Tectonophysics 682 (2016) 264–277

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Rupture processes of the 2015 Mw 7.9 Gorkha earthquake and its Mw 7.3 aftershock and their implications on the seismic risk

Chengli Liu [a], Yong Zheng [a,*], Rongjiang Wang [b], Bin Shan [a], Zujun Xie [a], Xiong Xiong [a], Can Ge [c]

[a] State Key Laboratory of Geodesy and Earth's Dynamics, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan 430077, China
[b] GFZ German Research Centre for Geosciences, D-14473 Potsdam, Germany
[c] School of Resources and Environmental Engineering, Hefei University of Technology, Hefei 230009, China

ARTICLE INFO

Article history:
Received 23 February 2016
Received in revised form 26 April 2016
Accepted 19 May 2016
Available online 21 May 2016

Keywords:
Gorkha earthquake
Gedetic datasets
Rupture process
Seismic risk

ABSTRACT

The rupture processes of the 2015 April 25 Gorkha earthquake and its strongest aftershock occurred on May 12 in Nepal are investigated by joint inversion of seismological and geodetic data. Synthetic test shows that the sedimentary layers in the source region play an important role in the rupture process inversion. Our optimized model of the mainshock shows that the rupture has a unilateral propagation pattern. The dominant mechanism is pure thrust with maximum slip of 5.8 m, the rupture scale extends ~60 km along dip and ~150 km along strike, and the largest static stress change is ~7.6 MPa. The total seismic moment is 7.87×10^{20} N m, equivalent to Mw 7.9. Most seismic moment was released within 80 s and the majority seismic moment was released at the first 40 s. The rupture propagated in main slip asperity with a velocity of ~3.0 km/s. The strong aftershock magnitude is about Mw 7.3, and the peak slip is about 5.0 m, close to the peak slip of the mainshock. Moreover, the slips of the mainshock and the aftershocks are in good complementary, suggesting a triggering relationship between them. Considering the strain accumulation, the Gorkha earthquake ruptured only part of the seismic gap alone, thus still poses high earthquake risk, especially in the west side of the mainshock rupture zone.

1. Introduction

The Indian Plate is subducting northward beneath the Eurasia Plate with a convergence rate of ~3.6 cm/yr (Altamimi, 2009). Due to this rapid convergence, the Himalayan arc is prone to strong earthquakes frequently (Bilham, 2004; Lavé et al., 2005; Kumar et al., 2006; Bettinelli et al., 2006). The central Nepal is located at the central part of the Himalayan collision zone, an active tectonic zone. Based on comparative studies of historical seismic records and the convergent rate, the central Nepal has accumulated significant tectonic strain; and it is highly possible that large earthquakes with estimated seismic magnitude larger than Mw 7.7 will occur there in the future (Feldl and Bilham, 2006; Bilham et al., 2001; Mukhopadhyay et al., 2011).

On 25 April 2015, a devastating earthquake struck the Gorkha region in the central Nepal (hereinafter as the Gorkha earthquake), resulting in numerous casualties and properties loss. The epicenter (28.147°N, 84.708°E) reported by USGS (http://earthquake.usgs.gov/earthquakes/eventpage/us20002926#general_summary) was ~77 km northwest of the Nepalese capital of Kathmandu, with a hypocenter depth of 15 km. The global Centroid-Moment Tensor (GCMT) solution of this event (http://www.globalcmt.org/CMTsearch.html) indicates that it is a nearly pure thrust event with fault geometry of strike 293°, dip 7°, and rake 108°. Its centroid depth is ~12 km and the centroid epicenter is to the southeast of the hypocenter (27.7°N, 85.37°E), with a seismic moment of 7.76×10^{20} N m, corresponding to a moment magnitude of Mw 7.9. The Gorkha earthquake was followed by a substantial aftershock sequence, among which, the largest aftershock occurred on May 12, 2015 and had a magnitude of Mw 7.3 (07:05:19 UTC, 27.819°N, 86.080°E, and the hypocenter depth 15 km) to ~150 km east of the mainshock (Fig. 1).

An accurate rupture model is of fundamental importance for further studies on source properties and seismic hazards, such as computing Coulomb stress transfer, characterizing the seismic cycle and hazard assessment related to the Himalayan thrust fault system. Moreover, following the mainshock, many aftershocks occurred; some of the aftershocks were quite big and also caused severe damages to the source region. Considering the active tectonic environment and the seismicity in the Nepal region, studying on the source parameters and the relationship between the mainshock and the strong aftershocks may help understand the seismogenic environment and evaluate the potential seismic hazard in the Himalayan fault zone.

Lots of rupture models have been derived for this event by using teleseismic data (Zhang et al., 2015; Wang et al., 2015; Fan and Shearer, 2015; Yagi and Okuwaki, 2015), geodetic data (Wang and Fialko, 2015; Lindsey et al., 2015; Diao et al., 2015; Feng et al., 2015),

* Corresponding author.
E-mail address: zhengyong@whigg.ac.cn (Y. Zheng).

http://dx.doi.org/10.1016/j.tecto.2016.05.034
0040-1951/

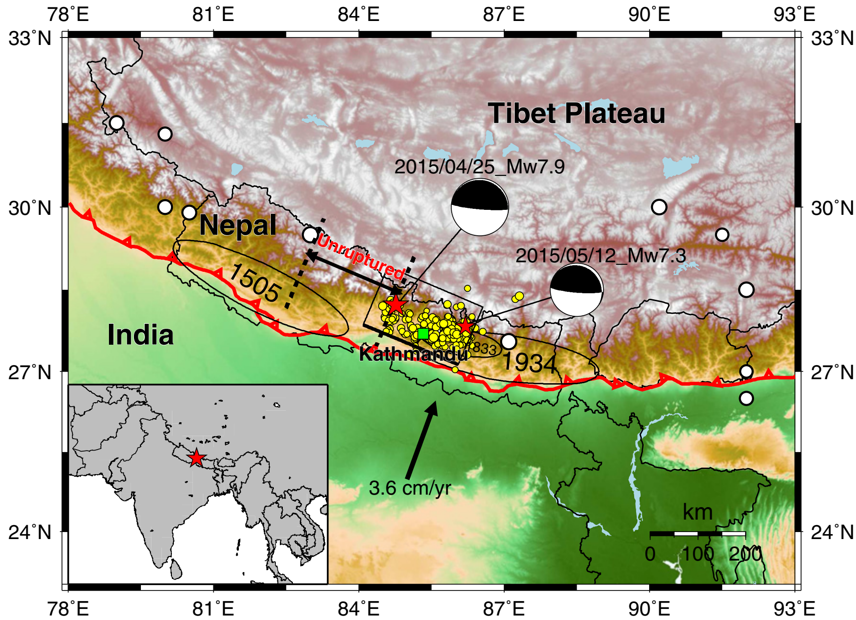

Fig. 1. Tectonic setting of the 2015 Mw 7.9 Gorkha earthquake and its aftershocks distribution. The red barbed line indicates the Himalayan Thrust fault. The black arrow shows Indian plate motion relative to Eurasia computed using the rotation poles of Eurasian plate in ITRF 2005 from Altamimi (2009). Black ellipses show estimated locations and possible rupture areas of historical earthquakes (Ader et al., 2012). Red stars show the relocated epicenter of the mainshock and its largest aftershock, and its aftershocks from April 25, 2015 to June 8, 2015 indicated by yellow circles (Adhikari et al., 2015), which are shown scaled with symbol size proportional to seismic magnitude. The focal mechanisms are GCMT best double-couple solutions for the mainshock and the May 12, 2015 Mw 7.3 aftershock. The green square is the location of the Nepalese capital of Kathmandu. The black rectangle is the fault plane used in this study.

or joint inversion with multiple datasets (Galetzka et al., 2015; Zhang et al., 2015; Grandin et al., 2015; Avouac et al., 2015). Most of models indicate that the Gorkha earthquake is a unilateral rupture event. Finite fault rupture models determined by teleseismic indicate that the largest rupture slips are concentrated in the area to the east of hypocenter with magnitude of 5–7.5 m (http://www.earthobservatory.sg/news/april-25-2015-nepal-earthquake; Wang et al., 2015; Yagi and Okuwaki, 2015). However, due to the well-known propagation effects, teleseismic body waves are insufficient for resolving rupture processes in detail. On the other hand, geodetic data (e.g., InSAR data and static GPS coseismic offsets) can provide near field constraints, and is more sensitive to the detailed slip pattern of the rupture model. The inversions of geodetic data show that the large slips of the Gorkha earthquake tend to concentrate in the central region of the rupture zone, and the largest rupture is also located east to the hypocenter (Lindsey et al., 2015; Diao et al., 2015; Feng et al., 2015; Wang et al., 2015). The distributions of along strike slip in these models are generally similar, with unilateral rupture expanding ~150 km along strike.

There are remarkable differences in the total slip and the distribution of along dip slip among the geodesy-based models. Most of these models do not have significant surface ruptures; however, Galetzka et al. (2015) and Lindsey et al. (2015) found 1–2 m slip near the surface at the up-dip part of the southern slip patch. Avouac et al. (2015) investigated the coseismic slip pattern by inverting teleseismic and InSAR datasets; their rupture model is consistent with most of the geodetic based models, with no significant slip near the surface. Grandin et al. (2015) developed a coseismic rupture model using teleseismic waves, strong motion data, high-rate GPS, static GPS, and synthetic aperture radar (SAR) data. The rupture pattern appears simple in their slip model, largely as a result of low-frequency waveform data used in their studies or the smoothing factor used in their inversion. These differences may be mainly due to non-uniform spatial sampling, different data types and difference between InSAR data from different satellites. Moreover, an accurate location of the hypocenter is important for the inversion of rupture process. For most large earthquakes, near-field or regional recordings are not available timely. So the current proposed rupture models almost adopt the location of U.S. Geological Survey National Earthquake Information Center (NEIC), and its error usually is as large as 25 km (Engdahl et al., 1998), which might be another reason for the model differences.

Here, we jointly used teleseismic waves, strong motion data, high-rate GPS, static GPS displacement, and Interferometric Synthetic Aperture Radar (InSAR) data, and take into account the influence of the thick sediments in Kathmandu basin to seismic waveforms, to obtain a refined model of the spatiotemporal history of slip for the Gorkha earthquake and its strongest aftershock. Based on our rupture models and the distribution of the aftershocks, we then discuss the potential seismic risk in the Himalayan Thrust fault after the occurrence of the Gorkha earthquake.

2. Data and methods

2.1. Geodetic data

Near-field observations, especially near-field static displacements, are particularly useful for constraining the slip distribution of large complex ruptures. The Gorkha earthquake is the first occurrence of a large continental thrust earthquake which is well recorded by a group of high-rate GPS stations closely encompassing the rupture area (Fig. 2a). In addition, the rupture area of the Gorkha earthquake is also well covered by InSAR line-of-sight displacement data from ALOS-2 observations, with both the ascending and descending paths (Fig. 2b and c), which can provide well-constrained slip distribution. The combination of these measurements provides an extraordinary opportunity to study the kinematics of the source process. In this work, both GPS and InSAR datasets are collected and inverted for the rupture processes of the mainshock together with seismic data. The geodetic dataset consists of 19 coseismic GPS displacements and 5 high-rate GPS from the Tectonics Observatory network in Nepal (Galetzka et al., 2015), and displacement in the Line of Sight direction obtained from ALOS-2 resampled at 4180 points (Lindsey et al., 2015).

2.2. Seismic data

We downloaded teleseismic data from the Incorporated Research Institutions for Seismology (IRIS) network within epicentral distances