

# **Chapter 1**

## **Overview and History of the Expanded Shale, Clay and Slate Industry**

**April 2007**

**Expanded Shale, Clay & Slate Institute (ESCSI)  
2225 E. Murray Holladay Rd, Suite 102  
Salt Lake City, Utah 84117  
(801) 272-7070 Fax: (801) 272-3377  
[info@escsi.org](mailto:info@escsi.org) [www.escsi.org](http://www.escsi.org)**

## CHAPTER 1

- 1.1 Introduction
- 1.2 How it started
- 1.3 Beginnings of the Expanded Shale, Clay and Slate (ESCS) Industry
- 1.4 What is Rotary Kiln Produced ESCS Lightweight Aggregate?
- 1.5 What is Lightweight Concrete?
- 1.6 Marine Structures
  - The Story of the Selma
  - Powell River Concrete Ships
  - Concrete Ships of World War II (1940-1947)
  - Braddock Gated Dam
  - Off Shore Platforms
- 1.7 First Building Using Structural Lightweight Concrete
- 1.8 Growth of the ESCS Industry
- 1.9 Lightweight Concrete Masonry Units
  - Advantages of Lightweight Concrete Masonry Units
- 1.10 High Rise Building
  - Parking Structures
- 1.11 Precast-Prestressed Lightweight Concrete
- 1.12 Thin Shell Construction
- 1.13 Resistance to Nuclear Blast
- 1.14 Design Flexibility
- 1.15 Floor and Roof Fill
- 1.16 Bridges
- 1.17 Horticulture Applications
- 1.18 Asphalt Surface Treatment and Hotmix Applications
- 1.19 A World of Uses – Detailed List of Applications
  - SmartWall® High Performance Concrete Masonry
  - Asphalt Pavement (Rural, City and Freeway)
  - Structural Concrete (Including high performance)
  - Geotechnical
  - Horticulture Applications
  - Specialty Concrete
  - Miscellaneous

**Appendix 1A**      ESCSI Information Sheet #7600 “*Expanded Shale, Clay and Slate-  
A World of Applications...Worldwide*”

## 1.1 Introduction

The purpose of this reference manual (RM) is to provide information on the practical application of expanded shale, clay and slate (ESCS) lightweight aggregates.

ESCS lightweight concrete has played an important part in the increasingly sophisticated construction techniques that have developed in recent years. Besides imparting substantial economies in a number of applications, it has also made for feasible design concepts that could not have been undertaken with the usual heavy concrete, and in effect has opened up whole new vistas of form and utility in the structures that are part of the modern environment and culture.

This remarkable environmentally friendly product is widely used in a very large range of construction, where its properties of light weight, high strength and durability suit it ideally for both the stringent structural engineering requirements as well as esthetic and artistic forms and shapes that provide pleasant places to live and work. ESCS gives designers greater flexibility in creating solutions to meet the challenges of dead load, terrain, seismic conditions, construction schedules and budgets in today's marketplace. Living in harmony with our environment starts with the design process and includes a holistic perspective. This reference manual shows some of the many ways lightweight aggregate contributes to the overall sustainability of our world...

From the perspective of a brief overview, lightweight aggregate provides weight reduction that significantly reduces the number of trucks needed to carry concrete products to the job site. This reduces congestion and improves safety in urban settings. Weight reduction also translates into better fire rating and improved thermal performance which, improves life safety and provides a major decrease in energy consumption. When the dead load of a structure is decreased fewer overall materials and excavations are needed.

Lightweight aggregate also extends the service life of concrete by providing enhanced hydration of cementitious material and better elastic compatibility between the aggregate and matrix. These properties have been shown to improve the long-term durability of concrete and reduce the formation of cracks that can contribute to corrosion of reinforcing steel. Consequently this material has found favor with designers of high-rise construction, bridges, precast/prestressed elements, concrete masonry and pavements for almost a century.

It was during World War I that the potential of lightweight aggregate began to be fully realized, and the spirit of research and experimentation which preceded the first patent issued in 1918 is very much alive today. The limited resources and technology available to Stephen J. Hayde, working as a building contractor in Kansas City in 1908, have been superseded by the improved technology and organized research and shared knowledge and shared financial support offered by the Expanded Shale, Clay and Slate Institute. The institute was founded in 1952 and now comprises an organization of plants in North and South America, Europe and Asia.

## 1.2 How it started

Lightweight aggregates have been used in construction since before the days of the Roman Empire. The earliest types of lightweight concrete were made by using Grecian and Italian vesicular volcanic aggregates as lightweight aggregate. Ordinary hydrated burned lime was used as the cementitious material in the mix. These early lightweight concretes, by reason of the obviously weak materials, fell short in structural strength and performance of what we expect and achieve today. They were, however, amazingly durable, and existing examples of these early lightweight concretes can still be found in various early structures in the Mediterranean area.

The Romans, in their militaristic expansion and colonization, introduced and established the use of concrete wherever and whenever suitable local materials were available, such as limestone for preparation of quick lime as a cementing material.

Many different materials have been used for lightweight concrete since Roman days, and some have shown remarkably better structural qualities than the Roman materials. Up to the 20<sup>th</sup> century, however, such improvements were associated with the strength of the cementing materials used rather than with improvements to the lightweight aggregates.

The first such improvement to the strength of concrete came about in the course of Roman colonization when their need for widely scattered building activity forced the use, on some occasions, of various impure grades of limestone for the preparation of required burned lime. In those instances where the impurities happened to be silica, alumina and iron oxides, the strength of concrete was found to be substantially greater than where pure limes were used. This superior material was referred to as gray lime, and subsequently became known throughout Europe as Roman cement.

This material was the first cement to demonstrate hydraulic properties, or the first capable of hardening under water, but it was not a consistent performer. The strength varied widely between production localities and the particular composition of the impure limestone's used. Even so, Roman cement was used in all concrete work where hydraulic properties and water-tightness were required from that time until the first half of the nineteenth century.

In 1824 Joseph Aspdin, an English bricklayer, conceived the idea of intermixing pulverized raw limestone and pulverized impure siliceous materials in varying percentages. He then subjected these mixtures to the high temperatures of coke fires, and pulverized the resultant clinkers. Aspdin thereby determined the approximate raw compounding required for maximum strength, and likewise removed for all time the dangerous inconsistencies of the older Roman cements. This was the birth of that highly valuable building material that we rely upon today for all major construction: Portland cement, so called because when hardened it resembled a popular building stone quarried on the Isle of Portland, off the coast of England.



Before Aspdin's time, cements were relatively weak, so weak in fact, that the aggregates, both heavy and light, had greater structural strength than the cementing binder used. And heavyweight and lightweight concretes had been roughly comparable in performance.

Aspdin's Portland cement provided a cementing medium that for the first time was capable of exceeding the structural strength of lightweight aggregates used at that time. Because of their low stiffness and their consequent tendency to shear and crush under compressive stress, the lightweight concretes produced from natural lightweight aggregates could not achieve the strength of heavyweight rock and sand concretes. This differential in performance was intensified as additional cement improvement came with refinements in grinding equipment, the introduction of the rotary kiln to cement production, and closer scientific control in the processes of manufacture.

Inasmuch as very substantial economies, greater versatility in concrete uses, and many other advantages can result from decreasing the weight of concrete, innumerable new materials were used as lightweight aggregates in an attempt to capitalize on the greater strength of cement. Pumice, scoria, volcanic cinders, and vesiculated lava were among the natural lightweight aggregates used. None, however, was capable of providing structural qualities matching that of heavyweight concrete.

### **1.3 Beginnings of the Expanded Shale, Clay and Slate (ESCS) Industry**

It is interesting that an industry which is so closely identified with the construction of lofty skyscrapers and other land structures should have first come to national attention through its use in ocean-going ships. For although the first work on expanded shale, clay and slate was undertaken in 1908, it was not until almost a decade later during World War I (1917-1920) that the product saw any large scale use, and that in the concrete shipbuilding program undertaken by the United States Fleet Corporation, an arm of the Federal Government. The organized research undertaken by the National Bureau of Standards in connection with that program, as well as the national publicity the program received, were important factors in the development of the industry.

Stephen J. Hayde of Kansas City, Missouri, is universally recognized as the founder of the industry. Like many industrial pioneers, he got his start by trying to solve one problem and ending up solving another one of even greater magnitude. Mr. Hayde was a contractor and brick maker, and a perennial problem of the industry for centuries had been the abnormal bloating of some of the brick as the shale or clay expanded (excessively from a brick-makers perspective) when subjected to high heats during the burning process.

Mr. Hayde had considerable practical knowledge of construction and construction problems, coupled with an inquiring, inventive and resourceful mind. It occurred to him that the bloated lightweight material which was then being discarded had potential characteristics for a lightweight aggregate: consisting of generally non-connecting air cells produced by the formation and expansion of gases within the vesicular aggregate

when subjected to heat, and with a glass-like hardness, the material satisfied the basic requirements of aggregate hardness and durability and yet had significantly less density than conventional aggregates such as sand and gravel. His reasoning, which was later borne out by practical experimentation, was that an aggregate of this nature could substantially reduce the dead load of concrete structures and thereby help solve problems of both cost and engineering.

The logistics problems created by the entry of the United States into World War I in 1917 were compounded by the shortage of high-grade plate steel for building ships. The United States Fleet Corporation, an arm of the Federal Government, was charged with planning a shipbuilding program using material other than steel. One of these materials was reinforced concrete, which had already been used in shipbuilding in the Scandinavian countries.

The basic problem was reduction of deadweight, and tests were made of concrete made with natural aggregates, such as pumice, cinders and scoria, but these were found to be unsuitable because of their low strength and lack of uniformity. Researchers learned of Mr. Hayde's work and undertook further experimentation which confirmed his findings that certain shales, clays and slates could be processed so as to produce a lightweight, vesicular product which was similar in appearance to the volcanic basalts used centuries before by the ancient Romans, but far more uniform in character and quality and therefore better fitted for concrete aggregate. This in turn led to an investigation of Mr. Hayde's product, which was still in the developmental stage.



### ***Expanded Shale, Clay and Slate Lightweight Aggregate***

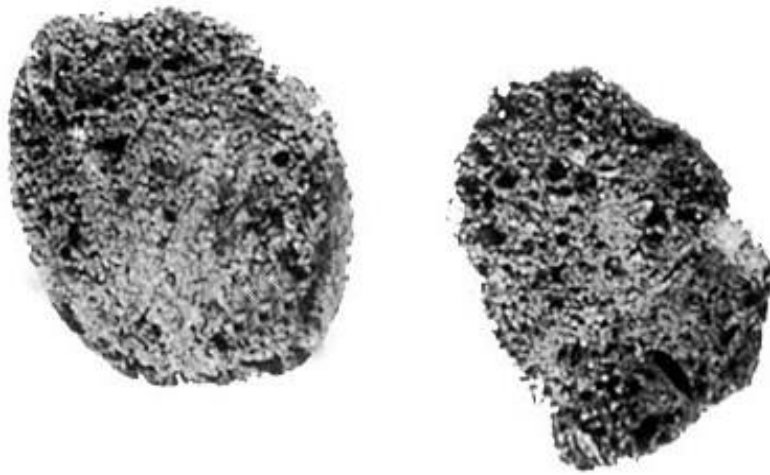
The National Bureau of Standards was assigned, first, the task of further research and experimentation, and then, in 1918, the quantity production of the aggregate. In February of that year, Mr. Hayde was granted a patent on his process (U.S. Patent No. 1,255,878), and he granted free use of his patent rights to the Federal Government for both the experimental and construction phases of the shipbuilding program.

After the war, progress was made in commercializing the product. The American Aggregate Company was formed in Kansas City to license the operation of lightweight aggregate plants. By 1941 there were eight licensed operations in the United States and

Canada. However, rapid growth did not occur until the Haydite patents expired in 1946; many new companies were formed in the late 1940's and early 1950's to produce lightweight aggregate to supply the post World War II building boom.

The Haydite name is still well known in the construction industry and is a trademark of three ESCSI members. Buildex Inc. of Ottawa Kansas operations trace directly to Hayde's original plant. Hydraulic Press Brick Company of Indianapolis Indiana is one of the original licensees. DeiGeronimo Aggregates LLC, Independence Ohio has the only original licensee plant site still in operation.

#### **1.4 What is Rotary Kiln Produced ESCS Lightweight Aggregate?**



##### ***Vitreous, Porous, Ceramic Aggregate***

What is ESCS? It is a unique, ceramic lightweight aggregate prepared by expanding select minerals in a rotary kiln at temperatures over 2000° F. The production and raw materials selection processes are strictly controlled to insure a uniform, high quality product that is structurally strong, stable, durable and inert, yet also lightweight and insulative. ESCS structural grade aggregate is composed of a strong, ceramic, vitreous material encapsulating a system of general non-interconnected pores. Although, the particle density is approximately one half that of natural aggregates, this aggregate when used in concretes achieve the usual structural strengths.

Concrete is fundamental to the American environment – in buildings, highways, bridges and other structures – and is so taken for granted that most people assume all concrete is alike; massive and heavy. Yet this is not the case.

For concrete consists of aggregate held together by paste made of Portland cement and water, and, depending on the type of aggregate used, will cover a wide range of weight, and applications. It is possible to design for many different levels of strengths, durability,

heat and sound insulation, and water tightness. By placing steel in concrete, either as reinforcing bars or in the form of high tensile wire, the range is broadened further.

The term “Lightweight Aggregate” describes a range of special use aggregates that have a relative density considerably below that of ordinary sand and gravel which were at one time used in almost all concrete.

Lightweight aggregates range from the extremely light materials used for insulative and non-structural concrete (Vermiculite and Perlite, relatively low strength concrete can be made with these aggregates weighing as little as 20 pounds per cubic foot) all the way to ESCS used for high performance structural concrete. Since the lightness of these aggregates derives from the air-trapped in each individual particle, the more air that is trapped per particle unit the lighter the weight and the better the insulation, but, conversely, the lower the particle strength, but as will be shown later not necessarily a lower concrete strength.

In the manufacturing process of ESCS there are a few variations in the way the material is prepared for the rotary kiln. In one option the raw material is pre-sized before entering the kiln so that only limited crushing after burning is necessary. Still another variation consists of extruding or pelletizing fine raw material as a means of pre-sizing the raw kiln feed. Combinations of these variations are found throughout the industry.

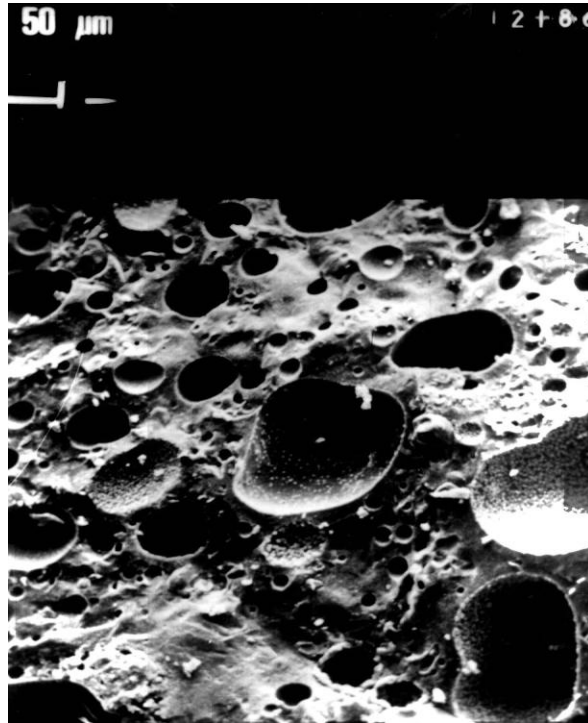
Although statistics are not available, it is estimated that expanded shale, clay or slate aggregate produced by the rotary kiln method is used for more than 95 percent of the structural lightweight concrete placed today.

## **1.5 What is Lightweight Concrete?**

Expanded shale, clay and slate aggregates produced by the rotary kiln method will produce a structural lightweight concrete ranging from 85 to 115 pounds per cubic foot. Specified density concrete ranging from 115 to 145 pounds per cubic foot also incorporates ESCS and is commonly used in precast, offshore structures and bridge members.

Beyond this, there are the air-cooled slag aggregates and ordinary aggregates such as sand and gravel and crushed stone, which produce conventional concretes weighing 135 to 155 pounds per cubic foot.

In general, the low density non-structural lightweight aggregate concretes are used primarily for insulating purposes, as they have relatively low compressive strength, while those in the middle range are used for insulation and fill.



*Micro-structure of Lightweight Aggregate*

Insofar as concrete properties are concerned, there is no distinction between aggregates produced from materials classified as shale, clay or slate, so that the term “expanded shale” or ESCS is frequently used generically to cover the aggregates produced by the rotary kiln method, regardless of which of the three raw materials was actually used.

The aggregate particle itself is a hard, highly cellular product of uniformly great structural strength, each cell being surrounded by a hard, vitreous matrix. The bulk density of the aggregate will range from 30 to 65 pounds per cubic foot, dry and loose. The coarse fraction (nominal dimensions 3/4" by 3/8") generally weighs between 30 and 60 pounds, the fines between 45 and 70. The maximum size of lightweight aggregate is nominally minus three-quarters or one-half of an inch, varying somewhat with type of material.

The relative density of the dry lightweight aggregate (ranging from 1.1 to 1.8) is significantly less than that for conventional aggregates, with  $2.6 \pm$  being commonly assumed. Structural lightweight concrete made from these aggregates is generally 20 to 35 percent lighter than heavy concretes made with ordinary aggregates.

The hardened properties of structural lightweight concrete are similar to those of normal concrete. ACI 318 defines structural lightweight concrete as a concrete having a 28-day compressive strength of 2,500 pounds per square inch or more, and an equilibrium density not to exceed 115 pounds per cubic foot. The aggregate for lightweight concrete

may consist of 100 percent lightweight aggregates, or a combination of lightweight and normalweight aggregates (usually local sand).

Strictly speaking, the term “lightweight” is relative, and the reason for the use of lightweight concrete is usually for the economy in steel and foundations that can be realized by weight reduction. Concretes in the compressive strength range of 3,000 to 6,000 psi made with 100 percent lightweight aggregates weigh between 85 and 105 pounds per cubic foot. By replacing part or the entire lightweight fine fraction with natural sand, these weights will increase by from 5 to 15 pounds per cubic foot. Comparable concrete made with ordinary aggregates has a weight of 145 to 155 pounds per cubic foot.

Besides the lower density, lightweight concrete has substantially better fire resistant qualities than normalweight concrete, and significantly lower heat transmission. Its remarkable moisture resistance and durability is evidenced in samples which have been subjected to daily cycles of wetting and drying in salt water for more than 80 years, showing an increase in compressive strength from 5,550 pounds per square inch to more than 10,000 pounds per square inch, and with a cover of only 5/8-inch thickness, completely protecting the steel reinforcement from the corrosive action of the salt water.

For architects and engineers, structural lightweight concrete has opened up a broad range of applications: tall building frames, long-span roof and bridge structures, thin shell construction.

## 1.6 Marine Structures

### The Story of the Selma



*Launching, U.S.S. Selma, June, 1919, Mobile, Alabama*

Although small concrete ships had been built successfully in the Scandinavian countries, the project envisioned by the Fleet Corporation was on a much larger scale: a 7,500-ton

tanker with a length of 434 feet, a beam of 43 feet and a full cargo draft of 26 feet. Needless to say, the construction of a concrete ship of these dimensions required-in addition to the development of suitable lightweight aggregate innovations in both form construction and in placing the concrete in the heavily reinforced thin sections.

Such a ship was in fact constructed, and it was launched in June, 1919. She was christened the U.S.S. Selma, after the city in Alabama and honoring it for a Liberty Loan drive. The Selma was not the first concrete ship to be constructed in the United States, the 3,000-ton Atlantis had been launched in December, 1918-but she was the largest. Since the research had indicated that more uniform lightweight aggregate could be produced by the rotary kiln method, the Atlas Portland Cement Company was contracted to produce expanded shale aggregate in certain kilns at Hannibal, Missouri.

The material was supplied in two gradings: fine material with an average weight of 69 pounds per cubic foot, and coarse material with an average weight of 44 pounds per cubic foot. In all, 176 carloads, or 7,350 tons of this expanded aggregate were shipped from Hannibal to the Fred T. Ley Company of Mobile, operators of the government shipyard there.

The ship's reinforced expanded shale lightweight concrete hull had a thickness of five inches on the bottom and four inches on the side. Her construction required 2,660 cubic yards of concrete reinforced with 1,550 tons of smooth reinforcing bars, or 1,165 pounds of reinforcing steel per cubic yard of concrete.

Another technological breakthrough achieved during construction of the Selma was the initial step in the development of the "slump cone" test, ASTM Designation C-143. In order to obtain good placement of concrete in the thin hull sections in and around the heavy mats of reinforcing steel, it was necessary to use an extremely fluid, easily-placed concrete. One of the engineers developed an apparatus which successfully overcame the difficulty of controlling the consistency of this type of concrete and producing it uniformly batch after batch. The apparatus consisted of a 6 x 12 inch cylinder mold and an arrangement of fixed vertical tracks by which the mold could be raised. The cylinder was filled with concrete, and then raised, and the drop of the mass was measured, with the result reported as the "consistency drop" in inches. As far as is known, this was the first successful effort to control the consistency of concrete in the field.

Another "first" scored by the Selma was that she was the first large vessel to be launched sideways, and although there was some concern as to whether the launching would be successful, 20 shipyard employees confidently rode the ship down the ways.

World War I was over by the time Selma was outfitted, but she immediately went into service transporting crude oil from Tampico to Texas ports, and had a short but satisfactory service record, three years of continuous service in all.

In July, 1953, the engineers Testing Laboratory, Inc. of Houston, Texas, was employed by the Expanded Shale, Clay and Slate Institute to inspect the hull of the Selma in Galveston Bay and make a preliminary investigation and report on the concrete, which at

that time had been in sea water for 34 year. They cut specimens out of the hull and interior compartment ribs, examined the condition of the steel and also observed the general condition of the concrete. Specimens from the hull were taken in that band which was alternately exposed to sea water and salt air by action of wind and tides. Specimens from the compartment ribs had been exposed to salt air only.

The report dated September 10, 1953, stated that the concrete was in excellent condition in both of these areas; some of the hull concrete was chipped out to a depth of 1/4 inch and at that depth the concrete appeared to be dry and without discoloration from absorbed water. An examination of the interior of the hulk showed that the concrete was in very good condition and no cracks were visible. The report found the reinforcing steel in excellent condition with no pitting of the bars, and concluded that the slight coating of rust could well have been on the bars when they were placed. The report also pointed out that in many places there was only 5/8 inch of concrete over the reinforcing steel. Another coring of the Selma in 1979 confirmed the earlier findings and was reported at the 1980 ACI/CANMET International Conference of Durability of Concrete in a Marine Environment.

### **Powell River Concrete Ships**

#### *Powell River, British Columbia, Canada*

Ten concrete ships are being used as a floating breakwater at the Pacific Paper Powell River Plant. Evaluation of the ships for long-term service durability of the lightweight concrete was recently conducted. The ships range in age from 55 to 80 years, with one ship constructed in the 1920's, and the other nine in the 1940's. These ships demonstrate the excellent performance of structural lightweight concrete after more than a half-century of marine exposure.



***Powell River Concrete Ships***



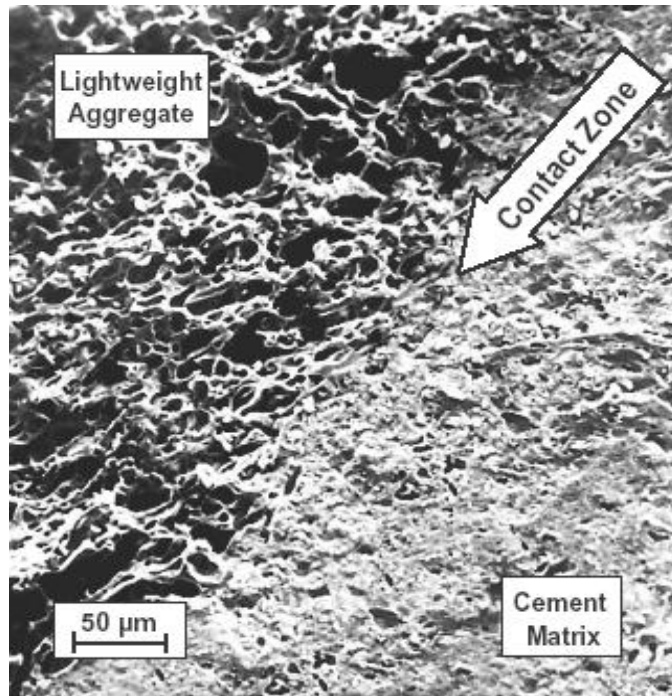
Petrography studies conducted at CTL (Construction Technology Laboratory) revealed limited microcracking, excellent aggregate/matrix contact zone, complete hydration of the cement, and insignificant damage due to freezing and thawing. This microscopic examination clearly showed evidence of continued hydration and development of the cement matrix. This continued maturation of the concrete has contributed to the development of compressive strengths in the ships' hulls well beyond (up to 8700 psi) the minimum design strength (5000 psi) of the concrete. Concrete densities range from 106 lb/ft<sup>3</sup> to 130 lb/ft<sup>3</sup>.

According to the inspectors' report, the "paste-aggregate bond is consistently excellent in all the examined concrete specimens, in part attributed to mostly beneficial reactions along the paste-aggregate interface. Overall, the manufactured lightweight concrete used in the construction of the ships has performed exceptionally well in a harsh marine environment". *Text taken from the ACI publication, SP-189-7, "Evaluation of Lightweight Concrete Performance in 55 to 80 Year-Old Ships," by R.D. Strum, N. McAskill, R.G. Burg and D.R. Morgan.*



#### ***Powell River Ships Core Sample***

Drilled core sample revealed that the SLC of the ship's hull had continued to mature and strengthen well beyond its design strength.



*Paste-Aggregate Interface*

Scanning electron microscope photograph of aggregate/matrix contact zone; from the cover of the *“State-of-the-Art Report on High-Strength, High Durability Structural Low-Density Concrete for Applications in Severe Marine Environments”* by Thomas A. Holm and Theodore W. Bremner.

**Note:** Additional information on the properties and performance of lightweight concrete can be obtained by viewing the reference publication by Holm and Bremner on the Army Corps of Engineers web site “Reports Page”  
<http://www.wes.army.mil/SL/INP/reports.htm>



***World War II Concrete ship passing under San Francisco-Oakland Bay Bridge, San Francisco. Both ship and bridge made extensive use of structural lightweight concrete.***

### **Concrete Ships of World War II (1940-1947)**

By the time of World War II (1940-1947), ESCS was widely used as a construction material – and again it was put to use in ship construction. The important difference was that where the 14 World War I ships had been largely experimental, those built in World War II – 104 in all, with cargo capacities ranging from 3,200 to 140,250 tons – saw widespread wartime service in battle zones.

Twenty-four of these ships were large sea-going vessels and 80 were sea-going barges of tremendous size. The total cargo capacity represented was about 488,000 tons, or the equivalent in capacity of 46 Liberty ships. The total cost of the project was \$167 million.

In its report on these lightweight concrete ships, the U.S. Maritime Commission indicates that the ships exhibited good handling, good performance, and unexpectedly high resistance to near misses of shells and depth bombs. One report indicated that when a bomb exploded directly astern of one of the ships, the ship “shook like an earthquake” and was showered with shell fragments but suffered no damage. Another told of six near misses from depth bombs, with no impairment of the structure or damage to the cargo.

The commission also reported that the hulls appeared to be completely watertight in service, carrying cargoes of wheat and sugar with no damage, mold or caking from either seepage or sweating. There is no better testimony of low permeability of “real crete” structures as opposed to “labcrete” specimens. This was true even of those ships which had experienced near misses from bombs. It also pointed out that certain cargoes like sulphur, which is very destructive to steel, can be carried to advantage in concrete hulls.

The riding qualities of the ships were superior to steel, the Commission added, because of their bulk and rigidity; there was little vibration, and the interiors were cooler and more comfortable. It predicted that repairs in service would probably be less costly and less frequent, and that, with no rusting or attack by sea water, the life of the hulls should be greater.

The Maritime Commission concluded its report by saying that “There is ample evidence that concrete hulls are dependable, seaworthy, and structurally as sound as hulls of any other material used for seagoing vessels. Concrete hulls have been put to as severe tests as have been given any other vessels, and it has been shown conclusively that when properly designed, properly built, and well equipped, they will perform on an equal basis with comparable steel vessels...”.

### **Braddock Gated Dam**



***Braddock Gated Dam (2002)***

In initiating the final phase of modernizing the locks and dams on the Monongahela River, the U.S. Army Corps of Engineers, Pittsburgh District, used float-in and in-the-wet technology to build the New Braddock dam (Tasillo, Neeley and Bombich 2004). This is the first use of such technology for an inland navigation project in the United States, and was employed to eliminate the cost and construction time associated with a conventional cofferdam for mass concrete construction. The new Braddock dam design was fabricated as two large, hollow-core segments. Unlike such applications used for offshore structures, the inland applications were limited by navigational draft, and lock and bridge clearances. This restricted the overall dimensions and mass of the segments. The use of lightweight concrete in a significant portion of the two large dam segments was central to the success of the design. Good planning, an understanding of the concrete materials, and quality control were critical to project success.

## Offshore Platforms

To satisfy the Hibernia Offshore Platform requirement of constructability, concrete production and placement, and durability, a 10,000 psi (69 Mpa) normal density concrete was originally specified for this project. Among other characteristics, this concrete was to consistently have the following: *high strength, high modulus of elasticity, high tensile strength, high freeze and thaw resistance, high workability and slump with no segregation, low permeability, and high pumpability* (ESCSI #4700.0, 2001).

To improve the buoyancy of the GBS, it was later determined that a reduction of about 10% in concrete density would be advantageous. The weight reduction had to be achieved without affecting the strength, durability and constructability spelled out in the original design. To achieve these objectives, approximately 50% (by volume) of the normal density coarse aggregate needed to be replaced with a lightweight aggregate of the highest possible quality.



*Hibernia Offshore Platform (1998)*



The Heidron floating concrete offshore platform floats above the Heidron oil fields in the cold, stormy North Sea. Because of the need to achieve the required buoyancy, the concept of using high-strength low density concrete (HSLDC) was introduced early in the planning stages. The hull of the floating structure is constructed entirely of HSLDC (60 MPa/8,700 psi cube strength). Almost 70,000 m<sup>3</sup> (91,000 yd<sup>3</sup>) of HSLDC with a maximum density of 2,000 kg/m<sup>3</sup> (125 lb/ft<sup>3</sup>) and a required elastic modulus of 22 GPa ( $3.19 \times 10^6$  psi) were used.



*Heidron Floating Concrete Offshore Platform  
(ESCSI #4700.0, 2001)*

## **1.7 First Building Using Structural Lightweight Concrete**

The World War I era research on lightweight aggregates put the expanded shale industry into its first commercial production, and after the war, additional experiments were conducted by private enterprise, using a small 3-1/2 x 25 foot kiln in eastern Kansas.

As a result, as early as June, 1919, the chief engineer of the Turner Construction Company of New York could suggest that lightweight structural concrete could offer significant construction economies – through reduction in reinforcing steel requirements – in high-rise commercial construction. Speaking at the 15<sup>th</sup> convention of the American Concrete Institute at Atlantic City 1919, he said: “In additions to the saving in steel reinforcement there is a saving in concrete in the columns due to the reduced weight of the floor construction.”

The first commercial plant dedicated to expanded shale aggregate began operating in Kansas City, Missouri, in 1920 under the name Haydite Company. Where wartime production had been handled at brick and cement plants, the Haydite Company was a bona fide expanded shale aggregate plant, with a mission to both produce the material and introduce it into the commercial construction market.

Even so, there were few design criteria available that could apply to uses of lightweight concrete in building construction, and little inclination among architects, engineers and builders to risk their reputations by experimenting with the new material. It was part of “traditional wisdom” that in order to be impermeable as well as durable and strong, concrete had to be of maximum density and weight. So it was not until 1922 that the industry had a “living example” – a building employing lightweight structural concrete and demonstrating both its economics and its construction reliability.

This was a gymnasium addition to the Westport High School in Kansas City, the first lightweight concrete building using expanded shale in history. Designed by a pioneering architect, the building employed lightweight concrete to avoid the difficult foundation work that would have been required with conventional weight concrete because of the poor load-bearing characteristics of the soil at the site. At the time, the expanded shale aggregate sold at \$6.00 per cubic yard, as contrasted with \$2.50 per cubic yard for sand and gravel, and yet the economies in foundation engineering made possible by the reduction in deadweight load more than compensated for the price differential.

The first major project employing structural lightweight concrete was undertaken in 1928 and 1929, in the form of an addition to the Southwestern Bell Telephone Company office in Kansas City. The building was originally designed as a 14-story structure, and the company had found that the foundations and underpinning would support an additional eight floors, taking into account the additional dead load of conventional heavyweight concrete.



***Southwestern Bell Telephone building addition Kansas City, MO.***

However, analysis by the designers indicated that by the use of lightweight expanded shale concrete rather than conventional sand and gravel concrete 14 floors could be safely added rather than eight – in affect, doubling the above-ground height of the building and producing a skyscraper with a total of 28 floors. The project was undertaken with concrete mixed on-site (this was before the day of the ready-mix plant) with the relatively crude mixing equipment of the day. There were naturally some technical problems, primarily in producing a uniform and workable mix and placing the concrete in column and beam forms, but these were overcome by applying technical knowledge developed at the University of Kansas.

When completed, the building addition showed a total dead load reduction of more than nine million pounds through use of lightweight expanded shale aggregate: six million pounds through the use of lightweight structural concrete, and three million pounds through the use of Haydite brick in the walls in place of structural clay units. Compressive strength of the lightweight concrete was 3,500 pounds per square inch at 28 days – an almost unprecedented high at the time. And the building has stood for more than 75 years as a demonstration of the practicality and economics of lightweight structural concrete.



The first structural lightweight concrete high-rise building was the Park Plaza Hotel in St. Louis (now the Chase-Park Plaza). Built in 1929, this 28-story structure made extensive use of structural lightweight concrete in both frame and floor systems, as well as for fireproofing.



*Chase-Park Plaza Hotel, St. Louis, Missouri*

With these demonstrations of the feasibility of lightweight structural concrete in high-rise buildings, acceptance of the product was established, and succeeding years saw an increasing number of architects and engineers specifying it for major construction projects. One example is the Crystal Mall pictured below showing several high-rise lightweight concrete buildings.



*Crystal Mall, Arlington, Virginia*

## **1.8 Growth of the ESCS Industry**

To some extent, the growth of the ESCS industry was limited both by the scarcity of technical knowledge and by the fact that the material could be produced only under license from Mr. Hayde or his assigns, and venture capital was not readily available for the substantial investment required, particularly during the depression years of the 1930's. As a result, by 1941 there were only seven licensed operations in the United States and one in Canada. Nevertheless, it was during this period that numerous studies of design and physical properties of both structural and masonry lightweight concrete were conducted.

Five studies in particular developed some very important data on the properties of ESCS concretes. These were:

- Construction and Design Features of Haydite Concrete, Richart & Jensen, ACI Journal Oct. 1930.
- Strength and Stability of Concrete Masonry Walls, Richart, Moorman, Woodworth, Bulletin #251, Engineering Experiment Station, University of Illinois, 1932.
- Tests of the Fire Resistance and Strength of Walls of Concrete Masonry Units, Menzel, PCA Publication, Jan. 1934.
- Tests on Concrete Masonry Unit Using Tamping and Vibration Molding Methods, Wendt & Woodworth, ACI Journal, November 1939.
- Tests of the Fire Resistance and Thermal Properties of Solid Concrete Slabs and Their Significance, Menzel, ASTM Proceedings, Vol. 43, 1943.

Thus by the time the Hayde patents expired in 1946 a considerable body of technical knowledge had been built up and acceptance of the product had accelerated, with the result that by 1955 there were 33 producing plants in operation in the United States and Canada, with still others in various stages of design and erection. Today there are plants operated by members and associates of The Expanded Shale Clay and Slate Institute in North and South America, Europe and Asia.

In the spring of 1952, acting on the invitation of a producer active in the field, ESCS producers from the United States and Canada met in St. Louis to discuss a plan to form an organization of producers. The meeting resulted in the formation of the Expanded Shale, Clay and Slate Institute as a non-profit, technical organization supported by the producers of expanded shale, clay or slate that use the rotary kiln process. The major objectives of the organization are:

1. To improve and extend the uses of expanded shale, clay and slate aggregate through research and development;
2. To disseminate the authentic data developed to the architectural and engineering professions and to the construction industry;
3. To cooperate and collaborate with other technical organizations interested and active in the field of concrete;
4. To maintain standards for uniformly high quality of product among the membership.

Soon after the organizational meeting, international headquarters were established in Washington, D.C.



*University Club Tower, Tulsa, Oklahoma &  
Inwood Manor, Houston, Texas*

## **1.9 Lightweight Concrete Masonry Units**

Shortly after World War I, F.J. Straub pioneered the so-called “cinder block”, a manufactured concrete masonry unit using coal cinders as the aggregate. Then, in 1923 Dan F. Servey of Kansas City introduced the first masonry block employing lightweight expanded shale as the aggregate, and expanded shale aggregate quickly achieved popularity among both block manufacturers and users of the end product.

The general characteristics of the lightweight masonry unit are that it provides a high degree of insulation, fire resistance, light weight, and a uniform compressive strength equal to heavyweight block with equal cement content. The block manufacturers found that the lightweight aggregate produced a block which was readily specified by architects and engineers and from a practical point of view, the blocks were approximately one third less weight than the heavy concrete blocks made with ordinary aggregate, so that transportation costs to the job were also radically reduced.

Their high degree of insulation against heat, fire and sound made the ESCS blocks particularly attractive to architects and engineers, as did their structural integrity, and contractors favored them because the light weight enabled greater productivity of crews

with fewer injuries. Individual masons found the lightweight blocks much less tiring to work with; in an average day, they might lift 4,000 pounds less than they would with the usual heavy concrete blocks! Thus extending their working career and the sustainability of the workforce.

Lightweight concrete masonry units can be found in every type of building – from barns and other farm buildings to homes, commercial and industrial structures, schools, theaters, multiple story buildings, warehouses, recreation buildings, and churches. Increasing acceptance of the textured block surface as an element of interior design has seen more and more buildings where the block is used for partitioning with an attractive surface left exposed for painting.

This type of application is particularly useful for educational facilities – school classrooms, library units and the like. The lightweight masonry units meet the most rigid fire regulations, and the economies achieved in their use without wall covering are enhanced by their remarkable insulative, durability, and acoustical properties.



*Mason laying SmartWall®*



*First Warren Tire Center, Queensbury, NY.  
SmartWall® Project in Up-state New York*

### **Advantages of Lightweight Concrete Masonry Units**

Lightweight masonry units employing ESCS aggregate have become a part of the construction scene because of their ease of handling so that some of their other advantages are sometimes overlooked. And, to maintain current technical information in all types of applications, Expanded Shale Clay and Slate Institute studies are constantly investigating fire resistance, thermal insulation, and other properties of ESCS concrete masonry. The following is a very brief review of the qualities that make this type of block particularly useful.

1. *Lighter weight and greater strength.* The reduction of dead load is a major advantage in all construction using lightweight aggregate. This is enhanced by the fact that the lowering of wall weight by using lightweight block is accomplished without sacrifice of load bearing capacity, while improving fire safety and other necessary properties.
2. *Fire resistance.* Lightweight masonry units made from ESCS have no combustible content, inasmuch as the aggregate – clay, shale or slate – is thoroughly vitrified, chemically inert and, because of its cellular composition, an ideal heating insulator. Exposure to standard test conditions give a typical 8" lightweight ESCS CMU a two-hour rating, i.e., the critical temperatures on the exposed face as defined by the Standard ASTM E 119 Fire Test Specification, are not reached in less than two hours.
3. *Thermal insulation and moisture resistance.* Coupled with fire resistance is the thermal insulation provided by an ESCS aggregate masonry block. Heat loss through a wall is reduced to a minimum, and changes in outside

temperatures are minimized at the interior surface so that the possibility of condensation of moisture contained in the air of the heated interior is essentially eliminated.

4. *Sound insulation.* The unique cellular nature of lightweight aggregate makes it particularly suitable for masonry wall construction where reduction of sound transmission is an important consideration. As mentioned, this application is particularly useful in schools and libraries; the University of Utah Learning Center Library (which makes extensive use of structural lightweight concrete in its frame and floor system) uses lightweight masonry units for 1,100 student cubicles in the stack area, as well as for 160 private faculty research offices and for all interior walls in the building. The economies of this type of masonry are also applicable to other institutional construction as well as to office buildings, apartments and hotels.
5. *Wall strength.* Elsewhere in this handbook are described the results of the Yucca Flats atomic explosion tests, where single-story houses constructed of expanded shale masonry units survived, with little or no structural damage, a blast that completely demolished frame and brick veneer dwellings at the same location. It is important to note that these lightweight buildings were not specifically designed or “souped up” for the test, but were built in accordance with the Pacific Coast Building Code for earthquake regions. This type of construction is equally well adapted to regions where tornadoes and hurricanes are a threat.
6. *Textured finish and workability.* Lightweight masonry units have the added value of permitting direct nailing of wood trim, and direct application of plaster and stucco. However, many contemporary structures make use of the block surface itself as a textured wall finish and use one or several of the coursed or random patterns to achieve design effect consistent with the architectural theme. Such usage will be found in the entire range of buildings where people live, work or assemble; in homes, offices, schools and churches.

## **1.10 High Rise Building**

### ***Lightweight structural concrete in high rise construction***

Several high rise concrete frame buildings using lightweight concrete floors have been trend setters at time of construction for example, Bank of Georgia Building in Atlanta (390 feet), Marina Towers in Chicago (588 feet) 1962, 1000 Lake Shore Plaza in Chicago (601 feet), Australia Square in Sydney (602 feet), and Lake Point Tower in Chicago (645 feet) 1968 and Nations Bank in Charlotte (830 ft.) 1996. The advantage of structural lightweight concrete in this type of construction is in the significant reduction in dead load, which not only saves on foundation costs but also permits smaller supporting columns and minimizes the seismic inertial effect of dead load in earthquake areas.





*Nations Bank Charlotte, NC.*

In a number of instances, use of lightweight has permitted addition of extra floors beyond the original design. In the classic example, Southwestern Bell Telephone Company was able to double the height of its existing building – from 14 to 28 stories, 6 more than would have been possible with normalweight concrete. An office tower in Ottawa, Kansas originally designed as a 22-story building using normalweight concrete was extended to 25 stories by changing concrete specification above the eight floor level to lightweight. A huge increase in height was feasible for the Magnolia State Savings and Loan Association Building in Jackson, Mississippi. Originally only two stories, the building now stands six stories high.

The use of ESCS lightweight aggregate in structural concrete has increased dramatically, as architects, engineers, and builders have availed themselves of greatly increased research activity and improved application technology. The first “skyscraper” using structural lightweight concrete throughout its above-ground structure was the 18-story Dallas Statler-Hilton, built in 1955. Since that time, there have been many others: the twin towers of Chicago’s famed 60-story Marina City, for example, rise 588 feet above street level and set a new world record for height of reinforced-concrete-framed structures, using structural lightweight concrete for all floors and beams. An elegant tower in Sydney, Australia – part of the ambitious Australia Square project – set a new record as the world’s tallest reinforced lightweight concrete building, standing 602 feet high and featuring 36-foot span beams, slabs columns, precast concrete and even bricks made of lightweight concrete. This record was subsequently broken by Chicago’s Lake Point Tower at 645 feet.





***Marina City, Chicago, Illinois,  
Park Regis, Sydney, Australia &  
Lake Point Tower, Chicago, Illinois***

But advances in lightweight construction have not been limited to high-rise apartment and office buildings. Equally spectacular achievements have been made in bridge construction, offshore oil platforms, stadiums, churches, educational facilities, and commercial structures such as warehouses, manufacturing plants, piers, and even sewage treatment plants.

For wherever light weight and structural strength are important considerations in material specification, it is highly likely that lightweight structural concrete made with ESCS aggregate is being used, either cast-in-place or in precast or prestressed applications.

The versatility of ESCS lightweight aggregate is such that it lends itself as well to precasting on the site or at a remote location as it does to placing at the site using ready-mix concrete. This permits efficient coordination of the different elements of a job and of course makes for improved construction schedules and lower costs. Additionally, it provides a greater range for architectural and engineering versatility.

Cast-in-place applications represent a rather substantial percent of use of structural lightweight concrete, and generally include such components as floor systems, columns, ramps, backup and insulation, large monolithic casting and the like, where forms are assembled in position and ready-mix concrete is placed in them. Structural members may be cast-in-place or precast, depending on which method is most suitable to the particular structure.

Pretensioning lends itself extremely well to structural lightweight concrete construction components such as load-bearing beams, where it is desirable to obtain maximum structural efficiency. As one example, the Heatley Avenue Overpass in Vancouver, B.C. combines 60 pretensioned lightweight girders and a lightweight concrete deck crossing 14 railroad tracks with a curved ramp made up of five spans of post tensioned lightweight concrete flat slabs. The longest girder – 90 feet – weighed 40 tons, while a normalweight concrete girder of the same dimensions would weigh about 40% more, and required only 12 days to place, which was an important consideration because interruption of train service had to be kept to a minimum. The use of lightweight aggregate structural concrete in this application demonstrated a considerable savings over the alternate design using steel beams.



*Precast Lightweight Parking Garage, White Plains, NY...*

### **Parking Structures**

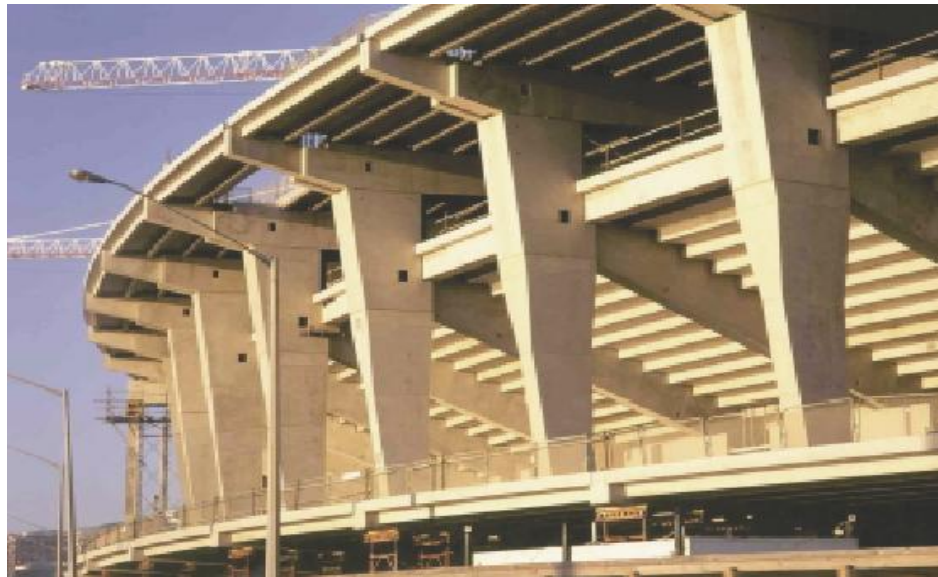
Many parking garages have provided excellent examples of high quality, rapidly assembled structures. The structural system includes precast columns and tee-beams, some with cast-in-place floor slabs. By coordinating job elements, these structures were completed in a few months after ground breaking. The use of lightweight concrete in the floor slabs permitted longer spans and smaller columns, so that parking bays 62 feet wide were attainable. This added a measure of efficiency in the buildings operations by increasing the buildings usable capacity and by making parking easier and faster.

## 1.11 Precast/Prestressed Lightweight Concrete

New methods and mixture designs being applied to building component fabrication and erection are finding increasing precast/prestressed application. The strength and light weight of ESCS aggregate makes it ideal for the associated technology of handling, storing, transporting and lifting such components into place. In many instances, it is only through the use of lightweight aggregate that the economies of large-unit plant precasting can be fully realized, particularly in the case of large members whose weight would exceed highway weight limits if cast in normalweight concrete or require expensive heavy-lift handling equipment.

Precasting of lightweight structural concrete is particularly advantageous in the case of bridges and similar structures where physical conditions or traffic movement make conventional procedures difficult or impractical. A lollipop-shaped, 1,310 foot fishing pier at Venice, California, for example, employs 215 lightweight deck slabs and 103 lightweight pier caps, which were cast in a five-acre parking lot near the shore end of the pier and then moved into position.

Another recreation application was in the construction of the Wellington Stadium, New Zealand, where all of the structural members – including floors, beams, columns and stairways – were precast with conventional reinforcement at a casting yard near the site, then hoisted into place and connected to make the stadium proper. All above-ground elements of the stadium are lightweight aggregate concrete.



*Wellington Stadium, New Zealand (1999)*

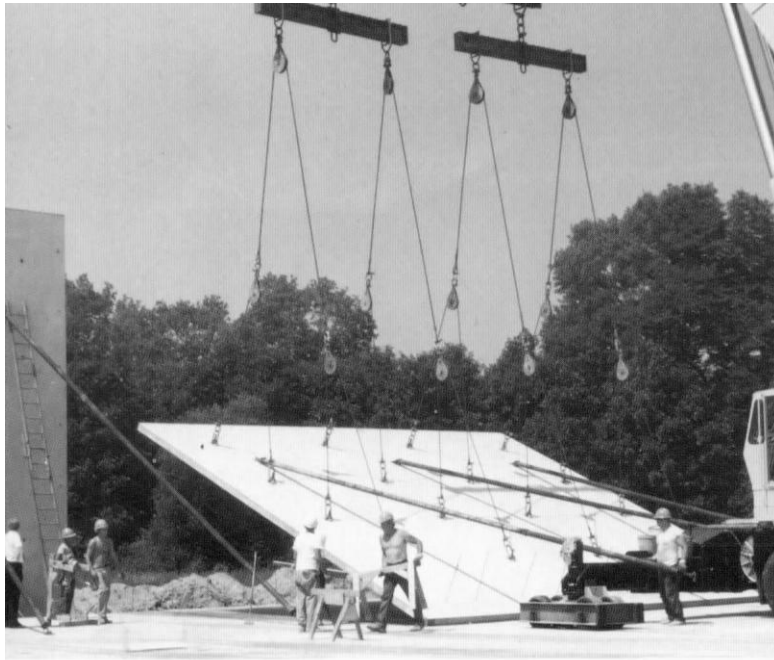
Nor is distance from site a barrier to use of precast lightweight concrete. The Radiation Research Laboratory of Notre Dame University is faced with 74 three-story high precast – but not prestressed – panels of lightweight concrete, which were

delivered to the building site by truck from a precasting plant 300 miles away. A major reason for using the lightweight aggregate in this instance was the reduction in weight which permitted substantial savings in handling and shipping costs.

Precast lightweight concrete can also provide substantial economies where intricate designs, modules or repetitive forms are involved. And the weight savings offered by lightweight aggregate makes it possible to deal with large and complex shapes using conventional lifting and transportation equipment. In the construction of the Oakland Airport, precast structural lightweight played an important part in obtaining economies of this type. Forty-eight 30-foot square hyperbolic paraboloid roof shapes for the TWA terminal building were precast using only two forms, while more than 20 conoid shapes for the airline's ticketing building were similarly precast using only two forms. Handling and positioning of the roof elements was done by a single mobile gantry crane, even though some of the conoid elements were 71 feet long. With normalweight concrete, two cranes would have been required. Mass production and simplified erection of the thin shell shapes of Oakland resulted in a roof cost significantly lower than the next lowest cost method – a savings of nearly 40 percent.



*Chateau on the Lake, Branson, MO.  
8 x 4 ft section 128 ft. (39 m) Lightweight Double Tee*



***Large Tilt-up Panel Construction Facilitated  
by Lightweight Concrete, New Jersey***

The gigantic new research center of the Hyster Company near Portland, Oregon, is made up of tilt-up wall panels approximately 25 feet square and 6 inches thick. The size of the panels made the weight reduction offered by lightweight aggregate especially important, and the ease of handling was evident in the brief period of time required for construction – less than eight months. An unusual application of this principle was seen in the new manufacturing addition to the Dominion Cellulose plant in Toronto, where standard double-tee floor slabs were stood on end with the tees out to make a wall panel, 177 square feet in place in one simple addition. Approximately 200 of the precast structural lightweight concrete elements were used in the structure, with provisions made to re-erect them on another foundation in the event of future expansion.

## **1.12 Thin Shell Construction**

In the 50's and 60's lightweight concrete opened up new vistas of design freedom to architects and engineers with the advent of thin shell construction. The hyperbolic paraboloid and conoid roof shapes are just two examples of the possibilities of lightweight structural concrete that can be cast to minimum thickness and still provide the necessary strength. Thin shell construction can be either precast or cast-in-place.



*United States Post Office, Providence, Rhode Island*

North Shore Congregation Israel, Glencoe, IL, is an outstanding example of design virtuosity made possible through the use of structural lightweight concrete. The roof consists essentially of 16 free-standing fan vaults with an 81-foot span, and originally designs specified normalweight concrete with fiber insulation to be applied on the exterior roof surfaces. But excessive dead load threatened to make the desired 81-foot span impractical and prohibitive in cost. Substitution of lightweight concrete made the original design feasible, and the high thermal insulative properties of the expanded shale concrete permitted complete elimination of the fiber insulation. Reusable forms for columns and vaults were fiberglass lined, which produced the “impeccable” smooth finish specified by the architect.

The Sports Complex at Colorado College in Colorado Springs makes an interesting use of thin shell construction, using seven 29-foot wide barrel vaults spanning 120 feet to cover the 203-foot long skating rink building, which is open sided except for a masonry tile solar screen on the south. At right angles to the shells over the rink are three more barrels, sheltering the enclosed swimming pool building.



*Sears, Roebuck & Company, Tampa, Florida*

### **1.13 Resistance to Nuclear Blast**

Resistance to nuclear blast was studied in the Yucca Flats tests, known as “Operation Cue”, the objective was to determine the effect of atomic blast on structures made from various materials, including brick, lumber, and aluminum, precast lightweight concrete and lightweight concrete masonry. Of all the buildings in the test, only four – the two lightweight concrete masonry houses and the two lightweight structural precast concrete houses – survived without major damage; the others were all virtually destroyed. The houses employing lightweight concrete were built in a conventional manner, the masonry houses reinforced to withstand earthquakes in accordance with the Pacific Coast Building Code, and the slab houses in accordance with the American Concrete Institute Code.

The slab and masonry houses at 4700 feet from ground zero suffered only minor structural damage, while a frame and brick veneer house at the same location was completely demolished. Said the official report:

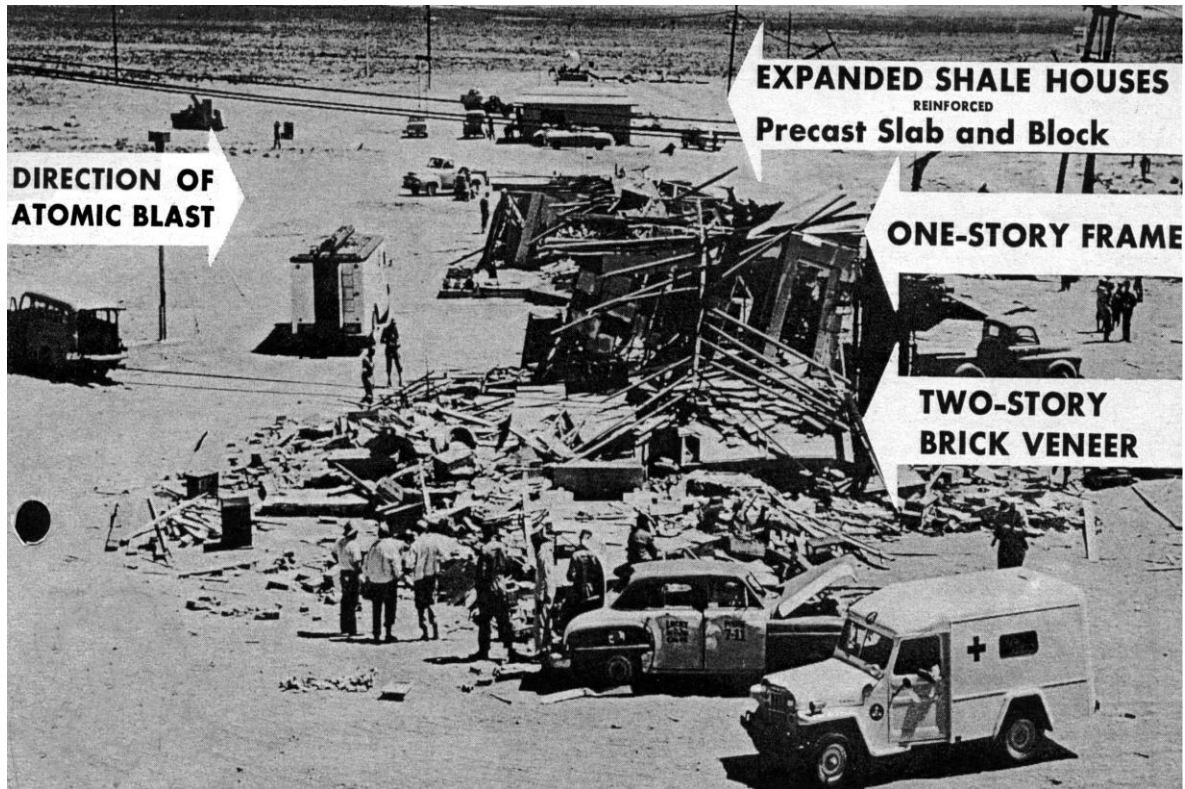
“The one-story frame rambler located near the two-story brick dwelling 4700 feet from the explosion was likewise almost completely destroyed...

Both the one-story reinforced lightweight concrete block house and the one-story precast lightweight concrete house suffered only minor structural damage. These houses were also located 4700 feet from the explosion. With the replacement of doors and window sashes, both houses could be made habitable.

The one-story precast light aggregate concrete house and the one-story reinforced masonry block house, both located 10,500 feet from the explosion, suffered relatively minor damage...



“The one-story rambler, also located 10,500 feet from the explosion, suffered relatively heavy damage...



*How lightweight concrete withstood atomic blast  
(10,500 feet from the explosion)*

Despite its grim overtones, the Operation Cue test at Yucca Flats was a landmark achievement in the history of ESCS aggregate. With hundreds of testimonials dotting the land – buildings, bridges and other structures demonstrating the practicality of the medium – the survival of the lightweight buildings when exposed to the greatest forces known to man would convince even the most skeptical that lightweight aggregate had proved its worth.





*University of Illinois Assembly Hall, Urbana, Illinois (1962)*

#### **1.14 Design Flexibility**

Structural lightweight concrete is found in projects such as the thin shell “bird in flight” roof of the TWA Terminal at John F. Kennedy Airport (1960); the towering Southland Center in Dallas; the ultra-modern Learning Center-Library at the University of Utah, notable for its long spans and high load design; the huge, futuristic Dodger Stadium in Los Angeles; the University of Illinois Assembly Hall (1962), with a concrete dome roof of near record proportions; and of course a number of buildings designed by such architectural giants as Eero Saarinen and Frank Lloyd Wright – and all of these are examples of trends in construction facilitated by the use of lightweight structural concrete.



*TWA Terminal, John F. Kennedy International Airport*

## 1.15 Floor and Roof Fill

Although the primary uses of ESCS aggregate are in construction applications employing structural lightweight concrete or masonry units, or both, the versatility of this remarkable product is demonstrated in a number of other applications where lightness of weight, insulation and durability, and surface texture are important considerations.

One such use is a special fill. Floor fill and roof fill applications, where the insulative and protective properties combine with the weight factor to make lightweight concrete especially suitable to account for a substantial volume. There is a growing use, too, as fill under slabs and in grade foundations, and some use for fill under refrigerated areas, where the thermal properties provide an added measure of economy.

## 1.16 Bridges

Among the more spectacular and sensational landmarks in the growth of lightweight structural concrete applications have been its use in a number of major bridges.

In the construction of the San Francisco-Oakland Bay Bridge, for example, the use of lightweight concrete floor in the upper deck permitted weight reduction of 25 pounds per square foot, or a total of 31.6 million pounds for the entire structure. This in turn permitted reduction in the area and cost of members in the superstructure, and materially reduced the direct load on foundations and the stresses on foundations and superstructure due to seismic forces. In all, the cost savings affected were estimated at \$3 million.



*San Francisco-Oakland Bay Bridge, San Francisco, California*

It is in bridge construction, in fact, that ESCS aggregate has made some of its most significant contributions to construction efficiency. A bridge across Sebastian Inlet on the east coast of Florida is a case in point. Three conditions were imposed on the designers: (1) The structure had to be unaffected by the corrosive action of salt air; (2) The channel had to be kept open all during construction, and could not be

constricted by false work; (3) the main span had to be 180 feet long to comply with Corps of Engineers requirements. The 180-foot main span was achieved by using 120-foot drop-in girders of structural lightweight concrete supported by anchor-cantilever girders of conventional weight concrete cantilevering 30 feet beyond the channel piers of the bridge. By way of contrast, the 6-foot deep, 120-foot girders of lightweight concrete weighed only 51 tons each, while the 65-foot anchor-cantilever girders of conventional weight concrete weighed 42 tons each.



*Sebastian Inlet Bridge (1964)*

The 131-foot Klickitat River bridge, completed in 1965, represented a gigantic stride forward in slightly more than a decade from the footbridge erected in Prairie Village, Kansas in 1954 – heralded at the time as the longest prestressed lightweight concrete beam in the United States...measuring 52 feet long! Earlier, history was made when lightweight concrete pavement was used for the upper deck of the San Francisco – Oakland Bay Bridge, resulting in a \$3 million saving. When a 7-year reconstruction program was completed in the mid-1960's, lightweight concrete was used in four major portions of the vast modernization program.

In 1994 high strength specified density concrete (7,000 psi in 5-days) in combination with pre-stressed/post-tensioned strands reduced 17% of the weight on 96 girders, 175 ft. long 7.5 ft. high used on the Wabash River Bridge, 231 bypass, Lafayette, Indiana.



***Bridge Girders for the Wabash River Bridge***

## **1.17 Horticulture Applications**

An increasingly common use of ESCS (Trademarked as SOILMatrix™) is as soil amendments for horticulture and in landscaping and such special uses as golf green construction. This environmental friendly material is non-toxic, 100% inert, durable, and insulative and acts as an environmental buffer by retaining as much as 12% to 35% of its weight in absorbed water and water-borne nutrients. ESCS is angular, stable and porous. Its ceramic nature ensures an adequate supply of air to enable plants to be established quickly and develop healthy root systems.

ESCS has become the standard for creating planting media for roof top gardens. The use of ESCS in green roof design helps address important issues such as managing storm water runoff, improving water quality, reducing urban heat, conserving energy, lowering dead load and increasing green space.





*Decorative Ground Cover & Mulch*



*See Starter & Potting Mix*



*Elevated Plazas  
Lightweight Fill & Drainage Vehicle*



*Golf Greens & Lawns  
Soil Conditioner & Drainage Medium*

### ***Amending Soils for Turf***

A number of sports fields and dirt tracks (baseball, bike, horse, stock car, etc.) throughout North America now use ESCS lightweight aggregate.

## 1.18 Asphalt Surface Treatment and Hotmix Applications

When used in flexible bituminous pavements, ESCS shows two distinct advantages. First, pavements made with ESCS aggregate have a high and long lasting skid resistance. The high skid resistance present immediately after paving is due to the rough surface texture of the aggregate and the aggregate is outstanding in its ability to retain its skid resistance under traffic. Pavements made with such natural aggregates as certain limestone and dolomites will polish under the action of traffic and lose a large percentage of the initial skid resistance, but lightweight aggregates do not polish as they wear. Under wear, fresh cells are exposed which have sharp, ceramic-like edges which continue to show a high skid resistance.



***State Highway 183, N.W. Fort Worth, TX, 19 year old ESCS Hotmix overlay, since 1985 over jointed concrete.***

Tarrant County, TXDOT (Texas Department of Transportation), SH 183 from Azle Blvd. to SH 199, still in service after 19 years beginning in 1985. Average daily traffic is 16,000 both directions with 11% trucks. Tarrant County also had multiple installations of ESCS hotmix asphalt overlays installed around 1975, which lasted into the 1990's.

The other distinct advantage of the lightweight aggregate is that when it is used in seal coats and surface treatments breakage of auto glass from “flying” stones is practically eliminated. Much of the windshield and headlight damage experienced by motorists on flexible pavements occurs when ordinary aggregate stones in the pavement loosen and are picked up and “thrown” by a tire. Numerous tests

conducted at Texas A & M University indicate that when lightweight aggregate is used, glass breakage of this type is almost non-existent, both because of the light weight of the material and the higher wind resistance of the roughly textured particles – a property which also causes the aggregate to stick to the asphalt surface better, hence fewer “flying” particles.



***41-mile chip seal project  
Cowley, Kansas***

This manual does not document all the uses of lightweight that are either current or projected on the basis of experimental and developmental work under way. Some idea of the range of possibilities has been outlined here, and producer members of the Expanded Shale, Clay and Slate Institute are prepared to work with users who are interested in these applications, as well as in any application where the unique properties of expanded shale will provide benefits.



## **A World of Uses**

### **SmartWall® High Performance Concrete Masonry**

- Concrete Masonry Units (CMU's) above and below grade
- Architectural units (split face, colored, etc.)
- Larger CMU's (8" x 8" x 24", etc.)
- Prison Construction
- Concrete brick (all shapes and colors)
- Segmental retaining walls
- Privacy fences and sound barrier walls
- Sound absorption walls
- Other (pre-cast lintels, loose fill, core insulation, pavers, patio units, etc.)

### **Asphalt Pavement (rural, city and freeway)**

- Surface treatments (chip seal, seal coat, etc.)
- Plant mix seal overlay and open-graded friction coarse
- Hot mix surface coarse
- Micro-surfacing (slurry seal)
- Cold mix (pothole patch, minor repairs, etc.)

### **Structural Concrete (including high performance)**

- Floors in steel frame buildings (fill on metal deck)
- Precast and prestressed elements (beams, double-tees, tilt-up walls, raised access floor panels, planks, hog slats, utility vaults, pipes, bridge decks, ornamentals, etc.)
- Concrete frame building and parking structures (all types, including post-tensioned floor systems)
- Floating docks, boats and offshore platforms
- Bridge decks, piers and AASHTO girders (prestressed, post-tensioned and normal reinforcement)
- Topping over precast concrete

**Geotechnical**

- Waterfront structures
- Landscape and elevated plaza fills
- Bulkheads and retaining walls
- Structural repairs and rehabilitation
- Fill over poor soils and marshlands
- Insulating backfill and insulating road base
- Shallow foundations
- Enveloping underground conduits and pipelines for insulations or when in unstable soil conditions
- Landfill leachate drainage systems

**Horticulture Applications**

- Green roof (intensive, extensive)
- Bioswales
- Soil conditioner (planting, golf greens, potting soil, etc.)
- Soil conditioner for sports fields (baseball in-fields) and dirt tracks (running, bike, horse, stock car)
- Ground cover (decorative and insulating)
- Herbicide and fertilizer carrier
- Hydroponics

**Specialty Concrete**

- Topping on wood floor systems
- Roof fill for flat roofs (insulation and slope)
- Insulating fill around temperature sensitive elements
- Bagged concrete mix
- Cement wallboard
- Artificial stone
- Refractory (fireplace logs and boxes, chimney liners, etc.)
- Insulating refractory for industrial uses in kilns, boilers, stacks, petrochemical refining, etc.)
- Ferrocement and shotcrete
- Animal and environmental structures (sewage treatment, etc.)
- Lightweight concrete roof tiles

**Miscellaneous**

- Grog for clay brick
- Coverstone and ballast on built-up roofs
- De-slicking/traction grit for icy roads
- Medium in wastewater treatment and water filters
- Fire protection for impermeable plastic liners

# **1A**

**ESCSI Information Sheet #7600**  
**“Expanded Shale, Clay and Slate**  
**A World of Applications...Worldwide”**

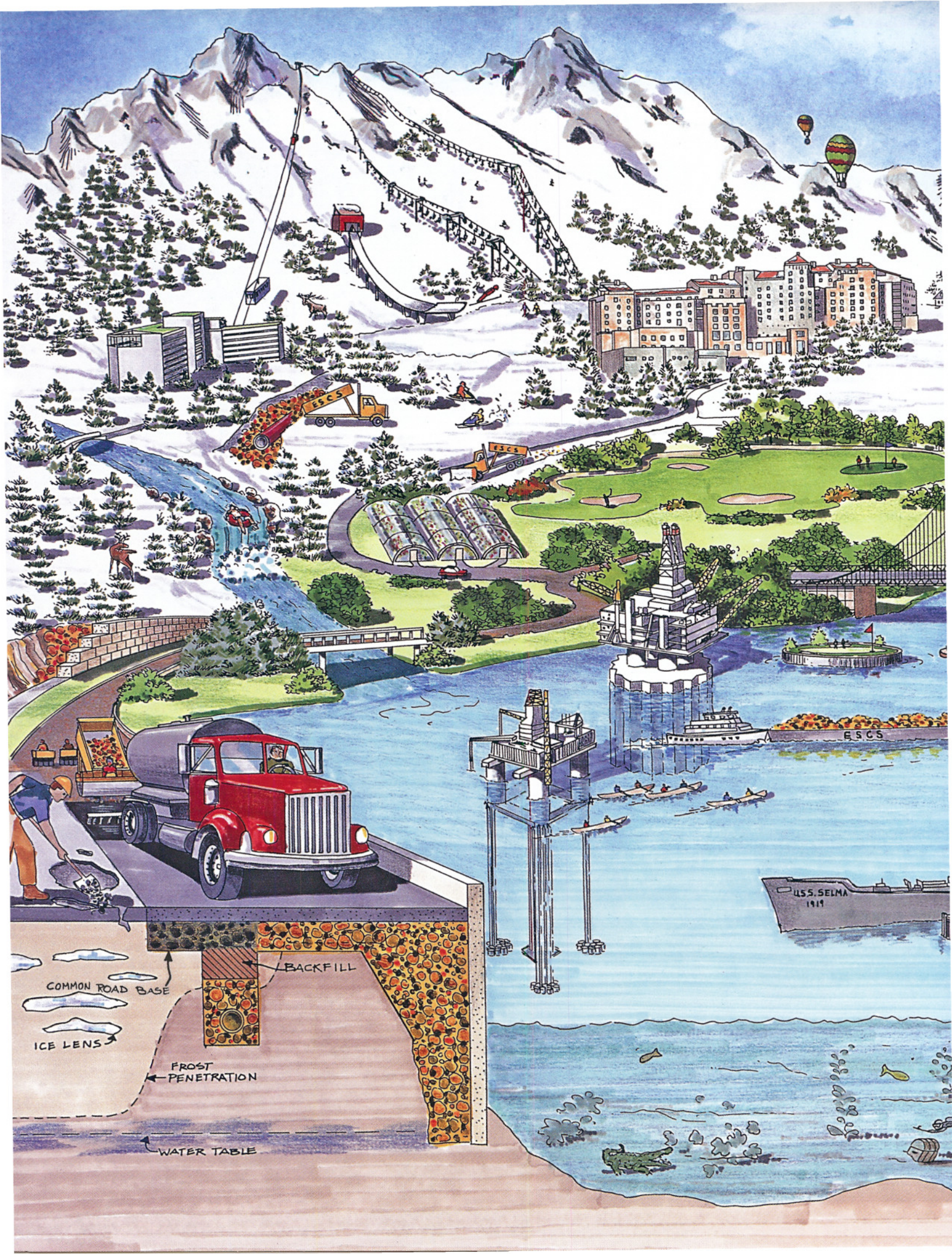


# Expanded Shale, Clay & Slate

A World of Applications . . . Worldwide.

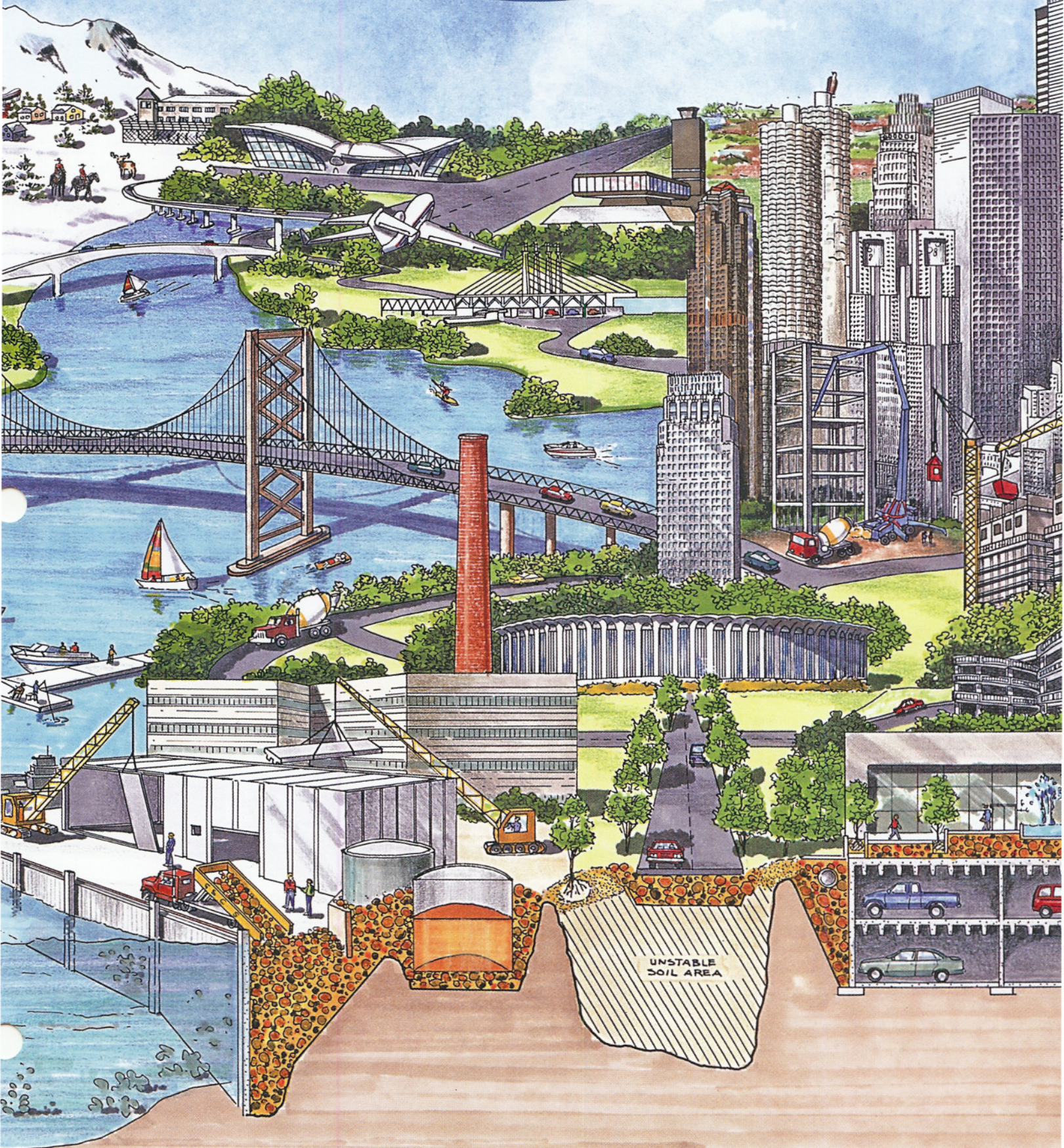








ESCSI







Artist's conception - For illustration only.



## A World of Uses

### **SmartWall® High Performance Concrete Masonry**

- Concrete Masonry Units (CMU's) above & below grade
- Architectural units (split face, colored, etc.)
- Larger CMU's (8" x 8" x 24", etc.)
- Prison construction
- Concrete brick (all shapes & colors)
- Segmental retaining walls
- Privacy fences & sound barrier walls
- Sound absorption walls
- Other (pre-cast lintels, loose fill core insulation, pavers, patio units, etc.)

### **Structural Concrete (including high performance)**

- Floors in steel frame buildings (fill on metal deck)
- Precast & prestressed elements (beams, double-tees, tilt-up walls, raised access floor panels, planks, hog slats, utility vaults, pipes, bridge decks, ornamentals, etc.)
- Concrete frame building & parking structures (all types, including post-tensioned floor systems)
- Floating docks, boats & offshore platforms
- Bridge decks, piers & AASHTO girders (prestressed, post-tensioned & normal reinforcement)
- Topping over precast concrete

### **Asphalt Pavement (rural, city & freeway)**

- Surface treatments (chip seal, seal coat, etc.)
- Plant mix seal overlay & open-graded friction coarse
- Hot mix surface coarse
- Micro-surfacing (slurry seal)
- Cold mix (pothole patch, minor repairs, etc.)

### **Geotechnical**

- Landscape & elevated plaza fills
- Fill over poor soils and marshlands
- Waterfront structures
- Bulkheads & retaining walls
- Structural repairs & rehabilitation
- Insulating backfill & insulating road base
- Shallow foundations
- Enveloping underground conduits & pipelines for insulation or when in unstable soil conditions
- Landfill leachate drainage systems

### **SOILMatrix™ Horticulture Applications**

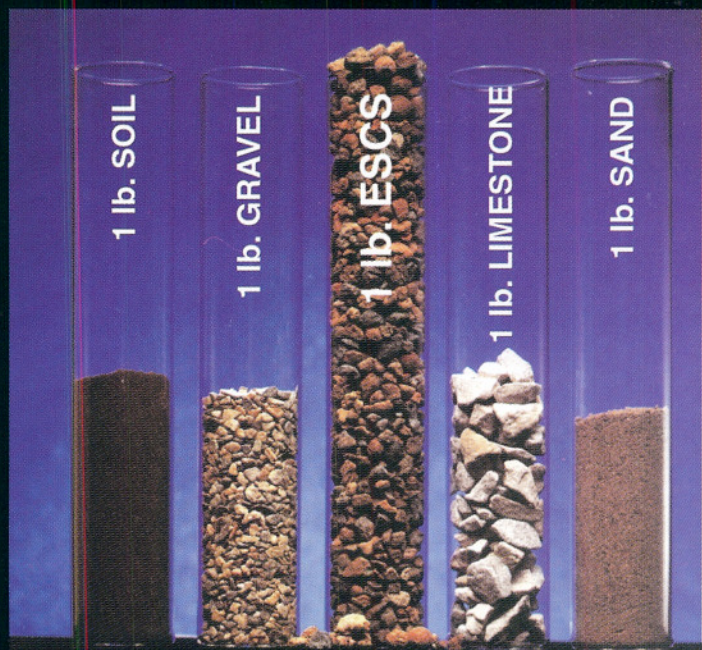
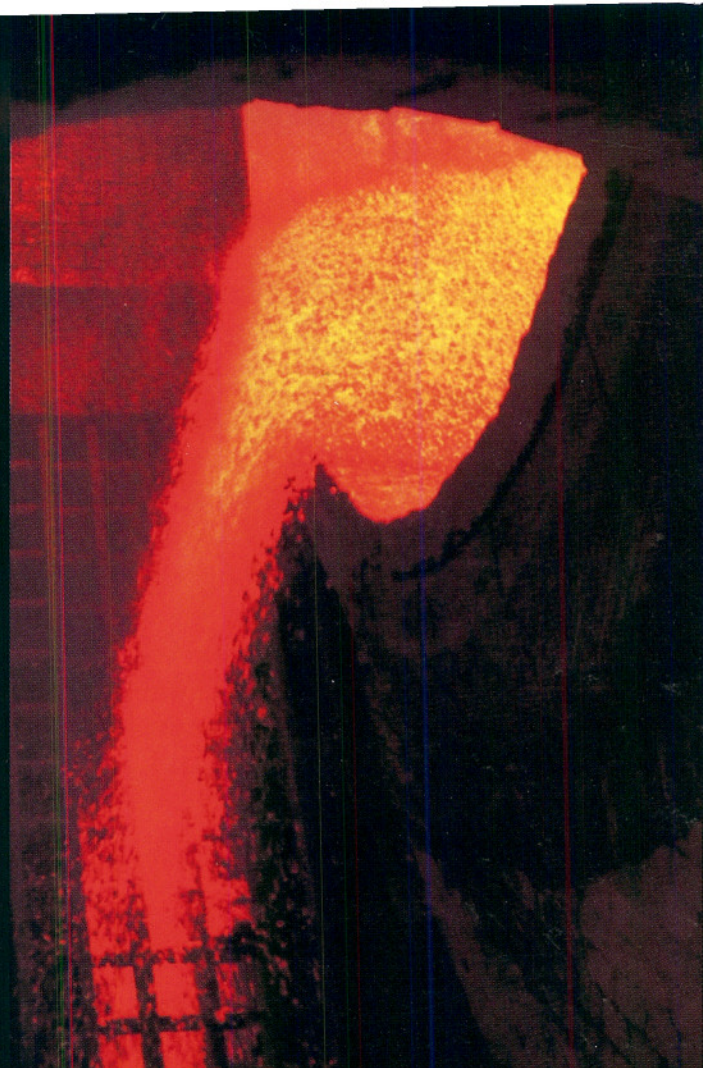
- Green roof (intensive, extensive)
- Bioswales
- Soil conditioner (planting, golf greens, potting soil, etc.)
- Soil conditioner for sports fields and dirt tracks (running, bike, horse, stock car)
- Ground cover (decorative & insulating)
- Herbicide & fertilizer carrier
- Hydroponics

### **Specialty Concrete**

- Lightweight concrete roof tiles
- Cement wallboard
- Artificial stone
- Bagged concrete mix
- Topping on wood floor systems
- Roof fill for flat roofs (insulation & slope)
- Insulating fill around temperature sensitive elements
- Refractory (fireplace logs & boxes, chimney liners, etc.)
- Insulating refractory for industrial uses in kilns, boilers, stacks, petrochemical refining, etc.)
- Ferrocement & shotcrete
- Animal & environmental structures (sewage treatment, etc.)

### **Miscellaneous**

- Medium in wastewater treatment & water filters
- De-slicking/traction grit for icy roads
- Grog for clay brick
- Coverstone & ballast on built-up roofs
- Fire protection for impermeable plastic liners



**Produced at temperatures in excess of 2000° F, ESCS aggregate offers more than twice the volume for the same weight of conventional aggregates.**



# Expanded Shale, Clay and Slate (ESCS) Structural Lightweight Aggregate's Holistic Contribution to Sustainable Development

## Our Commitment to Sustainable Development

The Expanded Shale, Clay and Slate Institute (ESCSI) and its member companies are committed to the long-term performance of our products and the sustainable development of the building industry. We realize that to create a vibrant and sustainable society, innovative, practical and responsible designs need to be combined with realistic construction practices. The use of green products in these designs promotes sustainable development and enhances the ability of future generations to meet their own needs.

ESCS structural lightweight aggregate has been successfully used for well over two millennia. It has had widespread use for the past eighty years. This track record

of proven performance has demonstrated how ESCS contributes to sustainable development by conserving energy, lowering transportation requirements, maximizing structural efficiency and increasing the service life of structural concrete, concrete

masonry, and asphalt chip seal. The use of lightweight aggregate in site development assists designers in addressing the important issue of storm water management by making on-site treatment a viable option. ESCS can help to reduce heat island effects by amending soil to improve landscaping and making the use of "green roofs" not only desirable, but economically feasible.



Structural lightweight aggregate particle showing interior voids



Intensive Roof Garden, North Park 400, Atlanta, GA

## The Holistic Picture



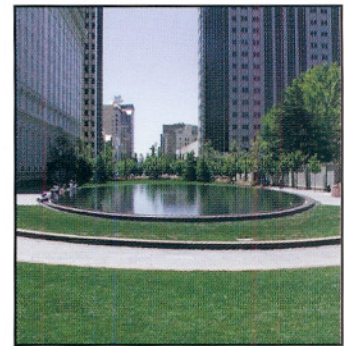
Bioswale using free-draining lightweight aggregate as planting medium

Rotary kiln produced ESCS structural lightweight aggregate is an environmentally friendly product that saves material, labor and transportation cost, as well as improves the performance and service life of concrete and other products made with it. Additionally, using lightweight aggregate will lower the overall energy consumption of structures thereby reducing the associated life cycle costs throughout the structure's useful life. These benefits support sustainable development and contribute to projects becoming LEED (*Leadership in Energy and Environmental Design*) certified.

When viewed from an overall perspective, the utilization of ESCS lightweight aggregate is a significant and important step forward. The lightweight aggregate industry acknowledges that for the successful achievement of truly sustainable development, a

fundamental shift in attitudes, beliefs and conscious behavior must take place. Considering the fact that architecture (building performance) accounts for a major part of total U.S. energy consumption, initial cost should no longer be the sole determining criteria when evaluating the usefulness of a product or structure.

All construction materials must be evaluated from a total life cycle assessment. This is the only way to determine the total impact of a product or structure. To develop a sustainable world we must shift from our current short-term ways and attitudes, and embrace a long-term, holistic mind-set that recognizes performance and the interdependence of all life.

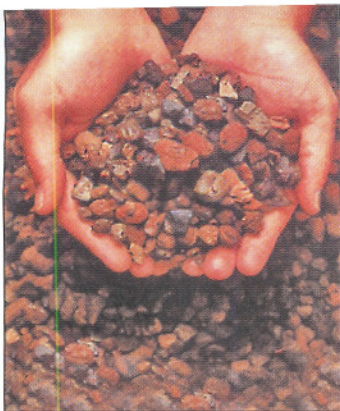


Garden and pool over Main Street Plaza parking structure, Salt Lake City, Utah



Sedums growing in SOILMatrix lightweight aggregate medium





## Wherever you live, work or play, ESCS Structural Lightweight Aggregate improves your world!

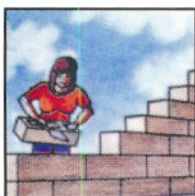
For nearly a century ESCS (Expanded Shale, Clay and Slate) has been used

with great success around the world in more than 50 different types of applications. The most notable among these are concrete masonry, high-rise building, concrete bridge decks, precast and prestressed concrete elements, asphalt road surfaces, soil conditioner and geotechnical fills.

What is ESCS? It is a unique, ceramic lightweight aggregate prepared by expanding select minerals in a rotary kiln at temperatures over 2000° F. The production and raw materials selection processes are strictly controlled to insure a uniform, high quality product that is structurally strong, stable, durable and inert, yet also lightweight and insulative. ESCS gives designers greater flexibility in creating solutions to meet the challenges of dead load, terrain, seismic conditions, construction schedules and budgets in today's competitive marketplace.



### SmartWall® Concrete Masonry

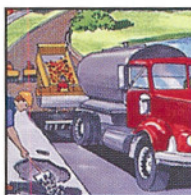


SmartWall concrete masonry units are up to 40% lighter than traditional masonry units. This lighter weight results in increased mason productivity, lower construction costs and reduced injuries.

SmartWall masonry provides superior insulation by combining high R-values with thermal mass and low thermal bridging, and offers superior fire resistance, effective sound absorption, excellent seismic performance, low shrinkage and high strain capacity.

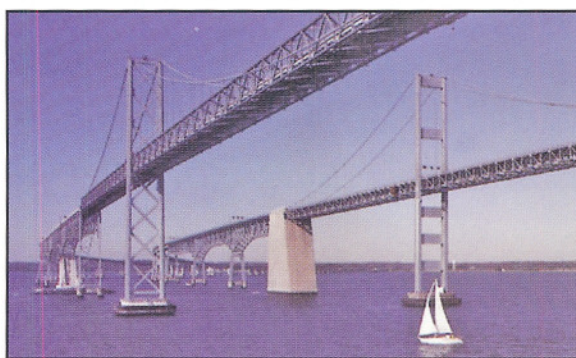


### Asphalt Pavement



When bonded to asphalt, ESCS creates an advanced road surface that is safer, more economical and longer lasting than conventional aggregate surfaces. Wet or dry, road surfaces of ESCS aggregate

provide superior skid resistance that is maintained throughout the surface life, because ESCS does not polish as it wears. Because it is lightweight, ESCS affords shipping and handling cost advantages to the contractor. Also, damage to windshields, headlights and paint caused by "flying" stones is virtually eliminated with ESCS, thus avoiding costly insurance claims and motorist complaints.



### Structural Concrete



ESCS structural lightweight concrete solves weight and durability problems in buildings and exposed structures. ESCS concrete has strengths comparable to normal weight concrete, yet is typically 25% to 35% lighter. ESCS offers design flexibility and substantial cost savings by providing less dead-load, improved seismic structural response, longer



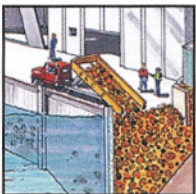


spans, better fire rating, thinner sections, decreased story height, smaller size structural members, less reinforcing steel and lower foundation costs. Precast elements have reduced transportation and placement costs. The excellent durability performance of ESCS is a result of the ceramic nature of the aggregate,

and its exceptional bond to and elastic compatibility with the cementitious matrix.

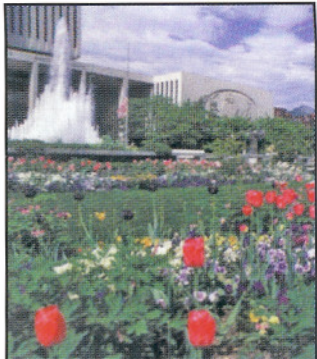


### Geotechnical

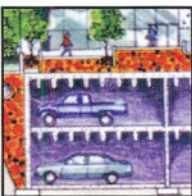


ESCS compacted fills are about half the weight of common fills. This advantage, coupled with its high internal friction angle, can also reduce lateral forces by more than one-half. It has been used

effectively to solve numerous geotechnical engineering problems and to convert unstable soil into usable land. ESCS also provides permanent insulation around water and steam lines, and other thermally sensitive elements. ESCS is a reliable, economical geotechnical solution.



### SOILMatrix™ Horticulture Applications



ESCS SOILMatrix is environmentally friendly. It is non-toxic, odorless, 100% inert and will not compress, degrade, decompose, or react with agricultural or horticultural chemicals.

It acts as an insulator in the soil mixture and protects plants from rapid temperature extremes. SOILMatrix retains a high percentage of its weight in absorbed water and waterborne nutrients, making it an excellent buffer. SOILMatrix is user friendly because it is lightweight, inert, pH adjustable, easy to handle, economical and readily available.

### Specialty Concrete and Miscellaneous Uses



The superior qualities of ESCS are effective and economical in many other applications. Examples include roof tile, cement wallboard, artificial stone, bagged concrete mix, wood floor topping, refractory, traction grit, insulating fill, and medium in wastewater treatment and water filters.

Expanded shale, clay and slate aggregate, as manufactured by the rotary kiln process (originally developed in 1908 and patented in 1918 as Haydite), is available throughout the world.



Rotary Kiln Produced  
Structural Lightweight Aggregate

### Expanded Shale, Clay and Slate Institute

Suite 102 • 2225 Murray-Holladay Road • Salt Lake City, Utah 84117  
801-272-7070 • Fax 801-272-3377 • e-mail: [info@escsi.org](mailto:info@escsi.org) • [www.escsi.org](http://www.escsi.org)