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RISK ANALYSIS IN THE INITIAL DESIGN PHASE OF SUBSEA CONSTRUCTION VESSELS

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Xülasə. *Məqalədə sualtı-texniki işləri təmin edən gəmilərin layihələndirilməsi zamanı yaranan risklərin aşkar edilməsi, təhlili və idarə olunması məsələləri araşdırılmışdır. Bir gəmilərdə çoxsaylı texnoloji avadanlıqların və mürəkkəb mühəndis sistemlərinin birləşdirilməsi istismar zamanı yüksək risk səviyyəsinə gətirib çıxara bilər. Təhlükəsiz və səmərəli layihələndirməni təmin etmək məqsədilə sistemli analiz üsullarından istifadə olunmuş, risklərin struktur modeli və riyazi təsviri hazırlanmışdır. Konstruktiv, texnoloji, istismar və ekoloji kateqoriyalar üzrə risklər müəyyənləşdirilmiş, onların qiymətləndirilməsi aparılmış və qabaqlayıcı tədbirlər sistemi formalaşdırılmışdır. Təklif olunan yanaşma layihənin təhlükəsizliyini artırmağa və oxşar texniki sistemlərin layihələndirilməsi zamanı tətbiq edilə biləcək metodoloji əsas yaratmağa imkan verir.*

Abstract. *In this article questions of identification, the analysis and risk management, arising at design of subsea construction vessel. Association on one vessel of a large number of technology equipment and complex engineering systems can result in high risk level at operation. For ensuring safe and effective design methods of the system analysis were used, the structural model and the mathematical description of risks of the project are developed. Risks on constructive, technological, operational and ecological categories are revealed, their assessment is carried out and the system of preventive measures is created. The offered approach allows to increase safety of the project and to create a methodological basis of its application at design of similar technical systems.*

Аннотация. *В данной статье рассмотрены вопросы выявления, анализа и управления рисками, возникающими при проектировании судов обеспечения подводно-технических работ. Объединение на одном судне большого количества технологического оборудования и сложных инженерных систем может привести к высокому уровню риска при эксплуатации. В целях обеспечения безопасного и эффективного проектирования были использованы методы системного анализа, разработаны структурная модель и математическое описание рисков проекта. Выявлены риски по конструктивным, технологическим, эксплуатационным и экологическим категориям, проведена их оценка и сформирована система превентивных мер. Предложенный подход позволяет повысить безопасность проекта и создать методологическую основу его применения при проектировании аналогичных технических систем.*

Açar sözlər: *risklərin analizi, gəmilərin layihələndirilməsi, çəki yükünə nəzarət, sualtı təminat gəmisi, gəminin sürəti*

Key words: *risk analysis, ship design, weight control, subsea construction vessel, vessel speed*

Ключевые слова: *анализ рисков, проектирование судов, контроль весовой нагрузки, судно обеспечения подводно-технических работ, скорость судна*

Introduction. Use of a large amount of expensive technology equipment, the apparatus and diving complexes described in many sources [1-9] of the subsea operation concentrated within one subsea construction vessel, raises degree of risk of operation of the perspective vessel. For anticipation of emergencies and ensuring safe work, we made the analysis of the main risks arising during the work of the subsea construction vessel. The risks connected with design of subsea construction vessel are considered and carried out: systematization, identification, description, analysis of risk, mathematical model also developed, sources of risks were identified and a system of actions to prevent risks was developed.

System analysis and mathematical model of risk analysis. Design and further operation of such complex technical systems as the sea vessel, in particular the subsea construction vessel (SCV), is a multifaceted task requiring strict systematization of the actions performed. At the same time, at design of the vessel on the basis of the theory of risk, use of methods of the system analysis [10, 11] repeatedly increases the probability of faultless design and will allow to systematize the factors participating at design. Thus, solving the problems described in the real work the structural model describing the sequence of performance of risk analysis at design of the SCV was made. Lower the formula (1), described mathematical model of process of risk analysis at design of the SCV.

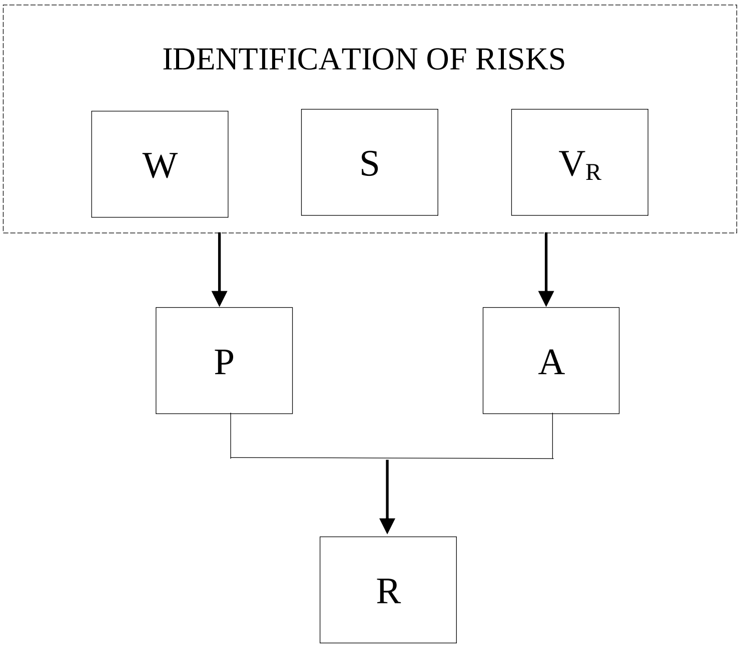

Fig. 1. *The block diagram of risk analysis at design of the vessel*

here W – the risks arising when forming weight loading of the vessel;
S – the risks arising when forming the main dimension of the vessel;
V_R – the risks arising when calculating vessel speed;
P – description of risks;
A – risk analysis;
$A_{(X)}$ – sum of private factors of risk analysis (1);
R – system of actions anticipatory risks.

$$A_{(X)} = A_W + A_S + A_v \quad (1)$$

here A_W – risk analysis when forming weight loading of the vessel;
A_S – risk analysis when forming the main dimensions of the vessel;
A_v – risk analysis when calculating vessel speed;

$$A = A_{(X)}(W, S, v) \cap P\ (W, S, v) \quad (2)$$

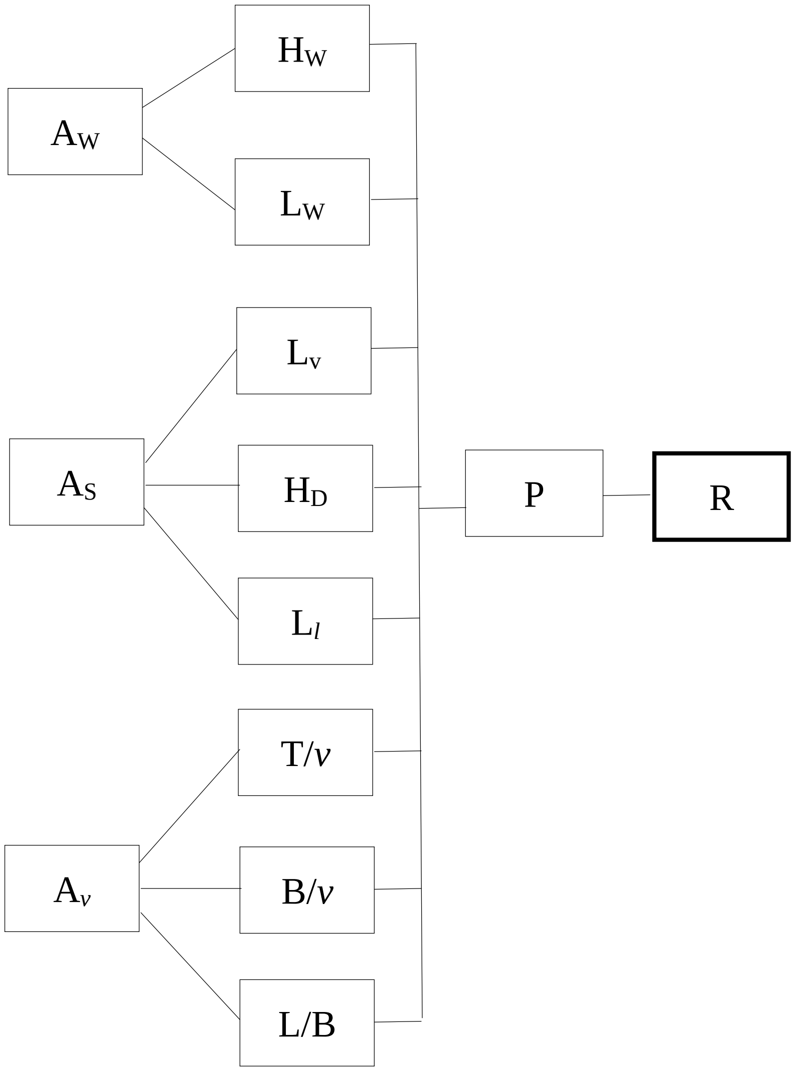

Fig. 2. *The block diagram of a system of the actions anticipating risks at design of the vessel*

here H_W – factor risk analysis describing weight increase of the vessel;
L_W – factor risk analysis describing weight decrease of the vessel;
L_v – factor risk analysis describing reduction of vessel speed;
H_D – factor risk analysis describing increase in displacement of the vessel;
L_l – factor risk analysis describing deterioration in stability of the vessel;
T/v – factor risk analysis describing the incorrect select of ratios of draft and vessel speeds;
B/v – factor risk analysis describing the incorrect select of ratios of width and vessel speeds;
L/B – factor risk analysis describing the incorrect select of ratios of length and vessel width;

Being guided by block diagrams (see fig. 1 & 2.) and the mathematical model describing formation of risk analysis (2) identification, the description is carried out and the system of actions anticipating risks described by formula (3) is developed.

$$R = P(A_W(H_W, L_W) \cap A_S(L_v, H_D, L_l) \cap A_v(T/v, B/v, L/B)) \quad (3)$$

Thus the developed block diagram and mathematical model of risk analysis, gives the chance to systemically make the analysis, identification and the description of risks, to define sources of their emergence. It will give the chance to offer the system of actions for anticipation of risks and to classify the risks arising when forming weight loading, the main dimensions and when calculating vessel speed.

Identification risks. Identification and classification risks. In a designing process of the vessel providing carrying out subsea operation, the correct identification and classification of risks is one of key stages. This stage demands the system analysis of information arriving from various sources including normative documents on design and operation, results of similar projects and also expert estimates.

Risks were identified and classified by the following main categories:

• **Design risks (DR):**
- Inexact assessment of loading capacity of the vessel;
- Insufficient calculation of durability of the hull;
- Non-optimal select of the main dimension of the vessel.

• **Technological risks (TR):**
- Technological uncertainty at placement of the subsea equipment;
- Ignoring of hydrodynamic influences;
- Incompatibility at integration of the equipment.

• **Operational risks (OR):**
- Probability of refusal of diving complexes;
- Interruptions in the system of power supply;
- Shortcoming or delay in delivery of spare parts.

• **Ecology and Environmental risks (EER):**
- Ignoring of changes in the marine environment;
- Probability of emergence of environmental impacts;
- Inefficiency of countermeasures in the conditions of natural disasters.

Within each category of risks concrete risk factors and extent of their influence on the project were defined and analyzed. In the course of identification of risk, the following methods were applied (see Table 1):

• Expert polls and assessment;
• Databases of the previous similar projects;
• Risk matrixes and trees of decisions;
• Analyses SWOT & PEST.

Table 1

Further risks were grouped in extent of influence and probability of emergence as follows:

Risk level	Extent of influence	Emergency probability	Priority
A (High)	Strong	High	Urgent measures
B (Average)	Average	Average	Planned measures
C (Low)	Low	Low	Monitoring

Based on this classification, the basis for risk analysis and management strategies were formed in subsequent stages of the project.

When forming the appearance of a prospective vessel, among a large number of risks, the following risks are highlighted as the most important ones when forming the design constraints of the designed vessel (see Table 2):

– the risks arising when forming weight loading at a stage of initial (research) design of the vessel;

- the risks arising when forming the main dimension of the perspective vessel at a stage of initial (research) design;
- the risks arising when calculating speed of the designed vessel.

Table 2

The analysis of the identified risks

Risks, when forming weight loading of the vessel	**Risks, when forming the main dimension of the vessel**	**The risks arising when calculating vessel speed**
Errors of the designed vessel weight loading, as a result can bring: 1. To weighting of the vessel that in turn will effect on: – displacement increase; – increase in the actual draft; – loss of speed (in connection with v/T ratio); – to reduction of loading capacity, as a result possibilities of use of technology equipment are narrowed. 2. To weight loss of the vessel that in turn will effect on: – reduction of displacement; – deterioration in stability of the vessel; – increase in value of "ballast "weight; – problems when using technology equipment.	The incorrect select of the main dimension ratios and formation of the main dimension on the select ratios, as a result can bring to: –receiving less than predicted speed; –receiving more than predicted displacement; –to deterioration of stability. In the all listed cases can lead problems in operation of technology equipment.	Errors when calculating vessel speed can bring to: – incorrect select of T/v ratios; – incorrect select of B/v ratios; – incorrect select of L/B ratios.

Description of risks. Analysis and risk assessment. At design of the vessel providing carrying out subsea operation, each of the revealed risks it was analyzed and estimated on extent of influence and probability of emergence. Risk analysis purpose – to reveal risks with a high priority and to provide timely acceptance of the appropriate measures on their prevention.

Risk analysis was carried out via two main directions:

1. The analysis on the basis of quality indicators – classification of risks on the basis of expert opinion, data on similar projects and to standard documentation;
2. The analysis on the basis of quantitative indices - calculation of degree of risk with application of mathematical modeling, statistical data and probability theory.

At assessment for each risk factor the following parameters were determined (see Table 3):

- Extent of influence (T) – potential negative impact of risk on the project or operation;
- Emergence probability (E) – probability of realization of this risk;
- Index of risk (RI) – the indicator defining the total risk level calculated by the following formula (4):

$$RI = T \times E \quad (4)$$

here:

• T – influence force on a scale from 1 to 5 points (1 – minimum, 5 – critical),
• E – probability on a scale from 1 to 5 points (1 – very low, 5 – very high).

Table 3

Evaluation criteria:

Range RI	Risk level	Influence	Type of actions
16–25	High	Critical	Urgent intervention, change of the progect
9–15	Average	Considerable	Detailed analysis and preventive measures
1–8	Low	Insignificant	there is enough monitoring and control

For example, if for risk of structural instability at load distribution on the vessel to accept T = 5 & E = 4, that RI = 20, what corresponds to category of high risk and demands immediate intervention.

As a result of the risk assessment, all risks were classified according to their priority level, and an action plan for their management was developed.

The risks arising at a stage of initial design, in particular formation of weight loading definition of the main dimension and calculation of vessel speed are described as:

– errors of weight distribution formation of weight loading;
– incorrect select of the main dimension’s ratios;
– errors when calculating vessel speed.

In table 2, the analysis of the identified risks for initial design stage is provided. The insufficient weight load according to part concerning the displacement of the designed vessel can be sources of risks. At the initial design stage, when forecasting weight load for displacement of the designed vessel a large number of factors should be influences. It is possible to carry errors of the select of the weight loading in the top and lower limits to similar factors, unjustified forecasts of the equipment weight, a mistake when calculating and selecting coefficients of completeness and the main dimensions.

The incorrect select of ratios of the main dimensions of the perspective vessel, on initial design stage, can arise at the incorrect select of the sizes in the maximum and minimum limits of the main dimension’s ratios.

As link with the previous risk, the greatest influence on vessel speed among big quantity of factors, in relation to the considered task renders errors when selecting the main dimensions and coefficients of completeness.

Risk management and preventive measures system. Risk management is a complex of the consecutive and system actions which are carried out for the purpose of minimization of dangers at design and operation stages. For prevention of the hi-tech and design risks arising at design of the vessel providing carrying out subsea operation the comprehensive strategy of risk management was developed.

This strategy includes the following main stages:

1. Mitigation in risks:
   • Application of alternative technical solutions in design;
   • Planning of reserve decisions (redundancy) for critical components;
   • Optimal material selection and integration of modern technologies;
   • Check of loading by means of test models in the conditions approximate to real.
2. Transfer in risks:
   • Transfer of separate technical risks through insurance or to contractors;
   • Accurate distribution of responsibility in contracts with suppliers.
3. Acceptance in risks:
   • Monitoring of risks of low level with the minimum influence;
   • Development of reserve plans (the Plan B) on a case of realization of such risks.

4. Prevention of the risks:
   • Strengthening of the tests procedures and checks;
   • Carrying out the training programs for risk management for technicians and design group;
   • Application of iterative (repeated) checks at a design stage.

The main objective of a control system is expressed as follows (5):

$$R_{eff} = R - (M + T + P) \quad (5)$$

Here • R – initial risk level;
• M – efficiency of actions for risk reduction (mitigation);
• T – the volume of the transferred risks (transfer);
• P – the size of the prevented risks (prevention);
• R_{eff} – residual risk, i.e. real risk level which is subject to management after end of the project.

The developed system of preventive measures allows to reduce risks to the acceptable manageable level and ensures compliance of the project to criteria of quality, safety and functionality.

Description of risks. Risk analysis is made for formation of actions for anticipation of the identified risks at a stage of initial (research) design.

System of actions anticipatory risks.

1. It is necessary for anticipation of the risks connected with formation of weight loading:
– at initial design stages to make the reasonable select of the predicted values of weight loading being based on the data of the vessel of a prototype or statistical data on the same vessels;
– at initial design stages to predict, necessary value of a stock of displacement;
– at all stages of creation of the vessel, from development of the idea before delivery of the vessel in operation to make strict control of formation of weight loading.
2. It is necessary for anticipation of the risks connected with formation of the vessel main dimensions:
– at initial design stages to show consideration and carry out evidence-based calculations of the main sizes of the perspective vessel;
– to show consideration for the select of a close prototype or statistical data of the same vessels;
– when selecting or calculating the main dimensions of the vessel to consider the most adverse operating conditions of technology equipment and complexes.
3. It is necessary for anticipation of the risks connected with calculation of speed:
– at all design stages and constructions of the vessel to watch closely change of the conditions considered during the calculating of speed, a research in the model testing basin and at computer modeling of the shell (CFD);
– at a design stage to connect theoretical calculations of seagoing qualities of the vessel with calculation of vessel speed.

Thus, the carried-out analysis, identification and the description of risks, defined sources of their emergence. Are brought the system of actions for anticipation of risks. By the analysis of the identified risks it is established that all considered risks are interconnected. Anticipation of the identified risks it has to be made at all design stages and construction of the perspective vessel. Risks when forming weight loading, the main dimension are classified and the vessel speeds arising when calculating.

Conclusion. As a result of a research the complex methodology on identification, the analysis and risk management, arising at design of the vessels providing carrying out subsea operation was developed. Thanks to the carried-out system analysis and mathematical modeling at an analytical stage of the project the following main results were received:

1. The main risks arising in a designing process were revealed, their sources were analyzed and their structuration was executed;
2. Risks were classified by character on designs, technological, operational and ecological groups and also estimated on the probability of emergence and extent of influence;
3. On the basis of mathematical model calculation of indexes of risk is made and their priorities was carried out;
4. The four-stage system of preventive measures for risk management (mitigation, transfer, prevention and acceptance) is created;
5. As a result of application of this technique effective mechanisms on decrease in the general level of risks within the project and to increased security were offered.

The received results demonstrate that system risk management at design of difficult technological objects, such as subsea construction vessel, is an important condition of successful and reliable implementation of the project. The developed model and methodology can be applied and improved in other similar projects of marine engineering.

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