This paper presents the seismic hazard assessment for the State of Kuwait. In the present study, historical and instrumental seismicity data in the Kuwait area and its vicinity are compiled to form the base earthquake catalogue covering the period from 860 to 2000. Seismic zones characterization was performed assuming an exponential model for magnitude distribution and a Poisson time occurrence model. Probabilistic seismic hazard analysis employed herein is based on Cornell’s methodology.

INTRODUCTION

The presented work is part of an ongoing research project for assessing the seismic risk of residential buildings in Kuwait whose closeness to Zagros belt warrants the assessment. The State of Kuwait is located in the northeastern part of the Arabian Peninsula at the northwestern end of the Arabian Gulf. Kuwait is located to the southwest of the Zagros belt, which is capable of producing strong earthquakes of magnitudes 7.5. Local seismicity in Kuwait is characterized by several local earthquakes of magnitudes up to 5 mainly in the southern part of the Minagish oilfields.

The prime concern of the present paper is to assess the seismic hazard in the State of Kuwait. Seismic hazard assessment in areas of low to moderate seismic activity such as Kuwait poses a challenge to engineers due to the scarcity and incompleteness of seismological data required as input to seismic hazard analysis.

As for attenuation relationships, no specific relations have been developed for the region and due to the absence of instrumented data of peak ground accelerations, expert judgement was exercised as for the selection of a conservative attenuation formula.

None of the previous studies of regional seismic hazard assessment in the Gulf area has considered the local seismicity in the State of Kuwait as defined by the present catalogue is shown in Figure 2a. For the purpose of recurrence-rate analysis, events are classified into historic events prior to 1900 and the remaining events are instrumental events.

SEISMOEVTONICS OF KUWAIT

The Arabian plate is defined by five tectonic features, with the Zagros and Taurus mountain in the northeast defining the continental collision between the Arabian, Persian and Turkish plates, Figure 1. In the east, the Arabian plate subducts beneath the Makran region of Pakistan and Iran, and southeast is the Owen Fracture zone. In the south and southwest are the spreading centers on the sea floor along the axis troughs in the Gulf of Aden and the Red Sea. Kuwait is located off the coast of the northwest tip of the Arabian Gulf.

THE EARTHQUAKE CATALOGUE

A primary component of any probabilistic seismic hazard is the earthquake catalogue associated with the analysis. The present catalogue is the result of searching the World Seismicity Database, WSD, of the British Geological Survey, BGS, for the Kuwait area consisting of a ten-degree square (24.00 to 34.00 latitude, 43.00 to 53.00 longitude) centered on Kuwait City (latitude 29.33, longitude 48.00).

The catalogue consists of 1939 earthquake events including historical and instrumental events covering the period from 860 to 2000 and with magnitudes ranging between 2 and 8. The seismicity map for the Kuwait area as defined by the present catalogue is shown in Figure 2a. For the purpose of recurrence-rate analysis, events are classified into historic events prior to 1900 and the remaining events are instrumental events.

Seismic hazard computation was performed using CRISIS99 program.
Figure 1. Tectonic boundaries of the Arabian Peninsula

Figure 2a. Regional seismicity of the Kuwait area.
LOCAL EVENTS

Seismic monitoring in the State of Kuwait began in March 1997. The Kuwait National Seismograph Network (KNSN) consists of seven three-component short period and one broad band seismometers (shown in Figure 3). The seismic data is transmitted via two-way full duplex error-correcting digital telemetry to the recording center at the Kuwait Institute for Scientific Research (KISR) in Kuwait City.

All seismic data recorded by the seismometers is digitized using 24-bit digitizers, with a sampling rate of 100 samples/s [1]. The network can detect local, regional and teleseismic earthquake events. Local events are defined as the earthquake events recorded within the boundaries of the State of Kuwait. The spatial distribution of the local events is depicted in Figure 4. The largest event is of magnitude 4.3, December 1997, and located in the southern part of Kuwait and such area has been relatively active as compared to other areas of the State of Kuwait.

DATA PRE-PROCESSING

Any complete earthquake catalogue is generally non-Poissonian, i.e. earthquakes are not entirely time independent events since a cluster of after-shocks whose occurrence is dependent of the main shock usually follows any major earthquake. Probabilistic seismic hazard analysis assumes that seismicity follows a Poisson process and hence it is essential to remove any non-Poissonian behaviour from the earthquake catalogue by eliminating the dependent events. A variety of approaches can be used for that matter. In the present study the spatial and temporal windows or filters proposed by Maeda [2] are employed to eliminate the accessory events from the original data as follows.

SEISMIC SOURCE ZONATION

A seismic source zone is defined as a seismically homogeneous area, in which every point within the source zone is assumed to have the same probability of being the epicenter of a future earthquake. It is not always possible to compile detailed information of the several fields required for the ideal delineation of source zones. As an alternative, a careful consideration of the main tectonic structures and their correlation with the current seismicity can be the basis for the delineation of the source zones.

Four sources were delineated in the present study and their details are given in Figures 5 and 6. The first source accounts for the Zagros belt and is of Poisson type for which a complete recurrence rate analysis was performed to define its parameters. The other three sources account for the local events and are of the characteristic type, that is the time span of monitoring and number of events are very limited and do not warrant a meaningful statistical analysis and are mainly characterized by a maximum credible earthquake. Upon the request of the client, local sources were excluded in the seismic hazard analysis.
Figure 3. Location of the seismic stations of KNSN

Figure 4. Local seismicity of the state of Kuwait (1997-2002)
Earthquake Recurrence Rate

For source 1, the following parameters defining occurrence of earthquakes in the source zone are evaluated: $M_o$, threshold magnitude below which no engineering significant damage expected; the upper bound magnitude $M_{max}$ representing the maximum expected magnitude; the Gutenberg-Richter earthquake recurrence parameter $b$-value, representing the slope of the magnitude-frequency of occurrence relation; the activity rate $\lambda$, which is the annual number of earthquakes above the lower bound magnitude; and the average hypo-central depth. The following values were assigned to these parameters.

- $M_o = 4.00$
- $M_{max} = 7.5$
- $B = 0.87$
- $\lambda = 11.50$
ATTENUATION RELATIONSHIPS

Strictly speaking, attenuation laws are site dependent and need to be determined for each location. Such information is not readily available for the Arabian Gulf region. For the purpose of the present study the attenuation relationship developed by Sadigh et al. [4] was used. However, a dedicated study on the influence of attenuation laws on the resulting seismicity in the Arabian Gulf area is highly needed.

SEISMIC HAZARD COMPUTATIONS

The probabilistic seismic hazard computations were performed using CRISIS99 software [5] whose calculations are based on the well-known Cornell approach [6] to compute seismic hazard in extended regions. Basic input data are geometry of the sources, seismicity of the sources and the attenuation relations. Using a recursive triangularization algorithm, spatial integration of hazard equations are performed optimizing number of calculations, so CRISIS99 will integrate with more points for the nearest sources and less points for distant sources. Hazard estimations are made for points in a grid not necessarily rectangular. Data validation options are available and parameters can be given in a user-friendly graphic environment.

The resulting seismic hazard map of the State of Kuwait is shown in Figure 7. The map shows expected peak ground accelerations for a 10% probability of exceedance over a 100 year return period. It should be noted the great influence that local seismicity has on the seismic hazard in Kuwait.

CONCLUSION

The present study performed probabilistic seismic hazard analysis in the State of Kuwait. The analysis considered regional seismicity accounting for the Zagros belt and more important the local seismicity defined by earthquake events recorded within the State of Kuwait. The resulting product of the study is a seismic hazard map of the State of Kuwait showing expected peak ground accelerations with 10% probability of exceedance over 100 year return period. It is clearly demonstrated that local seismicity is important and should be included in future studies of hazard assessment.

It is recommended to perform fault tree analysis including all uncertainties involved in seismic hazard assessment to better judge the influence of a given parameter on the ground motion estimate and prediction.

REFERENCES