REINFORCED EARTH WALLS WITHSTANDING NORTHRIDGE EARTHQUAKE

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ABSTRACT: The Northridge Earthquake occurred near Los Angeles, California in January 1994 causing severe damage and collapse of significant highway and commercial structures. There are 23 Reinforced Earth structures within the affected area of the earthquake. There was no structural damage to any of these walls and only one was found to have minor concrete spalling.

1 BACKGROUND

The 6.7 Richter magnitude Northridge Earthquake which occurred on January 17, 1994, caused severe structural damage to buildings and freeways. The earthquake occurred in the densely populated San Fernando Valley in Northridge, California, 20 miles northwest of downtown Los Angeles. The earthquake was responsible for 621 deaths, 9,000 injuries and $30 billion in damages and is reported as one of the costliest natural disasters in U.S. history.

The Northridge earthquake generated the highest vertical ground accelerations ever recorded in California. Ground accelerations were recorded as high as 1.82 g horizontal and 1.18 g vertical 3 miles from the epicenter. The extensive structural damage included the collapse of 6 major freeway bridges, 18 parking buildings with garages and carports on the first floor.

A review of the Reinforced Earth structures near the epicenter of the earthquake was conducted by engineers from The Reinforced Earth Company. Many of these structures are owned by the California Department of Transportation (CalTrans) and were also reviewed by CalTrans officials. A total of 23 Reinforced Earth structures are located within the affected area of the Northridge Earthquake.

2 PERFORMANCE OF REINFORCED EARTH STRUCTURES

The structures include 21 Reinforced Earth walls supporting the Los Angeles Metrolink Rail Line, CalTrans mountain highways, freeways and on/off ramps, city streets in San Pedro and Los Angeles, Chevron refinery oil storage tanks, a housing development in Los Angeles and 2 Reinforced Earth bridge abutments in Corona. One of the walls is the first Reinforced Earth structure constructed in the United States in 1972. The distance of the Reinforced Earth structures from the quake epicenter range from 8 to 52 miles. Three Reinforced Earth structures are located less than 9 miles from the epicenter. In this area, ground accelerations ranged from 0.46 to 0.66 g horizontal and from 0.18 to 0.29 g vertical as shown in Figure 1. Regardless of wall locations, all structures have performed as intended and are structurally sound and intact.

Only one wall, Lyons Avenue shown in Figure 2, located 10 miles from the epicenter in Valencia, suffered superficial damage to the bottom facing panels. The Lyons Avenue wall supports the southbound exit ramp from Interstate 5 and is located 10 miles North of the epicenter. This area suffered major structural damage including the collapse of nearby freeway bridges on the Interstate 5 at Bull Creek, 1 mile south of the wall (see Figure 3) and the Antelope Valley Interchange, 13.5 miles south of the wall. Superficial damage (spalling) occurred in some of the lowermost panels as shown in Figure 4. The panels are 1.5 m x 1.5m width, 14 cm thickness and consist of 28 MPa (4000 psi) reinforced concrete. The two 2 cm thick EDPM Rubber Bearing Pads located between the panels appeared to be flattened at the spalled panels. Ground accelerations, recorded, ranging from 0.63 to 0.91 g horizontal and 0.35 to 0.62 g vertical, were high enough to cause the wall to move up and down. It appears that since movement of the lower panels was restricted by embedment, the second row of panels literally “bounced” against the top of the lower panels causing the spalling. Although enough movement occurred to cause spalling in some panels, the wall panels remain in alignment. The building next to the wall suffered severe structural damage and was posted “Unsafe” to enter after the earthquake.

3 SEISMIC DESIGN

3.1 External Stability

External stability computations are made by considering in addition to static forces, the horizontal inertia force, P_{IR} of the effective reinforced soil mass acting simultaneously with fifty (50) percent of the dynamic horizontal thrust, P_{AE}, and is determined using the pseudo-static Mononabe-Okabe method. One-half of the resultant (0.5 P_{AE}) is applied to the back surface of the effective reinforced soil mass at a height equal to 0.6 times the height of the back surface of the effective soil mass, H_2. The inertia force, P_{IR},is applied simultaneously at a height concentric with the centroid of the effective reinforced soil mass. For a vertical wall with a horizontal backfill and a retained soil having an angle of internal friction of 30°, a free field acceleration, A, of 0.4g, the values of A_m (the average maximum horizontal acceleration), P_{IR} (the inertia of the effective reinforced soil mass) and P_{AE} (the dynamic horizontal thrust) may be determined by the following equations:

$$A_m = (1.45-A)A \qquad \text{(equation 3.1)}$$
$$P_{IR} = 0.5\, A_m\, H^2 \qquad \text{(equation 3.2)}$$
$$P_{AE} = 0.375\, A_m\, H^2 \qquad \text{(equation 3.3)}$$

For other accelerations and for soils with shear strength other than 30°, the Mononabe-Okabe equations must be used to determine P_{AE}.

For structures with sloping backfills, the inertia force, P_{IR}, is based on an effective reinforced soil mass having a height, H_2, and a base width equal to $0.5H_2$ determined as follows:

$$H_2 = H \frac{\tan \; x \; 0.5H}{1 - 0.5 \tan} \qquad \text{(Equation 3.4)}$$

Under combined static and dynamic loads, factors of safety against sliding and overturning may be reduced to seventy-five (75) percent of the factors of safety customary for static only conditions.

3.2 Internal Stability

The earth reinforcements are designed to withstand, in addition to static forces, the horizontal dynamic forces generated by the inertia of the soil being retained by the earth reinforcements.

The inertia force, Pi, per unit length of wall, is equal to the force generated by the inertia of the soil between the actual line of maximum tension and the facing. This equates to two-thirds (2/3) of the weight of soil within the idealized active zone envelope shown in figure 3.2, multiplied by the average maximum horizontal acceleration A_m.

For a wall with level top conditions, and reinforced with discrete linear metallic reinforcing strips, the inertia force, P_p per unit length of structure has been confirmed by F.E.M. modeling to be less than or equal to the following:

$$P_i = 0.15\, H^2 A_m \qquad \text{(Equation 3.5)}$$

The inertia force, P_p is distributed to the reinforcements proportionally to the available resistance of the reinforcements at each level within the structure.

For the seismic loading condition, the pullout resistance of the earth reinforcements is conservatively taken as (80) percent of the resistance used for the static only condition in recognition that vertical accelerations during a seismic event can reduce pullout resistance by up to twenty (20) percent when accelerations are as high as 0.4g.

Factors of safety against pullout and rupture of the earth reinforcements, under combined static and seismic loads, may be reduced to seventy-five (75) percent of the factors of safety required for static only conditions.

Generally, traffic surcharge is omitted from the determination of static and seismic loads.

4 Conclusion

The performance of Reinforced Earth structures in seismic events can be attributed to many factors. Reinforced Earth is flexible, allowing significant differential movement to occur within the reinforced mass without risking the integrity of the wall or its supporting structure. The Reinforced Earth granular backfill serves as an excellent damping medium. Panel joints are open allowing pore pressures (if any) to dissipate. The strength and flexibility inherent in Reinforced Earth structures allows the structures to withstand seismic events many times greater than 6.7 Richter magnitude Northridge earthquake.

REFERENCES

California Division of Mines and Geology-Office of Strong Motion Studies, 1994. *Quick Report on CSMIP Strong-Motion Records from the January 17, 1994 Northridge Earthquake.*

Civil Engineering, March, 1994. *Northridge Earthquake*.

SEISMIC ACCELERATIONS - NORTHRIDGE EARTHQUAKE

REINFORCED EARTH PROJECTS	DISTANCE FROM EPICENTER (MILES)	ESTIMATED GROUND ACCELERATION	
		HORZ	VERT
Lyons Avenue Wall	10	.63-.91	.34-.62
Calabasas Wall	8	.46-.66	.18-.29
Berkeley Hall School Wall	8	.46-.66	.18-.29
Mountaingate Subdivision Wall	9	.46-.66	.18-.29
Metro Green Line Walls	23	.13	.04
San Diego Freeway Wall	23	.13	.04
Chevron Refinery Wall	22	.13	.04
I-110 Walls in Wilmington	32	.12-.25	.06-.08
Cabrillo Beach Wall	36	.11-.25	.07-.08
I-605 Wall in Norwalk	32	.23	.14
Crestview Bridge Abutments	52	.12	.03
Angeles Crest Highway Wall	20	.23-.35	.11-.15
Route 39 Wall	38	.07-.15	.04-.07

Figure 1. Northridge Earthquake Seismic Accelerations (California Division of Mines and Geology, 1994)