CHAPTER – 10

IMPLICATION FOR EARTHQUAKE HAZARD

The Kachchh region is included in seismic zone V of the seismic zoning map of India, which reflects the highest level of seismic risk in India. The seismic risk in the Kachchh basin all the more obvious since the occurrence of 2001 Bhuj earthquake along with prolonged aftershock sequence and the ongoing low to moderate seismic activity. A review of historical and current seismic activity in the basin is summarised previously in Chapter – 2. The post-2001 seismic activity in the basin is found to be concentrated in the eastern part covering areas around the eastern extremity of KMF, SWF, GF and IBF. This part in eastern Kachchh is now recognised as the Kachchh seismic zone (Figure 1.1). All studies on Seismic Hazard Analysis (SHA) and mitigation strategies carried out in Kachchh during the last two decades are based primarily on the seismic data available from the Kachchh seismic zone. Significantly, the Kachchh seismic zone does not include the KHF, the area of present study. This means that the seismic risk due to the KHF is underestimated in the overall seismic risk assessment of the region.

The present study carried out along the KHF in central mainland Kachchh is mainly based on its seismotectonic evaluation from a geological perspective. The geological data presented in the previous chapters clearly show that the KHF has produced at least three surface rupturing events attributed to high magnitude seismic events, during the last ~ 30 ka B.P. The study also shows that ~ 21 km length of the KHF was ruptured at the surface during the three events. The calculated M_w values of the three surface rupturing events range from 6.6 – 7.1. This indicates that the KHF is an active seismogenic fault that also presents a potent surface rupture hazard in the region. It is important to note that no other fault in the Kachchh basin is known to possess surface rupture hazard. Also, the KHF is located in the close vicinity (< 10 km) of the Bhuj town, the largest town in the Kachchh basin. The available seismic risk assessment and hazard mitigation is, therefore, skewed. In the present chapter, an overview of the available seismic assessment of the region is provided followed by recommendations arising as a consequence of the present study carried out along the KHF. The purpose of the present chapter is to provide a framework of the existing seismic assessment of the region and suggest guidelines for improving the regional scale assessment and further such studies in the region. This chapter describes a preliminary reappraisal of the seismic hazard in the Kachchh region on the basis of present findings about Late

Quaternary surface faulting events, and associated rupture length, displacement and slip rates. It is to be noted that every potential source of seismic activity, i.e., other faults in the basin, could contribute to ground motion and therefore a revised seismic hazard assessment of Kachchh is suggested.

EARTHQUAKE HAZARD IN KACHCHH BASIN

Probabilistic views

Probabilistic views on SHA of Kachchh region are shared by various workers such as Tripathi (2006), Yadav et al. (2008), Nath and Thingbaijam (2012) and Bashir and Basu (2018). Using the earthquake data of M > 5 of Gujarat region from 1819 to 2001, Tripathi (2006) estimated the probability of earthquakes of M > 5, 6. He observed a high probability of occurrence of an earthquake after 28 to 42 years from the last earthquake in 2001 for M 5 and after 47 to 55 years from the last earthquake in 2001 for M 6. He also mentioned about the Weibull model being the most suitable model for the Kachchh region of Gujarat and the *b*-value was estimated to be 0.72 for the Gutenberg-Richter recurrence relationship. The results are for the whole Kachchh basin. No data of KHF has been used in this work. In the data used by Tripathi (2006), all the earthquakes of M $\geq$ 5 from whole of the Gujarat region is used, which has resulted in the loss of individuality of each earthquake event and the risk of the earthquakes being smeared together is increased. The results cannot be generalised for the whole region of Gujarat, as Kachchh is the most seismically active region as compared to Mainland Gujarat and Saurashtra regions.

Yadav et al. (2008) used the 3 models (Weibull, Gamma and Lognormal) for the estimation of the probability of earthquake recurrence in Gujarat and the adjoining region. The parameters of recurrence of earthquakes for M 5.0 during the period 1819 to 2006 in the Kachchh region and the probability of occurrence of earthquakes was estimated. They concluded that the probability of occurrence of an earthquake is high between 21 to 29 years from the last earthquake (2006) in the Kachchh region. Yadav et al. (2008) divided Gujarat into Kachchh, Mainland Gujarat and Saurashtra regions, and results were obtained for only the Kachchh region of Gujarat. Here, it can be argued that the results obtained from Yadav et al. (2008) can be considered comparatively more reliable than those of Tripathi (2006) because of the distinction between the three regions is considered, which reduces the chances of the earthquakes being smeared together.

Nath and Thingbaijam (2012) performed the probabilistic seismic hazard analysis for India by incorporating new data and concepts in seismogenic source considerations, ground motion predictions and treatment of the associated inherent uncertainties. They presented the seismic hazard maps corresponding to spatial distribution of PGA and PSA (peak spectral acceleration) at 0.2 sec and 1 sec computed for 10% and 2% probability of exceedance in 50 years, which correspond to return periods of 475 years and 2,475 years, respectively. Their results indicate that the hazard distribution in the country as specified previously by GSHAP and BIS (2002) is significantly lower.

Bashir and Basu (2018) performed the probabilistic seismic hazard assessment for Gujarat region. They used only 1 GMPE instead of logic tree approach and considered two return periods of 2475 years representing the maximum considered earthquake (MCE) and 475 years representing a design basis earthquake (DBE). They used b-value for Kachchh 0.696, M_{max} for Kachchh is M_w 8.5. GMPE provided by Raghu Kanth and Iyengar (2007) was used. They calculated the PGA hazard associated with the 475 years of return period at the bedrock and for the soil sites A to D as per NEHRP classification and attained similar results as Bhatia et al. (1999) and Nath and Thingbaijam (2012) for 475 years of return period of hazard for Bhuj. The data below represents the result of PGA hazard associated with the 475 years of return period calculated from Bashir and Basu (2018) at the bedrock and for the soil sites A to D as per NEHRP classification.

475 years of PGA in Bhuj – bedrock (0.28), soils-A (0.39), B (0.45), C (0.46), D (0.42).

2475 years of PGA in Bhuj – bedrock (0.49), soils-A (0.70), B (0.80), C (0.75), D (0.63).

Deterministic views

In this section, an overview on the different approaches to seismic hazard analysis performed in the Kachchh basin, emphasizing their results is given. Deterministic studies on seismic hazard in the Kachchh basin are done by very few workers such as Parvez et al. (2003), Shukla and Choudhury (2012), Chopra et al. (2012) and Mohan (2014).

Parvez et al. (2003) were the first to prepare a first order deterministic seismic hazard map of India and adjoining regions using numerically simulated ground motion. They used preliminary source parameters from the 2001 Bhuj earthquake such as Ms = 7.9, strike = 292, dip =36, slip =136, depth =15 km, and found that 0.8 g value for near field ground motion as predicted by Hough et al. (2002) can be compared to the value predicted by them. They mainly concentrated on their DGA values along the Himalayan plate boundary, northeast India, the Burmese arc and the Andaman-Nicobar Islands, which differed considerably from the results of Khattri et al. (1984) and Bhatia et al. (1999) due to their choice of the attenuation relation with distance.

Chopra et al. (2012) synthesised the strong ground motion time histories along the identified 19 probable earthquake source zones (all over Gujarat) at bed rock as well as at surface level from possible scenario earthquakes along active faults using the stochastic finite fault modelling based on dynamic corner frequency (Motazedian and Atkinson, 2005). For KHF, addressed as Bhuj-Katrol Hill fault by them, parameter estimates such as length = 30km, width = 40km, strike = 90°, dip = 50° and magnitude 7.5 had been assigned. They observed that the seismic hazard in the Gujarat state is maximum in Kachchh region, where, it is maximum in eastern part, moderate in central part and minimum in western part and reported that PGA of >800 cm/s2 at surface can be expected in Bhachau–Rapar area from a large earthquake in the eastern part of Kachchh.

Shukla and Choudhury (2012) determined seismic sources and their corresponding magnitudes in Gujarat state to obtain deterministic response spectra of the horizontal component of ground motion for different natural periods of structures. The names of the faults are not mentioned. The fault numbered as F13 looks like KHF, as its total length considered is 69.07 and rupture length is 23.02. The maximum magnitude calculated using different methods for this fault is 6.66 (lowest value), which is correct according to the calculation in the present study, but upper limit of M_w 7.5 might be an overestimation of magnitude. They considered only KMF (fault numbered F12 – 125 km) in the Kachchh region as a controlling fault for Bhuj city on the basis of shortest distance criteria. In a seismically active region like Kachchh, which is characterized by a number of seismic source zones, there cannot be one fault that acts as a controlling factor for Bhuj city, as the Bhuj city itself is surrounded by more than one seismic source. According to the present study, the KHF which has produced high magnitude surface faulting events in the past, lies at a distance, which is very less as compared to the controlling fault F12 from Shukla and Choudhury (2012), which lies at a larger distance from the Bhuj city. They have then compared the results to provisions made in IS:1893- Part I (2002). Based on their study, the recommended PGA values for Bhuj city is 0.64 g.

Mohan (2014) prepared the PGA distribution maps from the scenario earthquake of large magnitude earthquakes along major faults such as the Kachchh Mainland fault (KMF), and Katrol Hill fault (KHF) in the central part of Kachchh, Allah Bund fault (ABF) and Island Belt fault (IBF) and South Wagad fault (SWF) and also prepared a deterministic seismic hazard map of the of the Kachchh region. As the parameters (scenario earthquake) of simulation to prepare the PGA zonation map of the Kachchh region, he considered the dip of the fault plane to be 50° S, downward extension 42 km; rupture length to be 36 km, rupture area 1806 km^2 and magnitude of 7.5 along KHF for 3 events. Further, he divided the Katrol Hill Fault (KHF) into three parts (segment A-western, B-central, C-eastern) based on consideration of fault length and magnitude, formulated PGA distribution map for all three segments based on M_w 7.5. The maximum PGA of the order of 850 cm/s^2 is computed for all three segments. The above calculated PGA is also considered true for a worst-case scenario along KHF, in which, rupture with M_w 7.5 is considered at any part of KHF. According to the present study carried out along the KHF, the variable dip of the fault plane in different segments of the fault with a surface rupture length of 21 km and magnitude range between M_w 6.6 – 7.1 should be considered for preparing the PGA maps of the region around KHF.

NEED FOR COMBINED PSHA AND DSHA APPROACH IN KACHCHH

While studies utilising combined approaches of PSHA and DSHA are non-existent in the Kachchh regions, the same has been demonstrated as the most reliable indicator of seismic risk in other parts of the globe. The assessment of seismic hazard associated with the stable continental regions (SCR) poses a difficulty to earth scientists because most of the hazard assessments for plate interiors are based principally on statistical analyses of the seismicity parameters (Nishenko and Bollinger, 1990). The assessment of seismic hazard acts as a challenge to earth science and engineering communities due to the following hindrances to be faced:

i. The fact has been established that potentially damaging earthquakes occurring in the stable continental regions (SCR) are most of the times one to two orders of magnitude less frequent as compared to those occurring along the plate boundaries, which results in poor public awareness and concern about the severity of the earthquake hazard.
ii. Additionally, the comparatively lesser attenuation of seismic energy of large earthquakes in stable continental regions leads to destruction across unusually large areas (Hanks and Johnston, 1992).
iii. Moreover, due to relatively infrequent nature of large earthquakes and apparently long recurrence interval of surface rupturing events in stable continental settings has left the earth scientists with a scarcity of examples to relate and compare.

Late Quaternary surface rupturing earthquakes in stable continental regions can be expected even with the absence of any previous movement along faults (Crone et al., 1997) and that the presently known seismicity can certainly not represent the future seismic activity due to limited time frame of observation (Camelbeeck et al., 2008). Owing to the above-mentioned difficulties, a necessity arises for the future seismic hazard assessments to be based on the geologic data that imparts better knowledge about paleoseismicity of intra-plate faults like the details about potential seismogenic sources in the region (Crone et al., 1997).

As Kachchh is a seismically active peri-cratonic rift basin, the seismic hazard analysis of both deterministic and probabilistic approaches had been performed, which utilized different input parameters for same fault and obtained varying results in terms of the probabilities of exceedance of ground motion and their return periods. Major work done in the field of seismic hazard assessment till date is described in the beginning of the chapter.

The different approaches of probabilistic assessment of seismic hazard in the Kachchh region performed by Tripathi (2006) and Bashir and Basu (2018) used different b-values of 0.72 and 0.69 respectively and also, there is noticeable difference between periods showing the highest probability of occurrence of earthquakes as reported by Tripathi (2006) and Yadav et al. (2008) using approximately similar methodology, which is between 28 and 40 years for $M \geq 5$ and between 47 and 55 years for $M \geq 6$ after the last earthquake (2001) (from Tripathi, 2006) for whole Gujarat region and between 21 and 29 years (from Yadav et al., 2008) from the last earthquake (2006) for the Kachchh region. In the data used by Tripathi (2006), all the earthquakes of M $\geq$ 5 from whole of the Gujarat region is used and reported that the highest probability of occurrence of earthquakes is between 28 and 40 years for $M \geq 5$ and between 47 and 55 years for $M \geq 6$ after the last earthquake (2001), which has resulted in the loss of individuality of each earthquake event and the risk of the earthquakes from a large region like Gujarat being smeared together is increased (Krinitzsky, 1998). The results cannot be generalised or compared to the whole region of Gujarat, as it contains Kachchh as the most seismically active region as compared to Mainland Gujarat and Saurashtra regions, which show considerably low seismicity rates. Yadav et al. (2008) divided Gujarat into Kachchh, Mainland Gujarat and Saurashtra regions, and results were obtained for only the Kachchh region of Gujarat. Here, it can be argued that the results obtained from Yadav et al. (2008) can be considered comparatively more reliable than those of Tripathi (2006) because of the distinction between the regions considered, which reduces the chances of the earthquakes being smeared together (Krinitzsky, 1998). Bashir and Basu (2018) in performing the probabilistic seismic hazard assessment for Gujarat region divided it into 3 zones – Kachchh, mainland Gujarat and Saurashtra and used the Gutenberg-Richter relation (for $M_w > 3.5$) to obtain b-value of 0.696 for Kachchh region. The observations from Wesnousky et al. (1984), Watanabe (1989), Wesnousky and Leffler (1992) and many other workers who worked in the large areas such as Madrid, confirmed the deviation of large earthquakes from the *b*-line (Krinitzsky, 1993). Since the significance of large earthquakes is already known for engineering structures, mainly in the Kachchh basin (Tiwari et al., 2021), the methods adopted for performing the seismic hazard analysis should be free from the question of its reliability. Nath and Thingbaijam (2012) performed the probabilistic seismic hazard analysis for India using logic tree framework of GMPE. Various probability enhancements such as logic-tree are employed to correct some of the deficits in the probabilistic analysis. The logic-tree approach to obtain earthquake ground motion groups different models is derived from different opinions, and averages them (Krinitzsky, 2002). In this approach, the investigator assigns weights to each model according to his own opinion of relative merit (Krinitzsky, 1998). The different models used do not belong to a uniform data set, and hence are not averageable (Krinitzsky, 2002). Averaging different data sets produces results that are erroneous and illogical (Krinitzsky, 2002).

Reported 475 years of PGA hazard values for the Bhuj city in Gujarat by different workers are given in the following Table 10.2.

Table 10.1 PGA hazard values for the Bhuj city in Gujarat worked out by different workers.

Study	PGA value (g)
Bhatia et al (1999)	0.20
Peterson et al. (2004)	0.2-0.7
Jaiswal and Sinha (2007)	0.25
NDMA (2010)	0.12
Nath and Thingbaijam (2012)	0.42
Shukla (2012)	1.11
Bashir and Basu (2018)	0.28
Bureau of Indian Standards (BIS, 2002)	0.18
Global Seismic Hazard Assessment Program (GSHAP)	0.20

As it can be noticed from the table above that all the different workers have obtained a distinct PGA value that lies in a broad range between 0.12g – 1.11g. A measure of seismic hazard of all the regions in India is required mainly by policy and decision makers such as Bureau of Indian Standards (BIS).

It can be said that the DSHA approach for the Kachchh region has resulted into different results in the form of different measures of PGA, as the input fault parameters used by Mohan (2014), Chopra et al. (2012) and Shukla and Choudhury (2012) are entirely different for KHF. The three above mentioned works have used three entirely different data sets for the same fault of KHF. In the above deterministic scenarios, the input fault parameters of KHF and other faults of Kachchh region should be fixed for use each time and they should be evaluated individually because any meaningful seismic hazard analysis approach involves collection of appropriate input data (Klügel, 2008). So, in order to perform a correct seismic hazard analysis for an area, there shouldn't be different fault parameters considered for the same fault. This points towards performing proper seismic source characterization and then using those seismic source zone values in any calculations pertaining to the assessment of seismic hazard. The fault parameters deduced in the present study such as the length, displacement and slip rate using multi-proxy approach should be used as KHF fault parameters in any study dealing with the seismic hazard assessment. Additionally, in a seismically active region like Kachchh, which is characterized by a number of seismic source zones, there cannot be one fault that acts as a controlling factor for Bhuj city, as the Bhuj city itself is surrounded by multiple seismic sources. According to the present study, the KHF, which has produced high magnitude surface faulting events in the past, lies at a distance of ~5.5 km towards south of Bhuj city, which is very less distance as compared to the controlling fault F12, which lies at a much larger distance from the Bhuj city.

Parvez et al. (2003) used only the preliminary source parameters of the 2001 Bhuj earthquake for the prediction of ground motion. They have generalised this result for the entire Bhuj region, which is also surrounded by many other significant faults such as KHF, which has proved to produce three high magnitude surface faulting events (Tiwari et al., 2021). In a seismically active terrain as Kachchh basin characterized by multiple seismically active faults, there cannot be one fault controlling the seismicity of a region, as is considered by Parvez et al. (2003). The above listed deterministic approaches are a good example of a site-specific study but the PGA for Bhuj city cannot be considered coming from a single fault source input data. Probabilistic process should be used to know about the hazard related to the whole Kachchh basin and should always be used to supplement the deterministic information, which involves site-specific investigations.

As there are many models and different results of seismic hazard analysis carried out, it becomes difficult for decision-making organisations to come to a reasonable conclusion. Also, there are a few models with similar approaches but different input data for the same area or fault zone, which results into significant differences in the final output values. Such models may lack legitimate and logical data. On account of all such difficulties faced, an approach, which combines both deterministic and probabilistic methods is suggested. With the increased understanding of the faulting processes and different earthquake mechanisms, the type of data that are needed as input in DSHA and PSHA can be identified, characterized and analysed. There is always a certain amount of effort in collecting and synthesizing the data required for any seismic hazard analysis. This in turn should produce results, which are accurate and reliable, as most of the Kachchh region's population and economy depends upon proper estimation of the earthquake hazard that had several times destroyed most of facilities of the region. Thus, in order to generate the most reliable seismic hazard estimates, the combined approach involving both DSHA and PSHA is advised to be employed when performing seismic hazard analysis of any area, whether it's on local (site-specific) or large scale shouldn't be a greater concern. Consequently, reliable decisions can be made to select the seismic design, to make insurance and demolition decisions, and to optimise the use of resources to cut down the earthquake risk along with other causes of loss. The seismic hazard maps should be updated on a regular basis owing to the dynamic nature of earthquakes, and to keep up with the latest knowledge. All potential sources of seismic activity that might contribute to ground motions should be identified and characterized by considering all the geologic, tectonic and historic evidences of its active nature. All the more, the seismic hazard computations need to include information of an important seismogenic source i.e., KHF located towards the south of Bhuj city and probably redefine the hazard estimates according to new data, in order to produce accurate results of the seismic hazard assessment for Bhuj region. The present study suggests to utilize the contribution of the fault sources to regional seismic hazard and, thereby, update the seismic hazard estimations in Kachchh region by including an important seismogenic source – KHF, and related parameters for enabling better mitigation strategies. As directed by the level of seismic risk, the regional seismic hazard, which includes the KHF as a potential seismic source should be of priority to facilitate and support a wide range of earthquake engineering applications.

Applying the above discussed method of combining the DSHA and PSHA approaches of seismic hazard assessment for Kachchh basin may involve some difficulties due to lack of adequate amount of data. Nevertheless, with the improved proficiency on the geological and geomorphological processes, the data that are essential for the seismic hazard analysis can be identified, characterized and applied. Next section emphasizes the importance of geological and geomorphological data in evaluating seismic hazard for Kachchh region.

INTEGRATING EARTHQUAKE HAZARD APPROACHES ALONG KHF IN REGIONAL PERSPECTIVE

The seismic hazard analysis strives to deliver better results for developing superior building codes by correlating a multitude of data. In order to achieve this, the development of models based on fault parameters data, which is entirely based on geological evidences poses as a significant task to be accomplished (Morell et al., 2020). For achieving this, different methods, which impart long-term and comprehensive paleoseismic records, as provided by fault rocks studies and geochronologic data are required, which incorporate multi-proxy evidences (Morell et al., 2020). At this point, the geological methods for overcoming the above specified tasks, which involve the use of detailed paleoseismic data quantifying the fault systems and their behaviour, are outlined in the upcoming paragraphs.

Paleoseismic data such as information related to the magnitudes, locations, and types of earthquakes associated with long recurrence intervals (~ thousands of years) can provide information that is largely absent from most historical, geodetic, or seismicity records (~ tens to hundreds of years). Such information forms an essential part of any seismic hazard assessment process and can be assessed by employing various geological and geomorphological techniques (Morell et al., 2020). The information provided by the geologic and geomorphologic analysis is used to develop earthquake models, which delivers important knowledge about the location, dynamics and geometry of active faults; estimates of former fault rupture magnitude and its timing of occurrence (Field et al., 2014; Petersen et al., 2015). Comprehensive field surveys along the faults and other associated tectonic structures observed in the Holocene and Late Pleistocene, and more complete and detailed seismicity data from expanded seismograph networks has permitted improved characterization of paleoseismic sources. Additionally, the advancement in the identification and characterization of enigmatic faults by utilizing topographical and geomorphological knowledge may also contribute towards the development of secure building codes (Morell et al., 2020). Due to consideration of large amount of historical data, the seismic hazard analysis is characterized by substantial amounts of uncertainties, which can be addressed or considerably reduced by using the geological data, generally where the region is characterized by shallow seismicity and has experienced Quaternary faulting (Wesnousky et al., 1984).

The intra-plate seismic source zones and paleoseismicity are associated with each other out of necessity, because only the paleoseismic data can quantify most of the intra-plate zones that are distinguished by having long recurrence intervals between significant earthquakes, which form an important input for evaluation of seismic hazard (Johnston, 1987). A processed earthquake catalogue in which foreshocks and aftershocks have been removed serves as a primary input data, which should comprise of the location, time of occurrence and magnitude of historical earthquakes in the region. Additionally, the designation of active faults specifying its geometry, slip sense, segmentation behaviour, rupture length as a function of magnitude and the maximum magnitude of each fault acts as the essential input parameters that provide a framework for evaluating paleoseismicity from the geological record (McGuire, 1993).

For the understanding and mitigation of seismic hazard and risk, the geologic parameter that contributes the most is the *fault slip rate*, which can be measured through numerous geologic methods (Petersen et al., 2014). The most common types of methods such as offset from Quaternary markers (Sieh and Jahns, 1984; Lavé and Avouac, 2001; Zielke et al., 2010) and paleoseismic trenching (Scharer et al., 2007) assess the slip rates by dividing the measure of the fault offset by the period of accumulating of that offset ranging from early Quaternary to present. Such geologic data not only unveils the average repeat time of past earthquakes, but also reveals the approximate age of last major earthquake on most of the intraplate faults.

In addition to the previous studies on the fault systems that ruptured during the Wenchuan and Gorkha earthquakes, recent studies along the Katrol Hill Fault (KHF) (Maurya et al., 2021) demonstrate the topographic and geomorphologic effects that characterize the properties of seismogenic faults. In this work, the morphometric parameters, Chi (χ) and field photographs (described in the Chapter – 8) emphasized the KHF as a potential seismogenic source by establishing surface faulting during Late Quaternary. The KHF fault along with the Yingxiu-Beichuan fault (Morell et al., 2020) are two of the many examples that have successfully elucidated the efficacy of topographic and geomorphic analyses in characterizing enigmatic seismogenic faults. The different fault parameters related to KHF such as its surface rupture length, displacement, slip-rate and maximum magnitude (M_w) are calculated using different geological methods (Tiwari et al., 2021). The surface rupture length along the KHF was evaluated using the field evidences displaying deformed miliolite beds to the south of Bharasar, vertically deformed Quaternary miliolite beds found south of Bhujodi village and offsetting Quaternary deposits found in the Khari river cliff section. The presence of KHF in the Quaternary at places other than the three above-mentioned sites was performed by using the GPR, which conformed that the occurrence of surface faulting along the trace of KHF from south of Bharasar in the west to Ler village in east. Further, the microscopic evidences obtained using the optical microscope and SEM also indicated deformed Quaternary deposits, which showed quartz microtextures such as excessively broken and fractured grains, adhering particles, striations, and exfoliation. Thus, the three techniques of field studies, GPR studies and microscopic studies using SEM and optical microscope facilitated in the estimation of surface rupture length. The displacement was measured in the field by the help of Quaternary offset markers encountered in the Khari river section. The displacement obtained was then divided by the three faulting events reported by Kundu et al. (2010) to attain the slip rate estimates. The slip-history diagram (Figure 5.5) showing displacement along KHF plotted against time for a better idea about slip-rate estimation is given in Chapter – 5. Finally, for assigning the maximum magnitude to the three surface faulting events along the KHF, various empirical relationships between fault parameters such as surface rupture length, displacement, slip-rate and magnitude established by Slemmons (1982), Wells and Coppersmith (1994) and Anderson et al. (1996) were used. A narrow magnitude range from 6.6 – 7.1 was obtained for the three events along KHF by incorporating fault parameter values in the above equations. The results produced in this work are similar to those carried out by Wesnousky et al. (1982; 1983; 1984), which also advocates the application of geologic data to anticipate the spatial distribution and size of earthquakes. Moreover, the correlation between different subfields, as is carried out in the present study to evaluate fault parameters, leads to the enhancement of the skill to integrate data of adequate efficacy from geologic and geomorphic domains, which eventually assist in estimating seismic hazard, and thus, contribute towards designing of safe building codes and alleviate the loss to economy (Morell et al., 2020). The results obtained through this approach may principally be exercised in the areas that have experienced active faulting and characterized by rather very short or absence of historical seismicity (Wesnousky et al., 1984).

Uncertainties are involved in paleoseismic data, which utilizes meagre or insufficient data for developing models, which, in turn reflects the appearance of systematic error owing to the lack of data (Anagnos and Kiremidjian, 1988). As more and new data becomes accessible over time, the uncertainty can be minimised. Recent observations of fault parameters related to KHF such as surface rupture length, displacement, slip rate and the assigned maximum magnitude, have raised questions on the reliability of the models used for hazard analysis by Mohan (2014), Chopra et al. (2012) and Shukla and Choudhury (2012).

However, some of the prior studies assumed the same seismicity parameters for the entire region, which is questionable and unlikely to capture the actual seismic scenario (Tripathi, 2006; Yadav et al., 2008) of Gujarat region and Kachchh region. Assigning different quantities of fault parameters like maximum magnitude and rupture length will directly affect the computation of ground prediction equations required to determine ground motion intensity measures.