Project Area Maps

Table 9 shows a comparison of the hazard values computed on a one-degree grid for the project area with those at common grid points in México, Central America and South America. Although the IPGH computations were made using a return period of 474.56 yr, the values at grid points in common with those in México and Central America have been adjusted to a return period of 500 yr. At first glance this table might appear redundant to Tables 5 to 8. However, this IPGH grid has been computed independently of the IPGH grids used for the regional comparisons and a good comparison would confirm the regional results.

Table 9

Comparison of One Degree-spaced Seismic Hazard Values for the Project Area with those for México and Central and South America

Range	México and Central and South America			IPGH		
gal	Number of Events	Average Value gal	RMS Dispersion gal	Number of Events	Average Value gal	RMS Deviation gal
>500	46	598	75	27	587	100
250-500	256	335	64	296	334	61
125-250	409	182	34	439	186	36
62.5-125	211	96	16	263	94	18
<62.5	535	14	17	432	22	18

Like those for Tables 5 - 8 the comparison shown in Table 9 seems excellent, with the largest difference being the number of "high" hazard values - 27 in the IPGH grid as opposed to 46 in the combined regional grids The best explanation would appear to involve some combination of differences in the methods of computing seismic hazard and in the attenuation relations employed, although we emphasize that in the case of Central America the attenuation relations are the same for both grids.

Tables 5 to 9 show only the mean values for each zone without regard to their distribution - that is, each set of mean values has been computed without reference or comparison to individual values in either grid. Figs 15, 16 and 18-23 compensate this shortcoming to some extent through their visual presentation of the distribution of seismic hazard throughout the region, although varying degrees of smoothing could distort this comparison to some extent

A different perspective on the comparison of results can be provided by computing mean differences (regional minus IPGH values) for individual grid points within each range of seismic hazard and for the area as a whole. These results are given in Table 10 which shows a much more variable comparison. Several observations stem from the results shown in this table·

- the positive differences in the two high ranges and the negative differences in the lower ranges would tend to confirm the results of Fig. 10 which shows that the CLIM94 attenuation relation gives lower PGA (for larger events at least) near the epicentre and, with the exception of the Kausel and Woodward-Clyde relations, attenuates more slowly than the others,

- part of the explanation for the pattern of positive and negative differences may lie in the smoothing due to the use of random numbers,

- individual differences at grid points can evidently be quite large if the RMS deviation is any indicator, but this might be expected because of differing methods of computing seismic hazard, the various attenuation relations used and the use of random numbers by IPGH,

- despite some large differences at individual grid points throughout the project area the overall mean difference for the project area is within 10 gal of zero,

- given the disparity in the properties of the attenuation relations and the difference in the methods used to compute seismic hazard, the agreement between the IPGH grids and those provided by the regions, as expressed by the average of differences at all grid points, does suggest that the IPGH grid gives a fair representation of the overall level of seismic hazard

Table 10

Mean Differences between One-degree Gridded Values for Project Area and those for México and Central and South America

Range gal	Number of Events	Mean Difference gal	RMS Dispersion gal
>500	46	197	132
250-500	256	30	85
125-250	489	-20	85
62.5-125	211	-29	66
<62.5	535	-33	61
All	1537	-10	70

Although the results equivalent to those of Table 10 have not been shown for each of the regions, comparisons of the IPGH grid with those for México and South America show a pattern similar to that of Table 10. The same is not true for Central America where, in all ranges, the mean differences are strongly negative (i e., seismic hazard values for Central America are consistently lower despite the use of the same attenuation relation by IPGH). This confirms the results of other comparisons and while this does not demonstrate the Central American results are in error, it does indicate that future investigations should concentrate in part on the reason for this circumstance.

Fig. 25 shows the probabilisitic seismic hazard map, for solid rock or equivalent, for the project area compiled from the same one-degree grid used for the summaries of the IPGH contribution to Tables 9 and 10. Like the IPGH maps presented earlier, the data used to compile this map have been smoothed in three separate stages: first by the use of pseudo-random numbers during the computation of the original grid, second by matrix smoothing in SURFER during the compilation of the plotting grid and third during the contouring process of SURFER.

Although Table 9 indicates the presence of values of what are here classified as "high" seismic hazard, they have been removed by SURFER in the process of smoothing the grid and contouring the map. However, it turns out that the peak values on the smoothed grid used to compile the map are just on or below that of the lower boundary value for the "high" seismic hazard range.

On several occasions, individuals involved with the project, either expressed interest in or produced some version of what is called here a "one-time maximum" map of a particular earthquake-related parameter. Early in the project, maps of maximum intensity due to a single event were published in the annual reports, but later the interest turned toward maps of one-time maximum PGA experienced at any point in the project area.. This interest has developed because the catalogue now covers a span of about 500 yr, which is approximately the return period used for most probabilistic seismic hazard estimates Even though this catalogue is by no means complete, most or all of the largest events have probably been logged into it and there is interest in seeing how this "one-time maximum" map compares with probabilistic seismic hazard.

Fig. 26 shows the "one-time maximum" PGA for solid rock or equivalent due to a single event computed on a grid throughout the project area using the CLIM94 attenuation relation. The patterns of contours on this map resemble those of the probabilistic seismic hazard map (Fig. 25), but the PGA values are lower. This map shows the contoured levels of one-time maximum PGA experienced (as estimated using the CLIM94 attenuation relation and iterating 10,000 times with random numbers) throughout the project area over the last 500 years, but does not predict in any way what might be experienced in any location over any period of time. Therefore this map, while interesting, has no meaning in a probabilisitic sense.

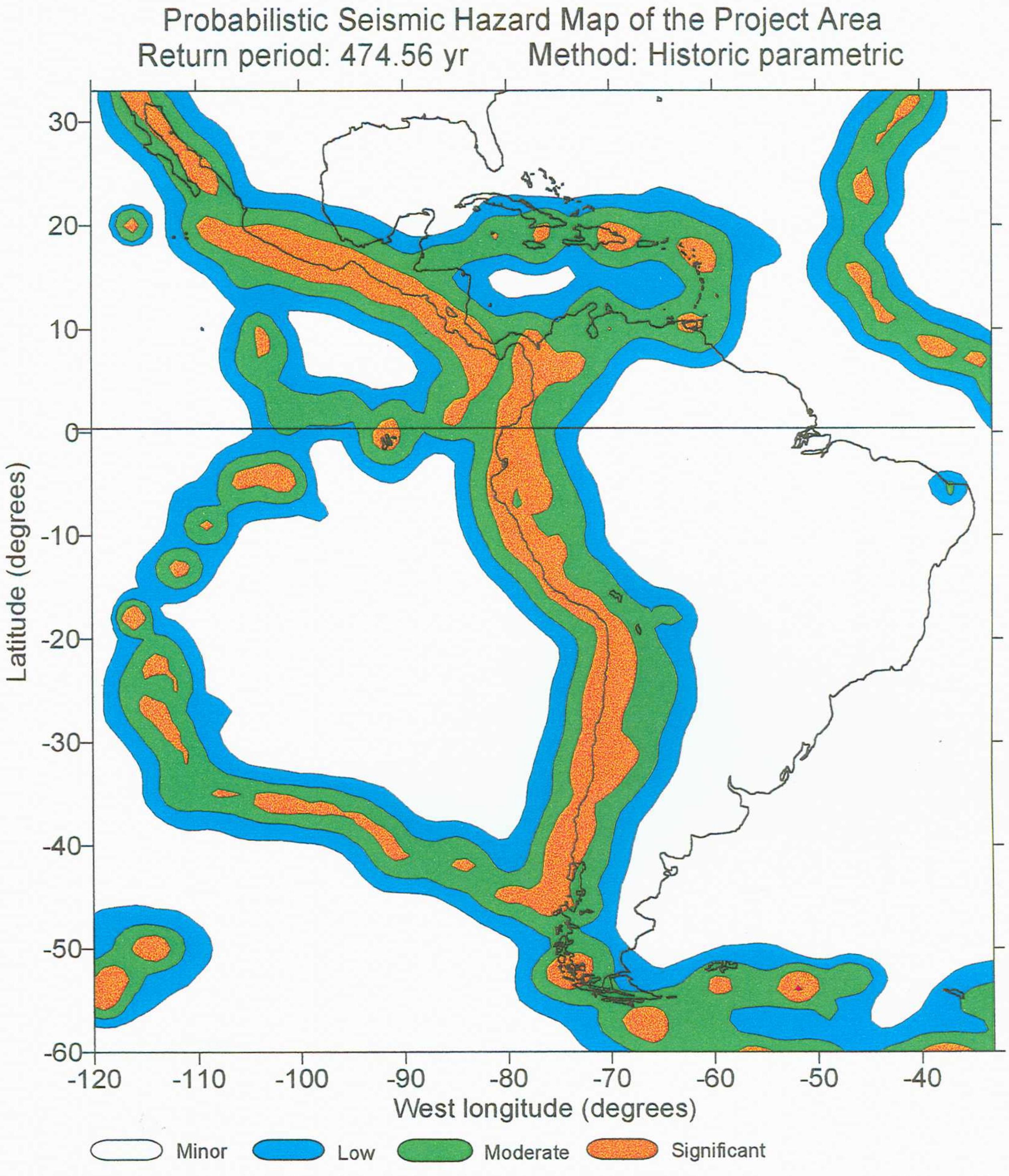

Figure 25. Seismic hazard map (solid rock or equivalent) of the project area computed from the IPGH catalogue using the CLIM94 attenuation law (Climent et al, 1994). .The grid interval for the computations is one degree (1^0). All values determined after 100 iterations using random numbers to scale estimated uncertainties iin all parameters used for the calculations.

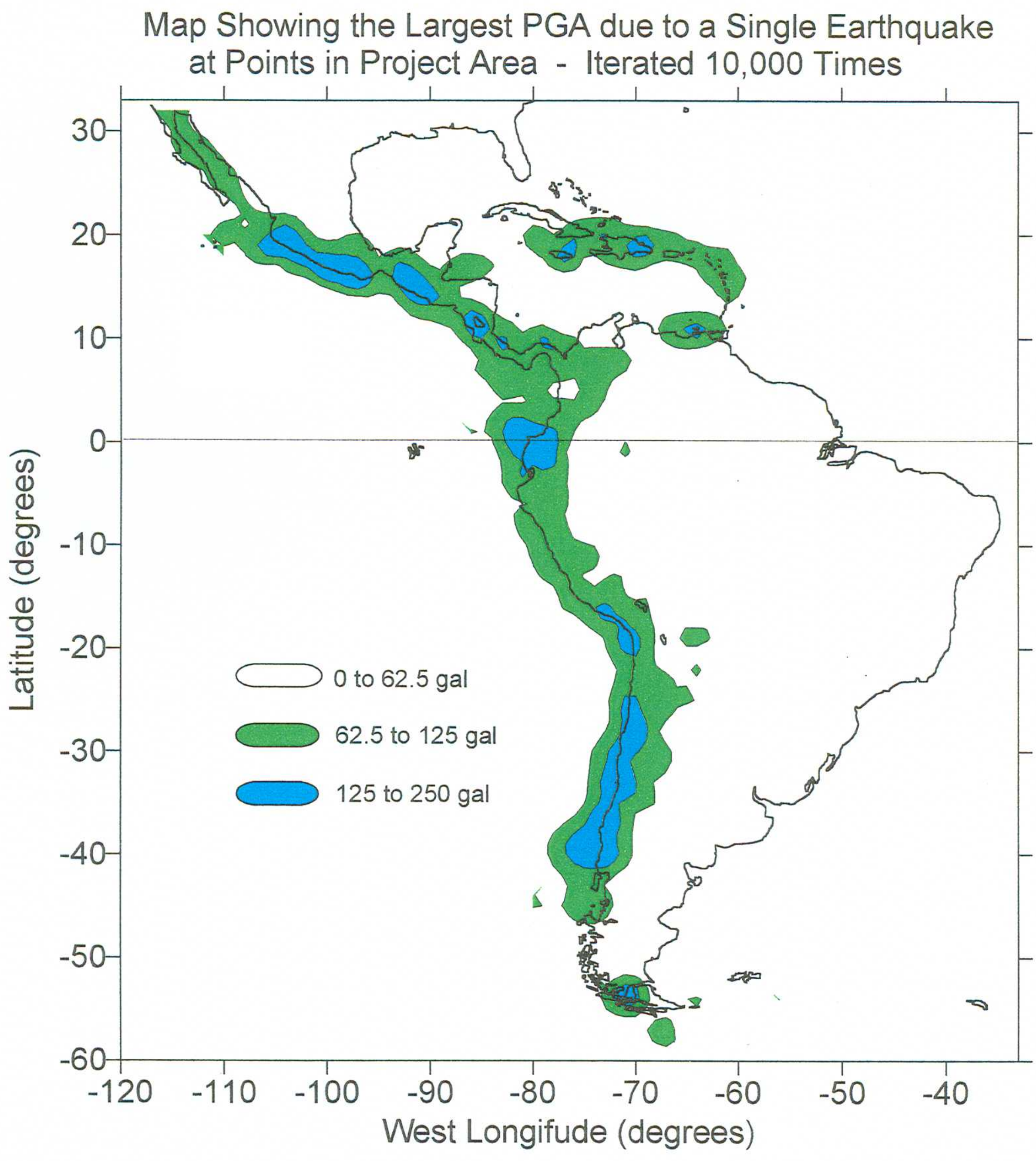

Figure 26. Map showing the largest PGA (solid rock or equivalent) due to a single event at points throughout the project area. The data used to compile the map have been computed (using the CLIM94 attenuation relation) from the IPGH catalogue on a one degree grid. Values detemined from 10,000 iterations with random numbers to scale estimated uncertainties in earthquake parameters used for the calculations.

Conclusions

1. The method of extrapolation of the observed data computed with the historic parametric method is central to the results obtained. We have chosen a method embodying the idea of the extrapolation process being asymptotic to a maximum possible value rather than some other method such as a power law fit. This approach yields results that are lower or less conservative than other methods, but would appear justified on nothing other than common sense.

2. There is nothing subjective about the application of the historic parametric method - the earthquakes selected from the catalogue speak for themselves via the appropriate attenuation relation - i e., there is no requirement to group them according to tectonic concepts, patterns of seismicity or other criteria.

3. The Gutenberg-Richter equation is assumed to apply to all earthquakes, small and large. This may not be true Many seismologists (see for example, Scholz, 1990 for a discussion) believe that earthquakes large enough to crack right through the rigid part of the lithosphere may not follow the same recurrence relationships as the smaller events If this is so, the rate of recurrence of larger events can not be predicted by this method.

4 The assumption that earthquakes occur randomly in time is one that needs examination. Clearly, the occurrence of foreshocks and aftershocks ensures that earthquakes cluster in time to some extent at least Also, calculations for locations within zones that are generally active seismically and have shown low levels of activity in the past, but may show higher levels in the future, will give misleading results using the historic parametric method.

5. The attenuation relation used for the computations for the IPGH maps has been chosen from a list specified by the Steering Committee: a list which reflects regional preferences. This list is not regarded as the last word on the topic and we hope that attenuation laws better representing the true situation will be developed in the future. Some detail of the attenuation laws used regionally can be obtained from their reports on seismic hazard which appear as part of this series. Our conclusion here would be the obvious·

- reliable attenuation relations are critical to the calculations and uncertainties in them are by far the largest source of error in the computations,

- much more research and many more strong motion records are required before we can be satisfied that we understand the attenuation of seismic waves throughout the project area - this is not to suggest the attenuation laws used here are incorrect, but rather they must be subjected to considerable further evaluation,

- the attenuation law determined by Climent et al (1994) for Central America has proved useful for this work and it (along with the Boore et al (1993) relationship) is the best documented to date of those available for the project area.

6. Comparisons with the regional seismic hazard estimates both in tabular and map form generally confirm that the IPGH map provides a good reference level for seismic hazard throughout the project area The somewhat lower hazard values in Central America as compared to the results obtained by IPGH, México and South America need to be investigated to determine their cause The absence of a narrow zone of "high" hazard along the west coast in Chile is not regarded as serious as the smoothed gridded IPGH results sit on the border between the zones of "high" and "significant" hazard (500 gal).

7. We need to move on to the next phase of seismic hazard , the so-called spectral seismic hazard. Climent et al (1994) have computed a spectral version of their attenuation law and its use would appear a good place to start in this next phase. This is an urgent task as GSHAP has decided to go this route in a schedule that calls for completion of a first global seismic hazard map in about two years.

8. In an area which contains some of the most active and fastest moving plates observed anywhere on the globe, funds are needed to purchase digital seismographs and GPS receivers to be co-located at critical points throughout the project area to assist in improving our understanding of seismicity, seismic hazard and attenuation of seismic waves in greater detail. Most countries in the region have the trained personnel and institutes capable of operating such equipment, but many lack the funds to purchase this equipment which for reasons of economy, efficiency and quality of results should be standardized Therefore, the financial help of agencies such as IDRC is still needed despite the generally improving conditions in the area

Conclusiones

1. El método de extrapolación de los datos observados, usando el método paramétrico histórico, fue básico para los resultados obtenidos. Escogimos el uso de un método que incorporaba la idea de un proceso que es asimptótico a un valor máximo posible, en lugar de algún otro método como un ajuste a una ley de potencias. Este enfoque proporciona resultados que son menores o menos conservadores que otros métodos, pero parecen justificados sobre todo en el sentido común.

2. La aplicación del método paramétrico histórico no tiene nada de subjetiva - los sismos seleccionados del catálogo hablan por sí mismos vía la relación de atenuación apropiada - i.e. no se requiere agruparlos de acuerdo a conceptos tectónicos, patrones de sismicidad u otros criterios.

3. Se asume que la ecuación Gutenberg-Richter se aplica todos los sismos, grandes o pequeños . Esto puede no ser cierto. Muchos sismólogos (ver por ejemplo, Scholz, 1990 para una discusión) creen que los sismos suficientemente grandes como para romper a través de la parte rígida de la litósfera no siguen las mismas relaciones de recurrencia de los sismos pequeños. Si esto es así, la tasa de recurrencia de los eventos mayores no puede predecirse por este método.

4. La suposición de que los sismos ocurren aleatoriamente en el tiempo debe ser examinada. Claramente, la existencia de precursores y réplicas prueba que, en cierto sentido, existe una acumulación temporal de los sismos. Al mismo tiempo, los cálculos usando este método, para localidades dentro de zonas que son en general sísmicamente activas y que han mostrado bajos

niveles de actividad en el pasado, pero que pueden tener mayores niveles en el futuro, pueden conducir a conclusiones erróneas utilizando el método paramétrico histórico

5. La relación de atenuación utilizada para calcular los mapas del IPGH fue seleccionada de una lista especificada por el Comité Directivo una lista que refleja preferencias regionales. Esta lista no debe considerarse como la última palabra sobre el tema, y esperamos que en el futuro se desarrollen leyes de atenuación que representen mejor la situación real. Pueden obtenerse detalles de las leyes de atenuación utilizadas de los reportes regionales sobre peligro sísmico que aparecen como parte de esta serie de reportes finales. Nuestras conclusiones aquí son las obvias:

- tener relaciones de atenuación confiables es básico para los cálculos, y las incertidumbres en ellas son, con mucho, la mayor fuente de error en los cálculos,

- se requiere mucho más investigación y muchos más registros de movimientos fuertes en el área del proyecto antes de que podamos sentirnos satisfechos de que entendemos la atenuación de las ondas sísmicas en el área del proyecto - no queremos sugerir que las leyes de atenuacióin usadas aquí sean incorrectas, sino que deben estar sujetas a evaluaciones futuras considerables,

- la ley de atenuación determinada por Climent et al (1994) para América Central, demostró ser útil para este trabajo, ya que es (junto con la relación de Boore et al (1993)) la mejor documentada a la fecha en el área del proyecto.

6 Las comparaciones con los resultados regionales tanto en forma tabular como en mapas confirman, en general, que el mapa del IPGH proporciona un buen nivel de referencia para peligro sísmico en toda el área de proyecto. Se requiere investigar los valores de peligro ligeramente menoras en América Central, en comparación con los resultados obtenidos por el IPGH, México y Sudamérica para determinar la causa La ausencia de una zona angosta de alto peligro en la costa occidental de Chile no es considerada como seria, ya que los valores del IPGH en esa rejilla se ubican en la frontera entre los valores de peligro "alto" y "significativo" (500 gal) y son suavizados en el proceso de compilación.

7. Necesitamos movernos a la siguiente fase de peligro sísmico, el llamado peligro sísmico espectral. Climent et al (1994) calcularon la versión espectral de su ley de atenuación y basados en nuestros resultados, su uso parece ser un buen lugar para empezar la siguiente fase. Este es un trabajo urgente ya que GSHAP ha decidido seguir esta ruta en su camino a integrar un primer mapa de peligro sísmico global en aproximadamente dos años.

8. En un área que contiene algunas de las placas más activas y de movimiento más rapido observadas en cualquier lugar del globo, se requiere financiamiento para adquirir sismógrafos digitales y receptores GPS para colocar ambos en puntos críticos distribuidos en el área del proyecto y ayudarnos a mejorar nuestra comprensión de la sismicidad, el peligro sísmico y la atenuación de las ondas sísmicas en mayor detalle La mayoría de los países de la región tienen personal entrenado e institutos capaces de operar estos equipos, pero muchos carecen de fondos para su adquisición, la que por razones de economía, eficiencia y calidad en los resultados debería

estandarizarse Por lo tanto, aún se requiere el apoyo financiero de agencias como el IDRC, a pesar de que en general, las condiciones en el área están mejorando.

References

Algermissen, S.T., D.M. Perkins, P.C. Thenhaus, S.L. Hanson and B.L. Bender, 1982. Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States. USGS Open File Report 82-1033

Boore, David M , William B Joyner and Thomas E. Funal, 1993. Estimation of response spectra and peak accelerations from western North American earthquakes: an interim report U.S. Geological Survey, Menlo Park, CA, Open File Rept 93-509, 72p

Boore, David M , William B. Joyner and Thomas E. Funal, 1994. Estimation of response spectra and peak accelerations from western North American earthquakes: an interim report, Part2. U.S. Geological Survey, Menlo Park,CA, Open File Rept 94-127, 43p.

Cornell, C.A., 1968 Engineering seismic risk analysis. Bull Seismol Soc. Amer., 58, 1583-1696

Climent, Alvaro, Waldo Taylor, Mauricio Ciudad Real, Wilfried Strauch, Guillermo Santana, Mario Villagran, Anders Dahle and Hilmar Bungum, 1994. Spectral strong motion attenuation in Central America. NORSAR, Tech. Rept. No. 2-17, 46p.

Davis, Scott D., and Cliff Frolich, 1993 Single-link cluster analysis and earthquake aftershocks; decay laws and regional variations. J. Geophys. Res., 96, 84, 6335-6350.

Grases, J., 1990. Peligro sismico con fines de ingenieria. Segunda Jornados de Ingenieria Sísmica, Caracas, 1-2 June, 1990

Gumbel, E., 1958. Statistics of Extremes. Columbia University Press, 375p.

Gutenberg, B. and C.F Richter, 1954. Seismicity of the Earth and Related Phenomena Princeton University Press, Princeton, N.J.

Joyner, W.B. and D. M. Boore, 1981. Peak horizontal acceleration and velocity from strong motion records including records from the 1979 Imperial Valley, California earthquake Bull Seismol. Soc Amer., 71, 2011-2038

Joyner, W.B. and D.M. Moore, 1993. Methods for regression analysis of strong motion data. Bull Seismol Soc. Amer., 83, 469-487.

Makropoulos, K.C. and P.W Burton, 1986. HAZAN: a FORTRAN program to evaluate seismic hazard parameters using Gumbel's theory of extreme value statistics. Computers and Geoscience, 12, 1, 29-46.

Press, William H., Saul S. Teukolsky, William T. Vetterling and Brian P. Flannery, 1992. Numerical Recipes in FORTRAN, The Art of Scientific Computing, Second Edition. Cambridge University Press, 963p.

Richter, C.F., 1957. Elementary Seismology. Freeman Press, San Francisco.

Scholz, C.H., 1990. The mechanics of earthquakes and faulting. Cambridge University Press, Cambridge, 439p.

Shepherd, J.B. and W.P. Aspinall, 1983. Seismicity and earthquake hazard in Trinidad and Tobago, West Indies, Earthquake Eng and Struct. Dynam., 11, 2, 229-250.

Shepherd, J.B., D.M. Beckles, W.P. Aspinall and S. Clarke, 1986. Recent seismicity of the Trinidad/Tobago Gulf of Paria region. Proc. Sixth Caribbean Geological Conference.

Shepherd, J.B., J.G. Tanner and L. Prockter, 1994. Revised estimates of the levels of ground acceleration and velocity with 90% probability of non-exceedance in any 50-year period in the Trinidad and Tobago region. Proc. Caribbean Conference on Earthquakes, Volcanoes, Windstorms and Floods, Oct. 11-15, 1993.

Singh, S.K., L Ponce and S.P. Nishenko, 1985. The great Jalisco, México earthquake of 1932: subduction of the Rivera plate. Bull. Seismol. Soc. Am., 75, 1301-1313.

Singh, S.K., E. Bazan and L. Esteva, 1980. Expected earthquake magnitude from a fault. Bull. Seismol. Soc. Am., 70, 903-914.

Veneziano, D., C.A. Cornell and T. O'Hara, 1984. Historic method of seismic hazard analysis. Elec. Power Res. Inst., Report NP-3428, Palo Alto, CA.

Woodward-Clyde Consultants, 1982. Development and initial application of software for seismic exposure evaluation. Report for NOAA. Vol. II.