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Annex II

Seismotectonic and Seismic Hazard Analysis

**China Non-Ferrous Metal Industry's
Foreign Engineering and Construction Co. Ltd
(NFC)**

**Report on
Seismotectonics & Seismic Hazard Analysis
and Site Effect
South Aluminum Smelter Plant**

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**خدمات مهندسی مکانیک خاک
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Comprehensive earthquake catalog of Lamerd area with a radius $R=150$ km for the site

Abstract

Ground motion is defined in terms of peak ground acceleration, response spectra and accelerograms time-history. Three levels of earthquake ground motion will be determined. These three levels are including level one, Seismic Design (SL1), Level two Seismic Design (SL2) and level three, Maximum Credible Earthquake (MCE).

Firstly, we have calculated Peak Ground Accelerations (PGA) and response spectra for MCE, SL1 and SL2 by Deterministic and probabilistic Approach for basement of rock site.

Selections of the target magnitude and distance range are based on area's seismotectonics.

Postulated credible scenarios (combinations of magnitude and distance), based on the regional seismotectonics are used in ground motion attenuation relationships to define peak ground accelerations and response spectra and time-history for the MCE of basement.

Secondly; we have applied dynamic analysis to sediment layer to understand amplification factor at different periods and also in order to transferee acceleration time-history from basement to ground surface. Finally, we have recommended peak ground accelerations and Design response spectra as well as time-histories for all of seismic design levels.

Probabilistic ground motion analysis methods used to determine the return period (or annual exceedance probabilities) of the peak ground accelerations and response spectra associated for each level of basement.

A logic diagram which describes the overall methodology is shown in Figure 1.1.

This report describes the procedures used to define the seismic hazard at the Lamerd Factory site in South of Iran. The results of this analysis will be used in the seismic design of this Factory's structures and its equipments.

The Seismic Hazard is described in terms of ground motions. The procedures used to select the ground motions are completely described in this report.

Section 2 gives a brief description about seismotectonics of the region surrounding the site. In section 3 we are presenting the seismicity parameters and return period of earthquakes Magnitude of the same place. Section 4 discusses the strong ground motions at the basement of our site and selected ground motion for several levels. Ground motions are defined in terms of ground accelerations. Three levels of earthquake ground motion for Bedrock will be determined. These are introduced below:

Ground Motion Level Year and Level	Horizontal PGA _h (g)	Vertical PGA _v (g)
475 (SL1)	0.28	0.16
2475 (SL2)	0.38	0.23
MCE	0.57	0.36

Section 5 and 6 is about the application of statistical methodology to define the response spectra and simulated accelerations for several levels of seismic design for basement. Section 7 dynamic analysis applied to sedimentary layer in order to transfer ground motion from basement to ground surface. Finally, in the last section we have presented the main conclusions and a complete description of the ground motions (peak accelerations, response spectra and accelerograms) to be used for seismic design of structure. Design response spectra and accelerograms are provided on an attached diskette.

Final peak horizontal and vertical ground accelerations at the surface were estimated as mean values of single-component PGA's and are presented in the below:

Level	PGA _h (g)	PGA _v (g)
SL1	0.3	0.16
SL2	0.41	0.23
MCE	0.64	0.37

Section 1

1.1 Introduction

A seismic hazard analysis consists of estimating the annual probabilities that various levels of earthquake ground motion will be exceeded at a site.

Three inputs to the computational procedure are necessary:

a description of sources of earthquakes (faults, other tectonic features, or zones of the earth's crust with similar earthquake characteristics), an estimation of the probability that earthquakes of various sizes will originate within these sources, and an attenuation function to estimate the ground motion at a selected site given a future earthquake at a location within a source. The hazard analysis then consists of integrating over all possible future earthquake occurrences (in size and location).

Because the sources of earthquake occurrences and associated ground motions are not well understood in the Zagros provinces, the inputs to the analysis are uncertain. As a result, it is important to quantify estimates of the uncertain parameters and their ranges, and to incorporate this in the results. Sources and effects of uncertainties are identified and represented in seismic hazard evaluations.

The representation of earthquake ground motion hazards should have several qualities.

First, it should reflect the choice of seismic sources, the recurrence models for earthquakes, the seismicity parameters for those models, and the attenuation functions.

Second, all biases should be removed for each piece of input. The results should, as a whole, reflect best estimates, and should not build in conservatism or un-conservatism.

Third, the results should reflect uncertainties in the input in a convenient way, so that conclusions about the uncertainty in seismic hazard can be properly interpreted and reviewed.

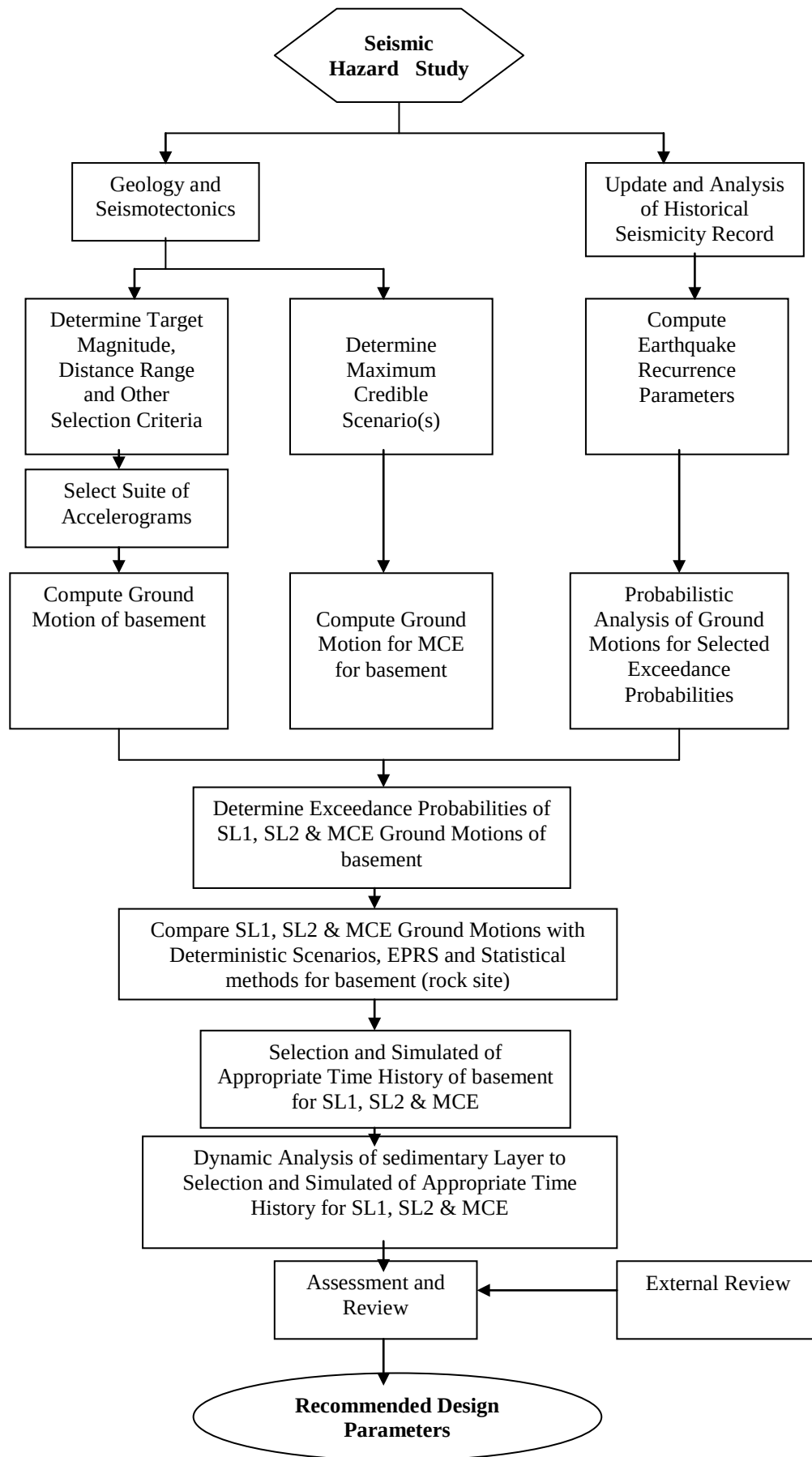


Figure 1.1: Logic diagram of methodology of this study

The product of a seismic hazard assessment is a hazard curve, which describes the annual probability that various levels of ground motion will be exceeded at a site. A hazard curve is defined to capture the random component of earthquake occurrences and ground motion hazards. Uncertainty in the input, a fundamentally different type of uncertainty, results in uncertainty in the hazard curves.

In the follows, a final report on “Seismicity, Seismotectonic and Seismic Hazard & Strong Ground Motion will be presented”.

1.2. Seismic hazard model

The methodology to calculate the seismic hazard at a site is well established in the literature for a single source on group of sources. The fundamental method requires specification of three inputs:

- 1- Geometry of the seismic source (S):
- 2- Seismicity (distribution of earthquake magnitude and their occurrence in time and space) within the source(s), characterized for example by a rate of occurrence of events larger than some lower bound M_c , on exponential magnitude distribution with specified slope parameter β or b value and maximum magnitude M_{max} .
- 3- An attenuation function allowing estimation of ground motion as a function of earthquake magnitude and distance.

1.3. Terms & Definitions

Capable Fault: A capable fault is a fault which has exhibited one or more of the following characteristics:

- (1) Movement at or near the ground surface at least once within the past 35,000 years
- (2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
- (3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could be reasonably expected to be accompanied by movement on the other.

Earthquake Fault: An Earthquake Fault is a ground fracture formed in association with a shallow earthquake, usually by reactivation of a pre-existing geological fault.

Fault: A fault is a tectonic structure along which differential slippage of the adjacent earth materials has occurred parallel to the fracture plane. It is distinct from other types of ground disruptions such as landslides, fissures, and craters. A fault may have gouge or breccia between its two walls and includes any associated monoclinial flexure or other similar geologic structural feature.

Historical Earthquake: A Historical Earthquake refers to earthquake that occurred before 1900 A.D. These earthquakes are limited to historical books, logs and different documents.

Instrumental Earthquake: An Instrumental Earthquake defines as an earthquake that occurred after 1900 A.D. These earthquakes have been recorded by many seismograms and presented by seismological centers or agencies.

Intensity: The intensity of an earthquake is a measure of its effects on man, on man-built structures, and on the earth's surface at a particular location. Intensity means the numerical value on the Modified Mercalli scale.

Magnitude: The magnitude of an earthquake is a measure of the size of an earthquake and is related to the energy released in the form of seismic waves. Magnitude means the numerical value on a Richter scale.

Quaternary Fault: A fault is considered Quaternary if it can be shown that displacements have occurred along it during Pleistocene and Recent epochs (2 million years ago to the present day).

Surface Faulting: Surface faulting is differential ground displacement at or near the surface caused directly by fault movement and is distinct from nontectonic types of ground disruptions, such as landslides, fissures, and craters.

Tectonic Province: A tectonic province is a region of the North American continent characterized by a relative consistency of the geologic structural features contained therein.

Seismic Level 1 (SL1):

This Earthquake may be expected to occur during the lifetime of Structure. The SL1 represents the level of ground motion at the site which only minor damage is acceptable.

The structures should remain functional and damage easily repairable from the occurrence of earthquake shaking not exceeding the SL1. In this study return period of occurring of the SL1 is 475 years.

Seismic Level 2 (SL2):

This earthquake is large, but low probability of occurrence. The SL2 will produce the level of ground motion for which the structure should be designed or analyzed. The structure should stay “fail safe”. For structures whose failure would present a large social hazard, the SL2 will normally be characterized by a level of motion to be induced by the return period of occurring of 2475 years.

Maximum Credible Earthquake

The largest earthquake judged possible given the seismic history and tectonics of the region surrounding the site. The Return Period of occurring of the MCE is more than 10000 years.

The Maximum Credible Earthquake (MCE) is the largest reasonably conceivable earthquake that appears possible along a recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework. The MCE is generally defined as an upper bound of expected magnitude.

Section 2

2. Tectonic, Seismotectonic and Seismicity

2.1. Regional tectonic, seismotectonic and seismic zonation

The region under study is north of Persian Gulf. According to Nabavi [1], the studied region falls under structural zone of Zagros. This zone separated by Minab-Zendan Fault in the east of Hormoz Strait system from Makran zone (Figure 2.1).

The northern coastlines of Persian Gulf forms the southeastern part of the Zagros geological-structural province. It is characterized by NW-SE trending fold-thrust belts, folded and deformed by the latest phase of the Alpine orogeny in Plio-Pleistocene times. Geological formations may range in age from Palaeozoic Late Tertiary time and include diapire related to the early Palaeozoic Hormuz series, which have been active up to recent times. This area has been tectonically active since late Tertiary time, as part of the southern deformational front or convergence belt (Mesopotamian foreland and Persian Gulf basin) and as part of the Arabia – Iran continent- continent compressional and collision plate margins [2][3][4][5][6].

2.1.1. Zagros

The Zagros mountain range, which extends over a length of over 1500 Km from eastern Turkey, through parts of Iraq and Iran, to the Gulf of Oman, is one of the key structural elements in the Alpine and recent tectonics of the Middle East. Structurally, it appears to result from the collision of the continental plate of Arabia in the southwest with Central Iran in the northeast (Figure 2.2). The range acquired its present-day structure through a series of compressive tectonic phases, the principal ones occurring at the end of Triassic, at the end of Jurassic, at the end of the Cretaceous, during the Oligocene and during the Pliocene. Extensional interludes probably also took place, in particular during the earlier phases. The intense present-day seismicity of the region indicates that tectonic deformations are still in progress [7].

The orogeny is bounded to the northwest by the East Anatolian left-lateral strike-slip fault (EAF) and to the southeast by the Oman Line (OL) [8], which is here considered to be a transform fault inherited from the opening of Neo-Tethys.

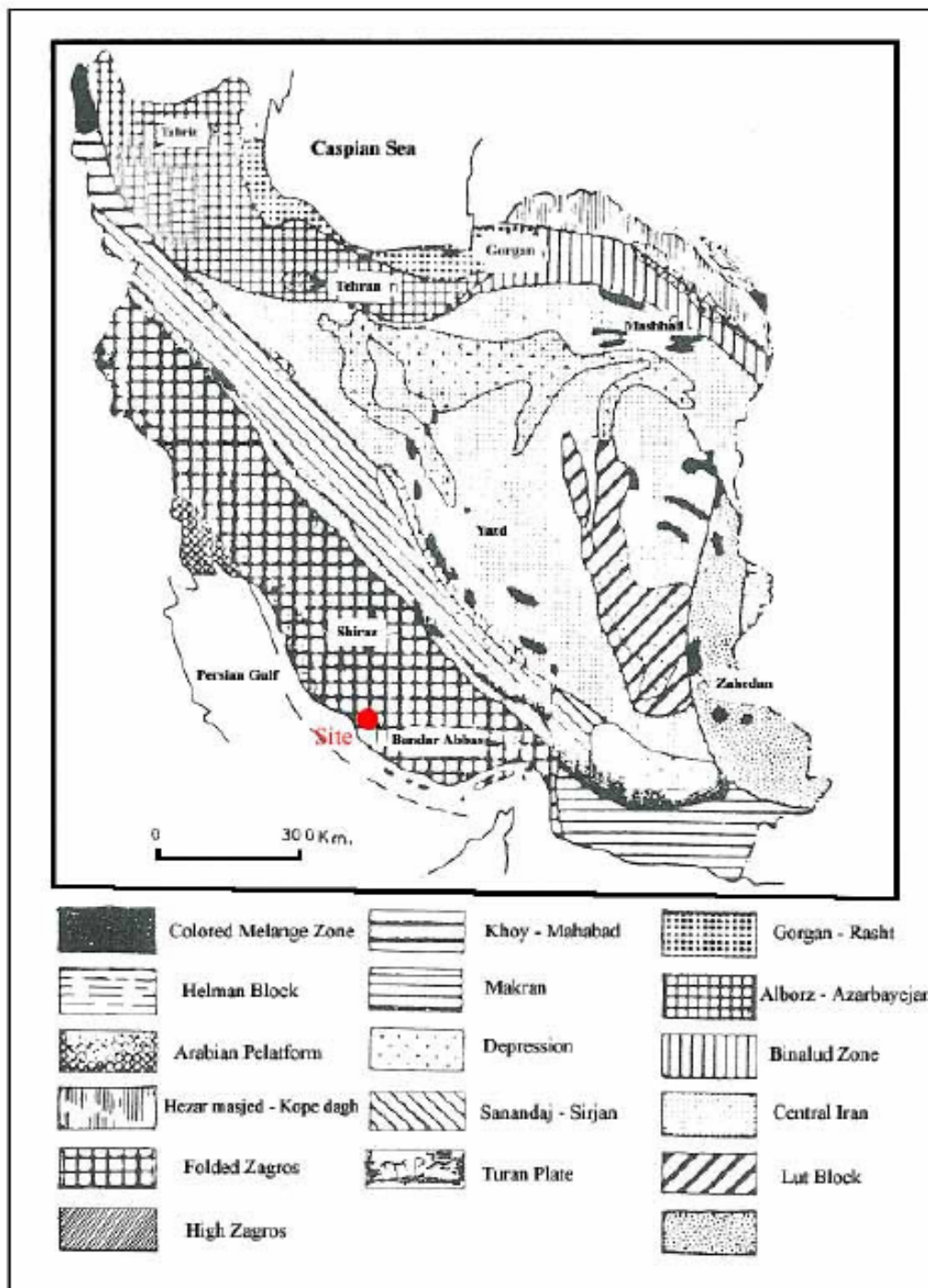


Fig. 2.1: Structural units of Iran [1]

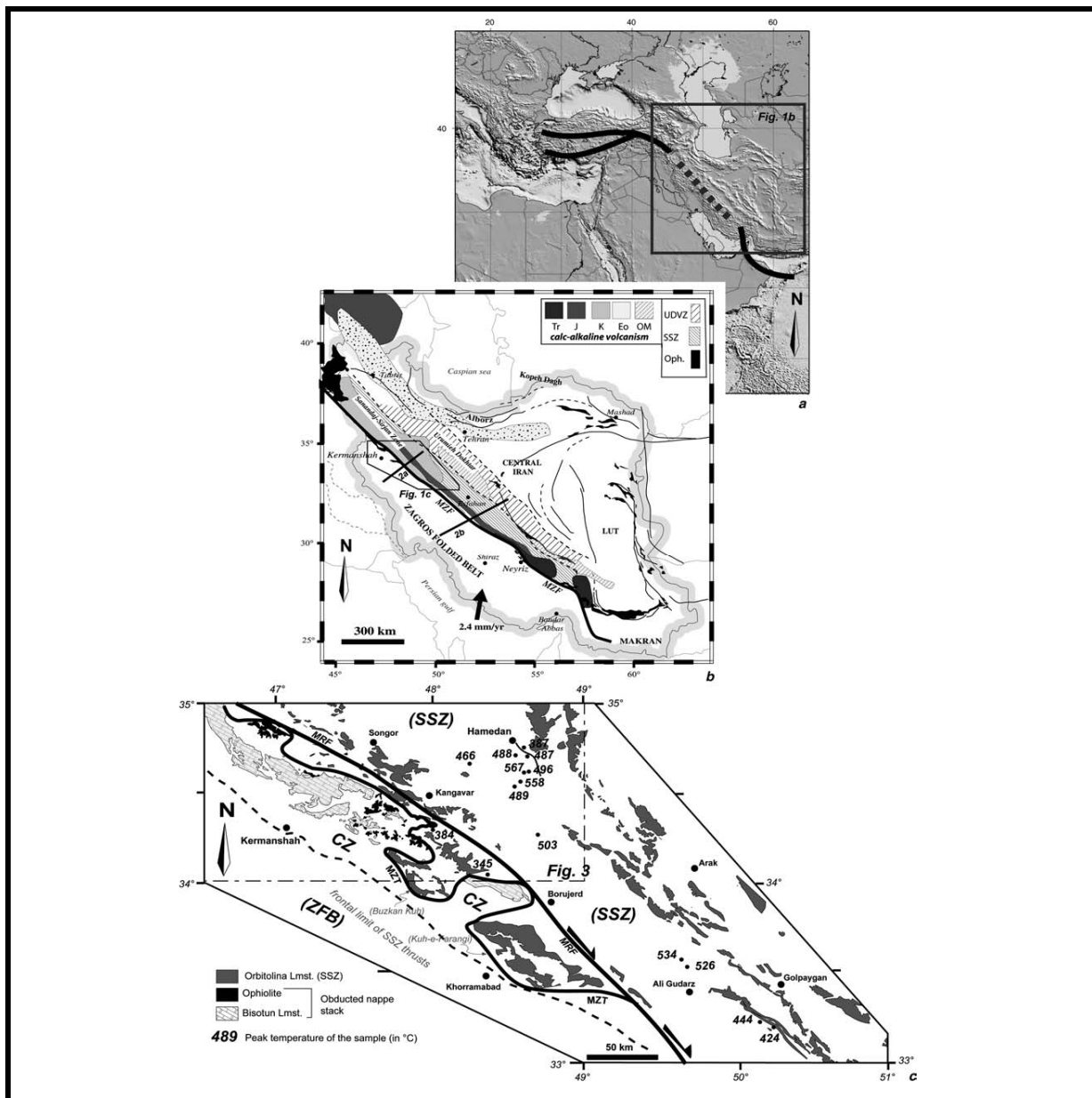


Fig. 2.2: Location of Zagros and its subzones [2]

Location map from the Aegean Sea to Makran. Box: location of Figure 2.2a,b. b) Simplified map recalling some of the main features of the geology of Iran, with special emphasis on the internal zones of Zagros. The extension of the Sanandaj-Sirjan zone (SSZ) and the Urumieh-Dokhtar volcanic zone (UDVZ) are indicated (hatching parallel or perpendicular to the Zagros trend, respectively). Ophiolites (Oph.), shown in black, only crop out in two places (Kermanshah and Neyriz) to the SW of the Main Zagros fault system (MZF; thick black line) Box: location of Figure 2.2 c. c) Simplified structural sketch of the northern Zagros range, along the MRF and the MZT. The limits of the so-called 'Crush zone' (CZ), between the SSZ and the ZFB (to the SW of the dashed line), are indicated.

2.1.1.1. Zagros tectonic units

Geomorphotectonically, Zagros can be divided to 3 units, high Zagros, folded Zagros and Khuzestan Plain. Based on structural pattern, however it could be classified to folded belt, Dezful embayment and Abadan Plain. Integrating both approaches, a more general categorization would be found to define two subzones: Thrust Zone and Folded Zagros [9]. Since the study region is situated in Folded Zagros, it would be described more precisely.

Thrust Zone (High Zagros) is a high altitude band of variable width (10 to 65 km), and since it includes the highest mountains in Zagros, it is sometimes called “High Zagros”. Eastern north boundary of this zone is Main Zagros Thrust. This zone with imbricated tectonic slices comprising Mesozoic limestones, radiolarites, obducted ophiolite remnants and Eocene volcanics and flyschs, which are all thrust onto the ZFB.

Zagros Fold belt has a width of 150 to 250 km and could be identified as marginal trough and as the craton of Arabian Shield. In general, this zone which consists of ca. 13–14 km of shelf deposits of Permo–Triassic to Late Cretaceous / Paleocene age similar to those of Arabia followed by a more complex pattern of sedimentation up to the recent Pliocene [10][11]. These deposits were folded into a succession of NW–SE-trending folds after the Mio–Pliocene (Bakhtiari conglomerates and perhaps earlier. The Zagros fold-thrust belt (Figure 2.3), which extends for about 2000 kilometers from southeastern Turkey through northern Syria and Iraq to western and southern Iran, with its numerous supergiant hydrocarbon fields, is the most resource-prolific fold thrust belt of the world. This fold and thrust belt is a result of the structural deformation of the Zagros (peripheral) proforeland system, whose present-day expression is the marine Persian Gulf and continental Mesopotamia basins [12][13][14][15], and underlying preproforeland, mostly platformal and continental shelf deposits. The belt has structurally evolved as a prism of stacked thrust sheets, composed of uppermost Neoproterozoic and Phanerozoic sedimentary strata approximately 7 to 12 kilometers thick, in the external part of the southwest-migrating Zagros orogenic wedge [16][17]. The latest systematic account of the stratigraphy of the Zagros fold-thrust belt is that of James and Wynd (1965), which includes only Mesozoic and Cenozoic units. More recent investigations have added considerable amounts of information, which require a more comprehensive analysis, and major revision of the stratigraphy of the region. Specifically, it is now well established that a significant part of the stratigraphy of the Zagros fold-thrust belt

developed in an epicontinental, synorogenic proforeland basin, whose evolution has been intimately related to the tectonic and structural events of the associated Zagros orogen. Foreland basins, as synthesized by DeCelles and Giles (1996), have attracted the attention of many earth scientists. Being the sites of favorable conditions of hydrocarbon generation, migration, and accumulation, they have been the subjects of a considerable number of stratigraphic, sedimentological, structural, and geodynamic studies. The Zagros proforeland basin (being a specific type within the general category of the foreland systems; for terminology see: [18][11], as an integral part of the Zagros fold-thrust belt, with all its economic significance, however, has remained problematic. In Iran, geological investigations of the Zagros fold-thrust belt have extended over nearly a century since the earliest petroleum discovery in the region, and many petroleum geologists have contributed significantly to a better understanding of the geology of this petroliferous tectono-sedimentary zone [19]. In these contributions, the belt has frequently been referred to as a “foreland” or “foredeep” basin, but no detailed accounts have been presented of the stratigraphic architecture and various depozones, nor have specific correlations been suggested between sedimentological evolution and related tectonic events that shaped the interior part of the orogen. In recent years, as a result of extensive geological mapping in various segments of the internal and external parts of the orogen, a better understanding of the evolution of this mountain belt and its proforeland basin has emerged. Recent detailed investigations concerning sedimentological aspects of the Iranian segment of the basin in the context of a better-constrained tectonic framework, and the areal distributions and interrelationships of rock units in light of new developments in sequence stratigraphy and deformation/sedimentation relationships, as well as geodynamic concepts, have resulted in a more comprehensive stratigraphy. Such work forms the basis for a synthesis of the uppermost Neoproterozoic through Phanerozoic successions, and provides a framework upon which a scheme for Zagros proforeland evolution can be established [20].

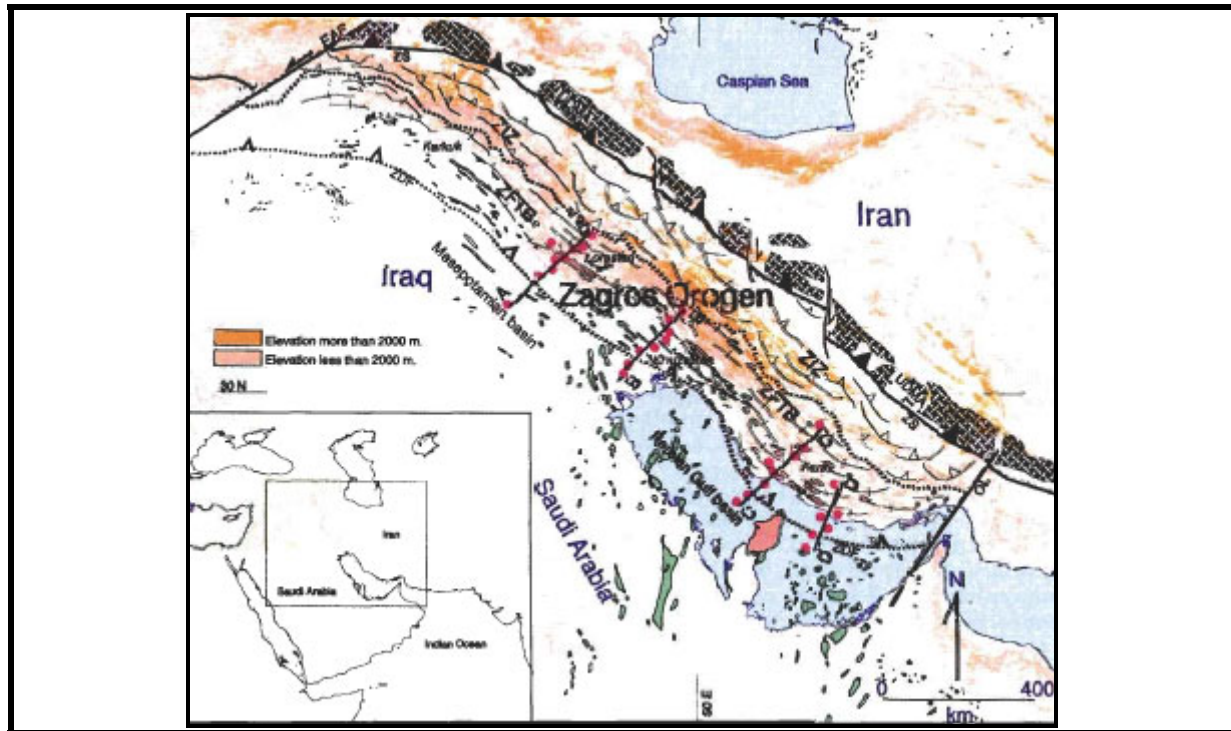


Fig. 2.3: The Zagros orogenic belt and its subdivisions [20]

Abbreviations: EAF - East Anatolian fault; OL - Oman line; UDMA - Urumieh-Dokhtar magmatic arc; ZDF - Zagros deformational front; ZFTB – Zagros fold-thrust belt; ZIZ - Zagros imbricate zone; ZS - Zagros suture. Red dots show locations of the stratigraphic columns.

2.1.1.2. Structural evolution of Zagros

The Zagros orogen provides a unique opportunity within the Alpine system to evaluate the interplay between a young Tertiary collision and earlier subduction/ obduction processes. The Zagros orogen results from the convergence between the Iran block and the Arabian plate, as the Neo-Tethyan realm (whose rifting had started in the Upper Permian– Lower Trias, when the Central Iranian block separated from Gondwana and Arabia) disappeared through a succession of subduction/obduction/collision stages. Convergence was first accommodated by a northeastward subduction (with respect to the present geographic position) of the oceanic domain below the Iran block (itself earlier accreted to Eurasia by Late Triassic; [21][22]) from the Late Triassic–Early Jurassic or the Late Jurassic [23]. A major obduction stage (running from Turkey to Oman and then onto the Himalayas; [17]) is known to have taken place approximately 100–70 Ma ago in Iran [24]. The shortening rate across the Crush zone since the Mid-Miocene (20– 15 Ma) is estimated at a minimum 3–4 mm/year.

Zagros represents an intermediate situation between the obduction stages preserved along the Makran–Oman transect and the full obduction-collision (and crustal collapse) observed in

Turkey. Although the timing of the final oceanic closure or the inception of collision are not known with precision (Late Cretaceous : [2][25]; Eocene: [26][27]; Neogene: [28]; Miocene: [29]), Zagros is thought to represent a young analogue of well-developed collisional settings (e.g., the Himalayas) and expected to give insights into the early stages of collision.

Therefore three major sequential geotectonic events: (1) subduction of the Neo-Tethyan oceanic plate beneath the Iranian lithospheric plates during Early to Late Cretaceous time, (2) emplacement (“obduction”) of a number of Neo-Tethyan oceanic slivers (ophiolites) over the Afro-Arabian passive continental margin in Late Cretaceous (Turonian to Campanian) time, and (3) collision of the Afro-Arabian continental lithosphere with the Iranian plates in Late Cretaceous and later times [2].

2.2. Seismotectonic provinces and their characteristics

Iranian plateau is a broad zone of compressional deformation. The plateau is a relatively weak belt affected by several collisional orogenic movements and is being compressed between two blocks of Arabia and Eurasia with greater rigidity. In this plateau, the active deformation is not uniformly distributed, and no single fault accommodates a large percentage of plate convergence [30]. Seismicity is mainly concentrated beneath the Zagros active thin-skinned fold-thrust belt in the southwest, the Koppeh Dagh active thin-skinned fold belt in the northeast, partly in Turkmenistan, the Alborz thrust belt bordering oceanic crust of the South Caspian Depression, the Central Iranian thick-skinned range and basin province with reverse-slip and strike-slip earthquakes [31] and in the Makran where a remnant part of the Tethys oceanic lithosphere subducts northwards beneath southeastern central Iran [32][33]

Zagros seismotectonic province is known by a NW-SE trend. Evaporites have been prominently involved in Zagros tectonism. This important evaporite layer separates the sedimentary column from the basement [28].

The very high twentieth century seismicity of the Zagros Active Folded Belt is characterized by a large number of shocks in the magnitude 5 or 6 range, and a very small number with magnitude equal to or greater than 7. The precision of depth calculation of the Zagros is very poor, and without special studies little can be said on the subject. The total thickness of the sediments above the metamorphosed Precambrian basement cannot be more than 10 to 15 (or a possible maximum of 18) kilometers. Thus the earthquakes occurring within this depth

range may be related to deformation of the sediments and or movements of the salt layers and their diapirism. However, many earthquakes occur at greater depths, and salt diapirism would not necessarily be associated with thrust faulting, whereas the focal mechanisms of most earthquakes are thrust faults. It would therefore appear that most of the earthquakes are subsedimentary and probably related to the basement or upper mantle and that reactivation of some basement faults during readjustment of the basement causes subsedimentary earthquakes within the Zagros Active Folded Belt [18].

2.2.1. Fault data

2.2.1.1. Earthquake Faults

During last 500 years, surface ruptures associated with large earthquakes have appeared and been documented in various places in Iran, which are the main criteria in classifying them as earthquake faults. Most of these ruptures occurred along the capable faults that have moved repeatedly in the Quaternary, thus constituting evidence that these active faults have the potential of reactivating in future [34]. There are several earthquake faults in the study Region. For example, Assaluyeh and Ghir faults are two of them (Figure 2.4).

2.2.1.2. Quaternary Faults

This type of fault is recognized to be active based on observation of Quaternary landforms; however, they are not known to be seismically active. This could be due to very long recurrence interval along these faults or resulted from creeping, which continuously move slowly without necessarily causing earthquakes [35]. Figure 2.4 shows the seismic and quaternary faults in the region under study.

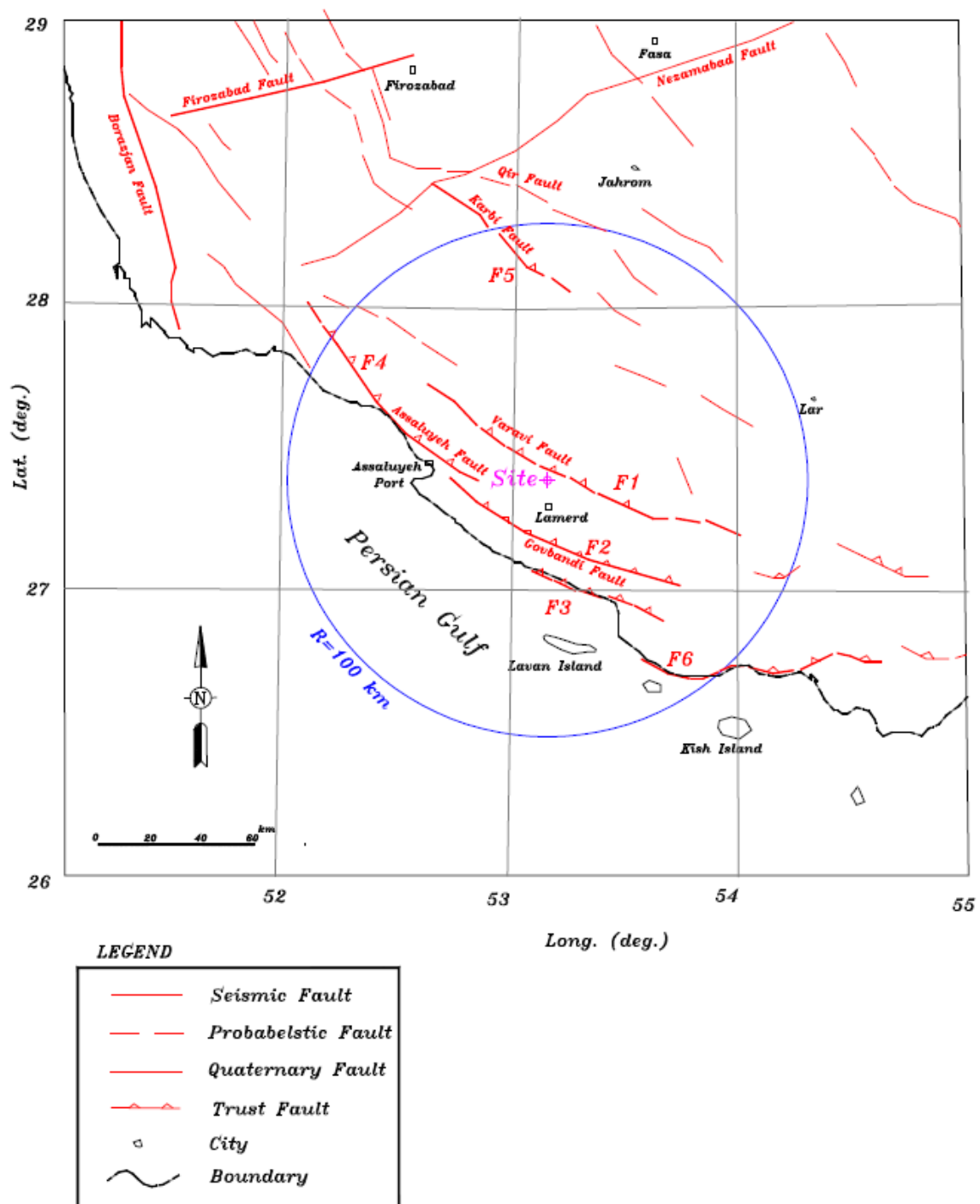


Fig. 2.4: Active and quaternary faults at the around the site

Assaluyeh fault

This fault is included in the studies based on Berberian, 1981 [37]. This trend contained 10 damaging and destructive earthquakes (Figure 2.5 and Table 2.1). This fault is included of several branches (F2, F3 and F4) as shown in figure 2.4.

Table 2.1: Major earthquakes related to Assaluyeh seismic trend [37]

DATE	mb	MMI
0978.06.17		VIII
1008.00.00		VII
1865.00.00		
1883.10.16		
1950.01.22	5.7	VII
1950.02.02	4.7	VI
1954.08.20		
1973.06.09	4.5	VI
1977.02.14	4.6	V
1977.07.14	4.3	V

There are several indications that the Assaluyeh seismic trend (buried seismic reverse fault) coincides with sedimentary facies changes. The Assaluyeh seismic trend is near the southwestern boundary between the Jurassic shallow marine carbonates (Surmeh Formation in the NE) and the lagoonal-reefal carbonates (Sargelu Formation in the SW) [38]; it lies along the change between the Eocene neritic to basinal marls of the Pabdeh Formation in the south and the transitional shallow marine carbonates and neritic to basinal marls (Jahrom-Pabdeh Formation) In the north [38][39]; it is approximately the southern limit of the Early to Middle Miocene Mishan sea with shale and marl depositions . it lies parallel to the main Tertiary foredeep, and finally it corresponds to the present dividing line between the Zagros fold thrust belt in the NE and the Arabian platform in the SW, and also corresponds to the boundary between the mountain front and the foothills of the Zagros belt [37]. This fault is included of several segments, such as Assaluyeh and F2 or Gavbandi faults (Figure 2.4).

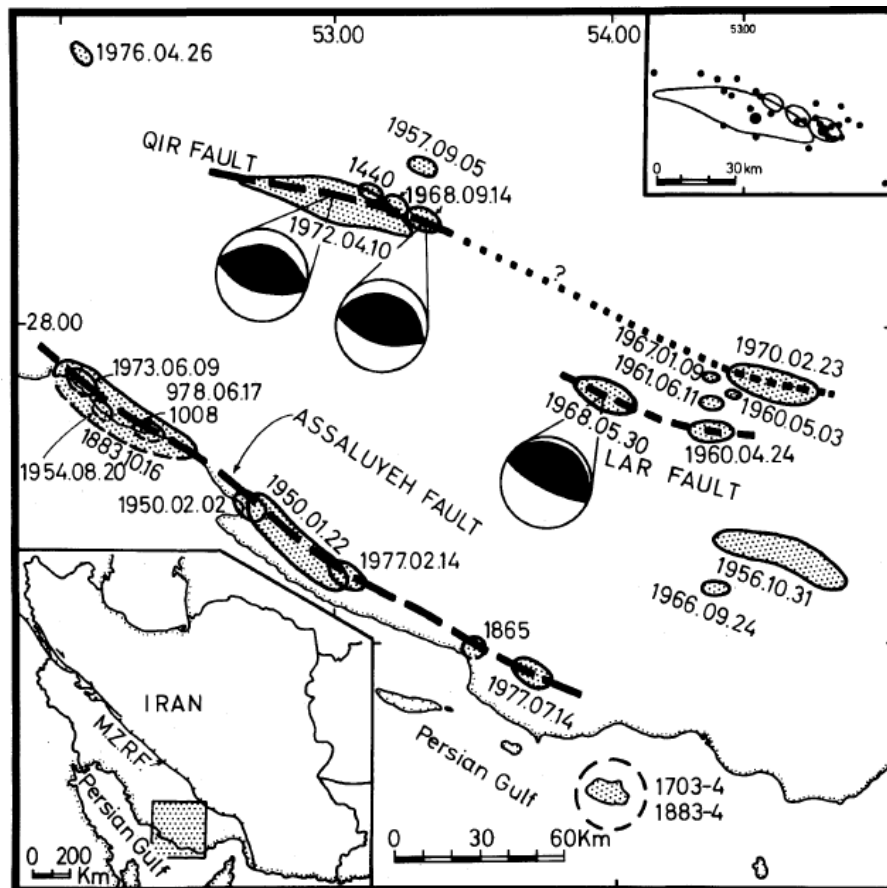


Fig. 2.5: Assaluyeh buried seismic trend [37]

Ghir Fault

The Ghir destructive earthquake of 10 April 1972, which killed about 5,000 people and injured about 1300, destroyed about 5,000 houses in the central part of the Zagros Active folded belt. The earthquake occurred at 02h 06m 52.9s GMT, at 28°.43'N, 52°,79'B, with estimated magnitude of 6.9 and shallow focal depth (Fig.2.5), [40]. The earthquake was associated with minor ground fractures of uncertain tectonic origin (ground deformation of small amplitude and of secondary nature) and rock falls; many stones thrown up. The long and continuous fractures were extensively developed during the earthquake on the ground [47, 48]. Some of these fissures could be clearly related to lurching, differential settling, or collapse of Qantas, but others could not (probably of tectonic origin). The evidence is insufficient to distinguish between primary faulting and secondary strain readjustments on pre-existing faults and lines of weakness. According to Ambraseys et al. (1982), it is very probable that the main fracture associated with the Ghir earthquake involved formations underlying the Zagros series, and that deep rupturing with a few tens of centimeters relative displacement was absorbed or distributed by the Zagros series and did not reach the surface,

Ground features found after the earthquake may or may not reflect features of the causative fracture. Ambraseys (1975) put a fracture of secondary nature in Ghir area associated with the 1972 Ghir earthquake. The length of the fault zone (?) was about 20km with approximate strike of N 120°E.

The Kazerun-Borazjan active strike-slip fault

The Kazerun-Borazjan active fault [37][40] is located along a line marking the projected continuation of the Qatar Peninsula into Iran. It is an N-S-trending fault crossing the Zagros trend with bending, dragging and offsetting the fold axes in a right-lateral sense (Figure 2.6). Cumulative right-lateral displacement of 140 and 150 km of the Zagros Mountain Front (MFF) and the Zagros Foredeep faults (ZFF) can be measured, respectively, along the Kazerun-Borazjan active strike-slip fault. If slip began after deposition of the Lower Miocene Gachsaran Formation (around 10 Ma), it yields an average slip rate of 14.5 mm/yr. The fault consists of two right-stepping segments of the Kazerun (to the north) and Borazjan (to the south) faults with a gap in between [37]. Apparently, the Kazerun- Borazjan active fault forms the effective western limit of the Hormoz Salt-intruded Zagros and is associated with two Hormoz Salt plugs. This may indicate that the main Hormoz Salt basin was located east of the Kazerun-Borazjan active fault in the Fars arc of the Simple Fold Belt. The fault is clearly visible on the aeromagnetic map of the region as a sharp magnetic lineament [41].

The Kazerun segment is situated 15 km west of Kazerun, with a surface length of about 125 km. The 1986.07.12 earthquake (mb 5.7, Ms 5.5 and Io=VII) with a right lateral CMT solution (HRVD) took place along the Kazerun active fault. Historical earthquakes of 1824.06.02 of Io = VIII and 1891.12.14 of Io = VIII [10] took place near the Kazerun active fault. The macroseismal regions of the latter shock with that of 1986.7.12 (Ms 5.5) lie on the Kazerun fault and have N-S orientation in line with the fault. It is important to note that the 1824.6.2 (Io= VIII) earthquake took place south of a sharp bend along the Kazerun fault, while the 1986.7.12 event took place north of this bend. This may indicate that the 1824 and the 1986 ruptures presumably initiated from this fault bend and propagated southward (1824 earthquake) and northward (1986 earthquake) along the Kazerun active fault. Similar cases of changes of fault strike and rupture initiation/termination have been documented elsewhere [42].

The Borazjan segment, with a length of about 180 km, is located south of the Kazerun segment with a right-stepping gap. Due to right-lateral motion along the Borazjan segment, the NW-SE-striking anticlinal axes of Khormuj and Gisakan in the west are dragged and folded to a N-S trend and the Qaleh Dokhtar anticline between them have N-S-striking axes. The basement NW-SE-trending reverse faults are also dragged; the CMT solution of the 1990.12.16 earthquake (HRVD) in the Kalameh area (near the Siah anticline) yielded NNW-SSE oriented nodal planes indicating rotation of the basement (blind) active thrust due to the dragging effect of the Borazjan right-lateral fault. The Borazjan fault scarp is clearly visible from the area north of Borazjan to Ahram and Khormuj. Several thermal and sulphur springs are aligned at the foot of the fault scarp [43]. Fig.2.8 Shows Central segment of the Kazerun fault zone and Kazerun fault segment with slickenside on the fault plane

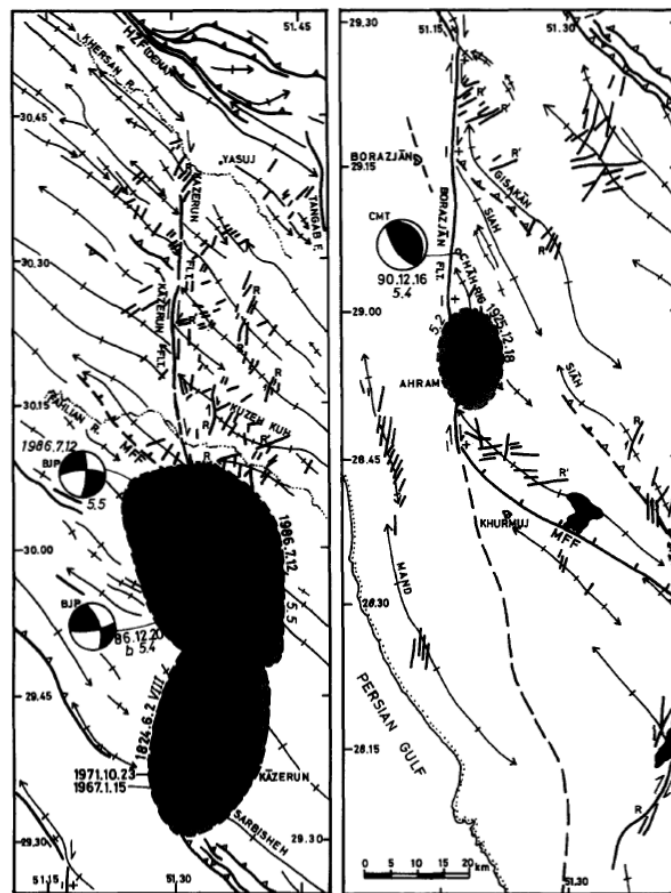


Fig. 2.6: Regional neotectonic features of the Kazerun Borazjan fault system [43]

Kazerun (left)-Borazjan (right) transverse right-lateral active fault in western Fars of the Zagros Mountains. The map on the right is the southern continuation of the one on the left. Black patches are outcrops of the Lower Cambrian Hormoz Salt complex. R and R', on the minor faults in the Kazerun-Borazjan fault zone, denote right-lateral Riedel shear (R) and left-lateral conjugate Riedel shear (R'), possibly associated with the Kazerun-Borazjan active fault motion.

All along Kazerun fault's length, individual fault planes are either vertical or steeply dip to the west. Further to the south, recent activities of the fault and its dextral kinematics are more evident. Numerous right lateral offsets have been found at the foot of the mountainous west flank of the Rud-e Sefid River valley, west and southwest of the ruins of the Sassanian capital of Bishapur (nowadays the Shahpur village). Here, near the village of Ouladmizan, the anticline cored by the Miocene complexes is offset dextrally about 750_800 m and vertically about 150 m, with the west side up. This yields a long-term ratio between two components amounting to 5. In places, strike-slip movements along the fault caused capturing of one of the neighboring watercourses by the other. Further south, down to the village of Teng-e Tarkan, the fault provides many good examples of displaced elements of drainage network. Characteristic amplitudes of right lateral offsets measured there cluster around 3_5, 12_14, and 25_30 m. The faulted drainage within the downthrown east fault side entrenches a terrace-like surface. With the age of the surface remaining uncertain, we tentatively estimate the lateral displacements as Late Quaternary. Vertical offsets are rarely observed, only in places amounting to 1–2 m.

The area is known for several recent earthquakes of magnitudes $M_s > 6$ [44], and the ruins of Bishapur still bear signs of previous seismic impacts of about the same magnitude, judging by historical records [43].

Kazerun fault has been trenched where it crosses, in a form of a low scarp, a small triangle-shaped inlet of the depression surface. The Rud-e Sefid River valley drains into the mountainous west fault side. The trench walls expose about the upper 3 m of mostly slope wash deposits accumulated at the depression margin (Figure 2.7). These are loam, loamy sand, and sand, partially calcareous, and intercalating with lenses and layers rich in debris of various grain sizes. Near the trench bottom, either bedrock or large boulders of Miocene gypsum outcropping west of the scarp may represent the base of slope wash material. Basing on the content of coarser and finer materials, as well as on bedding pattern and partially absolute ages obtained, all five sedimentary units are identified all five sedimentary units [45].

Unit 1, which is hard brownish loam nearly free of debris, was recognized only within the western sector of the trench. This unit is of Late Pleistocene, as the thermo-luminescence (TL) age of $36,600 \pm 6000$ years of a sample collected in the upper part suggests. Well-layered unit 2 is represented by the same hard loamy sand and sand with extensive debris-containing

lenses and layers. It is characterized by four TL ages, which are 8600 ± 970 , $12,500 \pm 420$, 8750 ± 1080 , and $11,350 \pm 1200$ years. Unit 3 is of the same material but is looser, and with lenses of debris that are thinner and rarer. The upper part of the unit has the TL age of 9080 ± 870 years. Unit 4 was first identified to the east of the scarp as that of loose fine sediments with only the lens of debris and the TL age of its middle horizon being 7700 ± 700 years. West of the scarp, recognition of the same unit 4 is based on similar lithological composition and TL determination of 5200 ± 680 years. Finally, unit 5 is the soil profile annually subjected to plowing [45].

There is no clearly defined fault plane found except maybe for one or two fine steep fractures not extending above the top of unit 1. As the bearing of unit 2 evidences, deformation of the strata proceeded, first, through flexuring. Since no fault plane extends up the ground surface, it could be concluded that the surface scarp has also undergone mostly flexuring, and that this flexuring is a specific manifestation of the fault movement in the upper relatively loose clastic sediments, close to the Earth's surface. Most likely, the fault plane projects upward to the foot of the flexure forelimb [45].

Paleoseismologically, interpretation of the deformations in the trench may be summarized as follows. Trench exhibits signs of at least two paleo-earthquakes that occurred on the fault during last about 9,000 years. During each of the earthquakes, vertical fault motion was around 1.5 m and caused the flexuring of the superficial strata. Based on the long-term ratio between right lateral and vertical components, net slip during each seismogenetic fault movements can be estimated to have been about 7.5 m [45].

The above interpretation cannot be considered as definite in terms of recurrence intervals and amplitudes of individual fault displacements because, firstly, one more intermediate seismic event could have occurred, for example, during the accumulation of unit 2, although the observed portion of the unit strongly affected by seismic and postseismic movements does not give much keys for distinguishing it. Secondly, the foot of the monotonous slope where the fault runs has always been the area of unsteady and inconstant accumulation of clastic materials coming mostly through slope wash, and the units observed are most likely of local occurrence, both in space and in time. The southern segment of the Kazerun zone demonstrates evidences of oblique (combined right lateral and vertical) Quaternary motion,

but some manifestations of the Late Quaternary activity were found only near the village of Kamaraj [45].

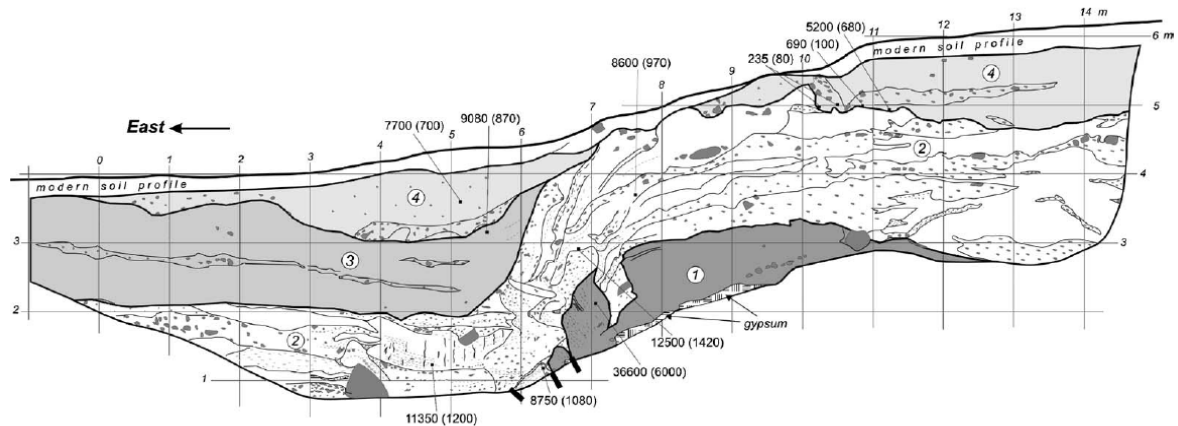


Fig. 2.7: South wall of the trench crossing the Kazerun fault [45]

Figures are the absolute ages (BP) obtained with the thermo-luminescence method, except the youngest two values, which are the radiocarbon ages (standard deviations in brackets). Encircled numerals are the horizons unidentified.



Fig. 2.8: Shows Central segment of the Kazerun fault zone and Kazerun fault segment with slickenside on the fault plane

Sabzpushan Fault

A transverse deformation zone of local NNW-SSE-trending right-lateral strike-slip (minor) faulting exists east of the Kareh Bas and west of the Sarvestan faults, extending from Shiraz to east of Ghir [49]. Right-lateral flexural distortion and drag of NW-SE-striking fold axes along the Sabz Pushan fault zone can be readily observed. For example, east of Ghir, the Chaghal, Alhar and Bandobast anticlinal axes have been dragged right-laterally by the Sabz Pushan zone. The course of the Mand River (Qara Aghaj), which is a large transverse stream that separates the Ghir from the Tang-e-Ruin Valleys, seems to be partly controlled by the Sabz Pushan fault zone. The zone also locally marks the limit between the Eocene Asmari Formation fades (to the west) and the Asmari-Jahrom Formation facies (to the east).

No seismic activity associated with the Sabz Pushan fault has yet been documented, although, the meizoseismal region of the northwestern Shiraz earthquake of 1824.06.25 ($M_s = 6.4$, Ia - VIII) (Ambraseys and Melville, 1982) is elongated parallel to the northwestern extension of the Sabz Pushan transverse fault).

Andalibi and Oveysi [50] suggested the Sabpushan fault as a shear zone defined by two major members: Sabzpushan Fault (I) and (II).

The 90Km length Sabzpushan (I) fault passes through west of Shiraz land with 160° - 180° azimuth extension. It has right lateral slip-strike mechanism. Therefore in general slide view, it is a diagonal slip fault which on the major surface of the fault, vertical throw is less than horizontal separation. Sabzpushan (I) fault is attached to Bazin fault at north and is connected to Mishvan fault at southern terminal portion of the fault. Kavar dam position, in south of Shiraz, is located at terminal portion of the fault.

The absolute movement of the fault is considered as under thrust. Sabzpushan fault is an active fault which displacement traces can be observed not only in late Quaternary but also in recent times. The following earthquakes may occur because of Sabzpushan (I) fault:

- 09 May 1964, - 29 Dec 1971, $M_s 4.9$, - 19 Oct 1972, $m_b 4.3$, $I=V-IV$, - 17 Sep 1979, $M_s 4.4$
- 28 Mar 1987, $m_b 4.2$, $I=IV-V$, - 06 Jul 1988, $m_b 4.6$, - 18 Apr 1991 in Darangun land (South west-west of Shiraz expanse), $m_b = 4.1$, $I=V$, - 10 Apr 1992, $M_s 3.9$, $m_b 4.6$, $I=V$

The Sabzpushan Fault (II) with 155° - 180° azimuth excitation is a part of Sabzpushan(I) fault. Both of them create tension stress field between two faults. The mechanism of the fault is

slip-strike with right lateral major component and therefore can be assumed to be diagonal slip fault like Sabzpushan (I) fault. The following earthquakes are relevant to Sabzpushan (II) fault excitation:

- 09 May 1964, Depth=17Km, - 17 Sep 1979, mb4.4, - 18 Apr 1991, mb4.1, I=IV.

Firouz Abad Fault

The Firouz Abad reverse fault runs sub-parallel to the Qasr-e-Ghan fault. The fault has a convex trace towards north on the geological maps and towards west it terminates against Qasr-e-Ghand fault. The fault lengths is about 116 Km.

Gavbandi Fault

Gavbandi fault is one of the fault segments of Zagros Mountain Front fault (MFF) with about 85Km. length. The trend of the fault is approximately north west-south east to west-east. It has thrust mechanism. The fault is extended parallel to the Persian Gulf.

Kareh Bas Fault Zone

Field observation were carried out in the northern part of the Kareh Bas fault zone ([70] in Figure 2.4), between the villages of Kareh Bas and Maserem, and in its segment to the south-west of Furizabad.

Where examined in the field a straight line of the fault strikes NS, but south of the Chenarpariab village its about 4 km stretch NE 20-25°. The western side of this NE-striking segment is occupied with a Late Pleistocene terrace, the surface of which bears a narrow depression. An outcrop exposing that side of the depression which is closer to the fault shows two normal fault planes along which alluvial pebbles and gypsum-bearing clays of the Gachsaran (Razak) formation underlying them are offset 1.4 and 2.2 m. Narrow NW-oriented grabens feather NS-striking Kareh Bas fault just north of the village of Kareh Bas. Further south (between Kareh Bas and Jemadu) the fault is heading SSW, and in this part vertical component appears again. Correlation of extension features with the fault segments and its splays of SW-NE orientation suggests that the north-trending and NNW-trending fault segments without noticeable normal motions are mostly right-lateral.

The fault zone gains farther south step-like in plan view geometry - NS-striking segments cut through folds, whereas its elements of SE-orientation parallel fold axes and go regularly along their south-western steep limbs.

The N-S fault segment displays 4 km right-laterally a large anticline west and south-west of Firuzabad. It cuts also clear across a salt dome. The fault can be trace in the surface of the dome but vaguely. Clear young displacements were found south of the dome where the fault separates sandy-calcareous complex with gypsum (east side) from Quaternary (probably of Late Pliocene age in lowermost horizon) alluvial complex (west side). The latter is mainly conglomerate with lens-like interlayers of sand.

The fault south of the salt dome strikes nearly N-S ($0-10^{\circ}$ NNW), dipping steeply to the east (Figure 2.9A). Conglomerate of the west side dips away from the fault, and close to the fault display $70-90^{\circ}$ -dip (at one place overturned). Angles of dip decrease with distance from the fault. Five km south of the salt dome, alluvium does not show larger than 25° angles of dip. Three km south of the dome the northern segment is extended with a right-step by another segment (Figure 2.9B). At the site of stepping the contact of conglomerate and older sandstone outlines a drag fold, tens of meters in size, with steep hinge line, created by dextral fault movements. The same sense of motion is seen in striation on the fault plane ($15-20^{\circ}$, inclined to the north).

The fault displays right-laterally watercourse and other young land forms. Amplitudes of strike-slip offsets range from 2,5-3 m (2 km south of the salt dome) to 10-20 and 45 m. Three larger valleys are displayed laterally 90-100 m.

Thus, the segment of the Kareh Bas fault studied is a right-lateral strike-slip fault with minor reverse component of motion, east side up. Offset values pointed out are results of fault motions during different periods of time. The 2.5-3 m-offset can be a consequence of one-act seismogenic motion.

The fault zones south of the area studied turns to the south-east and gains the appearance of flexure-fault zone with elements of thrusting. It makes there the western boundary of High Zagros. Figure 2.10 shows isoseismal map of Kreh Bas earthquake.



Fig. 2.9A: The Kareh Bas fault south of the salt dome strikes nearly N-S (0-10° NNW), dipping steeply to the east

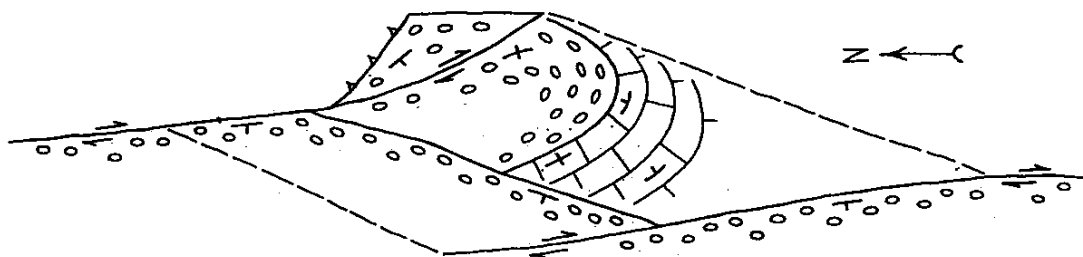


Fig. 2.9B: Kareh Bas fault south-east of Firuizabad: drag fold in Quaternary conglomerate at echelon junction of two minor faulty segments

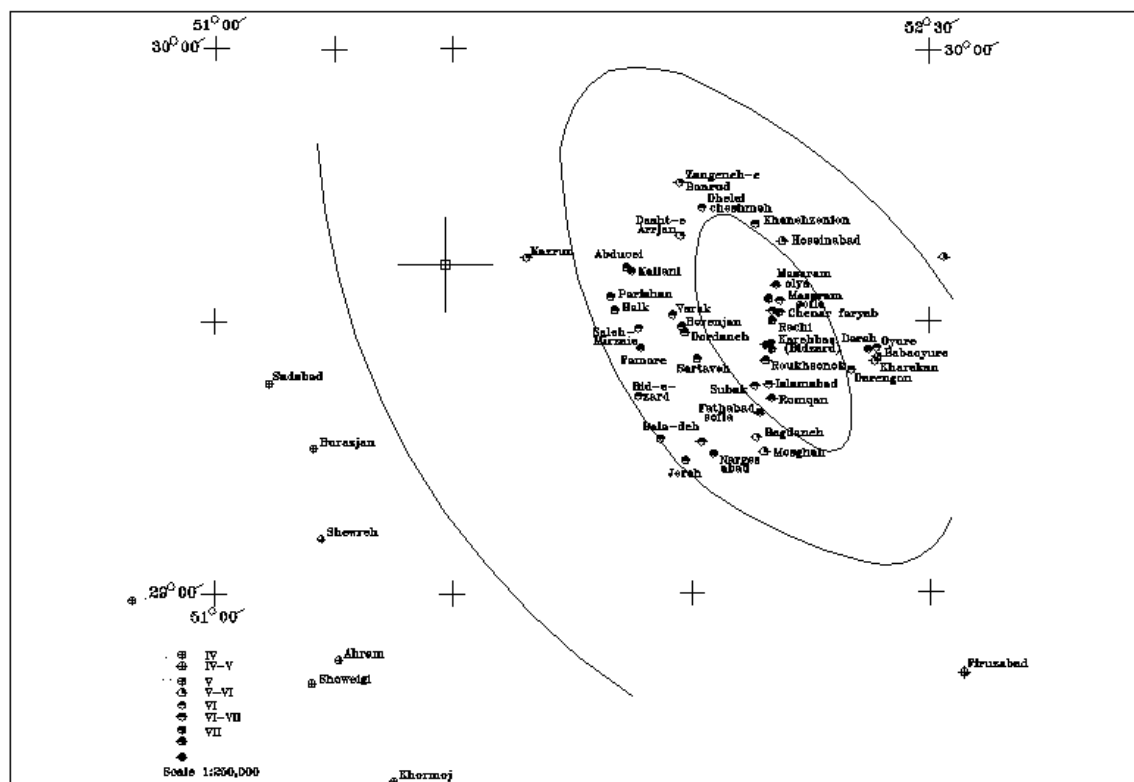


Fig. 2.10: shows isoseismal map of Kreh Bas earthquake

Nezam Abad, Bastak and Bostaneh

East of the Kazerun fault, the Bastak, Nezamabad and Bostaneh faults are all left-lateral strike-slip faults with NE-SW trends (Fig.2.11 & Fig.2.4); all have been attributed by previous workers to the reactivation of basement faults. Based on the regional isopach maps, Bahroudi and Talbot [75] suggested that the Bostaneh Fault can be regarded as a basement features whereas Bastak and Nezam Abad fault formed in the sedimentary cover.

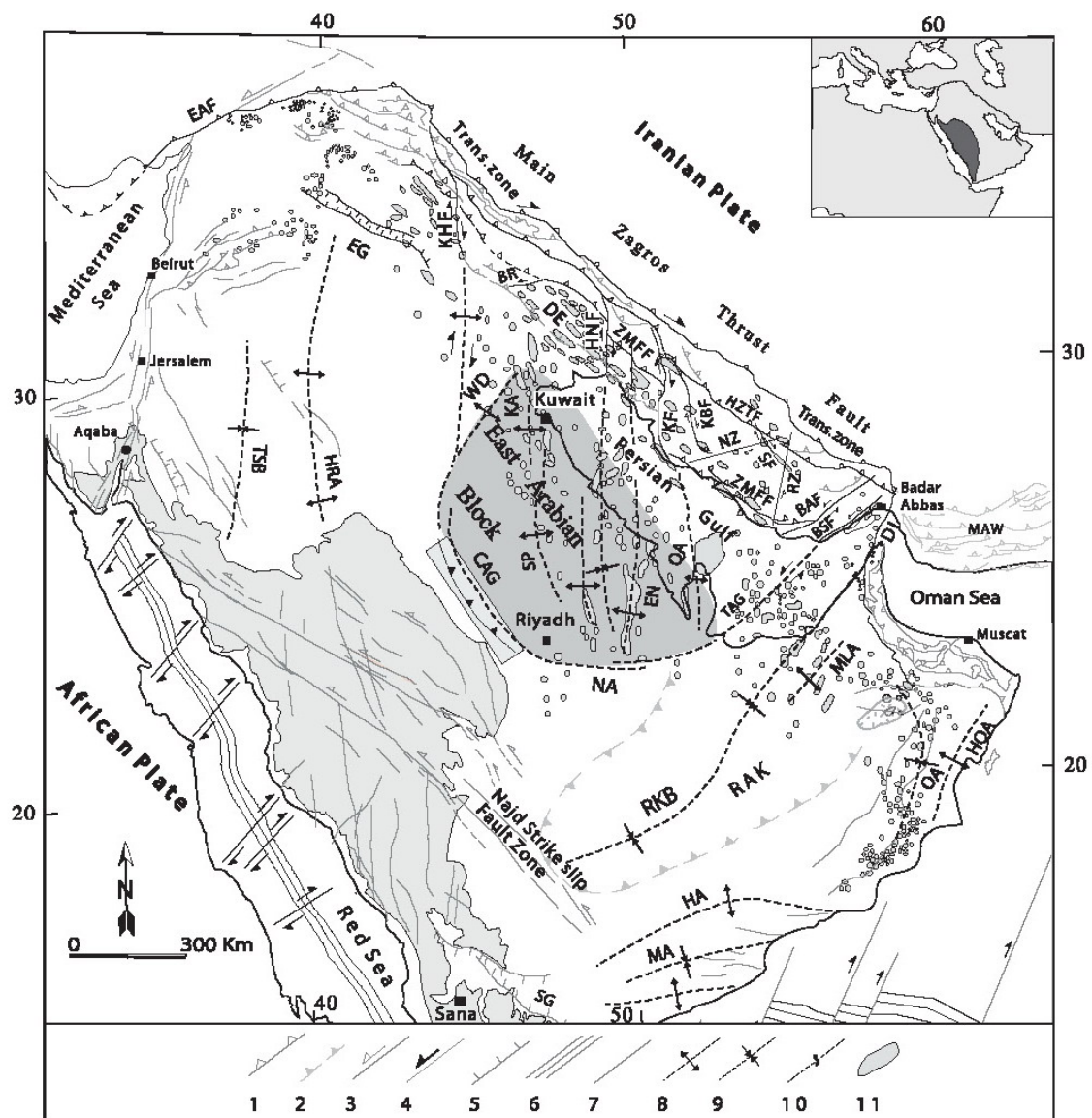


Fig. 11: Main structures in the Arabian plate: (1) Contractional Fault, (2) Intercontinental basin, (3) Strike-slip Faults: DI, Dibba fault; BSF, Bostaneh fault; BAF, Bastak fault; RZ, Razak fault; NZ, Nezamabad fault; SF, Savastan Fault Zone; KBF, Kar Bas Fault Zone; KF, Kazeran Fault Zone; HNF, Hendijan fault; BR, Bala Rud fault; and KHF, Khanqin fault; EAF, East Anatolian Fault; (4) Transform Fault, (5) Normal Fault, (6) Spreading Axis, (7) Master Fracture, (8-10) Basement lineaments in Arabia (Anticline/Arch, Syncline/Basin, and Flexure) including TSB, Tabuk Basin; MH, Mardin High; EG, Euphrates Anah Graben; HRA, Hail Ga'ara Rutbah Arch; WSB, Widyah Basin; TAG, Trans Arabian lineament; CAG, Central Arabian Graben; KA, Kuwait Arch; SP, Summan Platform; EN, En Nala Safaniya Trend; QA, Qatar Arch; RKB, Rub Al Khali Basin; MLA, Mender Lekhwair High; OA, Oman basin lineament; HQA, Huqf Arch; WD, Wadi Al-Batin lineament; HA, Hadhramout Arch; MA, Mukalla Arch; NA, Nisahasahba lineament; SG, Sadah Graben, (11) Oil and gas fields [75].

2.2.1.3. Pre-Quaternary Faults

A Pre-Quaternary fault is a fault which is not proved to offset Quaternary deposits. According to Berberian (1994) most faults which are defined as minor faults in Tectonic map of Iran [46], are Pre-Quaternary faults. These faults which are rarely named in tectonic maps could be mostly considered as derivations from major faults. They are of limited length and low (or no) seismicity.

2.2.2. Seismology

2.2.2.1. Regional seismicity

Iranian Plateau is a structurally complex and inhomogeneous collision regions, in which seismicity is not the result of the activity of a few faults but is due to fault activity in zones sometimes nearly one hundred kilometers wide [37][51]. Obviously even the assumption of highly accurate seismic data will not solely suffice to locate all existing active faults. This is mainly due to these reasons [52]:

- 1) Many earthquakes are caused by blind faults (mainly earthquakes occurring in the Zagros region [43][53],
- 2) Some damaging earthquakes with magnitude less than 6.5 may not leave ruptures on the ground surface
- 3) The gradual movement along many active faults over a long period of time is the result of a creep regime which does not result in a large earthquake [56].

As mentioned before, the region under study falls under structural zone of Zagros. The Zagros Mountains form a linear intercontinental fold and fault belt trending NW-SE between the Arabian shield and central Iran. The belt is seismically very active, with frequent reverse and strike-slip faulting earthquakes of up to M_s 7.0 [55], however, large earthquakes are not very frequent. Early studies used the presence of earthquakes deeper than 50 km in several catalogues to postulate subduction of the continental Arabian shield beneath Iran in Zagros [57]. However neither local seismograph networks nor the modeling of teleseismic body waves from the large earthquakes have found any focal depths deeper than 15-20 km [58]. Figure 2.12 shows Histograms of focal depth distributions of earthquakes and Moho depths of several zones [55].

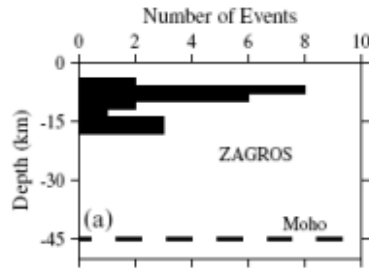


Fig. 2.12: Histograms of focal depth distributions of earthquakes and Moho depths [55]

In the Zagros, approximate Moho depths are shown in all figures, based on receiver function studies.

2.2.2.2.Surface faulting and earthquakes

The very high twentieth century seismicity of the Zagros Active Folded Belt is characterized by a large number of shocks in the magnitude 5 or 6 range, and a very small number with magnitude equal to or greater than 7. The precision of depth calculation of the Zagros is very poor, and without special studies little can be said on the subject. The total thickness of the sediments above the metamorphosed Precambrian basement cannot be more than 10 to 15 (or a possible maximum of 18) kilometers. It appears that most of the earthquakes are sub sedimentary and probably related to the basement or upper mantle [59] and that reactivation of some basement faults during readjustment of the basement causes sub sedimentary earthquakes within the Zagros Active Folded Belt [60].

Fault plane solution of earthquakes in the Zagros [61][62][57] show thrusting with high-angle planes at depth (dipping NE or SW) with a NW-SE strike roughly parallel to the fold axes of the sedimentary cover. Intense seismicity spread over the entire belt indicates that a large number of reverse basement faults are being reactivated in the Zagros, and that the basement in the folded part of the belt is intensely thrustured [63].

In the Zagros the earthquakes cannot generally be correlated with the known surface faults, because of the special salt-tectonics character of the region [30]. Movements along basement faults can cause earthquakes in the Zagros active fold-thrust belt without producing surface faulting in the overlying sedimentary cover, presumably due to the presence of the plastic Hormoz deposits [64]. Due to aforementioned phenomenon, surface faults change from high-angle reverse (in depth) to near horizontal thrust (listric), or die out altogether, and usually no earthquake rupture is observed at the surface [37].

2.2.2.3. Seismicity of project region

Project region is considered as part of Zagros Mountains from geological point of view, and the Zagros is regarded as a highly seismic region in Iran Fig. 2.13. In the near and far past times destructive earthquakes have occurred in the Southern Zagros, causing heavy destructions and casualties; the cities of Bushehr, Kazerun, Shiraz, Siraf and Ghir have been completely devastated several times.

The seismicity of a region is investigated in two steps; historical earthquakes pre-20th century and killing many people in the first step, and instrumental earthquakes (from the beginning of the 20th century to the present time) in the second step.

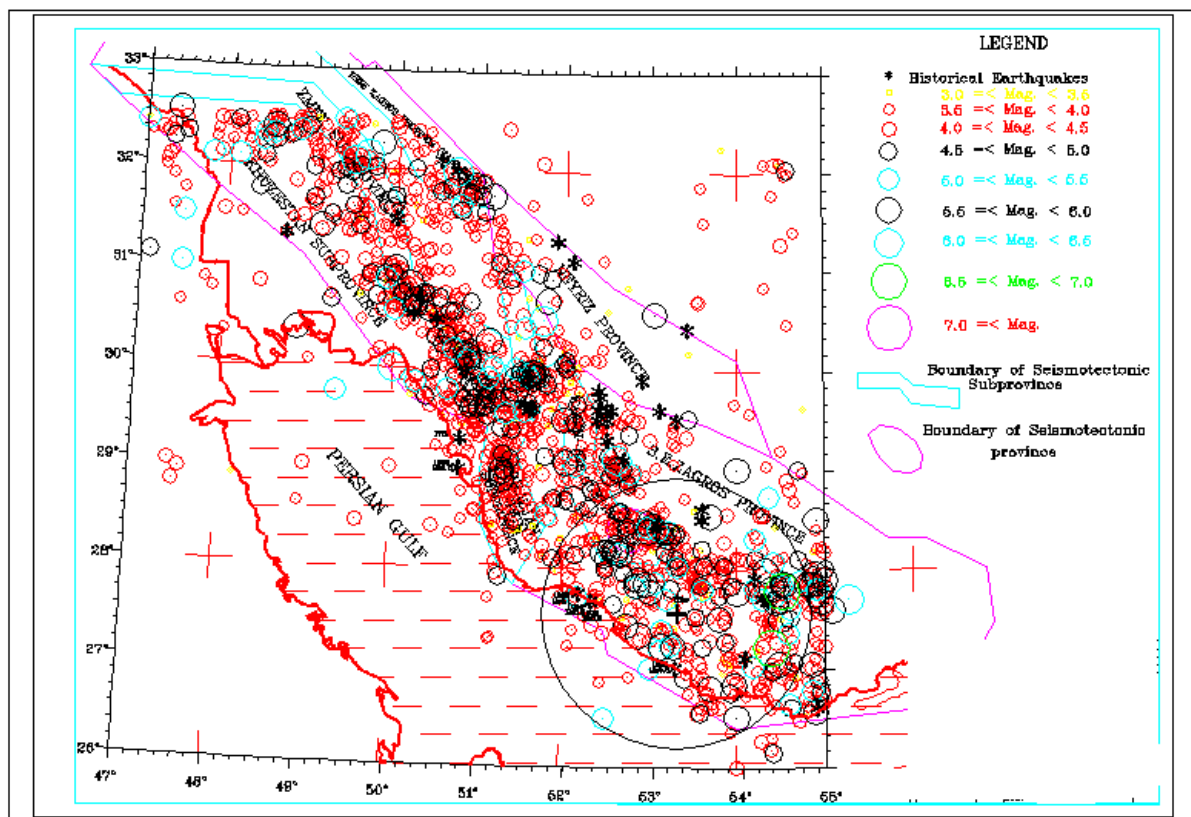


Fig. 2.13: Seismicity map of Zagros regarded as a highly seismic region in Iran. Lamerd Factory site area (R=150km) located in the south-east of Zagros.

In the present study as well, historical and instrumental earthquakes are dealt with first. It should be mentioned that strong earthquake data related to both historical and instrumental earthquakes are presented in the table 2.1. These data include the date and time of occurrence, coordinates of epicenter, focal depth, magnitude and intensity, source of data, meizoseismal region and the quality of some earthquakes.

To have a better understanding of the seismicity of the area, the most important earthquakes in both historical and instrumental period are briefly introduced in the following sections. A comprehensive earthquake catalog of the area with a radius $R=150$ km from the site is presented in appendix I as well.

Luckily, the area of our interest is covered with several publications belonging to the class, which we are looking for: compilations containing descriptions of macroseismic events linked with initial sources and critical analysis of general context. The most comprehensive publication concerning the historical seismicity is Ambraseys N., Mellville [47], Moinfar A., Mahdavian A. [67] and Berberian, M. [68] and we present here the analysis of these sources.

The most remarkable feature of this catalog is that it presents not only textual descriptions of macroseismic effects for the considerable part of the catalog entries but also critical analysis of the reliability of sources. Besides, in its Introduction, it presents historical review, which helps to understand the general context of the situation, completeness of data, and possible accuracy of final conclusions. At the same time, parametric entries from this catalog could not be used directly, as the intensities of earthquakes are scaled according to the original scale elaborated in Ambraseys N., Mellville, [47].

2.2.2.3.1. Historical earthquakes

Siraf earthquake 17 June 978 [65]

On 17 June 978, an earthquake shocked the port town of Siraf, the present port of Taheri in Bushehr province (Fig.2.14). The earthquake had an estimated magnitude of 5.3 [47] and its hypocenter is assumed to be at $52^{\circ} 18' E$ $27^{\circ} 42' N$. 100 were Killed and land shook for seven days. Epicenter distance to site was 100 km. This earthquake is assumed to have an estimated magnitude of 5.3 by Ambraseys N., Mellville [47].

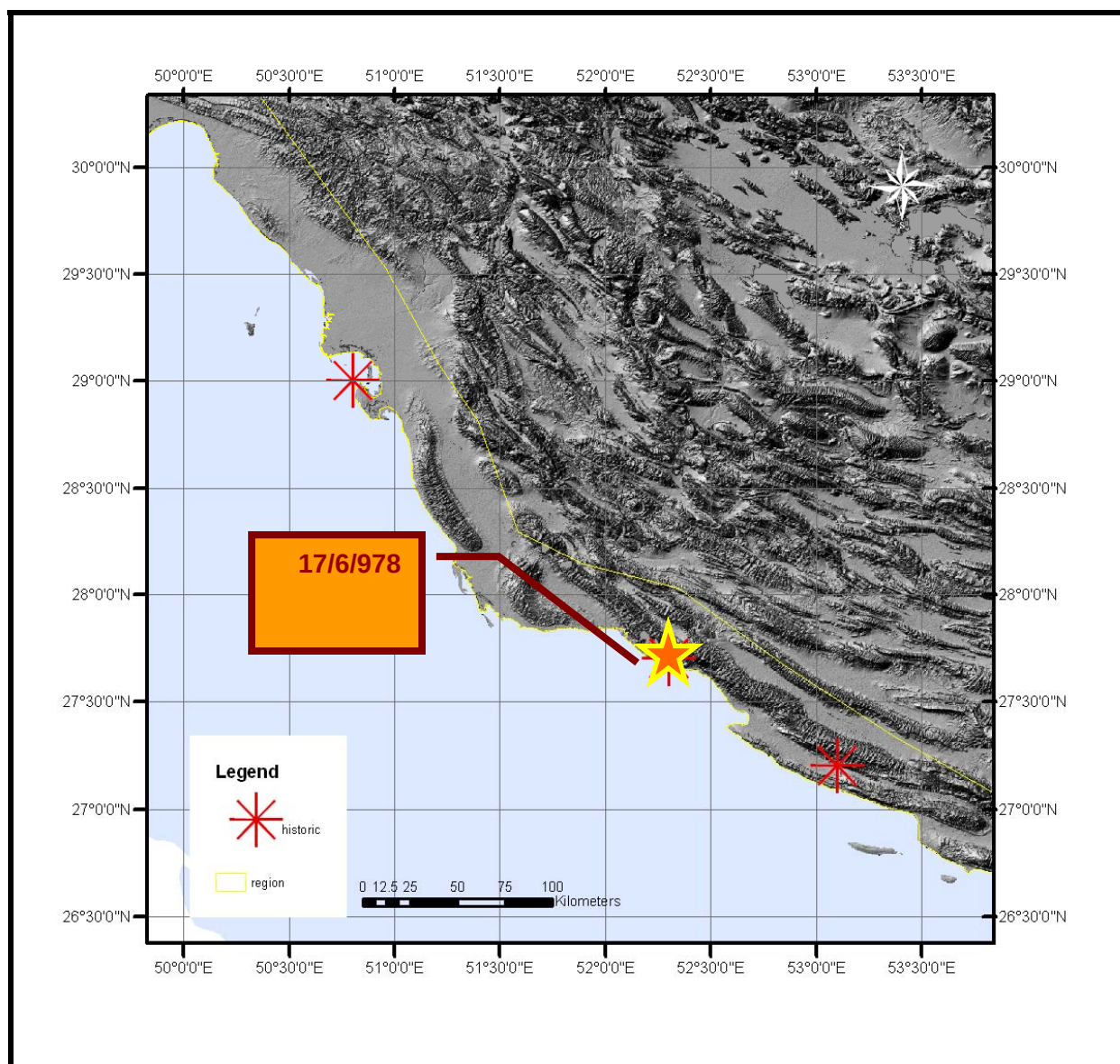


Fig. 2.14: Location of Siraf earthquake 17 June 978 [47]

Siraf earthquake spring 1008 [40]

This earthquake happened in the port town of Siraf, (the present port of Taheri in Bushehr province (Fig.2.15) with distance to 100 km to the Lamerd factory site. it is indicated by some authors that many people were killed when “the sea inundated the land” [66]. This earthquake is assumed to have an estimated magnitude of 6.5 3 by Ambraseys, N. N., Mellville [47],and epicenter of 52° 18′ E 27° 42′ N.

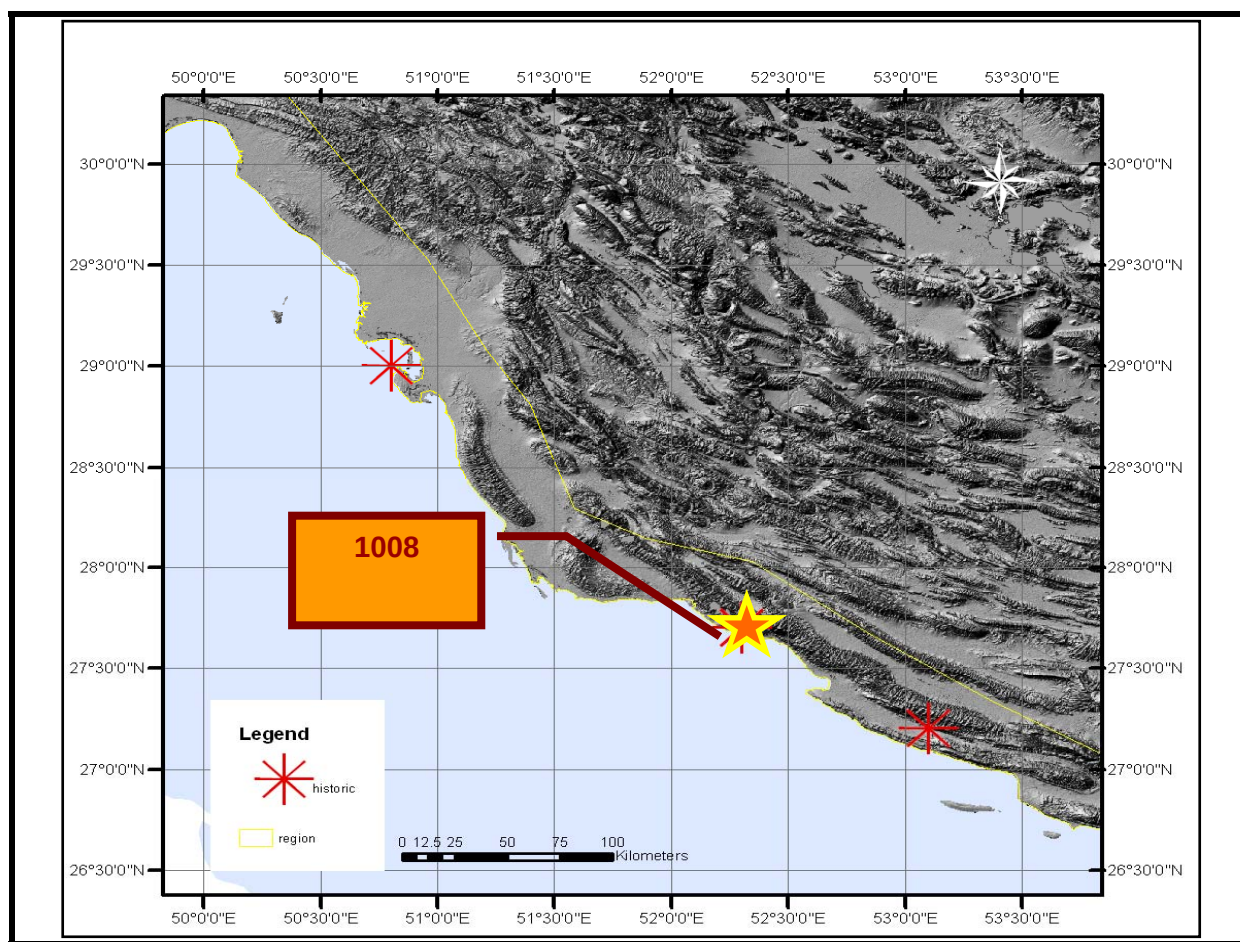


Fig. 2.15: Location of Siraf earthquake spring 1008 [47]

Lar Earthquake 1400 [47]

The information on this earthquake is very scarce: «An earthquake in Lar destroyed 500 houses» [47], Ambrayes adds «large number of people» were killed. In comments, AM82 draw attention to the fact that confirmation on this earthquake has not yet been found in the Muslim sources. Note, that $H = 18$ km derived from $I_o = 6-7$ and $M = 5.3$, remarkably well coincides with our fixed depth (20 km). From this we derived magnitude limits of 5.2 – 5.5. The epicenter was 27.7N, 54.3E [47]

Karzin Earthquake 1440 [47]

The only description available to us is in [47] : «A destructive earthquake in southern Fars in 844 AH caused considerable damage and loss of life at Karzin, and also in other parts of the district of Shiraz, killing nearly 10000 people». The number of victims is the only information for intensity assessment (8-9); of course, this is very rough

estimation. As the text does not mention any other localities we assumed coordinates of Karzin as the epicenter position. From magnitude reported in AM82 (7.1) and assessed intensity (8-9), we found $H = 28$ km, and epicenter coordinate was 28.4°N , 53.1°E .

Lar Earthquake 1593 [47]

The textual description derived from [47]: "A destructive earthquake affected Lar in the late summer of 1001 H. Three shocks occurred in forty-eight hours. The second of these, in the early evening, destroyed all the large houses and major buildings. The ground opened up, in some places by as much, as two to three meters, causing the collapse of many houses and the destruction of the cisterns for rain water. The third shock dislodged great boulders from the mountains at the foot of which Lar is situated, and landslides overwhelmed the rest of the town. The earthquake destroyed more than 1200 houses and caused the death of 3000 people. The greater part of the walls was destroyed and the castle on the east side of the town collapsed. Although solidly built on the rock. The earthquake, which was preceded by foreshocks, does not seem to have affected a large area." In principle, estimation of intensity of several successive shocks could not be done accurately, even in the case of detailed description of effects. So, our estimation of intensity (8-9) is rather related to the cumulative effects of earthquakes. This uncertainty is reflected in the relatively large error limits (± 1). At the same time, the local character of the event enables rather reliable determination of coordinates ($\pm 0.5^{\circ}$). The depth of 15 km is obtained from magnitude reported in [47]. The fixed depth (20 km) and its possible limit 15-30 km, and epicenter coordinate were 27.7°N 54.3°E .

Lar Earthquake 1677 [47]

Description from [47] tells: «Several settlements and caravanserais on the road north from Lar to Bunaru (in Ambraseys – Bonarud, on map – Banarud), particularly at Pa-yi Kutal, were destroyed by two earthquakes which also affected Biriz and Lar itself.» The location of epicentral area seems to be determined enough accurately, but the intensity evaluation is rather uncertain (because of possible cumulative effect of 2 earthquakes and the absence of detailed description). Magnitude (6.4) reported in Ambraseys [47] is derived from the felt area with the corresponding depth of 25 km, and epicenter coordinate was 27.9°N 54.2°E .

Jahrom Earthquake 1808 [47]

These original sources were not available to us, AM82 did not give the description of the event. We evaluated intensity based on the correlation between [47] intensity classes and modern macroseismic scale. Magnitude, determined from the felt area is 5.4?, from fixed depth and intensity, 5-6. The good agreement between both values allows us to give relatively small error limits for the depth, and epicenter coordinate was 28.5°N and 53.6°E.

Bastak Earthquake 1880 [47]

Description is found in Razani [69] reported during this quake One hundred twenty deaths. A strong earthquake occurred in Bastak and villages of Faramarzan. In the village of Jonah about 35 km SW Bastak, there was extensive loss of life and property where many buildings and mosques were destroyed. This earthquake occurred during Friday noon prayer. In Jonah alone it killed about 80 people while some were praying. The magnitude is calculated for the fixed depth of 20 km; magnitude range is 5.8 and epicenter coordinate was 27.1°N and 54.1°E.

Kangan Earthquake 1883 [47]

Description is given NAB78, BT76 (with reference to Wilson, 1930; Persian Gazetteer): «A severe earthquake shock was experienced at Kangan, 'Assalu and Taheri and in their neighbourhoods, where much damage was done. Tremors continued until the 24th October. The main shock was also felt at Bushire.» Berberian [68] also mentioned an aftershock that we could not identify anywhere else. The depth and magnitude are determined from the isoseismal map (Fig. 2.16). The epicentral intensity estimated is 7. The magnitude was 5.8, and epicenter coordinate was 27.7°N and 52.3°E.

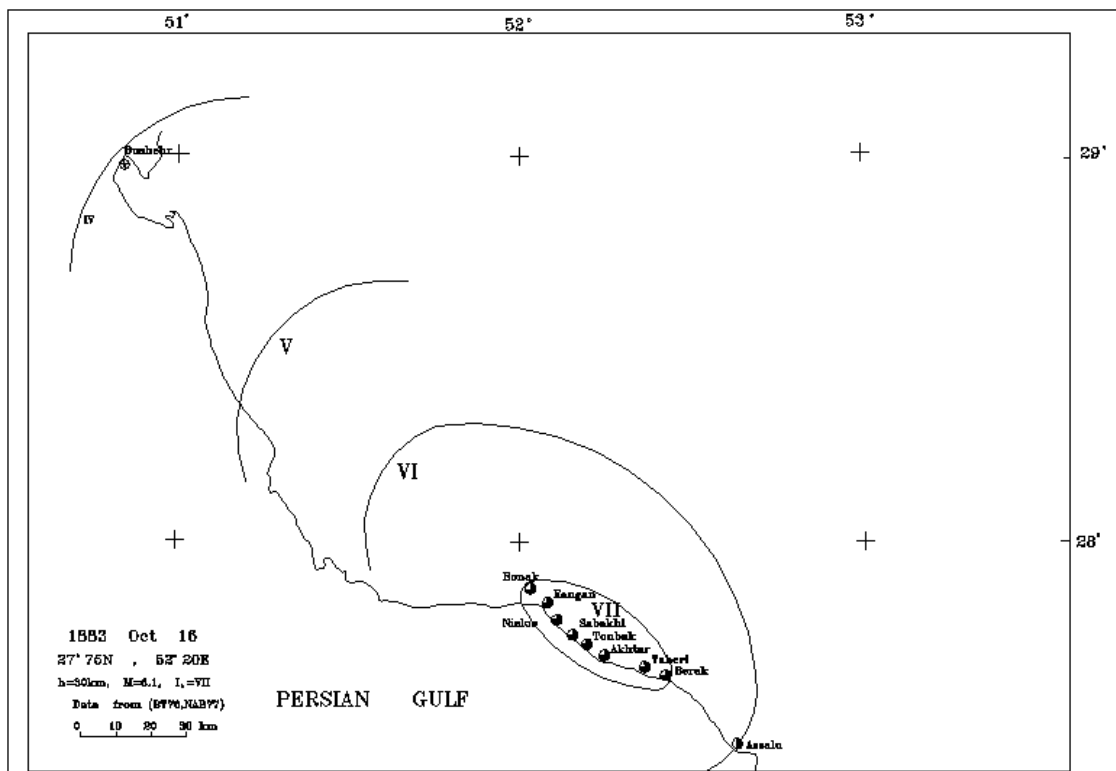


Fig. 2.16: Intensity distribution of 1883 Kangan Earthquake

2.2.2.3.2. Instrumental earthquakes

Dehno (Assaluyeh) earthquake, 22 January, 1950 [40]

The earthquake, centered in a small coastal valley southeast of Assaluyeh, damaged villages extending along about 50km between Assaluyeh and Gavbandi (Fig.2.17). Its magnitude was estimated 5.8. The villages of Dehno, Akhand, Askari, Khiaru, Bostanu, Einossadeh, and Berkeh Dogan were completely destroyed, and a total of about 30 people were killed. Assaluyeh, Daruk, Kolluz, Chah Mobarak, Maru, Dozdoneh, Nahir, Bandu, Amani, Gavbandi and Faryab were severely damaged. Many rockfalls occurred in the mountains bordering the valley in the northeast. Minor damage was reported from Taheri, and the shock was strongly felt in Kangan and Bushehr. Eleven aftershocks were felt in the epicentral region on the same day as the main shock. The strongest aftershock occurred on the 2nd of February at about 8 p.m. (Local time).

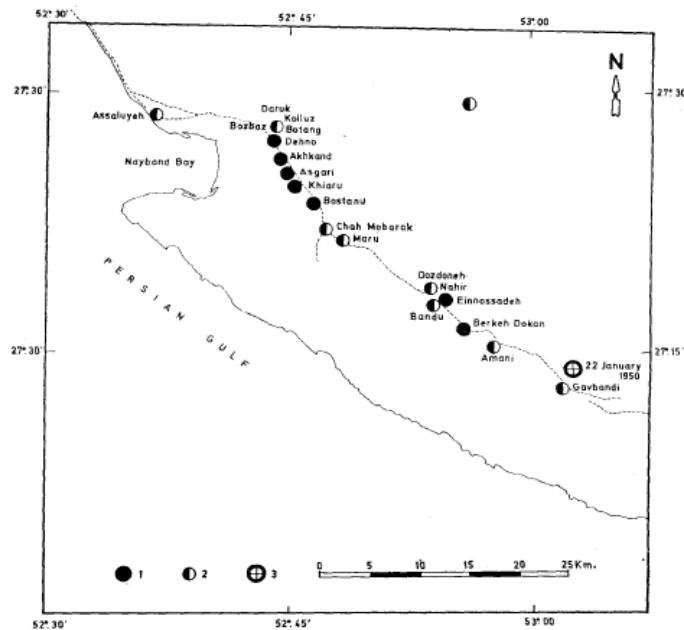


Fig. 2.17: Epicentral region of the Dehno (Assaluyeh) earthquake of 22 January 1950 [40].
1. Villages completely destroyed, 2. Villages severely damaged, 3. Instrumentally epicenter.

Tonbak earthquake, 20 August, 1954 [40]

The earthquake occurred at 15h 30m 15s GMT (B.C.I.S.) and was probably the magnitude of 4 to 5 range (Fig.2.18). It destroyed all the houses of Tonbak and Sabakhi, and about half of those of Akhtar. The mosque of Akhtar were badly fissured. In Kangan 5 or 6 houses collapsed and others were slightly damaged. As during the summer people live out of doors there were no casualties in the village, but one person was killed by a rockfall in the mountains north of Tonbak.

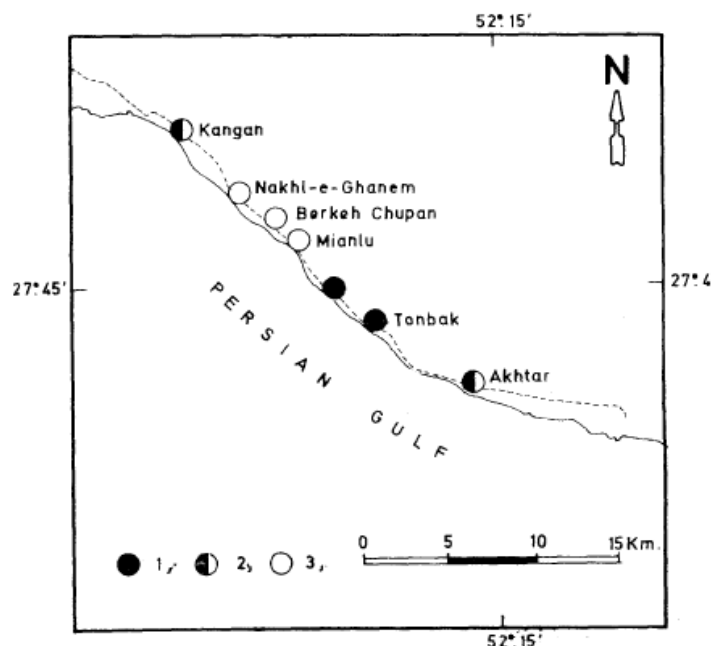


Fig. 2.18: Epicentral region of the Tonbak earthquake, 20 August 1954 [40].
1. Villages completely destroyed, 2. Villages severely damaged, 3. Instrumental epicenter.

Gowdeh (Bastak) Earthquake, 31 October, 1956 [68]

The Gowdeh destructive earthquake of magnitude 6 to 6.8 occurred at 14h 03m 43s GMT at $27^{\circ} 25' N$, $54^{\circ} 43' E$ (ISS) with a normal focal depth. During this earthquake nine villages in Gowdeh vally underwent severe damage and destruction, and many houses fissured in Bastak. The earthquake killed 270 people and injured 203.

Lar earthquake, 24 April, 1960 [68]

A destructive earthquake of magnitude 5.9 demolished the city of Lar and all the buildings were completely ruined. 400 dead, 600 injured and 5,000 became homeless (Fig.2.19).

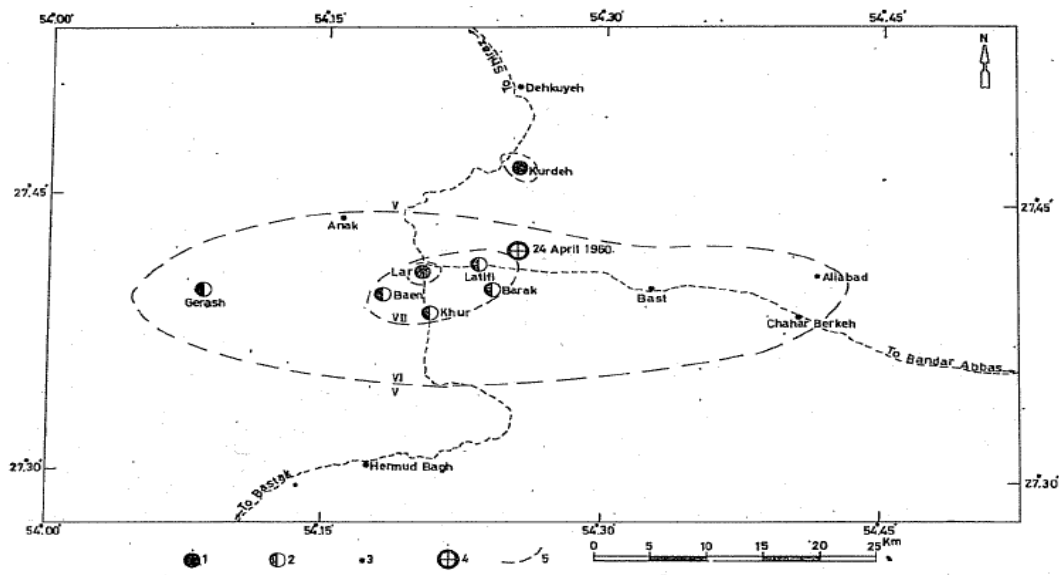


Fig. 2.19: Epicentral region of 24 April 1960 Lar earthquake [68]. 1. Extensive damage, 2. Slight damage, 3. Insufficient data, 4. Instrumental epicenter, 5. Isoseismal lines.

Dehkuye-Lar earthquake, 11 June, 1961 [68]

An earthquake with a Magnitude $M_{6.8}$ occurred at a point $27.75^{\circ}N$ and $54.33^{\circ}E$ at the Dehkuye-Lar area. Dehkuye completely destroyed and 58 people were killed; 54 houses were destroyed and two people were killed in Khaneh. Lar, Shagheb, Nokhriz and Bighu were damaged.

BARIKHUN Earthquake 14 Sep.1968 [47]

An earthquake with a Magnitude M6.1 occurred at a point 28.35°N and 53.25°E at the arikhun area. Barikhun completely destroyed and several houses were destroyed and several people were killed.

Ghir-Kazerun Earthquake of 10 April 1972

Early in the morning of 21 Farvardin 1351, a destructive earthquake with $M_s=6.9$ and $m_b=6.3$, shook large areas of Fars, totally destroying the towns of Ghir, Kazerun and Afzar. The earthquake killed about 5000 and injured about 1700 people in 50 villages, a less of life that amounted to about 20% of the population of the region. The town of Ghir was totally destroyed except a 120-m long 10 span reinforced concrete bridge across the Mand River and two elevated steel water tanks that survived the shock with in significant damage. The earthquake caused the following deformations at the area:

- Severe damage to the groundwater channels and variation of water flow in the surviving channels.
- 5 km of channels and 180 wells collapsed.
- Development of temporary springs at the east part of the Ghir town and north of the Tang-e-Ruyin.
- Liquefaction of soil at several locations and local slide of some rivers banks.
- Rockfall and landslide in the northern mountains of Ghir.

In Jahrom, Firuzabad and Fassa, about 60 km from Ghir, damages were little and some people were also injured. In Shiraz, 135 km from Ghir, several adobe houses were cracked and the window-glasses of the upper stories of the 12-storey Kurosh Hotel crashed. The earthquake also frightened people in Kerman, Bandar Abbas and Lar. Aftershocks followed the main earthquake for one year. The intensity of the earthquake was estimated at $I_0=2$ (IX MM) based on the five-fold classification of Ambraseys [47]. This earthquake occurred at a point 105 km from the site.

Distribution of Intensity: About 80% of the villages were inspected to study the distribution of intensity.

In Ghir where casualties were heavy and, except the elevated steel water tank structure, all buildings, including even the reinforced-concrete building of a modern clinic and a public bath made of lime mortar, bricks and I-beams collapsed, the intensity was estimated at about IX.

- In Tang-e-Ruyin, which was confirmed by indications by the epicenter of the earthquake, the intensity was estimated at IX. There was no wall to have survived the earthquake in this village, even the concrete walls of an underground carosene tank were broken and; one kilometer northeast of this village, the breaks were seen irregularly within an area of 600 mx150 m.

The intensity of earthquake at Menal, Dehbeh, Karzin bayan, Azizabad, Fakhrabad, Gavaky, Fath-abad, Khomar, Galaf and other villages of the region were estimated at about VIII-IX.

The Fig.2.20, shows intensity distribution in the Ghir region.

In Islamabad with 100% destruction, the intensity was estimated at VII-VIII. Near this village, the abutment of the big Islamabad Bridge was moved and the retaining wall was thrust forth.

- In Najafabad, 5 km east of Ghir, and at Ghadam village 9 km east of Ghir, intensity was estimated at VII. Estimates of intensity were VI-VII at Hangam village and the villages around it and V-VI in Firuzabad, Jahrom and Khonj towns.

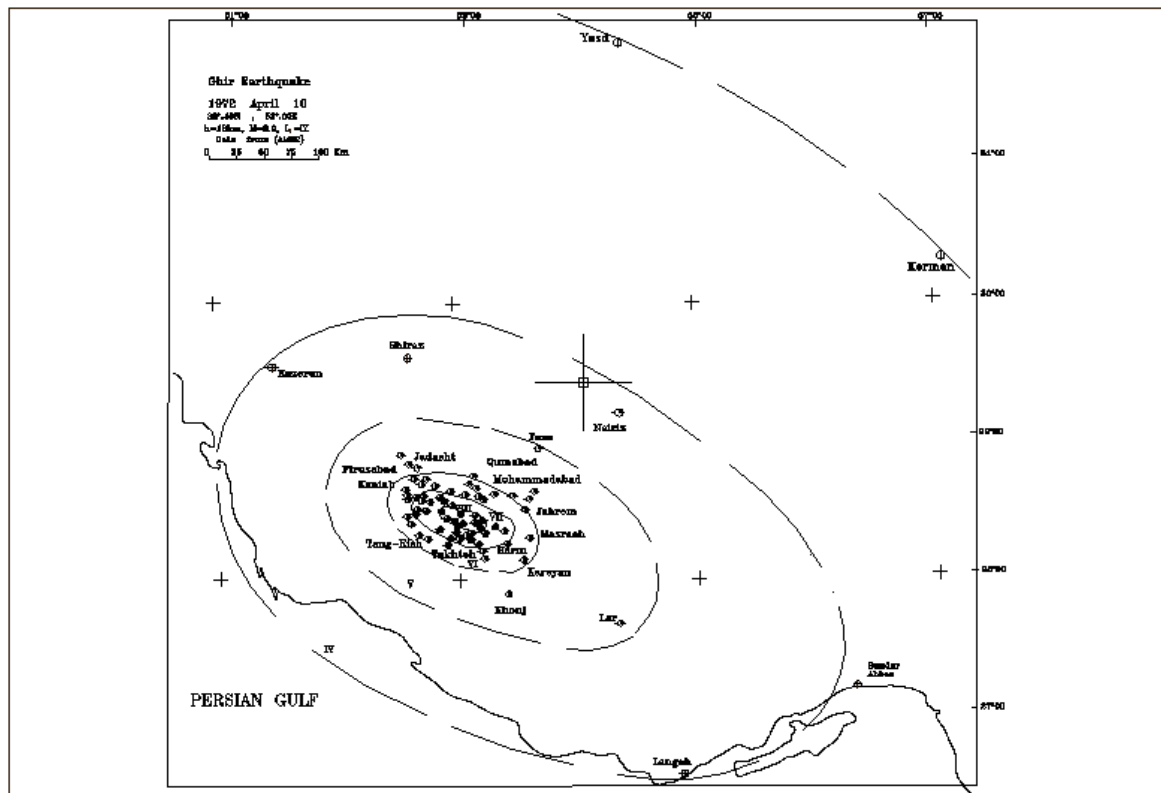


Fig. 2.20: shows intensity distribution in the Ghir region

Khurgu earthquake, 21 March, 1977 [60]

The Khurgu earthquake of magnitude M_s 7.0 occurred on March 21, 1977, in the mountains about 40 km north of Bandar Abbas (Fig.2.21.). The earthquake area is located approximately along the central axis of the Khurgu anticline, an E-W double plunging anticline, immediately and north of the Bandar Abbas coastal plain. The epicentral region is geologically situated in the southeastern extremity of the "Zagros active folded belt" of southern Iran. This earthquake occurred at the distance 320 km far from the site. Then we decided to describe this event to understand the better seismicity of region. This event is the biggest earthquake that happened in the zagros seismotectonic Active Folded Belt from 1900 up to now. The earthquake occurred at 21h18m54.6s (UTC) on March 21, 1977; the local time was early in the morning on March 22. A strong foreshock accompanied by a roaring noise was felt in the whole epicentral region. Foreshock acted as a warning signal: many people were awakened and had enough time to rush outdoors before the arrival of the main shock. By timing people's actions in a reconstruction of the event in the epicentral region, the time interval between the foreshock and the main shock was estimated at 10 to 15 sec.

The earthquake killed 152 and injured 556 people out of a population of 11,117. Destruction occurred over an area of 550 km and 1,500 houses were damaged beyond repair (Fig.2.22.). The preliminary determination earthquake from the U.S.G.S. is as follows:

Date: March 21, 1977; Time: 21h18m54.6 (UTC); Epicenter: 27.69N, 56.49E

Magnitude: Ms 7.0; Focal Depth: 33

After relocation of instrumental earthquakes of Iran, using EHB [72][73] algorithm, magnitude and location of this earthquake are modified as bellow:

Epicenter: 27.581N, 56.359E; Magnitude: Ms 6.7

Focal Depth: 12

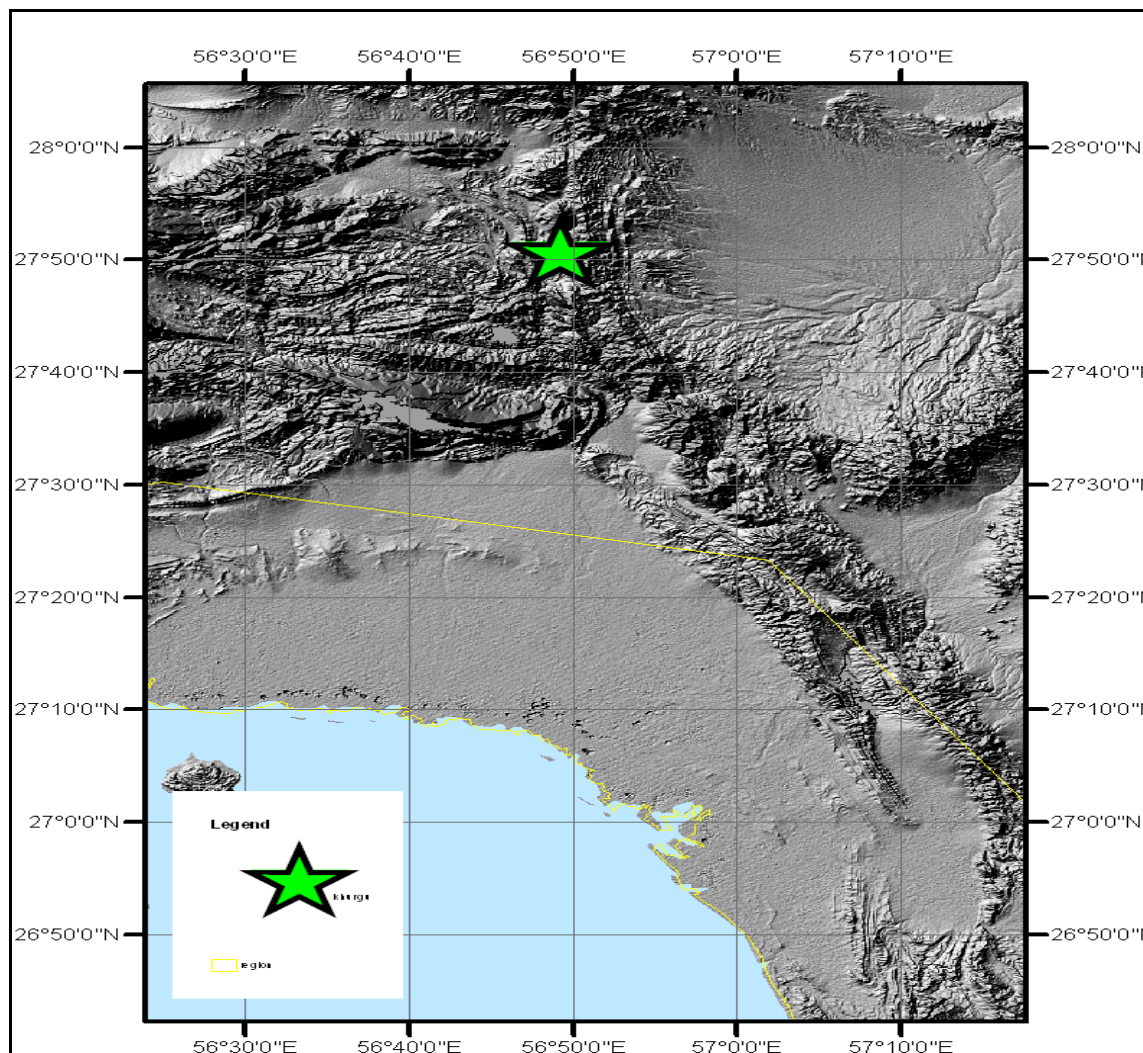


Fig. 2.21: Macroseismic area of Khurgu (north Bandar Abbas) 21 March 1977 earthquake [60]

The destructive shock was followed by several aftershocks in the magnitude range of 5 to 6, one of which (about 12 hr after the main shock) hit Sardareh and the surrounding villages and produced a pocket of more intense damage inside the macroseismic area of the main shock. The Khurgu earthquake shook Bandar Abbas to the verge of structural damage. Induced architectural damage cannot be easily separated from the effects of previous recent earthquakes.

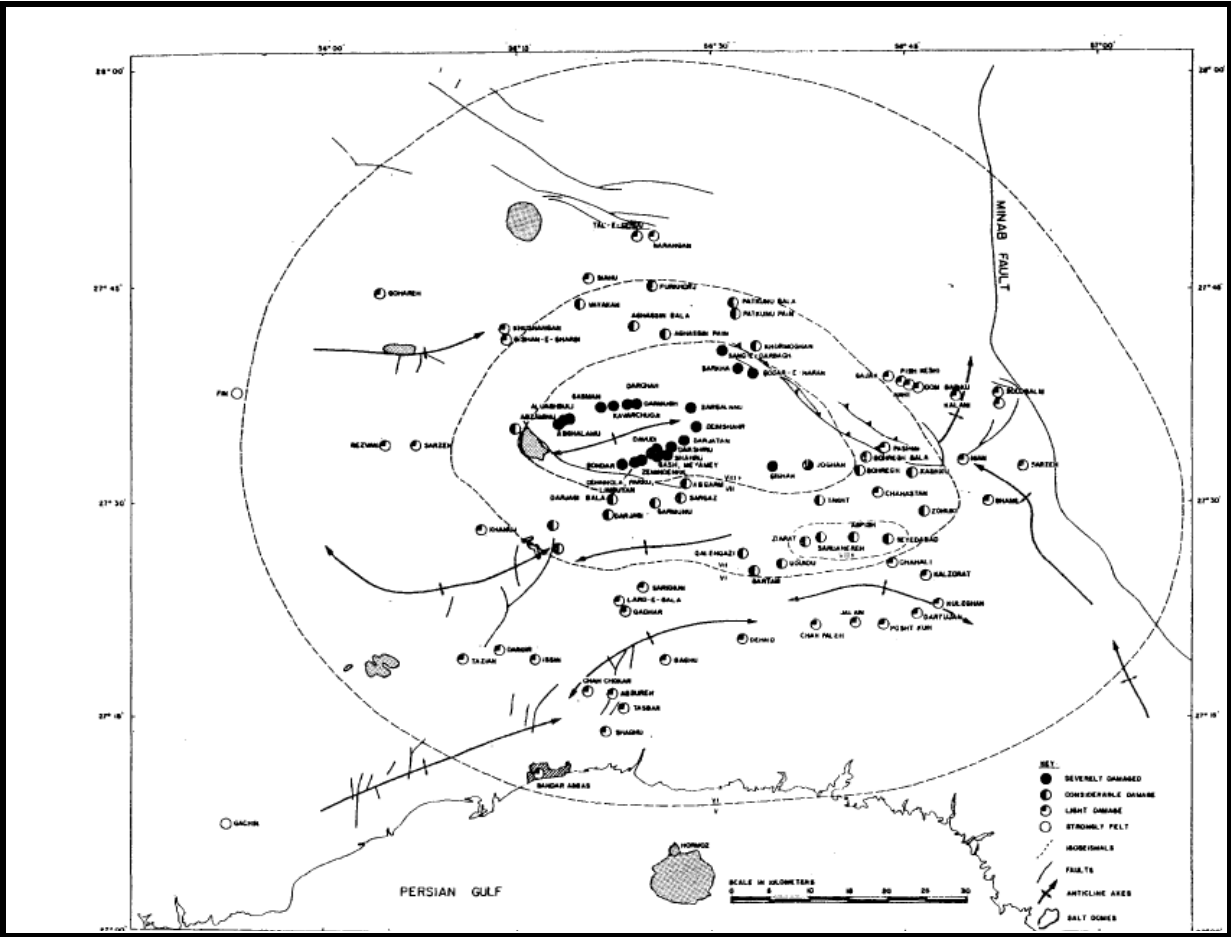


Fig. 2.22: Map of the earthquake area showing the main tectonic and damage features. The intensity grades correspond to the Modified Mercalli Scale [60]

The extent of the epicentral region indicates an average source dimension of about 30 km. On the other hand, the thickness of the sedimentary cover in the Khurgu region is about 8 km [71] and it is difficult to conceive that a source of an average size of 30 km can be accommodated inside the sedimentary layer without a surface break. Further evidence that the center of seismic energy release was in the basement structure, below the sedimentary column, comes from rough processing of the macroseismic data. Field evidence indicates

that the Khurgu earthquake of March 21, 1977, of magnitude 7 is another "Subsedimentary Zagros-Type Earthquake" case in the Zagros Active Folded Belt. Reactivation of some basement faults at depth during the readjustment of the basement caused no tectonic deformation at the top of the sedimentary layers, presumably due to the presence of the Hormoz plastic deposits [60].

Fath-abad (Ghir-e-Fars) Earthquake, 2 February. 1985

Fifty two minutes past 20 GMT, Saturday, Feb. 2, 1985, a destructive earthquake hit Ghir of Firuzabad in Fars province, shaking a large area, including Firuzabad, Ghir and Jahrum triangular region. The recently-built (after the earthquake of March 1972) rural township of Fath-abad, 8 km southeast of Ghir suffered heavy damages, loss of five lives and injury of about 80 people.

Epicenter: As reported by the Geophysical Institute of Tehran University, the epicenter of the earthquake was located at 28.50°N and 53.00°E , very close to the city of Ghir and about 10 km northwest of Fath-abad township (measured on direct line) where damages were concentrated. The concentration of damages at a small area suggested that the epicenter of the earthquake be around Fath-abad Township.

Magnitude: $M_l=5.6$ (reported by Geophysics Institute of Tehran University "IG").

Focal depth: The small area of damaged zone suggested that the quake must have been a surface type with a focal depth of less than 10 km.

Intensity: Maximum about VII (modified Mercali) at Fath-abad township, V-VI in Ghir city and about IV in cities of Firuzabad and Jahrom.

Area of damaged zone: the area that suffered considerable damages was as limited as having a radius of not more than 2 km, or exactly the recently-built township of Fath-abad, south of Ghir city the nearest residential zone to the mentioned township. Damages to the city of Ghir were not remarkable and consisted merely in cracking of some walls.

For example, in a Hoseyniyh building made of hollow concrete blocks (walls), and I-beams with barrel vault, the damage was limited to a transversal crack on the wall.

At Fath-abad Township, damages were mostly limited to cracking of walls, while some buildings suffered considerable damages and some others totally collapsed.

Most of the houses at Fath-abad Township were made of hollow concrete blocks in walls, great many of them being reinforced. The latter ones survived the earthquake but the former ones (non-reinforced walls), especially those with low quality mortar, were severely damaged, and some of them totally failed and their roofs totally collapsed. In addition, there were a number of adobe buildings that suffered great damages.

2.2.3. Seismotectonic of Zagros

The Zagros is one of the important seismic regions between Anatolian region and eastern Asia. More than 50 percent of teleseismically recorded earthquakes in Iran have occurred within the Zagros. Earthquakes occurred throughout 200-300 Km width of the belt with an abrupt limit in the northeast (Fig. and 2.23), roughly coincident with the Main Zagros fault.

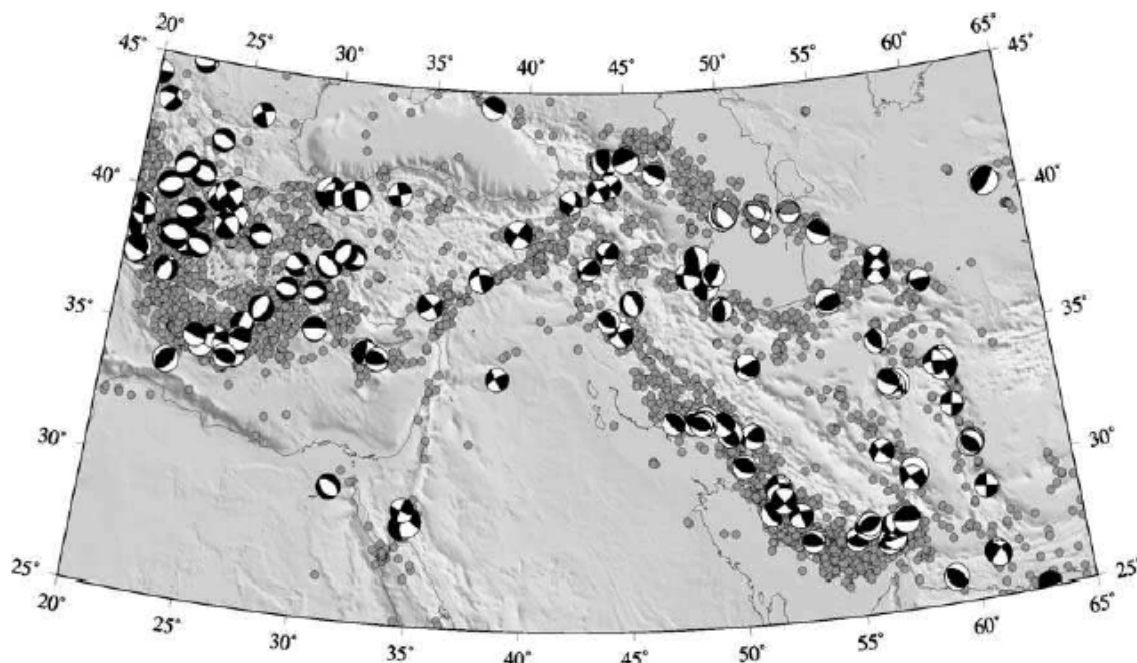


Fig. 2.23: Best-double-couple CMT solution {Iran and Anatolian region} from the Harvard catalogue for earthquakes with depth <30 km, Mw > 5.5 and double-couple component >70%. in the interval 1977-2001. Focal mechanisms in gray in the Caspian Sea are for earthquakes deeper than 30 km and are taken from Jackson et al. 2002. Epicenters are from the catalogue of Engdahl et al. 1998. Earthquakes deeper than 30 km associated with the subduction zones in the Makran and Hellenic Trench have been omitted (After Allen et. al. 2004).

Early seismic studies of the Zagros Mountains in south western Iran found evidence of seismicity at upper mantle depths (deeper than 50 Km in the International Seismological

Center (ISC) or US Geological Survey (USGS) catalogues, indicating the occurrence of brittle deformation in the upper mantle. these have been used to postulate subduction of the continental Arabian shield beneath the Zagros (Nowroozi 1971, Haynes & McQuillan 1974, Bird et al. 1975). Recent re-calculation of source depth of earthquakes at teleseismic distance, however, has found no evidence of seismicity within the upper mantle beneath the Zagros Mountains. Neither local seismograph networks, nor the modeling of teleseismic body waves from the larger earthquakes have found any focal depths deeper than 15-20 Km (e.g. [53], [54], [55]) investigated three large earthquakes and showed that they were all shallow (10-15 Km). They proposed that there was no evidence for any earthquakes deeper than about 20 Km in the Zagros.

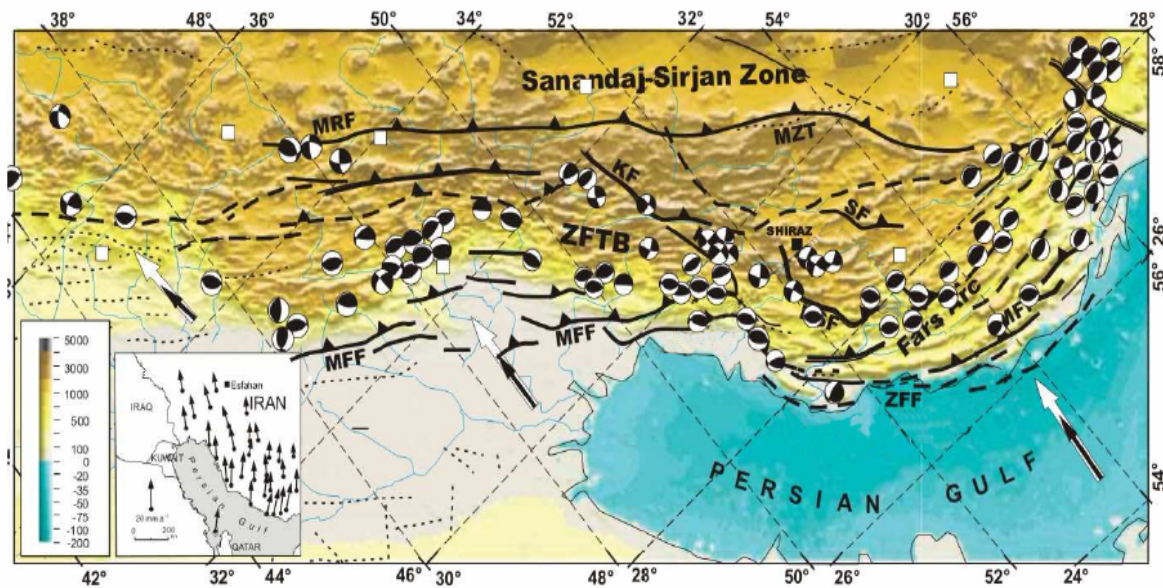


Figure 2.24: Map of fault plane solutions in the Zagros (modified from Talebian and Jackson 2004 [74]). Arrows are the directions and rates of the overall Arabia-Eurasia motion from De Mets et al. (1994, big arrow) and Sella et al. (small arrow) the white show NUVEL-1 plate motion relative to Eurasia. Insert in left panel shows present-day shortening rates and direction in a Eurasia-fixed reference frame for the period 1998-2001 (After Oveisi 2006).

A recent study Talebian and Jackson [74] confirms this view. Thus, there is no evidence at least in the form of sub- crustal earthquakes for counting subduction of Arabia beneath Iran. Most teleseismic determinations of focal mechanisms in the Zagros show reverse faulting with strike parallel to those of the local fold axis (fig 2.25). Talebian and Jackson [74] show that seismicity appears to be confined to the upper half of the crust through the Zagros which is a result also found by microearthquake surveys (Tatar et al. 2004). The centroid depths (Fig.) are compatible with the majority of earthquakes occurring in the basement beneath the sedimentary cover.

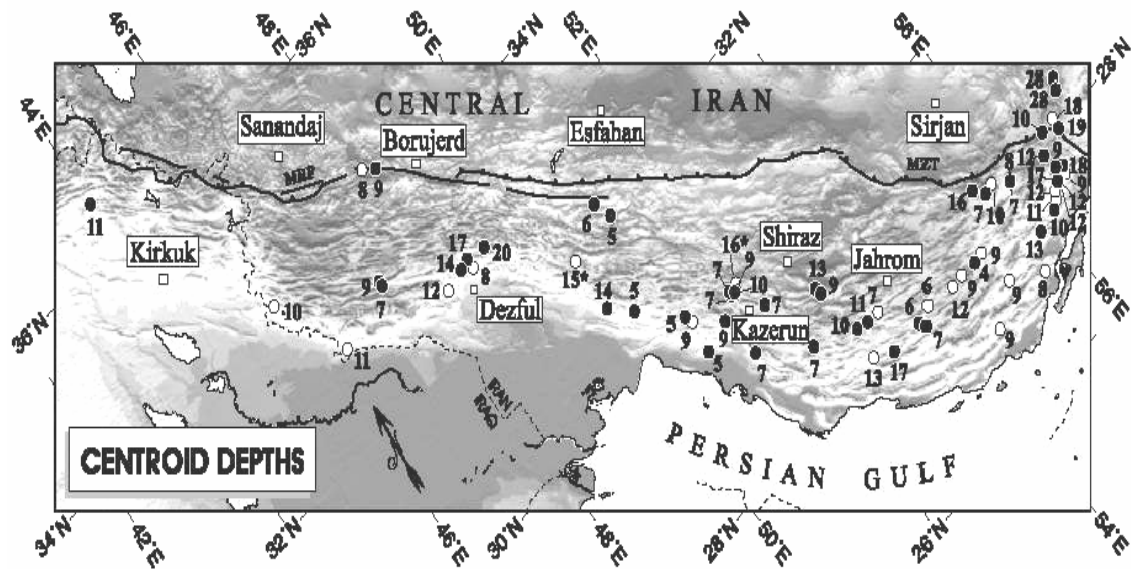


Fig. 2.25: Earthquake centroid depths determined from waveform modeling [74]. Numbers are depths in km. Black circles are those determined from long-period P and SH waves. Open circles are those determined from P waves alone [74].

2.2.4. Geological Description of Site Area

The morphology of site area is smooth and ground surface has a gently dip if about 0.16% toward the South East. Average elevation of the site is 404m above the sea level. The general topography of the site is shown in figure 2.26. There are several small rivers or flood ways at the site. The site area is drowned in water for a few months in autumn or winter and this area can be assumed as a winter marsh.

Geology map of site area, prepared by Iranian Oil Companies is shown in figure 2.27. Based on this map and field studies, Site area is located on a syncline filled by young fine sedimentary deposits. This area is limited from north to Varavi anticline and south to Assaluyah anticline. Several satellite pictures from site area showed in figures 2.28 and 2.29. Bedrock is understood as alternation of marlstone and sandstone with intercalation limestone layers known as Aghajari formation (Aghajari formation is a geology formation that consisted of alternation of marlstone and sandstone which deposited in Pliocene period). Figure 2.30 shows a schematic geological section of Plant region. View of the North Mountains of plant area is shown in Figure 2.31. Figure 2.32 shows the mountain that is located at southern part of Plant area consists of marlstone and limestone layers with a bed dipping about 30° to North. All the site area is covered with fine grained deposits (Figure

2.33). There are some gypsum crystals in soil layers as formation. Gypsum content is not more than 3%. A picture from gypsum crystals is shown in Figure 2.34.

The extent of these fine grained deposits is approximated to be about 60 to 80 meters deep. Groundwater level is various and it depends on the ground surface water. During site investigation average groundwater depth was 3.4m [36].

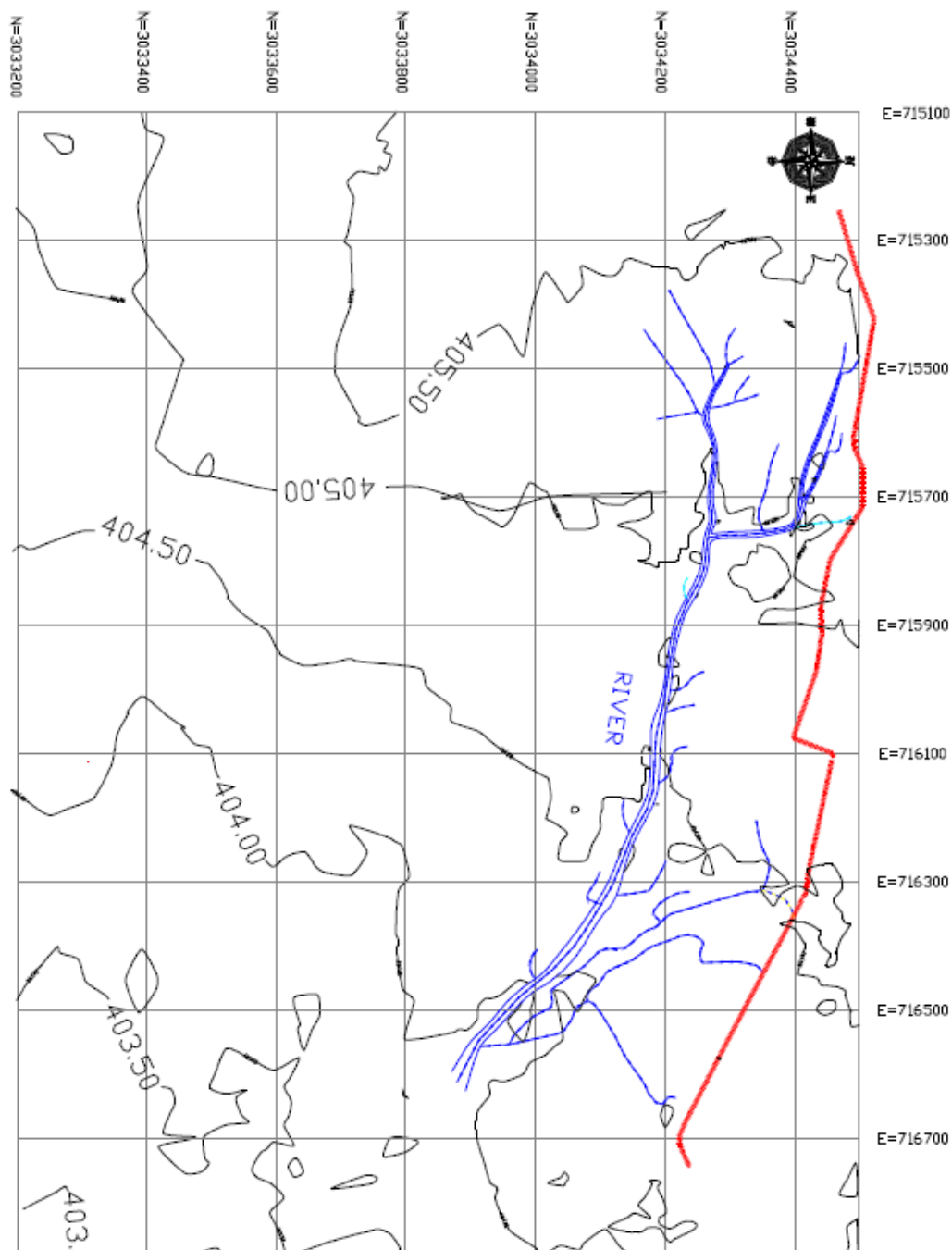


Fig. 2.26: General topography map of studied site area

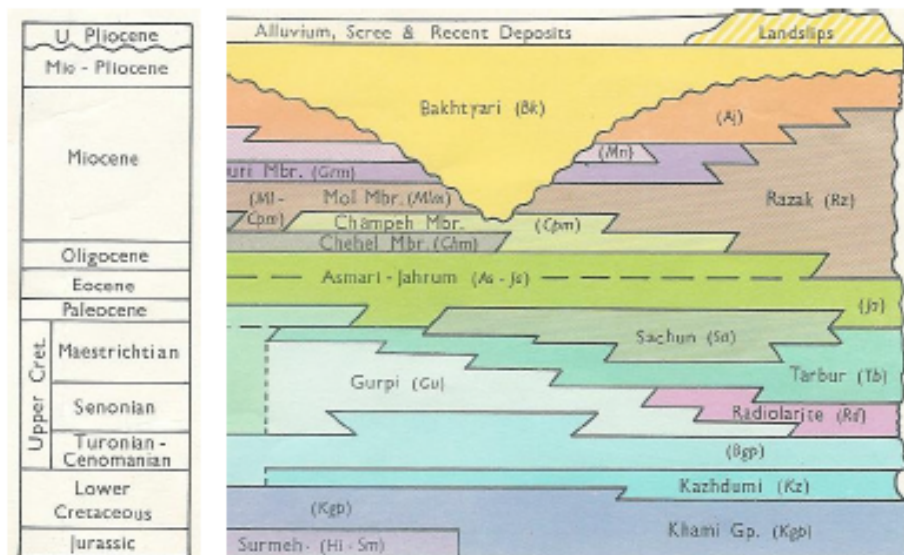
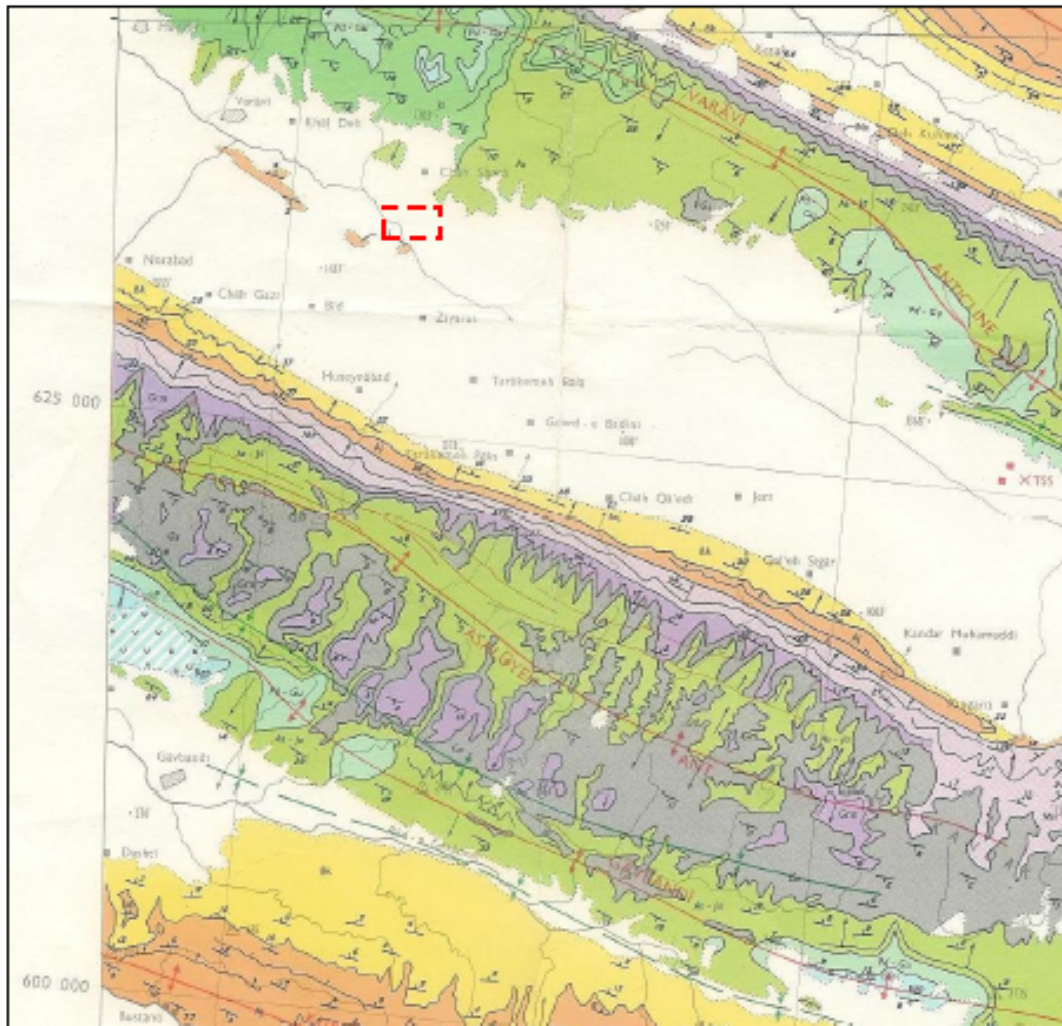


Fig. 2.27: Geological map and stratigraphy column of plant region (from South-East Fars Geological map of I.O.O.C. 1965)



Fig. 2.28: Satellite photo of Plant area



Fig. 2.29: Satellite photo of plant area (side view)

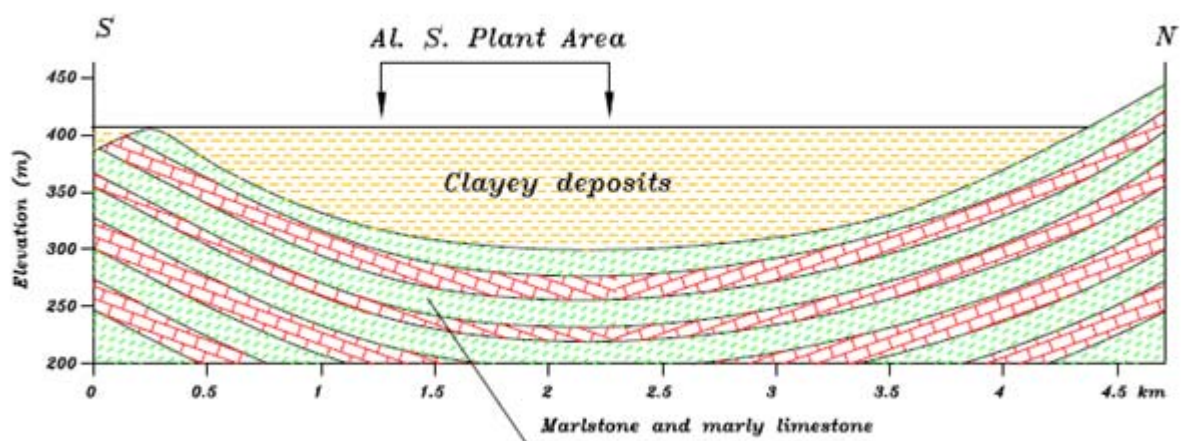


Fig. 2.30: Schematic geological section of Plant region



Fig. 2.31: View of plant area and Northern Mountains



Fig. 2.32: Mountain located at southern part of site and considered from marlstone and limestone layers with dipping bedding about 30° to North



Fig. 2.33: View of plant area covered with fine grained deposits



Fig. 2.34: Fine gypsum crystals as floatation in soil.

Section 3

3. Seismic Sources

Recall that a structured procedure was developed to provide earth science specialist with a framework to interpret scientific knowledge about the activity of tectonic features and to ultimately translate this information in to seismic sources. Because of the uncertainty associated with whether a sources is active or inactive (i.e. it has a probability other than 0 or 1 that it is active), there are multiple combinations of sources that may be simultaneously active in a region.

Each combination has a probability that represents the spatial distribution of future seismicity.

3.1 Description of Seismic Sources

For the probabilistic assessment of seismic hazard, possible locations of future earthquakes in the vicinity of a site must be defined. The basic tool to do this is the seismic source, which is a region of the earth's crust in which future seismicity is assumed to follow specified probability.

The procedures to develop seismic sources involve a structured approach for earth science specialist to identify tectonic features that might be potential sources of seismic activity (i.e., faults, and ...), interpret scientific knowledge concerning the causative mechanisms of earthquakes in the study region and ultimately to delineate seismic sources.

The steps to define seismic sources begin with an identification of potentially active tectonic features. A tectonic feature is an active fault in the study area as discussed in the chapter 2 of this report. Each seismic source is defined according to its geographic location and the probability that the source is active.

3.2. Seismicity Parameters

This study presents an extension of the maximum likelihood estimation of earthquake hazard parameters (Maximum regional magnitude M_{max} , activity rate, and b or β value parameter in the Gutenberg-Richter relation) to the cases of mixed and uncertain data. By mixed data, we understand a catalog containing two types of information: macroseismic observations of

strongest seismic events which occurred from 978 and complete recent instrumental data up to 2013.

Earthquake magnitudes are never exactly known. They are determined to ± 0.15 units at best (1964-1998). The older earthquake (1900-1963) data give magnitude to ± 0.2 units. Some of them recovered from historical records are known only within an accuracy of ± 0.3 to ± 0.5 unit.

3.2.1. Estimation of seismic hazard parameters

The derived procedure has been used to estimate seismicity parameters and seismic hazard for area under study of Lamerd Factory, (Radius 100, 150 km & seismotectonic provinces of South-East Zagros).

The first part is the Extreme catalog of the historical earthquakes (before 20th century). The second part contains the complete catalog for the period 1900 to 1963. The third part contains the complete catalog for the period 1964 to 2013. In addition, it was assumed that for each data set, magnitude uncertainties is $\Delta M_1=0.3-0.4$, $\Delta M_2=0.2$ and $\Delta M_3=0.15$ respectively.

3.2.1.1. Likelihood Function of Seismic Hazard Parameters for Interval Magnitude Data

Assume the Poisson occurrence of earthquakes with the activity rate λ and the doubly truncated Gutenberg-Richter distribution $F(m)$ of earthquake magnitude m .

$$f(m) = \Pr(M \leq m) = \frac{A_1 - A(m)}{A_1 - A_2}, m_{\min} < m < m_{\max}$$

Where:

$$A_1 = \exp(-\beta m_{\min}), A_2 = \exp(-\beta m_{\max}) \text{ and } A(m) = \exp(-\beta m)$$

$M_{\max}$ is the maximum regional magnitude value; $m_{\min}$ is the threshold magnitude and β is a parameter.

The desired seismicity parameters are $\theta = (\beta, \lambda)$ and $m_{\max}$

3.2.1.2 Likelihood Function of Hazard

Parameters for Extreme Part of the Catalog

The assumption of the Poisson occurrence of earthquakes with mean rate λ and doubly truncated Gutenberg- Richter magnitude distribution, implies that earthquakes of magnitudes greater than m can be represented by a Poisson process with the mean rate of occurrence $\lambda [1-F(m)]$.

Thus, the probability that m , the largest magnitude within a period of t , will be less than some specified magnitude m is given by :

$$G(m | t) = \exp[-v_0 t \frac{A_2 - A(m)}{A_2 - A_1}],$$

Where:

$$v_0 = \lambda [1-F(m_0)], \quad A_1 = \exp(-\beta m_0)$$

and m_0 is the threshold magnitude for extreme part of catalog ($m_0 > m_{min}$)

From relation above, it follows that the probability of the strongest earthquake within a period of t having its magnitude between $\underline{m}$ and m is :

$$p(\underline{m}, m | t) = G(m | t) - G(\underline{m} | t)$$

After introducing the probability, the likelihood function of θ , following the extreme part of the catalog becomes:

$$L_0 (\theta | m_0) = \text{const} \prod_{i=1}^{n_0} P(\underline{m}_{oi}, m_{oi} | t_i)$$

In relation above, the observational data are $\langle \underline{m}_{oi}, m_{oi} \rangle$, the lower and upper magnitude limits of the largest earthquake which occurred during time interval $t_i (i=1, 2, 3, \dots, n_0)$

n_0 denotes the number of earthquakes in the extreme part of the catalog. For convenience of notation, magnitude limits $\underline{m}_{oi}, \overline{m}_{oi}$ are grouped into a matrix of dimension ($m_0 \times 2$):

$$m_0 = | m_{oi}, \overline{m}_{oi} |, i=1, 2, 3, \dots, n_0$$

For the same reason, time intervals t_i are grouped into a vector $t = (t_1, t_2, t_3, \dots, t_{n_0})$, const is a normalization constant independent of θ .

3.2.1.3 Likelihood function of hazard

Parameters for complete part of the catalog

Let us assume that the second, complete part of the catalog can be divided into s subcatalogs. Each of them has its span T_i and is complete starting from the known threshold magnitude $m_i (i=1,2,3,...,s)$. Let us also assume that the values $\langle \underline{m}_{ij}, m_{ij} \rangle, j=1,2,3,...,n_i$ denote the lower and upper limits of the magnitude. Intervals defined in this way contain the real unknown magnitude, n_i denotes the number of earthquakes in subcatalog, and s denotes the number of complete subcatalogs. If the size of events is independent of their number, the likelihood function of θ for each catalog can be written as a product of two functions.

$$L_i(\theta | m_i) = L_{i\beta} \cdot L_{i\lambda}$$

Where m_i denotes the $(n_i \times 2)$ matrix of magnitude values contained in subcatalog $(i=1,2,3,...,s)$.

From the assumption that the earthquake magnitude m is a random variable distributed according to the doubly truncated Gutenberg-Richter distribution, it shows that the probability of an earthquake having its magnitude between $\underline{m}$ and m is :

$$P(\underline{m}, m) = (\underline{A} - A) / (A_1 - A_2)$$

Where : $\underline{A} = \exp(-\beta \underline{m})$, $\bar{A} = \exp(-\beta \bar{m})$,
 $A_2 = \exp(-\beta m_{\max})$ and $A_i = \exp(-\beta m_i)$ for $i=1,2,...,S$

Function above generates $L_{i\beta}$ of the following form:

$$L_{i\beta} = \text{const} \prod_{i=1}^{n_i} P(m_{ij}, \underline{m}_{ij})$$

Where const is a normalization factor independent of θ . The assumption that the number of earthquakes per unit time is a Poisson random variable, gives:

$$L_{i\lambda} = \text{Const} \exp(-v T_i) (v T_i)^{n_i}$$

Where const is normalizing factor,

$$v T_i = \lambda [1 - F(m_i)],$$

λ is the activity rate corresponding to the threshold magnitude

$$m_{\min} < \min(m_i), i=1,2,3,\dots,S, \text{ Equations}$$

$$Li(\theta/m_i) = L_{i\beta} \times L_{i\lambda} \text{ \& } vt = \lambda[1-F(m_i)]$$

Define the likelihood function of parameters for each complete subcatalog.

According to the principle of combination of data the joint likelihood on all data, i.e. The likelihood function for extreme and complete parts of the catalog is given by :

$$L(\theta/m) = \prod_{i=1}^s li(\theta/m_i)$$

3.2.2 Estimation of M_s – M_b Relationship and seismicity parameters

The derived procedure has been used to estimate seismicity parameters and seismic hazard for area understudy of Lamerd Factory site, the first part is the Extreme catalog of the historical earthquakes (before this century). The second part contains the complete catalog for the period 1900 to 1963. The third part contains the complete catalog for the period 1964 to now.

Because the lack of M_w , we estimate the relationship between M_s and m_b based on data recorded within the area about 150 km far from the site.

This relationship is:

$$M_s = 0.90818 M_b + 0.10676, \quad R=0.81,$$

We didn't find a good relationship between M_s and m_b magnitudes, and then we applied Ambraseys N. N. and Melville [47] relationship for Iran data.

Figure 3-1 shows the estimated relationship in this study and Ambraseys N. N. and Melville [47] relationship.

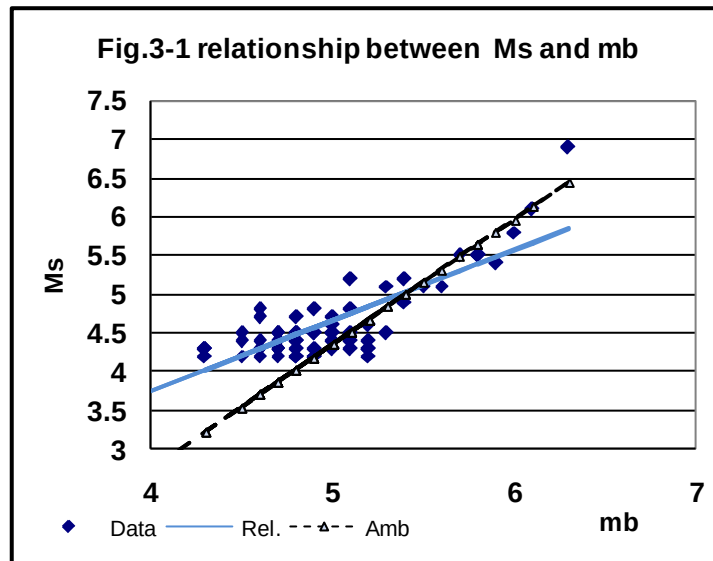
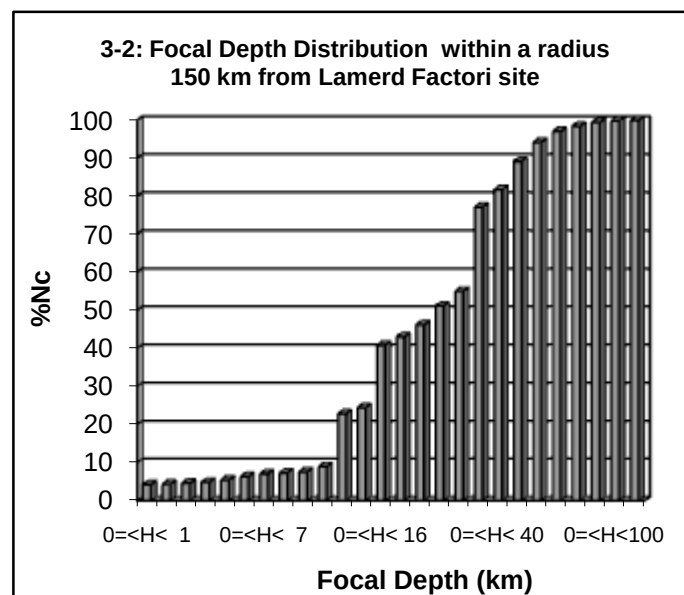


Figure 3-2 also shows the distribution of focal depth vs. number of data within R=150 km from the site.



I) Region R=100 Km of the Site

An application of the parameters estimation procedure described gives:

Gutenberg-Richter function:

$$\text{Log } N_c = 5.98508 - 0.95829 * M$$

$$R = 0.97866, M_t = 4.2$$

Kijko & Sellevoll Method:

$$\beta = 2.70 \pm 0.10, \quad \lambda \text{ (for } M_t=4.2\text{)} = 0.442, \quad M_{\max} = 7 \pm 0.5 \\ M_{\text{obs}} = 6.5 \pm 0.35$$

II) Region R=150 Km of the Site

An application of the parameters estimation procedure described gives:

Gutenberg-Richter function : $\text{Log } N_c = 5.60793 - 0.79474 * M$
 $R = 0.9918 \quad M_t = 4.2$

Kijko & Sellevoll Method:

$$\beta = 2.56 \pm 0.07, \quad \lambda \text{ (for } M_t=4.2\text{)} = 0.827, \quad M_{\max} = 7.2 \pm 1.01 \\ M_{\text{obs.}} = 7.1 \pm 0.35 \text{ (1440 Earthquake)}$$

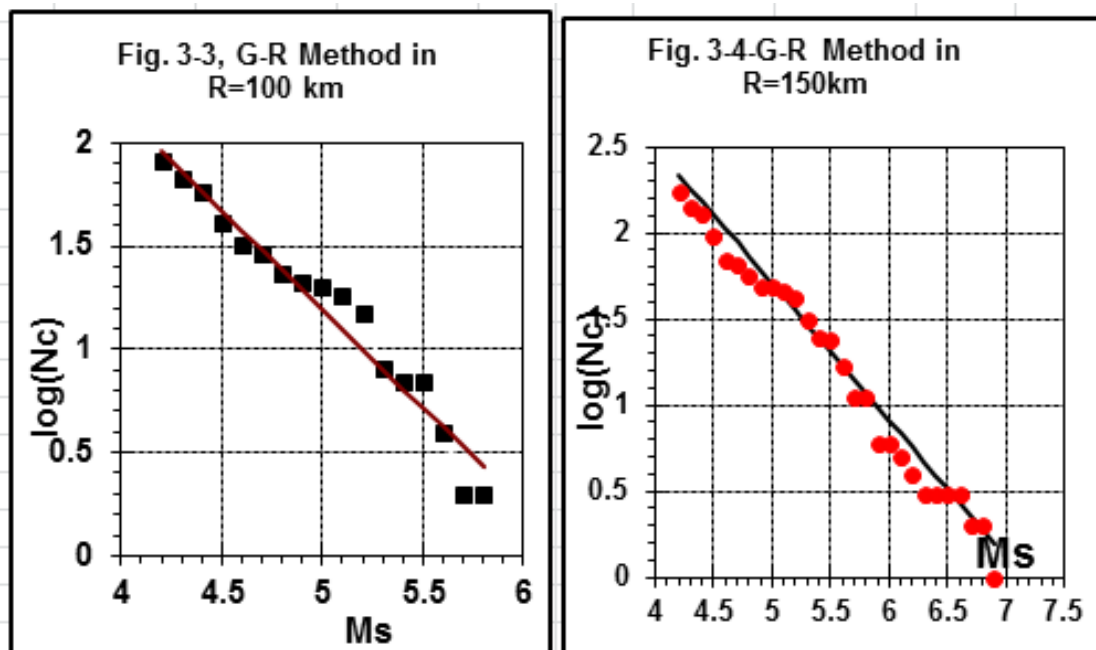
III) South-East Zagros

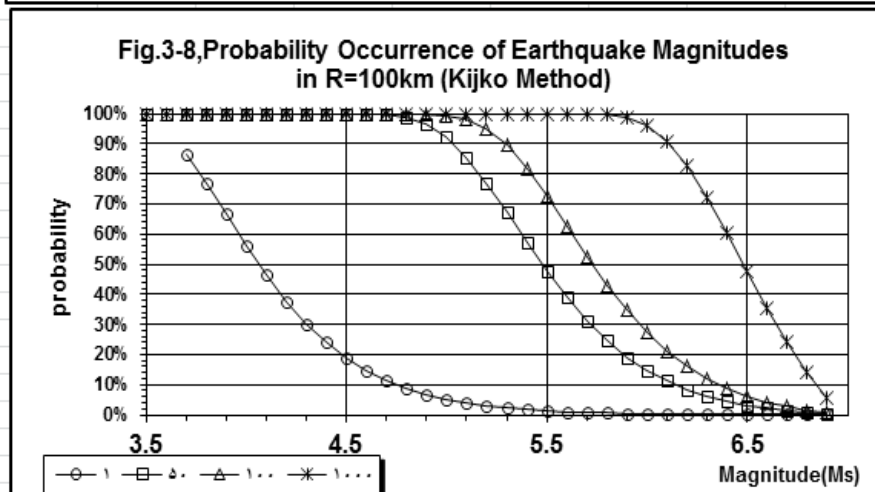
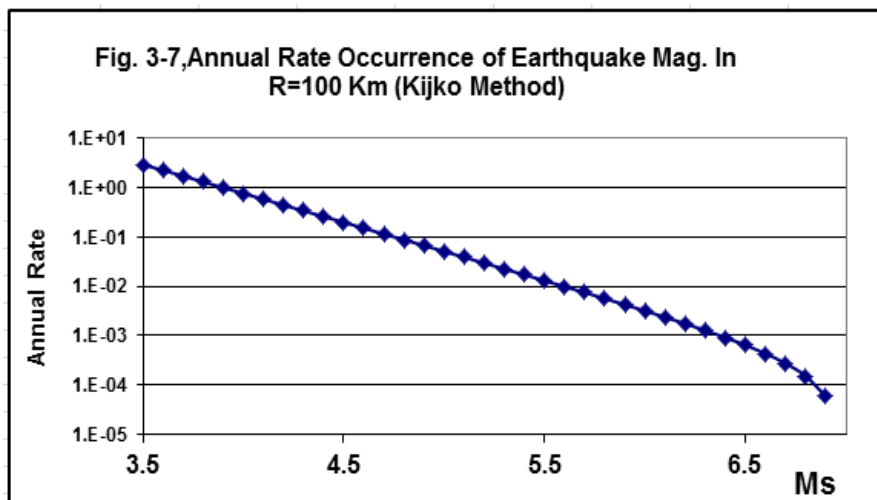
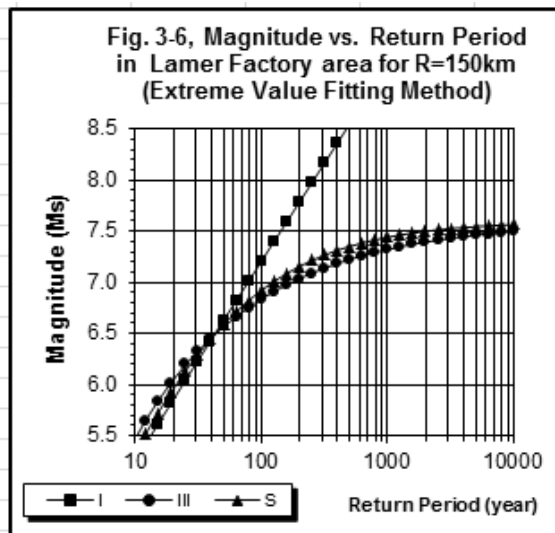
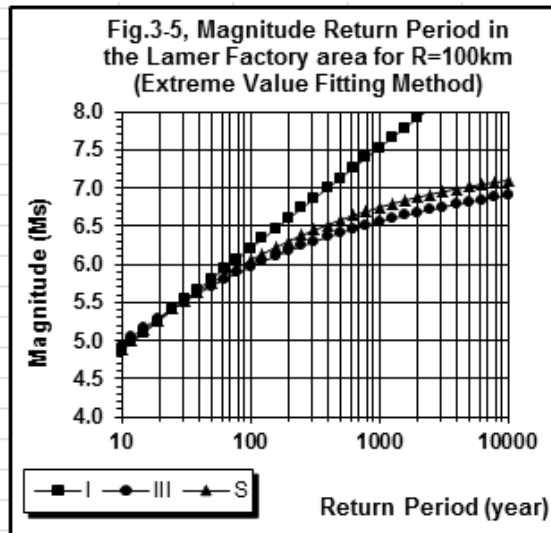
Kijko & Sellevoll Method:

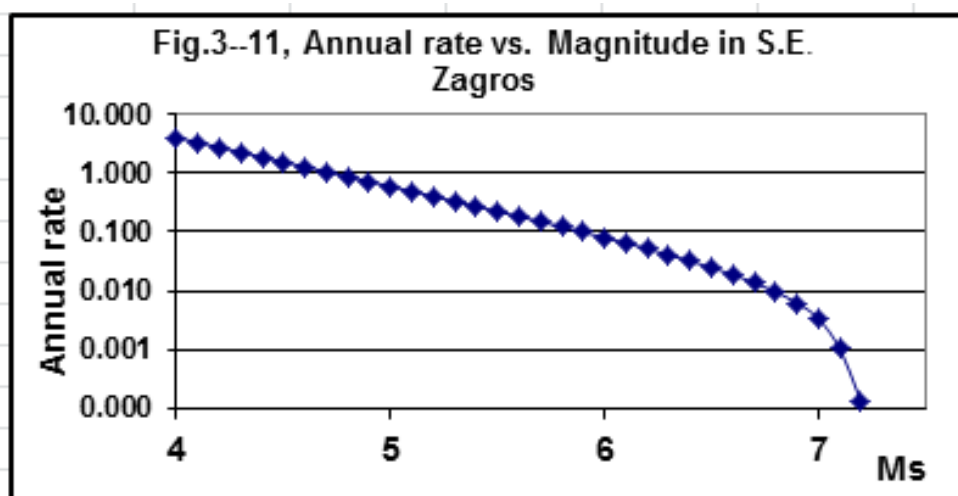
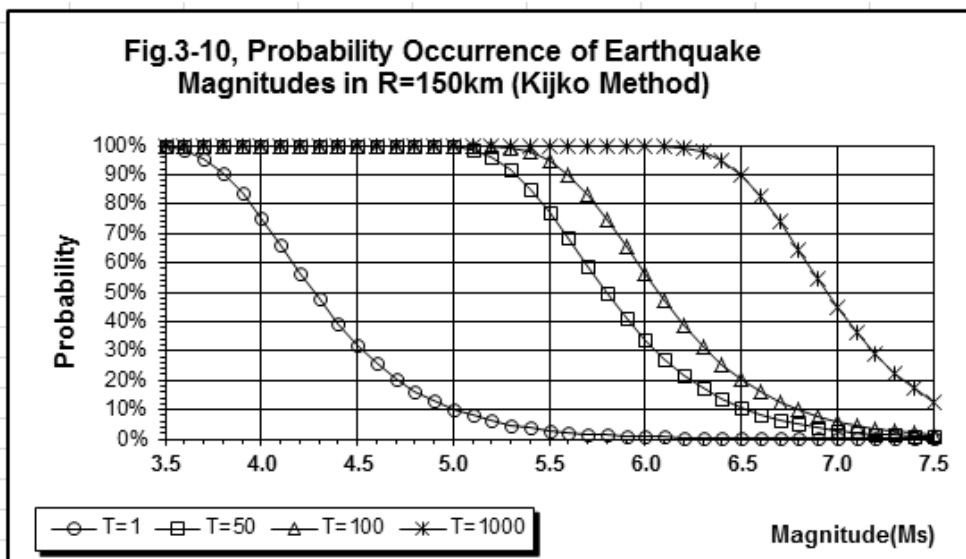
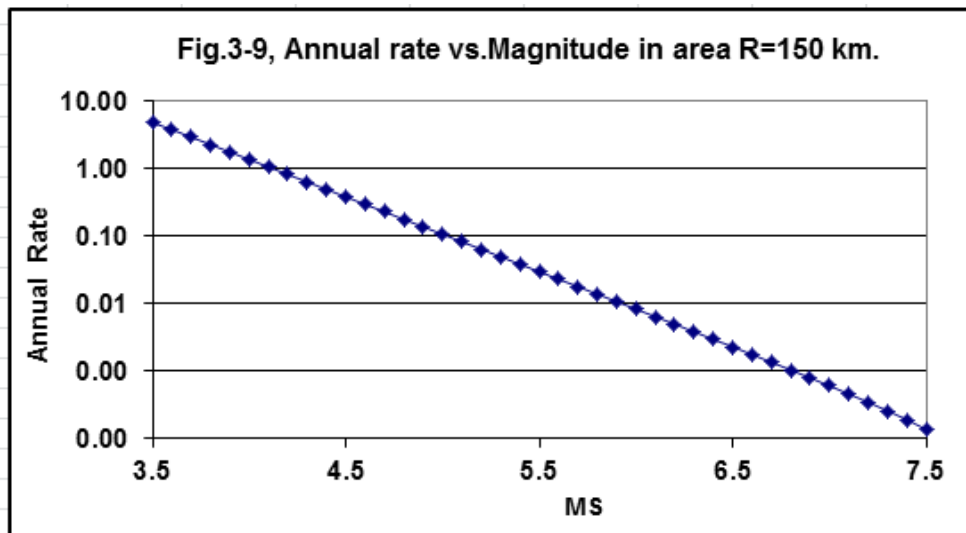
$$\beta = 1.91 + 0.05, \quad \lambda \text{ (for } M_t=4.2\text{)} = 2.7, \quad M_{\max} = 7.2 \pm 0.5 \\ M_{\text{obs.}} = 7.1 \pm 0.35$$

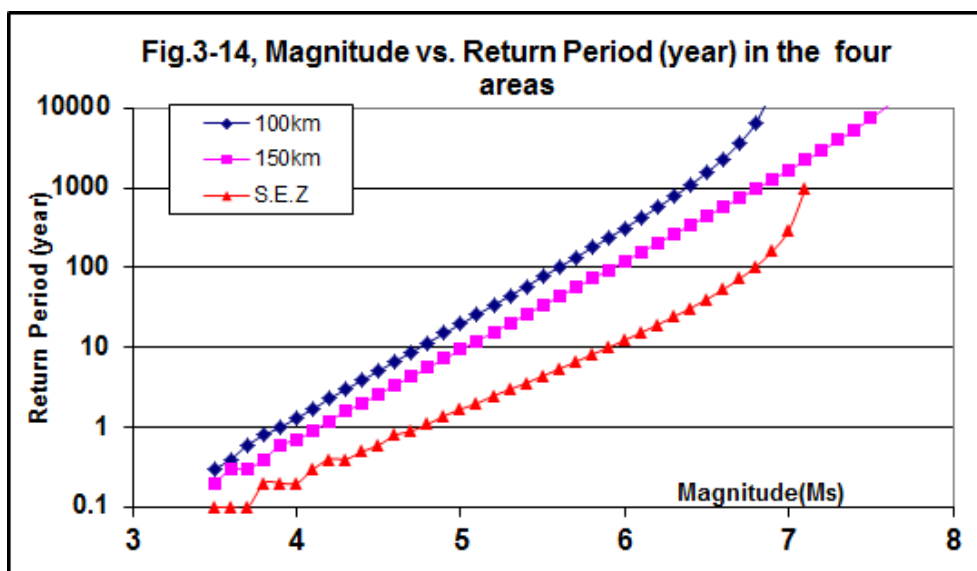
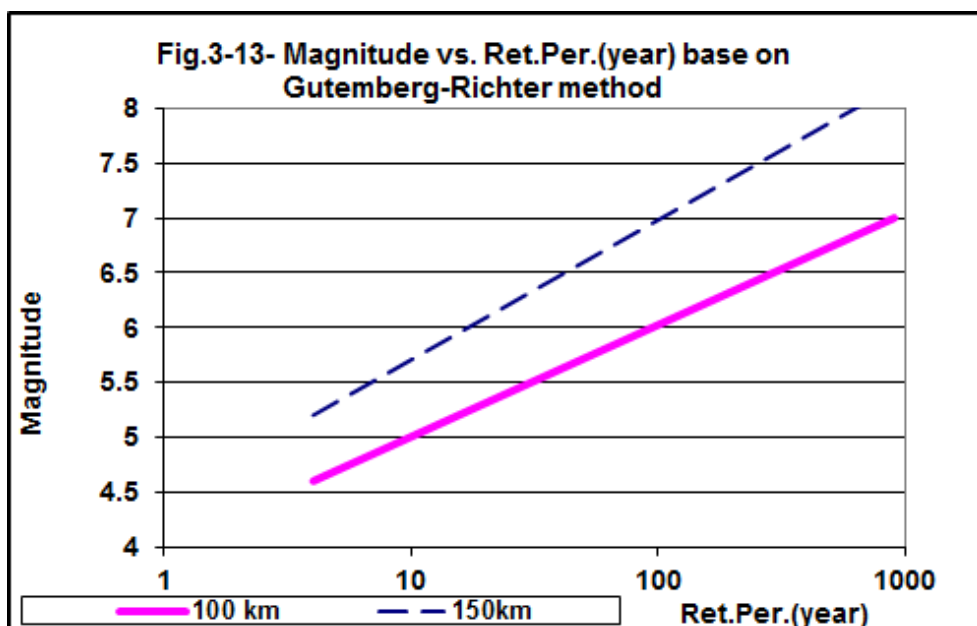
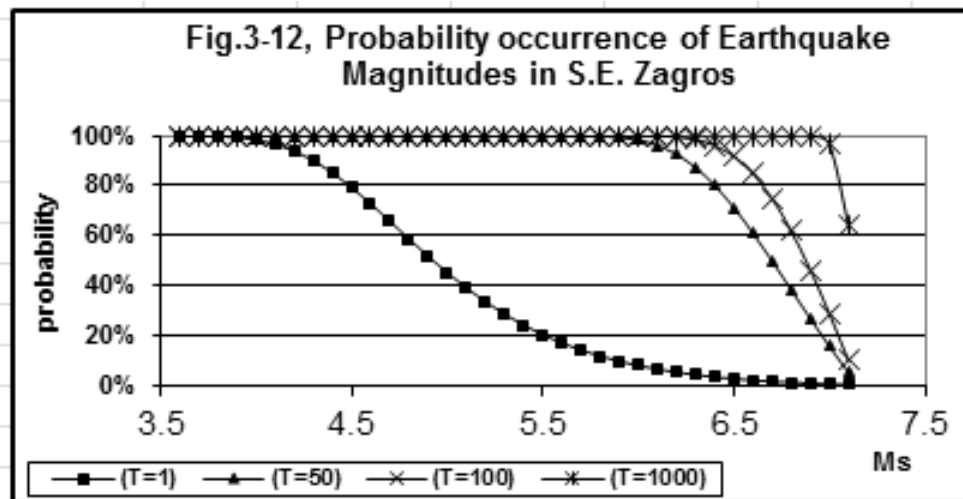
Results:

Figures 3-3 to 3-12 and tables 3-1 to 3-7 show the estimated of these methods in this study.









As mentioned above, the maximum likelihood function hazard parameters method, and other methods estimated return period of magnitude in area under study (R=100 and 150 Km and S.E-Zagros province).

The results of this study are shown in Tables 3.1, 3.2, 3.3, 3.4 and 3.5 for region in R=100 & 100 Km far from Lamerd site and S.E-Zagross.

Table 3.1: G-R Method (Least Square) in R=100 km

Ms	Data Results		G-R Results	
From ($\leq$)	No.	Cum. No.	Log (Nc)	Log (Nc) Cal.
4.2	14	81	1.9085	1.96094
4.3	9	67	1.8261	1.86511
4.4	17	58	1.7634	1.76928
4.5	9	41	1.6128	1.67345
4.6	3	32	1.5051	1.57762
4.7	6	29	1.4624	1.48179
4.8	2	23	1.3617	1.38596
4.9	1	21	1.3222	1.29013
5	2	20	1.301	1.1943
5.1	3	18	1.2553	1.09847
5.2	7	15	1.1761	1.00264
5.3	1	8	0.9031	0.90681
5.4	0	7	0.8451	0.81098
5.5	3	7	0.8451	0.71515
5.6	2	4	0.6021	0.61932
5.7	0	2	0.301	0.52349
5.8	2	2	0.301	0.42766

Table 3.2: G-R Method (Least Square) in R=150 km

Ms	Data Results				G-R Results				
From ($\leq$)	No.	Cum. No.	Log (Nc)	Log (Nc)	From ($\leq$)	No.	Cum. No.	Log (Nc)	Log (Nc)
4.2	30	173	2.238	2.341392	5.6	6	17	1.2304	1.228756
4.3	14	143	2.1553	2.261918	5.7	0	11	1.0414	1.149282
4.4	32	129	2.1106	2.182444	5.8	5	11	1.0414	1.069808
4.5	27	97	1.9868	2.10297	5.9	0	6	0.7782	0.990334
4.6	4	70	1.8451	2.023496	6	1	6	0.7782	0.91086
4.7	9	66	1.8195	1.944022	6.1	1	5	0.699	0.831386
4.8	8	57	1.7559	1.864548	6.2	1	4	0.6021	0.751912
4.9	1	49	1.6902	1.785074	6.3	0	3	0.4771	0.672438
5	2	48	1.6812	1.7056	6.4	0	3	0.4771	0.592964
5.1	4	46	1.6628	1.626126	6.5	0	3	0.4771	0.51349
5.2	11	42	1.6232	1.546652	6.6	1	3	0.4771	0.434016
5.3	6	31	1.4914	1.467178	6.7	0	2	0.301	0.354542
5.4	1	25	1.3979	1.387704	6.8	1	2	0.301	0.275068
5.5	7	24	1.3802	1.30823	6.9	1	1	0	0.195594

Table 3.3: Annual Rate occurrence of Earthquake Magnitude vs. Improbability in the area R=100 km.

Improbability						Improbability					
Mag.	Lambda	year	year	year	year	Mag.	Lambda	year	year	year	year
Ms		1	50	100	1000	Ms		1	50	100	1000
3.5	2.9	0.998195	1	1	1	5.3	0.0224	0.023441	0.674346	0.89395	1
3.6	2.24	0.943541	1	1	1	5.4	0.0171	0.017881	0.574087	0.818598	1
3.7	1.71	0.864771	1	1	1	5.5	0.013	0.013616	0.477246	0.726728	0.999998
3.8	1.3	0.769352	1	1	1	5.6	0.00985	0.01035	0.388754	0.626378	0.999947
3.9	0.994	0.665641	1	1	1	5.7	0.00746	0.007849	0.311252	0.525626	0.999423
4	0.759	0.561908	1	1	1	5.8	0.00564	0.005936	0.245543	0.430794	0.99643
4.1	0.579	0.464555	1	1	1	5.9	0.00424	0.004474	0.191197	0.345838	0.98565
4.2	0.442	0.377533	1	1	1	6	0.00318	0.003356	0.147093	0.27255	0.958502
4.3	0.337	0.302591	1	1	1	6.1	0.00237	0.002502	0.111816	0.211129	0.906662
4.4	0.258	0.239865	0.999997	1	1	6.2	0.00175	0.00185	0.083909	0.160778	0.826712
4.5	0.197	0.188495	0.999946	1	1	6.3	0.00128	0.001352	0.062019	0.120191	0.722102
4.6	0.15	0.147118	0.999446	1	1	6.4	0.00092	0.000971	0.044957	0.087893	0.601474
4.7	0.114	0.114211	0.996722	0.999989	1	6.5	0.000645	0.000681	0.031725	0.062444	0.475227
4.8	0.0873	0.088293	0.987271	0.999838	1	6.6	0.000435	0.000459	0.021502	0.042541	0.352559
4.9	0.0666	0.068031	0.964142	0.998714	1	6.7	0.000274	0.00029	0.013625	0.027065	0.239957
5	0.0508	0.052279	0.920947	0.993751	1	6.8	0.000152	0.000161	0.00757	0.015083	0.140997
5.1	0.0387	0.040086	0.855456	0.979107	1	6.9	5.85E-05	0.000062	0.002923	0.005838	0.056873
5.2	0.0295	0.030679	0.770886	0.947507	1						

Table 3.4: Annual Rate occurrence of Earthquake Magnitude vs. Improbability in the area R=150 km.

Annual Probability						Annual Probability					
Ms	Rate	T=1	T=50	T=100	T=1000	Ms	Rate	T=1	T=50	T=100	T=1000
		year	year	year	year			year	year	year	year
3.5	4.9	0.999631	1	1	1	5.5	0.0297	0.029518	0.774031	0.948938	1
3.6	3.83	0.98534	1	1	1	5.6	0.023	0.022926	0.683787	0.900009	1
3.7	2.97	0.955387	1	1	1	5.7	0.0178	0.017791	0.589804	0.831739	1
3.8	2.3	0.906042	1	1	1	5.8	0.0138	0.013795	0.498225	0.748222	0.999999
3.9	1.78	0.837334	1	1	1	5.9	0.0107	0.01069	0.413478	0.655992	0.999977
4	1.38	0.753416	1	1	1	6	0.00825	0.008278	0.338133	0.561932	0.99974
4.1	1.07	0.66086	1	1	1	6.1	0.00638	0.006407	0.273196	0.471756	0.998308
4.2	0.827	0.566559	1	1	1	6.2	0.00493	0.004955	0.218562	0.389355	0.992791
4.3	0.64	0.47622	1	1	1	6.3	0.00381	0.00383	0.173447	0.31681	0.977848
4.4	0.496	0.393718	1	1	1	6.4	0.00294	0.002957	0.136726	0.254759	0.947159
4.5	0.384	0.321118	1	1	1	6.5	0.00227	0.002281	0.107172	0.202859	0.896402
4.6	0.297	0.259041	1	1	1	6.6	0.00175	0.001757	0.083592	0.160197	0.825508
4.7	0.23	0.207135	0.99999	1	1	6.7	0.00134	0.001351	0.064904	0.125595	0.738709
4.8	0.178	0.164475	0.999866	1	1	6.8	0.00103	0.001036	0.05017	0.097823	0.642795
4.9	0.138	0.129882	0.998996	0.999999	1	6.9	0.000787	0.000793	0.038601	0.075711	0.544931
5	0.107	0.10212	0.995231	0.999977	1	7	0.0006	0.000604	0.029544	0.058216	0.451073
5.1	0.0828	0.080019	0.984066	0.999746	1	7.1	0.000455	0.000458	0.022472	0.04444	0.365281
5.2	0.0641	0.062533	0.959443	0.998355	1	7.2	0.000342	0.000345	0.01696	0.033633	0.289734
5.3	0.0496	0.048765	0.916386	0.993009	1	7.3	0.000255	0.000257	0.01267	0.02518	0.225104
5.4	0.0384	0.037965	0.853577	0.97856	1	7.4	0.000188	0.000189	0.009335	0.018583	0.171039

Table 3.5: Annual Rate occurrence of Earthquake Magnitude vs. Improbability in the area S.W. Zagross Province.

Annual Probability						Annual Probability					
Ms	Rate	year	year	year	year	Ms	Rate	year	year	year	year
Ms	LAMBDA	(T=1)	(T=50)	(T=100)	(T=1000)	INT/MAG	LAMBDA	(T=1)	(T=50)	(T=100)	(T=1000)
3.6	8.71E+00	0.999989	1	1	1	5.4	2.74E-01	0.239947	0.999999	1	1
3.7	7.26E+00	0.999447	1	1	1	5.5	2.25E-01	0.201479	0.999987	1	1
3.8	5.99E+00	0.99766	1	1	1	5.6	1.84E-01	0.168223	0.9999	1	1
3.9	4.95E+00	0.993085	1	1	1	5.7	1.50E-01	0.139695	0.999459	1	1
4	4.09E+00	0.98343	1	1	1	5.8	1.23E-01	0.11538	0.997821	0.999995	1
4.1	3.38E+00	0.966079	1	1	1	5.9	9.95E-02	0.094768	0.993108	0.999952	1
4.2	2.79E+00	0.938793	1	1	1	6	8.05E-02	0.077371	0.98215	0.999681	1
4.3	2.30E+00	0.900379	1	1	1	6.1	6.48E-02	0.062741	0.960808	0.998464	1
4.4	1.90E+00	0.851043	1	1	1	6.2	5.18E-02	0.050475	0.924926	0.994364	1
4.5	1.57E+00	0.79232	1	1	1	6.3	4.10E-02	0.040217	0.871532	0.983496	1
4.6	1.30E+00	0.726693	1	1	1	6.4	3.22E-02	0.031655	0.799734	0.959893	1
4.7	1.07E+00	0.657076	1	1	1	6.5	2.48E-02	0.024522	0.710959	0.916455	1
4.8	8.83E-01	0.586347	1	1	1	6.6	1.88E-02	0.018587	0.608567	0.84678	1
4.9	7.28E-01	0.517013	1	1	1	6.7	1.37E-02	0.013654	0.497079	0.74707	0.999999
5	6.00E-01	0.451024	1	1	1	6.8	9.60E-03	0.009559	0.381337	0.617257	0.999933
5.1	4.94E-01	0.389736	1	1	1	6.9	6.18E-03	0.006162	0.26583	0.460994	0.99793
5.2	4.06E-01	0.333953	1	1	1	7	3.35E-03	0.003346	0.154258	0.284721	0.964944
5.3	3.34E-01	0.284024	1	1	1	7.1	1.01E-03	0.001012	0.04936	0.096283	0.63665

3.2.3. Return Period of Magnitude Occurrence

As mentioned upper part of report the maximum likelihood function hazard parameters method, and other methods estimated return period of magnitude in area understudy (R=100 and 1500 Km and S.E. Zagros province).

The results of this study are shown in several Tables that mentioned in tables 3.6, 3.7 and 3.8 for region in R=100 & 150 Km far of the site and S.E. Zagros province.

Two levels of earthquakes will be determined. These are defined as below:

I) Seismic Level 1 (SL1):

This Earthquake may be expected to occur during the lifetime of Structure. The SL1 represents the level of ground motion at the site which only minor damage is acceptable.

The structures should remain functional and damage easily repairable from the occurrence of earthquake shaking not exceeding the SL1. In this study return period of occurring of the SL1 is 475 years.

II) Seismic Level 2 (SL2):

This earthquake is large, but low probability of occurrence. The SL2 will produce the level of ground motion for which the structure should be designed or analyzed. The structure should stay “fail safe”. For structures whose failure would present a large social hazard, the SL2 will normally be characterized by a level of motion to be induced by the return period of occurring of 2475 years.

III) Maximum Credible Earthquake

The largest earthquake judged possible given the seismic history and tectonics of the region surrounding the site. The Return Period of occurring of the MCE is more than 10000 years.

The Maximum Credible Earthquake (MCE) is the largest reasonably conceivable earthquake that appears possible along a recognized fault or within a geographically defined tectonic province, under the presently known or presumed tectonic framework. The MCE is generally defined as an upper bound of expected magnitude. The magnitude of this level has been estimated based on the potential of the seismicity of the Asaluyeh, Kazerun, Borazjan, Karebas and ... faults.

Table 3.6: Distribution of Magnitude vs. Return Period (year) based on data recorded in R=100 and 150 Km and Gutenberg- Richter Value

Ret. Per.	100 km	150 km	Ret. Per.	100 km	150 km
1	4	4.5	21	5.4	6.1
2	4.3	4.9	22	5.4	6.2
3	4.5	5.1	23	5.4	6.2
4	4.6	5.2	24	5.4	6.2
5	4.7	5.4	25	5.4	6.2
6	4.8	5.5	50	5.8	6.6
7	4.9	5.5	75	5.9	6.8
8	4.9	5.6	100	6.1	7
9	5	5.7	125	6.2	7.1
10	5	5.7	150	6.2	7.2
11	5.1	5.8	175	6.3	7.3
12	5.1	5.8	200	6.4	7.4
13	5.2	5.9	300	6.5	7.6
14	5.2	5.9	400	6.7	7.7
15	5.2	6	500	6.8	7.9
16	5.2	6	600	6.9	8
17	5.3	6	700	6.9	8.1
18	5.3	6.1	800	7	8.1
19	5.3	6.1	900	7	8.2
20	5.3	6.1	1000	7.1	8.2

Table 3.7: Distribution of Magnitude vs. Return Period (year) based on data recorded in R=100 and 150 Km and Extreme Value Fitting Method type I, III and S

Return Period (year)	Magnitude (Ms)			Magnitude (Ms)		
	100 km			150 km		
	I	III	S	I	III	S
10	4.864	4.937	4.895	5.259	5.477	5.343
12	4.974	5.043	5.004	5.418	5.647	5.517
15	5.107	5.166	5.134	5.61	5.835	5.719
19	5.246	5.288	5.267	5.813	6.013	5.92
25	5.407	5.42	5.414	6.046	6.196	6.135
31	5.532	5.518	5.525	6.228	6.324	6.29
39	5.666	5.616	5.639	6.421	6.447	6.442
50	5.809	5.716	5.756	6.63	6.566	6.59
63	5.943	5.804	5.86	6.823	6.666	6.714
79	6.073	5.886	5.957	7.012	6.755	6.823
100	6.209	5.966	6.053	7.209	6.838	6.924
125	6.337	6.038	6.139	7.395	6.909	7.008
158	6.472	6.11	6.225	7.59	6.976	7.087
199	6.604	6.177	6.305	7.782	7.036	7.155
251	6.737	6.241	6.381	7.976	7.09	7.215
316	6.869	6.301	6.452	8.167	7.139	7.267
398	7.001	6.358	6.519	8.359	7.183	7.313
501	7.133	6.412	6.582	8.55	7.223	7.352
630	7.264	6.462	6.64	8.74	7.259	7.386
794	7.397	6.511	6.695	8.933	7.292	7.416
1000	7.529	6.557	6.747	9.124	7.321	7.442
1258	7.66	6.601	6.795	9.315	7.348	7.464
1584	7.792	6.642	6.84	9.506	7.372	7.483
1995	7.924	6.681	6.882	9.698	7.394	7.499
2511	8.056	6.718	6.92	9.889	7.413	7.514
3162	8.188	6.753	6.957	10.08	7.431	7.526
3981	8.32	6.787	6.99	10.271	7.447	7.536
5011	8.451	6.818	7.022	10.462	7.462	7.545
6309	8.583	6.849	7.051	10.653	7.475	7.553
7943	8.715	6.877	7.077	10.845	7.487	7.56
10000	8.847	6.904	7.102	11.036	7.498	7.566

Table 3.8: Distribution of Magnitude vs. Return Period (year) based on data recorded in R=100, 150 Km and S.E. Zagros and Kijko & Sellevoll Method.

Mag.	100 km	200 km	S.E.Z	Mag.	100 km	200 km	S.E.Z
3.5	0.3	0.2	0.1	5.7	134.1	56.1	6.6
3.6	0.4	0.3	0.1	5.8	177.5	72.5	8.2
3.7	0.6	0.3	0.1	5.9	235.6	93.7	10
3.8	0.8	0.4	0.2	6	314.3	121.2	12.4
3.9	1	0.6	0.2	6.1	421.7	156.7	15.4
4	1.3	0.7	0.2	6.2	570.5	202.7	19.3
4.1	1.7	0.9	0.3	6.3	780.9	262.5	24.4
4.2	2.3	1.2	0.4	6.4	1087.1	340.1	31.1
4.3	3	1.6	0.4	6.5	1551.1	441.1	40.3
4.4	3.9	2	0.5	6.6	2299.8	572.7	53.3
4.5	5.1	2.6	0.6	6.7	3645.2	745.1	72.7
4.6	6.7	3.4	0.8	6.8	6582.3	971.5	104.1
4.7	8.7	4.3	0.9	6.9	17094.3	1269.9	161.8
4.8	11.5	5.6	1.1	7		1667.2	298.5
4.9	15	7.2	1.4	7.1		2199.5	987.9
5	19.7	9.4	1.7	7.2		2922	
5.1	25.9	12.1	2	7.3		3923	
5.2	33.9	15.6	2.5	7.4		5329.4	
5.3	44.6	20.1	3	7.5		7384.5	
5.4	58.6	26	3.6	7.6		10526.4	
5.5	77.1	33.6	4.4	7.7			
5.6	101.6	43.4	5.4				

According to the above tables, the estimated magnitudes of the earthquakes based on region R=100 km for selected return periods are introduced to tables 3-9 and 3-10.

Table 3.9: Magnitude vs. Return Period (year) estimated by several methods.

Method	Area	Ret. Per. (Y)	Magnitude
G & R	100km	475	6.7
		2475	7.2
	150km	475	7.1
		2475	> 7.1
Like (Type III)	100km	475	6.4
		2475	6.7
	150km	475	7.2
		2475	7.4
Kijko & Sel.	100km	475	6.1
		2475	6.6
	150km	475	6.5
		2475	7.1
	E.S. Zag.	475	>7
		2475	>7.2

It is clear; that the results obtained using different models can have some differences. It is believed the best estimation is weighted value. To develop the weights the follows can be taken into accounts:

- Use of G&R model;
- Use of selected type III model;
- Use of Kijko&Sel model;

According to this method the weights for G&R, Type III and Kijki&Sel can be taken as 10%, 20% and 70%.

The magnitude estimations using obtained weights are shown in table

Table 3.10: Magnitude estimated for two return periods (year)

Area	Re. Per (Y)	Ms
100 km	475	6.2
	2475	6.7
150km	475	6.7
	2475	7.2
E.S. Zag.	475	>7
	2475	>7.2

We suggested the following values of earthquakes for SL1 and SL2 in the area of this project:

Return Period	Level of Earthquake (Years)	Magnitude (Ms)
475	SL1	6.2
2475	SL2	6.7

Section 4

4. Seismic Strong Ground Motion of Bedrock

4.1 Introduction

In the seismic hazard model, the ground motion at a site is modeled by an attenuation function which defines the complementary cumulative distribution function that any ground motion level $a^*(g)$, for a given magnitude m and distance r . The common assumption confirmed by observations is that PGA $(m,r) = a^*(g)$ is a log normal distribution is adopted. This probability can be evaluated based on the identity,

$$PGA(m,r) = F(u)$$

The standard normal variation is defined as a function of the predicted intensity of ground motion, which is a function of magnitude and distance, the variability in ground motion, and the ground motion level of interest, $a(g)$. thus, the standard normal variation is:

$$u = \frac{\ln(a^*) - \ln(a)}{\sigma \ln a}$$

Where, U = standard normal random variable.

A standard form of the attenuation equation was used:

$$\ln(a) = C1 + C2m + C3\ln d + C4d \quad 3-1$$

Where, $C1$, $C2$, $C3$ and $C4$ are coefficients derived by theoretical or empirical methods. $\sigma \ln a$ is the logarithmic standard deviation of a .

The attenuation model above predicts the mean of the natural logarithm of a , the ground motion parameter. The assumed functional form in equation 3-1 is efficient for seismic hazard computations, but the methodology is not restricted to this form. It is assumed that this form of the attenuation model is applicable in Iran and USA such as region of Zagros.

Logic trees are applied within the scope of individual phases of the seismic hazard analysis (e.g., evaluation of seismic sources) and on a global scale to display the multiple hypotheses, assumptions and uncertain parameters in the analysis. In the context of overall evaluation of the uncertainty in seismic hazard, progressing is:

- Seismic source combinations
- Seismicity parameter (i.e., recurrence rates, b-values)
- Maximum magnitudes
- Ground-motion attenuation functions.

4.2. Maximum Magnitude

For each seismic source, an estimate is made of the maximum magnitude that can be generated. Because prediction of the maximum magnitude is based on maximum potential of faults and limited historical seismicity data and judgmental extrapolations, the estimates of $M_{s_{max}}$ are uncertain. Experience in this study indicates there is often considerable uncertainty as to the choice of methods that should be used to obtain maximum magnitudes and for a given approach; there is uncertainty in the input parameters and/or uncertainty in the statistical relationships used to estimate the maximum magnitude.

There are two methods for prediction of maximum earthquake that will probably occur in the project area:

1. Estimation of maximum rupture dimension that will occur in future and relation of the dimension with earthquake magnitude.
2. Investigation of seismicity history and characteristics of occurred earthquakes in the studied region.

First method was being applied in this section. In order to decrease the uncertainty in estimation of the maximum magnitude a logic tree method was applied. We estimated maximum potential of active faults based on average value of several relations in the table 4.2.1.

Second method will be employed in the historical and instrumental earthquakes part:

Iranian historical earthquakes have been compiled in “A history of Persian Earthquakes” book written by Ambraseys & Melville [47] and Moeinfar & Mahdavian [67]. Historical earthquakes in accuracy in meizoseismal area, occurrence time and location, estimated magnitude and intensity, cause these data should be confirmed by applying instrumental data and field observation. Discussion of different techniques to estimate β , rate of occurrence and Maximum Magnitude are given in Item 3.2.2 and 3.2.3 of chapter 3.

Table 4.2.1: Maximum Potential of active faults around the site

Item	Fault Name	Fault Length (km)	Rupture Length (Km)	Distance (km)	Mechanism	Dip	Maximum Magnitude (Ms)					
							Nowroozi 1985	A. & J. 1998	W. & C. 1994	Bonilla 1984	Slemmons 1977	Final
1	Assaluyeh F4	98	46.0	27.0	Thrust	45°	7.06	7.00	7.02	7.22	7.00	7.1
2	Assaluyeh F2	104	52.0	18.0	Thrust	45°	7.13	7.05	7.08	7.25	7.05	7.1
3	Gavbandi	52	26.0	23.0	Thrust	45°	6.75	6.74	6.74	7.04	6.72	6.8
4	Varavi F1	115	66	4.0	Thrust	45°	7.25	7.16	7.22	7.33	7.17	7.2
5	Karebas	63	32.0	73.0	SS	90°	6.86	6.84	6.84	7.11	6.82	6.9
6	F6	103	52	76	Thrust	45°	7.13	7.05	7.09	7.25	7.05	7.1
7	Kazerum Boraz.	125	62	>100	SS	90°	7.22	7.13	7.19	7.31	7.14	7.2

4.3. Ground Motion Attenuation Uncertainty

The uncertainty in ground motion is incorporated in the seismic hazard analysis by considering multiple attenuation models, $GA | m, r (a^*)$. Weights may be assigned to each model by experts, based on the credibility that is given to the hypothesis that it is the “true” ground motion. In the content of the seismic hazard calculation, hazard curve results are generated for each attenuation model and all combinations of seismic sources and seismicity parameters. In this study, we used three empirical Attenuation Relationships of Peak Ground Acceleration (PGA), were published in the several Journals or international conferences.

It was decided to use the relationships given by Campbell and Bozorgnia (2003 and 2008) [82] and Ambraseys and Douglas (2005) [111] since they are based on a more worldwide set of accelerograms and Mahdavian (2006) [112], that his relationship is based on Iranian accelerograms data recorded on Zagross region. These relationships are for both horizontal and vertical components on Hard rock, soft rock and soils sites. Also each relationship has a parameter related to the style of faulting.

4.4 Selection of Contributing Sources

Identification of contributing sources is done for each site by examining the sources specified by each team in the region of the site. For applications, seismic hazard should be calculated for all sources within approximately 100 km of the Lamers factory site. For the Asaluyeh, Borazjan-Kazerun and Karez-Bas and another sources representing these high seismicity regions.

These sources contribute to hazard at distant site, only for ground motion characteristics that attenuate slowly with distance (generally long-period measure of motion).

4.5. Seismic Hazard Analysis

The seismic hazard at site due to a specific source is obtained by evaluating probabilistic approach for specified input on:

- 1-Geometry of the seismic sources (Based on Tectonic and seismotectonic maps).
- 2-Seismicity (β value activity rate of occurrence, M_{max}) within the Sources (Based on item 3.2.).
- 3-An attenuation function allowing estimation of ground motion as a function of earthquake magnitude and distance (Based on three attenuation relations).

4.5.1. Probabilistic Approach

In this method, cumulative distribution functions was used to evaluate peak horizontal and vertical ground motions for different return periods at the Lamerd Factory site.

The method used in this analysis is a variant of the Cornell method [86], McGuire 1976, 1978) and [99] and is similar to formulation given in Bender and Perkins [113]. The programs which used for this analysis are SHAZAP (1990) (Seismic Hazard Analysis Program). This program is based on Seisrisk III (1987) [113] program.

The algorithms used in SHAZAP are more efficient and result in a much more compact program. In order to evaluate peak horizontal and vertical ground acceleration at the site site all the major line sources (Hidden Faults & Capable Fault) and seismic source ones in the area under study were modeled. By using the several attenuation relationships in the SHAZAP program, values of Peak Ground Acceleration were computed.

According to this estimation of the Peak Ground Acceleration (PGA) for several return periods is introduced in tables and figures 4.5.1 and 4.5.2 for several return periods (year). The PGA for seismic levels SL1 and AL2 with return periods 475 and 2475 years on the basement of rock site are as following:

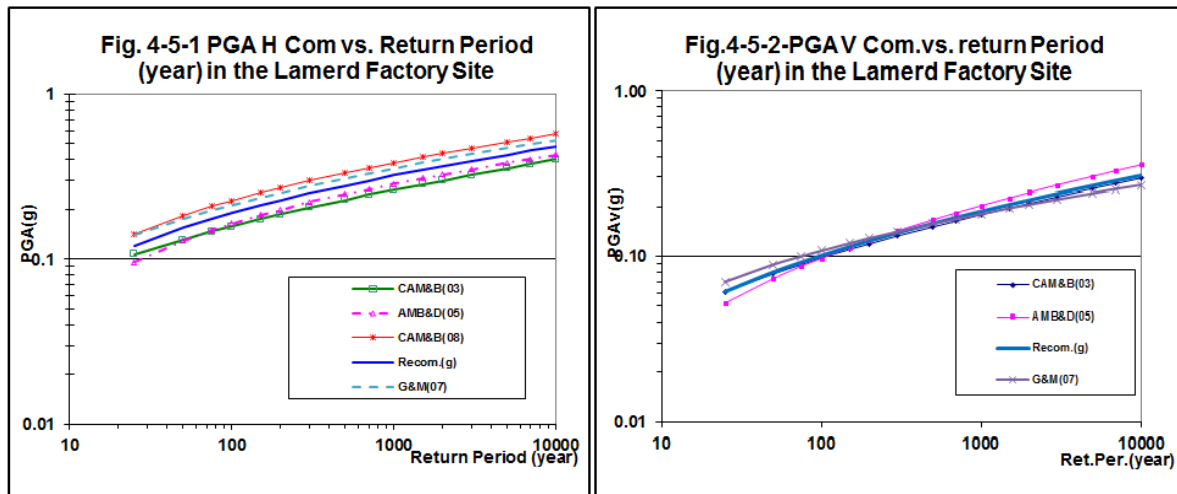
Return Period (years)	PGA(h) (g)	PGA(v) (g)
475 (SL1)	0.28	0.16
2475 (SL2)	0.38	0.23

Table 4.5.1: Peak Ground Hor. Acc. Vs. Ret.Per.(year) in the Lamerd Factory Site

RP(year)	CAM&B(03)	AMB&D(05)	G&M(07)	CAM&B(08)	Recom.(g)
25	0.107	0.096	0.14	0.1416	0.121
50	0.131	0.129	0.175	0.1824	0.154
75	0.147	0.15	0.197	0.2082	0.176
100	0.158	0.164	0.213	0.2262	0.190
150	0.175	0.185	0.236	0.2526	0.212
200	0.187	0.199	0.252	0.2706	0.227
300	0.205	0.221	0.277	0.2988	0.250
500	0.228	0.248	0.309	0.3342	0.280
700	0.245	0.266	0.331	0.3582	0.300
1000	0.263	0.286	0.355	0.3846	0.322
1500	0.284	0.309	0.383	0.4152	0.348
2000	0.3	0.326	0.403	0.4374	0.367
3000	0.324	0.35	0.433	0.4698	0.394
5000	0.355	0.382	0.471	0.5118	0.430
7000	0.377	0.403	0.498	0.5406	0.455
10000	0.402	0.427	0.526	0.5718	0.482

Table 4-5-2 Peak Ground VER. Acc. Vs. Ret.Per.(year) in the Lamerd Factory Site

RP(year)	CAM&B(03)	AMB&D(05)	G&M(07)	Recom.(g)
25	0.061	0.052	0.07	0.061
50	0.078	0.073	0.089	0.080
75	0.089	0.087	0.1	0.092
100	0.098	0.097	0.108	0.101
150	0.11	0.113	0.12	0.114
200	0.119	0.125	0.129	0.124
300	0.133	0.143	0.141	0.139
500	0.151	0.167	0.158	0.159
700	0.164	0.184	0.169	0.172
1000	0.179	0.203	0.181	0.188
1500	0.196	0.226	0.196	0.206
2000	0.209	0.243	0.206	0.219
3000	0.229	0.269	0.221	0.240
5000	0.256	0.303	0.241	0.267
7000	0.274	0.328	0.255	0.286
10000	0.295	0.355	0.269	0.306



4.5.2. Deterministic Approach

The deterministic method consists of a combination of a maximum credible earthquake and distance, which can be used, together in attenuation relationships to compute Peak Ground Acceleration. As it was mentioned in this study three different attenuation relationship were used to compute the PGA for different scenario near to the site. The most important deterministic scenario is identified based on the seismotectonic studied of the Factory project region. According to this study the most important sources to Lamerd factory site is a segments of M.F.F. fault with the name of Asaluyeh(F2) and Varavi (F1) faults, which are located very near the site. Table 4.5.2.1 shows the results of PGA and also other useful parameters of these faults and also for some other important faults which are located near to site. It must be mentioned that final results are obtained based on a logic tree approach using three different attenuation relationships as it was shown in table 4.5.2.1.

Table 4.5.2.1: shows the results of PGA and also other useful parameters based on Deterministic approach.

Fault Name	Distance (km)	Dip Deg.	rjb	FD KM.	M	Com.	PGA (g)				Recom. PGA (g)
							Cam&B.03	Cam&B.08	Amb&D.05	Mah.	
Assaluyeh F2	21	45°	7	10	7.1	H	0.612	0.622	0.471	0.586	0.573
	21	45°	7	10	7.1	V	0.47		0.391	0.221	0.361
Varavi F1	3	45°	8.5	10	7.2	H	0.61	0.56	0.441	0.585	0.549
					7.2	V	0.466		0.367	0.22	0.351
Assaluyeh F4	23	45°	20	10	7.1	H	0.35	0.29	0.235	0.366	0.317
					7.1	V	0.258		0.165	0.153	0.144

4.6 Design Peak Ground Accelerations for Basement

Ground motions are defined in terms of ground accelerations. There are 3 levels of earthquake ground motion will be determined. These are introduced below:

<u>Ground Motion Level</u>	<u>Horizontal</u>	<u>Vertical</u>
<u>Year and Level</u>	<u>PGA_h (g)</u>	<u>PGA_v (g)</u>
475 (SL1)	0.28	0.16
2475 (SL2)	0.38	0.23
MCE	0.57	0.36

Section 5

Design Response Spectra for bedrock

5.1. General approach

To study the dynamic behavior of a structure during strong earthquakes and then design it safe and economical, it is necessary to consider the effects of strong ground motion characteristics at the location where the structure is to be built. It should however be noted that PGA alone cannot show the extent of the effect of vibrations of a structure. For example, in the Zanjiran earthquake of 20.3.1994 ($M_s = 5.8$) whose peak horizontal acceleration was recorded more than 1 g at a school building with relatively good masonry material, the building completely survived the quake. This shows that not only peak ground acceleration, but also other factors such as strong motion duration, geological setting at the site, frequency content of strong ground motion of the site and the corresponding structural behavior and, in all, the amount of the released energy govern the extent of detraction or damage suffered by a structure. Thus, an earthquake with certain peak horizontal acceleration and long significant duration can cause more damage than another earthquake with the same peak horizontal acceleration and shorter significant duration. Should the dominant frequency of the resulting spectrum from an earthquake at a certain location be close to the range of the vibration frequency of a structure, the vibration of the structure will be amplified and will results in more damages.

Several methods can be used to generate response spectra; such as a Standard response spectrum, Site specific response spectrum and Uniform confidence response spectrum. However, the best method is the one by which the relevant spectrum is generated on the basis of the recorded accelerograms of different earthquakes at the same location. Therefore, more suitable design spectrum can be prepared for a place if sufficient number of accelerograms be available for that place, but due to the lack of sufficient number of accelerograms, they available ones can be divided into different groups and then, design spectra are prepared.

The most important factors that affect the shapes of response spectra are as follows:

- The amount of the released energy due to the earthquake which is usually shown by seismic moment or magnitude of earthquake.

- Physical properties and thickness of the site foundation material.
- Distance from the earthquake focus to the point where the accelerogram has been recorded, and geological setting of the waves passage course.
- Mechanisms of the earthquakes.

These data can be obtained using the recorded accelerograms. Also local geological setting may demonstrate its effect at any frequency, but this effect is quite clear on the relevant spectra mostly at lower frequencies (higher periods). These factors can help us in our attempt to classify the accelerograms response spectra suitably. Response spectra represent the maximum response (in acceleration, velocity, or displacement) as a function of frequency, for a given damping ratio, of a single-degree of freedom system subjected to a time-dependent excitation. Response spectra characterizing the SL1 and SL2 may be determined from peak ground acceleration, velocity and displacement consideration [115]; [116], or by using site-dependent or site-independent generalized spectra shapes.

When calculated in this manner, these are sometimes referred to as pseudo-acceleration, pseudo-relative velocity, or pseudo-relative displacement response spectrum values.

The increase of damping causes the decrease of response values of the system and more uniformity of the curve shape of spectrum, which is very irregular when damping is close to zero. In other words, the sensitivity of system to the period decreases with the increase of damping. In very low periods, damping of the system does not affect its response as the system behavior as a rigid body.

In this study, attempt has been made to show the results of different methods to estimate Design Response Spectra for Bedrock of Lamerd factory Site that located in the south of Iran, Zagros region.

5.2 Equal Probability Response spectra

Using the data described in item 4 we computed equal probability response spectra (EPRS) corresponding to exceedance probabilities in the range 10^{-4} to 10^{-2} years. The resulting spectra for the mean horizontal and the vertical components by several relationships and average value of these relations are shown in Figures 5-1- to 5-2 and table 5.1.

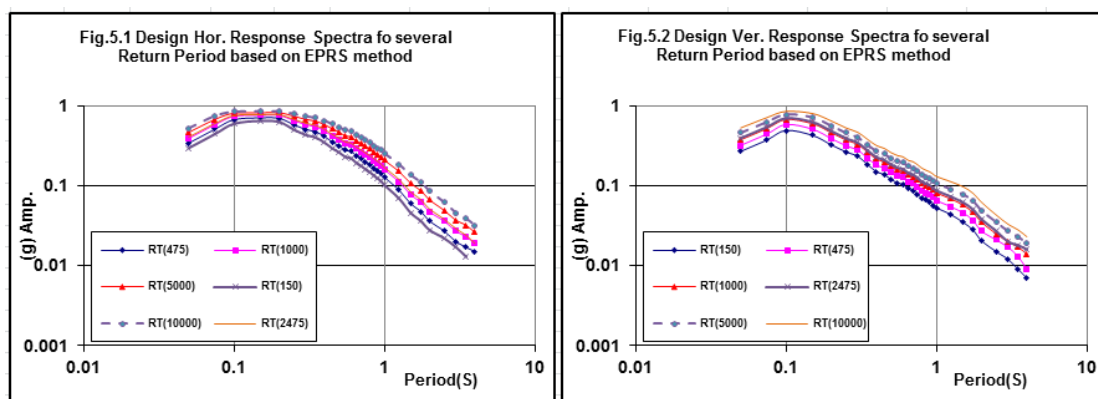


Table 5.1; Design Spectra for the mean horizontal and the vertical components, base on EPRS method.

Period	V Component			H. Component		
	v(475)	v(2475)	V(10000)	H(475)	H(2475)	H(10000)
0.05	0.319	0.393	0.527	0.34	0.406	0.524
0.075	0.444	0.544	0.712	0.51	0.601	0.748
0.1	0.5815	0.698	0.8475	0.669	0.7521	0.8398
0.15	0.5085	0.6245	0.7985	0.706	0.7725	0.849
0.2	0.3885	0.4825	0.6435	0.695	0.7706	0.8497
0.25	0.3165	0.3925	0.529	0.578	0.6736	0.7898
0.3	0.278	0.344	0.4645	0.506	0.6034	0.7383
0.35	0.219	0.274	0.377	0.471	0.5669	0.7044
0.4	0.181	0.2275	0.317	0.412	0.5056	0.6532
0.45	0.166	0.2095	0.2935	0.352	0.4393	0.5887
0.5	0.1455	0.1845	0.259	0.315	0.3961	0.541
0.55	0.132	0.168	0.238	0.278	0.3532	0.4921
0.6	0.1265	0.1615	0.2295	0.268	0.3407	0.4761
0.65	0.1125	0.1445	0.2075	0.237	0.3034	0.4289
0.7	0.1065	0.1375	0.1995	0.218	0.2813	0.4012
0.75	0.0965	0.1255	0.1825	0.198	0.256	0.3688
0.8	0.0865	0.1125	0.166	0.183	0.2388	0.347
0.85	0.0815	0.1065	0.1565	0.167	0.2184	0.3179
0.9	0.0775	0.1015	0.1495	0.154	0.202	0.2969
0.95	0.071	0.0935	0.14	0.143	0.1876	0.2766
1	0.0655	0.087	0.1305	0.128	0.1696	0.2536
1.25	0.0545	0.073	0.112	0.088	0.12	0.1864
1.5	0.046	0.062	0.0975	0.06	0.0837	0.1356
1.75	0.037	0.0505	0.0805	0.048	0.0668	0.1109
2	0.027	0.038	0.062	0.036	0.0512	0.0862
2.5	0.021	0.027	0.043	0.027	0.038	0.062
3	0.017	0.02	0.033	0.02	0.029	0.046
3.5	0.013	0.018	0.028	0.017	0.024	0.039
4	0.009	0.016	0.023	0.015	0.019	0.032

5.3 Statistical Responses Spectra

5.3.1. Accelerogram Selection criteria

In this section, the criteria used to select accelerograms from available data bases are discussed. Selection criteria include earthquake magnitude, distance range, site conditions and focal mechanism. The justification or rationales for these criteria are also discussed. The purpose of these criteria is to render the accelerogram suite as site-specific as possible.

5.3.1.1 Target Magnitude

The target magnitude is the midpoint of a range of earthquake magnitudes that are likely to control design. The magnitude of the causative earthquake of a recording in the selected suite should lie within 0.5 magnitude units or less of the target magnitude. As discussed in Kimball [117], the magnitude range about the selected target magnitude is chosen to account for the uncertainty in the assumed target magnitude and to ensure that a large enough data sample can be obtained. However, if the magnitude units, the amplitude and possibly the frequency content of the accelerogram will change significantly.

In Section 3, we calculated the rate of seismicity in the area under study. The historical record indicates several events of M6.5 or greater. However, based on the Historical and 20th century of record data as discussed in the Section 3, the return period of earthquake with M6.2 is about 475 year and for M6.7 is about 2475 year in the study area.

Another possible scenario is the occurrence of a large earthquake on the branch of MFF fault with the name Assaluyeh(F2) fault with 98 km with dip 45° set to the factory site and which surface rupture lies approximately 18 Km from the site. The magnitude of such an event may be as less than as Ms7.1, assuming rupture along the length of fault.

Another fault with the name Varavi fault (F1) located with surface rupture approximately 4km from the site and with maximum potential Ms7.2.

The appendix 1 (earthquake list) shows that in the area with a radius $R < 150$ km several historical and instrumental events occurred with magnitude between Ms6 to Ms7.1.

Such events will therefore control the seismic design of the most structure at the site. Ground motions from larger magnitude, more distant earthquakes may affect

structures having natural periods greater than 0.5 second. However, the comparison of several data suggests that peak ground acceleration due to moderate magnitude, near-field events would be at least equal or greater. Thus, we believe selected target magnitude is Ms 6.6. Therefore, a scenario during the lifetime of the site is the occurrence of M6.1 to M7.1 events.

5.3.1.2 Distance Range

Kimball [117], Bernreuter [118], and recommend that, in the absence of a well-defined localized source, the distance from the recording site to the rupture surface ranges between 0 to 30 Km with an average distance of 15 Km. Studies by Bernreuter [118] suggest that the greater the distance from the recording site, the greater the effects of inelastic attenuation and the greater the likelihood that waves travel through rock units with widely differing properties.

As mentioned in Section 2, the focal depths of large earthquakes are less than 20 km in the area.

A minimum distance criterion greater than 4 Km was therefore applied since the minimum distance from the Lamerd factory site to the rupture surface of the future large earthquake would be the depth to the seismic zone layer. A reasonable estimate of the minimum focal distance for the reactivity of the Assaluyeh and Varavi faults are less than 20 km. Thus the distance range for selection of accelerograms are less than 20 km.

5.3.1.3 Site Conditions

In this step calculated Design Spectra for basement of the site. The basement of sites at which the accelerograms selected for this study, were recorded on rock. Such conditions would best match those at the Lamerd factory site. Then, the first step of this study we use of accelerograms recorded on Rock sites.

5.3.1.4 Focal Mechanism

The focal mechanism of the causative earthquakes should be strike-slip and reverse mechanisms. Similar to the focal mechanisms observed in the south of Iran. The basis for this criterion is that some ground motion variability can be attributed to variation in focal mechanism [118].

5.3.2 Selected Accelerograms

Table 5-2-1 lists the selected accelerograms. A total of 46 recordings (two horizontal and one vertical component) were obtained, resulting in a total of 34 horizontal component accelerograms and 12 vertical components. Other relevant data for the causative earthquakes are also given in the table. Note that a few of the earthquakes in Table 5-2-1 do not satisfy the selection criteria. However, the recordings were included either because their response spectra are similar in shape and amplitude to those of accelerograms due to earthquakes that satisfied the criteria.

Table 5.2.1: List of Selected Accelerations time history for Statistical Method

Event Name	Event Date	Mag. (M)	Record Name	Recording Station	Dis. (Km)	Site Condition	Data Correction	Source	PGA	PGA
									H.(g)	V.(g)
North Ridge, USA	Oct.21,1954	6.5	LEU	Eureka Federal Bld.	8.0	Partly sediment Rock	BP,I	N.G.D.C.	0.217	0.1
Ahar Eq. First Eq. Azarbaijan	Aug. 11,2012	6.4	5558-01	Nahand St.	45	Hard sediment (Rock)	BL, BP	BHRC	0.204	0.093
Ahar Eq. First Eq. Azarbaijan	Aug. 11,2012	6.4	5579-1	Varzaghan	19	Hard sediment	BL, BP	BHRC	0.4	0.24
Karebas	MAY 6, 1999	6.3	2131_2	Baladeh	24	Rock	BP,BL	BHRC	0.43	0.177
Imperial Valley	Oct.15,1979	6.7	IVCOM	Compuertas	15	Rock	BL, BP	N.G.D.C.	0.168	.06
Irpinia, Ita.	Nov. 23, 1980	6.8	IRB	Brienza	18	Rock	BL, BP	N.G.D.C.	0.207	0.19
San Fernando, USA	Nov. 23, 1980	6.5	SFCA	Castaic	23	Thin soil	BL, BP	N.G.D.C.	0.29	0.156
Friuli	May,06 1976	6.5	FRTO	Tolmezzo	16	Soft Rock	BL, BP	BHRC	0.318	0.278
Irpinia, Ita.	Nov. 23, 1980	6.8	IRS	Sturno	19	Rock	BL, BP	N.G.D.C.	0.281	0.232
Ahar Eq. First Eq. Azarbaijan	Aug. 11,2012	6.4	5583-1	Nahad Dam	46	Rock	BL, BP	BHRC	0.12	0.07
Ahar Eq. second Eq. Azarbaijan	Aug. 11,2012	6.3	5583-3	Nahad Dam	34	Rock	BL, BP	BHRC	0.241	0.051
San Fernando, USA	Feb. 09, 1971	6.5	40GFS	Santa Felicia Dam	33	Sand &Shale	BP,I	D.D.S-7	0.21	.07
Changooreh-Avaj(2756-1)	Jun. 22, 2002	6.3	2748_1	Abegarm	33.0	soft Rock	BP	B.H.R.C.	0.125	0.05
Naghan	Apr.06-1977	6.2	1054-1	Naghan		soft Rock	BP	B.H.R.C.	0.65	0.48
Chngoleh-Avaj Iran	June 22, 2002	6.5	2756	razan		Rock	BL, BP	BHRC	0.186	0.113
Spitak	Dec.7,1988	6.8	SPIT	Gukasyan	28	Rock	BP,I	N.G.D.C.	0.18	0.135
Imperial Vally, USA	Oct. 15, 1979	6.7	IVDEL	Delta	21.8	Rock (Prob.)	BP,I	N.G.D.C.	0.289	0.151

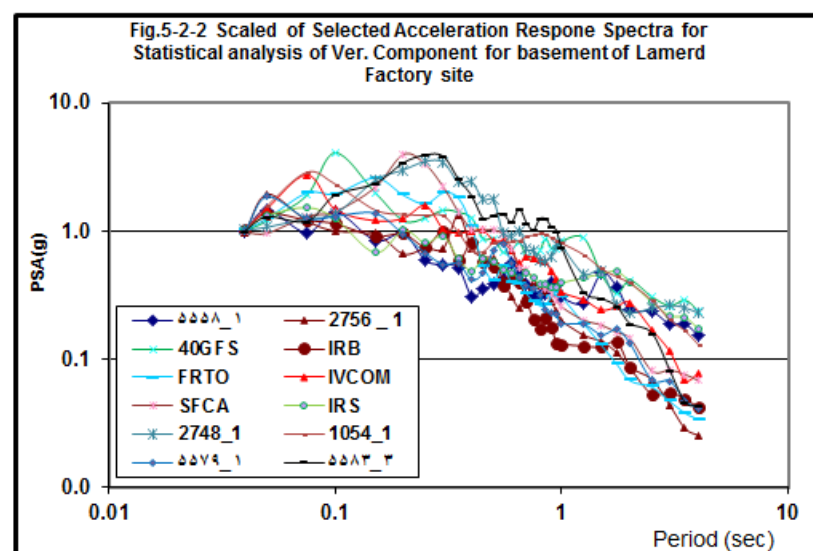
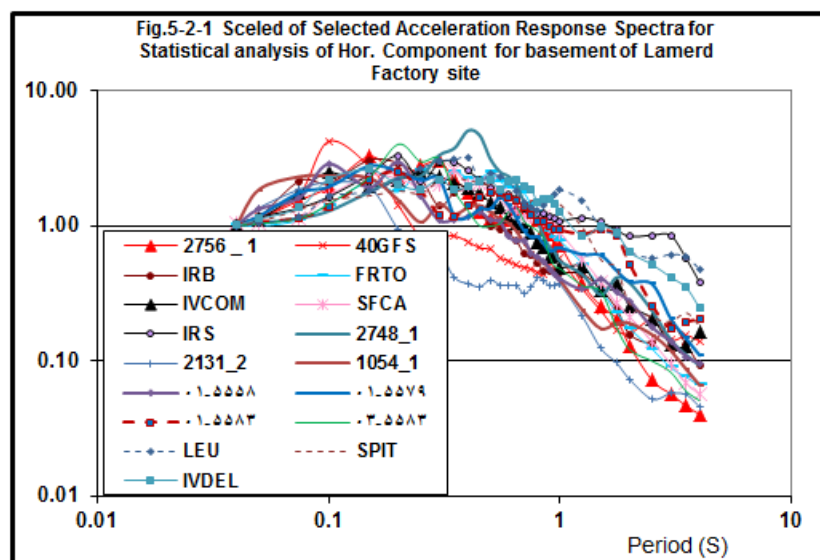
B.H.R.C: Building and Housing Research Center
 BL: Baseline Correction
 BP: Bandpass Filter
 I: Instrumental Corrections

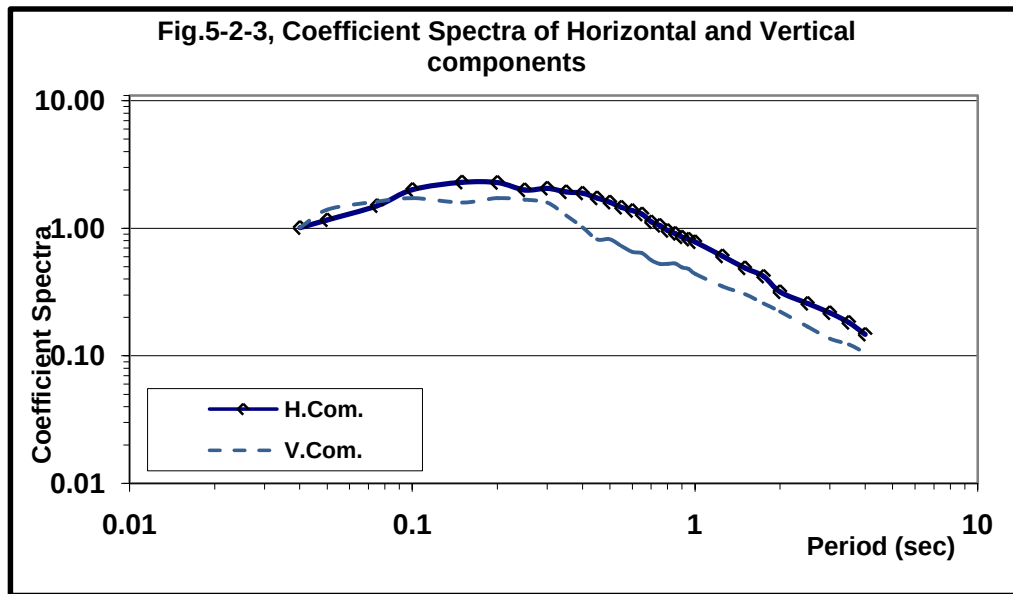
5.3.3 Design Response Spectra based on Statistical method for SL1 and SL2 for bedrock of site

The result of the selection process is a suite of accelerograms. The response spectrum of each accelerogram is then computed resulting in a suite of response spectra. Then, scaled all accelerogram timehistory to maximum acceleration of records and calculated response spectra of each component. Plots the scaled response spectra to maximum PGA of suit accelerograms are shown in Figures 5-2-1 & 5-2-2.

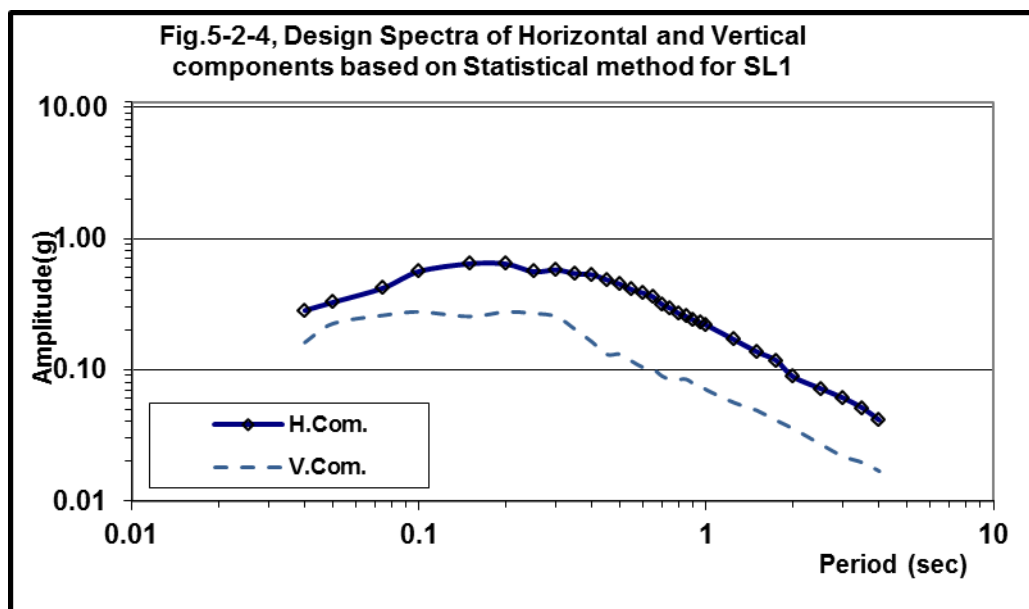
Finally, we calculated average value of all horizontal and vertical components separately and named coefficient spectra. Figure 5-2-3 shows the coefficient spectra of Horizontal and Vertical components.

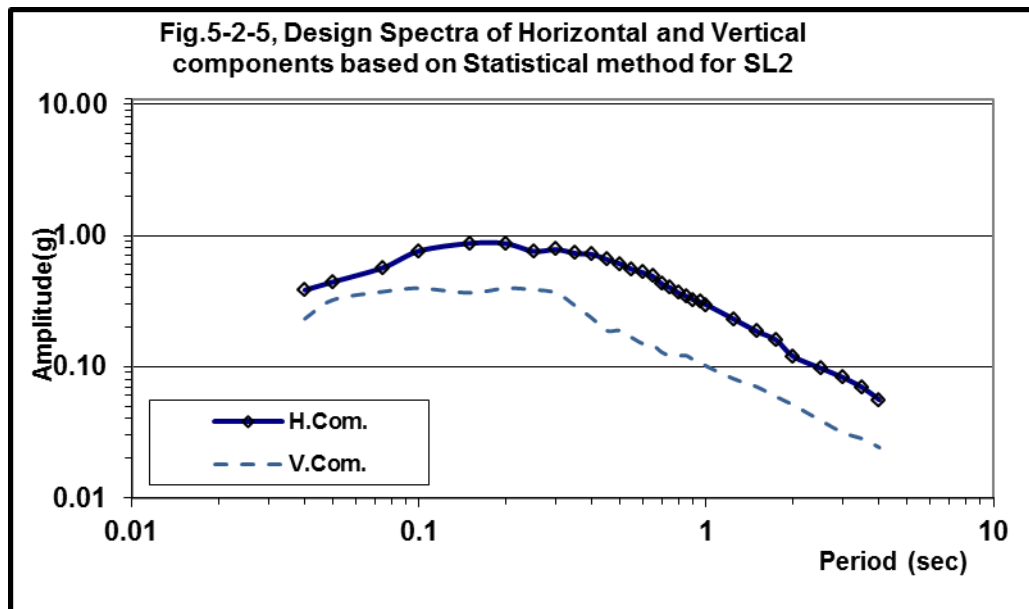
In the chapter 4 estimated Maximum Peak Horizontal Ground Acceleration 0.28g and 0.38g and Maximum Peak Vertical Ground Acceleration 0.16g, 0.23g for level SL1 and SL2 seismic design levels respectively.





In this part (statistical method) Design Response Spectra calculated for SL1 and SL2 level based on multiplied coefficient spectra to maximum value of PGA for Horizontal and Vertical components. Figure 5.2.4 and 5.2.5 show the Design Spectra for SL1 and SL2 levels of H. and V. components.





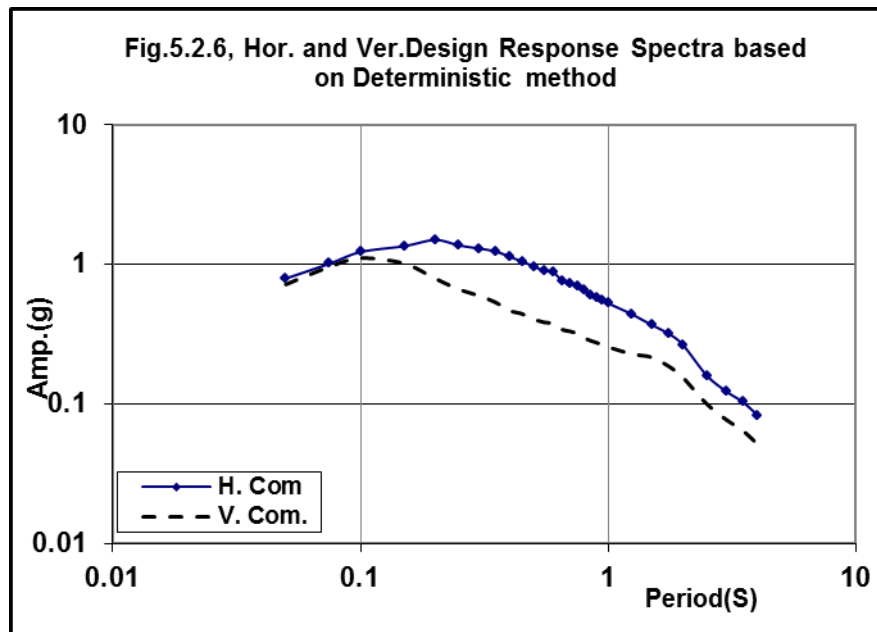
5.3.4 Design Spectra for Maximum Credible Ground Motions

Deterministic seismotectonic information can be used to define a maximum credible scenario composed of a combination of a maximum earthquake magnitude and a minimum distance to the fault rupture surface. Given this scenario, corresponding ground motions can be computed using an attenuation relationship and suitable time histories can be selected from the empirical data base. As discussed in Section 2, focal depths of large earthquakes in the area under study is between 10-15 Km, or seismogenic layer is between 10-15 km.

A minimum of the above range of focal depths is 10 Km. The minimum credible distance to the fault rupture surface is about 10 km.

Since the most seismic active fault in this area for the Factory site is Assaluyeh fault (f2) with reverse mechanism with 45° to the azimuth the site. Then the maximum magnitude calculated based on length of fault rupture is about Ms7.1.

The Design Spectra of earthquake scenario is presented in Figure 5-2-6. The Magnitude of earthquake scenario, M7.1 at D=18 and Rjb=8.5 Km and Seismogenic layer 10-15 km, is assumed along the following of most active Fault.



5.4. Design Response Spectra of bedrock

Response Spectra for 5% damping has been calculated by two methods for SL1 and SL2 and compare with together. Figures 5.2.7 and Table 5-2-2 show there are very good agreement between statistical method Design Spectra (SL1 and SL2) with 475 and 2475 year Design Spectra by EPRS method. This figure also show the design Spectra of MCL for 5% damping estimated by deterministic has a good agreement with design spectra estimated by EPRS for return period of 10000 years. Finally the target Design Spectra for each level and for basement of Lamerd Factory is selected.

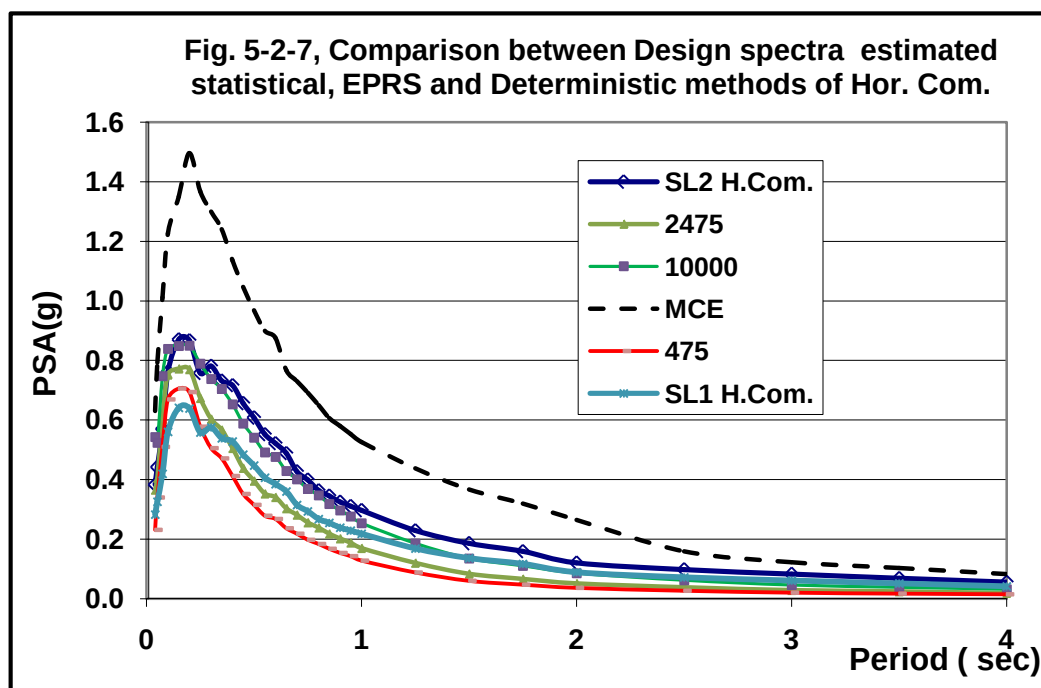


Table 5: Result of Statistical method of Seismic Design Spectra (SL1 and SL2) with 475, 2475 and 10000 year Design Spectra by EPRS and Deterministic methods.

	SL1	SL2	Det.		EPRS	
per.	H.Com.	H.Com.	MCE(84%)	475	2475	10000
0.040	0.283	0.383452	6.31E-01	2.31E-01	0.366	0.543
0.050	0.326	0.442286	7.93E-01	3.40E-01	0.406	0.524
0.075	0.420	0.569763	1.01E+00	5.10E-01	0.601	0.748
0.100	0.561	0.761403	1.23E+00	6.69E-01	0.752	0.8398
0.150	0.642	0.871026	1.35E+00	7.06E-01	0.773	0.849
0.200	0.639	0.867695	1.50E+00	6.95E-01	0.771	0.8497
0.250	0.558	0.757964	1.37E+00	5.78E-01	0.674	0.7898
0.300	0.576	0.781371	1.30E+00	5.06E-01	0.603	0.7383
0.350	0.539	0.731541	1.24E+00	4.71E-01	0.567	0.7044
0.400	0.528	0.716908	1.14E+00	4.12E-01	0.506	0.6532
0.450	0.484	0.656354	1.05E+00	3.52E-01	0.439	0.5887
0.500	0.448	0.607676	9.69E-01	3.15E-01	0.396	0.541
0.550	0.407	0.552342	9.00E-01	2.78E-01	0.353	0.4921
0.600	0.385	0.522106	8.76E-01	2.68E-01	0.341	0.4761
0.650	0.360	0.488947	7.67E-01	2.37E-01	0.303	0.4289
0.700	0.315	0.427076	7.31E-01	2.18E-01	0.281	0.4012
0.750	0.294	0.399119	6.92E-01	1.98E-01	0.256	0.3688
0.800	0.268	0.364066	6.50E-01	1.83E-01	0.239	0.347
0.850	0.254	0.345251	6.07E-01	1.67E-01	0.218	0.3179
0.900	0.239	0.324555	5.80E-01	1.54E-01	0.202	0.2969
0.950	0.229	0.311021	5.53E-01	1.43E-01	0.188	0.2766
1.000	0.218	0.296335	5.26E-01	1.28E-01	0.170	0.2536
1.250	0.169	0.229394	4.37E-01	8.83E-02	0.120	0.1864
1.500	0.137	0.185497	3.67E-01	5.96E-02	0.084	0.1356
1.750	0.118	0.159602	3.19E-01	4.75E-02	0.067	0.1109
2.000	0.089	0.120291	2.65E-01	3.62E-02	0.051	0.0862
2.500	0.072	0.097448	1.60E-01	2.70E-02	0.038	0.062
3.000	0.061	0.082459	1.23E-01	2.00E-02	0.029	0.046
3.500	0.051	0.069171	1.03E-01	1.70E-02	0.024	0.039
4.000	0.041231	0.055957	8.30E-02	1.50E-02	0.019	0.032

Figures 5.2.8 and 5.2.9 and Tables 5-2-3 recommended of Horizontal and Vertical Components of SL1, SL2 and MCE Seismic Design Spectra for Basement of Lamerd Factory.

Fig. 5-2-8, Recommended Seismic Design spectra for basement of SL1, SL2 and MCE for Horizontal Component

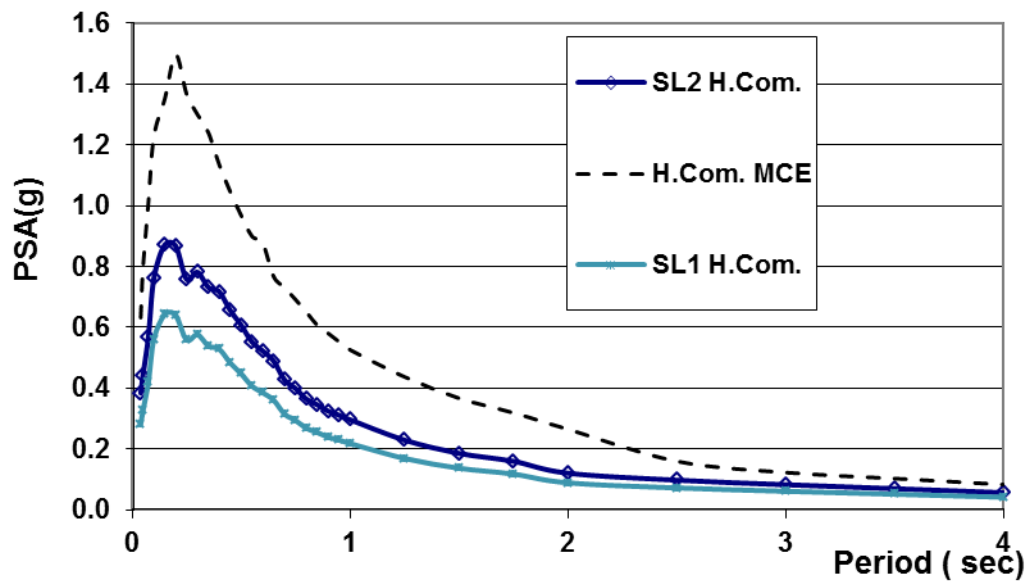


Fig. 5.2.9 Recommended Seismic Design Spectra for basement of SL1, SL2 and MCE for Vertical Component

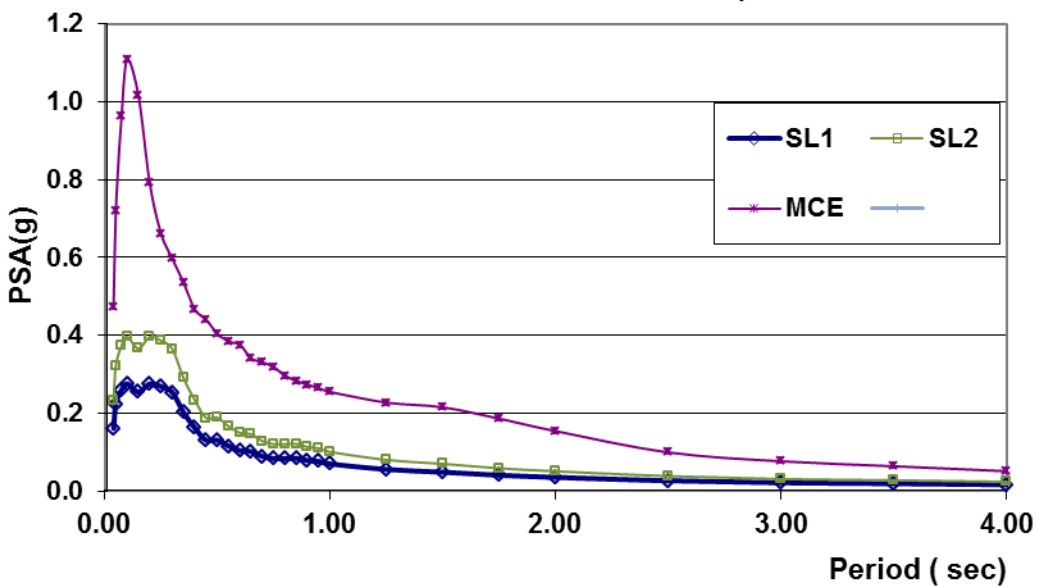


Table 5.2.3: Design response spectra for SL1, SL2 and MCE of Horizontal and vertical Components of basement of Lamerd Factory

Period	SL1		SL2		MCE	
SEC	H.Com.	V.Com.	H.Com.	V.Com.	H.Com.	V.Com.
0.04	0.283	0.161	0.383	0.232	0.632	0.472
0.05	0.326	0.225	0.442	0.323	0.793	0.719
0.08	0.420	0.260	0.570	0.373	1.012	0.962
0.10	0.561	0.276	0.761	0.396	1.227	1.108
0.15	0.642	0.255	0.871	0.366	1.351	1.016
0.20	0.639	0.276	0.868	0.396	1.497	0.791
0.25	0.558	0.269	0.758	0.386	1.368	0.662
0.30	0.576	0.254	0.781	0.365	1.300	0.597
0.35	0.539	0.202	0.732	0.290	1.241	0.535
0.40	0.528	0.163	0.717	0.234	1.135	0.467
0.45	0.484	0.131	0.656	0.188	1.047	0.441
0.50	0.448	0.131	0.608	0.189	0.969	0.405
0.55	0.407	0.116	0.552	0.167	0.900	0.385
0.60	0.385	0.104	0.522	0.150	0.876	0.376
0.65	0.360	0.102	0.489	0.146	0.767	0.341
0.70	0.315	0.090	0.427	0.129	0.731	0.331
0.75	0.294	0.084	0.399	0.121	0.692	0.319
0.80	0.268	0.084	0.364	0.121	0.650	0.297
0.85	0.254	0.085	0.345	0.122	0.607	0.283
0.90	0.239	0.079	0.325	0.113	0.580	0.274
0.95	0.229	0.077	0.311	0.110	0.553	0.264
1.00	0.218	0.070	0.296	0.101	0.526	0.255
1.25	0.169	0.056	0.229	0.081	0.437	0.228
1.50	0.137	0.049	0.185	0.070	0.367	0.216
1.75	0.118	0.041	0.160	0.059	0.319	0.186
2.00	0.089	0.036	0.120	0.051	0.265	0.154
2.50	0.072	0.027	0.097	0.039	0.160	0.100
3.00	0.061	0.022	0.082	0.031	0.123	0.077
3.50	0.051	0.020	0.069	0.028	0.103	0.064
4.00	0.041	0.017	0.056	0.024	0.083	0.051

Section 6

6- Scaling Filter Accelerogram for Basement (Rock) of Site

The scaling procedure is described below:

An accelerogram value $a(t)$ is first transformed to the frequency domain by means of the Fourier transform.

$$a(t) \longrightarrow A(f)$$

Frequency domain scaling coefficients are then computed as the ratio between the desired (target) amplitude of spectral ordinate “ s ” at the natural frequency “ f_i ” and the value of the spectral ordinate computed for “ $a(t)$ ”

$$H(f_i) = \frac{S(M, R, f_i)}{S(f_i)}$$

Where the numerator is computed using the attenuation relationships given the desired Magnitude M and distance R . The scaling is applied by multiplication in the frequency domain.

$$A_s(f) = H(f) A(f)$$

Scaling coefficients at frequencies not available in the relationships in probabilistic Hazard Analysis are obtained by linear interpolation. The inverse Fourier transform is then applied to A_s to obtain a scaled accelerogram.

The procedure may be applied iteratively in order to obtain a suitable match to the target spectrum. Generally, this is done until the average relative difference between the target spectrum and the computed spectrum is 10% or less.

6.1. Design Accelerograms of Bedrock

Several recordings were selected to scale for the basement (rock) of site for SL1, SL2 and MCE levels. The recordings were scaled by means of the procedure described in the upper part, so that their response spectra matched those of either the SL1, SL2 and MCE at 5% damping. The recordings are listed below and their scaled versions are recorded in a floppy diskette for bedrock of Lamerd factory Site.

1-SL1- Acceleration

5579-1L.DAT Horizontal Com.
5579-1T.DAT Horizontal Com.
5579-1V.DAT Vertical Com
1486-1L.DAT Horizontal Com.
1486-1T.DAT Horizontal Com.
1486-1V.DAT Vertical Com
5558-1L.DAT Horizontal Com.
5558-1TT.DAT Horizontal Com.
5558-1V.DAT Vertical Com

2- SL2- Acceleration

1493-2L.DAT Horizontal Com.
1493-2T.DAT Horizontal Com.
1493-2V.DAT Vertical Com.
2749-1T.DAT Horizontal Com.
2749-1T.DAT Horizontal Com.
2749-1V.DAT Vertical Com.
5583-3L.DAT Horizontal Com.
5583-3T.DAT Horizontal Com.
5583-3V.DAT Vertical Com.

3-MCE- Acceleration

Horizontal Com. 20EFA.DAT
Horizontal Com. 20EFB.DAT
Vertical Com. 20EFV.DAT
Horizontal Com. 1701-1L.DAT
Horizontal Com. 1701-1T.DAT
Vertical Com. 1701-1V.DAT
Horizontal Com. IVCOMH1.DAT
Horizontal Com. IVCOMH2.DAT
Vertical Com. IVCOMV.DAT

Section 7

7.1. SITE EFFECT

According to the studies down by Streeter et al. (1974) and Fin et al. (1978) the seismic response of soils overestimated when using equivalent linear approach. This happens due to pseudo-resonance at periods corresponding to the strain-compatible stiffness used in the final elastic iteration analysis. Additionally in the equivalent linear analysis material behaviour remains elastic so it cannot produce permanent deformations. in addition, Soil nonlinearities seems to be more significant in frequency band between 0.5 to 4 Hz (Darragh and shakal, 1991; Field et al, 1997; Beresnev, 2002) and have significant effect on motions with a PGA value greater than 0.1 – 0.2g and shear strain larger than 10^{-5} to 10^{-4} (Chang et al, 1989; Chin and Aki, 1991; Beresnev and Wen, 1996; Trifunac and Todorovska, 1996). With respect to the condition that we have in this project (peak ground acceleration is greater than 0.2 g) it is necessary to conduct a nonlinear dynamic approach. This approach will explain in following subsections. This section can be divided into three parts: Namely, soil model, one dimensional site response, and numerical formulation of solution [119].

- Soil model

In the early 1960s a soil model proposed by Konder and Zelasko (1963) is presented in Eq. (1):

$$\tau = \frac{G_{mo} \gamma}{1 + \left(\frac{G_{mo}}{\tau_{mo}} \gamma \right)} \quad (1)$$

Where τ is the shear stress and γ is the shear strain; G_{mo} the initial shear modul; τ_{mo} the shear stress at approximately 1% shear strain. After that Matasovic (1993) modified this model by adding parameters β and s and proposed a new model that can represent a wider range of maser soil behaviour as shown in Eq.(2) as following:

$$\tau = \frac{G_{mo} \gamma}{1 + \beta \left(\frac{G_{mo}}{\tau_{mo}} \gamma \right)^s} = \frac{G_{mo} \gamma}{1 + \beta \left(\frac{\gamma}{\gamma_r} \right)^s}, \quad (2)$$

In this model $\gamma_r = \tau_{mo} / G_{mo}$ is the reference shear strain and considered as a soil constant parameters (Hardin and Drnevich, 1972). After that Hashash and Park (2001) introduce a new formulation for the reference strain, γ_r , to capture the influence of confining pressure on modulus degradation and damping ratio by the Eq.(3):

$$\gamma_r = a \left(\frac{\sigma_r'}{\sigma_{ref}} \right)^b \quad (3)$$

Where a and b are curve fitting parameters and σ_{ref} is reference confining pressure of 0.18 Mpa.

- One dimensional site response

The main assumption in one dimensional site response analysis is propagation of SH waves (Horizontal Shear Waves), an approximation of earthquake ground motion, through a horizontally layered sediment. In this situation, the behaviour of soil can be modelled as a Kelvin-Voigt model. In early 1970s an equivalent linear method has proposed to model nonlinear cyclic response of soil for a certain ground motion acceleration time history and initial values and curves for module reduction and damping for each layer (Schabell et al., 1972). This approach needs an iteration scheme to solve the problem. After that studies done to involve dependency of soil parameters to pressure and frequency (Sugito, 1995; Assimaki et al., 2000). The advantage of these new models was the capturing of some high frequency components of strong ground motions that were filtering by older models. However, these models do not address full range of soil nonlinear behaviour like modules degradation due to number of loading cycles, residual strain of soils and pore pressure generation.

- Numerical formulation and time domain solution

The equation of motion for one dimensional propagating shear waves through an unbounded medium can be written as Eq. (4):

$$\rho \frac{\partial^2 u}{\partial z^2} = \frac{\partial \tau}{\partial z} \quad (4)$$

Where ρ = density, τ = shear stress, u = displacement and z = depth below the ground surface.

Soil behaviour is approximated as a Kelvin – voigt solid. The shear stress – shear strain relationship is expressed as Eq.(5):

$$\tau = G\gamma + \eta \frac{\partial \gamma}{\partial t} \quad (5)$$

Where G = shear modulus, γ = shear strain and η = viscosity.

Substituting Eq.4 to Eq.5 results in Eq.(6):

$$\rho \frac{\partial^2 u}{\partial t^2} = G \frac{\partial^2 u}{\partial z^2} + \eta \frac{\partial^3 u}{\partial z^2 \partial t} \quad (6)$$

In time domain analysis the soil column is idealized as discrete lumped mass system as shown in Figure 7.1 (Matasovic, 1993). The wave propagation equation is written as Eq.(7):

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = -[M]\{I\}\ddot{u}_g \quad (7)$$

Where $[M]$ = mass matrix; $[C]$ = damping matrix; $[K]$ = stiffness matrix; $\{\ddot{u}\}$ = vector of nodal relative acceleration; $\{\dot{u}\}$ = vector of nodal relative velocity and $\{u\}$ = vector of nodal relative displacement. $\ddot{u}_g$ is the acceleration at the base of sediment and $\{I\}$ is the unit vector. Eq 4, is solved numerically at each time step using the Newmark β method (Newmark, 1959). The Newmark β (average) method is unconditionally stable and does not introduce algorithmic damping.

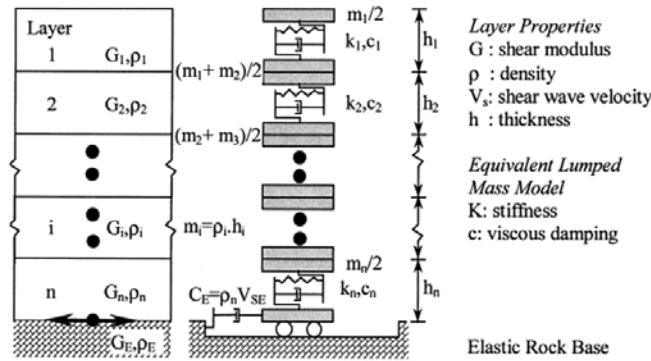


Figure 7.1: Idealized soil column as discrete lumped mass system (Matasovic, 1993)

Each individual layer i is represented by a corresponding mass, a nonlinear spring and a dashpot for viscos damping. The $[K]$, $[M]$ and $[C]$ matrices are assembled using incremental properties of the soil layers. This procedure needs a constitutive model that describes the cyclic behaviour of soil. The mass matrix forms by Lumping half mass of each of two consecutive layers at their common boundary and in order to consider nonlinearity of soil, the stiffness matrix is updated at each time increment and for each layer i , is defined as Eq.(8):

$$K_i = \frac{G_i}{h_i} = \frac{\Delta \tau_i \gamma_i}{h_i \Delta \gamma_i} \quad (8)$$

Where G_i is the shear modulus and h_i is the thickness of layer i .

Matrix $[C]$ represents additional viscos damping at very small strains where the soil behaves linear. This matrix is frequency dependent. In the original damping formulation proposed by Rayleigh and Lindsay (1945), this matrix is a combination of mass and stiffness matrices that can be represented as Eq.(9):

$$[C] = \alpha_0 [M] + \alpha_1 [K]. \quad (9)$$

But here the damping matrix $[C]$ is dependent on natural mods of soil column in addition to mass and stiffness. Scalar values of α_0 and α_1 can be computed using tow significant mods m and n by Eq.(10) as following:

$$\begin{bmatrix} \varepsilon_m \\ \varepsilon_n \end{bmatrix} = \frac{1}{4\pi} \begin{bmatrix} 1/f_m & f_m \\ 1/f_n & f_n \end{bmatrix} \begin{Bmatrix} \alpha_0 \\ \alpha_1 \end{Bmatrix} \quad (10)$$

Usually in site response analysis the natural frequency of selected mode calculated using Eq.(11) (kramer, 1996)

$$f_n = \frac{V_s}{4H} (2n - 1) \quad (11)$$

Where n is mode number and f_n is the natural frequency of the corresponding mode

Equation 11 results in a frequency dependent damping ratio even if the specified damping ratios in selected modes are equal. Since soil behaviour in medium to strong earthquakes like those predicted for this project is inelastic, the linear and equivalent linear solutions are no longer valid. In this study in order to capture important parameters mentioned earlier, a nonlinear approach that solves dynamic equation of motion in discrete time increments has been used. In this approach the dynamic equation of motion is integrated in time domain and soil nonlinearity can accurately modelled.

According to guidelines proposed by Park and Hashash (2004), to performing nonlinear site response layer thickness must calculate by using Eq.(12) to avoid filtering of relevant frequencies.

$$f_{max} = \frac{(V_s)_i}{4h_i} \quad (12)$$

Where f_{max} = maximum frequency that layer i can propagate, $(V_s)_i$ = shear velocity, h_i = thickness of each layer.

It is a common practice to set the maximum frequency to 25 Hz in a non-linear site response analysis (Hashash et al., 2011). The frequency used here is equal to $f = 60\text{Hz}$.

Since the conventional guideline of using the first and higher mod of soil column or predominant period of the input motion will not always result in a good match whit the linear frequency domain solution. Appropriate frequencies for the viscos damping formulation are chosen based on the linear analysis for each soil profile and each input motion.

In the given work, the account of the transfer characteristics of the soil thickness and seismic intensity increments with the help of DEEPSOIL computer program was executed.

As discussed the transfer functions computational method is realized on the basis of the initial engineering-geological, seismic, geotechnical and seismological data on the structure and physical-mechanical characteristics of the soil thickness of the site and acceleration time-histories simulated according to the results of bedrock as detailed on section 6 of this seismic report. The transfer functions of the layered soil thickness are calculated at the given seismic loading. Local response spectra of the basement and functions of amplification of the vibrations for model of structure and properties of the soil thickens corresponding to the site are determined.

The data obtained on the calculated local maximum accelerations of the soil vibrations and the response spectra, as well as the relative intensity increments computed on this basis are used for compiling by the transfer functions method.

Program DEEPSOIL was developed at the 2002-2015 Board of Trustees of University of Illinois at Urbana-Champaign and Youssef Hashash. The program is intended to account for the influence of the layered soil medium on the dynamic characteristics of seismic vibrations with a source in a half-space, at the surface of the soil or in any of the layers. One-dimensional (vertical) wave propagation is simulated in the assumption that the layers are horizontal. Thus, acceleration T.H.s, recorded at surface of sedimentary thickness can be used for generating acceleration T.H.s referring to rock basement. The latter, in turn, can be used as an input initial loading at the basement of sedimentary thickness with other properties and structure.

7.2. Velocities Models of Soil Massif

In this project, many boreholes exhaustive underground investigation including SPT measurements, geophysics related to Vs and Vp parameters measurements, the soil layers mechanic and dynamic properties of each layer are performed.

in addition to subsurface soil layers properties, surface geology plays a crucial role in site effect Frankel et al. (2002) computed soil- to- rock spectral ratio for 35 locations using recordings of the Nisqually earthquake (M=6.8) and its aftershock (M_L=3.4) to study site response and basin effects in the region. They found that site amplification was correlated to surficial geology and the nonlinearity of soft soils. Whit studying Miyagi-Oki earthquake Tsuda et al. (2006) observed that nonlinear soil behavior occurred at the stations with a softer near-surface velocity structures.

To estimate Velocity Model of Soil Massif, For Lamerd factory project, we used the results of boreholes SPT tests and using Shear wave velocities that we had measured along the boreholes. In our point of view we have compared Shear wave velocities along the boreholes with the result of Shear wave velocities estimated by Nspt test. There is no significant difference of Shear wave velocity along the boreholes that estimated by geophysical method. Figure 7.2.1 shows the results of SPT tests for all boreholes. About 2-5 m deposit will be influenced by water table fluctuations, strength parameters decrease or excavated in the future for structure's basement; therefore we have not used SPT of first 5 m of boreholes in this study. Based on this figure we recommended SPT=12, 17 and over 30 for depths 5-15 m, 15-25m and more than 25 m respectively. To estimate Shear wave velocities we used mean value of results from relationship between Nspt and Shear wave velocity for clay introduced by Hasancebi and Ulusay 2007 (CL), Hasancebi and Ulusay 2007 (ALL), Pitilakis et al. 1999 (Clay), Jafari et al 2002 (Clay) and Lee 1992 for Clay. The shear wave velocities of layers calculated 230, 250 and 350 m/s for depths 5-15 m, 15-25m and 25-50 m respectively. We selected bedrock at the depth more than 50 m. We selected this typical soil profile to use as initial data for computational model.

Average volume density values for the layer is ρ between 0.16 to 0.2 g/cm³.

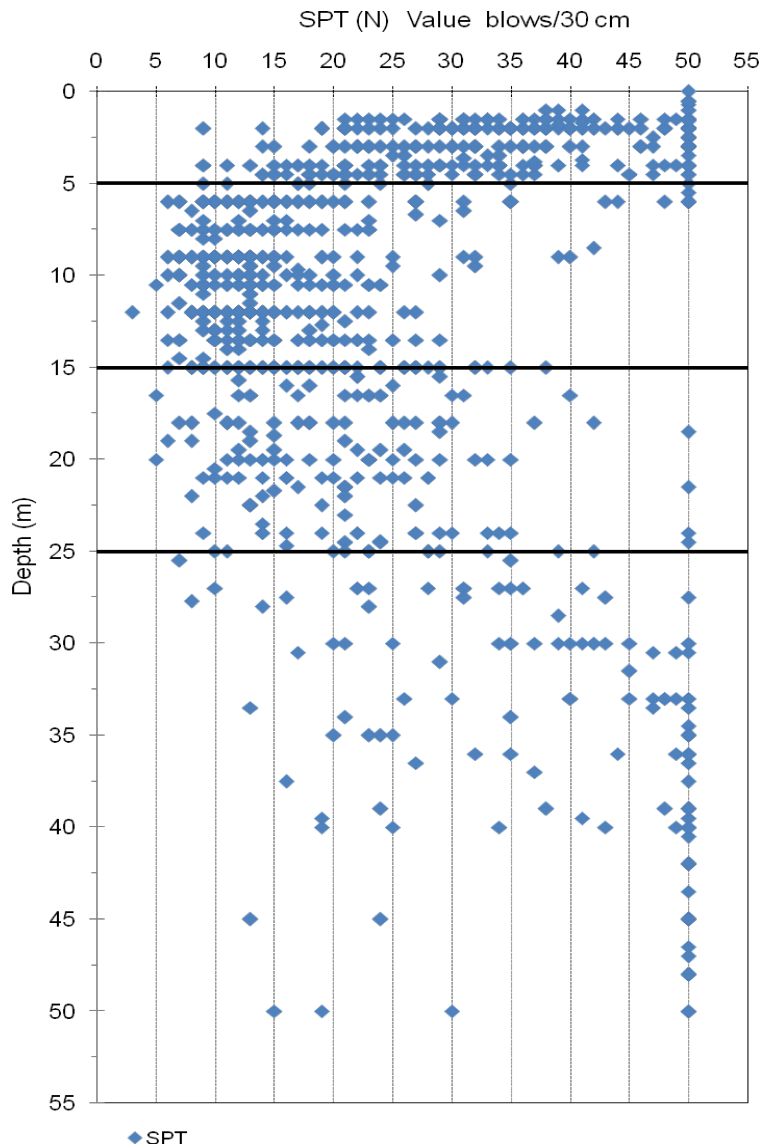


Figure 7.2.1: SPT numbers and depth of all tests from Lamerd factory project.

7.3. Estimating of Site-specific Amplification Spectra

Site-specific amplification spectra were estimated by computer program DEEPSOIL.

Acceleration time histories of seismic loading from SL-1, SL-2 and MCE level earthquakes (as discussed in the section 6) were accepted as initial data for the site-specific parameters computations.

Site-specific typical soil profiles were used as initial data for compiling of the site soil thickness computational model. The soil frequency properties and strong motion

characteristics at the considering seismic loading were calculated for the typical soil profile which serve as soil bases for the main buildings and constructions of the Lamerd factory.

According to this depth profile data dependencies of cumulative layer velocity versus depth and their approximations were constructed. Based on the data approximate resonance layer thicknesses were calculated. As a boundary between soil thickness and rigid basement (hard rock basement) the soil thickness of 50 m was adopted.

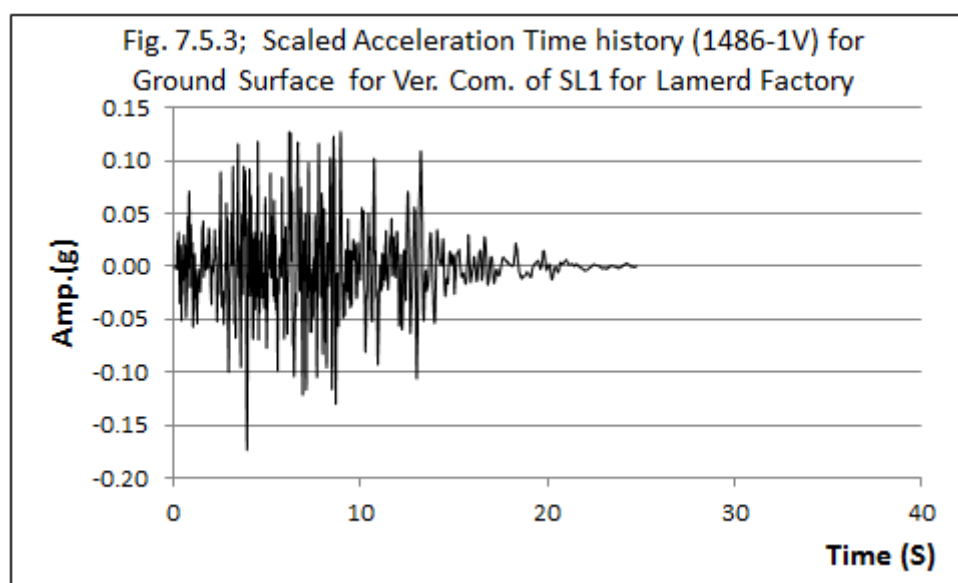
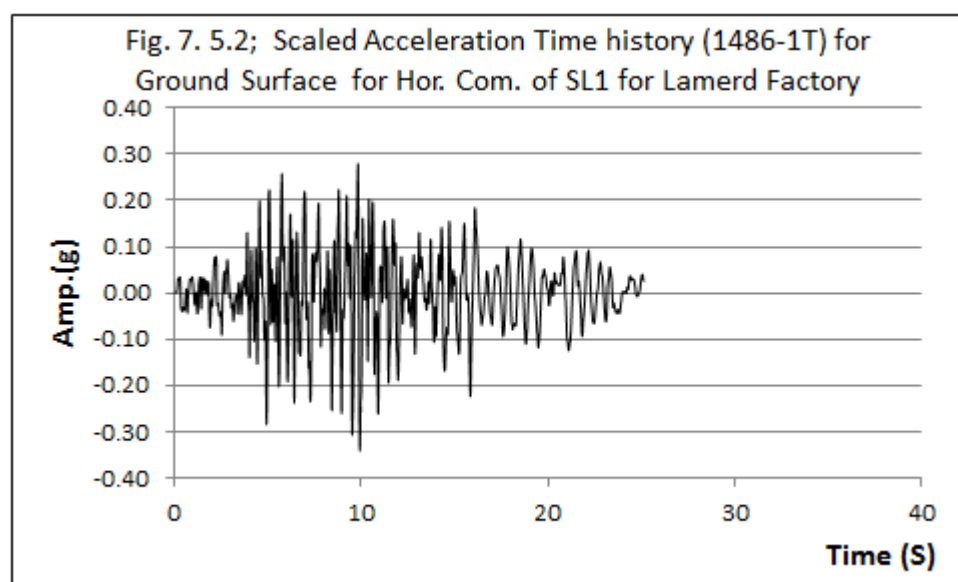
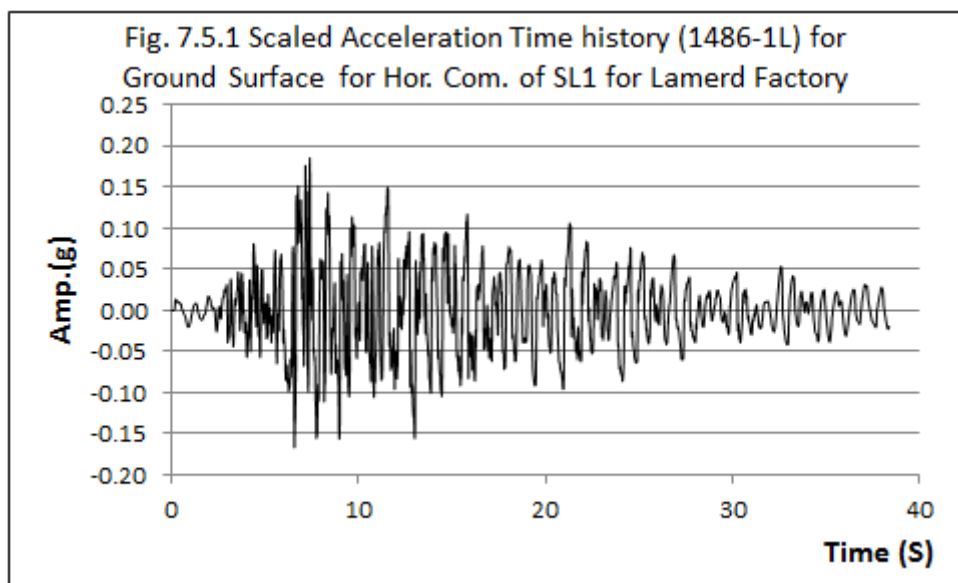
7.4. Site-specific Horizontal Vibration Amplification Spectra

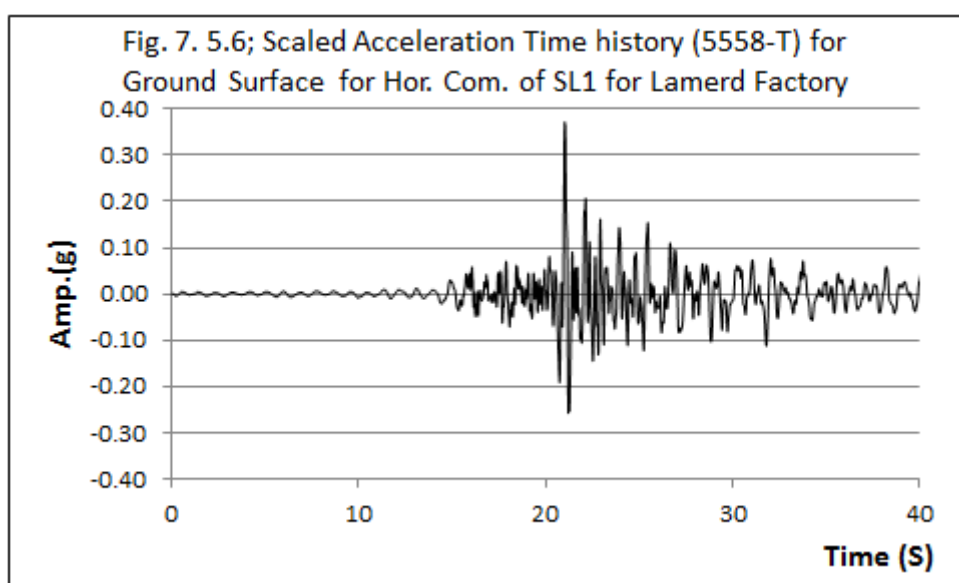
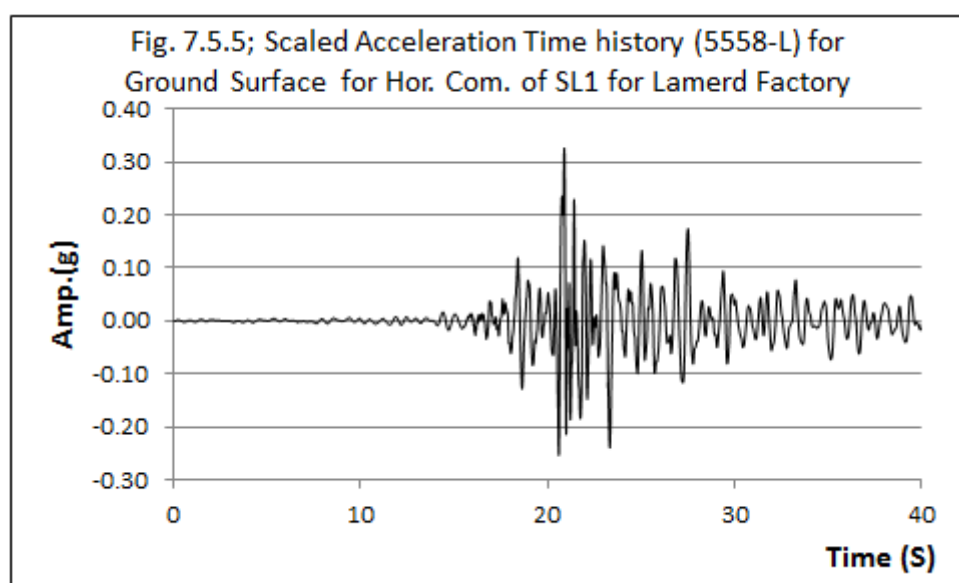
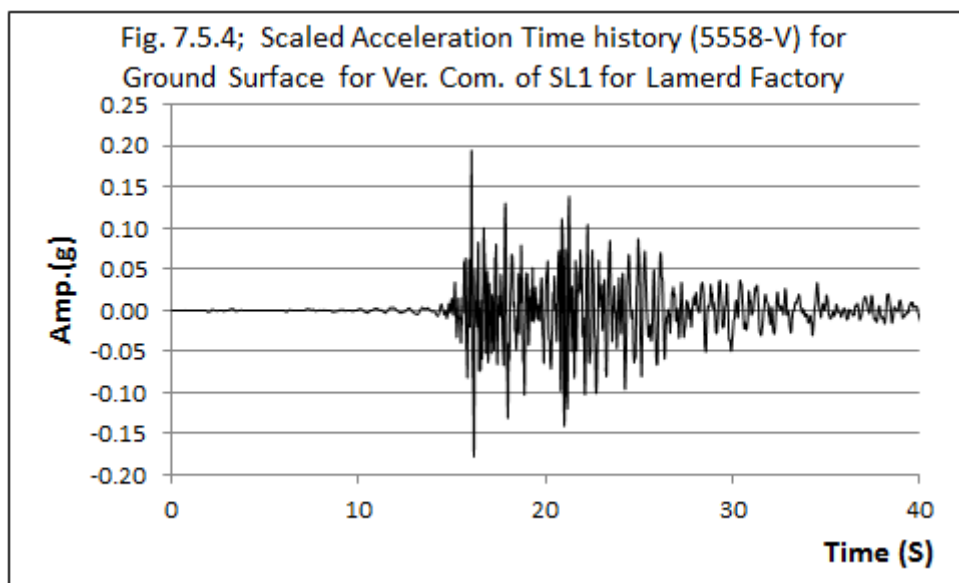
Calculated with DEEPSOIL program horizontal and vertical spectra for the main seismic loading and soil thickness models were discussed at section 7.2.

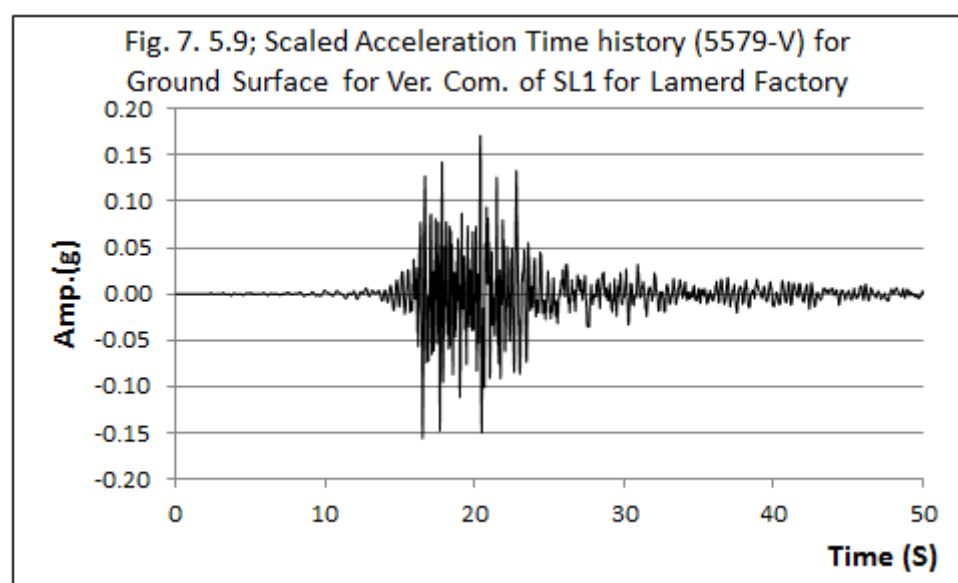
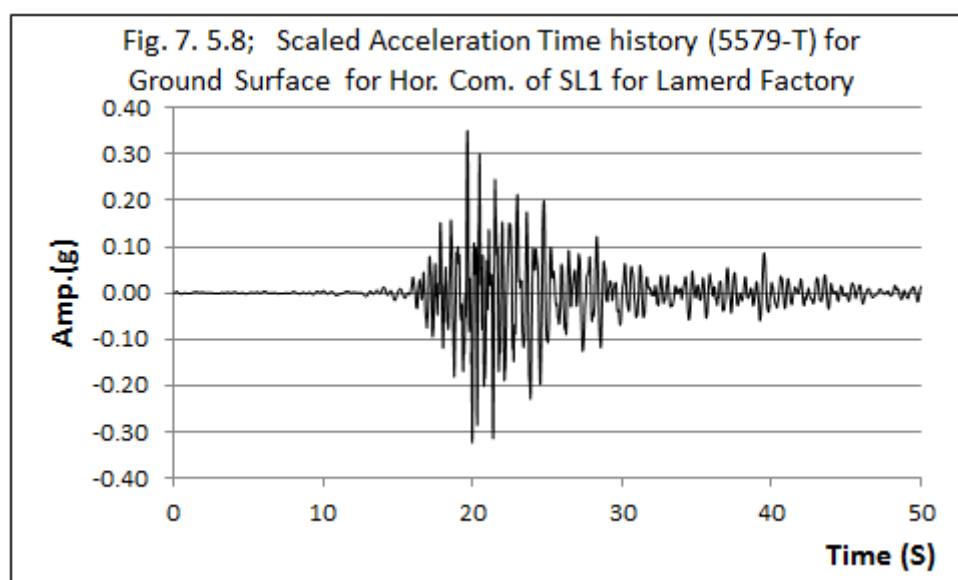
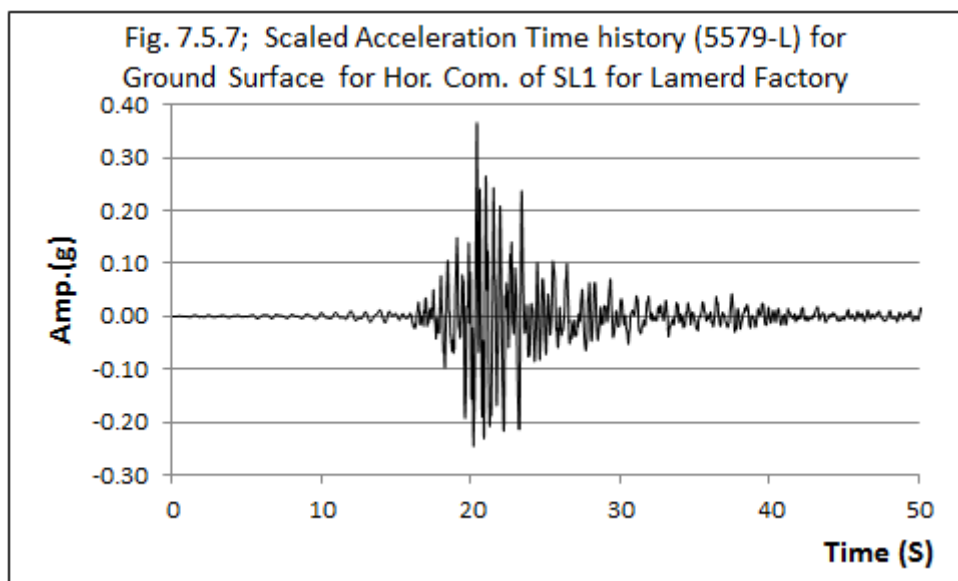
Predominant period of spectral of the fundamental soil is (about 0.17—0.6 second) .

7.5. Estimating Site-specific Strong Motion Acceleration Time Histories

For the main model of seismic loading /27/ wave motions (section 6.1. Design Accelerograms) accepted as initial ones given at the site soil extended profile free surface were recalculated down to virtual hard rock basement free surface using DEEPSOIL program. Then, these motions were taken as new initial object motions at the depth of more than 30 m and their seismic effect at the site soil extended profile were evaluated. The results are shown at the Figures 7.5.1 to 7.5.27 for the case of the extended soil profile, because the acceleration T.H.s for the extended soil profile coincides with corresponding input T.H.s related to average soil conditions.







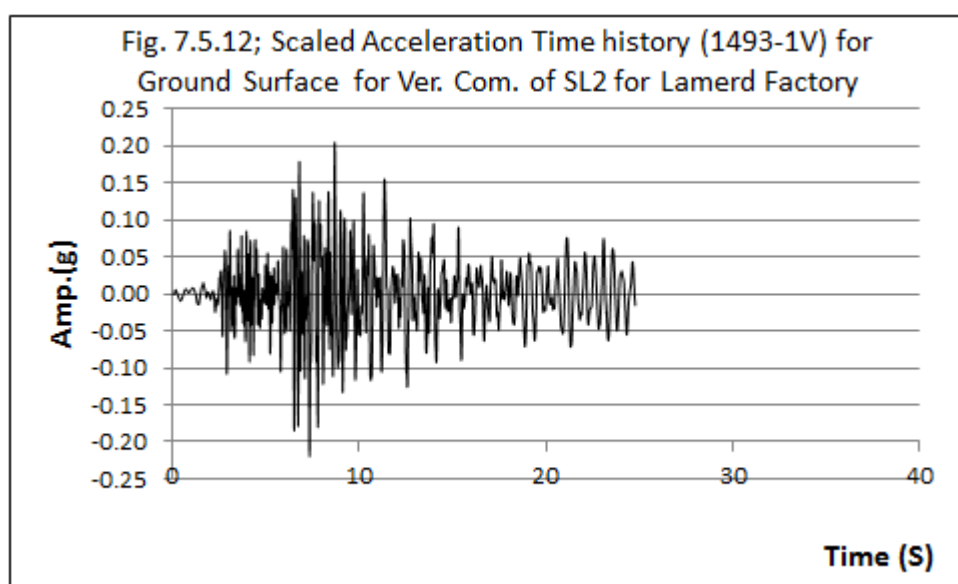
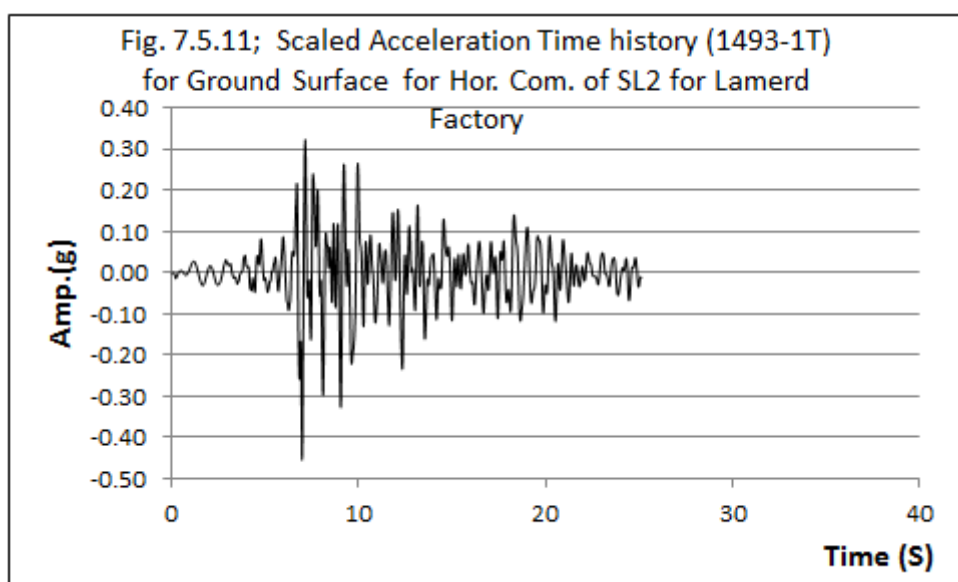
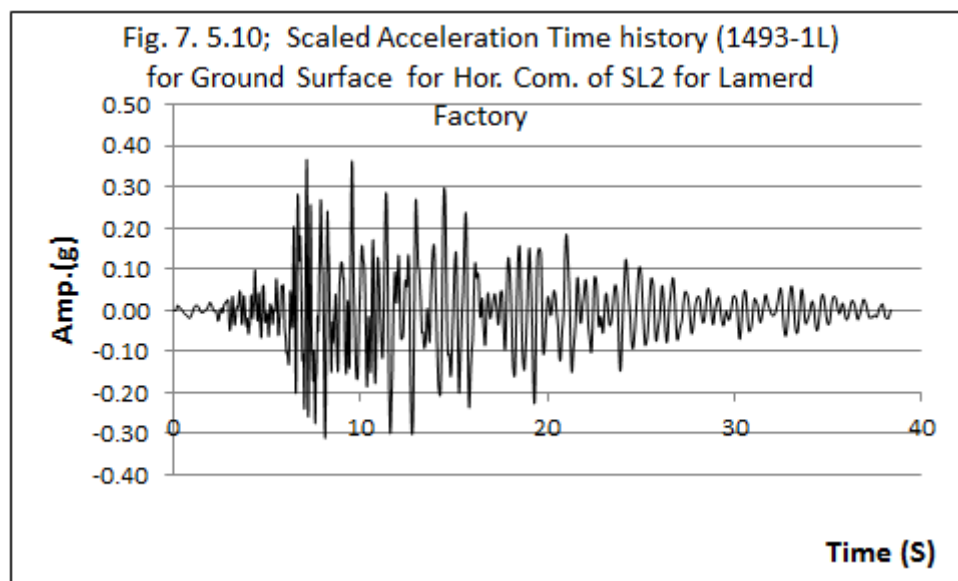


Fig. 7.5.13; Scaled Acceleration Time history (2749-V) for Ground Surface for Ver. Com. of SL2 for Lamerd Factory

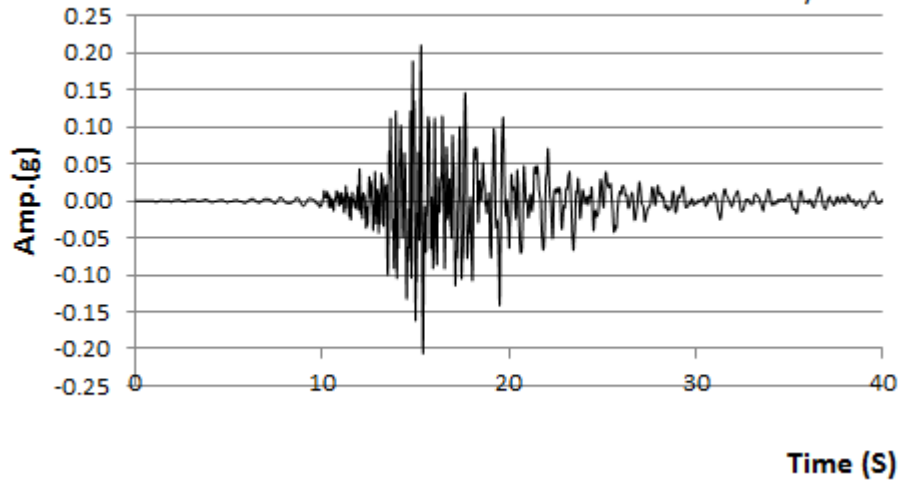


Fig. 7. 5.14; Scaled Acceleration Time history (2749-L) for Ground Surface for Hor. Com. of SL2 for Lamerd Factory

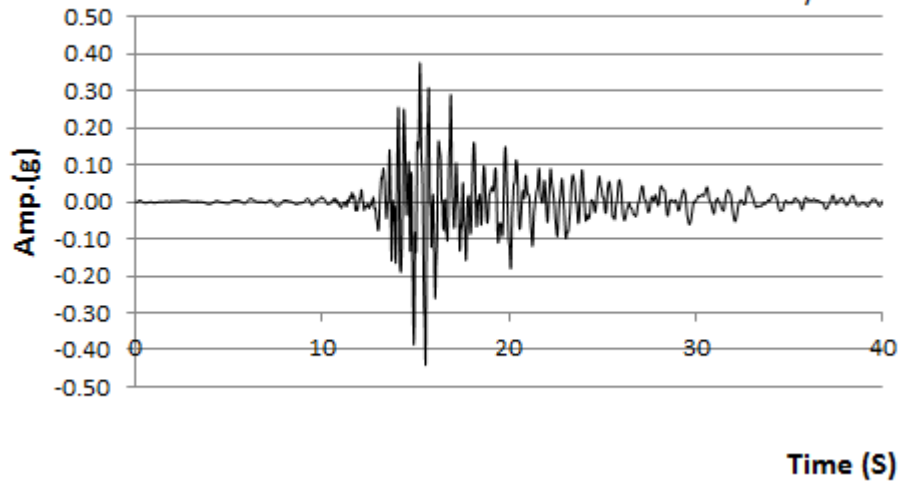


Fig. 7.5.15; Scaled Acceleration Time history (2749-T) for Ground Surface for Hor. Com. of SL2 for Lamerd Factory

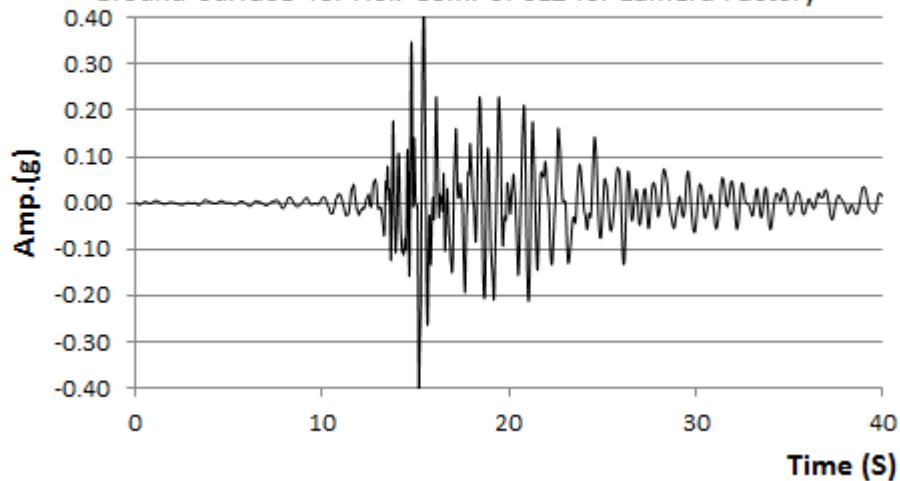


Fig. 7. 5.16; Scaled Acceleration Time history (5583-L) for Ground Surface for Hor. Com. of SL2 for Lamerd Factory

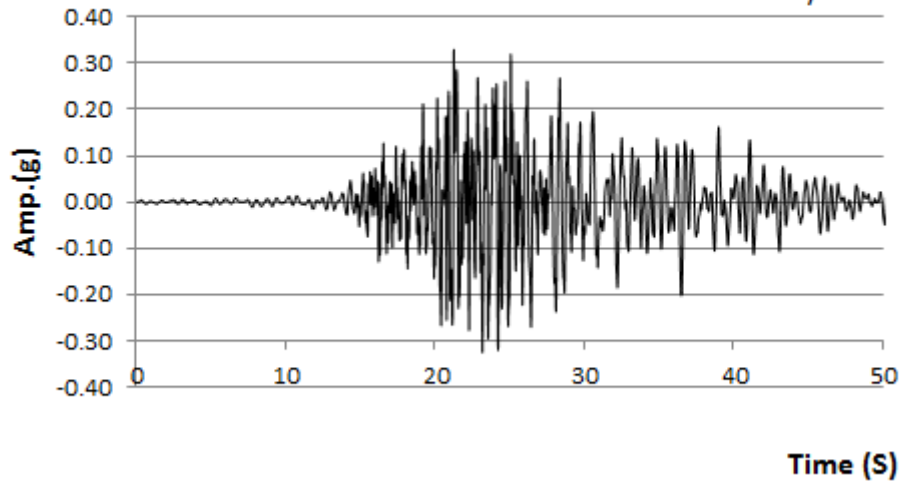


Fig. 7. 5.17; Scaled Acceleration Time history (5583-T) for Ground Surface for Hor. Com. of SL2 for Lamerd Factory

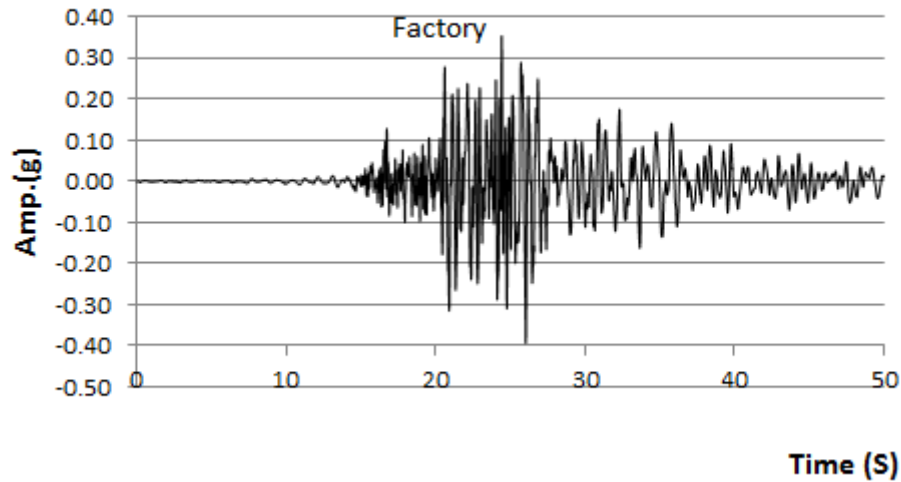
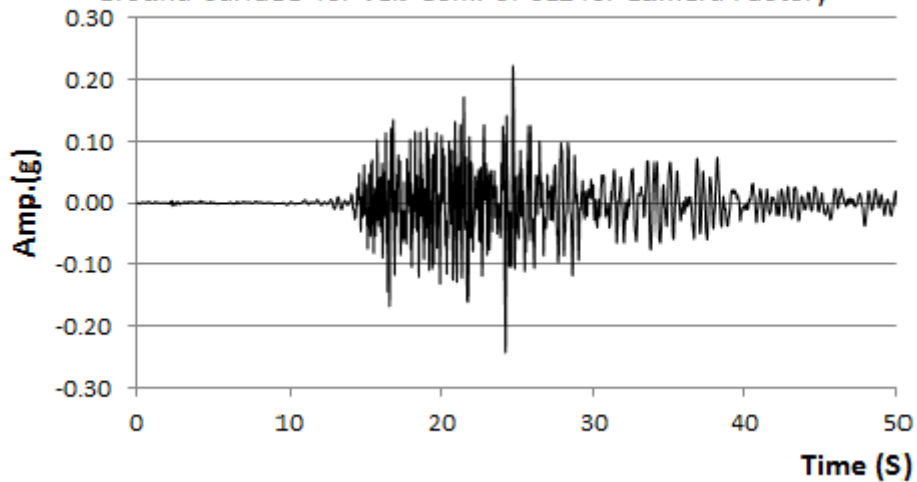
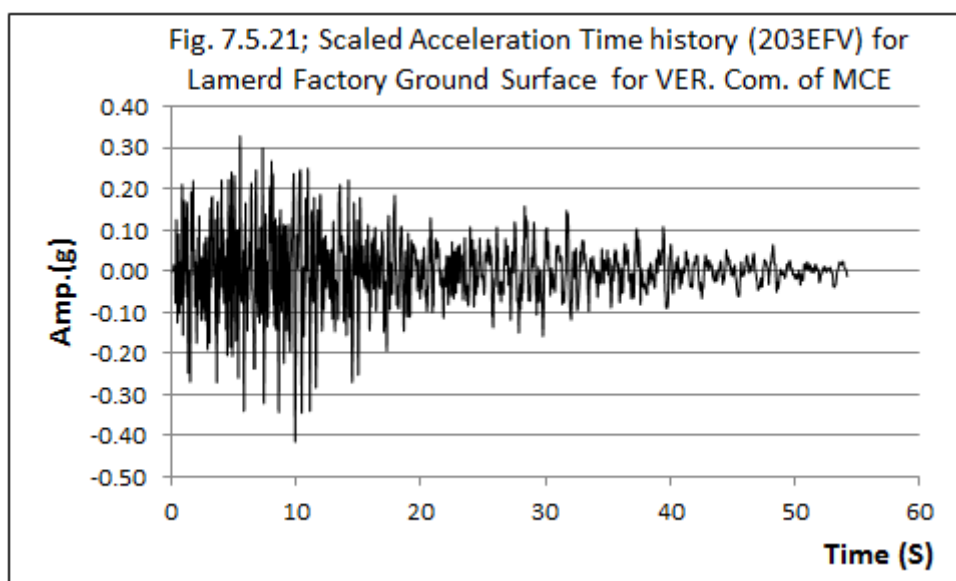
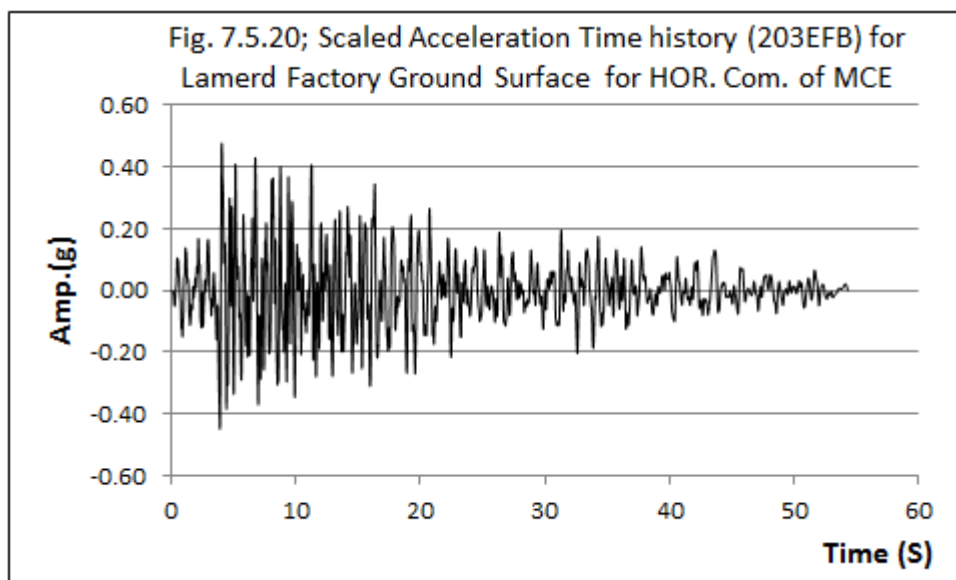
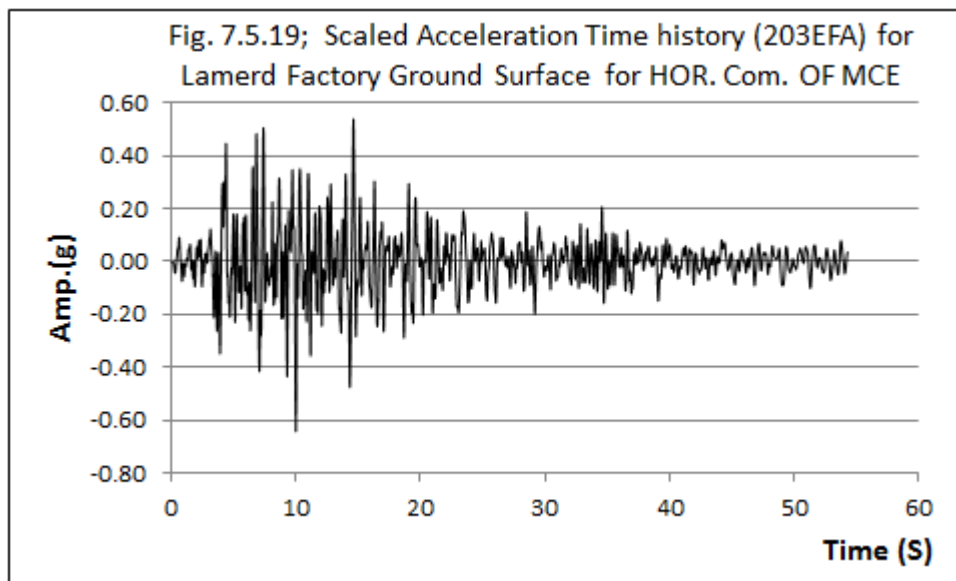
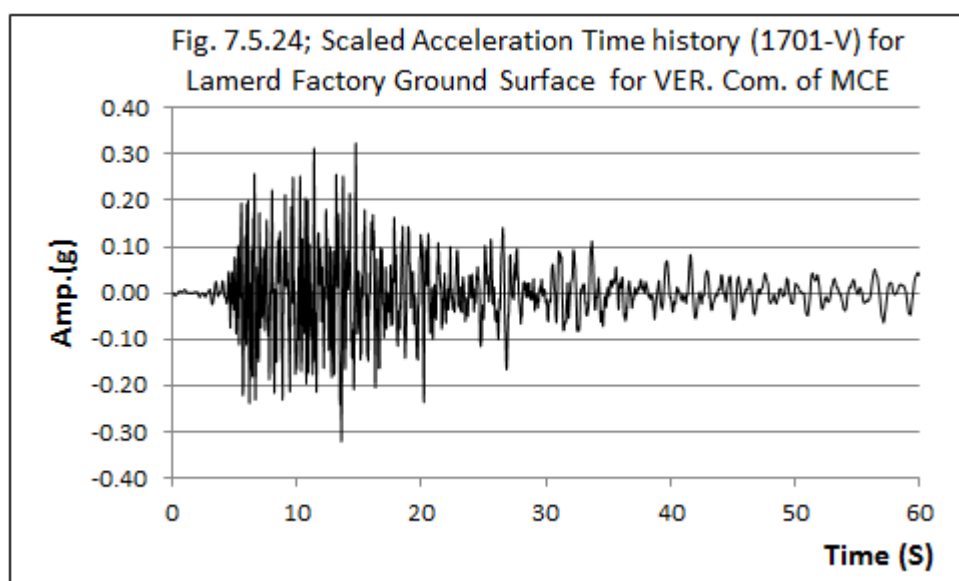
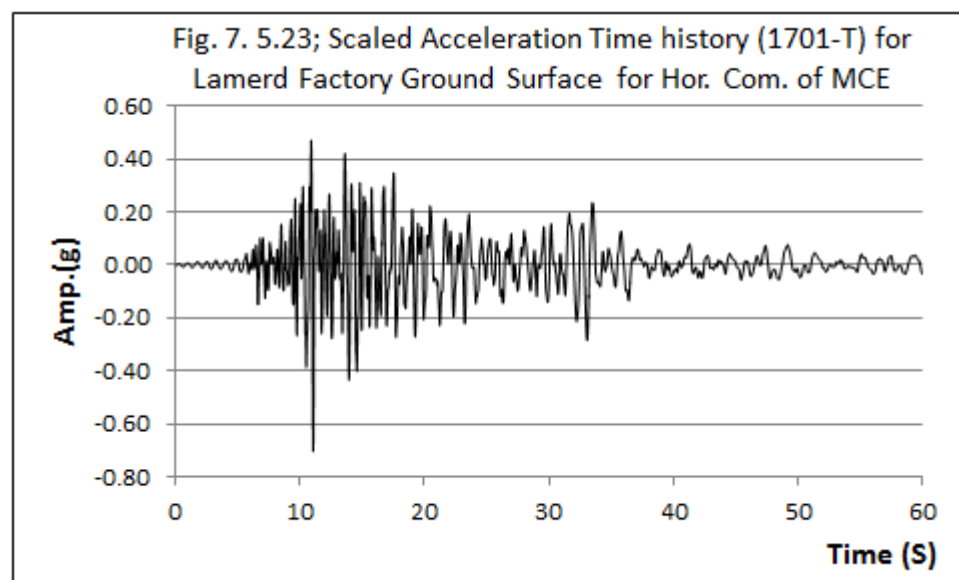
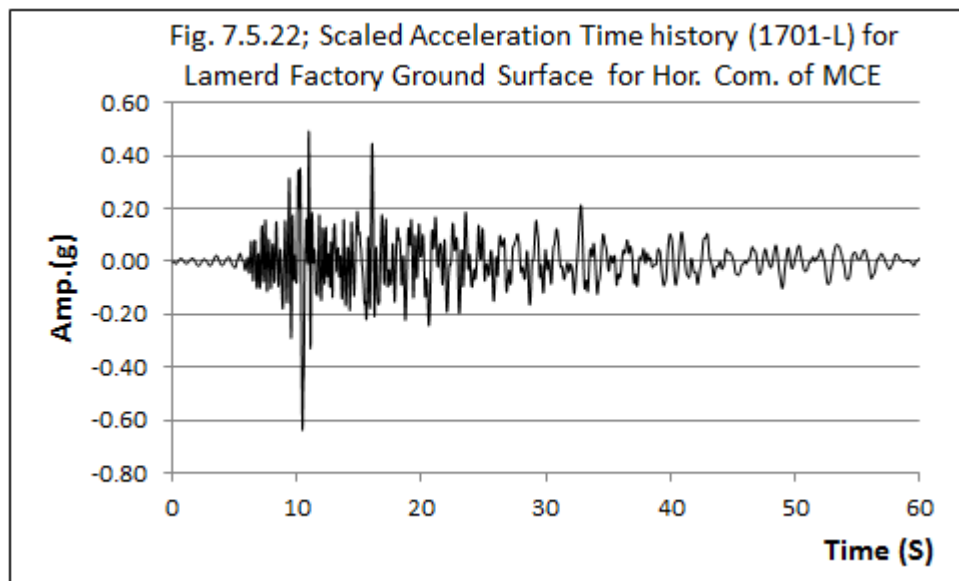
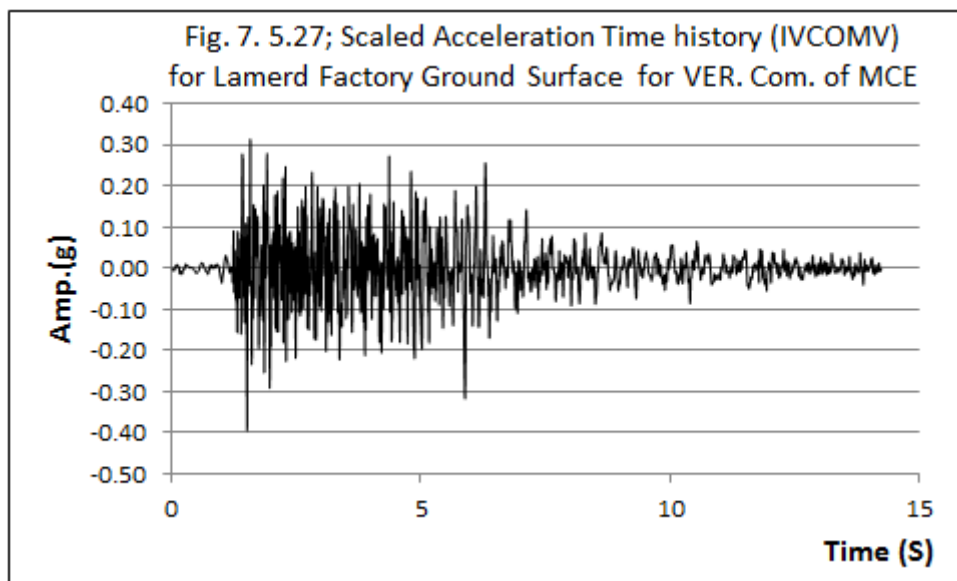
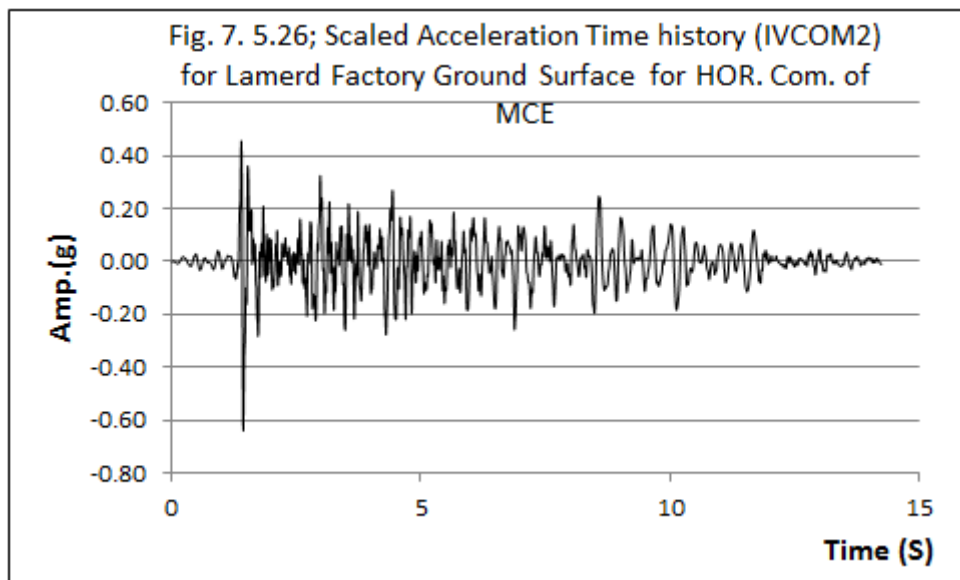
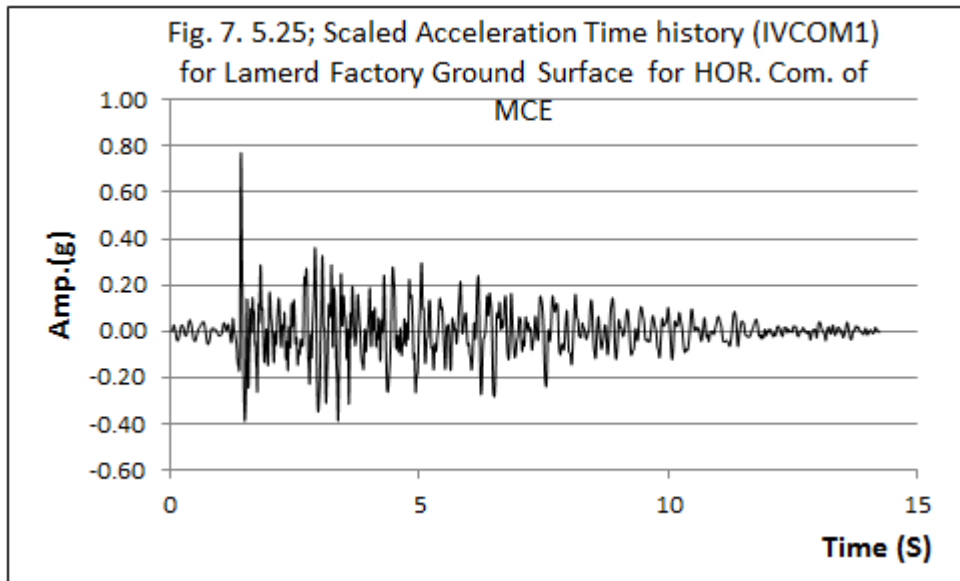


Fig. 7. 5.18; Scaled Acceleration Time history (5583-V) for Ground Surface for Ver. Com. of SL2 for Lamerd Factory









7.6. Site-specific Response Spectra and Peak Horizontal and Vertical Ground Accelerations

Final Design Response Spectra of the input seismic loading recalculated to virtual free surface of hard rock basement are shown at the Figures 5.2.7 and 5.2.8.

Calculated response spectra for the case of vertical wave incidence for the main models of seismic loading and typical extended site soil for damping values of, 5%, .

Mean peak horizontal and vertical ground accelerations were estimated as mean values of single-component PHGA's and are presented in the below:

<u>Level</u>	<u>PGAh(g)</u>	<u>PGA_v(g)</u>
SL1	0.3	0.16
SL2	0.41	0.23
MCE	0.64	0.37

Finally, Lamerd site-specific generalized design response spectra of horizontal acceleration of SL1, SL2 and MCE presented for damping values of 5%.

Table 7.6-1 and 7.6.2 show presented the result of Site-specific design response spectra (with damping 5%) expected at the Lamerd factory site during seismic loadings of SL-1, SL-2 and MCE levels for Horizontal and Vertical Components.

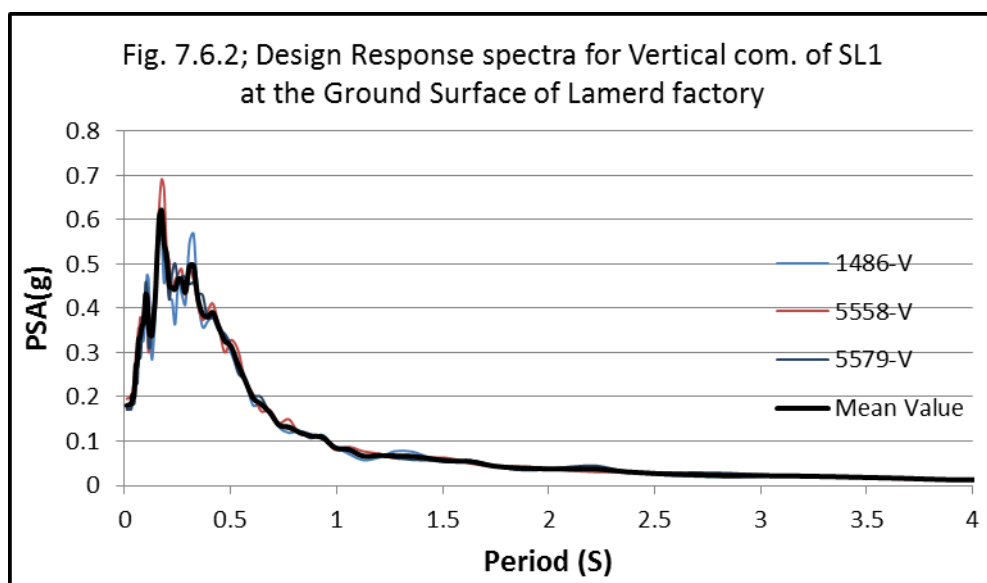
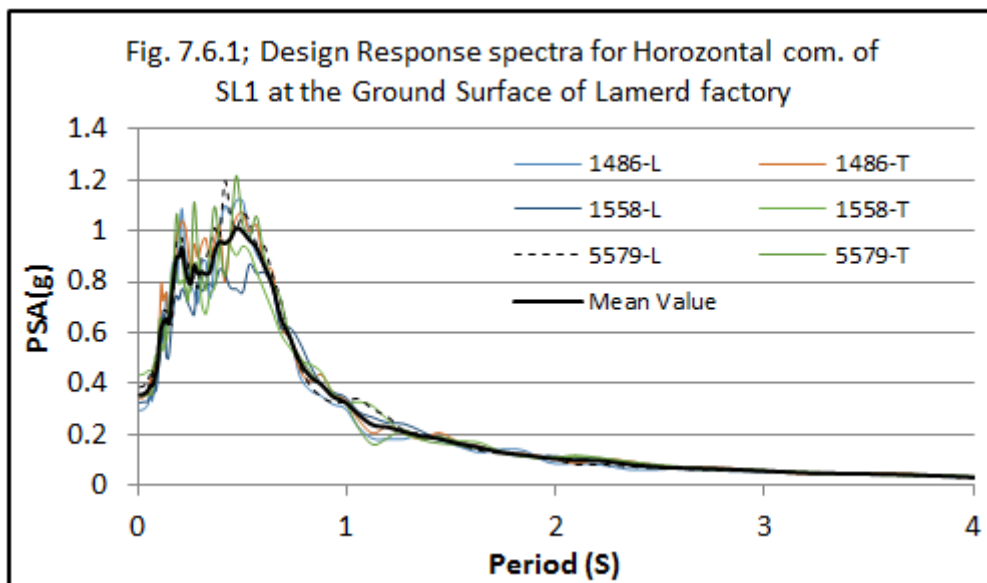


Figure 7.6.1 and 7.6.2: horizontal and Vertical acceleration Design response spectra (damping 5%) for SL-1 input model Lamerd factory site

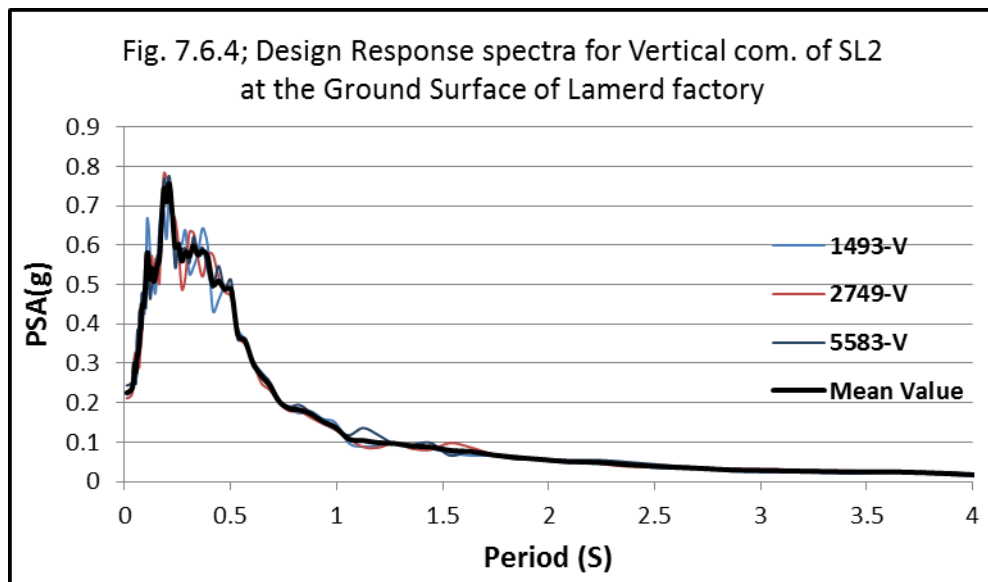
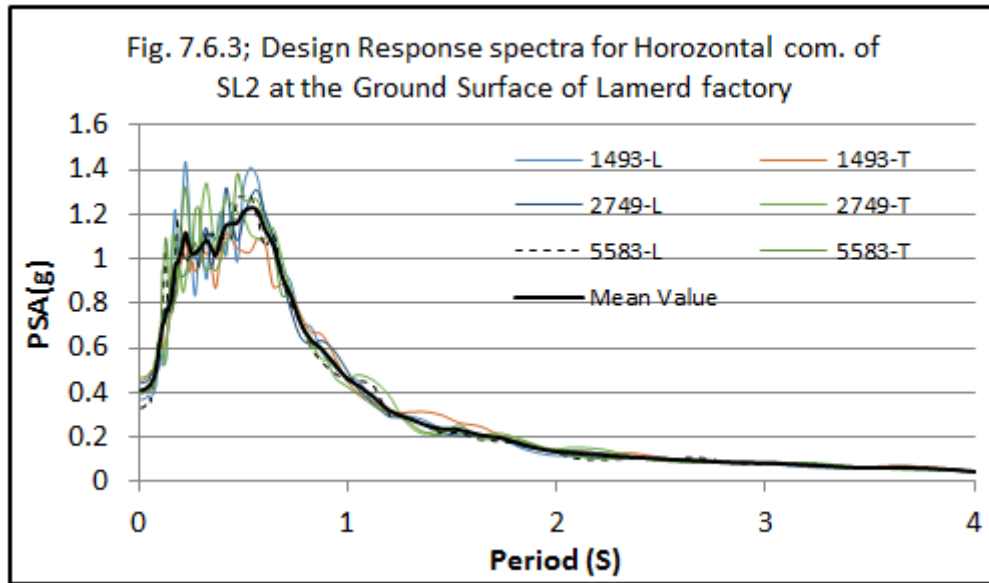


Figure 7.6.3 and 7.6.4: horizontal and Vertical acceleration Design response spectra (damping 5%) for SL-2 input model Lamerd factory site

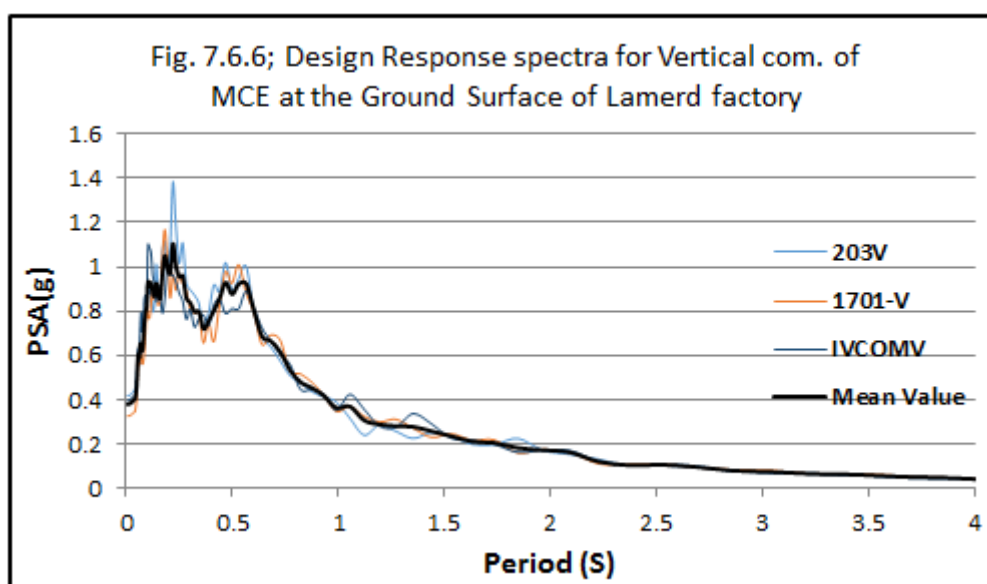
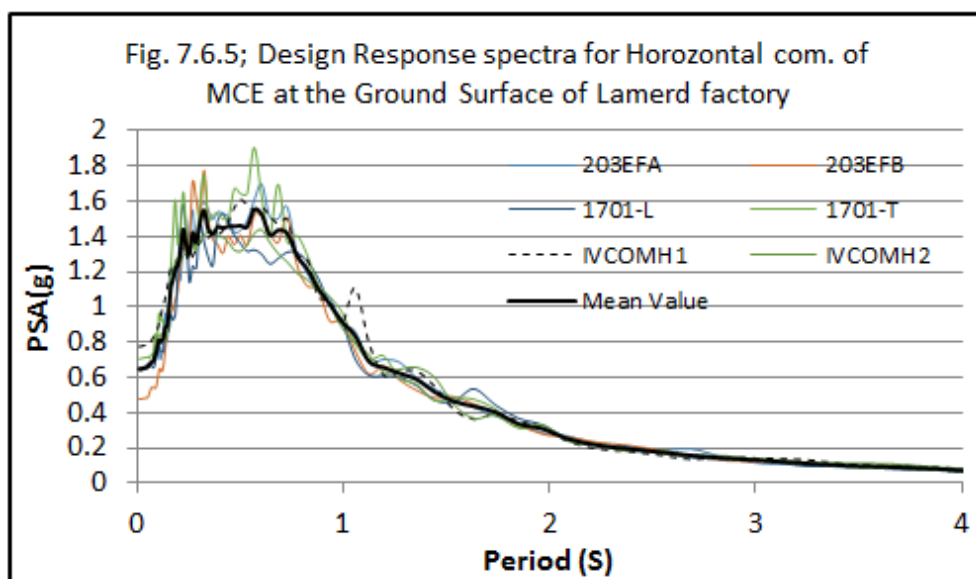


Figure 7.6.5 and 7.6.6 horizontal and Vertical acceleration Design response spectra (damping 5%) for MCE input model Lamerd factory site

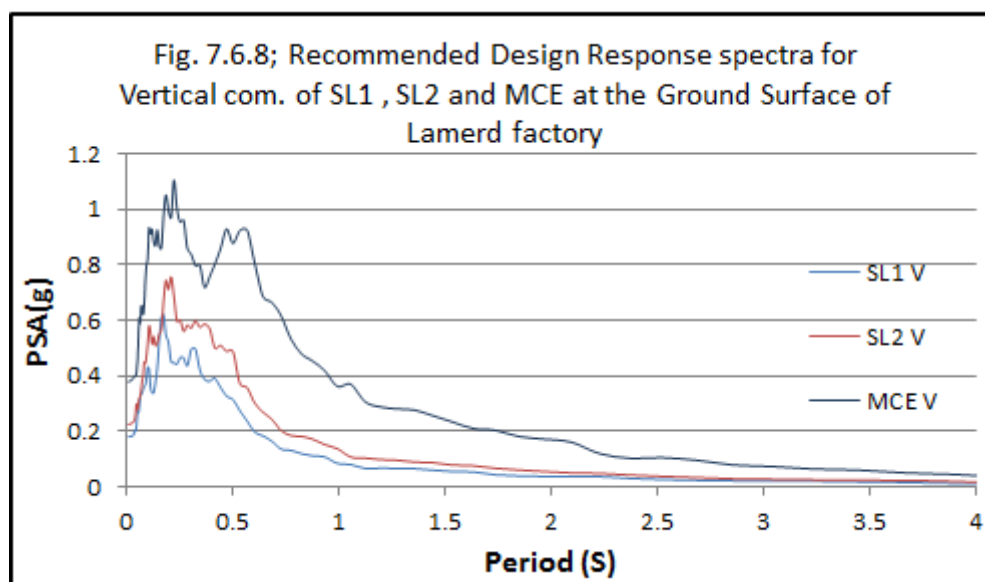
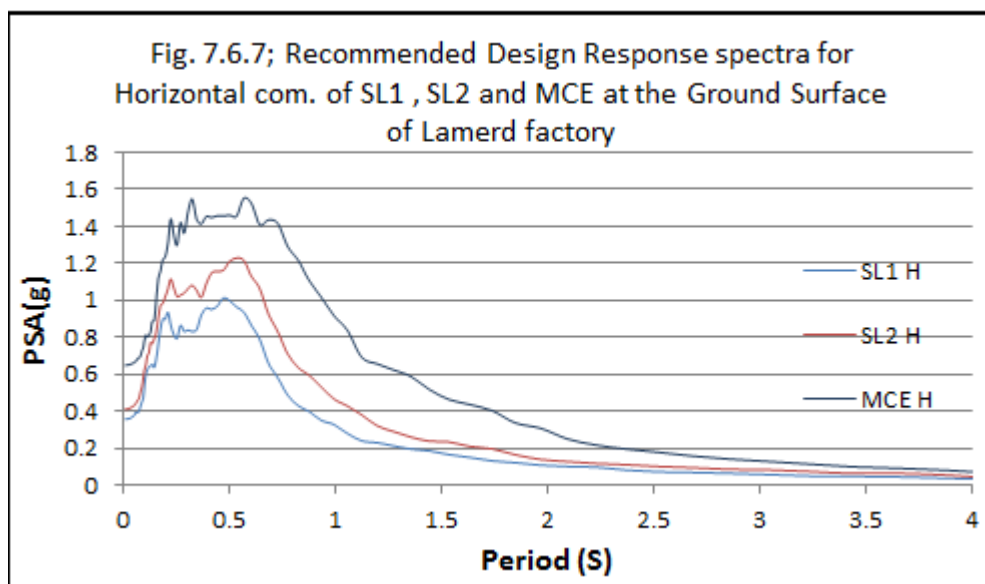


Figure 7.6.7 and 7.6.8: Recommended horizontal and Vertical acceleration Design response spectra (damping 5%) for SL1, SL2 and MCE input model Lamerd factory site

Table 7. 6-1: Site-specific design response spectra (with damping 5%) expected at the Lamerd factory site during seismic loadings of SL-1, SL-2 and MCE levels for Horizontal Component

(sec)	SL1 H	SL2 H	MCE H	(sec)	SL1 H	SL2 H	MCE H
0.01	0.356485	0.409738	0.647911	0.237944	0.812429	1.066063	1.351107
0.010641	0.356555	0.409837	0.64798	0.2532	0.793561	1.020381	1.297345
0.011324	0.356632	0.409946	0.648062	0.269435	0.864326	1.027402	1.421013
0.01205	0.356725	0.410079	0.648169	0.286711	0.831985	1.038944	1.363372
0.012822	0.356835	0.41022	0.648281	0.305094	0.839395	1.063667	1.478227
0.013644	0.356955	0.410375	0.648383	0.324656	0.830255	1.080833	1.548123
0.014519	0.357077	0.410563	0.648532	0.345472	0.841074	1.053412	1.436993
0.01545	0.35724	0.410762	0.648689	0.367623	0.920015	1.015618	1.413207
0.016441	0.357417	0.410996	0.648879	0.391194	0.95819	1.089756	1.453797
0.017495	0.357606	0.411257	0.649082	0.416277	0.951147	1.148292	1.447912
0.018617	0.357866	0.411595	0.649274	0.442967	0.969026	1.157042	1.457162
0.01981	0.358119	0.411916	0.649554	0.471369	1.012272	1.162787	1.456097
0.02108	0.358392	0.41235	0.649807	0.501593	0.997933	1.211228	1.461078
0.022432	0.358715	0.412758	0.650172	0.533754	0.964161	1.228162	1.454193
0.02387	0.359162	0.413334	0.650564	0.567977	0.935411	1.21618	1.55289
0.025401	0.359555	0.413893	0.651004	0.604394	0.862934	1.129115	1.52386
0.027029	0.360109	0.414617	0.65149	0.643146	0.788516	1.063481	1.409297
0.028762	0.360765	0.415429	0.652102	0.684384	0.658944	0.925354	1.434872
0.030607	0.361461	0.416336	0.652669	0.728265	0.580949	0.830608	1.416823
0.032569	0.362304	0.417433	0.653424	0.774959	0.486829	0.710703	1.29093
0.034657	0.363438	0.418624	0.654237	0.824648	0.429647	0.63586	1.216365
0.036879	0.364842	0.420158	0.655198	0.877523	0.397667	0.59312	1.104987
0.039244	0.367002	0.421724	0.656275	0.933788	0.350226	0.530939	1.016463
0.04176	0.369095	0.424692	0.657376	0.99366	0.32764	0.465964	0.916178
0.044438	0.370062	0.427186	0.658967	1.05737	0.278952	0.427785	0.836412
0.047287	0.373197	0.427167	0.660315	1.12517	0.238921	0.379349	0.690496
0.050319	0.378778	0.430357	0.662517	1.19731	0.229906	0.320978	0.655549
0.053545	0.380851	0.434584	0.665548	1.27408	0.212229	0.289882	0.623177
0.056979	0.392685	0.438625	0.670008	1.35577	0.194995	0.260309	0.58832
0.060632	0.395762	0.446004	0.671897	1.4427	0.18542	0.238	0.517749
0.06452	0.39122	0.4533	0.680621	1.5352	0.16515	0.233449	0.463433
0.068656	0.391739	0.461074	0.686625	1.63364	0.150028	0.209694	0.436181
0.073058	0.39904	0.467135	0.687131	1.73838	0.131783	0.19622	0.403514
0.077743	0.413948	0.488677	0.691889	1.84984	0.121112	0.163931	0.336372
0.082728	0.435555	0.512891	0.707142	1.96845	0.108012	0.138932	0.30755
0.088032	0.452642	0.537483	0.730373	2.09466	0.100963	0.12745	0.249697
0.093676	0.467919	0.582151	0.744127	2.22897	0.096976	0.11755	0.216596
0.099683	0.539676	0.625078	0.785983	2.37188	0.081668	0.110202	0.195379
0.106074	0.599168	0.651765	0.812561	2.52396	0.071973	0.100956	0.17771
0.112875	0.623324	0.701254	0.800305	2.6858	0.068342	0.094131	0.157346
0.120112	0.63878	0.714311	0.810261	2.858	0.063701	0.085613	0.141095
0.127814	0.644276	0.770106	0.827138	3.04125	0.056901	0.08292	0.128319
0.136009	0.654554	0.765181	0.886053	3.23625	0.049369	0.074028	0.113577
0.14473	0.636392	0.790377	0.889206	3.44375	0.047292	0.063329	0.099058
0.154009	0.675196	0.820713	0.989231	3.66456	0.044075	0.063611	0.090978
0.163884	0.755923	0.898759	1.111776	3.89952	0.036816	0.053298	0.079273
0.174392	0.840293	0.9717	1.156552	4.14955	0.029432	0.034591	0.061124
0.185573	0.897655	0.983026	1.217462	4.41561	0.021934	0.02591	0.046541
0.197472	0.897823	1.02014	1.23556	4.69873	0.016801	0.020353	0.035817
0.210134	0.935015	1.062104	1.311017	5	0.013719	0.017684	0.029254
0.223607	0.86579	1.116003	1.440202				

Table 7. 6-2: Site-specific design response spectra (with damping 5%) expected at the Lamerd factory site during seismic loadings of SL-1, SL-2 and MCE levels for Vertical component

(sec)	SL1 V	SL2 V	MCE V	(sec)	SL1 V	SL2 V	MCE V
0.01	0.180495	0.225457	0.379096	0.237944	0.443179	0.595489	1.000131
0.010641	0.180529	0.225561	0.379242	0.2532	0.466164	0.602144	0.95371
0.011324	0.180611	0.225651	0.37943	0.269435	0.464146	0.560156	0.960193
0.01205	0.180779	0.225779	0.379631	0.286711	0.43636	0.583277	0.85872
0.012822	0.180844	0.225943	0.379866	0.305094	0.495514	0.572003	0.838235
0.013644	0.180955	0.226128	0.380163	0.324656	0.496818	0.599641	0.796546
0.014519	0.181092	0.226324	0.380465	0.345472	0.421764	0.575275	0.797939
0.01545	0.181208	0.226505	0.380803	0.367623	0.387334	0.586108	0.719524
0.016441	0.181317	0.226826	0.381226	0.391194	0.380923	0.571649	0.755555
0.017495	0.181408	0.227061	0.381637	0.416277	0.390481	0.500641	0.802465
0.018617	0.181514	0.227388	0.38212	0.442967	0.358626	0.509441	0.857725
0.01981	0.181693	0.227778	0.382784	0.471369	0.327043	0.488425	0.928849
0.02108	0.181966	0.228264	0.383472	0.501593	0.314529	0.488827	0.877135
0.022432	0.18242	0.228609	0.384168	0.533754	0.274826	0.372366	0.922882
0.02387	0.182766	0.229119	0.385076	0.567977	0.237743	0.357762	0.925236
0.025401	0.183103	0.229724	0.386177	0.604394	0.198301	0.302389	0.806184
0.027029	0.183302	0.230598	0.387241	0.643146	0.183853	0.269184	0.685527
0.028762	0.183968	0.231772	0.388675	0.684384	0.165072	0.244073	0.665031
0.030607	0.184577	0.232845	0.390073	0.728265	0.136385	0.203677	0.617027
0.032569	0.186725	0.234534	0.392054	0.774959	0.131994	0.18528	0.532934
0.034657	0.191191	0.236109	0.394091	0.824648	0.119831	0.182094	0.478758
0.036879	0.20083	0.238997	0.396466	0.877523	0.112133	0.172004	0.453217
0.039244	0.205163	0.246971	0.39878	0.933788	0.10832	0.152612	0.418915
0.04176	0.199222	0.257121	0.401571	0.99366	0.084828	0.137852	0.36221
0.044438	0.202913	0.28675	0.401021	1.05737	0.080953	0.107713	0.369464
0.047287	0.223696	0.299489	0.415234	1.12517	0.066433	0.103963	0.306152
0.050319	0.253663	0.277294	0.44286	1.19731	0.067794	0.098304	0.288099
0.053545	0.273125	0.28323	0.486674	1.27408	0.066799	0.096442	0.280932
0.056979	0.268215	0.309509	0.562452	1.35577	0.06585	0.089782	0.277327
0.060632	0.289725	0.319106	0.609351	1.4427	0.060591	0.087484	0.256987
0.06452	0.325258	0.329177	0.588534	1.5352	0.055409	0.078914	0.234606
0.068656	0.333505	0.348969	0.651343	1.63364	0.054011	0.076151	0.210273
0.073058	0.336607	0.380985	0.652921	1.73838	0.044035	0.067259	0.204098
0.077743	0.349941	0.395612	0.619744	1.84984	0.039597	0.060788	0.181653
0.082728	0.361383	0.449709	0.648908	1.96845	0.037834	0.055708	0.171982
0.088032	0.3659	0.443384	0.740014	2.09466	0.037611	0.050568	0.161688
0.093676	0.392046	0.469124	0.795461	2.22897	0.037174	0.048614	0.119988
0.099683	0.432543	0.514595	0.818922	2.37188	0.030615	0.042825	0.103369
0.106074	0.425093	0.580539	0.932087	2.52396	0.02666	0.037845	0.105853
0.112875	0.358672	0.555733	0.910624	2.6858	0.023999	0.034077	0.096277
0.120112	0.339409	0.514531	0.928393	2.858	0.022196	0.02951	0.079239
0.127814	0.338358	0.54154	0.88417	3.04125	0.021894	0.027578	0.07358
0.136009	0.375846	0.508427	0.868011	3.23625	0.020754	0.025921	0.064645
0.14473	0.429571	0.5199	0.926004	3.44375	0.018712	0.024059	0.061029
0.154009	0.526474	0.55016	0.868934	3.66456	0.016193	0.023721	0.051052
0.163884	0.609166	0.565109	0.857449	3.89952	0.012811	0.01982	0.045244
0.174392	0.621378	0.668952	0.977698	4.14955	0.012161	0.013777	0.034829
0.185573	0.547631	0.744421	1.051449	4.41561	0.009722	0.010208	0.025954
0.197472	0.521384	0.710534	0.995875	4.69873	0.008406	0.007989	0.019865
0.210134	0.450568	0.756503	0.970596	5	0.00675	0.006647	0.016392
0.223607	0.446884	0.687035	1.105314				

7.7. Conclusion:

1. The seismic effects from near the site are as follow: maximal possible Horizontal acceleration of SL -2 is evaluated for 2475 year 0.41g and maximal expected acceleration of SL-1 for 475 years 0.31g.
2. The seismic effects caused by mximum potential of Assaluyeh fault can be supposed to be 0.64g Ground Horizontal acceleration at the site.
3. Calculations based on the strong motion data are in a good agreement with the estimation using the recent formula (Campbell) and empirical relation.
4. Design Response Spectral for SL1, SL2 and MCE estimated based on sismotectonic of region, strong motions acceleration time-histories and geology condition of the site.
5. The synthetic accelerograms scaled on all the main parameters of seismic effect from the expected earthquakes are constructed on the base of the obtained estimates of the clay parameters.

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