Geotechnical Earthquake Engineering: Homework #2

Due on November 16, 2022 at 9:00am

Professor Byungmin Kim 9:00-10:15

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Problem 1

Choose two earthquake scenarios. e.g., **M7**, epicentral distance of 20 km, and $V_{S,30}$ of 500 m/s etc. Collect two acceleration time series corresponding to these two earthquake scenarios. Select a slope. i.e., choose the reasonable friction angle, cohesion, unit weight for the soil, and choose your own slope angle. Then, perform Newmark sliding block analyses to estimate permanent displacements for the slope that you selected. In addition, perform pseudostatic slope stability analyses to estimate factors of safety assuming a thickness of the slope mass in an infinite slope (e.g., 1–3 m).

Solution

The two selected earthquake scenarios are:

- **1999 Chi-chi Earthquake.** It is an earthquake that occured in Chi-Chi, Nantou County, Taiwan on September 21, 1999 (1:47:12 local time). The magnitude of earthquake is M 7.7 at depth of 33.0 km.

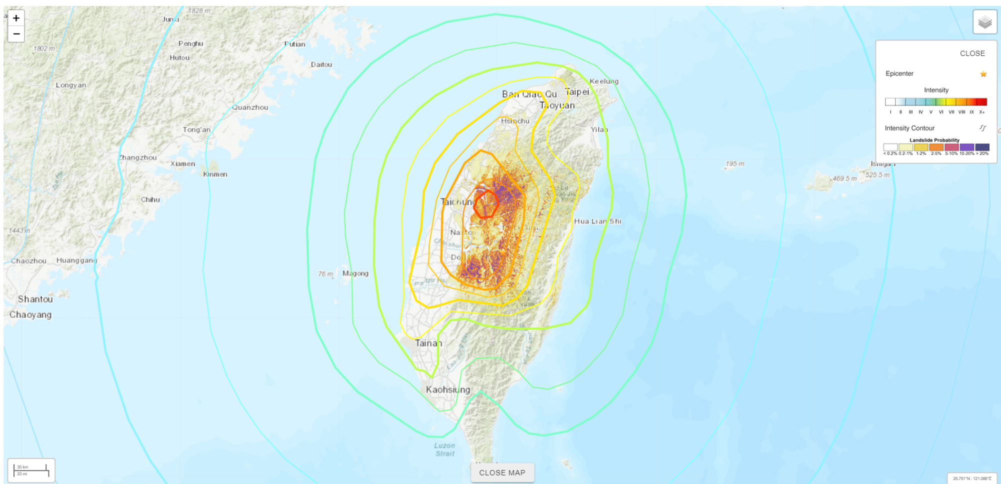

Figure 1: Shakemap of 1999 Chi-chi Earthquake [acquired from USGS website]

- **1992 Cape Mendocino Earthquake.** It is an earthquake that occured in Lost Coast of Northern California on April 25, 1992 (11:06:06 local time). Its magnitude is M 7.2 with depth of 9.9 km.

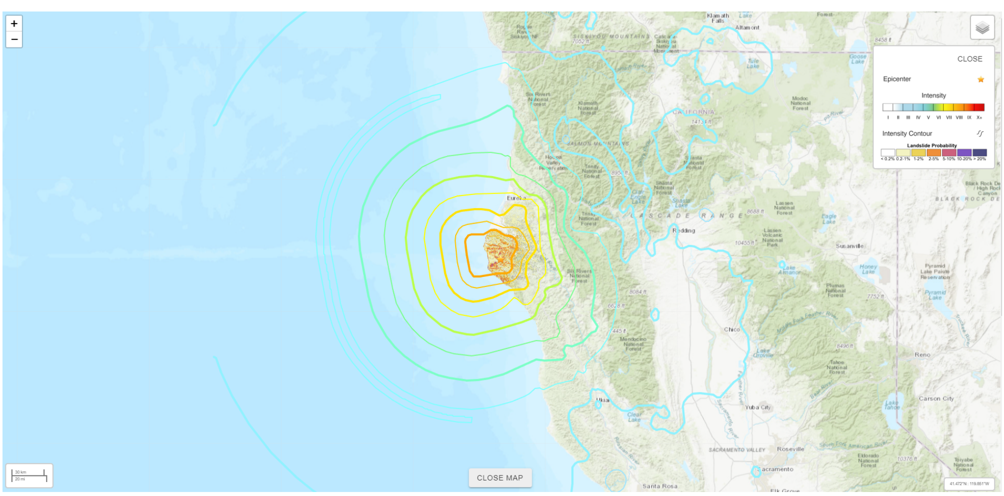

Figure 2: Shakemap of 1992 Cape Mendocino Earthquake [acquired from USGS website]

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The collected time series are plotted below. The properties of each recorded acceleration at the specific station is given in the table below.

Record ID	EQ Event	PGA	Epicental Distance	VS30
CHY086-000	Chichi 1999	0.204	60.2	553
TCU045-000	Chichi 1999	0.512	77.5	705
SHL-000	Cape Mendocino 1992	0.229	36.3	514
RIO-270	Cape Mendocino 1992	0.385	22.6	312

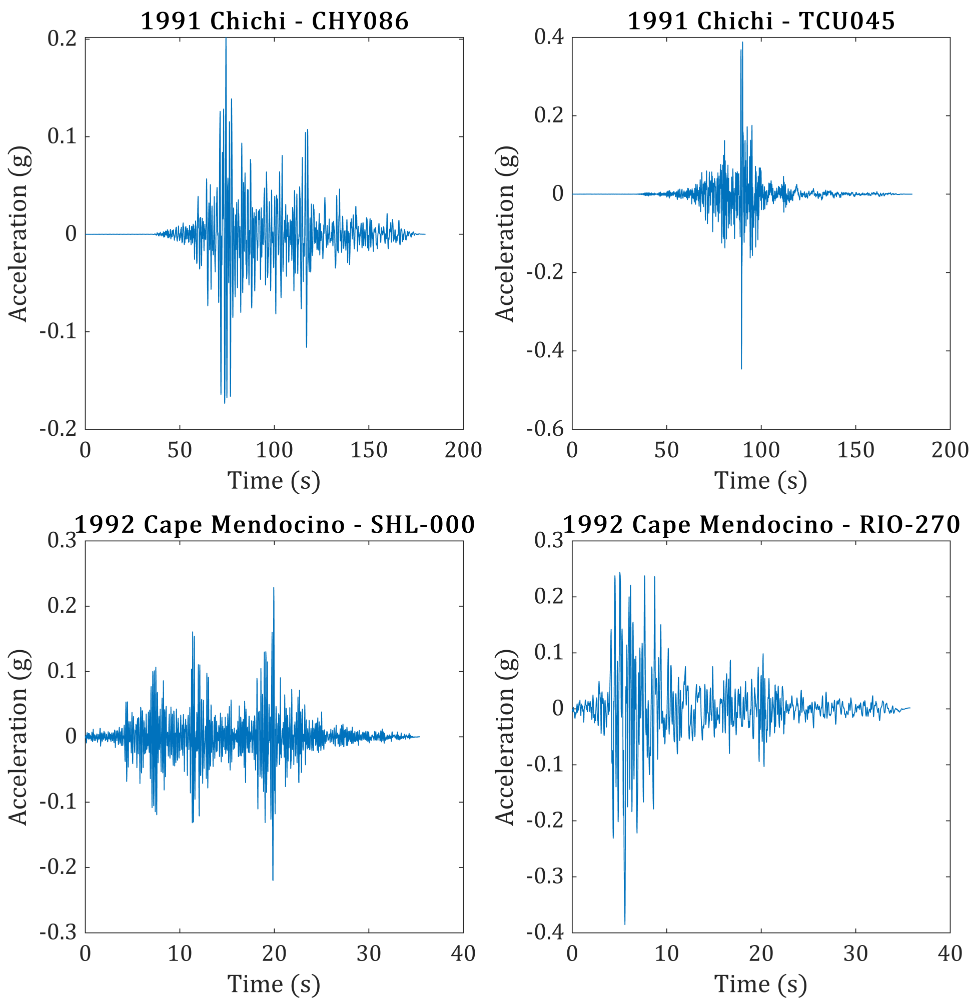

Figure 3: Gathered Time Series plot

Static Slope Stability Analysis (Limit Equilibrium)

A limit equilibrium analysis is first performed using GeoStudio Slope/W software. The model geometry used in the stability analysis is shown below. The other model definition are listed below.

	Value
Friction angle	20°
Cohesion	15 kPa
Unit Weight of soil	15 kN/m^3
Slope angle	47.5°
Analysis Type	Morgenstern-Price
Side Function	Half-Sine

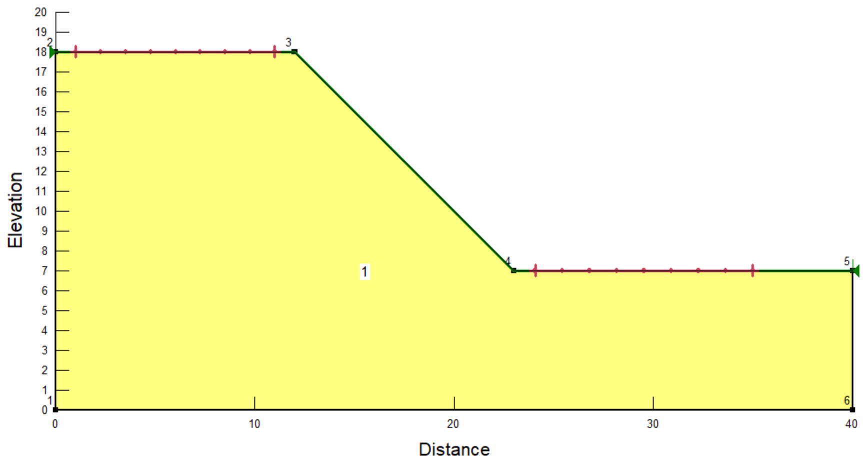

Figure 4: Slope/W Model

After the analysis, the following results were gathered from Geo-studio. The calculated values for the critical slip surface is given in the table below. The critical slip surface is also shown below.

Parameter	
Factor of Safety	1.243
Total Volume	59.972 m^3
Total Weight	899.58 kN
Total Resisting Moment	8,643.8 kN·m
Total Activating Moment	6,951.9 kN·m
Total Resisting Force	472.16 kN
Total Activating Force	379.75 kN

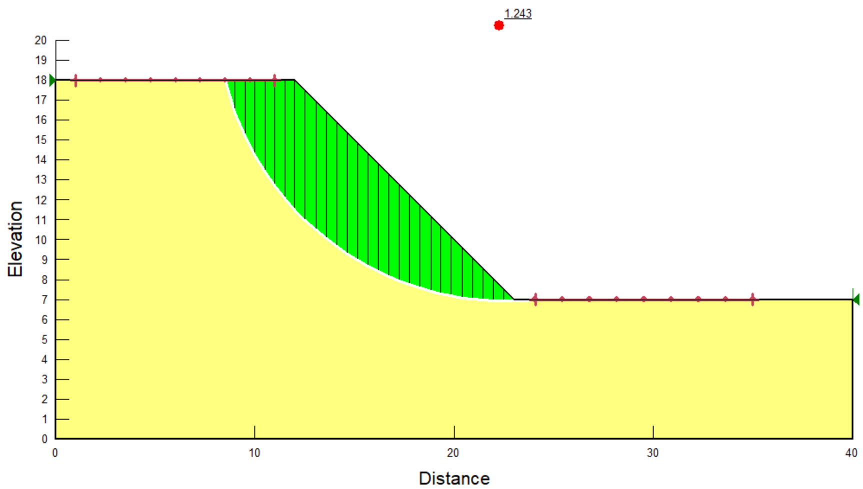

Figure 5: Critical Slip Surface

The other slip surfaces calculated by Slope/W is also illustrated below with its corresponding factor of safety.

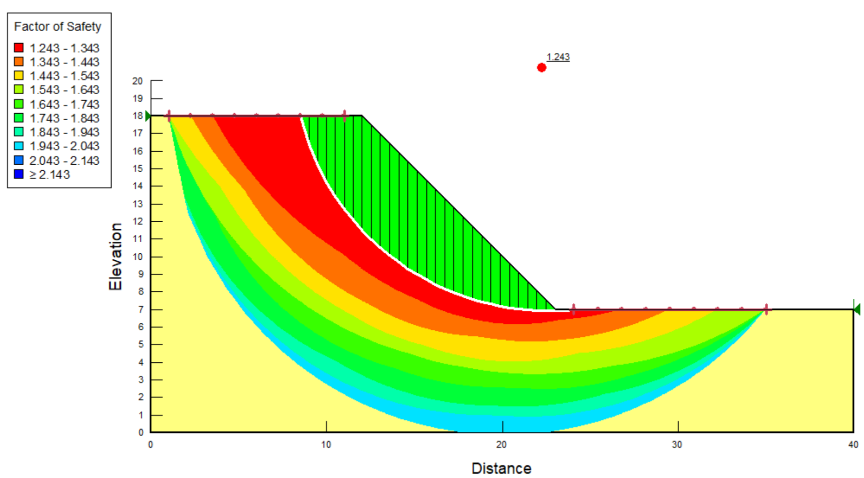

Figure 6: Critical Slip Surface

Newmark sliding block analysis

The Seismic LAndslide Movement Modeled using Earthquake Records or Slammer software from USGS is used to conduct sliding block analysis. The two earthquake records for the 1999 Chichi Earthquake available in Slammer software that corresponds to the time series plot shown above were selected. A rigid block analysis is then chosen (with downslope only). The critical acceleration a_c is approximated using the equation

$$a_c = (\text{FOS} - 1)g \sin \alpha$$

where FOS (which is equals 1.243 as calculated from above) is the static factor of safety and α is the angle from the horizontal of the sliding surface. It is assumed that the angle of sliding surface equals the slope angle. The critical acceleration is

$$a_c = (1.243 - 1)g \sin 47.5 = 0.179g$$

This value is used in the slammer software. The results of the rigid block analysis for the two earthquake scenarios are listed in the table below.

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Earthquake	**Record**	**Rigid Block (cm) Normal**	**Rigid Block (cm) Inverse**	**Rigid Block (cm) Average**
Cape Mendocino 1992	RIO-270	1.1	3.2	2.2
Cape Mendocino 1992	SHL-000	0.0	0.1	0.0
Chi-Chi, Taiwan 1999	CHY086-000	0.1	0.0	0.0
Chi-Chi, Taiwan 1999	TCU045-000	5.4	0.6	3.0
	Mean value	1.7	1.0	1.3
	Median value	0.6	0.3	1.1
	Standard deviation	2.2	1.3	1.3

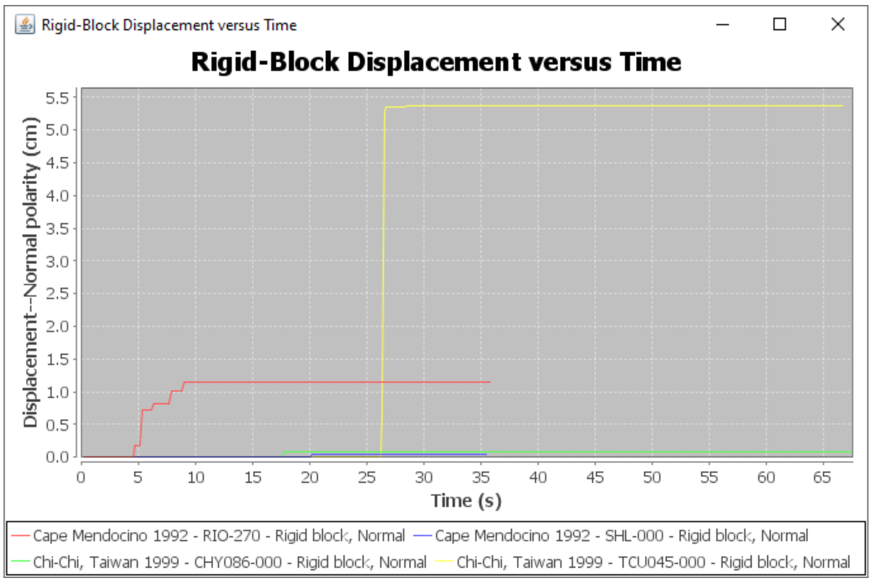

Figure 7: Estimated Permanent Displacement

Pseudostatic slope stability analysis

The factor of safety FS for an infinite slope equation is given by:

$$FS = \frac{[(1-k_v)\cos\beta - k_h \sin\beta]\tan\phi + \frac{c}{\gamma D}}{(1-k_v)\sin\beta + k_h\cos\beta}$$

where k_h, k_v are horizontal and vertical pseudostatic coefficients, β is the slope angle (which is assumed to be the same with the slip surface), ϕ, c, γ are soil parameters defined above and D depth of the sliding mass (assumed here to be 3.0 m). It is further assumed here the vertical component of the pseudo static component of the dynamic force is zero ($k_v = 0$) while k_h is calculated as $k_h = 0.5 \cdot a_{max}/g$. For the Chichi earthquake time series considered, $a_{max} = 0.512g$, thus, $k_h = 0.5 \cdot 0.512 = 0.256$. The k_h for the Cape Mendocino Earthquake similarly calculated as $k_h = 0.5 \cdot 0.385 = 0.1925$. Thus, the Factor of safety of the considered slope for the Chichi Earthquake is

$$FS = \frac{[(1-0)\cos 47.5^\circ - 0.256\sin 47.5^\circ]\tan 47.5^\circ + \frac{15}{15\cdot 3.0}}{(1-0)\sin 47.5^\circ + 0.256\cos 47.5^\circ} = 0.95$$

while the factor of safety for the Cape Mendicino Earthquake is

$$FS = \frac{[(1-0)\cos 47.5^\circ - 0.1925\sin 47.5^\circ]\tan 47.5^\circ + \frac{15}{15\cdot 3.0}}{(1-0)\sin 47.5^\circ + 0.1925\cos 47.5^\circ} = 1.06$$

Additionally, a pseudostatic slope stability analysis can also be done in Slope/W (using trial license). A seismic load can be defined using values k_h and k_v. The slip surfaces are shown below with the critical failure surface of 0.878 for the Chichi earthquake. This difference between the calculated factor of safety is expected since there is a difference in assumption on how the sliding mass is defined.

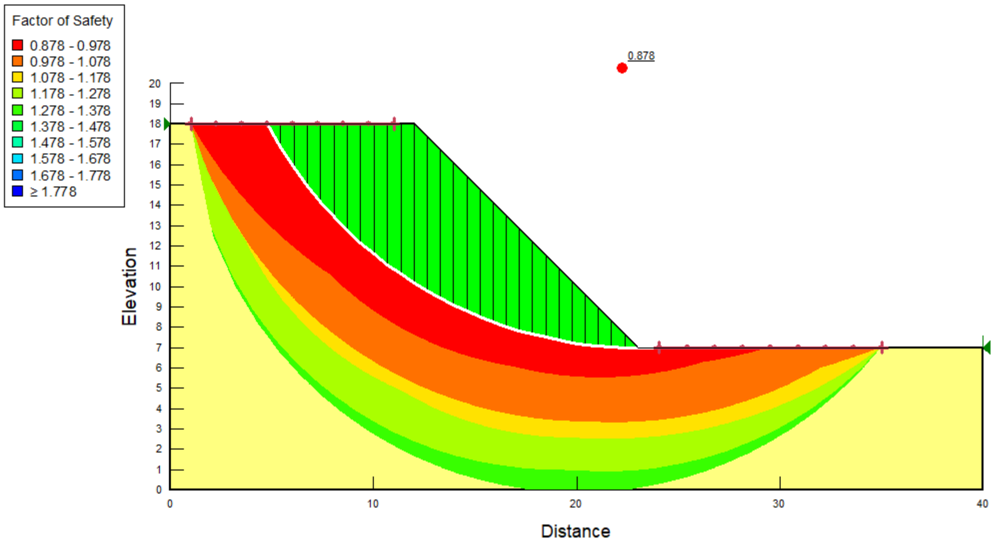

Figure 8: Pseudo Static Analysis for Chichi earthquake

The pseudostatic analysis for the Cape Mendicino earthquake was also done and the factor of safety calculated by Slope/W is 0.96.

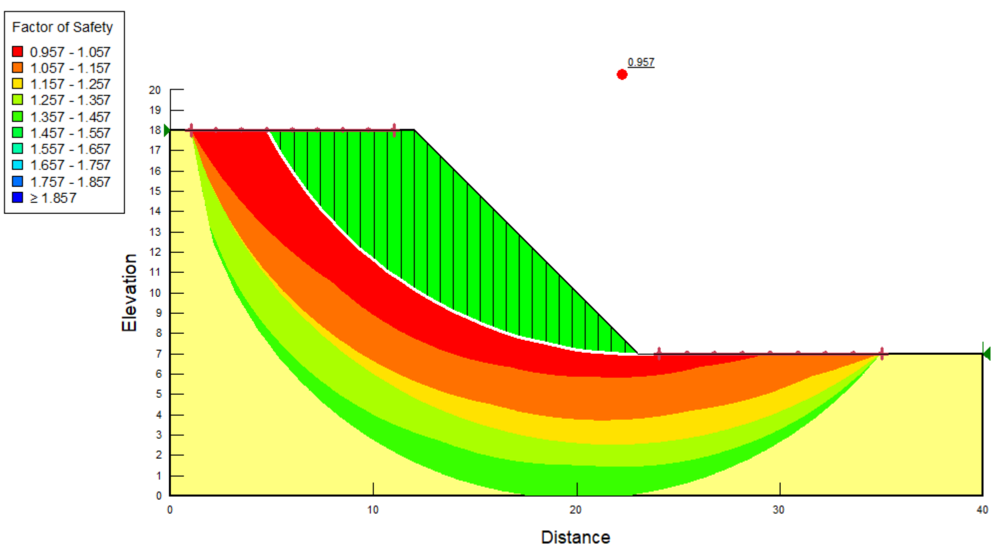

Figure 9: Pseudo Static Analysis for Cape Mendicino earthquake