Load mode analysis of pipe-layers operating on swampy grounds

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Abstract: This article is devoted to modelling results of pipe-layers loading during the major overhaul of main pipeline linear sections. Basic loads affecting the pipe-layer in operation are considered in this research. The results obtained prove that at the major overhaul of the main pipeline linear section, efforts of hoisting the pipe constitute only 60% of overall process duty, 20-40% are variable and depend on the weight of technological vehicles in operation. The suggested model of loads calculation allows to improve accuracy of loads calculation, affecting the pipe-layer during the technological process which, in its turn, allows both to select appropriate vehicles for linear pipeline section repair and to increase operational safety by forecasting possible conditions of pipe-layers rollover.

In construction of the main pipelines pipe-layers are universal hoisting machines and are used in practically all kinds of work: as a part of insulating-stacking column laying pipelines in the ditch, at installation and welding, at transportation, pipes loading and unloading and strings as well as at assembly and other load and hoisting operations [1,2]. The principle differences of pipe-layers from other hoisting machines are: when operating in a column laying pipelines in the ditch, the pipe-layer hook load is variable [3-5], as it depends on the elevated pipeline section mass and elasticity, relief of the terrain and coordination of operators’ actions. Cyclogram of standard pipe-layers operation, currently accepted for loads calculation is shown in Figure 1.

As for pipelines calculation methods at construction: initially elastically bent pipeline section being lowered used to be viewed as a line, described by a cosine curve equation. Such approximation ensured satisfactory reproducibility of results (with respect to data obtained by more complex methods, in particular by integrating general differential equation of elastic line [6]), when calculating pipeline swags. However, when determining bending moments the obtained error reached 41%.
This circumstance encouraged researchers to use more exact methods, however, based on
trigonometric functions. These functions as different from many other analytical expressions are easy
to integrate for the following reason. The well-known in structural mechanics Rayleigh-Ritz variation
method is based on this “easiness” property, providing preliminary expansion of the studied function
into a Fourier series.

Applying the classical principle of mechanics, according to which at elastic system equilibrium,
difference variation of potential energy (internal forces elastic energy) and the work of external active
forces is equal to zero, general equation of this equilibrium can be written in the following form:

$$
EJ \int_0^l \left( \frac{d^2 y}{dx^2} \right)^2 \, dx - \sum_{k=1}^K P_k \delta y_k + \sum_{j=1}^N G_j \delta y_j + 2q \delta \int_0^l y \, dx
$$

(1)

where $P_k$, $G_k$ – concentrated forces, directed upwards respectively (efforts of pipe-layers) and
downwards (loads of technological vehicles weight); $l$ – length of the pipeline section in question; $\delta$-
variation symbol.

Basing on the theory of Fourier series, the pipeline swag at the section of length $l$ is presented as a
function:

$$
y = \sum_{n=1}^\infty a_n \cos \frac{(2n-1)\pi x}{2l}
$$

(2)

Selection of appropriate coefficients $a_1$, $a_2...a_n$ and further rearrangement of equations (1) and (2)
allow to determine pipeline swags in any arbitrary sections as well as to find bending moments,
appearing in places of string support on hoisting devices. Besides, according to this method it is
possible to find response values, impacting the pipeline from the jaws (trolley pipe-holders) i.e.
determine loads on pipe-layers or what is most important in this research – determine loads acting on
the pipe-layer from the pipeline.

Figure 1. Cyclogram of loads on the pipe-layer hook according to the following operations: 1 –
loading-unloading; 2 – in the column when using electrical welding; 3 – in the column when using
manual welding
In general, pipeline swag equation can be written as:

$$EJy(x) = EJ_0 + EJ \varphi_0 x + M_0 \frac{x^2}{2} + R_0 \frac{x^3}{6} + \sum_{i=1}^{m} P_i \frac{(x-l_i)^3}{6} - \sum_{k=1}^{m} Q_k \frac{(x-l_k)^3}{6} - \frac{qx^4}{24}$$  \hspace{1cm} (3)$$

where $EJ$- pipeline bending stiffness (as a beam); $y(x)$ – pipeline swag at a current point, away from the origin of coordinates at a distance $x$; $\varphi_0$ - pipeline swag at the point, where $x=0$; $R_0$ - ground reaction to the pipeline at $x=0$; $P_i$ and $Q_k$ – concentrated loads from pipe-layers and technological vehicles operation; $l_i$ and $l_k$ – distance from the coordinates origin of coordinates to respective loads application points; $q$ - pipeline length unit weight (vertical load intensity).

Support moments values for this task are determined by ratio:

$$M_1 = M_2 = M_3 = 0.52 \sqrt{EJh}$$  \hspace{1cm} (4)$$

Effective span $l$ is calculated by formula:

$$l = 2.46 \sqrt{\frac{EJh}{q}}$$  \hspace{1cm} (5)$$

Bearing in mind that load on the pipe-layers complex can be obtained from equation:

$$M_1 = M_2 = M_3 = P\ell \rightarrow P = \frac{M}{\ell} = \frac{0.52 \sqrt{EJh}}{2.46 \sqrt{\frac{EJh}{q}}} = 0.21lq.$$  \hspace{1cm} (6)$$

this equation solution is given in non-dimensional values. In order to obtain actual force values it is necessary to multiply a non-dimensional value by the distance between pipe-layers on the route:

$$P_f = PL = 0.21lqL.$$  \hspace{1cm} (7)$$

It is worth mentioning that the distance between pipe-layers (or their groups) cannot be arbitrary, as it influences strain development in the pipeline. According to [7] the distance between pipe-layers should be determined by expression:
\[ L = 1.2 + 1.94 \sqrt{\frac{EJ_h}{q}}. \]  

Then equation 7 acquires the following form:

\[ P_T = PL = 0.33 \sqrt{EJ_h q^3}, \]

and if there are technological vehicles on the pipeline then:

\[ P_T = G_{K_{max}} + PL = G_{K_{max}} + 0.33EJ_h q^3, \]

where \( G_{K_{max}} \) – maximum weight of production equipment, used in pipeline repair.

Solution of this equation for the existing pipeline types [8] is shown in Fig.3 At this, actual load change on the pipe-layers hook, taking into account technological vehicles passage, looks as it is shown in Figure4

\[ L = 1.2 + 1.94 \sqrt{\frac{EJ_h}{q}}. \]  

Figure 3. Pipe-layers required hoisting capacity depending on the required pipeline hoist height;  
1 – for diameter 560 mm; 2 – for diameter 720 mm; 3 – for diameter 1200 mm; 4 – for diameter 1400 mm;

Figure 4. Cyclogram of loads on the pipe-layer hook when operating in the column at the major overhaul of linear pipeline section

The obtained data show that at the major overhaul of linear pipeline section efforts of hoisting the pipe constitute only 60% of overall process duty, 20-40% are variable and depend on the weight of technological vehicles in operation. The suggested model of loads calculation allows to improve
accuracy of loads calculation, affecting the pipe-layer during the technological process which, in its turn, allows both to select appropriate vehicles for the main pipeline linear section repair and to increase operational safety by forecasting possible conditions of pipe-layers rollover. This work is one of the recent studies of Nizhny Novgorod Scientific School [3,7,9,10] considering the vehicle interaction with weak substructure [11-14]. The vehicle interaction with weak substructure is extremely dangerous bearing in mind the vehicle possible rollover affected by variable load moment.

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