Lightweight Concrete

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INFORMATION SHEET

EXPANDED SHALE CLAY AND SLATE INSTITUTE — ROCKVILLE, MARYLAND 20852

Fire Resistance of Expanded Shale Clay and Slate Structural Concrete Slabs

INTRODUCTION

Since the early part of the Nineteen Sixties, the Expanded Shale Clay and Slate Institute has been conducting floor slab fire tests designed to determine the relationship between slab thickness and fire endurance based on heat transmission through the slab. The work included pilot and full scale tests of structural lightweight concrete made with many different rotary kiln aggregates. This Information Sheet presents the results of these tests and brief discussions of related information, including the fire resistance values recognized by model building codes.

FIRE TESTING

Fire testing in the United States and Canada is conducted in accordance with the "Standard Methods of Fire Tests of Building Construction and Materials", ASTM Designation E119.

The purpose of this test method is to compare the fire resistance properties of materials and assemblies in order to classify walls, columns, floors, and other building elements under a common exposure condition. Building codes then specify minimum construction types, and fire resistance ratings, in an effort to provide constructions that are safe, that are not a menace to neighboring structures nor to the public, and that will offer reasonable protection to fire fighting personnel and equipment. If we think of fire ratings in the vein that the constructions should also offer protection to adjoining buildings and to the fire fighters, 3 and 4 hour ratings become logical.

ESCSI FIRE TESTING PROGRAM

CONCRETE PROPERTIES

Except for the two prestressed concrete elements (Tests 5 and 6) all concretes in Table 1 were proportioned for a 3000 psi deisgn strength with 3 to 4 inch slump and approximately 6 percent air entrainment. The cement contents ranged from 470 to 570 pounds of cement per cubic yard of concrete. For the prestressed concrete tests, the cement contents were higher to meet the higher design strengths.

About 36 percent of the tests were conducted on concrete specimens containing lightweight coarse aggregate and normal weight sand replacing all or part of the lightweight fine aggregate. The use of normal weight sand as the fine aggregate is typical practice for many parts of the United States and Canada. Table 1 lists the weights of the concretes used in these tests and indicates those containing normal weight sand replacement. In all cases the concretes with normal weight sand contained a minimum of 10 cubic feet by absolute volume of lightweight aggregate. Although no attempt has been made to determine the amount, these tests indicate that the replacement of lightweight fines with normal weight sand results in a reduction in fire endurance.

TEST METHODS

ASTM E119 was followed in all full scale tests with the floor slabs loaded to the prescribed superimposed loads. The pilot tests had surface areas of less than 180 ft^2 and were not tested with superimposed loads. In all cases the slabs were in equilibrium with a relative humidity of approximately 68 percent to 74 percent at the time of test. The end-point for all tests was determined by heat transmission through the slab.

RESULTS

The results of these investigations are presented in Table 1, and are plotted in Figure 1 according to type of fines (normal weight sand or lightweight) and type of test (full scale or pilot).

BUILDING CODE REQUIREMENTS

The three model building codes in the United States are the BOCA National Building Code (BOCA); the ICBO Uniform Building Code (UBC) and the SBCCI Standard Building Code (SBC). Each code lists (or references) the minimum concrete thicknesses required for a particular fire resistance rating, depending on the type of aggregate used in the concrete. These requirements are the same* for all three codes, and are listed in Table 2 and are plotted as curves in Figure 1 along with the actual fire test results on lightweight and sand-lightweight aggregate concrete. Earlier versions of this Information Sheet did not include model code requirements in Figure 1.

Note that the floors are tested in a horizontal position in ASTM E119, compared to an upright position for wall tests. In each test, the terminal temperature is reached across a concrete assembly, without structural failure, passage of flames, or the failure of the hose stream test. Wood or metal stud assemblies suffer structural compromise or failure. Fire insurance rates are therefore lower for concrete buildings, since the structure doesn't support combustion and normally survives the fire intact. Because the fire test results are similar for both horizontal and vertical constructions of monolithic concrete, the model codes require the same thickness for both concrete walls and for floors, assuming a given aggregate type and fire resistance rating.

FIRE RATINGS OF OTHER CONCRETE ASSEMBLIES

The ratings discussed above apply only to monolithic concrete slabs, and are not generally applicable to other concrete products such as concrete masonry, precast/prestressed single or double tees, or hollow-core concrete planks.

Concrete masonry is assigned a fire resistance rating by both the Underwriters Laboratories (UL) and by the model building codes based on the aggregate type and equivalent thickness of the concrete masonry unit. The UL requirements are more detailed, and in some cases more restrictive, than those found in the building codes, but UL classification is usually not required for acceptance by the model building codes.

*BOCA varies slightly for the 4 hour rating of siliceous aggregate concrete.

More information on concrete masonry fire ratings is contained in the Institute's Lightweight Concrete Information Sheet No. 14, "Fire Resistance of Expanded Shale, Clay and Slate Concrete Masonry," as well as the National Concrete Masonry Association's TEK 35C, "Fire Safety With Concrete Masonry."

Manufacturers of concrete products such as single and double tees and hollow-core concrete plank usually have their products "classified" by Underwriters Laboratories, Inc. (UL). UL publishes an annual Fire Resistance Directory which lists the producer's names and the specifications for their concrete products which have the assigned fire resistance ratings.

UL's Fire Resistance Directory also lists a large number of lightweight and normal-weight concrete floor assemblies which have been tested and assigned a fire resistance rating. These assemblies are typically concrete floors in steel frame buildings, where the assembly tested would include the concrete poured on ribbed metal decking supported by steel beams or bar joists. Because there are many possible combinations of trench headers, suspended ceilings, spray-on fire proofing, etc., each unique assembly is fire tested and assigned its own fire resistance rating.

When lightweight concrete is poured in a 1½ inch thickness on wood joist floors, fire ratings of one hour or more are normally achieved, depending on the thickness of the gypsum wallboard typically used as the bottom layer(s) of the floor assembly. These designs are not listed in the UL Fire Resistance Directory, but generic lightweight concrete is included in several floor-ceiling designs listed in the Fire Resistance Design Manual published by the Gypsum Association.

There are several other sources of fire ratings on generic concrete products and assemblies. The American Insurance Services Group, Inc. has a publication called "Fire Resistance Ratings" which lists the fire rating achieved by numerous beam, column, floor-ceiling and wall assemblies. There are also ratings published by the Prestressed Concrete Institute, Portland Cement Association, and the Concrete Reinforcing Steel Institute.

CALCULATED FIRE ENDURANCE

Model building codes allow analytical calculation methods to be used to determine the fire endurance of homogeneous concrete with a complex cross-section and also multi-wythe walls that contain concrete or concrete products.

Much more detailed information concerning fire testing, code requirements, and analytical calculations is contained in Fire Protection Planning Report No. 13, "Analytical Methods of Determining Fire Endurance of Concrete & Masonry Members - Model Code Approved Procedures," published by the Concrete & Masonry Industry Fire Safety Committee.

FIRE TESTING AND FIRE RATING AGENCIES

Some confusion seems to exist as to the role of various organizations in the testing of assemblies and the recommendation of fire ratings.

The function of the Underwriters' Laboratories, Inc., with offices and testing stations in Northbrook, Illinois; Melville, Long Island, New York; Santa Clara, California; and Tampa, Florida, seems to be frequently misunderstood. This organization's primary function is to examine and test materials and assemblies to determine if they comply with applicable safety standards. A fire resistant assembly is tested in accordance with ASTM E119. As a result of this test, an assembly meeting the stipulated specifications within close tolerances is given a specific fire resistance rating.

Some of the individual products used in the assembly are "classified" by UL for use in the assembly and must bear a UL classification marking and be subject to inspection under UL's follow-up service if the assembly is to maintain a fire resistance rating recognized by UL. (Everyone is familiar with the UL label on electrical wiring and equipment).

Products that are normally "classified" include precast/prestressed concrete tees, concrete masonry units, metal decking for use in steel building floors, and spray-on fireproofing. Generally, normal weight or lightweight structural concrete is not "classified" by UL; rather, aggregate type and concrete performance are specified on a generic basis.

The UL of Canada functions in a similar manner.

The UL does not base its opinion on tests by other laboratories but such test data are used to supplement its own findings.

The American Insurance Services Group, Inc., (AISG), formerly the American Insurance Association, does not conduct fire tests. AISG analyzes fire test data from all sources and recommends fire resistance ratings. In addition to ratings based on tests AISG will recommend estimated ratings from analyses of several fire tests.

The National Fire Protection Association (NFPA) has compiled fire studies from all sources and publishes generally accepted ratings together with a vast amount of valuable fire protection information in its "Fire Protection Handbook."

Among the laboratories equipped to conduct fire tests in accordance with ASTM E119 are the National Research Council of Canada (NRCC), National Institute of Standards and Technology (NIST), formerly National Bureau of Standards (NBS), Ohio State University (OSU), and the Construction Technology Laboratories of the Portland Cement Association (CTL-PCA), in addition to the Underwriters' Laboratories.

The model building codes will either (1) list the properties of a material required for that material to achieve a certain fire resistance rating, (2) require fire testing of an assembly, or (3) allow calculation of its fire endurance based on approved analytical methods.

For example, a bare concrete slab falls under situation Number 1, where the codes specify that a lightweight concrete floor slab must be at least 3.6 inches thick to achieve a fire resistance rating of 2 hours.

If this same concrete is poured on metal decking in a steel framed building, the entire assembly would be fire tested by UL and the assembly's design number would be submitted to the building official as evidence of performance - this is situation Number 2.

In the third situation, the lightweight concrete may be part of a multi-wythe wall, which includes an inner layer of gypsum wallboard, a layer of lightweight concrete, a layer of insulation, and a layer of architectural masonry.

Although the assembly has never been fire tested, the model codes allow analytical calculation of the fire endurance using the properties of the individual materials which are well known. The above referenced Fire Protection Planning Report No. 13 contains more information on this subject.

The "Fire Rating Story" might be classified into four parts:

1. Classification Service: Underwriters' Laboratories, United States & Canada.
2. Fire Testing: UL, CTL-PCA, NRCC, NIST, OSU, etc.
3. Recommended Fire Ratings: AISG, NFPA, NIST.
4. Fire Rating Requirements: The model building codes.

(There has been no attempt to list all of the laboratories or fire rating organizations and their complete functions in this paper. The main purpose has been to clarify the difference between UL and AISG. The mention of other groups has been to assist in the clarifications).

TABLE 1

STRUCTURAL LIGHTWEIGHT CONCRETE FLOOR SLAB FIRE TESTS

Test No.	Year	Lightweight Aggregate	Fine Aggregate	Slab Thickness (inches)	UNIT WEIGHT (pcf) Plastic	28 Days	Test	Time (min.)	Test Scale	File No.
1	1960	Z	LW	2.5	98.5	94.2		68	Pilot	
2	1960	Z	LW	5.0	98.5	94.2		262	Pilot	
3	1961	X	LW	2.5	104.8	99.8		55	Pilot	
4	1961	Z	LW	2.5	98.4	96.8		58	Pilot	
5	1961	X	NW	4.5		108.0*		190	Full	PCI-UL R4123-5-7-8
6	1962	Z	LW	4.0		95.0*		140	Full	PCI-UL R4123-9
7	1963	Z	LW	4.03		95.0*		141.75	Full	PCA S-14
8	1963	Z	LW	3.25		95.0*		82.5	Full	PCA S-15
9	1963	Z	LW	5.25	100.0	95.0*		304	Full	UL R-3746
10	1964	X	NW	3.0		107.8	106.4	79	Pilot	
11	1964	X	LW	3.0		97.8	96.2	88	Pilot	
12	1964	X	LW	2.5		97.5	96.5	68	Pilot	
13	1964	Y	NW	3.0	118.6	117.4	116.6	76	Pilot	
14	1964	Y	LW	3.0	110.0	107.7	106.0	97	Pilot	
15	1964	Y	NW	3.0	117.0	115.3	114.4	84	Pilot	
16	1964	Y	NW	2.5	119.0	118.0	116.0	47	Pilot	
17	1967	T	NW	2.0	117.6	114.0		41	Pilot	
18	1967	T	NW	5.18	117.6	114.0		222	Pilot	
19	1967	U	LW	2.0	86.0	79.0		61	Pilot	
20	1967	U	LW	3.46	86.0	79.0		165	Pilot	
21	1967	U	LW	5.0	86.0	79.0		368	Pilot	
22	1970	X	NW	2.3	109.0		106.0	41	Full	PCA S-46

LW = Lightweight Aggregate Fines NW = Natural (or manufactured) normal weight fine aggregates

*Estimated

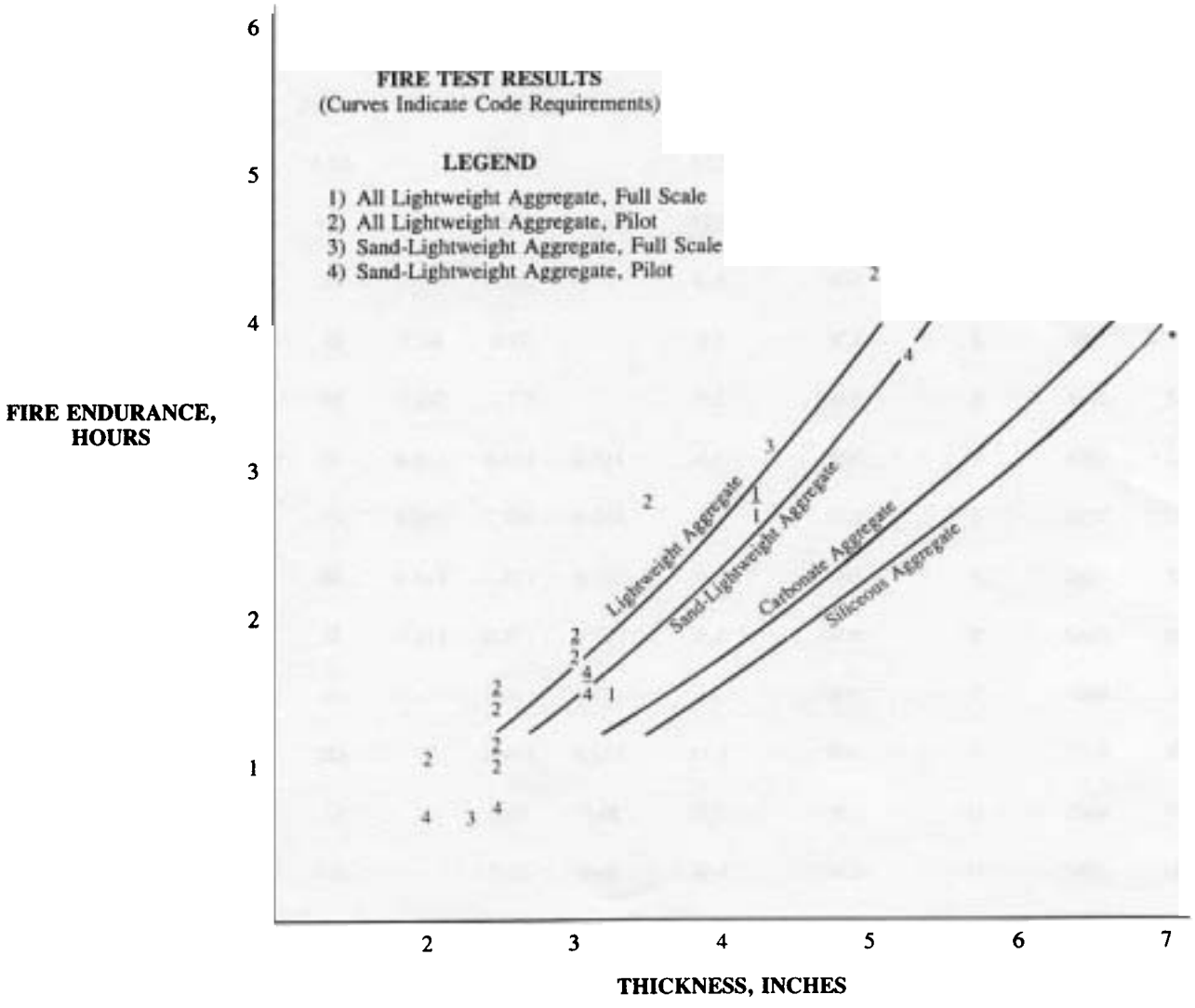
TABLE 2

BUILDING CODE REQUIREMENTS -
MINIMUM SLAB THICKNESS FOR CONCRETE FLOORS, ROOFS, OR WALLS

(Applicable to BOCA, SBC, and UBC)

CONCRETE TYPE	MINIMUM THICKNESS (INCHES) FOR FIRE-RESISTANCE RATING OF:				
	1 Hr.	1½ Hr.	2 Hr.	3 Hr.	4 Hr.
Siliceous	3.5	4.3	5.0	6.2	7.0*
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

FIGURE 1



*Note: For Walls (but not floor/ceilings), BOCA requires, by reference, an approximate 7. inch thickness for a 4 hour rating when using siliceous aggregate.