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# CREATION OF MATHEMATIC MODEL OF DEFINITION OF MAIN DIMENSIONS OF SUBSEA CONSTRUCTION VESSEL OF NEW GENERATION: INFLUENCE OF PIPE-LAYING EQUIPMENT

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***Abstruct.*** *The article is devoted to the scientifically substantiated selection of the main dimensions of the FPSO for operation as a pipe-laying vessel on the Caspian shelf at the initial design stages.*

*On the basis of practical experience of using specialized pipe-laying vessels it is proposed to use universal subsea engineering support vessels (SESV). A system analysis was carried out and a mathematical model was formed to determine the main dimensions of SESV when using pipe-laying equipment. The influence of pipe-laying operations and equipment on the main dimensions of SESV was assessed.*

*On the basis of the research, the previously developed nomogram of formation of main dimensions of SESV taking into account the use of pipe-laying equipment has been supplemented.*

*The model of optimization of the main dimensions of SESV obtained on the basis of the performed dependences and the developed nomogram was formed. With the help of this model the parameters of SESV are determined for pipe-laying operations in the Caspian Sea basin.*

***Keywords:*** *subsea construction vessel, pipe lay operation, pipe lay equipment, main dimensions, optimization model.*

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# СТВОРЕННЯ МАТЕМАТИЧНОЇ МОДЕЛІ ВИЗНАЧЕННЯ ОСНОВНИХ РОЗМІРІВ ПІДВОДНОГО БУДІВЕЛЬНОГО СУДНА НОВОГО ПОКОЛІННЯ: ВПЛИВ ТРУБОУКЛАДАЛЬНОГО ОБЛАДНАННЯ

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***Анотація.*** *Статтю присвячено науково обґрунтованому вибору головних розмірів СОПТР для експлуатації як трубоукладального судна на Каспійському шельфі на початкових стадіях проектування. На основі практичного досвіду використання спеціалізованих суден для укладання труб пропонується використання універсальних суден забезпечення підводно-технічних робіт (СОПТР). Проведено системний аналіз і сформовано математичну модель визначення головних розмірів СОПТР під час використання трубоукладального обладнання. Зроблено оцінку впливу трубоукладальних операцій та обладнання на головні розмірності СОПТР. На основі дослідження, була доповнена розроблена раніше номограма формування головних розмірів СОПТР з урахуванням застосування трубоукладального обладнання. Сформовано модель оптимізації головних розмірів СОПТР, отриману на базі виконаних залежностей і розробленої номограми. З її допомогою визначено параметри СОПТР, для виконання трубоукладальних робіт у басейні Каспійського моря.*

***Ключові слова:*** *підводне будівельне судно, трубоукладальна операція, трубоукладальне обладнання, основні розміри, оптимізаційна модель*

## 1. Introduction.

The smooth functioning of a sea oil field requires ensuring the laying and repair of pipelines on a sea bottom. Performance of a pipe-lay operation on a sea oil field in the Caspian Sea, a long time is operated a pipe-lay vessel, the «RR-25» design number

(ISRAFIL GUSEYNOV) and the «904» design number (SULEYMAN VEZIROV), (see Table 1). The practice of operating a pipe-pipe-laying vessel on the Caspian Sea [1, 2] shows that pipe-lay vessels, in contrast to other types of vessels in a sea oil field, have such features as idle time between projects. Considering this factor, in real life, applying a pipe-lay complex on the universal subsea construction vessel (SCV) in the absence of the pipe-lay projects allows the vessel to be engaged in other subsea construction and repair works [3-6]. Within the research, the system analysis and the mathematical model are carried out to define the main dimension of the vessel and ensure the optimum application of pipe lay equipment on SCV.

To obtain the optimal main dimensions of the SCV for the pipe-laying equipment used, an assessment of the influence of pipe-laying operations and equipment on the main dimensions of the SOPTR was carried out using the obtained database of world fleet vessels. Using the conducted studies, the previously developed nomogram [7, 8] for the formation of main dimensions was supplemented, taking into account the use of pipe-laying equipment, Fig. 11.

Using the conducted research, the main dimensions of the SCV were formed for work in the Caspian Sea basin (see Table 3) according to the parameters of pipe-laying operations, taking into account the geographical features.

To ensure the optimum application of pipe lay equipment on SCV within the research, the system analysis and the mathematical model are carried out during the research. To ensure the optimum application of pipe lay equipment on SCV within the research, the system analysis is carried out, and the mathematical model of the

**Objective of the work:** Performance of the evidence-based choice of the main dimension of SCV for operation in quality a pipe lay vessel on the Caspian Sea.

**Scientific innovation:** The method of definition of the main dimension of SCV using parameters pipe lay is developed, guided by the developed nomogram of the definition of the main dimension and dependences received from the database of pipe lay vessels of the Caspian and world fleet.

**2. The pipe lay vessels and operations carried out in the Caspian Sea and their prospect.** For ensuring smooth functioning of a sea oil field particularly important questions of laying of subsea pipelines and cable lines become.

The most progressive way which is widely applied in world practice in the course of arrangement of the field is laying of the subsea pipeline and cable lines from watercrafts.

The wide complex of technical and operational requirements is imposed to pipe-cable lay watercrafts. Their design, ship and technological the equipment and a system have to provide:

- safety of the laid pipeline or cable, without allowing their damages to laying process;
- the minimum course deviation of the movement throughout the route of the laid pipeline or a cable irrespective of the changing hydro meteorological conditions;
- the high performance allowing to reduce the cost of pipelines and cable lines operation;

– mechanization of the heavy and labor-consuming auxiliary operations connected with their laying.

Floating pipelines and cable lines facility can be classified by the following signs:

– as the laid pipelines and cable lines (main, intra-field, communication cables, power cables);

– on a way of storage and transportation of pipes and cables (in the form of a deck caravan in stacks, in winch, in bays);

– on architectural structurally type (barges platforms with the simplified contours, one-case vessels, semisubmersible installations);

– on means of the movement (self-propelled, not self-propelled);

– on a way of positioning (the anchor, dynamic systems of deduction);

– on a design of the basic and trigger device (the stinger, a vertical stage sending to the trench).

Technical development of pipelines and cable lines watercrafts is defined: on the one hand – need of conducting works for more severe hydro meteorological conditions and at big depths of the sea, and with another – increase in diameter and extent of pipelines and cable lines.

The pipe-lay vessel is an essential element of the construction and repair of offshore pipelines. Table 1 below illustrates the main parameters of pipe-lay vessels successfully utilized in the Caspian Sea. The nature of the pipe-lay vessel operations consists of a pipe laying offshore and inshore, as well as laying of the trans-Caspian pipelines and repair of pipelines. When developing the SCV parameters with pipe-lay equipment, the main parameters of pipe-lay vessels should be used, considering the international experience of designing pipe-lay vessels.

*Table 1*

*The pipe lay vessels operate in the Caspian Sea*

| **Project № PP-25 «Israfil Guseynov»** | **Project № 904 «Suleyman Vezirov»** |
|---|---|
| **Main dimension** | |
| Length – 115,2 m;<br>Width – 33,0 m;<br>Depth – 13,0 m;<br>Draft – 7,0 m;<br>Cargo capacity – 7500 t;<br>Displacement – 25540 t. | Length – 108,3 m;<br>Width – 25,6 m;<br>Depth – 7,0 m;<br>Draft – 3,5 m;<br>Cargo capacity – 2966 t;<br>Displacement – 8900 t. |
| **Pipe lay parameters** | |
| Pipe diameter – 219 – 820 mm;<br>Pipe lay depth – 10-300 m;<br>Pipe repair depth – 60 m;<br>Pipe lay speed -1500 m/day. | Pipe diameter – 219 – 813 mm;<br>Pipe lay depth – 195 м. |

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*Continuation of the Table 1*

| | |
|---|---|
| **Cargo gear** | |
| Main crane – 250 t;<br>Deck crane – 60 t;<br>Deck crane – 30 t;<br>Bridge crane – 15 t;<br>Crane boom – 40t (5pies.) | Caterpillar crane – 100 t;<br>Rotate crane – 60 t;<br>4-non rotate crane – 40 t. |
| **Pipe lay equipment** | |
| Stinger – 100 m;<br>Tensioners – 2 pies.;<br>Working post – 8 шт.;<br>Pipe alignment post. | Stinger – 100 м;<br>Tensioners;<br>Working post;<br>Pipe alignment post;<br>Pipe store – 593 pies. |

**3. The system analysis and mathematical model of formation of the main dimension of SCV when using pipe lay pipe-lay equipment.** Many interconnected factors exist when developing SCV with pipe-lay equipment. For the definition of conditions on the research of formation of the main dimension of SCV, the block diagram is developed (fig. 1.), interferences of parameters a pipe laying on elements a pipe laying equipment with the developed vessel.

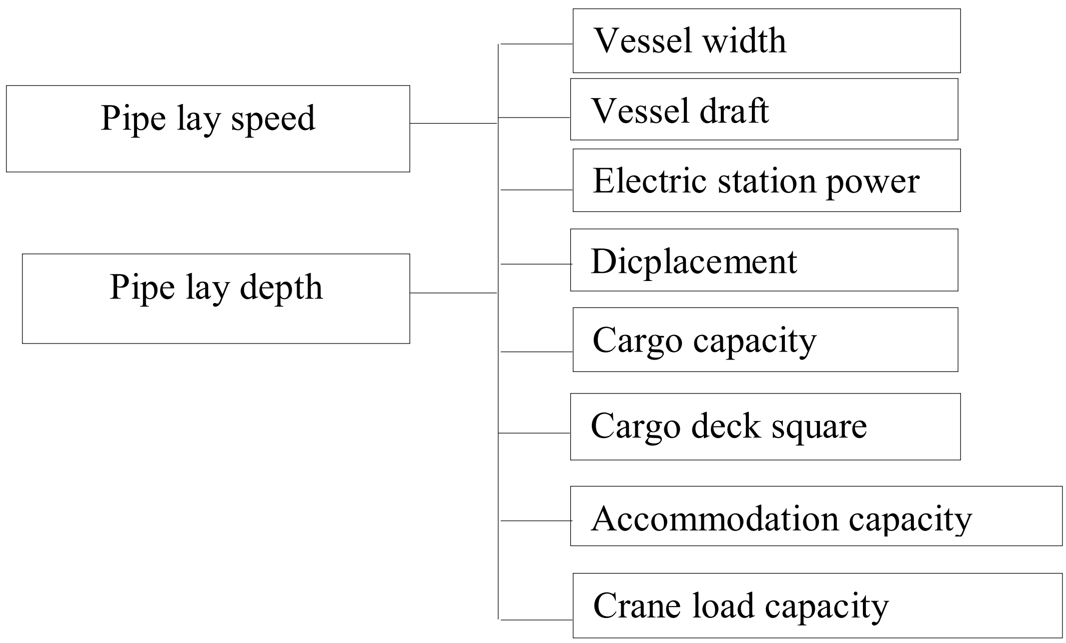


*Fig. 1. The block diagram of interference of parameters a pipe laying on elements a pipe lay equipment SCV*

Considering the parameters reflected in the block diagram in Fig. 1, the criterion function (1), is developed, reflecting conditions of a research study of the influence of parameters a pipe laying on the main dimension of the SCV. At the same time, the sequence of formation of elements of the main dimension is reflected in Fig. 2. The model of the sequence of formation of the main dimension is reflected by criterion function (2).

$$U = A_{P.D}, A_{P.S.} f(\Sigma S_{P.O.}), \quad (1)$$

here U – function of pipe lay equipment the SCV;

$A_{P.D.}$ – pipe lay depth;

$A_{P.S.}$ – pipe lay speed;

$S_{P.O.}$ – SCV pipe lay equipment parameters.

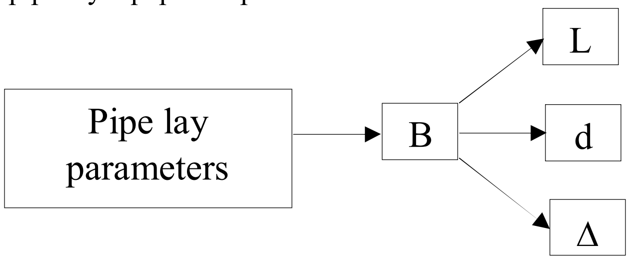


*Fig. 2. The block diagram of formation of the main dimension of SCV taking into account a pipe lay equipment*

$$L, d, \Delta = A_{P.D.}, A_{P.S.} f(B), \quad (2)$$

here L, d, Δ – length, draft and displacement;

B – the vessel width.

**4. Impact assessment of the pipe-lay equipment to the main dimension of SCV.**

Based on the developed structural diagram and target functions, using the database of pipe-laying vessels of the world fleet, the dependencies of the factors of pipe-laying equipment and the vessel (Fig. 3-31) were developed and described by formula (3). Also, using the database, the ratios of the main dimensions of pipe-laying vessels (Fig. 32-33) were formed, which are necessary for determining the main dimensions of the SOPTR using pipe-laying equipment.

$$C_n = b * S_{p.o.} - C_n / S_{p.o.} \quad (3)$$

here $C_n$ – research parameters ($C_\Delta$, $C_P$, $C_S$, $C_M$, $C_s$, $C_{C.P.}$, $C_N$, $C_B$, $C_d$, $C_{MG}$);

$C_\Delta$ – displacement;

$C_P$ – the vessel cargo capacity;
$C_S$ – cargo deck square;
$C_M$ – accommodation capacity;
$C_s$ – pipe lay speed;
$C_{C.P.}$ – crane cargo capacity;
$C_N$ – electric station power;
$C_B$ – the vessel width;
$C_d$ – the vessel draft;
$C_{MG}$ – number of Main Diesel – Generators (MDG);
$S_{p.o.}$ – elements of the SCV pipe lay options ($S_{d.p}, S_{sp}, S_N, S_\Delta, S_P, S_M, S_{C.P}, S_S$);
$S_{d.p}$ – pipe lay depth;
$S_{sp}$ – pipe lay speed;
$S_N$ – electric station power;
$S_\Delta$ – displacement;
$S_P$ – the vessel cargo capacity;
$S_M$ – accommodation capacity;
$S_{C.P.}$ – cargo crane capacity;
$S_S$ – cargo deck square.
$b$ – correlation coefficient the considering regularity of the considered ratios determined by a formula (5);
$C_n / S_{p.o.}$ – ratios of the studied and measured parameters.

Thus, ratios of the studied and measured parameters it is described by expression (4):

$$C_n / S_{p.o.} = \sum_{i=1}^{n} C_i \text{-} b * \sum_{i=1}^{n} S_{p.o.} \tag{4}$$

At the same time, the correlation coefficient, is described by expression (5):

$$b = \frac{\sum_{i=1}^{n}\left(C_n / S_{p.o.} - \overline{C_n / S_{p.o.}}\right)\left(C - \overline{C}_i\right)}{\sqrt{\sum_{i=1}^{n}\left(C_n / S_{p.o.} - \overline{C_n / S_{p.o.}}\right)^2 \sum_{i=1}^{n}\left(C - \overline{C}_i\right)^2}} \tag{5}$$

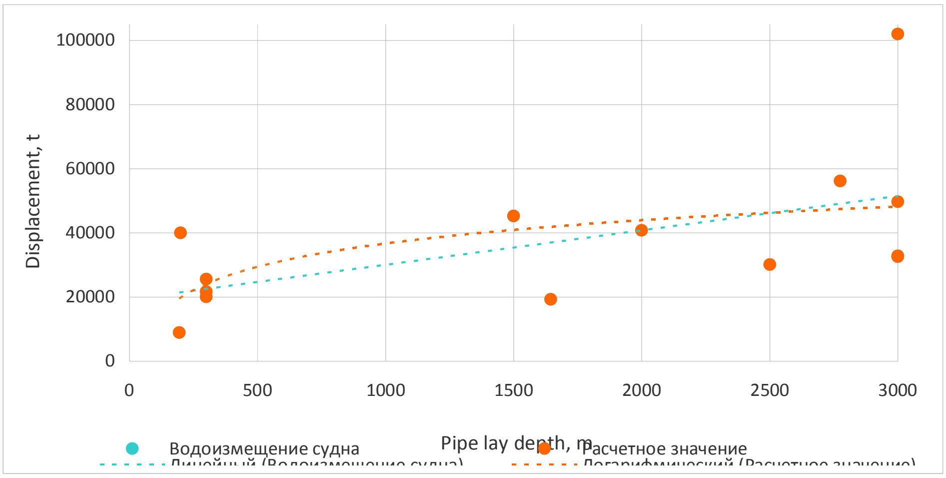


*Fig. 3(a). Dependence of the pipe lay depth and pipe lay vessel displacement*

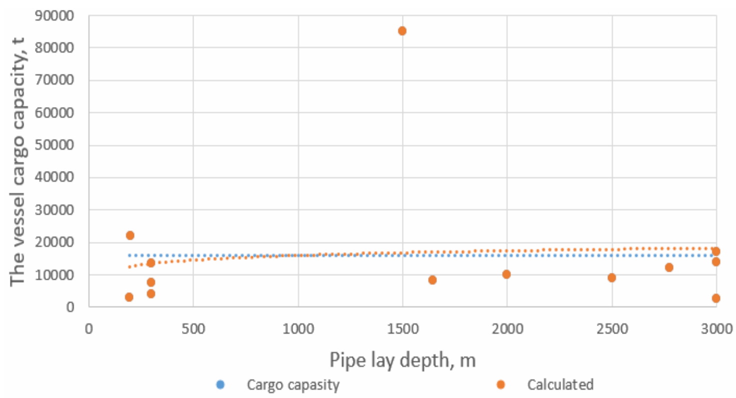


*Fig. 3(b). Dependence of the pipe lay depth and pipe lay vessel cargo capacity*

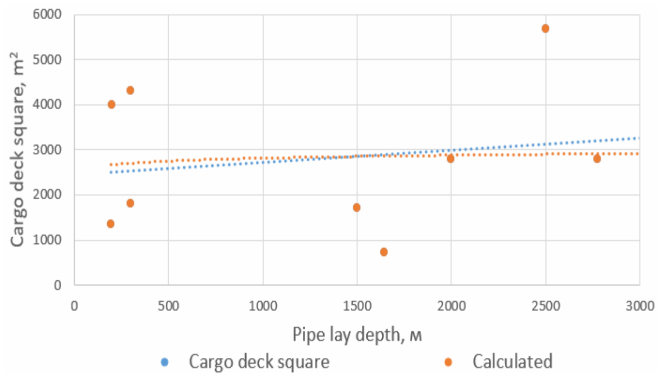


*Fig. 3(c). Dependence of the pipe lay depth and pipe lay vessel cargo deck square*

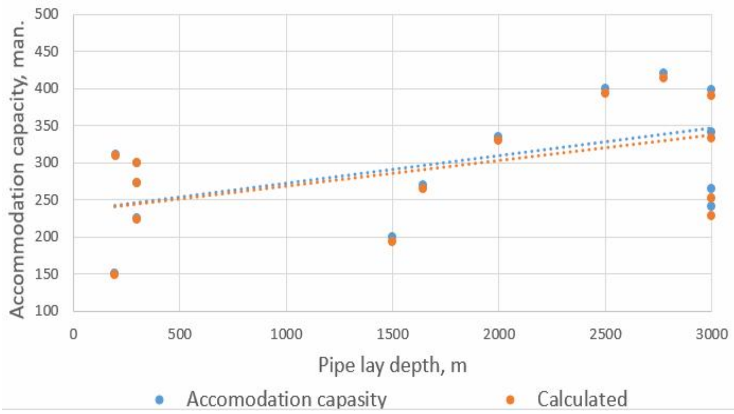


*Fig. 3(d). Dependence of the pipe lay depth and pipe lay vessel accommodation capacity*

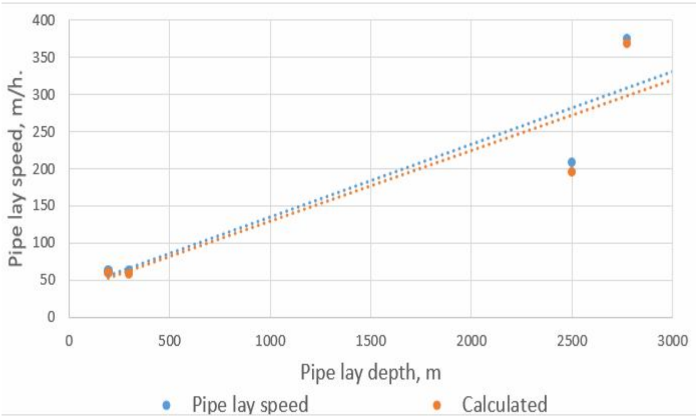


*Fig. 3(e). Dependence of the pipe lay depth and speed*

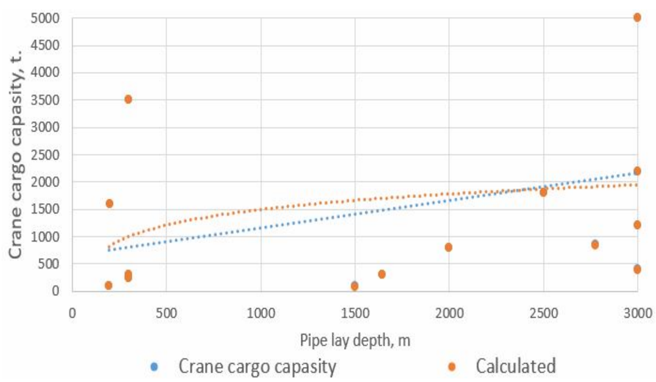


*Fig. 3(f). Dependence of the pipe lay depth and crane cargo capacity*

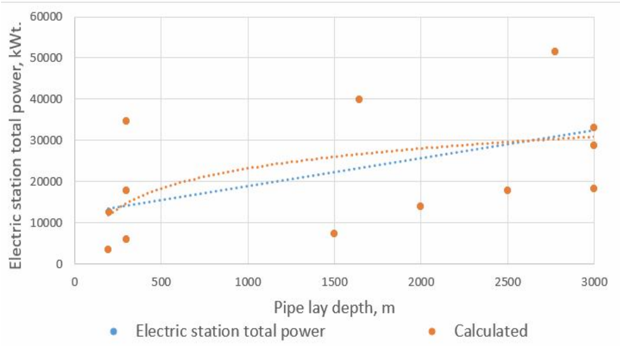


*Fig. 3(g). Dependence of the pipe lay depth and electrical station power*

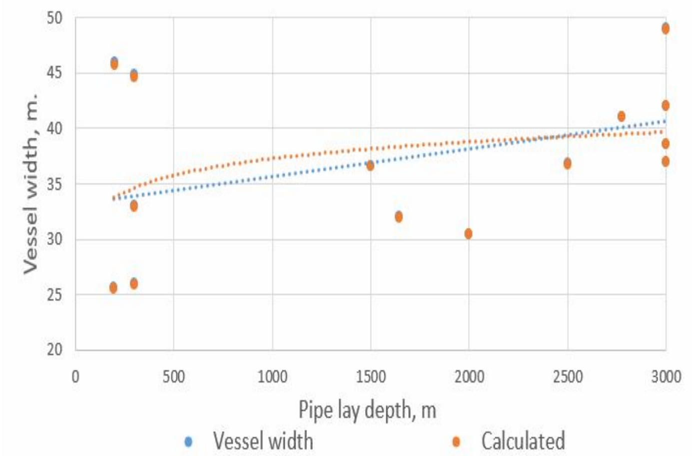


*Fig. 3(h). Dependence of the pipe lay depth and vessel width*

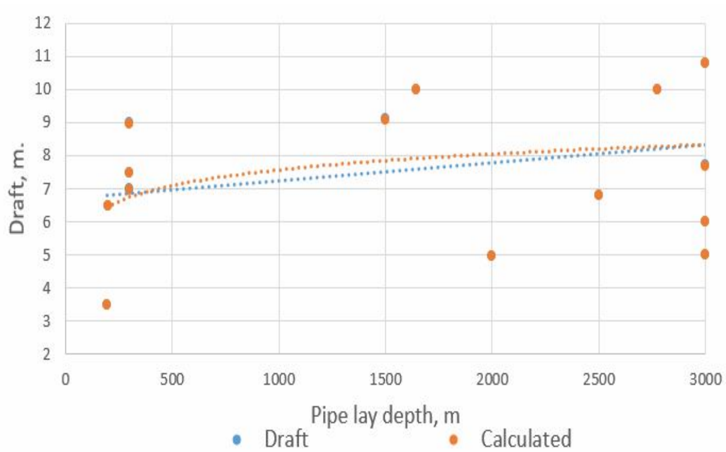


*Fig. 3(i). Dependence of the pipe lay depth and vessel draft*

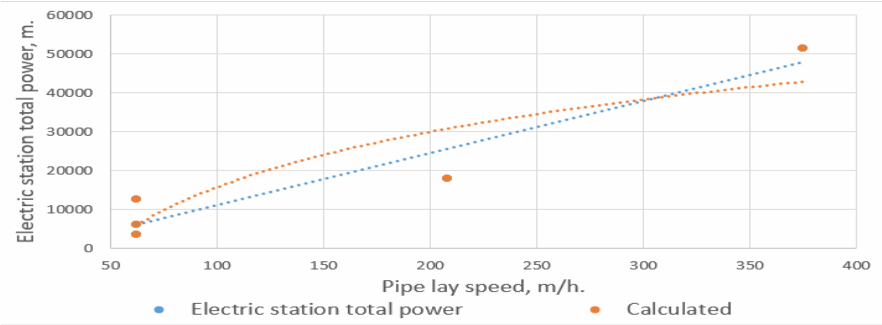


*Fig. 4(a). Dependence of the pipe lay speed and electrical station power*

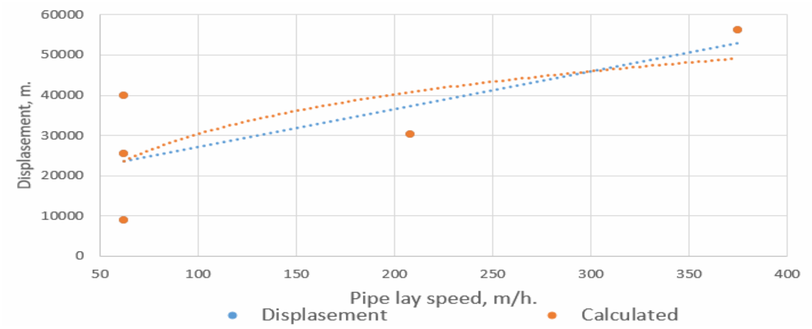


*Fig. 4(b). Dependence of the pipe lay speed and vessel displacement*

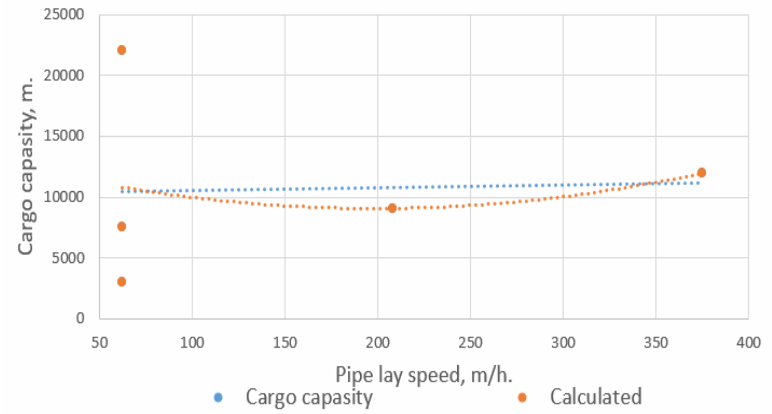


*Fig. 4(c). Dependence of the pipe lay speed and vessel cargo capacity*

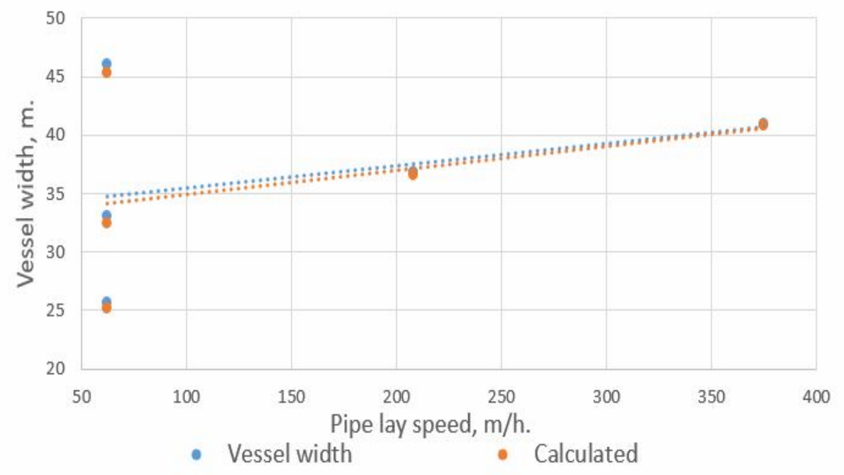


*Fig. 4(d). Dependence of the pipe lay speed and vessel width*

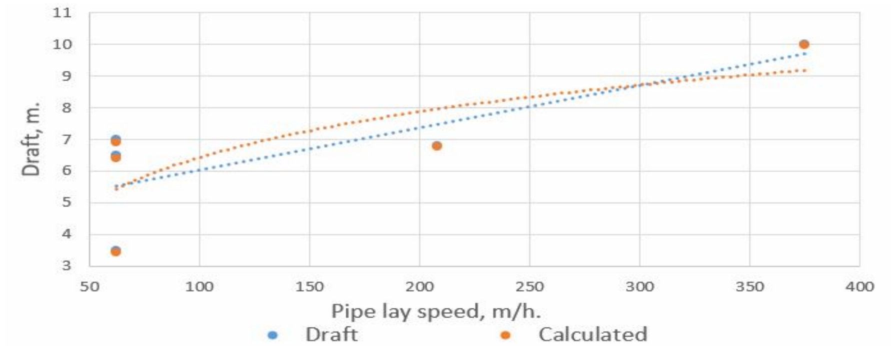


*Fig. 4(e). Dependence of the pipe lay speed and vessel draft*

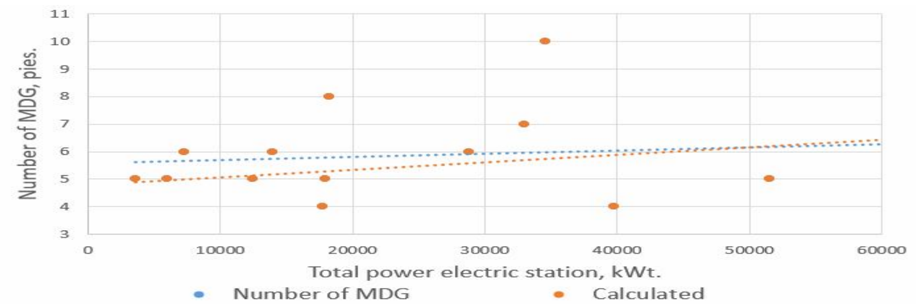


*Fig. 5(a). Dependence of the total power and number the vessel MDG*

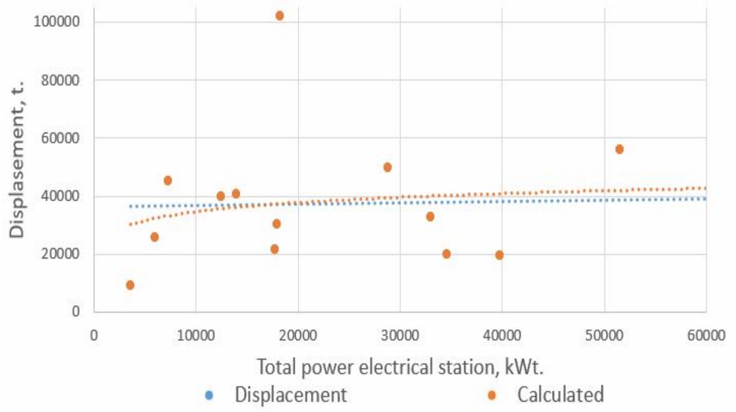


*Fig. 5(b). Dependence of the total power electric station and vessel displacement*

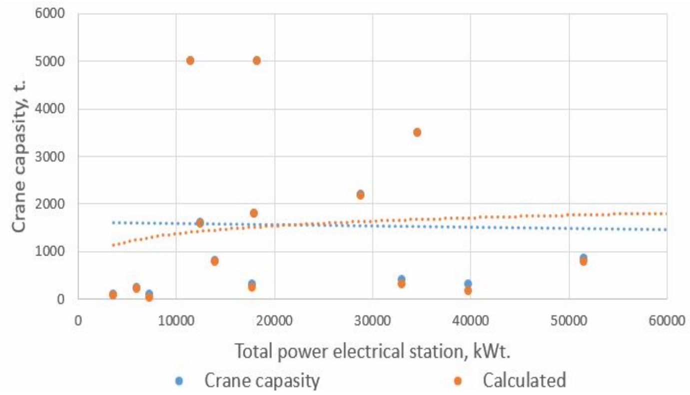


*Fig. 5(c). Dependence of the total power electric station and crane cargo capacity*

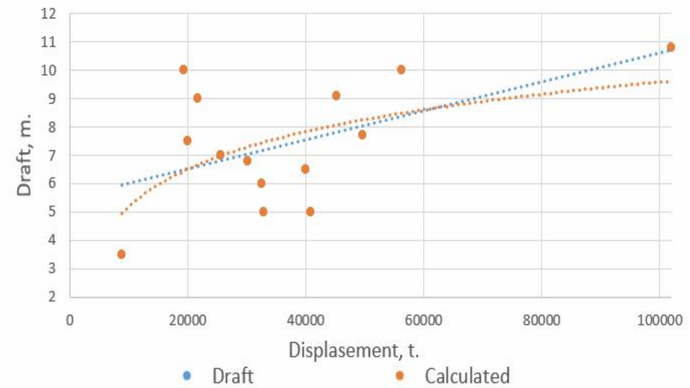


*Fig. 6(a). Dependence of the vessel draft and displacement*

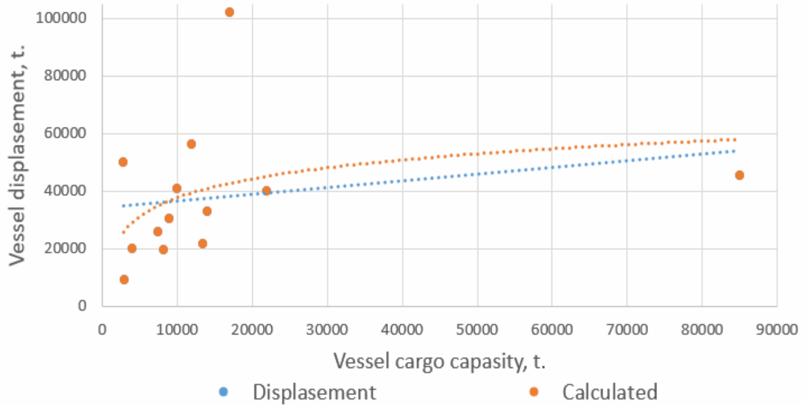


*Fig. 6(b). Dependence of the vessel displacement and cargo capacity*

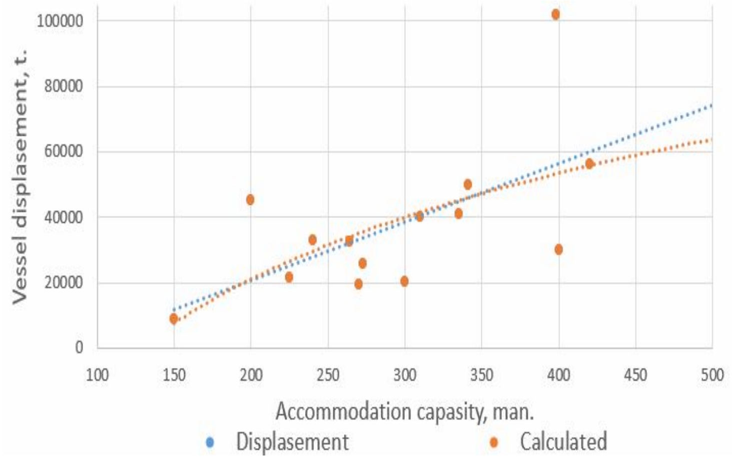


*Fig. 6(c). Dependence of the vessel displacement and accommodation capacity*

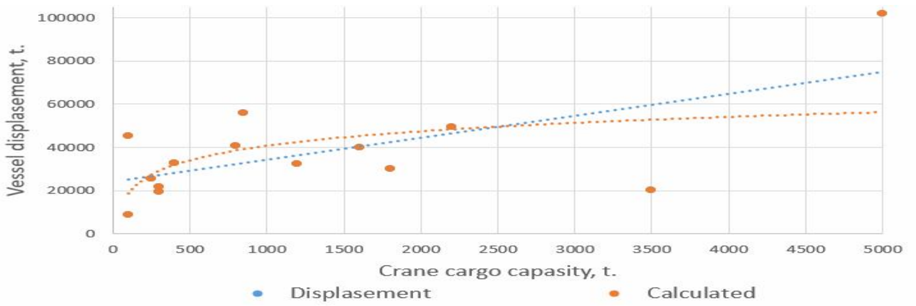


*Fig. 6(d). Dependence of the vessel displacement and cargo crane capacity*

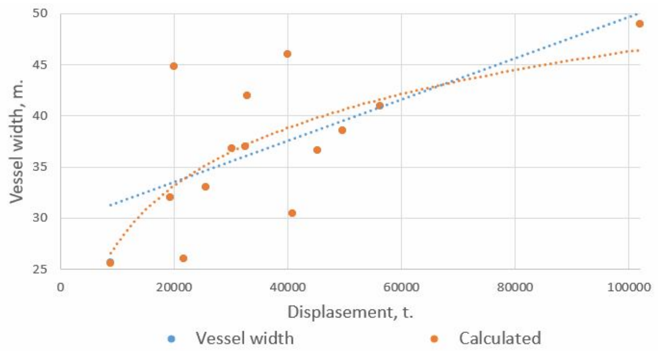


*Fig. 6(e). Dependence of the vessel displacement and width*

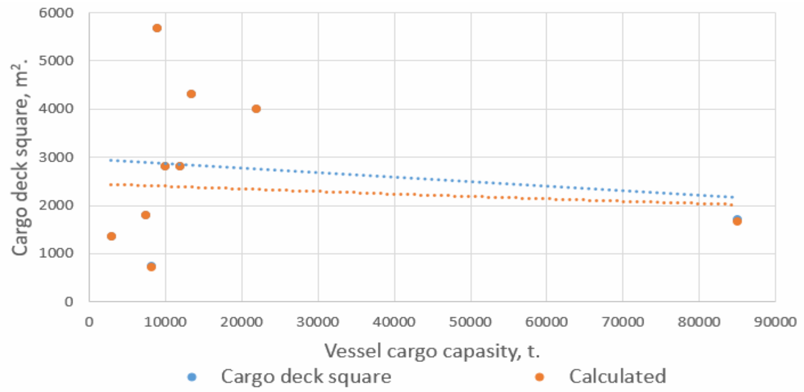


*Fig. 7(a). Dependence of the vessel cargo capacity and cargo deck square*

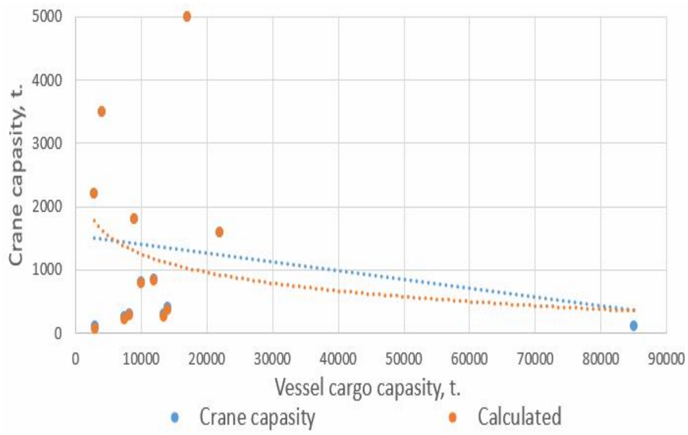


*Fig. 7(b). Dependence of the vessel cargo capacity and crane cargo capacity*

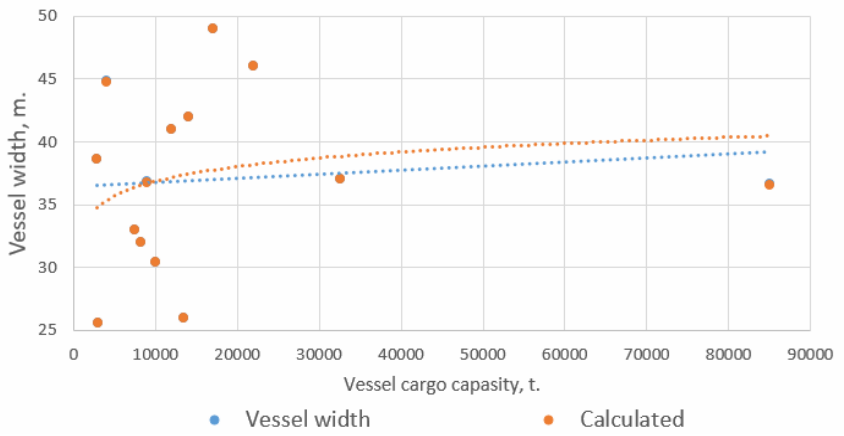


*Fig. 7(c). Dependence of the vessel cargo capacity and width*

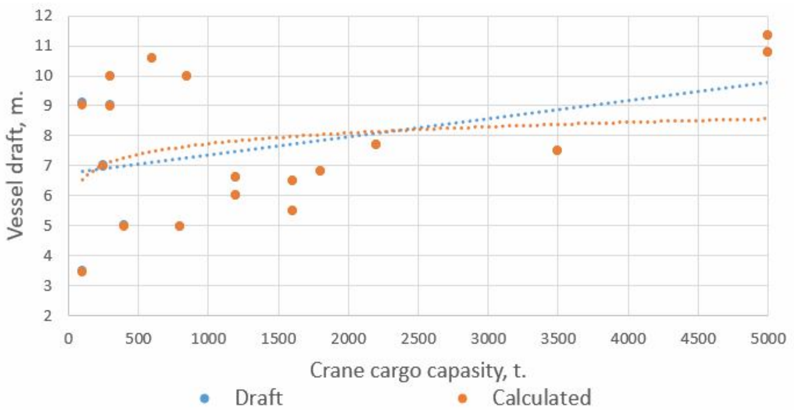


*Fig. 8(a). Dependence of crane cargo capacity and vessel draft*

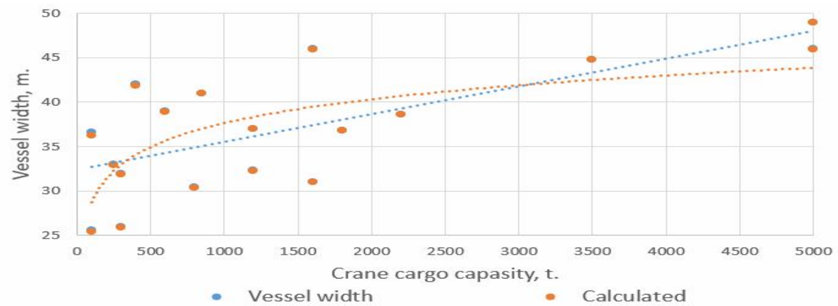


*Fig. 8(b). Dependence of crane cargo capacity and vessel width*

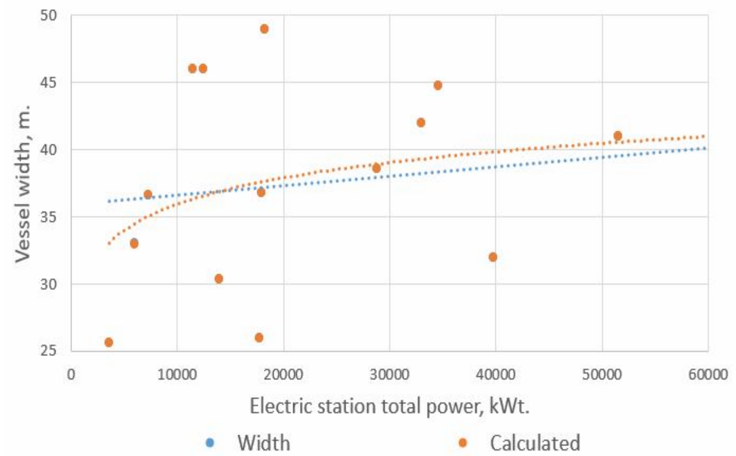


*Fig. 9(a). Dependence of the vessel power station total power and vessel width*

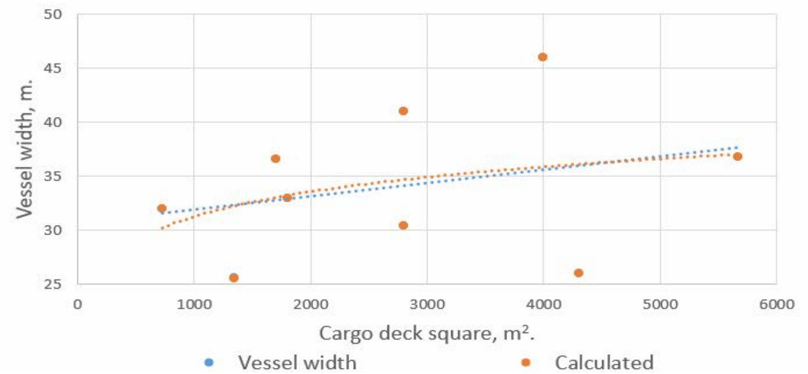


*Fig. 9(b). Dependence of the vessel cargo deck square and vessel width*

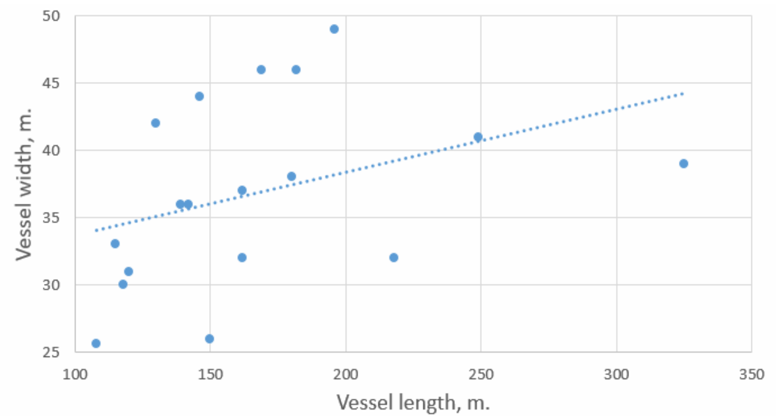


*Fig. 10(a). Dependence of the vessel length and width*

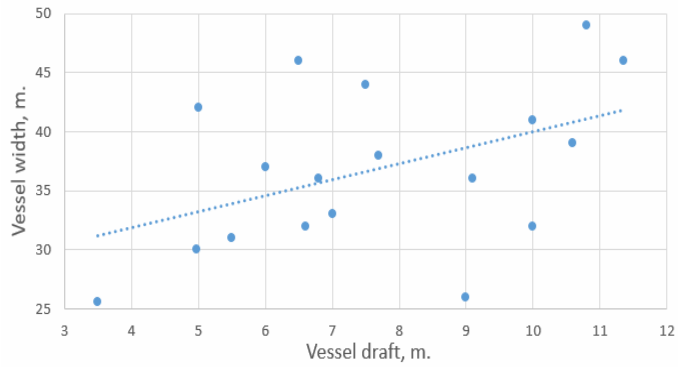


*Fig. 10(b). Dependence of the vessel draft and width*

Using the conducted research, the nomogram [8-10], which was earlier developed and described in publications, was added with parameters of pipe lay equipment. The definition of the main dimension, according to the new nomogram in Fig. 11., is made in the listed below sequence:

**1.** The selection width of the vessel in the presence of a pipe lay equipment in parameters reflected in horizontal scales at the bottom of the nomogram:

– is select the value added to the nomogram, depths or speeds a pipe laying, set in the conditions of design of the vessel (set in the lower part of the nomogram);

– we draw a vertical line before crossing from a curve the corresponding name up;

– from the point of intersection of the vertical line and the corresponding curve it is drawn a horizontal line before crossing with a vertical scale of the width of the vessel to the right;

– the point of intersection of a horizontal line and vertical scale indicates the required width of the vessel.

**2.** Finding the greatest value of the width of the vessel:

– having carried out actions on depth and speed a pipe laying to independence from each other, we receive various values of width of the designed vessel;

– from the received width values, the greatest gets out for the designed vessel.

**3.** Select the vessel length:

– from the received value of the width of the vessel on a vertical scale, we draw a horizontal line before crossing from the curve length of the vessel with pipe-lay equipment;

– from the point of intersection of a horizontal line and the corresponding curve length of the vessel, we draw a vertical line to a horizontal scale in the top part of the nomogram reflecting vessel length with a pipe lay equipment;

– The point of intersection of the vertical line and horizontal scale of the vessel's length reflects the vessel's length and the necessary value of the length of the designed vessel.

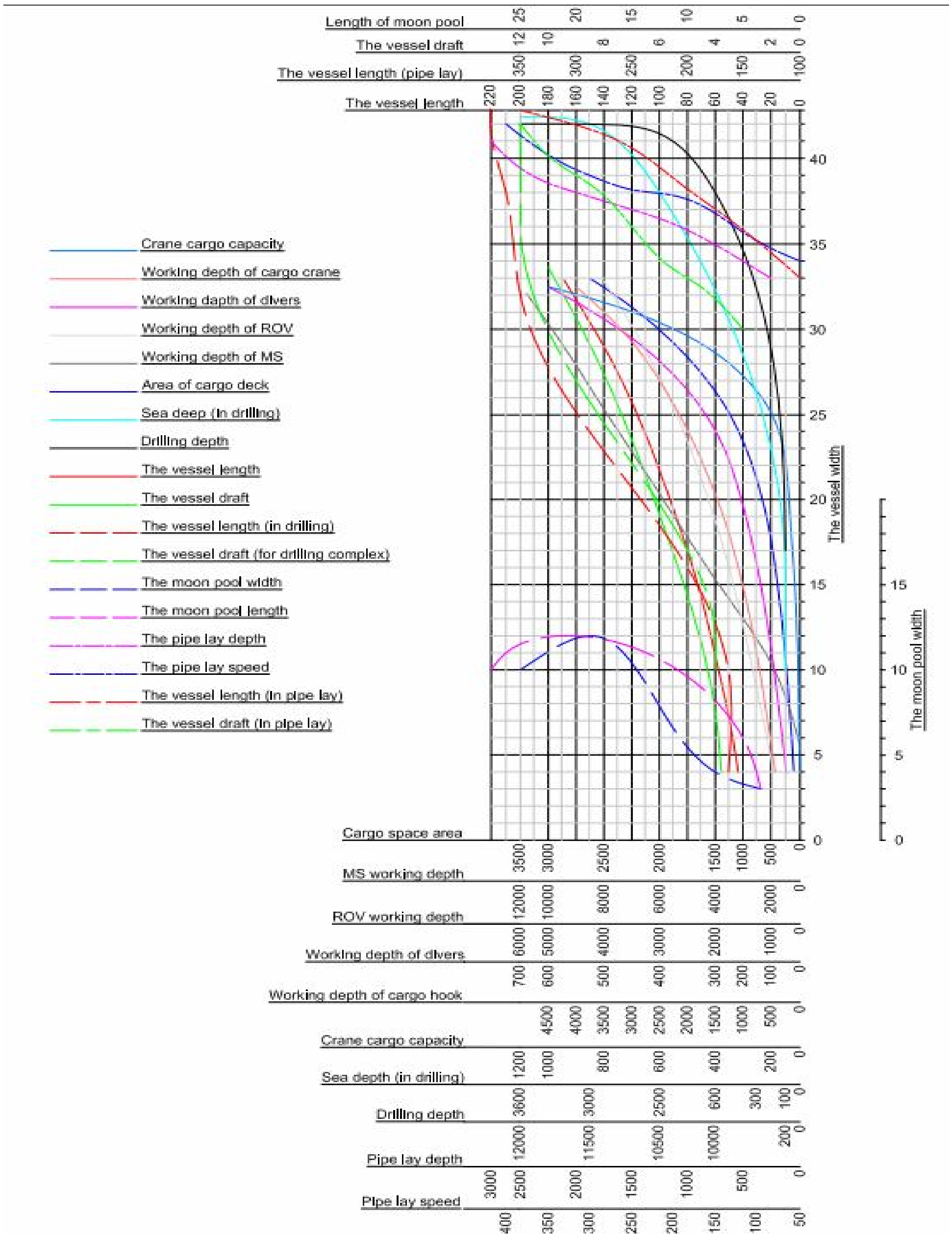


*Fig. 11. The nomogram of definition of the main dimension of SCV the complemented pipe lay equipment*

**4. Select the vessel draft:**

– from the received value of the width of the vessel on a vertical scale, we draw a horizontal line before crossing from the curve draft of the vessel with pipe-lay equipment;

– from the point of intersection of a horizontal line and the corresponding curve draft of the vessel, we draw a vertical line to the horizontal scale in the top part of the nomogram reflecting the vessel draft up;

– the point of intersection of the vertical line and horizontal scale of the vessel's draft reflects the necessary value of the draft of the designed vessel.

**5. Formation of the main dimension of SCV in parameters a pipe lay operations.** Counting main dimension of SCV in parameters assumed to installation on the vessel a pipe lay equipment, with use of models of optimization (6), (7) and (8), we select optimization conditions:

$$L_{\left(S_{dp} \cup S_{sp}\right)} = C_n \left(\sum_{n=1}^{n} X_L\right) \to L_{mid} \tag{6}$$

$$B_{\left(S_{dp} \cup S_{sp}\right)} = C_n \left(\sum_{n=1}^{n} X_B\right) \to B_{max} \tag{7}$$

$$d\left(S_{dp} \cup S_{sp}\right) = C_n \left(\sum_{n=1}^{n} X_d\right) \to d_{min} \tag{8}$$

here $L$ – the vessel length, m;

$B$ – the vessel width, m;

$d$ – the vessel draft, m;

$L_{mid}$ – average size of length of the vessel;

$B_{max}$ – maximum size of the vessel width;

$d_{min}$ – minimum size of the vessel draft.

Having received the main dimension of SCV (see Table 2) determined by the nomogram (Fig. 11) with use of such parameters as depth and speed a pipe laying, we select optimum main dimension of SCV taking into account optimization conditions on models (6), (7) and (8). Using the formula (3) and dependences received from the database (fig. 3-9), we receive the SCV other parameters in Table 3.

*Table 2*

*Matrix of optimization of the main dimension of SCV*

| **Parameters a pipe laying according to the nomogram (fig. 34)** | **L** | **B** | **d** |
|---|---|---|---|
| On depth pipe laying | 110 | 33,5 | 5,5 |
| On speed pipe laying | 110 | 34,5 | 6 |
| **The received main dimension** | **110** | **34,5** | **5,5** |

Thus we receive key parameters of the SCV when using a pipe lay equipment (see Table 3).

Considering that the nature of the work of the SCV consists of the joint work of the installed technological complexes, each of them leaves its mark on the formation of the main dimensions of the SCV. The subsequent stages of the study are supposed to consider the influence of the installed mobile technological complexes on the main dimensions of the SCV and derive the optimal values of the main dimensions.

*Table 3*

*Basic data of SCV, in parameters a pipe lay complex*

| | |
|---|---|
| Length, m | 110 |
| Width, m | 34,5 |
| Draft, m | 5,5 |
| Cargo deck square, $m^2$ | 2000 |
| Cargo deck dimension, (length × width), m | 60×33,4 |
| Displacement, t | 18000 |
| Cargo capacity, t | 7650 |
| Specific load of cargo deck, $t/m^2$ | 2,5 |
| Main cargo crane capacity, t | 300 |
| Block coefficient, $C_b$ | 0,862 |
| Electric station total power, кВт | 15000 |
| Number of main diesel-generators, pies. | 6 |
| Accommodation capacity, man. | 250 |
| Pipe lay depth, m | 300 |
| Pipe lay speed, m/h. | 65 |
| The pipe diameter, mm | 1500 |

## 6. CONCLUSION.

The work describes the parameters of pipe-laying vessels that have been successfully operating in the Caspian Sea for a long time.

A system analysis was conducted, and a mathematical model was developed to study the design process of the SCV, taking into account the use of pipe-laying equipment on the vessel.

The dependencies of the parameters of the pipe-laying equipment and the vessel were compiled and described. The previously developed nomogram for determining the main dimensions of the SCV when using pipe-laying equipment was supplemented.

A model for optimizing the main dimensions of the SOPTR was formed based on the dependencies performed and the developed nomogram.

The main necessary and sufficient parameters of the SOPTR were developed to perform pipe-laying operations in the Caspian Sea basin.

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