VIBRATION FORECASTING BY THE RESULTS OF SYNCHRONOUS CONTROL OF WATER LEVEL CHANGES IN SEVERAL OBSERVING WELLS

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The article presents the results of approbation the vibration forecasting methodology based on the synchronous measurement results of water level fluctuations in several observing wells. These fluctuations are caused by the shocks impact generated in a distant source of a maturing vibrations. The approbation demonstrated the reliable forecast possibility of earthquake time and its epicenter coordinates.

KEYWORDS

Vibration forecast, lunar-tidal harmonic, trend of the tidal harmonic amplitude, forecast model, shocks environment criticality.

1 INTRODUCTION

Forecasting an earthquake based on the results of monitoring its precursors is a very urgent task [Kanamori 2004]. Thus, it was found [Nagornyi 2018a] that, based on the results of studying the changes in linear soil seismic fluctuations during the observed period, it is possible to reliably forecast the time, the strength [Nagornyi 2018b,c] and the epicenter [Nagornyi 2018d] of earthquakes.

The water-saturated soil volumetric deformations are widely considered along with the soil seismic fluctuations. These deformations are indirectly evaluated by the change in the water level registered in the observed deep wells [Wang 2010].

During the strongest earthquakes of magnitude 8-9, the seismic waves influence is registered at up to tens of thousands of kilometers from the epicenter [Roeloffs 1998, Pigulevskiy 2011], so this reflects the earthquakes planetary effect on the Earth's hydrosphere [Brodsky 2003]. This, in turn, makes it possible to forecast a future earthquake at wells far from its epicenter by monitoring volumetric soil fluctuations caused by the seismic waves impact reaching the well [Cooper 1965].

In this regard, the above-mentioned earthquake forecast methodology approbation, which has demonstrated its effectiveness when considering the dynamics of changes in the soil linear seismic fluctuations [Nagornyi 2018d], is very relevant in the case of analyzing the soil volumetric deformations. At the same time, the water level synchronous monitoring at several wells allows obtaining additional information that allows forecasting the future earthquake epicenter coordinates [Panda 2014, 2018a,b, 2019 ; Valicek 2016 and 2017, Macala 2009 and 2017, Pandova 2018, Balara 2018, Monkova 2013, Gombar 2013, Murcinkova 2013, Bielousova 2017, Dyadyura, 2017, Duplakova 2018, Krehel 2013, Flegner 2019, 2020, Markulik 2016, Mrkvica 2012, Modrak, 2019, Chaus 2018, Pollak 2020, Olejarova 2017, Rimar 2016, Zaborowski 2007, Michalik 2014, Straka 2018a,b].

The information obtained at three observed wells in Ukraine was used as the initial data analysis [Kanamori 2004, Nagornyi 2018, Wang 2010, Roeloffs 1998, Brodsky 2003, Cooper 1965, Bower 1978, Pigulewskiy 2011 and 2012].

2 RESEARCH METHODOLOGY

It is assumed that the seismic disturbances propagation in the space surrounding the earthquake epicenter obeys the spherical wave equation:

$$\xi = \frac{A_0}{R} \cdot \cos(\omega \cdot t - k \cdot r + \varphi_0), \tag{1}$$

where A_0 – source amplitude; R – epicentral distance; ω – source frequency; φ_0 – oscillation source phase; k – wave number.

The problem solution of forecasting an earthquake, provides for the earthquake place and time determination. Let's consider the solution to each of the problems.

Determining the epicenter coordinates.

Based on equation (1), we write down the equations system (2) for the fluctuations amplitudes ξi, the water level in each of the observed wells.

$$\xi_i = \frac{A_0}{R_i}, \tag{2}$$

We solve each of this system equations relative to the source amplitude A0, and we obtain the equations system (3).

$$A_0 = \xi_i \cdot R_i. \tag{3}$$

Equating the equations left-hand sides that make up system (3), we obtain the working equations system (4).

$$\begin{cases} \xi_i \cdot R_i - \xi_{i-1} \cdot R_{i-1} = 0, \\ \xi_i \cdot R_i - \xi_{i+1} \cdot R_{i+1} = 0, \\ \xi_{i-1} \cdot R_{i-1} - \xi_{i+1} \cdot R_{i+1} = 0. \end{cases} \tag{4}$$

System (4) is solved numerically relative to the epicentral distances R_{i-1}, R_i, R_{i+1}. Using expressions (5), which determines the distance between sphere two points, we pass from the epicentral distances R, provided that the wells coordinates are known, we directly determine the earthquake epicenter (longitude E °, and latitude N °).

$$R_i = arctg\left[\frac{\sqrt{(\cos x_O \sin \Delta y_i) + (\cos x_i \sin x_O - \sin x_i \cos x_O \cos \Delta y_i)^2}}{\sin x_i \sin x_O + \cos x_i \cos x_O \cos \Delta y_i}\right] \cdot 6372.8 \tag{5}$$

where x_O, y_O – earthquake epicenter coordinates ($N = x_O$, $E = y_O$); x_i and y_i – the geodetic latitude and longitude of the location of the i - th observing well, respectively; Δy_i – parameter equal to the difference in degrees of location longitude of the i - th observing well and the epicenter ($\Delta y_i = y_0 - y_i$).

Determining the earthquake time.

The results of water levels measurements in observing wells are subjected to spectral analysis to increase their informativeness. The spectrum informative component according to [Nagornyi 2018, Bower 1978] is the lunar-tidal frequency component of water level fluctuations. The repeatability of this component is 1.94 times a day.

Based on this component amplitude, synchronously registered in each of the three wells, the same component amplitude is determined in the observing well, conventionally located at the forecasted earthquake epicenter

$$A_0(t_i)=\sqrt{\sum_{j=1}^{m}\left(\xi_j(t_i)\cdot R_j\right)^2} \qquad (6)$$

As a result of minimizing the "discrepancy" (7) of the water level trend $A_0(t_i)$ and the forecast model graph A_{mod} (8), one of its parameters T_{for} is determined, which numerically coincides with the earthquake sought time

$$U=\sum_{j=1}^{m}\left(A_0-A_{\mathrm{mod}}\right)^2 \Rightarrow \min\ . \qquad (7)$$

$$A_{\mathrm{mod}}=A\cdot\left[1+\alpha\cdot\left(\frac{t_i-t_0}{T_{for}-t_i}\right)^{\beta}\right], \qquad (8)$$

where: T_{for} – earthquake time forecasting; A,α,β – model parameters determined in the minimizing the "discrepancy"; t_0, t_i – calendar time at the water level registration for the first and subsequent measurements cases, respectively.

3 RESEARCH RESULTS

The initial data for the analysis [Pigulevskiy 2011 and 2012] were registered for 50 days (from December 16, 2004 to February 4, 2005) in three observing wells as shown in Fig. 1.

The wells coordinates are as follows:

- well № 1 N: 47.91°, E:33.39°;
- well № 2 N: 48.46°, E:35.14°;
- well № 3 N: 47.49°, E:34.59°;

Figure 1. Observing wells location map in the central part of Ukraine: 1 - Krivorozhskaya; 2 - Dneprovskaya, 3 - Mikhailovskaya

The research results are shown in Figs. 2-7 and are presented in the Table 1. So, Fig. 2 shows graphs (trends) of changes in water levels registered in each of the considered wells. Here and below, we consider the water levels average values that were measured over the past week. Fig. 3 presents the water level fluctuations spectra, which show the lunar-tidal and daily components of the fluctuations, the last is due to the Earth rotation. Graphs of changes in the lunar-tidal component level registered in each of the wells during the observed period are shown in Fig. 4. The lunar-tidal component trend calculated by formula (6) for the observing well, conventionally located at the epicenter of the predicted earthquake, is shown in Fig. 5. For convenience, the graph is normalized by the first value of observed trend of this fluctuations component

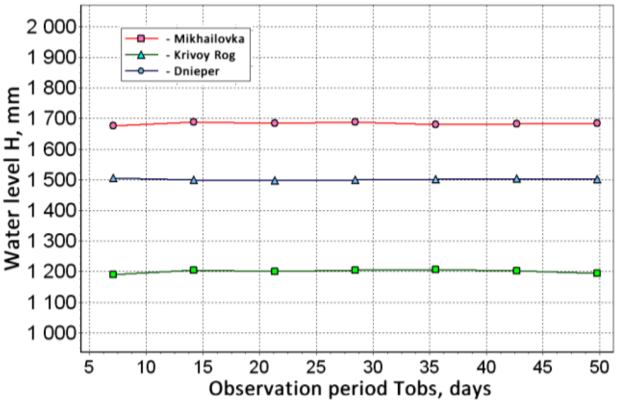

Figure 2. Change in average weekly water levels over the observation period

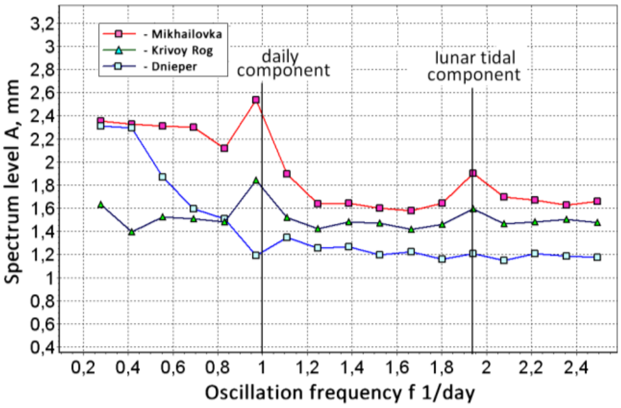

Figure 3. Fluctuations spectra registered in observing wells

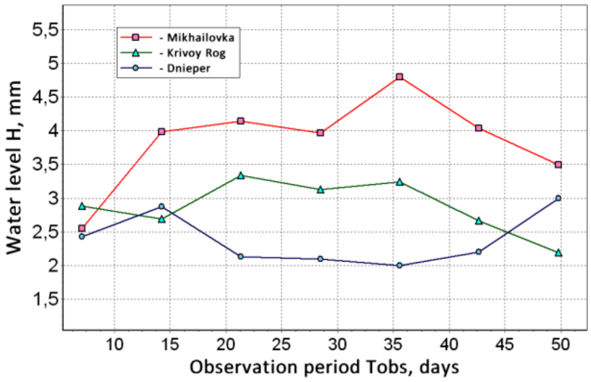

Figure 4. Change over the observation period of the average weekly levels of the lunar tidal component

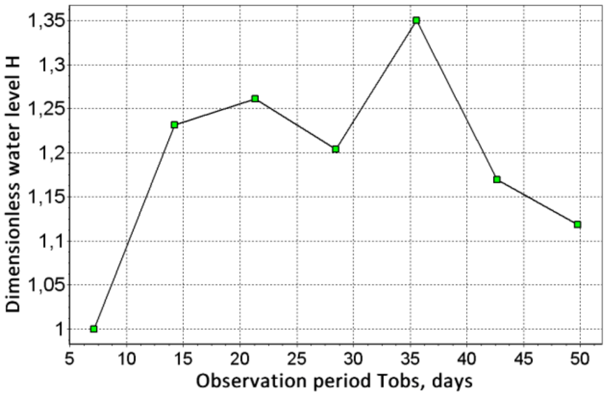

Figure 5. Change in the average weekly levels of the lunar tidal component, reduced to the earthquake epicenter during the observation period

The graphs characterizing the change in the forecast of the future earthquake epicenter's geodetic coordinates at the end of 2004 and beginning of 2005 are shown in Fig. 6 and 7.

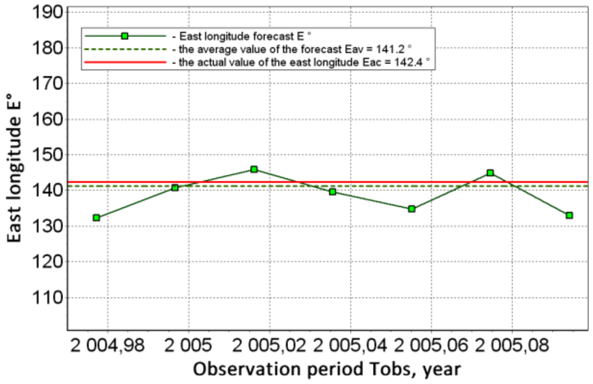

Figure 6. The eastern longitude forecast of the Fukushima earthquake epicenter

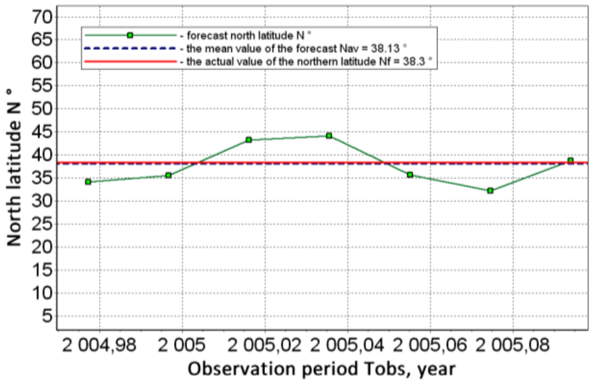

Figure 7. The northern latitude forecast of the Fukushima earthquake epicenter

The nature of changes in the earthquake time during the monitoring observations when forecasting the calendar time is shown in Fig. 9 and in the Table 1.

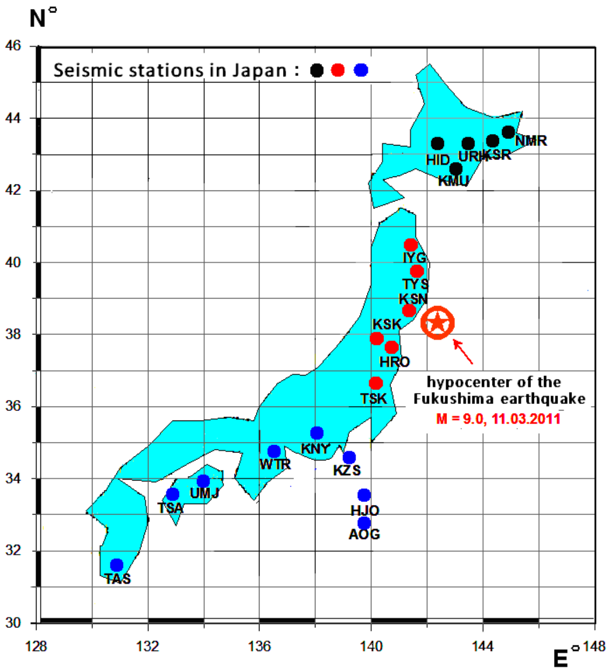

Figure 8. The Fukushima earthquake epicenter

Table 1. Forecast table

Forecast Date	13.1.2005	20.1.2005	27.1.2005	4.2.2005
Earthquake Date Forecast	11.2.2005	5.3.2005	26.8.2006	11.3.2011
The forecast deviation from the actual date in %	-97.5 %	-96.4 %	-72.8 %	0.0 %

4 THE RESULTS DISCUSSION

From figure 1 it follows that the observation wells are spaced relative to each other at a considerable distance. This ensures the receipt of the necessary information content for reliable forecasting of the initial data. The water levels, depending on the well, varied from 1200 to 1700 mm (Fig. 2).

In the spectrum of water level fluctuations, daily and lunar-tidal components are distinguished (Fig. 3). The highest level of the lunar-tidal component is recorded at well No. 3, the lowest at No. 2 (Fig. 4). An oscillation during the observed period (Fig. 5) of this component, recalculated according to formula (6) to the epicenter of the earthquake, is distinguished by a noticeable unevenness, reaching 35%.

The forecast of the mean value of the epicentre coordinates, as it later turned out, differs within 1° from the actual values the earthquake coordinates, that occurred on March 3, 2011 in the area of the Japanese city of Fukushima (Fig. 8).

The forecast of the date of the earthquake does not differ from its actual value.

5 CONCLUSIONS

The research novelty lies in the seismic hazard forecasting was carried out according to the analysis results of the dynamics of changes in the water component in the geological environment presented in this article.

The initial observations for the analysis were first obtained as a result of synchronous monitoring measurements of the water level in three control wells in the territory of the hydro-geodetic test site.

As a result, 6 years before the earthquake, it was possible to unmistakably locate and forecast the earthquake date, in this case the Fukushima one, which is also a novelty of the material published in the article.

Further research will be aimed at developing a methodology for forecasting the strength of an expected earthquake based on the results of monitoring observations of fluctuations in the groundwater level in control wells located at large distances from each other.

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