The Scientific Bulletin of VALAHIA University
MATERIALS and MECHANICS –Vol. 15, No. 12

DOI 10.1515/bsmm-2017-0008

THE STABILITY OF LONGITUDINAL MOVEMENT DURING THE TRANSPORTATION OF INDUSTRIAL OVERSIZED EQUIPMENT ON A PLATFORM WITH AN EVEN NUMBER OF AXLES. GENERAL CASE

Radu IATAN [1], Mihai STĂTESCU [2], Cristina SALCA [1]

[1]University POLITEHNICA of Bucharest; [2]Walter Tosto WTB Bucharest

E-mail: r_iatan@yahoo.com

Abstract. *It is known that the transportation of oversized technological equipment raises particular poroblems, both from the economical and technicall point of view. Knowing the loads in the platform-equipment assembly, the intensity and the direction of the wind loads, the condition of roads and the way these act is imperative. The present paper seeks to determine the expression of the loads obtained on a platform with an even number of axles, loaded with a technological equipment and neglecting or not the deformation of the suspensions and tires.*

Keywords: Oversized equipment, platform for transportation

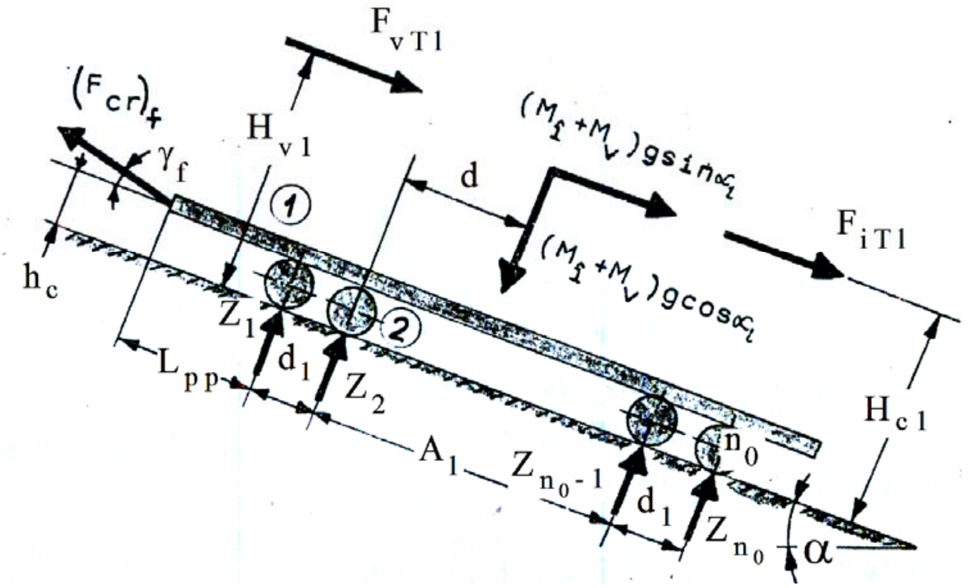

Figure 1. Platform for transportation with even number of axles

1. INTRODUCTION

Concern professionals (designers, manufacturers, transporters and users) in putting into operation and use of technically safe industrial mechanical equipment in general and those working under pressure in many practical cases with particularly dangerous substances from the chemical point of view and / or mechanicall, in particular, it is especially current [1 – 4]. It is known that 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 explosionx 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:

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

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

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

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:

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

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

$$a_{11} = 4\cdot d_1;\quad a_{12} = d_1;\quad \ldots\ldots\ldots\ldots$$

$$a_{i(j-1)} = a_{i(j+1)} = d_1;\quad i \neq j;$$

$$a_{ij} = 4\cdot d_1;\quad i \neq j;\ i = \overline{2,n_0-3};\ j = \overline{2,n_0-3};$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$a_{n_0-2,n_0-3} = d_1;\ a_{n_0-2,n_0-2} = 4\cdot d_1; \quad (3)$$

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

$$b_1 = d_1 \cdot M_f;\ \ldots.. b_{\frac{n_0}{2}-1} = 6\cdot A_{\frac{n_0}{2},\left(\frac{n_0}{2}+1\right)/\left(\frac{n_0}{2}+1\right)};$$

$$b_{\frac{n_0}{2}} = 6\cdot A_{\frac{n_0}{2},\left(\frac{n_0}{2}+1\right)/\left(\frac{n_0}{2}\right)};\ \ldots\ldots\ b_{n_0-2} = d_1 \cdot M_s. \quad (4)$$

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

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

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:

$$Z_1 = -k_{crf}\cdot\left(F_{cr}\right)_f \cdot sin\,\gamma_f + \left(M_2 - M_f\right)/d_1;$$

$$Z_2 = \left(M_f - 2\cdot M_2 + M_3\right)/d_1;\ldots\ldots\ldots$$

$$Z_i = \left(M_{i-1} - 2\cdot M_i + M_{i+1}\right)/d_1;\ i = \overline{3,\left(n_0/2\right)-1};$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$Z_{n_0/2} = \left(1 - d/d_1\right)\cdot\left(M_{\hat{i}} + M_v\right)\cdot g\cdot cos\,\alpha_l +$$

$$+\left(M_{n_0/2-1}-2\cdot M_{n_0/2}+M_{n_0/2+1}\right)/d_1;$$
$$Z_{n_0/2+1}=(d/d_1)\cdot(M_{\hat{i}}+M_v)\cdot g\cdot\cos\alpha_l+$$
$$+\left(M_{n_0/2}-2\cdot M_{n_0/2+1}+M_{n_0/2+2}\right)/d_1;$$
....
$$Z_{n_0-1}=\left(M_{n_0-2}-2\cdot M_{n_0-1}+M_s\right)/d_1;$$
$$Z_{n_0}=-k_{crs}\cdot(F_{cr})_s\cdot\sin\gamma_s-\left(M_s-M_{n_0-1}\right)/d_1. \tag{6}$$

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

$$c_s\cdot\Big|F_{vlT}\cdot(H_{v1}-H_{c1})+(F_{cr})_f\cdot\Big\{k_{crf}\cdot\Big[L_{pp}+ +\left(\frac{n_0}{2}-1\right)\cdot d_1+d\Big]\cdot\sin\gamma_f+(H_{c1}-h_c)\cdot\cos\gamma_f\Big\}+ +\sum_{i=1}^{n_0/2}Z_i\cdot\left[d+(n_0/2-1)\cdot d_1\right]\Big|\le$$
$$\le f\cdot\left[(M_{\hat{i}}+M_v)\cdot g\cdot\cos\alpha_l-k_{crf}\cdot(F_{cr})_f\cdot\sin\gamma_f-\right. -k_{crs}\cdot(F_{cr})_s\cdot\sin\gamma_s\Big]+(F_{cr})_s\cdot\Big[k_{crs}\cdot\Big(L_{pps}+ +\frac{n_0}{2}\cdot d_1+d\Big)\cdot\sin\gamma_s+(H_{c1}-h_c)\cdot\cos\gamma_s\Big]+ +\sum_{i=(n_0/2)+1}^{n_0}Z_i\cdot\left[(i-n_0/2)\cdot d_1-d\right]. \tag{7}$$

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 he equality of the form (1). The non zero expressions of the items of the matrix $\left[A_{M(n_0-2)}\right]$ are:

$$a_{11}=4\cdot d_1+\frac{6\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{p1}}+\frac{4}{n_{p2}}+\frac{1}{n_{p3}}\right);$$
$$a_{12}=d_1-\frac{12\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{p2}}+\frac{1}{n_{p3}}\right);$$
$$a_{13}=d_1-\frac{6\cdot E\cdot I}{n_{p3}\cdot d_1^2\cdot k_{ap}^*};$$
…………………………………..
$$a_{i(j-2)}=\frac{6\cdot E\cdot I}{n_{pi}\cdot d_1^2\cdot k_{ap}^*};\quad i\ne j;$$
$$a_{i(j-1)}=d_1-\frac{12\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{pi}}+\frac{1}{n_{p(i+1)}}\right);\ i\ne j;$$
$$a_{ij}=4\cdot d_1+\frac{6\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{pi}}+\frac{4}{n_{p(i+1)}}+\frac{1}{n_{p(i+2)}}\right);\ i=j;$$
$$a_{i(j+1)}=d_1-\frac{12\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{p(i+1)}}+\frac{1}{n_{p(i+2)}}\right);\ i\ne j;$$
$$a_{i(j+2)}=\frac{6\cdot E\cdot I}{n_{p(i+2)}\cdot d_1^2\cdot k_{ap}^*};\quad i\ne j;$$
$$i=\overline{2,\,n_0-4};\quad j=\overline{2,\,n_0-4};$$
....
$$a_{(n_0-3)(n_0-5)}=\frac{6\cdot E\cdot I}{n_{p(n_0-3)}\cdot d_1^2\cdot k_{ap}^*};$$
$$a_{(n_0-3)(n_0-4)}=d_1-\frac{12\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{p(n_0-3)}}+\frac{1}{n_{p(n_0-2)}}\right);$$
$$a_{(n_0-3)(n_0-3)}=4\cdot d_1+\frac{6\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{p(n_0-3)}}+\frac{4}{n_{p(n_0-2)}}+\frac{1}{n_{p(n_0-1)}}\right);$$
$$a_{(n_0-3)(n_0-2)}=d_1-\frac{12\cdot E\cdot I}{d_1^2\cdot k_{ap}^*}\cdot\left(\frac{1}{n_{p(n_0-2)}}+\frac{1}{n_{p(n_0-1)}}\right);$$
$$a_{(n_0-2)(n_0-4)}=\frac{6\cdot E\cdot I}{n_{p(n_0-2)}\cdot d_1^2\cdot k_{ap}^*};$$

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

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

while the free terms have the equasions:

$$b_1 = d_1 \cdot M_f + \frac{6 \cdot E \cdot I}{d_1} \cdot \left(f_{10} + 2 \cdot f_{20} \right);$$

$$b_2 = \left(6 \cdot E \cdot I / d_1 \right) \cdot f_{20}; \ldots\ldots\ldots\ldots\ldots\ldots$$

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

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

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

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

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

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

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

where

$$f_{1,0},\ f_{2,0},\ f_{n_0/2,0} = f_{4,0},\ f_{n_0/2+1,0} = f_{5,0}, \quad f_{n_0-1,0} = f_{7,0},\ f_{n_0,0} = f_{8,0}, \quad (10)$$

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

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

$$f_{20} = M_f \Big/ \left(n_{p2} \cdot d_1 \cdot k_{ap}^* \right);$$

$$f_{40} = \frac{1}{n_{p4} \cdot k_{ap}^*} \cdot \left(1 - \frac{d}{A_1} \right) \cdot \left(M_{\hat{\imath}} + M_v \right) \cdot g \cdot \cos \alpha_l;$$

$$f_{50} = \frac{1}{n_{p5} \cdot k_{ap}^*} \cdot \frac{d}{A_1} \cdot \left(M_{\hat{\imath}} + M_v \right) \cdot g \cdot \cos \alpha_l;$$

$$f_{70} = M_s \Big/ \left(n_{p7} \cdot d_1 \cdot k_{ap}^* \right);$$

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

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:

$$\left(F_{cr} \right)_f = K_T \cdot \left[\left(M_{\hat{\imath}} + M_v \right) \cdot g \cdot \left(\sin \alpha_l + f \cdot \cos \alpha_l \right) + F_{vTl} + F_{iTl} \right], \quad (12)$$

where:

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

Other notations: $\left(F_{cr} \right)_f -$ tractive force of the loaded platform; $\left(F_{cr} \right)_s -$ breaking 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; $M_{\hat{\imath}}$, $M_v -$ 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); $k_{crf} = 1$, for angle γ_f positive (up direction), respecively $k_{crf} = -1$, for the angle γ_f negative; g – gravity acceleration; α_l – the angle of inclination from the horizontal road; n_p – the number of tires belonging to an axle; γ_f – the angle between the drawbar towing and horizontal; $k_{crs} = 1$, for the angle γ_s positive (situated up), respectively $k_{crs} = -1$, for the angle γ_s negative; γ_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.

REFERENCES

[1] * * * Transports exceptionnels (definition des convois – types et regles pour la verification des ouvrages d'art) SETRA Octobre 1982 (http://dtrf.setra.fr/pdf/pj/Dtrf/0002/Dtrf-0002509/DT2509.pdf - accesat la 20.03.17)

[2] * * * Convoi exceptionnel (https://fr.wikipedia.org/wiki/Convoi_exceptionnel (accesat la 20.03.17)

[3] * * * http://holleman.ro/services/transporturi-agabaritice/ - accesat la 20.03.17); http://movers-auto.md/ro/shop/treyler-transport-perevozki-tyazhyolyih-negabaritnyih-gruzov.html (accesat la 20.03.17)

[4] * * * Regulament specific de acreditare în domeniul reglementat "Echipamente sub presiune transportabile" / RENAR, 2014

[5] Felegeanu Daniel – Cătălin, Managementul riscurilor şi securității industriale pentru prevenire, protecția şi intervenție în caz de accidente majore la un obiectiv tip SEVESO, teză de doctorat, Universitatea "Vasile Alecsandri" din Bacău, 2016.

[6] Iatan I. R., Salca Cristina, Stătescu M., Stabilitatea mişcării longitudinale a platformelor tip 4 x 4 pentru transportarea echipamentelor tehnologice agabritice, Sinteze de Mecanică Teoretică şi Aplicată, vol. 7, nr. 1, 2016, p. 51 – 62 (http://search.proquest.com/openview/5218606c8647d4ed1c282ef0543690d9/1?pq-origsite=gscholar&cbl=2029206 (accesat la 20.03.17)

[7] Buzdugan Gh., Rezistența materialelor, Editura Tehnică, Bucureşti, 1980.

[8] Iatan I. R., Vasilescu I., Transportarea utilajelor tehnologice agabaritice, Editura MatrixRom, Bucureşti, 2002.

[9] Marin C., Rezistența materialelor (partea I – solicitări simple), Editura Bibliotheca, Târgovişte, 2013.