

Aftershock Activity And Interpretation of Båth Law for 2001 Bhuj Aftershock Sequence : Implication of January 26, 2001 Mainshock of Mw 7.7 Over Kachchh Region of West India.



Earth Science

KEYWORDS : Båth's law, aftershock sequence, 2001 Bhuj earthquake, Kachchh region.

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ABSTRACT

Earthquakes are more deadly than any other natural disaster events. Each earthquake generates aftershock as a result of stress transfer mechanism and studies of aftershocks provide important insight into earthquake processes over the region. Kachchh region of western India has become seismically very active after 2001 Bhuj earthquake. In present study, Båth law is applied to 2001 Bhuj earthquake following a brief review of scaling laws. Catalogue data of India Meteorological Department (IMD) and Institute of Seismological Research (ISR) are extensively used for the period from January 26, 2001 to March 31, 2015. Magnitude difference Δm between mainshock and largest aftershock is found to be 2.0, 0.4 and 1.0 for 2001 Bhuj mainshock of $M \sim 7.7$, 2006 Gedi fault event of $M \sim 5.2$ and 2011 Talala seismic events of $M \sim 5.2$ respectively. Due to geophysical parameters and local geology of Kachchh, Δm for Kachchh aftershock sequence differs from the value suggested by Båth.

Introduction

Earthquakes are more deadly than any other natural disaster events. By any means we cannot avoid them like other natural disasters. Only we can do is to reduce its effects by preparedness and mitigation measures. Scientists across the globe are taking this issue as the biggest challenge and prime time necessity. An abundance writings are available in scientific literature on earthquake. Even though, we could not develop any method that forecasts earthquake accurately. Nevertheless, scientists worldwide are engaged to develop such models on the basis of statistical analysis that help to predict earthquake up to certain extent. Chinese scientists have successfully forecasted 1975 Hai-cheng earthquake of $M \sim 7.3$ on the basis of geophysical precursors (Bolt, 1988). The change in stress caused by main shock is great enough to trigger aftershocks on other nearby faults and it is widely accepted that aftershocks are caused by stress transfer during the mainshock. When an earthquake occurs, there are adjacent regions where the stress increases. The relaxation of these stresses causes aftershocks. It is possible to quantify properties of an aftershock sequence in such a way that future activity of that sequence can be anticipated by closely examining its beginning (Reasenber and Jones., 1989). Distribution of aftershocks, productivity, rate of decay, magnitude difference between mainshock and biggest aftershock are important and very useful properties of any aftershock sequence. There are three main factors that determine the character of any aftershock sequence and each relates to one of the constants in either of three empirical laws i.e. Gutenberg-Richter power law (1954), Omori's decay law (1894) and Båth's law (1965). Magnitude distribution forecasted by Gutenberg-Richter law describes the number of aftershocks relative to magnitude which is represented by the slope i.e. parameter 'b-value'. At the same time productivity term 'a' again by Gutenberg-Richter law relates to the amount of aftershock that a sequence produces whereas Omori's decay law describes the severity of the decline in the frequency of aftershocks after the mainshock which is represented by the parameter 'p-value'. Finally, Båth's law gives a prediction of the expected size of the potentially most destructive aftershock that follows a mainshock and very important from a societal view point.

Kachchh region of western India comes under seismic zone V and has become seismically very active after the 2001 Bhuj earthquake of M_w 7.7. In the present study, Båth's law is applied to 2001 Bhuj earthquake aftershock sequence. Figure 1 shows the study area of the present work.

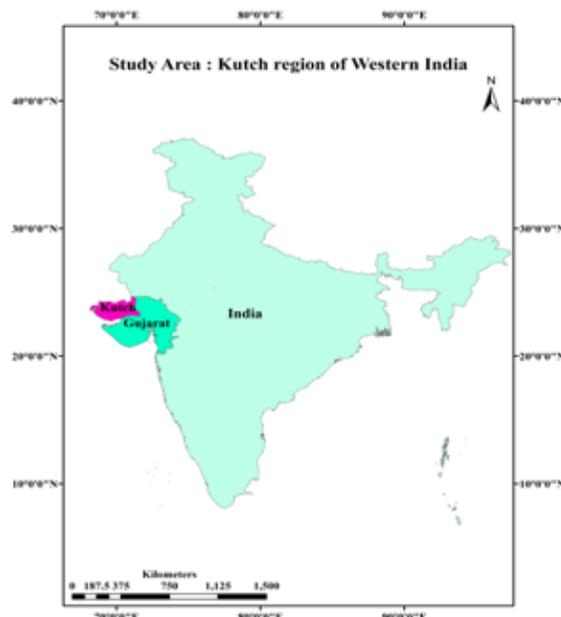


Figure 1 Study area i.e. Kachchh region of western India.

Data and Methodology

In the present study, the aftershock sequence is checked for Båth law. Catalogue data for the period from January 26, 2001 to March 31, 2015 recorded by India Meteorological Department (IMD) is used. Later on the establishment of dense network of Institute of Seismological Research (ISR), records from ISR is also used in this study. Figure 2 represents the seismotectonics, epicenters of earthquakes and aftershocks under the study.

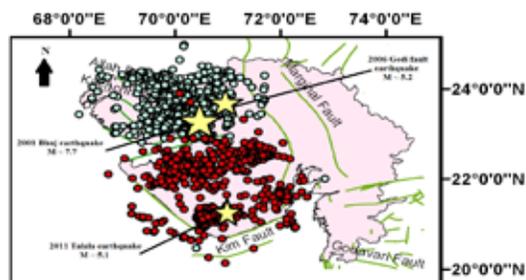


Figure 2 Seismotectonics, epicenters of earthquakes and aftershocks under the study.

The long-term relations between the main earthquake and its aftershocks are studied for the entire period for three different tectonic regimes. An overview of properties of aftershock sequence, three empirical laws of seismology are reviewed briefly first. The Gutenberg-Richter frequency-magnitude power law (1954) states that the number of aftershocks $N(\geq m)$ of magnitude equal to or greater than magnitude m , in a particular region and in a given time interval, can be approximated by the following relation,

$$N(\geq m) = 10^{a-2bm} \tag{1}$$

Where, 'a' and 'b' are the constant and a gives the productivity of aftershocks and 'b' is the slope that represents the number of aftershocks relative to magnitude.

The Omori decay law (1894), that gives idea on the decay rate of the aftershock sequence and describes severity of the decline in the frequency of aftershocks after the mainshock in time 't' which is represented by the parameter 'p' and can be represented as follow,

$$N(t) \propto t^{-p} \tag{2}$$

In the modified form (Utsu, 1961), it can be written as follow,

$$N(t) = \frac{K}{(t+\tau)^p} \tag{3}$$

Now on the accountability of Bath law (1965), the difference between a mainshock magnitude

m_{ms} and the largest aftershock magnitude $m_{as}^{max} m_{as}^{max}$ is approximately a constant and can be given as,

$$\Delta m = m_{ms} - m_{as}^{max} \approx 1.2 \tag{4}$$

Where, Δm is the difference between two magnitudes i.e., mainshock and maximum aftershock. However, Δm varies widely from 0 to 3 or sometimes more (Utsu, 2002). A modified version of Bath's law proposed by Scherbakov et al. (2004) in its general form extrapolates the G-R relation for aftershocks and gives the relation,

$$N(\geq m) = 10^{b(M_{max} - m - \Delta m)} \tag{5}$$

In the present study, the Bath law is practically applied for 2001 Bhuj earthquake. According to IMD catalogue, the mainshock magnitude is of 7.7 recorded on January 26, 2001 at 08:46 hours local time and the largest aftershock of 5.7 magnitude occurred on January 28, 2001 at 06:32 hours local time. As stated earlier, it is observed that during the mainshock rupture, stress releases and stress transfer occurs in the adjoining region. As a part of the sequence and result of stress transfer to neighbouring faults; earthquake of magnitude 5.2 is recorded at Gedi fault on March 7, 2006 at 18:20 hours local time and taking this event as an individual earthquake we have largest aftershock of the magnitude 4.9 recorded at 12:02 hours local time at the same tectonic regime. In many cases, it is also found that the stress passes to distant faults. As a result of such kind of stress transfer mechanism, diffused seismicity is observed over Saurashtra region of Gujarat state. According to ISR catalogue, earthquake of magnitude 5.1 occurred near Talala, Junagarh district on October 20, 2011 at 17:18 hours local time and when we consider this event as a mainshock over Talala region and as a consequence it has generated its own aftershocks. We have records of magnitude 4.1 at the same tectonic region on October 21, 2011 at 03:07 hours local time as a largest aftershock of the sequence generated by $M \sim 5.1$ earthquake. Results of the analysis are followed in the subsection.

Results and Discussion

Table 1 summarizes the results of the study. To verify that the 2001 Bhuj aftershock sequence follows the Bath's law, we refer the IMD catalogue. As stated earlier we have $m_{ms} = 7.7$ and $m_{as}^{max} m_{as}^{max} = 5.7$.

Now according to Bath law,
 $\Delta m = m_{ms} - m_{as}^{max}$
 $= 7.7 - 5.7$
 $= 2.0$
 For the Gedi fault event, we have $m_{ms} = 5.2$ and $m_{as}^{max} = 4.8$.
 $\Delta m = m_{ms} - m_{as}^{max}$
 $= 5.2 - 4.8$
 $= 0.4$
 Similarly, on the basis of ISR catalogue, for 2011 Talala seismic event, we have $M_{ms} = 5.1$ and $m_{as}^{max} = 4.1$.
 $\Delta m = m_{ms} - m_{as}^{max}$
 $= 5.1 - 4.1$
 $= 1.0$

Table 1 Summary of results for Bath law

| Earthquake | m_{ms} | m_{as}^{max} | Δm |
|----------------------------|----------|----------------|------------|
| 2001 Bhuj earthquake | 7.7 | 5.7 | 2.0 |
| 2006 Gedi fault earthquake | 5.2 | 4.8 | 0.4 |
| 2011 Talala earthquake | 5.1 | 4.1 | 1.0 |

In this way, for Gujarat region, Δm is found to be 2.0, 0.4 and 1.0 for 2001 Bhuj mainshock of

$M \sim 7.7$, 2006 Gedi fault event of $M \sim 5.2$ and 2011 Talala seismic events respectively. Many scientists have studied different earthquake sequence and verified the Bath's law. Many researchers have carried out studies on the statistical variability of Δm of Bath's law (Vere-Jones, 1969; Console et al., 2003; Helmstetter and Sornette, 2003; Trivedi, 2014). Whereas Kisslinger and Jones (1991) studied properties of aftershocks in southern California; Tsapanos (1990) for Pacific Belt and Felzer et al. (2002) for Hector Mine earthquake of 1992 M_w 7.3 Landers earthquake. The difference between the magnitudes of the main shock and the largest aftershock depends on the stress condition and heterogeneity of the rock mass. As discussed above, for large normal shallow earthquakes, the difference between magnitudes of the main shock m_{ms} and the largest aftershock $m_{as}^{max} m_{as}^{max}$ is 1.2 i.e., $\Delta m = 1.2$. A similar result was obtained by Papazachos (1971) for 216 aftershock sequences with $m_{ms} \geq 5$ occurred in Greece. The same law is checked for the Bhuj aftershocks sequence. The ratio of these magnitudes $m_{ms} / m_{as}^{max} m_{as}^{max}$ is 1.35, 1.08 and 1.24 which is quite high. The earthquakes at Gedi fault and adjoining area and Saurashtra region are not aftershocks of 2001 Bhuj earthquake in a strict sense; however we can consider it appropriate to include them in this analysis, since they are most likely triggered by the mainshock.

Aftershock sequence are an ideal environment to study geophysical mechanisms that influence the earthquake-size distribution, the relationship between the main shock and the aftershocks, the spatial distribution of aftershocks and the duration of aftershock sequences. Variations in these parameters may be related to the main shock stress drop, the state of stress in the fault zone, tectonic settings and local geology of the region.

Conclusion

Bath's law is an important scaling law that helps to understand the characteristics of aftershock sequence. It provides useful information on earthquake processes over the region. In this study, difference in magnitudes is calculated by analyzing catalogue data i.e. validity of Bath's law for the region is checked out. In this study, entire 2001 Bhuj aftershock sequence demonstrates

$\Delta m = 2.0$, 2006 Gedi fault earthquake-aftershocks shows $\Delta m = 0.4$ and 2011 Talala earthquake-aftershocks displays $\Delta m = 1.0$ instead $\Delta m = 1.2$ as suggested by Båth (1965). Several geophysical parameters that control aftershock activity over the region are responsible for the different values of Δm on different tectonics of Kachchh and Saurashtra region of Gujarat state.

Acknowledgement

The author is grateful to India Meteorological Department for providing valuable data and permission to publish the work. I am thankful to Institute of Seismological Research for catalogue data and Dr. Jayanta Sarkar for his kind co-operation.

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