# Chapter 10

# EPOLLS Model for Variation of Horizontal Displacement

## 10.1. Overview of Model Development.

To estimate maximum likely displacements, the predicted average and standard deviation of the horizontal deformations are used in conjunction with the gamma distribution. As shown in Chapter 8, the gamma distribution provides an effective representation of the variation in horizontal displacement magnitudes across the surface of a lateral spread. EPOLLS model equations for predicting the average horizontal displacements (*Avg_Horz*) were developed in Chapter 9. In this chapter, three compatible model equations are developed for predicting the standard deviation of horizontal displacements (*StD_Horz*). Predicting maximum displacements with the EPOLLS model is discussed in the last section of this chapter.

In designing the EPOLLS model, it was hypothesized that the average displacements could be correlated to parameters representing the average site conditions. Indeed, the model equations for *Avg_Horz* in Chapter 9 are expressed in terms of the average depth to liquefied soil, average surface slope, and peak acceleration. On the other hand, it was postulated that the variation in displacement magnitudes across a lateral spread could be related to the size and shape of the slide area as well as the variation in subsurface soil conditions. Variables such as *Rng-Z_TopLiq* (range in depths to the top of liquefied soil across the slide area) and *Divergence* were considered for inclusion in the EPOLLS models for *StD_Horz.* However, the regression analysis described in Section 10.2 showed that effective model equations for *StD_Horz* could be developed as a simple function of the predicted average horizontal displacement.

In Figure 10.1, values of *StD_Horz* from the EPOLLS database are plotted against the observed *Avg_Horz*. A fairly strong linear relationship between the average and standard deviation is evident for the measured horizontal displacements. Recall that the standard deviation divided by the mean of a data set defines the *coefficient of variation*. For the forty case studies in the EPOLLS database with both *Avg_Horz* and *StD_Horz*, the coefficient of variation is generally between 36% and 70% and has an average value of 53%. This is equivalent to saying that the standard deviation of the measured horizontal displacements is about one half of the average displacement, as indicated on Figure 10.1. Hence, one option for estimating *StD_Horz* is to simply divide *Avg_Horz* by two. However, the EPOLLS model user will not have the measured *Avg_Horz*, but only a prediction of the average displacement from one of the three model components in Chapter 9. Therefore, models for *StD_Horz* must be developed from predicted values of *Avg_Horz*.

## 10.2. Development of Model Components for Standard Deviation of Horizontal Displacement.

***Regional-EPOLLS component.***

Recall that the Regional-EPOLLS (or R-EPOLLS) component is restricted to making predictions based only on seismological parameters. The R-EPOLLS model for *Avg_Horz* is written in terms of *EQ_Mw*, *Fault_Dist*, *Accel_max*, and *Duration*. Other seismological parameters available in the EPOLLS database, which similarly represent the level of seismic shaking, were discarded in developing the model for *Avg_Horz* and were not re-introduced as candidate variables for the *StD_Horz* model. A regression of $(StD\_Horz)^{0.5}$ on *EQ_Mw*, *Fault_Dist*, *Accel_max*, and *Duration* yields a model with $R^2$=0.44 and $\overline{R}^2$=0.38 for forty case studies. Collectively, however, these four variables represent the average horizontal displacement as given by Equation 9.3. This suggests that a simpler model could be developed by regressing *StD_Horz* on the average horizontal displacement predicted by the R-EPOLLS model. A model of this form is also suggested by the data in Figure 10.1 as discussed above.

In Figure 10.2a, the observed *StD_Horz* is plotted against the average horizontal displacement predicted with the R-EPOLLS model ($Avg\_Horz_R$). A simple linear regression on forty case studies gives the following equation:

$$StD\_Horz = 0.0256 + 0.577\,(Avg\_Horz_R) \qquad (10.1)$$

where $Avg\_Horz_R$ is the average horizontal displacement computed with Equation 9.20. However, the intercept value of 0.0256 in Equation 10.1 is significant to only a 10% level in a partial *F*-test and is approximately equal to zero. From a conceptual viewpoint, a lateral spread with "zero" average displacement should also have *StD_Horz* equal to zero.

Therefore, restricting the intercept term to zero, the simple linear regression model becomes:

$$StD\_Horz = 0.589\,(Avg\_Horz_R) \qquad (10.2)$$

Equation 10.2 gives $R^2$=0.477 and $\overline{R}^2$=0.400 indicating a better fit to the data than a separate regression on the four seismological parameters. Equation 10.2 is thus chosen for predicting *StD_Horz* in the Regional-EPOLLS model. This model, significant to the 99.97% level in a global *F*-test, is shown in Figure 10.2a with the model residuals plotted in Figure 10.3a. No variable transformations are suggested by these plots.

***Site-EPOLLS component.***

The first model investigated for the Site-EPOLLS component was a simple linear regression of *StD_Horz* on the average horizontal displacement predicted with the S-EPOLLS model ($Avg\_Horz_S$). As was the case with the R-EPOLLS model in Equation 10.1, the intercept term was not significant and was restricted to zero. The fitted regression equation is then:

$$StD\_Horz = 0.560\,(Avg\_Horz_S) \qquad (10.3)$$

where $Avg\_Horz_S$ is the average horizontal displacement predicted with Equation 9.21. For the thirty-nine case studies with all relevant parameters known, Equation 10.3 yields $R^2$=0.590, $\bar{R}^2$=0.481, and a 99.97% level of significance in a global *F*-test. That is, a somewhat better fit to the data is achieved from Equation 10.3 than for Equation 10.2.

Next, other potential parameters were considered for the regression model. A slightly better model ($R^2$=0.606) was found by adding the variable *Direct_Slide* to a model with $Avg\_Horz_S$. However, the small improvement does not seem to justify the addition of another parameter to the model. Other candidate models defined with a direct regression of *StD_Horz* on the available seismological, geometrical, and topographical parameters were also examined. The best of these models is of the form:

$$StD\_Horz = f(EQ\_Mw, Fault\_Dist, Accel\_max, Duration, Slide\_Length, Face\_Height) \qquad (10.4)$$

A model specified according Equation 10.4 yields $R^2$=0.615 and $\bar{R}^2$=0.541 on thirty-nine case studies.

While Equation 10.4 gives a better fit (higher $R^2$), the simpler model in Equation 10.3 is almost as good in representing the available data. In addition, Equation 10.3 maintains a consistent structure between the Regional- and Site-EPOLLS models. Therefore, Equation 10.3 was adopted for the S-EPOLLS model for the standard deviation of horizontal displacements. The fit of the equation to the available data is shown in Figure 10.2b with the residuals plotted in Figure 10.3b. These plots do not indicate the need for any transformations of the model parameters. As can be seen in Figure 10.2, the Site-EPOLLS model is noticeably better at predicting *StD_Horz* than the Regional-EPOLLS model.

***Geotechnical-EPOLLS component.***

Following the form of the chosen Regional- and Site-EPOLLS models for *StD_Horz*, the first equation investigated for the Geotechnical-EPOLLS component was a simple regression on the predicted average displacement. Again, the intercept term was not significant and restricted to zero. The resulting, fitted model is:

$$StD\_Horz = 0.542\,(Avg\_Horz_G) \qquad (10.5)$$

where $Avg\_Horz_G$ is the average horizontal displacement estimated with Equation 9.22. Equation 10.5 gives $R^2$=0.608 and $\bar{R}^2$=0.402 for the thirty case studies where all of the necessary parameters are known. In a global *F*-test, the regression is significant to a 97.95% level. In terms of $\bar{R}^2$, which is adjusted to account for the additional site parameters required to predict *Avg_Horz,* Equation 10.5 is roughly equal to the performance of the Regional-EPOLLS model in Equation 10.2.

A fairly large number of geotechnical parameters, including those representing the range in values across a site, are also available for inclusion in the G-EPOLLS model. However, all of these values are known, together with *StD_Horz,* in only four case studies. Preliminary analyses were used to eliminate from consideration potential parameters that were known in few case studies, or were less significant than some other variable representing the same contributing factor. Formal variable selection procedures, described in Section D.5, were then used to identify potential models for *StD_Horz.* However, none of these candidate models produced a fit as good as that for Equation 10.5. On the other hand, the variable *Avg-Thick_Liq* emerged as a potentially significant regressor in a G-EPOLLS model for *StD_Horz*. Hence, the following model was considered:

$$StD\_Horz = f(Avg\_Horz_G,\ Avg\text{-}Thick\_Liq) \qquad (10.6)$$

which gives $R^2$=0.614 and $\bar{R}^2$=0.378. Because $\bar{R}^2$ is less for this model than for Equation 10.5, the addition of the parameter *Avg-Thick_Liq* is not justified.

Equation 10.5 was thus selected for the G-EPOLLS model for the standard deviation of the horizontal displacements. The fit of the equation to the available data is shown in Figure 10.2c and the residuals are plotted in Figure 10.3c. These plots do not indicate the need for any transformations of the model parameters.

***Evaluation for influential observations and multicollinearity.***

Tests for influential observations, described in Section D.7, were performed with the models selected for *StD_Horz*. In fitting one or more of these model equations, seven case studies were identified as possible high influence points: Slide Nos. 25, 26, 30, 31, 34, 35, and 37. All of these lateral spreads are located in Niigata, Japan, and involved relatively large deformations. Because the dispersion of displacements is also relatively large, these case studies are high leverage points. However, since a large number of displacement vectors were measured on the Niigata lateral spreads, these are some of the best-documented case studies in the EPOLLS database and were not discarded in fitting the models for *StD_Horz*. All of the available data, as indicated in Table 10.1, were used to fit the EPOLLS model equations.

Because the model equations chosen here for *StD_Horz* involve simple linear regression on the predicted *Avg_Horz*, tests for possible multicollinearity are unnecessary. The absence of significant multicollinearity in the three preceding models for *Avg_Horz* was confirmed in Chapter 9.

## 10.3. Evaluation of EPOLLS Model for Standard Deviation of Horizontal Displacement.

The EPOLLS model equations for predicting the standard deviation of the horizontal displacements on a lateral spread are given in Equations 10.2, 10.3, and 10.5. These model equations are:

- **Regional-EPOLLS** ($Avg\_Horz_R$ computed from Equation 9.20):

$$StD\_Horz = 0.589\,(Avg\_Horz_R) \qquad (10.7)$$

- **Site-EPOLLS** ($Avg\_Horz_S$ computed from Equation 9.21):

$$StD\_Horz = 0.560\,(Avg\_Horz_S) \qquad (10.8)$$

- **Geotechnical-EPOLLS** ($Avg\_Horz_G$ computed from Equation 9.22):

$$StD\_Horz = 0.542\,(Avg\_Horz_G) \qquad (10.9)$$

Because these three regression equations are used only in conjunction with the EPOLLS model predictions of *Avg_Horz*, additional tests for possible extrapolation are not required.

The data used to fit Equations 10.7 through 10.9 are shown in Table 10.1. The data and the three fitted model equations are also shown in the plots of Figure 10.2. Going from the R-EPOLLS component in Figure 10.2a to the G-EPOLLS component in Figure 10.2c, a better fit to the data can be observed by comparing these plots. The quality of fit for each model equation is also indicated by the values of $R^2$ and $\overline{R}^2$ in Table 10.2. Analogous to Table 9.3, the values in Table 10.2 indicate the quality of the regression for the model components when evaluated against the same subset of the EPOLLS database. For example, for the thirty case studies with all of the parameters required to use the Geotechnical-EPOLLS component, the R-EPOLLS, S-EPOLLS, and G-EPOLLS models yield, respectively, $R^2$ values of 0.484, 0.596, and 0.608 in predicting *StD_Horz*. In the shaded portion at the bottom of Table 10.2, values of $R^2$ and $\overline{R}^2$ computed for the maximum number of case studies are shown for each model component.

From the shaded entries in Table 10.2, $R^2$ is seen to increase from 0.477 for the R-EPOLLS model to 0.608 for the G-EPOLLS component. However, the largest value of $\overline{R}^2$=0.481 is for the S-EPOLLS model. As discussed in Section D.4, the statistic $\overline{R}^2$ is adjusted to indicate the relative benefit of employing additional regressor variables to improve the fit of a model. Here, the model chosen to predict *StD_Horz* must be consistent with the prediction of *Avg_Horz*. That is, if an engineer has sufficient site data to employ the Geotechnical-EPOLLS model, Equations 9.22 and 10.9 should be used in conjunction to predict the average and standard deviation of the horizontal displacements. Because the model chosen to estimate *StD_Horz* depends on the model used to predict *Avg_Horz* in the preceding step, and no additional regressor variables are required, higher or lower values of $\overline{R}^2$ are essentially irrelevant to the selection of a "best" model. The choice among Equations 10.7 through 10.9 will be made based on the level of site information available to predict the average horizontal displacement. The important conclusion to be drawn from Table 10.2 is that $R^2$ increases (indicating a better fit to the available data) as one moves from the R-EPOLLS to the S-EPOLLS and G-EPOLLS model components.

Recall from Figure 10.1 that the underlying relationship between the *measured Avg_Horz* and *StD_Horz* is fairly linear with a coefficient of variation equal to about one half. Indeed, the regression coefficient (0.589, 0.560, and 0.542) in Equations 10.7 to 10.9 converges toward the average coefficient of variation of 53% for the EPOLLS case studies. Actually, the improvement in the model quality going from Equations 10.7 to 10.9 results from better predictions of *Avg_Horz* in each succeeding component of the model. That is, as the predicted values of *Avg_Horz* get closer to the measured values, the regression coefficients get closer to the ratio of *Std_Horz* to *Avg_Horz* observed in the compiled data. This effect can also be seen in the plots of Figure 10.2. The Site-EPOLLS model predicts the average displacement more precisely than the Regional-EPOLLS model, such that the scatter plots indicate a stronger linear relationship in Figure 10.2b than in Figure 10.2a.

## 10.4. Prediction of Maximum Horizontal Displacement.

The primary reason for predicting the standard deviation, in addition to the average displacement, is to then estimate the maximum likely horizontal displacement. In Chapter 8, the gamma distribution was found to give an effective representation of the variation in displacement magnitudes across the surface of a lateral spread. Moreover, the 99.5 percentile of the gamma distribution was found to give a reasonable, conservative estimate of the maximum horizontal movement on a lateral spread.

To demonstrate how the maximum deformation can be estimated, consider Slide No. 29 from the EPOLLS database. This lateral spread occurred in 1964 in Niigata, Japan, and has the following site parameters:

$M_w$ = 7.6 $R_f$ = 13.0 km
$A_{max}$ = 0.17 g $T_d$ = 19 sec
$L_{slide}$ = 520 m $S_{top}$ = -0.7 %
$H_{face}$ = 4.6 m

For this example, assume that liquefaction and lateral spreading will occur, but no detailed data is available on the subsurface soil conditions. Hence, the Site-EPOLLS model will be used to predict the horizontal displacements. The average horizontal displacement is predicted with Equations 9.17, 9.18, and 9.21:

$$D_R = ( 613 \cdot 7.6 - 13.9 \cdot 13.0 - 2420 \cdot 0.17 - 11.4 \cdot 19 ) / 1000. = 3.85$$
$$D_S = ( 0.523 \cdot 520 + 42.3 \cdot (-0.7) + 31.3 \cdot 4.6 ) / 1000. = 0.386$$
$$Avg\_Horz = ( 3.85 + 0.386 - 2.44 )^2 + 0.111 = 3.34 \text{ m}$$

The standard deviation is then predicted with Equation 10.8:

$$StD\_Horz = 0.560\ (3.34) = 1.87 \text{ m}$$

Next, the two parameters defining the gamma distribution (see Table 8.3) are computed:

$$\lambda = Avg\_Horz^2 / StD\_Horz^2 = 3.34^2 / 1.87^2 = 3.19$$
$$\beta = StD\_Horz^2 / Avg\_Horz = 1.87^2 / 3.34 = 1.05$$

The values of $\lambda$ and $\beta$ define a gamma distribution representing the variation in displacement magnitudes across the surface of this lateral spread. The maximum likely movement can then be conservatively estimated at the 99.5 percentile of a gamma distribution with $\lambda$=3.19 and $\beta$=1.05. Interpolating the values in Table 8.8, the maximum likely horizontal displacement is about 10.1 m (this compares to a maximum displacement of 8.82 m measured on Slide No. 29). This prediction can be stated more accurately as: "99.5% of the horizontal displacements on this lateral spread are expected to be less than 10.1 m".

Predictions of the maximum horizontal displacement, made at the 99.5 percentile of the gamma distribution, are plotted in Figure 10.4 against the maximum measured displacement. Plots are shown for predictions made with the Regional-EPOLLS, Site-EPOLLS, and Geotechnical-EPOLLS components for *Avg_Horz* and *StD_Horz*. As can be seen in each of the plots in Figure 10.4, the predicted maximum displacement exceeds the maximum measured displacement for most cases. This results from using the 99.5 percentile of the gamma distribution to get a conservative prediction of the maximum likely displacement. The error in any particular prediction is often as much as 4 m, and sometimes as high as 6 m. However, remember that the maximum *measured* displacement is a single observation that may or may not represent the largest movement that occurred on a given slide. It is possible that the maximum movement occurred in a location that was not measured in the site study. Consequently, the maximum displacement is known with less confidence for any case study than either the average or standard deviation of displacements, which are based on multiple measurements.

***Comparison with Youd and Perkins' LSI model.***

EPOLLS model predictions of the maximum horizontal displacement can be compared with predictions from Youd and Perkins' (1987) LSI model. The empirical LSI model, described in Section 4.4, relates the "LSI" to earthquake magnitude and distance as shown in Equation 4.6. The *Liquefaction Severity Index* (LSI) represents the general maximum ground deformation, measured in millimeters divided by 25, in a typical lateral spread. Hence, the maximum horizontal displacement in meters (*Max_Horz*) on a lateral spread is related to LSI with:

$$Max\_Horz \text{ (m)} = 25 \cdot LSI / 1000. \qquad (10.10)$$

Youd and Perkins assign an upper limit of LSI=100, corresponding to a maximum value for *Max_Horz* of 2.5 m. In addition, the LSI model (Equation 4.6) was fit to data from sites in western North America and may not be valid for other regions of the world.

In Figure 10.5, LSI model predictions (from Equations 4.6 and 10.10) of the maximum horizontal displacement at the EPOLLS case study sites are compared with predictions from the EPOLLS model. This comparison is made only for the EPOLLS sites located in western North America where the LSI model is valid. The Regional-EPOLLS component, which requires only seismological parameters, was chosen for this analysis to be consistent with the level of information used in the LSI model. As can be seen in Figure 10.5, the R-EPOLLS model tends to predict larger maximum displacements at these sites than the LSI model, excluding those sites where the LSI model predicts an upper limit of *Max_Horz*=2.5 m. Recall, however, that the R-EPOLLS predictions of *Max_Horz*, made at the 99.5 percentile of the gamma distribution, are intended to conservatively over-predict the maximum displacement. For most of the sites in Figure 10.5, the Regional-EPOLLS model predicts maximum horizontal displacements that are within about 1.2 m of the corresponding predictions from Youd and Perkins' LSI model.

**Table 10.1.** Data used to fit and evaluate the EPOLLS model for the standard deviation of horizontal displacements.

| Slide_ID | Earthquake | StD_Horz | EQ_Mw | Fault_Dist | Accel_max | Duration | Slide_Length | Face_Height | Top_%Slope | Avg-Z_TopLiq | Avg-Z_MnFS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1906: San Francisco, California | 0.40 | 7.7 | 13.0 | 0.44 | 45. | 1360. | 0.0 | 0.6 | 1.7 | 3.3 |
| 2 | 1906: San Francisco, California | 0.70 | 7.7 | 12.0 | 0.46 | 45. | 790. | 0.0 | 1.3 | 2.0 | 4.0 |
| 5 | 1923: Kanto, Japan | 0.49 | 7.9 | 20.0 | 0.24 | 87. | 480. | 2.4 | 0.7 | 1.0 | 2.4 |
| 8 | 1948: Fukui, Japan | 0.71 | 7.0 | 0.0 | 0.25 | 4. | 250. | 0.0 | 0.4 | 12.2 | 12.2 |
| 9 | 1948: Fukui, Japan | 0.65 | 7.0 | 0.0 | 0.25 | 4. | 290. | 0.0 | 0.3 | 6.9 | 11.0 |
| 14 | 1964: Prince William Sound, Alaska | 0.18 | 9.2 | 60.0 | 0.31 | 75. | 90. | 1.8 | 0.05 | 5.1 | 9.1 |
| 16 | 1964: Prince William Sound, Alaska | 0.45 | 9.2 | 60.0 | 0.31 | 75. | 125. | 3.0 | 0.2 | 1.4 | 4.2 |
| 26 | 1964: Niigata, Japan | 2.97 | 7.6 | 16.0 | 0.16 | 19. | 370. | 5.5 | 0.0 | 3.0 | 7.0 |
| 27 | 1964: Niigata, Japan | 1.94 | 7.6 | 15.0 | 0.16 | 19. | 470. | 4.6 | 0.0 | 1.0 | 4.5 |
| 28 | 1964: Niigata, Japan | 1.21 | 7.6 | 15.0 | 0.16 | 19. | 330. | 4.2 | 0.0 | 1.8 | 2.8 |
| 29 | 1964: Niigata, Japan | 1.98 | 7.6 | 13.0 | 0.17 | 19. | 520. | 4.6 | -0.7 | 3.2 | 6.9 |
| 30 | 1964: Niigata, Japan | 2.64 | 7.6 | 14.0 | 0.17 | 19. | 320. | 5.0 | 0.0 | 3.0 | 8.7 |
| 31 | 1964: Niigata, Japan | 0.41 | 7.6 | 14.0 | 0.17 | 19. | 320. | 0.0 | 0.0 | 2.2 | 6.4 |
| 32 | 1964: Niigata, Japan | 1.01 | 7.6 | 14.0 | 0.17 | 19. | 500. | 0.0 | 0.3 | 1.9 | 5.5 |
| 33 | 1964: Niigata, Japan | 2.39 | 7.6 | 13.0 | 0.17 | 19. | 480. | 3.5 | -0.3 | 3.4 | 4.3 |
| 35 | 1964: Niigata, Japan | 2.66 | 7.6 | 11.0 | 0.17 | 19. | 450. | 3.3 | 1.0 | 2.4 | 9.4 |
| 37 | 1964: Niigata, Japan | 1.55 | 7.6 | 12.0 | 0.17 | 19. | 910. | 0.0 | 0.2 | 2.2 | 6.7 |
| 38 | 1964: Niigata, Japan | 2.10 | 7.6 | 12.0 | 0.17 | 19. | 370. | 0.0 | 0.6 | 2.6 | 5.4 |
| 39 | 1964: Niigata, Japan | 1.43 | 7.6 | 11.0 | 0.18 | 19. | 740. | 0.0 | 0.3 | 2.0 | 2.9 |
| 40 | 1971: San Fernando, California | 1.19 | 6.7 | 0.5 | 0.50 | 15. | 930. | 9.0 | 1.0 | 7.0 | 12.4 |
| 41 | 1971: San Fernando, California | 0.58 | 6.7 | 1.0 | 0.50 | 14. | 1340. | 0.0 | 1.8 | 5.7 | 6.3 |
| 43 | 1979: Imperial Valley, California | 1.19 | 6.5 | 1.6 | 0.46 | 14. | 110. | 1.5 | 0.3 | 1.8 | 3.4 |
| 45 | 1983: Nihonkai-Chubu, Japan | 0.66 | 7.9 | 60.0 | 0.25 | 30. | 245. | 0.0 | 5.2 | 1.3 | 6.7 |
| 46 | 1983: Nihonkai-Chubu, Japan | 0.43 | 7.9 | 60.0 | 0.25 | 30. | 325. | 0.0 | 2.1 | 0.9 | 10.5 |
| 47 | 1983: Nihonkai-Chubu, Japan | 0.83 | 7.9 | 60.0 | 0.25 | 30. | 535. | 0.0 | 1.0 | 2.5 | 5.9 |
| 48 | 1983: Nihonkai-Chubu, Japan | 0.42 | 7.9 | 60.0 | 0.25 | 30. | 600. | 0.0 | 0.8 | 2.9 | 4.0 |
| 49 | 1983: Nihonkai-Chubu, Japan | 0.58 | 7.9 | 60.0 | 0.25 | 30. | 870. | 0.0 | 0.4 | 2.6 | 5.9 |
| 52 | 1987: Superstition Hills, California | 0.06 | 6.5 | 24.0 | 0.21 | 26. | 20. | 2.4 | -0.47 | 2.2 | 3.5 |
| 56 | 1989: Loma Prieta, California | 0.04 | 7.0 | 1.0 | 0.39 | 11. | 150. | 4.3 | 0.15 | 5.3 | 7.6 |
| 114 | 1993: Hokkaido Nansei-oki, Japan | 0.41 | 7.7 | 15.0 | 0.25 | 60. | 90. | 0.0 | 1.0 | 1.5 | 3.8 |
| 6 | 1948: Fukui, Japan | 0.84 | 7.0 | 0.0 | 0.25 | 4. | 270. | 0.0 | 0.4 | | |
| 7 | 1948: Fukui, Japan | 0.99 | 7.0 | 0.0 | 0.25 | 4. | 190. | 0.0 | 0.5 | | |
| 25 | 1964: Niigata, Japan | 2.45 | 7.6 | 16.0 | 0.16 | 19. | 290. | 6.0 | 0.7 | | |
| 34 | 1964: Niigata, Japan | 0.64 | 7.6 | 13.0 | 0.17 | 19. | 140. | 3.0 | 0.5 | | |
| 109 | 1993: Hokkaido Nansei-oki, Japan | 1.06 | 7.7 | 12.0 | 0.25 | 60. | 350. | 0.0 | 0.37 | | |
| 110 | 1993: Hokkaido Nansei-oki, Japan | 0.35 | 7.7 | 13.0 | 0.25 | 60. | 380. | 0.0 | 0.08 | | |
| 115 | 1993: Hokkaido Nansei-oki, Japan | 0.29 | 7.7 | 15.0 | 0.25 | 60. | 160. | 1.3 | 0.54 | | |
| 116 | 1993: Hokkaido Nansei-oki, Japan | 0.27 | 7.7 | 15.0 | 0.25 | 60. | 160. | 0.7 | -0.1 | | |
| 117 | 1993: Hokkaido Nansei-oki, Japan | 0.90 | 7.7 | 15.0 | 0.25 | 60. | 140. | 0.8 | 1.33 | | |
| 121 | 1994: Northridge, California | 0.03 | 6.7 | 12.1 | 0.46 | 14. | | | | | |

Data used to fit Regional-EPOLLS component

Data used to fit Site-EPOLLS component

Data used to fit Geotechnical-EPOLLS component

Not used in fitting model, values unknown

**Table 10.2.** Quality of fit statistics for the EPOLLS model components for standard deviation of horizontal displacement.

| *Component of EPOLLS model:* | | **Regional** (Eq. 10.7) | **Site** (Eq. 10.8) | **Geotechnical** (Eq. 10.9) |
|---|---|---|---|---|
| *Number of case studies used to fit component:* | | 40 | 39 | 30 |
| Based on ***40*** case studies with all four variables required for the Regional-EPOLLS model | $R^2$ = | 0.477 | | |
| | $\bar{R}^2$ = | 0.400 | | |
| Based on ***39*** case studies with all seven variables required for the Site-EPOLLS model | $R^2$ = | 0.457 | 0.590 | |
| | $\bar{R}^2$ = | 0.375 | 0.481 | |
| Based on ***30*** case studies with all nine variables required for the Geotechnical-EPOLLS model | $R^2$ = | 0.484 | 0.596 | 0.608 |
| | $\bar{R}^2$ = | 0.376 | 0.442 | 0.402 |
| Evaluation of model components using all case studies with no missing data | *# Cases* = | 40 | 39 | 30 |
| | $R^2$ = | 0.477 | 0.590 | 0.608 |
| | $\bar{R}^2$ = | 0.400 | 0.481 | 0.402 |

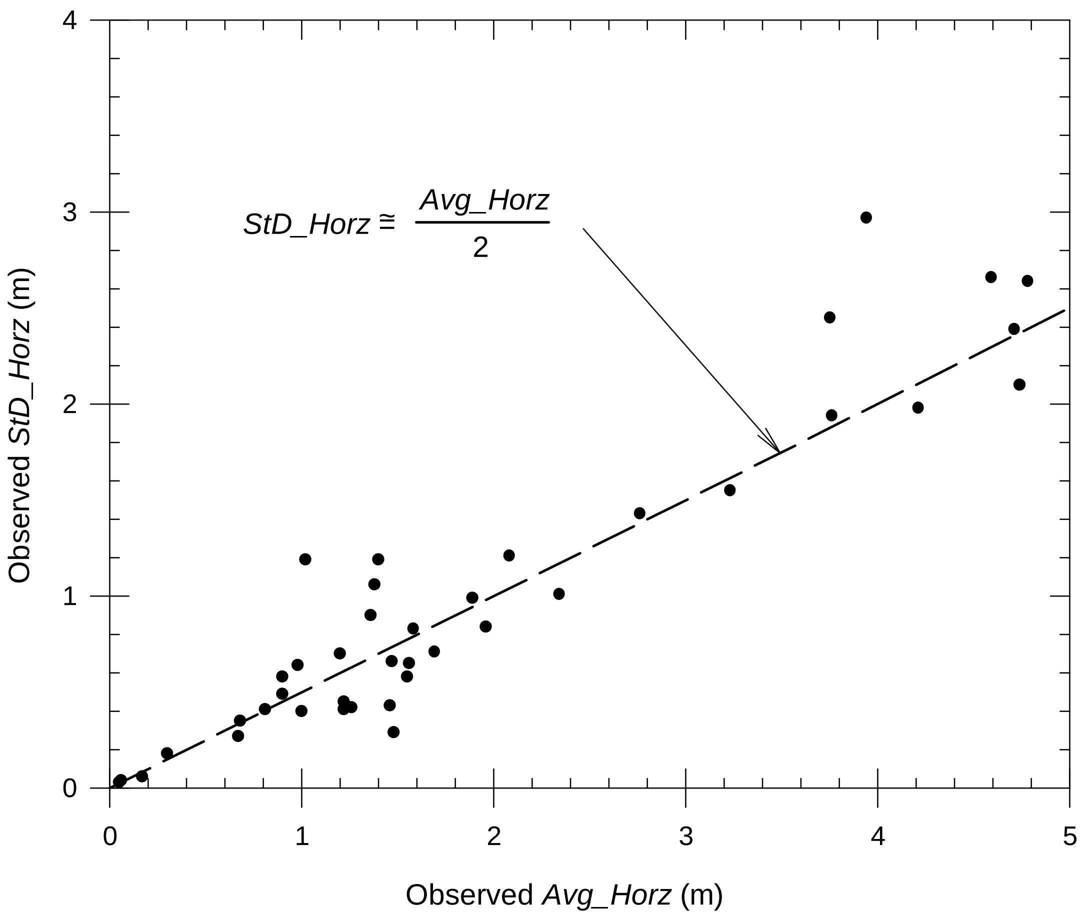



**Figure 10.1.** Observed relationship between the average and standard deviation of horizontal displacements in the EPOLLS database.

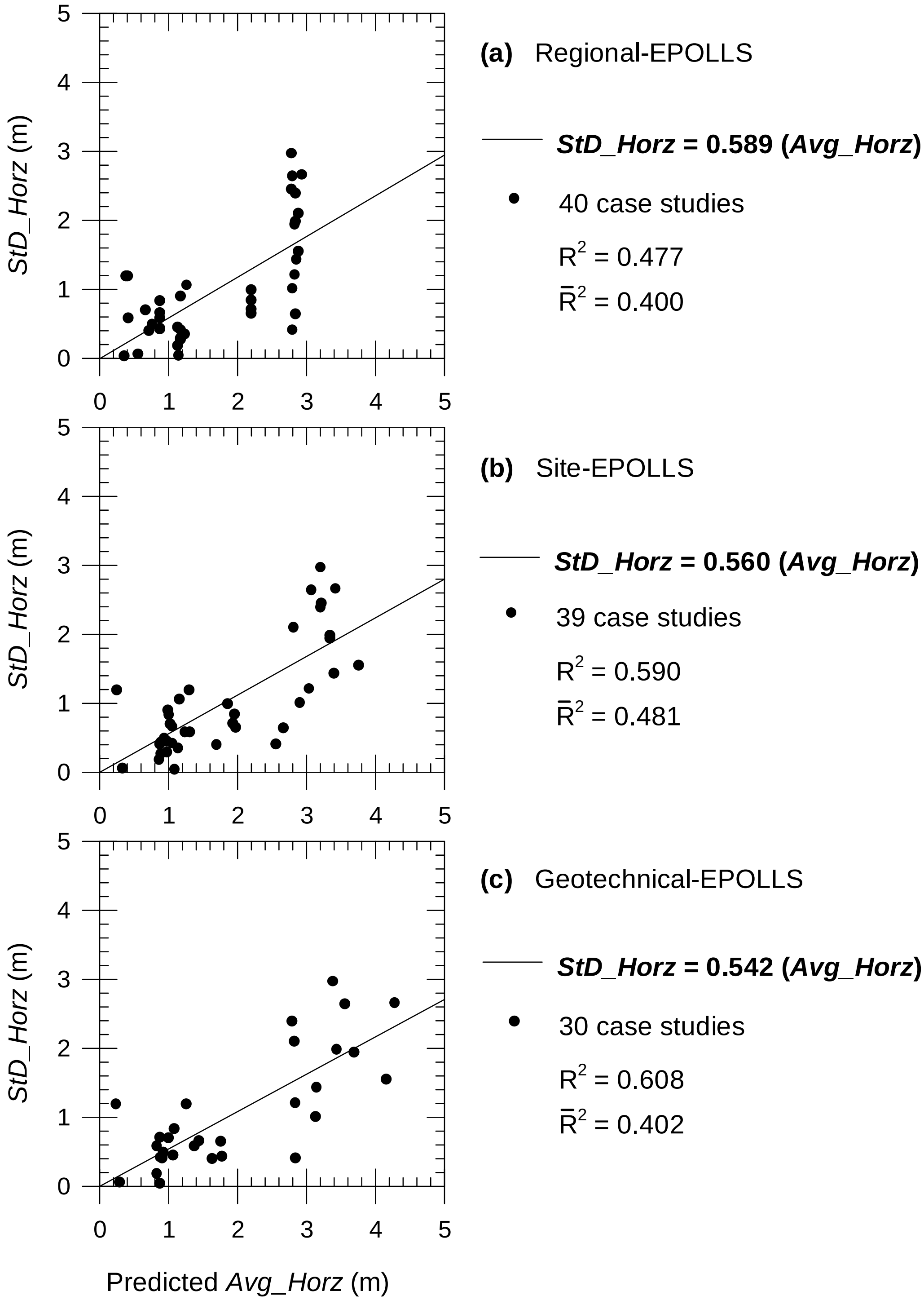



**Figure 10.2.** (a) Regional-EPOLLS, (b) Site-EPOLLS, and (c) Geotechnical-EPOLLS model components for standard deviation of horizontal displacements.

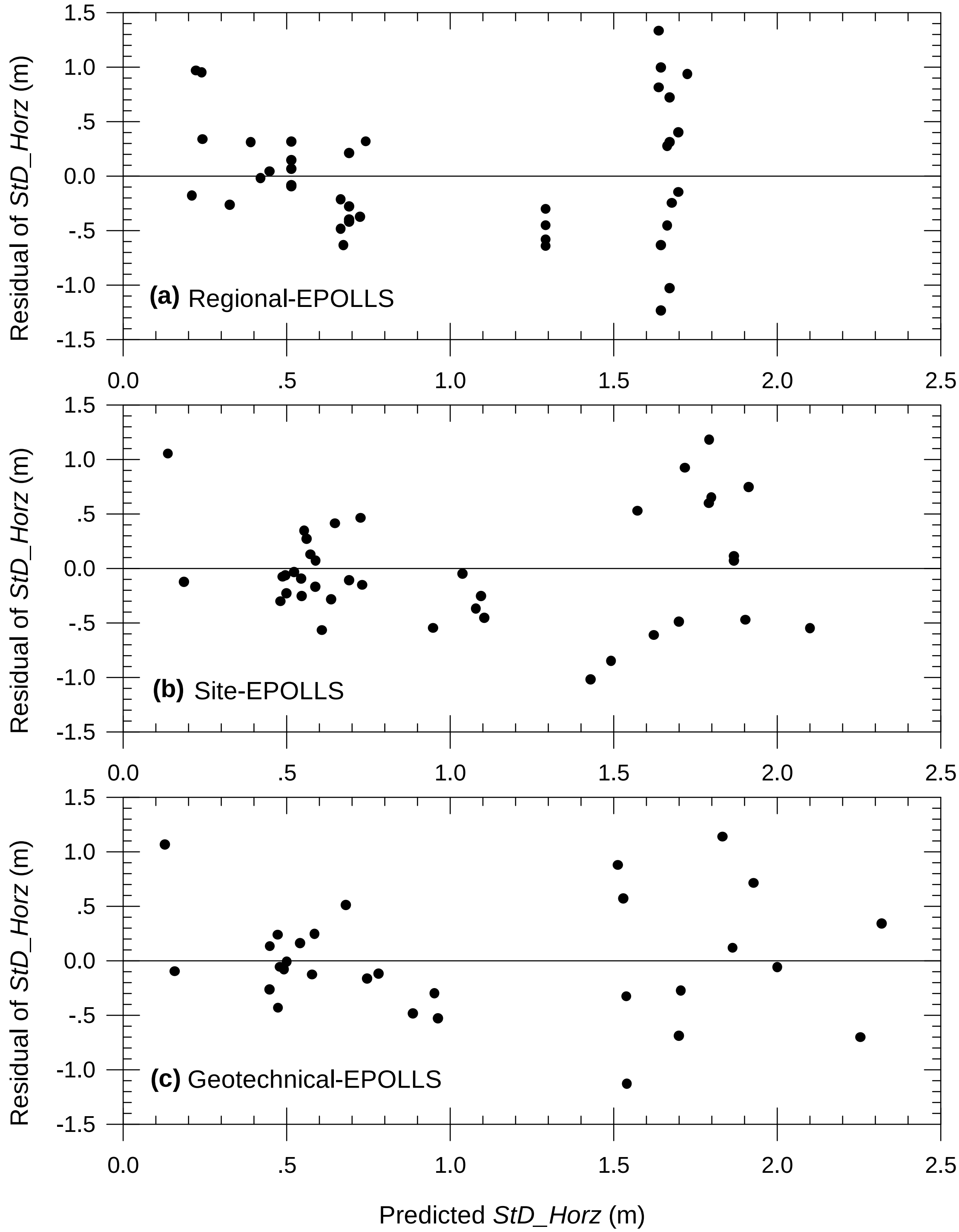



**Figure 10.3.** Residuals of the fitted (a) Regional-EPOLLS, (b) Site-EPOLLS, and (c) Geotechnical-EPOLLS model components.

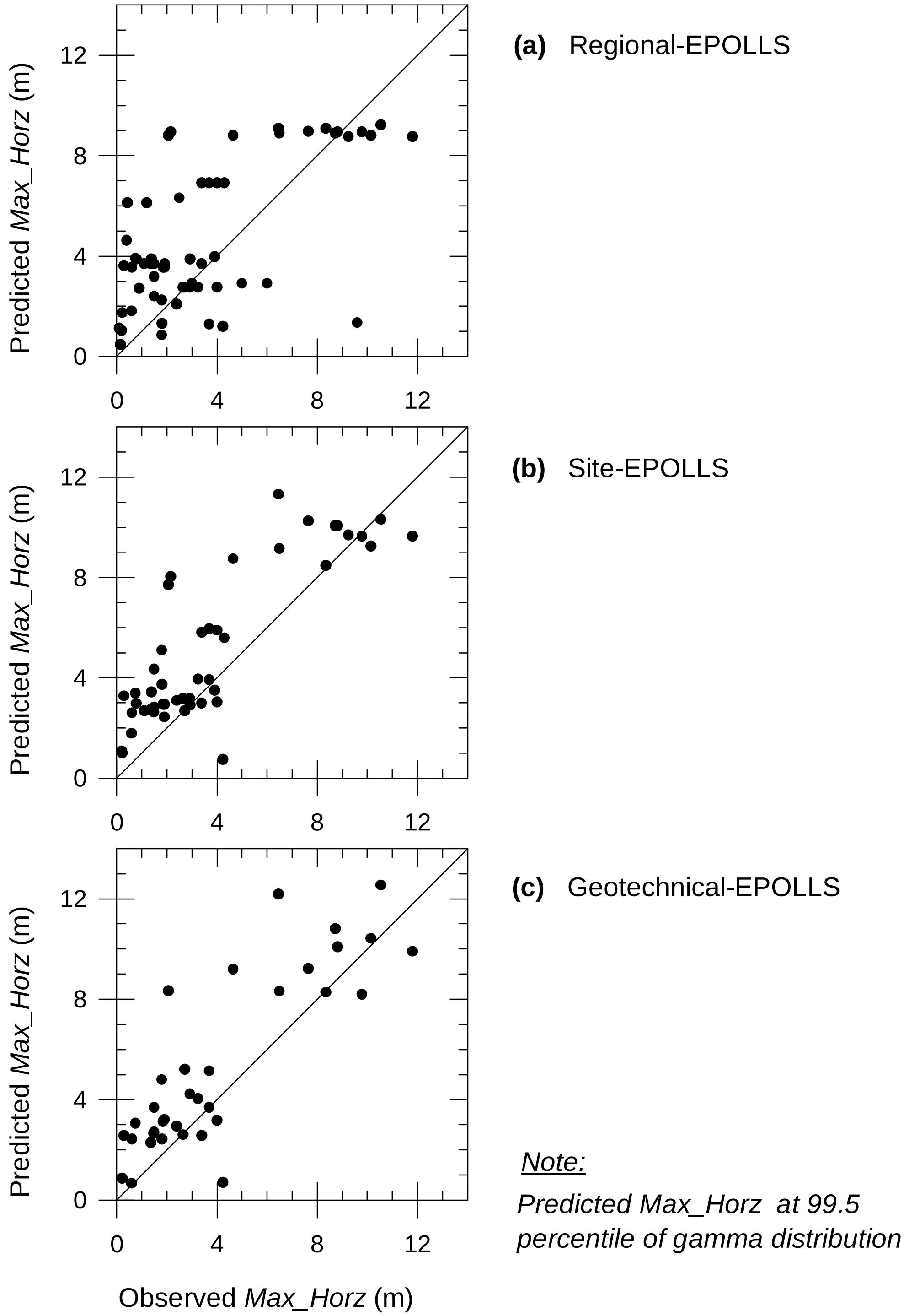
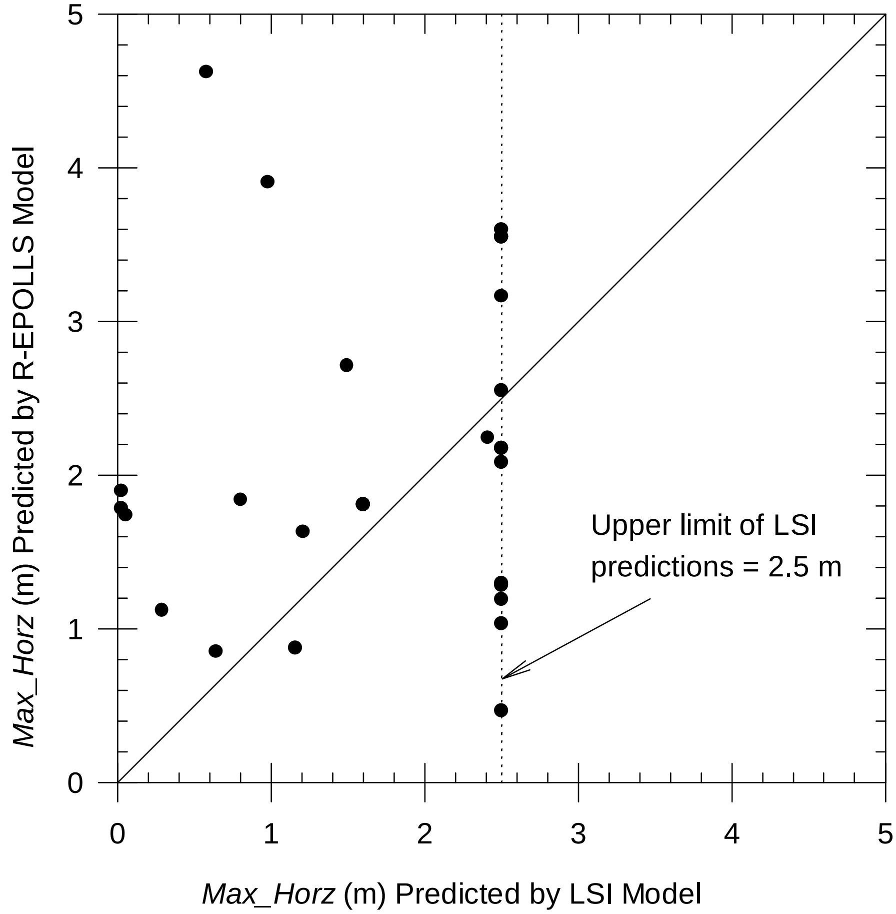



**Figure 10.4.** Performance of the (a) Regional-EPOLLS, (b) Site-EPOLLS, and (c) Geotechnical-EPOLLS components in predicting maximum horizontal displacements.




<u>*Notes:*</u>

*Comparison only for EPOLLS sites in western North America*

*Max_Horz predicted at 99.5 percentile of gamma distribution for R-EPOLLS model*

**Figure 10.5.** Comparison between maximum horizontal displacements predicted with R-EPOLLS model and Youd and Perkins' LSI model.