



COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

HENRY WARD
COMMISSIONER OF HIGHWAYS

November 2, 1960

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

A-1-9

MEMO TO: A. O. Neiser
Assistant State Highway Engineer

SUBJECT: Expanded-Shale Lightweight Aggregate
(Kenlite) Concrete for Bridges

Sometime ago Mr. H. R. Creal, Assistant State Highway Engineer, and then Chairman of the Specifications Committee, requested that the Research Division review work performed by the Department on Kenlite aggregate and subsequent research on Kenlite and similar expanded shale, lightweight aggregates. Mr. J. H. Havens, Assistant Director of Research, who has been closely associated with work performed in the Research Laboratory, has prepared our report on this study in the form of a discussion which is attached.

Laboratory studies on concrete produced from Kenlite aggregate indicated that satisfactory compressive strength with adequate bond strength could be obtained. The 1953 project further indicated poor durability to freezing and thawing (ASTM C 290) as compared to the reference limestone aggregate. The producers of Kenlite aggregate and others have questioned the method of laboratory evaluation of the freezing and thawing for durability. We do not have enough actual field performance to substantiate the level of design requirements. For instance, we do not know the number of cycles of freezing and thawing (ASTM C 290) that would be comparable to a normal service life of lightweight concrete. This test appears to be quite severe on the Kenlite aggregate based upon performance of comparable expanded shale aggregates elsewhere.

As Mr. Havens points out, we have been observing scaling and apparent de-icing salt damage on normal weight concrete bridge decks rather early. Higher cement factors, entrained air, and protective coatings should be safe-guards against this type deterioration and could increase the service-life of both lightweight and normal weight concretes.

November 2, 1960

Due to the limited experience with Kenlite concrete (three highway structures noted in attached report), we would recommend that its use in exposed structural concrete be on an experimental basis. It would appear that prefabricated, pre-stressed, structural members would be ideal for realizing any economic advantage of lightweight concrete.

Respectfully submitted,



W. B. Drake
Associate Director of Research

WBD:dl
Encs.

Commonwealth of Kentucky
Department of Highways

A DISCUSSION ON THE DURABILITY OF
EXPANDED SHALE AGGREGATE FOR EXPOSED
CONCRETE STRUCTURES (BRIDGES)

by

Jas. H. Havens
Assistant Director of Research

Highway Materials Research Laboratory
Lexington, Kentucky

November, 1960

During the period between 1924 and 1934, in particular, numerous reinforced concrete bridges were built in Kentucky and elsewhere. Although many of them are still in service, they are some 30 years old and are showing the effects of time and weather. While it is true, of course, that they were constructed without the benefit of air-entrainment and without many present-day control practices, the influences of aggregate quality and freeze-thaw are usually apparent. The advent of the de-icing salt era, about 1940 and following World War II, introduced an additional deteriorating influence gnawing at old and new structures alike. The problem of maintaining and repairing older bridges is seriously compounded by the fact that newer bridges seem to have a relatively shorter maintenance-free life-expectancy because of the de-icing salt treatment.

It is known that some types and sources of aggregates perform consistently well while others do not. Specifications are being strengthened at every opportunity -- to provide more discriminatory selectivity in quality of aggregates. These criteria of quality are reliable to a significant degree even though some troublesome aggregates are not detected and eliminated by them. From the standpoint of early performance, say up to 10 or 15 years, they are usually sufficiently discerning. It is, then, the long-time durability that is most difficult to predict; and our tests and criteria do not appear to be capable of discerning quality to this extent.

In many respects the mechanics of freeze-thaw in concrete is like a water-pipe that freezes and bursts. If highly porous aggregate is used in concrete, and if it becomes saturated and freezes, the inevitable

happens. The mortar in the concrete is no less immune if it is porous and is easily saturated. Air entrainment enhances the density of the mortar (lower w/c); and, by virtue of the reduced permeability (water-proofness) which it imparts to the mortar, it is capable of compensating the durability of inferior aggregates.

Water-proofing is, by and large, the key to concrete durability. Laboratory freeze-thaw tests have shown repeatedly that damage is related to porosity, rate of water absorption, and the degree of saturation. Concretes which have been moist-cured and then oven-dried before the onset of freeze-thaw exposure are more resistant because they do not re-saturate as readily. Air-entrainment and higher cement factors likewise enhance durability. However, the cement factors needed by inferior aggregates to achieve resistance to freeze-thaw are greater than that needed to achieve the required strength. Air-entrainment is not a reliable cure-all. Too frequently the air entrained in the mixed concrete is dissipated by unnecessary manipulations during placing and finishing. Over-vibration, over-finishing, and bleeding expel air and invite spalling and scaling.

Concrete that is never exposed to water after curing and air drying can hardly be damaged by freeze-thaw temperatures. Likewise, if internal resistance to water can not be assured, then certainly consideration should be given to exterior protection such as shelters or protective coatings, i. e. paints.

Light-weight concretes, exposed, are more vulnerable to freeze-thaw damage because the aggregate is highly porous; and, therefore, their use in exposed structures is rightly viewed skeptically unless

special measures are taken to compensate for its inherent weaknesses in this respect.

The principal use of light-weight concrete is still in the construction of buildings where it is usually well protected. In the past, some states and highway agencies have dared to use it exposed in bridges. It is being promoted extensively by producers for bridges and for folded, canti-levered, parabolic, modernistic, roof structures (exposed).

In 1918, S. J. Hayde, a Chemist, of Kansas City, discovered that some shales could be bloated by firing and fusing to about 2000°F. Near the end of World War I, considerable effort was being made to use it as light-weight aggregate to build concrete hulls for ships. A few were built. Apparently, the Atlas Cement Company in Kansas City burned the shale in rotary kilns (They also developed Type III cement for this work during World War II). In 1920, a plant was built in Kansas City, Mo., in which shale was burned and expanded to make light-weight aggregate for commercial use. Around 1926, a patent covering the process was issued to John Hayde and the product was called "Haydite". In 1928, a bridge spanning the Ohio River at Paducah was built in which Haydite was used in the concrete deck. The bridge was designed by the firm of Harrington, Howard and Ash of Kansas City. In June 1929, a 12-ft. section of the deck failed; between 1940 and 1952, 207 patches ranging between 3 ft. by 5 ft. and 8 ft by 10 ft. were made and the deck surfaced with rock asphalt. A 1957 tabulation by the Expanded Shale Clay and Slate Institute listed some 35 bridges in this country and Canada as having used expanded shale aggregate prior to 1946, when the Hayde

patent expired. From 1946 to 1956, inclusive, 48 bridges are listed. Some are quite impressive structures, and the use of light-weight concrete decks on them should not, by any means, be adjudged as a reckless venture. More than half of those listed from 1946 were built in the Kansas, Nebraska, Missouri, Chicago and Cleveland areas where local natural aggregates are of notoriously poor quality for concrete.

In 1937, ASTM published a tentative specification for light-weight aggregates for concrete. It was adopted as a Standard in 1939 (ASTM C 130-39). The original and the 1942 revision thereof included a provision for soundness which is cited below:

"Light-weight aggregate, when subjected to five cycles of the accelerated sulfate soundness test, shall lose not more than 12 percent. . . in weight, provided, however, that an aggregate failing in this requirement may be accepted if it passes a satisfactory freeze-and-thaw test. The engineer may waive the soundness test requirement for light-weight aggregate for concrete not to be exposed to moisture."

In 1953, C 130-39 was replaced by C 330-53T (Light-weight Aggregate for Structural Concrete), C 331-53T (Light-weight Aggregate for Concrete Masonry Units), and C 332-54T (Light-weight Aggregates for Insulating Concrete). C 330 and C 331 both contained the following paragraph:

"In the absence of a proven record of satisfactory durability. . . , lightweight aggregates may be required to pass an accelerated soundness test or a concrete freezing and thawing test satisfactory to the purchaser."

Both C 330 and C 331 contained provisions regarding staining, drying shrinkage, tests for popout materials, and freezing and

thawing. C 330-53T (structural) contained provisions limiting the absorption and unit weights of concretes, thus:

<u>Avg. 28-Day Compr. Str. psi</u>	<u>Avg. Absorption Max. % by Vol.</u>	<u>Avg. Unit Weight Max.</u>
4000	15	115
3000	18	110
2000	21	105

The most recent revision, C 330-59T, deleted the limitation on absorption but retained the limitation on maximum allowable unit weights. Apparently the thinking behind this action was that the absorption necessarily varies inversely as the unit weight of concrete, and that the durability provision should govern. In other words, if the purchaser or engineer were satisfied by durability tests or service records, it would be rather immaterial as to the absorptivity of the concrete. However, this simply means that the engineer must seek the necessary confirmation of durability in spite of high absorptivity of light concrete.

Note: High absorptivity necessarily means a high volume of void, but a high volume of voids does not necessarily mean that the concrete would be highly absorptive. For instance, if the aggregate surfaces were water-proofed or if the concrete surfaces were water-proofed, no absorption could occur and no damage would result from freezing temperatures.

Thus, the problem reverts to the idea that water-proofness is, by and large, the key to durability.

Kentucky Department of Highways' Standard Specifications... (1956), articles 7.4.2. (Crushed Limestone), para. D (Concrete Aggregates)

provides for not more than 15% loss in sodium sulphate soundness test and not more than 40% loss in percent wear. These and other provisions are quality requirements used in lieu of freeze-thaw durability testing. Article 7.4.4 (Gravel), para. D (Gravel for Concrete) provides for not more than 35% wear and, in lieu of the sodium sulphate soundness, allows not more than 3% absorption (by wt.). This is in obvious conflict with the high absorptivity that would have to be allowed for light-weight aggregates.

Following the expiration of the Hayde patent, in 1946, an expanded shale (New Providence), light-weight aggregate plant was built near Shepherdsville, Kentucky, in 1953 by Kentucky Light Aggregates, Inc. (Kenlite), a division of the Ohio River Sand Company, Inc. In September, 1953, the Kentucky Department of Highways (Research Laboratory) initiated a rather comprehensive study, investigation and evaluation of the Kenlite aggregate in regard to the durability (freeze-thaw) of the concrete (Apparently, this was considered a necessary recourse in view of earlier experience in connection with the Paducah bridge). An intra-departmental report* was made in December 1954. The findings reported therein are

* Brown, C. M. Jr.; Strunk, L. H.; and Sawyer, D. H.; "Studies on the Suitability of Expanded Shale Aggregate for Use in Cement Concrete," Reports of the Highway Materials Research Laboratory, Vol. IX, 1954, p. 213; also Bulletin No. 38, Engineering Experiment Station, U. of Ky. 1955.

summarized below:

1. Compressive strengths approximately equal to that of comparable dense concrete mixes was obtained; however, flexural strengths were slightly lower.

2. Mixes made with saturated surface-dry aggregate and without air-entrainment had very poor resistance to freeze-thaw.
3. Mixes made with the S.S.D. aggregate and with air-entrainment gave significantly better performance in freeze-thaw.
4. Drying the concrete after the usual period of moist-curing and prior to the onset of freeze-thaw also improved durability.
5. Mixes made with wetted aggregate, not saturated, gave improved durability.

Note 1: The highest cement factor used in this series of tests was 5.75 sacks per cu. yd.

Note 2: The method of freeze-thaw testing was in close accordance with one of the methods specified in ASTM C 350-59T for evaluating the durability of concrete made with light-weight aggregate.

The research report has been criticised variously by producer interests. The main criticism is that it reflects unfavorably upon the durability of light-weight concrete; and this is quite true insofar as the concrete designed, mixed and cured according to the recognized practices of making normally dense concretes are concerned.

In 1954, in connection with work contracted by the Department to Katterjohn Concrete Products Company at Owensboro, involving pre-cast sections for 60 bridges, permission was obtained to cast four light-weight sections (1 curb-and-gutter and 3 filler sections). The cement factor was 7.5 sacks per cu. yd. The bridge (MP 8-130-1) containing these light-weight sections was erected June 23, 1955, on Ky. 18, 3 miles west of Florence, Kentucky*. Although it was

* Sawyer, D. H.; "Observations of the Manufacture and Placement of Prefabricated Bridge Sections . . .," Reports of the Highway Materials Research Laboratory, Vol. X, p. 291; 1955.

originally intended to leave the bridge completely exposed, the road was re-surfaced soon thereafter and the deck was surfaced also. Only the curb-section extending above and outside the deck remains exposed. An inspection of the exposed concrete, October 21, 1960, revealed no evidence of deterioration.

Similarly in 1957 (?) a pre-cast, pre-stressed bridge manufactured at Madisonville was erected on Brush Creek just off Ky. 15 near the Clark-Powell County line (MP 99-100-9). The details of the design are not known. This bridge was inspected July 12, 1960, by W. B. Drake. No popouts were observed; however, there were some broken edges and corners which were not attributable to weathering.

In 1956 (August) the curbs and sidewalk sections of the Hill St. (L & N) overpass on the North-South Expressway, Louisville, were constructed with Kenlite aggregate. The designed cement factor was 6.5 sacks per cu. yd., and designed water requirement was 8 gallons per sack of cement. The concrete was air-entrained. There are two parallel two-lane bridges, and presumably the inside curb and sidewalk sections, at least, are removable for the future addition of lanes. These bridges have been inspected from time-to-time in comparison to other structures on the X-way. It is somewhat surprising that the light-weight sections have few, if any, transverse cracks between joints while most of the normal concrete sections on the other bridges have cracks which extend completely through the section. Very few popouts were observed in the light-weight concrete. There were a couple of joints where corners were broken off and where the curbs were scored by the rims of truck wheels. The redish color of the expanded shale

is apparent; but there is no significant deterioration attributable to weather (at this time). Again in somewhat surprising contrast, the curb and gutter sections elsewhere on the Expressway are showing telltale signs of spalling and scaling due to salt and weathering, particularly along the curb elevations .

Note: These appear to be examples of entrained air having been dissipated by over-vibrations and over-finishing, etc.

The recent case histories within the state are not of sufficient age to provide very much re-assurance of long-time durability or to repudiate the performance of the Paducah bridge or the laboratory evaluations reported in 1953 and 1954. Elsewhere in the country, experience is much broader and appears to be equally as varied. It appears from the literature, in fact, that the Kentucky laboratory evaluations were the first critical study of the durability of expanded shale concrete to be published. Since 1954, the Portland Cement Association's Research Laboratory has made an extensive study which, in a manner of judgement, largely confirms the Kentucky report. Likewise, the Bureau of Public Road's Physical Research group has a study in progress which, from personal interview and a preview of their results, in no way conflicts with or refutes the findings of the Kentucky study. The Kentucky report implies that satisfactory durability can not be achieved by the normal mix-design and placement practices. The PCA report* implies that satisfactory durability can be achieved by special

* Klieger, Paul; and Hanson, J. A.; "Freezing and Thawing Tests of Light-Weight Aggregate Concrete," Tentative Report, presented, Annual Convention of ACI, March 14-17, 1960, New York.

design and placement practices. The special requirements were obvious in the Kentucky report. They are:

1. Air entrainment is essential
2. Near-dry (not saturated aggregate) is essential but complicates the control of mixing water.
3. Higher cement factors are required.

The Journal of the American Concrete Institute, May 1960, p. 15, summarized the PCA report as follows (in part):

"The results of these tests indicate the necessity for providing intentionally entrained air to attain a high level of durability, the importance of the moisture content of the aggregate, and the influence of strength level, i. e., water cement ratio on the durability. The results point to the desirability of evaluating a light-weight aggregate by means of laboratory freezing and thawing tests of air-entrained concrete made with the aggregate, as is generally done for normal weight aggregate."

The Research Division has done this, the PCA has done this, and the BPR is doing it. There are no significant differences in the results obtained thus far. There are, however, differences in viewpoints as to what the results indicate. J. J. Shideler, Manager, Products and Applications Development Section, PCA, Research and Development Laboratories* is quoted, in part (complete copy attached hereto):

* Letter to Mr. E. D. Smith, Director of Bridges, Kentucky Department of Highways, dated Sept. 22, 1958.

"Results of laboratory tests indicate that the Kenlite aggregate would be satisfactory for bridge decks in the Louisville area."

Likewise, an inquiry to the BPR concerning the matter yielded the following statement of policy* (complete copy attached hereto):

* Communication 25-12; May 26, 1960; from Mr. Harold Allen to Mr. R. H. Harrison.

"In his letter of May 11 to Mr. Cobb, Mr. Drake inquired of our policy regarding the use of lightweight aggregates in concrete subjected to freezing. As a general rule, we have recommended to the Office of Engineering that approval be given to the use of lightweight aggregates when requested by a State. Usually, State Specifications refer to ASTM Specification C 330 for grading and unit weight of the aggregate and do not include a requirement for durability in a freezing and thawing test. Until we have sufficient information that indicates the need for a durability requirement we shall continue to recommend approval of expanded shale lightweight aggregates in concretes for both mild and severe exposures."

In view of all the items discussed, the following is a summary of the factors involved in the use of light-weight aggregate in concrete exposed to freeze-and-thaw weather conditions:

1. Higher cement factors, entrained air, and the use of unsaturated aggregate, together can yield concrete more nearly equal to normal concrete in durability. However, these same provisions (higher cement factor) would likewise enhance the durability of normal concretes or otherwise compensate for an inferior aggregate. Heretofore durability of concretes have been evaluated at the cement factors necessary to achieve design-structural strength, and it has not heretofore been considered a justifiable practice to resort to higher cement factor in order to use a poor quality aggregate (gravels, cherts, sandstones and shales might be improved by this means also). Higher cement factors may become necessary as one means of increasing the resistance of so-called normal concretes (bridges) to de-icing salts -- either this alone or in combination with water-proof coatings.

2. The use of unsaturated, highly porous, aggregate introduces difficulties into the design and control of mixes. The absorption of the expanded shale aggregate is about 10% (by wt. of dry aggregate). If the aggregate is delivered to the mixer in a dampened condition (not saturated), a certain amount of mix-water will be absorbed during mixing, placing and initial setting. The amount of this absorption must be estimated beforehand and added to the net mixing water. If this absorption does not proceed according to the extent and rate expected, the concrete may stiffen unexpectedly or otherwise be soupy. Thus, precise calculations of yield, etc. may be difficult.
3. Excessive vibration or floating during placement and finishing may cause the aggregate (which is lighter) to float to the top (segregate) and make finishing difficult.

Note: Aggregate in normal concrete tends to sink, and mortar rises to the top.

4. Experience elsewhere has not disclosed any tendency for light-weight concrete to abrade or wear excessively under traffic.

BUREAU OF PUBLIC ROADS

Mr. Robert H. Harrison
Regional Engineer, Chicago, Ill.

May 26, 1960

Harold Allen, Chief, Division of Physical Research
25-12 Washington 25, D. C.

Durability of Expanded Shale Aggregate

Reference is made to your memorandum of May 18 to Mr. E. H. Holmes that requested information on our freezing and thawing tests of expanded shale lightweight aggregates.

Our durability tests are being made on 3 by 4 by 16-inch concrete beams of 6- or 8-bag cement content. The lightweight aggregates include 13 expanded shales and two slags. The concretes are being frozen in water or air in conformance with ASTM Methods C 290 or C 291. Control concretes of the same cement contents, prepared with natural fine and coarse aggregates, are being frozen with the lightweight aggregate beams. All concretes contain from 5 to 9 percent total air.

Our freezing and thawing tests on lightweight concretes have not been completed, and we prefer not to release any of the results obtained to a State until all tests have been made, including check tests. The results obtained to date have shown poor durability for some of the lightweight concretes. We must check these results not only with respect to our preparation of test specimens but also with respect to our conduct of the freezing and thawing tests.

In his letter of May 11 to Mr. Cobb, Mr. Drake inquired of our policy regarding the use of lightweight aggregates in concrete subjected to freezing. As a general rule, we have recommended to the Office of Engineering that approval be given to the use of lightweight aggregates when requested by a State. Usually, State specifications refer to ASTM Specification C 330 for grading and unit weight of the aggregate and do not include a requirement for durability in a freezing and thawing test. Until we have sufficient information that indicates the need for a durability requirement, we shall continue to recommend approval of expanded shale lightweight aggregates in concretes for both mild and severe weather exposures.

A paper "Freeze-Thaw Resistance of Concrete Made with Lightweight Aggregates" was presented by Mr. Paul Klieger of the Portland Cement Association, at the annual meeting of the American Concrete Institute in March 1960. Copies of this paper should be available on request to Mr. Klieger.

C
O
P
Y

PORTLAND CEMENT ASSOCIATION
Research and Development Laboratories
5420 Old Orchard Road
Skokie, Illinois

September 22, 1958

E. D. Smith
Director of Bridges
Department of Highways
Frankfort, Kentucky

C
O
P
Y

Dear Mr. Smith:

Your letter of September 10, requested information on the freezing and thawing durability and wear resistance of lightweight-aggregate concrete to be used for bridge decks. A "Bridge Deck Survey" published by the Expanded Shale, Clay and Slate Institute, National Press Building, Washington, D. C., describes the condition of about 60 bridge decks in which lightweight aggregate concretes have been used. If you have not read this report, I am sure it will be of considerable interest to you.

Our work with structural quality lightweight aggregate is summarized in the enclosed Bulletin D17. The principal conclusion from these tests is that concrete of very high quality can be made with many of the lightweight aggregates now commercially available.

The freezing and thawing resistance of lightweight-aggregate concrete has generally been regarded as very good, but the tests conducted at the University of Kentucky showed poor results with a particular aggregate. Our tests on freezing and thawing are nearing completion, but no data have been published.

I presume that one of the aggregates under consideration is Kenlite. This aggregate was not included in the study reported in Bulletin D17 but has been included in a program to investigate the freezing and thawing resistance of several lightweight-aggregate concretes. Aggregates were used in an air dry and saturated condition and the concretes were made with and without air entrainment. Strength loads of approximately 3000 and 4500 psi were obtained for each test condition.

Results of laboratory tests indicate that the Kenlite aggregate would be satisfactory for bridge decks in the Louisville area. However, air entrainment is an absolute essential, and it is desirable also that the aggregate be in less than a saturated condition at the time it is introduced into the mixer. These precautionary measures apply to most concretes but are particularly important for concrete containing Kenlite aggregate. The 4500 psi concrete containing 6 sacks of portland cement showed considerably better performance than the 3000 psi concrete. It might be wise to insist that at least 6 sacks of cement be used in the bridge concrete and that mixing water be kept to a minimum to assure a high quality concrete.

The Kenlite aggregate concrete appeared to be very workable and produced equal strengths at somewhat lower cement contents than most of the other aggregates.

Very truly yours,

JJS:gc

Joseph J. Shideler, Manager
Products & Applications
Development Section