Seismicity, seismological network and seismic protection in Ukraine

Oleksandr Kendzera
Institute of Geophysics of NAS of Ukraine, Kiev, Ukraine
kendzera@igph.kiev.ua

Abstract— **Seismicity of the territory of East European platform within the Ukraine boundary is defined with influence of the powerful seismic active belt of planet, which includes the western, south-western and south regions of country as well as is linked with the large-scale local geological processes in the Earth's crust and upper mantle. When the man-caused load being increased and the basic funds in Ukraine are exposed to considerable wear-out, then the risks associated with the hazardous influence of earthquakes are essential growth. In turn, it can raise the level of man-caused risk in different branches of national economy. The seismological network of National Academy of Sciences of the Ukraine is supplying the data about seismic effects on the territory of country, on basis of which the science-based prediction of the values of seismic hazard parameters are determined. They are necessary for the central and local authorities for planning the building and providing the stable development of seismic regions. The main problems solved on the basis of seismic monitoring provided by seismic stations are protection of population, housing and other structures against earthquakes (seismic protection) and investigation of deep structures and Earth's geodynamics for purposeful search of minerals. Both problems can be successfully solved provided a dense seismic monitoring network. It determines necessity of its further development at Ukraine.**

Keywords— earthquakes; seismic hazard; seismic network; seismic hazard zoning; design accelerograms

I. INTRODUCTION

According to UN data [1], seismic disaster forms about 51% of the total number of cataclysms and prevails among different natural catastrophes. The problem of seismic protection is growing swiftly with development pressure and urbanization of seismic areas increase. In the context of considerable wear of capital assets in different branches of national economy, the risks related to hazardous effects of earthquakes have grown, raising in turn the level of anthropogenic hazard. Even minor earthquakes accompanied with landslides, mudflows and other dangerous phenomena can cause the serious material and social damage.

Citizens of the country have the right to protection of life and health against effects of natural and anthropogenic disasters, including earthquakes. This right must be secured, within their competence, by all subjects of state authority and economic agents in the country territory. However, for their successful performance, seismologists have to provide them with information on parameters of the design seismic effects. Basing on this information, design engineers and builders must provide the seismic stability of housing and industrial structures, using technical actions of seismic protection adequate to the current hazard level.

Prediction of the future earthquakes effects is an important problem, the reliable practical solution of which is possible, when only the knowledge geological, geophysics, hydrogeological, seismological, geotechnical and seismic design engineers and builders being combined.

The main issue in prediction of the earthquakes aftermath is what will be happen with the concrete object exposed to maximal earthquake that can occur with the given nonexceedance probability over a conventional period, which as a rule is taken as 50 years.

II. SEISMIC HAZARD AND SEISMIC RISK

The probabilistic assessment of relative loss in an object cost caused by destruction or loss of functional capacity is called the seismic risk. As is clear from Fig.1, the seismic risk consists of probabilistic assessment of seismic hazard and seismic vulnerability of an object.

Figure 1. Components of seismic risk.

The seismic hazard is a probabilistic assessment of formation of maximal seismic impacts (vibrations) at caused by earthquakes from the possible initiation zones, which are hazardous for the specified site. This estimate is expressed in points of macroseismic scale, or time acceleration series. It is the most fully described by means of design accelerograms.

The seismic vulnerability of an object defines its resistance to seismic effects of various values, including effects conditioned by the seismic hazard of its location area. The quantitative estimate of seismic vulnerability is probabilistic and is determined for buildings and structures in design stage by means of the theoretical calculations or the physical modeling. The seismic vulnerability of existing objects is most reliably determined through experimental engineering seismometric observations. Ideally, the vulnerability should be represented as probabilistic curves, on which the relative degree of damage (loss of functional capability) depends on various characteristics of seismic hazard.

The seismic hazard is an objective characteristic of locality of the area. It depends on the natural environment of the locality: seismicity of the territory, distance to focus zones, parameters of maximal earthquakes that can occur in those areas, their recurrence in time, local soil conditions, relief, presence of ruptured tectonic structures, spectral distribution of vibrations and other factors.

III. SEISMIC HAZARD IN THE TERRITORY OF UKRAINE

The level of seismic hazard is determined by the complex of geophysical methods in the context of next works: the general seismic hazard zoning (GSZ) of the country's territory, the detailed seismic hazard zoning (DSZ) of its certain regions, and the seismic hazard microzoning (SMZ) of sites of objects' location.

The GSZ works are mainly based on the technical approaches developed in the process of implementation of the international program «Global Seismic Hazard Assessment Program» (GSHAP) [2-6]. The probabilistic maps of general seismic hazard zoning of the territory of Ukraine GSZ-2004 (A, B and C) were included as Appendix B in the State Building Codes DBN B.1.1-12:2006 "Building in seismic regions of Ukraine" [7]. The zones of seismic intensity on maps A, B and C correspond to 90%, 95% and 99% nonexceedance probability of seismic impacts intensity in the nearest 50 years.

If to compare the GSZ-2004 maps for the territory of Ukraine with the map of general seismic hazard zoning SR-78 [8,9], which acted in the country from 1978 to 2007, one can easily see that at the old map the actual seismic hazard for a number of regions was considerably underestimated. It should be noted that, following the analysis of earthquakes in Spitak (Armenia), Rachejava (Georgia), Gazli (Kazakhstan) and Severo-Sakhalinsk, the actual seismic hazard for some other areas of the USSR on the SR-78 was underestimated on 1-2 points, which led to human casualties and significant material damage. Let us also point out that the disastrous earthquakes of 12.05.2008 in China and 12.01.2010 in Haiti have caused death of tens and hundreds of people and inflicted immense damage to the economies of those countries, because the estimated (standard) seismic hazard of GSZ maps of their territories was two points below that actually registered one in the epicentre areas.

The paradox consists in that the most part of structures in the regions with relatively low level of natural seismic hazard, including considerable part of the territory of Ukraine is not designed as earthquake-proof. This leaves them unprotected against the seldom but possible seismic effects (seismically vulnerable). On the other hand, owing to the low recurrence of earthquakes and lack of sufficiently dense seismological network in such territories, there are usually no exist the data on possible local earthquakes. As a result, the seismic risk of the located in territories of low seismicity man-caused and ecological hazardous objects is quite high.

It should be noted that the seismic hazard assessment in terms of accelerations of soil vibrations (for instance, in fractions of gravity acceleration), due to wide spread of values of peak accelerations at the same intensity of seismic impacts, cannot be determined reliably at the stages of general (GSZ) and detailed (GSZ) seismic hazard zoning. The earthquake intensity depends not only on the parameters of the source such as magnitude, dimensions, depth, dropped stress tensor, source radiation pattern, but also on such factors as constructive interference that creates conditions for emergence of standing waves, as well as on combination of spectral distribution of soil vibrations and natural periods of objects located on the soil. As a result, the design peak accelerations of the soil, form, length and spectral distribution of vibrations are determined by means of studying the seismic hazard microzoning (SMZ) of specific areas.

The advantage of GSZ maps in terms of accelerations, which are built with supposition of proportional relationship between seismic intensity and peak accelerations, does not exceed the advantage of maps, which are built in terms of seismic intensity. Moreover, the latter reflect better the actual macroseismic effects.

Determination of actual parameters of seismic hazard requires the presence of data of instrumental seismological observation of local seismic activity and manifestations of intense remote seismic events.

IV. SEISMICITY OF THE TERRITORY OF UKRAINE

Western, south-western and southern parts of Ukraine are located within the massive seismically active belt of the planet formed as a result of collision of Eurasian and African continental plates, spanning from the Azores via the Mediterranean, the Black Sea and Caucasus and farther to Hindu Kush. This belt also includes the Carpathian Arc with major subcrustal earthquakes in Vrancea zone, which were sensed in the last century not only in the territory of Ukraine, but even in Moscow and St. Petersburg, too. The earthquakes occurred in the territory of Ukraine in the past, are observed at present (registered by seismic stations and sensed by people) and, unfortunately, will occur in the future.

At present, the local earthquakes occured in the territory of the Autonomous Republic of Crimea, in the Carpathian region, Chernivtsi, Odessa, Vinnitsia, Kirovohrad, Ternopil, Khmelnytskiy, Luhansk regions and in the north of Lviv region. The strong subcrustal earthquakes in the focus zone of Vrancea (Romania) are felt by people almost in the whole territory of the country. The Fig. 2 shows focuses of local earthquakes and isoseismals of strong subcrustal earthquakes in Vrancea zone (Romania).

According to historical evidence given in [10] and on the map of isoseismals of origins of earthquakes at the East European platform (EEP) [8], the local seismic events that emerged with 5-7 points intensity of impacts occurred on the border between Kirovohrad and Cherkasy regions – 7 points (1873), in Donetsk region (around Konstantinovka) – 6 ± 1 points (1937), in Kharkiv region – 5-6 points (1858 and 1913), in Chernigiv region – 5 ± 1 points (1905); in Ternopil region – 6 points (2002), and in a number of other locations.

The magnitudes of seismic events observed in Lviv, Ternopil, Chernivitsi, Khmelnytskiy, Kirovohrad, Odessa, Donetsk, Kharkiv, Cherkasy and Chernigiv regions with intensity of 5-7 points on MSK-64 scale, corresponded to M = 4,2-5,3 [3,8,10,13].

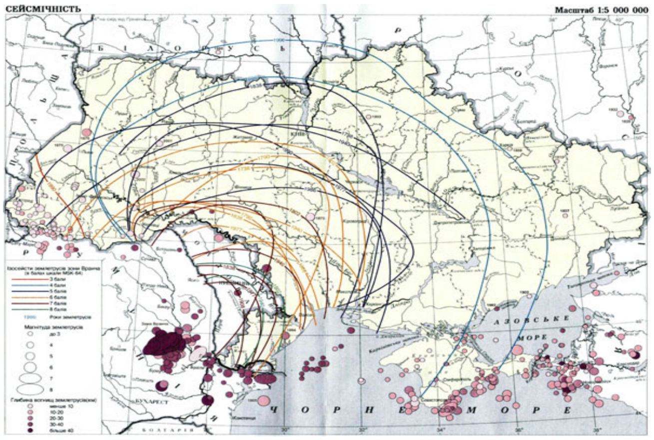

Figure 2. Seismicity of the territory of Ukraine. Origins of local earthquakes and isoseismals of strong subcrustal earthquakes in Vrancea zone (Romania).

V. Seismic Engineering

Experience in seismic protection of such countries as Japan, USA, Canada, France, Italy, etc., shows that the basic concept of seismic protection should be the application of seismic design of housing and industrial objects based on objective knowledge of quantitative parameters of actual seismic hazard in their location areas and on their construction sites. Knowledge of actual seismic hazard, alongside with reliable data on seismic vulnerability, is necessary for seismic design of new objects and development of measures to reduce the seismic risk of already existing ones. The objective data for seismic protection activity are provided by the seismic observation networks.

Unfortunately, at present the reliable method of prediction of time of future destructive earthquakes is absent. Thus, provision of correct seismic design (reconstruction) of housing and important industrial objects in seismic regions of the country remains the most efficient way of reducing the seismic risk for population and economy.

As the well-known American seismologists J. Gere and H. Shah put it neatly, "earthquakes don't kill people, bad constructed buildings do." [14]. Taking this into account, the seismic protection consists first of all in construction of earthquake-proof buildings and structures that are capable of enduring without disastrous destructions the maximal earthquakes potentially possible in their location areas.

Provision of seismic protection of population, objects of economy and national patrimony in Ukraine against the adverse effects of emergency situations is regarded as an integral part of the state policy, national security and state construction, as one of the most important functions of the central and local bodies of executive power.

The seismic protection of structures, objects and territories against the future earthquakes must be secured by all subjects of state authority and economic agents in the territory of Ukraine within their competence. The state represented by central authorities must provide reliable and unified information on the hazard via the seismological service of the National Academy of Science of Ukraine (NAS of Ukraine). Such information includes the data on quantitative parameters of seismic hazard: in the form of general seismic hazard zoning maps of the country and the databases of digital records of soil vibrations observed during local and remote earthquakes in different regions. The state must also form legislation, which will encourage application (by proprietors and managers of objects) of engineering actions to reduce the seismic risk.

The latter requirement is partially realized now. The New State Building Codes DBN B.1.1-12:2006 "Building in seismic regions of Ukraine" are in effect in the country since 2007 [7]. In the Codes, the predicted level of seismic hazard is specified in the form of general seismic hazard zoning maps, as well as the requirements are formed and measures are proposed to ensure the seismic stability of buildings and structures in specific seismic conditions.

Due to the permanent change of geodynamic situation, acquisition of new geophysical data and development of new improved methods for determination of the level of seismic hazard, it is necessary to renew regularly the GSZ maps of the territory of country.

The general seismic hazard zoning (GSZ) maps show the level of seismic hazard in points of macroseismic scale MSK-64 for the second seismic category of soils. Each of potential construction sites can be characterized by its own soil, morphological and tectonic conditions. Besides that, the existing relationship among the seismic intensity of a site and such predicted physical parameters of seismic vibrations as acceleration, velocity, displacement, distribution of income time of seismic waves of different types, duration of vibrations in the maximal phase, spectral density, ratio of vibration vector components, etc. are characterized by ambiguous statistical relations.

VI. Seismic Stations Network

The basic information for objective assessment of predicted seismic hazard (not only in seismic intensity but also in quantitative values of physical parameters of predicted seismic actions) is provided by operating seismological stations. The important goal of secured seismological and engineering seismological monitoring is collection of objective data for adjustment of redaction of future editions of state building codes, as well as for development of new techniques of seismic design of important structures, which should be improved continuously with allowance for new seismological knowledge, construction technologies and materials.

The natural changes in geodynamic situation lead to the corresponding changes in the stress-strain distribution of geological environment in the foundation of buildings and structures. Taking this into account, the study of seismic situation and determination of design seismic effects on important, atypical (experimental) and multi-storied buildings, which is usually performed only in the pre-design period meanwhile, should be supplemented with constant control of stability of soil properties on the construction site and seismic stability of objects in the process of their operation. The aim of such study is to obtain the objective data on the object's condition and, if necessary, the operational development of engineering measures to reinforce the weakened structures and to reduce the seismic risk. The data of operating seismic monitoring are used during these works.

Seismology has a wide arsenal of theoretical methods, but the reliable prediction of physical parameters of seismic vibrations during future earthquakes can be performed only basing on the direct instrumental seismological observations of earthquakes, explosions and microseisms. The strong earthquakes from origin zones, which are hazardous for construction sites, occur rarely. As a rule, such earthquakes are not registered in the relatively short design period. To some extent, their models can be obtained by recalculating the seismic vibrations registered on stationary constantly operating (profile) seismic stations for the construction site.

The closer to the construction site a constantly operation profile seismic station is located, the more reliable will be determination of qualitative values of physical parameters of predicted seismic vibrations during future earthquakes. With this in view, the network of operating seismic stations should be sufficiently dense.

Historically, the problems of determination of seismic hazard for the territory of country as whole, human settlements and individual construction and operation sites in Ukraine were in the sphere of divisions of the National Academy of Science of Ukraine. In particular, a network of seismic stations is operating at the NAS of Ukraine, which provides necessary data of instrumental monitoring for determination of qualitative parameters of actual seismic hazard and facilitates development of scientific methodical base for activity in the field of seismic protection of population and national economy.

It is known that number of earthquakes occurring in the world, with their power decreasing, increases exponentially. Sensitivity of seismological network can be increased to registration of minor earthquakes, which are not sensed but detected instrumentally, by increasing the number of seismic stations in the territory of country. That will allow one to study (confirm or disprove) empirically the actual geodynamic activity of different tectonic structures, where earthquakes can occur, and use the obtained seismic statistical data to determine the seismotectonic potential of such structures.

According to Fig. 3, density of seismic stations is relatively high in western areas of Ukraine (Carpathian region), in the Crimea and near Kiev. Another two seismic stations and one geophysical station are located in Odessa region and 1 seismic station in Poltava city. The rest of territory of country virtually has no data of seismological monitoring, which does not allow to determine reliably the level and quantitative characteristics of its seismic hazard. The further development of seismological network is extremely essential for provision of optimal seismic design and construction of important and ecological hazardous objects, housing and public structures.

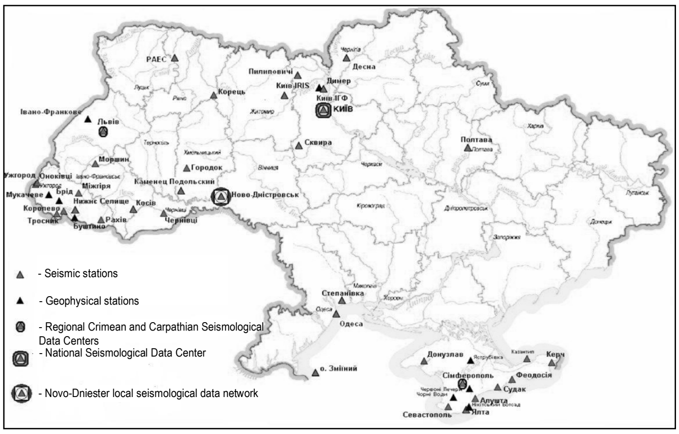

Figure 3. Network of seismic and geophysical stations of NAS Ukraine for June 2012.

VII. OBJECTIVES AND PROSPECTS

To provide the maximal safety, objects of particular importance, specifically the Ukrainian nuclear power plants, were built on the platform (in the regions with stable tectonics). Such placement was considered to be a guarantee against the dangerous geodynamic effects on those objects. But data on the local earthquakes with origins on the ancient platforms of the planet, including the East European platform, demonstrated that geodynamic and seismotectonic activities have not be ignored [3,5,10,11].

The basing on analysis of earthquake catalogue results on statistics of seismic regime obtained recently by the well-known seismologist Y. Kagan allowed him to draw a conclusion of universality of parameters of recurrence curves for continental areas. Seismicity of one continental area and that of another differs only in intensity of earthquake flow – the average number of events per unit of time [12]. Peculiarity of "aseismic" areas, within this model, is not a smaller value of the possible strongest earthquakes but a larger period of recurrence of such events. Kagan's conclusion is supported by references to data of paleoearthquakes and values of tectonic deformations in intercontinental areas.

The study of parameters of seismic regime of platform areas requires either the sufficiently long time monitoring by the existing network of seismic stations or considerable crowding of the network, which will allow reliable registering the weaker earthquakes that occur much more often.

Considering the above-mentioned, the urgent and vital problem is also study of seismic stability of existing buildings and structures in the regions, in which the seismic hazard as specified on the new map GSZ-2004 [7] turned out to be higher compared with the old standard map SR-78 [9]. At that, the materials of instrumental monitoring of local and teleseismic earthquakes at seismic stations closest to the studied structures should be used as the initial data.

The objective data for seismic protection activity are provided by networks of seismic and seismometric monitoring, supplemented with materials of macroseismic research.

The existing in the world modern evidence-based technics of prediction of the earthquake aftermath and seismic protection include determination of quantitative values of parameters of actual seismic hazard, reduction of vulnerability of buildings and structures by increasing seismic stability of existing ones and seismic design of new ones, development and practical application of antiseismic building codes corresponding to the actual seismic hazard and considering the latest achievements in the field of seismic protection of construction, implementation of state and public control of seismic design and construction and actual seismic stability of existing buildings and structures, raising public awareness in the sphere of seismic protection by means of education and trainings, rapid warning of strong earthquakes and rapid response, assistance to the population, insurance against aftermath of natural disasters, including earthquakes.

VIII. CONCLUSIONS

The located in seismic areas objects should be protected against earthquakes by their proprietors and managers but only the state can provide them with unified information as to what to protect them against. The target state financing of operation of seismological network is therefore necessary. This network providing data used for general seismic hazard zoning of the territory of country, its regions and construction (operation) sites.

The basic concept of seismic protection should be implementation of seismic design and construction of housing and industrial objects based on objective knowledge of quantitative parameters of actual seismic hazard in their location areas and on their construction sites. Knowledge of quantitative parameters of the seismic hazard, alongside with reliable data on the seismic vulnerability of buildings, is necessary for seismic design of new objects and development of measures to reduce the seismic risk of already existing ones. The further development of the seismological network as the main source of objective data for provision of optimal seismic design and construction is thereby extremely essential.

To implement the efficient state policy in the field of protection of population and economy of the country from earthquakes, it is necessary to develop first the seismological and engineering seismological monitoring networks. Their data will allow controlling the stress-strain state of geological medium, determining the quantitative parameters of seismic hazard and to creating the prerequisites for further development of the scientific methodical and regulatory country bases.

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