

# LIGHTWEIGHT CONCRETE

□ HISTORY

□ APPLICATIONS

□ ECONOMICS

EXPANDED SHALE CLAY AND SLATE INSTITUTE

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Gulf Life Tower, Jacksonville, Florida

## History of the Industry

**T**HE purpose of this booklet, quite simply, is to inform you of the practical application of lightweight concrete manufactured with expanded shale, clay and slate aggregate.

This remarkable product is widely used in building construction today, where its properties of light weight, high strength and impermeability suit it ideally for both the stringent engineering requirements of building in the modern city and the esthetic and artistic forms and shapes which make such cities better places to live and work in.

But there are other uses, too, for lightweight concrete—and in a world which is already taxing its rarer natural resources it is significant that lightweight concrete has been successfully used to replace steel plate in ship construction during wartime, and has withstood the forces of both hurricanes and atomic blasts.

Even in the face of such grim reminders, however, we find lightweight concrete being used to restore and preserve man's nobler creative expressions: the beloved classic sculpture of the San Francisco Palace of Fine Arts, originally envisioned as a temporary structure of the Panama-Pacific Exposition of 1915, had by 1957 become so much a part of the heritage of that unique and individualistic city that the decision was made to restore it to its original state of art, replacing the eroded and disintegrated plaster with a lightweight concrete material which would faithfully capture and preserve for future generations the original lines of architecture and ornament.

Between these extremes of atomic blast and enduring art, lightweight concrete has found countless uses in the structures which house the pursuits of man: the buildings in which he works, as well as those in which he lives; the buildings in which his



recreation is obtained, as well as those where he finds inspiration; the buildings where he governs and is governed, as well as those where he heals and is healed. All of these—the soaring skyscrapers of office and apartment buildings, the vast athletic stadia, the magnificent churches, hospitals and public buildings—are counterpoint to the handsome and functional buildings of modern industry, the structures of highway and bridge and pier and tunnel and airport which beat with the pulse of commerce.

It is no coincidence that this booklet should be published as the expanded shale, clay and slate industry enters its second half-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 an individual more than half a century ago, have been superseded by the improved technology and organized research possible only through the shared knowledge and shared financial support offered by a formal industry association, the Expanded Shale Clay and Slate Institute, founded in 1952 and now comprising an organization of more than 55 plants in the United States, Puerto Rico, Canada, Australia, Switzerland and Japan.

To the extent that it serves the interests of these members by describing the services and products they offer, this booklet serves an immediate and practical use; but it is a fact of business life that business enterprises survive and grow only when the product they manufacture or sell represents a fair value for the payment received. Lightweight concrete has proved its value in this economic context beyond any shadow of a doubt, and if this booklet serves only to make more people aware of such value, it will have served its purpose.



United States Post Office, Providence, Rhode Island.



San Francisco Palace of Fine Arts, San Francisco, California.

## How It Started

**L**IGHTWEIGHT concretes 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 pumice as the 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 far short in structural performance of what we expect and achieve today. They were, however, amazingly durable, and existing examples of these early lightweight concretes are still to be found in various early structures of the Mediterranean area.

The Romans, in their militaristic expansion and colonization, introduced and established the use of lightweight concretes 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 20th 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 have 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 limestones 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 astounding 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 birthday 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.

But 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 relative softness 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.

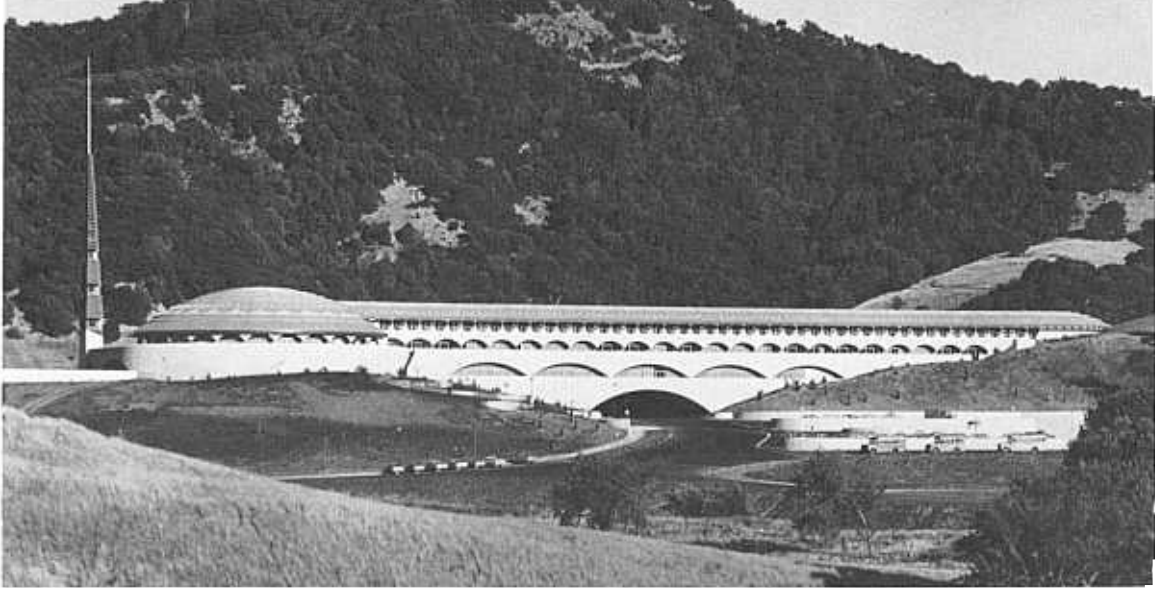
Inasmuch as very substantial economies, greater versatility in concrete uses, and many other advantages can result from decreasing the weight of concrete, innumerable



University Club Tower, Tulsa, Oklahoma.

Second Lake Washington Floating Bridge, Seattle, Washington.

Inwood Manor, Houston, Texas.



Marin County Civic Center, Marin County, California.

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 strength matching that of heavyweight concrete.

### *Beginnings of the Expanded Shale 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—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 brickmaker, and a perennial problem of the industry for centuries had been the abnormal bloating of some of the brick as the shale expanded 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 non-connecting air cells produced by the formation and expansion of gases within the shale when subjected to heat, and with a glass-like hardness, the material satisfied the basic requirements of aggregate—hardness and impermeability—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 deadload 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 materials 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 comparatively low strengths and their permeability 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 burnt 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 investigation of Mr. Hayde's product, which was still in the developmental stage.

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.

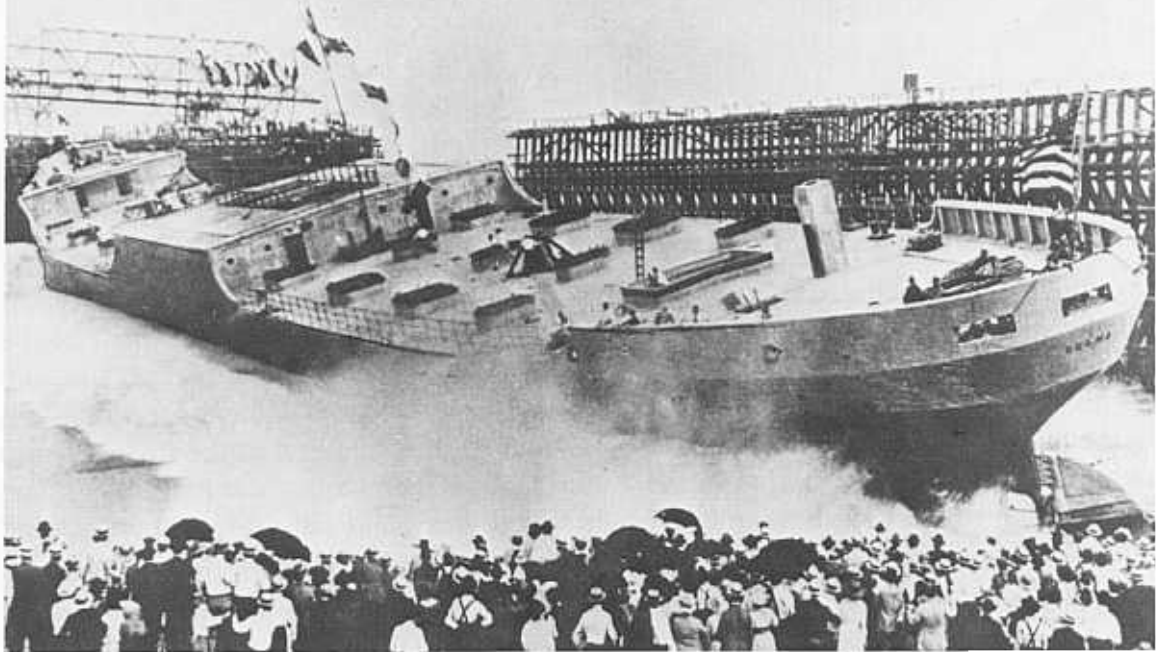
### *The Story of the Selma*

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 draft with full cargo of 26 feet. Needless to say, the construction of a concrete ship of these dimensions required—in addition to the development of a 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



U.S. Naval School Command Barracks, Treasure Island, California.



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

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 of their kilns at Hannibal, Missouri.

The material was supplied in two gradations: 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 shale 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, 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 years. 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 in. and at that depth the concrete appeared to be dry and without discoloration from absorbed water. An examination of the interior of the hull 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 in. of concrete over the reinforcing steel.

### *Concrete Ships of World War II*

By the time of World War II, expanded shale aggregate had come into its own 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 unexpected 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. 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



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.

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. . . .”

#### *First Buildings Employing Structural Lightweight Concrete*

The World War I 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 southern 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 15th convention of the American Concrete Institute at Atlantic City in 1919, he said: “In addition 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 taken for granted 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 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 built 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 deadload of conventional heavyweight concrete.

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 effect, 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 deadload 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 almost 40 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



Southwestern Bell Telephone Company, Kansas City, Missouri.



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

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.

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.

Another early milestone in construction applications was the introduction in 1923 of the first lightweight expanded shale concrete block. The block, besides being light in weight, offered a high degree of insulation, a nominal shrinkage factor, and a uniform compressive strength equal or superior to a heavyweight block with an equal cement content.

#### *Growth of the Expanded Shale Industry*

To some extent, the growth of the expanded shale 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 expanded shale 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 Units 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 some 55 operated by members of the Expanded Shale, Clay and Slate Institute in the United States, Canada, Australia, Switzerland, and Japan.

In the Spring of 1952, acting on the invitation of a producer active in the field, expanded shale 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 by the rotary kiln process. The major objectives of the organization are:

1. To improve and extend the uses of expanded shale 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. A more complete description of the Expanded Shale, Clay and Slate Institute, including a list of charter members and locations of current members, appears in Chapter 8.

### *Bridges . . . and Bombs*

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, and in test buildings used in the historic atom bomb tests at Yucca Flats, Nevada, in 1955.

In the construction of the San Francisco-Oakland Bay Bridge, for example, the use of a 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 assumed seismic forces. In all, the cost savings effected were estimated at \$3 million.



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

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, aluminum, expanded shale concrete and 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 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 a brick veneer house at the same location were completely demolished. Said the official report:

“The above ground portion of the two-story brick and cinder block house located 4700 feet from the explosion was almost completely destroyed, and the first floor system was partially collapsed into the basement. None of the brick work remained standing, and the structure as a whole was beyond repair. . . .

“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 expanded shale 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 sash, both houses could be made habitable.

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

Despite their grim overtones, the Operation Cue tests at Yucca Flats were a landmark achievement in the history of expanded shale 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.



# What is Lightweight Aggregate?

**C**ONCRETE is a constant of 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 weights, shapes and uses. It is possible to design for many different degrees of strengths, durability, heat and sound insulation, and watertightness. 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 an apparent specific gravity considerably below normal sand and gravel which were at one time used in almost all concrete.

These lightweight aggregates will range from the extremely light materials used for insulative and non-structural concrete all the way to expanded clays and shales used for 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 strength.

The accompanying “Concrete Spectrum” shows the relative weights and differing applications of the various lightweight aggregates now in use. At the extreme left are Vermiculite and Perlite, which are sometimes referred to as the “super lightweights.” Concrete can be made with these aggregates weighing as little as 15 or 20 pounds per cubic foot.

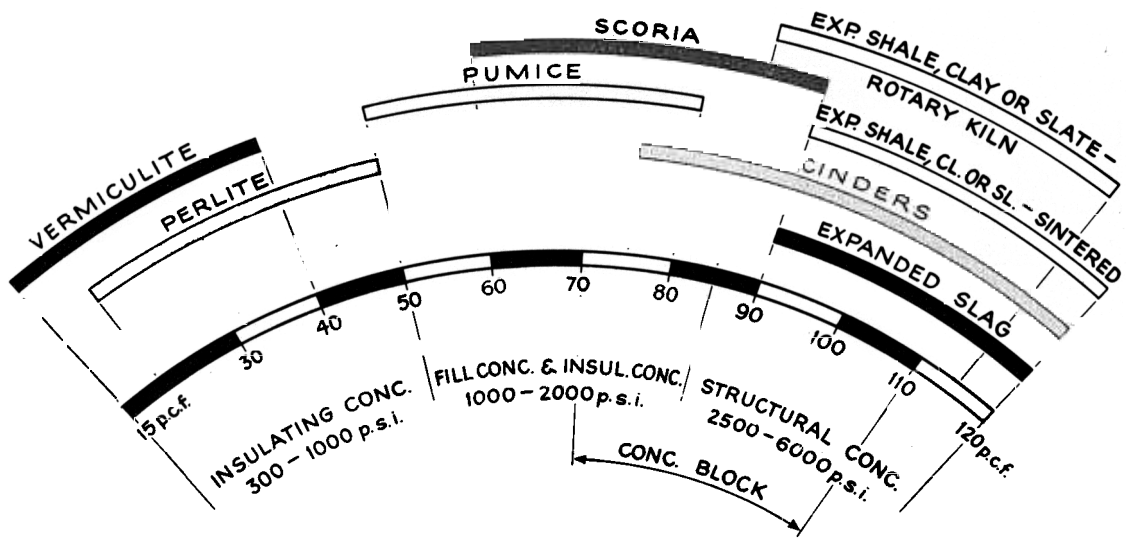
Next are the natural aggregates, Pumice and Scoria, for example. These can be made into concrete weighing about 25 or 30 pounds, and it also may run as high as 65 pounds per cubic foot.

Overlapping these are coal cinders, with a range from 75 to 120 pounds, and expanded shale, clay and slate aggregates produced by the rotary kiln method, which will produce a structural concrete ranging from 85 to 115 pounds per cubic foot. Expanded shale, clay or slate produced by sintering, and expanded slag, range from 90 to 120 pounds and complete the spectrum.

Beyond this, there are the air-cooled slag aggregates and the hard-rock aggregates such as sand and gravel and crushed stone, which produce conventional concretes weighing 135 to 150 pounds per cubic foot.

In general, the low density lightweight aggregate concretes at the lower end of the scale 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. The lightweight concretes at the upper end of the spectrum develop excellent compressive strength and are found in a number of structural applications.

The first commercial production of expanded shale aggregates was undertaken



WEIGHT SPECTRUM OF LIGHTWEIGHT CONCRETES

in 1917 near Birmingham, Alabama, but commercial development was somewhat restricted until 1946, when the original patents for the rotary kiln process expired. Since that time, the industry has grown substantially.

By way of explanation, two processes of production are employed, involving application of heat both to shale, clay and slate under controlled conditions. These are the rotary kiln method, which is the oldest and the method used by the majority of producers, and the sintering method.

The raw material used is a highly siliceous clay or shale that exhibits a bloating characteristic. The bloating is achieved by gas-forming minerals which liberate gases at the temperature of incipient fusion—the raw material is heated to the point that it becomes soft and pliable, but not to the point of completely melting.

In the rotary kiln method, shale is crushed and introduced at the upper end of a kiln similar to the type used in the portland cement industry. In passing through the kiln, the material reaches a temperature of 1800 to 2200 degrees Fahrenheit, and begins to become plastic. Internal gases cause the material to expand, or bloat, and create a mass of small, unconnected air cells, which are retained after the material cools and solidifies. After leaving the kiln, the material is cooled and then crushed and graded.

There are a few variations in the rotary kiln process. In one case, all material retained on a 3/4 inch screen after burning is crushed. In another, the raw material is pre-sized before entering the kiln so that crushing after burning is not 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 three variations are found throughout the industry.

In the sintering process, raw clay or shale is mixed with pulverized fuel and burned and expanded under controlled conditions on a moving grate. The mechanics of this method in some cases require twenty or thirty percent of the burnt material to be remixed with raw material and reburned on the traveling grate.

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 80 percent of the structural lightweight concrete placed today.

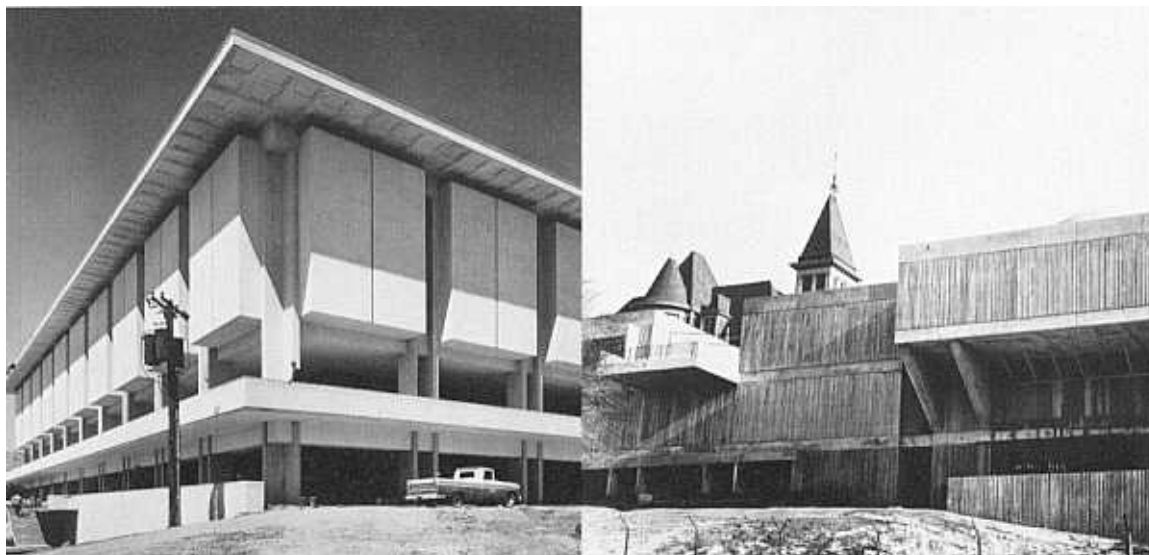
Insofar as concrete properties are concerned, there is no distinction between aggregates produced from materials classified as shale, clay or slate, so that the term "expanded shale" is frequently used generically to cover the aggregates produced by the rotary kiln method, regardless of which of the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

The aggregate particle itself is a hard, highly cellular product of uniformly great structural strength, each cell being completely surrounded by a hard, vitreous, water-proof membrane. The unit weight 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 50 pounds, the fines between 45 and 70. The maximum size of lightweight aggregate is nominally three-quarters of an inch, varying somewhat with type of material.

The specific gravity of the dry aggregate is significantly less than for conventional aggregates, ranging from 1.1 to 2.2, and structural lightweight concrete made from these aggregates is generally 20 to 30 percent lighter than conventional concrete.

The hardened properties of structural lightweight concrete are similar to those of normal concrete. Generally speaking, structural lightweight concrete is defined as a concrete having a 28-day compressive strength of 2,500 pounds per square inch or more, and air dry weight 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 normal weight 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 90 and 110 pounds per cubic foot. By replacing part or all of the lightweight fine fraction with natural sand, these weights will increase by from 5 to 10 pounds per cubic foot. Comparable concrete made with conventional aggregates has a weight of 145 to 150 pounds per cubic foot.



Learning Center-Library, University of Utah, Salt Lake City, Utah.

Hudson River Museum and Public Branch Library, Yonkers, New York.



Crystal Mall, Arlington, Virginia

Besides the weight savings, lightweight concrete has substantially better fire-resistant qualities than normal weight 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 30 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.

The use of lightweight aggregate in masonry blocks permits increased labor productivity because the decreased weight makes for greater speed and ease of handling. Similar considerations apply in the case of precast elements and tilt-up construction using lightweight structural concrete. In these as well as in cast-in-place applications, contractors find that the same sound controls used with other materials and processes will produce a highly serviceable end product.

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, including the hyperbolic paraboloid roof structure, sculpture and special design effects in form and texture.

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; 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, 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 made possible by lightweight structural concrete.



Department of Defense Personnel Records Center, St. Louis, Missouri

## From Building Blocks . . . to Bridges . . . to Skyscrapers

**L**IGHTWEIGHT expanded shale concrete has played an important part in the increasingly sophisticated construction techniques that have developed since the end of World War II. Besides imparting substantial economies in a number of applications, it has also made feasible design concepts that could not have been undertaken with conventional weight concrete, and in effect has opened up whole new vistas of form and utility in the structures that are part of the environment and culture.

The most common uses of expanded shale aggregate in construction are in the form of lightweight blocks and in structural concrete. Within the structural classification, there is a further division into cast-in-place concrete, on the one hand, and pre-cast and prestressed, on the other.

### *Expanded Shale Lightweight Concrete Masonry Units*

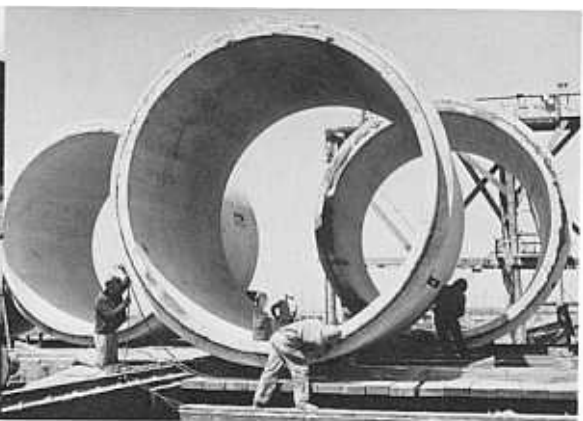
Shortly after World War I, F.J. Straub pioneered the so-called "cinder block," a manufactured concrete masonry unit using coal cinders as the aggregate. Then, in 1923 Dan F. Servey of Kansas City introduced the first masonry block employing lightweight expanded shale as the aggregate, and expanded shale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

The general characteristics of the lightweight masonry unit were that it provided a high degree of insulation, light weight, nominal shrinkage, and a uniform compressive strength equal to a heavyweight block with equal cement content. The block manufacturers found that the lightweight aggregate produced a block which was easier to sell to architects and engineers and, from a practical point of view, the blocks were slightly more than half the weight of the normal weight concrete blocks of the time, so that transportation costs to the job were radically reduced.

Their high degree of insulation against heat, fire and sound made the expanded shale 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. 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 normal weight concrete blocks!



Three Sisters Overpass, Alberta, Canada.



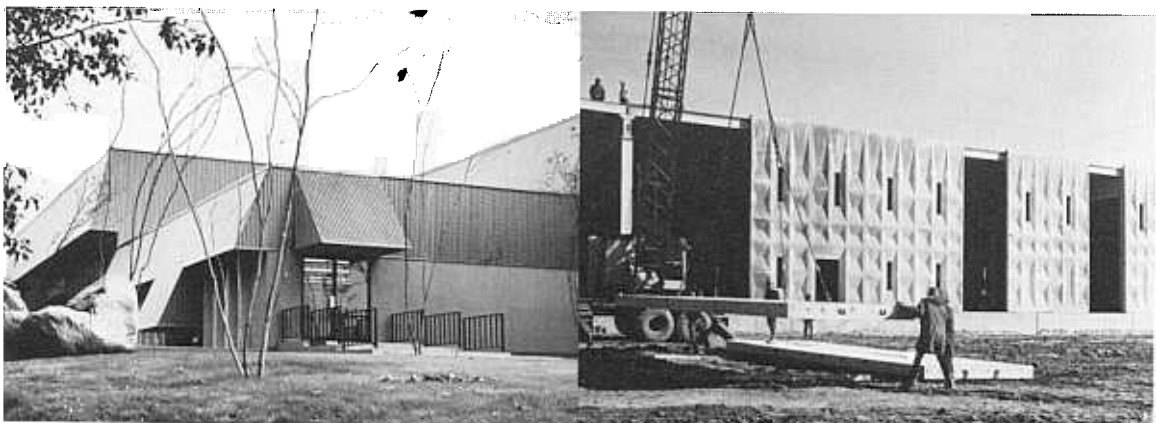
Sections of lightweight concrete pipe for steam generating plant, Huntington Beach, California.

Since that time, uses have multiplied so rapidly that it is estimated that the demand for the standard lightweight block now exceeds one billion blocks annually: enough to build a 60 foot high wall from New York to San Francisco.

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 the 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 and acoustical properties.

An interesting sidelight is that per capita consumption of block has been highest in two areas of extreme opposite climatic conditions: Florida and Alaska. In Florida, concrete masonry has proved an effective solution to the dual problems of hurricanes and termites. In Alaska, the lightweight blocks are widely used in military installations because of their fire-resistive and insulative characteristics, as well as their ability to withstand the penetrating “horizontal rains” that sweep in from the Pacific.



Hyster Technical Research Center, Troutdale, Ore.

Minneapolis Space Center, Minneapolis, Minnesota.





Sears, Roebuck & Company, Tampa, Florida.

Lightweight masonry blocks are ideal for all types of exterior and interior walls, both load bearing and non load bearing. Because manufacturers supply a wide range of special unit styles, such as joist blocks, reinforced lintels, square-end units, jamb blocks and special grooved units for steel windows, the use of blocks in construction actually places fewer demands on craftsmen for special work, and increases productivity all along the line by minimizing delays when such special work is encountered. This is becoming an increasingly important consideration in larger projects where the Critical Path Method and similar techniques are being used for coordinating jobs and scheduling work to maximize productivity.

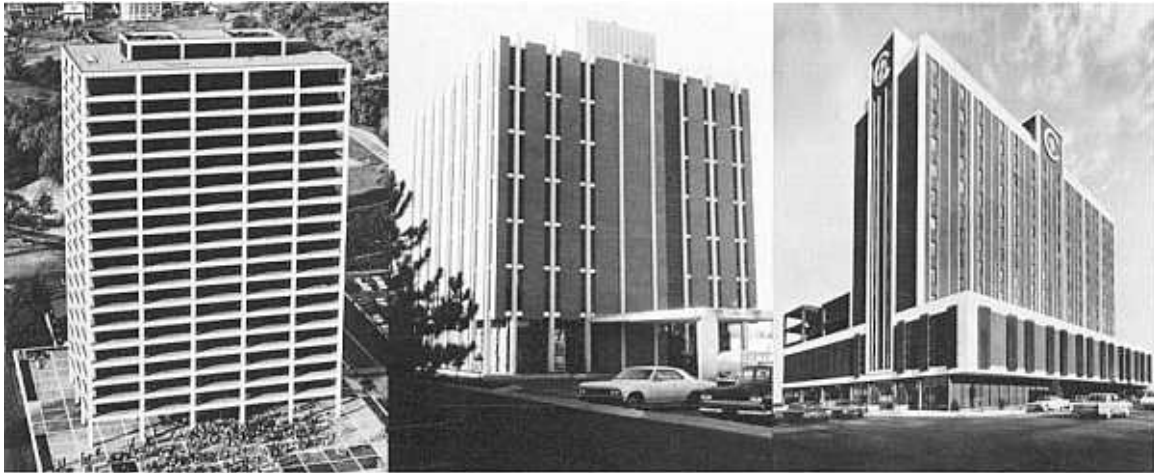
#### *Construction Advantages of Lightweight Masonry Units*

Lightweight masonry units employing expanded shale aggregate have become so much a part of the construction scene because of their ease of handling 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 expanded shale 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 naturally a major advantage in all construction using expanded shale 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, fire safety or other necessary properties.

2. *Fire resistance.* Lightweight masonry units made from expanded shale 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 heat insulator. Exposure to standard test conditions gives a typical lightweight expanded shale block a two-hour rating, i.e., the critical temperatures on the exposed face as defined by the Standard 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 expanded shale aggregate masonry blocks, which



Business Men's Assurance Company of America, Kansas City, Missouri.

Medical Towers, Jackson, Mississippi.

Central Bank and Trust Company, Birmingham, Alabama.

is far above that of any comparable substance. Heat loss through walls is reduced to a minimum, and changes in outside temperatures affect the walls so slightly that the possibility of condensation of moisture contained in the air of the heated interior is eliminated almost entirely. Similarly, the nature of the aggregate in the blocks offers a high degree of resistance to moisture through seepage or weather.

4. *Sound insulation.* The unique cellular nature of lightweight aggregate makes it particularly suitable for masonry wall construction where elimination of sound transmission is an important consideration. As mentioned, this application is particularly useful in schools and libraries; the recently-completed 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 graduate student carrels or 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 book 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.



Lake Point Tower, Chicago, Ill.

Marina City, Chicago, Illinois.

Park Regis, Sydney, Australia.

### *Expanded Shale Lightweight Structural Concrete*

The use of expanded shale lightweight aggregate in structural concrete has increased dramatically since World War II, 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. A similar 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 load bearing precast lightweight concrete formwork and 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.

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, 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



Watergate East, Washington, D.C.

of expanded shale aggregate is being used, either cast-in-place or in precast or pre-stressed applications.

The versatility of expanded shale 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 and then positioned, depending on which method is most suitable to the particular structure.

A parking garage in Dubuque, Iowa provides an excellent example of coordinated use of the two methods. The structural system includes precast columns and tee-beams, and cast-in-place floor slabs. By coordinating job elements, the four-level structure was completed in just five and one-half 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—considerably wider than in most parking garages—were possible, and added a measure of efficiency in the building's operations by increasing the building's usable capacity and by making parking easier and faster.

Both cast-in-place and precast structural concrete applications make use of prestressing techniques, which generally permit the use of less concrete than in conventional reinforcing methods. Prestressing may be either by pretensioning methods, usually done at a precasting plant, or posttensioning, which may be done either at a plant or at the job site. Both methods use high tensile wire in the concrete which is in effect stretched so that it will compact the concrete. In pretensioning, the wires are placed in the form and tensioned before concrete is placed; after the concrete has hardened the ends of the wires are cut in a planned sequence and the tension is transferred to the concrete. In posttensioning, wires are placed through holes in the hardened concrete, tensioned and locked into place with steel plates. Because of the specialized equipment required, pretensioning is usually done at a plant. Posttensioning can be accomplished at the job site, which makes it particularly applicable to large floor slabs or roof sections which could not easily be transported or positioned.

On the other hand, pretensioning lends itself extremely well to such structural lightweight concrete construction components as load-bearing beams, where it is desirable to obtain maximum load-bearing strength with minimum weight. 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 posttensioned lightweight concrete flat slabs. The longest girder—90 feet—weighs 40 tons, while a normal weight concrete girder of the same dimensions would weigh about 40% more, and would have required larger and more costly cranes for positioning. As it was, the girders 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 savings of some \$50,000 over the alternate design using steel stringers.

#### *Evolution of Structural Lightweight Concrete in Bridge Construction*

It is in bridge construction, in fact, that expanded shale 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 falsework; (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.

Harking back to the concrete ships of World Wars I and II is the Evergreen Point floating bridge across Lake Washington into Seattle, where the use of lightweight structural concrete for the top slabs and superstructure of pontoons to reduce their displacement was central to a design that resulted in a cost of \$24 million, as contrasted with the alternative of building piers 400 feet or more into the muddy lake bottom at an estimated cost of \$50 million.



Wyoming National Bank, Casper, Wyoming.

Also in the state of Washington is what is believed to be the longest single-span precast lightweight concrete bridge in the United States. Stretching over southern Washington's Klickitat River, the 131-foot span consists of four beams set side by side, each 4 feet wide and 4 feet 11 inches deep and weighing 105,000 pounds, yielding a weight savings of 37,000 pounds per beam over a sand and gravel concrete beam. To avoid costly job site casting and posttensioning, beam casting and prestressing were done at the aggregate supplier's yard in Portland, Oregon, and the beams were then transported by rail flat car to within 500 feet of the bridge site. As an indication of the tight scheduling possible using these techniques, casting began on November 3 in order to meet a completion date of December 15 in order to be usable before winter snows and to participate in Federal funds allocated for floor repairs.

The 131-foot Klickitat River bridge, completed in 1965, represented a gigantic stride forward in slightly more than a decade from a 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.

#### *How Precasting Facilitates Construction*

Precasting of lightweight structural concrete is particularly advantageous in the case of bridges and similar structures where physical conditions or traffic movement





University of Illinois Assembly Hall, Urbana, Illinois.

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 Los Angeles Dodger Stadium in Chavez Ravine, where most 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 expanded shale aggregate lightweight concrete.

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 expanded shale aggregate in this instance was the reduction in weight which permitted substantial savings in handling and shipping costs.

Precasting can also provide substantial economies where intricate designs, modules or repetitive forms are involved. And the weight savings offered by expanded shale 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 normal weight concrete, two cranes would have been required. Mass production and simplified erection of the thin shell shapes of Oakland resulted in a roof cost of \$1.55 per square foot, as contrasted with \$2.25 per square foot by the next lowest cost method—a saving of nearly 40 percent.

Another example of the economies inherent in this type of construction is provided by an addition to a Colorado church, in which 11 folded plate arches form both walls and roof. Rising 39 feet and spanning 50 feet at ground level, each arch was cast in two pieces, but since all 22 pieces required for the addition were practically identical it was possible to use the same form for all. Each piece was hauled individually by truck to the site, and two cranes were used for erection. Lifted into position, the two legs of each arch were butted at the crown and then welded in position. An interesting sidelight here was that plasterers applied the final finish coat of plaster on most of the inside surface of the arches before they were erected and while they were still in storage at the fabricator's plant. This eliminated the cost of the high forest of scaffolding that would have been required if plastering had been done after the building had been erected.

#### *Tilt-up Construction Facilitated by Lightweight Concrete*

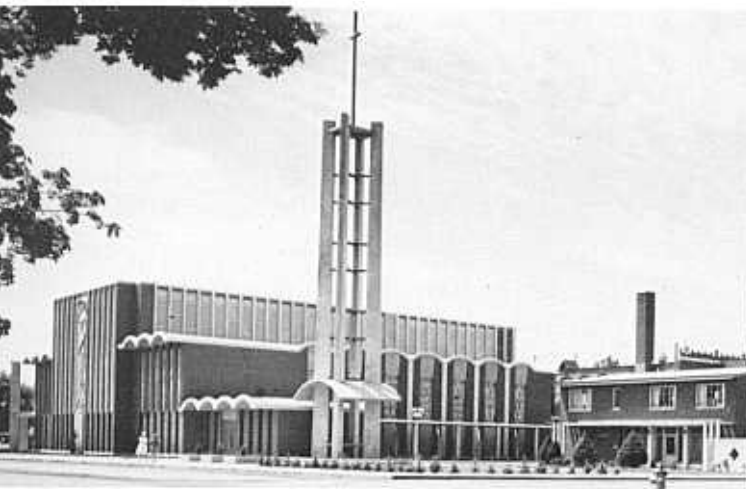
Tilt-up construction employing similar techniques of precasting is becoming increasingly popular in industrial and commercial buildings. The gigantic new research center of the Hyster Company near Portland, Oregon, is made up of tilt-up wall panels approximately 25 feet square and 6 inches thick. The 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.

#### *Thin Shell Construction Opens New Design Vistas*

Church and airport construction in particular demonstrates the whole new vistas of design freedom that have been opened to architects and engineers with the advent of thin shell construction using expanded shale lightweight aggregate concrete. The hyperbolic paraboloid and conoid roof shapes are just two examples of the possibilities of a lightweight structural concrete that can be cast to minimum

TWA Terminal, John F. Kennedy International Airport.





St. Charles Parish, Spokane, Washington.



University Lutheran Church, Lawrence, Kansas.

thicknesses and still provide the necessary strength. In the hyperbolic paraboloid roof of the TWA terminal, for example, due to lightweight concrete's strength, the shell thickness was shaved to 2-1/2 inches, and still provided a 33 percent safety factor for supporting a full water load should the central drain become restricted.

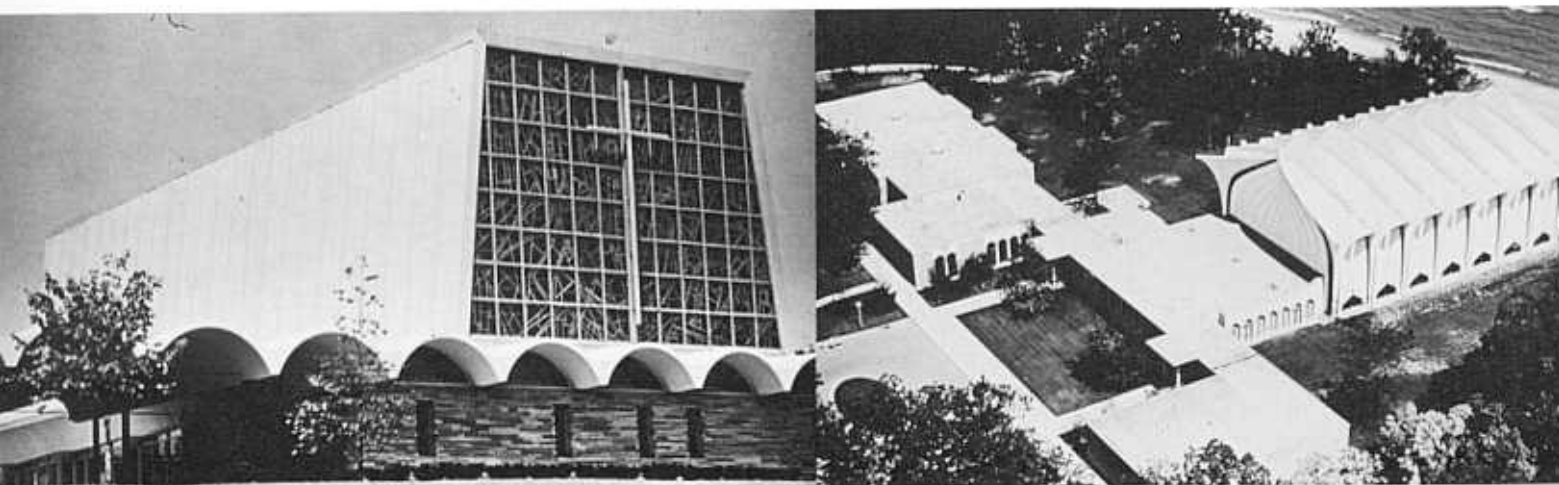
Thin shell construction can be either precast or cast-in-place. The large new mechanized post office facility at Providence, R.I., has six identical cast-in-place roof bays, totalling 420 by 300 feet, with only two interior columns; as much as 540 cubic yards of lightweight concrete had to be placed in one continuous operation. The Bacardi Rum Distillery bottling plant and museum in Catano, Puerto Rico, has a roof structure of 29 folded plates and barrel shells which were originally designed to be precast in a nested configuration, but were actually cast in place when the project got under way.

North Shore Congregation Israel, Glencoe, Ill., 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 original designs specified normal weight 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 opensided 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.

*Lightweight structural concrete goes up . . . and up . . . and up*

So many new records have been set, in recent years, for buildings employing structural lightweight concrete framing and floor systems that at any given moment it is



Kenwood Baptist Church, Cincinnati, Ohio.

North Shore Congregation Israel, Glencoe, Illinois.

difficult to point with certainty to the “world’s tallest” lightweight concrete building. At one time or another, records have been set by such structures as Bank of Georgia Building in Atlanta (390 feet), Marina Towers in Chicago (588 feet), 1000 Lake Shore Plaza in Chicago (601 feet), Australia Square in Sydney (602 feet), and Lake Point Tower in Chicago (645 feet). 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 is an important factor in computing wind effects, as it is in minimizing the whiplash effect of dead load in earthquake areas.

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 normal weight concrete. An office tower in Ottawa, originally designed as a 22-story building using normal weight concrete, was extended to 25 stories by changing concrete specification above the eighth floor level to lightweight. A 200 percent 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.

#### *Use of lift-slab construction technique*

A technique which is seeing increasing use is that of lift-slab construction, in which floor and slabs are cast at ground or basement level around previously set structural columns and then lifted vertically into position and secured. The 17-story Canyon Crest Apartments located 1,000 feet above downtown Salt Lake City used the “slip lift” method of pouring lightweight concrete towers while the floors were being raised, employing this method for forming the elevator shafts and other components, in addition to the walls. The 14-story Republic Tower Building in Baton Rouge, Louisiana, another building erected by the lift-slab method, used a cast-in-place reinforced lightweight concrete wall—adopted by the structural engineer to meet the stresses of hurricane-force winds common to the area—which was constructed concurrently with the lifting operation. The nine-story Habersham Cooperative Apartment in Atlanta contains 28,900 square feet of floor area on each floor, and the nine slabs were cast one

upon the other around previously set columns, then divided into smaller slabs for convenient lifting. By casting all the slabs on one easy-to-reach level, only 34 working days were required to complete the placing and finishing of all lift-slabs. An important contribution of structural lightweight concrete is that its lighter weight reduces the number of jacks required for lifting, thus reducing the contractor's overhead costs.

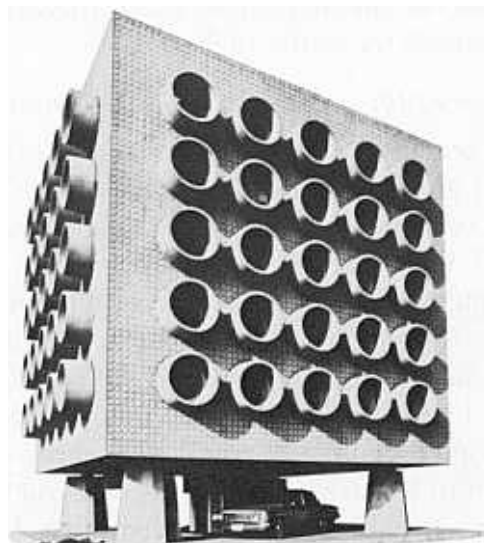
### *Greater Lightweight Use Predicted for Future*

The rapid strides in the technology of structural lightweight concrete in recent years have resulted in a sharp growth in demand for expanded shale aggregate. New methods of mass production applied to building component fabrication and erection are finding increasing application, and the strength and light weight of expanded shale aggregate makes it ideal for the associated technology of handling, storing, transporting and lifting such components into place. In many instances, in fact, 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 normal weight concrete, and which would otherwise require expensive heavy-lift handling equipment.

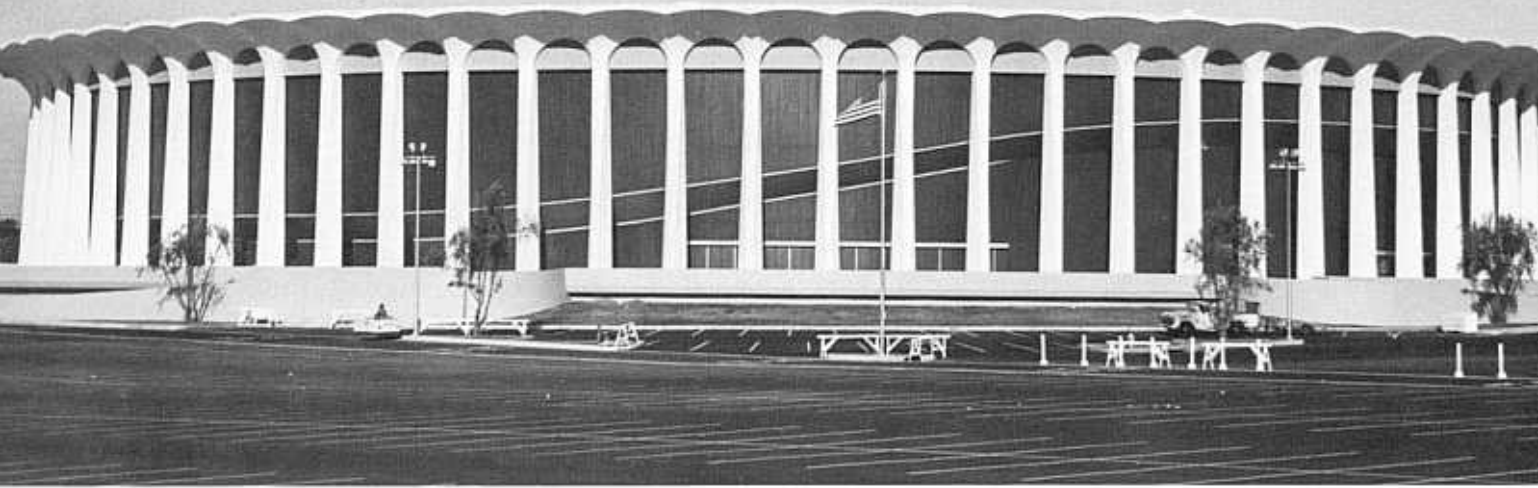
Along with the economies that result essentially from reduction in dead load comes also the design freedom that is being exhibited in more and more buildings of all types, from barrel-vaulted warehouses to magnificent contemporary churches and futuristic building shapes that are advanced even by contemporary standards.

More than a decade ago, Frank Lloyd Wright, whose genius is reflected in many buildings employing lightweight concrete construction, described the years ahead in construction, saying: "Our era has provided us with the greatest tool box on earth. We can truly build anything with it, but we are only just beginning to realize what it is in our power to build."

The landmarks in architecture, engineering and construction that have been achieved in the intervening years demonstrate how that promise is being borne out.



House of a Hundred Windows," Tokyo, Japan.



Forum, Inglewood, California.

## The Many Auxiliary Uses of Expanded Shale Aggregate

**A**LTHOUGH the primary uses of expanded shale aggregate are in direct 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 water resistance, and surface texture are important considerations.

One such use is as a special fill. Floor fill and roof fill applications, where the insulative and protective properties combine with the weight factor to make expanded shale especially suitable, account for a substantial volume—more than 270,000 cubic yards annually. 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; refrigeration costs alone in a typical 120,000 square foot refrigerated warehouse with 20 foot clear stack height will run as high as \$6,000 a month, so that any savings in refrigeration becomes quite important.

The increasing use of the material for its texture and design properties has caused decorative uses of expanded shale aggregate to account for an impressive 232,000 cubic yards annually—132,000 yards in decorative precast panels, and another 100,000 yards in decorative cast-in-place applications. An important factor here is the lightness of weight which permits delicate sculptured effects.

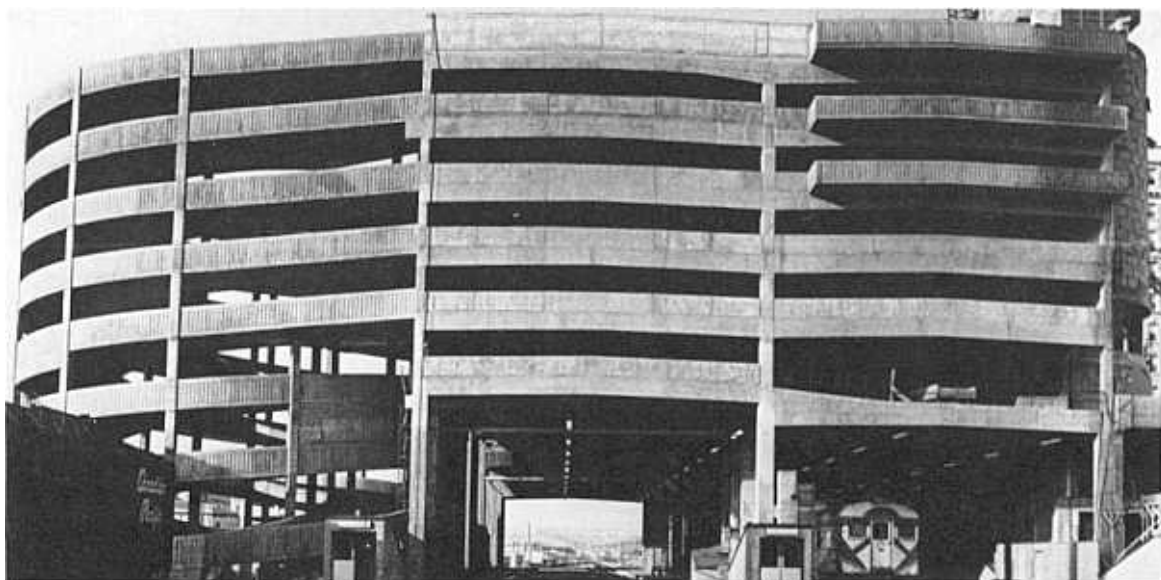
An increasingly common use of the aggregate is as soil amendments for horticulture and in landscaping and such special uses as golf green construction. Research undertaken at the Ohio State University addressed itself specifically to the question of growing orchids in expanded shale aggregate, and reported that: "Providing anchorage, support, excellent drainage and aeration, these materials do not decay as does osmunda. Desirable moisture content is easily maintained." Experimental use in hydroponic farming is also under way, as is testing for use in miniature gardens, aquariums and the like.

A number of running tracks in the United States and Canada now use expanded shale aggregate, and experimentation is under way to determine applications for sports grounds, race tracks and similar applications in recreational facilities.

An extremely promising use for expanded shale aggregate is in flexible bituminous pavements, where the material shows two distinct advantages. First, pavements made with expanded shale aggregate have a high skid resistance. The high skid resistance present immediately after paving is due to the rough surface texture of the aggregate, but the aggregate is outstanding in its ability to retain its skid resistance under traffic. Pavements made with such natural aggregates as certain limestones and dolomites will polish under the action of traffic and lose a large percentage of the initial skid resistance, but expanded shale 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.

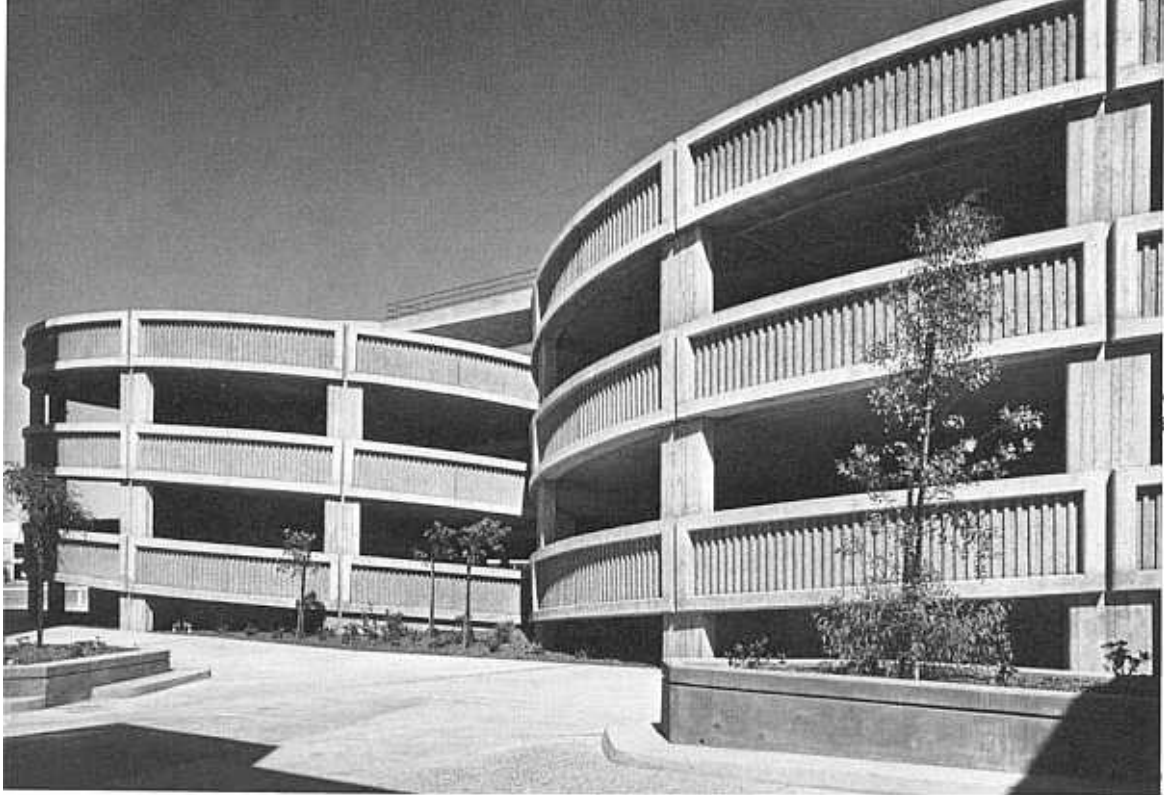
The other distinct advantage of the expanded shale aggregate is that when it is used in seal coats and surface treatments breakage of auto glass from "flying" stones is practically eliminated. Much of the windshield and headlight damage experienced by motorists on flexible pavements occurs when normal weight 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 expanded shale 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.

It would be impossible to document all the uses of expanded shale 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.



Palliser Square parking structure, Calgary, Alberta, Canada.





Parking facility, Santa Rosa, California.

## Economics of Lightweight Concrete

**C**ONCRETE is composed principally of cement and aggregate—"aggregate" being a generic term for any hard, inert substance used to provide bulk and rigidity to products like concrete and plaster. Sand and gravel are natural and abundant aggregates whose only major drawback is their density; conventional concrete made with these aggregates has a unit weight of approximately 150 pounds per cubic foot.

Expanded shale aggregate, which makes possible concrete of one-third less unit weight—100 pounds per cubic foot—is a product created by processing raw shales, clays or slates in rotary kilns at extremely high temperatures, and under rigid controls.

Even with this brief background (the process is described in greater detail elsewhere in this booklet), it is understandable that concrete made from lightweight aggregates must necessarily be significantly more expensive than concrete from natural aggregates which have undergone relatively little processing. Assuming that apart from weight there are no major differences between conventional and lightweight concrete, what are the economics that justify the use of lightweight?

Essentially, these economics revolve around engineering considerations where weight is a critical factor, although there are also instances where lightweight is an economical substitute for more expensive structural materials like steel, and those where its properties of insulation and impermeability specifically recommend its use. Basically, however, the question is one of weight: useful as concrete is in construction, the thousands of cubic yards which typically comprise a structure create millions of pounds of deadweight which must be provided for in foundation and building engineering—a particularly troublesome and expensive problem where soil has low load-bearing characteristics.

How important these economics can be was shown as early in the history of the industry as 1922, when a gymnasium addition to the Westport High School in Kansas City, Missouri, became the first lightweight concrete building in history. The price of expanded shale aggregate at that time was \$6.00 per cubic yard as contrasted with \$2.50 per cubic yard for sand and gravel, yet the load-bearing value of the soil was low enough that the expanded shale aggregate was justified by the even greater cost of the engineering that would have otherwise been required to support the deadweight of conventional concrete.

Another demonstration of these economics occurred in 1928 and 1929, when the Southwestern Bell Telephone Co. office building in Kansas City was doubled in height from its existing 14 stories to a total of 28 stories. Engineering studies had indicated that the foundations and underpinnings of the existing structure would permit the addition of eight floors using conventional heavyweight concrete, but further studies showed that the substitution of expanded shale aggregate would so reduce the deadweight as to permit adding a total of 14 floors to the building.

The use of lightweight brick in the place of structural clay units resulted in a total dead-load reduction of more than 3 million pounds, while the lightweight structural concrete saved another 6 million pounds, for a total of 9 million pounds deadweight savings over conventional concrete—had the building been able to support the weight in the first place.

The economics of air rights were important, even in those days; although today's advanced technology for producing uniform mixes was not available and the concrete was mixed at the site with comparatively crude mixing equipment, the payout on the investment—the occupancy of six additional floors for 38 years to date—has more than justified both the cost of the materials and of the construction pioneering itself that went into this landmark building.

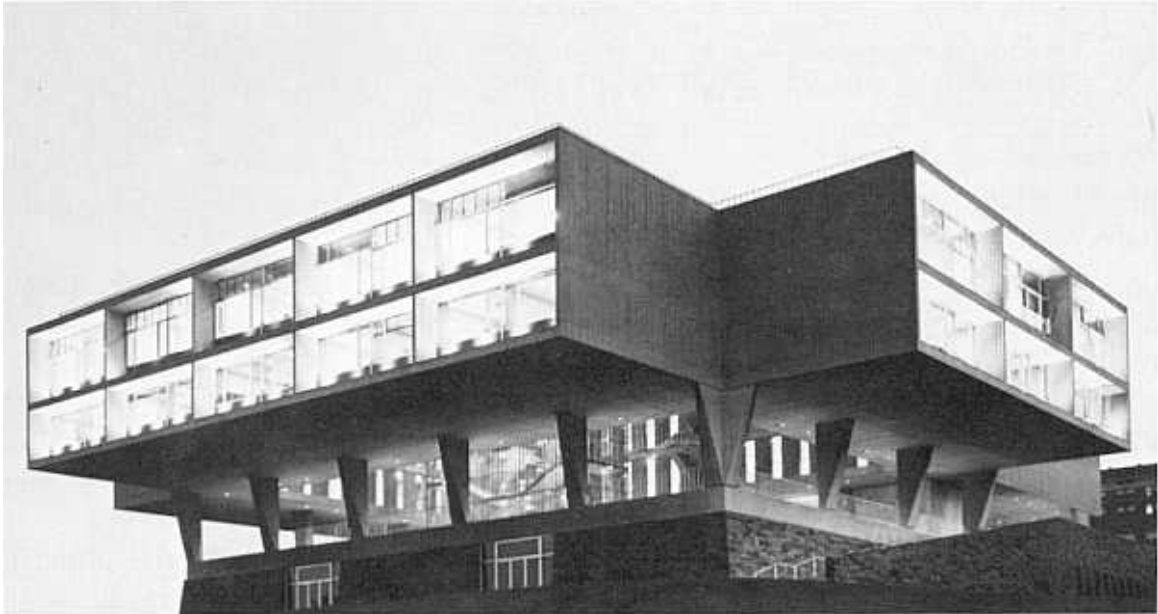
Elsewhere in these pages several more recent examples are cited: the Place de Ville in Ottawa, where a change from normal weight concrete to lightweight permitted increasing building height from a planned 22 stories to 25 stories, even though the change in concrete was not undertaken until the building was at the eighth-floor level; and the Magnolia State Savings and Loan Association Building in Jackson, Mississippi, which was enlarged 200 percent from an existing two-story structure to one six stories high, thanks to the use of structural lightweight concrete.

Ten Main Building, Kansas City, Missouri.

Royal Bank of Canada Building, Montreal, Canada.

Illuminating Building, Cleveland, Ohio.





Milwaukee War Memorial, Milwaukee, Wisconsin.

The Sears Roebuck Catalog Order Annex in North Kansas City, Missouri, a 480,000 square foot structure, had to be sited on low-bearing river silt. This required that dead loads be kept to a minimum, which was accomplished through a system of lightweight concrete tilt-up panels, with lightweight aggregate roofing granules over the built-up roof.

Tilt-up construction of this type is one of a number of cost-saving construction techniques which are made possible by the light weight of the expanded shale aggregate. Described elsewhere are various types of precasting applications, where on-site or remote pre-casting can help avoid the expensive scaffolding, falsework and materials handling operations that have been traditional with major construction projects. The light weight of precast members and components usually makes it possible to handle them with lower-cost equipment which would not have sufficient capacity for normal weight concrete. Particularly in the case of bridges, piers and similar structures where working conditions are difficult, precasting minimizes actual erection time and minimizes exposure of workers to hazardous conditions.

Where structures of this type are associated with traffic arteries—a bridge over a channel, highway or railroad tracks, for example—one of the important economic benefits is the minimum interference with traffic achieved when precast structural members are used. Since projects of this nature are usually funded by public bodies which are responsible as well for the cost impacts of traffic delays, rerouting and the like, economic benefits of this nature can provide a strong inducement for the use of structural lightweight concrete, over and above its direct cost benefits in the construction itself.

A dramatic example of construction cost reduction in bridge construction is provided by the Tacoma Narrows single-deck, four lane suspension bridge, replacing the original two-lane bridge known as "Galloping Gertie" which collapsed so spectacularly in the early 1940's. The new four-lane bridge is supported on the original piers designed

for a two-lane structure; this change, together with consideration of probable earthquake disturbances, required strict attention to the bearing pressure of the old piers. The use of expanded shale concrete for the bridge deck made it possible to save: 368 tons in structural steel, 363 tons in suspension and suspender cables, 2,060 tons in bridge deck weight, and a cost savings in the above-pier portion of the project of \$320,000. But the dramatic cost saving was achieved through re-use of the original piers: an impressive \$4 million.

The San Francisco—Oakland Bay Bridge also illustrates the economies of expanded shale lightweight concrete. The Design Engineer, Glenn B. Woodruff, estimated that the use of this material in the upper deck of the bridge resulted in a savings of \$3 million to the structure. The Heatley Avenue Overpass in Vancouver demonstrated a saving of \$50,000—more than 10 percent of the total cost—over the alternate design by using lightweight structural concrete, and precast girders spanning busy railroad tracks required only nine days to place.

The 30 percent reduction in dead weight that can typically be achieved through use of lightweight concrete is reflected both in savings in steel and in reduction of column size and foundation requirements. One area of construction where this is demonstrated is in parking garages and apartment and office buildings incorporating parking ramps; in these structures reduction of column size, combined with longer spans, increases capacity and at the same time increases utilization by minimizing obstructions. Similar considerations apply in the case of warehouses, where bay size—frequently determined by column spacing—has a marked effect on storage costs and handling efficiency.

The Learning Center-Library at the University of Utah combines many of the different types of savings possible through use of expanded shale aggregate lightweight concrete. First, the use of lightweight concrete produced about 30 percent savings in column footings, about 30 percent in slab weight, and about 12% in reinforcing steel—a major consideration. In addition, the heavy load-bearing structural members made



Co-op City, the Bronx, New York City, New York



Synagogue, St. Petersburg, Florida

possible large open stack areas supporting a per-square foot loading considerably in excess of most industrial buildings, which in turn permits most effective functional space utilization. Thinner slabs achieved with lightweight structural concrete provided at least two inches additional headroom. Finally, use of lightweight concrete minimized engineering problems caused by location of the structure on a seismic fault, by reducing the contributory factor of excessive deadweight to the whiplash effect such deadweight produces during earthquakes.

Besides savings in actual construction and basic material costs, expanded shale aggregate offers important related savings in such aspects as fire protection, thermal insulation and interior and exterior finishing. The fire resistance and low thermal conductivity of lightweight aggregate masonry and structural concrete usually eliminates the need for secondary protective materials, and resistance to moisture, corrosive salt air and insects is an important benefit in many locations. The textures and design effects available with both the lightweight block and special finishes of the lightweight concrete have provided significant savings in both interior and exterior finishing applications, simply by leaving the aggregate surface exposed and painting in conventional manner. Lightweight masonry units, which must be positioned by hand, also enhance productivity of masons, and, because they are nailable, simplify carpenters' work when attachment of facing materials is involved.

But tons-and-pounds and dollars-and-cents comparisons with conventional weight concrete do not tell the whole story of the economics of expanded shale lightweight aggregate, nor do the special features of the product and its labor-saving applications. For it is a fact that lightweight concrete has made possible structures for which there are no normal weight alternatives. The economic utility achieved from additional floors of usable space which could not otherwise be built, for example, represents one class of such structures; others would be included in applications where the desired design and engineering—whether for functional or decorative effect, or both—could not be achieved except with lightweight concrete.

In short, while the immediate economics of expanded shale lightweight aggregate are tied to important benefits in construction costs and materials, the long-range benefits of economic utility of the structures themselves may well be quite as important. In any economy where return on investment is measured either by cash, in the case of profit-oriented enterprises such as apartments and commercial structures, and in social benefits in recreational and religious facilities, the quickness of completion and the high utilization of available space become major considerations. And the use of lightweight concrete insures that both are realized.

# Test and Research Data on Expanded Shale Lightweight Aggregate

**T**HE growth in use of expanded shale lightweight aggregate in recent years has resulted from a unique combination of applied research and practical inventiveness. Public and private organizations and academic institutions have participated widely in research and publication of technical papers; individual architects, engineers and builders have provided the priceless catalyst of practical experience. Problems have been solved in the laboratory and on the job—and frequently neither could have solved the problem without the other.

Nothing is more convincing than actual demonstration, however, and individual producers have played an important role in this respect. The use of pretensioned lightweight concrete, for example, was given considerable impetus in 1956 when a producer invited more than 600 architects, engineers and other top members of the construction industry to its plant to watch a test demonstration. During the six-hour demonstration, tests were conducted on double-tee roof slabs of 40 to 50 foot spans, composite box bridge units with 32 foot spans, and tapered girders with 64 foot spans.

A major purpose of the Expanded Shale Clay and Slate Institute at its formation in 1952 had been to correlate and publicize test results such as this, as well as the research undertaken by such bodies as the National Bureau of Standards, various universities, the Bureau of Reclamation, the Corps of Engineers, and the Portland Cement Association. The accompanying bibliography, while by no means complete, lists representative publications and literature issued by the institute and by others.

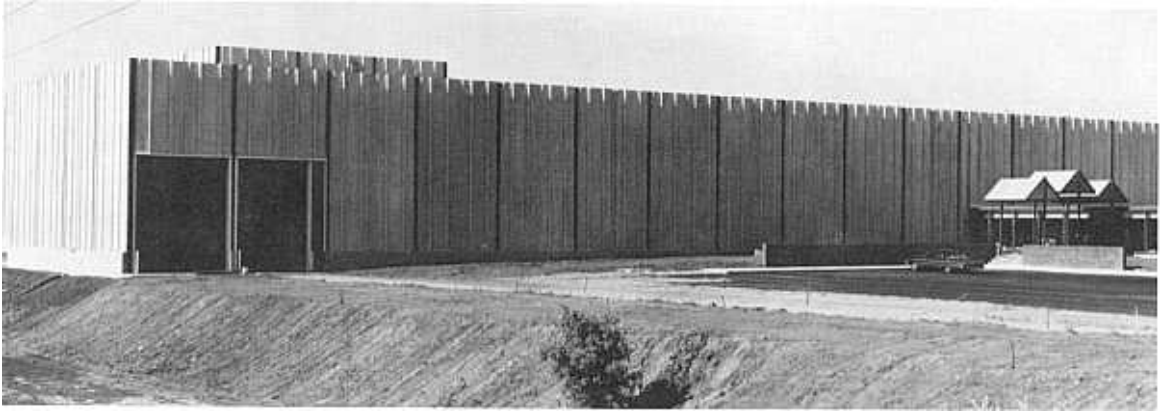


World Trade Center, New York, N.Y.



Edmonton House, Edmonton, Alberta





Arrow Tank & Engineering Co., Mendota Heights, Minn.

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(These are but a very few of numerous references for additional information. Many of the following contain additional references, particularly #11, the ACI 213 Guide.)

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# The Expanded Shale Clay and Slate Institute

**F**UNCTIONING both as a technical clearing house and as the trade association in the field, the Expanded Shale Clay and Slate Institute was formed in 1952. The mission of the Institute included both coordination of existing research and cooperation with other technical organizations in advancing the state of the art. The development of new technology, education, and the dissemination of technical information are also primary objectives.

The development of standards of the industry has been a major undertaking of the Institute, and from the beginning a primary requisite for membership has been that the producer-member should process expanded shale aggregate by the rotary kiln method and consistently conform to the American Society for Testing Materials specifications for structural lightweight aggregate. A producer's membership in the institute assures the architect, engineer and builder that the product supplied will have the high performance characteristics and uniformity called for in those specifications.

There were fourteen charter members of the Expanded Shale Clay and Slate Institute:

*California*

McNear Brick Company, San Rafael

*New York*

John H. Black Co., Buffalo

*Illinois*

Poston Brick and Conc. Products, Springfield

*Oregon*

Smithwick Concrete Products, Portland

*Kansas*

Buildex, Inc., Ottawa

*South Dakota*

Light Aggregates, Inc., Rapid City

*Kentucky*

Kentucky Light Aggregates, Inc., Louisville

*Texas*

Featherlite Corporation, Dallas

Texas Industries, Inc., Dallas

Texas Lightweight Aggregates Co., Dallas

*Louisiana*

La. Lightweight Aggregates, Inc., Alexandria

*Canada*

Cooksville Co., Ltd., Toronto

*Missouri*

Carter-Waters Corporation, Kansas City

Hydraulic Press Brick Co., St. Louis

Since its founding, the Institute has acquired many members in the United States and Canada, as well as members in Australia, Japan and Switzerland. It now represents about 90% of the production by the rotary kiln process in the United States, and 100% of the production in Australia and Canada. A roster of members and map showing locations in North America appears on the following pages.



Glenn A. Black Laboratory of Archaeology,  
Indiana University, Bloomington, Indiana.



El Conquistador Hotel, San Juan, Puerto Rico.

## Epilogue

**T**HE publication of this booklet marks the beginning of the second half-century of the expanded shale industry—which in these fast-moving times is taken as a sign of maturity. Yet the pace of technological innovation has quickened with each passing year, and most of the major advances in lightweight concrete have been made within the last ten to fifteen years.

This is another way of saying that the expanded shale industry has approached that dynamic state where the lessons of experience are being translated vigorously and creatively into ever-broadening economic and imaginative applications of concrete to the environment and to the economy.

For if this booklet is the measure of fifty years' accomplishments, it is equally the measure of the strength, resourcefulness and vitality that arise in a competitive business system, and the members of the Expanded Shale Clay and Slate Institute recognize that effective competition in the marketplace of materials demands from them a continuing, dynamic advancement of the frontiers of concrete technology and usage.

They recognize, too, that the development of systems of living to house, shelter and foster the proliferating pursuits of man is barely under way; that building the buildings of the future, the cities, highways and the yet-to-be-invented structures that will be needed represents a challenge to the practical businessman even as much as to the creative architect and engineer.

Hopefully, this booklet will have imparted to you some of the enthusiasm they feel as they face this challenge.