STRONG MOTIONS IN ALASKA-TYPE SUBDUCTION ZONE ENVIRONMENTS

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SUMMARY

Peak accelerations of Alaska-Aleutian strong motion records are compared with those collected mostly in the western U.S. The most prominent difference is the larger scatter of Alaskan peak accelerations. The high scatter is attributed primarily to high variability of stress drops typical for some subduction zones. For critical engineering projects that must satisfy high probabilities of non-exceedence it implies that in Alaskan-type environments higher design peak accelerations may have to be adopted than under comparable circumstances in the western U.S.

INTRODUCTION

Many of the probabilistic strong-motion scaling laws now in use - for instance percentile of non-exceedence of peak or rms acceleration as a function of distance and magnitude - are strongly dominated by data collected in the western U.S. and other similar tectonic settings. Strong-motion data for moderate earthquakes ($4 \leq M_W \leq 7.5$) in Alaska and perhaps other similar subduction zones systematically differ from those in predominantly strike-slip and shallow-depth earthquake environments. These differences affect the strong-motion scaling laws and thus, design considerations. First, we observe that for a given magnitude and distance, peak accelerations in Alaska tend to vary by substantially more than one order of magnitude. Since magnitude is based on low-frequency radiation (1 Hz for m_b, 0.05 Hz for M_S), while peak accelerations are typically at high frequencies (2 to 10 Hz), stress-drop variations across source sub-dimensions of up to a few kilometers are inferred to be larger at subduction zones than in purely shallow-depth earthquake settings. For some Alaskan subduction events, especially at depths between 30 and 50 km, static and dynamic stress drops of several hundred bars have been measured, while the large majority of stress drops averages between 10 and 100 bars and thus is comparable to other tectonic settings. The greater variance in stress drop, possibly related to a larger depth range in hypocenters, is an important difference of at least some subduction zones versus other tectonic settings. The smaller scatter of peak accelerations in tectonic settings typical for western U.S. implies that design peak acceleration rises only slowly for increasing levels of probability of non-exceedence, whereas in Alaskan-type tectonic settings it rises rapidly. In physical terms, seismic risks related to high frequency seismic radiation are controlled in Alaska more strongly by stress drop and

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source depths while in the western U.S. they are controlled mostly by horizontal distance and magnitude for a given type of site. No data on large earthquakes (M_S or M_W > 7.5) have yet been observed, but attempts to do so are presently underway in the Shumagin seismic gap. These measurements are important for design and siting of critical off-shore installations.

DATA

The authors have recently compiled peak acceleration data for Alaska for which the associated earthquakes, their magnitudes and hypocenters are known (Ref. 1). The obtained peak accelerations are uncorrected for instrument and site response. Magnitudes were recalculated according to a uniform moment magnitude scale M_W.

It is a common practice to scale strong motion quantities against distance to determine empirical attenuation laws, further parameterized by magnitude. Figure 1 shows such a plot for the Alaskan peak accelerations in comparison to peak acceleration curves derived by Joyner and Boore (Ref 2). Their curves were obtained by multivariate regression of a large data set that is dominated by peak accelerations of shallow-depth earthquakes from western U.S. tectonic settings. The Joyner-Boore regression yielded

$$\log A = -1.02 + 0.249M_W - \log r - 0.00255\, r + 0.26P$$

$$\text{for } 5.0 \leq M_W \leq 7.7 \text{ with } r = (d^2 + 7.3^2)^{1/2}$$

and A peak horizontal acceleration in g, M_W moment magnitude, d closest distance in km to the surface projection of the ruptured fault, and P is zero for 50-percentile, and unity for the 84-percentile values of exceedence. The curves actually drawn in Figure 1 are those for P = 0 (i.e., 50-percentiles) and must be uniformly raised by the amount indicated by the bar (upper right corner of Figure 1) to yield 85-percentile curves.

Comparison of the Alaskan data set with the plotted attenuation relationship derived by Joyner and Boore (Ref. 2) suggests that there may be a DC shift and a large scatter in the Alaska data. The Joyner-Boore 50-percentile curve for M = 6.5 exceeds only 19% of the Alaska data in the magnitude range 6 < M < 6.9, and the 84-percentile curve (not plotted) still exceeds only 38% of the Alaska data for the same magnitude bracket. Thus, at a given distance from an earthquake of given magnitude, the range of likely peak accelerations appears much larger for Alaska than that for the western U.S. Also, the slopes of the Joyner-Boore curves appear to be steeper than the Alaskan data suggest: i.e., at surface distances larger than about 50 km most of the Alaska data seem to yield higher peak values while at shorter distances they tend to yield smaller values. This trend may suggest that attenuation is stronger in the western U.S. tectonic setting than it is in the Alaska subduction zone environments.

These features, i.e., scatter, offset and slope, may be, however, only an artifact from plotting the data versus horizontal surface distance rather than inclined distance between source and receiver. Joyner and Boore used data from shallow earthquakes whose depths rarely exceed 10 or 15 km. Therefore, they were justified to assume a constant shallow fault depth. In subduction zone environments, however, where Benioff-zone crustal events (>30 km) are common, this approach is not valid since horizontal distance is sometimes only a fraction of the depth. Another, physically more important difference in the Alaskan versus western U.S. data lies in the variability of stress drops, which is known to be larger in subduction zones than it is in strike-slip tectonic settings.

HIGHLY VARIABLE STRESS DROPS

House and Boatwright (Ref. 3) have determined stress drops of almost one kbar for two ≈40 km deep Shumagin Island earthquakes of magnitudes $M_w = 5.6$ and 5.8. Their associated peak accelerations (included in Figure 1) exceed those of the 50%-curve of Joyner and Boore for a $M_w = 7.5$(!) earthquake at the same surface distance.

Moreover, Mori (Ref. 4) showed that stress drops of Aleutian earthquakes, particularly at depths between 30 and 50 km near the so-called aseismic front, are highly erratic in stress drops which varied for his data sample from ≈5 to ≈500 bar. Even more extreme stress drops were obtained by Mori and Shimazaki (Ref. 5) from Japanese strong motion data for the $M_w \approx 8.2$ Tokachi-Oki earthquake. Subevents within this earthquake had stress drops of 3 to 5 kbar and caused peak accelerations of 0.15g to 0.32g at distances of 230 to 65 km; these values are in excess of any peak values shown for the Alaskan data set (Figure 1). Since stress drop scales linearly with peak-acceleration (Ref. 6) we suggest that the Joyner-Boore regression for peak-acceleration versus distance, parameterized by magnitude and percentile of non-exceedence, does not apply well in at least those subduction zone tectonic settings, which are characterized by large stress drop variations.

COMPARISON WITH ALTERNATIVE ATTENUATION RELATION

We compared the Alaska data set also with other attenuation laws that were specifically designed to apply to Alaska-Aleutian shelf environments. Woodward-Clyde (Ref. 5) proposed two different attenuation laws for peak-accelerations, their type-A (non Benioff-zone earthquakes) and their type-B attenuation relationship (for Benioff zone earthquakes, all source depths> 6 km, stiff rock sites). This latter attenuation law is

$$A_{max} \text{ (median value)} = 210 \, (e^{0.5M_w}) \times (r + C)^{-0.85}$$

where A_{max} is the median value of the maximum acceleration in cm/sec^2, r is the closest distance in km to the rupture plane, and C is a magnitude-dependent distance-normalizing parameter with

$$C = 0.864 \, e^{0.463M_w}$$

Note that for normally or other symmetrically distributed acceleration data ensembles the median value corresponds to the 50-percentile value of non-exceedence.

In Figure 2 we compare the Alaska peak-accelerations with the B-type attenuation curves. Note that the abszissa now represents the <u>inclined</u> distance (r) to the nearest portion of the rupture plane, rather than distance at the surface. We find that in the magnitude bracket $6 \leq M_W \leq 6.9$ only 13% of the data for Alaska exceed the $M_W = 6.5$ type B-curve (proposed for Benioff zone events) and only 4% exceed the $M_W = 7.5$ curve. Hence, this B-type attenuation relation seems sufficiently conservative at least for distances > 50 km.

CONCLUSIONS

Strong motion data in subduction zones are scarce and yet are urgently needed for engineering projects in these environments. We address here only peak accelerations. The equally severe problem of sustained low-frequency shaking from giant earthquakes ($M_W \approx 9$) typical for subduction zones must be left out until pertinent strong motion data become available. However, the scarce peak acceleration data from Alaska-type tectonic settings indicate already that stress drop variability introduces a large scatter into peak accelerations. Stress drop seems in some instances more important than other variables such as distance to the source or magnitude of the event. An important consequence of this finding of subduction zone stress drops emerges for earthquake resistant design. It implies that near subduction zones rather high design peak accelerations will have to be adopted if high probabilities of non-exceedence at a given site must be complied with. Our results are too few to obtain more than a qualitative statement at this time. Substantially more strong-motion data must be collected at places like Japan and Alaska to quantify this preliminary result.

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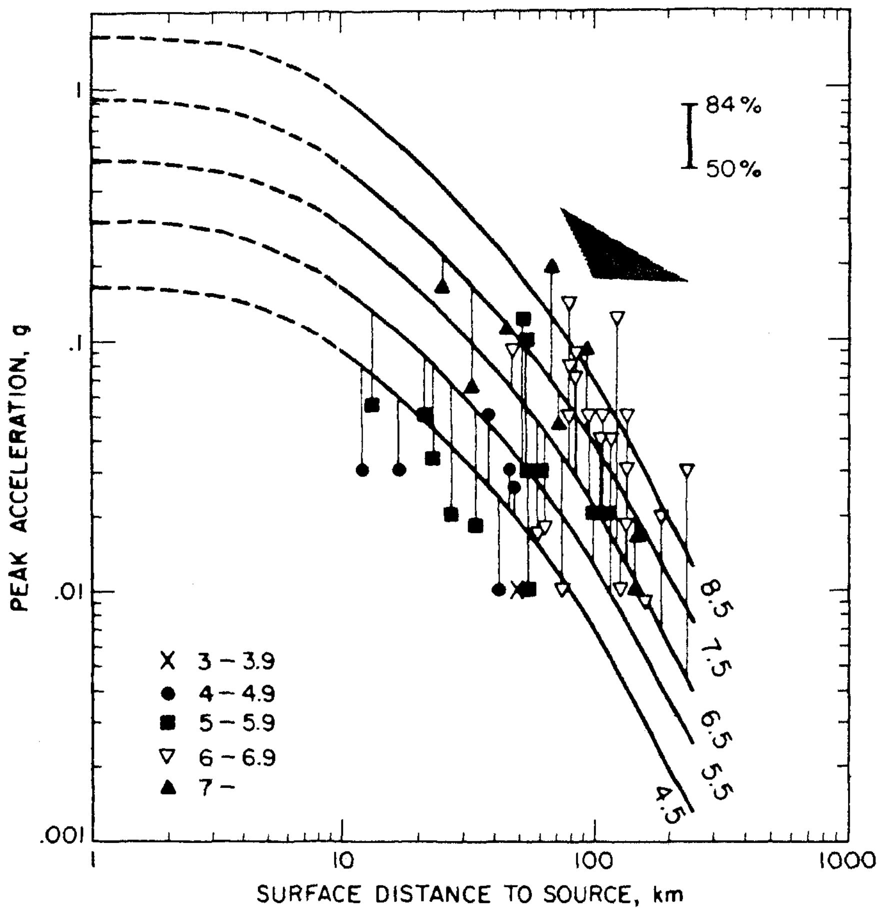

Figure 1. Comparison of peak horizontal accelerations for Alaska with empirical attenuation laws obtained by Joyner and Boore (Ref. 2) by regression of mostly western U.S. strong motion data. The continuous curves correspond to the 50-percentile level of non-exceedence; 84-percentile curves would be offset to a higher level by a constant amount shown in the upper right corner. Symbols represent magnitude ranges M_W as indicated in lower left corner. Stippled field shows Japanese data for the $M_W \approx 8.2$ Tokachi-Oki earthquake (Ref. 5).

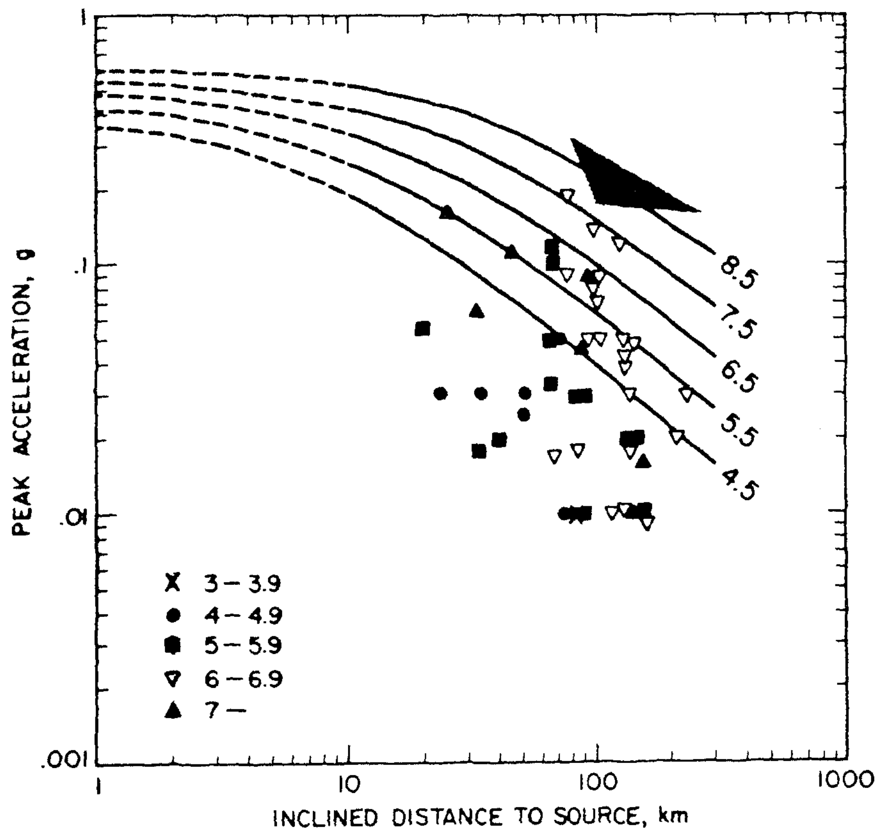

Figure 2. Comparison of Alaska peak horizontal accelerations with B-type attenuation relations proposed by Woodward-Clyde (Ref. 7) for Benioff-zone earthquakes. Curves are for stiff sites and represent the median. For other details compare legend of Figure 1. The stippled field represents Japanese peak acceleration data for the $M_W \approx 8.2$ ($M_S = 7.9$) Tokachi-Oki earthquake (Ref. 5) discussed in the text.