PERFORMANCE OF THE PLATEAS WINGWALL DURING THE 1981 EARTHQUAKES IN GREECE

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SUMMARY

This study presents the findings on the type and magnitude of the movement experienced by an earth retaining structure during the February and March, 1981, earthquakes in Greece. The facility under investigation involves a concrete wingwall adjacent to a massive bridge located near the town of Plateas, only two miles from the main ground rupture. The geometry and material conditions are described and measured wall movements are given along a characteristic cross-section of the wall. An analytical procedure capable of predicting magnitudes of movements is applied and the results are compared with actual observations.

INTRODUCTION

The concrete wingwall under examination is a part of a highway bridge and a torrent draining facility located about 1 km east of the Town of Plateas and about 55 km northwest of Athens, Greece. In Fig. 1 is shown a plan view of the facility with the wingwall corresponding to the shaded section. Figs. 2 and 3 show schematically the cross-sections of the wall at locations B-B and C-C (Fig. 1), respectively. From Figs. 2 and 3, it is seen that the backfill has an inclination with the horizontal varying from 0° (at B-B) to 7° (at C-C) and that the ground surface is located at an average distance of 0.40 m (1.31 ft.) from the wall crest.

The February-March 1981 seismic activity caused severe damage to buildings and other facilities in or near the Town of Plateas (Ref. 1). In Table 1 are listed the dates of the principal shocks, the local intensities (in MMI scale), the surface magnitudes (in Richter scale) and the values of the horizontal ground accelerations. The latter were estimated with the aid of the Gutenberg and Richter (Ref. 2) empirical formula $\log A_h = I/3 - 0.5$, in which I is the MM Intensity and A_h is measured in cm/sec^2.

WALL PERFORMANCE PRIOR TO THE EARTHQUAKES

After the construction of the facility and prior to the seismic events, a vertical crack had developed in the wingwall near its connection with the bridge (point F, Fig. 4). The two structures, though separated by the crack, exhibited no visible transverse movement. The average width of the crack was 2.01 cm (0.79 in.), a value sufficiently large to render the wingwall (segment FG, Fig. 4), independent of the rest of the facility. Thus, the wingwall

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could behave as a gravity-type retaining wall in contact with the backfill material. A settlement of the backfill material that occurred at a later time varied along the wall, as shown in Fig. 4, with a maximum value of 0.35 m (1.15 ft.).

The cause of the preceding failure can be attributed to inadequate structural design of the facility at the critical section. It is postulated that the bending moment and shear forces produced by the load of the backfill soil (composed primarily of coarse-grained material with a small admixture of silt) exceeded the structural capacity of the concrete wingwall at the vicinity of its joint with the rest of the facility. Another contributing factor may be the excessive settlement of the embankment overlying the backfill that produced a further increase in the magnitude of the load against the wall.

WALL PERFORMANCE DURING THE EARTHQUAKES

The seismic activity resulted in a movement of the wall relatively to the much more massive adjacent structure. In Fig. 5 is shown the cross-section of the wall at the location of the crack and the mangitude of the movement that occurred during the ground shaking. At the ground level, the wall moved outwards a horizontal distance equal to 8 cm (0.26 ft.) while the outward movement of the top of the wall was 15 cm (0.49 ft.).

According to the Greek Aseismic Code, the seismicity of the site of the wall is characterized as Type II and the corresponding value of the horizontal seismic coefficient k_h to be used for design purposes depends on the quality of the soil medium. Three types of soil "qualities" are distinguished, namely: Quality I, for "soil with small seismic hazard"; Quality II, for "soil with intermediate seismic hazard"; and Quality III, for "soil with high seismic hazard". The suggested values of k_h for the three soil types are given in Table 2. Because the design details of the facility are not known to the authors, all three values of k_h are considered in the subsequent analysis.

A back-calculation of the permanent horizontal displacement (d_p) of the wall is performed using a semi-empirical formula (Ref. 3) expressed in the form

$$d_p = 0.087 \frac{v^2}{A_h} \left(\frac{k_h}{a_h}\right)^{-4} \tag{1}$$

in which d_p is measured in inches, A_h ($=a_h \cdot g$) is the maximum horizontal acceleration due to the earthquake in in/sec^2, v is the corresponding maximum horizontal velocity in in/sec, g is the acceleration of gravity, and k_h is the design horizontal seismic coefficient in g's. The value of the horizontal velocity v is approximated by the following expression:

$$v \simeq \frac{a_h \cdot g \cdot T}{2\pi} \tag{2}$$

in which T is the predominant period in sec. Combining Eqs. (1) and (2), one has

$$d_p \simeq 0.087 \frac{a_h \cdot g \cdot T^2}{4\pi^2} \left(\frac{k_h}{a_h}\right)^{-4} \tag{3}$$

On the basis of the locations of the epicenters and the intensities in the region of the facility, it was considered that only the first and the third of the principal shocks (Table 1) contributed to the wall movement. The estimated values for the predominant periods of these two shocks are $T_1 = 0.3$ sec and $T_2 = 0.55$ sec, respectively.

The resulting values of the permanent displacement d_p are given in Table 3. These were determined for each design value of k_h appearing in the Greek Aseismic Code. From Table 3, it is seen that the total displacement predicted for the case where $k_h = 0.08$ g is approximately equal to the observed value $d_p = 0.08$ m (0.28 ft.) shown in Fig. 5.

DISCUSSION AND CONCLUSIONS

Documented studies of the performance of earth retaining structures during earthquakes are rare. Yet, failures of such structures are common and costly occurrences. This study presented the actual movement experienced by a wingwall during a seismic sequence, characteristic parameters of the seismic activity, and the design values of the seismic coefficient. This information was obtained by the authors during detailed investigations at the sites affected by the February-March, 1981, earthqueks in Greece.

Moreover, an empirical formula was used to back-calculate the permanent horizontal displacement of the wall. The resulted value was found to be in close agreement with the measured displacement for a seismic coefficient $k = 0.08$ g (in accordance with the Greek Aseismic Code). On the basis of the obtained results, it is concluded that, when enough information is available to quantify the parameters entering the empirical formula, the latter can provide reasonable estimates for the permanent horizontal movement of rigid earth retaining walls.

ACKNOWLEDGEMENT

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TABLE 1

CHARACTERISTICS OF THE SEISMIC ACTIVITY

DATE	LOCAL MMI	EPICENTRAL MAGNITUDE (in Richter's Scale)	A_h (cm/sec^2)	α_h (in g's)
2/24/1981	7	6.6	68.13	0.07
2/25/1981	6	6.3	31.62	0.03
3/4/1981	8.5	6.2	215.44	0.22

TABLE 2

DESIGN SEISMIC COEFFICIENTS SUGGESTED BY THE GREEK ASEISMIC CODE (in g's)

	TYPE OF SOIL		
Soil Quality	Small Seismic Hazard I	Intermediate Seismic Hazard II	High Seismic Hazard III
Coefficient k_h	0.06	0.08	0.12

TABLE 3

TOTAL HORIZONTAL PERMANENT DISPLACEMENT OF THE WALL

DESIGN SEISMIC COEFFICIENT IN GREEK ASEISMIC CODE	HORIZONTAL DISPLACEMENT		
	1st EARTHQUAKE (T_1=0.3 sec, α_{h_1}=0.07g)	2ND EARTHQUAKE (T_2=0.55 sec, α_{h_2}=0.22g)	TOTAL
k_{h_1} = 0.06 g	0.0099 in d_{11} = (2.51×10^{-4} m)	10.22 in d_{12} = (0.2596 m)	0.8525 ft d_{p1} = (0.2598 m)
k_{h_2} = 0.08 g	0.0031 in d_{21} = (7.87×10^{-5} m)	3.2337 in d_{22} = (0.0821 m)	0.2697 ft d_{p2} = (0.0822 m)
k_{h_3} = 0.12 g	0.006 in d_{31} = (1.52×10^{-4} m)	0.6388 in d_{32} (0.0162 m)	0.0537 ft d_{p3} = (0.0164 m)

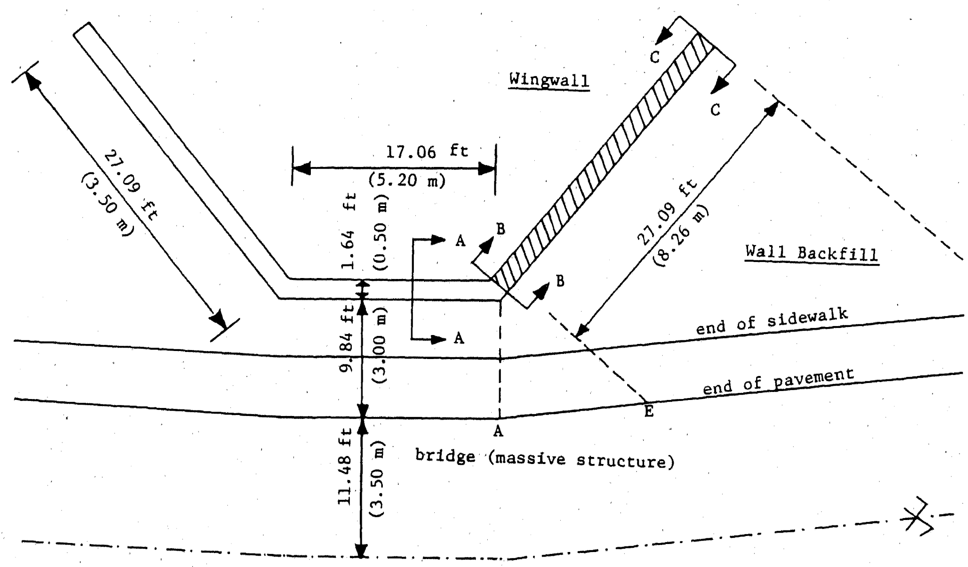

FIG. 1 PLAN VIEW OF THE WINGWALL AND ADJACENT STRUCTURES

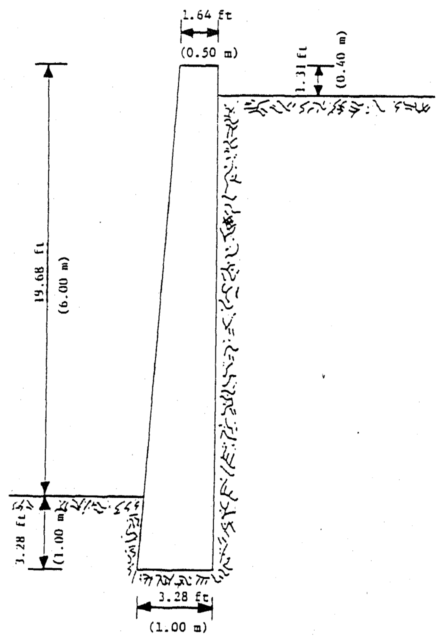

FIG. 2 CROSS-SECTION OF WINGWALL AT LOCATION B-B (from Fig. 1)

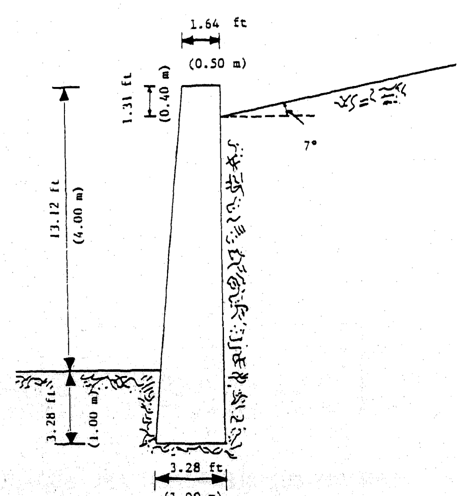

FIG. 3 CROSS-SECTION OF WINGWALL AT LOCATION C-C (from Fig. 1)

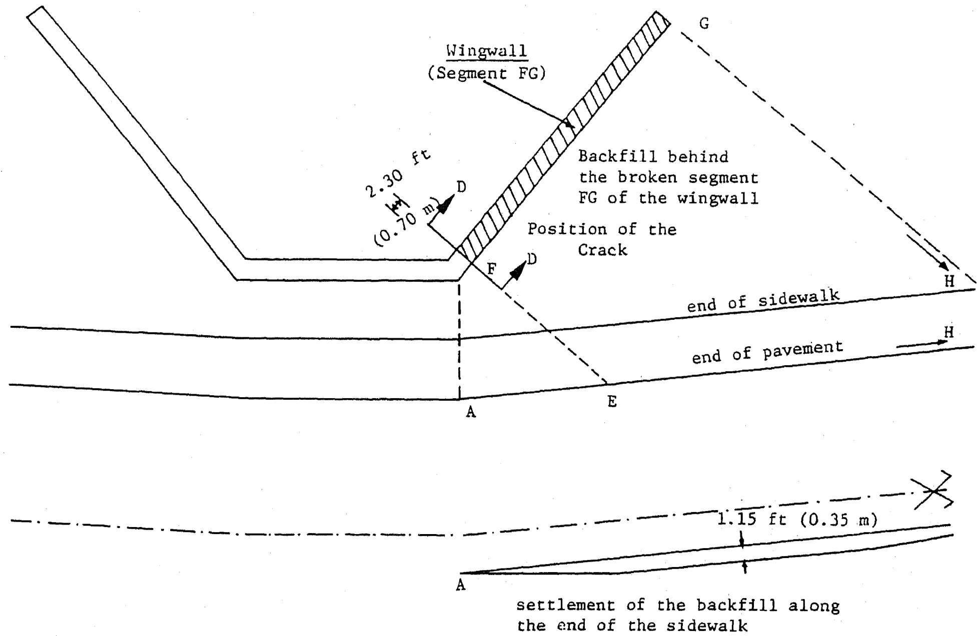

FIG. 4 PLAN VIEW OF THE WINGWALL ILLUSTRATING THE POSITION OF THE CRACK AND THE DISTRIBUTION OF THE SETTLEMENT OF THE BACKFILL

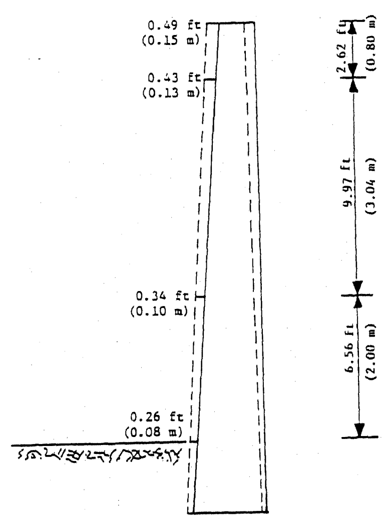

FIG. 5 CROSS-SECTION OF THE WINGWALL AT LOCATION D-D AND THE REALIZED MOVEMENT DUE TO THE EARTHQUAKE