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Deterministic Seismic Hazard Analysis of Tindharia Site using ANBU-13 GMPE.

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Abstract. India has been prone to several major to minor earthquakes from ancient times. Although the prediction of earthquake time is unreliable, prior seismic hazard studies may help against significant earthquake loss. Seismic hazard studies effectively exhibit solutions for future events at a particular location by combining different mathematical models and addressing uncertainties and challenges. This paper has carried out the seismic hazard analysis of the Tindharia landslide, Darjeeling Sikkim Himalayas and its surroundings based on the deterministic approach considering an updated historic earthquake database and models within a 300 km radius. The method determines the worst-case ground motion for the best maximum magnitude (M_{max}) at the shortest source-to-site distance (R_{min}). The hazard analysis was carried out using linear seismotectonic data considering faults, lineaments and shears zones collected from different sources. The M_{max} is calculated using the five most widely used empirical relations involving magnitude and fault rupture length. The maximum among them is considered the maximum magnitude of the fault. The peak ground acceleration for each source has been calculated using the ANBU-13 attenuation equation at 30, 50 and 75 km focal depth. The controlling earthquake of the site is carried out by comparing the levels of PGA produced by various earthquake sources.

Keywords: Deterministic seismic hazard analysis, Maximum magnitude, Peak ground acceleration.

1 Introduction

Devastating indented earthquakes in the Indian subcontinent have been occurring since ancient times. Northern India (Himalayan belt) is one of the world's seismically active regions due to its interplate movement at the rate of 50mm/year [1]. The utmost care must be taken for seismically active regions like the Himalayan belt. Although the prediction of earthquake occurrence is unreliable, researchers and scientists have tried their best to predict the ground motions at the place of interest. The peak ground motion is the key essential input in earthquake-resistant design in earthquake-prone regions. Prior seismic hazard studies play a critical part in determining peak ground acceleration at a particular location, which may help against significant earthquake loss.

The seismic hazard of a particular location can be determined deterministically or probabilistically. The present study has been carried out using deterministic seismic hazard analysis (DSHA) by considering all possible sources of seismic activity for generating future strong ground motion. The DSHA is a straightforward and simple framework used to estimate PGA, referred to as controlling the earthquake closest to the site [2]. The study lacks consideration of all possible sources, size, location, and rate of recurrence of earthquakes, in its evaluation of seismic hazards. Nevertheless, numerous researchers support DSHA more than PSHA [3] because the estimated seismic hazard is a time-invariant in deterministic analysis. Thus, DSHA is considered more reliable than earthquake occurrences with high uncertainty. According to [4 & 5], the hazard assessment of DSHA is helpful in emergency planning and critical facilities.

In the present study, the Tindharia site is selected as the target and considered the centre of the study area. A 300km radial distance around the site is taken into account based on the active sources within the region (see Fig 1a). The Tindharia landslide, located in Darjeeling district of west Bengal state of India, is a historic landslide that occurred during the 2011 Sikkim Nepal earthquake and destroyed the world heritage site, Darjeeling toy train track that is used for tourism (see Fig 1b). The region belongs to the foothills of the eastern Himalayas, and it is accommodated with major folded thrust faults [6]. The study area is the most popular tourist destination, attracting many tourists every year and causing fear among the people due to frequent earthquakes and landslides. Hence seismic stability has become a significant issue. Therefore, estimating seismic hazards is essential in planning and executing earthquake-resistant designing.

The deterministic seismic hazard map and its relative PGAs of the present study area are not entirely reported and updated. Therefore, this study attempts to conduct a DSHA analysis for a 300km circular area at a depth range of 30, 50 and 75km.

2 Details of the study area

2.1 Methodology

DSHA is one of the approaches in seismic hazard studies. The approach involves four key steps to assess the PGA parameters based on knowledge of seismic sources and attenuation equation to identify the Maximum credible earthquake (MCE). The steps involved in this approach, according to [7], are a collection of past seismo-tectonic sources, determination of input data (focal depth of seismic sources, shortest distance from source to site and maximum possible magnitude (M_{max})), selection of ground motion prediction equation (GMPE) to identify the most probable deterministic ground motion at a selected site and evaluation of seismic hazard (MCE).

2.2 Seismo-tectonic settings

The main contribution of the DSHA is to understand the seismo-tectonic features [8]. The study area is situated in a high seismic zone surrounded by major to minor tectonics and earthquakes (see Fig 1a). The faults located at a distance of 300km from the site don't generally cause any damage. Therefore the tectonic features above 300kms have not been considered in the present study. A total of 19 linear seismic sources were traced from the seismio-tectonic atlas of India [9] within the study area. They are East Patna Fault (EPF), Munger-Saharsa Ridge Fault (MSRF), Munger-Saharsa Ridge Marginal Fault (MSRMF), Rajmahal Fault (RF), Rajmahal Fault (RF), Jangipur Fault (JF), Gaibandha Fault (GF), Dhubri Fault (DF), Katihar Nailphamuri Fault (KNF), West Patna Fault (WPF), Sainthia Bahmani Fault (SBF), Malda Kishanganj fault (MKF), Gouri Shankar Lineament (GSL), Everest Lineament (EL), Arun Lineament (AL), Kanchenjunga Lineament (KL), Purnea Everest Lineament (PEL), Tista Lineament (TL), Main Boundary Thrust (MBT) and Main Central Thrust (MCT). The total fault length and rupture length distance are mentioned in Table 1.

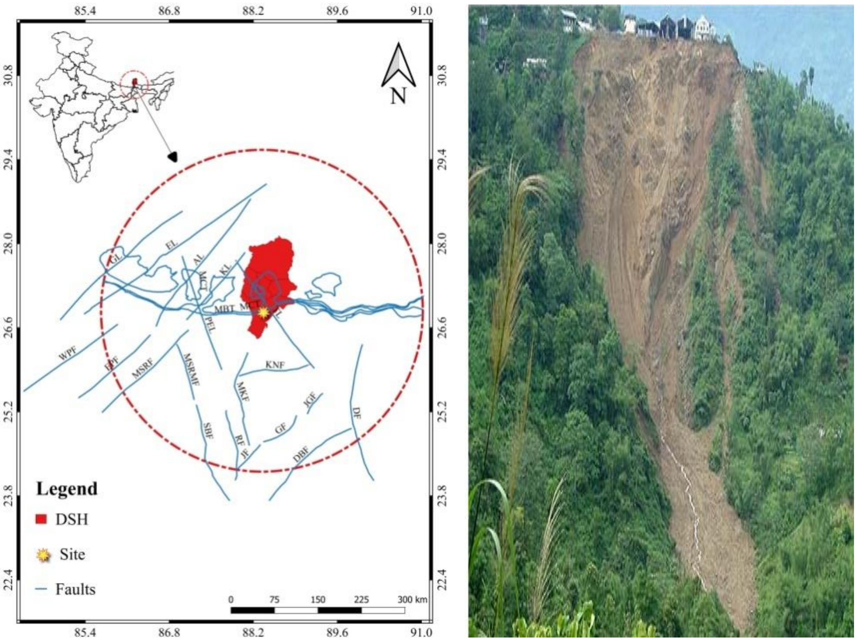

Fig. 1a. Geographical location along with seismo-tectonic details of near study area; 1b. Tindharia landslide failure during 2011 Sikkim Nepal earthquake.

3 Determination of maximum magnitude (M_{max})

The M_{max} is the magnitude at which the source can generate, and no earthquakes are expected to cause a magnitude greater than M_{max} [10]. The maximum magnitude for the faults can be evaluated through many empirical correlations between the fault parameters. Although we have many empirical relations to estimate, no single method is universally applicable due to uncertainty in predicting an accurate value. Accordingly, the M_{max} is calculated using the four most widely used empirical relations involving magnitude and fault rupture length, namely, [11, 12, 13 & 14], and an incremental method. The maximum magnitude using five methods is calculated, and the maximum among them is considered the maximum magnitude of the fault.

Table 1. Maximum magnitude of each source calculated using five empirical relations

Fault code	M_w^{obs}	TFL	RLD	M_{max}					M_{max}
				By incre-mental	Slemmons (1982)	Bonilla et al. (1984),	Nowroozi (1985)	Wells & Coppersmith (1994)	
JF	4.1	58.5	19.5	6.62	6.69	7.04	6.87	6.61	7.04
GF	4.2	76.7	25.6	6.71	6.83	7.11	7.02	6.74	7.11
MSRF	5.4	208.6	69.5	7.22	7.59	7.55	7.57	7.22	7.59
WPF	5.4	198.3	66.1	7.2	7.56	7.53	7.54	7.19	7.56
RF	5.5	130.5	43.5	7.03	7.31	7.4	7.31	6.98	7.4
TL	5.5	236.8	78.9	7.1	7.41	7.42	7.63	7.28	7.63
SBF	5.6	188.9	63.0	7.18	7.53	7.52	7.51	7.17	7.53
GSL	5.6	283.4	94.5	7.16	7.5	7.46	7.73	7.37	7.73
MSRMF	5.7	105.2	35.1	6.95	7.18	7.34	7.19	6.87	7.34
KNF	5.7	120.8	40.3	7	7.26	7.38	7.27	6.94	7.38
MKF	6.2	178.3	59.4	6.7	7.49	7.5	7.48	7.14	7.5
PEL	6.7	217.8	72.6	7.2	7.61	7.56	7.59	7.24	7.61
EPF	6.8	165.8	55.3	7.3	7.45	7.48	7.44	7.1	7.48
AL	6.8	281.7	93.9	7.3	7.99	7.46	7.73	7.41	7.99
KL	6.8	155.7	51.9	7.3	7.41	7.46	7.41	7.07	7.46
MCT	7	917.1	305.7	7.5	8.58	7.78	8.37	8.03	8.58
DF	7.1	257.9	86.0	7.6	7.94	7.44	7.68	7.36	7.94
EL	7.1	383.8	127.9	7.6	7.66	7.55	7.9	7.52	7.9
MBT	8	590.8	197.0	8.5	8.36	7.66	8.13	7.8	8.5

4 Selection of controlling earthquake

The PGA is calculated using the various GMPEs, which is the function of magnitude, distance, depth, soil conditions, etc. The best suitable ANBU 13 attenuation equation devolved by Anbazhagan [15], among the many GMPEs for the study area, is selected in this study to calculate the deterministic PGA presented in equation 1.

$$logY = c_1 + c_2M - blog(X + e^{c3M}) + \sigma, \quad (1)$$

The closest rupture distance calculated in QGIS software is mentioned in Table 2. The linear sources at depth ranges of 30, 50, and 75 km were considered, and the calculated PGA for each source is shown in Table 2.

Table 2. PGA calculations using ANBU 13 GMPE.

Fault code	The closest distance to rupture surface (R_{rup})	M_{max}	PGA using ANBU 13 at various fault depths		
			30 km	50 km	75 km
JF	244.67	7.04	0.13	0.13	0.12
GF	198.64	7.11	0.15	0.15	0.15
MSRF	128.96	7.59	0.26	0.25	0.24
WPF	243.04	7.56	0.17	0.17	0.16
RF	191.92	7.4	0.18	0.18	0.17
TL	11.11	7.63	0.68	0.49	0.39
SBF	204.38	7.53	0.19	0.18	0.18
GSL	229.53	7.73	0.19	0.19	0.19
MSRMF	155.26	7.34	0.2	0.2	0.19
KNF	105.43	7.38	0.27	0.26	0.24
MKF	79.25	7.5	0.34	0.32	0.29
PEL	100.2	7.61	0.31	0.3	0.28
EPF	192.64	7.48	0.19	0.19	0.18
AL	137.54	7.99	0.31	0.3	0.29
KL	90.34	7.46	0.31	0.29	0.27
MCT	8.18	8.58	1.02	0.76	0.61
DF	174.55	7.94	0.26	0.25	0.25
EL	184.91	7.9	0.24	0.24	0.23
MBT	3.94	8.5	1	0.74	0.59

The PGA within a 300km radius of the study area varied from 0.1 g to 1.02g. The PGAs for the 30, 50, and 75 km fault depth ranges from 0.13g to 1.02g, 0.13 g to 0.76g, and 0.12g to 0.61g, respectively. The maximum PGA among the 19 tectonic sources for MCT has produced the maximum peak acceleration of 1.02g at a 30 km depth at a distance of 8.18 km from the site. Next, we observed the MBT and Tista lineament at 3.94 and 11.11 km with PGAs of 1.0 and 0.68g, respectively, at 30 km depth.

5 Conclusion

The DSHA is performed for the Tindharia landslide site, DSH, India. The 19 linear active fault thrusts and lineaments have been selected for deterministic analysis. The maximum earthquake for each fault has been calculated using four empirical relations. The maximum magnitude for each fault using five different empirical correlations has been calculated. The PGA using ANBU-13 has been evaluated for each fault for depth ranges of 30, 50, and 75 km. The PGA varies from 0.1 to a maximum of 1.02g within the 300 km range from the site. The MCE evaluated is 1.02g at 8.8 km from the site for 30kms focal depth, 0.76g for 50kms and 0.61g for 75km focal depth. The results are further used for earthquake-resistant design and planning.

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