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Predictive models for the localization of soil liquefaction in earthquakes on the Main Sayan Fault (*southern East Siberia*)

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Abstract

Predictive models for the localization of soil liquefaction for seismic events with magnitudes $M_S = 7.5$ and 8.0 were constructed based on available data on a possible earthquake in the zone of the Main Sayan Fault. It has been established that for $M_S = 7.5$, liquefaction will extend over a distance of 40 km from the causative seismogenic fault. For $M_S = 8.0$, the limiting distance from the activated segment of the Main Sayan Fault will be 112 km. The calculation models take into account the effect of faults on the predicted process, which allows a more accurate identification of areas with different probabilities of this event. Zones of possible liquefaction at $M_S = 7.5$ include the towns of Kultuk, Sludyanka, Baikal'sk, Arshan, and Podkamennaya. At $M_S = 8.0$, the liquefaction process will spread over a large area including the cities of Usol'e-Sibirskoe, Angarsk, and Irkutsk, especially localities near the Angara River and its major tributaries. Similar evaluation can also be made for other natural situations with known seismogenic faults, fault-block divisibility of the Earth's crust for the Pliocene–Quaternary stage of tectonism, earthquake magnitude, and potentially liquefiable soils within the model area.

Keywords: liquefaction; earthquake; faults; prediction

Introduction

The Main Sayan Fault (MSF) strikes NW from the southern tip of Lake Baikal to the Man River basin and is the largest structural boundary between the crystalline protrusion of the Siberian Platform basement and the Sayan–Baikal folded area (Figs. 1 and 2). The length of the fault is nearly 1000 km. Structurally, it consists of zones of subparallel dislocations, accompanied by fragmentation, fracturing, and mylonitization. Originating in the Precambrian, the deep fault actively influences the tectonic setting of the boundary zone between the Siberian Platform and the folded area. Currently, the seismic potential of its southeastern segment corresponds to $M_S = 8$ (Imaev et al., 2015).

Using methods of seismology and GPS geodesy, it has been found that the MSF is currently in the locked state; in the area of its dynamic influence, there is accumulation of elastic stresses, whose relaxation will be accompanied by a strong earthquake (San'kov et al., 2004). Also, it was calculated that at a frequency probability of 95%, the Main Sayan Fault may present a hazard starting from about 2120. With a decrease in the probability to 72%, the start of the period of potential hazard is reduced to about 2030 (Ivanov et al., 2009). Since the MSF is located near major population centers and even crosses federal-aid highways, it is necessary to study the distribution of geological hazards near the Main Sayan Fault.

As is known, strong earthquakes can be accompanied by liquefaction of water-saturated dispersive soils under the action of seismic waves, with an almost complete loss of their bearing capacity. It is assumed that seismic liquefaction is caused by a sudden reduction in the strength of cohesive soil due to the destruction of structural bonds upon passage of seismic waves (Voznesenskii et al., 2005). This results in deformations involving soil mass flow. Such events can have catastrophic effects. In this regard, the evaluation of the liquefaction of water-saturated dispersive soil in expected earthquakes and the associated effects is an important and complex engineering problem for the design and construction of facilities in seismic areas, as well as for the prevention of emergency situations in population centers in the area of seismic hazard.

In many countries, considerable attention has been paid to the study of the soil susceptibility to liquefaction during

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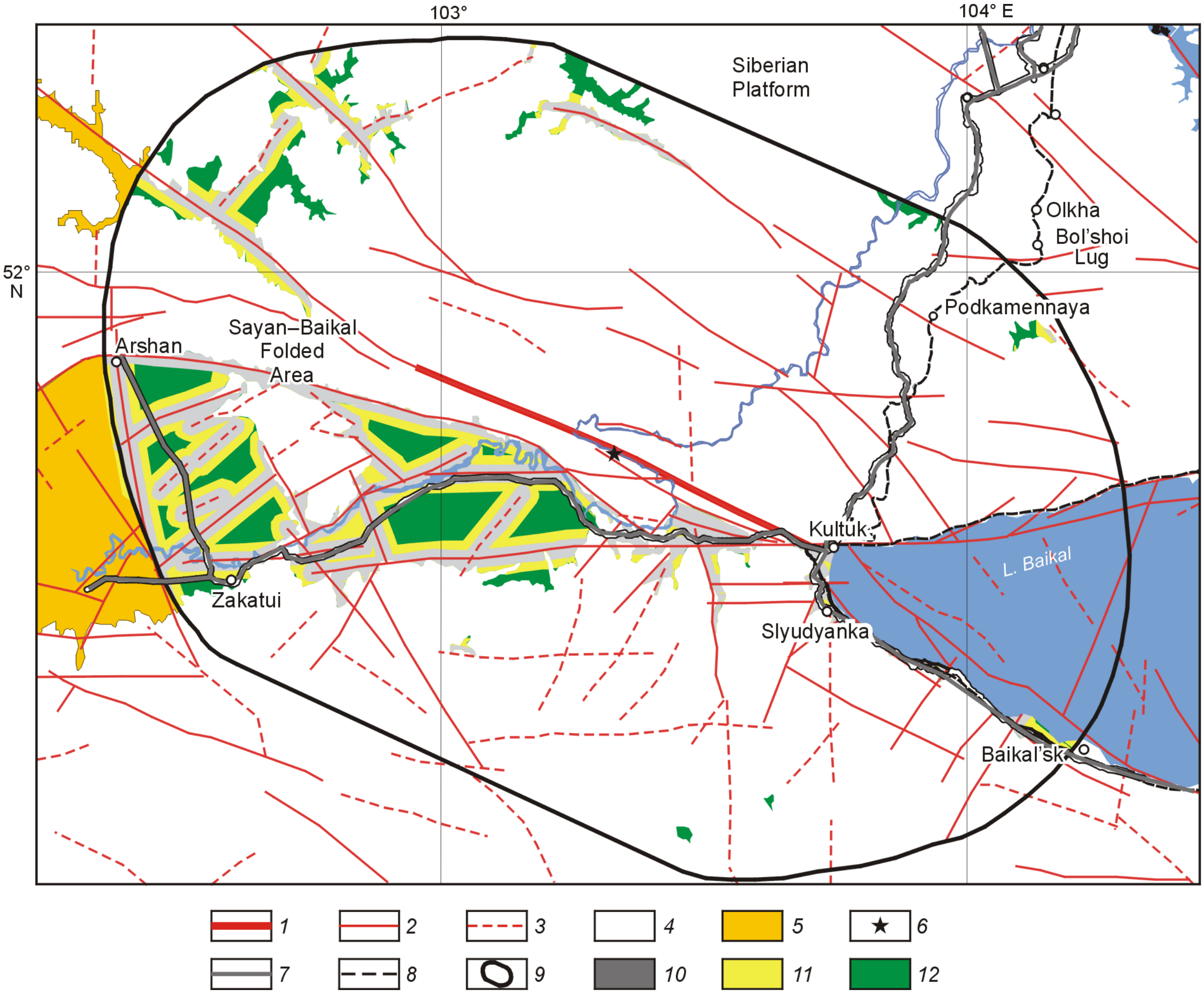

Fig. 1. Model for the localization of liquefaction for an earthquake of magnitude 7.5. *1*, seismogenic fault segment used for the modeling; *2*, proved faults; *3*, inferred faults; *4*, root fractures; *5*, Quaternary deposits not subjected to liquefaction; *6*, center of the East Sayan paleoseismodislocation (Chipizubov and Smekalin, 1999); *7*, highways; *8*, railroads; *9*, boundary within which liquefaction is possible; *10*, liquefaction zone at a distance of 1 km from the axial part of the fault with an occurrence probability of 0.68; *11*, liquefaction zone at a distance of 2 km from the axial part of the fault probability occurrence probability of 0.18; *12,* liquefaction zone at a distance of 8 km from the axial part of the fault with an occurrence probability of 0.14.

seismic events. For example, the US Geological Survey performed studies in northwest Alameda County and composed a map of soil liquefaction at $M_S = 7.1$ (Holzer et al., 2010). In addition, US researchers are moving toward the development of a new type of maps (LiqueMap) of soil response to earthquakes which will reflect geological hazards in real time during 20 min after an earthquake (Holzer et al., 2006a,b). After a disaster, it will be possible in a relatively short time to predict online the damage to vulnerable infrastructure targets and immediately sent a rescue team to the site. In Russia, there are no such maps, at least, in the public domain, and there are few studies of the soil susceptibility to liquefaction.

The purpose of this paper is to construct predictive models for the localization of soil liquefaction for possible earthquakes in the MSF area.

Background and method of constructing the models

To construct predictive models, we used the relationships between the magnitude of an earthquake and the distance to which the liquefaction effect extends from the seismic epicenter and nearest faults (Lunina et al., 2014). In evaluating potentially hazardous areas, we primarily considered the soil type and composition. In the study area (Figs. 1 and 2), liquefiable soils consist mainly of Quaternary inequigranular sands, gravel and sandy loam. Another important factor is the presence of groundwater. In this area, the groundwater depth varies on average from 0.3 to 25 m, depending on the identified aquifers (Laperdin et al., 2016), which is favorable for earthquake-induced liquefaction to occur (Obermeier et al., 2005; Seed, 1979). The process becomes active in earthquakes with $M_S \geq 5.2$ (Andreev and Lunina, 2012). In our case, it is