PROBABILISTIC DETERMINATION OF SEISMIC DESIGN CRITERIA

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SUMMARY

A probabilistic technique of forecasting bedrock iso-acceleration contours in terms of time, magnitude, and exceedance probability is presented along with examples from field applications. The relationships among recurrence intervals, return periods, mean rates of occurrence, time, exceedance probabilities, and nominal design levels are discussed and illustrated. It is shown that nominal deterministic design levels can be readily related to probabilistic measures including the influence of the design life and importance of the facility.

It is shown that a consistent risk level for a given class of structure located in different seismic zones can be maintained. Seismic zoning, based on the concept of acceptable risk for a given class and use of structure is developed. Illustrative examples from practice are included.

1. Introduction

After all major seismic events, one is reminded of the devastation and far-reaching consequences of major earthquakes. The planning and rebuilding efforts following such events bring up many questions. Are existing code requirements adequate? Can the future damage be reduced by zoning ordnances? What are the future seismic consequences for a given region? What level of future risk is acceptable? How should the acceptable risk level be translated into acceptable design parameters? Should similar land uses be permitted in the future for areas which suffered major damage? These and numerous other questions become especially relevant after a significant damaging event.

By their very nature, expected future hazard and expected risk have an implication of uncertainty. Hence, it is not surprising that principles of probabilistic forecasting and decision making are essential in any seismic hazard or seismic risk analysis.

2. Iso-acceleration Maps

There is considerable work done in the area of probabilistic estimation of seismic load parameters. In particular, probabilistic forecasting in terms of iso-seismal and iso-acceleration maps have been studied by various researchers. These models are based on the following parameters and assumptions.

1. Point, line or area seismic sources can be identified, based on past seismic data.
2. For each source, a recurrence relationship - linear or bilinear - can be developed.
3. Forecasting of future events can be made by using the Poisson model of occurrence, where the mean rate of occurrence above a given Richter magnitude is given by the recurrence relationship.
4. A suitable attenuation relationship on intensity or acceleration can be obtained to fit regional geological and geotechnical conditions.

Reference 1 shows the derivation of probabilistic peak ground acceleration at a site due to various line and area sources in a given region. Figure 1 shows a typical iso-acceleration map developed for Nicaragua. For Nicaragua, ten line and three area sources were identified. For each source, a bilinear recurrence relationship was fitted. A Poisson model was used to forecast future seismic events and the attenuation relationship used was in the following form:

$$A = \frac{b_1 \exp(b_2 M)}{(R_u + b_4)^{b_3}} \tag{1}$$

where A = Peak Ground Acceleration in cm/sec^2.

R_h = Hypocentral distance from source to site (in kms).

M = Richter Magnitude.

b_1, b_2, b_3 and b_4 are constants depending on the region. For the map developed in Figure 1, the values of the above constants selected were:

$b_1 = 5000$; $b_2 = 0.8$

$b_3 = 2.0$ and $b_4 = 40$.

It can be seen from Figure 1 that there are three variables associated with any iso-acceleration map.

1. Peak ground acceleration.

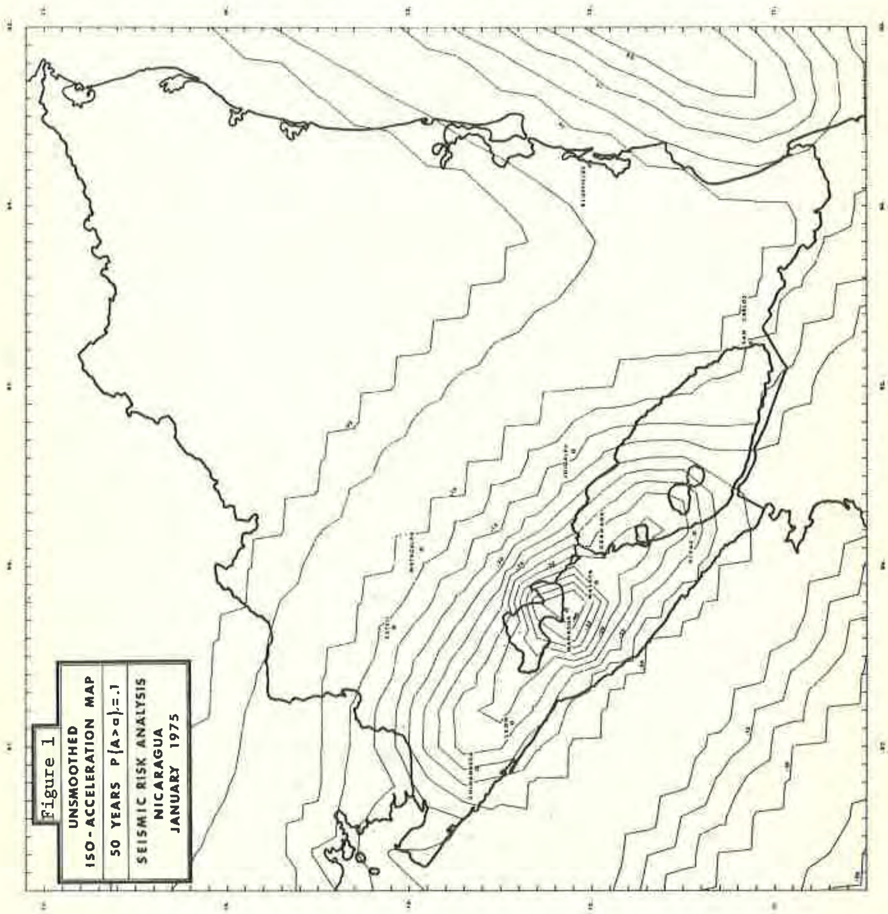


Figure 1
UNSMOOTHED
ISO-ACCELERATION MAP
50 YEARS P(A>a)=.1
SEISMIC RISK ANALYSIS
NICARAGUA
JANUARY 1975

2. Economic or Exposure time of the structure.
3. Probability of exceeding the peak ground acceleration at a point during the economic life of the structure.

Thus, for a fifty year economic life of the structure, there is a 10% chance that the peak ground acceleration in Managua will exceed 44% of g. Such an event corresponds to a mean return period of 475 years. This aspect will be discussed shortly. It can be seen that for different economic lives and probabilities, several iso-acceleration maps are needed. However, for all possible mean return periods and the corresponding peak ground accelerations at any given site in a country, a composite graph called the Acceleration Zone Graph (AZG) can be developed.

3. Acceleration Zone Graph

Based on the iso-acceleration maps, the relationship between the mean return period and the peak ground acceleration can be developed. Consider, for example, the City of Managua. For this region, from iso-acceleration map, the probability of exceeding 0.20g in fifty years is 0.963.

i.e. $P_{50}[A > 0.20g] = 0.963$

or $P_{50}[A > 0.20g] = .037$.

Hence, $P_{50}(0)$ = Probability of not exceeding 0.20g in 50 years.

$= (1 - p)^{50} = 0.037$.

Therefore, $p = 0.063$.

But Mean Return Period $= \frac{1}{p}$.

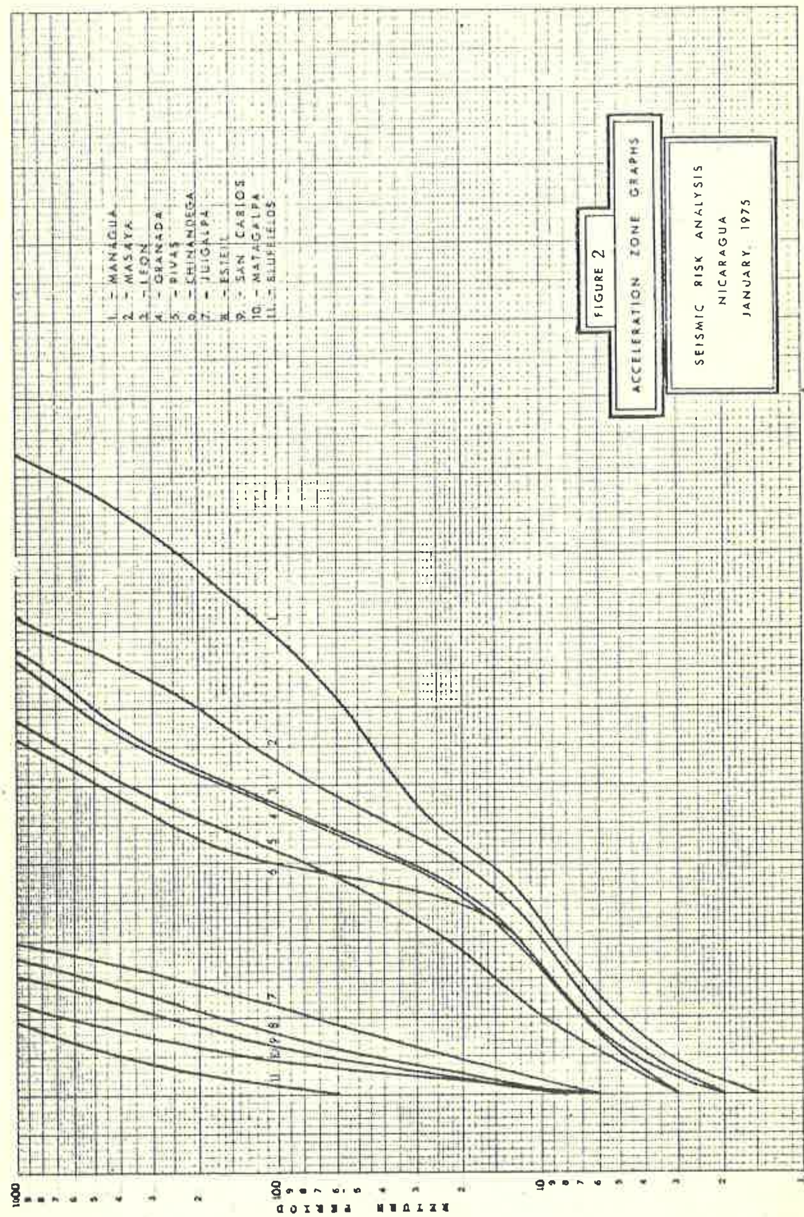
$\therefore$ Mean Return Period corresponding to 0.20g in Managua = 16 years.

Using such derivations, relationships between mean return periods and peak ground accelerations at any part of the region of interest can be developed. Figure 2 shows such Acceleration Zone Graphs for eleven regions in Nicaragua. In using the concept of mean return period, the following statements should be understood.

1. A return period is the mean (or average) waiting time for an event of interest. Thus, the average waiting time between two events producing 0.20g in Managua is approximately 16 years.
2. The probability that an event corresponding to a return period RP will occur in any given year is given by $p = \frac{1}{RP}$. Thus the probability of exceeding 0.20g in Managua in any given year is $\frac{1}{16} = 0.063$.
3. The probability that not a single event of the RP type will occur in RP years is given by $1/e$ where $e = 2.718$, the Naperian base. Thus, the probability that in 100 years, there will not be a single event producing a peak ground acceleration of 0.35g in Managua is given by 0.36.

Figure 3 shows an Acceleration Zone Graph for a region east of Los Angeles in Southern California. Currently, we are developing such graphs and iso-acceleration maps for California.

The graphs shown in Figures 2 and 3 by themselves do not help in selecting a mean return period for design as a function of risk level and economic life of the structure. The next step, in any seismic zoning procedure is to obtain a relationship between the economic life of a structure, the level of risk one is willing to take and the return period consistent with the risk level and economic life. Table 1 and Figure 4 show this relationship. It can


1. - MANAGUA
2. - MASAYA
3. - LEON
4. - GRANADA
5. - RIVAS
6. - CHINANDEGA
7. - JUIGALPA
8. - ESTELI
9. - SAN CARLOS
10. - MATAGALPA
11. - BLUEFIELDS
FIGURE 2
ACCELERATION ZONE GRAPHS
SEISMIC RISK ANALYSIS
NICARAGUA
JANUARY, 1975
PEAK GROUND ACCELERATION - GRAVITY UNITS
RETURN PERIOD

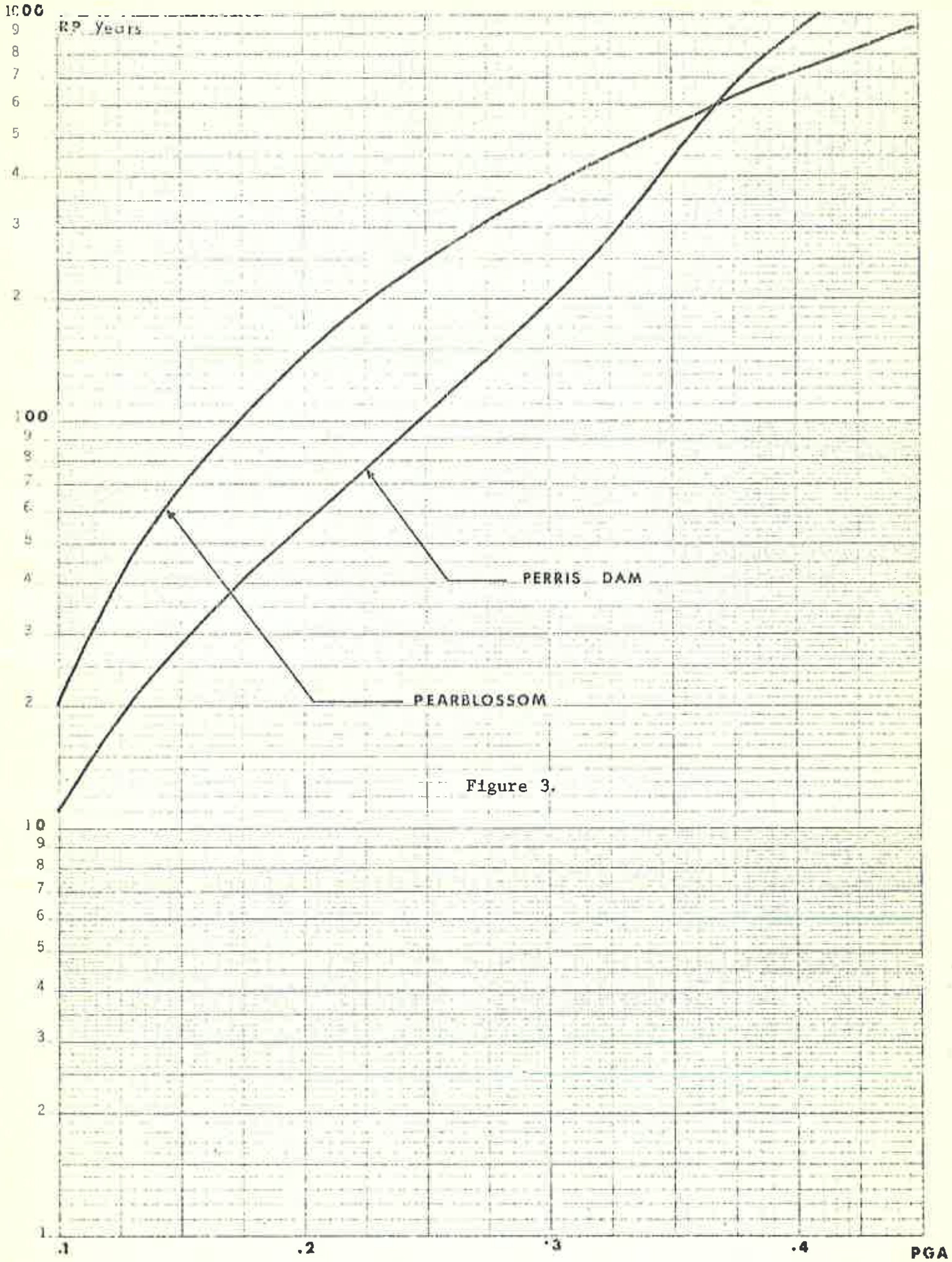


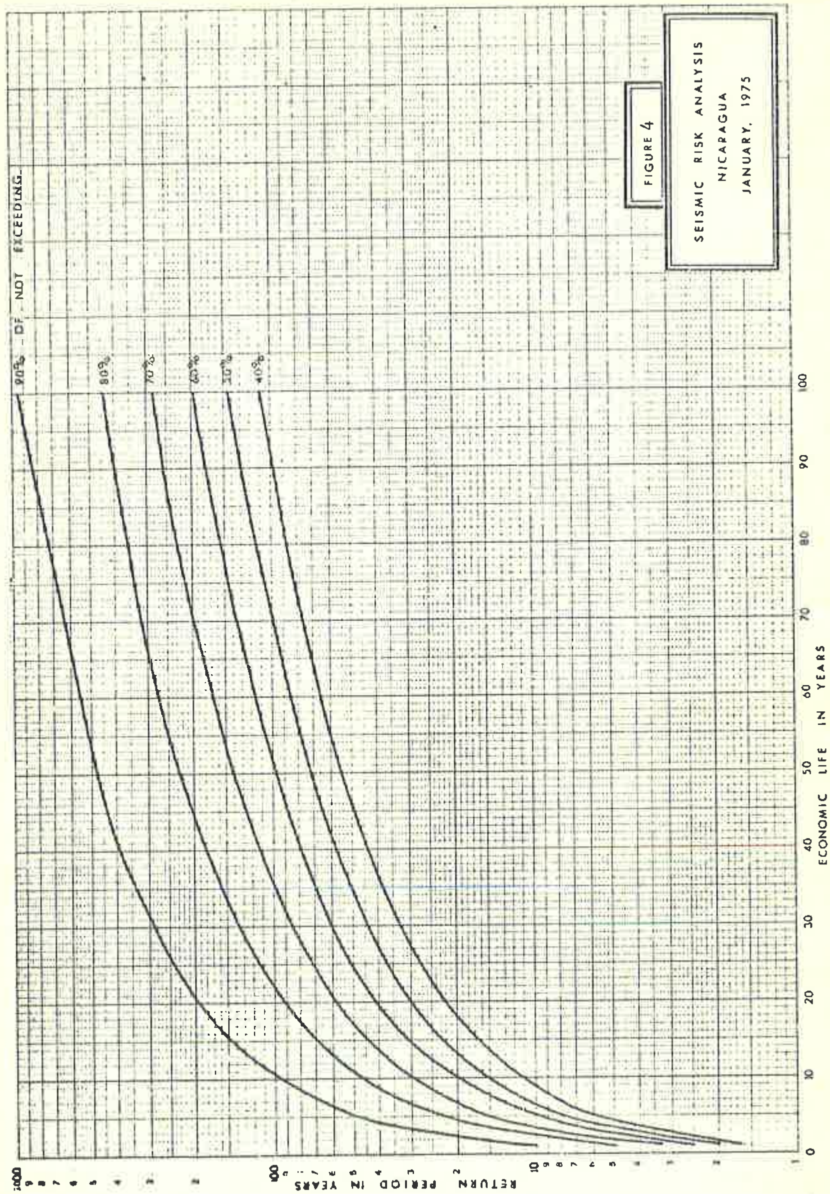
Figure 3.

Table 1

Return Period as a Function of Economic Life and Probability of Non-exceedence

Economic Life Years / Probability of not exceeding %	10	20	30	40	50	100
90	95	190	285	390	475	950
80	45	90	135	180	225	449
70	29	57	84	113	140	281
60	20	40	59	79	98	196
50	15	29	44	58	72	145
40	11	22	33	44	55	110
30	9	17	25	34	42	84
20	7	13	19	25	31	63
10	5	9	14	18	22	44
5	4	7	11	14	18	34
1	3	5	7	9	11	22
0.5	2	4	6	8	10	19

K


90% - OF - NOT EXCEEDING
80%
70%
60%
50%
40%
FIGURE 4
SEISMIC RISK ANALYSIS
NICARAGUA
JANUARY, 1975
ECONOMIC LIFE IN YEARS
RETURN PERIOD IN YEARS

be seen from Table 2 and Figure 4 that for a given economic life, we can determine the relationship between risk level and the return period. As an example, if the structural economic life is 10 years, and if one accepts 10% chance of exceeding the design loading level during the 10 year life, then the return period for which the structure should be designed is 95 years. Similarly, for a 20% risk level and 50 year economic life, the corresponding return period should be 225 years.

Knowing such a mapping or transfer function, we could obtain the desired return period value for the structure. Using figures such as 2 or 3, one can determine the corresponding design load level. The following example will demonstrate the total procedure in determining the peak ground acceleration at a given site as a function of economic life of the structure and the acceptable risk level.

Assume that two class A type of structures with 100 year economic life are to be designed in two different seismic locations.

Location 1 - Southern California (East of Los Angeles)

Location 2 - Managua, Nicaragua.

Assume that the consequences of damage and failure due to future seismic events are similar for both structures. Assume the following acceptable risk levels (100 year economic life).

P_D	Return Period	P_C	Return Period
20%	450	10%	950

where P_D = Probability of Damage

P_C = Probability of Condemnation.

Corresponding to these two return periods, the peak ground accelerations are obtained from Figures 2 and 3. Figure 2 gives peak ground acceleration for Managua and Figure 3 gives peak ground acceleration for Southern California.

	Damage Level	Condemnation Level
Managua	.43g	.46g
Southern California	.33g	.45g

Thus, for a consistent damage risk level, the peak ground accelerations in Managua and Southern California should be .43g and .33g respectively. For consistent risk of condemnation, the corresponding values of the peak ground acceleration should be 0.46g and 0.45g.

Consider now two structures of different classes (a power plant and an office building) to be designed for one seismic region. Assume that the economic life of the power plant is 50 years and the office building is 20 years. Also, assume the following acceptable risk levels.

	P_D	RP (Yrs.)	P_C	RP (Yrs.)
Power Plant (50 yrs.)	20%	225	10%	475
Office Building (20 yrs.)	30%	57	10%	190

It should be noted that the return periods corresponding to economic life and the acceptable risk level are obtained from Figure 4 or Table 2.

Having obtained the desirable mean return periods, one can now obtain the necessary peak ground accelerations from Acceleration Zone Graphs for the region of interest. Again, assume that the two facilities of interest are to be built east of Los Angeles in Southern California. Then, from Figure 3, one gets

	Damage Level	Condemnation Level
Power Plant (50 yrs.)	.24g	.33g
Office Building (20 yrs.)	.14g	.22g

The above values are consistent with the economic life and the acceptable risk levels of damage and condemnation.

It is obvious that such a methodology is a first step in achieving a consistent and rational risk level. A lot of more work is needed before one can include the concepts of life loss, impact loss and socio-economic loss. Inclusion of micro characteristics in the above methodology is also needed before one can translate the macro zoning maps, such as iso-acceleration or Acceleration Zone Graphs, to design values.

References

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