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Development of the Seismic Hazard Zoning Maps and Seismic Building Codes in Georgia (History of Evolution and Critical Analysis)

Otar Sh. Varazanashvili

M. Nodia Institute of Geophysics, Iv. Javakhishvili Tbilisi State University, Georgia
e-mail: otar.varazanashvili@tsu.ge

ABSTRACT

This work reviews the published seismic hazard assessments available for Georgia as well as the seismic loads included in the building code in order to show the state-of-the-art of the seismic hazard assessment studies for the country. The review includes the history and development of seismic hazard assessments and the adoption of seismic building codes in Georgia. All the previous studies were analyzed in order to conclude that a new seismic hazard assessment according to the state-of-the-art is desirable, as well as a change in the hazard description for the actual Georgian building code.

Keywords: *Seismic hazard, seismic zoning, area source model, fault source model, seismic activity, fault slip rates, seismic code.*

1 Introduction

Earthquakes in its destructive effects, fatalities, property damage, take one of the first places among other disasters. Negative consequences of catastrophic earthquakes may be felt for several decades and absorb a significant portion of the national income.

Today scientists and engineers have alot of information about earthquakes, where they are most likely to occur, how deep they originate, and how they affect land. They apply this knowledge to predict where and with what magnitude the next earthquake might occur and for constructing buildings and installations that are considered to be the most resistant to strong earthquakes.

An important step towards reducing human losses and damage caused by strong earthquakes is a reliable seismic hazard zoning, creating seismic norms and the corresponding adequate seismic design. A solution to these and other problems can provide seismic safety of the country.

Reduction of damage in earthquake-prone areas requires modern building codes that should be continuously updated to reflect the improvement in our understanding of the physical effects of earthquake ground shaking on buildings and the increase in the quality and amount of seismological and tectonic studies, among other factors (Sawires et al., [38]).

Seismic zoning (SZ) is a mapping of a seismic hazard at the national level and is based on the study of regional seismicity and major active structures. SZ maps are part of the normative documents providing antiseismic design, land management, economic development, environmental protection and, ultimately, the seismic safety of the country. SZ allocates the homogeneous areas on a map in terms of selected parameters of seismic hazard, it estimates the forecasted maximum seismic impacts in the area in terms of macroseismic intensity, maximum acceleration, etc., the level of which may be exceeded with a given probability over a given time interval.

It should be noted that the current work does not aim at performing seismic hazard analysis in Georgia but rather reviews the history of the development and critical analysis of seismic hazard zoning maps and seismic building codes and main published works regarding this topic.

2 Development of seismic hazard maps in Georgia

Seismic hazard assessment and drawing appropriate zoning maps for Georgia in the past is related with the works on drawing of seismic zoning maps of the former Soviet Union, the part of which was then Georgia.

Historical review of the seismic zoning in former Soviet Union and the methods used are described in many papers (see e.g., Bune et al., [9]; Seismic zoning..., [40]; Mokrushina and Shebalin, [30], [31]; Tsipenyuk, [46]; Gusev, [24]; Gusev, Shumilina, [25]; Ulomov, Shumilina, [47]; ets.).

The first normative map of seismic zoning (Fig. 1) throughout the former Soviet Union (ed. by G. Gorshkov), including the territory of Georgia was published in 1937 (Gorshkov, [19]), and in 1947 was released the new edition of this map (Gorshkov, [20]) and in 1949 was approved as normative (Fig. 2). Both these deterministic seismic zoning maps (SZ-37, SZ-49) in terms of macroseismic intensity were built on the principle of seismic actualism: where have occurred the last strong earthquakes – they will occur in the future.

Fig. 1. SZ-37 map for USSR (editor: G. Gorshkov).

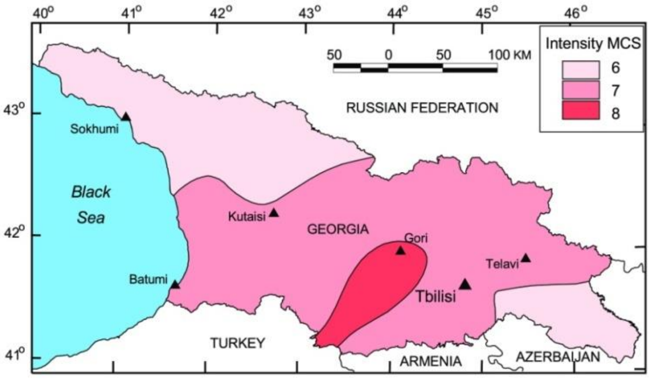

Fig. 2. SZ-49 map for Georgia (editor: G. Gorshkov).

However, in late 40s the foundation of the two-step method had already been laid for estimating seismic hazard with the elements of the prediction (see e.g., Gorshkov, [20]; Medvedev, [28]; Gubin, [22]; Riznichenko, [36]). According to this concept, in the first stage the potential source zones are allocated, and in the second – total shakes generated by them on the earth's surface are calculated. With that, these new methodological approaches have practically not found proper application in all subsequent seismic zoning (SZ) maps - 1957 (eds. by S. Medvedev, B. Petrushevsky, Fig. 3) (Medvedev, [29]), 1968 (ed. C. Medvedev, Fig. 4) (Seismic zoning..., [39]) and 1978 (ed. M. Sadovsky, Fig. 5) (Seismic zoning..., [40]). It should be noted that in the creation of the last two SZ maps the scientists from the former Soviet republics were actively involved (Ulomov, Shumilina, [47]).

The map of 1978 introduced the probabilistic characteristics of recurrence shaking for the first time. In particular indexes 1,2, and 3 near the value of intensity at the same map (e.g., 7_1, 7_2, 7_3) reflect repeatability of seismic shaking once in 100, 1000, and 10 000 years. However, it made a confusion when using maps and seismic risk turned out different in different seismic areas (Gusev, [24]).

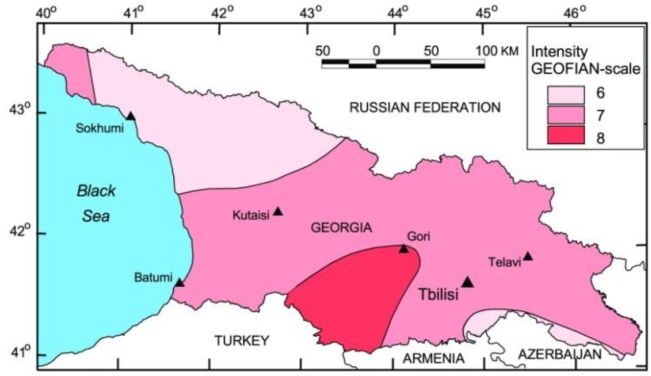

Fig. 3. SZ-57 map for Georgia (editors: S. Medvedev, B. Petrushevsky).

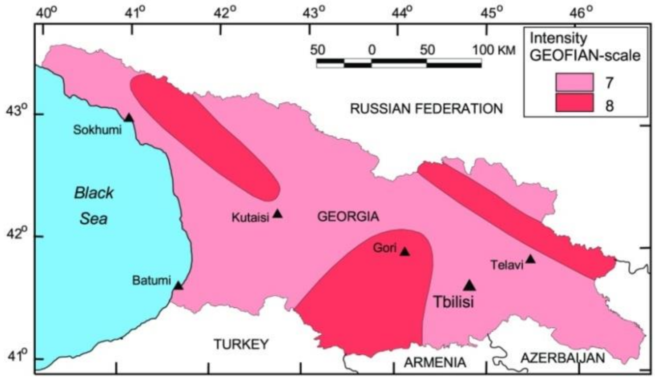

Fig. 4. SZ-68 map for Georgia (authors: Ye. Bius, A. Tskhakaya, M. Rubinshtein)

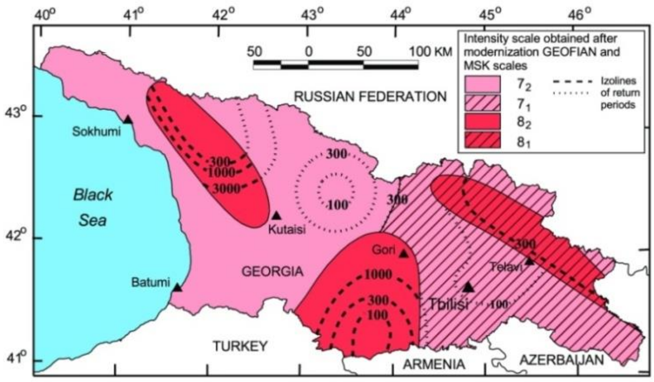

Fig. 5. SZ-78 map for Georgia (authors: I. Aivazishvili, E. Jibladze, V. Papalashvili, M. Rubinshtein).

With the accumulation of new information about earthquakes and development of the methodology SZ maps periodically have improved, but really they were changed almost after every destructive earthquake, which occurred in zone of SZ map with comparatively lesser predicted intensity. For example, Spitak destructive earthquake in 1988 (in Armenia) with I_o=10 MSK and Racha destructive earthquake in 1991 (in Georgia) with I_o=9 MSK emerged on the SZ-78 map in areas with predictable intensity 7, caused the preparation of a new SZ-91 map for Georgia (ed. M. Aleksidze) (Gotsadze et al., [21]).

SZ-91 map, developed by Georgian scientists (Fig. 6), was the first successful example of the implementation of the two-step method SZ in Georgia. Here the calculation of seismic hazard in terms of macroseismic intensity is really implemented on the basis of constructed seismic sources zones (SSZ) and their parameters. Though this map had some drawbacks: firstly, when editing this small-scale (1:2 500 000) map, under the influence of the recent cases of Spitak and Racha seismic catastrophes, all the zones of expected intensity 7 were removed, which undoubtedly affected its detailing; secondly, the hazard zones were obtained for the events with a mean recurrence of 1000 years, though clear criteria for how this was done was not described; third, these hazard zones, as on all previous SZ maps, were attributed to the average ground conditions, which in its turn, introduced additional uncertainty in the map.

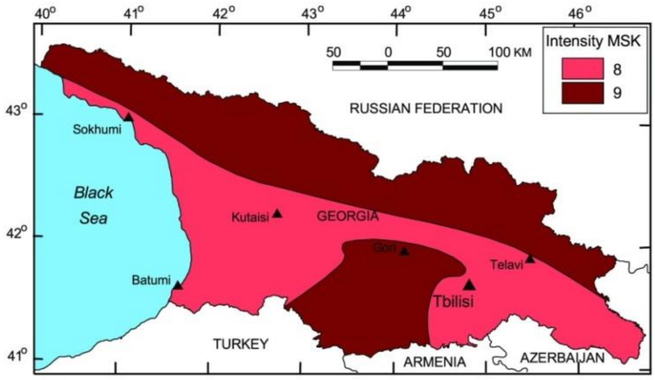

Fig. 6. SZ-91 map for Georgia (authors: O. Varazanashvili, O. Gotsadze, E. Jibladze).

Despite the fact that in the SZ-91 and SZ-78 maps some probabilistic characteristics of shake recurrence were introduced for the first time, they were almost deterministic (as the previous SZ-37, SZ-49, SZ-57, SZ-68 maps). These maps do not give an assessment of seismic hazard in terms of probability of exceedance of a given time interval, the idea of which was most developed in western Europe, the U.S. and Japan, in the works of Cornell,[13] and other scientists (Algermisser, Perkins, [2]; Bender, Perkins, [5]).

Taking into account this and several other reasons (noted above) a set of SZ-99 maps was built in 1999 for Georgia. The maps included 5%, 2% and 1% probability of exceedance in 50 years (ed. I. Gamkrelidze) in terms of macroseismic intensity (scale MSK) and peak ground acceleration (PGA) using well known computer software SEISRISK III (Bender, Perkins, [5]). It was agreed, in terms of macroseismic intensity, to select as normative of the three maps the one that best matched the observed macroseismic data for the entire historical period (Chelidze et al., [10]). Such was SZ-99 map with 2% probability of exceedance, i.e. for the event with a mean recurrence of 2475 years and it, along map with 2% in terms of PGA were presented for approval as a normative (Fig. 7). However, the process of creating new Georgian building codes was stretched in time and approval of SZ-99 map was also postponed. Only 10 years later in 2009, the edited version of this map (SZ-09) was accepted as normative (Fig. 8). Editing mainly touched area of the city Tbilisi where in 2002 there was an earthquake (M_S=4.6, I_o=7.5 MSK) with intensity of at 0.5 MSK higher than it was shown on the SZ-99 map.

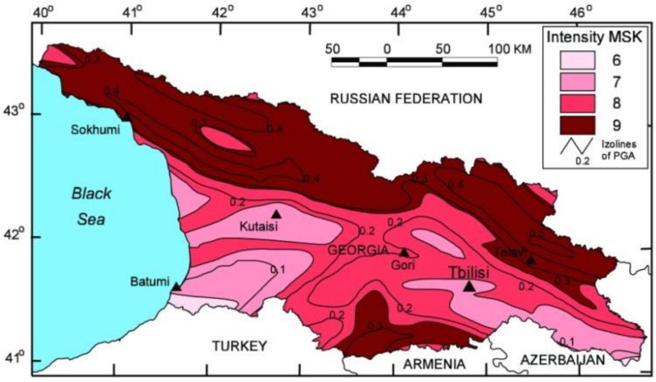

Fig. 7. SZ-99 map for Georgia (authors: T. Chelidze, Z. Javakhishvili et al.)

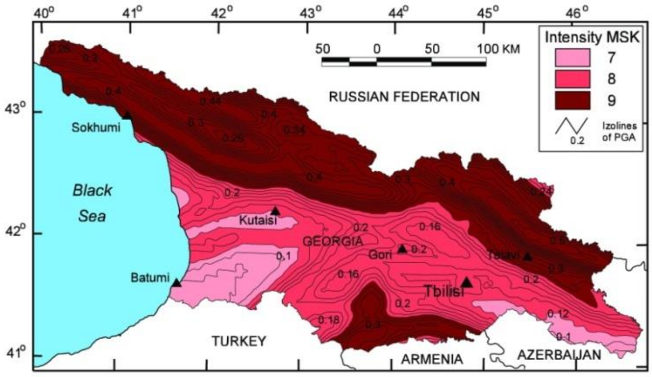

Fig. 8. SZ-09 map for Georgia (editors: I. Gamkrelidze, G. Gabrichidze et al.)

However, further analysis of the SZ-09 map and its comparison with other maps of seismic hazard assessment for Georgia from the international projects and some new works showed significant shortcomings of this map. In particular, a comparison of this map with the maps of seismic hazard calculated in the framework of the project GSHAP (Balassanian et al., [3]), the project EMME,[14] and the work Slejko et al.,[44] showed significant differences in the results of generalization. SZ-09 map shows lower hazard, both on MSK intensity and especially on PGA and these differences are even greater when you consider that the SZ-09 map is built for 2% (average return period of events 2475 years) probability of exceedance in 50 years and the remaining maps for 10% (average return period of events 475 years) probability of exceedance in 50 years. In addition, maps from the GSHAP and Slejko et al.,[44] were calculated by the same software SEISRISK III. These facts suggest that at the time of calculating maps SZ-99 and SZ-09 serious errors were made (Varazanashvili et al., [50]). In addition, the hazard zones on these maps (as in all previous SZ maps), were related to average ground conditions. It became apparent that the present normative seismic hazard map (SZ-09) of Georgia requires urgent recalculation and it is needed to draw a new SZ map in terms of maximum acceleration to rocks.

For the completeness of a historical review of seismic hazard mapping for Georgia below are the maps of seismic hazard (SH), built by individual authors or groups of authors.

Before starting of work on the SZ-78 map, guidelines for seismic zoning were issued (Guidelines..., [23]), where, as an example, a map of the maximum possible shake of southern European part of the former USSR was presented. This map, which also includes the territory of Georgia (Fig. 9), was based on the zones of earthquake source occurrence (ESO) identified through a detailed study of geological, geomorphological and geophysical structural features of the seismogenic zones. Further to move from zones of ESO to shake on the surface, were used data on the average radiuses of isoseists (Guidelines…, [23]; Bune et al., [8]). However, despite widespread use of geological, geomorphological and geophysical data, this deterministic map has turned nonstructural and an obvious tendency to "skip goals" (skip maximum shake with intensity 9).

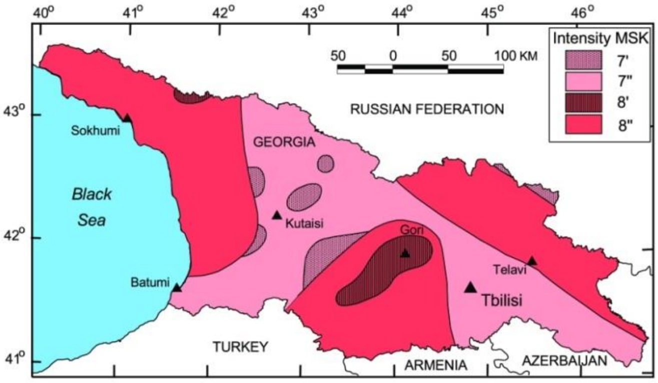

Fig. 9. SH-74 map for Georgia (authors: V. Bune, I. Kirillova et al.).
7´, 8´ – areas intensity seven and eight MSK, where the appropriate intensity shakes in historical time occurred; 7”, 8” – areas of intensity seven and eight MSK with possible manifestation of shakes of appropriate intensity.

In 1995 a paper (Jibladze et al., [26]) was published. It included a SH map for Georgia, built on the basis of the methodology developed in the theory of seismic shakability by Y. Riznichenko (Seismic shakeability..., [41]). The map showed the hazard zones in terms of macroseismic intensity (MSK), indicating in each of them the probability of occurrence in % (or mean return period) 7, 8 and 9 intensity for waiting time 100 years. Difficult-readability was the main drawback of this map. Fig. 10 shows the map of hazard zones in terms of macroseismic intensity only for mean return period T=1000 years.

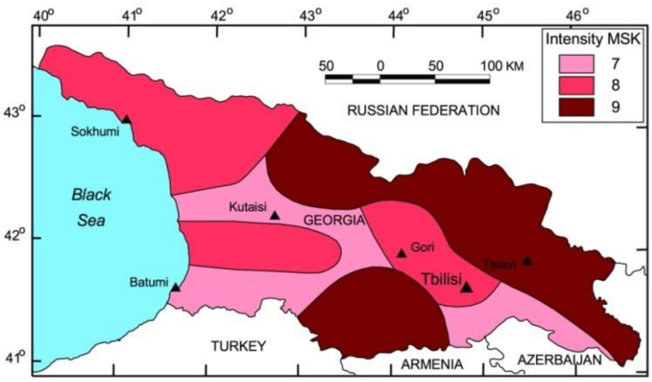

Fig. 10. SH-95 map (for T=1000 years) for Georgia (authors: E. Jibladze, N. Butikashvili et al.)

In 1991-1997, based on the new methodology, a set of probability maps SH-97 (10%, 5%, 1%) of seismic zoning of the Russian Federation and adjacent territory was created. It reflected different degrees of seismic hazard in terms of macroseismic intensity (scale MSK) for average soil conditions (Ulomov, Shumilina, [47]). SH-97 maps have indicated a higher seismic hazard than the one assumed before in many regions of the country and its adjacent areas. However, for the territory of Georgia, this map showed unrealistically large seismic hazard. In particular, as proven (see Varazanashvili et at., [48]), for twenty centuries historical observations of shake with an intensity 9 had covered only 16% of the entire territory of Georgia, where as, for example, on 5% (average return period 1000 years) SH-97 map (Fig. 11) shake with an intensity 9 cover 97% territory of the country, which makes it impossible to consider this set of maps as a normative for Georgia.

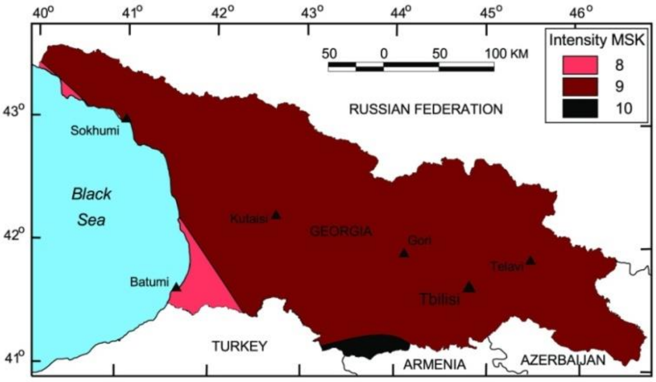

Fig. 11. SH-97 map (5%) for Georgia (authors: V. Ulomov, L. Shumilina et al.).

In 1998 the work on a set of probability (40%, 10%, 5%, 2%, 1%) maps SH-98 (Fig. 12) of seismic hazard for waiting time 50 years in terms of macroseismic intensity (MSK) was completed (Varazanashvili, [48]). Was used the original method of estimating SH, based on models of seismic source zones (SSZ), segments of structural seismic activity and isoseists. Analysis of the obtained maps showed the following: a) The reliability of the results of seismic hazard assessments (both the form and the value of the hazard zones) is more dependent on the reality degree of the SSZ models and their parameters; b) Allocation of segments of structural activity along the SSZ according to data of time interval of 100 years does not give an opportunity to fully reveal the level of seismic activity of SSZ and also solve the problem of calm areas that reduces the value of predicted seismic hazard. Therefore, in the future, instead of seismic activity we should adopt the so-called conditional activity, which besides the number of earthquakes also uses data of modern tectonic movement obtained from GPS network (unfortunately for Georgia full GPS data is not yet available). The main drawback of this work was that the used method was not formalized and published. Moreover SH zones of the set maps were attributed to the average soil conditions.

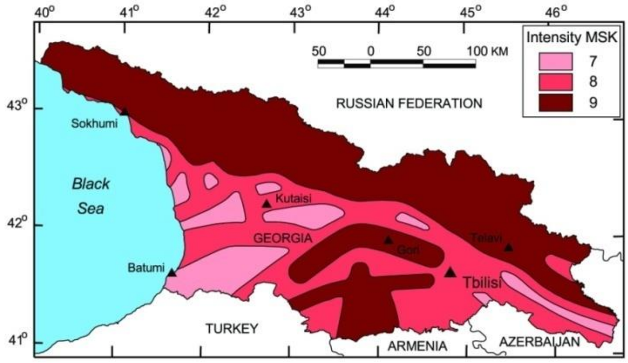

Fig. 12. SH-98 map (2%) for Georgia (author: O. Varazanashvili).

In 1999, SH-99 map of Georgia was published (Fig. 13). It was based on a study of the block structure of the lithosphere of the Caucasus and allocation seismogenic faults (Sikharulidze et al., [43]). Unfortunately, this deterministic SH map for medium soil conditions to a greater extent was committed to the principle of seismic actualism.

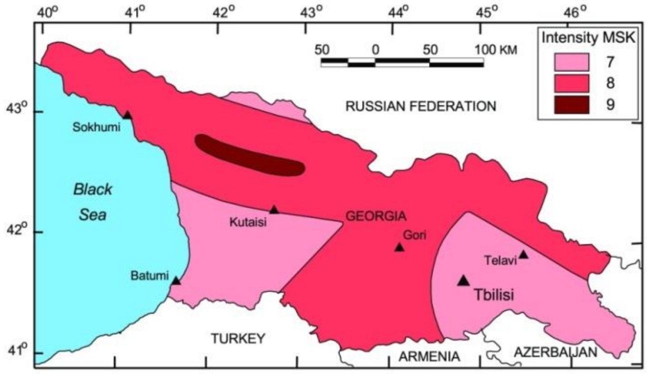

Fig. 13. SH-99 map for Georgia (authors: D. Sikharulidze, V. Papalashvili et al.).

The Global Seismic Hazard Assessment Program (GSHAP) was carried out between 1992-1998. The GSHAP Global Seismic Hazard Map has been compiled by joining the regional maps produced for different GSHAP regions and test areas. It depicted the global seismic hazard as Peak Ground Acceleration (PGA) with a 10% chance of exceedance in 50 years, corresponding to a return period of 475 years (Giardini et al., [18]).

The GSHAP CAUCAS test area was established with the goal of improving global standards in seismic hazard assessment in the Caucasus and included the entire territory of Georgia, Armenia, Azerbaijan, the North Caucasus and Kopetdag. The mapping of probabilistic seismic hazard was implemented on the basis of areal Seismic Source Zones (SSZ) model, compiled according to the lineament model of the region. Maximum magnitudes of SSZs were mainly defined by magnitude of a corresponding seismotectonic structure depending on the magnitude of the strongest earthquake of that zone. In the seismic hazard assessment, the ground motion attenuation model of Joyner and Boore [27] was adopted and calculation of accelerations was done using SElSRlSK III by Bender and Perkins [5], using only the areal homogeneous source zone model. Two seismic hazard maps for rocks and for the reference 475 years return period and for standard logarithm deviation 0.5 and 0.6 were computed (Balassanian et al., [3]). Fig. 14 shows the SO-99 Map for Georgia under the GSHAP project (standard deviation 0.5). As can be seen in Fig. 14, the seismic hazard level in the Greater Caucasus is less than in southern Georgia, which contradicts the observed historical seismicity. In addition, the use of only one ground motion attenuation equation reduces the calculated seismic hazard value and precision of their assessment for the region.

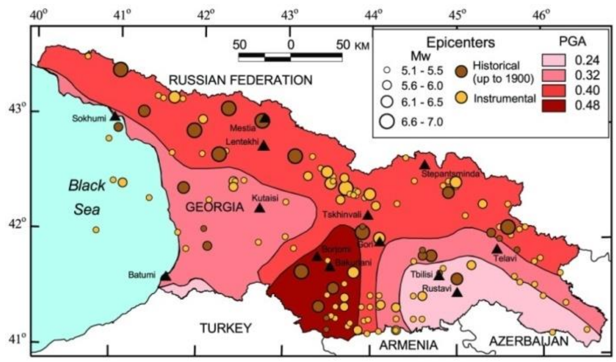

Fig.14. SH-99 map for Georgia from GSHAP project (authors: D. Giardini, G. Gruntal et al.).

The EMME (Earthquake Model of Middle East) Project was established in 2009 and was active until 2015. It was made with the objective of developing a unified framework to evaluate the seismic hazard and the associated risks in one of the most seismically active and vulnerable regions of the world: the Middle East and the Caucasus (Erdik et al., [15], [16]). A comparison of the GSHAP seismic hazard map (representing a previous generation of regional hazard studies (Giardini et al., [18]) with an adequate EMME map (Sesetyan et al., [42]) reveals considerable differences and an increased level of detailing in the resulting seismic hazard distribution on the new generation map. First an enhanced understanding of seismic activity parameters based on the accumulated data in the recent decades and improvement of hazard modelling tools induced changes in the hazard estimate levels and distribution throughout the region and second, an increased level of detail is obtained mainly due to the incorporation of the fault source model in the EMME maps. Active faults provide a longer recurrence interval for the large earthquakes when slip-rates are available. On the other hand one drawback of the present model is that, sliding speeds are sometimes determined very approximately which may result in some cases in hazard levels lower or larger than anticipated. Given the fact that a fault source model cannot be considered fully complete, it is subject to further improvement as more data become available.

OpenQuake hazard engine (Pagani et al. [35]) is the PSHA software used for hazard calculation within the EMME project. The EMME project delivered a reference, homogeneous probabilistic seismic hazard model for the sub-region under study. Being a reference model implies that it can be different than the national seismic hazard models, but may serve as a reference and basis for updating national scale hazard models. Today, the EMME project delivers, fully harmonized datasets and models align with the high-standards adopted and promoted by Global Earthquake Model - GEM (Sesetyan et al., [42]).

Fig. 15 shows the SH-2014 Map for Georgia constructed within the framework of the EMME project. To compare the predicted PGA values with the observed seismicity, the epicenters of strong earthquakes (M_w> 5) for the entire historical period are plotted on the map. As can be seen on the map, almost all epicenters of strong earthquakes are located in the PGA>0.25 g zones, which is a good result for predictive maps and excludes an error such as missing a target.

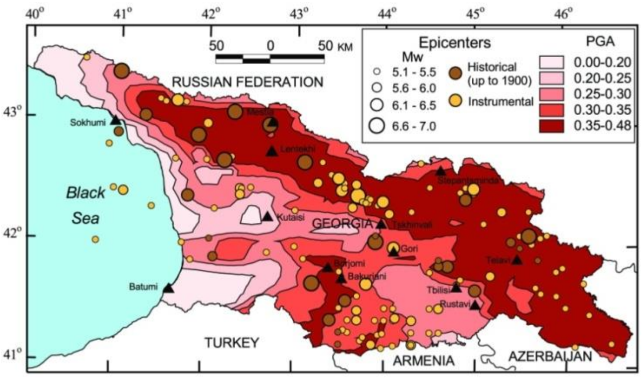

Fig.15. SH-2019 map for Georgia from EMME project (authors: L. Danciu, N. Tsereteli et al.).

In 2019, Lawrence Livermore National Laboratory technical report (Onur et al., [33]) was published, followed by an article (Onur et al., [34]), which outlined the improvements made to the earthquake catalog in Georgia using legacy data and the new hazard assessment based on this improved dataset. Using these improvements in the earthquake catalog in conjunction with new research on active tectonics and hazard analysis concepts, PSHA was conducted to generate new seismic hazard maps for Georgia. PSHA OpenQuake software was used to calculate the hazard (Pagani et al., [35]). According to the authors of these works a subset of active faults with relatively reliable data was selected for the PSHA study, and seismic hazard from the rest of the faults as well as diffuse seismicity were represented using area sources. Maximum magnitudes were assigned to each source zone based on various considerations. Generally, no zone was assigned a maximum magnitude lower than Mw 7.2., and for the study of the recurrence parameters of source zones, preference was given to the non-declustered catalog. Fig. 16 represents the SH-2020 map for Georgia for the peak ground acceleration with a 10% chance of exceedance in 50 years by Onur et al.,[33], [34]. The main drawback of this seismic hazard map (like all other hazard maps by Onur et al.,[33], [34] is that to the west of the meridian passing approximately through the cities of Kutaisi and

Mestia, the seismic hazard fall sharply compared to other parts of the map. The statement that the PSHA results in these works generally reflect the change in rate of seismic activity from west to east is wrong. This is evidenced by the history of the development of SZ in Georgia. In particular, in the first half of the last century, there was an opinion among the scientific community that seismic activity in Western Georgia is lower than in Eastern Georgia, and this was reflected in the corresponding maps of SZ (see SZ-37, SZ-49, SZ-57). Since 1948, after more than ten medium and strong earthquakes with magnitudes Mw 4.5-6.4 occurred within 15 years, the situation changed and this was reflected in subsequent maps of SZ (see SZ-78, SZ-91, etc.). It turned out that the seismicity of Western Georgia is characterized by earthquake swarms and temporarily calm areas (especially in the western part of the Greater Caucasus), and not to low activity compared to the eastern part of the country. This is also evidenced by the historical seismicity (up to 1900) of Georgia (see EMME [14], Varazanashvili et al. [49], [51]), which apparently was not taken into account when carrying out PSHA in the above-mentioned works of Onur et al. [33], [34].The improved catalog of earthquakes in Georgia, which is much talked about in these works, has not been published anywhere and is not available for analysis.

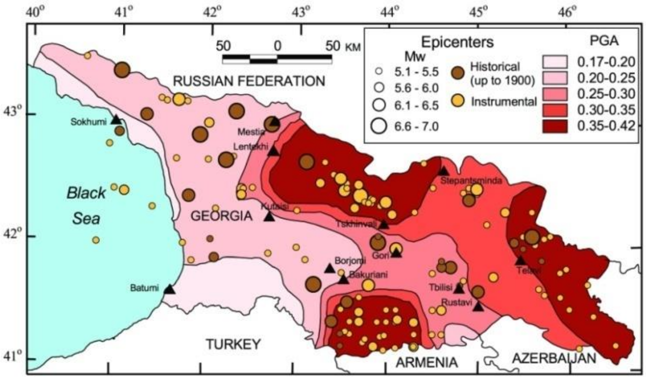

Fig.16. SH-2020 map for Georgia (authors: T. Onur, R. Gok et al.).

As mentioned above, the EMME project delivered a homogeneous probabilistic seismic hazard model for the Middle East and Caucasus sub-region, which may serve as a reference and basis for updating national scale hazard models. The national, updated, probabilistic seismic hazard model for Georgia was presented in 2020 by Tsereteli et al. [45], obtained leveraging from the experience in the EMME project. Input seismic data were homogenised using national data and seismic source models were specified at national level. Georgia Seismic Hazard Model 2020 (SH-2020) reflects the latest scientific findings, i.e. principle of stationary seismicity, active faults and uncertainties quantification and updated datasets i.e. updated earthquake catalogue, revised estimates of the historical catalogue, a homogeneous magnitude scale, improved fault source models and the area source models (for more details see Tsereteli et al. [45]. The drawbacks of this hazard model are related to issues that are common for all modern maps of this type. In particular, a big step forward in the improvement of the PSHA methodology was the use, in conjunction with seismic activity (giving a short-term picture of activity), the sliding velocity of faults (giving a long-term picture of activity). They complement each other well. However, future efforts should be made in the direction of improving estimates the fault slip rates of the region, by incorporating most recent studies. In the process of updating and homogenizing the earthquake catalog, conversion formulas of different magnitudes are used, the effects of their use remains to be studied in future efforts. Limited data on strong ground motion for Georgia and the whole Caucasus have not yet allowed the inclusion of any local model for Georgia in the Logical Tree scheme of ground motion hazard assessments, so the creation of such a model will be one of the subjects of future updates. Fig. 17 shows the SH-2020 map for Georgia by Tsereteli et al. [45], the quality of the forecast pattern of the seismic hazard of a region is determined by how adequate it is to the observed seismicity for the entire historical and modern period. For this, all zones with PGA≥0.32 g from the SO-2020 map (Fig. 17) were compared with the zones with MSK intensity I≥8 from the distribution map of the maximum observed MSK intensity in Georgia (Fig. 18). The results of alignment and comparison of the corresponding zones showed that 75% of the zone with PGA≥0.32 g, 80% -PGA≥0.43 g and 90% -PGA≥0.53 cover zones with I≥8, which is a good result if we take into account the accuracy of delineation the boundaries of zones on these maps and testifies to the adequacy of this hazard forecast map.

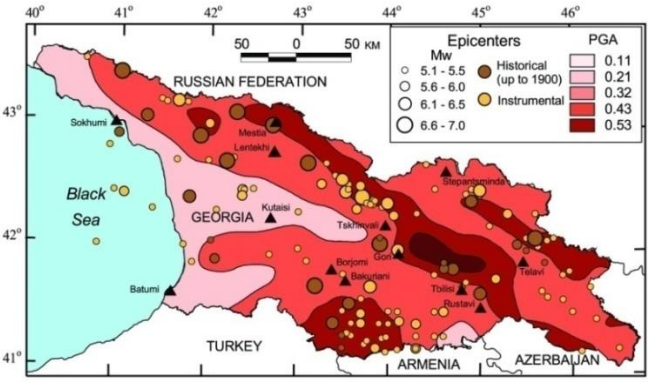

Fig.17. SH-2021 map for Georgia (authors: N. Tsereteli, L. Danciu et al.).

Fig. 18 shows a map of the distribution of maximum MSK intensity (7, 8, and 9 points MSK) from strong earthquake on Georgian territory throughout the historical past. Based on the analysis of these data for twenty centuries it is possible do several important conclusions:

- The area of the region encompassed by intensity 9 MSK for each one out of 19 centuries A.D. the average is ~500 km^2, which practically coincides with the total area of intensity 9 MSK of the well-studied earthquakes of the 20th century. This in its turn means that during 20 centuries only a few of strong (M_S>6.5, I≥9) seismic events have been missed.
- For the area covered by 8 MSK intensity there is quite a different picture. In particular, for each one out of 19 centuries the area of this intensity is on average 1.5 times less than the well-delineated area with an intensity 8 MSK of 20th century, and it means that many historical earthquakes with such intensity are still not detected.
- The area covered by intensity 7 MSK is the background to the whole territory of Georgia and if we take into account the results presented in the previous paragraph, a large part of this area must have intensity 8 MSK.

In addition, on this map, between two large areas of the axial part and the southern slope of the Greater Caucasus thereis clearly visible seismic gap, which was partially filled in 1991 by the strongest Racha earthquake with intensity 9 MSK and its strong aftershocks with an intensity 8 MSK (Varazanashvili et al., [49]).

It should be noted that for Georgia, rigorous statistical validation of probabilistically estimated ground motion is very difficult to take nowadays due to short observational time of the main input datasets (i.e. although the instrumental earthquake catalogue covers about 100 years, strong ground motion data have been recorded only in the last decades, Tsereteli et al., [45]). Therefore, under the conditions of Georgia, the observed maximum macroseismic field shown in Fig. 18 is practically the only controlling factor for predictive assessments of seismic hazard.

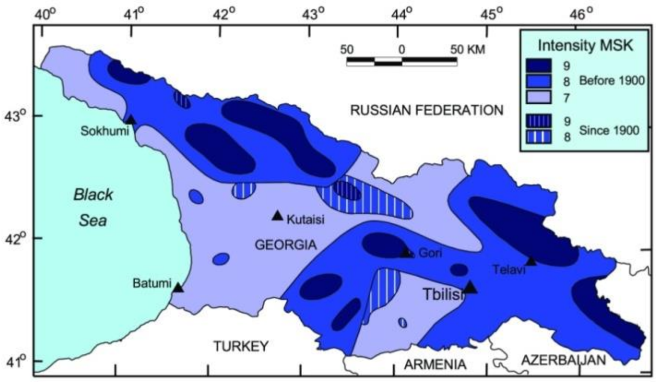

Fig. 18. Map of the total maximum MSK intensity distribution in Georgia during the entire historical past (author: O. Varazanashvili).

3 Development of building codes in Georgia

The history of the creation of building codes in Georgia is closely related to their development from the beginning in the Russian Empire (before 1918), and then in the former Soviet Union (1921-1990), a part of which Georgia was for that time. Since 1991, Georgia has become an independent country and has intensively been developing its national building codes.

More specifically, we can say that in the first quarter of the 20th century in the Russian Empire and in the USSR, the so-called “Established Norm” (Fig. 19), which in modern language is called a collection of construction resource estimates and which represented the construction technologies of the beginning of the last century. In 1927-1930, due to obsolescence, the “Established Norm” was replaced by the "Set of Production Building Codes" drawn up by the USSR Construction Commission (Abramova, [1]). It should be noted that seismic loads did not appear in both of these collections of normative documents.

Fig. 19. Established Norm of the 1918 issue.

In 1937, the first seismic zoning map of the USSR (SZ-37) was prepared, which was included in the official normative publication - “Rules for Anti-seismic Construction” (Rules ..., [37]). The next new seismic zoning map appeared in 1949 (SZ-49), and the first edition of building codes and regulations (SNiP) was put into effect in 1955 (Building codes ..., [6]). Then, in 1957, after the creation of a new map of seismic zoning of the USSR (SZ-57), codes appeared: SN 8-57 (Norms and rules ..., [32]) and SNiP II-A.12-62 (Building codes ..., [7]) (Fig. 20), in which the intensity of the earthquake in the area or at the construction site was taken according to the GEOFIAN intensity scale (Barosh, [4]).

Fig. 20. SNiP II-A.12-62 of the 1963 issue.

Since seismic zoning maps (SZ) are an integral part of regulatory documents that ensure earthquake-resistant construction, updated seismic codes were often published after the appearance of new SZ maps, for example: SZ-68 - SNiP II-A.12-69 * (Construction norms ..., [11]), SZ-78 - SNiP II-7-81 * (Construction norms ..., [12]).It should be noted that in SNiP II-A.12-69 * the seismicity of the construction site was assessed according to the GEOFIAN scale, and in SNiP II-7-81 * - according to the scale obtained after the modernization of the GEOFIAN and MSK-64 scales. The first map of the SZ of independent Georgia was compiled in 1991, but it was included in the structure of the previous codes - SNiP II-7-81*. Only in 2010 it became possible to create new seismic codes for Georgia PN 01.01-09 (Georgian building code,]17]), which included an edited version of the 1999 SZ-99 map (rather outdated), and seismicity was given using the macroseismic intensity on the MSK-64 scale and peak ground accelerations. Today there is a need for a new map of SZ and new seismic code, closest to the European Codes (EC8).

Conclusions

As a result of more than 80 years of research in the field of seismic hazard zoning, the concept of seismic hazard in Georgia has changed significantly and the level of understanding of the hazard model has improved radically. This is evidenced by the entire history of the development of seismic zoning, presented above. Suffice it to say that deterministic assessments in terms of macroseismic intensity for average soil conditions were taken as the calculated hazard for Georgia in the 30s to the beginning of the 90s, and probabilistic hazard estimates are now accepted in terms of peak and spectral ground accelerations for rock.

During this period, the concept and configuration of seismic source models changed significantly, from simple seismically homogeneous are sources to complex “dual” source models: the areal source model and the fault source model, which successfully complement each other. A big step forward in improving the hazard assessment methodology was the combined use of seismic activity and fault slip rates, use of a logic tree scheme in hazard calculations, etc.

As for the ground motion model for Georgia, it was represented by a set of regional or global ground motion prediction models, selected according to the tectonic zoning scheme, as the limited data on strong ground motion for Georgia did not allow them to be included in the hazard assessment logical tree as a local model.

The seismic hazard model and corresponding zoning maps are an integral part of regulatory documents that ensure earthquake-resistant construction, so updated seismic codes are often published after the appearance of new seismic zoning maps. Today there is a need for a new normative map of seismic zoning for Georgia and for new building codes close to the European ones.

Thus, the efforts of researchers in the field of seismology, geology, geophysics and engineering, which created various models of seismic hazard and the corresponding building codes, analyzed the results of their application, studied the properties of earthquake sources and surroundings, as well as the spatial structure of seismicity, led to great progress in understanding the nature of seismic hazard and earthquake-resistant construction on the territory of Georgia. It should be admitted that the degree of knowledge of the danger of Georgian earthquakes is insufficient. Much work remains to be done in order to provide the engineering community and government agencies with a fully reliable performance of potentially destructive ground motion.

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სეისმური საშიშროების ზონირების რუკებისა და სეისმური სამშენებლო კოდების შემუშავება საქართველოში (განვითარების ისტორია და კრიტიკული ანალიზი)

ო. ვარაზანაშვილი

რეზიუმე

ეს ნაშრომი მიმოიხილავს სეისმური საშიშროების გამოქვეყნებულ შეფასებებს, რომლებიც ხელმისაწვდომია საქართველოსთვის, აგრეთვე სამშენებლო კოდებში შეტანილ სეისმურ ზემოქმედებებს, რათა ინახოს ქვეყანაში სეისმური საშიშროების შეფასების კვლევების დონე. მიმოხილვა მოიცავს საქართველოში სეისმური საშიშროების შეფასების ისტორიას და განვითარებას და სამშენებლო კოდების მიღებას. ყველა წინა გამოკვლევის ანალიზის შედეგად გაკეთებულ იქნა დასკვნა, რომ სასურველია სეისმური საშიშროების ახალი შეფასება, რომელიც თანამედროვე მიღწევებს შეესაბამება, აგრეთვე არსებულ ქართულ სამშენებლო კოდებში საშიშროების აღწერილობის შეცვლა.

Разработка карт зонирования сейсмической опасности и сейсмических строительных норм в Грузии (история развития и критический анализ)

О. Ш. Варазанашвили

Резюме

В этой работе рассматриваются опубликованные оценки сейсмической опасности, доступные для Грузии, а также сейсмические воздействия, включенные в строительные нормы, чтобы показать состояние исследований по оценке сейсмической опасности в стране. Обзор включает в себя историю и развитие оценок сейсмической опасности, и принятие строительных норм в Грузии. Все предыдущие исследования были проанализированы, чтобы сделать вывод о том, что желательна новая оценка сейсмической опасности в соответствии с последними достижениями, а также изменение описания опасности для действующих строительных норм Грузии.