Cyclic Plate Load Tests on Lightweight Aggregate Beds

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In recent years lightweight aggregates have been used increasingly with or without polymeric reinforcement in geotechnical applications. Results of a series of plate load tests performed on beds of expanded shale lightweight aggregate with or without geogrid reinforcement are presented. All tests were performed in a large test facility so that lightweight aggregate beds could be prepared using light compaction equipment. The relative density of the aggregate and locations of the polymeric reinforcement with respect to the base of the plate were varied in the experimental program.

The present testing program is part of an ongoing research project to determine the geotechnical properties of expanded shale lightweight aggregate at the University of New Brunswick, Canada. The research program began in 1985, and initially large-size one-dimensional compression and direct shear tests were carried out on lightweight aggregate specimens (*1*). The large direct shear apparatus was also used for determining angle of friction between geotextiles and expanded shale lightweight aggregate (*1*). Model footing tests on peat-geotextile-lightweight aggregate systems were undertaken following the direct shear and compression testing. Some of the results of this model testing have been reported by Valsangkar and Holm (*2*).

The scope of the testing program reported in this paper was to carry out preliminary laboratory plate load tests on beds of lightweight aggregate with or without geogrid reinforcement. The variables studied were relative density of the aggregate and location of the geogrid with respect to the base of the plate.

MATERIALS

Expanded shale aggregate manufactured by Solite Corporation was used in this study. This aggregate is manufactured by heating shale in a rotary kiln at a temperature of about 1150°C. At this temperature the shale particles reach a pyroplastic condition and expand through formation of gases that result from the decomposition of some of the compounds. The expanded, vitrified particles are screened to produce the desired gradation for a particular application. In the geotechnical applications, coarse aggregates with particle sizes between 5 and 25 mm are commonly used.

The lightweight aggregate used in the present study has a grain size distribution from between 19 and 4.7 mm with a uniformity coefficient of 1.4. Table 1 gives the shear strength data for the lightweight aggregates from two sources, along with the data for limestone aggregate.

The polymeric reinforcement used in the testing was a low-strength HDPE geogrid (Tensar SR-1). The properties of this geogrid as reported in Koerner (*3*) are shown in Table 2. The critical properties of the geogrid for its use as a soil reinforcement are aperture size in relation to particle size of the soil, long-term design load, tensile modulus at low strain levels, and service life of the grid (*3*).

EQUIPMENT AND PROCEDURE

Plate load tests were performed in a test pit 3.2 × 3.2 × 1.6 m deep. The facility is equipped with loading frames, and the reaction beam can be adjusted in the vertical position depending on the thickness of the soil in the test pit. The schematic details of the test setup are shown in Figure 1. A standard steel plate 300 mm in diameter was used in all the tests. The loads were applied by a hydraulic ram, and the settlements were monitored using two dial gauges. The data from the dial gauges and the level vial mounted on the plate were used to ensure that plate tilting did not occur during testing.

In all the tests performed, the thickness of the lightweight aggregate was at least 900 mm. Loose relative density was achieved by end dumping the aggregate in the test pit. An average dry density of 800 kg/m^3 was achieved when the aggregate bed was prepared by end dumping.

After completion of testing of the loose lightweight aggregate, the aggregate was removed from the test pit. A small vibratory plate compactor (530- × 610-mm plate) was then used to compact 150-mm-thick lifts of lightweight aggregate. Density measurements made after compaction indicated that an average dry density of 950 kg/m^3 was achieved.

Polymeric reinforcement was used in combination with compacted aggregate. In one series the geogrid was located 150 mm below the bottom of the plate, and in the second series, at a depth of 200 mm. The location of geogrid below plate was selected on the basis of previous research, which concluded that for one layer of soil reinforcement to be effective, it has to be placed within a depth equal to or less than the width of the footing (*4*).

When the plate was properly seated, load was applied with the hydraulic ram. For loose aggregate beds, the loads were monotonically applied in increments of 1 kN until a settlement of 12 mm was achieved. For the compacted aggregate bed, monotonically increasing loads were applied in increments of about 2 to 3 kN until the plate settlement reached 12 mm.

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TABLE 1 Angle of Internal Friction for Coarse Aggregates (*1*)

Material	Dry Density kg/m³		Angle of friction, degrees	
	Loose	Compact	Loose	Compact
Solite	840	934	40.0	45.5
Minto[a]	929	1,062	40.5	48.0
Limestone	1,706	1,887	37.0	---

[a] Minto expanded shale lightweight aggregate has the same gradation as Solite.
--- Unavailable

TABLE 2 Properties of SR-1 Uniaxial Geogrid (UX1400) (*3*)

Property		Value	
Structure		Punched-sheet drawn	
Polymer composition		Polyethylene	
Mass/unit area		512 g/m² ASTM D3776-84	
Aperture size:			
	Machine direction	145 mm	
	Cross machine direction	15 mm	
Thickness:			
	at rib	0.8 mm	ASTM D1777-64
	at junction	2.8 mm	ASTM d1777-64
Wide width strip tensile:			
	2% strain	14.6 kN/m	
	5% strain	24.8 kN/m	
	ultimate	54.0 kN/m	

Load increments for reinforced aggregate varied from 4 to 6 kN during the monotonic application of loads. Irrespective of the magnitude of the load increment, each load increment was maintained until the rate of settlement was less than 0.02 mm/min for a minimum of three successive minutes.

The choice of 12-mm settlement as the maximum settlement was adopted on the basis of the ASTM standard for plate load testing (ASTM D1195-64). However, load cycling before reaching 12-mm settlement was not carried out as recommended in ASTM D1195-65, because the primary objective of the study was to determine the coefficient of subgrade reaction for monotonic loading. The other reason for adopting the 12-mm settlement criterion and not cycling the load before this much settlement occurred is found in the work by DeBeer (*5*), which concluded that the settlement at the onset of bearing capacity failure of granular soils with high relative density is on the order of 5 percent of the width of the loaded area.

In all the tests performed, cyclic loads were applied after the monotonic load was applied to achieve a 12-mm settlement. In each case the maximum load corresponding to 12-mm settlement was applied six to eight times to study the behavior under cyclic loading. Each test was done at least twice to ensure that data and trends were reproducible.

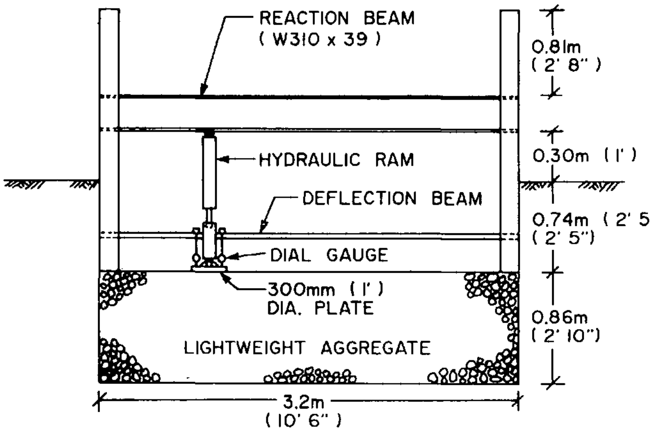

FIGURE 1 Test setup.

RESULTS

Plate load test results for unreinforced lightweight aggregate are presented in Figure 2 for compact and loose beds. The bearing stress for 12-mm settlement increased from 116 kPa to 456 kPa because of moderate compaction. The values of coefficient of vertical subgrade reaction were determined from the slope of the bearing stress–versus–settlement data obtained during the monotonic loading. The results are given in Table 3. Typically, values of coefficient of vertical subgrade reaction of 8 MN/m³ (loose) and 38 MN/m³ (compact) are used for normal-weight coarse-grained soils (*6*). Thus, the plate loading tests confirm that the behavior of tested coarse

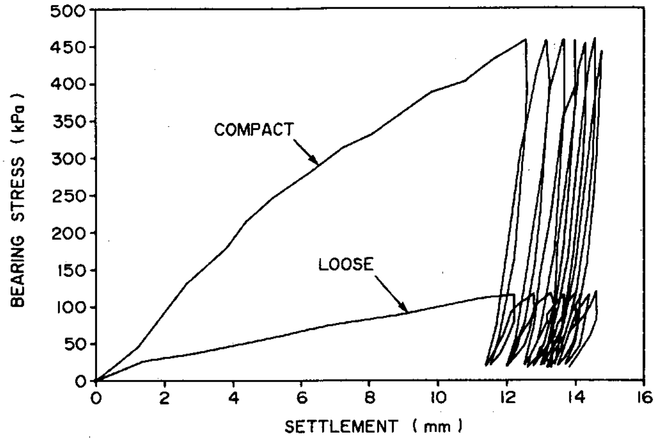

FIGURE 2 Effect of relative density on plate settlements.

lightweight aggregate is similar to that of normal-weight aggregates.

The effect of cyclic loading on plate settlements is given in Figures 2 and 3. From Figure 2 it is seen that the slopes of the unloading and reloading curves are very steep when compared with the slope of the bearing stress–versus–settlement data during initial monotonic loading. The reloading coefficient of subgrade reaction for loose and compact aggregate beds is evaluated to be 190 and 1500 MN/m^3, respectively.

Figure 3 shows the effect of repetition of loading on the cumulative settlements for both loose and compact lightweight aggregate beds. Note that the linear trend observed between number of load cycles plotted on the logarithmic scale and cumulative settlement on natural scale, which is common for coarse-grained normal-weight soils (*7*), is also applicable to lightweight soils.

The beneficial effect of including geogrid reinforcement in compacted lightweight aggregate is seen from the data given in Figure 4. The bearing stress to cause 12-mm plate settlement increased from 456 to 1000 kPa, irrespective of whether the geogrid was located 150 or 200 mm below the base of the plate. The coefficient of vertical subgrade reaction due to the inclusion of geogrid reinforcement increased from 42 to 130 MN/m^3.

Figure 5 gives the effect of cyclic loading on the cumulative settlements. Again a linear trend is observed between the magnitude of settlement and number of cycles plotted on the logarithmic scale. Also, it is seen that the cumulative settlements observed for aggregate with geogrid reinforcement of 150 mm deep were somewhat lower than when the geogrid was at a depth of 200 mm (Figure 5). However, more testing is required to delineate this trend.

TABLE 3 Coefficient of Vertical Subgrade Reaction for Coarse Lightweight Aggregate

Test No.	Plate Diameter mm	Relative Density	Coefficient of Subgrade Reaction, MN/m^3
1	300	Loose	9
2	300	Loose	10
2	300	Compact	42
4	300	Compact	38

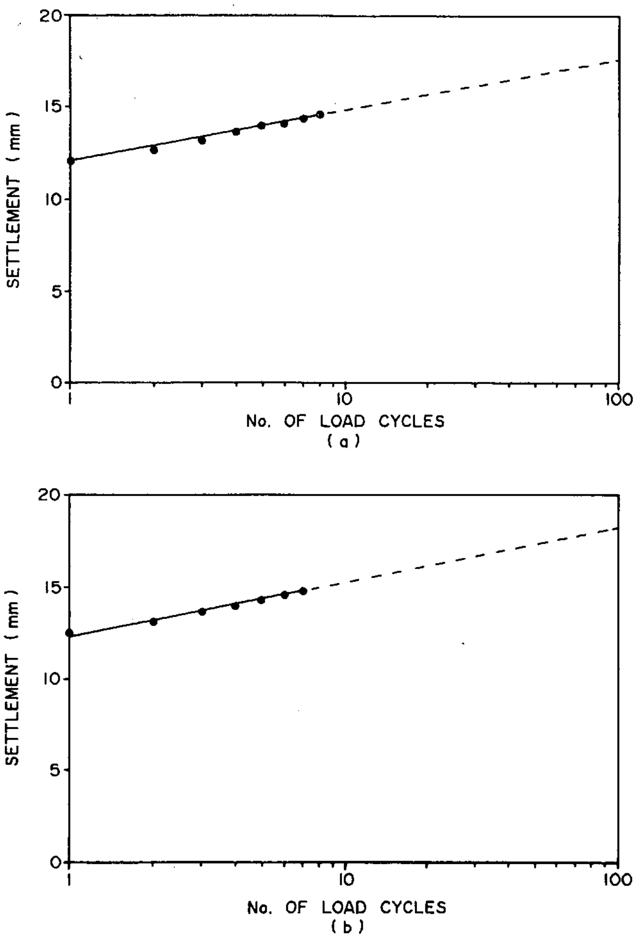

FIGURE 3 Cumulative settlements due to cyclic loading: *top*, loose, bearing stress = 116 kPa; *bottom*, compact, bearing stress = 456 kPa.

CONCLUSIONS

Results of the preliminary plate load testing program reported in this paper indicate that the coefficient of vertical subgrade reaction values of lightweight aggregates is similar to that of normal-weight aggregates used in roadway and engineered fill applications. The inclusion of geogrid as a soil reinforcement enhances the compressibility characteristics of the lightweight aggregate similar to the normal-weight aggregate. Even though relatively few tests have been done in this program, the extensive testing done previously at the University of New Brunswick, with the results of the present investigation, indicates that geotechnical behavior of coarse lightweight aggregate is similar to that of normal-weight aggregate.

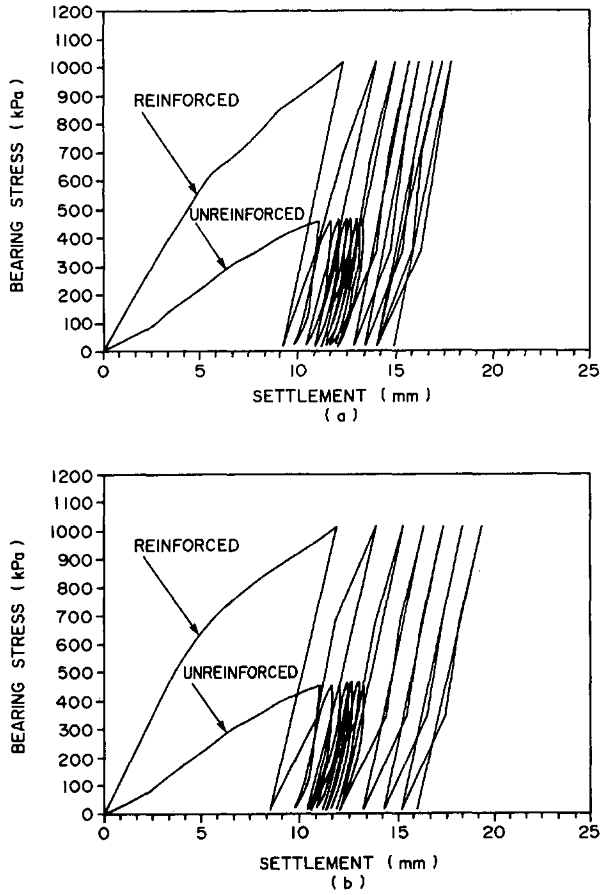

FIGURE 4 Effect of geogrid reinforcement on plate settlement response: *top*, geogrid at 150-mm depth; *bottom*, geogrid at 200-mm depth.

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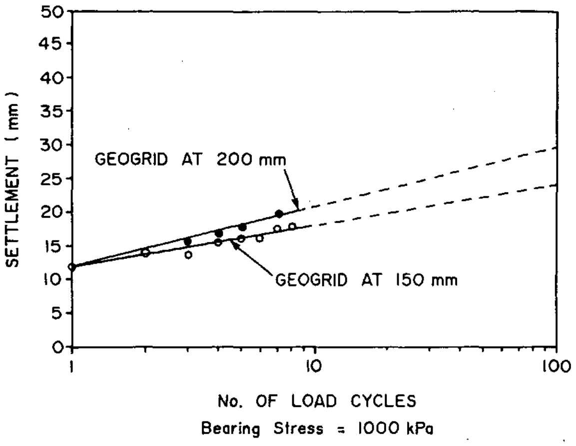

FIGURE 5 Cumulative settlements due to cyclic loading for geogrid-reinforced aggregate.

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