Regional Rupture Character of Delhi Folding Geological Formation

Shiny Valencia and P. Anbazhagan

Abstract The energy release and propagation of an earthquake depend on seismic source factors like shear strength, frictional stability, and rupture character of the rock. These are dependent on the geological formation of the region. However, limited studies are available to relate the region's geology and seismic source rupture character. The approach aims to understand the rupture character by accounting for the geology and seismicity in the geographic information system. India is divided into different geological zones. Seismic source rock characters like mineral composition, age, strength, and lithostratigraphy in these regions are different and depend on the geological formation. Different geological zones with past earthquakes and seismic sources from Geological Survey of India have been understood, and the regional rupture character of Delhi folding geological zone has been established in this paper. The subsurface rupture length and percentage fault rupture for past earthquakes are estimated using Wells and Coppersmith in (Bull Seismol Soc Am 84:975–1002, 1994 [1]) and the method proposed by Anbazhagan et al. in (J Seismol 19:695–719, 2015 [2]). The fault lengths are included, aiding in identifying the regional rupture for different length segments. The newly estimated regional rupture can be used to obtain the maximum potential magnitude of each geology, which can be related to the rock formations in the region. In the Delhi folding formation, it is observed that the maximum magnitude that occurred in the past is 5.7 and the predicted maximum magnitude is 6.8. The predicted maximum value aligns with the observed maximum value + 1 increment.

Keywords Maximum magnitude · Regional rupture character · Geological formation · Seismic sources · Rock types

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1 Introduction

In the 2022 Syria-Turkey earthquake, the number of deaths rose to about 55,000 people. Such cases pose a threat to mankind by damaging infrastructural property and causing loss of lives. Although strong earthquakes occur infrequently in India, cases of extreme earthquakes such as the 1905 Kangra earthquake and 1950 Assam earthquake have had devastating damage to life and property. Thus, it is extremely important to strengthen the preparedness and mitigation measures of the country.

Studies show that 59% of the Indian landmass is prone to earthquakes, and it is essential to analyze the maximum potential magnitude that can occur in different regions. This can be done by various methods, such as analyzing historic seismic activity, stress accumulation models, subduction zone characteristics, etc. With advancements in high-quality instruments, it is convenient to record the frequency and magnitude of earthquakes. This study utilizes such past moment magnitude data as an input to predict the maximum magnitude that can occur. The main objective of the study is to estimate the maximum potential magnitude that can occur in Delhi folding geological zone.

1.1 Data Set

The epicenter location data of past earthquakes is obtained from Bhukosh—Geological Survey of India (GSI) [3] in shape file format. The location of seismic sources—fault lines including all types, major and minor lineaments, thrusts, shear zones, and folds are also obtained from Bhukosh—Geological Survey of India [3]. The files are loaded onto Quantum GIS (QGIS) software and spatially analyzed. Since the seismic sources along the Indian boundary extend to neighboring countries, it is essential to ensure that the total length of the seismic source is considered. To understand the different geological zones present, Indian Standard 1893:2016 [4] principal tectonic features map is used, where India is divided into zones based on the tectonic features present.

2 Establishing Regional Rupture Character

The approach used in this method involves establishing a regional rupture character for the geological zone as per Anbazhagan et al. [2, 5, 6]. Wells and Coppersmith [1] have established empirical relationships between various parameters by considering worldwide historical earthquake data. The relationship between moment magnitude (M_W) and subsurface rupture length (RLD) in km is used for this study. Conventionally, the subsurface rupture length (RLD) is taken as half of the total fault length (TFL) of the seismic source as given in Anbazhagan et al. [7]. The method of finding

RLD by Wells and Coppersmith [1] can be considered to be more comprehensive since it takes earthquake M_W into consideration.

For each seismic source (e.g., fault lines, lineaments, shear zones, etc.), the maximum value of earthquake M_W that occurred due to that particular source in the past is taken. The location of the seismic source and its corresponding past maximum M_W is associated by visualizing using a Geographic Information System.

$$\text{Log RLD} = 0.5M_W - 1.88 \quad (1)$$

$$\text{Log RLD} = 0.58M_W - 2.42 \quad (2)$$

$$\text{Log RLD} = 0.62M_W - 2.27 \quad (3)$$

$$\text{Log RLD} = 0.59M_W - 2.44 \quad (4)$$

The equation for RLD varies for different fault types—normal, reverse, strike slip, and all other types as given in Eqs. (1), (2), (3), (4), respectively. The equations are obtained from Wells and Coppersmith [1]. The subsurface rupture length (RLD) of earthquakes above 4.8 M_W considered in the study area is estimated. It is evident that the RLD (km) increases as M_W of past earthquakes increases. For M_W value of 4.8, the corresponding RLD calculated as per Eq. (4) is 2.47 km. Whereas, the RLD for the same value of 4.8 M_W caused by a strike slip fault is 2.55 km as per Eq. (3).

With the total fault length (TFL) in km and the RLD obtained from M_W, the percentage fault ratio (PFR) is obtained. According to Anbazhagan et al. [2], PFR is given as a ratio of RLD to TFL. A plot between TFL and PFR is plotted, and we find a similar trend for all geological zones. A smaller fault length has a higher PFR value compared to a longer fault length. The TFL is divided into length bins (e.g., < 100 km, 100–300 km) in accordance to the TFL values in the geological zone. This is done to find the potential maximum magnitude with respect to the fault length range.

The minimum, maximum, and average value of PFR is found for each length bin. The worst case scenario is calculated to be 5 times the average PFR, which is established as a good measure to be prepared for severely damaging earthquakes as per Anbazhagan et al. [2]. This can be further used to find the potential maximum magnitude for each seismic source using Wells and Coppersmith approach [1].

2.1 Delhi Folding Analysis

Delhi folding rock type is taken as an example to establish the regional rupture character. The earthquake sources, along with their respective maximum moment magnitudes, are depicted in Fig. 1. The RLD is computed from the M_W and the TFL

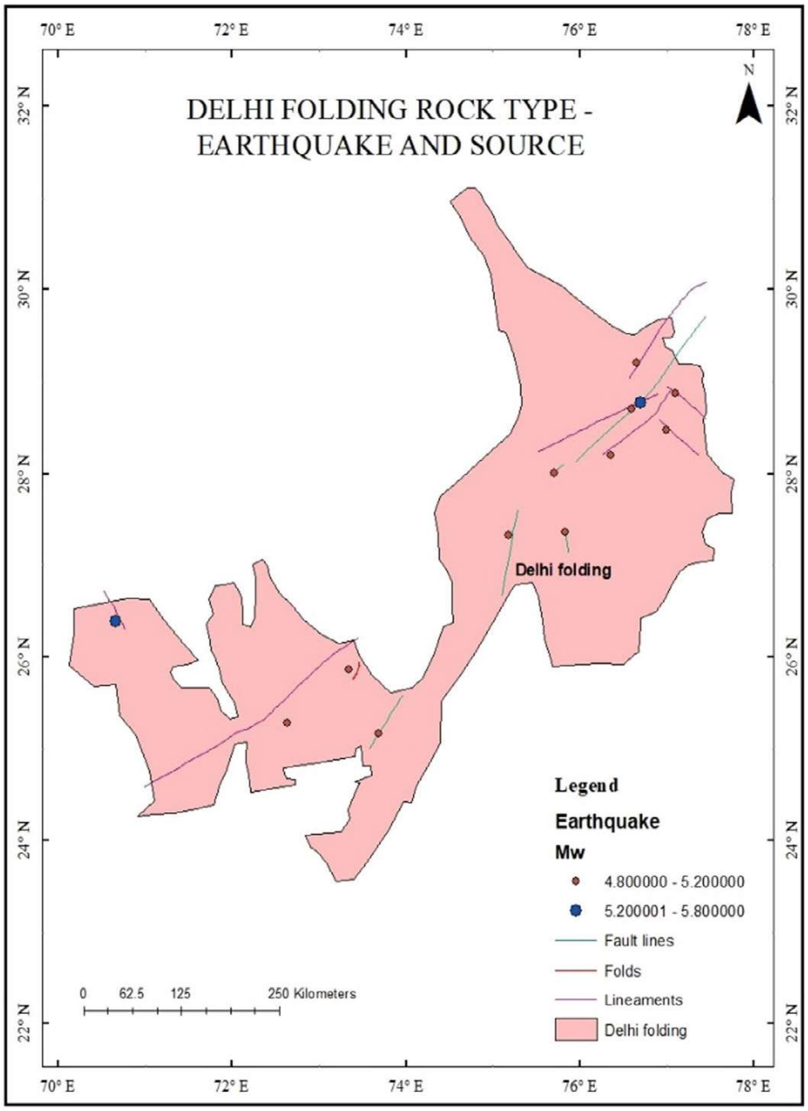

Fig. 1 Delhi folding zone

is obtained through GIS data (Table 1). The PFR is computed, and the region is split into 2 length bins—< 100 km and > 100 km and the data is given in Table 2. The trend line between TFL and PFR for this region is shown in Fig. 2.

3 Maximum Magnitude Estimation

By taking the worst case scenario as a measure of the TFL, an updated RLD value is obtained. This RLD is substituted in the Wells and Coppersmith [1] equation to find the potential maximum magnitude for each source, as given in Eq. (5). The values are provided in Table 3.

Table 1 Delhi folding—earthquake data

Date	M_W	RLD (km)	Source	TFL (km)	PFR (%)
6/2/2001	4.8	2.54	Strike strip fault (Mahendragarh Dehradun fault)	309.99	0.82
29/01/1995	4.8	2.46	Fault involving basement and cover/ gravity fault	21.58	11.42
8/11/1991	5.7	8.37	Minor lineament	54.56	15.35
9/11/2010	4.8	2.46	Fault involving basement and cover (Kishangarh-Chipri fault)	77.98	3.16
3/1/1974	4.8	2.46	Neotectonic fault/gravity fault	108.99	2.26
20/10/2000	4.8	2.46	Neotectonic fault	28.07	8.78
5/3/2012	5.2	4.24	Minor lineament	158.37	2.68
27/08/1960	5.1	3.70	Minor lineament	65.27	5.67
17/01/2000	4.8	2.46	Minor lineament	114.22	2.15
20/02/1974	4.8	2.46	Minor lineament	116.89	2.10
3/11/1990	4.8	2.46	Minor lineament	214.50	1.14
13/03/2002	4.8	2.46	Major lineament (Luni Sukri)	535.08	0.46
2/11/1987	4.8	2.46	Synform fold	22.63	10.89

Table 2 Delhi folding—PFR statistics

Length bins (km)	Minimum PFR (%)	Maximum PFR (%)	Average PFR (%)	Worst case PFR (%)
< 100	3.16	15.32	9.21	46.07
> 100	0.46	2.68	0.80	8.31

$$\text{Max}\, M_w = 4.38 + 1.49\, \text{Log RLD} \tag{5}$$

A similar analysis is followed for other regions.

3.1 Geological Formation

The narrow belt stretches from Delhi westwards into Rajasthan and was formed around 1 billion years ago. The rocks were exposed to folding and fracturing due to forces from tectonic events that occurred during their evolution [8]. In this

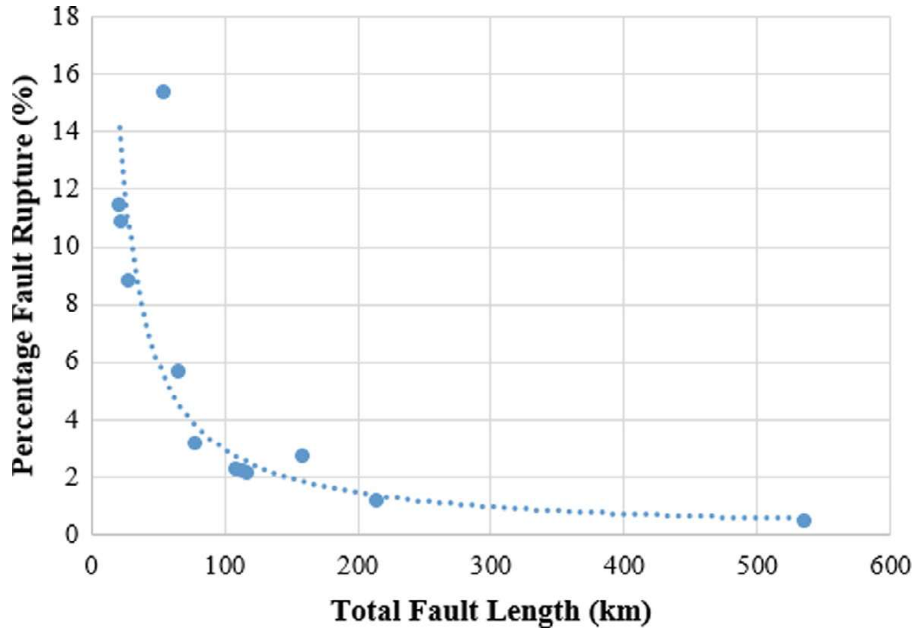

Fig. 2 Delhi folding—TFL versus PFR trend line

Table 3 Delhi folding—Max M_W

M_w	RLD (km)	TFL (km)	PFR (%)	Updated RLD (km)	Max M_w
4.8	2.54	309.99	0.82	25.78	5.4
4.8	2.46	21.58	11.42	9.94	5.8
5.7	8.37	54.56	15.35	25.14	6.4
4.8	2.46	77.98	3.16	35.93	6.6
4.8	2.46	108.99	2.26	9.06	5.8
4.8	2.46	28.07	8.78	12.93	6
5.2	4.24	158.37	2.68	13.17	6
5.1	3.70	65.27	5.67	30.07	6.5
4.8	2.46	114.22	2.15	9.50	5.8
4.8	2.46	116.89	2.10	9.72	5.8
4.8	2.46	214.50	1.14	17.84	6.2
4.8	2.46	535.08	0.46	44.50	6.8
4.8	2.46	22.63	10.895	10.42	5.8

region, metamorphic rocks are majorly found, which include schists, quartizites, calc-silicates, etc. Delhi folding can be divided into two parts—North and South Delhi folding [9]. They are a part of Aravalli-Delhi mountain belt. North Delhi folding evolved due to rifting and is divided into 3 subgroups namely—Bayana-Lalsot, Alwar, and Khetri [10]. These belong to the meso-proterozoic era and contain mafic volcanic rocks that are prone to copper mineralization [10]. The South Delhi belt developed into an oceanic trough, closed by subduction followed by the formation of a trench. It contains metasedimentary and granitic rocks.

4 Summary

From the analysis performed on Delhi folding zone, it is analyzed that the observed maximum magnitude value from past data is 5.7. Whereas, the predicted maximum magnitude, according to regional rupture character for fault length range of < 100 km, is 6.6 and for fault length range > 100 km, it is 6.8. As per existing literature [11], it is seen that the potential maximum magnitude aligns with the value of observed maximum magnitude added to 1 [12]. In this study, the predicted maximum value, which is 6.8 lies around the observed maximum magnitude value + 1 increment, which is 6.7. This increment method can be used for validation [7].

The geological formation shows that the region was formed due to folding and deforming and is abundant in metamorphic rocks. It can be noted here that Delhi is not only affected by the Delhi region's seismic events but also seismic events in another nearby geological region, including plate boundaries, which need to be accounted for disaster preparedness of the region.

The future scope includes performing similar analysis for other geological zones in India—namely Vindhyan, Gondwana, Eastern Ghats folding, Himalayan tectonic, etc. The predicted maximum magnitude can be associated with the rock types and their formations in the regions. The predicted maximum magnitude according to regional rupture character can further be compared with other methods of maximum magnitude estimation [2]. This will serve as a reference to predict the maximum magnitude in all parts of the country.

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