APPENDIX R – Seismic Loads

CALCULATING COMPATIBLE RETURN PERIODS FOR EARTHQUAKE DESIGN OF THE JOHNSON STREET BASCULE BRIDGE, WHEN THE BRIDGE IS EITHER IN THE NORMAL POSITION OR WHEN THE BRIDGE IS UP.

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Background notes

Suppose that earthquakes at a site occur with an arrival frequency λ per year, or mean number of earthquakes per year. This information is obtained from the seismicity of the site. For example, $\lambda = 0.1$ / year implies, on average, that earthquakes occur once every 10 years. This number could be given for all earthquakes (regardless of magnitude) or for a range of magnitudes (for example, only for earthquakes with magnitude $M > 4$).

Given the occurrence of an earthquake, let P_E be the probability that the PGA (a_G) could exceed a level a_{G0}, or, alternatively, that the spectral acceleration S_a for a period T could exceed a level S_{a0}. Then, assuming that the earthquakes arrive following a Poisson process, the probability P_E can be related to the probability that a_G could exceed a_{G0} (or S_a could exceed S_{a0}) per year (annual exceedance probability P_A):

$$P_A = 1 - \exp(-\lambda P_E) \qquad [1]$$

If the annual exceedence is set at $P_A = 1/2475$ (or 0.02 in 50 years), then the earthquake has a corresponding exceedence probability P_E of

$$P_E = \left(-\ell n\left(1 - 1/2475\right)\right)/\lambda \qquad [2]$$

Thus, for $\lambda = 0.1$, if the design S_{a0} has an annual exceedence probability of 1/2475, the earthquake event, when it occurs, will exceed S_{a0} with a probability $P_E =$ 0.00404.

Now, Eq.[1] can be equally applied only to those earthquakes that occur when the bridge is up. In this case, the mean arrival frequency must be computed for the arrival of the combination of two events: that the earthquake occurs and that the bridge is up. This new arrival rate, λ^*, can be computed according to

$$\lambda^* = \lambda \lambda_B (d_E + d_B) \qquad [3]$$

in which λ_B is the mean arrival frequency of bridge openings (number of times per year that the bridge is up) , d_E is the mean duration of the earthquake and d_B is the mean duration of a bridge opening. These durations must be expressed in years.

Using Eq.[1], we want now to find an earthquake event, while the bridge is up, that corresponds to an exceedence probability P^*_E and an annual exceedence P^*_A for the arrival frequency λ^*:

$$P_A^* = 1 - \exp(-\lambda^* P_E^*) \qquad [4]$$

We want to find this earthquake so that the annual exceedence probability (the design requirement) be the same whether the bridge is up or not. That is, we impose that

$$P_A = P_A^* \qquad [5]$$

Or, from Eqs. [1] and [4], this implies that

$$P_E^* = \frac{\lambda}{\lambda^*} P_E \qquad [6]$$

Having found this earthquake, we now use again Eq.[1] to find out the corresponding annual exceedence probability P_A :

$$P_A = 1 - \exp(-\lambda P_E^*) \qquad [7]$$

It can be shown, by carrying out the algebra using Eqs. [1]-[7], that the value of P_A from Eq.[7] is only dependent on the frequency λ_B of bridge openings, the mean duration of these openings and the exceedence probability used for design (1/2475, 1/475, etc.).

Numerical results

Numerical results are shown in the next examples, obtained by running the attached program BASCULE.EXE.

To execute BASCULE simply copy BASCULE.EXE into a folder and then type BASCULE. An output file, also named BASCULE, will be stored in the same folder.

BASCULE prompts for the required inputs:

<u>Inputs (example):</u>
Normal design return period: 2475 years, corresponding to an exceedence probability of 0.02 in 50 years.

Mean arrival rate for earthquakes: 0.10 or, on average, one earthquake every 10 years.

Mean duration of an earthquake: 30 seconds
Mean number of bridge openings per day: 5

Mean duration of each bridge opening: 0.5 hours

Calculated return period of the earthquake which, in combination with the bridge being up, is consistent with an annual exceedence probability of 0.02 in 50 years: **262.6 years**

Thus, the earthquake that should be used in design with the bridge in the up position is one that has a return period of 262.6 years.

If the design standard is changed to the one as in the previous Code (return period of 475 years, corresponding to 0.1 in 50 years), then the return period of the earthquake for the bridge up condition reduces to **50.8 years** (smaller earthquake).

To calculate the earthquake S_a corresponding to a return period of 262.6 years, one can use a lognormal probability distribution to interpolate. This distribution has two parameters, its mean and its standard deviation, and they can be found from two Victoria data: the S_a for a return period of 2475 years (as per the new Code) and the S_a for a return period of 475 years (as per the old Code).

Attachments:
Source code BASCULE.FOR (Fortran program)
Executable code BASCULE.OXO (the extension OXO is used to allow e-mailing, rename it .EXE before using it).

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