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Ice load monitoring system for an ice-resistant self-propelled drifting platform "North Pole"

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ABSTRACT

The ice-resistant self-propelled drifting platform (IRSPP) is intended to perform the functions of a research station in prolonged drift conditions, lasting up to two years, together with the surrounding ice massif. The platform is equipped with a unique ice load monitoring system (ILMS), which will perform two functions: operational function - ensuring the safe operation of the IRSPP in the ice conditions and scientific function - to be a measuring tool for research the mechanics of deformation and destruction of ice at interaction with engineering structures and natural objects. A distinctive feature of the system is that the strain sensors are installed not only on the platform hull, but also in the surrounding ice field during the drift. The technical requirements to the ILMS were developed in the Department of Ship Performance in Ice of the AARI. The contents of the system was determined based on the characteristics of the operating modes of the IRSPP, the analysis of ice conditions and ice loads impact scenarios on the hull, the results of model tests in the ice tank, as well as the expedition "Transarktika-2019" onboard the R/V "Akademik Tryoshnikov", where the technology of ice loads monitoring system in drift conditions had been tested. The ILMS allows to get the following set of data: parameters of the stress-strain state of the IRSPP hull; stress-strain state of the surrounding ice field; kinematic parameters of the IRSPP motion; parameters of the surrounded hydrometeorological conditions; parameters of the IRSPP propulsion complex; IRSPP coordinates, speed, course. Equipping the IRSPP with such a monitoring system gives the platform hull the function of a measuring instrument for a wide range of studies.

KEY WORDS: Monitoring system; Ice loads; Drifting ice-resistant platform; Arctic research.

INTRODUCTION

At the present time many engineering structures and ships operating under the ice conditions are equipped with ice load monitoring systems (ILMS) in order to prevent unfavorable consequences from the ice impact.

The ILMS presents a complex system, which performs a continuous control of the strain-stress state of the structure under the action of ice loads using instrumental methods. The ILMS consists of the set of sensors, the main goal of which is to measure physical values, and the software part, which is intended for processing of signals. If the values of signals exceed the established threshold, the system gives a warning. In this case the system's operator can undertake measures to decrease the acting load level.

On 18 December of 2020 the ice-resistant self-propelled drifting platform (IRSPP) "North

Pole” was launched at the JSC “Admiralty Shipyards” (Saint-Petersburg, Russia). This platform will replace the classical drifting research stations “North Pole”, which based earlier on drifting ice floes of the central massifs of the Arctic Ocean. The platform is intended for performing functions of research station under the conditions of drift together with the surrounding ice massif. The duration of continuous drift will be up to two years.

A wide range of scientific work will take place during the drift of the IRSPP. Its scientific complex includes 16 different laboratories and there is a laboratory of ice loads monitoring among them. The platform is a unique facility, the peculiarities of its operation required developing of a non-standard system of monitoring ice loads. In addition to providing safe operation of the platform, the system has to perform scientific functions. So, ILMS will become a measuring complex for fulfilling the scientific objectives in the area of mechanics of sea ice deformation and destruction at interaction with ships and marine structures. The system was designed by specialists of the Department of Ship Performance in Ice of AARI jointly with the “NTI” Company. The article describes the stages of development and operating procedures of ILMS for the IRSPP.

GENERAL DESCRIPTION OF THE IRSPP

The IRSPP presents a self-propelled displacement-type steel vessel. The hull strength at the sides and bottom corresponds to Ice class Arc8 of Russian Register classification, which allows the ship to withstand pressures of multiyear ice. The platform will have the following main particulars: length overall / by DWL — 83.1 / 76.7 m, breadth overall / by DWL — 22.5 / 21.8 m, the height at the middle-body — 11.4 m, draft by DWL / minimal — 8.6 / 7.5 m. The maximum displacement will be about 10400 t. At the power plant capacity of 4200 kW, the cruise speed in quiet deep water will be not less than 10 knots. 3D-model of the IRSPP and photo of real platform launched at the JSC “Admiralty Shipyards” are shown in Figure 1.

Figure 1.General view of the IRSPP: 3D model (left) and the IRSPP launched to water (right)

The IRSPP will make it possible to address the scientific objectives in high latitudes of the Arctic, providing safe and comfortable conditions for the scientists onboard. The objectives will be fulfilled as during the drift in ice as during transits from/to the point of basing. A more detailed description of the IRSPP scientific complex was discussed in (Makarov, et al., 2019).

PRELIMINARY STAGES OF ILMS DEVELOPMENT

Ice load scenarios and ice conditions

Joint analysis of scenarios of ice load impact on the IRSPP and ice conditions for different stages of IRSPP operation was performed. As a result, the most exposed to ice action areas of the hull were identified.

The main scenario of platform operations is the drift in ice and carrying out scientific studies. The platform should also make a transit from the point of basing to the place of the drift and back. Therefore, the following two main scenarios of ice impact on the IRSPP hull of can be identified:
– impact loads on the bow and stern at motion under the ice conditions (both during transit and mooring to an ice floe);

– loads from compression ice on the midbody part of the platform during ice drift.

It is supposed that the platform will begin its drift in the Eastern sector of the Arctic, similar to the traditional drifting stations “North Pole”. Thus, the route to the point of the drift start will pass from west to east, crossing the seas of the Russian Arctic. Analysis of long-run annual data on the navigation conditions at the routes of the Northern Sea Route (NSR) (Borodachev, 1998; Gorbunov, et al, 2008; Alekseeva, et al, 2018, Buzuev, et al, 1981) shows that August-September are the most suitable months for the IRSPP transit to the point of the drift start.

In spite of relatively small thickness of residual ice in the summer-autumn period, interaction of the platform with ice features up to 3 m thick is not excluded. It can be impact with ice ridge or rafted ice. But the ice cover is at the stage of melting and therefore it has low strength. And also, the platform motion speed will not exceed 10 knots even at the maximum shaft power. Thus, impact ice loads on the platform will be relatively low at navigation ice conditions during the summer-autumn period.

The IRSPP will operate in the same regions as the drifting research ice stations "North Pole". Therefore, for assessment of ice conditions of platform operation, an analysis of ice conditions from stations “North Pole” in 2004—2015 was performed. At the drift beginning (September—October) the ice thicknesses mainly comprised about 1.5—2.0 m. The maximum ice thickness achieved in the spring period and exceeds 2.5 m in most measurements.

Thus, at any stage of IRSPP operation, interaction with ice more than 3 m thick is possible. However, taking into account that the most of the time (about 95%) the platform will drift in ice, the monitoring system is primarily aimed at monitoring the state of the midship part of the hull under ice compression. Nevertheless, the need of monitoring the bow and the aft end at motion in ice conditions is not excluded.

Model tests

To evaluate the influence of ice compression on the IRSPP hull, model tests were carried out in the AARI ice tank (Svistunov, et al, 2019; Svistunov, 2020). The aim of model tests was to obtain an experimental assessment of the loads from compressed ice to midship part of hull (Figure 2). During the experiments, ice loads, and size and distribution of ice piles along the sides of the platform and under the bottom were recorded. Based on the results of model tests, the areas of hull which should be equipped by sensors of ILMS for monitoring ice loads during IRSPP drift were determined.

Figure 2. Model tests of the IRSPP in the ice tank

Testing of technology of ice load monitoring under the drift conditions

In spring of 2019, the expedition “Transarktika-2019” onboard the research-expedition vessel (R/V) “Akademik Tryoshnikov” (Figure 3) was carried out with the purpose of testing the technologies of platform operation. The ship was frozen into ice and during the month the scientific studies were made both from the ship herself and from the camp, deployed on the ice. One of the expedition objectives was to collect the data required for development of ILMS for the platform and testing of the IRSPP prototype under the drift conditions (Maksimova, et al, 2020).

Figure 3. The drift of the R/V “Akademik Tryoshnikov”

The R/V “Akademik Tryoshnikov” is equipped by factory installed ice loads monitoring system. To carry out measurements in the “Transarktika-2019” expedition, the standard ILMS was supplemented with additional strain gauges in the midsection of the hull. Based on the results of measurements a number of peculiarities in the operation of ILMS was determined, which were taken into account in the design of the monitoring system for the IRSPP. The following decisions were accepted:

- use of fiber-optic sensors instead of electric ones (due to their greater reliability and durability);
- need for use of the temperature compensation sensors (to eliminate hull deformations associated with air temperature changes);
- include the subsystem of the stress-strain ice floe state and the subsystem of control of meteorological situation in ILSM (to expand the range of scientific problems that can be solved using this system).

FUNCTIONS OF ILMS

As mentioned above, the tasks of the ILMS include performing both operational and scientific functions. They are as follows.

Operational function

For this an instrumental evaluation of the stress-strain state (SSS) of the IRSPP hull is performed, including:

- provision of navigator with real-time information about the IRSPP hull state at motion in ice and during the drift;
- comparison of the actual stress level with established threshold values;
- issuance of warning in the case where readings approach the threshold values.

It should be noted that the architectural and structural type of the platform and its main dimensions are such that the overall strength of the hull is guaranteed to be ensured under any ice actions. Therefore, the control of the overall strength of the hull is not included in the tasks of the ice load monitoring system.

Scientific function

The scientific function of ILMS is provision of overall studies of mechanics of ice deformation and destruction.

Of greatest interest appear to be the processes of platform hull interaction with ice, occurring at ice compression during the drift. An important problem is the full-scale measurements of ice loads, in particular, an assessment of non-uniformity of ice pressures, estimate of pressure dependence on the ice characteristics and parameters of the contact spot and evaluation of the peak and mean pressure ratio.

The ILMS will allow to investigate the processes of ice destroying longways the platform's hull, formation of ice piles near the side, ice spreading to beneath the bottom, and also perform measurements of these ice loads. Such studies were not possible before, as the monitoring systems installed onboard the ships are not intended for measurement of loads under the conditions of ice compression.

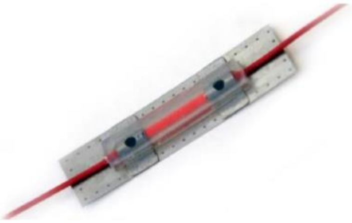
Another important task is joint study of the stress-strain state of the adjoining ice cover and the stress-strain state of the IRSPP hull. The sensors of the monitoring system provide a unique opportunity, when ice compression occurs, to perform synchronous measurements of both stresses in the ice cover and stresses in hull structures and then compare the obtained values. Such data will help develop new, more accurate models of ice destruction and ice/structure interaction.

Finally, an important task is verification of the existing methods of calculation of the stress-strain state of the hull at ice loads.

ARCHITECTURE OF THE ICE LOAD MONITORING SYSTEM OF THE IRSPP

The following subsystems were included to ILMS to provide all the functions of the ILMS.

The main ILMS subsystem is the **hull stress monitoring subsystem**, which is necessary for measurement of the IRSPP hull stress-strain state parameters under the action of ice loads at various operation modes of platform. The measurements will be performed using a branched system of fiber optic sensors located on the hull structure elements. The following sensors are included to the subsystem:
– uniaxial fiber optic strain gauge ASTRO A521 (Figure 4 (a));
– triaxial fiber optic strain gauge ASTRO A527 (Figure 4 (b);
– fiber optic temperature sensor ASTRO A513 (Figure 4 (c)).



(a)

(b)

(c)

Figure 4. Fiber optic sensors used in hull stress monitoring subsystem

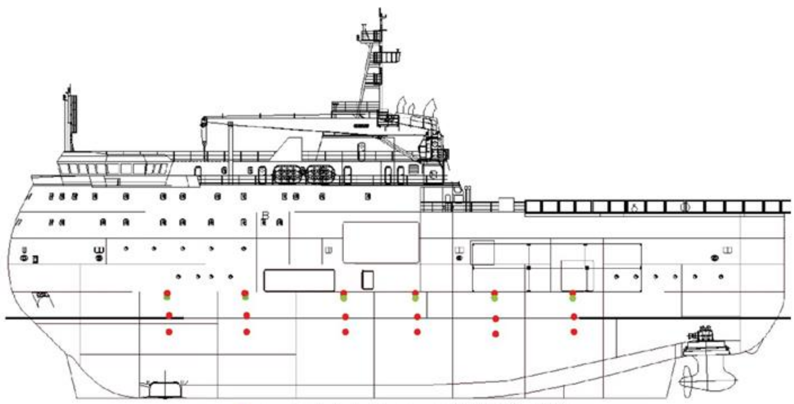
The fiber optic strain gauge ASTRO A521 is intended for measuring deformations of a structural element in one direction. The fiber optic strain gauge ASTRO A527 is intended for measuring deformation simultaneously by three axes and determine a full strain tensor for a flat stress-strain state of a structural element. The fiber-optical temperature sensor ASTRO A513 is intended for temperature measurement of the IRSPP structure elements. The second purpose of the sensors of this type is provision of temperature compensation of strain gauges. The signals recorded by hull stress monitoring subsystem are received by 8-channel analyzer ASTRO A313. Each channel allows connection of up to 25 sensors.

The finite element analysis of the stress-strain state of the IRSPP hull under the action of ice load was carried out in order to determine the installation locations of the subsystem sensors. The finite-element model was created for one of the midship sections since the hull structure is practically constant over much of the hull. The section is located between the main transverse bulkheads by the length and between the base plane and the upper deck by the side height. The results of calculations were the maximum equivalent stresses in the shell plating and in the frames, longitudinal stresses in the free upper fibers of the frames at single pressure, maximum equivalent stresses in the plating assembly structure at single pressure, maximum stress coefficient value, and failure pressure values.

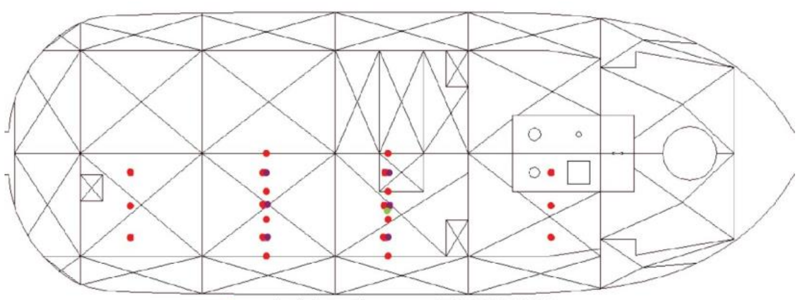
Since the stress-strain state of free upper fibers of the frames is close to one-dimensional, the uniaxial sensors are used for them. The stress-strain state on the surface of shell plating is flat, therefore, three-axial sensors are mounted.

The finite-element analysis allowed to determine the optimal number of sensors for performing all functions of hull stress monitoring subsystem. The subsystem includes 148 uniaxial strain gauges A521, 16 tri-axial strain gauges A527 and 20 temperature gauges A513. The sensors arrangement scheme at the platform's hull is given in Figure 5.

(a)



(b)



(c)

Figure 5. Location of sensors for monitoring the stress-strain state of the IRSPP hull: (a) — starboard; (b) — port side; (c) — bottom

The hull structure of the IRSPP is made according to transverse framing, including web frames, main frames and intermediate ice frames. The web frames spacing is 2100 mm, main frames spacing - 700 mm, and the intermediate frames spacing - 350 mm.

Uniaxial sensors are located on every third frame over 53.9 m along the hull length, with the horizontal pitch of the sensors is 2100 mm. The horizontal pitch of the sensors is reduced by 2 times in the midship and is 1050 mm over 18.2 m. This pitch of the sensors will provide a good system resolution and will allow to determine ice loads parameters during ice compressions, including its unevenness along the hull length.

Cant framing is used for the bow part of the platform. There are 8 sensors only located at the bow. This number of sensors is selected based on the fact that the active navigation in ice is not the main operation mode of the IRSPP. In addition, the IRSPP has limited power and speed, so the level of impact ice loads on the bow will be low. The expected transit period of IRSPP from August to October also contributes to the reduction of loads because the sea ice in the Arctic has the lowest strength characteristics during this period. In this regard, the authors believe that installing more sensors at the bow end will not bring any meaningful scientific information.

In connection with a significant change of the platform draft during the drift, the sensors are located in the form of two horizontal lines, which correspond to the maximum and minimum drafts.

From a scientific point of view, the distribution of loads both along the length of the hull and along the height of the side is of interest. In this regard, in several cross-sections of the platform, the sensors are located much deeper from the design waterline.

Some of the sensors are located on the bottom due to the possible spread of ice during compressions under bottom.

Uniaxial sensors of the A521 type are located on hull framing at points determined by the finite element method, in which the typical direction of deformation is clearly expressed. Uniaxial sensors are located under the upper deck to measure the deformation of the hull, which occurs due to the influence of ambient temperature. Their location is chosen in such a way as to avoid the ice impact. On the portside there are 18 gauges A521 type and at the starboard — 124, of which 20 are installed on the bottom.

The tri-axial sensors A527 type are located on the shell plating for measurement of the flat stress-strain state components. To evaluate the ratio of the stress-strain of framing and plating, the gauges are located near the frames, equipped with uniaxial strain sensors. All gauges A527 type are installed on the starboard (with 6 of them located at the bottom).

The temperature sensors A513 type are located on the shell plating near the strain gauges, placed under the upper deck, and also in the cross-sectional plane of the 55½ frame. There are 6 sensors A513 type on the port side and 14 sensors on the starboard are installed, of which 1 sensor is installed at the bottom.

The number of sensors was determined taking into account the limitations of the signal processing capabilities of the 8-channel analyzers used in the subsystem. Due to the limited number of sensors, they are mainly located along the starboard. There are a small number of sensors on the port side, and the points of their location are symmetrical to the points of the sensors on the starboard.

One more important ILMS subsystem is the **monitoring subsystem of SSS parameters of ice adjoining the IRSPP**, which is necessary for investigation of processes of ice floe interaction with the platform hull. This subsystem is additional and will connect with the ILMS during the platform drift only. 16-channel analogue-digital converter (ADC) will be used for data collection of the subsystem. A sampling rate of each channel is not less than 100 Hz. The digitized signal will be transferred to the ILMS server for record to united database. Any sensor with a current output of 4–20 mA can be connected to ADC. These sensors can be different in shape, size, number of measured parameters and measurement range. At the initial stage of platform operation, it is envisaged to use 6 most simple membrane pressure sensors with a diameter of about 20 cm filled with hydraulic fluid. These gauges are intended for freezing into the ice cover at a distance from the IRSPP of not less than 100 m. The membrane hull provides measurement of pressures, occurring in the ice cover up to 5 MPa. Six sensors can be installed at different horizons across the ice thickness. In general, authors want to get an idea of the ratio between stresses in the ice cover and the pressure that the ice exerts on the platform's side.

It should be noted that the number of the ADC channels provides extension of measuring capabilities in the future based on experience of real platform operation. The decision on the array of gauges will be made based on the actually chosen drift variant and morphometric peculiarities of the ice floe. From the experience of drifting stations “North Pole”, it is sufficient to measure the ice thickness at the same point once every 10 days to obtain a clear picture of the ice thickness change. The physical and mechanical properties of ice adjoining the IRSPP will be measured with the same frequency. Measurements can be performed more frequently if necessary (for example, at significant changes of air temperature or atmospheric precipitation). Also, the ILMS can be supplemented with a video recording system of the processes occurring near the platform side in the future.

The monitoring subsystem of IRSPP hull motions parameters as a solid body receives the data about yaw, pitch and roll angles, longitudinal, lateral and vertical accelerations of the platform hull from the general ship system of gyrocompass during IRSPP motion and interaction with ice.

The monitoring subsystem of meteorological parameters receives data about the wind speed and direction, air temperature and atmospheric pressure from the general automatic ship weather station. In addition, standard meteorological observations will also be conducted from a camp deployed on ice.

The monitoring subsystem of IRSPP coordinates receives data about geographical coordinates of the platform and motion parameters (speed, heading) from the general ship navigation system.

The monitoring subsystem of parameters of the IRSPP propulsion complex provides data about RPM, power, torque and rotation angle of azimuth thruster.

The subsystem of data collection, processing and analysis collects and stores data from all measurement subsystems. Recording is made with a frequency of 100 Hz in the form of united database. The storage capacity will make it possible to store information during 1 year of continuous recording.

SOFTWARE OF ILMS

The software package was designed by the NTI Company (St. Petersburg, Russia) on the basis of technical requirements developed by the AARI Department of Ship Performance in Ice. It should be noted that at the moment the software is a demo version and is being tested. The software has several insets with different functions:

- The inset "General view" presents main views of the platform with display of location of the strain gauges. The value for each gauge is given in the tabular form. It also displays current meteorological parameters, parameters of propulsion system and parameters of ship motion.
- The inset "Current data" displays data in real time in graphical format;
- The inset "Ice Floe SSS sensors" shows the location of sensors installed in the ice and the current value for each gauge;
- The inset "Database" displays any data of the system for the chosen time interval from the recorded archive in the graphical format; it is also possible to save the selected event to a separate file;
- The inset "Signaling" is intended for navigator and give information on hull structure stress levels during operation in ice. The main view of platform is divided into sectors, which are highlighted in different colors depending on the load level;
- The inset "List of events" displays the events recorded by the system in the tabular form (high hull structure stress level, faults in the system). Here it is also displayed a histogram with depiction of the number of events for the chosen time interval;
- The inset "Notes" displays the notes made manually in the tabular form with time marks;
- The inset "System" schematically displays the system architecture with color indication of the state and health of the system elements;
- The inset "Adjustments" allows to make adjustment of the system parameters.

The external view and the functional of the software can be changed in the future.

CONCLUSIONS

The developed ILMS is unique due to specifics of its purpose and platform operation conditions. Equipment of the IRSPP with such monitoring system gives to the platform hull functions of the measuring instrument for a wide range of studies. The use of the ILMS under drift conditions in ice will make it possible to carry out a set of measurements for investigating the processes of ice-IRSPP interaction. In this case, data will be obtained not only about the hull structure response to ice loads, but also about the parameters of the state of the environment, including the parameters of ice cover. In addition, installation of ILMS on the IRSPP will also allow to significantly increase safety of its operation in ice conditions.

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REFERENCES

Makarov, A.S., Maksimova, P.V., Likhomanov, V.A., Sokolov, V.T., Frolov, I.Ye., Chernov, A.V., Svistunov, I.A. Savitskaya, A.V. Perspectives of using a drifting ice-resistant platform of the "North Pole" type, which is under construction, as a multifunctional research complex in the Arctic. *Proceedings of the 25th International Conference on Port and Ocean Engineering under Arctic Conditions June 9–13, 2019, Delft, The Netherlands*. Available at: http://poac.com/Papers/2019/pdf/POAC19-123.pdf. [accessed 16.12.2019].

Borodachev, V.E., 1998. *Kara Sea ice*. Gidrometeoizdat: Saint-Petersburg. (In Russian).

Gorbunov Yu.A., Losev S.M., Dyment L.N., 2008. *Ice drift patterns in the Arctic Basin at typical baric situations. Reference manual*. SPb. AARI Publ, 35 p. (In Russian).

Atlas of the hydrometeorological and ice conditions of the seas of Russian Arctic: Generalization of the archive materials and field studies of the "Arctic Scientific-Designing Center of the Offshore Development" Ltd in 2012-2013. 2015. Moscow.: Neftyanoye Khozyaistvo (Oil Industry), 128 p. (In Russian).

Alekseeva T.A., Serovetnikov S.S., Frolov S.V., Sokolov V.T., 2018. Ice conditions of navigation in the Arctic Basin in summer 2018. *Russian Arctic*, 2, pp. 31–40. (In Russian).

Buzuev, A.Ia., Fediakov, V.E.,1981. *Variability of ice conditions on the way of navigation*. Meteorology and hydrology (In Russian).

Svistunov, I.A., Maksimova, P.V., Likhomanov, V.A., Chernov, A.V., Krupina, N.A., Experimental-analytical study of the platform "North Pole" stability under the conditions of intensive ice pressures. *Proceedings of the 25th International Conference on Port and Ocean Engineering under Arctic Conditions June 9–13, 2019, Delft, The Netherlands.* Available at: http://poac.com/Papers/2019/pdf/POAC19-124.pdf. [accessed 26.12.2019].

Svistunov, I.A., 2019. Determination of the heeling moment acting during ice compression on the ice-resistant self-propelled platform "North pole" by the method of model tests. *Arctic: ecology and economy*, 3(35), pp.97–106. (In Russian).

Maksimova, P.V., Chernov, A.V., Likhomanov, V.A., Krupina, N.A., Likhomanov, V.A., 2020. Research of R/V "Akademik Tryoshnikov" hull structures response to ice actions during the first stage of the expedition "Transarktika-2019". *Problems of Arctic and Antarctic*, 66(1), pp.82–101. (In Russian).