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Seismic hazard and design criteria for Saudi Arabia

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ABSTRACT: An earthquake data file for the Kingdom is derived from the world-wide sources and the acquired data are treated for incompleteness, missing magnitudes and bias. Seismotectonic study for delineation of source borders and assessment of risk are undertaken to obtain seismic zonation. Essential parameters of seismic design are evaluated for the Kingdom. The study furnishes criteria for seismic design of buildings in the Kingdom.

1 INTRODUCTION

Kingdom of Saudi Arabia (KSA) is a country of low seismic activity and scarce past earthquake data. The seismographic installations in the country were first commissioned in 1984. Contrary to common belief, there are regions in the country where peak ground acceleration reaches 0.2g and 0.3g in 50 years for 10 and 5 percent probabilities of exceedance respectively.

The development of earthquake hazard maps and seismic design code in such a situation, therefore, requires a coordinated and comprehensive approach. The steps involved in such an endeavor and undertaken to accomplish this study are:

1. compilation of earthquake catalogue and preparation of a seismotectonic map for delineation of the boundaries of seismic sources;
2. treatment of the seismicity data for clusters, missing magnitudes and incompleteness;
3. development of recurrence relationships and evaluation of maximum credible magnitude;
4. preparation of iso-acceleration and seismic zone maps;
5. evaluation of the seismic design parameters and development of a preliminary seismic design code for KSA.

The study at various stages of its progress was augmented by expert consultation on the following aspects:

1. seismic source identification and regionalization;
2. installation of an expert system for risk analysis, and its adaptation to local conditions;
3. determination of ground motion attenuation parameters, performing risk analysis and defining a seismic design philosophy;
4. preparation of seismic design provisions and detailing requirements.

A brief description of these procedural steps is provided below.

2 TECTONIC AND SEISMOLOGICAL STUDY

2.1 Data file

Well recognized and readily available international records of earthquake occurrence data were utilized in preparation of a "Saudi Arabian Earthquake Data File (SAEDF)" by extraction of events in geographic region bounded by 10° N to 32° N and 30° E to 60° E. On time scale, the data collected spans from 2150 B.C. to March 1990 A.D.

2.2 Data processing

SAEDF contained events which were reported more than once. The events, for the purpose of this study, were considered repeated if they had time-origin difference of 20 seconds or less and location difference of 150 km of less. In a set of repeated events, so isolated, an event which had a magnitude and "preliminary determination of epicenter (PDE)" associated with it was retained while the rest were deleted. In a set of events in which none of the events had a magnitude or intensity record, an event with a PDE-record was retained.

2.3 Neo-tectonic characterization

This aspect of study involves identification of seismic sources and regionalization of these sources.

A preliminary seismotectonic map of Figure 1 is developed by combining a compiled tectonic map and the seismicity map. The map distinguishes the clustering of epicenters and determines association of the epicenters with the main tectonic features. This information is essential in delineation of the borders of seismic regions.

There is a good correlation of the epicenter distribution with the major tectonic features, excepting in some regions.

The low seismic activity in Red Sea northern region as compared to southern region is possibly due to seismic-gaps where the faults are locked and do not generate earthquakes. This region as such, has a high potential for future earthquake.

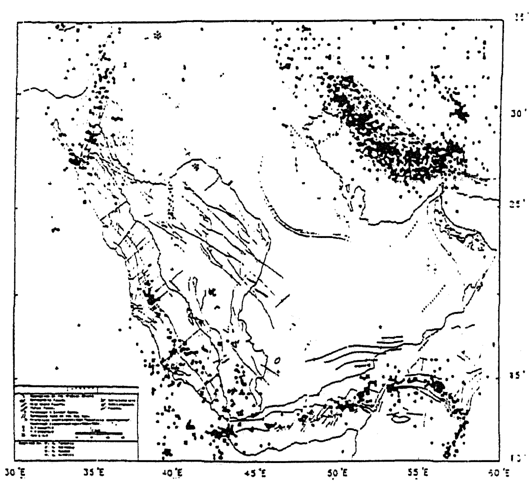

Figure 1. Seismotectonic map

3 SEISMIC RISK ASSESSMENT

3.1 Data treatment

It is seldom possible to have the available data completed in all respects. This is specially the case in regions which lack both in the historical records and the seismographic network. This also is the situation in the KSA. The process of data treatment normally involves the following major steps:

1. identification and elimination of clusters (secondary events which come in the wake of major events);
2. evaluation and distribution of missing magnitudes;
3. incompleteness analysis of the earthquake catalogue.

Merz (1973) demonstrated that the contribution made by aftershocks to seismic hazard estimates is small and that the sole consideration of main shocks is sufficient for engineering purposes. In this study clusters were identified and eliminated by using the time and space windows algorithm developed by Gardner and Knopoff (1974).

Some historical events in the earthquake catalogue were with missing magnitudes. These events were assigned magnitudes depending upon possibility of being felt and reported in historic time by people, presence of seismographic network, and historical growth of population.

Incompleteness of earthquake catalogues introduces bias in the estimation of the recurrence model parameters when the entire historical record is to be analyzed. It was a common notion, in both the early and recent studies, to handle the incompleteness by using the earthquake detection and reporting probabilities which vary with time and size of earthquake. This notion was also adopted in this study. Stepp, et al. (1965) and Kelly, et al. (1969).

3.2 Recurrence relationship

The corrected earthquake catalogue for the KSA was then employed to develop the recurrence relations for all the identified seismic sources in the region. The magnitude-frequency relationship for each individual source was assumed to follow the Gutenberg Richter relationship given by,

$$\ln N(M) = \alpha + \beta M \qquad (1)$$

where N(M) is number of events greater than or equal to the magnitude M, and α and β are the regression constants.

3.3 Maximum credible magnitude

One of the most controversial and important variable of interest in representing source seismicity is the size of the maximum credible earthquake to be used as the upper cut off magnitude in the linear recurrence relationship. In this study, the cut off magnitude is taken to be the observed maximum magnitude developed by the source plus 0.25.

3.4 Iso-acceleration mapping

The recurrence relationships developed above represent the past seismic history of the region. In order to perform seismic risk analysis for KSA, a model for forecasting of future events is needed. In this study, the Poisson model is used because of its simplicity and wide-spread use in the literature.

Evaluation of the seismic hazard at sites requires the prediction of the strong ground motion that will be generated by the potentially dangerous earthquakes. Attenuation relationships which express a parameter of the strong ground motion (usually the peak ground acceleration, PGA) in terms of the parameters characterizing the earthquake source, size, propagation medium and the local site geology, are generally used for the prediction purposes. There is a vast number of strong-motion attenuation relationships proposed throughout the years. Recently, as more strong ground motion data have become available for specific regions, a relationship of the following form is developed to obtain PGA, Campbell (1981).

$$\ln A = b_1 + b_2 M + b_3 \ln [R + b_4 \exp (b_5 M)] \quad (2)$$

where R is the distance between the site and the source, M is the earthquake magnitude, and b_1 through b_5 are constants that jointly depend on the type of seismic source, the transmission path between the source and the site, and the local soil conditions at the site.

Due to the scarcity of strong-motion data in the Kingdom, not much information is available on attenuation of acceleration. However, Eq. 2 was utilized by Thenhaus et al. (1986) representing a region-specific adjustment of the coefficients provided by Campbell (1981) for the western region of the Kingdom. This form of the attenuation was also adopted for this study. The attenuation constants suggested by the reference are:

b_1 = -3.303, b_2 = 0.85, b_3 = -1.25, b_4 = 0.087, and b_5 = 0.678.

Using the attenuation relationship given by Eq. 2, the probability distribution of the peak ground acceleration at a site is obtained through utilization of the numerical step-by-step procedure, presented in Shah.

The procedure was implemented by the Stanford Seismic Hazard Analysis (STASHA), Lamarre (1988), expert system which is employed in this study to construct hazard curves at specific sites and the iso-acceleration map for the Kingdom. Two such maps are presented in Figs. 2 and 3.

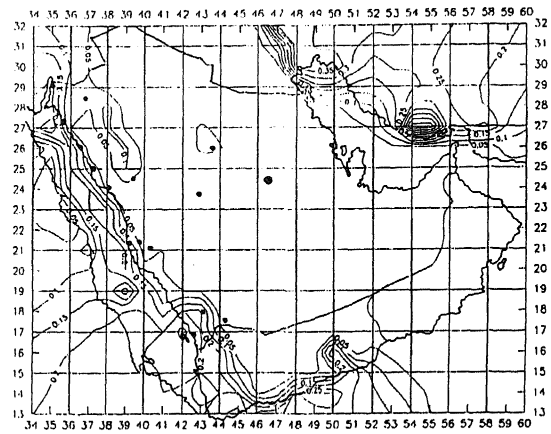

Figure 2. Iso-acceleration map (in g's) for 10% probability of being exceeded in 50 years

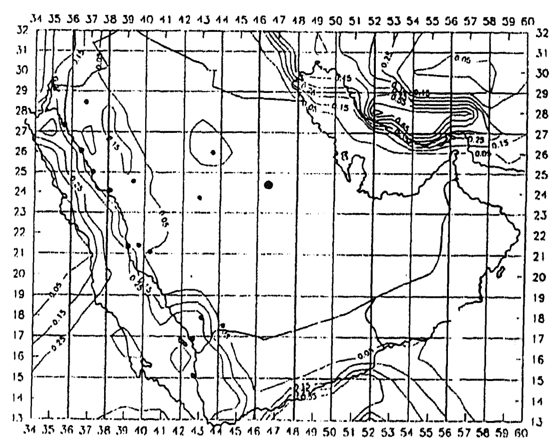

Figure 3. Iso-acceleration map (in g's) for 10% probability of being exceeded in 100 years

4 FEATURES OF DESIGN CRITERIA

4.1 General

The first line of thought in preparing preliminary version of the design criteria for KSA was to develop them in a fashion that will,

1. assist researchers and regulatory bodies in reduction of seismic hazard in new and existing building at present or at a point in time in future;
2. provide engineer-expert with relevant seismic parameters for the Kingdom as an input to recognized standards and codes; and
3. provide professional engineer with ready to use formulation for evaluation of seismic loads and the related effects, and furnish basic guidance for analysis and design of the building structures in situations where the codes provisions are not applicable.

The second line of thought was to develop the design criteria within a framework of a seismic code that is well recognized and accepted internationally and nationally. Based on critical screening and evaluation of world wide earthquake resistance design codes the most widely used U.S. Official codes, SEAOC (1988) and UBC (1988) were selected as the models for development of the seismic design recommendations suitable for and consistent with the type of the buildings and construction practices in vogue in KSA. The manuscript of the Preliminary Design Criteria, Al-Haddad et al. (1992), follows the SEAOC-format in general and is written in descriptive text rather than in a formal code type format. It presents the background and the basis which led to the selection or adoption of various provisions. In this paper, only the crucial issues and the parameters of the SEAOC or UBC are discussed to show how they were evaluated, modified and adopted.

4.2 Seismic zonation and factors

50-year PGA contours given in Fig. 2 are used to zone the Kingdom for seismic design purposes. The Kingdom is divided into four seismic area zones, shown in Fig. 4, based on the level of PGA as shown in Table 1.

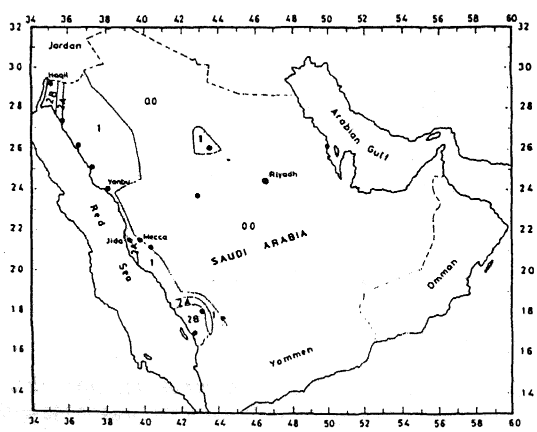

Figure 4. Seismic zonation map

Table 1. Basis of seismic zone number (SZN) assignment

SZN	PGA in g's
0	less than 0.05*
1	0.05 to 0.10
2	0.10 to 0.15
3	0.15 and above **

* PGA for 10% probabilities of exceedance in 50 year
** the highest value of the PGA is about 0.2g.

The seismic zone factor, Z, consistent with the philosophy of SEAOC and UBC is calculated according to recommendations of ATC (1984). The Z-value represents the effective peak acceleration (EPA) as a decimal fraction of the acceleration due to gravity, g. The EPA is calculated as a proportional acceleration ordinate of an appropriate elastic response spectrum constructed for the area for which the Z-value is available. The Z-values for the four seismic zones in the Kingdom are presented in Table 2.

Table 2. Seismic zone number (SZN) and seismic zone factor, Z

SZN	0	1	2A	2B
Z	0.05	0.075	0.15	0.20

4.3 Seismic performance category (SPC)

SPC is mainly considered as a measure of degree of protection provided to the public and the building occupants against the seismic hazard. The concept of SPC is presented by ATC and is not considered by SEAOC and UBC. As shown in Table 3, three SPC's, A to C, are employed for the Kingdom. The SPC A represents the least and C the most severe demand on a structure.

The design criteria employ SPC as a control in prohibiting the use of certain structural types and limiting the heights of buildings as shown in Table 4. This table is an adoption of Table G of SEAOC and UBC where these limits are based on seismic zone factor regardless of the occupancy type.

Table 3. Seismic performance category

OC / SZN	ES	SP	ST
2B	C	C	B
2A	B	B	A
1	B	A	A
0	No seismic requirement on the structures in this zone		

Notes: OC occupancy category, ES essential, SP special, ST standard

4.4 R_w - values

SEAOC and UBC call R_w as the "system performance factor", while ATC as the "response modification factor". No solid basis is available in these documents to justify the values specified for the factor. As a matter of fact these values form the most controversial part in the development of seismic design provisions.

The code development authorities have employed consensus of engineering judgement and observed structural performance, during earthquakes, of the buildings designed according to the earlier versions of the codes in arriving at the stipulated values. However, the experts at the present point in time consider the specified values to be high.

According to the current state-of-the-art, R_w is considered to be function of overstrength and ductility of a structure. This definition is expected to lead to a more accurate evaluation of R_w values in future.

The values specified in Table 4 are lower than those specified by SEAOC and UBC. The following considerations led to selection of the values:

1. specification of ACI (1989) provisions for design and detailing requirement which employ lower values of load factors than those specified by SEAOC and UBC;
2. prevalent information of lesser ductility of Saudi reinforcing steel as compared to ASTM Grade-60 steel, specially under cyclic load;
3. prevailing understanding that quality control, specially in private construction sector, is not up to the mark; and
4. lack of knowledge of response to an earthquake of the buildings and structural systems employed in the Kingdom.

Table 4. Structural System, R_w and Height Limit, H (in meters)

Lateral Load Resisting System	R_w	H
Moment Resisting Frame		
1 Special Moment Resisting Space Frames (SMRSF)		
Steel	8	NL[3]
Reinforced Concrete	8	NL
2 Concrete Intermediate Moment Resisting Frames (IMRSF)[1]	5	
3 Ordinary Moment Resisting Space Frames		
Steel[1]	6	
Reinforced Concrete[2]	2	
Building Frame System		
1 Steel Eccentric Braced Frame (EBF)	8	75
2 Shear Walls		
Reinforced Concrete	6	75
Reinforced Masonry	4	50
3 Steel Concentric Braced Frame	6	50
Dual System		
1 Shear Walls		
Concrete with SMRSF	8	NL
Concrete with Concrete IMRSF[1]	5	160
2 Steel EBF with Steel SMRSF	8	NL
3 Concrete Braced Frames		
Steel with Steel SMRSF	8	NL
Steel with Concrete SMRSF	6	50
Bearing Wall System		
1 Shear Walls		
Reinforced Concrete	4	50
Reinforced Masonry	3	35
Undefined System		
1 Inverted Pendulum Structures	3	
2 Tanks, Vessels, Trussed Towers	3	

[1] Prohibited in Seismic Performance Category C
[2] Prohibited in Seismic Performance Categories C,B
[3] No Limit

5 CONCLUSIONS

The study can serve as a guide for development of seismic design criteria for country of low seismic activity and scarce data. Essential features of such a task lie in development of earthquake catalogue, elimination of clusters, development of probabilistic criteria for assigning magnitudes to historic events, and treatment for bias and incompleteness. On the design criteria side, the zonation, determination of seismic performance categories and evaluation of overstrength and ductility factors for various structural framing systems form a major contribution.

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