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Actual and Forecast Impact Assessment of Earthquakes on the Global Economic System

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Problem of strong earthquakes impact on the global economic system is considered. Geoscientists suggest that increase in Earth's seismicity is highly unlikely, but experts in economic geography say that existing facts indicate increase in seismic risk for economic systems. Using the example of an earthquake in the Tahoku region (Japan, 2011), a comprehensive assessment of economic consequences of a strong earthquake is presented as a part of analysis of three blocks of statistical information: 1) macroeconomic indicators of Japan; 2) stock market indicators; 3) industry indicators of the global economy. Results of the assessment pointed to a new feature of strong earthquakes effects in economically developed regions of the world: globalization processes are spreading regional effects of large earthquakes throughout the world economic system. To understand the magnitude of strong earthquakes problem, estimate of world economy loss from a probable earthquake near the United States, similar to Tahoku, is given. It was established that economic losses would be 2.6 times greater: a drop in the global S&P Global 1200 index would be about 15 %. The farther in time this probable earthquake protects from the Tahoku earthquake, the more globalization will increase losses.

***Key words*:** strong earthquakes; economic system; risks; assessment; forecast; economic losses

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Introduction. The most important fundamental task of both social and natural sciences is to assess and forecast the impact of possible geological events on economy of the world and regions. An essential component of this task is assessment of strong earthquakes impact on economy of the world and regions. The relevance of such an assessment is determined by invariable social significance of the results for accounting in economic activity. Scientific interest is caused by unclearness of a number of theoretical and methodological aspects of such a study in economics, limited ability to predict strong earthquakes in seismology, pronounced interdisciplinarity of the study, which generates methodological problems of research and data interpretation.

Formulation of the problem. Assessment of the impact of strong earthquakes on economy of the world and regions, at first glance, suggests the following research sequence: 1) to consider areas where intense and violent earthquakes occur, as well as areas subject to devastating tsunami; 2) to predict possible catastrophic events and their impact on natural-technological systems; 3) calculate the damage and assess the impact on global and regional economies. At the same time, strong and especially intense earthquakes are rare; modern science cannot predict them. In case of forecasting catastrophic consequences of these geological events, likelihood of options implementation is even more reduced. It is required to change the problem statement, which will change the research algorithm. A new statement of the problem can be formulated as follows: based on the transfer of largest seismic events analogues from the past to the present, as well as analysis of the instrumental data obtained on strong seismic events, tsunamis to assess their possible impact on global and regional economic systems.

The aim of the work is to consider strong earthquakes impact on the global economic system.

Tasks of research: 1) substantiate actualization of the problem of strong earthquakes impact on the economy; 2) identify methodological prerequisites for assessing such an impact; 3) provide actual and forecast estimates of strong earthquakes impact on the global economic system.

Literature review. Numerous and diverse studies in the field of forecast estimates of strong earthquakes impact on global and regional economies can be conditionally reduced to two major components.

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1. Forecast of earthquakes and their natural consequences. Relevance and complexity of solving the problem of forecasting seismic events has been the subject of a significant number of publications and various studies [2, 4, 7, 11, 13, 19, 22]. Despite the variety of approaches, a detailed classical formulation of the problem of predicting earthquakes was developed back in 1976 by the Commission for the Forecast of Earthquakes of the US National Academy of Sciences, chaired by C.Allen [12]. Forecast methods at the technology level, especially in the forecast of intense and strongest earthquakes, have not been developed.

Solution to the problem of making reliable forecasts moves in three intersecting directions.

The first direction is creation of theoretically based models of mechanisms of geological changes and earthquakes, including works of experimental forecasting. Significant achievements in this area are presented in the works of S.V.Baranov, L.R.Botvina, P.N.Shebalin, I. B.Oparina, S.Vorden, M.Gerstenberger et al. [2, 4-6, 9, 13].

The second direction is discovery of patterns that have no explanation, at least at the present level of science development (or having an incomplete explanation), including works of experimental forecasting. The development of this direction is highlighted in the works of G.M.Molchan, P.N.Shabalin, A.Helmsteter, D.Sornette and others [7, 13, 19]. The essence of processes and models of energy exchange in a rock mass – the cause of dangerous dynamic phenomena – are in the work of E.V.Lodus, E.V.Goncharov [6].

The third direction is search and classification of reliable earthquake precursors, including tasks of formalizing them. Generalization and development of this direction is considered in the works of G.A.Sobolev, A.V.Ponomarev, M.Hauakava, Yu.Khobara and others [11, 29].

It is rather difficult to distinguish the first and second directions of research: it is very difficult to verify explanatory hypotheses and theories. The third way can be partially connected with the second. For example, specific behavior of animals before some earthquakes is unclear, but is an unconditional consequence of changes in certain unknown physical parameters.

Some progress that has been outlined in solving the problem of forecasting strong earthquakes gives grounds for a number of geophysicists to suggest a fundamental possibility of resolving it. For example, in Russia, for many years, a joint Russian-American project is underway to forecast strong earthquakes, based on the Mendosino Scenario and M8 algorithms. The documented projection forecasts and publications by V.G.Kosobokov, L.L.Romashkova, V.I.Keilis-Borok, D.Haley [29] indicate progress in determining increased likelihood of a strong earthquake. However, at the moment, we have to admit that there are no fundamental models and equations that reliably describe geophysical processes that can determine the time of occurrence of strong earthquakes. Therefore, there is no reliable forecast.

Review and synthesis of the research results of L.P.Zonenshayn, M.I.Kuzmin, I.A.Karlovich, E.V.Lodus, E.V.Goncharov, G.A.Sobolev and others [4-6, 11, 13] make it possible to single out objective factors that impede construction of reliable forecasts: 1) the reasons for release of accumulated mechanical energy in the earth's crust are unknown; 2) determinate and nondeterministic factors of geological changes are not clearly defined; 3) directly observed earthquakes are not the main, but a side effect in the chain of global processes. Only a very small fraction of accumulated energy is released in the form of seismic waves that directly affect buildings and structures. However, the zones of occurrence of possible earthquakes have been studied in detail. A number of studies should be noted that offer reliable methods for assessing the consequences of geological changes for natural environment (for example, the works of I.A.Karlovich, I.E.Karlovich, A.I.Karlovich, A.V.Petukhov) [5, 9].

All this knowledge will be used by us in assessing the effects of strong earthquakes in combination with expected losses and corresponding changes in the global economy.

2. Assessment of economic impact of changes in geological environment, including earthquakes. In this sphere, activity of world scientific thought is concentrated on «point», regional studies of economic losses statistics determined by amplitudes of surface waves and probability of a tsunami, etc. The verified statistical methods are used. Assessment of economic consequences is usually of a narrow practical nature. Development of this direction is presented in the works of V.V.Voronts, O.A.Sakharov, A.M.Uzdin, I.Klimat, K.Morita and others [3, 16, 24]. Wider, generalizing works, as a rule, consider social losses from the standpoint of geoecology (for example, the work of V.I.Osipov [8]).

When the authors prepared series of publications on assessing economic consequences of strong earthquakes for the world economic system [1, 10, 14, 27], it turned out that there were practically no such studies. This is due to the absence in recent history (before the earthquake and tsunami of March 11, 2011) of such a geological event that would be noticeable in the considered global economic indicators and would affect the entire world economic system. However, earthquakes effects are described in detail from the standpoint of assessing direct impact on natural-technological systems, regions, and specific sectors of the economy. Consequences of the earthquake and tsunami on March 11, 2011 are presented in a series of works by scientists from different countries: V.Cooper, D.Donelly, R.Johnson, Z.Haderi, D.Henderson and others [17, 18]. An analysis of these works shows that development of a generally accepted methodology for assessing the cost of natural disasters, which is emphasized in the works of K.Morita and Y.Nagai [24], remains the most important scientific task.

The problem is not only in the difference of approaches and estimation methods, which leads to differences in the results [20, 24], but also in the multidimensional nature of disaster results, functional complexity of large redistribution effects [17, 22]. Studies by G.Komatsu, K.Morita, and Yu.Nagai on economic consequences of major geological changes, in particular, the event of March 11, 2011 near the eastern coast of Japan, determine significant not only direct, but also indirect natural and economic losses [22, 24]. This indicates that direct economic costs, i.e. price expression of what was damaged or lost as a result of the earthquake is not sufficient to assess the potential hazard. It is indirect effects that have a decisive effect on the economies of countries and industries, determine the dynamics of economic growth. So, a few years ago, the world constantly debated the question – can natural disasters in reality be a potential obstacle to economic development? An analysis of the GDP dynamics of various countries showed that natural disasters, indeed, can lead to negative consequences, and the greatest danger is not direct losses, but indirect ones, determined by the size of shock, scale and speed of recovery investments [22, 26]. This allows us to emphasize the need for a deeper understanding of the economy of natural disasters and to offer several promising aspects of research on this topic.

Despite the unclearness of a number of important issues in the economics of natural disasters, it was in this «economic» component where scientific research, that stimulated overcoming of significant gap between natural and social scientific disciplines, appeared. In our case, valuable developments linking engineering-geological, environmental, social processes, for example, various aspects of environmental geology, economic geography [7, 8, 24] are valuable. In addition, in the context of global nature of public tasks, scientists note the importance of consolidating efforts to solve global problems of mankind, including the response to natural disasters [5, 8, 14, 15, 20].

Methodological background of the study. Analysis of the literature on the research topic allowed us to draw three important conclusions that are significant for the formation of methodological prerequisites for assessing the impact of expected earthquakes on the economy: 1) zones of expected strong earthquakes and volcanic eruptions are well known; 2) it is not expected in the near future to develop and test a geodynamic model that allows determining the time of the event; 3) in the forecast

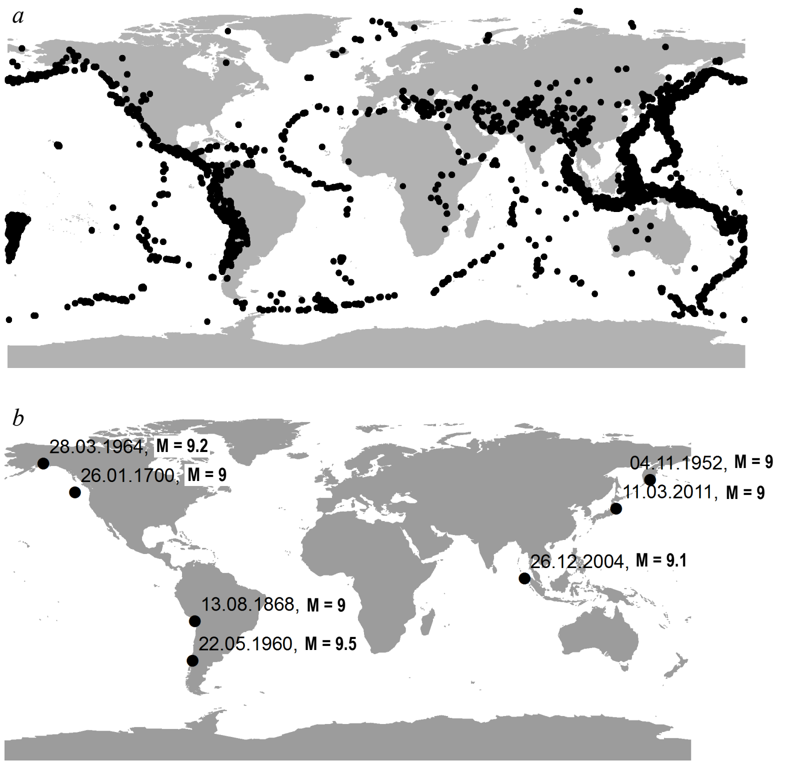

Fig.1. Earthquakes with magnitude M = 6 or more over the period 1973-2018 (*a*) and M = 9 or more for the period 1700-2018 (*b*) (according to USGS [25])

of risks for natural-technological systems it is impossible to take into account the frequency of geological changes, and therefore, their consequences.

Thus, for the purposes of risk assessment and economic forecasting of the effect of earthquakes on the global economic system, it is necessary to analyze: firstly, not cyclical, but intermittent, relatively rare, but regular events; secondly, regularity refers to regular events regarding the memory of mankind, including a particularly valuable period of instrumental observations (no more than 7 thousand years, with a special focus on the last 150 years); thirdly, such regular events that bring significant changes to large natural-technological systems, as well as significant economic losses on a regional or global scale.

Research results. In our works [1, 14], an analysis of strong earthquakes with a magnitude of M > 8.5 and their consequences that occurred in the period since 1900 was carried out. It was established that out of 17 such earthquakes, six occurred in the period from 2004 to the present. Consequently, the current 12-year period (10.4 % of the total period of 115 years) accounts for 35 % of all strong earthquakes. A similar picture is observed for the strongest earthquakes with a magnitude of 9 and above (Fig.1). From 1700 to the present, seven such earthquakes occurred on the Earth, five of them after 1952, i.e. in the timespan of 20 %, 71 % of the strongest earthquakes are located. Note that in the case of intense and strongest earthquakes, missing events is impossible.

Earth sciences operate with extra-long time ranges in terms of human life, therefore it is impossible to talk about increasing seismicity of planet Earth. However, in social sciences, the data on intense and strongest earthquakes indicate an increase in the risks of natural-technological systems of subduction zone and territories covered by likely consequences of geological changes. Since subduction zones run along the most economically developed regions of the world (Fig.1), there is reason to talk about an increase in seismic risks for regional and global economies.

An analysis of economic consequences of the earthquake with M = 9 near the east coast of Japan in March 2011 testifies to the increasing influence of globalization, which spreads the effects of earthquakes for regional natural-technological systems, on the world economy.

The relative rarity of this event for the natural-technological system of Japan and uniqueness of the event in terms of its impact on world economic processes indicate the need to develop a specific algorithm for economic assessment of its impact on world economic processes. In our studies, we developed an algorithm consisting of three blocks [1, 14].

The first block is an assessment from the perspective of the Japanese economy as a whole. Dynamics of the national currency of Japan relative to the US dollar after the disaster, dynamics of export and import with elimination of seasonal fluctuations, dynamics of GDP of Japan are analyzed.

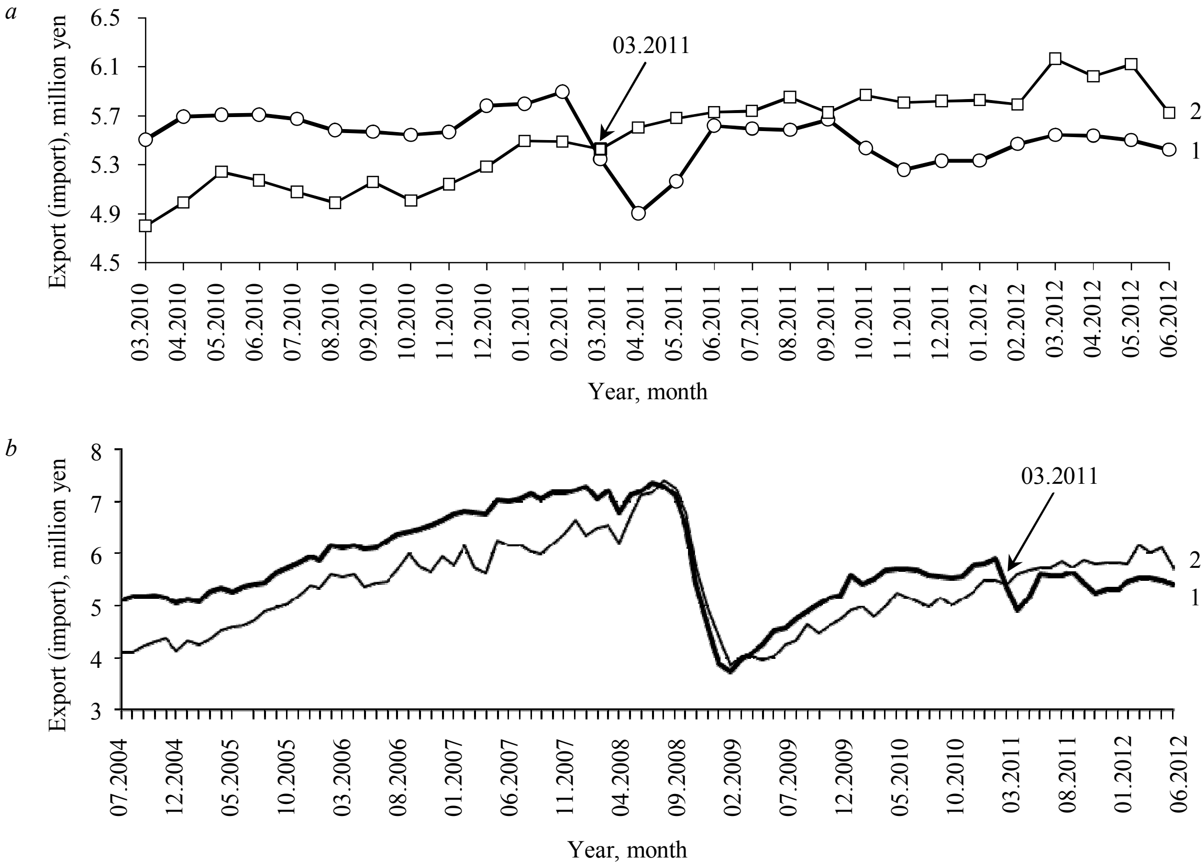

Fig.2. Export and import of Japan: *a* – March 2010 – April 2011; *b* – June 2004 – May 2012 [23]
1 – export; 2 – import

Significant fluctuations in the yen/dollar rate were observed within two weeks after the earthquake (82.9-78.3 yen/dollar), however, regulatory efforts of the Japanese government kept the course in the framework of maintaining optimal production profitability (the rate in 2011 was about 80,5 yen/dollars). An analysis of export dynamics indicated that depth of its fall in the first two months after the catastrophe significantly exceeded the impact of the global financial crisis of 2008-2009, then during the year the situation stabilized almost at the «pre-catastrophic» level (Fig.2). Japanese imports showed positive dynamics until the beginning of 2012, which is explained by increase in external procurement to restore the country's economy.

An analysis of Japan's GDP dynamics shows that the earthquake and tsunami of March 11, 2011 caused a short-term drop in Japan's GDP by 3 % (from 517 billion yen in the 4th quarter of 2010 to 502 billion yen in the 2nd quarter of 2011) (Fig.3). However, by the 3rd quarter of 2011, GDP almost reached

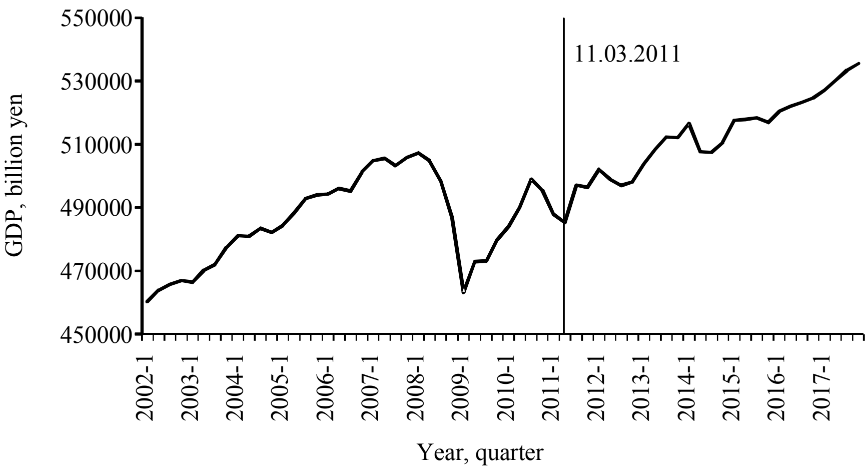

Fig.3. The dynamics of Japan's GDP (quarters) at constant prices with the removal of the seasonal component [30]

the level of the 4th quarter of 2010. Thus, the earthquake of March 11, 2011 actually delayed the recovery of the Japanese economy after the global crisis of 2008 for a year.

The second block is an assessment from the standpoint of world exchanges reaction. This section analyzes the dynamics of indexes reflecting the state of the Japanese stock market (S&P Japan 500), global stock market (S&P 1200), European markets (S&P Europe 350), USA (S&P 500) and Asia (S&P Asia 50). The analysis showed that effects of the earthquake significantly and synchronously affected the dynamics of indicators of all stock markets. The maximum fall depth and the longest recovery period were expectedly demonstrated by the Japanese (S&P Japan 500) and Asian (S&P Asia 50) indexes (Fig.4).

The third block is an assessment from the standpoint of reaction of the world economy sectors. Composite index of industrial activity of Japanese industries, the American manufacturing index (PMI Composite), and the European composite manufacturing index are analyzed [15, 21].

The catastrophic consequences of the earthquake changed dynamics of exports and imports (see Fig.2). The sharp decline of industrial production in Japan significantly affected the US manufacturing index (the reason was the shortage of equipment from Japan for US mechanical engineering), but practically did not affect production in Europe (Fig.5).

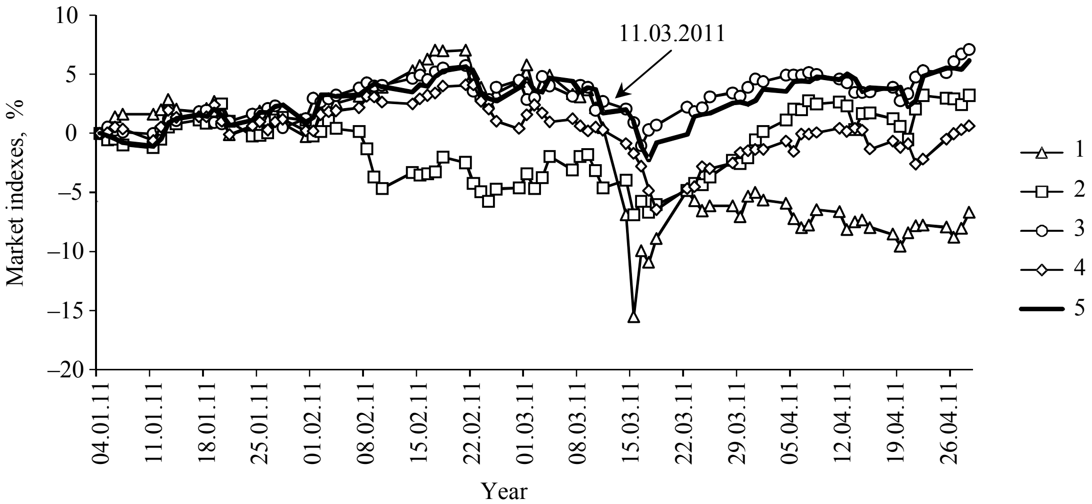

Fig.4. Dynamics of market indexes reflecting the state of stock markets S&P Japan 500 (1); S&P Asia 50 (2); S&P 500 (3); S&P Europe 350 (4); S&P Clobal 1200 (5), January – April 2011 [28]

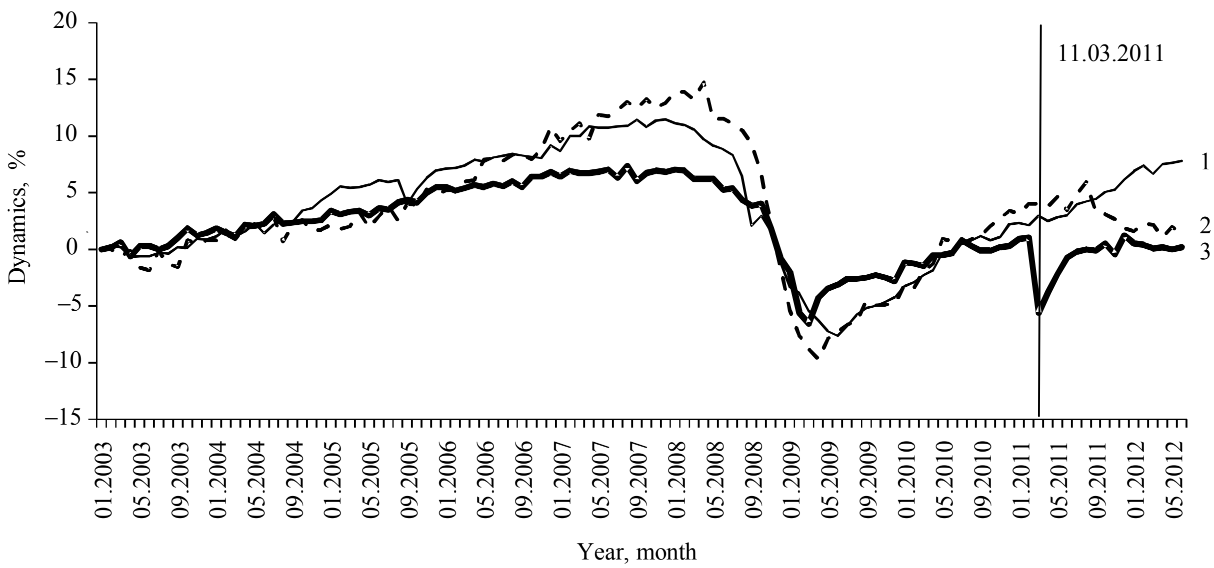

Fig.5. Dynamics of American (PMI Composite), Japanese (Industry Activity), European (Industrial Production) production indexes, January 2003 – April 2011 [30]

1 – USA; 2 – Europe; 3 – Japan

Analysis of three blocks of information suggests that the earthquake of March 11, 2011 near Japan significantly influenced not only the regional markets, but also the entire world economic system. The phenomenon of globalization ensured realization of seismicity risks for world economic processes, and increased economic losses.

Thus, increased seismic risks for natural-technological systems and their consequences for world economic processes are confirmed by two arguments: observed increase in the number of strong seismic events in recent decades and influence of globalization, which extends regional economic effects of strong earthquakes to the global economy.

All this determines actualization of research in the framework of the problem of assessing effects of predicted strong earthquakes on local and global world economic processes. Relevance includes two critical components. Firstly, practical significance determined by prognostic nature of information. There is an opinion among economists that if exact time of an earthquake, eruption, tsunami is not known, then it is not of interest to large regions and the global economy, especially from the standpoint of analyzing global financial flows. However, even knowledge of the possibility of a major disaster allows you to prepare for it, therefore, to minimize losses. Secondly, scientific component, which consists in the integration of natural-scientific and humanitarian knowledge.

Discussion of the results. The analysis of the obtained instrumental data allows us to talk about increased seismicity risks for global economic processes. At the same time, it is important to understand expected extent of changes in the global economy, for example, if a point event occurs near the United States. Such an event off the northwestern coast of the USA was already in 1970. It is logical to assume that impact of such an earthquake on the world economy will be as many times stronger than the US GDP is greater than the GDP of Japan.

US GDP in 2011 amounted to 15.52 trillion dollars, GDP of Japan – 5.91 trillion dollars [23, 28, 30]. Thus, the loss of the world economy from a similar earthquake near the United States would be 2.6 times greater. So, if the fall of the global S&P Global 1200 index as a result of the earthquake and tsunami near Japan was 5.7 % (1500.04 – before the event, 1413.86 – after the event), then if the situation near the United States was similar, the fall would be about 15 %. The farther this earthquake is from the Tahoku earthquake, the more globalization will increase losses.

As globalization grows, impact of strong earthquakes on the global economy will increase, with a simultaneous exponential increase in losses. When a severe earthquake occurs in weakly globalized natural-technological systems, this is practically not reflected in the world economy, despite huge human losses. Examples are the earthquake with $M = 9.1$ and the tsunami that occurred in 2004 in the Sumatra region, and the Chilean earthquake with $M = 9.5$ in 1960 (see Fig.1). The last event is the most powerful earthquake in the history of instrumental observations. The greatest risks to global economic processes are disasters in the most developed regions of the world.

Separately, we note the effect of earthquakes on the national economy of Russia. In general, it can be argued that Russia, located mainly in the aseismic zone, demonstrates significant competitive advantages for deployment of productive forces. However, Russia has a fairly large number of seismically dangerous territories: the Caucasus and Crimea, Altai, Baikal and Pribaikalye, the Kuril-Kamchatka region, Sakhalin, the Magadan region (a set of General Seismic Zoning maps – OSR-2015). The peripheral nature of these territories does not remove the importance of taking into account seismic hazard: densely populated and industrially developed southern territories, gas pipelines, offshore oil and gas production, etc.

Significance of strong earthquakes impact on global and regional economic systems determines the need for another task – leveling risks. The modern world system for responding to natural disasters includes the UN institutions, hazard warning system, service system in various countries, etc. Consideration of the response mechanisms of various countries services to earthquake threats reveals problems and development prospects. So, on the whole, good organization and high quality

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of the work of the Ministry of Emergencies of Russia in disaster management, in the field of emergency response, in protecting population and territories from emergency situations, as well as in the implementation of emergency humanitarian response, including outside the Russian Federation, is noted.

Japan's best practices in preparing for and responding to natural disasters and man-made disasters are widely known. The Tahoku earthquake clearly demonstrates that it was precisely the quick response to the tsunami threat that minimized the casualties (according to official data from the Japanese government in 2018, 15896 people died as a result of the earthquake and tsunami, 2536 people are missing). The wave reached the coast of Japan 10-30 minutes after the main earthquake shock. In less than 2 minutes after the signal about a possible tsunami, evacuation of people began. Thus, not only implementation of normative regulation, including technical regulations in the field of construction, taking into account hazard classes in order to prevent and mitigate the consequences of emergencies, but also the speed of making a series of decisions during a natural disaster, in particular on evacuation, are key factors in reducing the consequences, including the number of victims from catastrophic geological changes.

An example of catastrophe when it was possible to reduce the number of victims by a multiple: the strongest earthquake in the Indian Ocean on January 26, 2004, which caused a tsunami; the total number of people who died from the earthquake and tsunami is 235 thousand people, tens of thousands are missing. Despite a delay of 50 minutes to several hours between the earthquake and the tsunami strike, tsunami came unexpectedly for almost all coastal settlements. The reason is the lack of a tsunami detection system in the Indian Ocean and a general warning system for coastal populations.

In 2006, such a system was created by the UN decision, however, the latest seismic events of 2018 in this region indicate the need for its improvement, especially in terms of the public warning system.

The main proposals in the field of minimizing effects of strong earthquakes are of a natural character: further movement to institutionalize the solution of global problems caused by geological changes; joint solution by the world scientific community of a set of scientific and organizational tasks to improve monitoring and warning system, which allows minimizing the consequences of dangerous events.

Conclusion. Thus, increased risks of seismic activity indicate the feasibility of further development and refinement of research in the field of forecasting and assessing the impact of strong earthquakes on economy of the world and regions.

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