COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

PENNDOT RESEARCH

PENNDOT

EVALUATION OF STRUCTURAL FILL TO DESIGN RETAINING WALL

University-Based Research, Education and Technology Transfer Program
AGREEMENT NO. 359704, WORK ORDER 24

FINAL REPORT

September 2001

By G. Sabnis

PENNSTATE

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Pennsylvania Transportation Institute

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-PA-2001-016-97-4 (3)		

4. Title and Subtitle	5. Report Date
Cathodic Protection of Bridges in Pennsylvania	September 18, 2001
	6. Performing Organization Code
7.Author(s)	**8. Performing Organization Report No.**
Dr. Gajanan M. Sabnis, P.E.	PTI 2002-07 (3)
9. Performing Organization Name and Address.	**10. Work Unit No. (TRAIS)**
The Pennsylvania Transportation Institute Transportation Research Building The Pennsylvania State University University Park, PA 16802-4710	
	11. Contract or Grant No.
	359704, Work Order 24
12. Sponsoring Agency Name and Address	**13. Type of Report and Period of Covered**
The Pennsylvania Department of Transportation Bureau of Planning and Research Commonwealth Keystone Building 400 North Street, 6th Floor Harrisburg, PA 17120-0064	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The purpose of this research is to evaluate the performance and the cost of Lightweight Aggregate used in structural backfill. The material that is the primary focus of this research is called Solite. This material has a unit weight of 60 pounds per cubic foot, which is about half the unit weight of normal structural backfill.

This report details the performance of Solite and documents the properties of other existing alternatives.

17. Key Words	18. Distribution Statement
Lightweight Aggregate, structural backfill, expanded aggregate, retaining wall	No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

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Prepared for

Commonwealth of Pennsylvania
Department of Transportation

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This work was sponsored by the Pennsylvania Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration. The contents of this report reflects the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the Federal Highway Administration, U.S. Department of Transportation, or the Commonwealth of Pennsylvania at the time of publication. This report does not constitute a standard, specification, or regulation.

PTI 2002-07 (3)

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EXECUTIVE SUMMARY

Many bridges are constructed every year across the United States. Each of these bridges is comprised of abutments, piers, and decking. The cost of abutments becomes a significant factor in bridge design, especially on short bridges. Design of abutments is affected by the selection of backfill material. Reducing the weight of the backfill material offers the opportunity to reduce the size of the abutment walls and the foundation of the abutments thus reducing cost.

The purpose of this research project is to evaluate the performance and the cost effectiveness of using lightweight aggregate as structural backfill in the retaining wall constructed in 1995. The Solite Corporation manufactured the backfill material used in the wall. By using both normal weight and lightweight aggregates as backfill in the design of a retaining wall, observations are made regarding the loading of the retaining wall on the underlying soil and the resulting factors of safety. Cost information is provided based on the current studies.

Documentation for this project will serve as a primary source of information for this research.

1.0 PROJECT OBJECTIVE

The objective of this project is to evaluate the performance and cost effectiveness of lightweight aggregate as structural backfill. In addition, this report will identify and discuss a suitable alternative to lightweight aggregate as structural backfill. The criteria used for identification of this alternate material were: one, comparable unit weight and other geotechnical properties; two, ease of compaction; and three, comparable cost.

There are many aggregates that are available and in use today. These materials fall into many different classes and come in a variety of shapes, sizes, and unit weights. While these other materials continue to be the primary source of materials used as backfill for retaining walls, lightweight aggregates offer the following advantages:

- Low unit weight - reduced soil thrust and bending moments.
- Less weight - less cantilever reinforcement.
- Free draining - controlled gradation allows draining and minimizes hydrostatic pressure; this may also be included with the selection of backfill.
- Less construction weight - easier movement within existing projects.

2.0 PROJECT SITE LOCATION

A project was constructed and completed in September 1995. The backfill employed primarily one lightweight aggregate to reduce the horizontal loads on the wall and is evaluated in this research project. This project site is located in the north section of Philadelphia on Fox Street, between Hunting Park Avenue (S.R. 0013) and Allegheny Avenue (S.R. 2016). The bridge structure is over a South Eastern Pennsylvania Transit Authority (SEPTA) line. Figure 1 illustrates the project location.

3.0 PROJECT DESCRIPTION

This research project will evaluate the use of "lightweight aggregate," as structural backfill, in the contained area (between an existing and newly constructed abutments and wing walls) on that project site. The resulting soil thrust, moments, and stresses of other types of lightweight aggregates will also be introduced.

4.0 MATERIAL DESCRIPTION

The "lightweight aggregate" that is focused on in this research is the SOLITE lightweight aggregate, which is manufactured by the Northeast Solite Corporation, P.O. Box 437, Mt. Marion, New York, 12456. Other types of lightweight aggregates are introduced into this report for the purpose of comparisons.

This material is produced by heating shale in a rotary kiln under carefully controlled conditions at temperatures of approximately 2,100°F (1,150°C). The expanded vitrified mass that results from this process is then screened to produce the desired gradation for a particular application. The material displays a continuous, coarse aggregate gradation that exhibits a minimum angle of friction of 40 degrees. The pores formed during expansion are generally non-interconnecting and the particles are subangular in shape and lightweight. The resulting material is durable, chemically inert and relatively insensitive to moisture.

The manufacturer's specification of the geotechnical properties of the aggregate at the time of construction of the Philadelphia project were as follows:

- The dry, loose unit weight shall be less than 50-pounds-per-cubic-foot (pcf).
- The compacted density shall be less than 60-pounds-per-cubic-foot (pcf).
- The angle of internal friction shall be greater than 40 degrees.
- The gradation of the material shall conform to the requirements for AASHTO No. 67 Coarse Aggregate, as specified in the department's Publication 408 Specifications, Section 703.2.

The company's latest technical bulletin has revised specifications that reflect the following:

- The dry loose unit weight shall be less than 55-pcf (880-kg/m3).

- The compacted density shall be less than 60-pcf (960-kg/m3) when measured by a one-point test conducted in accordance with ASTM D-698 "The Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures using a 5.5lb. hammer and 12 inch drop" (AASHTO T-99).
- The angle of internal friction shall be greater than 40 degrees when measured in a triaxial compression test on a laboratory sample with a minimum diameter of 10 inches.
- The maximum Los Angeles Abrasion loss when tested in accordance with ASTM C-131 (B grading) shall be 50 percent.
- The maximum chloride content shall be less than 100-ppm chloride when measured by FHWA-RD-77-85.

5.0 CONSTRUCTION PROCEDURES

The construction report states that the "Lightweight Aggregate" was transported to the job site and deposited on the existing roadway. The material was then placed into the contained area by a backhoe. The backhoe dropped the material approximately 25 feet to the grade below. Segregation of the material was not observed due to the small amount of fine aggregate. Laborers shoveled the backfill material into position in 8-inch lifts to obtain a final height of 19-feet. Each lift of material was compacted with three 3 to five 5 passes of a vibratory walk-behind roller (with a roller weight of 300-pounds-per-inch) and a vibratory plate tamper to tighten the top of each lift. Non-movement of the in-place backfill material was the criteria used for placing additional lifts.

The "Lightweight Aggregate" material had a gradation identical to AASHTO No. 67 Coarse Aggregate and contained less than 20 percent retained on the ¾" sieve. The construction report states that it was not practical to determine the in-place density using the Pennsylvania Test Method No. 403 titled, "Determining In-Place Density and Moisture Content of Construction Materials by Use of Nuclear Gauges" as specified by the manufacturer.

The report also states that the lack of fines and the large amount of voids present within the "Lightweight Aggregate" material produced unreliable and unrealistic results in the multi-point Proctor Test. It goes on to state that the use of a nuclear gauge was not feasible and non-movement of the material under a roller was utilized as an indicator of adequate compaction. The report adds that there is no proof that this method of compaction would achieve favorable results in an unconfined area. Non-movement of the backfill material was documented using the department's Form TR 478A. The in-place density was determined by calculating the volume of cubic feet behind each abutment and dividing by the total tonnage of "lightweight aggregate" placed.

6.0 CONSTRUCTION COSTS

The report states that the lump sum bid price for the lightweight aggregate was $116,000.00 for approximately 1,588 cubic yards (CY). The calculated cost of the in-place fill was $73.00 per cubic yard (CY). The report further states that the price did not appear to be cost-effective when compared with other suitable backfill material. However, the report states that there was an initial cost saving of $50,000 resulting from the use of spread footing as opposed to other alternate designs. The use of spread footings was made possible by the reduction of the soil thrust and moments resulting from the use of lightweight aggregate.

7.0 TESTING PROCEDURES AND RESULTS

Samples were taken and tested according to AASHTO and PENNDOT specifications were followed during construction of the project:

- AASHTO T 180-86 titled, "Moisture-Density of Soils Using A 10-lb Rammer And An 18" Drop" to determine the relationship between density and moisture content (replaced since by AASHTO-T-99)
- AASHTO T 2-84 titled, "Sampling Aggregates" to control the material at the supply source and to control the material at the supply source and to control its use at the construction site.

- PENNDOT Publication 408 Specifications, Section 703.2 titled, "Coarse Aggregates" to test gradation, uniformity of physical properties and the quality of the aggregate.

The sample material submitted for evaluation met the gradation criteria for AASHTO No. 67 Coarse Aggregate. The recorded loose unit weight was 46.9-pounds-per-cubic-feet (pcf). Based on these criteria the material was determined to be suitable for placement. However, acceptance sampling on-site produced unfavorable results. The sampled material was heavier than the specifications stated. Sampling was done by removing compacted aggregates from the lift and placing it in a unit weight box. The box and the material were weighed to determine the compacted density.

The construction report records that a technical representative from Northeast Solite performed the compacted density test in the presence of the resident engineer. The manufacturer's expected loose weight was no more than 54-pounds-per-cubic-foot (pcf). The average result based on 12 samples was 58.2-pounds-per-cubic-foot (pcf). Four sieve analyses were performed and of those, one sample failed to meet the gradation requirements for AASHTO No. 67. Ninety-five percent of the compacted density tests failed to meet the manufacturer's specifications.

The construction report also records that the use of AASHTO T 180-86 test (Modified Proctor) was found to be inappropriate and counter-productive to the backfill operations. The results produced an increase in density. Instead, AASHTO T-99 Method D (A One Point Proctor Test) was incorporated into the contracted specifications and employed. The test results provided enough compaction effort to obtain the stability in the field with a maximum compacted density of 60 pounds per cubic foot (pcf).

8.0 MATERIAL EVALUATION

Table 1, entitled "Index of Geotechnical Properties of Lightweight Aggregates," presents a summary of the material properties of natural granular fill, Solite and some of the other major brands of lightweight aggregate marketed across the United States. The list of manufacturers and brands was obtained from the 1999 directory of the Expanded

Shale, Clay, and Slate Institute. Contact information for the manufacturers is provided in appendix H.

The information presented in the table is grouped for ease of reference. The types of aggregate are presented in the first row of the table and the material properties are presented in the first column of the table. The second column presents the test methods used in evaluating the materials. These tests are grouped by individual material properties. The physical properties of a particular material can be determined by following the values in a particular column. Moving across a particular row/group and observing the values according to the particular test procedure will provide a quick comparison of a specific property of all the materials evaluated.

Table 1 is presented using information provided by manufacturers in their sales brochures as well as directly from their internal test results. Material testing was outside the scope of this project. Thus, the author assumes no responsibility for the accuracy of any or all the data contained therein. Reliance on the information presented should be done only after independent verification thereof. Additional Information on the geotechnical properties of these materials is presented in appendix A.

Appendix B presents a summary of the difference in the resulting horizontal thrust and the moments caused by the variation of unit weight and angle of internal friction of the major brands of lightweight aggregate. These results are compared to that of natural granular fill. The results indicate a significant difference between the thrust of the natural granular fill and that of the lightweight aggregate. These values are significant in the design of the retaining wall and account for the difference in foundation type mentioned previously in the report. Appendix D, which is an extension of appendix B, shows the resulting stress on the underlying soils caused by the different types of lightweight aggregates.

Table 1. Index of Geotechnical properties of Lightweight Aggregates[1]

	Test Method	Natural Granular Fill	Norlite	Solite	Stalite	Buildex	Arkalite	Utelite	Gravelite
Dry Loose Density	ASTM (D-4254)	89.0 pcf	40.2 pcf				35.0 pcf		
	ASTM (C-29)				48 pcf				
	Unspecified			55 pcf		43 pcf			
Dry Compacted Density	ASTM (D-4253)	146.0 pcf	45.5				40.1 pcf		
	ASTM (D-698)			60 pcf					
	ASTM (C-29)				55 pcf				
	Unspecified					48 pcf			
Strength	Consolidated Drained (medium, dense)	36° - 42°	42° - 53°				40.6°		
	Angle of Internal Friction (Loose)				40°				
	Unspecified			40°		38° - 42°			
Gradation	ASTM (C-330)			See Appendix A		See Appendix A			
	ASTM (C-136)	See Appendix A	See Appendix A						
Soundness	ASTM (C-88)	<6%	5.1%						
Abrasive Resistance ∞Los Angeles Abrasion	ASTM (C-131) B Grading	30 – 45%	32%	50%			29.4%		
	AASHTO (T–103)				25%				
Abrasive Resistance Modified	FM 1 – T 096	30 – 45%	21%				24.2%		
Permeability	ASTM (D-2434)	0.016 cm/sec	13.4-15.0 cm/sec						
Chloride Content	CalDOT (422)		<5 – 46 ppm						
	FHW-RD-77-85			100ppm					
	AASHTO (T 260)						<0.001%		
	Unspecified				0.60 ppm				
Sulfate Content	CalDOT (417)		146ppm						
Thermal Conductivity	ASTM (C-177)	9 – 12 Btu/hr ft^2°F/in	0.98 Btu/hr Ft^2°F/in						
Specific Gravity Dry	ASTM (C-127)				1.45				
Specific Gravity Saturated Surface Dry	ASTM (C127)				1.50				
California Bearing Ratio (CBR)						10			

[1] refer to appendices A and D for additional information

9.0 DISCUSSION

The primary reason for using lightweight aggregate was to minimize the cost of the project. Based on the recommended structural practices, the confined area where the abutment was located did not provide adequate length for the base of a cantilever retaining wall. A check of the structural calculations revealed that there was no load transfer from the existing abutment wall to the proposed abutment wall (appendix C). Based on these calculations, a cantilever retaining wall was proposed that would not exceed the bearing capacity of the soil. To achieve that, the weight of the backfill would have to be kept to a minimum. Lightweight aggregate was proposed to minimize the weight. Because sliding was not a major concern of the design, the primary concern of the design was ensuring that the bearing capacity of the soil was not exceeded. Thus, of significance to the design, was assuring an adequate factor of safety in bearing. A static design method was used to verify that the bearing capacity of the soil was not exceeded. The use of a cantilever retaining wall eliminated the need for a more expensive type of foundation such as pile foundation for the wall.

A summary of the factors of safety using the imposed loads of the different types of lightweight aggregates and the soil bearing on-site is presented below. The results show that the factor of safety required cannot be achieved using natural granular fill. The information provided also shows that of the lightweight aggregates examined, Solite returned the lowest factor of safety in bearing. Thus, better field results are possible. It must be pointed out however that there is not considerable variation in factors of safety using the different types of lightweight aggregate. Calculations of these factors of safety are provided in appendix D.

Solite aggregate appears to fall in the mid-range of values for unit weights for all the available choices of lightweight aggregate. It must be noted, however, that the specified unit weight of this aggregate could not be obtained during field placement.

Table 2. Calculated factors of safety for lightweight aggregate

Factor of Safety / Aggregate	Sliding (Min. Allowable = 1.5)	Overturning (Min. Allowable = 2.0)	Bearing (Min. Allowable = 1.5)
Natural Granular Fill	1.99	3.45	1.27
Norlite	3.76	4.16	1.86
Solite	2.40	3.26	1.60
Stalite	2.47	3.27	1.63
Buildex	2.73	3.41	1.70
Arkalite	2.78	3.32	1.73
Utelite	N/A	N/A	N/A
Gravelite	N/A	N/A	N/A

While the other major brands showed improved factors of safety in bearing, there are two overwhelming issues that seriously impede the use of lightweight aggregate: 1) assuring adequate compaction; and 2) availability. These mitigating measures seriously affect the viability of using lightweight aggregate in these special applications.

One alternative material that was examined addressed both issues of availability and adequate compaction. Controlled Low Strength Materials (CLSM) as described in the report of Committee 229 of the American Concrete Institute has a comparable unit weight and has reduced placement costs. Table 1.1 of the American Concrete Institute (ACI) Committee 229 Report: "Cited advantages of controlled low-strength materials" of the Controlled Low Strength Materials (CLSM) (ACI 229R-94) is presented in appendix E. It provides a summary of the advantages of using CLSM. Although increasing in cost with a decrease in unit weight, the unit weight of CLSM can be reduced to the range of 45-pcf to 70-pcf, exhibited by lightweight aggregate. CLSM has the added advantage of being self-compacting. This property eliminates some of the key difficulties of ensuring adequate compaction, which was experienced on this project.

Controlled Low Strength Materials (CLSM) are defined by "Cement and Concrete Terminology (ACI 116R)" as materials that result in a compressive strength of 1,200 psi or less. Most current CLSM applications limit the unconfined compressive strength to 300-psi or less to allow for future excavation. CLSM is described as a self-compacted, cementitious material whose unit weight and strength can be readily modified by the use of admixtures. CLSM is used primarily as backfill. CLSM exists under a number of different names including flowable fill, controlled density fill and unshrinkable fill. CLSM is delivered to the site in concrete trucks as slurry and pumped into the confined area(s) where it is needed. Unlike lightweight aggregate, it does not require storage or subsequent removal of excess material on site after construction.

CLSM can be produced by any ready-mix concrete manufacturer. CLSM is manufactured using cement, water, sand or fly ash, and admixtures. Fly ash based CLSM offers an additional advantage over sand based CLSM. The use of fly ash does not show any long-term increase in strength. This is a very useful property, which would allow an easy excavation of backfill during the service life after its placement. Appendix F provides additional information on the use and cost of CLSM.

10.0 CONCLUSIONS

Solite aggregate appears to fall in the mid-range of values for unit weights for all the available choices of lightweight aggregate. Since no unit weight of Solite aggregate was available (during the field placement) from earlier reports, no direct conclusion could be drawn. In spite of the range of unit weights for all the different lightweight aggregates, the factors of safety remained relatively close to warrant any significant effect on the design of the wall using such aggregates. This conclusion is based on the parametric study conducted during this research and is presented in appendix D.

Concerns about settlement and consolidation led to the inclusion of 16-inch-thick slab at the approach at both ends of the bridge, which significantly reduced the possible savings in the project.

It is recommended that settlement and/or consolidation be checked during the service life. Present conditions do not indicate any evidence of either. In the future, savings may be increased in similar project by eliminating wing walls allow any inspection and to justify the use of lightweight aggregates as backfill.

Controlled Low Strength Materials (CLSM) can be produced at a specified unit weight and without any sign of settlement or consolidation problem can also used. In addition, flyash based CLSM with no strength gain over a long period will allow easy removal or excavation, if necessary during the service life of the wall.

11.0 ACKNOWLEDGEMENTS

The author wishes to acknowledge the contribution by the following in supplying the information included in the report (appendices):

- The Norlite Corporation of Cohoes, New York.
- The Northeast Solite Corporation of Mt. Marion, New York.
- The Carolina Stalite Company of Salisbury, North Carolina.
- Buildex, Inc. of Ottawa, Kansas.
- Arkalite of West Memphis, Arizona.
- The Utelite Corporation of Salt Lake City, Utah.
- Big River Industries of Alpharetta, Georgia.
- The Dyna Corporation of Annapolis, Maryland.

The author also wants to acknowledge the assistance of Mr. Anthony Rogers, Construction Engineer and Mr. Darin Gatti, design engineer both from the city of Philadelphia for their outstanding support extended to this research project. Their assistance was very important in ensuring a successful completion.

12.0 REFERENCES/AVAILABLE INFORMATION

American Concrete Institute. (1994). "Controlled Low Strength Materials (CLSM)" Reported by ACI Committee 229 (ACI 229R-94).

American Concrete Institute. (1987). "Guide to Structural Lightweight Aggregate" Reported by ACI Committee 213 (ACI 213R-87).

Everard, N.J. (1993). "Schaum's Outline of Theory and Problems of Reinforced Concrete Design." McGraw-Hill, Inc. New York.

Expanded Shale, Clay and Slate Institute (ESCSI) (1999). "1999 Directory ESCSI Rotary Kiln Produced Structural Lightweight Aggregate."

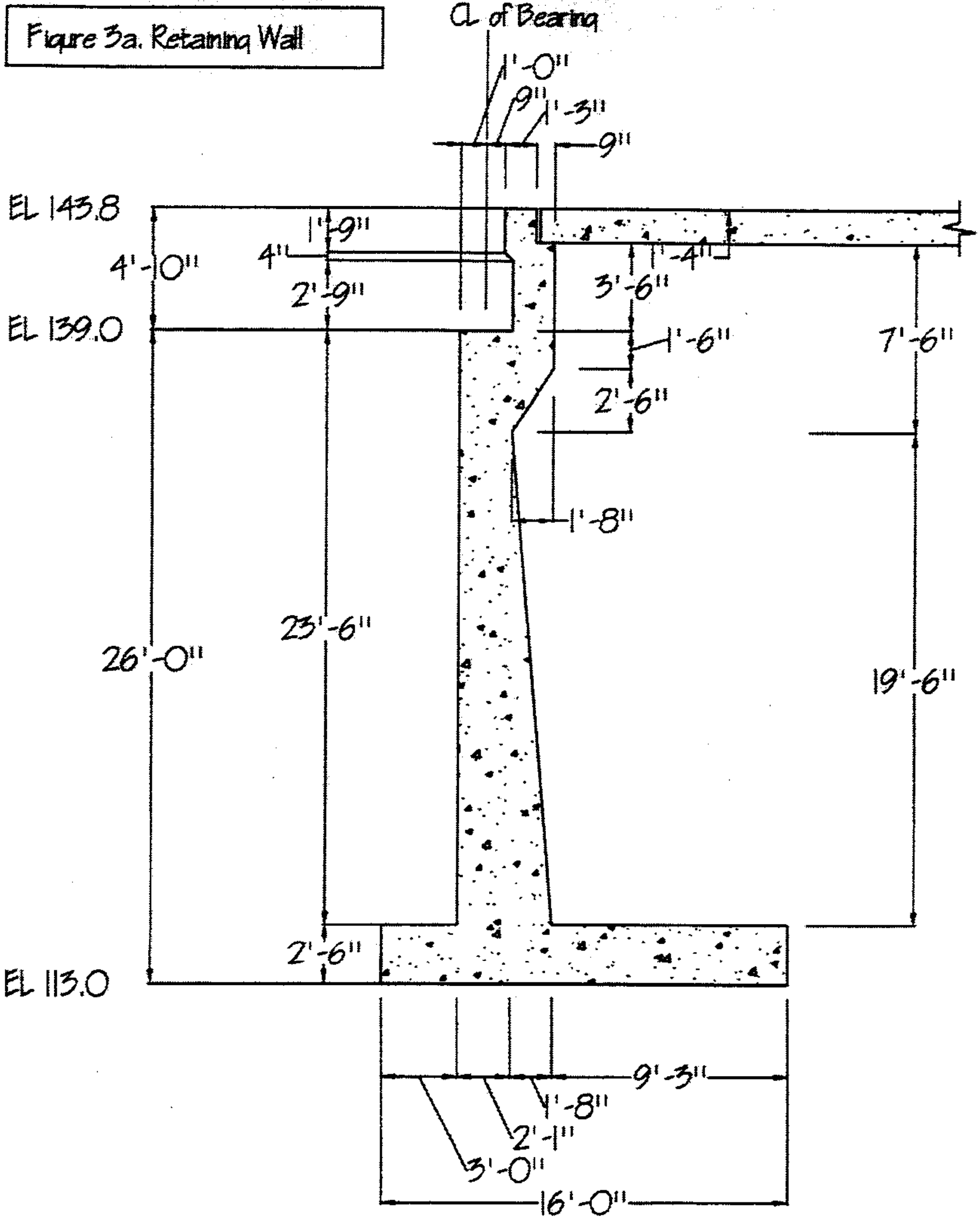
Rogers, A. Research Project No. 91-060: Structural Backfill using lightweight aggregate "Construction Report September 1995".

Conversion Factors

1-ft	=	0.3048-m
1-in.	=	25.4-mm
1-yd^3	=	0.7646-m^3
1-lb	=	0.454-kg
1-psi	=	6.895-kPa
1-lb/ft^3	=	16.02-kg/m^3
1-lb/yd^3	=	0.5933-kg/m^3
1-ft/sec	=	30.5-cm/sec

APPENDIX A: Properties of Different Lightweight Aggregates

Figure 3a. Retaining Wall



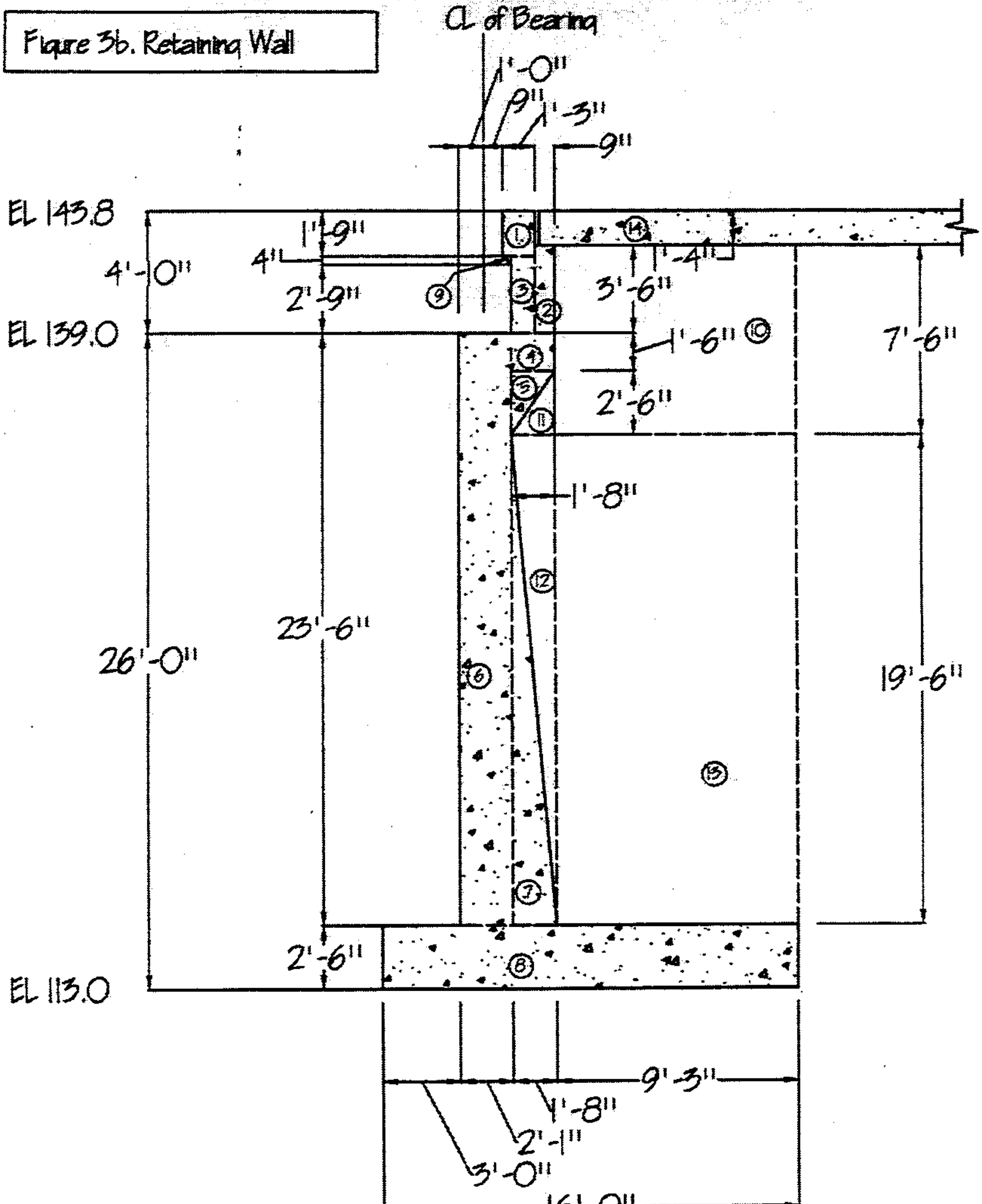
Footing Length = 93.427'

Abutment Length = 91.79'

Average Distance Between Wingwalls = 85.94'

Average Wingwall Length = 9.5 Normal, 14.76 Skew

Figure 3b. Retaining Wall



Footing Length = 93.427'

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Average Distance Between Wingwalls = 85.94'

Average Wingwall Length = 9.5 Normal, 14.76 Skew

EXPANDED SHALE LIGHTWEIGHT FILL: GEOTECHNICAL PROPERTIES

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SOLITE®

INTRODUCTION

Expanded shale lightweight aggregate has been used by the construction industry for many decades to produce lightweight structural concrete and lightweight concrete masonry units. The aggregate is expanded by heating shale (shale is used throughout this article to represent shale, clay or slate) in a rotary kiln under carefully controlled conditions at temperatures of approximately 2,100°F (1,150°C). The expanded, vitrified mass that results from this process is then screened to produce the desired gradation for a particular application. The pores formed during expansion are generally noninterconnecting and the particles are subangular in shape and very light in weight because of the vesicular nature of expanded shale. They are durable, chemically inert and insensitive to moisture.

Recently, lightweight aggregates have been found to be cost-effective alternatives in certain applications in the field of geotechnical engineering (2). Typical examples of where lightweight aggregate may offer significant advantages are the construction of controlled fills over very soft, compressible soil and backfill next to structural elements where there is the potential for excessive earth pressure or a stability problem when using ordinary fill materials. In order to evaluate the potential advantage of using lightweight aggregate, it is necessary to know both the unit weight and the mechanical properties of the aggregate under various kinds of loading. Most aggregate manufacturers can furnish data on the physical and engineering properties of aggregate produced at a particular plant. However, information on the stress-strain-strength response of unbonded lightweight aggregate is virtually non-existent. Information on such properties as the angle of internal friction and the compressibility of a fill under various levels of overburden stress is essential for any rational evaluation of the potential use of these materials in a geotechnical application.

The purpose of this paper is to present data from tests on lightweight aggregate from several different locations in the eastern United States. Large scale triaxial compression tests were performed on specimens from five different locations and uniaxial strain tests (consolidation tests) were run on aggregate from one of the sites. The results may be compared with data for ordinary fills when the lightweight aggregate is being considered as a design alternative.

TRIAXIAL TESTS

All of the triaxial tests were run on specimens approximately 10 in. (25.4 cm) in diameter and 24 in. (61.0 cm) long. Specimens were confined in a rubber sleeve with a wall thickness of approximately 1.5 mm. Isotropic confining stress was applied to specimens by connecting a controlled vacuum through a port in either the top or bottom platen. All tests were run at a constant rate of axial displacement which was equivalent to an average strain rate of 0.7% per min.

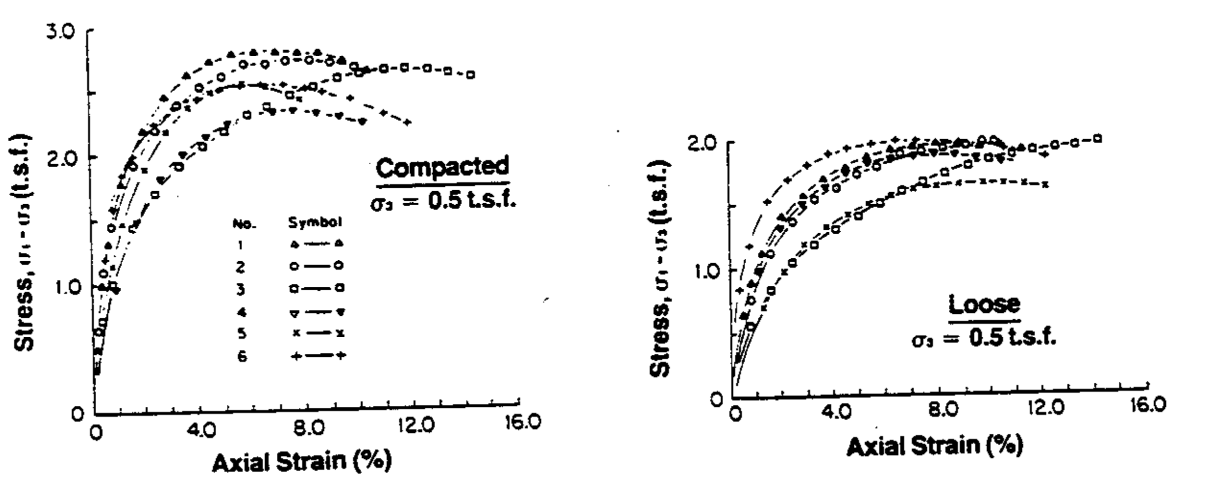
Tests were run on "loose" and "compacted" specimens for each different material. The loose specimens were prepared by gently placing the aggregate into the forming mold one scoop at a time, with an effort made to avoid vibration or other disturbance. Once in place the aggregate was not leveled or rearranged. In the tests on "compacted" aggregate, each specimen was compacted in five layers with 25 blows of a 5.5 lb. (24.5 N) hammer falling 12 in. (30.5 cm) on each layer. The densities produced by these procedures as well as other information about the source of the samples are given in Table 1. The difference in density between the loose and compacted specimens is about the same as the difference between the maximum and minimum dry densities that resulted when the standard ASTM tests for the relative density of cohesionless soils (ASTM D2049) were performed.

Fig. 1 shows the stress-strain curves obtained for six sets of tests. Most of the tests were run at the moisture content "as received" in the lab. Four of the tests (1 through 4) were run on a coarse fraction (passing the ¾ in. sieve and retained in the No. 4 sieve) which is commonly available from stock at many of the plants. From the figure it is obvious that there is a difference in response between aggregates 1 and 2 and that of aggregate 3. A physical inspection revealed a difference in the general shape and hardness of the particles. While there is some variation in the angle of friction determined at the peak stress, a more significant difference may be the amount of strain that is required to develop the full shearing strength.

TABLE 1.—Source and Other Information for Aggregates Used in Tests

Number in figure (1)	Source of aggregate (2)	Gradation passing/ retained (3)	Water Content at Test Time (%)		Dry Unit Weight (pcf)	
			Compact (4)	Loose (5)	Compact (6)	Loose (7)
1	Saugerties, New York	¾ in./No. 4	5.3	7.1	~52	~46
2	Aquadale, N. Carolina	¾ in./No. 4	7.2	6.7	53.4	47.6
3	Bremo, Virginia	¾ in./No. 4	4.0	6.0	49.2	41.7
4	Green Cove, Florida	¾ in./No. 4	8.1	8.4	50.6	46.4
5	Green Cove, Florida	¾ to Pan	8.2	8.4	61.9	53.9
6	Hubers, Kentucky	⅜ in./No. 8	0.1	1.4	53.0	47.1

FIG. 1.—Stress-Strain Curves for Triaxial Compression Test (1 t.s.f. = 95.8 kPa)



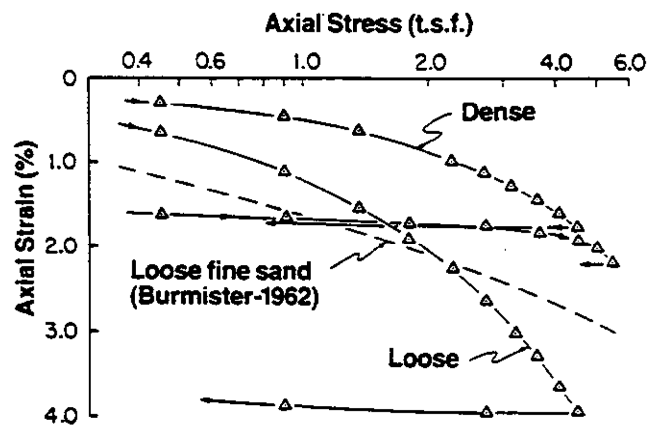
Aggregates 5 and 6 in Fig. 1 contain intermediate and fine fractions which are also commonly available at many processing plants. In these materials the coarsest particles are those passing the ⅜ in. sieve and there is a more noticeable stress drop-off after the peak, as is typical in many well graded granular soils. In general, the curves shown in Fig. 1 are quite similar to what is obtained for many common gradations of ordinary fill. For the compacted aggregates, the angle of internal friction corresponding to the peak stress difference varies from 44.5 to 48°, whereas for the loose material the range of φ is from 39.5 to 42°.

In the case of the Saugerties, New York aggregate (No. 1), tests were performed at several different confining pressures to insure that the Mohr envelope was essentially a straight line passing through the origin. In addition, tests were run on this material after it had been soaked in water for a period of five weeks. In the tests on water-soaked aggregate, the angle of internal friction was 1 to 2° lower than for the tests on the air dry or slightly moist materials.

CONSOLIDATION TESTS

Consolidation tests were performed on aggregate No. 1 using a 10 in. diameter floating ring with 1 in. wall thickness for lateral confinement and a specimen thickness of 4.5 in. Test results for a compacted and a loose specimen are shown in Fig. 2. In addition to the test curves, a consolidation curve for "loose fine sand" given by Burmister (1) has been included in Fig. 2 for reference. In the case of the lightweight aggregates, the curvature and the slope of the stress-strain curves corresponding to the first monotonic loading increases rather rapidly after a stress level of about 1 t.s.f. (98.8 kPa) is exceeded. On the other hand, when the specimen is unloaded and then reloaded, the reload curve is much flatter than one would expect, even on the first cycle of unloading and reloading in a typical cohesionless soil. This suggests that some degradation may be occurring during the first monotonic loading, and that once the interparticle contacts have been stabilized, the material reacts in a much stiffer manner to subsequent load applications. Further testing is planned to verify this conjecture.

FIG. 2.—Consolidation Stress-Strain Curves for Coarse New York Aggregate (1 t.s.f. = 95.8 kPa)



SUMMARY AND CONCLUSIONS

In summary, our tests on expanded shale lightweight aggregates from several different sites showed that the response under triaxial loading was similar to that of many ordinary coarse fill materials; the principal difference is that the lightweight aggregates weigh roughly half as much as their naturally-occurring counterparts. Thus the lightweight aggregates may prove to be useful substitutes for ordinary fill materials when the combination of low weight and substantial shear strength warrant the increased cost. The mechanical properties of the aggregate tend to vary somewhat from source to source so that they should be verified in each instance. However, once the properties have been established for a given plant, the variation will be much less than is normally encountered by a designer utilizing ordinary fill from a borrow area.

APPENDIX.—REFERENCES

1. Burmister, D.M., "Physical, Stress-Strain, and Strength Response of Granular Soil," *Special Technical Publication No. 322*, ASTM, 1962, pp. 87-93.
2. Childs, K., Porter, D. I., and Holm, T. A., "Lightweight Fill Helps Albany Port Expand," *Civil Engineering*, ASCE, Apr., 1983, pp. 54-57.

Suggested SOLITE® Soil Fill Specifications

The information listed below is a suggested specification for SOLITE® Lightweight Aggregate soil fill. It is best to consult with SOLITE® engineering and sales representatives during a project's conceptual design phase in order to call for the most appropriate geotechnical and material physical properties.

Materials

Lightweight Aggregate fill shall be SOLITE® Lightweight Aggregate or approved rotary kiln substitute meeting all the requirements of a recently completed (2 years max.) ASTM C-330 certification. No by-product slags or cinders are permitted. Lightweight aggregate shall have a proven record of durability and be non-corrosive (less than 100 ppm chloride when measured by FHWA-RD-77-85) with the following physical properties:

A. Delivered Gradation

Sieve Size	% Retained
1" (25 mm)	____
½" (13 mm)	____
#4 (5 mm)	____

B. The dry loose unit weight shall be less than 55 pcf (880 kg/m³). The lightweight aggregate producer shall submit verification of a compacted density of less than 60 pcf (960 kg/m³) when measured by a one point test conducted in accordance with ASTM D-698 "The Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using a 5.5 lb. Hammer and 12 inch Drop" (AASHTO T-99).

C. The lightweight aggregate producer shall submit verification that the angle of internal friction shall be greater than 40° when measured in a triaxial compression test on a laboratory sample with a minimum diameter of 10 inches.

D. The maximum Los Angeles Abrasion loss when tested in accordance with ASTM C-131 (B grading) shall be 50%.

SOLITE®

Lightweight Precast Elements
Lightweight Masonry Units
and Structural Concrete

OFFICES:

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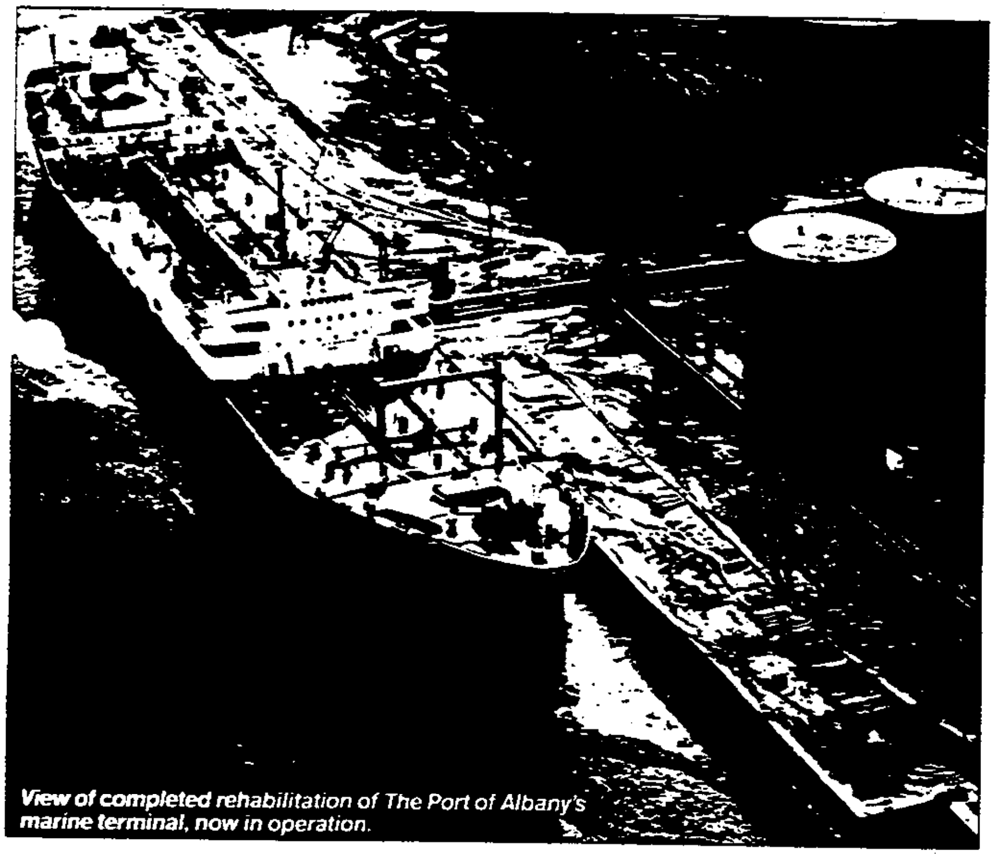
P.O. Box 987, Albemarle, NC 28001 (704) 474-3165
P.O. Box 297, Green Cove Springs, FL 32043 (904) 264-6121
P.O. Box 39, Brooks, KY 40109 (502) 957-2105

PLANTS:

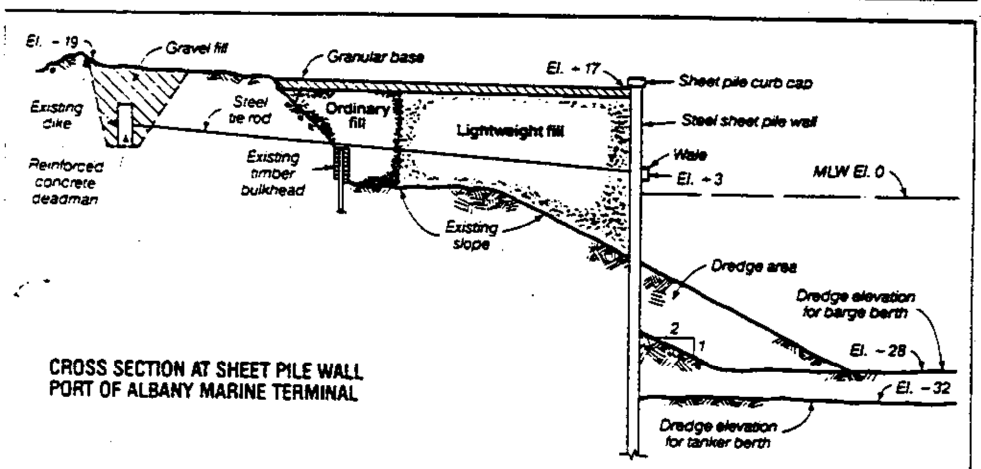
Saugerties, NY
Leaksville Junction, VA
Bremo Bluff, VA
Aquadale, NC
Green Cove Springs, FL
Hubers, KY

SOLITE LIGHTWEIGHT AGGREGATE SOIL FILL

The controlled lightweight aggregate for use in special soil mechanics engineering applications.



View of completed rehabilitation of The Port of Albany's marine terminal, now in operation.



CROSS SECTION AT SHEET PILE WALL
PORT OF ALBANY MARINE TERMINAL

SOLITE lightweight aggregate is similar to natural aggregates in particle shape and gradation. The reason for its lightness is the multitude of fine pores generated within each particle during the expansion phase of the manufacturing process.

As a replacement for natural aggregates, SOLITE has over the past 42 years been used in millions of cubic yards of structural concrete —including 60-story concrete frames, high strength prestressed concrete, and miles of exposed concrete bridge decks. Due to the reduction of dead load, the projects are more economical to the owner because of smaller foundations, lower tonnages of reinforcing steel and less bulky columns.

In a number of schematically shown actual situations, engineers familiar with its long term excellent structural performance have called for SOLITE to replace stone, gravel or natural soil when reduction in ground loading dead weight has become a critical necessity.

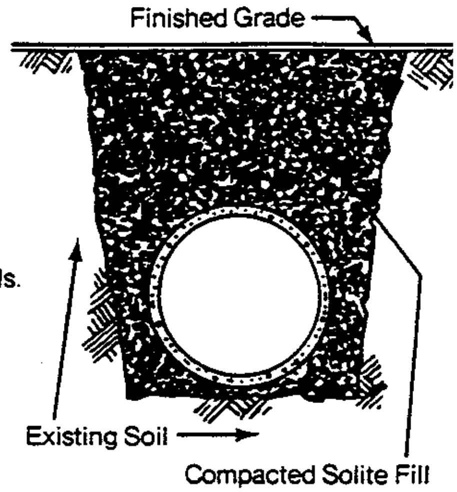
SOLITE structural grade lightweight aggregate can provide the solution to difficult soil mechanics situations because of its optimum combination of low compacted density (less than 60 pcf) and high inherent stability (angle of internal friction greater than 40°).

SOLITE

Illustrations of completed

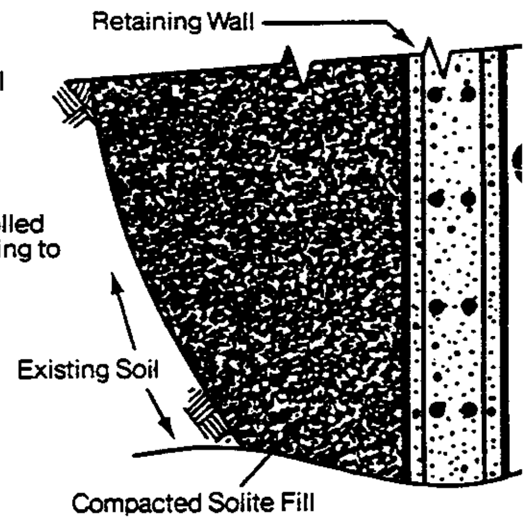
Controlled Solite Soil Fill over Buried Pipe Structures

- Lighter—approximately half the in-place density of usual soils.
- Controlled—manufactured aggregate for consistent weight and gradation
- Durable—resists freeze—thaw cycles.
- Inert—no corrosive chemicals.
- Insulating—low coefficient of thermal conductivity; counteracts frost heaving; protects buried pipes from freezing.
- Free-draining—minimizes hydrostatic potential.



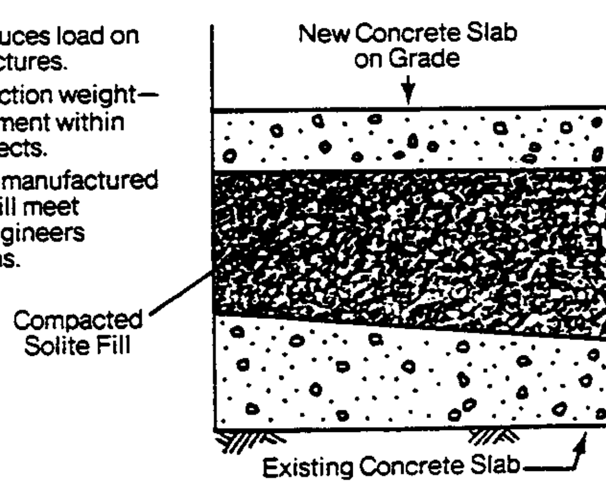
Controlled Solite Soil Fill behind Retaining Walls

- Lighter—to reduce soil thrust and bending moments.
- Less weight—reduces cantilever steel.
- Free-draining—controlled gradation allows draining to minimize hydrostatic potential.



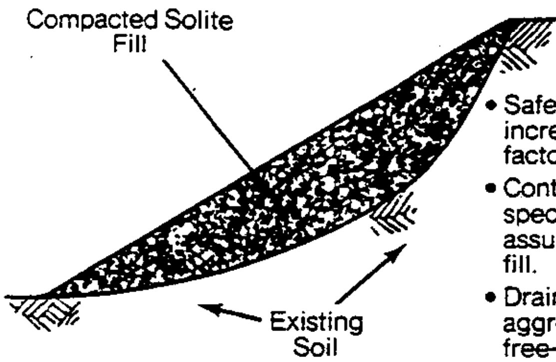
Controlled Solite Soil Fill on Rehabilitation Projects

- Lighter—reduces load on existing structures.
- Less construction weight—easier movement within existing projects.
- Controlled—manufactured aggregate will meet structural engineers specifications.



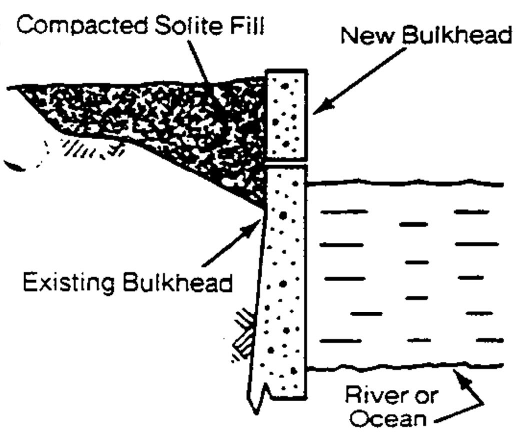
SOLITE soil fill applications

Controlled Solite Soil Fill Improves Embankment Stability



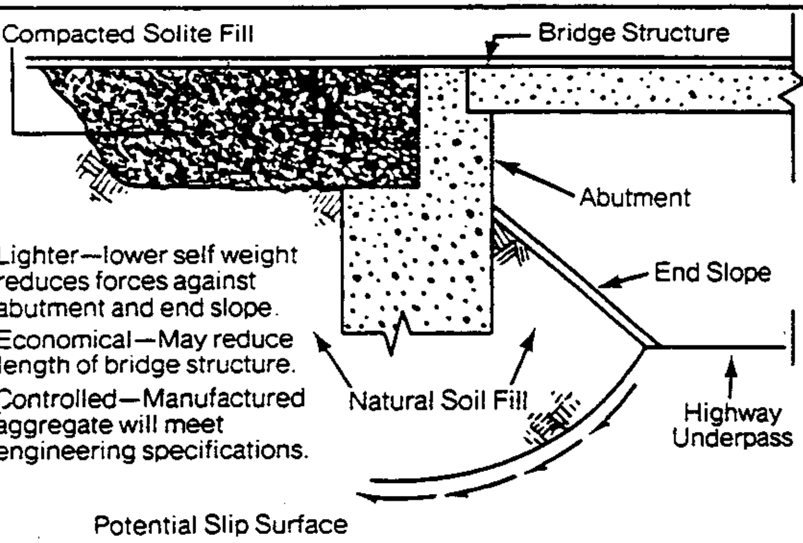
- Safety—lower self weight increases stability and safety factors on slope.
- Control—designer can specify in-place density with assurance using Solite soil fill.
- Drainage—manufactured aggregate is predictably free-draining.
- Surface to surface friction resists movement after compaction.

Controlled Solite Soil Fill Improves Safety of Waterfront Structures



- Safety—lower weight reduces thrust and bending moments on bulkhead.
- Control—designer can specify in-place density with assurance using manufactured Solite soil fill.
- Drainage—manufactured free-draining lightweight aggregate provides controlled permeability.

Controlled Solite Soil Fill Improves End Embankment Stability



- Lighter—lower self weight reduces forces against abutment and end slope.
- Economical—May reduce length of bridge structure.
- Controlled—Manufactured aggregate will meet engineering specifications.

Suggested SOLITE® Soil Fill Specifications

The information listed below is a suggested specification for SOLITE® Lightweight Aggregate soil fill. It is best to consult with SOLITE® engineering and sales representatives during a project's conceptual design phase in order to call for the most appropriate geotechnical and material physical properties.

Materials

Lightweight Aggregate fill shall be SOLITE® Lightweight Aggregate or approved rotary kiln substitute meeting all the requirements of a recently completed (2 years max.) ASTM C-330 certification. No by-product slags or cinders are permitted. Lightweight aggregate shall have a proven record of durability and be non-corrosive (less than 100 ppm chloride when measured by FHWA-RD-77-85) with the following physical properties:

A. Delivered Gradation

Sieve Size	% Retained
1" (25mm)	_____
½" (13mm)	_____
#4 (5mm)	_____

B. The dry loose unit weight shall be less than 55 pcf (880 kg/m³). The lightweight aggregate producer shall submit verification of a compacted density of less than 60 pcf (960 kg/m³) when measured by a one point test conducted in accordance with ASTM D-698 "The Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using a 5.5 lb. Hammer and 12 inch Drop" (AASHTO T-99).

C. The lightweight aggregate producer shall submit verification that the angle of internal friction shall be greater than 40° when measured in a triaxial compression test on a laboratory sample with a minimum diameter of 10 inches.

D. The maximum Los Angeles Abrasion loss when tested in accordance with ASTM C-131 (B grading) shall be 50%.

Solite Lightweight Aggregate Physical Properties

(For more specific data consult with your local Solite Sales or Engineering Representative.)

Bulk Loose Unit Weight

45-60 pcf (720-1120 kg/m³) depending on plant source and gradation. Compacted unit weight will be higher. For compacted density check with local Solite Sales or Engineering Representative.

Gradation

Carefully controlled to meet exacting specifications of masonry and concrete applications. Generally available in coarse ¾" to #4 (20-5mm) and fine ⅜" to 0 (10-0mm). Other sizes have been furnished for special applications, including crusher run clinker 6" to 0 (150-0mm).

Durability

Excellent—concrete specimens have been exposed more than 300 cycles of freeze/thaw without deterioration.

Chemical Stability

Totally inert; all organic materials burned out at 2000°F (1090°C) during expansion process; non-corrosive; insensitive to moisture.

Ask about standard and innovative applications. Call us for Solite samples and physical properties. Solite will provide the assistance you want from any of our offices.

SOLITE®

OFFICES:
P.O. Box 437, Mt. Marion, NY 12456 (914) 246-9571
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P.O. Box 987, Albemarle, NC 28001 (704) 474-3165
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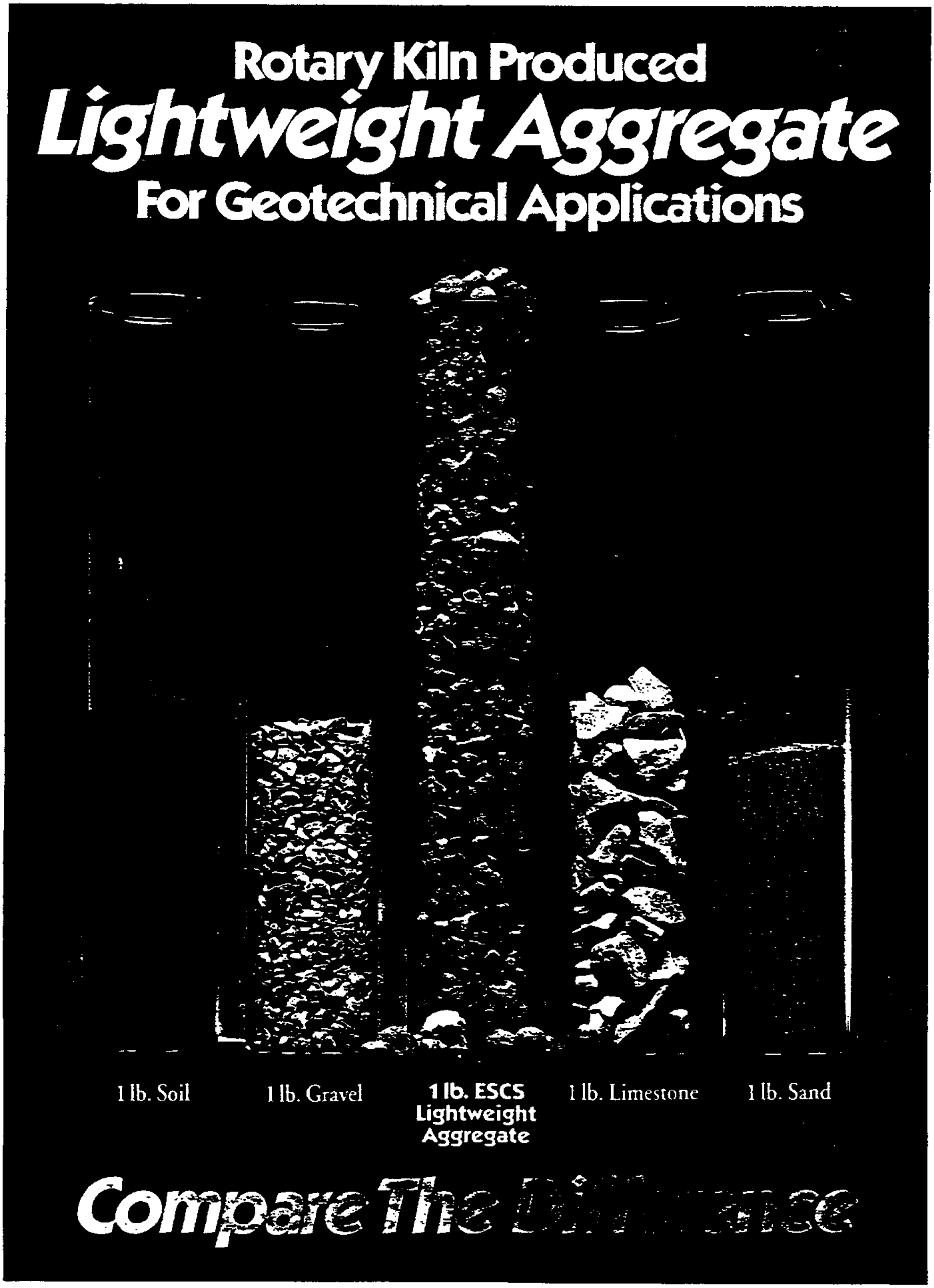
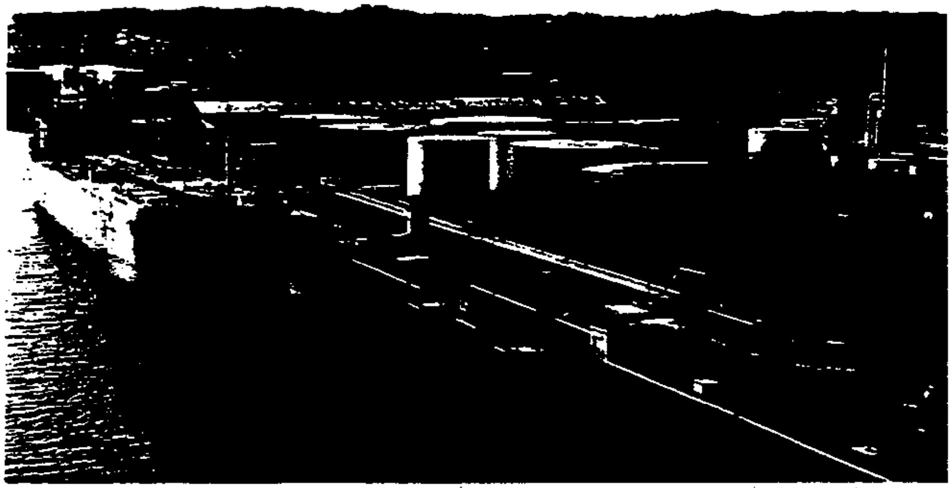
Hubers, KY


Rotary Kiln Produced
Lightweight Aggregate
For Geotechnical Applications
1 lb. Soil
1 lb. Gravel
1 lb. ESCS Lightweight Aggregate
1 lb. Limestone
1 lb. Sand
Compare The

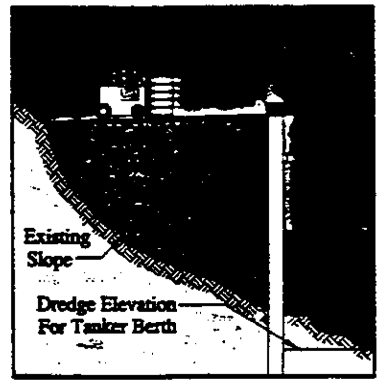


Port of Albany Marine Terminal Expansion ✦ *Albany, New York*
Engineer: Childs Engineering, Inc., Medfield, Mass.

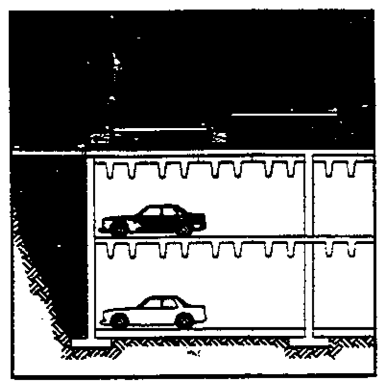
Modifications to the Port Albany Marine Terminal reclaimed an area of approximately 1500' x 80' in an unstable slope area and provided increased dockside draft to permit service by large oil tankers. LWA backfill minimized lateral earth pressures, while also reducing overburden pressures on the sensitive silts. Transportation, placement and compaction of the LWA soil fill was readily accomplished in a minimum time frame and without logistic difficulties. Peak delivery rates were 1300 tons, approximately 55 truck-loads per day.

Retaining Wall Backfill ✦ *Providence Rhode Island*
Engineer: C.E. Maguire Engineers, Mansfield, Mass.

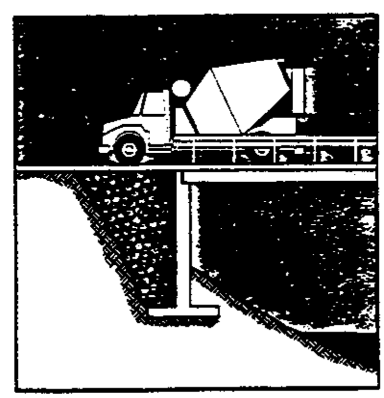
This project involved the construction of a retaining wall behind the Rhode Island State House at the Providence River. The weight of the entire project, including the wall, the backfill, and a future roadway at the top of the wall, was quite significant. With the area's soft clay strata, there were engineering concerns that too much weight might force the existing bulkhead toward the river. The use of approximately 3,500 cubic yards of LWA fill reduced the total project weight so dramatically that the probability of deep seated bulkhead failure was virtually eliminated.



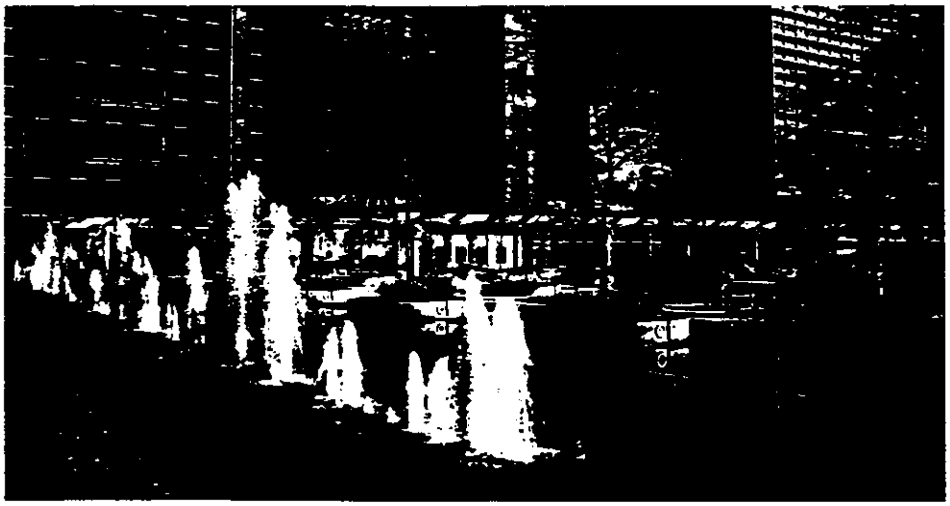
Waterfront Structures
- Allows economical modification to marine terminals
- Allows increased dockside draft
- Reduces lateral thrust/bending moments
- Allows free drainage and control of in-place density



Landscape & Plaza Fills
- Minimizes dead loads
- Free draining helps minimize hydrostatic potential
- More planters and levels can be added
- Easy to transport and install



Bulkheads & Retaining Walls
- Reduces soil thrust as well as bending moments
- Reduces forces against abutment and end slope
- Allows free drainage
- Improves embankment stability

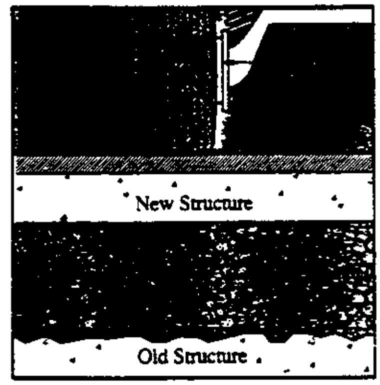


Barney Allis Plaza ❖ *Kansas City, Missouri*
Architect/Engineer: Marshall & Brown Incorporated

6000 cubic yards of LWA (expanded shale) was used as loose granular fill on top of an existing underground parking garage. The material provided subsurface drainage, weight reduction and long term stability. In addition, the LWA material established the grade and contour for a plaza area which was built on top of the parking structure. The LWA material was graded ASTM C330 3/4" x No. 4.

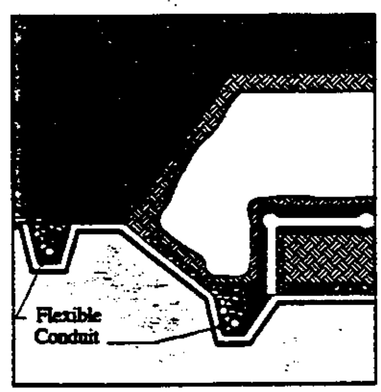
Calgary Pipeline ❖ *Calgary, Canada*
Engineers: City of Calgary / Pildysh & Associates Consultants, Ltd.

Watermains must be installed below the level of frost penetration. In Calgary this requires deep, wide trenches. Such trenches are expensive and often dangerous to workers. The insulating properties of LWA fill allowed engineers to reduce trench depth from 3.3 meters to 2.1 meters. This provided safer working conditions and reliable freeze protection with an environmentally "friendly" material. LWA backfill will also afford easier winter excavation for pipe repair, reduce disruption of water supply and street traffic by decreasing construction time, and eliminate the need for synthetic insulating board and wide trenches. With LWA backfill, present and future savings in capital costs alone are expected to be in the millions.



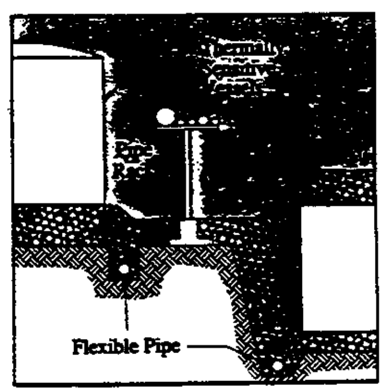
Structure Repair & Rehabilitation

- ❖ Reduces dead load on existing structures
- ❖ Easy transportation and installation increase productivity
- ❖ Precise gradations allow for a uniform and controlled in-place density



Landfill Drainage

- ❖ Inert; high chemical stability
- ❖ Reduces deadloads on pipes
- ❖ Allows free drainage of leachate/water
- ❖ Acid insoluable

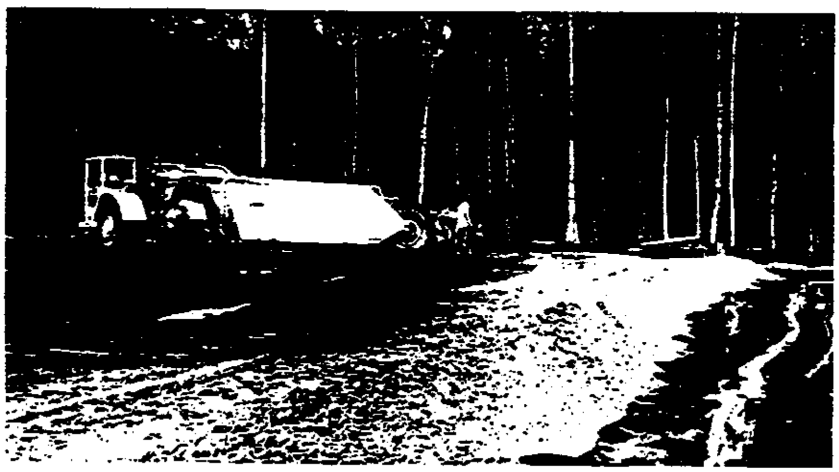


Insulating Backfill

- ❖ Substantially reduces ground movement-induced stresses on buried pipes and structures
- ❖ Counteracts frost heaving, resists freeze/thaw cycles and highly insulative
- ❖ Inert, non-corrosive and stable

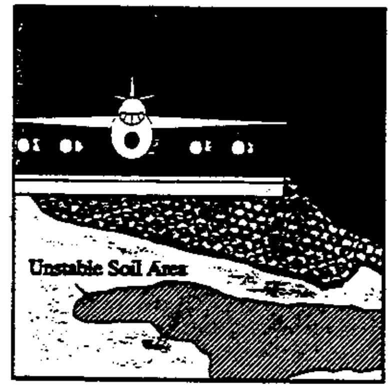
Runway Repair ❖ *Norfolk Naval Air Station* ❖ *Norfolk, Virginia*
Engineer: Patton, Harris, Rust & Associates

Much of this facility was built on marsh land. Poor soil conditions and intense traffic loads produced differential settlements and "alligator" cracking of the taxiway after only 3 years. High soil stability and relief from overburden pressures were provided by substituting compacted LWA for heavy, unstable soil to a depth of 4 feet. LWA material was placed at 6 inch lifts and hand compacted with a vibratory plate. Field compaction and projected yields were monitored using a nuclear densometer. The compacted base was then paved and air traffic restored in a timely manner. Differential settlement was economically solved.



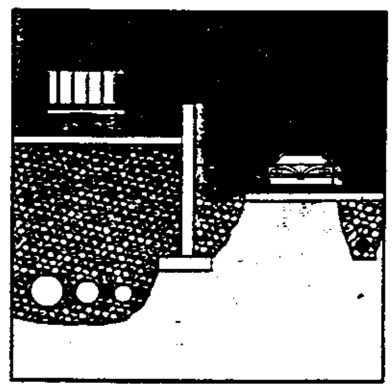
Embankment Fill ❖ *Louisiana DOT D Test Project* ❖ *Morgan City, Louisiana*

Highway embankment fills over unstable soils present particularly difficult problems. Uneven settlement can produce a "Roller Coaster" ride, as well as significant maintenance problems. The Louisiana Department of Transportation and Development constructed a series of roadway test sections with sand fill 9.5 ft. in depth. In one section, 2.5 ft. of sand was replaced with 2.5 ft. of LWA fill. The reduction in weight, coupled with the increase in long term stability provided by the LWA's high angle of internal friction, reduced settlement 40% to 60% as compared to the all-sand fill. Considerable savings in highway maintenance, repairs and replacement can be realized if differential settlement is reduced.



Fills Over Poor Soils & Marsh Lands

- ❖ Allows otherwise unuseable land to be reclaimed and developed
- ❖ Design elevations are achieved with low fill weight
- ❖ Low fill weight increases slope stability
- ❖ Controlled gradations assure uniform and consistent in-place density
- ❖ Long-term settlement is controlled and reduced
- ❖ Controlled fill allows uniform load distribution



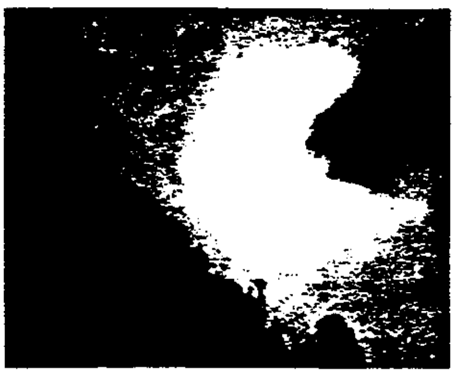
Underground Conduits & Pipelines

- ❖ Reduces dead loads on buried structures
- ❖ Allows construction of higher fills
- ❖ Minimizes hydrostatic potential
- ❖ Provides thermal insulation to underground facilities
- ❖ Economic alternative to flowable fills

Contact a Rotary Kiln Expanded Lightweight Aggregate producer listed on the back of this brochure for complete information and specifications.

THE PROVEN SOLUTION

For almost 50 years Rotary Kiln produced Expanded Lightweight Aggregate (LWA) has been effectively used to solve geotechnical engineering problems and to convert unstable soil into usable land. Lightweight aggregate can reduce the weight of compacted geotechnical fills by up to one-half. Where thermal stability is required, LWA provides significantly greater thermal resistance when compared to soil, sand or gravel fill. It affords permanent economical insulation around water lines, steam lines and any other thermally sensitive vessel. This inert, durable, stable, free-draining and environmentally "friendly" lightweight aggregate is extremely easy to handle and provides economical long term solutions for geotechnical challenges.



THE MATERIAL

Expanded shale, clay and slate lightweight aggregate (LWA) has a long track record of quality and performance. Since its development in the early nineteen hundreds, LWA produced by the rotary kiln process has been used extensively in asphalt road surfaces, concrete bridge decks, high-rise buildings, concrete precast/prestressed elements, concrete masonry and geotechnical applications. The quality of LWA results from a carefully controlled manufacturing process. In a rotary kiln, selectively mined shale, clay or slate is fired in excess of 2000° F. The LWA material is then processed to precise gradations. The result is a high quality, lightweight aggregate that is inert, durable, tough, stable, highly insulative, and free draining, ready to meet stringent structural specifications.

DESIGN ADVANTAGES

- Reduces Dead Loads
- Reduces Lateral Forces
- Reduces Over Turning Forces
- Provides High-Friction Angle
- Controlled Gradations
- Free Draining
- Water Insoluable
- Acid Insoluable
- High Insulation Value
- Chemically Inert
- High Strength & Durability
- Easy to Handle and Install
- Readily Available
- Environmentally "Friendly"

PHYSICAL PROPERTIES

The physical properties for specific types of rotary kiln expanded light-weight aggregate may vary according to manufacturer. For precise information on unit weight, specific gravity, compacted density, friction angle, thermal conductivity and the other physical properties of a particular LWA material, consult the rotary kiln expanded shale, clay or slate producers listed on the back of this brochure.

Expanded Shale, Clay And Slate Institute Members

Expanded shale, clay and slate aggregate, as manufactured by the rotary kiln process, is readily available throughout the United States, Canada and much of the world. The material is economically shipped long distances because its density is less than half that of normal sand and gravel. For further information on the advantages of expanded shale, clay and slate lightweight aggregate fill, contact these aggregate suppliers, or the Expanded Shale, Clay And Slate Institute.

UNITED STATES

Arkalite
West Memphis, AR
(870) 735-7932
Fax (870) 735-5467

Atlanta, Georgia 30350
(404) 804-8070
◊ *Livingston, AL* ◊ *Erwinville, LA*

Buildex, Inc.
PO Box 15
Ottawa, Kansas 66067
(913) 242-2177
◊ *Marquette, KS* ◊ *New Market, MO*
◊ *Ottawa, KS*

Carolina Stalite Company
PO Drawer 1037
Salisbury, North Carolina 28145-1037
(704) 637-1515
◊ *Gold Hill, NC*

Chandler Materials Company
5805 East 15th Street
Tulsa, Oklahoma 74112
(918) 836-9151
◊ *Tulsa, OK* ◊ *Choctaw, OK*

Hydraulic Press Brick Company
705 Olive Street, Suite 924
St. Louis, Missouri 63101
(314) 621-9306
◊ *Brooklyn, IN* ◊ *Cleveland, OH*

Lehigh Portland Cement Company
7960 Donegan Drive, Suite 212
Manassas, Virginia 22110
(703) 330-6003
◊ *Woodsboro, MD*

Norlite Corporation
628 South Saratoga Street
Cohoes, New York 12047
(518) 235-0401
◊ *Cohoes, NY*

UNITED STATES

Pacific Lightweight Products Co.
715 North Central Ave., Suite 101
Glendale, California 91203
(818) 240-5160
◊ *Frazier Park, CA*

Port Costa Materials, Inc.
1800 Sutter, Suite 570
Concord, California 94520
(510) 602-1200
◊ *Port Costa, CA*

Solite Corporation
PO Box 27211
Richmond, Virginia 23261
(804) 321-6761
◊ *Green Cove Springs, FL* ◊ *Brooks, KY*
◊ *Mount Marion, NY* ◊ *Aquadale, NC*
◊ *Cascade, VA* ◊ *Arvonia, VA*

Texas Industries, Inc.
7610 Stemmons Freeway
Dallas, Texas 75247
(214) 647-6700
◊ *Streetman, TX* ◊ *Clodine, TX*

Utelite Corporation
PO Box 387
Coalville, Utah 84017
(801) 467-2800
◊ *Coalville, UT*

JAPAN

Nihon Cement Company, Ltd.
Asano-Lite Div.
Tokyo, Japan

Nihon Mesalite
Industry Company, Ltd.
Chiba-Ken, Japan

CANADA

Cindercrete Products Limited
Victoria & Fleet Street
Regina, Saskatchewan S4P 3A1
(306) 789-2636
◊ *Regina*

Consolidated Concrete Limited
5340 1st Street SW
Calgary, Alberta T2H OC8
(403) 259-3559
◊ *Calgary* ◊ *Edmonton*

Kildonan Concrete Limited
221 Panet Road
Winnipeg, Manitoba R2J OS4
(204) 233-5666
◊ *Winnipeg*

EUROPE

Aker ExClay A.S.
Oslo, Norway

Fratelli Buzzi S.p.A.
Corso Giovane, Italy

Gralex S.A.
Brussels, Belgium

LIAPOR
Lias-Franken Leichtaustoffe
Pautzfeld & Tuningen, Germany

S.M.A.E.
Societa Meridionale Argille
Espanse S.p.A.
Roma, Italy

SOUTH AMERICA

Agregados Livianos C.A.
Caracas, Venezuela

◊ *Location Of Lightweight Aggregate Manufacturing Facility*

Expanded Shale Clay & Slate Institute
2225 East Murray Holladay Rd. Suite 102, Salt Lake City, Utah 84117 • Phone (801) 272-7070 / FAX (801) 272-33
Publication #660

REPORT OF RESULTS
[L8030A]

SUPPLEMENTAL TESTING OF LIGHTWEIGHT AGGREGATES FOR GEOTECHNICAL APPLICATIONS

Submitted To

ARKALITE
P.O. Box 1567
West Memphis, Arkansas 72303

Submitted By

CONSTRUCTION QUALITY CONSULTANTS ®
ENGINEERING - INSPECTION - TESTING
1579 THREE PLACE
MEMPHIS, TENNESSEE 38116

July 22, 1998

REPORT OF RESULTS
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SUPPLEMENTAL TESTING
OF
LIGHTWEIGHT AGGREGATES
FOR
GEOTECHNICAL APPLIÇATIONS

INTRODUCTION

At the request of Mr. Bryan Powers of Arkalite, Construction Quality Consultants, Inc. has performed a series of chemical and physical tests to evaluate the lightweight aggregate materials produced at the client's West Memphis facilities with respect to typical requirements of Specification for Lightweight Aggregate for Geotechnical Fill. These tests have been performed on aggregate materials sampled by the client and delivered to CQC's Memphis laboratory and represent a random sample of routine production.

Following is a listing of the individual tests performed on this aggregate Material:

Test Designation	Title of Standard Procedure
AASHTO T 260	Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials
ASTM C 131	Standard Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine.
FM1-T-096	Florida Modified L.A. Abrasion Test
ASTM D 4253	Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
ASTM D 4254	Standard Test Methods for Minimum Index Desity and Unit Weight of Soils and Calculation of Relative Density
Corps of Engineers EM1110-2-1906 Appendix X	Consolidated Drained Triaxial Test

It should be noted that all testing of lightweight aggregate materials was performed in accordance with applicable Standard Specifications as noted, and acceptance criteria, if shown, is typical for geotechnical fill material applications.

TEST DATA

AASHTO T 260
Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials

Property	As Tested
Acid-Soluble (Total) Chloride Ion Content	< 0.001 %

ASTM C 131
Resistance To Abrasion of Small Size Coarse Aggregate By Use of the Los Angeles Machine

	As Tested	Typical Specification Limits
Percentage Wear	29.4 %	Less Than 45%

Florida DOT Test Method FM1-T 096
Florida Modified Los Angeles Abrasion

	As Tested	Typical Specification Limits
Percentage Wear	24.2 %	Less Than 45%

TEST DATA

ASTM C 136
Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates

Sieve Size	As Tested (% Passing)
3/4 "	100.0
1/2 "	92.4
3/8 "	70.1
No. 4	16.4
No. 8	6.8
No. 16	4.2
No. 50	2.3
No. 100	1.5

ASTM D4253
Maximum Index Density of Soil Using A Vibratory Table

Maximum Index Density = **40.1 pcf**

ASTM D4254
Minimum Index Density of Soil and Calculation of Relative Density

Minimum Index Density = **35.0 pcf**

Commentary of Compaction

Because Arkalite is a free-draining, cohesionless material, field compaction requirements should be expressed as a minimum relative density requirement rather than a minimum percentage of Proctor density. Quantitative in-place density values and resultant compaction values can be obtained in the field using a nuclear moisture-density gauge only after the gauge has been specifically calibrated for this material.

A recommended alternative to quantitative in-place density testing would be a Method-Based Specification containing the following:

1) gradation range
2) maximum lift thickness (loose, prior to compaction)
3) type of compaction equipment
4) number of passes with compaction equipment

Compaction of Arkalite is best accomplished using rubber-tire equipment to avoid particle crushing and degradation caused by steel-track type equipment.

TEST DATA

Corps of Engineers Test Method EM1110-2-1906, Appendix X
Consolidated Drained Triaxial Test

Effective Internal Friction Angle = **40.6°**

Three (3) specimens were molded using a vibratory method with Arkalite in a saturated surface-dry condition. Consolidated drained triaxial testing was performed utilizing consolidating stresses of 0.5, 1.0 and 2.0 kilograms per square centimeter. The resultant effective internal friction angle was determined. Complete laboratory data for this test procedure is available for review, upon request, at CQC's Memphis Office.

Should you have any questions or points needing clarification, feel free to contact our Memphis Office.

Respectfully submitted
CONSTRUCTION QUALITY CONSULTANTS, INC.

All Rocks Are Not Created Equal. . .

STALITE

. . . . STALITE is the High Performance Lightweight Aggregate

A Unique Raw Material . . .

Unlike other slate, shale or clay deposits formed from mineral or organic sediments, the slate used in STALITE was formed from volcanic ash. This volcanic ejecta, free of impurities which were burned away at very high temperatures, was deposited in a wet environment and compressed under extreme pressures for millions of years. The resulting material is an extraordinary slate deposit whose unique properties contribute to making STALITE the very finest **high performance lightweight aggregate** in the world.

Since its formation in 1950 Carolina Stalite Company has been committed to manufacturing the finest quality, high strength, low absorption lightweight aggregate in the world. As a part of this commitment to quality, we procure the highest grades of raw materials, utilize current testing and manufacturing technologies, employ the most knowledgeable and experienced people, and constantly research new approaches that will improve both our process and our product.

As a quality-driven company, we know the value of listening to our customers, our employees and our community. Their observations and suggestions are factored into who we are and what we produce. We have earned their trust and feel a strong sense of responsibility to keep it. Stalite's customers know that they can depend on the quality of our product and our technical services. Our employees can count on the company to provide safe, stable working conditions around which they can plan for the future. Our high ethical standards and long record of socially and environmentally responsible policies allow us to function as a positive influence in the community at large.

The quest for quality has led us to develop a number of patented processes for improved manufacturing of lightweight aggregate. Additionally, from our experience in the operation of dust collectors, we invented a new diffuser that improves their effectiveness. From this invention a new business, *Staclean Diffuser Company*, was born. In 1991, we began to focus our pyro-processing expertise on solving the environmental problem of petroleum contaminated soils. *Stalite Environmental*, a soil remediation company, was formed in 1992 to address this need.

We believe our past to be the best indicator of our future. Built on a strong foundation of quality consciousness, service and dedication to customer satisfaction, Stalite's future is bright. We are committed to the continuing search for improved production methods, innovative applications, and expanded technical knowledge. We set high standards for ourselves and our products. By meeting those standards today, we are better prepared to meet the challenges that lie ahead in the 21st Century.

In view of the global trend toward rebuilding the world's infrastructure, the demand for **high performance lightweight aggregate** is growing. The rugged durability and outstanding performance record of Stalite Lightweight Slate Aggregate make it the clear choice for meeting the international demand for a high quality lightweight material that will consistently meet or exceed the design and engineering parameters for buildings, bridges and highways around the world.

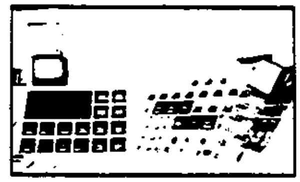
Frances H Johnson

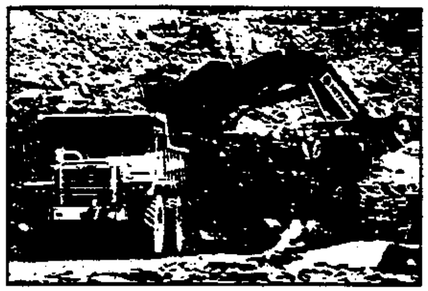
Frances Johnson
Managing Partner

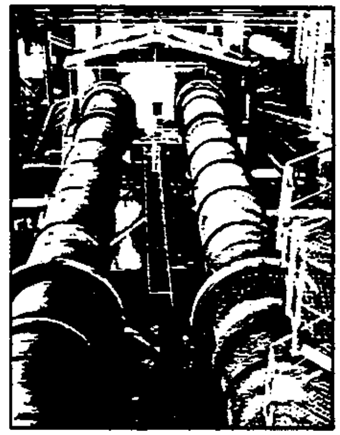
Charles B Newsome

Charles Newsome
Executive Vice President
& General Manager

Process And Quality Control







STALITE is the finest **high performance lightweight aggregate** in the world. Through thermal expansion of high quality slate in rotary kilns, we consistently produce the hardest, most durable, least absorbent lightweight aggregate on the market today. In short, STALITE is lightweight rock of the highest quality.

Driven by quality, Carolina Stalite Company is acutely aware of the critical importance of maintaining high standards throughout its operation. For nearly half a century we have cultivated strong, long-term alliances with suppliers and clients who share our commitment to quality. These relationships help us to optimize our resources, improve communication, and make it possible to consistently meet our customers' needs. We maintain the highest level of customer satisfaction and enjoy undisputed leadership in the **high performance lightweight aggregate** market.

We understand that even though we utilize the finest raw materials and the latest technologies in our production process, it is the dedicated expertise of our employees that ultimately results in the consistent, high performance product we deliver. To maximize this human resource, the company provides on-going training programs in the areas of statistical process control, systems automation, safety, maintenance and customer service.

By monitoring quality at every step in our operation, we provide the assurance that STALITE will be available whenever and wherever it is needed.

Raw Material

At Carolina Stalite, quality considerations begin with the raw material. Slate possesses the high strength and lasting durability necessary to create a superior lightweight aggregate. The quarry is adjacent to our manufacturing plant, and has been geologically and chemically surveyed in order to create a three-dimensional map of the rock quality characteristics. This information serves as a guide for selective mining of the slate that is best suited for the production of STALITE. The quarry's location allows the raw slate to be efficiently conveyed directly to the plant in the most desirable sizes for processing, and minimizes the need to maintain large stockpiles of raw material. Stalite has confirmed reserves of raw material to supply our needs throughout the 21st Century.

Quality Features:

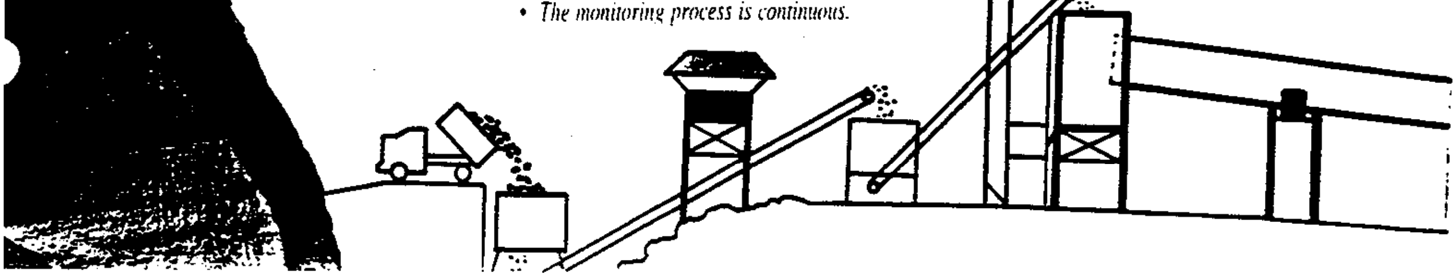
- *Slate is selectively mined to provide raw material that will yield the highest quality STALITE lightweight aggregate.*
- *Reserves of raw material are geologically and chemically analyzed.*
- *Three-dimensional mapping facilitates optimum raw material selection.*
- *Mining plan is based on detected quality features of raw material.*
- *Raw slate is conveyed directly from the quarry to the STALITE plant.*
- *The monitoring process is continuous.*

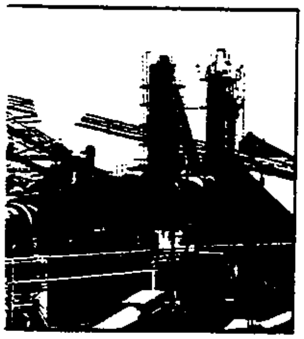
Rotary Kiln Processing

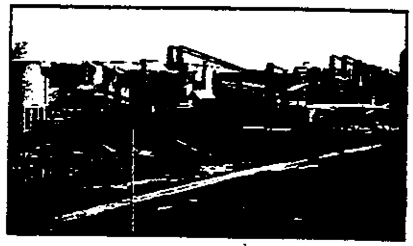
After being crushed to optimum size for processing, the raw slate is fed into Stalite's patented preheater in order to "condition" the rock before entering the rotary kiln. In the kiln, the slate is heated to 2100° F following a temperature profile previously determined in the laboratory. At high temperature the rock becomes plastic and the escaping gases are entrapped. As internal pressure increases, the gases are released, forming small unconnected voids within the bloated stone. When the expanded material cools, the cells remain giving STALITE its unique high performance characteristics: high strength, low weight and low absorption.

Quality Features:

- *High-BTU coals are selected for use and lab tested for thermal properties.*
- *Temperature profiles are precisely controlled to achieve optimum slate expansion.*
- *Expanded material is tested for unit weight variations every 30 minutes.*
- *Expanded material is cooled by a forced-air process to preserve the integrity of the product by minimizing temperature shock.*







Grading

The cooled, expanded slate is conveyed to the classification area. Here it is conditioned to meet weight consistency and particle shape criteria prior to crushing. After crushing, the different size fractions are kept separate. By means of Carolina Stalite's unique automatic controlled blending system, requested 'ations are developed to meet the most stringent grading requirements for our customers. After blending, actual moisture content is automatically adjusted to a predetermined level. Then the STALITE is tested for moisture content, specific gravity and unit weight prior to shipment.

Quality Features:

- *Expanded, uncrushed material is conditioned to maintain a consistent unit weight and uniform particle shape.*
- *Individual size fractions of crushed material are kept separate in color-coded silos for better gradation control.*
- *Automatic blending and moisture control systems allow for the development of consistent and uniform size gradations.*
- *Material is tested for unit weight, specific gravity and moisture content.*

Storage

After testing is completed, STALITE is stored or conveyed directly to trucks or railcars for shipment. Two proven procedures are used to minimize segregation during storage: 1. Fine grades are stored in low-height silos that feature a unique perimeter port feeding developed by Stalite to further minimize segregation. 2. Coarse grades are stored in low-elevation stock piles that feature a moisture control system. Ample controlled storage allows the company to supply on-time delivery for any size project.

Quality Features:

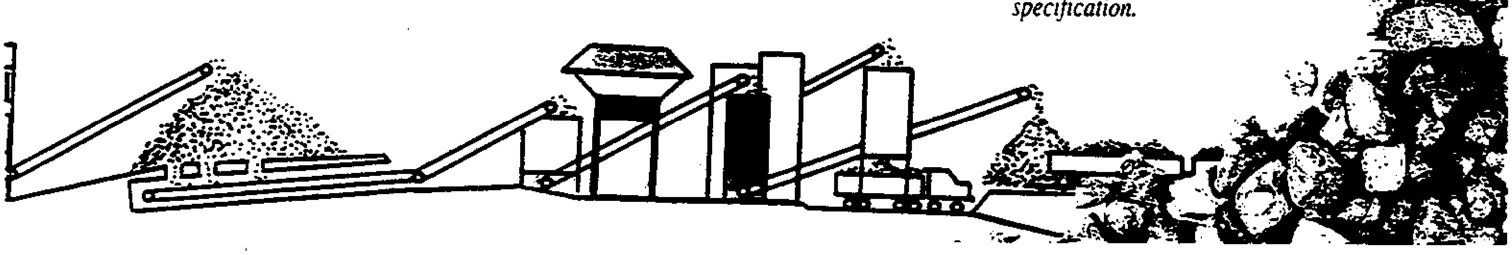
- *Material is thoroughly tested prior to shipping or storing.*
- *Material can be conveyed directly to trucks or railcars.*
- *Fines are stored in low-height, coded silos.*
- *Fine material silos are specially designed to minimize segregation.*
- *Coarse material stockpiles are kept at low height and maintained with adequate moisture levels to provide ready-to-use material.*

Shipping

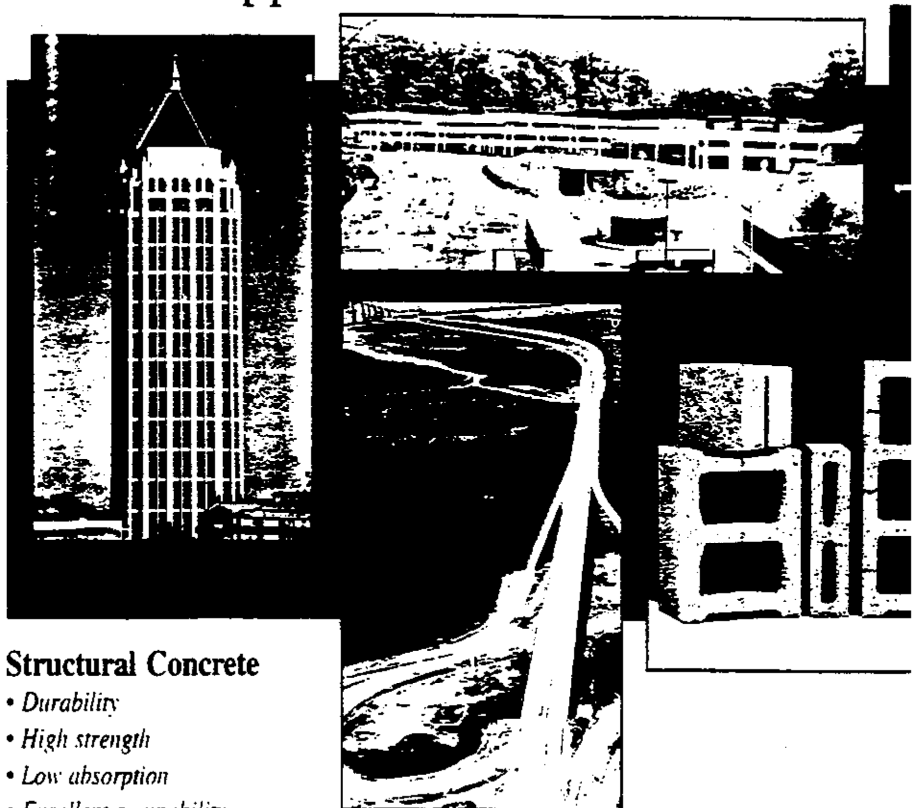
Prior to loading and shipping, trucks and railcars are inspected for cleanliness and washed when needed. Shipping facilities have been designed for versatility, efficiency and high capacity. Our installation allows trucks or railcars to be loaded directly from the conveyor after testing. Railcars and trucks can be loaded simultaneously from both storage silos and stockpiles. A particular procedure is carefully followed when loading material from a stockpile to be certain that aggregate consistency is maintained. A detailed testing program confirms compliance with the customer's specified needs. Efficient and clear communication within Stalite, as well as with customers, assures accurate and timely delivery.

Quality Features:

- *Trucks and railcars are inspected for cleanliness before shipping.*
- *Orders are verified with the client.*
- *Loading facilities are designed for high capacity while maintaining consistency of the material.*
- *A predetermined procedure is followed when loading from stockpiles to minimize segregation and maintain a uniform blend.*
- *Material is verified for compliance to specification.*



High-Performance Properties & Applications



Structural Aggregate, 3/4" (19mm) Physical Characteristics

Density

• Dry Loose (ASTM C29)	48 lbs/cf	769 kg/m³
• Dry Rodded (ASTM C29)	55 lbs/cf	881 kg/m³
• Saturated Surface Dry Loose (ASTM C29)	50 lbs/cf	800 kg/m³
• Maximum Dry Density (ASTM D4253)	60 lbs/cf	961 kg/m³

Specific Gravity

• Dry (ASTM C127)	1.45
• Saturated Surface Dry (ASTM C127)	1.50

Absorption

• Saturated Surface Dry (ASTM C127)	6%
• 1 Hour Boil In Water	8%
• Under high pumping pressure of 150 psi (1033 kPa)	9.4%

Soundness (% Loss)

• Magnesium Sulfate (ASTM C88)	0.01%
• Sodium Sulfate (ASTM C88)	0.23%
• After 25 Cycles Freezing and Thawing (AASHTO T103)	0.22%

Toughness

• Los Angeles Abrasion (AASHTO T96-B)	25%

Stability

• Angle of Internal Friction (Loose)	40°
• Angle of Internal Friction (Compacted)	43°-46°

Impurities

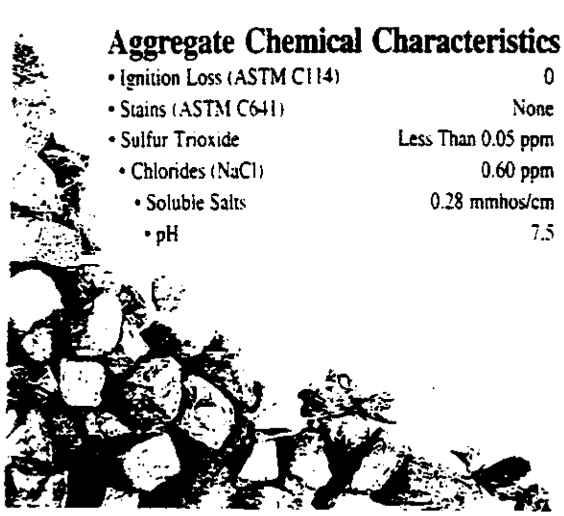
• Clay Lumps (ASTM C142)	0
• Organic Impurities (ASTM C40)	0

Electrical Resistance

• Dry	More than 5 x 10⁵ ohm-cm
• Saturated Surface Dry	2.6 x 10⁵ ohm-cm

Aggregate Chemical Characteristics

• Ignition Loss (ASTM C114)	0
• Stains (ASTM C641)	None
• Sulfur Trioxide	Less Than 0.05 ppm
• Chlorides (NaCl)	0.60 ppm
• Soluble Salts	0.28 mmhos/cm
• pH	7.5



Structural Concrete

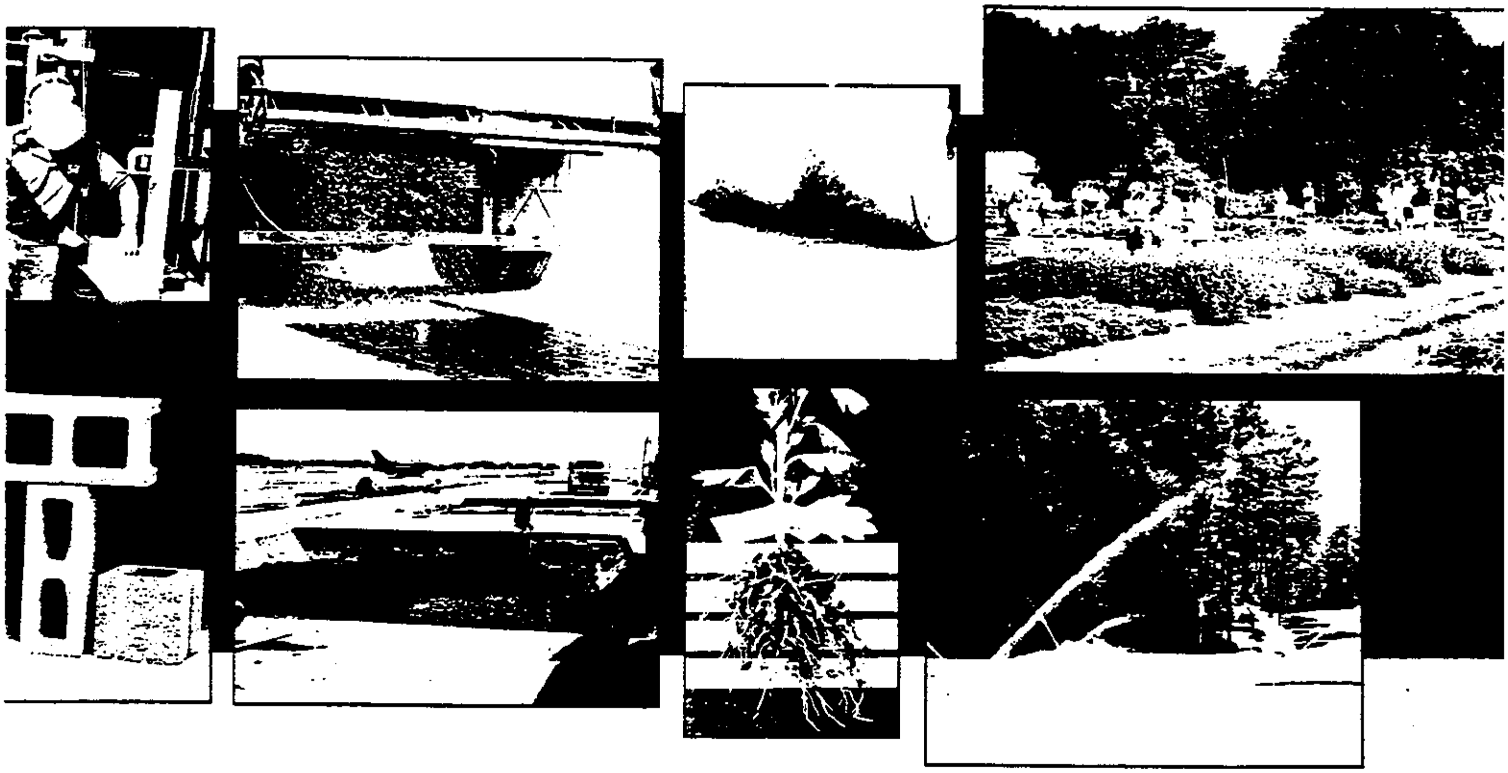
- *Durability*
- *High strength*
- *Low absorption*
- *Excellent pumpability*
- *Lightweight*
- *Fire resistant*

In structural concrete, STALITE is proven to be as good as or better than any normal weight aggregate. The unique nature of STALITE's slate raw material combined with the excellence achieved in its production process, results in an extremely **high performance lightweight aggregate** capable of producing very high strength at low concrete unit weights (up to **30%** less than normal weight concrete). Low absorption of approximately 6% and high particle strength are two of the factors that allow STALITE to achieve high-strength concrete in excess of **12,000 psi (82.7 MPa)**. STALITE's features of strength, durability and toughness have been tested in buildings, bridges and marine structures for almost half a century. The superior bond and compatibility of STALITE with cement paste reduces microcracking and enhances durability. Because of its low absorption, STALITE concretes are easy to mix and to pump over long distances and to higher elevations. In addition, STALITE is easy to finish. Since high strength can be achieved at different unit weight levels, it is particularly suited for both cast-in-place and precast operations.

Masonry

- *High structural strength*
- *Lightweight*
- *Consistent, controlled size gradation*
- *Dependable performance*
- *High productivity*

Masonry units made with STALITE are significantly lighter and easier to install. Compared to heavyweight units of the same size, weight reductions of up to **30%** can be achieved. Unlike aggregates made from by-products and waste, STALITE masonry materials are pure and produced under carefully controlled conditions to assure performance. In addition, the superior strength of STALITE particles make a significant contribution to the overall dimensional stability, reduced shrinkage and toughness of masonry walls. As a result, lighter yet stronger masonry walls can be built in less time. Masonry units of STALITE provide high sound absorption, high insulation values and fire ratings, and create single wythe load-bearing walls that are finished on both sides. These properties increase the value of the investment and extend the life and utility of the structure.



Geotechnical

- *Lightweight*
- *Strong and durable*
- *Stable (high angle of repose)*
- *Chemically inert*
- *Free draining*
- *Consistent, controlled gradations*
- *Economical to transport and place*

STALITE is a cost effective alternative to soil or heavyweight fills in geotechnical applications. Because of its lower weight, about **50%** of normal weight fills, STALITE reduces lateral pressures so that more economical retaining walls can be utilized. Dramatic savings in transportation and placement costs can be achieved since trucks and other equipment can be safely filled to capacity without exceeding weight limits or increasing wear. STALITE's high angle of repose provides very stable, long-lasting geotechnical fills, capable of supporting heavy, repetitive loads. The insulative qualities of STALITE make it a preferred material in applications where thermal sensitivity is a concern.

Asphalt

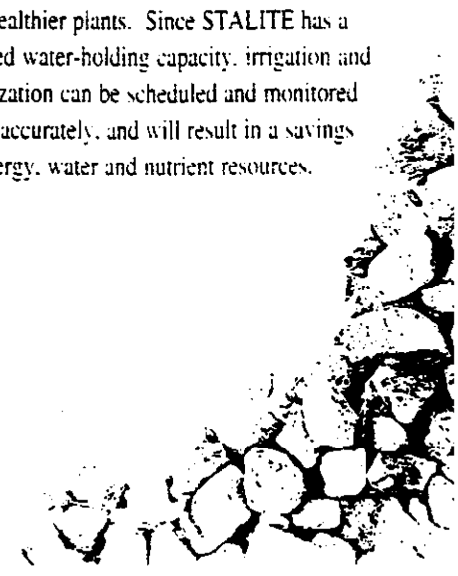
- *Tough and durable*
- *High skid resistance*
- *Low absorption*
- *Lightweight*
- *Consistent, controlled gradations*
- *Economical to transport and place*

In combination with asphalt, STALITE creates safer, longer-wearing road surfaces. The lower unit weight of STALITE affords significant productivity and cost advantages. Compared to heavyweight aggregates, STALITE yields more surface coverage per ton. Considerable savings in transportation and placement cost are achieved by safely filling trucks and paving equipment to capacity without exceeding weight limits. STALITE is non-polishing. As the aggregate surface wears, a new rough surface is exposed, maintaining the superior skid resistance characteristic of STALITE, and minimizing the incidence of hydroplaning. Less road maintenance is required because STALITE provides a superior bond with both asphalt and traffic paint. Unlike heavyweight aggregates, loose lightweight fragments present a dramatically reduced hazard to the windshields and painted surfaces of automobiles.

Horticulture

- *High moisture retention*
- *High aeration capacity*
- *Chemically inert*
- *Non-degradable*
- *Reuseable*
- *Lightweight*
- *Controlled sizes and gradations*

In horticultural applications STALITE can be used as an inert, root propagation medium, or in combination with soils to enhance moisture retention and aeration. STALITE particles will not degrade or compact over time, and will allow for the promotion of strong root growth and healthier plants. Since STALITE has a defined water-holding capacity, irrigation and fertilization can be scheduled and monitored more accurately, and will result in a savings of energy, water and nutrient resources.



Service

The depth and scope of knowledge compiled over nearly 50 years of experience in producing and utilizing STALITE makes our team of lightweight aggregate professionals exceptionally well qualified as materials and product consultants. We are prepared to provide advice and assistance to designers, specifiers, producers, developers and owners regarding materials evaluation, development of customized gradations, mix design optimization, and field and on-site technical support.

Additionally, we provide economic studies of construction alternatives, life-cost analysis, and energy conservation, and conduct training and technical seminars on the implementation of statistical process controls.

The quality of Carolina Stalite Company is directly reflected by the quality of both its products and its representatives. We believe that means we are meeting our goals to manufacture the finest **high performance lightweight aggregate**, to provide state-of-the-art technical assistance, and to work tirelessly to assure that our customers are consistently satisfied. At Stalite, the only thing stronger than our product is our dedication.

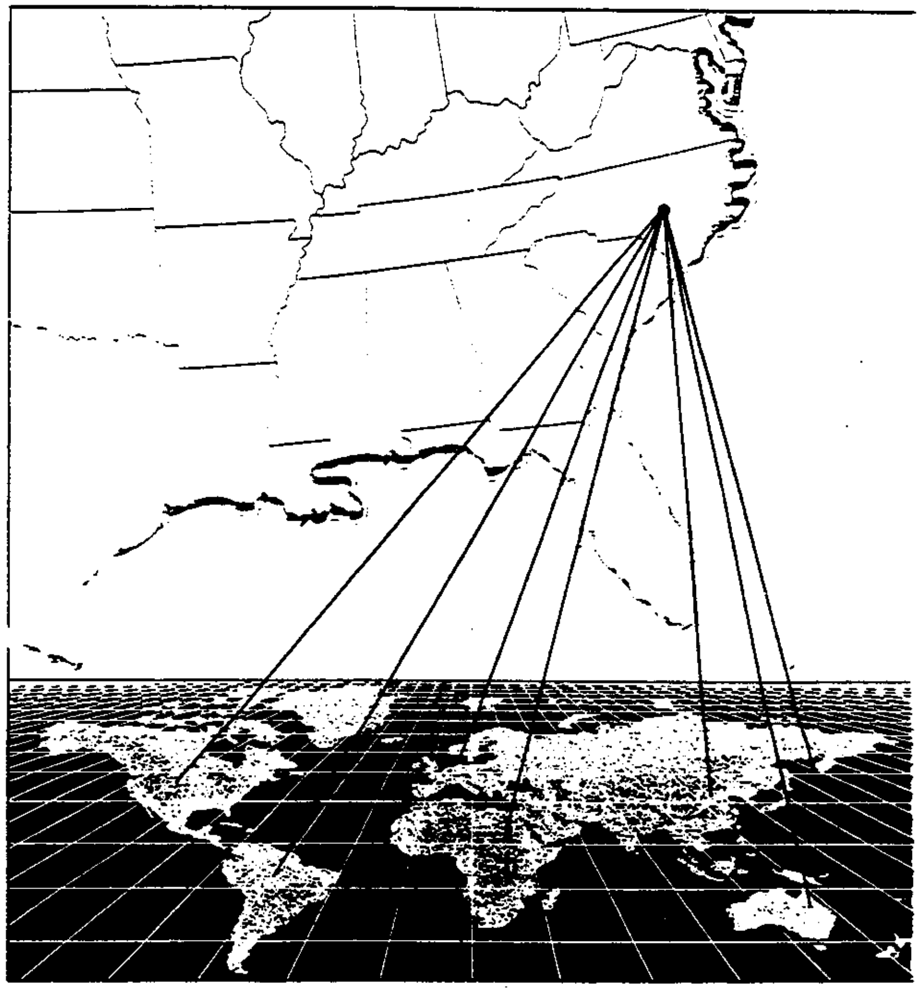
Location

The Carolina Stalite Company enjoys the advantages of a central east coast location. This beneficial geographic position provides quick and easy access to highways and rail lines serving the United States and Canada, and opens overseas markets to us through nearby ports. The advantage to our customers is one of reduced shipping cost and response time.

Users

The long record of dependable performance of STALITE lightweight aggregate, coupled with the excellent technical support provided by the company, has earned us broad-based customer loyalty.

In the United States and Canada, as well as in Europe and Asia, STALITE has proven to be the lightweight aggregate that sets the mark for **high performance lightweight aggregates:** *high durability, low absorption, high strength, superior consistency, and low weight.* Wheth the project is a building, a bridge, fill for a retaining wall, a road surface treatment or a manufactured product, STALITE is the preferred choice of designers, specifiers, product manufacturers, contractors, owners ar researchers. Once you try STALITE and enj the benefits of our quality service, you will be glad to be a part of our **High Performance Team**.



STALITE

Carolina Stalite Company

(**Plant**) Old Beatties Ford Road • Gold Hill, NC 28071 • 704-279-2166 • Fax 704-279-6603
(**Office**) 205 Klumac Road • PO Box 1037 • Salisbury, NC 28145-1037 • 704-637-1515 • Fax 704-638-0742

BUILDEX
Haydite *Expanded Shale*
Lightweight Aggregate

Buildex Expanded Shale Lightweight Aggregate for Geotechnical Fill

For geotechnical fill work, we recommend using a 1/2" x No. 4 gradation meeting ASTM C330 "Standard Specification for Lightweight Aggregates for Structural Concrete".

Following are typical physical properties of Buildex 1/2" x No. 4 aggregate produced at our New Market Missouri plant:

Unit weight (1): Loose: 43 lb/cu ft Compacted: 48 lb/cu ft

(1) Density at normal moisture content (6%) as delivered. Add 20% if aggregate is assumed to be in a water saturated state.

Angle of Internal Friction: 38 to 42 degrees

California Bearing Ratio (CBR): 10

The CBR test showed a linear stress-strain curve to over 300 psi stress. The unit weight and density tests are typical for our New Market MO plant Buildex. The friction and CBR tests were run on an expanded shale similar in physical properties to Buildex, but not actually produced by us.

We are always interested in working with designers on geotechnical applications for Buildex expanded shale lightweight aggregate. If further testing for mechanical properties is needed, please let us know. In the meantime, please call if you have any questions or if we can be of any further assistance.

11/14/96

Buildex, Inc. P.O. Box 77 Ottawa, KS 66067-0077
Tel (785) 242-2177 Fax (785) 242-1281
Toll Free (888)-HAYDITE (429-3483)
www.buildex.com

APPENDIX B: Comparison of Horizontal Earth Pressure caused by Different Types of Lightweight Aggregate

Calculations Showing Variation in Soil Pressure and Bending Moments with Dry Compacted Unit Weight and Angle of Internal Friction for The Different Types Of Lightweight Aggregates

- Natural Granular Fill
- Norlite
- Solite
- Stalite
- Buildex
- Utelite – Data was not available
- Gravelite – Data was not available

Horizontal Earth Pressure

Length of base L (feet) =	93.427
L_b (feet) =	85.94
z (feet) =	29.467
β (degrees) =	0

	φ (degrees)	γ (pcf)	W_b	H_z (K/ft)	M_z (K-Ft/Ft)
Natural Granular Fill	42	146	28.9414	11.558	113.527
Norlite	53	45.5	5.09391	2.034	19.982
Solite	40	60	13.0466	5.210	51.177
Stalite	40	55	11.9594	4.776	46.912
Buildex	42	48	9.51497	3.800	37.324
Arkalite	40.6	40.1	8.48326	3.388	33.277

$$W_b = \gamma \cos \beta \frac{\cos \beta - (\cos^2 \beta - \cos^2 \phi)^{1/2}}{\cos \beta + (\cos^2 \beta - \cos^2 \phi)^{1/2}}$$

APPENDIX C: Stability Check for Existing Abutment Wall

Stability Check For Existing Abutment

Section	Dimensions			Area	Unit Weight	Load (P)	Moment Arm (	Resisting Moment
	L (ft)	H (ft)	Multiplier					
A	1	4	1.0	4	0.15	0.60	2.00	1.20
B	2.5	4	0.5	5	0.15	0.75	2.67	2.00
C	4.5	5.5	1.0	25	0.15	3.71	6.25	23.20
D	1.5	9.5	1.0	14	0.15	2.14	13.25	28.32
E	4	9.5	0.5	19	0.15	2.85	11.67	33.26
F	1.5	28	1.0	42	0.15	6.30	4.75	29.93
G	3	28	0.5	42	0.15	6.30	6.50	40.95
H	2.5	4	0.5	5	0.12	0.60	1.33	0.80
I	4	8	1.0	32	0.12	3.84	2.00	7.68
J	3	28	0.5	42	0.12	5.04	7.50	37.80
K	9.5	28	1.0	266	0.12	31.92	13.25	422.94
L	4	9.5	0.5	19	0.12	2.28	14.83	33.81
					$\Sigma P =$	66.33	$\Sigma M =$	661.89

$P_{HDL} =$	17.33	K
$P_{HDL + LL\ SUR} =$	19.67	K
$M_{OT\ DL} =$	210.43	K-ft
$M_{OT\ DL + LL\ SUR} =$	249.71	K-ft

	Calculated	Allowable	Status
F.S.SLIP $_{DL}$ =	1.72	1.5	**ACCEPTABLE**
F.S.SLIP $_{DL + LL\ SUR}$ =	1.52	1.5	**ACCEPTABLE**
F.S. OVERTURNING $_{DL}$ =	3.15	2	**ACCEPTABLE**
F.S. OVERTURNING $_{DL + LL\ SUR}$ =	2.65	2	**ACCEPTABLE**

APPENDIX D

Calculations showing Variation of Stress Levels caused by the Foundation Base on the Soil due to the Compacted Unit Weight and Angle of Repose for Different Types of Lightweight Aggregates

Summary of Technical Data
Natural Granular Fill

Summary of Weight of Superstructure		
Total Weight of Steel	119,320	lbs
Roadway Slab	262,284	lbs
Roadway Haunch	5,348	lbs
Sidewalk Slab	206,263	lbs
Parapet	51,300	lbs
Protective Barrier	69,152	lbs
Protective Fence	2,052	lbs
Utility Weight	34,679	lbs
Total Weight of Superstructure	750,398	lbs
	750.398	Kips

Summary of Geotechnical Properties of Aggregate		
Angle of internal friction (ϕ) =	42	degrees
Unit Weight of Soil (γ) =	146	pcf
Height of wall (z) =	29.467	ft
Surchage =	150	lb/ft

Stabilizing Forces

Section	Dimensions				Unit Weight (lb/ft)	Total Force (K)	Force/ft (K/ft)	Moment Arm (ft)	Moment (K-ft/ft)
	L (ft)	W (ft)	H (ft)	Multiplier					
1	91.79	1.25	1.75	1.0	0.15	30.12	0.322	5.375	1.733
2	91.79	0.75	3.467	1.0	0.15	35.80	0.383	6.375	2.443
3	91.79	0.917	3.467	1.0	0.15	43.77	0.469	5.541	2.596
4	91.79	1.667	1.5	1.0	0.15	34.43	0.369	5.917	2.180
5	91.79	1.667	2.5	0.5	0.15	28.69	0.307	5.639	1.732
6	91.79	2.083	23.5	1.0	0.15	673.97	7.214	4.042	29.159
7	91.79	1.667	19.5	0.5	0.15	223.78	2.395	5.639	13.507
8	93.427	16	2.5	1.0	0.15	560.56	6.000	8.000	48.000
9	91.79	0.333	0.33	0.5	0.15	0.76	0.008	4.816	0.039
10	85.94	7.467	9.25	1.0	0.146	866.63	9.276	11.375	105.515
11	85.94	1.667	2.5	0.5	0.146	26.15	0.280	6.194	1.733
12	85.94	1.667	19.5	0.5	0.146	203.93	2.183	6.194	13.520
13	85.94	9.25	19.5	1.0	0.146	2,263.21	24.224	11.375	275.552
14	85.94	10	1.027	1.0	0.146	128.91	1.380	11.000	15.178
E. Wing Wall	27.57	2.125	14.76	1.0	0.15	129.71	1.388	11.500	15.966
W. Wing Wall	27.57	2.375	14.76	1.0	0.15	144.97	1.552	11.500	17.844
						ΣV =	**57.750**	ΣM =	**546.698**

Horizontal Earth Pressure

Angle of internal friction (ϕ) =	42	degrees
(ϕ) =	0.7330	radians
cos ϕ =	0.7431	
$\cos^2 \phi$ =	0.5523	
β =	0	degrees
β =	0	radians
cos β =	1.0000	
$\cos^2 \beta$ =	1.0000	
Unit Weight of Soil (γ) =	146	pcf
Height of wall (z) =	29.467	ft
W_b =	28.94	pcf/ft
Horizontal Thrust of Soil (H_z) =	1,079,832	lb
(Hz) =	11.558	k/ft
Moments due to Soil Thrust ($M_{z)}$ =	113.527	ft K/ft
Dead Load Surcharge		
Dead Load Surcharge (DLS) =	2,839.88	lb/ft
(DLS) =	2.84	K/ft
Dead Load Surcharge Moments (DLSM) =	41,841	lb/ft
(DLSM) =	41.841	K/ft

$$W_b = \gamma \cos \beta \frac{\cos \beta - (\cos^2 \beta - \cos^2 \phi)^{1/2}}{\cos \beta + (\cos^2 \beta - \cos^2 \phi)^{1/2}}$$

Summary of Forces

Stabilizing Forces

Load Description	Force (K/ft)	Moment (K ft/ft)
Dead Loads, Backfill, or Surchage	57.750	546.698
Dead Load Reaction From Superstructure	4.016	16.06
Live Load Reaction From Superstructure (3 Lane)	1.783	7.131
Live Load Reaction From Superstructure (2 Lane)	1.321	5.283

Overturning Forces

Load Description	Force (K/ft)	Moment (K ft/ft)
Earth Pressure	11.558	113.53
Wind Load	0.262	7.92
Wind on Live Load	0.050	2.024
Temperature	0.850	22.95
Longitudinal Force (5% LL) (3 Lanes)	0.028	1.022
Earthquake	0.402	10.53
Dead Load Surchage	1.280	18.852
Longitudinal Force (5% LL) (2 Lanes)	0.021	0.757

Load Combination Investigation

2 Lane Loading

Service Load Analysis

	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	57.75		57.75	57.75	57.75	57.75	57.75	57.75	57.75
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.32				1.32	1.32		1.32	
	Total Vertical	63.09		61.77	61.77	63.09	63.09	61.77	63.09	61.77
	Total Moment$_V$	568.04		562.76	562.76	568.04	568.04	562.76	568.04	562.76
Horizontal	Earth	11.56		11.56	11.56	11.56	11.56	11.56	11.56	11.56
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	12.84		12.84	13.10	13.21	13.69	13.95	14.06	13.24
	Total Moment$_H$	132.38		132.38	140.30	135.46	155.33	163.25	158.41	142.91
	% Stress	100		-	106	102	117	123	120	108

e	1.09		1.03	1.16	1.14	1.46	1.53	1.51	1.20
F.S. Sliding	2.21		2.17	2.12	2.15	2.07	1.99	2.02	2.10
F.S. Overturning	4.29		4.25	4.01	4.19	3.66	3.45	3.59	3.94

Load Combination Investigation

3 Lane Loading

Service Load Analysis

	Load \ Group	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	57.75		57.75	57.75	57.75	57.75	57.75	57.75	57.75
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.78				1.78	1.78		1.78	
	Total Vertical	63.55		61.77	61.77	63.55	63.55	61.77	63.55	61.77
	Total $Moment_V$	568.04		562.76	562.76	568.04	568.04	562.76	568.04	562.76
Horizontal	Earth	11.56		11.56	11.56	11.56	11.56	11.56	11.56	11.56
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	12.84		12.84	13.10	13.21	13.69	13.95	14.06	13.24
	Total $Moment_H$	132.38		132.38	140.30	135.72	155.33	163.25	158.67	142.91
	% Stress	100		-	106	103	117	123	120	108

	I	IA	IB	II	III	IV	V	VI	VII
e	1.14		1.03	1.16	1.20	1.51	1.53	1.56	1.20
F.S. Sliding	2.23		2.17	2.12	2.16	2.09	1.99	2.03	2.10
F.S. Overturning	4.29		4.25	4.01	4.19	3.66	3.45	3.58	3.94

Bearing Pressure Investigation

Length of Base (L)=	16 ft

Minimum and Maximum Bearing Pressure 2 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	63.09	61.77	61.77	63.09	63.09	61.77	63.09	61.77
e (ft)	1.09	1.03	1.16	1.14	1.46	1.53	1.51	1.20
Moment (K-ft)	69.03	63.75	71.67	72.11	91.98	94.62	95.06	74.28
ε_{max} (KSF)	5.56	5.35	5.54	5.63	6.10	6.08	6.17	5.60
ε_{min} (KSF)	2.32	2.37	2.18	2.25	1.79	1.64	1.71	2.12

Minimum and Maximum Bearing Pressure 3 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	63.55	61.77	61.77	63.55	63.55	61.77	63.55	61.77
e (ft)	1.14	1.03	1.16	1.20	1.51	1.53	1.56	1.20
Moment (K-ft)	72.73	63.75	71.67	76.08	95.68	94.62	99.03	74.28
ε_{max} (KSF)	5.68	5.35	5.54	5.75	6.21	6.08	6.29	5.60
ε_{min} (KSF)	2.27	2.37	2.18	2.19	1.73	1.64	1.65	2.12

ε_{max} (KSF)	6.29	ε_{min} (KSF)	1.64
ε_{max} (TSF)	3.15	ε_{min} (TSF)	0.82

Maximum Allowable Soil Bearing (TSF)	4.00	
Allowable Factor of Safety for Bearing	1.50	
Calculated Factor of Safety	1.27	**UNACCEPTBLE**

Design Summary

Angle of internal friction of soil (ϕ) =	42	degrees
Unit Weight of Soil (δ) =	146	lb/ft

Maximum Allowable Soil Bearing (TSF)	4.00
Maximum Stress On Base (TSF)	3.15
Minimum Stress on Base (TSF)	0.82

	Allowable	Calculated	Status
Factor of Safety Against Sliding	1.5	1.99	**ACCEPTABLE**
Factor of Safety Against Overtuning	2.0	3.45	**ACCEPTABLE**
Factor of Safety Against Bearing Pressure	1.5	1.27	**UNACCEPTBLE**

Summary of Technical Data
Norlite Lightweight Aggregate

Summary of Weight of Superstructure		
Total Weight of Steel	119,320	lbs
Roadway Slab	262,284	lbs
Roadway Haunch	5,348	lbs
Sidewalk Slab	206,263	lbs
Parapet	51,300	lbs
Protective Barrier	69,152	lbs
Protective Fence	2,052	lbs
Utility Weight	34,679	lbs
Total Weight of Superstructure	750,398	lbs
	750.398	Kips

Summary of Geotechnical Properties of Aggregate		
Angle of internal friction (ϕ) =	53	degrees
Unit Weight of Soil (γ) =	45.5	pcf
Height of wall (z) =	29.467	ft
Surchage =	150	lb/ft

Stabilizing Forces

Section	Dimensions				Unit Weight (lb/ft)	Total Force (K)	Force/ft (K/ft)	Moment Arm (ft)	Moment (K-ft/ft)
	L (ft)	W (ft)	H (ft)	Multiplier					
1	91.79	1.25	1.75	1.0	0.15	30.12	0.322	5.375	1.733
2	91.79	0.75	3.467	1.0	0.15	35.80	0.383	6.375	2.443
3	91.79	0.917	3.467	1.0	0.15	43.77	0.469	5.541	2.596
4	91.79	1.667	1.5	1.0	0.15	34.43	0.369	5.917	2.180
5	91.79	1.667	2.5	0.5	0.15	28.69	0.307	5.639	1.732
6	91.79	2.083	23.5	1.0	0.15	673.97	7.214	4.042	29.159
7	91.79	1.667	19.5	0.5	0.15	223.78	2.395	5.639	13.507
8	93.427	16	2.5	1.0	0.15	560.56	6.000	8.000	48.000
9	91.79	0.333	0.33	0.5	0.15	0.76	0.008	4.816	0.039
10	85.94	7.467	9.25	1.0	0.0455	270.08	2.891	11.375	32.883
11	85.94	1.667	2.5	0.5	0.0455	8.15	0.087	6.194	0.540
12	85.94	1.667	19.5	0.5	0.0455	63.55	0.680	6.194	4.214
13	85.94	9.25	19.5	1.0	0.0455	705.31	7.549	11.375	85.874
14	85.94	10	3.297	1.0	0.0455	128.91	1.380	11.000	15.178
E. Wing Wall	27.57	2.125	14.76	1.0	0.15	129.71	1.388	11.500	15.966
W. Wing Wall	27.57	2.375	14.76	1.0	0.15	144.97	1.552	11.500	17.844
						$\Sigma V =$	**32.994**	$\Sigma M =$	**273.888**

Horizontal Earth Pressure

Angle of internal friction (ϕ) =	53	degrees
(ϕ) =	0.9250	radians
$\cos\phi$ =	0.6018	
$\cos^2\phi$ =	0.3622	
β =	0	degrees
β =	0	radians
$\cos\beta$ =	1.0000	
$\cos^2\beta$ =	1.0000	
Unit Weight of Soil (γ) =	45.5	pcf
Height of wall (z) =	29.467	ft
W_b =	5.09	pcf/ft
Horizontal Thrust of Soil (H_z) =	190,059	lb
(Hz) =	2.034	k/ft
Moments due to Soil Thrust ($M_{z)}$ =	19.982	ft K/ft
Dead Load Surcharge		
Dead Load Surcharge (DLS) =	499.84	lb/ft
(DLS) =	0.50	K/ft
Dead Load Surcharge Moments (DLSM) =	7,364	lb/ft
(DLSM) =	7.364	K/ft

$$W_b = \gamma \cos\beta \frac{\cos\beta - (\cos^2\beta - \cos^2\phi)^{1/2}}{\cos\beta + (\cos^2\beta - \cos^2\phi)^{1/2}}$$

Summary of Forces

Stabilizing Forces		
Load Description	Force (K/ft)	Moment (K ft/ft)
Dead Loads, Backfill, or Surchage	32.994	273.888
Dead Load Reaction From Superstructure	4.016	16.06
Live Load Reaction From Superstructure (3 Lane)	1.783	7.131
Live Load Reaction From Superstructure (2 Lane)	1.321	5.283

Overturning Forces		
Load Description	Force (K/ft)	Moment (K ft/ft)
Earth Pressure	2.034	19.98
Wind Load	0.262	7.92
Wind on Live Load	0.050	2.024
Temperature	0.850	22.95
Longitudinal Force (5% LL) (3 Lanes)	0.028	1.022
Earthquake	0.402	10.53
Dead Load Surchage	1.280	18.852
Longitudinal Force (5% LL) (2 Lanes)	0.021	0.757

Load Combination Investigatior

2 Lane Loading

	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
					Service Load Analysis					
VERTICAL	DL, Bkfill, DLS	32.99		32.99	32.99	32.99	32.99	32.99	32.99	32.99
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.32				1.32	1.32		1.32	
	Total Vertical	38.33		37.01	37.01	38.33	38.33	37.01	38.33	37.01
	Total $Moment_V$	295.23		289.95	289.95	295.23	295.23	289.95	295.23	289.95
Horizontal	Earth	2.03		2.03	2.03	2.03	2.03	2.03	2.03	2.03
	WL				0.26	0.30		0.26	0.30	
	WII					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	3.31		3.31	3.58	3.69	4.16	4.43	4.54	3.72
	Total $Moment_H$	38.83		38.83	46.75	41.91	61.78	69.70	64.86	49.36
	% Stress	100		-	120	108	159	179	167	127

e	1.31		1.22	1.43	1.39	1.91	2.05	1.99	1.50
F.S. Sliding	5.20		5.03	4.66	4.68	4.14	3.76	3.80	4.48
F.S. Overturning	7.60		7.47	6.20	7.04	4.78	4.16	4.55	5.87

Load Combination Investigation

3 Lane Loading

Service Load Analysis

	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	32.99		32.99	32.99	32.99	32.99	32.99	32.99	32.99
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.78				1.78	1.78		1.78	
	Total Vertical	38.79		37.01	37.01	38.79	38.79	37.01	38.79	37.01
	Total $Moment_V$	295.23		289.95	289.95	295.23	295.23	289.95	295.23	289.95
Horizontal	Earth	2.03		2.03	2.03	2.03	2.03	2.03	2.03	2.03
	WL				0.26	0.30		0.26	0.30	
	WII					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	3.31		3.31	3.58	3.69	4.16	4.43	4.54	3.72
	Total $Moment_H$	38.83		38.83	46.75	42.18	61.78	69.70	65.13	49.36
	% Stress	100		-	120	109	159	179	168	127

	I	IA	IB	II	III	IV	V	VI	VII
e	1.39		1.22	1.43	1.48	1.98	2.05	2.07	1.50
F.S. Sliding	5.27		5.03	4.66	4.74	4.19	3.76	3.85	4.48
F.S. Overturning	7.60		7.47	6.20	7.00	4.78	4.16	4.53	5.87

Bearing Pressure Investigation

Length of Base (L)=	16 ft

Minimum and Maximum Bearing Pressure 2 Lane Load								
	IA	IB	II	III	IV	V	VI	VII
R (K)	38.33	37.01	37.01	38.33	38.33	37.01	38.33	37.01
e (ft)	1.31	1.22	1.43	1.39	1.91	2.05	1.99	1.50
Moment (K-ft)	50.25	44.97	52.89	53.34	73.20	75.84	76.29	55.50
ε_{max} (KSF)	3.57	3.37	3.55	3.65	4.11	4.09	4.18	3.61
ε_{min} (KSF)	1.22	1.26	1.07	1.15	0.68	0.54	0.61	1.01

Minimum and Maximum Bearing Pressure 3 Lane Load								
	IA	IB	II	III	IV	V	VI	VII
R (K)	38.79	37.01	37.01	38.79	38.79	37.01	38.79	37.01
e (ft)	1.39	1.22	1.43	1.48	1.98	2.05	2.07	1.50
Moment (K-ft)	53.95	44.97	52.89	57.30	76.90	75.84	80.25	55.50
ε_{max} (KSF)	3.69	3.37	3.55	3.77	4.23	4.09	4.31	3.61
ε_{min} (KSF)	1.16	1.26	1.07	1.08	0.62	0.54	0.54	1.01

ε_{max} (KSF)	4.31	ε_{min} (KSF)	0.54
ε_{max} (TSF)	2.15	ε_{min} (TSF)	0.27

Maximum Allowable Soil Bearing (TSF)	4.00	
Allowable Factor of Safety for Bearing	1.50	
Calculated Factor of Safety	1.86	**ACCEPTABLE**

Design Summary

Angle of internal friction of soil (ϕ) =	53	degrees
Unit Weight of Soil (δ) =	45.5	lb/ft

Maximum Allowable Soil Bearing (TSF)	4.00
Maximum Stress On Base (TSF)	2.15
Minimum Stress on Base (TSF)	0.27

	Allowable	Calculated	Status
Factor of Safety Against Sliding	1.5	3.76	**ACCEPTABLE**
Factor of Safety Against Overtuning	2.0	4.16	**ACCEPTABLE**
Factor of Safety Against Bearing Pressure	1.5	1.86	**ACCEPTABLE**

Summary of Technical Data Solite Lightweight Aggregate

Summary of Weight of Superstructure		
Total Weight of Steel	119,320	lbs
Roadway Slab	262,284	lbs
Roadway Haunch	5,348	lbs
Sidewalk Slab	206,263	lbs
Parapet	51,300	lbs
Protective Barrier	69,152	lbs
Protective Fence	2,052	lbs
Utility Weight	34,679	lbs
Total Weight of Superstructure	750,398	lbs
	750.398	Kips

Summary of Geotechnical Properties of Aggregate		
Angle of internal friction (ϕ) =	40	degrees
Unit Weight of Soil (γ) =	60	pcf
Height of wall (z) =	29.467	ft
Surchage =	150	lb/ft

Stabilizing Forces

Section	Dimensions				Unit Weight (lb/ft)	Total Force (K)	Force/ft (K/ft)	Moment Arm (ft)	Moment (K-ft/ft)
	L (ft)	W (ft)	H (ft)	Multiplier					
1	91.79	1.25	1.75	1.0	0.15	30.12	0.322	5.375	1.733
2	91.79	0.75	3.467	1.0	0.15	35.80	0.383	6.375	2.443
3	91.79	0.917	3.467	1.0	0.15	43.77	0.469	5.541	2.596
4	91.79	1.667	1.5	1.0	0.15	34.43	0.369	5.917	2.180
5	91.79	1.667	2.5	0.5	0.15	28.69	0.307	5.639	1.732
6	91.79	2.083	23.5	1.0	0.15	673.97	7.214	4.042	29.159
7	91.79	1.667	19.5	0.5	0.15	223.78	2.395	5.639	13.507
8	93.427	16	2.5	1.0	0.15	560.56	6.000	8.000	48.000
9	91.79	0.333	0.33	0.5	0.15	0.76	0.008	4.816	0.039
10	85.94	7.467	9.25	1.0	0.06	356.15	3.812	11.375	43.362
11	85.94	1.667	2.5	0.5	0.06	10.74	0.115	6.194	0.712
12	85.94	1.667	19.5	0.5	0.06	83.81	0.897	6.194	5.556
13	85.94	9.25	19.5	1.0	0.06	930.09	9.955	11.375	113.241
14	85.94	10	2.5	1.0	0.06	128.91	1.380	11.000	15.178
E. Wing Wall	27.57	2.125	14.76	1.0	0.15	129.71	1.388	11.500	15.966
W. Wing Wall	27.57	2.375	14.76	1.0	0.15	144.97	1.552	11.500	17.844
						$\Sigma V =$	**36.566**	$\Sigma M =$	**313.248**

Horizontal Earth Pressure

Angle of internal friction (ϕ) =	40	degrees
(ϕ) =	0.6981	radians
cos ϕ =	0.7660	
$\cos^2 \phi$ =	0.5868	
β =	0	degrees
β =	0	radians
cos β =	1.0000	
$\cos^2 \beta$ =	1.0000	
Unit Weight of Soil (γ) =	60	pcf
Height of wall (z) =	29.467	ft
W_b =	13.05	pcf/ft
Horizontal Thrust of Soil (H_z) =	486,781	lb
(Hz) =	5.210	k/ft
Moments due to Soil Thrust (M_z) =	51.177	ft K/ft
Dead Load Surcharge		
Dead Load Surcharge (DLS) =	1,280.20	lb/ft
(DLS) =	1.28	K/ft
Dead Load Surcharge Moments (DLSM) =	18,862	lb/ft
(DLSM) =	18.862	K/ft

$$W_b = \gamma \cos \beta \frac{\cos \beta - (\cos^2 \beta - \cos^2 \phi)^{1/2}}{\cos \beta + (\cos^2 \beta - \cos^2 \phi)^{1/2}}$$

Summary of Forces

Stabilizing Forces		
Load Description	Force (K/ft)	Moment (K ft/ft)
Dead Loads, Backfill, or Surchage	36.566	313.248
Dead Load Reaction From Superstructure	4.016	16.06
Live Load Reaction From Superstructure (3 Lane)	1.783	7.131
Live Load Reaction From Superstructure (2 Lane)	1.321	5.283

Overturning Forces		
Load Description	Force (K/ft)	Moment (K ft/ft)
Earth Pressure	5.210	51.18
Wind Load	0.262	7.92
Wind on Live Load	0.050	2.024
Temperature	0.850	22.95
Longitudinal Force (5% LL) (3 Lanes)	0.028	1.022
Earthquake	0.402	10.53
Dead Load Surchage	1.280	18.852
Longitudinal Force (5% LL) (2 Lanes)	0.021	0.757

Load Combination Investigation

2 Lane Loading

Service Load Analysis

	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	36.57		36.57	36.57	36.57	36.57	36.57	36.57	36.57
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.32				1.32	1.32		1.32	
	Total Vertical	41.90		40.58	40.58	41.90	41.90	40.58	41.90	40.58
	Total $Moment_V$	334.59		329.31	329.31	334.59	334.59	329.31	334.59	329.31
Horizontal	Earth	5.21		5.21	5.21	5.21	5.21	5.21	5.21	5.21
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	6.49		6.49	6.75	6.86	7.34	7.60	7.71	6.89
	Total $Moment_H$	70.03		70.03	77.95	73.11	92.98	100.90	96.06	80.56
	% Stress	100		-	111	104	133	144	137	115

	I	IA	IB	II	III	IV	V	VI	VII
e	1.69		1.61	1.81	1.76	2.23	2.37	2.31	1.87
F.S. Sliding	2.91		2.81	2.70	2.75	2.57	2.40	2.45	2.65
F.S. Overturning	4.78		4.70	4.22	4.58	3.60	3.26	3.48	4.09

Load Combination Investigation

3 Lane Loading

Service Load Analysis

	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	36.57		36.57	36.57	36.57	36.57	36.57	36.57	36.57
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.78				1.78	1.78		1.78	
	Total Vertical	42.37		40.58	40.58	42.37	42.37	40.58	42.37	40.58
	Total $Moment_V$	334.59		329.31	329.31	334.59	334.59	329.31	334.59	329.31
Horizontal	Earth	5.21		5.21	5.21	5.21	5.21	5.21	5.21	5.21
	WL				0.26	0.30		0.26	0.30	
	WII					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	6.49		6.49	6.75	6.86	7.34	7.60	7.71	6.89
	Total $Moment_H$	70.03		70.03	77.95	73.38	92.98	100.90	96.33	80.56
	% Stress	100		-	111	105	133	144	138	115

e	1.76		1.61	1.81	1.83	2.30	2.37	2.38	1.87
F.S. Sliding	2.94		2.81	2.70	2.78	2.60	2.40	2.47	2.65
F.S. Overturning	4.78		4.70	4.22	4.56	3.60	3.26	3.47	4.09

Bearing Pressure Investigation

Length of Base (L)=	16 ft

Minimum and Maximum Bearing Pressure 2 Lane Load								
	IA	IB	II	III	IV	V	VI	VII
R (K)	41.90	40.58	40.58	41.90	41.90	40.58	41.90	40.58
e (ft)	1.69	1.61	1.81	1.76	2.23	2.37	2.31	1.87
Moment (K-ft)	70.66	65.38	73.30	73.74	93.61	96.25	96.69	75.91
ε_{max} (KSF)	4.28	4.07	4.25	4.35	4.81	4.79	4.89	4.32
ε_{min} (KSF)	0.96	1.00	0.82	0.89	0.42	0.28	0.35	0.76

Minimum and Maximum Bearing Pressure 3 Lane Load								
	IA	IB	II	III	IV	V	VI	VII
R (K)	42.37	40.58	40.58	42.37	42.37	40.58	42.37	40.58
e (ft)	1.76	1.61	1.81	1.83	2.30	2.37	2.38	1.87
Moment (K-ft)	74.36	65.38	73.30	77.71	97.31	96.25	100.66	75.91
ε_{max} (KSF)	4.39	4.07	4.25	4.47	4.93	4.79	5.01	4.32
ε_{min} (KSF)	0.91	1.00	0.82	0.83	0.37	0.28	0.29	0.76

ε_{max} (KSF)	5.01	ε_{min} (KSF)	0.28
ε_{max} (TSF)	2.50	ε_{min} (TSF)	0.14

Maximum Allowable Soil Bearing (TSF)	4.00	
Allowable Factor of Safety for Bearing	1.50	
Calculated Factor of Safety	1.60	**ACCEPTABLE**

Design Summary

Angle of internal friction of soil (ϕ) =	40 degrees
Unit Weight of Soil (δ) =	60 lb/ft

Maximum Allowable Soil Bearing (TSF)	4.00
Maximum Stress On Base (TSF)	2.50
Minimum Stress on Base (TSF)	0.14

	Allowable	Calculated	Status
Factor of Safety Against Sliding	1.5	2.40	**ACCEPTABLE**
Factor of Safety Against Overtuning	2.0	3.26	**ACCEPTABLE**
Factor of Safety Against Bearing Pressure	1.5	1.60	**ACCEPTABLE**

Summary of Technical Data
Stalite Lightweight Aggregate

Summary of Weight of Superstructure		
Total Weight of Steel	119,320	lbs
Roadway Slab	262,284	lbs
Roadway Haunch	5,348	lbs
Sidewalk Slab	206,263	lbs
Parapet	51,300	lbs
Protective Barrier	69,152	lbs
Protective Fence	2,052	lbs
Utility Weight	34,679	lbs
Total Weight of Superstructure	750,398	lbs
	750.398	Kips

Summary of Geotechnical Properties of Aggregate		
Angle of internal friction (ϕ) =	40	degrees
Unit Weight of Soil (γ) =	55	pcf
Height of wall (z) =	29.467	ft
Surcharge =	150	lb/ft

Stabilizing Forces

Section	Dimensions				Unit Weight (lb/ft)	Total Force (K)	Force/ft (K/ft)	Moment Arm (ft)	Moment (K-ft/ft)
	L (ft)	W (ft)	H (ft)	Multiplier					
1	91.79	1.25	1.75	1.0	0.15	30.12	0.322	5.375	1.733
2	91.79	0.75	3.467	1.0	0.15	35.80	0.383	6.375	2.443
3	91.79	0.917	3.467	1.0	0.15	43.77	0.469	5.541	2.596
4	91.79	1.667	1.5	1.0	0.15	34.43	0.369	5.917	2.180
5	91.79	1.667	2.5	0.5	0.15	28.69	0.307	5.639	1.732
6	91.79	2.083	23.5	1.0	0.15	673.97	7.214	4.042	29.159
7	91.79	1.667	19.5	0.5	0.15	223.78	2.395	5.639	13.507
8	93.427	16	2.5	1.0	0.15	560.56	6.000	8.000	48.000
9	91.79	0.333	0.33	0.5	0.15	0.76	0.008	4.816	0.039
10	85.94	7.467	9.25	1.0	0.055	326.47	3.494	11.375	39.749
11	85.94	1.667	2.5	0.5	0.055	9.85	0.105	6.194	0.653
12	85.94	1.667	19.5	0.5	0.055	76.82	0.822	6.194	5.093
13	85.94	9.25	19.5	1.0	0.055	852.58	9.126	11.375	103.804
14	85.94	10	2.727	1.0	0.055	128.91	1.380	11.000	15.178
E. Wing Wall	27.57	2.125	14.76	1.0	0.15	129.71	1.388	11.500	15.966
W. Wing Wall	27.57	2.375	14.76	1.0	0.15	144.97	1.552	11.500	17.844
						$\Sigma V =$	**35.335**	$\Sigma M =$	**299.676**

Horizontal Earth Pressure

Angle of internal friction (ϕ) =	40	degrees
(ϕ) =	0.6981	radians
cos ϕ =	0.7660	
$\cos^2 \phi$ =	0.5868	
β =	0	degrees
β =	0	radians
cos β =	1.0000	
$\cos^2 \beta$ =	1.0000	
Unit Weight of Soil (γ) =	55	pcf
Height of wall (z) =	29.467	ft
W_b =	11.96	pcf/ft
Horizontal Thrust of Soil (H_z) =	446,216	lb
(Hz) =	4.776	k/ft
Moments due to Soil Thrust (M_z) =	46.912	ft K/ft
Dead Load Surcharge		
Dead Load Surcharge (DLS) =	1,173.51	lb/ft
(DLS) =	1.17	K/ft
Dead Load Surcharge Moments (DLSM) =	17,290	lb/ft
(DLSM) =	17.290	K/ft

$$W_b = \gamma \cos \beta \frac{\cos \beta - (\cos^2 \beta - \cos^2 \phi)^{1/2}}{\cos \beta + (\cos^2 \beta - \cos^2 \phi)^{1/2}}$$

Summary of Forces

Stabilizing Forces		
Load Description	Force (K/ft)	Moment (K ft/ft)
Dead Loads, Backfill, or Surchage	35.335	299.676
Dead Load Reaction From Superstructure	4.016	16.06
Live Load Reaction From Superstructure (3 Lane)	1.783	7.131
Live Load Reaction From Superstructure (2 Lane)	1.321	5.283

Overturning Forces		
Load Description	Force (K/ft)	Moment (K ft/ft)
Earth Pressure	4.776	46.91
Wind Load	0.262	7.92
Wind on Live Load	0.050	2.024
Temperature	0.850	22.95
Longitudinal Force (5% LL) (3 Lanes)	0.028	1.022
Earthquake	0.402	10.53
Dead Load Surchage	1.280	18.852
Longitudinal Force (5% LL) (2 Lanes)	0.021	0.757

Load Combination Investigation

2 Lane Loading

Service Load Analysis

	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	35.33		35.33	35.33	35.33	35.33	35.33	35.33	35.33
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.32				1.32	1.32		1.32	
	Total Vertical	40.67		39.35	39.35	40.67	40.67	39.35	40.67	39.35
	Total $Moment_V$	321.02		315.74	315.74	321.02	321.02	315.74	321.02	315.74
Horizontal	Earth	4.78		4.78	4.78	4.78	4.78	4.78	4.78	4.78
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	6.06		6.06	6.32	6.43	6.91	7.17	7.28	6.46
	Total $Moment_H$	65.76		65.76	73.68	68.85	88.71	96.63	91.80	76.29
	% Stress	100		-	112	105	135	147	140	116

	I	IA	IB	II	III	IV	V	VI	VII
e	1.72		1.65	1.85	1.80	2.29	2.43	2.36	1.92
F.S. Sliding	3.02		2.92	2.80	2.85	2.65	2.47	2.52	2.74
F.S. Overturning	4.88		4.80	4.28	4.66	3.62	3.27	3.50	4.14

Load Combination Investigation

3 Lane Loading

Service Load Analysis

	Load \ Group	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	35.33		35.33	35.33	35.33	35.33	35.33	35.33	35.33
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.78				1.78	1.78		1.78	
	Total Vertical	41.13		39.35	39.35	41.13	41.13	39.35	41.13	39.35
	Total $Moment_V$	321.02		315.74	315.74	321.02	321.02	315.74	321.02	315.74
Horizontal	Earth	4.78		4.78	4.78	4.78	4.78	4.78	4.78	4.78
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	6.06		6.06	6.32	6.43	6.91	7.17	7.28	6.46
	Total $Moment_H$	65.76		65.76	73.68	69.11	88.71	96.63	92.06	76.29
	% Stress	100		-	112	105	135	147	140	116

	I	IA	IB	II	III	IV	V	VI	VII
e	1.79		1.65	1.85	1.88	2.35	2.43	2.43	1.92
F.S. Sliding	3.06		2.92	2.80	2.88	2.68	2.47	2.54	2.74
F.S. Overturning	4.88		4.80	4.28	4.65	3.62	3.27	3.49	4.14

Bearing Pressure Investigation

Length of Base (L)=	16 ft

Minimum and Maximum Bearing Pressure 2 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	40.67	39.35	39.35	40.67	40.67	39.35	40.67	39.35
e (ft)	1.72	1.65	1.85	1.80	2.29	2.43	2.36	1.92
Moment (K-ft)	70.12	64.83	72.75	73.20	93.07	95.70	96.15	75.36
ε_{max} (KSF)	4.19	3.98	4.16	4.26	4.72	4.70	4.80	4.23
ε_{min} (KSF)	0.90	0.94	0.75	0.83	0.36	0.22	0.29	0.69

Minimum and Maximum Bearing Pressure 3 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	41.13	39.35	39.35	41.13	41.13	39.35	41.13	39.35
e (ft)	1.79	1.65	1.85	1.88	2.35	2.43	2.43	1.92
Moment (K-ft)	73.81	64.83	72.75	77.16	96.76	95.70	100.11	75.36
ε_{max} (KSF)	4.30	3.98	4.16	4.38	4.84	4.70	4.92	4.23
ε_{min} (KSF)	0.84	0.94	0.75	0.76	0.30	0.22	0.22	0.69

ε_{max} (KSF)	4.92	ε_{min} (KSF)	0.22
ε_{max} (TSF)	2.46	ε_{min} (TSF)	0.11

Maximum Allowable Soil Bearing (TSF)	4.00	
Allowable Factor of Safety for Bearing	1.50	
Calculated Factor of Safety	1.63	**ACCEPTABLE**

Design Summary

Angle of internal friction of soil (ϕ) =	40	degrees
Unit Weight of Soil (δ) =	55	lb/ft

Maximum Allowable Soil Bearing (TSF)	4.00
Maximum Stress On Base (TSF)	2.46
Minimum Stress on Base (TSF)	0.11

	Allowable	Calculated	Status
Factor of Safety Against Sliding	1.5	2.47	**ACCEPTABLE**
Factor of Safety Against Overtuning	2.0	3.27	**ACCEPTABLE**
Factor of Safety Against Bearing Pressure	1.5	1.63	**ACCEPTABLE**

Summary of Technical Data
Buildex Lightweight Aggregate

Summary of Weight of Superstructure		
Total Weight of Steel	119,320	lbs
Roadway Slab	262,284	lbs
Roadway Haunch	5,348	lbs
Sidewalk Slab	206,263	lbs
Parapet	51,300	lbs
Protective Barrier	69,152	lbs
Protective Fence	2,052	lbs
Utility Weight	34,679	lbs
Total Weight of Superstructure	750,398	lbs
	750.398	Kips

Summary of Geotechnical Properties of Aggregate		
Angle of internal friction (ϕ) =	42	degrees
Unit Weight of Soil (γ) =	48	pcf
Height of wall (z) =	29.467	ft
Surchage =	150	lb/ft

Stabilizing Forces

Section	Dimensions				Unit Weight (lb/ft)	Total Force (K)	Force/ft (K/ft)	Moment Arm (ft)	Moment (K-ft/ft)
	L (ft)	W (ft)	H (ft)	Multiplier					
1	91.79	1.25	1.75	1.0	0.15	30.12	0.322	5.375	1.733
2	91.79	0.75	3.467	1.0	0.15	35.80	0.383	6.375	2.443
3	91.79	0.917	3.467	1.0	0.15	43.77	0.469	5.541	2.596
4	91.79	1.667	1.5	1.0	0.15	34.43	0.369	5.917	2.180
5	91.79	1.667	2.5	0.5	0.15	28.69	0.307	5.639	1.732
6	91.79	2.083	23.5	1.0	0.15	673.97	7.214	4.042	29.159
7	91.79	1.667	19.5	0.5	0.15	223.78	2.395	5.639	13.507
8	93.427	16	2.5	1.0	0.15	560.56	6.000	8.000	48.000
9	91.79	0.333	0.33	0.5	0.15	0.76	0.008	4.816	0.039
10	85.94	7.467	9.25	1.0	0.048	284.92	3.050	11.375	34.690
11	85.94	1.667	2.5	0.5	0.048	8.60	0.092	6.194	0.570
12	85.94	1.667	19.5	0.5	0.048	67.05	0.718	6.194	4.445
13	85.94	9.25	19.5	1.0	0.048	744.07	7.964	11.375	90.592
14	85.94	10	3.125	1.0	0.048	128.91	1.380	11.000	15.178
E. Wing Wall	27.57	2.125	14.76	1.0	0.15	129.71	1.388	11.500	15.966
W. Wing Wall	27.57	2.375	14.76	1.0	0.15	144.97	1.552	11.500	17.844
						$\Sigma V =$	**33.610**	$\Sigma M =$	**280.674**

Horizontal Earth Pressure	
Angle of internal friction (ϕ) =	42 degrees
(ϕ) =	0.7330 radians
cos ϕ =	0.7431
$\cos^2 \phi$ =	0.5523
β =	0 degrees
β =	0 radians
cos β =	1.0000
$\cos^2 \beta$ =	1.0000
Unit Weight of Soil (γ) =	48 pcf
Height of wall (z) =	29.467 ft
W_b =	9.51 pcf/ft
Horizontal Thrust of Soil (H_z) =	355,013 lb
(Hz) =	3.800 k/ft
Moments due to Soil Thrust ($M_{z)}$ =	37.324 ft K/ft
Dead Load Surcharge	
Dead Load Surcharge (DLS) =	933.66 lb/ft
(DLS) =	0.93 K/ft
Dead Load Surcharge Moments (DLSM) =	13,756 lb/ft
(DLSM) =	13.756 K/ft

$$W_b = \gamma \cos \beta \frac{\cos \beta - (\cos^2 \beta - \cos^2 \phi)^{1/2}}{\cos \beta + (\cos^2 \beta - \cos^2 \phi)^{1/2}}$$

Summary of Forces

Stabilizing Forces

Load Description	Force (K/ft)	Moment (K ft/ft)
Dead Loads, Backfill, or Surchage	33.610	280.674
Dead Load Reaction From Superstructure	4.016	16.06
Live Load Reaction From Superstructure (3 Lane)	1.783	7.131
Live Load Reaction From Superstructure (2 Lane)	1.321	5.283

Overturning Forces

Load Description	Force (K/ft)	Moment (K ft/ft)
Earth Pressure	3.800	37.32
Wind Load	0.262	7.92
Wind on Live Load	0.050	2.024
Temperature	0.850	22.95
Longitudinal Force (5% LL) (3 Lanes)	0.028	1.022
Earthquake	0.402	10.53
Dead Load Surchage	1.280	18.852
Longitudinal Force (5% LL) (2 Lanes)	0.021	0.757

Load Combination Investigation

2 Lane Loading

Service Load Analysis

	Load \ Group	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	33.61		33.61	33.61	33.61	33.61	33.61	33.61	33.61
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.32				1.32	1.32		1.32	
	Total Vertical	38.95		37.63	37.63	38.95	38.95	37.63	38.95	37.63
	Total $Moment_V$	302.02		296.73	296.73	302.02	302.02	296.73	302.02	296.73
Horizontal	Earth	3.80		3.80	3.80	3.80	3.80	3.80	3.80	3.80
	WL				0.26	0.30		0.26	0.30	
	WII					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	5.08		5.08	5.34	5.45	5.93	6.19	6.30	5.48
	Total $Moment_H$	56.18		56.18	64.10	59.26	79.13	87.05	82.21	66.71
	% Stress	100		-	114	105	141	155	146	119

	I	IA	IB	II	III	IV	V	VI	VII
e	1.69		1.61	1.82	1.77	2.28	2.43	2.36	1.89
F.S. Sliding	3.45		3.33	3.17	3.22	2.96	2.73	2.78	3.09
F.S. Overturning	5.38		5.28	4.63	5.10	3.82	3.41	3.67	4.45

Load Combination Investigation

3 Lane Loading

Service Load Analysis

	Load \ Group	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	33.61		33.61	33.61	33.61	33.61	33.61	33.61	33.61
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.78				1.78	1.78		1.78	
	Total Vertical	39.41		37.63	37.63	39.41	39.41	37.63	39.41	37.63
	Total $Moment_V$	302.02		296.73	296.73	302.02	302.02	296.73	302.02	296.73
Horizontal	Earth	3.80		3.80	3.80	3.80	3.80	3.80	3.80	3.80
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	5.08		5.08	5.34	5.45	5.93	6.19	6.30	5.48
	Total $Moment_H$	56.18		56.18	64.10	59.52	79.13	87.05	82.47	66.71
	% Stress	100		-	114	106	141	155	147	119

	I	IA	IB	II	III	IV	V	VI	VII
e	1.76		1.61	1.82	1.85	2.34	2.43	2.43	1.89
F.S. Sliding	3.49		3.33	3.17	3.25	2.99	2.73	2.81	3.09
F.S. Overturning	5.38		5.28	4.63	5.07	3.82	3.41	3.66	4.45

Bearing Pressure Investigation

Length of Base (L)=	16 ft

Minimum and Maximum Bearing Pressure 2 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	38.95	37.63	37.63	38.95	38.95	37.63	38.95	37.63
e (ft)	1.69	1.61	1.82	1.77	2.28	2.43	2.36	1.89
Moment (K-ft)	65.74	60.45	68.37	68.82	88.69	91.32	91.77	70.98
ε_{max} (KSF)	3.97	3.77	3.95	4.05	4.51	4.49	4.59	4.02
ε_{min} (KSF)	0.89	0.93	0.75	0.82	0.36	0.21	0.28	0.69

Minimum and Maximum Bearing Pressure 3 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	39.41	37.63	37.63	39.41	39.41	37.63	39.41	37.63
e (ft)	1.76	1.61	1.82	1.85	2.34	2.43	2.43	1.89
Moment (K-ft)	69.43	60.45	68.37	72.78	92.38	91.32	95.73	70.98
ε_{max} (KSF)	4.09	3.77	3.95	4.17	4.63	4.49	4.71	4.02
ε_{min} (KSF)	0.84	0.93	0.75	0.76	0.30	0.21	0.22	0.69

ε_{max} (KSF)	4.71	ε_{min} (KSF)	0.21
ε_{max} (TSF)	2.35	ε_{min} (TSF)	0.11

Maximum Allowable Soil Bearing (TSF)	4.00	
Allowable Factor of Safety for Bearing	1.50	
Calculated Factor of Safety	1.70	**ACCEPTABLE**

Design Summary

Angle of internal friction of soil (ϕ) =	42 degrees
Unit Weight of Soil (δ) =	48 lb/ft

Maximum Allowable Soil Bearing (TSF)	4.00
Maximum Stress On Base (TSF)	2.35
Minimum Stress on Base (TSF)	0.11

	Allowable	Calculated	Status
Factor of Safety Against Sliding	1.5	2.73	**ACCEPTABLE**
Factor of Safety Against Overtuning	2.0	3.41	**ACCEPTABLE**
Factor of Safety Against Bearing Pressure	1.5	1.70	**ACCEPTABLE**

Summary of Technical Data Arkalite Lightweight Aggregate

Summary of Weight of Superstructure		
Total Weight of Steel	119,320	lbs
Roadway Slab	262,284	lbs
Roadway Haunch	5,348	lbs
Sidewalk Slab	206,263	lbs
Parapet	51,300	lbs
Protective Barrier	69,152	lbs
Protective Fence	2,052	lbs
Utility Weight	34,679	lbs
Total Weight of Superstructure	750,398	lbs
	750.398	Kips

Summary of Geotechnical Properties of Aggregate		
Angle of internal friction (ϕ) =	40.6	degrees
Unit Weight of Soil (γ) =	40.1	pcf
Height of wall (z) =	29.467	ft
Surchage =	150	lb/ft

Stabilizing Forces

Section	Dimensions				Unit Weight (lb/ft)	Total Force (K)	Force/ft (K/ft)	Moment Arm (ft)	Moment (K-ft/ft)
	L (ft)	W (ft)	H (ft)	Multiplier					
1	91.79	1.25	1.75	1.0	0.15	30.12	0.322	5.375	1.733
2	91.79	0.75	3.467	1.0	0.15	35.80	0.383	6.375	2.443
3	91.79	0.917	3.467	1.0	0.15	43.77	0.469	5.541	2.596
4	91.79	1.667	1.5	1.0	0.15	34.43	0.369	5.917	2.180
5	91.79	1.667	2.5	0.5	0.15	28.69	0.307	5.639	1.732
6	91.79	2.083	23.5	1.0	0.15	673.97	7.214	4.042	29.159
7	91.79	1.667	19.5	0.5	0.15	223.78	2.395	5.639	13.507
8	93.427	16	2.5	1.0	0.15	560.56	6.000	8.000	48.000
9	91.79	0.333	0.33	0.5	0.15	0.76	0.008	4.816	0.039
10	85.94	7.467	9.25	1.0	0.0401	238.03	2.548	11.375	28.981
11	85.94	1.667	2.5	0.5	0.0401	7.18	0.077	6.194	0.476
12	85.94	1.667	19.5	0.5	0.0401	56.01	0.600	6.194	3.713
13	85.94	9.25	19.5	1.0	0.0401	621.61	6.653	11.375	75.682
14	85.94	10	3.741	1.0	0.0401	128.91	1.380	11.000	15.178
E. Wing Wall	27.57	2.125	14.76	1.0	0.15	129.71	1.388	11.500	15.966
W. Wing Wall	27.57	2.375	14.76	1.0	0.15	144.97	1.552	11.500	17.844
						$\Sigma V =$	**31.664**	$\Sigma M =$	**259.229**

Horizontal Earth Pressure

Angle of internal friction (ϕ) =	40.6	degrees
(ϕ) =	0.7086	radians
$\cos \phi$ =	0.7593	
$\cos^2 \phi$ =	0.5765	
β =	0	degrees
β =	0	radians
$\cos \beta$ =	1.0000	
$\cos^2 \beta$ =	1.0000	
Unit Weight of Soil (γ) =	40.1	pcf
Height of wall (z) =	29.467	ft
W_b =	8.48	pcf/ft
Horizontal Thrust of Soil (H_z) =	316,519	lb
(Hz) =	3.388	k/ft
Moments due to Soil Thrust (M_z) =	33.277	ft K/ft
Dead Load Surcharge		
Dead Load Surcharge (DLS) =	832.42	lb/ft
(DLS) =	0.83	K/ft
Dead Load Surcharge Moments (DLSM) =	12,264	lb/ft
(DLSM) =	12.264	K/ft

$$W_b = \gamma \cos \beta \frac{\cos \beta - (\cos^2 \beta - \cos^2 \phi)^{1/2}}{\cos \beta + (\cos^2 \beta - \cos^2 \phi)^{1/2}}$$

Summary of Forces

Stabilizing Forces

Load Description	Force (K/ft)	Moment (K ft/ft)
Dead Loads, Backfill, or Surchage	31.664	259.229
Dead Load Reaction From Superstructure	4.016	16.06
Live Load Reaction From Superstructure (3 Lane)	1.783	7.131
Live Load Reaction From Superstructure (2 Lane)	1.321	5.283

Overturning Forces

Load Description	Force (K/ft)	Moment (K ft/ft)
Earth Pressure	3.388	33.28
Wind Load	0.262	7.92
Wind on Live Load	0.050	2.024
Temperature	0.850	22.95
Longitudinal Force (5% LL) (3 Lanes)	0.028	1.022
Earthquake	0.402	10.53
Dead Load Surchage	1.280	18.852
Longitudinal Force (5% LL) (2 Lanes)	0.021	0.757

Load Combination Investigation

2 Lane Loading

Service Load Analysis

	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	31.66		31.66	31.66	31.66	31.66	31.66	31.66	31.66
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.32				1.32	1.32		1.32	
	Total Vertical	37.00		35.68	35.68	37.00	37.00	35.68	37.00	35.68
	Total $Moment_V$	280.57		275.29	275.29	280.57	280.57	275.29	280.57	275.29
Horizontal	Earth	3.39		3.39	3.39	3.39	3.39	3.39	3.39	3.39
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	4.67		4.67	4.93	5.04	5.52	5.78	5.89	5.07
	Total $Moment_H$	52.13		52.13	60.05	55.21	75.08	83.00	78.16	62.66
	% Stress	100		-	115	106	144	159	150	120

	I	IA	IB	II	III	IV	V	VI	VII
e	1.83		1.75	1.97	1.91	2.45	2.61	2.53	2.04
F.S. Sliding	3.57		3.44	3.26	3.30	3.02	2.78	2.83	3.17
F.S. Overturning	5.38		5.28	4.58	5.08	3.74	3.32	3.59	4.39

Load Combination Investigation

3 Lane Loading

	Service Load Analysis									
	Load \ Grou	I	IA	IB	II	III	IV	V	VI	VII
VERTICAL	DL, Bkfill, DLS	31.66		31.66	31.66	31.66	31.66	31.66	31.66	31.66
	DL React	4.02		4.02	4.02	4.02	4.02	4.02	4.02	4.02
	LL React	1.78				1.78	1.78		1.78	
	Total Vertical	37.46		35.68	35.68	37.46	37.46	35.68	37.46	35.68
	Total $Moment_V$	280.57		275.29	275.29	280.57	280.57	275.29	280.57	275.29
Horizontal	Earth	3.39		3.39	3.39	3.39	3.39	3.39	3.39	3.39
	WL				0.26	0.30		0.26	0.30	
	Wll					0.05			0.05	
	Temp						0.85	0.85	0.85	
	Longitudinal					0.02			0.02	
	Earthquake									0.40
	DLS	1.28		1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total Horizontal	4.67		4.67	4.93	5.04	5.52	5.78	5.89	5.07
	Total $Moment_H$	52.13		52.13	60.05	55.47	75.08	83.00	78.42	62.66
	% Stress	100		-	115	106	144	159	150	120

e	1.90		1.75	1.97	1.99	2.51	2.61	2.60	2.04
F.S. Sliding	3.61		3.44	3.26	3.35	3.06	2.78	2.86	3.17
F.S. Overturning	5.38		5.28	4.58	5.06	3.74	3.32	3.58	4.39

Bearing Pressure Investigation

Length of Base (L)=	16 ft

Minimum and Maximum Bearing Pressure 2 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	37.00	35.68	35.68	37.00	37.00	35.68	37.00	35.68
e (ft)	1.83	1.75	1.97	1.91	2.45	2.61	2.53	2.04
Moment (K-ft)	67.57	62.28	70.20	70.65	90.52	93.15	93.60	72.81
ε_{max} (KSF)	3.90	3.69	3.88	3.97	4.43	4.41	4.51	3.94
ε_{min} (KSF)	0.73	0.77	0.58	0.66	0.19	0.05	0.12	0.52

Minimum and Maximum Bearing Pressure 3 Lane Load

	IA	IB	II	III	IV	V	VI	VII
R (K)	37.46	35.68	35.68	37.46	37.46	35.68	37.46	35.68
e (ft)	1.90	1.75	1.97	1.99	2.51	2.61	2.60	2.04
Moment (K-ft)	71.26	62.28	70.20	74.61	94.21	93.15	97.56	72.81
ε_{max} (KSF)	4.01	3.69	3.88	4.09	4.55	4.41	4.63	3.94
ε_{min} (KSF)	0.67	0.77	0.58	0.59	0.13	0.05	0.05	0.52

ε_{max} (KSF)	4.63	ε_{min} (KSF)	0.05
ε_{max} (TSF)	2.31	ε_{min} (TSF)	0.02

Maximum Allowable Soil Bearing (TSF)	4.00	
Allowable Factor of Safety for Bearing	1.50	
Calculated Factor of Safety	1.73	**ACCEPTABLE**

Design Summary

Angle of internal friction of soil (ϕ) =	40.6 degrees
Unit Weight of Soil (δ) =	40.1 lb/ft

Maximum Allowable Soil Bearing (TSF)	4.00
Maximum Stress On Base (TSF)	2.31
Minimum Stress on Base (TSF)	0.02

	Allowable	Calculated	Status
Factor of Safety Against Sliding	1.5	2.78	**ACCEPTABLE**
Factor of Safety Against Overtuning	2.0	3.32	**ACCEPTABLE**
Factor of Safety Against Bearing Pressure	1.5	1.73	**ACCEPTABLE**

APPENDIX E:

Advantages Of Controlled Low Strength Materials (CLSM) (Ref: ACI 229R-2)

Cited advantages of controlled low-strength materials (CLSM)[1]

- **Ready available** – Using locally available materials, ready mixed concrete suppliers can produce CLSM to meet most project specifications.
- **Easy to deliver** – Truck mixers can deliver specified quantities of CLSM to the jobsite whenever the material is needed.
- **Versatile** - CLSM mix designs can be adjusted to meet specific fill requirements. Mixes can be adjusted to improve flowability. Add more cement or fly ash to increase strength. Admixtures can be added to adjust setting times and other performance characteristics. Adding foaming agents to CLSM produces a lightweight, insulating fill.
- **Strong and durable** – Load-carrying capacities of CLSM typically are higher than those of compacted soil or granular fill. CLSM also is less permeable, thus more resistant to erosion. For use as a permanent structural fill, CLSM can be designed to achieve 28-day compressive strength as high as 1200 psi.
- **Can be excavated** - CLSM having compressive strengths of 50 to 100 psi is easily excavated with conventional digging equipment, yet is strong enough for most backfilling needs.
- **Requires less inspection** - during placement, soil backfill must be tested after each lift for sufficient compaction. CLSM self-compacts consistently and does not need this extensive field-testing.
- **Allows fast return to traffic** - Because many CLSM's can be placed quickly and support traffic loads within several hours, downtime for pavement repairs is minimal.
- **Will not settle** - CLSM does not form voids during placement and will not settle or rut under loading. This advantage is especially significant if the backfill is to be covered by a pavement patch. Soil or granular fill, if not consolidated properly, may settle after a pavement patch is placed and forms cracks or dips in the road.
- **Reduces excavation cost** - CLSM allows narrower trenches because it eliminates having to widen trenches to accommodate compaction equipment.

[1] ACI Committee Report 229R-2

- **Improves worker safety** - Workers can place CLSM in a trench without entering the trench, reducing their exposure to possible cave-ins.
- **Allows all-weather construction** - CLSM will displace any standing water left in a trench from rain or melting snow, reducing the need for dewatering pumps. To place CLSM in cold weather, heat the material using the same methods for heating ready-mixed concrete.
- **Reduces equipment needs** - Unlike soil or granular backfill. CLSM can be placed without loaders, rollers, or tampers.
- **Requires no storage** - Because ready-mixed concrete trucks deliver CLSM to the jobsite in the quantities needed, storing fill material on site is unnecessary. Also, there is no leftover fill to haul away.
- **Makes use of a by-product** - Fly ash is a byproduct produced by power plants that burn coal to generate electricity. CLSM containing fly ash benefits the environment by making use of this industrial byproduct material.

APPENDIX F: Additional Information on CLSM

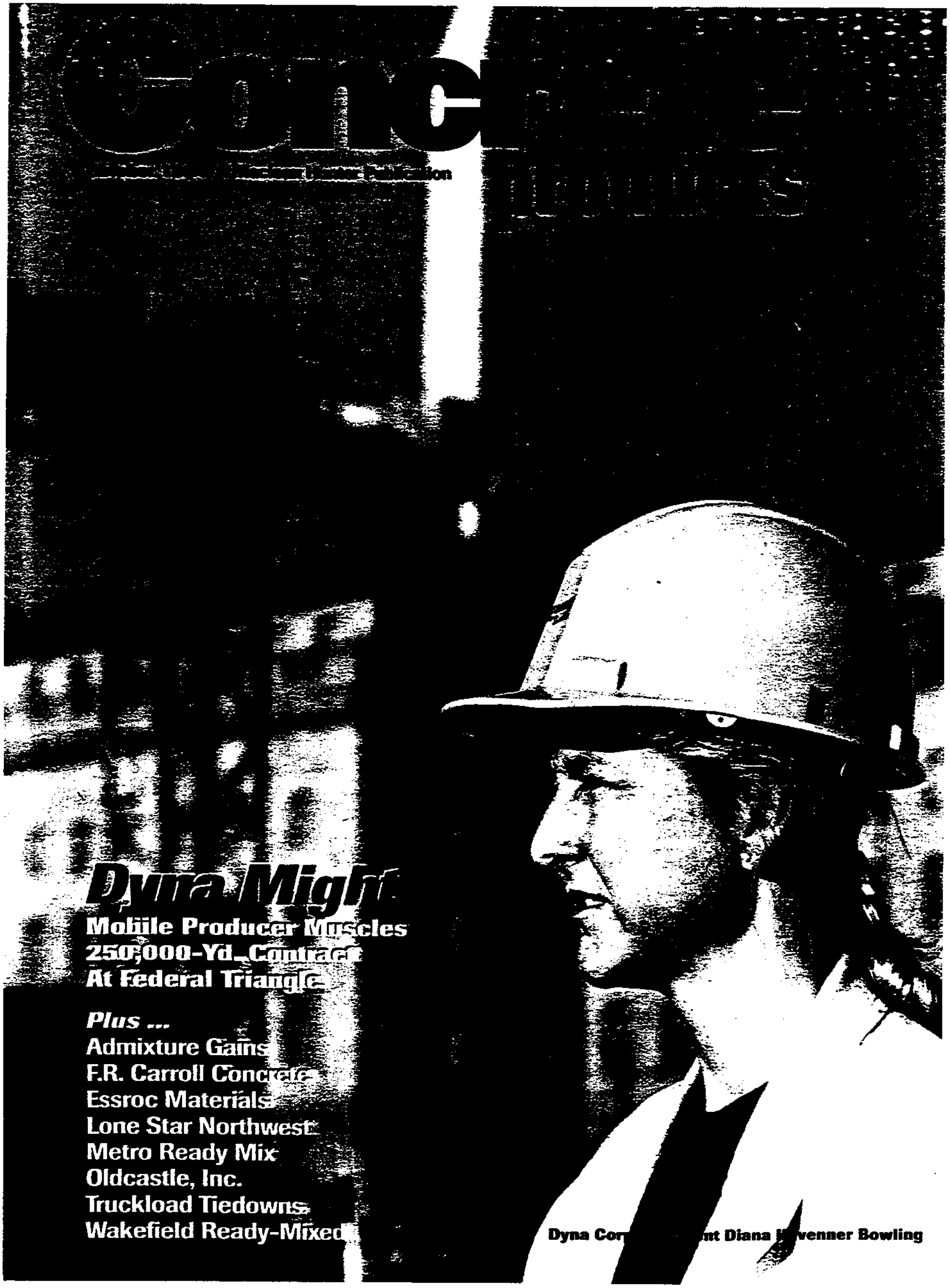
Comparable Cost Example

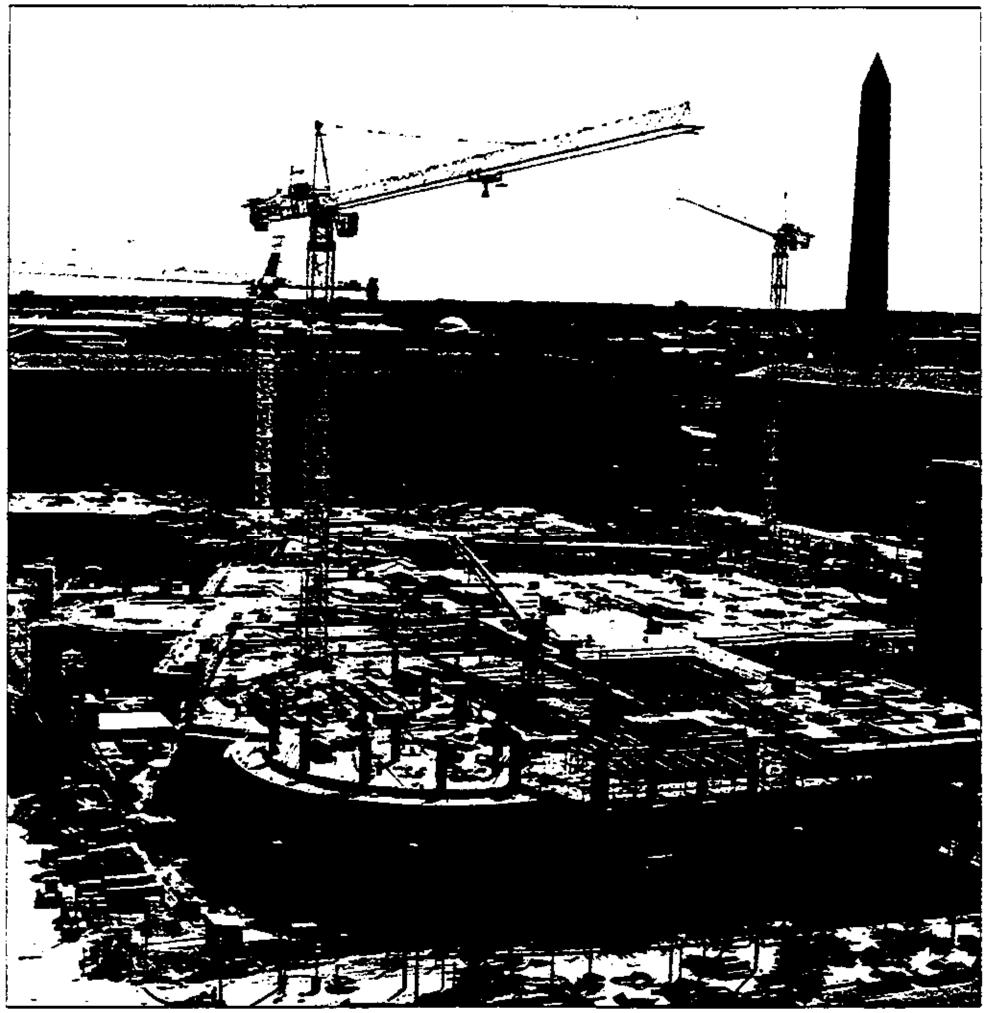
Problem: *Void of uncertain volume caused by underground pipe rupture. Estimated material volume requirements of 100 cubic yards.*

Question: DYNA-ASH vs. Soil Backfills?

	DYNA-ASH	Soil Backfills
Equipment		
Dump Truck for 8 hrs. @ $45	$0	$360
Backhoe for 8 hrs. @ $35	$0	$280
Gasoline Tamp for 8 hrs. @ $15	$0	$120
Daily Total	$0	$760
Labor		
Operator/Foreman for 8 hrs. @$17	$0	$136
Lead Laborer for 8 hrs. @ $11	$0	$88
3 Laborers for 8 hrs @ $10	$0	$240
1 Laborer for 8 hrs. @ $10	$80	$0
Daily Total	$80	$464
Benefits & Employment Taxes @ 20%	$16	$93
Overhead Burden @ 15%	$15	$198
Total Labor & Equip. Per Day	$111	$1,514
Number of Project Days	0.25	4
Extended Placement Cost	$28	$6,057
Material Unit Cost (Delivered)	$38.50 per CY	$16.00 per CY
Number Material Units	100	100
Extended Material Cost	$3,850	$1,600
Total Material & Placement Cost	$3,878	$7,657

DYNA-ASH... The Clear Winner.


Dyna Might
Mobile Producer Muscles
250,000-Yd. Contract
At Federal Triangle
Plus ...
Admixture Gains
F.R. Carroll Concrete
Essroc Materials
Lone Star Northwest
Metro Ready Mix
Oldcastle, Inc.
Truckload Tiedowns
Wakefield Ready-Mixed



DYNA MIGHT

Producer capitalizes on site production, DBE certification in Washington, D.C.

by Don Marsh

When contracts were being let two years ago on the concrete-rich Federal Triangle Building, earmarked for a confined Washington, D.C. site, most ready-mix contenders apparently saw trucks hauling from a stationary plant as the only means of delivering the job's 250,000+ yd.

But Diana Havenner Bowling, president and CEO of then E-Quality Concrete Inc. and now Dyna Corp., Upper Marlboro, Md., had a different read on the logistics: "I wondered how anyone could think of a plan other than site production for the concrete contract," she says. "The quantity of material and variety of mix designs that were going into the job would have required too many trucks discharging at too few accessible points for efficient pumping and casting."

With that in mind, she set forth to fit a square peg into what others thought was more of a round hole along Pennsylvania Avenue. She devised a plan with trade contractor Charles H. Tompkins Co. calling for about 35 percent trucked concrete, for mostly early phase pours, and a two-phase site production schedule for the remaining quantity.

Havenner Bowling applied the material management and quality control formulas she had on a previous site production job, factoring in great measure delivery of copious quantities of raw materials on round-the-clock schedules. The proposal seemed almost audacious at first, particularly on a job in a market crowded by trucks representing bigger league domestic and foreign players — Arundel (Florida Rock), Genstar Stone (Redlands) and Bardon. But as Tompkins moved forward in construction programming, site-produced concrete seemed less against the grain and more with the flow.

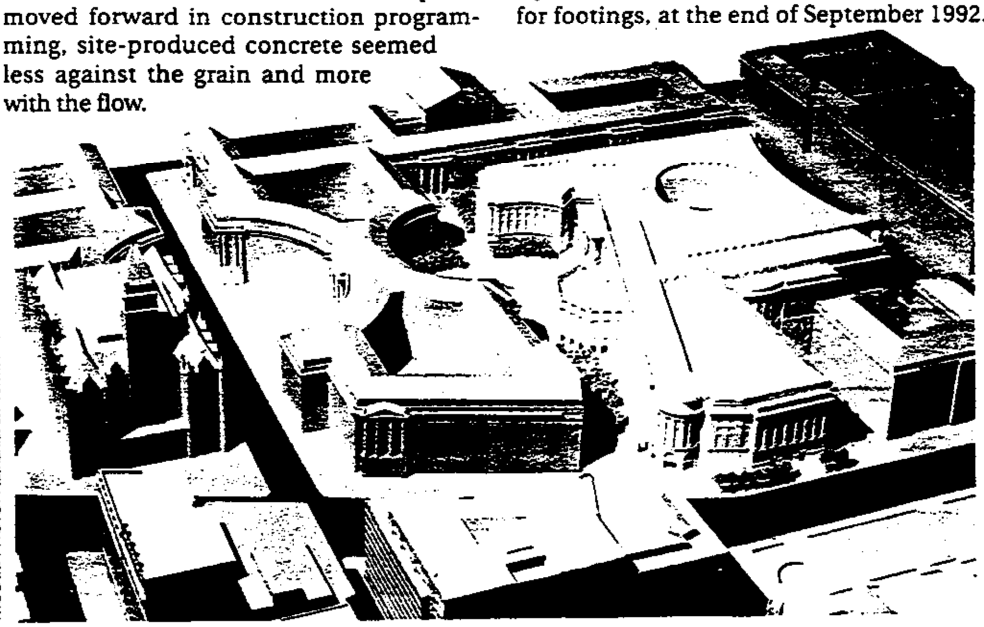
Convinced that Dyna could keep quality consistent on up to 20 different mixes, make spontaneous adjustments in mix characteristics, maintain sufficient volumes of material on hand, and secure adequate back up systems to minimize the risk of idling hundreds of workers in the event of a plant shutdown, Tompkins awarded Dyna a $13 million package. The producer joined four other major concrete subcontractors who were charged with placing and finishing up to 250,000 yd. for a late-1994 topout on the 3.1-million-sq.-ft. Federal Triangle Building.

Three-point production

The 14-level structure has risen on an 8-½-acre site within the Federal Triangle, bounded by the Washington Monument, White House and Capitol Building. It is the District's largest concrete building since the early 1940s construction of The Pentagon, which consumed more than 450,000 yd. The Federal Triangle Building's five subgrade levels are constructed with pan and joist, pan and skip joist and beam and girder systems; the nine above-grade levels are flat plate and beam and girder design.

Dyna's three-phase production scheme began with the hauling of about 29,000 yd. of concrete, ranging from lean to high-strength mixes, batched about two miles from the site at the Washington plant of its subcontractor, Opportunity Concrete. The project started 60 ft. below Pennsylvania Avenue and 40 to 50 ft. below the Potomac River level. Foundation work included placement of drainage pipes to carry water to seven pump out locations. Dyna delivered its first order, a 6,000 psi mix for footings, at the end of September 1992.

Diana Havenner Bowling



MODEL PHOTO: Nathaniel Lieberman for Pei Cobb Freed & Partners

Federal Triangle Building

PROJECT PRINCIPALS

Architect
Pei Cobb Freed & Partners
Ellerbe Becket Architects & Engineers

Construction Manager
Perini Corp.

Construction Consultant
Tishman Construction

Trade Contractor
Charles H. Tompkins Co.

Structural Engineer
Weiskopf & Pickworth

CONCRETE SUBCONTRACTORS

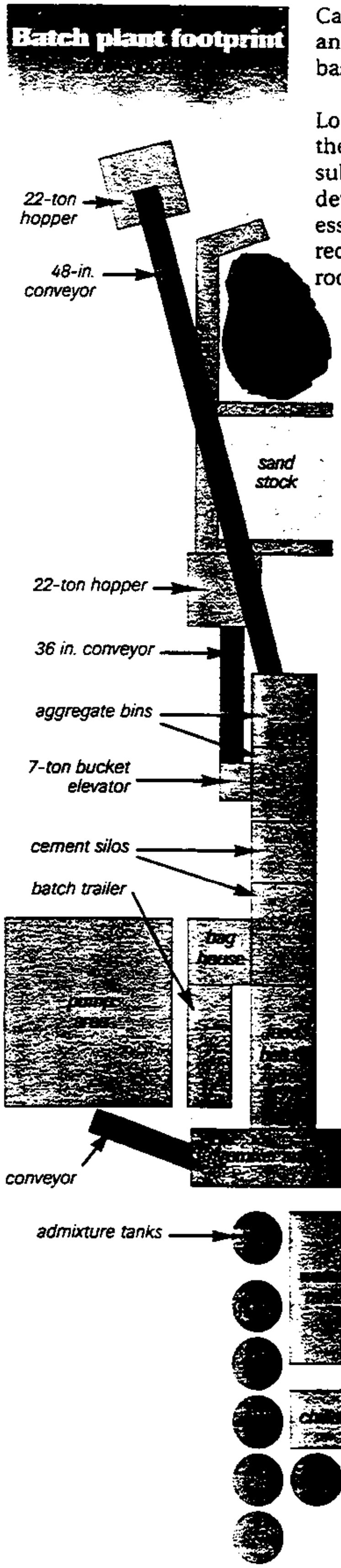
Ready-Mix Supplier
Dyna Corp.

Pumping
Brundage Bone Concrete Pumping

Formwork
Southern Pan & Shoring

Rebar Placement
Mid Atlantic Steel

Rebar Fabricator
Owens Steel



Casting of a 12 in.-thick mat slab followed and set a foundation for the building and base for the first site production phase.

The producer mobilized a new Con-E-Co Lo-Pro plant rated at 250 yd./hour and, with the assistance of equipment supplier and subcontractor, Material Systems, Inc., devised a scheme so that five levels would essentially be built around the plant, which required a footprint of about 2,700 sq. ft. plus room for stockpiling and transporting aggregate. Raw materials for the subgrade production phase were staged with street level, "curbside" conveyors that fed sand and coarse aggregate through drop chutes into piles against the foundation wall. Cement tankers pneumatically fed portland and blended slag loads into the plant's twin 1,000-bbl. silos from a parking spot near the aggregate conveyors. As space became more limited with subgrade level completion, the plant crew had to put aggregate in two vertical bins next to the silos. Daily material delivery rates throughout the site production phases have reached 925 tons of sand, 1,600 tons of coarse aggregate and 600 tons of cementitious material.

The first site concrete production phase began in spring 1993 and continued for a year; the second kicked in following a six-week demobilization, during which the plant was shifted from the west to the east side of the site, near the main construction entrance.

The bulk of concrete has been placed with two trailer pumps, combining for 180 yd./hour capacity, and three booms set up in a spider-like configuration to maximize placing distances and crew productivity. Mixes from the plant have been used to dispense into an agitating drum and double-gated remixer for discharge into two hoppers.

The concrete schedule lists 11 mix designs for the trucked portion and 20 additional designs for site production, including three 8,000 psi concretes for columns and five mixes specified for four-day, 4,200 psi to meet form stripping requirements. Dyna's quality control has been measured daily at its site testing lab, equipped with two troths and a new digital compression testing machine, and checked against specimens handled by outside labs.

The site production factor has been integral to maintaining specifications, according to Tompkins project manager, Homer Willis. "The plant has offered a tremendous advantage in quality control with multiple mixes and massive pours," he says. "After the foundation pours, we would not have had the mix consistency with truck-delivered concrete on this job because of the hauling, limited access and extensive pumping." Overall quality assurance has taken many forms, he adds, ranging from the higher strength mix production — relatively uncommon for the District — to compensation for mixes' 1 to 1.5 percent loss of air and 4 to 5 degree temperature gain in pumping.

Two-way street

The Federal Triangle project has put Dyna on both sides of laws governing labor and material procurement for federally funded construction. Havenner Bowling neither shuns reference to nor apologizes for the most obvious aspect: The job required that 28 percent of Tompkins' $81-million+ contract be awarded to firms certified as Disadvantaged Business Enterprises. "That provision got us in the door to bid, but from there the contractor weighed the benefits of all competing packages," Havenner Bowling explains.

"DBE certification has worked in the past to give us a first shot with certain customers," she affirms. "But when we pick up repeat business from those customers for jobs that are not bound by special requirements, our real ability to deliver quality concrete competitively bears out."

On the other side of the legal coin has been an adjustment in plant crew wages at Federal Triangle: During typical operation, the plant has been staffed with an eight-man crew, including two batch controllers, a loader operator and mechanic. In compliance with federal Davis-Bacon Act statutes, the crew has received prevailing wages, which are about 25 to 30 percent above those of workers in suburban Washington facilities. Offsetting part of the increased wage rate are workman's compensation and general liability coverage for the plant employees afforded by an automatically instituted Owner Controlled Insurance Program.

Dyna is winding down at Federal Triangle and has begun work on another site production contract in partnership with Opportunity Concrete. A new station for the Washington Metropolitan Area Transit Authority situated in Silver Spring, Md. and requiring 65,000+ yd., the project deploys Dyna's other portable batch plant, a 110-yd./hour dry batch model purchased for the 40,000-yd. Bi-County Water Tunnel project in 1991, its first site production job.

Mobile production suits Havenner Bowling professionally and personally. Rarely idle, she opted to change the name of her company after securing financing to take sole ownership of E-Quality Concrete in March 1994. Dyna is Greek for powerful and energetic, she says, and befits her field and Upper Marlboro operations and this year's banner activities in contracts and expansion.

An NRMCA-certified plant technician, Havenner Bowling brings a tireless female presence to old boy construction networks and the gritty ready-mix business. Her concrete career began with Charles County Concrete Co., Waldorf, Md., 20 years ago, and continued in the truck sales division of International Harvester (now Navistar) and home building ventures.

She founded E-Quality Concrete in 1988, opening the business with her own capital and some investment shareholders. She established a main plant with a fleet of five trucks, which peaked at 23 and has since tapered off to 20 due to a shift toward site production. With name and logo change official, Dyna is scoping other east coast contracts for site production and establishing formal services in bulk cement and material hauling, flowable fill and mobile mixer supply, and concrete repair and rehabilitation products.

Concrete equipment

PRODUCTION

- Con-E-Co Lo Pro plant
- Auto•Control 90/40 batch control
- American GeoThermal 50-ton water chiller
- Pearson 15,000-gallon hot water tank
- Erie-Strayer 10-yd. drum mixer
- Maxon agitating drum and remixer

PLACING

- Schwing trailer-mounted pumps
- Schwing 28-meter and 42-meter booms

Concrete parameters

Ready-mix
250,000 yd.

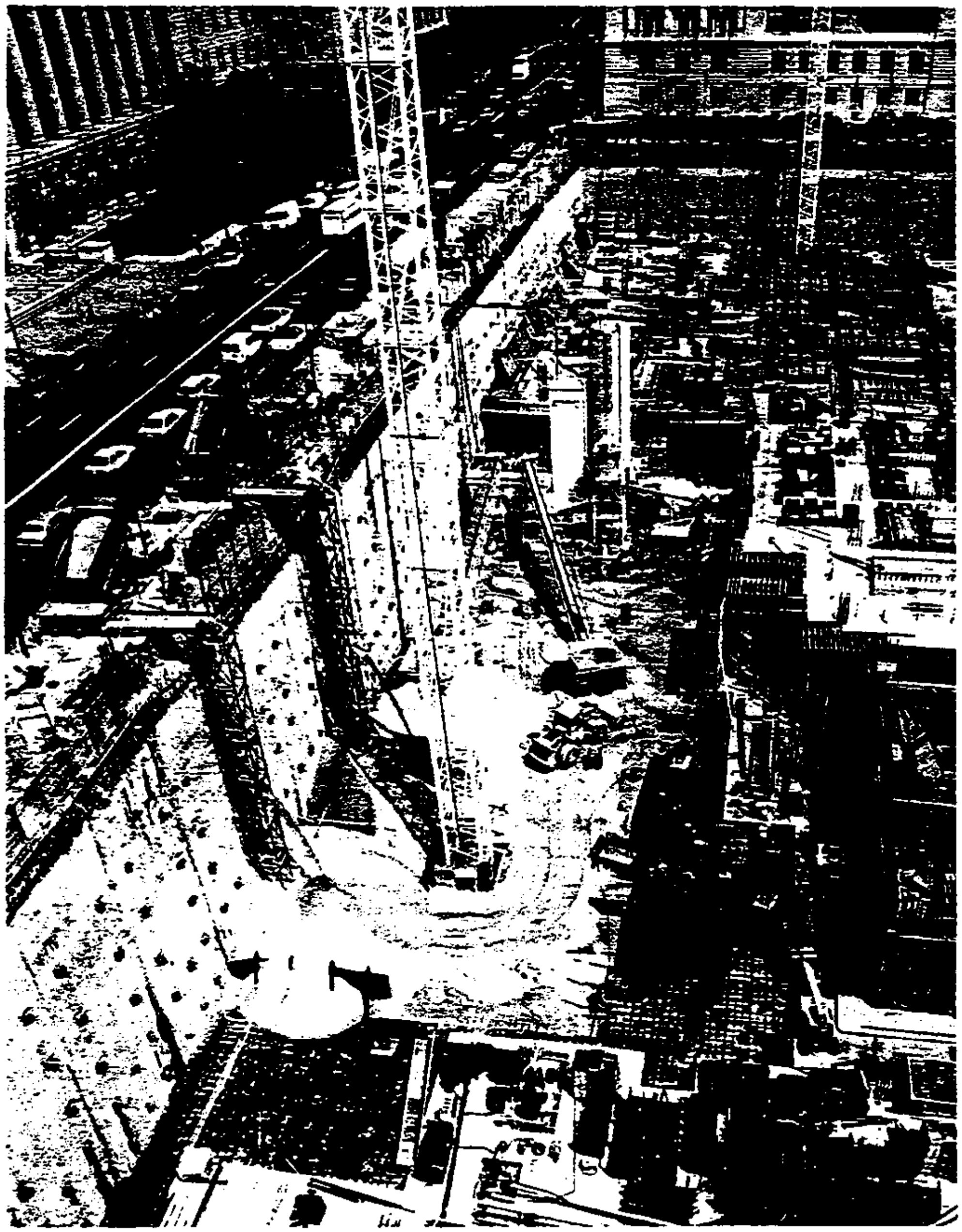
Coarse aggregate
230,000 tons

Fine aggregate
137,500 tons

Water reducer/retarder
42,000 gallons

High range water reducer
126,500 gallons

Largest single pour
1,680 yd., 22 hours



As staged during the first phase, the plant eventually batched nearly enough concrete to conceal itself below grade. Aggregate and cement haulers provided consistent curb service all along.

CON-E-CO is recognized worldwide as the innovator, the leader in mobile and portable concrete batch plant technology.

The knowledge and experience gained from CON-E-CO installations all across the United States, North America and other foreign nations enables us to design new solutions to new problems facing the concrete producer.

We maintain strong involvement in industry associations. We believe in keeping close, open communication with our customers. And we continually strive to engineer and manufacture the best, most efficient, most productive equipment in the industry.

Each and every one of our products--concrete batch plants, central mixers, conveyors, dust control systems, automation...is custom-engineered to the specific requirements of the individual producer.

So when you're looking for the best value to fit *your* needs, call on the concrete experts -- CON-E-CO. Concrete Equipment Company.

CONCRETE PLANT CPMB MANUFACTURERS BUREAU · PLANT MIXER PMMD MANUFACTURERS DIVISION · CONTROL SYSTEMS CSMD MANUFACTURERS DIVISION · MEMBER OF NATIONAL READY MIXED CONCRETE ASSOCIATION · CIMA

CON-E-CO

concrete equipment company

237 North 13th Street • P.O. Box 430 • Blair, NE 68008 • (402) 426-4181 • FAX (402) 426-4180

DYNA CORPORATION

DYNA-ASH™ FLOWABLE FILL

DYNA-ASH EXPRESS FILL™

DYNA-CRETE COMPACTIBLE FILL™

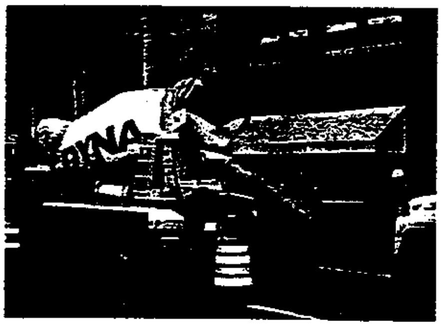
FLOWABLE & COMPACTED FILL PRODUCTS

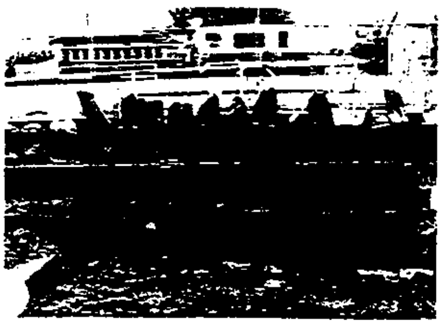
THE PRACTICAL BACKFILL WITH PREDICTABLE QUALITY

301-776-DYNA

SMART • INNOVATIVE • EXPERIENCED

DYNA CORPORATION — DYNA-ASH™ FLOWABLE FILL PRODUCTS


Emergency Utility Backfill


In-Place Bridge Abandonment


Tank Abandonment

DYNA-Ash™ Flowable Fill Products— The engineered backfill material.

DYNA-Ash™ Flowable Fill [illegible] alternative to conventional backfill materials. It is a mix[illegible] activator, water, and in certain applications, aggregate. ***DYNA-Ash™*** [illegible] is a flowable, self compacting, self leveling material that [illegible] for numerous applications. ***Think of it as liquid dirt.*** [illegible]

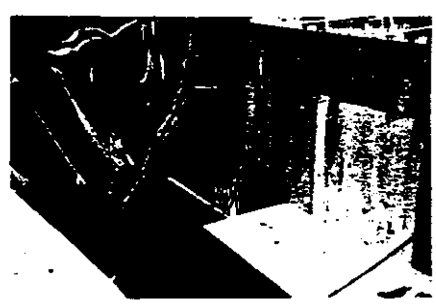
Delivered to your [illegible] ***DYNA-Ash™ Flowable Fill*** products virtually eliminate [illegible] equipment and labor, and is easily excavatable by hand after [illegible] place.

BENEFITS OF *DYNA-Ash™ Flowable Fill* Products:

- **READILY AVAILABLE** — Using locally available materials, DYNA Corporation can produce ***DYNA-Ash™ Flowable Fill*** products to meet project specifications.
- **EASY TO DELIVER** — Mixer trucks and mobile mixers can deliver specified quantities to the jobsite. 24-Hour emergency delivery is available upon request.
- **EASY TO PLACE** — Depending on the type and location of void to be filled, ***DYNA-Ash™ Flowable Fill*** products can be placed by chute, conveyor, pump, or bucket. Because it is self leveling, it needs little or no spreading or compacting. This speeds construction and reduces labor requirements. DYNA Corporation also offers placement services.
- **VERSATILE** — ***DYNA-Ash™ Flowable Fill*** mix designs can be adjusted by DYNA Corporation's engineering department to meet specific fill requirements. Mixes can be designed to meet specific flowability, strength, setting times, unit weight, and insulating characteristics.
- **STRONG & DURABLE** — Load-carrying capacities of ***DYNA-Ash™ Flowable Fill*** typically are higher than those of compacted soil or granular fill. ***DYNA-Ash™ Flowable Fill*** is also less permeable, thus more resistant to erosion. For use as a permanent structural fill, ***DYNA-Ash™ Flowable Fill*** can be designed to achieve strengths of 50 to 2500 psi.
- **EXCAVATABLE** — ***DYNA-Ash™ Flowable Fill*** having compressive strengths of 50 to 100 psi is easily excavatable with conventional digging equipment used for soil backfills, and yet is strong enough for most backfilling needs.
- **REQUIRES LESS INSPECTION** — During placement, soil backfill must be tested after each lift for sufficient compaction ***DYNA-Ash™ Flowable Fill*** self-compacts consistently and does not need this extensive field testing.
- **ALLOWS FAST RETURN TO TRAFFIC** — Because ***DYNA-Ash™ Flowable Fill*** can be placed quickly and support traffic loads within several hours, downtime for pavement repairs is minimal.


Wetlands Backfill Material


Soldier Pile Backfill


Confined Space Bac[illegible]

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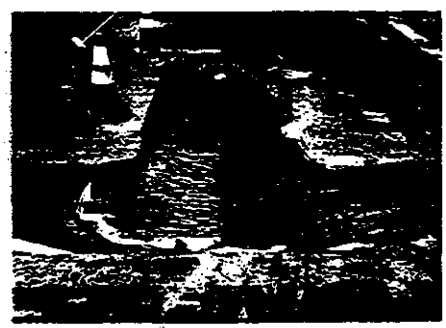
- **WILL NOT SETTLE** — ***DYNA-ASH™ Flowable Fill*** does not form voids during placement and will not settle or rut under loading. This advantage is especially significant if the backfill is to be covered by a pavement patch. Soil or granular fill, if not consolidated properly, may settle after a pavement patch is placed and form cracks or dips in the road.
- **REDUCES EXCAVATING COSTS** — ***DYNA-ASH™ Flowable Fill*** allows narrower trenches because it eliminates having to widen trenches to accommodate compaction equipment.
- **IMPROVES WORKER SAFETY** — Workers can place ***DYNA-ASH™ Flowable Fill*** in a trench without entering the trench, reducing their exposure to possible cave-ins.
- **ALLOWS ALL-WEATHER CONSTRUCTION** — ***DYNA-ASH™ Flowable Fill*** will displace any standing water left in a trench from rain or melting snow, reducing the need for dewatering pumps. To place flowable fill in cold weather, ***DYNA-ASH™ Flowable Fill*** is heated using the same methods for heating ready mixed concrete.
- **REDUCES EQUIPMENT NEEDS** — Unlike soil or granular backfill, ***DYNA-ASH™ Flowable Fill*** can be placed without loaders, rollers, or tampers.
- **REQUIRES NO STORAGE** — Because delivery trucks deliver ***DYNA-ASH™ Flowable Fill*** to the jobsite in the quantities needed, storing fill material on site is unnecessary. Also, there is no leftover fill to haul away.
- **MAKES USE OF A BY-PRODUCT** — Flyash, the main ingredient in ***DYNA-ASH™ Flowable Fill*** is a by-product produced by power plants that burn coal to generate electricity. ***DYNA-ASH™ Flowable Fill*** benefits the environment by making use of an industrial by-product material.

Pump Placement Service

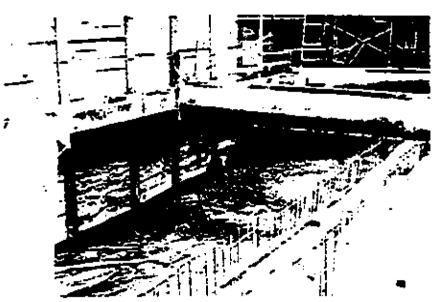
Ease of Placement



Rapid Repair with DYNA-ASH EXPRESS FILL™

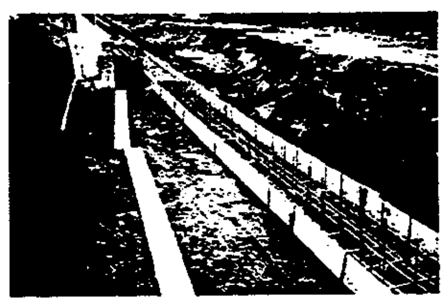
TECHNICAL FEATURES OF *DYNA-Ash™ Flowable Fill Products:*

Angle of Internal Friction	measures from 45 - 60 degrees
Atterberg Limits	nonplastic
California Bearing Ratio (CBR)	standard CLSM measured [illegible] and is not affected by subsequent freeze/thaw cycles
Coefficient of Permeability	standard CLSM measures at appoximately 3.75E07
Compressive Strength	standard CLSM measures in ranges of 50 - 200 psi; High strength, low density, or rapid setting mixes are also available to ***DYNA-Ash™ Flowable Fill*** customers.
Shrinkage	before setting between 3-5%, and under load is negligible
PH	measures between 8.5-12.9 depending upon PH of the cement and the curing age of the material
Removability	as measured by recommended procedure is between .45 and .85. Less than 1.00 is considered easily removable by manual methods
Resistivity	ohm-cm measured at 1 month is approximately 2000, measured at 30 months is approximately 7800
Unit Weights	air dry density measures between 65-72 lbs./cubic foot. Saturated plastic state measures between 90-103 lbs./cubic foot.



Mass Depth Backfill

Sheeting/Shoring Backfill



Slurry Wall Pre-trench Application

DYNA CORPORATION

YOUR MOST FREQUENT QUESTIONS

1. What is DYNA-ASH™ Flowable Fill?
DYNA-ASH™ Flowable Fill is offered exclusively by DYNA Corporation as the intelligent alternative to conventional backfill methods. ***DYNA-ASH™ Flowable Fill*** products are flowable — literally poured into service — and self-leveling, self-compacting and excavatable.

2. Is there a technical name for flowable fill?
Yes. Standard ***DYNA-ASH™ Flowable Fill*** products are classified as Controlled Low Strength Materials or "CLSM." They are considered low strength because they typically have compressive strengths between 50 and 200 psi.

3. Are there alternative DYNA-ASH™ Flowable Fill products available for my special needs?
Yes. Beyond the standard low strength ***DYNA-ASH™ Flowable Fill*** designs, the DYNA Corporation also offers controlled high strength flowable fill materials, known as ***DYNA-ASH™ Flowable Fill*** as well as rapid setting flowable fill materials, known as ***DYNA-ASH Express Fill™***.

4. How do the DYNA-ASH™ Flowable Fill products compare to traditional backfill methods using soil?
DYNA Corporation manufactures ***DYNA-ASH™ Flowable Fill*** to meet your fill and compaction needs, giving you a fill material that is clearly superior in performance at only a fraction of the cost-in-place for most soil or clay backfill operations.

5. What are the primary advantages of using DYNA-ASH™ Flowable Fill in lieu of conventional backfill?
DYNA-ASH™ Flowable Fill is superior to conventional backfill because it offers a designed/known strength, requires no testing, presents higher load bearing capacities and stability, can be placed in standing water, and all in less time and without special placement equipment or labor.

6. Can DYNA-ASH™ Flowable Fill save my project money?
Absolutely. ***DYNA-ASH™ Flowable Fill*** eliminates the need for expensive placement crews, tamping or other compaction work, so your labor cost for fill in place can almost evaporate. Time is money, and typically you can expect it to take as little as 1/6 the time to pour ***DYNA-ASH™ Flowable Fill*** in place versus conventional backfill materials.

7. How does DYNA-ASH™ Flowable Fill compare to other flowable fill (CLSM) products we see promoted?
Most other flowable fill products are made with aggregates that can contaminate flow performance and make future excavation a real nightmare. Furthermore, DYNA Corporation offers two stationary plant operations in the Washington/Baltimore area for the production and supply of ***DYNA-ASH™ Flowable Fill***, as well as a large number of on-site portable operations.

8. How are DYNA-ASH™ Flowable Fill products delivered?
Manufactured to exacting standards using our state-of-the-art batching systems. ***DYNA-ASH™ Flowable Fill*** is delivered to your project site via DYNA's fleet of radio dispatched ready mix type trucks.

9. Can DYNA-ASH™ Flowable Fill products be pumped into place?
Absolutely. ***DYNA-ASH™ Flowable Fill*** mixes are designed to work through a regular concrete pump, mud jack pump, or grout pump. In fact, DYNA Corporation also offers **turn-key pump placement services.**

10. Should I consider using DYNA-ASH™ Flowable Fill instead of concrete?
Yes. If the specifications which you desire are consistent in strength requirements, ***DYNA-ASH™ Flowable Fill*** is generally much less expensive, and more effective in 1 bag lean concrete mix applications.

11. How does rain or cold weather affect DYNA-ASH™ Flowable Fill?
DYNA-ASH™ Flowable Fill can be placed in cold weather or rain. It even can be poured and will set up in standing water! No more waiting on a brief thaw to work on frozen ground. No more productivity loss from crews working in cold weather. No more time lost for projects on hold during rain, sleet or snow. Because ***DYNA-ASH™ Flowable Fill*** eliminates the need for compacting in most applications, your bad weather headaches can be a thing of the past.

12. What is the compressive strength of standard DYNA-ASH™ Flowable Fill products?
Standard CLSM *DYNA-ASH™ Flowable Fill* products are designed for 50-75 psi in 24 hours, and 75-200 psi in 28 days. Custom designed mixes provide for strengths of up to 2500 psi, as well as accelerated set times which are particularly beneficial for paving applications where they can provide readiness for paving as soon as 2 hours from the time of placement with ***DYNA-ASH Express Fill™***.

13. Can DYNA-ASH™ Flowable Fill products be used for encasing electrical conduit?
Yes. Specially designed ***DYNA-ASH™ Flowable Fill*** mixes provide for the appropriate thermal conductuity to meet rho value standards for electrical conduit encasement applications.

14. At what quantity of DYNA-ASH™ Flowable Fill would an on-site manufacturing operation be more economical?
It will depend upon three major factors: overall quantity, hourly supply rate required, and time frame from start to finish. DYNA Corporation will analyze your project and propose the most economical method of manufacture and supply.

15. Is DYNA-ASH™ Flowable Fill approved for use by any local agencies?
Yes. As of 1997, most major jurisdictions and agencies in and around the MD/VA region have recognized and approved the use of ***DYNA-ASH™ Flowable Fill;*** including: the Maryland and Virginia Departments of Transportation; the Washington Area Transit Authority; the City of Annapolis; Baltimore City and County; Howard, Prince George's, and Anne Arundel counties; the Washington Suburban Sanitary Commission, Washington Gas Company, PEPCO, and Baltimore Gas & Electric. The District of Columbia has regularly approved the use of ***DYNA-ASH™ Flowable Fill*** through a project submittal process.

DYNA CORPORATION · SAFEGUARDING THE ENVIRONMENT

DYNA-ASH™ · FLOWABLE FILL

APPENDIX G: Listing of Standard Test Procedures Specified by Lightweight Aggregate Manufacturers

Listing Of Test Designations And Titles Specified By Lightweight Aggregate Manufactures

Test Designation	Title of Standard Procedure
AASHTO T-260	Standard Method of Test for Sampling and Testing for Chloride Ion in Concrete Raw Materials
ASTM C29	Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate
ASTM C88	Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
ASTM C127	Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate
ASTM C131	Standard Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
ASTM C136	Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
ASTM C177	Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus
ASTM C330	Standard Specification for Lightweight Aggregates for Structural Concrete
ASTM D698	Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft)
ASTM D2434	Standard Test Method for Permeability of Granular Soils (Constant Head)
ASTM D4253	Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using Vibratory Table
ASTM D4254	Standard Test Method for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
FM1-T-096	Florida Modified L.A. Abrasion Test

APPENDIX H:

Contact Information for some Manufacturers of Lightweight Aggregate

Contac Information For Manufacturers of Lightweight Aggregate

Norlite: Norlite Corporation
P.O. Box 694
628 S. Saratoga Street
Cohoes, NY 12047-0694
Tel: (518) 235-0030; Fax: (978) 433-8364
http://www.norliteagg.com

Solite: Northeast Solite Corporation
P.O. Box 437, 962 Kings Highway
Mt Marion, NY, 12456
Tel: (914) 246-2636 ext. 23; Fax: (914) 246-3356
www.nesolite.com

Stalite: Carolina Stalite Company
P.O. Box Drawer 1037
205 Klumac Road
Salisbury, NC, 28145-1037
Tel: 800-898-3772; Fax: (704) 642-1572
www.stalite.com

Buildex: Buildex Inc.
P.O. Box 77
Ottawa, Kansas, 66067-0077
Tel: (785) 242-2177; Fax: (785) 242-1281
www.buildex.com

Arkalite: Arkalite
P.O. Box 1567
West Memphis, AR, 72303-1567
Tel: (870) 735-7932; Fax: (870) 735-5467

Utelite: Utelite Corporation
1214 Wilmington Ave., #301
Salt Lake City, UT 84106
Tel: (801) 467-6763; Fax: (801) 529-3714

Gravelite: Big River Industries
3700 Mansell Road, Suite 250
Alpharetta, GA 30022
Tel: (800) 342-5483; Fax: (678) 461-2845