International Journal of Engineering & Technology, 7 (4.8) (2018) 36-40

International Journal of Engineering & Technology

Website:www.sciencepubco.com/index.php/IJET

Research paper

Probabilistic Aspects of Main Oil and Gas Pipelines Connections Calculation

Tatyana Nesterenko Sr.[1]*, Iryna Lartseva[2], Anatolii Kaliuzhnyi[3], Andrii Yaholnyk[4]

[1] Poltava National Technical Yuri Kondratyuk University, Ukraine
[2] Poltava National Technical Yuri Kondratyuk University, Ukraine
[3] Poltava National Technical Yuri Kondratyuk University, Ukraine
[4] Poltava National Technical Yuri Kondratyuk University, Ukraine
**Corresponding author E-mail: poltava.tanya.nesterenko@gmail.com*

Abstract

The article analyzes the existing calculation methods and highlights the main stages of main pipelines flanged connections calculation. A logical-structural scheme for the pipeline connection destruction is proposed. On the basis of the scheme developed, the analysis of usual flange connection destruction was carried out. As a result, formulas for determining safety characteristics of connection elements and equations for determining the failure-free operation probability for both individual elements of the connection and the connection as a whole were obtained.

Keywords: *connections calculating method, main pipelines, failure-free operation probability, flanged connections, single failure, structural schemes method.*

1. Introduction

When designing the main oil and gas pipelines, as a rule, typical connections are used. The choice of a typical flange connection is made depending on the type of connection, nominal diameter (D_n) and nominal pressure (R_n), taking into account those or other special requirements that may be imposed on flanged connections of pipelines. When choosing typical flange connections, it should be considered that existing regulatory documents on flange connections are usually designed under the assumption that the calculated corrosion allowance for carbon and low alloy steel flanges does not exceed 2 mm, and for flanges from austenitic chromium-nickel steels is equal to zero. In addition, these documents, as a rule, assume that the flanges and bolts (studs) of connections operated at elevated temperatures are made of the same class materials and have similar coefficients of linear expansion. Therefore, if these requirements are not met for any flanged connections, such connections should be considered as special and the possibility of their use should be confirmed by strength calculations [1].
In the works [2, 3], problems arising from the operation of flange bolted connections used in the chemical, petrochemical and power engineering industries are studied. The authors of the work are investigating the issue of pipelines calculating and the existing norms and rules for the flanged connections tightness. Additionally, an example of calculation of the connection is given according to current European and American norms and by using the finite element method [4, 5].
In [6], considerable attention is paid to the calculation of the pipeline and its elements on seismic effects impact, a non-standard flange connection of the pipeline was designed and tested for the effect of seismic loads. It is noted that further research and improvement of the calculation method are needed.
To assess the adequacy of existing methods for calculating pipeline connections and, further, comparing them, it is necessary to carry out a probabilistic calculation of main pipelines connections.
Reliability is a complex property, which, depending on the purpose of the object and the conditions of its operation, may include failure-free performance, durability, maintainability safety separately or a certain combination of these properties for both the object and its parts. In this case, such reliability index is used as the probability of failure-free operation of the connection. To determine it, it is necessary to know the statistical characteristics (expectation, variance, mean deviation) of the elements of connection.
Statistical characteristics determination of the elements is performed by the method of linearizing the function of a random argument, which is the bearing capacity of the connection. To analyze the reliability of statically undefined systems, methods that are used to calculate the reliability of complex systems can be applied [7]. Evaluation of the reliability of complex systems, as a rule, is performed using the method of structural schemes. The block diagram is a graphical representation of the system and reflects the ways in which elements are connected in terms of reliability.
In the theory of reliability, systems with sequential, parallel and mixed combination of elements are distinguished. In systems with a series connection of elements when a single element fails, a failure of the entire system (structure) occurs. The probability of failure-free operation of such a system, with a correlation between the failures of the elements, is:

$$P_c = r \cdot P_{i,\min} + (1-r)\prod_{i=1}^{n} P_i \,, \qquad (1)$$

where P_i *is* probability of failure-free operation of the construction element;
$P_{i,min}$ – the minimum value of safe operation probability for the weakest element in the structure;
r – the average value of the correlation coefficient between the structural elements ($r=0$ with independent elements).
The parallel connection of elements in the system is such a connection, under which the failure of the system occurs in case that all elements fail. The probability of failure-free operation of such a system is

$$P_c = r \cdot P_{i,\max} + (1-r)\left[1 - \prod_{i=1}^{n}(1-P_i)\right], \quad (2)$$

where $P_{i,max}$ is probability of failure-free operation of the most reliable element.
Mixed connection of system elements is a combination of serial and parallel connection of elements. Let us assume that the system n elements are connected in series, and m – in parallel. Then, the equation to determine the reliability of such a system looks as follows:

$$P_c = r \cdot P_{j,\max} + (1-r)\left[1 - \prod_{j=1}^{m}(1-P_j)\right], \quad (3)$$

$$P_j = r_{II} \cdot P_{i,\min} + (1-r_{II})\prod_{i=1}^{n} P_i \ , \quad (4)$$

where P_j – probability of operability of the j-th subsystem consisting of n series-connected elements;
r_{II} – generalized subsystem correlation.
However, statically undefined systems consist of a large number of elements, under failure of one of them the structure does not collapse, but only changes its design scheme. Therefore, to analyze their reliability, sequential structural schemes cannot be used.
The state method is used to compose the system reliability function in order to take into account the method of connecting elements, the type of failures and the sequence of failures of the system elements. Its use is possible for structures that have extra links, that is, for statically indefinable structures. This approach was used by [7].
The state graphs are based on the analysis of various options for failure of a structure as a result of its transition from one state to another. Possible ways of structures destruction are showed on the state graph, which includes all the possible states of structures and transitions from one state to another. Each state corresponds to its own design scheme and the respective distribution of efforts.
State graphs can be simplified using graph and state theory methods. In this case, subgraphs that have two or more simultaneous failures can be excluded, and then transition from one state to another occurs as a result of successive failure of the elements (Fig. 1).

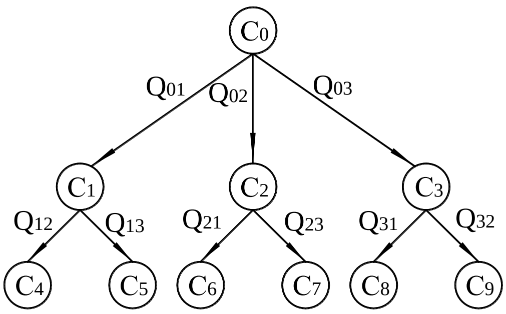

Fig. 1: System state graph

The state graph (Fig. 1) reflects the possible operational states – C_0, C_1, C_2, C_3 and disabled states, that is, the destruction of the structure – C_4, C_5, C_6, C_7, C_8, C_9, then the probability of failure-free operation and the probability of system failure as a whole are found as

$$P_c = \sum_{j=0}^{m} P_j^{Ï} P_j^{í} P_j \ ; \quad (5)$$

$$Q_c = \sum_{j=0}^{m} P_j^{Ï} P_j^{í} Q_j \ , \quad (6)$$

where $P^{Ï}\left(\tilde{N}_j\right)$ – probability of system transition to the state $\left(\tilde{N}_j\right)$;
$P^{í}\left(\tilde{N}_j\right)$ – probability of the state non-return $\left(\tilde{N}_j\right)$ to other working states;
$P^{Ï}\left(\tilde{N}_j\right) \cdot P^{Ï}\left(\tilde{N}_j\right)$ – probability of finding the system in a state $\left(\tilde{N}_j\right)$;
P_j, Q_j – probability of failure-free operation or probability of system failure in the state $\left(\tilde{N}_j\right)$.

2. Main body

Consider the work of the usual flanged connection (Fig. 2).

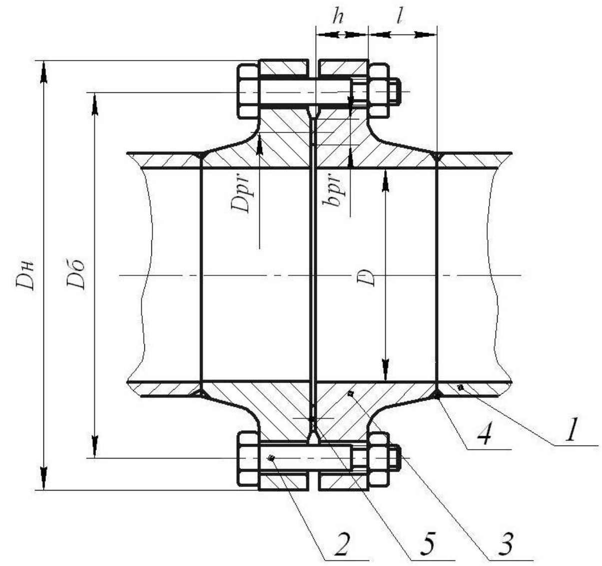

Fig. 2: Typical flanged connection of the main pipeline

The connection can be represented as a system consisting of five elements that work together: pipes 1, bolts (studs) 2, flanges 3, welds 4 and sealing gaskets 5.
The main requirements for the connection are its strength, stiffness and tightness.
In the calculations, it is assumed that, apart from internal or external pressure, flange connections of pipelines can also have axial and lateral forces, bending and torques, the values of which are determined on the basis of the stress-strain state of the pipeline as a whole. When choosing a typical flange connection, the specified power factors should be taken into account while determining the nominal pressure for which typical flanges are selected

$$P_y \geq \frac{P + \dfrac{4}{3.14G^2}\max\left\{\left(N + \dfrac{4|M|}{G}\right);0\right\}}{\grave{A}_{ð}}, \quad (7)$$

$$M = (M_x^2 + M_y^2)^{0.5}, \quad (8)$$

where M_x, M_y – bending moments acting in two mutually perpendicular planes passing through the axis of the pipe;
N – normal force acting on the flanged connection;
G – effective diameter of the gasket;

$$G = D_{ç} - 3{,}87\sqrt{b}, \quad (9)$$

$D_{ç}$ – outer diameter of the gasket.
Calculation of flange connections for strength and compactness (tightness) must be performed in all cases when unusual flange connections are used or the size of typical flanges is changed, or the conditions of their use differ from those provided by standards. The calculation of large diameter flange connections is recommended in accordance with the [1].
According to the existing standards, the calculation of the connection consists of several stages. First determine the magnitude of the bolts compliance, gaskets and angular compliance of the flange in accordance with the

$$y_{bt} = \frac{L_{bt}}{E_{bt}^{20} \cdot f_{bt} \cdot n}, \quad (10)$$

$$y_{pr} = \frac{h_{pr} \cdot K}{E_n \cdot \pi \cdot D_{\overline{pr}} \cdot b_{pr}}, \quad (11)$$

$$y_{fl} = \frac{\left[1 - \omega(1 + 0.9\lambda)\right]\psi_2}{E_{fl}^{20} \cdot h^3}, \quad (12)$$

where E_{bt}^{20}, E_n, E_{fl}^{20} – the modulus of the bolts, gaskets and flanges material elasticity at a temperature of 20 ºC and design temperature, respectively;
f_{bt} – bolt cross-sectional area of internal thread diameter;
n – number of bolts;
$D_{\overline{pr}}$ – average diameter of gasket;
h, h_{pr}, b_{pr} – the thickness of the flange, the thickness and width of the gasket, respectively.
Then a test of the gaskets, bolts and flanges strength is performed. Stress in the gaskets is found from the equation

$$\sigma_{pr} = \frac{N_{bt}}{\pi \cdot D_{\overline{pr}} \cdot b_{pr}}, \quad (13)$$

$$N_{bt} = \alpha(Q_q + N) + R_n - Q_t + \left|\frac{4\alpha_m \cdot M}{D_{\overline{pr}}}\right|, \quad (14)$$

$$Q_q = 0.785 \cdot D_{\overline{pr}}^2 \cdot p, \quad (15)$$

$$R_n = \pi \cdot D_{\overline{pr}} \cdot b_0 \cdot m \cdot p, \quad (16)$$

$$Q_t = \frac{1}{\eta_1}\left(2\alpha_{fl} \cdot h \cdot t_{fl} - \alpha_{bt} \cdot L_{bt} \cdot t_{bt}\right), \quad (17)$$

where N_{bt} – force in bolts in terms of installation,
α, α_m, α_{fl}, α_{bt} – coefficients of linear expansion;
Q_q – resultant internal pressure in the pipeline;
Q_t – additional load from thermal movement;
R_n – gasket reaction under operating conditions;
p – working pressure in the pipeline;
t_{fl}, t_{bt} – flanges and bolts temperature.
Stress in bolts is found from the equation

$$\sigma_{bt} = \frac{N_{bt} + \Delta N_{bt}}{n \cdot f_{bt}}, \quad (18)$$

$$\Delta N_{bt} = (1 - \alpha)(Q_q + N) + Q_t + \frac{4\beta_n \cdot M}{D_{\overline{pr}}}, \quad (19)$$

where ΔN_{bt} – bolts force increase in working conditions;
β_n – flange stiffness coefficient.
The strength condition of the flange under static load is as follows: during installation

$$\sigma_{fl}^m = \max\left\{\begin{array}{l}\sqrt{\sigma_{21}^2 + \sigma_{23}^2 - \sigma_{21} \cdot \sigma_{23}} \\ \sqrt{\sigma_{22}^2 + \sigma_{24}^2 - \sigma_{22} \cdot \sigma_{24}}\end{array}\right\}, \quad (20)$$

in working conditions

$$\sigma_{fl}^p = \max\left\{\begin{array}{l}\sqrt{\left(\sigma_{21} + \Delta\sigma_{21}\right)^2 + \left(\sigma_{23} + \Delta\sigma_{23}\right)^2 - \left(\sigma_{21} + \Delta\sigma_{21}\right) \cdot} \\ \sqrt{\left(\sigma_{22} + \Delta\sigma_{22}\right)^2 + \left(\sigma_{24} + \Delta\sigma_{24}\right)^2 - \left(\sigma_{22} + \Delta\sigma_{22}\right) \cdot}\end{array}\right.$$
$$\left.\begin{array}{l}\cdot\sqrt{\left(\sigma_{23} + \Delta\sigma_{23}\right)} \\ \cdot\sqrt{\left(\sigma_{24} + \Delta\sigma_{24}\right)}\end{array}\right\}, \quad (21)$$

where σ_{21}, $\Delta\sigma_{21}$, σ_{22}, $\Delta\sigma_{22}$ – meridial stresses and their growth in the shell on the outer and inner surfaces, respectively;
σ_{23}, $\Delta\sigma_{23}$, σ_{24}, $\Delta\sigma_{24}$ – circular stresses and their increase in the flange shell on the outer and inner surfaces, respectively.
The final step in the calculation is to check the stiffness of the connection.

$$\theta + \Delta\theta \le \left[\theta\right], \quad (22)$$

where θ, $\Delta\theta$, $\left[\theta\right]$ – the angle of the flanges rotation during installation, its increase in operating conditions and the allowable value of the angle of rotation, respectively. Allowable values are in accordance with the [1].
All other characteristics that are not given in the explanation of the formulas are dependent on the design features of the connection.
While investigating the probabilistic operation of the main oil and gas pipelines connections, it is necessary to determine the relationship between the elements for the probabilistic assessment of the connection operation as a whole.
Usually, the work of connecting oil and gas pipelines is (with a margin of safety) presented in the form of circuits with series connections. In case of one bolt (stud) failure there is a redistribution of forces between the bolts. Efforts in neighbouring bolts (studs) increase in 1.5-2 times, bolt failures have an avalanche-like chain character and the connection almost instantly fails.
For such a connection, damage occurs due to the following: destruction of the pipeline linear part (pipe at the flanged connection) 1, welds 2, deformation of the flanges 3, depressurization of the flanges (destruction of the gasket) 4 or destruction of the bolts 5. These failures are interconnected by parallel connections. Considering the above, a logframe of the connection and the «failure tree» of the system has been built (Fig. 3,4).

We assume that the failures are independent, that is, the correlation coefficients are zero (r = 0) in the first approximation.

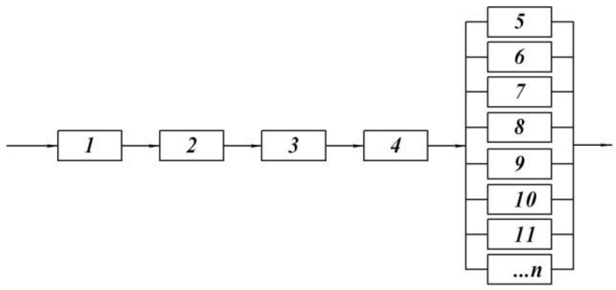

Fig. 3: Logical- structural diagram of flange connection

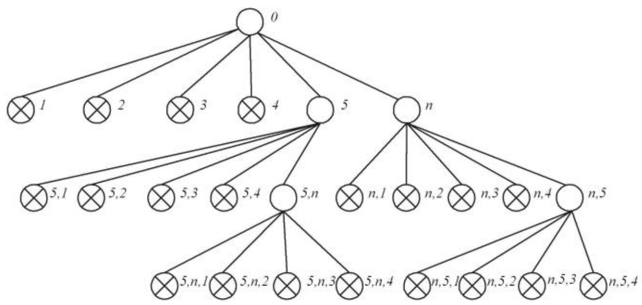

Fig. 4: State graph of flange connection system

The probability of survival for a simplified flanged connection system with independent element failures is

$$P = P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot (1 - Q_5 \cdot Q_6 \cdot Q_7 \cdot Q_n), \tag{23}$$

where P_1, P_2, P_3, P_4 – probability of survival of elements 1-4, respectively;

Q_5, Q_6, Q_7, Q_n – probability of failure of elements (connection bolts).

Based on the design experience, it can be argued that stress in the welds is much less than the tensile strength of the welds; therefore, the welds can be excluded from the structural-logical scheme. Given the complexity of the expressions (20, 21) and the complexity of the representation of the maximum function in a probabilistic form, we assume that the reliability of the flanges according to the criterion of strength and stiffness was ensured. Then expression (23) can be written as

$$P = P_1 \cdot P_4 \cdot (1 - Q_5 \cdot Q_6 \cdot Q_7 \cdot Q_n). \tag{24}$$

The reliability function for the connection gasket takes the form

$$\tilde{Y} = \tilde{R} - \tilde{S} \ge 0 . \tag{25}$$

For determining the reliability of the flange connections elements, we use the well-known method by A.P. Rzhanitsyn, then the probability of survival is

$$P = 1 - Q , \tag{26}$$

$$Q = 0.5 - \hat{O}(\beta) , \tag{27}$$

$$\hat{O}(\beta) = \frac{1}{\sqrt{2\pi}} \int_0^{\beta} \exp\left(-\frac{\tilde{o}^2}{2} \right) d\tilde{o} , \tag{28}$$

$$\beta = \frac{\overline{Y}}{\hat{Y}} = \frac{\overline{Y} + \sum_{i=1}^{n} A_i (X_i - \overline{X}_i)}{\sqrt{\sum_{i=1}^{n} \left[\frac{dY}{dX_i} (\overline{X}_1, \overline{X}_2 ... \overline{X}_n) \right]^2 \hat{X}_i^2}} =$$

$$= \frac{\overline{Y} + \sum_{i=1}^{n} A_i (X_i - \overline{X}_i)}{\sqrt{\sum_{i=1}^{n} A_i^2 \hat{X}_i^2}} , \tag{29}$$

де Q – probability of failure;

$\hat{O}(\beta)$ – the Laplace function, for the corresponding value of the security characteristic;

β – safety characteristic, which depends on the type of load distribution (strain, stress);

A_i – partial derivatives of each of its arguments.

We suggest considering each of the expression elements (23) separately. For pipelines, the model of failure probability is considered in the linear stage, therefore the failure criterion is the achievement of the yield strength of steel by ring stresses in the pipeline [8]. According to [8], the expectation and standard are respectively

$$\overline{Y} = \overline{R} - \overline{S} = \overline{\sigma}_y - \overline{\sigma}_{\hat{e}\ddot{o}} = \overline{\sigma}_y - \frac{\overline{p}D}{2t_{\hat{o}\grave{a}\hat{e}\grave{o}}} , \tag{29}$$

$$\hat{Y} = \hat{R} + \hat{S} = \hat{\sigma}_y + \hat{\sigma}_{\hat{e}\ddot{o}} = \sqrt{\left(\hat{\sigma}_y\right)^2 + \left(\frac{\hat{p}D}{2t_{\hat{o}\grave{a}\hat{e}\grave{o}}} \right)^2} , \tag{30}$$

where $t_{\hat{o}\grave{a}\hat{e}\grave{o}}$ – wall thickness, which is calculated by one of the standard methods.

Then the safety characteristic for the pipe, which is suitable for the connection, is

$$\beta = \frac{\overline{Y}}{\hat{Y}} = \frac{\overline{\sigma}_y - \overline{\sigma}_{\hat{e}\ddot{o}}}{\sqrt{\hat{\sigma}_y^2 + \hat{\sigma}_{\hat{e}\ddot{o}}^2}} = \frac{\overline{\sigma}_y - \frac{\overline{p}D}{2t_{\hat{o}\grave{a}\hat{e}\grave{o}}}}{\sqrt{\left(\hat{\sigma}_y\right)^2 + \left(\frac{\hat{p}D}{2t_{\hat{o}\grave{a}\hat{e}\grave{o}}} \right)^2}} . \tag{31}$$

The reliability function for the connection gasket takes the form

$$\tilde{Y} = \mathring{\sigma} - \mathring{\sigma}_{pr} \ge 0 . \tag{32}$$

The above mentioned enables rewriting expression (14) with expressions (15-17). We obtain forces in bolts in mounting conditions

$$N_{bt} = \alpha(0.785 \cdot D_{\overline{pr}}^2 \cdot p + N) + (\pi \cdot D_{\overline{pr}} \cdot b_0 \cdot m \cdot p) - \\ - \left(\frac{1}{\eta_1} \left(2\alpha_{fl} \cdot h \cdot t_{fl} - \alpha_{bt} \cdot L_{bt} \cdot t_{bt} \right) \right) + \left| \frac{4\alpha_m \cdot M}{D_{\overline{pr}}} \right| . \tag{33}$$

Thus, the equation (13) takes the form:

$$\sigma_{pr} = \frac{\alpha \cdot D_{\overline{pr}} \cdot p}{4b_{pr}} + \frac{\alpha \cdot N}{\pi \cdot D_{\overline{pr}} \cdot b_{pr}} + \frac{b_0 \cdot m \cdot p}{b_{pr}} - \frac{2\alpha_{fl} \cdot h \cdot t_{fl}}{\eta_1 \cdot \pi \cdot D_{\overline{pr}} \cdot b_{pr}} + \\ + \frac{\alpha_{bt} \cdot L_{bt} \cdot t_{bt}}{\eta_1 \cdot \pi \cdot D_{\overline{pr}} \cdot b_{pr}} + \frac{4\alpha_m \cdot |M|}{\pi \cdot D_{\overline{pr}}^2 \cdot b_{pr}} . \tag{34}$$

For the reserve of gasket we obtain:

$$\overset{\circ}{Y} = \overset{\circ}{\sigma} - \frac{\alpha \cdot D_{pr} \cdot \overset{\circ}{p}}{4b_{pr}} - \frac{\alpha \cdot \overset{\circ}{N}}{\pi \cdot D_{pr} \cdot b_{pr}} - \frac{b_0 \cdot m \cdot \overset{\circ}{p}}{b_{pr}} + \frac{2\alpha_{fl} \cdot h \cdot t_{fl}}{\eta_1 \cdot \pi \cdot D_{pr} \cdot b_{pr}} - \frac{\alpha_{bt} \cdot L_{bt} \cdot t_{bt}}{\eta_1 \cdot \pi \cdot D_{pr} \cdot b_{pr}} - \frac{4\alpha_m \cdot \overset{\circ}{M}}{\pi \cdot D_{pr}^2 \cdot b_{pr}}. \quad (35)$$

The coefficients for obtaining $\hat{Y}$ are determined by partial differentiation (35):

$$A_1 = \frac{dY}{d\sigma} = 1,$$
$$A_2 = \frac{dY}{dN} = -\frac{\alpha}{\pi \cdot D_{pr} \cdot b_{pr}},$$
$$A_3 = \frac{dY}{dp} = -\frac{0.25\alpha \cdot D_{pr} + b_0 \cdot m}{b_{pr}}, \quad (36)$$
$$A_4 = \frac{dY}{dM} = -\frac{4\alpha_m}{\pi \cdot D_{pr}^2 \cdot b_{pr}}.$$

Then the safety characteristic for gasket of the connection is

$$\beta_{pr} = \frac{\left(\bar{\sigma} - \frac{\bar{p}(0.25\alpha \cdot D_{pr} - b_0 \cdot m)}{b_{pr}} - \frac{\alpha \cdot \bar{N}}{\pi \cdot D_{pr} \cdot b_{pr}} + \frac{2\alpha_{fl} \cdot h \cdot t_{fl}}{\eta_1 \cdot \pi \cdot D_{pr} \cdot b_{pr}} - \frac{\alpha_{bt} \cdot L_{bt} \cdot t_{bt}}{\eta_1 \cdot \pi \cdot D_{pr} \cdot b_{pr}} - \frac{4\alpha_m \cdot \bar{M}}{\pi \cdot D_{pr}^2 \cdot b_{pr}}\right)}{\sqrt{\hat{\sigma}^2 + \frac{\alpha^2}{\pi^2 \cdot D_{pr}^2 \cdot b_{pr}^2} \cdot \hat{N}^2 + \frac{(0.25\alpha \cdot D_{pr} + b_0 \cdot m)^2}{b_{pr}^2} \cdot \hat{p}^2 + \frac{16\alpha_m^2}{\pi^2 \cdot D_{pr}^4 \cdot b_{pr}^2} \cdot \hat{M}^2}}. \quad (37)$$

Similar transformations are performed for the expression (18). The stress in the bolts is

$$\sigma_{bt} = \frac{N}{n \cdot f_{bt}} + \frac{\pi \cdot p \cdot D_{pr}}{4n \cdot f_{bt}}(4b_0 \cdot m + D_{pr}) + \frac{4M}{D_{pr} \cdot n \cdot f_{bt}}(\alpha_m + \beta_n), \quad (38)$$

then the safety characteristic for the bolt in the connection with consideration of the expression (25, 28) can be determined by the expression (39)

$$\beta_{bt} = \left(\bar{\sigma} - \frac{\bar{N}}{n \cdot f_{bt}} - \frac{\pi \cdot \bar{p} \cdot D_{pr}}{4n \cdot f_{bt}}(4b_0 \cdot m + D_{pr}) - \frac{4\bar{M}}{D_{pr} \cdot n \cdot f_{bt}}(\alpha_m + \beta_n)\right) \Big/ \left(\hat{\sigma}^2 + \frac{\hat{N}^2}{n^2 \cdot f_{bt}^2} + + \frac{\pi^2 \cdot D_{pr}^2}{16n^2 \cdot f_{bt}^2} \cdot (4b_0 + D_{pr})^2 \cdot \hat{p}^2 + \frac{16}{D_{pr} \cdot n \cdot f_{bt}}(\alpha_m + \beta_n) \cdot \hat{M}^2\right)^{1/2} \quad (39)$$

3. Conclusions

A review of existing investigation of flange connections showed that the connection was hardly ever considered from a probabilistic point of view. Analysis of the existing calculation methods enabled identifying the main stages and elements of the calculation of atypical connections.

We have analyzed possible options for the destruction of flange connections. Their destruction occurs as a result of the following: destruction of the linear part of the pipeline (pipe at the flange connection), welds, deformation of the flanges, opening of the flanges (destruction of the gasket) or destruction of the bolts.

Based on possible connection failures, logical-structural schemes developed for determining the reliability of the connection as a whole. The obtained analytical dependencies (24, 26, 27, 37, 39) can be used to determine the reliability of both typical and non-typical flange connections of oil and gas main pipelines.

Knowing the geometrical characteristics of the connection and having stochastic indicators of the values of the working pressure and internal forces arising in the connection, using expressions (24-27, 31, 37, 39), it is possible to obtain numerical values of the failure-free operation connections probability. These values can be compared with the normative ones and reveal the existing safety factors for both typical and non-typical connections of various pipe diameters. These issues require further research.

References

[1] *SNiP 2.05.06-85. Magistral'nyye truboprovody.* TSITP Gosstroya SSSR, (1988), 52 p.

[2] R. Walczak, J. Pawlicki, A. Zagórski,"Tightness and material aspects of bolted flange connections with gaskets of nonlinear properties exposed to variable loads", *Arch. Metall. Mater.*, Vol.61, No.3, (2016), pp:1063-1070, http://dx.doi.org/ 10.1515/amm-2016-0231.

[3] Speight J.G., *Oil and Gas Corrosion Prevention, From Surface Facilities to Refineries*, (2014), Elsevier, pp. 109–149.

[4] *ASME-b16.5-2003. Pipe flanges and flanged fittings*, ASME, (2008), 234 p.

[5] *DIN v 2505. Calculation of flanged joints*, Germany, (1986), 298 p.

[6] Paolacci F., Reza Md. S., Bursi O. S."Seismic design criteria of refinery piping systems", *III eccomas thematic conference on computational methods in structural dynamics and earthquake engineering*, Vol.7, No.2, (2011), pp:142-147.

[7] Chirkov V.P., *"Prikladnyye metody teorii nadezhnosti v raschetakh stroitel'nykh konstruktsiy"*, Marshrut, (2006), 620p.

[8] Pichugin S., Vynnykov P., "Probabilistic calculation of the buried petroleum and gas pipelines", *Problems of energy and nature use 2013*, (2014), pp.108 - 115.

[9] Pichugin S, Zyma O, Vynnykov P, "Reliability Level of the Buried Main Pipelines Linear Part " *Recent Progress in Steel and Composite Structures – Proceedings of the 13th International Conference on Metal Structures, ICMS 2016,* (2016), pp: 551–558. DOI: 10.1201/b21417-76

[10] Zotsenko, M., Vynnykov, Y., Doubrovsky, M., Oganesyan, V., Shokarev, V., Syedin, V., Meshcheryakov, G. (2013). Innovative solutions in the field of geotechnical construction and coastal geotechnical engineering under difficult engineering-geological conditions of ukraine. Paper presented at the 18th International Conference on Soil Mechanics and Geotechnical Engineering: Challenges and Innovations in Geotechnics, ICSMGE 2013, 32645-2648.

[11] Zotsenko, M., Vynnykov,Y., Lartseva, I. & Sivitska,S. (2018) Ground base deformation by circular plate peculiarities Paper presented at the MATEC Web of Conferences, 230 https://doi.org/10.1051/matecconf/201823002040