AIRCURRENTS

MODELING UNCERTAINTY IN EARTHQUAKE OCCURRENCE IN JAPAN

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EDITOR'S NOTE: AIR released a major update to its Earthquake Model for Japan in December 2008. The model incorporates research by AIR seismologists in concert with the results of recent studies conducted by Japan's Headquarters for Earthquake Research and Promotion (HERP). In this article AIR's director of earthquake hazard Dr. Mehrdad Mahdyiar discusses AIR's handling of uncertainty in time-dependent modeling of earthquake occurrence.

By Dr. Mehrdad Mahdyiar

INTRODUCTION

Japan is located in a region of considerable seismic risk. Japan's islands and the adjacent sea areas are located near the margins of the Pacific, Philippine Sea, Amurian and Okhotsk (Figure 1). Seismicity is dominated by the subduction of the Pacific plate under the Okhotsk plate and, in the region of the Nankai Trough in Southern Japan, the subduction of the Philippine Sea plate under the Amurian plate.[1] The complex interaction of these plates has produced a long history of damaging earthquakes.

The last truly devastating earthquake occurred on the morning of January 17th, 1995, approximately 20 miles from the city of Kobe. The Hyogo-ken-Nanbu, or Kobe, earthquake killed more than 6,000 people and caused more than USD 100 billion in damage. It registered a magnitude 7.3 on the JMA scale (equivalent to moment magnitude 6.9) and is generally regarded as the costliest natural catastrophe to befall a single country.

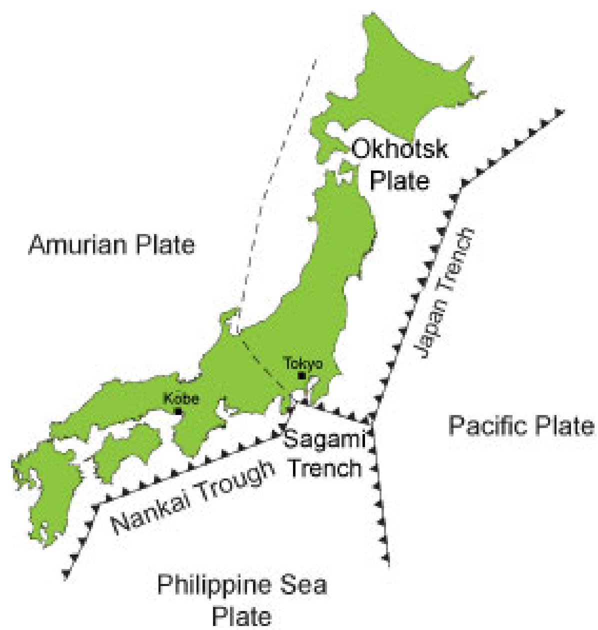

Figure 1: Japan's Tectonic Plates (the arrows show relative motion of the oceanic plates with respect to the continental plates). Source: AIR Worldwide.

THE HEADQUARTERS FOR EARTHQUAKE RESEARCH PROMOTION (HERP) REPORT

In response to the devastation wrought by the Kobe earthquake, the Japanese government enacted the Earthquake Disaster Management Special Measures Act with the goal of improving the scientific understanding of earthquake risk in Japan. The act established the Headquarters for Earthquake Research Promotion (HERP) and this organization began to drive new research on the seismic hazard facing Japan. With support from HERP, extensive new research was conducted by the National Research Institute for Earth Science and Disaster Prevention to develop a national seismic hazard map. After nearly 6 years of research effort, HERP published its report and map in 2005, with subsequent updates in 2006 and 2007.

The HERP report contains information on 98 major crustal faults, 178 minor crustal faults, and 47 subduction-zone segments in and around Japan. HERP includes information detailing the geometry, characteristic magnitude, and recurrence interval for major faults and subduction zones. Cascading rupture scenarios are also described whereby two or more adjacent fault segments rupture as one unit, resulting in larger earthquake magnitudes and longer rupture lengths than would be expected from the rupture of a single segment.

Finally, the HERP report provides estimates of time-dependent probabilities of occurrence of characteristic earthquakes on subduction zones and well-studied major crustal faults.

In time-dependent models of earthquake occurrence, the probability that an earthquake will occur in the coming year increases with the length of time elapsed since the last event. In general, time-dependent probabilities of earthquake occurrence will be different from those produced by time-independent or "memoryless" models; some will be higher and some will be lower, depending on when the last historical characteristic event occurred on a particular fault or subduction zone relative to the mean recurrence interval.

The recurrence interval of earthquakes along most crustal faults in Japan is typically quite long, while the recurrence intervals of events along subduction zones is usually much shorter. Yet even when the historical catalog extends back hundreds of years—as it does in the case of Japan—it will contain information about only a limited number of large magnitude earthquakes.

This scarcity of data on the historical occurrence of large earthquakes makes estimates of the mean recurrence intervals for the time dependent analysis highly uncertain. Indeed some scientists believe that the HERP report underestimates the uncertainty surrounding the parameters used in the generation of these probabilities—in particular, in the estimates of mean recurrence interval and what is known as the "aperiodicity" value. Aperiodicity is a measure of the irregularity, or random component inherent in an earthquake recurrence model and can be expressed as either a standard deviation or a coefficient of variation (CV). In other words, aperiodicity measures the extent to which an earthquake does not occur at exactly regular intervals, like clockwork.

THE AIR APPROACH TO MODELING UNCERTAINTY

To examine more closely the reasonability of the parameters used by HERP, AIR seismologists conducted an analysis of the sensitivity of HERP's assumptions regarding the mean recurrence and aperiodicity parameters using the available historic data. Using a Brownian Passage Time model[2] for the recurrence intervals—which HERP also adopted—a set of recurrence distributions with variable mean and aperiodicity values around the historic data were constructed. The goal was to identify the parameters that best replicate the historical record.

That is, for each distribution, one hundred thousand stochastic simulations were performed to study the resulting rupture-interval scenarios on subduction zones had the values for the mean recurrence interval or aperiodicity differed from those cited in the HERP report. Whenever all simulated recurrence intervals were within ±2 years of the historical intervals, the selected mean recurrence interval and aperiodicity of that distribution were counted as viable for generating the observed set of historical ruptures. Histograms of all viable solutions were created to assess how likely it would be for each of the possible means and aperiodicity values to produce sets of earthquakes that corresponded to the historical record.[3]

The results of AIR's analysis showed that when historical data on earthquake occurrence is limited, it is virtually impossible to uniquely determine the causative, or "true", mean recurrence and aperiodicity values for the observed recurrence distribution. That is, different combinations of the mean recurrence and aperiodicity values can reasonably reproduce the limited observed data.

The histograms in Figure 2 show the results of AIR's analysis for a rupture of the Tonankai segment of the Nankai Trough, whether singly or in combination with its neighboring Nankai and Tokai segments. Figure 2 also shows the HERP parameters and suggests that the HERP mean recurrence interval (86 years) may be too short, the aperiodicity value (0.2) may be too low and the resulting 30-year probability of rupture (62%) may too high.

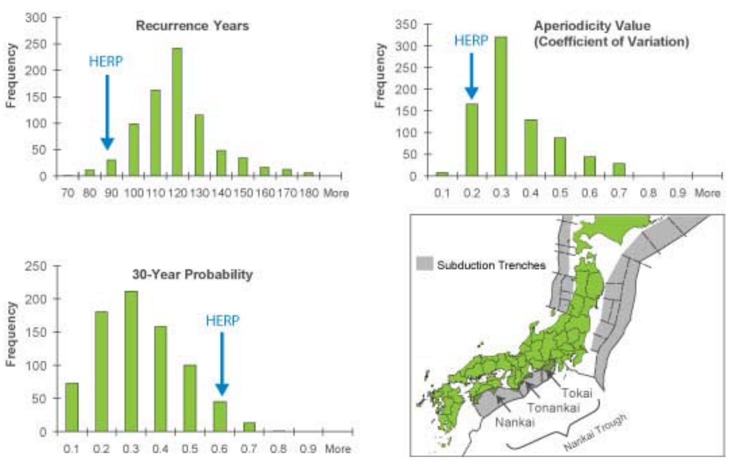

Figure 2. HERP and AIR simulated mean recurrence, coefficient of variation and 30-year probability of rupture of the Tonankai segment. Source: AIR

IMPLEMENTATION IN THE AIR EARTHQUAKE MODEL FOR JAPAN

In light of the findings from AIR's analysis of the uncertainties in time-dependent modeling of earthquake recurrence in Japan, AIR included alternative stochastic catalogs with the latest release of the AIR Earthquake Model for Japan.

In addition to a time-dependent catalog that strictly adheres to the assumptions in the HERP report, AIR offers a time-dependent catalog that supplements HERP's findings with AIR's own research, which reflects an additional level of uncertainty in the rupture distribution parameters.[4] AIR recommends this catalog and it is in fact the default in catalog in the latest model release.

Specifically, the AIR default catalog uses a weighted combination of the HERP results and the results of two time-dependent analyses to evaluate the effects that uncertainty may have on recurrence rates. In the first analysis, uncertainty is added to HERP's mean recurrence intervals and aperiodicity values (CVs) in the form of a distribution around each mean. In the second analysis, uncertainty is similarly added to the historical mean recurrence interval and historical CV using the likelihood statistical method. This takes into consideration the uncertainty associated with the exact dates of historical events themselves (there is more uncertainty surrounding both the magnitude and dates of older events than those of more recent ones) and whether segments ruptured singly or in combination.

Clearly, different assumptions regarding uncertainty will have implications for hazard and risk analysis. For example, looking once more at the Tonankai segment of the Nankai Trough, AIR seismologists estimate a 41% probability of rupture in the next 30 years. This compares to the 62% probability as estimated by HERP

PROVIDING A COMPLETE VIEW OF SEISMIC RISK

The fact that Japan is at significant seismic risk is undisputed. However, as this article suggests, multiple credible views of the risk exist among seismologists. By including alternative catalogs, each of which has been developed using rigorous, scientifically defensible methods, the AIR model provides the most comprehensive view of Japanese seismic risk, enabling companies to test the sensitivity of different scientific assumptions.

1 THERE IS STILL SOME DEBATE AMONG SEISMOLOGISTS AS TO WHETHER THE AMURIAN PLATE IS INDEPENDENT OR PART OF THE EURASIAN PLATE.

2 NOTE THAT MANY DISTRIBUTIONS CAN BE USED TO MODEL EARTHQUAKE RECURRENCE PROBABILITIES, INCLUDING BROWNIAN PASSAGE TIME, LOG NORMAL AND WEIBULL DISTRIBUTIONS. THE BROWNIAN PASSAGE TIME DISTRIBUTION IS CURRENTLY THE "STATE OF THE PRACTICE" AND ACCURATELY SIMULATES THE BUILDUP OF SEISMIC STRESS ON A FAULT PRIOR TO ITS RUPTURE.

3 FOR DETAILS OF AIR'S METHODOLOGY, PLEASE SEE "A STUDY ON THE UNCERTAINTIES IN EARTHQUAKE TIME-DEPENDENT PROBABILITIES IN JAPAN" BY MAHDYIAR, RONG, SHEN-TU AND GUIN PUBLISHED IN PROCEEDINGS OF THE 14TH WORLD CONFERENCE ON EARTHQUAKE ENGINEERING.

4 NOTE THAT THE AIR EARTHQUAKE MODEL FOR JAPAN ALSO OFFERS A THIRD, TIME-INDEPENDENT, OR MEMORYLESS, CATALOG—ONE IN WHICH THE AVERAGE ANNUAL PROBABILITY OF OCCURRENCE OF AN EARTHQUAKE ON ANY GIVEN FAULT IS INDEPENDENT OF WHEN THE LAST HISTORICAL EARTHQUAKE OCCURRED ON THAT FAULT. IT SHOULD BE SAID THAT TIME DEPENDENCE CAN MEANINGFULLY BE ESTIMATED ONLY FOR WELL-STUDIED FAULTS FOR WHICH THERE IS ABUNDANT SLIP RATE OR PALEOSEISMIC DATA. HENCE ALL THREE CATALOGS INCLUDED IN THE AIR EARTHQUAKE MODEL FOR JAPAN CONTAIN TIME-INDEPENDENT COMPONENTS.

ABOUT AIR WORLDWIDE CORPORATION

AIR Worldwide Corporation (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 50 countries. More than 400 insurance, reinsurance, financial, corporate and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, site-specific seismic engineering analysis, and property replacement cost valuation. AIR is a member of the ISO family of companies and is headquartered in Boston with additional offices in North America, Europe and Asia. For more information, please visit www. air-worldwide.com.

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