SEISMIC ENVIRONMENT ANALYSIS THROUGHOUT JAPAN

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SUMMARY

This paper discusses substantial seismic risk assessment throughout Japan based on the latest historical records of earthquakes applying the extreme value distribution analysis. The seismic risk maps are obtained in terms of the expected maximum ground accelerations.

INTRODUCTION

It has been more than 30 years since "Kawasumi Map" \textsuperscript{(1)} was published in 1951. Seismic risk zoning for structural design of architecture in Japan is still basically based on this map. However, many of the historical record informations of earthquakes in Japan have been modified. Additionally, reliability-based seismic design is required for some kind of structures such as atomic plants, etc. It is essentially associated with the seismic risk assessment i.e. the probability of earthquake occurrences. This paper analyzes the earthquake occurrence probability in terms of the expected maximum ground accelerations on the basis of the latest historical data of earthquakes.

HISTORICAL RECORDS OF EARTHQUAKES

Figure 1 shows the locations of the epicenters of the historical earthquake records provided by Chronological Scientific Tables \textsuperscript{(2)}. Significant increase of the number of earthquakes after 1603 is recognized. This is because less historical records are available before 1603. Therefore, this paper discusses the probability of earthquake occurrences based on the latest historical data after 1603 including the recently modified data.

METHODS AND RESULTS

The relationship between Seismic Scale (I) and Magnitude (M) at an arbitrary point \( \Delta \) km away from the epicenter is given by the following \textsuperscript{(3)}:

\[ I = I_{100} - b (\Delta - 100) \]  \hspace{1cm} (1)

where

\[ I_{100} = 1.45 M - 5.8 \]  \hspace{1cm} (2)

\[ \text{and} \]
Fig. 1 Number of Earthquakes from Historical Records
Using the above relationship, Seismic Scale at a certain site can be estimated from each historical record. Then the extreme value distribution analysis is applied to these estimated values.

Suppose there are annual maximum records of Seismic Scales during N years: \( X_1, X_2, \ldots, X_N \). These data are rearranged in increasing order as follows:
\[
X(1) \leq X(2) \leq \cdots \leq X(R) \leq \cdots \leq X(N)
\]
The cumulative distribution of \( X(R) \) is estimated by
\[
F(X_R) = R / (N + 1)
\]
Since
\[
F(X_R) = \exp[-\exp(-y_R)]
\]

with
\[
y_R = \alpha (X_R - u)
\]

for the extreme value distribution, \( y_R \) is given by the following:
\[
y_R = -\ln \bigg[ -\ln \left\{ \frac{R}{N+1} \right\} \bigg]
\]

By plotting \((X, y)\) on the probability paper with one axis for \( X \) and the other axis for \( y \) and drawing the straight line by the least square method, the values of \( \alpha \) and \( u \) can be determined. In this case it has been known that the variation of \( X \) is Gaussian distributed with the standard deviation given by
\[
\sigma = \left[ \left( .7100 + .1667 y + .6687 y^2 \right) \frac{S_X^2}{N} \right]^{1/2}
\]

where
\[
S_X^2 = \frac{R}{N} \left( \frac{\alpha}{\sqrt{\pi}} \right)
\]

Hence, the variation of \( X \) is also estimated for given \( y \). Figure 2 shows these relationship based on the historical data during 380 years after 1603 for ten cities: Kyoto, Tokyo, Nagoya, Fukuoka, Osaka, Hiroshima, Kochi, Niigata, Sendai and Kagoshima. The locations of these ten cities are shown in Fig. 3.

In Fig. 2 the middle solid straight lines have been determined by the method of least squares, whereas the envelop lines represent the bandwidths of \( \pm 2\sigma \) from the middle lines.

Provided an average return period is \( T_x \), then the cumulative distribution function is evaluated by
\[
F(X) = 1.0 / \left[ 1.0 - \exp \{ -\exp(-y) \} \right]
\]

where
\[
y = \alpha (X - u)
\]

with \( \alpha \) and \( u \) already obtained.

From both envelope lines in Fig. 2 two Seismic Scales are obtained for each city concerning given \( T_x \). Furthermore, there is a relationship between Seismic Scale (I) and the maximum ground acceleration (a) as follows (1):
\[
a = 0.45 \times 10^{0.51 I}, \quad I \leq 5.5
\]
\[
a = 20 \times 10^{0.2 I}, \quad 5.5 \leq I \leq 6.5
\]

From the above relationship two values of the maximum ground accelerations for each city are also obtained. They are shown in Table 1.

On the basis of the analysis above mentioned the expected maximum ground accelerations for 75 year and 100 year return periods are demonstrated throughout Japan in Figs. 4 and 5, respectively. In these figures the values are calculated without considering the variation.

**CONCLUDING REMARKS**

The seismic risk assessment throughout Japan has been discussed in terms of the expected maximum ground accelerations by applying the extreme value distribution analysis.
Fig. 2 Plotting Seismic Scales
Fig. 3 Locations of Ten Cities

Fig. 4 Expected Maximum Ground Accelerations for 75-year Return Period

Table 1 Expected Maximum Ground Accelerations

<table>
<thead>
<tr>
<th>Return Period</th>
<th>50</th>
<th>75</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyoto</td>
<td>88</td>
<td>191</td>
<td>121</td>
</tr>
<tr>
<td>Tokyo</td>
<td>155</td>
<td>238</td>
<td>268</td>
</tr>
<tr>
<td>Nagoya</td>
<td>56</td>
<td>155</td>
<td>120</td>
</tr>
<tr>
<td>Fukuoka</td>
<td>79</td>
<td>156</td>
<td>220</td>
</tr>
<tr>
<td>Osaka</td>
<td>77</td>
<td>159</td>
<td>231</td>
</tr>
<tr>
<td>Hiroshima</td>
<td>56</td>
<td>97</td>
<td>129</td>
</tr>
<tr>
<td>Kochi</td>
<td>54</td>
<td>105</td>
<td>147</td>
</tr>
<tr>
<td>Niigata</td>
<td>54</td>
<td>101</td>
<td>140</td>
</tr>
<tr>
<td>Sendai</td>
<td>86</td>
<td>125</td>
<td>152</td>
</tr>
<tr>
<td>Kagoshima</td>
<td>24</td>
<td>63</td>
<td>105</td>
</tr>
</tbody>
</table>

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When the variation is considered, the maximum ground accelerations show the significant differences even for the same average return period.

Additionally, it is expected that the seismic risk differs from site to site even in the same city when the ground features are considered. The analysis including the ground feature effects will be in future studies.

REFERENCES

1. Osaki, Y., Earthquake and Architecture, Iwanami, Tokyo, 1983
2. Chronological Scientific Tables, Tokyo Astronomical Observatory (ed.), Maruzen, Tokyo, 1987

Fig. 5 Expected Maximum Ground Accelerations for 100-year Return Period