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Geoboard Reduces Lateral Earth Pressures

ABSTRACT

A two level below grade parking garage under a forty story office building adjacent to a low rise retail plaza is nearing completion in Philadelphia, Pennsylvania. A subway is located adjacent to the south property line. The exterior grades at the north are approximately 2.2m (7 ft) higher than those at the south. The difference in elevations and the potential for a future excavation along the subway would result in unbalanced lateral earth pressures at the location of the plaza. It was not feasible to brace the north wall of the garage below the plaza or employ permanent tiebacks. A design was completed to reduce lateral at-rest earth pressures against the north basement wall be mobilizing active lateral earth pressures. Prefabricated, expanded polystyrene bead drainage geoboards were installed against the exterior face of the north basement wall. Compacted backfill was constructed against the 25 cm (10 in) thick drainage geoboards. Load cells and extensometers were installed to monitor the magnitudes of lateral earth pressures and deflections of the drainage boards. This paper presents the design and monitoring system data together with conclusions regarding the performance of the system.

INTRODUCTION

Figure 1 shows the project site which occupies a full city block in the business center of Philadelphia, Pennsylvania. The completed project will consist of a fourth story west office tower, a future forty story East office tower, and a centrally located plaza with one and two story retail areas. Two basement levels will provide parking below the entire site. The nearly completed West office tower is supported on drilled piers socketed in mica schist rock. The garage below the West tower and plaza is completed and supported on drilled piers and spread footings, respectively.

Figure 2 presents a cross-section through the plaza area. The lowest garage floor and the Market Street subway platform are approximately at the same elevation. Market Street grade is 2.2m (7 ft) below JFK boulevard grade. A temporary retention system consisting of soldier beams, wooden lagging, and soil tiebacks protected the north west, and south sides of the approximately 10 m (33ft) deep excavation. A 1.9 m (6 ft) diameter storm sewer was installed along the north wall of the excavation.

SITE engineers, inc. was retained by the owner to provide geotechnical engineering services in connection with design and construction. Figure 3 presents a summary of subsurface conditions based on borings drilled along the north retaining wall.

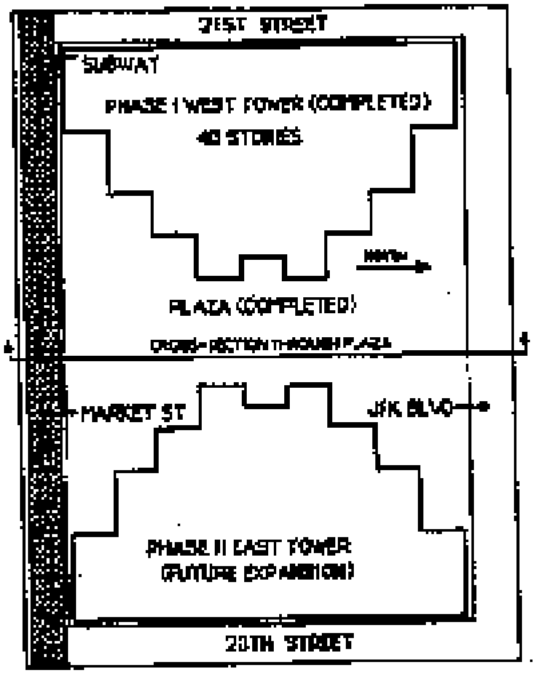

FIG. 1 LOCATION OF COMMERCE SQUARE TWIN TOWERS

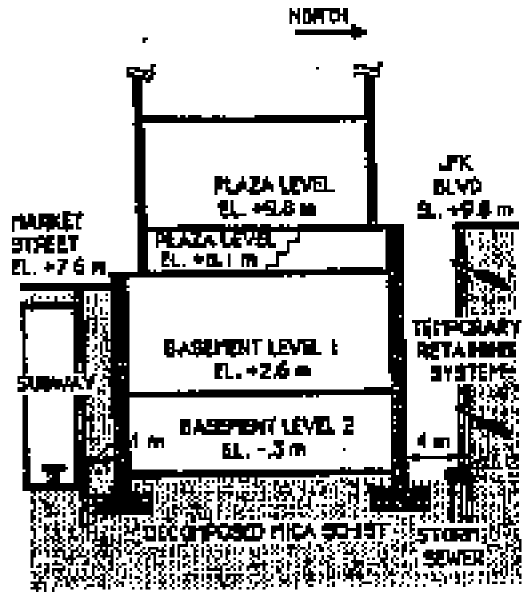

FIG. 2 CROSS SECTION THROUGH PLAZA DURING CONSTRUCTION

PRESENTATION OF PROBLEM

All below grade walls were designed to be non-yielding, braced by floors, and designed for the at-rest earth pressures computed on the basis of the existing soil conditions behind the temporary retention system. The design at-rest earth pressures are shown in Figure 3.

Due to differences in elevations between Market Street and JFK Boulevard, unbalanced lateral earth pressures exist for the length of the plaza as shown in Figure 4. The unbalanced design load computed by the Structural Engineer was on the order of 233 kN/lin m (16 kips/lin ft) of wall.

Further excavation along the Market Street subway for repair or reconstruction could further increase the unbalanced loading conditions, but such additional loading was not considered in the design since maintaining stability would be the responsibility of others.

The Structural Engineer's review disclosed that modification to the light plaza steel frame by providing bracing to the lateral loads was not feasible. Permanent tiebacks anchored under JFK Boulevard could not be considered due to easement problems beyond the JFK Boulevard property line. Therefore, it was necessary to search for methods of reducing the lateral earth pressures against the North wall of the plaza.

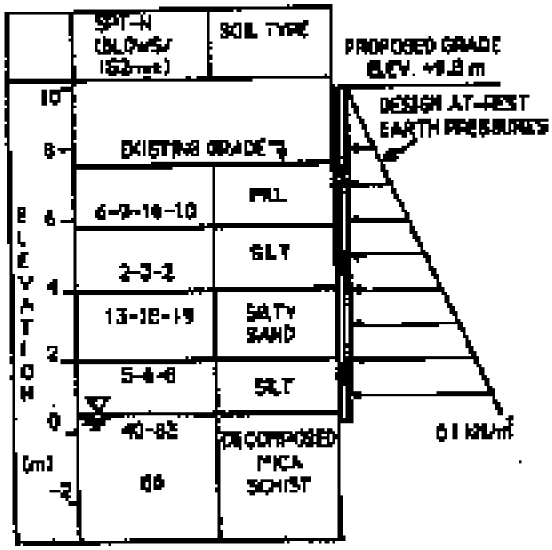

FIG. 3 TEST BORING RESULTS AND DESIGN AT-REST EARTH PRESSURES AT JFK BLVD WALL

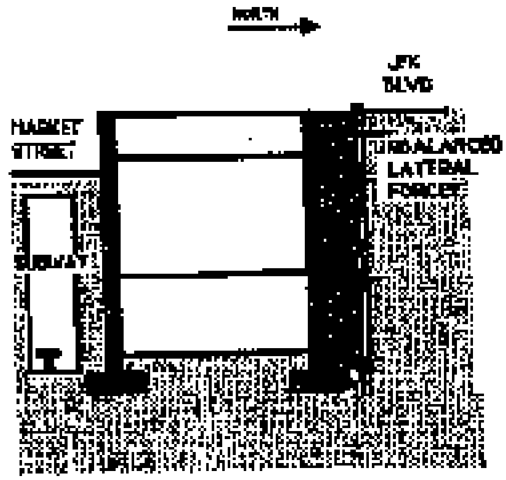

FIG. 4 UNBALANCED LATERAL FORCE AGAINST PLAZA NORTH WALL

METHODS OF REDUCING LATERAL EARTH PRESSURES

Several schemes were considered as listed in Table 1. The relevant functions of each method are also listed.

Table 1: Descriptions of Methods of Reducing Lateral Earth Pressures

	Description of Method	Function
1.	Light Weight Cellular Concrete BAckfill	- Reduction in density - Mobilization of high value of Cohesion
2.	Stabilized Backfill	- Increase of angle of internal friction - Increase of cohesion
3.	Elastic Drainage Board on Face of Wall	- Inducing quasi-active stress - conditions by providing yielding media

After taking into consideration costs, scheduling, etc., the Construction Manager selected the drainage board scheme.

DRAINAGE BOARD DESCRIPTION AND PROPERTIES

The basic use for drainage boards is to provide rapid drainage capability for below grade structures, thus eliminating build-up of hydrostatic pressures against retaining walls, foundations, etc. Most drainage boards consist of rigid, thin "egg crate" like sheets molded from polystyrene. One product, the "Geotech Drainage Board," consists of molded blocks of expanded polystyrene beads bonded together with adhesive compound. It deforms during load application. Application thicknesses vary from 2.5cm (1 in.) to 60 cm (24 in.). This product was selected on the basis of the predictability of stress-strain relationships and the availability of varying thicknesses.

A 3.8 cm (1.5 in.) thick by approximately 15 cm (6 in.) square manufacturer's sample was tested by uniaxial loading in an unconfined condition. The stress-strain relationships are presented in Figure 5.

Testing of two and three samples stacked-up provided results similar to those of the single sample board. The observed modulus of elasticity for the drainage board was approximately 220 kN/m^2 (2.34 tsf) in the load range of 12 kN/m^2 (0.13 tsf) and on the order of 414 kN/m^2 (4.4 tsf) above that load interval. These values are in general agreement with the stress-strain data provided by the manufacturer.

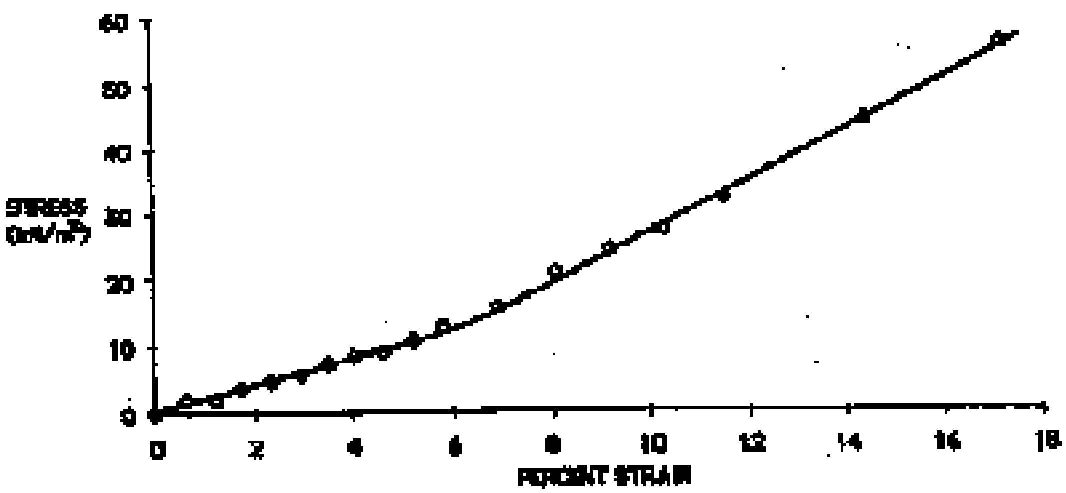

FIG.5 LABORATORY STRESS-STRAIN RELATIONSHIP FOR "GEOTECH" DRAINAGE BOARD

BACKFILL SOIL PROPERTIES AND DESIGN OF DRAINAGE BOARD

The excavated on-site granular materials were proposed as backfill for use the full height of the retaining walls. The physical and engineering properties of the on-site granular soils based on laboratory testing and the anticipated field properties are presented in Table 2.

Table 2: Design Backfill Soil Properties

Soil Description: Well graded sand, some gravel, some silt
USC Classification: SW-GW
Maximum Laboratory Dry Density*: 20 kN/m^3(121 pcf)
Laboratory Void Ratio (e) at Field Density: 0.36
Angle of Internal Friction: 36°
Cohesion (c): 0
Anticipated Average Field in-Place Dry Density: 19 kN/m^3 (121 pcf)
Anticipated Average Field in-Place Moisture Content: 10%
Field Percentage of Maximum Dry Density: 93% to 95%

* (ASTM D698)

A well graded, coarse, very angular crushed aggregate (stone) was specified around the storm sewer line to approximately Elev. 0.9 m (Elev 3 ft). The estimated range of internal friction is on the order of 60°, and the in-place density is approximately 22.8 kN/m^3 (140 pcf).

The drainage board thicknesses was then selected on the basis of the anticipated maximum earth pressure (at-rest condition) as shown in Figure 3, and compression of the board during translational displacement. A translational movement equal to approximately 0.3% of the wall height was estimated to mobilize a quasi-active state condition. (1)

The key design parameters are presented in Table 3.

Table 3: Design of Drainage Board:

Maximum Design Wall Pressure: 61 kN/m^2 (1200 psf)
Maximum Compression of Board: 2.5 cm (1 in.)
Minimum Thickness of Board: 15.2 cm (6 in.)
Selected Thickness of Board: 25.4 cm (10 in.)

The 25.4 cm board thickness was selected to provide a greater margin of safety because of the possibility that over-compression and some damage to the board could occur during backfill operations.

The vertical extent of the board was from approximately Elev. 1.5 m to Elev. 8 m (Elev 5 ft and Elev. 25 ft).

The recommended method of installation required gluing the 1.2 m by 1.2 m by 0.25 m (48 in. by 48 in. by 10 in.) thick panels to the wall in advance of the backfill operations. Since protection of the board was crucial, temporary protection (plywood on exterior face) was also specified, if conditions required.

Backfill specifications required placing fill in 20 cm to 30 cm (8 to 12 in.) thick lifts and compacting with a light duty self propelled vibratory roller, to achieve 93% to 95% of maximum dry density (ASTM D698).

INSTRUMENTATION

As part of the quality control during construction, it was critical to evaluate the behavior of the proposed system in order to assess the validity of the design. To provide data on actual lateral earth pressures against the retaining wall and the magnitude of drainage board compression, instruments were installed in the wall along a near vertical line as shown in Figure 6. The instrumentation consisted of the following:

Stress Monitoring Instruments

Type: Carlson S-25 Soil Stress Meter
Description: Resistance type "interface" stress meter approximately 28 cm (11 in) in diameter, installed in the retaining wall behind the drainage board.
Number of instruments: 3
Pressure Range: 0 to 170 kN/m^2 (0 to 25 psi)
Accuracy: ± 2% of full scale.

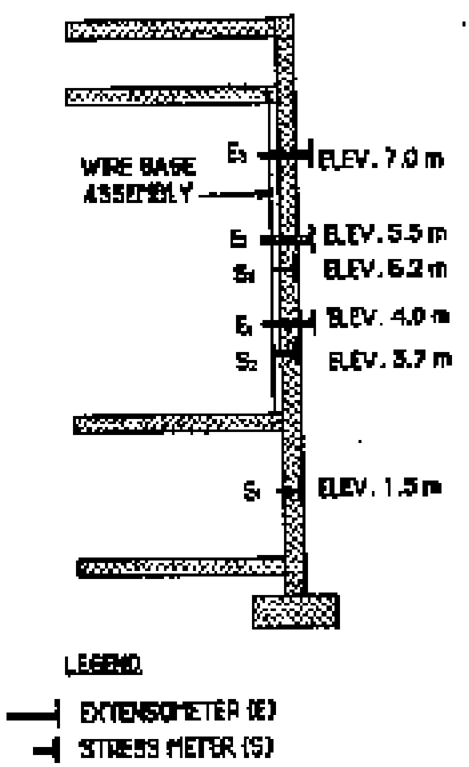

FIG. 6 STRESS METER AND EXTENSOMETER ELEVATIONS ON JFK RETAINING WALL

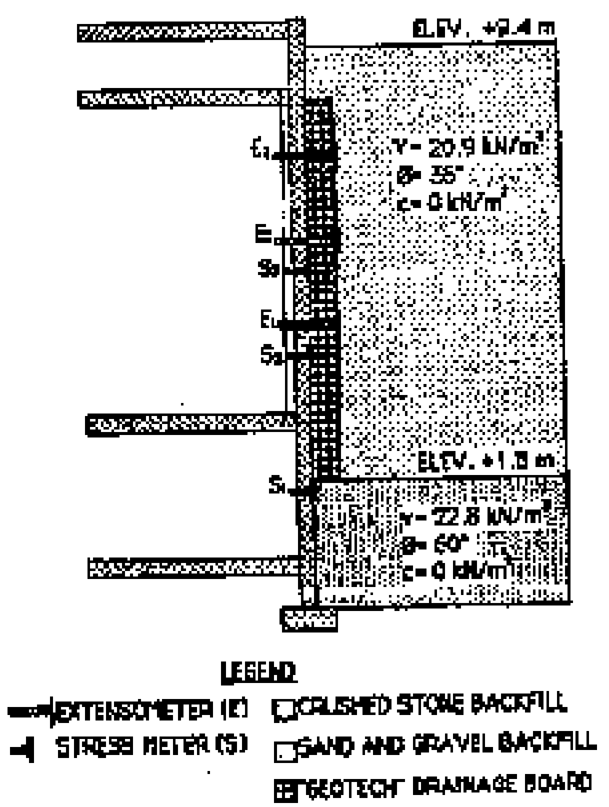

FIG. 7 BACKFILL MATERIALS (AS-BUILT)

Compression (Deflection) Monitoring Instruments

Type: Extensometer

Description: Field fabricated steel plate (.6 m x .6 m) (2 ft by 2 ft) in size, installed on the exterior face of the drainage board. Plate is provided with a steel rod and a scale which projects through a sleeve to the inside of the wall. Movements were read against a wire gauge suspended between floor and ceiling.

Number of Instruments: 3

Accuracy: ± .25 cm (0.1 in)

BACKFILL CONSTRUCTION AND DATA ACQUISITION

An addendum to the specifications was issued covering installation of instrumentation, the drainage board, and the placement and compaction of backfill. The instrumentation became a part of the quality control procedures. Backfill construction was completed in two phases. The initial backfill phase consisted of placement of the crushed stone layer. The contractor elected to backfill the entire width of excavation up to approximately Elev. 1.5 m (5 ft) with crushed stone after the stress meters were installed as shown in Figure 7. The crushed stone fill extended above the lowest stress meter S-1, which had not been anticipated. Installation of the drainage board and backfilling (Phase 2) commenced approximately one month later. Installation of drainage boards and extensometers was done during backfilling with increasing fill heights. Backfill was placed in accordance with the recommended procedures with the exception that protection of the drainage boards with plywood panels was not required. Total densities from 20.3 to 20.98 kN/m^3 (129 to 133 pcf) were measured in the field.

Stress and extensometer readings were obtained daily. Fill placement was completed in approximately two weeks time. Readings were also obtained for a period of four months after completion of the backfill.

Figure 8 presents the relationship between stresses and increasing fill heights at each of the three stress meter locations.

The data from Figure 8 are replotted and presented in Figure 9 to show the relationships between effective net fill heights above meter S-2 and S-3 and the correspond lateral pressures.

Figure 10 shows the relationship between fill elevation and the corresponding compression of the "Geoboard" for each of the extensometers. The computed field stress-strain relationship and the laboratory stress-strain data are shown in Figure 11.

Figure 12 shows the actual measured and theoretical at-rest and active lateral earth pressures for the completed backfill condition.

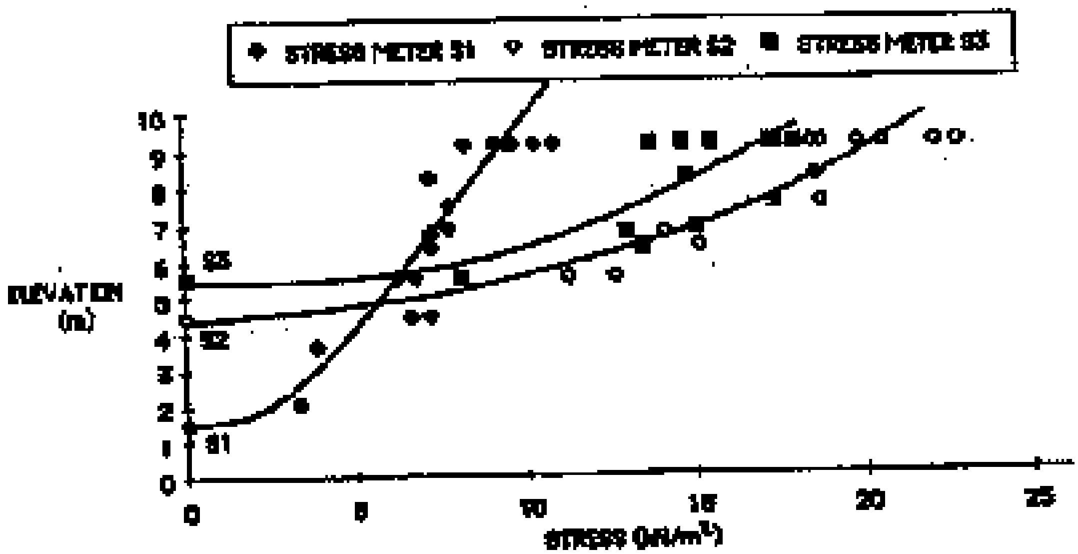

FIG. 8 FILL AND STRESS METER ELEVATIONS AND CORRESPONDING STRESS AT INDIVIDUAL METERS

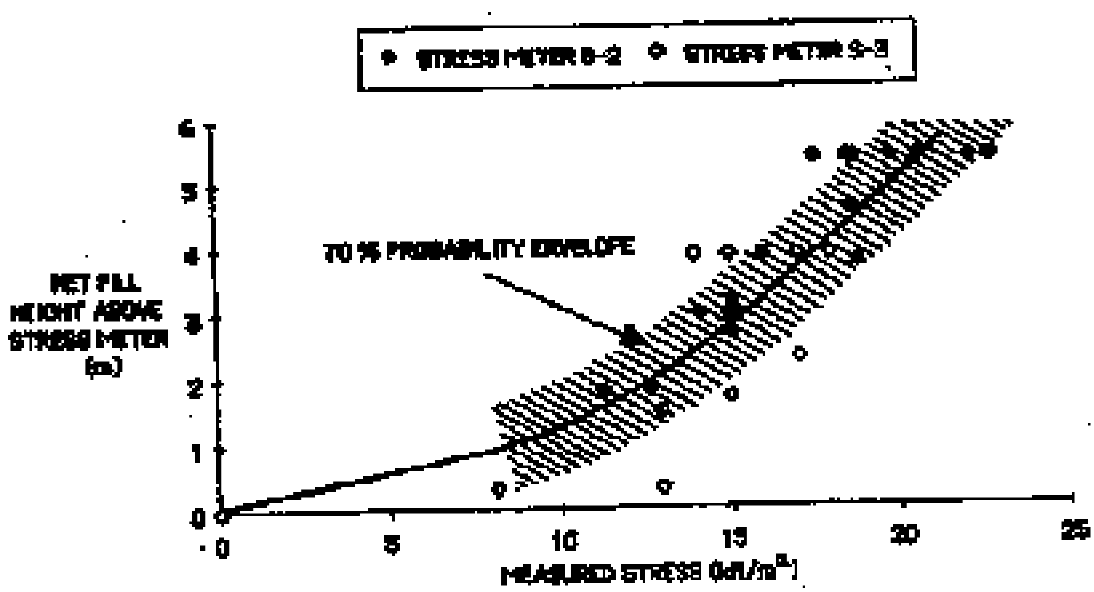

FIG. 9 RELATIONSHIP BETWEEN NET FILL HEIGHT AND STRESS

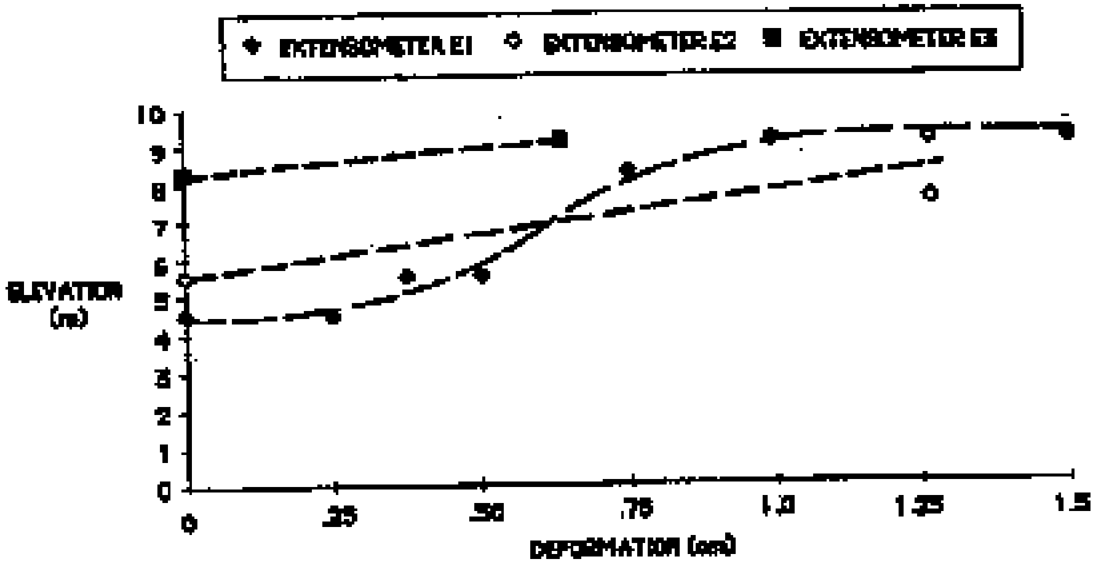

FIG. 10 FILL ELEVATION AND CORRESPONDING DEFORMATION OF "GEOTECH" DRAINAGE BOARD

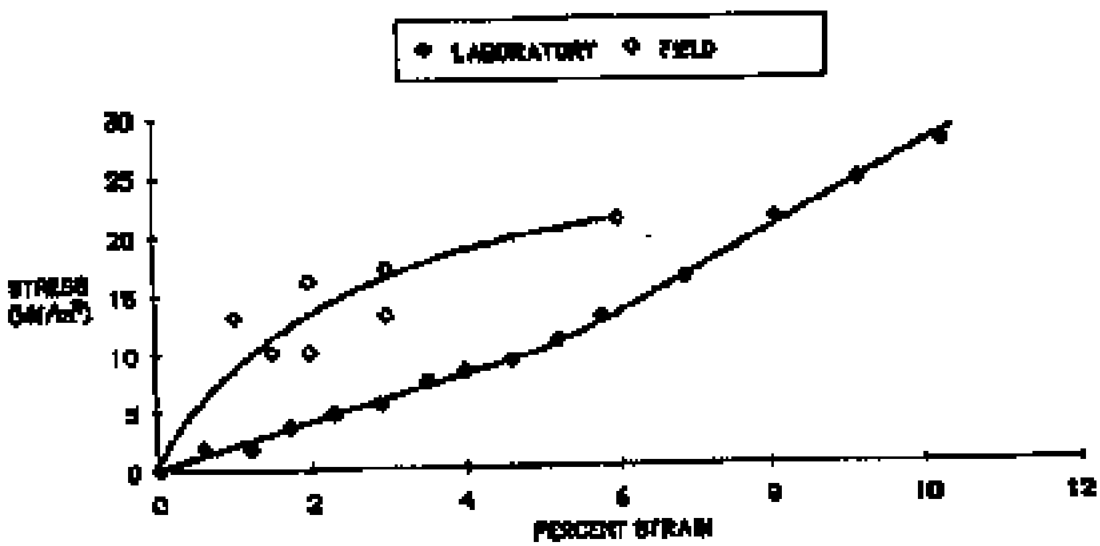

FIG. 11 LABORATORY AND FIELD STRESS-STRAIN RELATIONSHIPS FOR "GEOTECH" DRAINAGE BOARD

DISCUSSION

FIGURE 8

As shown in Figure 7 the stress meter S-1 was embedded in the stone fill. Review of the stress readings with increasing fill heights (Figure 8), indicates that at the location of meter S-1 a stress on the order of 3.5 kN/m^2 (75 pcf) was observed for a fill height of 0.5 m (1.5 ft). With increasing fill heights, a linear relationship of stress vs fill height is indicated by meter S-1. It is observed that at full fill height stress readings gradually increase from approximately 7.0 kN/m^2 (150 psf) to 10.1 kN/m^2 (215 psf) during a period of approximately four months.

Review of the readings for stress meters S-2 and S-3 indicate that they both follow a relatively parallel path. After completion of the full fill height, readings at meter S-2 and S-3 indicate stress values of 20.2 kN/m^2 (430 psf) and 16.9 kN/m^2 (360 psf), respectively. During the first week of fill completion the stress readings decrease by approximately 15%. Over the next month the stresses creep upwards upward until an equilibrium is established. The stress values observed at meters S-3 and S-2 at equilibrium are 17.2 kN/m^2 (365 psf) and 21.9 kN/m^2 (465 psf), respectively. The initial 15% reduction in stresses is due to the deformation of the board and relaxation of the soil mass. The increase of stresses after the initial decrease can be the result of soil readjustment and rain water percolation into the fill.

FIGURE 9

Figure 9 shows the net fill heights above meters S-2 and S-3 vs the observed stress readings. Information from meter S-1 is not included because of the crushed stone backfill behind the meter S-1.

A median curve plotted through the data points does not show a linear relationship but rather an exponential trend. A probability envelope of 70% was evaluated and is also shown on Figure 9.

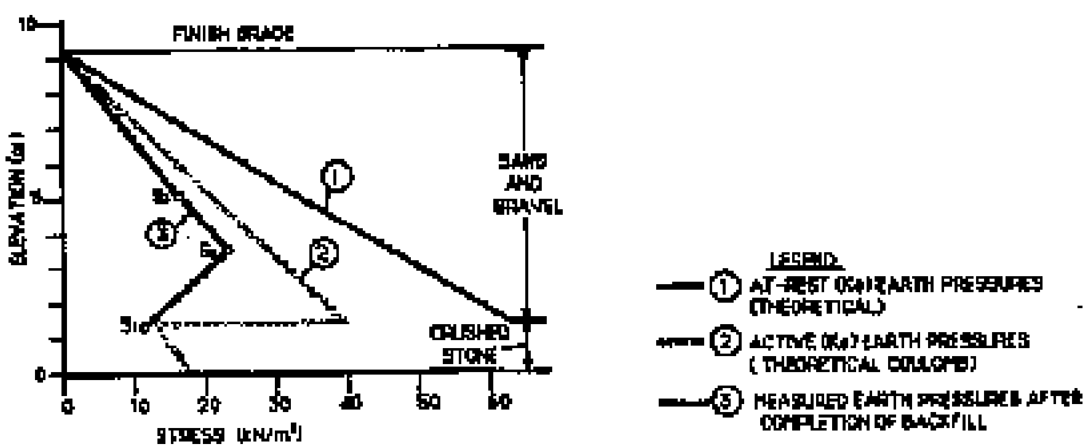

FIG 12 LATERAL PRESSURES AGAINST WALL AT FULL FILL HEIGHT

FIGURE 10 AND 11

Very small deformations were observed for the extensometers as shown in Figure 10. Maximum deformations of the drainage board at full fill heights are 0.25 cm (0.1 in.), 0.50 cm (0.2 in.), and 1.5 cm (0.6 in.) for extensometers E-3, E-2, E-1, respectively.

Figure 11 shows the computed strain-stress relationships for the field observations together with the laboratory data. Essentially fairly good correlation between field measurements and laboratory data is observed. Bothe curves appear to be nearly parallel, but there appears to be an apparent shift between the curves indicating that, under the same stress, the computed strain for the field condition is less than the laboratory curve. There may be several explanations:

- The laboratory curve is based on unconfined conditions. Field conditions are not unconfined. Therefore, deformations in a confined condition generally would be less than those in an unconfined state.

- The accuracy of the field readings is limited to 0.25 cm (0.1 in.). This is well below the accuracy of laboratory instruments with an accuracy of 0.0025mm (0.0001 in.).

- The extensometers required some seating load as backfill was being placed before the gauges were zeroed out. Thus it could be possible that measured total deformation, and subsequently the strain, is less than the true value.

FIGURE 12

Curve 1 in Figure 12 shows the at-rest earth pressure against the wall to the stone layer, based on theoretical relationships and not considering the influence of soil materials beyond the temporary retention structure.(5)

Curve 2 presents the theoretical relationship (Coulomb) of an active earth pressure against a wall due to the sand and gravel and stone backfills.(5)

Curve 3 presents the actual observed pressures against the wall at the three meter elevations and interpolation between the points. It is recognized that the actual pressure distribution may not be necessarily linear. (4)

Comparing Curves 1, 2, and 3 it is obvious that essentially a condition of very low lateral pressure against the retaining wall has been attained by application of a yielding material which in this case was the "Geotech" drainage board.

It is acknowledged that the temporary retention structure may not have permitted full development of the theoretical at-rest pressures; however, it should be noted that continuous monitoring of the temporary retention system indicated a steady creeping of the retention system toward the south direction during backfill construction. Thus we conclude that lateral pressures against the temporary retention system were transferred onto the backfill and subsequently onto the permanent basement wall.

CONCLUSIONS

1. Application of the "Geotech Drainage Board" against a non-yielding retaining wall mobilized a quasi-active lateral pressure by allowing translational displacement of the wall backfill.

2. The instrumentation and monitoring programs discussed in this paper were done as part of the quality control procedures for this project and were not done for research purposes. Thus, the accuracy of the instrumentation, particularly deformation measuring, could be improved.

3. We are not aware of work by others to reduce lateral earth pressures against non-yielding retaining structures. We propose that "Geotech Drainage Board" or similar products could be used for this purpose, but further field and laboratory testing by manufacturers, researches, etc., is warranted.

4. We offer to share our experience (good and bad) with those interested in similar applications.

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