; \\
 Z_{n_0} &= -k_{crs} \cdot (F_{cr})_s \cdot \sin \gamma_s - (M_s - M_{n_0-1}) / d_1.
 \end{aligned} \tag{6}$$

The condition for the stability of the moving assembly is presented in this case under the form:

$$\begin{aligned}
 c_s \cdot \left[ F_{vIT} \cdot (H_{v1} - H_{c1}) + (F_{cr})_f \cdot \left\{ k_{crf} \cdot [L_{pp} + \right. \right. \\
 \left. \left. + \left( \frac{n_0}{2} - 1 \right) \cdot d_1 + d \right] \cdot \sin \gamma_f + (H_{c1} - h_c) \cdot \cos \gamma_f \right\} + \\
 \left. + \sum_{i=1}^{n_0/2} Z_i \cdot [d + (n_0/2 - 1) \cdot d_1] \right] \leq \\
 \leq f \cdot \left[ (M_i + M_v) \cdot g \cdot \cos \alpha_i - k_{crf} \cdot (F_{cr})_f \cdot \sin \gamma_f - \right. \\
 \left. - k_{crs} \cdot (F_{cr})_s \cdot \sin \gamma_s \right] + (F_{cr})_s \cdot \left[ k_{crs} \cdot (L_{pp} + \right. \\
 \left. + \frac{n_0}{2} \cdot d_1 + d) \cdot \sin \gamma_s + (H_{c1} - h_c) \cdot \cos \gamma_s \right] + \\
 \left. + \sum_{i=(n_0/2)+1}^{n_0} Z_i \cdot [(i - n_0/2) \cdot d_1 - d]. \tag{7}
 \end{aligned}$$

**3. 2. The deformation of the suspension and tires is not neglected**

The first unknowns of the problem at hand – the bending moments of the supports considered, it is determined also by the equality of the form (1). The non zero expressions of the items of the matrix  $[A_{M(n_0-2)}]$  are:

$$\begin{aligned}
 a_{11} &= 4 \cdot d_1 + \frac{6 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{p1}} + \frac{4}{n_{p2}} + \frac{1}{n_{p3}} \right); \\
 a_{12} &= d_1 - \frac{12 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{p2}} + \frac{1}{n_{p3}} \right); \\
 a_{13} &= d_1 - \frac{6 \cdot E \cdot I}{n_{p3} \cdot d_1^2 \cdot k_{ap}^*}; \\
 &\dots\dots\dots \\
 a_{i(j-2)} &= \frac{6 \cdot E \cdot I}{n_{pi} \cdot d_1^2 \cdot k_{ap}^*}; \quad i \neq j;
 \end{aligned}$$

$$\begin{aligned}
 a_{i(j-1)} &= d_1 - \frac{12 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{pi}} + \frac{1}{n_{p(i+1)}} \right); \quad i \neq j; \\
 a_{ij} &= 4 \cdot d_1 + \frac{6 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{pi}} + \frac{4}{n_{p(i+1)}} + \right. \\
 &\quad \left. + \frac{1}{n_{p(i+2)}} \right); \quad i = j; \\
 a_{i(j+1)} &= d_1 - \frac{12 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{p(i+1)}} + \right. \\
 &\quad \left. + \frac{1}{n_{p(i+2)}} \right); \quad i \neq j; \\
 a_{i(j+2)} &= \frac{6 \cdot E \cdot I}{n_{p(i+2)} \cdot d_1^2 \cdot k_{ap}^*}; \quad i \neq j; \\
 &\quad i = \overline{2, n_0 - 4}; \quad j = \overline{2, n_0 - 4}; \\
 &\dots\dots\dots \\
 a_{(n_0-3)(n_0-5)} &= \frac{6 \cdot E \cdot I}{n_{p(n_0-3)} \cdot d_1^2 \cdot k_{ap}^*}; \\
 a_{(n_0-3)(n_0-4)} &= d_1 - \frac{12 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{p(n_0-3)}} + \right. \\
 &\quad \left. + \frac{1}{n_{p(n_0-2)}} \right); \\
 a_{(n_0-3)(n_0-3)} &= 4 \cdot d_1 + \frac{6 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{p(n_0-3)}} + \right. \\
 &\quad \left. + \frac{4}{n_{p(n_0-2)}} + \frac{1}{n_{p(n_0-1)}} \right); \\
 a_{(n_0-3)(n_0-2)} &= d_1 - \frac{12 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_{p(n_0-2)}} + \right. \\
 &\quad \left. + \frac{1}{n_{p(n_0-1)}} \right); \\
 a_{(n_0-2)(n_0-4)} &= \frac{6 \cdot E \cdot I}{n_{p(n_0-2)} \cdot d_1^2 \cdot k_{ap}^*};
 \end{aligned}$$

$$a_{(n_0-2)(n_0-3)} = d_1 - \frac{12 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_p(n_0-2)} + \frac{1}{n_p(n_0-1)} \right);$$

$$a_{(n_0-2)(n_0-2)} = 4 \cdot d_1 + \frac{6 \cdot E \cdot I}{d_1^2 \cdot k_{ap}^*} \cdot \left( \frac{1}{n_p(n_0-2)} + \frac{4}{n_p(n_0-1)} + \frac{1}{n_p n_0} \right);$$
(8)

while the free terms have the equations:

$$b_1 = d_1 \cdot M_f + \frac{6 \cdot E \cdot I}{d_1} \cdot (f_{1,0} + 2 \cdot f_{2,0});$$

$$b_2 = (6 \cdot E \cdot I / d_1) \cdot f_{2,0}; \dots\dots\dots$$

$$b_i = 0; \quad i = \overline{3, n_0/2 - 2}; \dots\dots\dots$$

$$b_{\frac{n_0}{2}-1} = 6 \cdot A_{\frac{n_0}{2}, (\frac{n_0}{2}+1)} / (\frac{n_0}{2}+1) - \frac{6 \cdot E \cdot I}{d_1} \cdot (2 \cdot f_{\frac{n_0}{2}, 0} - f_{\frac{n_0}{2}+1, 0});$$

$$b_{\frac{n_0}{2}} = 6 \cdot A_{\frac{n_0}{2}, (\frac{n_0}{2}+1)} / (\frac{n_0}{2}) - \frac{6 \cdot E \cdot I}{d_1} \cdot (f_{\frac{n_0}{2}, 0} - 2 \cdot f_{\frac{n_0}{2}+1, 0}); \dots\dots\dots$$

$$b_{\frac{n_0}{2}+1} = \frac{6 \cdot E \cdot I}{d_1} \cdot f_{\frac{n_0}{2}+1, 0}; \dots\dots\dots$$

$$b_i = 0; \quad i = \overline{n_0/2 + 1, n_0 - 3}; \dots\dots\dots$$

$$b_{n_0-3} = \frac{6 \cdot E \cdot I}{d_1} \cdot f_{n_0-1, 0};$$

$$b_{n_0-1} = d_1 \cdot M_s - \frac{6 \cdot E \cdot I}{d_1} \cdot (2 \cdot f_{n_0-1, 0} - f_{n_0, 0});$$
(9)

where

$$f_{1,0}, f_{2,0}, f_{n_0/2,0} = f_{4,0}, f_{n_0/2+1,0} = f_{5,0},$$

$$f_{n_0-1,0} = f_{7,0}, f_{n_0,0} = f_{8,0},$$
(10)

( $f_{i,0}$ ,  $i = 1, 2, 4, 5, 7, 8$ ) are given by the equalities:

$$f_{1,0} = - \frac{1}{n_{p1} \cdot k_{ap}^*} \cdot \left[ k_{crrf} \cdot (F_{crr})_f \cdot \sin \gamma_f + \frac{M_f}{d_1} \right];$$

$$f_{2,0} = M_f / (n_{p2} \cdot d_1 \cdot k_{ap}^*);$$

$$f_{4,0} = \frac{1}{n_{p4} \cdot k_{ap}^*} \cdot \left( 1 - \frac{d}{A_1} \right) \cdot (M_i + M_v) \cdot g \cdot \cos \alpha_i;$$

$$f_{5,0} = \frac{1}{n_{p5} \cdot k_{ap}^*} \cdot \frac{d}{A_1} \cdot (M_i + M_v) \cdot g \cdot \cos \alpha_i;$$

$$f_{7,0} = M_s / (n_{p7} \cdot d_1 \cdot k_{ap}^*);$$

$$f_{8,0} = - \frac{1}{n_{p8} \cdot k_{ap}^*} \cdot \left[ k_{crrs} \cdot (F_{crr})_s \cdot \sin \gamma_f + \frac{M_s}{d_1} \right].$$
(11)

The reactions between the tires and the ground, in this case, are established by the expressions (6), where there are introduced the bending moments inferred from the above. At the same time, the condition of stability is maintained (7), in which the required adjustments will be made on the case.

In the previous expressions it shall be taken into account relations like:

$$(F_{crr})_f = K_T \cdot \left[ \begin{array}{l} (M_i + M_v) \cdot g \cdot \\ (\sin \alpha_i + f \cdot \cos \alpha_i) + \\ + F_{vTl} + F_{iTl} \end{array} \right],$$
(12)

where:

$$K_T = 1 / (\cos \gamma_f + f \cdot \sin \gamma_f).$$
(13)

**Other notations:**  $(F_{crr})_f$  – tractive force of the loaded platform;  $(F_{crr})_s$  – braking force behind the platform;  $F_{vTl}$  – the total wind force developed along the platform (as a resistance force if it is opposed to the movement of the assembly);  $F_{iTl}$  – total inertia force in the case of accelerated or braked movement;  $E$  – the equivalent leasticity module of the platform, considered with an uniform geometry;  $I$  – moment of inertia of the cross section of the transport platform;  $M_i$ ,  $M_v$  – mass of the load respectively the vehicle mass;  $M_f$  – bending moment developed by the normal component of the tractive force on the road (front) [8];  $M_s$  – ;  $M_f$  – bending moment developed by the normal component of the braking force or pushing force on the road [8];  $d$  – the distance from the front end of the platform to the center of mass of the assembly;  $d_1$  – the distance between two consecutive axles;  $f$  – coefficient of rolling resistance of tires (considered the same for all

tires);  $k_{c r f} = 1$ , for angle  $\gamma_f$  positive (up direction), respectively  $k_{c r f} = -1$ , for the angle  $\gamma_f$  negative;  $g$  – gravity acceleration;  $\alpha_l$  – the angle of inclination from the horizontal road;  $n_p$  – the number of tires belonging to an axle;  $\gamma_f$  – the angle between the drawbar towing and horizontal;  $k_{c r s} = 1$ , for the angle  $\gamma_s$  positive (situated up), respectively  $k_{c r s} = -1$ , for the angle  $\gamma_s$  negative;  $\gamma_s$  – the angle between the drawbar of binding of the platform to the means of braking or pushing from behind.

#### 4. CONCLUSIONS

The paper addresses the stability of the the movement of convoys for transporting oversized industrial equipment, often in existing installations of process industries. The study is carried out for the case where the deformation of the suspension and tires is neglected, respectively opposite case. The platform for transportation is equivalent to a beam with constant stiffness over its entire length. It is inserted the effects of inertia forces, of wind forces and obviously the masses of the platform and transport equipment. In each case the user can make adjustments convenient in the case for downhill slope or hill.

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