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VERMICULITE AS FIRE PROTECTION FOR STRUCTURAL STEEL

by

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Summary

Exfoliated vermiculite although a relatively new insulating material is now widely used where resistance to high temperatures is required. This note describes the use of the material to protect structural steel from the action of fire, a use in which its versatility is particularly well shown. The results are given in general terms based on fire resistance tests conforming with B.S. 476 on protected steel columns.

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Introduction

Vermiculite is a hydrated magnesium aluminium silicate, a micaceous mineral which expands to many times its original thickness when heated. It was first marketed commercially in its expanded or exfoliated form in the United States of America in 1915. Exfoliated vermiculite (frequently referred to as vermiculite) has shown its value as an insulating material, particularly for high temperatures, since its fusing temperature is 2460°F. Its combined water gives it an advantage in constructions required to resist fire and the material lends itself to a variety of methods of application.

A number of tests have been carried out to measure the fire resistance, as defined in B.S. 476, of various elements of structure in which the main part of the protection was provided by vermiculite. These tests were all made at the request of private firms and did not therefore form a connected series. This accounts for the lack of test data for the full range of fire resistance ratings recognized by B.S. 476. The test results have been supplemented with estimates of performance for those forms of construction in which the thickness of protection necessary for any given fire resistance can be obtained without difficulty in practice.

The versatility of vermiculite as a material for fire protection is best shown when used in conjunction with structural steel or aluminium alloy, and in these tests all the current methods of application except the loose fill are exemplified. Although the tests were concerned only with columns the methods of construction are, without exception, suitable for beams.

In every instance the sponsor of the test undertook the protection of the steel stanchion, selecting the grades of vermiculite and the proportion of binder in the mix most suitable for his purpose.

Description of specimens

(1) Steel stanchion

One size of steel stanchion was used throughout, an 8 in. x 6 in. x 35 lb. British Standard Beam, provided at the ends with cap and base plates. The ends were protected with special refractory concrete insulators, designed to suit the test furnace, giving an unprotected length of 9 ft. 11 in. to which the insulation was applied (see Figure 1). After erection of the stanchion the steel was cleaned by wire brushing and thermocouples for measuring its temperature were peened into the flanges at selected points in the height.

(2) Protective encasement

Two types of binder were used with the vermiculite, namely Portland cement and calcium sulphate plaster, and three methods of application were included: (1) by spray; (2) with precast blocks having a plaster finish; (3) by trowel on metal lath or board. A cross section of each test column is shown in Figure 2, the reference numbers being those given in the brief specifications below.

1. Sprayed application, following profile of section, to give an approximately uniform thickness of protection at all points. The material consisting of exfoliated vermiculite and Portland cement in the proportions of 7 : 1½ by volume with the addition of lime was applied in layers by a compressed air gun, building up the thickness to a nominal ⅝ in. The surface was left rough without screeding or floating and no accurate measurements of thickness could be made.

2. Sprayed application to give a rectangular section of solid vermiculite plaster. The column was first wrapped with hessian scrim and the spaces between the flanges filled with a mix consisting of 4 parts of exfoliated vermiculite to $1\frac{1}{2}$ parts of Portland cement by volume with 10 parts of foam. After this light weight filling had set the hessian was removed and the section built up to the required size by applying several spray coats of material of the same composition as for Test 1. The intended thickness of protection over the face and tips of the flanges was $1\frac{1}{2}$ in. The approximate overall finished size of the section was 11 in. x $8\frac{3}{4}$ in. with a variation in both dimensions of $\pm\frac{1}{4}$ in.

3. Encasement of vermiculite concrete blocks 2 in. thick with a rendering $\frac{5}{8}$ in. thick of plaster. The blocks were cast from a mix of exfoliated vermiculite and Portland cement in the proportions of 5 : 1 by volume. The blocks after maturing were placed in position round the stanchion with vermiculite/cement mortar in the joints and secured with 4 in. wood screws. A single strand of 18 S.W.G. was used as reinforcement in each horizontal joint and alternate vertical joints were staggered. When all the blocks had been placed the encasement was wrapped with hessian strip which was then coated with cement slurry. A coat of cement/lime/sand plaster was then applied $\frac{1}{2}$ in. thick and finished with a skim coat of neat gypsum plaster. The finished dimensions of the column were $13\frac{3}{8}$ in. x 11 7/16 in. $\pm$ 1/16 in.

4. Encasement of vermiculite concrete blocks 2 in. thick with a rendering nominally $\frac{5}{8}$ in. thick of vermiculite plaster. Blocks of the same size and composition as those used in Test 3 were used for this column, being fixed by screws in the same manner, but without mortar or reinforcement in the joints. As each course of blocks was fixed the spaces between the blocks and the stanchion were filled with slag wool. The plaster consisting of a carefully graded mix of exfoliated vermiculite/Portland cement/diatomite was supplied ready-mixed and applied after gauging with water direct to the blocks in two coats with a wrapping of light wire mesh between the coats. The finished overall size of the column was 13 in. x 11 1/16 in. $\pm$ 1/16 in.

5. Encasement of precast vermiculite concrete cladding 1 in. thick finished with a skim coat of plaster. The cladding consisted of sections of metal lath on which four panels of vermiculite/cement 1 in. thick were cast, the width of the panels (8 in., 6 in., 8 in. and 6 in.) enabling the steel stanchion to be encased completely when the cladding was wrapped around it and wired in position. A mortar of vermiculite/cement mortar was used to point the joints between the panels and for the horizontal joints between lengths of cladding. A finish of neat gypsum plaster $\frac{1}{8}$ in. - 3/16 in. thick was applied to the cladding.

6. Encasement of vermiculite/cement plaster 2 in. thick on metal lath. As the metal lath ($\frac{3}{8}$ in. mesh x 28 S.W.G.) was wired in position round the steel stanchion the spaces between the lath and stanchion were filled with slag wool. The rendering of ready-mixed plaster of the same composition as for Test 4, was applied in three coats, the first about 1 in. thick, the second about $\frac{7}{8}$ in. thick and the third $\frac{1}{8}$ in. - 3/16 in. thick. A light wire mesh was wrapped round the column and wired firmly in position before the third coat was applied. The final dimensions of the column varied from 12 in. to $12\frac{1}{8}$ in. by 10 in. to $10\frac{1}{4}$ in.

7. Encasement of vermiculite/gypsum plaster $1\frac{1}{2}$ in. thick on $\frac{3}{4}$ in. gypsum plank. The gypsum plank cut in strips to suit the depth and width of the steel section were fixed in position by means of 16 S.W.G. wire wrapped spirally at approximately $1\frac{1}{2}$ in. pitch.

Three undercoats, $\frac{1}{2}$ in., $\frac{3}{8}$ in. and $\frac{1}{2}$ in. thick respectively, were applied, with a wrapping of light wire mesh interposed between second and third coats, followed by a finish coat $\frac{1}{8}$ in. thick. The proportions by volume for the undercoats were retarded hemihydrate gypsum plaster (haired) 1 part : medium grist exfoliated vermiculite 2 parts, and for the finishing coat retarded hemihydrate gypsum plaster 1 part : fine grist exfoliated vermiculite $\frac{3}{4}$ part. The final dimensions of the column were $12\frac{1}{2}$ in. x $10\frac{1}{2}$ in. - 1/16 in. + 0 in.

Method of testing

The tests were conducted in accordance with B.S. 476 (1) which specifies the procedure for fire resistance testing. The columns were subjected on all sides to temperatures which increased with time as defined by the standard curve shown in Figure 3.

An axial load was applied to the column before the test and maintained constant throughout the heating period. The test was terminated either at the end of a predetermined time or when the column could no longer support the imposed load. The magnitude of the load depended on the edition of B.S. 476 current at the time of the test: the 1932 edition specified $1\frac{1}{2}$ times the design load, the 1953 edition the design load only. An additional condition of test in the 1932 edition which was omitted from the 1953 edition related to a water test which required that after heating periods of 2 hours or more the column should be subjected to a jet from a fire hose for 1 minute for each hour of fire test. Columns 1, 2, 3, 5 and 6 were tested under the 1932 conditions, columns 4 and 7 under the 1953 conditions. The requirement that a column shall be able to support the test load 48 hours after the test appears in both editions.

The equipment used for fire tests of columns is described in detail elsewhere (2). The design load for the column was calculated in accordance with B.S. 449 : 1948 for uncased struts, assuming the column to be restrained in position and direction at both ends.

In all the tests the temperature of the steel stanchion and its change of length were measured at intervals and observations were made of the general behaviour of the column.

Results of tests

The following table gives the results of the tests on the seven columns. In the last column of the table estimated times for the steel to reach a temperature of 550°C have been included, obtained by extrapolation from the plotted curves of mean steel temperature against time. Tests to collapse of steel columns with encasements which give no assistance to the steel in carrying the load, have shown that failure is unlikely to occur when the test load is equal to the design load until the mean temperature of the steel exceeds 550°C. A column in which the steel temperature is less than 550°C at the end of test is likely to support reapplication of the test load 48 hours later.

Table 1

Results of fire tests on protected columns

Column No.	Description of protection	Test load (tons)	Duration of test (F denotes failure)	Mean steel temperature at end of test (°C)	Estimated time for mean steel temperature to reach 550°C
			hr. min.		hr. min.
1	Sprayed vermiculite/cement thickness $\frac{3}{4}$ in. following profile of section.	93	1 - 00 (F)	480	1 - 11
2	Sprayed vermiculite/cement to give rectangular section with thickness of protection $1\frac{1}{2}$ in. Foamed fill in voids.	93	2 - 00	220	3 - 48
3	Vermiculite/cement blocks 2 in. thick finished with $\frac{5}{8}$ in. plaster.	93	3 - 00	315	4 - 00
4	Vermiculite/cement blocks 2 in. thick with finish of vermiculite plaster $\frac{5}{8}$ in. thick.	62	5 - 01 (F)	560	-
5	Precast vermiculite/cement 1 in. thick on metal lath, finished with skim coat of plaster.	93	2 - 00 (F)	450	2 - 18
6	Vermiculite/cement/diatomite plaster 2 in. thick on metal lath.	93	4 - 00	380	5 - 00
7	Vermiculite/gypsum plaster $1\frac{1}{2}$ in. thick on $\frac{3}{4}$ in. gypsum plank.	62	4 - 00	450	4 - 30

Discussion of results

In order to obtain a better comparison between the protections provided by the various encasements, the last column in Table 1 has been included to give the fire resistance of each column, measured by the time for the steel to reach a temperature of 550°C and with a test load equal to the design load as specified in B.S. 476 : 1953.

Although the tests were made only on columns, the results are applicable to steel beams. Comparative tests have shown that, with a given type and thickness of protection, the fire resistance of 10 in. x $4\frac{1}{2}$ in. x 25 lb. steel beam is not less than that of an 8 in. x 6 in. x 35 lb. steel stanchion.

From the results Table 2 has been prepared in which the fire resistance of columns with various encasements is given, as determined by the test of B.S. 476 : 1953, including some assessed ratings for those types of protection which were suited to computation by simple methods. Only columns 1, 2, 5 and 6 were in this category.

Table 2

Fire resistance of protected columns and beams

Construction	Thickness in inches necessary to give period when tested in accordance with B.S. 476 : 1953			
	4 hours	2 hours	1 hour	$\frac{1}{2}$ hour
Vermiculite spray following profile of section.		$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{2}$
Vermiculite spray giving solid rectangular encasement.	$1\frac{3}{4}$	$\frac{3}{4}$		
Vermiculite/cement blocks 2 in. thick finished with vermiculite or ordinary plaster of thickness.	$\frac{5}{8}$			
Precast vermiculite/cement on metal lath finished with skim coat of plaster., Thickness of slabs.	$2\frac{1}{2}$	1	$\frac{1}{2}$	
Trowelled application on metal lath of vermiculite/cement/diatomite plaster.	$1\frac{5}{8}$	$\frac{3}{4}$		
Trowelled application of vermiculite/gypsum plaster on $\frac{3}{4}$ in. gypsum plank.	$1\frac{1}{2}$			

References

(1) British Standard No. 476 : 1932. Definitions for the Fire Resistance etc. of Building Materials and Structures. British Standards Institution. British Standard No. 476 : 1953. Fire Tests on Building Materials and Structures. British Standards Institution.

(2) National Building Studies. Research Paper No. 12, Fire Tests on Structural Elements. H.M. Stationery Office, London, 1953.

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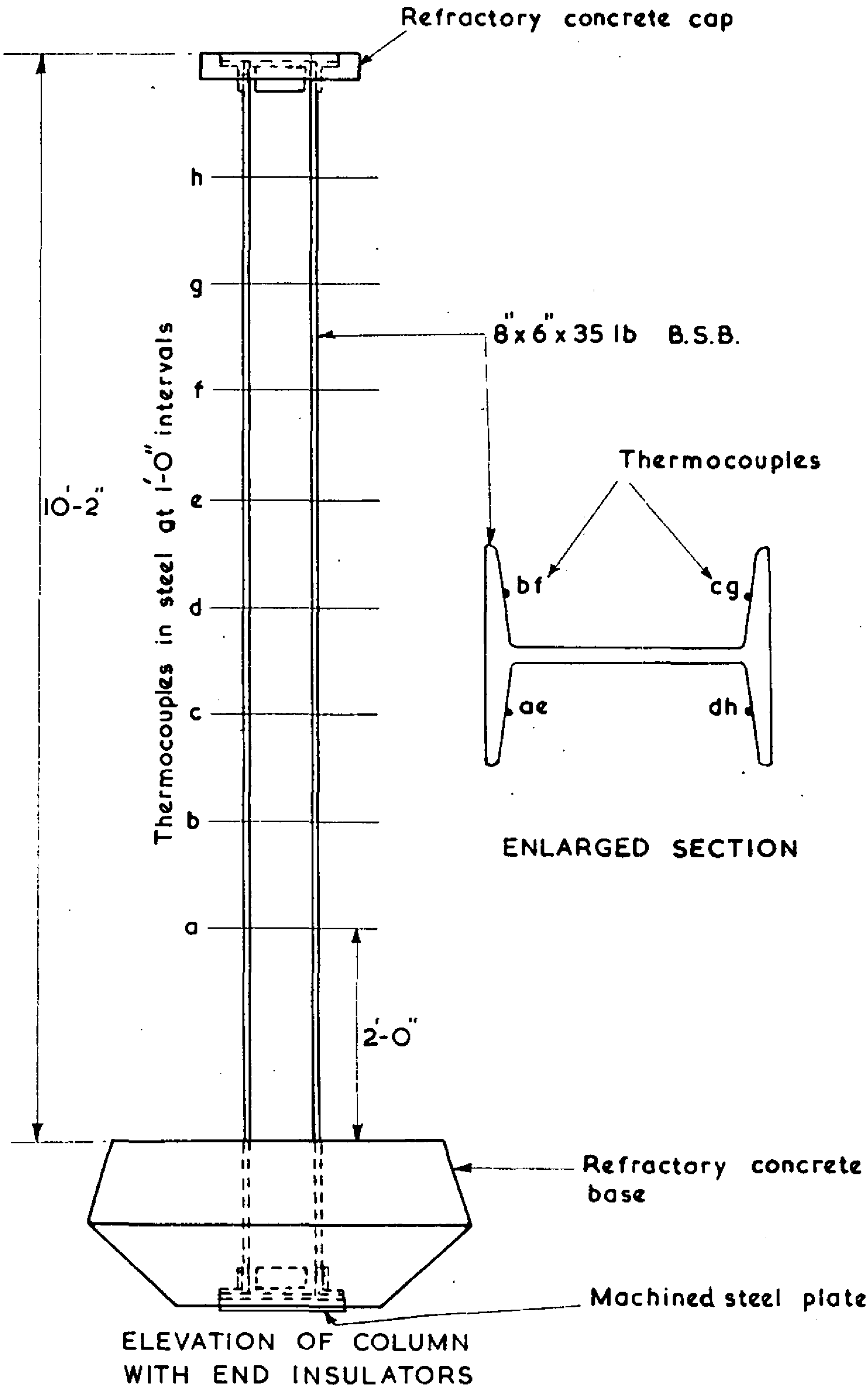
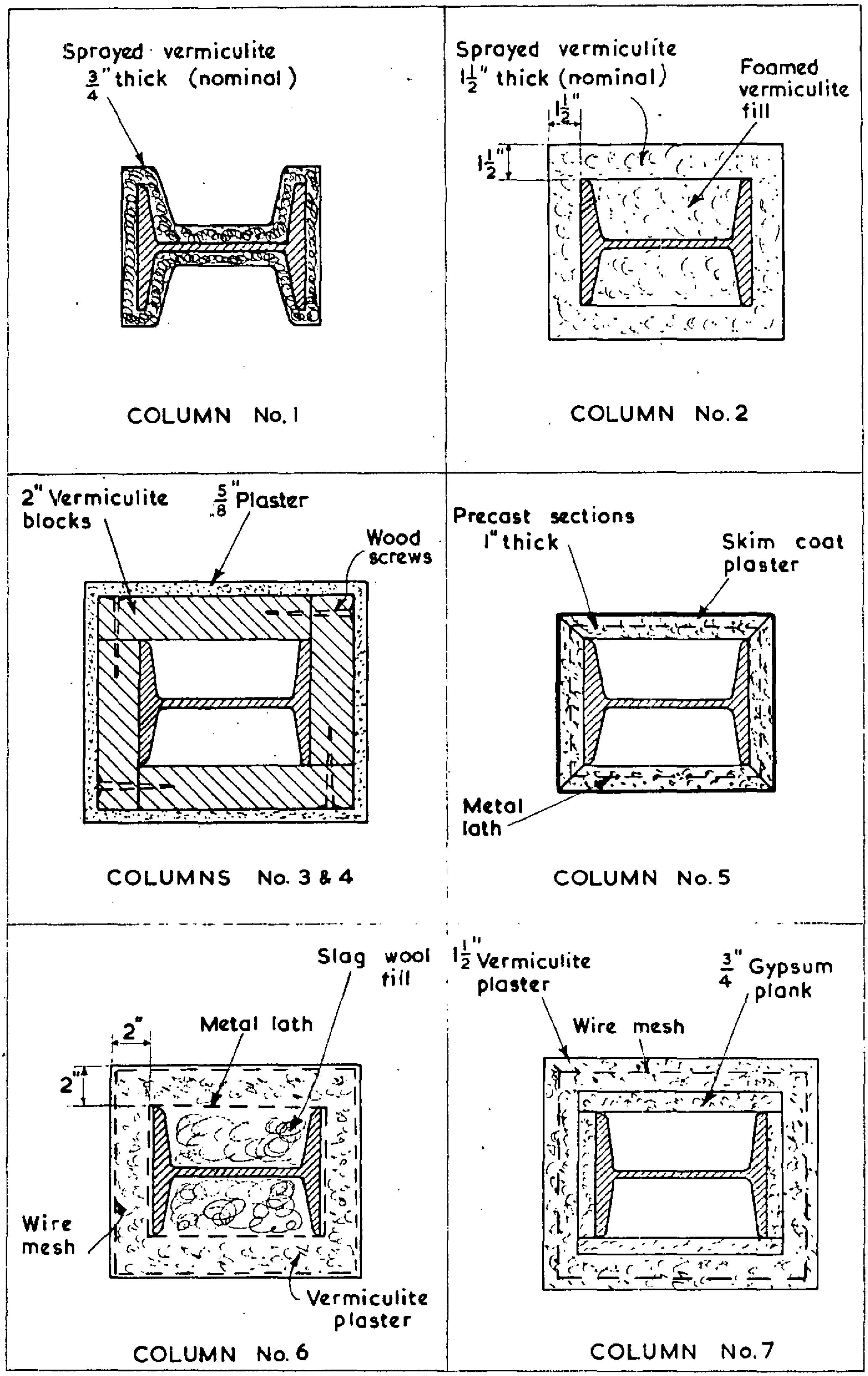


FIG. 1. STANDARD STEEL COLUMN FOR FIRE TEST



STEEL SECTION 8" X 6" X 35 lb. B.S.B. FOR EACH TEST

FIG. 2. CROSS SECTION OF ENCASED COLUMNS

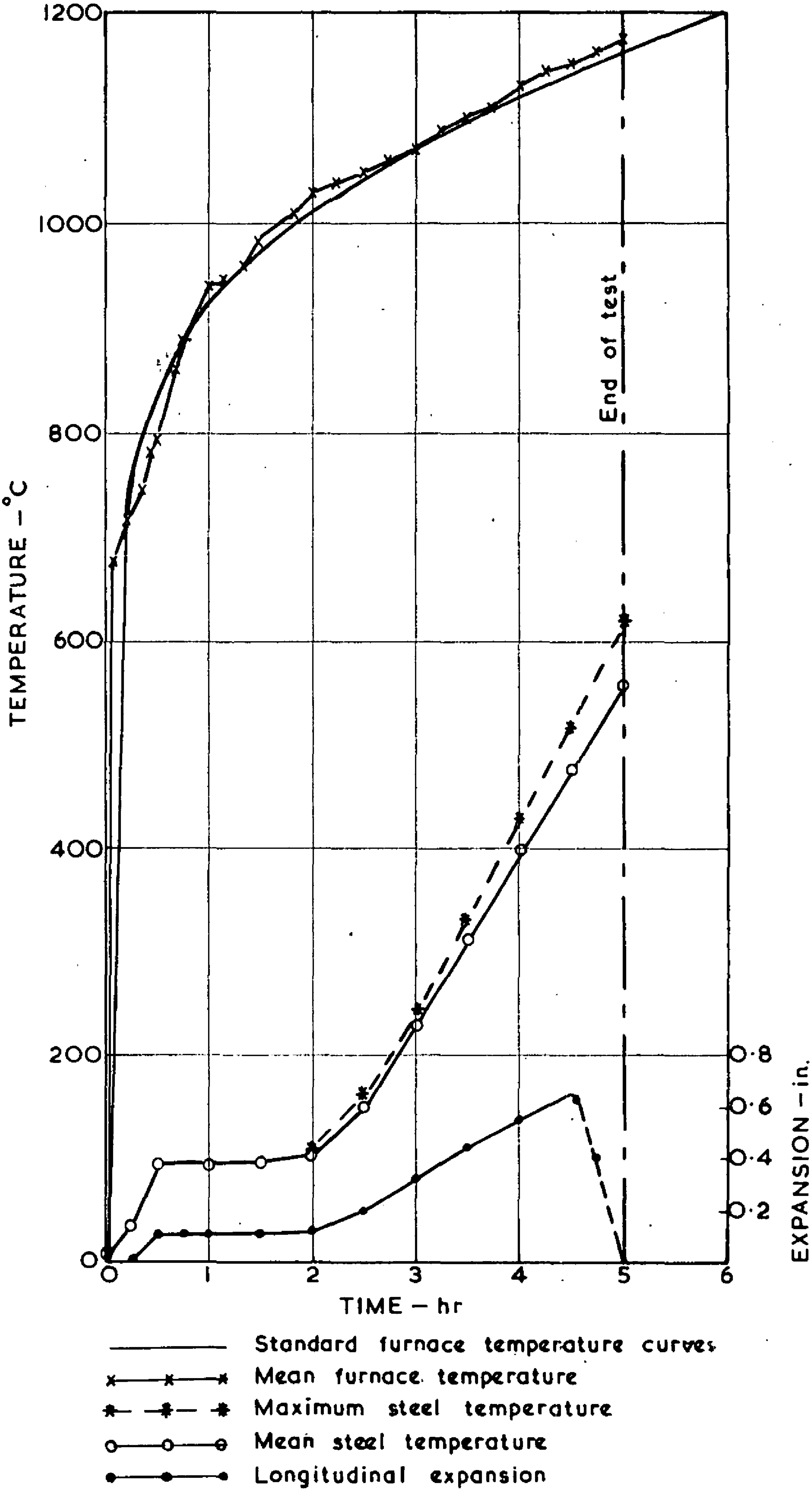


FIG.3. TYPICAL TEMPERATURE & EXPANSION CURVES

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