Appendix E

Example Application of the EPOLLS Model

The hypothetical site in Figure E.1 is used here to demonstrate application of the EPOLLS model in predicting surface displacements on a liquefaction-induced lateral spread. The example site is located in the floodplain on one side of a river, as shown in the plan view at the top of Figure E.1. A magnitude 7.4 earthquake, associated with a fault rupture 25 km away, is expected to cause extensive liquefaction at this site. With a mild surface slope and a free face, the resulting lateral spread will cause ground movements toward the river. In the two cross sections shown in Figure E.1, the crest of a low ridge can be seen 300 to 350 m back from the river bank. Horizontal deformations will occur in opposite directions to either side of this low ridge, which defines the upper edge of the slide area. Based on an analysis of SPT data in five soil borings, the extent of liquefied soil is identified in the two cross sections in Figure E.1. At each boring location, the computed profile of the factor of safety against liquefaction (FS_{liq}) is shown. Liquefaction is expected at all depths where FS_{liq} is less than one in saturated, cohesionless sediments. All of the relevant parameters required for the EPOLLS model are shown in Figure E.1. Note that the vertical scale is exaggerated by a factor of ten in the site cross sections.

Regional-EPOLLS model.

For the example site, the four parameters required for the Regional-EPOLLS models are:

$$M_w = 7.4 \qquad R_f = 25 \text{ km}$$
$$A_{max} = 0.23 \text{ g} \qquad T_d = 26 \text{ sec}$$

Assuming the site is located in western North America, the peak acceleration (A_{max}) was estimated with Equation 6.3. The duration of strong shaking (T_d) was estimated using Equation 6.5 by assuming a shallow fault rupture at a hypocentral distance of 30 km.

Before using the model, the site parameters are checked to confirm that the predictions do not involve extrapolation beyond the limits of the data used to fit the R-EPOLLS model. All of these values are well within the limiting bounds indicated in Table 9.6 and the histogram plots in Figure 9.8. Moreover, D_R = 3.336 (from Equation 9.17) is within the range of values given in Table 9.7; this also indicates that the prediction will not require extrapolation. To check for possible hidden extrapolation, the value of h_0 can be calculated according to Equation D.26:

$$for\ [x] = [\ 1.0\ \ 7.4\ \ 25\ \ 0.23\ \ 26\ ]\ ;\ \ h_0 = [x]\ ([X]^T[X])^{-1}\ [x]^T = 0.035$$

For the R-EPOLLS model, $([X]^T[X])^{-1}$ is given in Figure 9.9a. Here, h_0=0.035 is less than h_{max}=0.17 (from Table 9.8), which indicates that this prediction will not involve hidden extrapolation.

Now, using Equations 9.17 and 9.20, the average horizontal displacement (*Avg_Horz*) at this site is estimated:

$$D_R = (\ 613 \cdot 7.4 - 13.9 \cdot 25 - 2420 \cdot 0.23 - 11.4 \cdot 26\ ) / 1000. = 3.336$$
$$Avg\_Horz = (\ 3.336 - 2.21\ )^2 + 0.149 = 1.42 \text{ m}$$

The standard deviation of the horizontal displacements (*StD_Horz*) is then estimated with Equation 10.7:

$$StD\_Horz = 0.589\ (\ 1.42\ ) = 0.83 \text{ m}$$

The Regional-EPOLLS model predictions for the example site are summarized in Table E.1.

If desired, the prediction interval on *Avg_Horz* can be computed using Equation D.27. Recall that the prediction interval is based on $\hat{y}'$, the predicted response without the bias-reduction factor. That is:

$$\hat{y}' = (\ 3.336 - 2.21\ )^2 = 1.27 \text{ m}$$

From Table 9.9 for the R-EPOLLS model, MSE=0.149 and $t_{\alpha/2,n-p}$=1.669 for a 90% prediction interval. For this site, $[x]([X]^T[X])^{-1}[x]^T$=0.035 as computed above. Using Equation D.27:

$$90\%\ prediction\ interval\ for\ Avg\_Horz = 1.27 \pm 1.669 \cdot \{0.149(1+0.035)\}^{0.5} = 0.61 \text{ to } 1.93 \text{ m}$$

Hence, considering the uncertainty in the Regional-EPOLLS model, the average horizontal displacement should be within the range of 0.61 to 1.93 m in 90% of all lateral spreads with these site parameters. The prediction interval on the average displacement should not be confused with predictions of maximum displacement that are based on best estimates of *Avg_Horz* and *StD_Horz*.

The maximum horizontal displacement is estimated using the gamma distribution defined by the predicted *Avg_Horz* and *StD_Horz*. From Table 8.3, the parameters defining the gamma distribution are:

$$\lambda = Avg\_Horz^2 \;/\; StD\_Horz^2 = 1.42^2 \;/\; 0.83^2 = 2.93$$
$$\beta = StD\_Horz^2 \;/\; Avg\_Horz = 0.83^2 \;/\; 1.42 = 0.49$$

The values of λ and β define a gamma distribution representing the variation in displacement magnitudes across the surface of this lateral spread. The maximum movement is then conservatively estimated at the 99.5 percentile of a gamma distribution with λ=2.93 and β=0.49. Interpolating the values in Table 8.8, the maximum predicted horizontal displacement is 4.48 m. Stated more accurately, 99.5% of the horizontal displacements on this lateral spread are expected to be less than 4.48 m.

Site-EPOLLS model.

To use the Site-EPOLLS model, three additional parameters that describe the topography and size of the lateral spread are needed. For this site, representative parameters were determined by taking the average of the values from the two cross sections in Figure E.1:

$$L_{slide} = 380 \text{ m} \qquad S_{top} = 0.9\ \% \qquad H_{face} = 2.25 \text{ m}$$

At other sites, it may be better to determine these parameters from contours of the surface elevation. Note that L_{slide} is measured to the centerline of the river, where this slide mass meets a lateral spread in the floodplain on the other side of the river. Again, these parameters are well within the range of the values used to fit the model as indicated in Table 9.6 and Figure 9.8. Also, from Equations 9.17 and 9.18, (D_R+D_S) is equal to 3.643 which is within the limits in Table 9.7. Hence, this prediction will not involve extrapolation, although an additional test based on h_{max} is not shown for this prediction.

The average horizontal displacement (*Avg_Horz*) and the standard deviation of the horizontal displacements (*StD_Horz*) are now estimated using Equations 9.18, 9.21, and 10.8:

$$D_S = (\ 0.523 \cdot 380 + 42.3 \cdot 0.9 + 31.3 \cdot 2.25\ ) \;/\; 1000. = 0.307$$
$$Avg\_Horz = (\ 3.336 + 0.307 - 2.44\ )^2 + 0.111 = 1.56 \text{ m}$$
$$StD\_Horz = 0.560\ (\ 1.56\ ) = 0.87 \text{ m}$$

Note that D_R=3.336 is brought forward from the R-EPOLLS model.

The maximum horizontal displacement is then estimated using a gamma distribution defined by the predicted values of *Avg_Horz* and *StD_Horz*. Again, from Table 8.3, the two parameters defining the gamma distribution are:

$$\lambda = Avg\_Horz^2 \ / \ StD\_Horz^2 = 1.56^2 \ / \ 0.87^2 = 3.22$$
$$\beta = StD\_Horz^2 \ / \ Avg\_Horz = 0.87^2 \ / \ 1.56 = 0.49$$

Interpolating the values in Table 8.8, the maximum predicted horizontal displacement is 4.73 m (99.5 percentile of a gamma distribution with λ=3.22 and β=0.49). That is, based on the Site-EPOLLS model, 99.5% of the horizontal displacements on this lateral spread are expected to be less than 4.73 m.

Geotechnical-EPOLLS model.

Two additional parameters, Z_{FSmin} and Z_{liq}, are needed to predict horizontal displacements with the Geotechnical-EPOLLS model. These values are first determined for each of the five soil borings at the site as indicated in Figure E.1. Averaging the values from the five borings give:

$$Z_{FSmin} = 5.2 \text{ m} \qquad Z_{liq} = 2.0 \text{ m}$$

These values are within the limits of the parameters used to fit the model as indicated in Table 9.6 and Figure 9.8. From Equations 9.17 through 9.19, (D_R+D_S+D_G) = 3.734 which is within the range of values shown in Table 9.7. Hence, this prediction will not involve extrapolations beyond the field data used to fit the model.

The average horizontal displacement (*Avg_Horz*) and the standard deviation of the horizontal displacements (*StD_Horz*) are now estimated using Equations 9.19, 9.22, and 10.9:

$$D_G = (\ 50.6 \cdot 5.2 - 86.1 \cdot 2.0 \ ) \ / \ 1000. = 0.091$$
$$Avg\_Horz = (\ 3.336 + 0.307 + 0.091 - 2.49 \ )^2 + 0.124 = 1.67 \text{ m}$$
$$StD\_Horz = 0.542 \ (\ 1.67 \ ) = 0.91 \text{ m}$$

Here, D_R=3.336 and D_S=0.307 are from the R-EPOLLS and S-EPOLLS components, respectively.

Again using the gamma distribution to estimate the maximum likely displacement, the Geotechnical-EPOLLS predictions of *Avg_Horz* and *StD_Horz* give:

$$\lambda = Avg\_Horz^2 \ / \ StD\_Horz^2 = 1.67^2 \ / \ 0.91^2 = 3.37$$
$$\beta = StD\_Horz^2 \ / \ Avg\_Horz = 0.91^2 \ / \ 1.67 = 0.50$$

Interpolating the values in Table 8.8, the maximum likely horizontal displacement is 4.96 m. That is, based on the Geotechnical-EPOLLS model, 99.5% of the horizontal displacements on this lateral spread are expected to be less than 4.96 m.

Vertical-EPOLLS model.

Recall that Vertical-EPOLLS model is considerably less accurate and reliable than the

EPOLLS model components for predicting horizontal displacements. To get a rough estimate of the possible vertical displacements, four parameters are needed:

$$Avg\_Horz_R = 1.42 \text{ m} \qquad H_{liq} = 8.2 \text{ m}$$
$$Z_{FSmin} = 5.2 \text{ m} \qquad \Delta Z_{FSmin} = 5.9 \text{ m}$$

where Avg_Horz_R is the average horizontal displacement predicted earlier using the R-EPOLLS model. The other three parameters are computed from values at the five boring logs (H_{liq} and Z_{FSmin} are average values and ΔZ_{FSmin} is the maximum range). From Table 11.4 and Figure 11.6, these values are all within the range of parameters used to fit the V-EPOLLS model.

To estimate the average vertical displacement (*Avg_Vert*) and the standard deviation of the vertical displacements (*StD_Vert*), Equations 11.5 and 11.6 are used:

$$Avg\_Vert = (65.6 \cdot 1.42 + 28.4 \cdot 8.2 + 32.9 \cdot 5.2) / 1000. = 0.50 \text{ m}$$
$$StD\_Vert = (158 \cdot 1.42 + 38.8 \cdot 5.9) / 1000. = 0.45 \text{ m}$$

To estimate the maximum vertical displacements, the normal distribution (defined by *Avg_Vert* = 0.50 m and *StD_Vert* = 0.45 m) is used. Interpolating the 99.5 percentile values of the normal distribution listed in Table 8.9, the maximum settlement is estimated to be 1.66 m. Similarly, interpolating the values in Table 8.10, the maximum uplift or heave is estimated at the 1.0 percentile of the normal distribution to be -0.55 m. Recall that uplift is considered a negative vertical displacement.

For the example site, the EPOLLS predictions of average, standard deviation, and maximum displacement are summarized in Table E.1.

Table E.1. Summary of predicted displacements (meters) for the lateral spread in Figure E.1.

Model Component:	**Regional-EPOLLS**	**Site-EPOLLS**	**Geotechnical-EPOLLS**	**Vertical-EPOLLS**
Average horizontal	1.42	1.56	1.67	--
Standard deviation horizontal	0.83	0.87	0.91	--
Maximum horizontal	4.48	4.73	4.96	--
Average vertical	--	--	--	0.50
Standard deviation vertical	--	--	--	0.45
Maximum settlement	--	--	--	1.66
Maximum uplift	--	--	--	-0.55

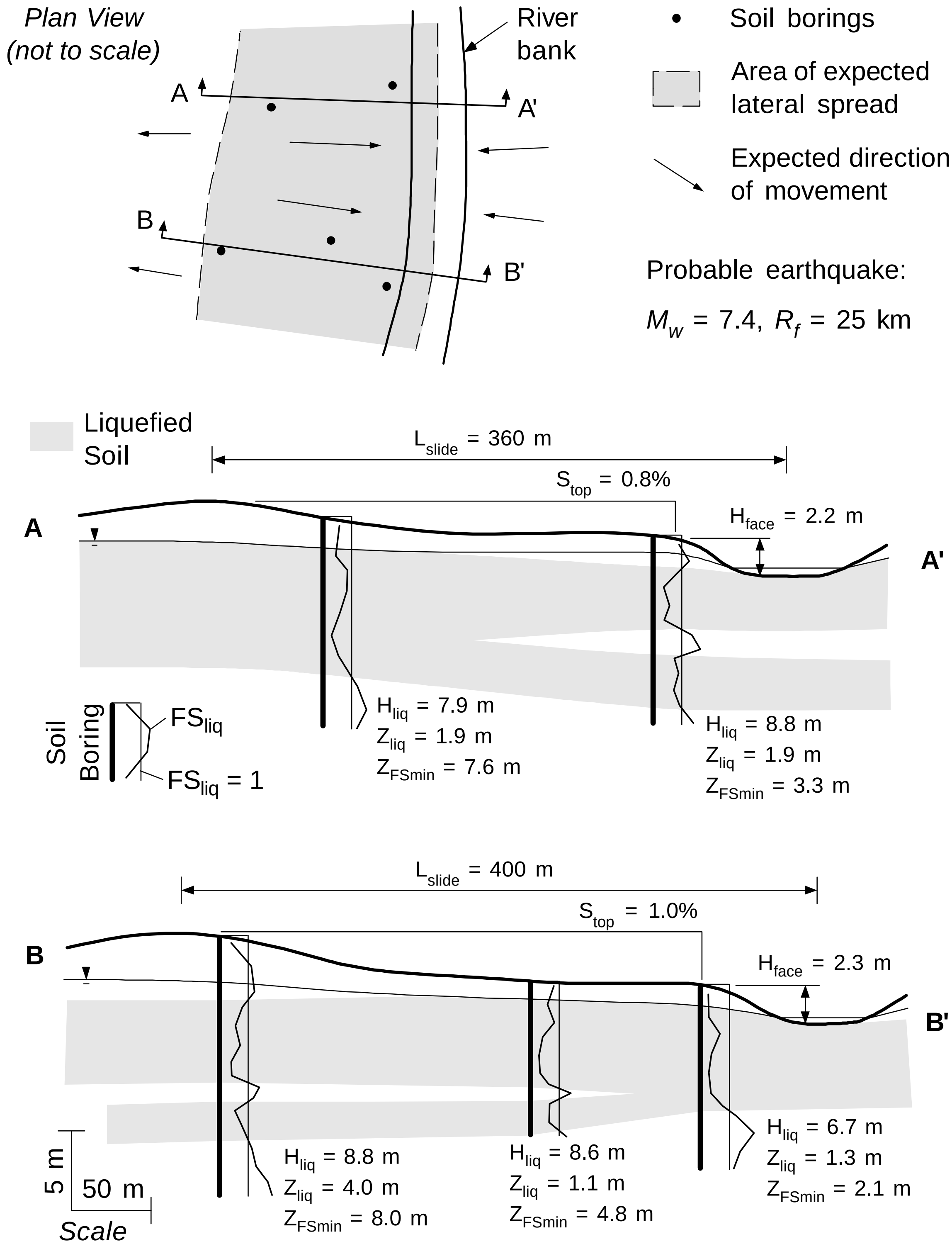

Figure E.1. Hypothetical site data for example application of the EPOLLS model.