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A note on double-sided reinforced earth model walls

Quelques résultats sur le comportement de modèles réduits de murs à double parement

RESUME

Les résultats de tests sur des modèles de murs a double parement en terre armée sont présentés. Les armatures furent fixées au parement a une extremité seulement afin de provoquer une rupture par défaut d'adhérence plutôt que par cassure des armatures. Soumis à des mouvements du type tremblement de terre, les murs présentèrent des déformations plutôt qu'un effondrement catastrophique. Dans différent essais, des modes de rupture simple ou double furent observés. En général, les murs à double parement présentèrent des caractèristiques semblables à celles des murs à simple parement. A cause de l'interaction des armatures alternées, une légère amélioration de la stabilité fut observée pour les murs à double face. Cependent, il est conseillé à ce stade d'utiliser les méthodes conventionelles, développées pour les structures en terre armée standard, lors du dimensionnement des murs à double parement.

INTRODUCTION

Most standard reinforced earth retaining walls are single-sided: one end of the reinforcing strips is attached to a face element while the other end lies freely in the backfill (Figure 1a).

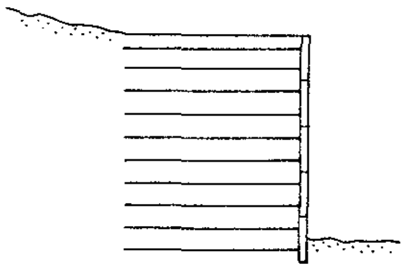
Double-sided reinforced earth walls have potential application in the construction of access ramps, in bulk material handling areas and as protective structures around liquid storage tanks.

The 15m high wall built in 1970 at Dunkirk has 20m long reinforcing strips attached at either end to steel face panels (Schlosser and Long, 1975) as schematically shown in Figure 1b.

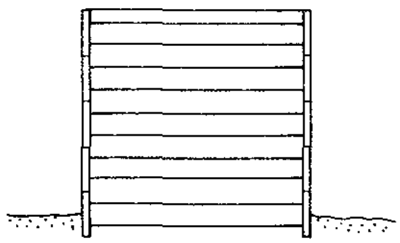
This paper describes experiments on double-sided reinforced earth model walls where the reinforcing strips are attached to the face panels at one end only (Figure 1c). These double-sided walls were subjected to simulated earthquake motions in an effort to determine the feasibility of such structures for civil engineering projects in seismically active areas of the world.

Earlier research at UCLA (Richardson and Lee, 1975) clearly showed two typical modes of failure when single-sided reinforced earth model walls were subjected to dynamic forces on a shaking table: Failure by rupture of the reinforcement and failure by slippage between the reinforcement and the soil, also referred to as "tie breakage" and "tie pullout". In these experiments it was noticed that when failure occurred by breakage of the reinforcing strips, it was catastrophic, resulting in a rapid and complete loss of wall integrity. On the other hand, when failure occurred as the result of insufficient friction between the backfill and the reinforcement, the wall structure deformed rather than collapsed during the dynamic test. A wall which was stable before applying a temporary seismic load remained stable after the shaking ceased.

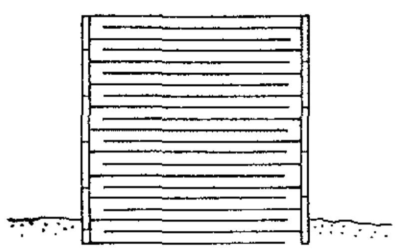
Recognizing the desirability for a structure to deform rather than collapse, the tests conducted in this study were designed to produce failure by slippage rather than rupture of the reinforcement. The reinforcing strips were made strong enough not to rupture during the test and were attached to the face panels at one end only, leaving the other end free in the sand backfill. Using this construction technique reinforcing strips attached to opposite faces overlap; but as none of the ties were in contact with each other, any slippage occurred within the soil backfill.



a. Single-sided (standard) wall.



b. Double-sided wall, strips attached at both ends.



c. Double-sided walls, strips attached at one end only.

FIGURE 1 : TYPES OF REINFORCED EARTH WALLS.

DESCRIPTION OF MODEL TESTS

The experiments described were carried out as a minor part of a comprehensive series of tests on reinforced earth model walls performed on the shaking table at the Richmond Field Station, University of California, Berkeley. This table is capable of applying an earthquake type motion in both the vertical and one horizontal direction through the use of an electronically controlled hydraulic jack system, with peak accelerations up to ±1g (acceleration of gravity).

The model walls were 300mm high, 800mm long and 300mm from face to face. Uniform fine, dry quartz sand with a mean grain size of 0.19mm served as backfill. It was placed by raining it from a spreader box kept 460mm above the surface of the sand. This procedure resulted in a uniformly dense backfill with a unit weight of 16.2 kN/m^3, corresponding to a relative density of about 80%.

The reinforcement consisted of strips of smooth mylar tape, 13 mm wide, approximately 0.025 mm thick, cut to lengths which varied from test to test. Five mylar strips were attached to plexiglass panels on either side of the walls. These panels were 76 mm high, equivalent to the vertical spacing of the reinforcement. The length of the face panels was equal to the width of the box. The use of long face elements made it easier to monitor the behaviour of the wall. Previous tests conducted at UCLA did not indicate significant differences in the behaviour of walls built with long plexiglass panels and walls with many individual face elements, each measuring 76mm x 76mm.

The instrumentation included accelerometers to measure the motions of the table and that of the surface of the backfill, both in horizontal and vertical directions. LVDT's were used to monitor the displacement of the top of each wall face relative to its base. Load transducers measured the tie forces at the point of attachment. Readings from each instrument were recorded digitally onto magnetic tape. In addition, selected channels were recorded continuously on a CRT recorder.

The input table motion used in the tests was a simulation of the July, 1952, Kern County Earthquake as recorded at Taft High School. The actual earthquake time histories were modified for use with the small reinforced earth models. The primary modification made to the original records was to increase the level of excitation to achieve peak table accelerations of 0.5g horizontally and 0.35g vertically; this was necessary in order to produce measurable wall deformation. Secondly, the frequency content of the motion was altered by decreasing the time interval between points on the digitized time history by a factor of $\sqrt{12} = 3.5$ as the model walls were intended to represent larger field walls. The frequency content of these modified Taft traces is shown in Figure 2 as 2% critically damped acceleration response spectra curves.

It is apparent from Figure 2 that the predominant frequencies for these two scaled records are in the range of 8 to 14 Hz, whereas the low strain fundamental frequency of the wall is in the range of 30 to 35 Hz. However, since double-sided reinforced earth walls such as tested in this study are essentially columns of soil, they could be expected to behave as strain softening systems. Therefore under significant base excitation the strained natural frequencies should approach the region of dominant input frequencies.

RESPONSE OF MODEL WALLS TO EARTHQUAKE SHAKING.

Due to the limited number of tests carried out, it was not attempted to quantitatively evaluate the behaviour of double-sided walls in form of an independent study. Emphasis was placed on comparing the results presented here with those of a much wider parallel study of the response of single-sided walls to earthquake motion. In addition, special attention was given to observe and record characteristic wall deformation and failure patterns.

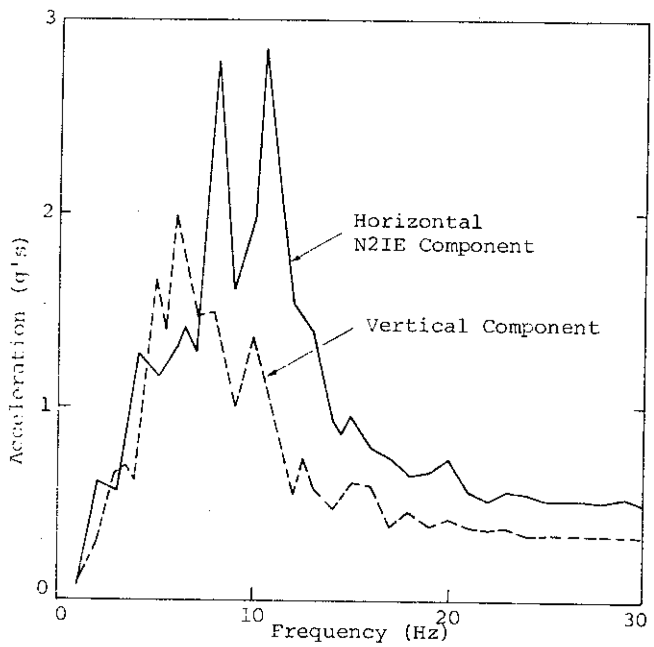


FIGURE 2 : TABLE MOTION RESPONSE SPECTRA (2% DAMPING)

In tests where the shaking table was only allowed to move in vertical direction, virtually no cyclic non-permanent outward movement of the wall could be observed and no significant increase in measured tie forces occurred. A similar finding was previously reported by Wolfe et al (1978) who concluded that for single-sided walls the effect of the vertical component was sufficiently small that it could be safely neglected in seismic stability considerations.

In contrast to the response to a simple vertical input acceleration time history, the application of a base motion in the horizontal direction caused significant wall movement as well as a considerable increase in the tie forces measured at the wall faces. Test results clearly showed that simple horizontal input motion was much more effective in producing deformations than vertical motion only. However it was decided to evaluate the performance of the model walls during multi-directional loading which more satisfactorily simulates actual earthquake motions than does either horizontal and vertical shaking alone.

Typical records of the time histories for bi-directional acceleration and some resulting response data are shown in Figures 3 and 4.

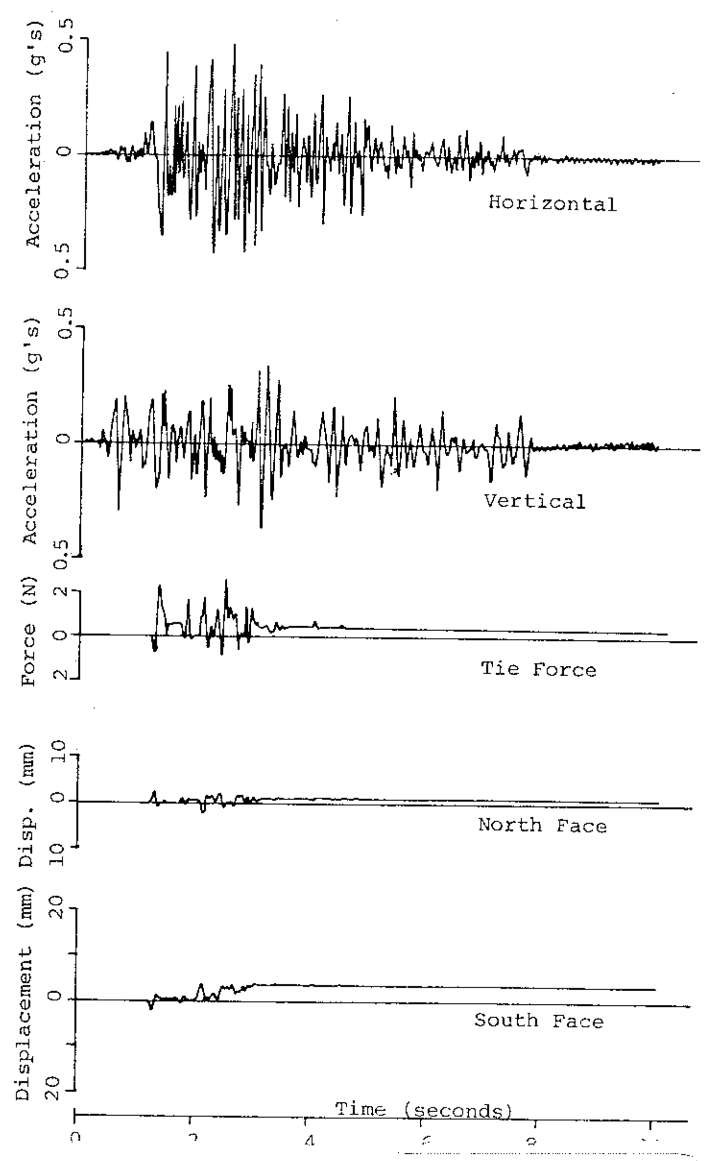


FIGURE 3 : WALL RESPONSE TIME HISTORIES (TEST NO.3)

A striking dissimilarity between single-sided and double-sided walls is the possibility for the latter to fail at either one or both faces. Figure 3 contains records which were obtained at a particular stage of testing of the wall shown in Figure 5 which deformed equally severely on both sides. Figure 4 and Figure 6 illustrate one-sided distortion of a similar model wall. The data obtained so far however is insufficient to determine conclusively what causes either one- or two-sided failure.

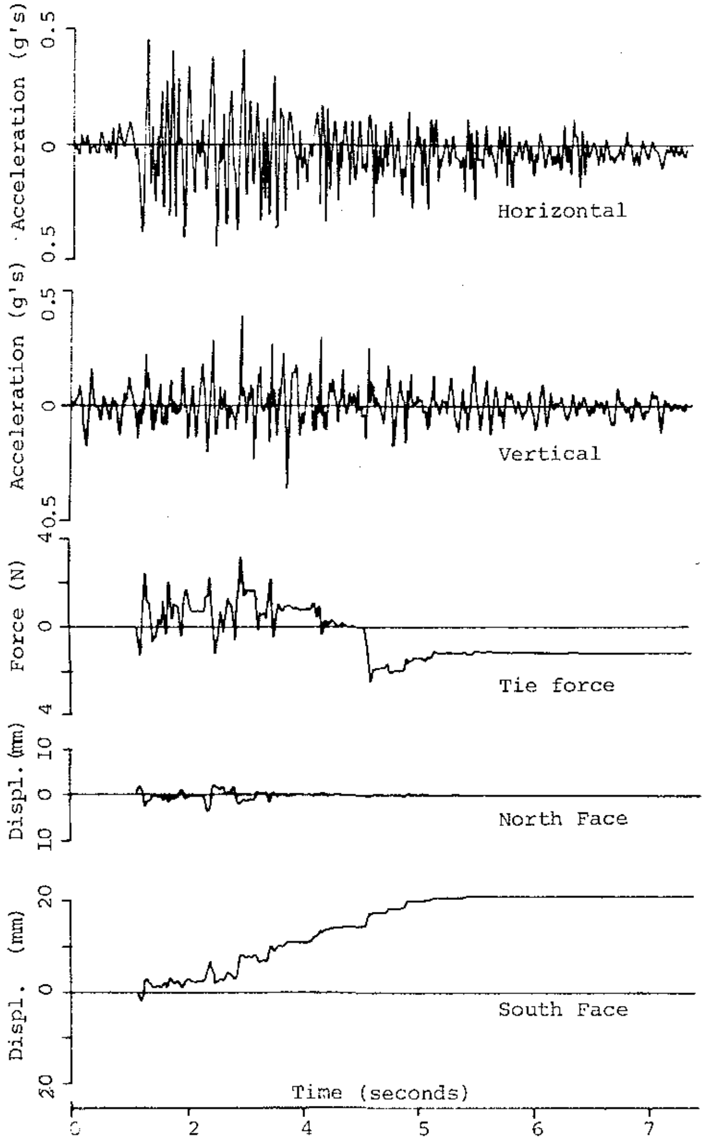


FIGURE 4 : WALL RESPONSE TIME HISTORIES (TEST NO. 6)

From Figures 5 and 6 it can be seen that although the walls were greatly deformed after being subjected to a series of earthquake motions, catastrophic collapse did not occur. This behaviour is consistent with the behaviour observed for single-sided retaining walls subjected to equivalent base motions.

The inclinations of the failure planes were found to be similar to those observed in tests of single-sided walls with the same geometry and reinforcement density. This angle was typically slightly less than 45 + $\phi/2$ degrees from the horizontal.

Double-sided walls tended to undergo less deformation under similar base motions than did single-sided walls of the same tie configuration. Although the two sides were not connected to each other, there seemed to be some interaction between reinforcing strips connected to opposite faces. This "reinforcing effect" is thought to be similar to that of loose strips placed behind a rigid model wall as discussed by Hausmann and Lee (1978). However, this stabilising effect appeared to be only small in the tests reported here.

FIGURE 5 : DOUBLE-SIDED FAILURE OF MODEL WALL

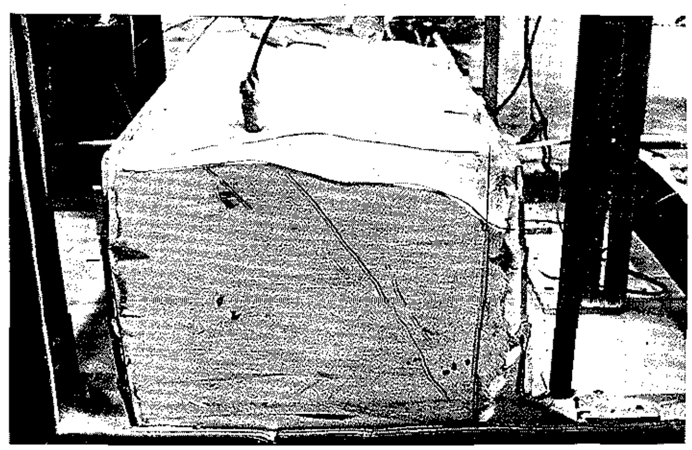


FIGURE 6 : ONE-SIDED FAILURE OF MODEL WALL

SUMMARY AND CONCLUSIONS.

The results of a research project which investigated the behaviour of model reinforced earth walls have been presented. These models have been called double-sided walls because the structures consisted of two vertical faces separated by a single zone of backfill, reinforced with horizontal tension members. The results show that in general the behaviour of the double-sided wall is similar to that of the more conventional single-sided reinforced earth retaining wall. The model walls tested were designed to fail by slippage rather than rupture of the reinforcement. The reinforcing strips were therefore attached to the face panels at one end only. Under earthquake type motion the walls showed deformation rather than sudden collapse. Vertical acceleration had little if any influence on deformation and tie forces, which were both essentially due to the horizontal component of the shaking force. However, some interaction between opposing and overlapping reinforcing strips does take place, resulting in an increase in the observed seismic strength of the double-sided wall as compared to the single-sided wall. This strength increase appears to be only slight and it is suggested that double-sided walls should be designed using conventional methods as developed for standard reinforced earth structures by considering the two halves as separate walls which happen to be in close proximity to one another.

ACKNOWLEDGEMENTS

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