# Tutorial on liquefaction evaluation

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A site in Japan underlain by clean, potentially liquefiable sand, had the measured SPT resistances reported in Table 1. Knowing that:

1) the SPT procedures used in Japan deliver about 72% of the theoretical free-fall energy to the sampler;

2) the water table is at a depth of 1.5 m;

3) the unit weights of the dry and saturated sand are 18.4 kN/m$^3$ and 21.4 kN/m$^3$, respectively;

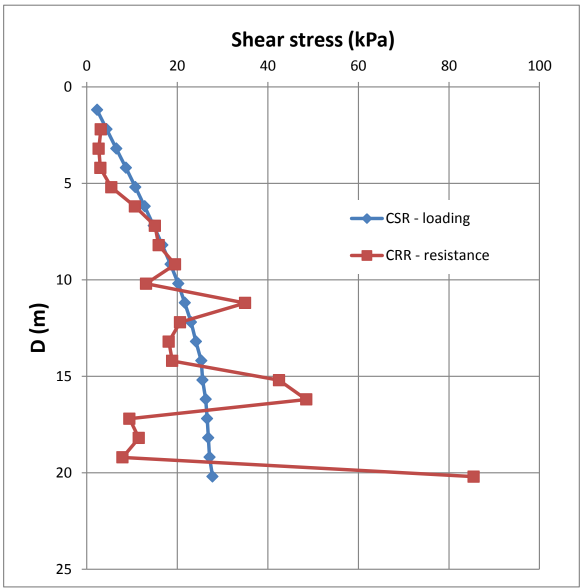
determine the extent to which liquefaction would have been expected in the 1964 Niigata earthquake ($M$ = 7.5) if the peak horizontal acceleration at the ground surface was 0.16 g.

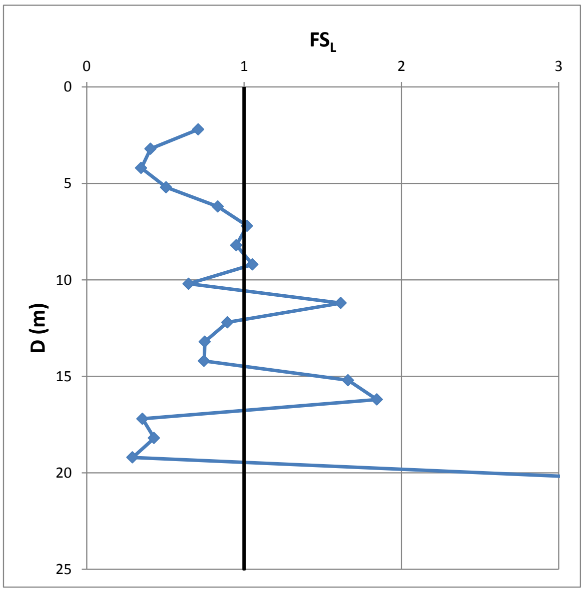
| Depth (m) | $N_m$ |
|---|---|
| 1.2 | 7 |
| 2.2 | 4 |
| 3.2 | 3 |
| 4.2 | 3 |
| 5.2 | 5 |
| 6.2 | 9 |
| 7.2 | 12 |
| 8.2 | 12 |
| 9.2 | 14 |
| 10.2 | 9 |
| 11.2 | 23 |
| 12.2 | 13 |
| 13.2 | 11 |
| 14.2 | 11 |
| 15.2 | 24 |
| 16.2 | 27 |
| 17.2 | 5 |
| 18.2 | 6 |
| 19.2 | 4 |
| 20.2 | 38 |

Table 1. SPT resistances

**Solution**

| | | from graph | calculated | given | | | | | from graph | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D (m) | $\sigma_{v0}$ (kPa) | $r_d$ | $r_d$ | $N_m$ | $\sigma'_{v0}$ (kPa) | $C_N$ | $(N_1)_{60}$ | $\tau_{cyc}$ (kPa) | $CSR_L$ | $\tau_{cyc,L}$ (kPa) | $FS_L$ |
| 1.2 | 22.1 | 0.994 | 0.998 | 7 | 22.1 | 2.08 | 17.5 | 2.28 | -- | -- | -- |
| 2.2 | 42.5 | 0.989 | 0.989 | 4 | 35.7 | 1.64 | 7.9 | 4.38 | 0.087 | 3.10 | 0.71 |
| 3.2 | 63.9 | 0.982 | 0.980 | 3 | 47.3 | 1.42 | 5.1 | 6.53 | 0.056 | 2.65 | 0.41 |
| 4.2 | 85.3 | 0.976 | 0.970 | 3 | 58.9 | 1.28 | 4.6 | 8.66 | 0.051 | 3.00 | 0.35 |
| 5.2 | 106.7 | 0.968 | 0.959 | 5 | 70.4 | 1.17 | 7.0 | 10.74 | 0.077 | 5.42 | 0.50 |
| 6.2 | 128.1 | 0.960 | 0.947 | 9 | 82.0 | 1.08 | 11.7 | 12.79 | 0.130 | 10.66 | 0.83 |
| 7.2 | 149.5 | 0.951 | 0.934 | 12 | 93.6 | 1.01 | 14.6 | 14.78 | 0.161 | 15.07 | 1.02 |
| 8.2 | 170.9 | 0.940 | 0.921 | 12 | 105.2 | 0.95 | 13.7 | 16.70 | 0.151 | 15.89 | 0.95 |
| 9.2 | 192.2 | 0.926 | 0.907 | 14 | 116.8 | 0.91 | 15.2 | 18.51 | 0.167 | 19.50 | 1.05 |
| 10.2 | 213.6 | 0.910 | 0.893 | 9 | 128.4 | 0.86 | 9.3 | 20.22 | 0.102 | 13.09 | 0.65 |
| 11.2 | 235.0 | 0.886 | 0.879 | 23 | 140.0 | 0.83 | 22.8 | 21.66 | 0.250 | 34.99 | 1.62 |
| 12.2 | 256.4 | 0.864 | 0.864 | 13 | 151.5 | 0.80 | 12.4 | 23.04 | 0.136 | 20.61 | 0.89 |
| 13.2 | 277.8 | 0.835 | 0.849 | 11 | 163.1 | 0.77 | 10.1 | 24.12 | 0.111 | 18.11 | 0.75 |
| 14.2 | 299.2 | 0.813 | 0.834 | 11 | 174.7 | 0.74 | 9.8 | 25.30 | 0.108 | 18.87 | 0.75 |
| 15.2 | 320.6 | 0.767 | 0.819 | 24 | 186.3 | 0.72 | 20.7 | 25.57 | 0.228 | 42.48 | 1.66 |
| 16.2 | 341.9 | 0.739 | 0.805 | 27 | 197.9 | 0.70 | 22.5 | 26.28 | 0.245 | 48.48 | 1.84 |
| 17.2 | 363.3 | 0.704 | 0.790 | 5 | 209.5 | 0.68 | 4.1 | 26.60 | 0.045 | 9.43 | 0.35 |
| 18.2 | 384.7 | 0.671 | 0.775 | 6 | 221.1 | 0.66 | 4.7 | 26.85 | 0.052 | 11.50 | 0.43 |
| 19.2 | 406.1 | 0.642 | 0.761 | 4 | 232.6 | 0.64 | 3.1 | 27.11 | 0.034 | 7.91 | 0.29 |
| 20.2 | 427.5 | 0.625 | 0.747 | 38 | 244.2 | 0.63 | 28.6 | 27.79 | 0.350 | 85.48 | 3.08 |




The following steps explain how to solve the problem for the specific depth of 6.2 m. The same steps should be followed for any other depth.

For the point at 6.2 m depth:

$$\sigma_v = 1.5 \cdot 18.4 + (6.2 - 1.5) \cdot 21.4 = 128.1 \text{kPa}$$

$r_d = 0.960$ obtained from Figure 9.25 on Kramer's book or from the graph provided in the lecture notes.

$$\tau_{cyc} = 0.65\frac{a_{\max}}{g}\sigma_v r_d = 0.65 \cdot 0.16 \cdot 128.1 \cdot 0.960 = 12.79\,\text{kPa}$$

$$\sigma'_v = 1.5 \cdot 18.4 + (6.2 - 1.5) \cdot (21.4 - 9.8) = 82.0\,\text{kPa}$$

$$C_N = \sqrt{\frac{1}{\sigma'_v\left[(0.01044\text{tons/ft}^2)/\text{kPa}\right]}} = \sqrt{\frac{1}{82.0 \cdot 0.01044}} = 1.08$$

$$(N_1)_{60} = N_m C_N \frac{E_m}{0.60 E_{eff}} = 9 \cdot 1.08 \cdot \frac{0.72}{0.60} = 11.7$$

From the graph shown below:

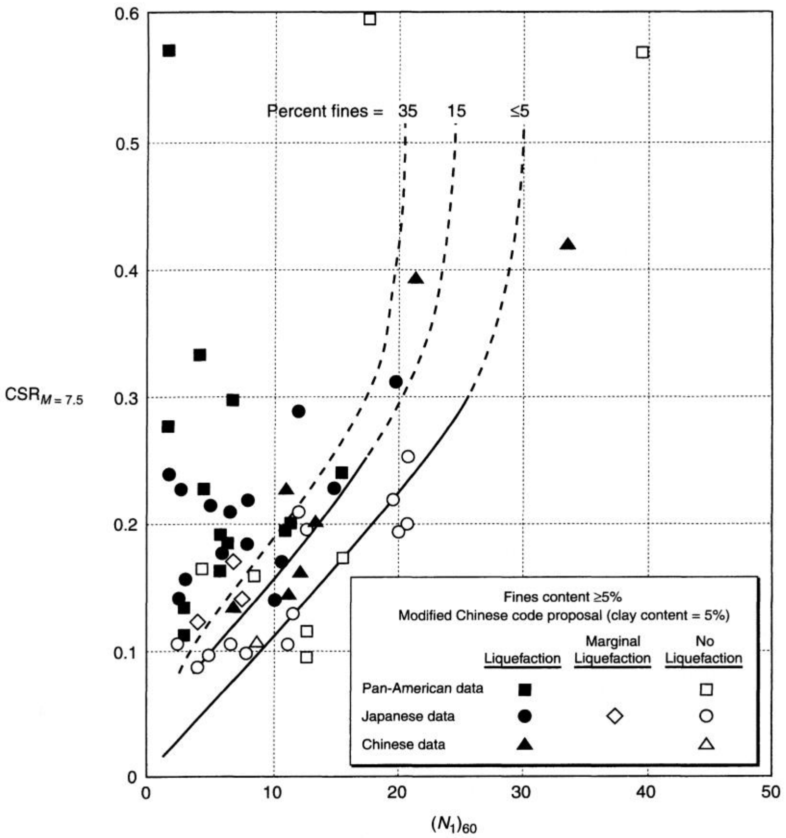



**Figure 9.31** Relationship between cyclic stress ratios causing liquefaction and $(N_1)_{60}$ values for silty sands in $M = 7.5$ earthquakes. (After Seed et al. (1975). Influence of SPT procedures in soil liquefaction resistance evaluations, *Journal of Geotechnical Engineering*, Vol. 111, No. 12. Reprinted by permission of ASCE.)

The value $(N_1)_{60} = 11.7$ corresponds to $CSR_{M=7.5} = 0.130$.

$$CSR_L = CSR_{M=7.5} = 0.130$$

$$\tau_{cyc,L} = CSR_L \sigma'_v = 0.130 \cdot 82.0 = 10.66\,\text{kPa}$$

$$FS_L = \frac{\tau_{cyc,L}}{\tau_{cyc}} = \frac{10.66}{12.79} = 0.83 < 1$$