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PROBABILISTIC SEISMIC LOADS IN RELATIVELY SHORT DURATIONS

Yozo YUI[1], Susumu HIROSE[2] and Eiichi KURIBAYASHI[2]

1 Tokyo Engineering Co. Ltd.
Chuo-ku, Tokyo, Japan

2 Department of Civil Engineering / Regional Planning
Toyohashi University of Technology, Toyohashi, Aichi, Japan

SUMMARY

This paper presents a probabilistic evaluation method for seismic loads in short durations which is used for the earthquake-resistant design of structures under construction. The significance of parameters which affect the ground motion intensity of short durations is studied. The ground motion intensity is analyzed using a model of the areal souce at a site on the straits of Akashi. With respect to structures under construction, a probabilistic approach to the restoration costs of a three span suspension bridge is also presented.

INTRODUCTION

The construction of long span bridges needs a prolonged construction term of as much as 5 years. The seismic loads expected for structures under construction are usually smaller than those after completion, because the service terms of completed structures are more than 50 years. However, there are some conditions in which a structure under construction is unstable or has less earthquake resistances compared with completed structures. In such conditions, the risk that a structure under construction is damaged by earthquakes, should be considered in construction planning and design.

In this paper, a probabilistic evaluation method for seismic loads in relatively short durations is proposed and an application to the installation models of a long-span suspension bridge is presented by using the probabilistic approach, in which initial construction costs, the probability of failure by seismic loads and restoration costs are taken account of.

EVALUATION METHOD FOR SEISMIC LOADS

The relation for the magnitude and frequency of occurrence of past earthquakes is represented by the Gutenberg-Richter formula, hereafter called the G-R formula, and the G-R formula may be modified as the formulae called the truncated G-R formula and the modified G-R formula 6).

The attenuation property of ground motion is required for predicting the ground motion intensity at a site based on the state of seismic activity in the source region. To this, the attenuation formula proposed 7) is as follows;

$$y = f(M, r) = A \cdot 10^{B \cdot M} \cdot (r + r_0)^C \qquad (1)$$

where

y : Ground motion intensity used for analysis,

M : Magnitude,
r : Distance from epicenters,
A, B, C : Constants.

The ground motion intensity is analyzed using a model of the areal source.[8)] The truncated G-R formula is used for evaluating the probability of exceeding a predetermined value of y for a site having the ground motion intensity, Y.

Taking the annual mean seismic occurrence of $M \geq M_0$ as ν_i for i-th areal source, its enclosed area has a common origin with the circle of radius $r_i = r_{1i} \sim r_{2i}$, and angle $\theta = \theta_{1i} \sim \theta_{2i}$. If there are N areal sources, then the frequency of occurrence at a site after taking consideration of all areal sources for $Y > y$ is as follows;

$$\lambda(y) = \sum_{i=1}^{N} \nu_i \int_{\theta_{1i}}^{\theta_{2i}} \int_{r_{1i}}^{r_{2i}} p(Y>y \mid E_i) \cdot r\,dr\,d\theta \qquad (2)$$

The Poisson process is adopted for deciding the probability of seismic occurrence.

SEISMIC CATALOGUES AND ATTENUATION PROPERTY

The seismic catalogues used for analysis are from references 9),10) and 11). Accordingly the magnitudes for the period from 1885 to 1925, 1926 to 1974 and 1975 to 1984 are taken to be, respectively, above 6.0, above 5.5 and above 5.0. The catalogue in reference 12) is used for studying the conceivable maximum magnitudes. The ratio of occurrence per unit area for magnitudes above 5.0 are grouped in the same areal souce as shown in Figure 1. The maximum magnitude recorded of each areal source for the period between 416 and 1984 are shown in Table 1.

The attenuation formula is adopted as the formula from reference 7). The maximum acceleration is as follows;

$$A_{max} = 1073.0 \cdot 10^{0.221 \cdot M} \cdot (r+30)^{-1.251} \qquad (3)$$

and acceleration response spectra with damping factor of 5% of critical is as follows;

$$S_A(T_k) = A(T_k) \cdot 10^{B(T_k) \cdot M} \cdot (r+30)^{C(T_k)} \qquad (4)$$

where $A(T_k)$, $B(T_k)$ and $C(T_k)$ for various natural period T_k are constants.

The dispersion index U, with respect to maximum seismic motion and its response spectra are $\sigma_{\log U_{Amax}} \fallingdotseq 0.216$ and $\sigma_{\log U_{S_A}} \fallingdotseq 0.252$ respectively[7)].

INFLUENCE OF PARAMETERS ON EARTHQUAKE GROUND MOTION

(1) G-R formula

The expected value of maximum ground motion has been calculated by using both of the truncated G-R formula and the modified one in order to compare with each other. The maximum magnitude Mu is used for the maximum values recorded that occured in each areal source. As a result, there are no significant differences between these formulae in the case of the short duration. The truncated G-R formula is adopted in this study.

(2) Minimum magnitude of the G-R formula.

For predicting seismic loads in short durations, the G-R formula is extrapolated to the range of magnitudes below 5.0. Taking the basic value of Mo = 0, the ratio of decrease with respect to period t for Mo = 2.0, 4.0 and 5.0 are obtained as shown in Figure 2. In this case, Mu is the maximum value from the record in the period between 416 and 1984 as shown in Table 1. From Figure 2 it can be considered that the expected value of the maximum ground motion for short durations becomes stable at the minimum magnitude Mo =2.0.

(3) Conceivable maximum magnitude

The following three cases are adopted.

(a) The maximum value in the period between 416 and 1984 from reference 12), is used for the respective areal sources.

(b) The maximum value obtained from the seismic data in the period between 1885 and 1984 be added with 0.1, is used for respective areal sources.

(c) The maximum value of Mu = 8.1 from reference 12), is used for the entire areal sources.

The minimum magnitude Mo is taken as possible as smaller than 0.1, when the maximum value from the record between 416 and 1984 is taken as the basic value. The ratio of increase for the other two cases are shown in Figure 3. Thus, Mu does not exert influence in the short period one years or less.

(4) Earthquake ground motion

The four conditions are used for evaluating the expected value of the ground motion intensity for an application period for short durations.

(a) The truncated G-R formula is used.

(b) The minimum magnitude, Mo of 2.0 is used.

(c) The conceivable maximum magnitudes, Mu are taken as the maximum value from the seismic catalogue in ref. 12).

(d) The radious of the entire areal source is 300km.

The relation of $\lambda \sim S_A$ is shown in Figure 4 and the expected value of acceleration response spectra in the respective divisions is shown in Figure 5.

NUMERICAL EXAMPLE

(1) Model of the installation of the bridge

The numerical example is examined in the case of three span suspension bridge under construction. In the course of an installation term of five years or more, the stiffened truss suffers from an earthquake during its installation period of one year and eight months. The installation model assumes that there are five stages in the installation of the stiffened truss and each stage is four months long.

The following are the assumptions in the evaluation of the axial force of the stiffened truss that resulted from the earthquake effect as shown in Figure 4 and 5.

(a) Assuming the inphase ground motion in the entire truss.

(b) Neglecting all loads except earthquake loads and dead loads.

(c) In the natural periods of 0.1 second or less and 3.0 seconds or more, the response spectra are extrapolated.

The axial resistant force of the stiffened truss chord and brace is determined by the yield strength of the material of each member. The mean value and standard deviation at the yield strength of the steel material is used.

(2) Probability of the failure

The probabilty of the failure of the chord, $P_{f,k,l,n}$ is given as follows;

$$P_{f,k,l,n}=\sum_{j=1}^{N_j} P(E)_{j,k,n}\cdot P(F\,|\,E)_{j,k,l} \qquad (5)$$

where

$P(E)_{j,k,n}$: Probability of the failure of the j-th division of the frequency of the occurrence,

N_j : Division number designated in Fig. 4,

k : Sequence number of the stage of the installation period,

l : Sequence number of the panel of the stiffened truss,

n : sequence number of the occurrence of the failure,

j : Sequence number of the division of the frequency of the occurrence.

(3) Expected value of the restoration cost

In restoring the damaged portion of the truss as same as the original construction, the restoration cost is assumed to be equal to the installation cost, but the cost of the installation term longer than the original schedules is not taken into account.

The restoration cost $C_{k,l}$ is defined as follows;

$$\overline{C}_{k,l}=\sum_{n=1}^{\infty} P_{f,k,l,n}\cdot r_{c,k,l}\cdot C_u \qquad (6)$$

where

$r_{c,k,l}$: Reduction coefficient of the restoration cost,
C_u : Restoration cost of a unit panel when the failure occures in a completely installed stiffened truss.

The expected value of the total restoration cost of the stiffened truss, $\overline{C}$ is as follows;

$$\overline{C}=\sum_{l=1}^{N_l}\sum_{k=1}^{N_k}\overline{C}_{k,l} \qquad (7)$$

where

N_k : Total number of division of installation,
N_l : Total number of panels.

The restoration cost ratio, Rc of the restoration cost to the original construction cost is as follows;

$$R_c = \overline{C} / C_0 \qquad (8)$$

where

C_0 : Initial construction cost (= $N_l \cdot C_u$).

Table 2 shows the expected value of failure frequency of the entire panels of the stiffened truss, and the restoration cost ratio. In this case, the total number of panel is 274.

CONCLUSION

In this paper a probabilistic evaluation method for seismic loads in short durations and an example of its application are presented. The main results may be summarized as follows;

(1) The expected value of the maximum ground motion for short durations becomes stable at the minimum magnitude Mo=2.0 or less,

(2) The conceivable maximum magnitude for short durations has a small effect upon the value of ground motion intensity estimated by using either the maximum value from the recent seismic data in the period between 1885 and 1984 or the maximum value indicated by historical seismic data.

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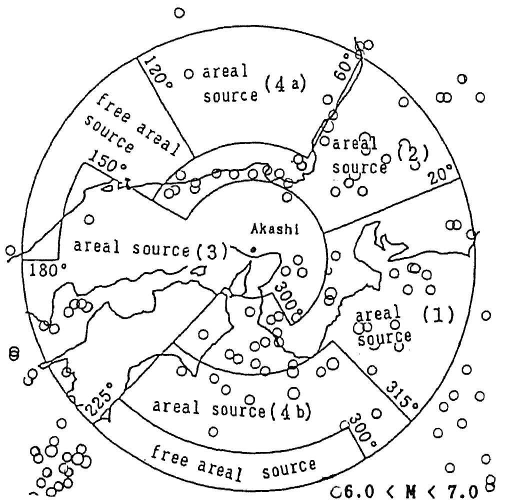
Note: Asterisk,* indicates the title literally translated from Japanese.

Table 1. Maximum magnitude for the period between 416 and 1984

Areal source	m_u	The data and epicenter of observed earthquakes for maximum magnitude in the period between 416 and 1984
1	7.9	Dec. 17 1096 137.3° E 34.2° N
		Dec. 23 1854 137.8° E 34.1° N
		Dec. 7 1944 136° 37'E 33° 48'N
2	8.0	Oct. 28 1891 136° 36'E 35° 36'N
3	6.9	Nov. 23 880 132.8° E 35.4° N
		Jun. 2 1905 132° 30'E 34° 06'N
4	8.1	Aug. 26 887 135.0° E 33.0° N

Table 2. Ratio of restoration cost

predetermined condition	ratio of restoration cost R_c (%)
Reduction of 50% for 2nd. panel from tip of the installation,and reduction of 25% for 3rd. and 4th panel from tip of the installation	5.5
reduction is not considered	7.5



(Note) Free areal source refers to those areas where only earthquakes with magnitudes less than 5 have occured during the past 100 years.

Fig. 1 Areal source model

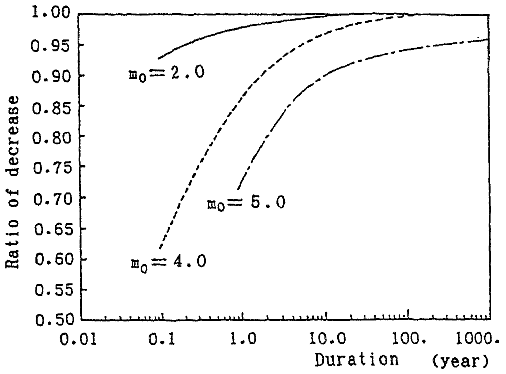


Fig. 2 Ratio of decrease expected value of maximum ground motion for variation in Mo

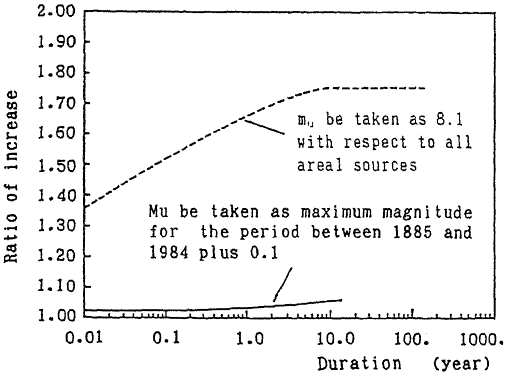


Fig. 3 Ratio of increase of expected value of maximum ground motion for variation in Mu

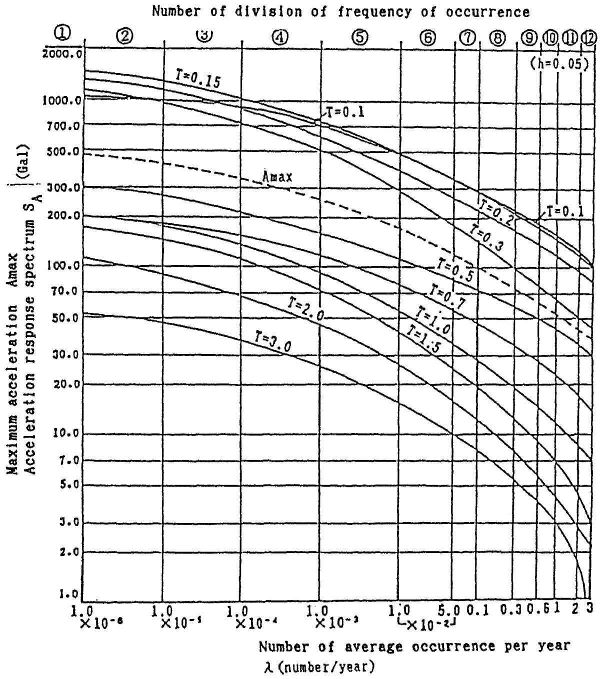


Fig. 4 Acceleration response spectrum for duration of 0.1 year to 1 year

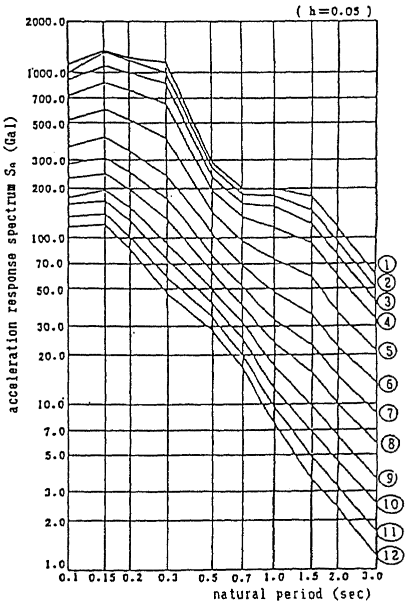


Fig. 5 Response spectrum curve for division of frequency of occurrence