New Results of the Method of Medium-Term Seismic Forecasting LURR (on the Example of New Zealand)

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Abstract. This paper is devoted to the method of strong earthquakes prediction based on the analysis of seismic catalogues with involvement of the Coulomb-Mohr’s criteria and basic laws of linear theory of elasticity. This method is well-known as LURR (load-unload response ratio). Inherently, it allows to identify attainment of the deformation process of the phase when medium response to loading can be no longer linear (predestruction). The technique has been successfully applied in Sakhalin and in the present work its capabilities were tested in the new conditions. The research is based on New Zealand seismic catalog with (Mw > 3). We have considered retrospective seismic events related to time and space distribution.

1. Introduction

Nowadays there are some achievements in long and short time earthquake prediction. We should mark some of them [1]. These approaches are mostly based on seismological data and predictions are made for 5-10 years (long-term) and 3-5 years (mid-term).

The method of mid-term prediction, named LURR, was invented in 90-th years of previous century and in accordance with [2] was successfully applied in different seismicity active regions. Besides, the methodology has been verified and accomplished in the laboratory tri-axial compression simulation together with numerical simulation. This method is used in the Institute of Marine Geology & Geophysics of Russian Academy of Sciences since 2014 year. We have made special software [3] to perform main calculations and get important result for seismic hazard of Sakhalin Island [4]. It’s useful to apply our proven software for New Zealand territory as seismic prediction collaboration. On the other hand, use of foregoing methodology in the Pacific region similar to Sakhalin is important for methodology itself.

The history of New Zealand seismicity is presented in numerous articles, some of them are here [5; 6] and others. Our observable area is located in the southwest part of the Pacific Ring of Fire generated by Pacific and the Australian plate’s interaction. In accordance with GNS Science reports the average periodicity of New Zealand seismicity is: several earthquakes with Mw = 6 – every year, one with Mw = 7 – every 10 years, and with one Mw = 8 – every century [7]. Tectonic plates relative movement is 47 mm/year in north part of New Zealand and 37 mm/year in south part [8]. There is a subduction zone of the Pacific plate underneath the Australian plate in the north part of New Zealand and there is another subduction zone of the Australian plate underneath the Pacific plate in the south part. Most part of New Zealand earthquake sources is bounded by Alpine fault on South Island and Wellington fault on North Island territories and system of satellite faults (Figure 1) [9]. Since
beginning of earthquake observation in 1840 year till nowadays there are some intervals of relative seismic activity slacks in periods from 1888 to 1929 and 1968 to 2001. There are most powerful seismic events happened after that slacks in Napier in 1931 year with Mw = 7.8 and Dusky Sound in 2009 year with Mw = 7.8 [7]. Thus, the territory of New Zealand is located in the area of high seismic activity and represents significant interest for research.

2. Methodology

The starting point of LURR method is equivalence of load-unload response rates during elastic state deformation \( X_+ = X_- (= 1) \). Since damage of material becomes more serious and goes beyond the bounds of elastic limit, the -parameter starts to increase. This relation grows as the rock is approaching to fast microcracking phase. We can consider that near critical behavior prior damage. The main concept and details of LURR method are expounded in the author’s articles [2].

![Figure 1. The major faults in New Zealand in accordance with [10] – on left, the map of distribution of earthquake epicenters in accordance with New Zealand catalog [11] (on center), computational zones (on right).](image)

In our calculations we have used our own software the “Seis-ASZ” created in the Institute of Marine Geology & Geophysics of Russian Academy of Sciences [3]. The “Seis-ASZ” software uses the original algorithms of LURR method as well as analytic correlations for tidal perturbation [12]. We have verified our “Seis-ASZ” tidal displacement simulation with [13] data of Berger’s program and satisfactory convergence was found.

In our previous papers we have chosen the forecast parameters for place and time in accordance with the original articles [2]: waiting time up to 2 years and place within 100-150 km (radius) of calculation zone where the earthquake precursor has been revealed (LURR values exceeding). Original LURR papers [2] didn’t pay attention to epicenter definition and time for predicted earthquake. We tried to do that for South part of Sakhalin Island. In case of Sakhalin we used two adjacent zones of the same dimension, one zone with center localized in the epicenter of Nevelskoe earthquake (2 August 2007) and other zone shifted at 1 degree of longitude to east. As it was mentioned in [3], the result in first zone is going better in comparison with the sample including all catalog on the side of precursor intensity, but without time variations. There was no any precursor before Nevelskoe earthquake at all in the second zone.
We got first results for north part of Sakhalin island [3] based on analysis of the data-rich network (with sufficient quantity of seismic stations) developed by Institute of Marine Geology and Geophysics Far Eastern Branch Russian Academy of Science in 2006 year. This network allows us confidently register earthquakes with $M_w = 2$ and more. As opposed to the result on the south part of Sakhalin Island, the results on the north part have shown efficient earthquake forecast [3]. Epicenter of future earthquake could be located in a zone with the following coordinates: $51–52^\circ N, 142–143.5^\circ E$ in compliance with our calculations. In accordance with our forecast, the beginning of the waiting period was set since February of 2015 year. This forecast has been successfully realized in the 14th of August 2016 on 11:15:13 UTC A. The local magnitude was $M_L = 6.1$. Epicenter coordinates are $50.351^\circ N, 142.395^\circ E$. The seismic event has happened at depth of 9 km, close to the Onor village. There is only latitude definition error, it is for $0.7^\circ N$.

Unfortunately, we have been limited with earthquake catalog for Sakhalin which does not allow selecting more zones to analyze. Due to this reason as well, we have selected New Zealand as good area for the methodology development. In this part of the Pacific region seismicity is revealed on the greater territory and seismic activity is significantly higher. We used GNS Science earthquake catalog, this catalog [11] covers the area of $16^\circ S$ and $15^\circ E$ and includes 36071 events from September 2003 to December 2011 (Figure 1). Selected territory has been divided into 21 zones (Figure 1). Four zones (1, 14, 20 and 21) didn’t fit for calculations due to lack of data. There are 9 earthquakes with $M_w > 6$ happened during the consider time. The LURR data plotting with the following parameters: floating window - 360 days, step-interval - 30 days, magnitude separation - $M_w = 3.3$–5. Here we ought to explain the meaning of a floating window. It relates to expectation time of coming seismic event. So, if, for example, the function has exceeded base level two or more times, this means the sign appearance. Precursor is going out to the maximum level, and finish of this process is return to the background level. If, for example, the point of return is January 2000, so adding to that value a half of window (180 days) we get data of last catalogue record which was used for function construction – June 2000 (we’ll use exactly this data in future, not the position on the graph). Beginning with this date the prognosis realization could be expected. Its a discussion question how long could this expectation period last. In original paper [2] this time range variates from a few months to a few years, but its long period. For instance, in Sakhalin island case we got minimum value in two months and we could expect in New Zealand case that terms will be not so great.

3. Results

We have selected zones No 12, 13, 16, 18, 19 due to representativeness of variations (exceeding two or more times). The LURR parameter in all other zones (2-11, 15, 17) has not shown any excess (precursor absence) during the consideration period (2003-2011 years). Precursor is evidently weak in zone 16, just a little increment of double rate. Zones 18 and 19 (Figure 2) have four and five times excess. Precursor developed in these zones (18, 19), that means the value of function has returned to a background level (LURR < 2) in June 2009. In zone No 16 generation of precursor was completed on July 2008 year. Precursors in zones 18 and 19 indicate the same prediction period. We could arrange prediction area on these zones, but little sign in zone 16 (with one-year delay) shows it to be different. We need to consider small variation in zone 16 during determination of forecast area. There is no any precursor in zone 17, and we can’t suppose two separate earthquake centers (No 18, 19 vs No16) due to short distance. So, there is an option to search earthquake center position between them in zone 17. Let’s assume the earthquake centers will be closer to zones 18 and 19 because precursor is weaker in zone 16 and not sufficient moved to zone 19. Period of expectation is set from June 2009. It has been estimated in a few years (one year in average) in accordance with original articles [2]. Let’s go by the average value, so the end of “alarm” will be at June 2010. In conclusion, prediction parameters are: 06.2009-06.2010, with coordinates range: 45-46ºS, 166-167ºE.
The most powerful variation of LURR is located in zone 12, this variation exceeds background level in 16 times. It took 7 months to return from maximum level in 13.02.2009 to background level in 11.09.2009. LURR variation reaches four times values in zone 13, from maximum level in 08.11.2008 returns to background level in 08.01.2009. Time difference between zones 12 and 13 is enough considerable, but we should interpret them together because of their closeness. According to the calculation result, the earthquake could be waiting from 08.01.2009 to September 2010. We need to mark LURR variation on 2005 year in zone 13 as well. This variation is essential by amplitude (more then 3). In this zone return to a background level occurred in 19.04.2006, so since that time till 19.04.2007 in zones near zone 13 (or itself) we can consider seismic hazard.

Thus, we have two forecasts for zones 12 and 13: 04.2006-04.2007, 42-44°S, 172-173°E.; 01.2009-09.2010, 42-44°S, 170-172°E. Retrospective graphic forecast for 2003-2011 years is presented on the (Figure 3). It is necessary to mark, that there are two strong events in the same time in two areas. These areas are significantly away from each other and there is zone No 14 with low seismicity between them.
Figure 3. Prediction areas and strong earthquakes for 2003-2011 years.

Analysis of seismic events from 1940 to 2003 years, which precede the period researched in this paper, from the papers [5] and others testifies to relative seismic slack in the zone No 14. This is mostly correct for deep-focus earthquakes. Such seismic activity reduction is probably related to stress release near the Alpine fault. In accordance with the data of The World Stress Map Project [14] this zone is described as strike-slip tectonic stress regime. So some stress reduction takes place here due to fault slip.

Let’s consider the list of earthquakes to mark the potential active zones on the prediction map. It is possible to find some interactions when doing careful analysis of epicenters and events depth. Remove secondary events (aftershocks) to get the reduced list (Table 1).

Table 1. Earthquakes list with major parameters.

| No | Year | Month | Day | Hour | Minute | Second | Latitude | Longitude | Depth | Magnitude |
|----|------|-------|-----|------|--------|---------|----------|-----------|-------|-----------|
| 1  | 2009 | 7     | 15  | 9    | 22     | 29.32   | -45.77   | 166.587   | 12    | 7.8       |
| 2  | 2010 | 9     | 3   | 16   | 35     | 41.84   | -43.527  | 172.168   | 11    | 7.2       |
| 3  | 2007 | 10    | 15  | 12   | 29     | 33.72   | -44.739  | 167.435   | 5     | 6.7       |
| 4  | 2006 | 8     | 13  | 4    | 29     | 25.8    | -41.764  | 172.652   | 94.1  | 5.9       |

Results are shown on the (Figure 3), combined with prediction zones. Earthquakes No 1, 2 and 4 perfectly fit to prediction map. There are three earthquakes (1, 2 and 4) in the forecast area. We have
expected seismic event from 2009 to 2010 in two areas. It happened in first (Figure 3) forecast area after 43 days since alarm announcement. It could be a question about perspective of forecast for second area after event with magnitude 7.8. The answer is coming from calculation in zone 12, where return to background happened in 11 September 2009, and this was two months later after earthquake No 1. The forecast for second area has been realized after a year. Such delay could be interpreted as stress released after first earthquake, and it took some time to release second event. Earthquake No 4 in 2006 year with magnitude Mw = 5.9 was revealed as LURR reaction after four months since the alarm announcement. Final result is achievement of maximum possible indicator for middle forecast category (target capture, pass target, false alarm). There is a good space localization of epicenter. We have found LURR amplitude variation with remoteness from epicenter on examples earthquakes No 7 and 8, but it was not proved for the earthquake No 2 (Mw = 7.2). The energy of forecast event does not relate to precursor amplitude. For the event in 2009 year (Mw = 7.8) expectation time is about a month (the same as for Sakhalin island). This duration is longer for the rest of events, but no longer than one year. The LURR method assumes regular earthquake catalog update because any replenishment delay for one month is comparable with delay of expected forecasted earthquake. We consider LURR method as promising for next investigations. In the future it’s possible to realize automatic zones scanning (it’s manual now), but that needs more powerful computers.

4. References
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