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A note on peak accelerations computed from sliding of objects during the 1969 Banja Luka earthquakes in former Yugoslavia

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ABSTRACT

Peak ground accelerations, computed from sliding of objects during the 1969 Banja Luka earthquakes in Bosnia and Herzegovina (former Yugoslavia) are computed assuming that the ground motion consists of simple rectangular or sinusoidal pulses. The results show good agreement with observed macroseismic estimates of shaking based on the Mercalli–Cancani–Sieberg (MCS) intensity scale. The results are also in compliance with recorded accelerations during the 1973–1986 period and with recent probabilistic hazard analyses for the Banja Luka region.

1. Introduction

Analyses of sliding and overturing of objects following the 1969 earthquakes in Banja Luka have played an important role in the formulation of microzonation maps, which have represented a basis for earthquake-resistant design of structures in the region since 1971. Likewise in other cities affected by earthquakes—and before the introduction of strong motion accelerographs—estimation of the shaking levels had been evaluated by indirect inverse analyses [2,11,16,20]), which are associated with non-unique outcomes, uncertainty, and in some cases under-estimates that may then result in biased and non-conservative design of structures. As new instrumental data becomes available and microzonation tools are developed, it is necessary to re-evaluate older microzonation methods so that the next generation of structures can be designed based on balanced and more accurate estimates of future strong motion demands [33]. With modern proposals for seismic microzonation of cities like Banja Luka [15], it becomes timely to reevaluate the older data on strong motion amplitudes and to test the consistency with new estimates. To this end, in this note we will revisit the data on sliding and overturning of objects described by Stojković et al. [28] and estimate the peak accelerations in the urban area of Banja Luka. We will also compare these estimates with recorded peak accelerations since 1971 and the recent mapping of microzonation in the same area [15]. We will not consider a detailed comparison of our estimates of peak accelerations with those of Stojković et al. [28]. This comparison is better made in the broader context of reevaluating the microzonation methodology in former Yugoslavia during the early 1970s [19].

Studies of sliding and the rocking of bodies caused by earthquakes pose difficult problems because no exact or unique solutions exist. Detailed forward studies can predict different sequences and combinations of sliding, rocking, and overturning, but inverse studies of sliding and overturning can yield only approximate and limited inferences about the causative motion. Since the pioneering works by Milne [21,22] and Perry [24], many studies by seismologists and earthquake engineers have been carried out [23,5,6–8]. The interest in this subject continues today with an emphasis on the motion of objects in the buildings [1, 17, 18,4,37] and on the overturning of precarious rocks in the field [3,26]. In this note we will consider only the simplest forms of inverse analysis to estimate the amplitudes of peak acceleration during strong shaking in terms of the data on sliding of objects caused by strong earthquake shaking.

On October 27, 1969, the city of Banja Luka (former Yugoslavia, today the Republic of Srpska, Bosnia and Herzegovina) was struck by an earthquake with M_L=6.4, I_0=VIII–IX °MCS (Fig. 1) [9]. In the wider region of Banja Luka, 60% of the buildings were damaged beyond repair, including most of the schools. Over 76,000 people were left homeless and the economic losses were substantial. After the earthquake, renewal and urban reconstruction efforts were initiated, with the city government requesting that a new master reconstruction plan be consistent with estimated effects of the local soil and geological-site conditions with regard to plausible future strong earthquake ground motions [27]. For this purpose, seismic microzonation was carried out in 1971 by a team from the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) in Skopje, Macedonia. In the microzonation, the level of

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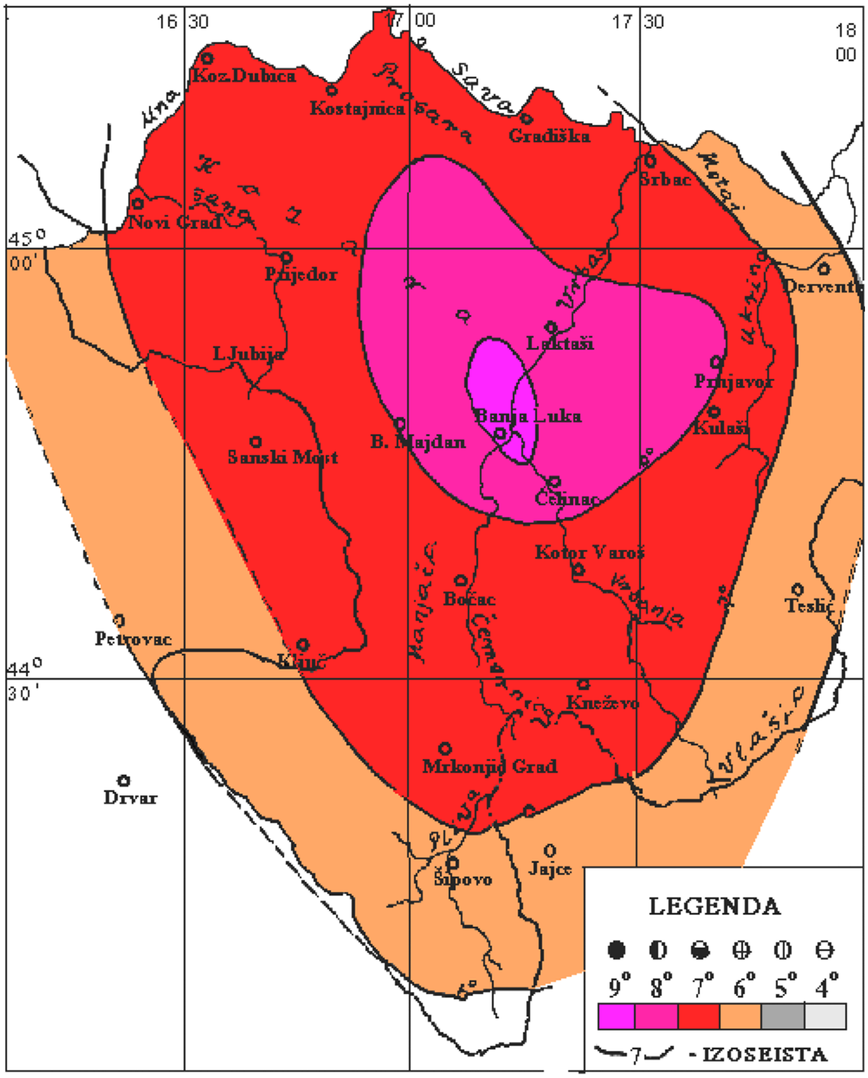

Fig. 1. Isoseismals (°MCS) of the October 27, 1969, M_L=6.4, Banja Luka earthquake (after [36]).

seismic action for the whole urban region of Banja Luka was formulated based on the 1969 main shock (M_L=6.4), which was considered at the time to be the strongest recorded historical earthquake. The urban area of Banja Luka was divided into three Zones in terms of the predominant periods of local soil and with estimated acceleration values of 80 cm/s^2 for Zone I, 140 cm/s^2 for Zone II, and 180 cm/s^2 for Zone III. Part of these studies involved tabulation and interpretation of the sliding and of overturning of objects during the earthquakes [28].

In early 1970s, SMA-1 strong motion accelerographs [10,32] were installed in Banja Luka at four locations: (1) Seizmološka Stanica (SS), (2) Borik BK-2 (BK2), (3) Borik BK-9 (BK9), and (4) the Institut za Ispitivanje Materijala (IIM) (Fig. 2). During the period from 1973 to 1986, approximately 40 earthquakes were registered with magnitudes M_L between 2.8 and 5.4 at these four locations [10,34]. Peak ground accelerations from earthquakes with a magnitude M_L between 3.7 and 4.2 ranged from 70 to 190 cm/s^2, that is, they were of the same order of magnitude as the values given in the 1971 IZIIS microzonation map, which were (as previously mentioned) estimated on the basis of the M_L=6.4 earthquake. The peak acceleration values from the strongest recorded earthquake during this period, with M_L=5.4 (August 13, 1981), ranged from 218 to 434 cm/s^2, which are 1.2–2.4 times larger than the values given in the 1971 IZIIS map. In other words, the earthquake with a magnitude one unit smaller than the 1969 earthquake produced twice as large values of acceleration than those in the 1971 microzonation map. This suggests that the peak ground accelerations during the October 27, 1969 earthquake were also larger than those estimated by IZIIS [28].

To investigate this apparent discrepancy we re-analyze the data used in the estimation of the peak ground accelerations. Our results are 2.2–2.9 times larger than the corresponding values estimated in 1971 in the case of the rectangular pulses, and 3.0–3.8 times larger for the assumed sinusoidal pulses. Our estimates of peak ground acceleration are in good agreement with the existing empirical relation between the macroseismic intensity and peak accelerations, which were developed for the northwestern Balkan region [35].

2. The 1969 Banja Luka earthquakes and the data on sliding and overturning of objects

The seismic activity in the region of Banja Luka, which began with several small-magnitude earthquakes (up to M_L=4.5) in late 1968 and in the spring of 1969, continued in September 1969, culminating with the strongest foreshock on October 26, 1969 (M_L=6.0, I_0=VII–VIII °MCS) and the main shock a day later (October 27, 1969; M_L=6.4, I_0=VIII–IX °MCS). The main earthquake was felt over a large area. The IX °MCS isoseismal covered