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The fire endurance of concrete masonry walls depends primarily on the aggregate used and the amount of solid per unit area of the wall. In the National Building Code of Canada, concretes are classified as types S, N, or L, according to the fire endurance characteristics of the aggregate.

The assumption that fire endurance is directly related to the amount of solid material present in the units is sufficiently accurate for most practical applications. It is understandable, therefore, that the concept of using "equivalent thickness" to correlate the results of fire tests has been widely adopted.

The equivalent thickness of a hollow masonry unit is usually defined as the product of the over-all thickness of a unit and the ratio of its net volume to its gross volume. The over-all thickness and gross volume can be determined from simple measurements. Determining the net volume, however, may often present some difficulties.

Methods of Determining the Net Volume of Units

There are several methods by which the net volume of a hollow masonry unit can be determined. A brief summary of these follows.

(a) The method described in ASTM C140-65T "Standard Methods of Sampling and Testing Concrete Masonry Units."

(b) A method essentially the same as above, except that the tests are performed on units the surfaces of which are covered with some impermeable coating (e. g. wax) to prevent water from entering the pores of the concrete.

(c) By determining the volume of cavities using the technique described in ASTM Designation D2167-66 (ASTM Standards, Vol. 11, 1970) for the in situ measurement of soil density.

(d) By determining the net volume of cavities using, instead of water, some 'pseudo-liquid' that does not enter the pores (e.g. natural sand, lead shot).

(e) By calculations based on actual measurements of the unit or taken from a drawing of the unit or of the mold.

The agreement between results obtained by various methods is sometimes no better than ± 10 percent.

The most widely recognized and accepted method in Canada for determining net volume of hollow masonry units is that described in ASTM C140-65T. Since this method is recommended in Supplement No. 2 to the National Building Code of Canada, it has been used by the Fire Research Section of the Division of Building Research in a comprehensive study of the fire endurance of concrete masonry constructions.

The ASTM C140-65T method is basically a water immersion technique. Although it is generally considered to be reliable, it may yield grossly erroneous results in the case of lightweight concretes of rough pore structure and surface texture. For such concretes a certain amount of the pore water (water that has penetrated into the pores of the concrete during a 24-hr period specified by the test) leaks out from the unit as it is removed from water and allowed to drain. Because of this loss of water the equivalent thickness determined by this method is less than the actual thickness obtained by calculation based on the geometry of the unit (1). In principle this problem can be eliminated by covering the external surfaces of units with an impermeable coating thus preventing the penetration of water into the open pored surfaces. Although a number of suitable 'sealant' materials are commercially available, it is difficult to apply them in reliably continuous layers. Even small imperfections in the continuity of the coat may permit seepage of water into pores and adversely affect the result.

The use of a non-penetrating liquid having a high contact angle with concrete has also been considered. Unfortunately, the high cost of liquids of this nature, e.g. mercury, would make their use impractical.

ASTM designation D2167-66 "Standard Method of Test for Density of Soil in Place by the Rubber-Balloon-Method" has also been suggested as a possible technique for determining core volumes of hollow masonry units. With this method a calibrated vessel is used which contains a liquid within a relatively thin, flexible elastic membrane. This vessel is placed over the cavity and the flexible membrane, inflated by the presence of water, is positioned snugly into the cavity whose volume is to be determined. The weight of liquid required to completely fill the cavity is given by the calibrated vessel.

Bulk granular materials consisting of particles of high sphericity such as some sands, lead or steel shot are suitable for determining the volume of cavities of hollow masonry units. Any such pseudo-liquid selected must meet two requirements: (a) it must have a fairly well reproducible bulk density, at least under some specified conditions, and (b) its bulk density must be insensitive to changes in humidity and the technique of application.

At the Division of Building Research No. 10 lead shot (diameter = 0.07 in., bulk density 0.24 $lb/in.^3$) has been used. Three techniques of application were examined in determining its bulk density: scooping, pouring and tamping. The differences in the bulk density of the shot obtained with these procedures were quite moderate. Its high and fairly well reproducible bulk density, and its insensitivity to the moisture conditions of the atmosphere, seem to make lead shot an ideal pseudo-liquid for volume measurements.

Clean, dry, free-flowing sand of specified gradation may be used in lieu of lead shot. Preference should be given to sands with negligible bulking factors and with fairly uniform particle sizes.

The advantages of using water or some pseudo-liquid for cavity volume determinations are especially obvious if one considers that the cavities are, in general, of grossly irregular shape. Although the manufacturers of concrete block machinery and of the associated moulding equipment are sometimes able to provide detailed drawings of unit masonry molds, calculating the cavity volumes from these drawings is generally very time-consuming. It is understandable, therefore, that the method of obtaining the volume of cavities by calculation has not gained widespread acceptance.

Comparison of Results Obtained by Three Methods

As mentioned earlier, from among the several methods available for determining net volume of hollow masonry, until now only one has gained widespread acceptance, i. e. that described in ASTM C140-65T. It was of some interest, therefore, to compare this "standard" method with two other methods, namely the lead shot method of measuring cavity volumes, as described by Harmathy (1), and the calculation method.

When using the lead shot method, the following formulae apply:

$$\lambda = \ell \frac{V_n}{V}$$

where:

λ = equivalent thickness, in.

ℓ = overall thickness of unit, in.

V_n = net volume of the unit, in.^{3}

V = gross volume of unit, in.^{3}

The weight of the lead shot required to fill the cavities is W_f (lb). The total volume of cavities, V_c (in.^{3}), is

$$V_c = W_f/\rho_f$$

where ρ_f is the bulk density of the lead shot (0.24 lb/in.^{3}). The equivalent thickness is therefore given by

$$\lambda = \ell \frac{V-V_c}{V}$$

In Tables I and II values of equivalent thicknesses calculated using this method are compared with those determined by the procedures of ASTM C140-65T and by direct calculation. For most units the data indicate reasonable agreement in the equivalent thickness values obtained by the three methods. The agreement is very poor, however, for units made with expanded slag and expanded shale aggregates. The lower values obtained by the procedures of ASTM C140-65T clearly indicate the sensitivity of this method to pore structure and surface texture of the concrete.

Conclusions

Several methods have been suggested for determining the net volume of hollow concrete masonry units. Some work has been done to explore the degree of agreement in the values of equivalent thickness.

References

1. Harmathy, T. Z. and E. W. Oracheski. Equivalent thickness of concrete masonry units. National Research Council, Division of Building Research, BRN No. 71, 1970.

TABLE I

EQUIVALENT THICKNESS DATA FOR HOLLOW CONCRETE MASONRY UNITS

Nominal Thickness, in.	Aggregate Type	No. of Cores	V, in.^{3}	W_f, lb	V_c, in.^{3}	λ, in.	λ*, in.	λ**, in.
4	Siliceous	2	428.69	26.40	109.91	2.71	2.70	2.77
6	Siliceous	2	669.40	58.26	242.55	3.58	3.62	3.71
4	Calcareous	2	428.87	25.74	107.16	2.71	2.76	2.74
4	Calcareous	3	430.64	25.26	105.16	2.74	2.66	2.68
6	Calcareous	2	673.08	56.41	234.85	3.67	3.74	3.72
4	Slag	2	437.66	29.17	121.44	2.64	2.34	2.78
6	Slag	2	678.23	55.79	232.26	3.72	3.42	3.73
4	Shale	2	432.74	28.16	117.24	2.66	2.57	2.77
4	Shale	3	433.33	26.09	108.62	2.74	2.47	2.70
6	Shale	2	672.23	59.44	247.46	3.56	3.32	3.72
4	Clay	2	427.78	28.16	117.24	2.63	2.61	2.75
6	Clay	2	663.44	68.64	285.76	3.19	3.13	3.31
4	Pumice	2	424.39	24.42	101.66	2.74	2.70	2.74
6	Pumice	2	665.75	65.43	272.40	3.33	3.27	3.32

NOTE: $V_c = W_F/\rho_F$, where $\rho_F = 0.24$ lb/in.^{3}

λ* Determined by the procedures outlined in ASTM C140-65T.

λ** Determined by direct calculation.

TABLE II

EQUIVALENT THICKNESS DATA FOR SOLID CONCRETE MASONRY UNITS

Nominal Thickness, in.	Aggregate Type	V, $in.^3$	λ*, in.	λ** (=λ), in.
4	Siliceous	428.72	3.60	3.60
6	Siliceous	672.43	5.61	5.62
4	Calcareous	427.81	3.60	3.62
6	Calcareous	664.09	5.63	5.59
4	Slag	432.98	3.10	3.64
6	Slag	674.62	4.79	5.62
4	Shale	429.70	3.23	3.61
6	Shale	664.83	4.88	5.60
4	Clay	429.83	3.58	3.63
6	Clay	666.18	5.53	5.60
4	Pumice	432.78	3.51	3.65
6	Pumice	666.81	5.46	5.62

λ* Determined by the procedures outlined in ASTM C140-65T.

λ** Determined by direct calculation.