Co-seismic groundwater-level and temperature changes of the 2011 Mw9.0 Japan earthquake in Chinese mainland

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Abstract: Co-seismic groundwater-level and temperature changes caused by the Mw9.0 Japan earthquake in Chinese mainland are described. The recorded water-level changes were mostly oscillations, with some step decreases mostly in the coastal area of Southeast China and step increases mostly in Northeast China and the North-South Seismic Belt. The water-temperature changes were mainly decrease with slow recovery in Sichuan-Yunnan, South China, and lower reaches of Jiangzhong, and sharp increase followed by sharp decrease, or vice versa, in North China and Northeast China. For wells that showed step changes in both water level and temperature, more showed them in the same direction than in the opposite direction.

Key words: Japan Mw9.0 earthquake; co-seismic change; groundwater level; groundwater temperature

1 Introduction

The occurrence of large earthquakes may cause significant changes of groundwater level and temperature not only near the epicenter but also at some sensitive wells hundreds of kilometers away. The study of co-seismic groundwater changes offers an effective and direct means of measuring crustal response to strain changes and may help to identify sensitive wells that may show possible premonitory changes.[1-7].

The Mw9.0 Japan earthquake on March 11, 2011, caused large-scaled co-seismic groundwater changes at monitoring stations over much of Chinese mainland. In this paper, we give a preliminary study of a selected set of water-level and temperature records from data provided by China Earthquake Network Center. The selection was made on the basis of the stations being in operation smoothly at the time of the earthquake and the recorded diurnal water-level and temperature variations being clear and stable. A total of 178 wells were selected for water-level study, and 193 wells for water-temperature study, 164 of them being in common (Fig. 1).

2 Co-seismic water-level changes

2.1 Types of changes

Among the 178 wells of water-level observation, 139 (80%) showed co-seismic changes (Tab. 1), basically in three types (Fig. 2): Oscillation with peak-to-peak amplitude of as much as several meters; step increase or decrease of several centimeters to tens of centimeter; and an aberrant type of tidal variation of several centimeters to tens of centimeter.

2.2 Analysis of the changes

It is well known that water wells respond to a far-away earthquake differently; the recorded water levels for the same earthquake may be greatly different in shape and amplitude at wells near each other, depending on different local hydrogeological conditions.

As shown in figure 3, most wells in Chinese mainland showed oscillatory water-level changes in response to the Mw9.0 Japan earthquake, while step decreases were recorded mostly in coastal area of Southeast China.
and step increases mostly in Northeast China and along the North-South Seismic Belt. The oscillations were the result of elastic volumetric compression/expansion of the well-aquifer system caused by the seismic waves, but the step decreases and increases were the results of some co-seismic changes in the well-aquifer media. Areas where the step changes concentrate are probably the areas much influenced by far-away earthquakes, and where we should pay attention to. However, if the step changes were due to co-seismic static stress-field changes in Chinese mainland, then we need to carry out some further research.

Table 1 Types of observed co-seismic water-level and temperature changes

<table>
<thead>
<tr>
<th>Measuring item</th>
<th>Type of change</th>
<th>Number of well point</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>water level</td>
<td>increase</td>
<td>29</td>
<td>16.29</td>
</tr>
<tr>
<td></td>
<td>oscillation</td>
<td>96</td>
<td>53.93</td>
</tr>
<tr>
<td></td>
<td>decrease</td>
<td>19</td>
<td>10.67</td>
</tr>
<tr>
<td></td>
<td>no change</td>
<td>34</td>
<td>19.10</td>
</tr>
<tr>
<td>water temperature</td>
<td>decrease</td>
<td>49</td>
<td>25.39</td>
</tr>
<tr>
<td></td>
<td>no change</td>
<td>113</td>
<td>58.55</td>
</tr>
</tbody>
</table>

2.3 Mechanism of the changes

By examining the different features of the recorded water-level changes, we think the differences are probably caused by two factors: (1) Change of the static-stress field of the earthquake itself; (2) Some earthquake-triggered local medium changes near the wells, including the occurrences of some smaller earthquakes and fault-creep activity.

3 Co-seismic water-temperature changes

3.1 Types of changes

Among the 193 wells for water-temperature observation, 80 (40%) showed co-seismic response (Tab. 1). Two types of co-seismic changes were observed (Fig. 4): A sharp drop in the range of 0.005 to 0.04 °C followed by a gradual rise and a sharp rise of 0.004 to 0.01 °C followed by a sharp drop, the former being more common.

3.2 Analysis of the changes

As shown in figure 5, the observed co-seismic changes follow certain pattern; A decrease mainly in Sichuan-Yunnan, Southern part in South China, and lower reaches of Jiangzhong; an increase followed by a decreases in North China and Northeast China, which deserves more concern.
Figure 2  Typical co-seismic groundwater-level changes on March 11, 2011

Figure 3  Distribution of different types of water-level changes

Figure 4  Typical co-seismic groundwater-temperature changes on March 11, 2011
3.3 Mechanism of the changes

Co-seismic water temperature changes are known to be caused by increased convection and mixing of groundwater as a result of ground shaking. Factors influencing such changes include stress condition of the relevant aquifer, temperature gradient around the well, water-movement direction caused by seismic waves, and the location of water-temperature probe in the well\(^\text{[10,11]}\).

4 Correlation between same-well water-level and temperature changes

4.1 Types of changes

Among the 164 wells that were monitoring both water level and temperature, 68 showed co-seismic step changes in either water level or water temperature, or both (Tab. 2). Among the 16 wells that showed co-seismic water-level increases, 14 showed water-temperature rises and 2 temperature falls. But among the 9 wells that showed co-seismic water-level falls, one showed water-temperature rise and 8 water-temperature falls. Most of the water-level and water-temperature changes in the same wells were in the same direction. The few exceptions were influenced by some special hydrogeological condition. Among the 43 wells that showed co-seismic water-level oscillations, 17 showed temperature rises and 26 temperature falls.

4.2 Response time of water-level and temperature changes

The delay time (Tab. 2) of co-seismic water-level changes increases with epicenter distance, being determined by seismic-wave arrival. The delay time of step-type water-temperature changes is from 2 to 6 minutes more than that of water level, but for the slow-change type it took up to several tens of additional minutes, indicating the complexity of the temperature response.

5 Conclusions

1) The co-seismic groundwater-level changes of the Mw9.0 Japan earthquake recorded in Chinese mainland were mainly oscillations, with some step decreases mostly in coastal area of Southeast China and step increases mostly in Northeast China and the North-South Seismic Belt.

2) The recorded co-seismic water-temperature changes were mainly decreases in Sichuan-Yunnan, South China, and lower reaches of Jiangzhong, and increase-followed-by-decrease type, or vice versa, in North
Table 2 Types of co-seismic water-level and temperature changes caused by Mw9.0 Japan earthquake

<table>
<thead>
<tr>
<th>Type of co-seismic water-level change</th>
<th>Number of wells</th>
<th>Delay time of co-seismic water-level change (minute)</th>
<th>Type of co-seismic temperature change</th>
<th>Number of wells</th>
<th>Proportion (%</th>
<th>Delay time of co-seismic water-temperature change (minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>increase</td>
<td>16</td>
<td>4 - 13</td>
<td>rise</td>
<td>14</td>
<td>20.59</td>
<td>7 - 46</td>
</tr>
<tr>
<td>oscillation</td>
<td>43</td>
<td>3 - 12</td>
<td>rise</td>
<td>17</td>
<td>25.00</td>
<td>9 - 34</td>
</tr>
<tr>
<td>decrease</td>
<td>9</td>
<td>5 - 15</td>
<td>rise</td>
<td>1</td>
<td>1.47</td>
<td>17</td>
</tr>
</tbody>
</table>

Figure 6 Co-seismic changes of water level and temperature in opposite directions on March 11, 2011

China and Northeast China.

3) The distribution of step changes of water level and temperature does not fit the quadrant feature of the earthquake’s known focal mechanism (low dip-angle thrust faulting in the subduction zone, where the Pacific plate is subducted westward under the Eurasian plate west of Japanese trench).

4) The co-seismic water-level and temperature changes in Chinese mainland basically disappeared several hours or several tens hours after the earthquake, showing no long-term or permanent post-seismic effect.

5) The sensitivities of different wells to seismic waves are different, depending mainly on the natural period of the well-aquifer system, the transmissibility coefficient of the aquifer, the observation system, the frequency of seismic waves, etc. The co-seismic water-level oscillation had a duration of about 4.6 hour with a peak-to-peak amplitude of 22.4 m at the Jiaohe well in Jilin province at an epicenter distance of 1420 km, and a duration of about 3.5 hour with a peak-to-peak amplitude of 10.2 cm at the Lasa well in Tibet at a distance of 4790 km. Although the amplitude and duration were inversely proportional to the epicentral distance, the sensitivity became much stronger when the natural vibration period of the well-aquifer system was comparable to that of the seismic waves. For example, Zhangdaokou well in Beijing at a distance of 2200 km had a duration of 4.5 hour and a peak-to-peak amplitude of 4.84 m.

References


