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Macroseismic Manifestation of Seismic Events of Different Intensity on Territory of Vladikakaz

V.B. Zaalishvili
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia
vzaal@mail.ru

I.L. Gabeeva
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

A.S. Kanukov
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

F.S. Morozov
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

D.A. Melkov
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

V.D. Makiev
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

A.F. Gabaraev
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

G.E. Tuaev
Geophysical Institute - the Affiliate of Vladikavkaz Scientific Centre of the Russian Academy of Sciences
Vladikavkaz, Russia

***Abstract*—Each perceptible earthquake provides unique information about its real manifestation on the investigated territory. That is why the data on the manifestation of even a weak earthquake are important for creating and refining seismic hazard maps of various levels. The analysis of available data of macroseismic survey of historical and past earthquakes on the territory of Vladikavkaz is carried out in the paper. The results of the macroseismic survey are compared with the current map of seismic microzonation. The earthquakes with the greatest intensity in the area under research are generated by seismic sources in the territory of neighboring Georgia, as well as the powerful Vladikavkaz fault M = 7.1 and others characterized by although relatively smaller seismic potential, but nevertheless, a noticeable hazard level of local seismic sources. So, quite strong earthquakes of 1915 and 1929, in Vladikavkaz, reached an intensity of 6-7 degree. At the same time, earthquakes generated by local seismic sources (1872, 1874, 1922) appeared with the same magnitude here. The paper shows that macroseismic data are a reliable basis for differentiating the territory according to local, including seismic, properties. The paper provides a rather detailed analysis of the manifestation of the earthquake of January 7, 2005, with the intensity of 3-4 points on the territory of Vladikavkaz, which, despite the low class of the event, made it possible to consider it as a direct indicator of the seismic properties of the soils.**

Keywords—intensity; seismic effect; macroseismic manifestation; seismic hazard; engineering and geological conditions; seismic microzonation

I. INTRODUCTION

Manifestation of each perceptible earthquake provides unique information about its real manifestation on the territory under research. The data on manifestation of any earthquake are important for creating and refining seismic hazard maps of various levels. Different aspects of earthquake macroseismic data for site effect analysis are considered in numerous papers [1-12]. It is enough to mention that such works are included in the first stage of seismic microzonation (SMR) work in Russian methodology, i.e. the study of earthquakes manifestation on the area under research. Information about earthquakes that have a weak manifestation is usually absent (unless it occurs during the period of such works); therefore any acquired data on the manifestation of a real earthquake under conditions of moderate and weak seismicity are important for predicting dangerous seismic effects on buildings and structures and specification seismic hazard maps. Fig. 1 shows the current schematic map of seismic microzonation of the territory of Vladikavkaz, combined with the current building-up of the town. The map was made on the basis on the results of the works in 2009-2012, including the specification of soil conditions and research with the help of instrumental methods [13].

The deep structure of the considered territory was investigated [14]. This was facilitated by the Kolka glacier collapse and the need to analyze the relevant instrumental data

[15]. A region is rich in various natural resources, [16] in the past it was represented by an active area of the mining industry. This has led to attempts to create advanced mining technologies, as well as difficult environmental problems [17, 18].

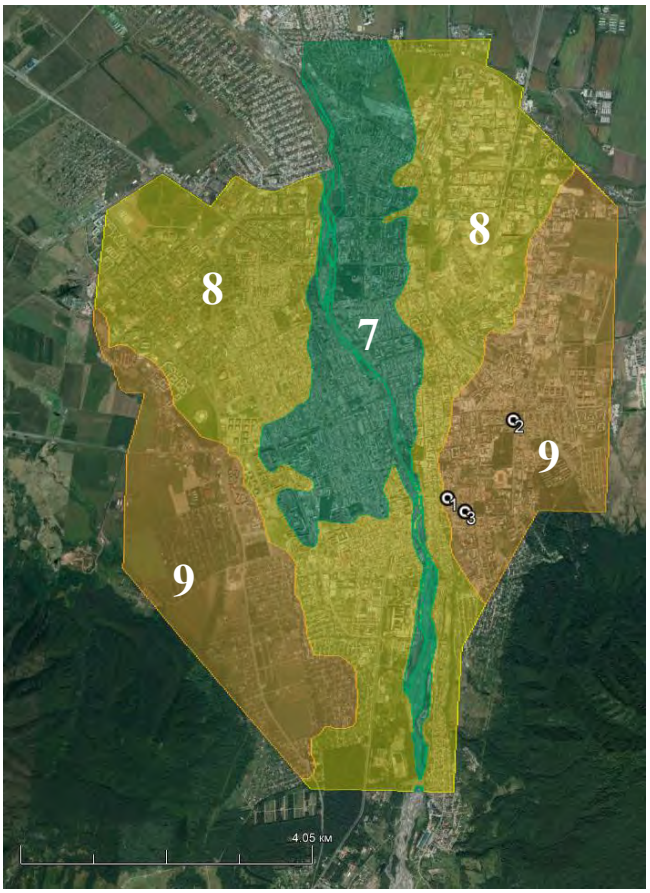

Fig. 1. Schematic map of seismic microzonation of Vladikavkaz, combined with the current building-up; the circles indicate the buildings in which damages caused by earthquakes of 1915 and 1929 were detected: 1 - the Ossetian church; 2 - North Ossetian State Medical Academy (NOSMA); 3 - private two-storey houses in the area of Pavlenko street

II. DATA ON HISTORICAL EARTHQUAKES

Various researchers at different times have carried out a macroseismic survey of the strong and destructive earthquakes effects in the territory of the Republic of North Ossetia-Alania in order to determine the features of seismic activity. Besides, the results obtained during the seismic microzonation of the territory of Ordzhonikidze (Vladikavkaz) in 1969 were considered and taken into account when examining the macroseismic effect of the Kolka glacier in 2002 (2004–2005) [19], including special studies in 2006–2007, as well as the results of international and Russian research projects carried out by us.

In 1969-1970, seismic microzonation of the territory of Vladikavkaz (at that time of Ordzhonikidze) and the adjacent areas was carried out with the help of several methods, including engineering-geological methods. In order to assess the manifestation of the earthquakes intensity and the differentiation of areas (specification of seismic magnitude), great attention along with other issues was paid to the survey of the existing buildings, structures, temporary structures and foundation soils. Besides, the following was done: an engineering examination of the state of buildings, ancient buildings that form building-up, and their foundation soils located outside the town within a radius of 30–50 km. At the same time, the results of the survey carried out on the territory of the town are of particular interest. We can say that it was in those years (1969-1970) that a macroseismic survey of the territory of the town was first carried out with reference to the engineering, geological and hydrogeological conditions of the territory of the town. Along with this, traces of past earthquakes (which by now, for the most part, have not been preserved) were first identified.

Based on the analysis of the obtained data and a local public enquiry, about 15 moderate and strong earthquakes that occurred on the territory of the town were identified on August 24, 1874, with an intensity of 4–5 points, November 8, 1881 - 3-4 points, October 16, 1886 - 6 points, December 18, 1890 - 4 points, September 22, 1896 - 3 points, September 2, 1903 - 5 points, August 10, 1912 – 4-5 points, January 14 1915 – 6-7 points, January 22, 1915 - 4 points, January 25, 1915 - 5 points, which caused strong vibrations of buildings. Finally, on February 10, 1929, at 19.15, a strong earthquake with a magnitude of 6-7 points occurred, the manifestations of which were felt by the population on the territory from Pyatigorsk to Vladikavkaz. This earthquake caused damage to buildings and numerous landslides in the mountains. The subsequent earthquakes (1940, 1947 and 1948) did not exceed 5-point intensity.

III. HISTORICAL BUILDING TYPES OF THE TERRITORY

The main types of buildings that underwent the earthquake effects of 1915 and 1929, and were preserved until the survey period, were one-, two-, and three-storey buildings of burned flat and ordinary red brick and stones from local materials, with clay and lime mortar, with light, wooden floors. Building surveys, public enquiry and data from local organizations performed in 1969–1970 showed that buildings of this type, built on thick dry pebbles, stood the earthquakes of 1915 and 1929. There were not deformation marks cause by earthquakes. In the same types of buildings, which for the most part were located on clay soils with a thickness of 3 to 16 meters (relatively weak soils according to seismic properties) in the southeast of the town, deformations of various degrees were found (from small cracks to destruction) and buildings, according to the current seismic scale, had "significant damage".

To establish the reasons of damage and to assess directly the seismic impact, buildings of the same type (undamaged and damaged buildings) were examined in detail. At the same time, foundation soils were examined in all cases. The summary of the main results of the survey is given below.

The Ossetian church, built in 1803, is situated in the south-eastern part of the town. It is a one-storey building; the attached part of the bell tower has three floors and it is a solid architectural construction, reflecting the main features of the local housing architecture.

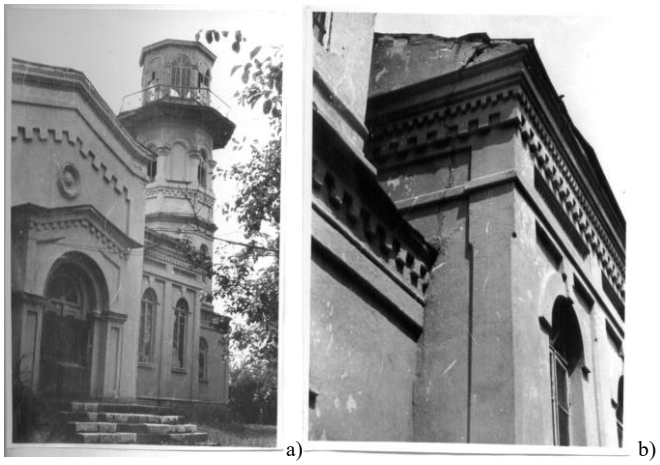

Fig. 2. The Ossetian church of 1803 and its buildings, examined in 1969

The building was constructed on a slope from the Khetagurov street at an altitude of 5-6 meters from the level of the pavement. The north side and the main architectural elements of the building are clearly seen in Fig. 2. The church has rubble stone foundations, the depth of which is about 5 meters. At the base of the structures, dry, highly compressible loams and clays (with a permissible standard pressure at a depth of 5 meters of about 2.5 kg/cm^2) underlie. There is no groundwater at the site in the zone of active influence of the foundations.

With the help of investigation and public enquiry (Khubetsov Radzhi, Ilyin and others) it was found out that the church was damaged as a result of the earthquake of 1929 with an intensity of 6–7 points. As for its state in 1969, the building had continuously inclined through cracks inside the building in the width in the arches and diagonal cracks in the dome from the outside, in the walls at the junction of longitudinal and transverse walls that are developed from above and do not reach the foundation. The latter indicates that the cracks were of seismic nature (Fig. 2 b). In some places due to the uneven foundation settlement, some cracks appeared and were developing “at present” (1970). This became evident from the fact that after a thorough overhaul carried out in 1960 the cracks appeared again in the same place.

North Ossetian State Medical Academy (NOSMA) is located in the southeastern part of the town along Pushkin Street. The complex of the NOSMA, built in 1902–1910, consists of one-story and two-story brick buildings. Figure 3a shows the two-storey part of the academic building, which is U-shaped in the plan. Next to this building, there is a single-storey laboratory building, to which a two-storied administrative and educational building adjoins. On the north side of these buildings, one and two-story educational and laboratory buildings are located. The floor height of the building is 4–5 m. The walls are built of common burnt brick with a lime mortar. The intermediate floor is wooden and the roof is light made of roofing iron. Depending on an organization of the basement the depth of the foundations is at different levels. Foundation soils are clays of a plastic-hard consistency with a thickness of up to 13 meters. Groundwater is located at a depth exceeding 10 meters under the surface.

Fig. 3. The building of the NOSMA, examined in 1969

It was established with the help of a detailed investigation and public enquiry that after the earthquake of 1929 these buildings had significant damage in the form of cracks in the plaster and walls with chopped off pieces of plaster. Buildings had continuous through cracks of 0.5–2 cm. These cracks can be divided into 2 groups according to their origin. The first group includes cracks caused by uneven settlement of the foundations, due to the local moistening of the soils of basement with atmospheric precipitation (Fig. 3, b-d). The second group includes cracks caused by seismic vibrations of the earthquake of 1929. These cracks are found in almost all the main walls, mainly in the separation walls and in the flat arches. They run from top to bottom along an inclined platform and do not reach the foundations of building, which indicates their seismic origin. According to the seismic scale, the mentioned buildings belong to group B, and according to the degree of damage they are referred to the group “significant damage”.

In the southeastern part of the town, thanks to enquiry of local old residents (Abaev Kabibulats Ubilisi, 75 y.o., Kundukhov Vano Vasilyevich, 80 y.o.), who remembered the 1929 earthquake well, one-storey and two-storey typical buildings were examined in K. Khetagurov Str., Tsagolov Str. and Pavlenko Str. The two-storey buildings of the old construction are shown in Fig. 4.

All of them have a symmetrical shape in the plan. Light overlappings and coverings are wooden; the roofs are made of flat tiles. The height of the floors is 3.5-4 meters. The depth of the foundation is between 0.8 and 1.5 meters. All load-bearing walls are made of burnt bricks 50 cm thick on a lime mortar. One of the characteristic features of these buildings is that the roofs made of flat tiles have large slopes and, in the absence of

wooden struts between the rafters, in the case of horizontal vibrations of an earthquake, large horizontal forces are transmitted to the longitudinal walls of the buildings, resulting in cracks and failure in the junction of transverse and longitudinal walls. The above-mentioned buildings have solid inclined cracks of seismic character with a width of 0.5-1.0 cm in “inclined” lintel blocks.

Fig. 4. Typical accommodation buildings common in the southeastern part of the town

According to the results of the 1969 works, the following can be noted: foundation soils of the investigated historical monuments, old public and accommodation buildings, the above-mentioned buildings in the southeastern part of the town, where earthquake effects are mainly observed, are usually dry clays and loamy clays at a height of groundwater level of hgl> 8 m. The described buildings are referred to the group B on the seismic scale and to the group “significant damage” according to the degree of destruction. There are a lot of such buildings, and therefore it can be concluded that the intensity of earthquakes which damaged them did not exceed 7 points.

IV. JANUARY 7, 2005 EARTHQUAKE

On January 7, 2005, a seismic network of the Geophysical Institute of the Vladikavkaz Scientific Center of the Russian Academy of Sciences recorded an earthquake with an intensity of 3-4 points on the territory of Vladikavkaz. The epicenter was located on the territory of Chechnya.

Traditionally, assessment of the earthquake intensity is based on the analysis of the results of macroseismic (engineering) examination of the building-up. In this case, the magnitude and distribution of buildings damage is recorded. In case of moderate and strong earthquakes, particular attention should be given to the manifestations in the environment and to the reports of the population. Often, in case of weak earthquakes, it is the enquiry approach that can be quite a reliable basis for determining earthquake intensity.

For this purpose the young employees of the Institute conducted a questionnaire survey of the population of the town. The number of the respondents was 350. At the same time, the area of the town and its surroundings were investigated. The results of the questionnaire survey, including the data on the respondent’s location, address, the type building, year of construction, number of floors, etc., as well as the manifestation of the event according to people's feelings, became the basis for the earthquake intensity assessment [1].

The results of the enquiry were compared with the points of the seismic intensity scale MSK-64 in the study. In addition, the European Macroseismic Scale 1992, developed in recent years in Europe and introduced in 1996, was used [12].

As a result of studying the enquiry materials, it was found out that almost half of the respondents (171 people) felt earthquake with different intensities. Thus, according to the feelings of 85 people, the studied earthquake was referred to an intensity of 3 points and according to the opinion of 86 people - to 4 points. Besides, 189 respondents did not feel the earthquake at all. It would be possible (based on the "unquestionable" fact of the earthquake) to refer the intensity, noted in the latter case, of 2 points, as in this case the earthquake occurs only under favorable conditions.

With the help of the study of the results, it was determined that various conditions influence the feelings of people.

1) The number of storeys in a building, when the vibrations on the upper floors increase.

2) The type and design of the building or structure (reinforced concrete, brick, block, wooden etc.).

3) Physical aging of a building-up (the presence or absence of damage, etc.)

4) The type of foundations soils of the building-up and their physical condition (gravel, clay, etc.)

So residents of both the upper and lower floors of the accommodation buildings in the district or horticultural co-operative "Vesna" felt the mentioned earthquake in the form of a high-intensity event. It should be noted that the foundation soils of the buildings located here include clay soils of flowing consistency (IL> 0.5).

On the other hand, the residents of the buildings with foundation soils in the form of a pebble stratum (Kirov Str.,

Prospect Mira, Miller Str., Tomaev Str, Etc.) and others did not feel the seismic event.

The population in the areas with multi-storey buildings felt the earthquake more clearly, for example, in Prospect Dovatora, Kuibyshev Str., Kutuzov Str. and Shmulevich Str. There respondents noted the swinging of chandeliers, the rattle of dishes, the creak of furniture, the splashing of water from baths, etc.

In most cases, the earthquake was felt by the population of the town areas which consist of soils with unfavorable conditions for construction.

It should be noted that the residents of the upper floors of multi-storey buildings with foundation soils in the form of dense pebbles also felt this event.

From the very beginning, seismic scales in the region of low intensity earthquakes included the feelings of population of low-rise buildings. Therefore, in the process of data analysis, the authors made amendments for the number of floors. Sometimes high intensity was observed in new areas in the northwestern part of the town in 9-storey buildings. Features of earthquake manifestation in multi-storey buildings were noted in particular when analyzing the earthquake that occurred in the Sea of Okhotsk and its manifestation in the territory of Moscow [3].

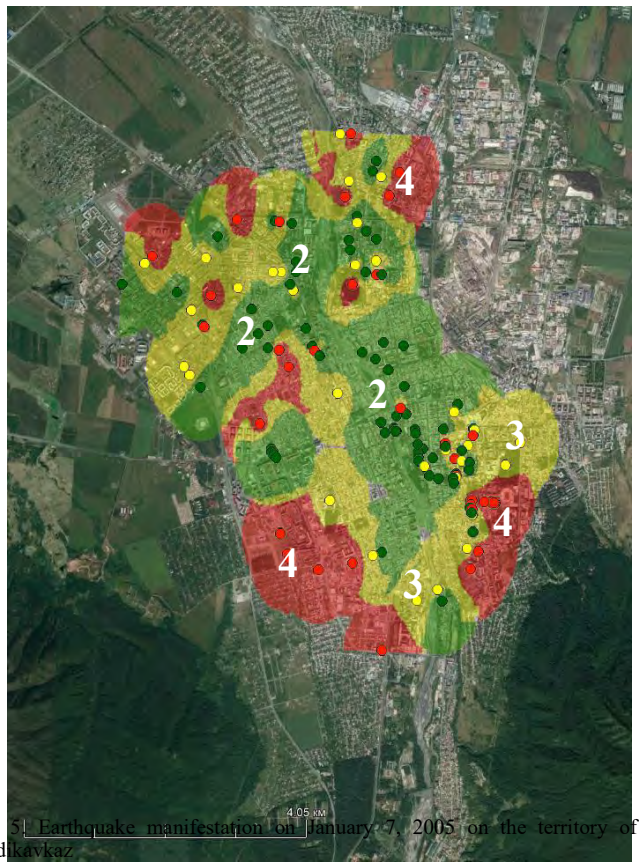

Fig. 5. Earthquake manifestation on January 7, 2005 on the territory of Vladikavkaz

The analysis of the obtained data allowed us to construct a macroseismic schematic map, which was compared with the map of seismic microzonation (Fig. 1) [13, 20]. The map was made based on the results of 2009–2012, including the specification of soil conditions and research using instrumental methods [21-26] on the basis of modern information technologies [27].

The study of spectral characteristics of soil conditions with the help of microseisms made it possible to increase the detail of the engineering-geological basis and, in particular, to additionally allocate the 9-point zone on the left bank of the river Terek [15], which initially was to be assigned to the 8-point zone [28], according to the original map. Intensification of seismic effect is confirmed by the data of a macroseismic survey of the earthquake on January 7, 2005. The macroseismic survey did not include the northeastern part of the town, where industrial facilities are located, as well as the southwestern part, which was underdeveloped by that time (Horticultural co-operatives "Iriston", "Terek", "Daryal", "Druzhba").

As a result of the study it was discovered that differentiation according to the degree of seismic hazard of the soils forming the territory of Vladikavkaz is carried out quite accurately or steadily.

Subsiding clay soils of fluid consistency are characterized by the greatest danger, clay soils of semi-solid consistency and pebbles with sandy-clay filler> 30% covered with clay soils (4–5 m thick) are referred to medium danger soils and pebbles with sandy-clay filler <30% are characterized by the least danger.

V. Conclusion

• The greatest intensity in the area of Vladikavkaz belongs to the earthquakes generated by seismic sources in the territory of neighboring Georgia, as well as the powerful Vladikavkaz fault M = 7.1 and weaker local sources. Seismic events of 1915 and 1929 were with the intensity of 6-7 points, as well as local earthquakes of 1872, 1874, 1922, occurred on the territory of Vladikavkaz.

• The earthquakes of 1915 and 1929 with the greatest intensity equal to 7 points manifested in the town building-up, where foundation soils were formed by stiff clay soils. At the same time, the zone referred to 9-point seismicity is composed of a thickness of clay soils with fluid consistency and the above-mentioned soils may be overlapped on the upside with stiff clay soils.

• The territory of the old part of the town on the right bank of the river Terek (on which the earthquakes of 1915 and 1929 occurred) is composed of hard plastic and stiff clays with a thickness of 3-20 meters and is located in the southeast of Vladikavkaz. Background seismicity of 8 points is assigned to these clay soils. The similar areas, composed of the same clay, are located on the left bank of the town with a thickness of 3-15 meters, being the so-called "average soil conditions" for the town. Pebbles with sandy-clay filler less than 30% are also referred to the 8-point zone.

• Areas of the town, which consist of pebbles with sandy-clay filler more than 30%, which are the underlying soils for all types of soils (200-500 m), reaching the surface mainly along the river Terek, belong to 7 points. The areas on both

banks of the river are composed by similar types of soils. Sometimes in the near-surface layers there are "temporary waters" (flooding with seasonal precipitation on waterproof clay soils). Their presence does not change a seismicity of the corresponding areas and they belong to the 7 points zones.

Data analysis of a macroseismic survey of a weak earthquake of January 7, 2005 in Vladikavkaz was useful for soils differentiating according to their seismic properties.

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