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TESTS OF THEATRE-PROSCENIUM CURTAINS

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ABSTRACT

Two types of steel curtains, four asbestos cloth curtains, and several kinds of asbestos cloth were subjected to fire tests. The single-ply wire-reinforced curtain of heavy asbestos cloth and the 2-ply curtain of plain asbestos cloth permitted the passage of smoke and flame during the test and glowed on the unexposed surface. Curtains made of two plies of wire-reinforced asbestos cloth separated by a steel frame afforded protection for about 15 minutes against a severe test fire. The steel curtains were tested for one half hour and gave indication of affording protection for somewhat longer periods. Suggested requirements for inclusion in building codes are available.

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I. INTRODUCTION

The theatre-proscenium curtain serves to close the opening through which the stage is viewed from the auditorium. Most cities require that such curtains be fire resistive because of occasional disasters resulting in great loss of life from fires on the stage. There is, however, great diversity in the requirements of city building codes with respect to the materials, construction, mounting, and operation of proscenium curtains. Even within the same city such curtains may cover a considerable range in these respects as was disclosed by surveys and inspections of several of the theatre-proscenium curtain installations in three cities. From these inspections the question arose as to what kinds of curtains would give the desired degree of protection to theatre audiences. The answer could be given, at least in part, from the results of tests; accordingly the tests reported herein were made.

Preliminary investigations indicated the desirability of making fire tests of as large sections of typical curtain constructions as feasible. The tests, therefore, were made by exposing one side of the curtains to fire in a large furnace used for fire tests of walls and partitions. The tests included two steel curtains and four asbestos cloth curtains. Effects of the fire exposure were visually observed during the progress of the test, and temperatures on the unexposed surface of the curtain as well as in the furnace were measured. Modifications of the equipment were made to study the behavior of the flexible asbestos cloth curtains when subjected to air pressure or both fire and pressure simultaneously.

II. FIRE TESTS OF CURTAINS

1. TESTING EQUIPMENT AND METHODS OF TESTING

The furnace, which accommodates panels 16 by 11 feet in size, is shown in plan and section in figure 1. Two blower fans produced the pressures within the furnace and the pull required to lower the curtains in the operating tests was measured by means of spring scales attached to the hauling cables. Temperatures were measured with base metal thermocouples, those on the surface of the curtains being covered with asbestos paper.

A schedule of heating was chosen to attain an average indicated furnace temperature of 1,700° F. at 15 minutes as compared with one hour specified by standard testing procedure [1] for most other classes of building construction. The choice was made because of the requirement specified by some cities that one side of such curtains must withstand a temperature of 2,000° F. (1,093° C.) for a given time without occurrence of temperature on the opposite side above some specified point, such as 350° F. (177° C.). The temperature rises were as indicated by figures 2 and 3, and it can be seen that those for the furnace were somewhat less than intended.

Two steel curtains, *A* and *B*, were subjected to fire tests for periods of 30 and 35½ minutes, respectively. The four asbestos cloth curtains were subjected for 15 minutes to fires of the intensity shown by the curves in figure 3. Three of them were also subjected to air pressure while exposed to fire.

[1] Tentative Standard Specification for Fire Tests of Building Construction and Materials, now before the American Standards Association for adoption as American Standard, 1933.

2. CURTAINS TESTED AND RESULTS

The curtain specimens were with one exception as large as the panel test frame of the furnace would accommodate. The sizes and general details of construction are given in table 1. The test specimens representative of steel theatre curtains were made as sections of actual curtain constructions. The asbestos cloth curtains were de-

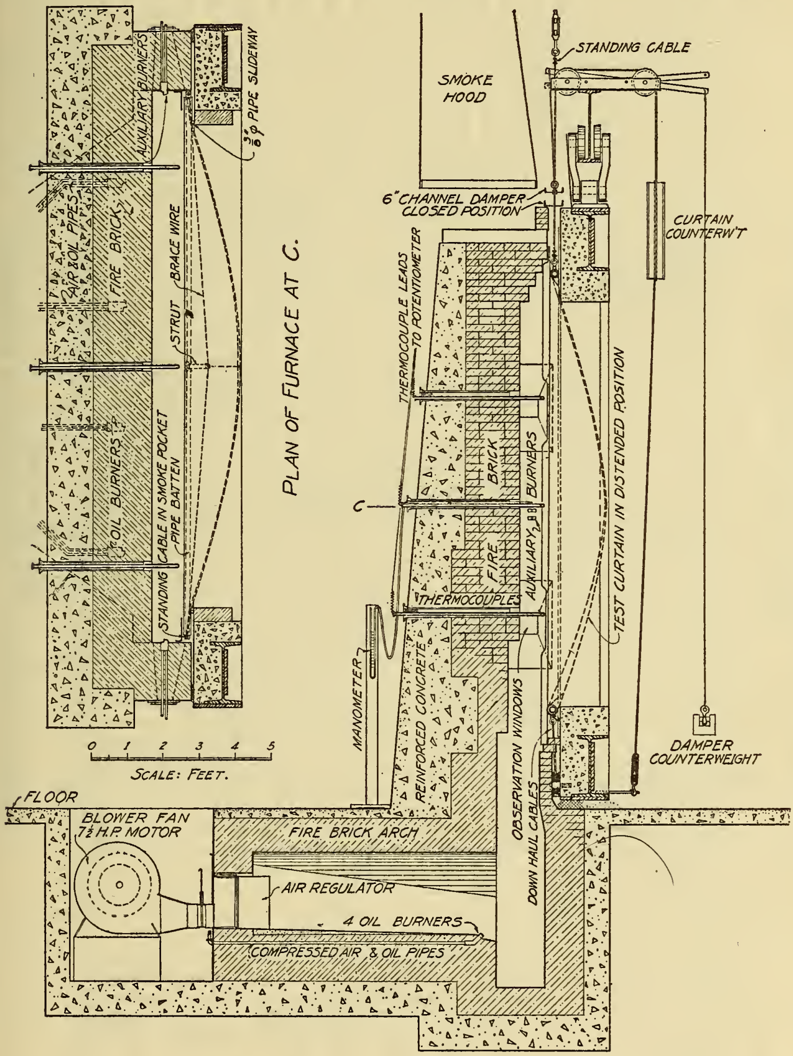

Figure 1.—*Vertical and plan sections of large panel furnace*

signed especially for these tests and were heavier and more substantial in every way than those usually installed in theatres. With one exception they had two thicknesses of cloth. Figures 4 to 9 also show some of the details of construction and the methods of mounting the curtains for the tests.

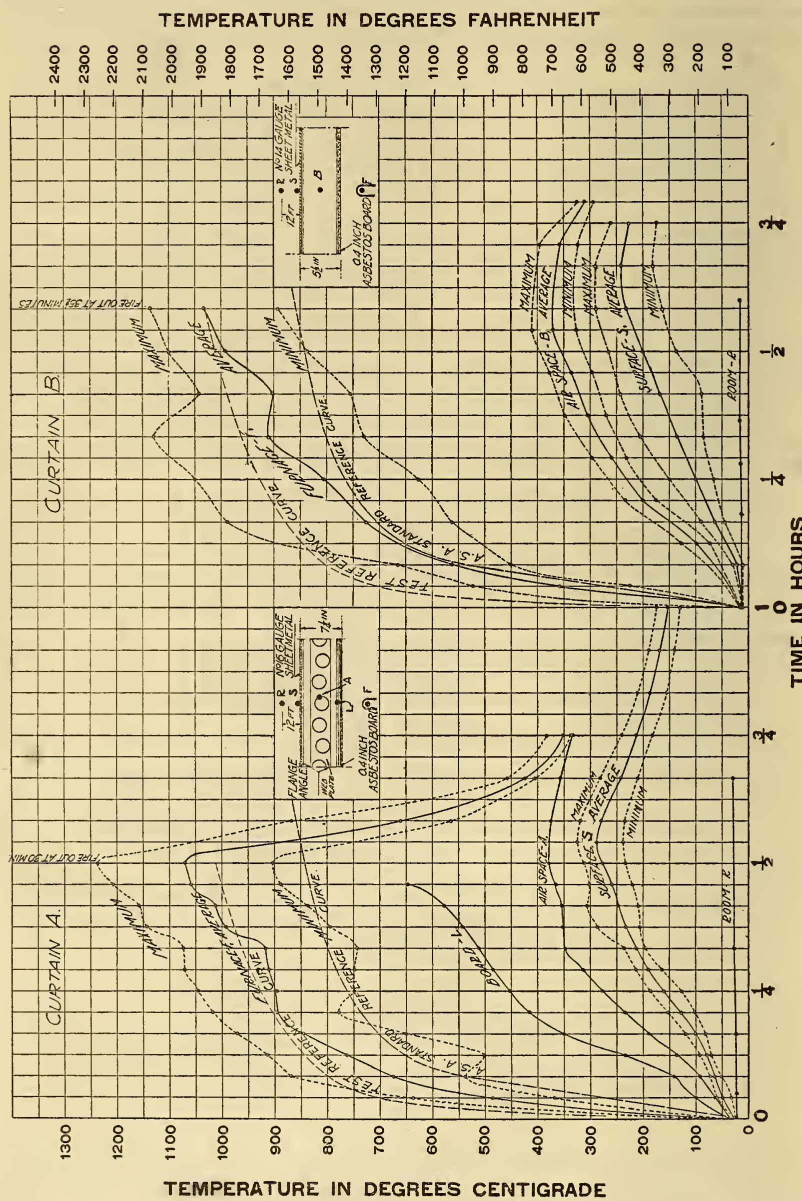

FIGURE 2.—*Temperature charts of fire tests of steel curtains*

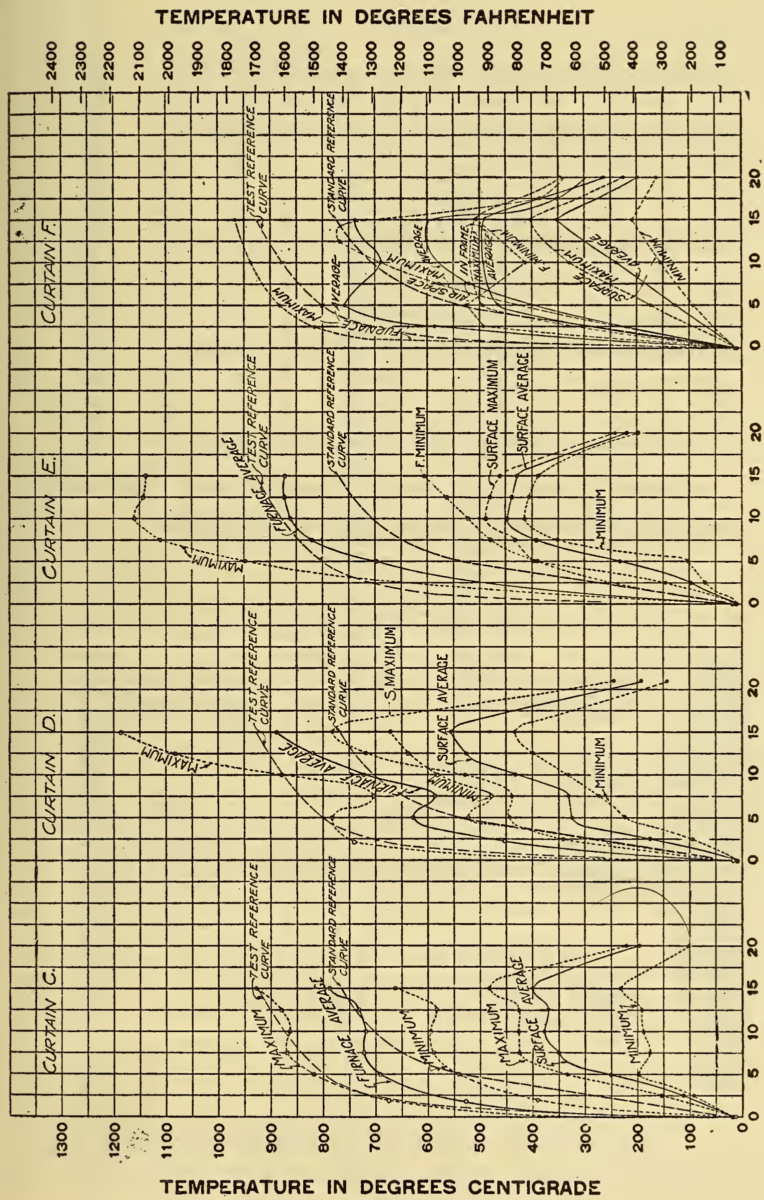

FIGURE 3.—*Temperature charts of fire tests of asbestos cloth curtains*

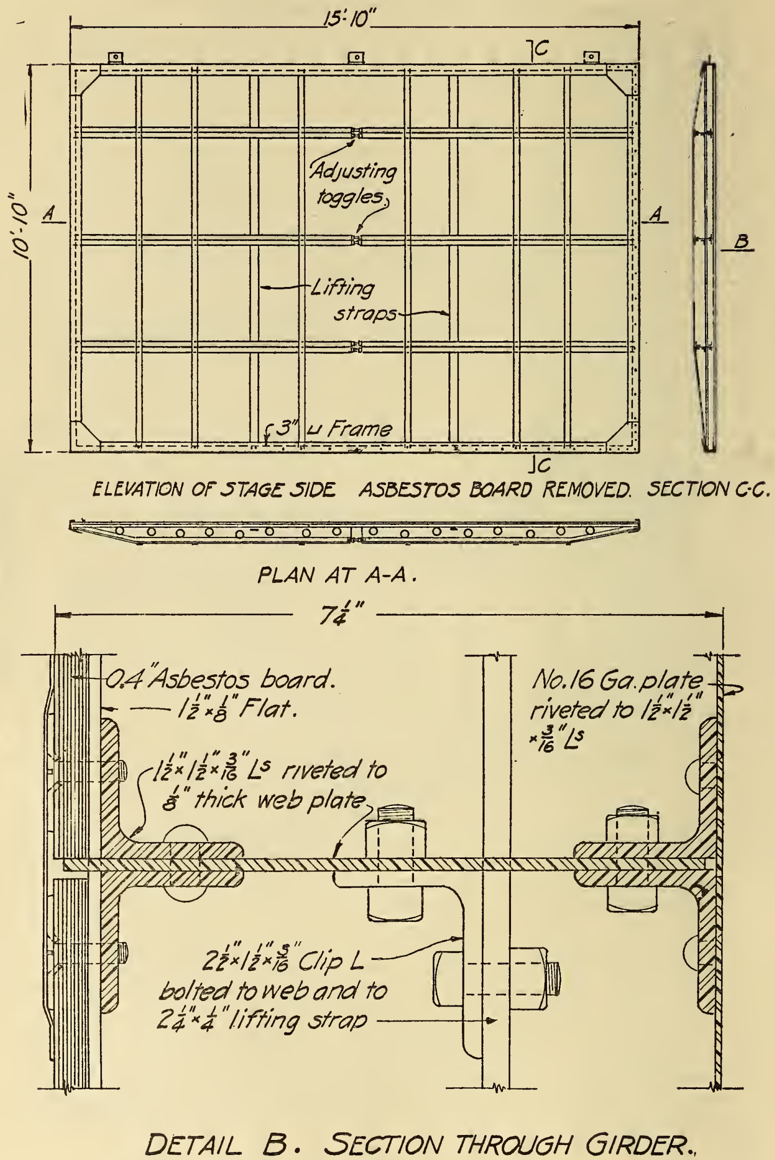

Figure 4.—*Elevation and details of steel curtain A, girder type*

TABLE 1.—*Details of test curtains*

Designation	Type of curtain	Size			Covering		General construction
		Width	Height	Thickness	Fire side	Unexposed side	
		Ft. in.	*Ft. in.*	*In.*			
A	Steel	15 10	10 10	7¼	0.4 inch thick asbestos millboard.	No. 16 gage steel plates	3-inch channel frame with 7-inch plate and angle girders placed horizontally.
B	do	9 0	6 0	5½	do	No. 14 gage steel plates	5 inches deep by 3 feet wide welded steel pans bolted together.
C	Flexible asbestos cloth curtain	16 6	12 0	¼	Single-ply plain asbestos cloth, 2.6 pounds per sq. yd.	Single-ply same as fireside	1¼-inch pipe battens top and bottom; three 5/16-inch diameter steel cables vertically between battens.
D	Flexible single ply asbestos cloth curtain.	16 6	12 0	⅛	Single ply of 4.6-pound asbestos cloth with Monel-Metal-wire reinforcement. Cables and battens covered with strips of cloth.		Do.
E	Semirigid 2-ply asbestos cloth curtain.	15 10	12 6	3¼	Asbestos cloth previously used in curtain *D*.	Single ply 3½-pound asbestos cloth with brass-wire reinforcement.	1¼-inch pipe across top, 5/16-inch cable in ½-inch pipe bottom batten. Sides, two 1½ by 1½ by 3/16-inch angles and one 4 by ⅛-inch plate.
F	do	15 4	12 0	3¼	Single ply 2¾-pound asbestos cloth with nickel-wire reinforcement.	Single ply 3¼-pound asbestos cloth with brass-wire reinforcement.	3-inch channel frame divided into 9 equal panels by 1¼-inch horizontal and vertical pipes.

Several factors other than heat transfer through the curtain by radiation and conduction influenced the results of the tests. Some of them were differences in pressure within the furnace chamber, the amount of combustibles in the fabric, or on the surfaces of the curtain, permeability to gases, and the closeness with which the edges of the curtain fitted the test frame.

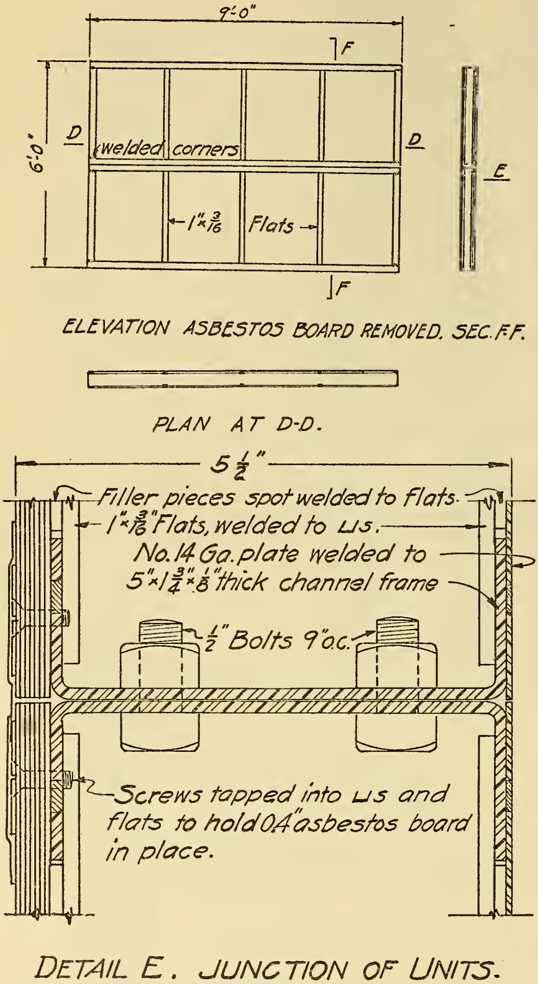

FIGURE 5.—*Details of steel curtain B, unit type.*

(a) CURTAIN A

This specimen curtain in all its essential details was like the full-sized curtains of this kind used in theatres. It consisted of a frame of 3-inch rolled channels and light plate and angle girders extending from side to side, with steel plates forming the face of the curtain and asbestos mill boards the back or stage side. The general structure of the test specimen is shown in figure 4.

There was excellent resistance to the passage of fire and smoke and no glow was visible on the front side of the curtain at any time during the test, notwithstanding some passage of flame around the edges and top of the curtain where the sheet metal fire stops warped out of place. The oil paint on the metal face of the curtain was charred black in some parts but during the test there was no appreciable amount of smoke.

During the test the curtain deflected a maximum of 1.94 inches towards the fire, equivalent to 7 inches center deflection in a 40-foot length, and there was local buckling of the faceplates. After the test the recovery of all parts to initial alignment was almost complete.

(b) CURTAIN B

This specimen consisted of two units such as are used to construct full-size curtains. The units were in the form of long pans, the edges of which were made of pressed steel channels welded to steel plates which formed the auditorium face of the curtain. The flanges of the channels next to the other face were connected by flat bars at intervals of 3 feet to tie the opposite sides of the pans together and to support the edges of the 0.4-inch-thick asbestos boards. The assembly of the test specimen and its principal details are shown in figure 5.

The bottom and vertical edges of the curtain as mounted in the 8-inch brick wall built within the test frame were protected by

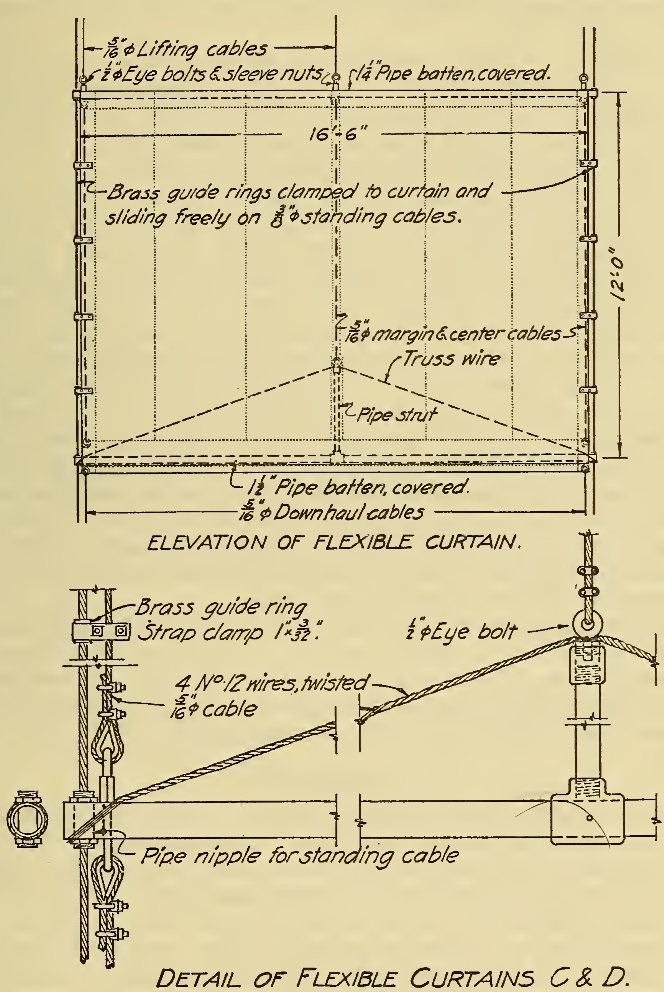

FIGURE 6.—*Details of asbestos cloth curtains C and D.*

mineral wool while the 1-inch space along the top was stopped by a sheet metal angle so that the top edge was exposed to the furnace fire.

Curtain *B* gave good performance in respect to holding back fire and heat and there was little local buckling of the face plates. The maximum center deflection in an 8-foot length was 0.3 inch, equivalent to 7½ inches in a 40-foot length. The recovery of the steel work from the deflections was as in the previous test, almost complete.

The asbestos boards on both curtains A and B buckled away from the fire at their centers, a few of them cracked, and all lost the greater part of their strength but remained in place during the test.

(c) CURTAIN C

This curtain was made of two separate curtains mounted on the pipe and cable frame shown in figure 6. The stitching twine was 3-ply asbestos reinforced with two no. 33 B. & S. gage brass wires. The seams joining the widths of cloth were double, the lap of the cloth being 1½ inches.

The priming or filler coat for the cloth-curtain decoration consisted of 1 part glue to 4 parts water with whiting and ocher added to give sufficient body. The coating was applied hot. The decorative coats were of 1 part glue to 9 parts water with equal parts of whiting and yellow ocher to give sufficient color body.

One minute after the fire test was started flames came around the sides of the curtain and under the bottom. From an initial pressure of approximately 1 lb./ft.^{2} the pressure within the furnace rose rapidly during the first part of the test due to fire; at three minutes it was 2¼ lb./ft.^{2} and at 6 minutes it had reached 2½ lb./ft.^{2} The cables attached to the bottom of the curtain had been made fast after the initial pressure from the fans had been applied with the top damper open. At 12 minutes after the start of the test with the damper still open, the force tending to lift the bottom batten as measured by the two dynamometers was 119 pounds. The pressure within the furnace at this time was approximately 2 lb./ft.^{2}. At 13 minutes after the start, because of the heat and strain, the cable holding the top right hand corner of the curtain broke allowing the batten to drop about 18 inches leaving an opening of about five square feet. This reduced the pressure to about ¾ lb./ft.^{2} and prevented application of additional pressure at the end of the fire test.

Soon after the start of the test the paint began to burn, giving off large volumes of black smoke, and at 11 minutes the surface of the cloth was glowing at the left side. When the curtain was removed from the furnace 3¾ hours after the close or the fire test the asbestos cloth was very brittle and broke along the sides, even with careful handling.

(d) CURTAIN D

Curtain D (fig. 6) was of the flexible type and consisted of a single-ply asbestos cloth with monel metal wire reinforcement. The mounting and paint were almost identical with that of curtain C. The wires trussing the bottom pipe batten were exposed to fire but all other portions of the cable and pipe framework for the curtain were covered with asbestos cloth. The total weight of the curtain and frame was 293 lb., 1.44 lb./ft.,^{2} the marginal members bringing the weight somewhat above the unit weights ordinarily encountered in practice.

Within a half minute after the start of the fire test, clouds of smoke came around the sides of the curtain and between the bottom batten and frame. The paint soon began to flake and fall off, the bare spots glowing briefly, probably because of the remaining combustibles. At 4½ minutes the paint had flaked off large areas of the curtain and the first steady glow of the curtain was observed at about five minutes. At 10½ minutes the curtain was glowing over about a third of its area and at 12 minutes more than half of the area was glowing brightly.

The glowing area increased until the end of the test. At 13 minutes 50 seconds the damper was closed and the pressure within the furnace increased to 4.1 lb./ft.^{2} without causing any breaks in the curtain. When pressure up to 3 lb./ft.^{2} was applied during the test, large quantities of gases and smoke leaked through the open mesh of the cloth.

Although this curtain had sufficient strength at the end of the fire test, the performance was in other respects not satisfactory. Dense smoke and glowing spots developed more quickly than with the double-ply curtain of plain asbestos cloth and the final glow was more pronounced.

(e) CURTAIN *E*

Curtain *E* had a frame of rigid members on the two vertical edges and the top and a comparatively flexible bottom member. The asbestos cloth curtain reinforced with monel-metal wire previously tested as curtain *E* was placed on the side to be exposed to fire. The unexposed side was of new asbestos cloth reinforced with brass wire. Details of the curtain are shown in figure 7. The side members, which consisted of two angles and a plate, were fitted with roller-bearing trolleys running in sheet metal tracks. The sizing and paint coats were of the same kind as used for the previous curtains, but had less glue in the priming coat. This curtain was designed and built after the two previously described had been tested with the object of overcoming their more serious defects.

During the first 1½ minutes of the fire test the damper at the top of the furnace was closed. This produced, with the single blower fan, a pressure of about 1½ lb./ft.^{2} While this pressure continued, smoke and flame were forced through an opening between the curtain and the frame at the lower left corner. At 2 minutes after the start of the fire the decorative paint was burning on the face of the curtain. There was not as much smoke from the glue in this paint as from that used in the previous tests nor was it dense, and at 5 minutes after the start the smoke was very much less in evidence than while the damper was closed.

The second fan was started at 8½ minutes and sounds were heard as of cloth tearing. At the center of the curtain glow was soon noticed, which increased slightly but covered only a small part near the center seam of the curtain. This curtain had only a marginal frame to keep the two plies of cloth apart and when subjected to the pressure from the fans, they were probably in contact near the middle. The cloth next to the fire was found, after the test, to have a tear about 30 inches long at the crease which had been made in folding the cloth after its removal from curtain *D*. If the new cloth had been used on both sides for this curtain it would undoubtedly have withstood the test better. Not only had a large part of the water of crystallization of the asbestos in the cloth on the fire side been driven off in the previous test, but the cloth was also more open to the passage of gases.

(f) CURTAIN *F*

The frame of curtain *F* was made of structural-steel shapes and pipes joined and trussed to form a relatively rigid structure on which were mounted the two plies of cloth (fig. 8). The seams were vertical and the plies were stretched tightly on the two sides and lapped around the edges of the frame to form an extra protection for the channel. While in actual installations asbestos cloth curtains having pipe frames of semirigid construction are mounted on I-beam tracks with ball-bearing trolleys attached to the sides of the frame, in the test the trolleys were replaced by guides cut from ⅜-inch steel plates. A

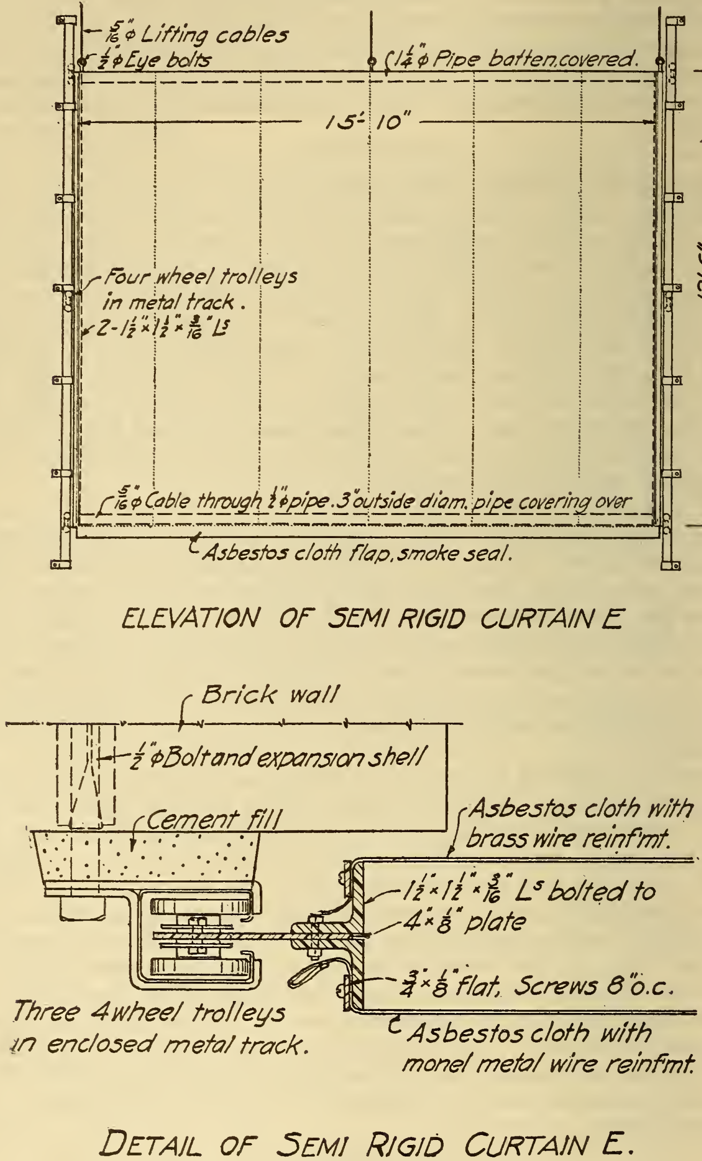

Figure 7.—*Details of curtain E.*

rigid type of frame mounted with sliding shoes on guide rails, resulting in less pull against the guides and proscenium wall than with the semirigid frame with the trolley mounting, is more generally used in recent installations.

FIGURE 9.—*Curtain F during fire test. Smoke leaking under bottom.*

The sizing and decorative coats were a casein and sodium silicate paint developed for the purpose because of the unsatisfactory behavior of the paints made with animal glue.

The fire test was conducted in the same manner as the others except that the air pressure was less. A small amount of smoke issued from under the lower left corner of the curtain at 1 minute 47 seconds after the start of the test because of a deficient bottom seal. At 1 minute 50 seconds the paint on the outer face of the curtain began to smoke and turn a reddish brown color and at 5¾ minutes (fig. 9) nearly all the surface was brown. The smoking of the face of the curtain was not serious but there was leakage of flame and smoke along more than half the length at the bottom. The rise of temperature of the furnace had been more rapid than for the previous tests of asbestos cloth curtains. At 8 minutes the smoking

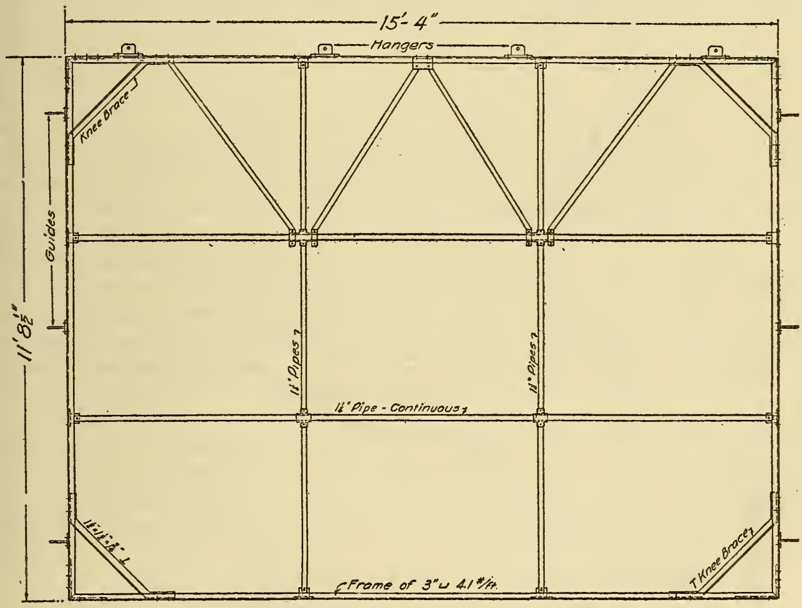

FIGURE 8.—*Details of the frame of curtain F.*

of the surface had ceased and within another minute there was no smoke coming under the curtain. At 9 minutes the flame was passing downward between the top of the curtain and the test frame, causing glow at this opening. At 12 minutes there was a slight glow in the lower right corner of the panel where the paint had not entirely filled the interstices in the cloth. At the end of the 15-minute test no more glow was visible than at 12 minutes. The expansion of the steel members sheared off the ½-inch diameter bolts and rivets fastening the ends of the guide rails and guard plates at the edges of the curtain. There was no passage of flame around the vertical edges of the curtain, but a better closure along the bottom and top than this curtain had during the test was indicated as desirable. The results with this curtain were better than those obtained with the three other asbestos curtains mainly because of the positive separation between the plies of the cloth, the better sealing of the vertical edges against the passage of flame, and the use of a decorative paint having only a small proportion of organic matter.

(g) COMPARATIVE PERFORMANCE

The resistance of the several curtains to the transmission of heat can be judged qualitatively by comparing the ratios of the rise of the average surface temperature during any period from the beginning to the average furnace temperature above its initial temperature maintained during thet period. The values of this ratio, *R*, for all six of the curtains have been plotted in figure 10. The difference between the curves for curtains *A* and *B* can be attributed largely to the exposure of the edges of curtain *A* to higher temperatures than was the case with the smaller curtain *B*. A part of the difference is probably due to the difference in the convection within the curtains. Guides and protective coverings for the vertical edges of the curtain such as are used in mounting curtains in theatres werenot used for mounting test curtains *A* and *B* in the furnace; hence such details of mounting for steel curtains were not tested.

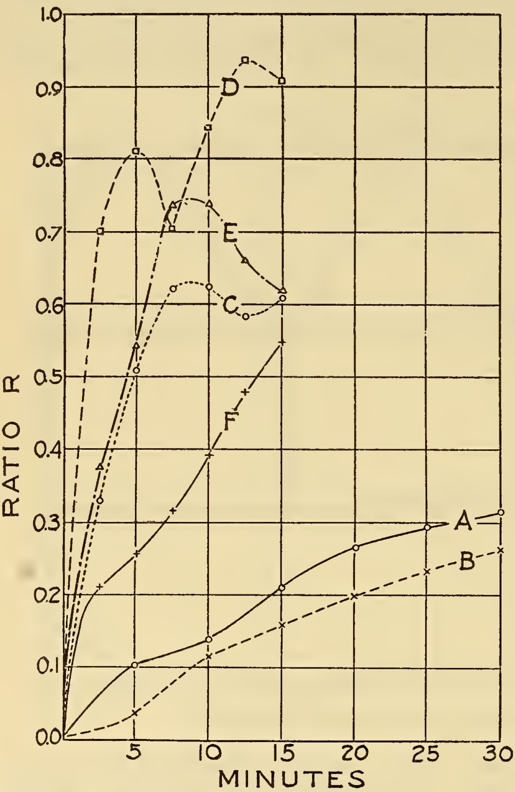

FIGURE 10.—*Ratio of rise of surface temperature of curtain to averge maintained temperature of furnace above its initial temperature.*

A part of the difference of ratios for the asbestos cloth theatre curtains must be attributed to difference in the temperatures in different parts of the furnace relative to the points where measurements on the surface of the curtain were made. In general, however, the ratio gives a fair measure of effectiveness in resisting heat flow.

With respect to the protection afforded by the steel curtains, the tests herein reported confirm the results of tests made at Underwriters' Laboratories, Chicago, soon after the Iroquois Theatre fire. Regarding these tests, John R. Freeman in his paper, "On the Safeguarding of Life in Theatres", says: "It was plain to all who witnessed these tests that the sheet-steel curtain, protected with some asbetic material on the fire side, possessed far greater strength than the simple asbestos. The thin sheet of steel, moreover, cut off the view of the fire that was apparent through the texture of the asbestos canvas.

"With care given to the design of the guides and fastenings at edges and top, so that after it was lowered the curtain could not be pulled out by warping, buckling, smoke explosions, or pressure of air, the steel curtains would have a value to the fire underwriter that no asbestos curtain can possess, and would probably hold a fire on the stage from entering the auditorium."[2]

III. OPERATING TESTS OF CURTAINS

Since some of the theatre curtains inspected during the survey would not close when subjected to small lateral forces, it was thought advisable to investigate this phase of the problem. Accordingly, the two asbestos cloth curtains mounted on pipe and cable frames and held between vertical cable guides were rigged in the panel frame for operating tests (fig. 1).

1. EQUIPMENT AND METHODS

Two 500-lb.-capacity spring scales were attached to the steel cables used to pull the curtains down over the opening in the test panel. (See fig. 1.) The pressures were produced by two small blower fans discharging into the combustion chamber of the furnace. All the openings around the test panel frame were stopped with mortar and the top of the furnace closed with an iron damper; but because of air leakage through and around the curtain and through the furnace walls the maximum pressure which could be developed in the furnace against the curtain was 4.6 lb/ft.^{2} notwithstanding the fact that the fans were capable of developing static pressures up to 25 lb/ft ^{2}.

For measuring the friction of sliding metal shoes against metal guide rails a piece of steel elevator guide rail was set horizontally and metal blocks or shoes, held in the bottom of a wooden block from which various weights were suspended, were drawn over it with a small windlass, the pull required being measured with a spring scale.

2. SLIDING FRICTION OF CURTAINS AND GUIDES

(*a*) OPERATING TESTS OF ASBESTOS CLOTH CURTAINS

The operating tests were planned to determine the friction when air pressure was applied to the asbestos cloth curtains. The guide rings on the vertical edges of the test curtains ran smoothly on the guide cables and the counterweights were adjusted so that little force was required to lower or raise the curtains. In the first tests with curtain *C* the cloth was allowed to rub against the brick and concrete surrounding the opening over which the curtain was hung. Afterwards slideways made of three-eighths inch iron pipe were provided at the vertical sides of the opening to reduce the friction. It will be observed that such slideways were not found in actual installations but were introduced here to determine the decrease in friction.

Coefficients of friction varied widely, but the average ranged between unity and one half. With pipe slideways the coefficients of friction were less than two thirds those found in the first tests.

[2] On the Safeguarding of Life in Theatres, John R. Freeman, Trans. A.S.M.E., vol. 27, 1906.

The large friction factors found in these tests were in keeping with the observations made in connection with the operation of curtains in theaters, where slight lateral pressures arrested the descent of curtains of this type.

The raising and lowering of curtain *E* showed that the roller-bearing trolleys moved within the closed track very easily, but due to the lack of internal diagonal bracing the curtain would bind when one end was lowered faster than the other. The time allowed for the tests did not permit correction of this defect and therefore the operating tests and friction measurements could not be made. As trolleys were not used in mounting curtain *F*, no tests were made to measure the sliding friction of this curtain.

(b) RESULTS OF FRICTION TESTS OF METAL BLOCKS ON GUIDE RAILS

The tests of metal blocks sliding on steel rails gave widely varying results, as it was not possible to secure guide rails with surfaces of uniform frictional properties throughout their length. The values in table 2 have been selected as suitable for use in the design of curtains and curtain rigging. The factors for rolling friction have been taken from other sources,[3] while those for sliding friction were taken from the results of the tests and in most cases have been checked against values reported by others.

TABLE 2.—*Friction of proscenium curtain guides*

Surface	Lubrication	Mill rolled steel rail [1]		Machined steel rail	
		Coefficient of friction	Required underbalance, pound per square foot of opening	Coefficient of friction	Required underbalance, pound per square foot of opening
Roller or ball bearing wheel trolleys	Oiled	0.03	[2] 0.15	0.025	[2] 0.125
Metal sliding shoes on steel guide rails	None	.25	1.25	.20	1.00
	Greased	.12	0.60	.10	.50
Asbestos cloth on rounded steel rail	None	.65	3.25		
Asbestos cloth on rough brickwork	do	0.8 to 1.0	4.0 to 5.0		

[1] The underbalances are the difference in weight of the curtain, including chains and lifting cables below sheaves, and the counterweight with its fastenings, cables, etc. The underbalance should be proportioned to the size of the curtain opening and should vary with the type of curtain mounting used. A lateral pressure on the curtain during closure of 5 pounds per square foot is assumed.

[2] It is recommended that underbalance less than 0.2 lb/ft.[2] never be used.

IV. FIRE TESTS WITH DECORATIVE PAINTS

The three curtains, *C*, *D*, and *E*, were unsatisfactory in that large volumes of dense smoke were given off from burning paint and combustibles in the cloth. Smoking began soon after the fire was lit in the first two tests and was in such quantity in all three tests that it might have caused a panic if coming from a curtain in a theater. A paint which would give off less smoke was therefore sought.

[3] Mechanical Engineer's Pocket Book, Kent, 10th Edition.

1. TESTING METHODS AND RESULTS

(a) BUNSEN-BURNER TESTS

Eighteen tests were made by painting pieces of reinforced asbestos cloth with dyes, casein, animal glue, or sodium silicate paints, and with combinations of some of them, and subjecting limited areas to a bunsen flame. The dyes gave the most pleasing appearance and the least smoke, but the combination of casein and sodium silicate with mineral pigments, although giving more smoke than the dyes, seemed more satisfactory from the standpoint of filling the interstices of the cloth.

(b) PANEL TESTS

Six 5- by 40-inch panels were then prepared so that comparison of the smoke given off could be made by exposing three parallel panels to a furnace fire at a time. The three panels were painted on a single piece of cloth and exposed directly to the furnace fire in one test. In the other test two plies of cloth were used, one on which the panels were painted and the other, filled by painting with two coats of sodium silicate and mineral pigment, was interposed between the test panels and the fire.

As in the small tests, the dyed panels again gave the least smoke, but the glow of the fire could be seen through the open mesh. The paint in which animal glue was used gave a black smoke and in the greatest volume. The paint composed of casein, sodium silicate, whiting, and ocher gave a bluish-colored smoke intermediate in volume between that from the other two panels. This paint was adjudged the most suitable of the several tried. The most satisfactory proportions tried, those used on curtain *F*, were as follows:

4 pounds powdered casein.
½ pound carbonate of soda.
10 pounds sodium silicate solution (commercial water glass, specific gravity 1.38).
20 pounds whiting and powdered yellow ocher mixed.
Water sufficient to give the desired consistency.

V. TESTS OF ASBESTOS CLOTH

1. STRENGTH AND STRETCH TESTS

(a) EQUIPMENT AND METHODS

Gas flames were used to heat the cloth in trial tests, but, as neither control nor measurement of temperature was satisfactory, electric heating was adopted. The necessary heating elements and temperature-measuring devices were added to a Scott horizontal textiles testing machine. Temperatures were measured by means of chromel-alumel thermocouples and a portable potentiometer. Stretch of cloth was measured by means of a scale and a pointer attached to the specimen at points 3 inches apart, after an initial pull of 3 pounds had been applied.

The specimens for strength and stretch tests were all cut 6 inches long by 1⅛ to 1¼ inches wide and then raveled to a definite number of threads in width for 1 inch as determined by thread counts over 5 inches or more width of cloth. For those specimens which were stronger at the elevated temperatures it was necessary to notch each side at the center to obtain the break within the heated region.

(*b*) ASBESTOS CLOTHS

Eleven of the twelve samples of asbestos cloths tested were of white, chrysotile asbestos, a hydrous silicate of magnesia, and one was of the African or Cape blue, crocidolite asbestos, an iron-sodium silicate.[4]

Eight samples had wire reinforcement in the yarns. The characteristics of the various cloth samples are given in table 3.

TABLE 3.—*Characteristics and strength of asbestos cloths*

Sample no.	Weight per square yard	Kind of cloth and reinforcement per strand	Number of strands per inch		Area of wire per strand	Strength per inch (width)		Strength per strand		Strength,[1] weight ratio	
			Warp	Filling		Warp	Filling	Warp	Filling	Warp	Filling
	Lb.				*Sq. in.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	2.44	Plain	21	11	----------	88	40	4.2	3.6	35.7	16.0
2	3.05	Reinforced two no. 36 brass	14½	10½	0.00002	161	77	11.1	7.3	52.8	25.2
3	2.29	Plain African blue	18	7	----------	159	31	8.8	4.4	69.5	13.5
4	4.31	Reinforced two no. 30 monel	16	9	.000068	302	175	18.9	19.4	70.0	40.7
5	3.06	Reinforced one no. 30 nichrome	16	9	.000072	212	137	13.2	15.2	69.3	44.8
6	5.21	Reinforced one no. 30 nichrome	16	8	.000072	353	199	22.1	24.9	67.9	38.2
7	2.53	Plain	20	11	----------	141	82	7.0	7.5	55.7	32.4
8	4.61	Reinforced two no. 32 monel curtains *D* and *E*	16	7	.000048	312	116	19.5	16.6	67.7	25.1
9	3.28	Reinforced two no. 32 brass wires	17	9	.00005	206	113	12.1	12.6	63.4	34.4
10	2.77	Reinforced two no. 34 nickel in warp. One no. 34 in filling	17	8	.00003	213	95	12.5	11.9	76.9	34.2
11	3.14	Reinforced two no. 33 brass	16	8	.000044	198	92	12.4	11.5	63.1	29.3
12	3.87	Plain	21	11	----------	84	30	4.0	2.7	21.7	7.8

[1] The ratio is derived by dividing the strength (lb./in. width) by the weight (lb./yds.^{2}).

(*c*) STRENGTH TESTS AT ORDINARY TEMPERATURES

The tests were made at room temperature which varied from 70° to 80° F. (21° to 29° C.). The values found show large variations, but for direct comparison of strength the last two columns of table 3 are most significant.[5] In these columns the relation of strength to weight of cloth has been given. While some of the white (chrysotile) plain asbestos cloths show low strength compared to the wire-reinforced cloths, on this basis the warps of the blue (crocidolite) plain asbestos cloth compared favorably in strength with the reinforced chrysotile cloths.

(*d*) STRENGTH AT ELEVATED TEMPERATURES

The strength of most of the samples listed in table 3 were also determined when heated in an electric furnace. The results are given in pounds per inch width in figure 11. There was an increase of strength of chrysotile asbestos cloths with increase of temperature up to approximately 300° C. (572° F.) after which there was a rapid

[4] The reader is referred to Non-Metallic Minerals, by Raymond B. Ladoo, for information on the occurrence, mining, preparation, and uses of the several asbestos minerals.

[5] Compare with values given by Freeman, "On the safeguarding of life in theaters." Trans. A.S.M.E. vol. 27, p. 110, 1906.

reduction of strength with further increase of temperature. The white unreinforced asbestos cloths when heated above 400° or 500° C. (752° or 932° F.) lost a considerable part of their strength, but the wire-reinforced cloths lost comparatively little strength until temper-

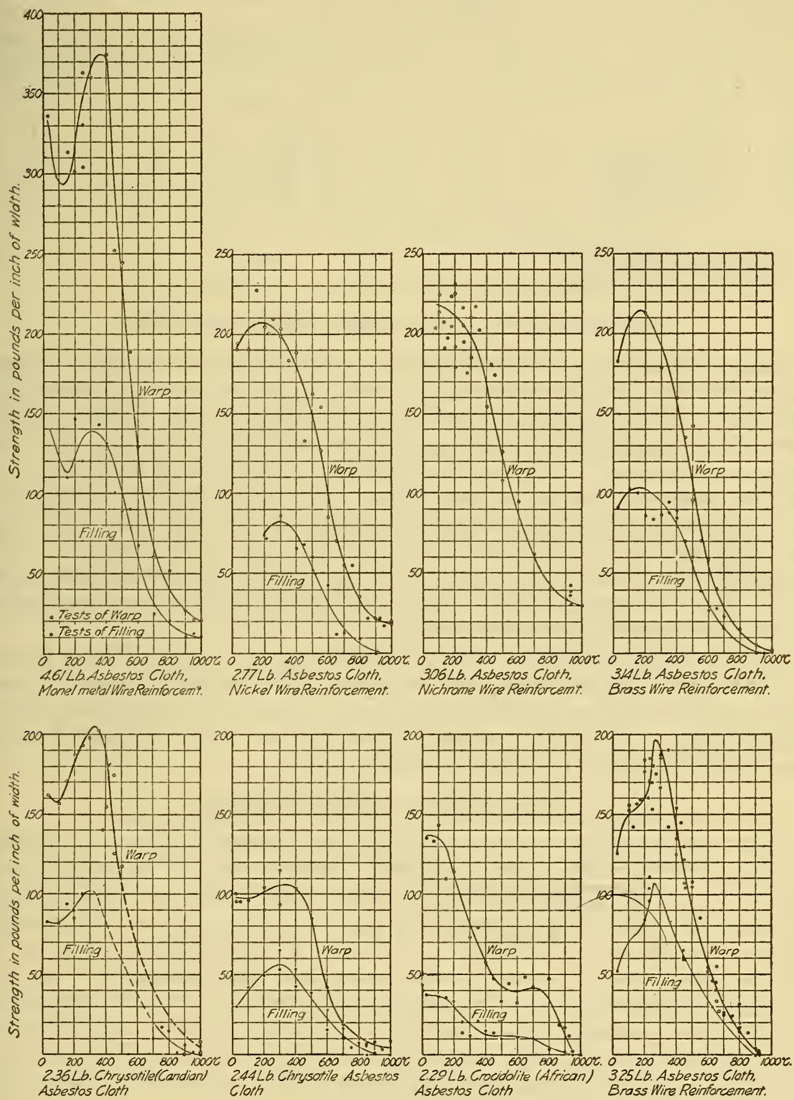

FIGURE 11.—*Strengths of asbestos cloths when subjected to heat in an electric furnace.*

atures exceeding 480° C. (906° F.) had been reached. There was marked contrast between some of the plain and reinforced cloths in this respect. Blue asbestos cloth lost strength after temperatures of 100° C. (212° F.) had been exceeded. The strengths of both plain and reinforced cloths were small at temperatures above 900° C. (1,652° F.).

TABLE 4.—*Strength of cloth samples cut from tested curtains*

Curtain	Kind of asbestos cloth	Weight per square yard	Strength before test		Strength after test				Percent of original strength remaining	
			Warp	Filling	Warp: Average	Warp: Minimum	Filling: Average	Filling: Minimum	Warp	Filling
		Lb.	*Lb. in.*	*Lb. in.*	*Lb. in.*	*Lb. in.*	*Lb. in.*	*Lb. in.*		
C(a)[1]	Plain	2.53	141	82	125	3	62	3	89	75
C(b)[2]	do	2.53	141	82	46	3	29	3	33	35
E(a)[1]	Brass reinforced	3.28	206	113	135	64	72	26	66	66
E(b)[3]	Monel reinforced	4.61	312	116	83	9½	46	4	27	40
F(a)[1]	Brass reinforced	3.14	206	103	191	130	85	48	93	82
F(b)[2]	Nickel reinforced	2.77	236	87	82	5	42	1½	35	48

[1] Ply of cloth not exposed to fire.
[2] Ply of cloth exposed to fire.
[3] This cloth had been subjected to two 15-minute fire tests.

(e) STRENGTH OF CLOTH FROM TESTED CURTAINS

After the asbestos cloth curtains had been tested in the large furnace nine samples of cloth were cut from each ply of each curtain, excepting curtain *D*, and subjected to tests for strength and for stretch. Samples of the unburned cloths were tested for tensile strength for comparison purposes. The results of these tests are given in table 4. It will be observed that samples of the cloth reinforced with brass wire were taken from double curtains and only from the side which was not exposed to fire, and hence had relatively high strength. The samples with nickel and monel metal wire reinforcements were taken from the fire-exposed sides only, the latter having been subjected twice to the 15-minute fire test.

The breaking strengths as determined by the tension tests do not indicate the brittleness of the samples. For example, many pieces from curtain *C* were broken while being cut from the larger samples of burnt cloth. The asbestos fiber of some of the wire-reinforced cloths was easily broken with slight bending.

(f) STRETCH OF ASBESTOS CLOTHS

The characteristic stretch of plain and metal reinforced asbestos cloth as determined on seven unburnt cloths is shown by the curves in figure 12. The filling strands in each case give an almost exact straight-line relation of stretch to load, while the warp has a somewhat greater initial rate of stretch. This can be explained as due to the greater sinuosity of the warp threads in the finished cloth.

Measurements of the stretch were also made on burnt samples of cloth from curtains *C*, *E*, and *F*. Generally there were six test pieces of each, warp and filling, from each location. The stretch of all of the cloths, except that reinforced with monel-metal wire, was found to have been reduced by the heating.

2. PERMEABILITY TO AIR

Tests for permeability to air were made on samples of cloth with pressures from 1/2 to 5 lb./ft.^{2} Some of these cloths were also given two coats of paint to fill the interstices to determine what improvement in resistance to air flow was obtained.

The apparatus for measuring permeability to air consisted of a cylinder with a flanged end to which a sample of the cloth could be clamped with the other half of its companion flange. The openings through the flanges were of two sizes. One was of 22.7 in.^{2} area for testing the less permeable specimens, and one of 5.7 in.^{2} for testing the cloths of open weave. Air was supplied to the cylinder through a positive displacement type gas meter and the pressure was measured by a water-column manometer. Samples 1 and 6, table, 3 were the least permeable. Under pressure of 2 lb./ft.^{2} these samples passed one half

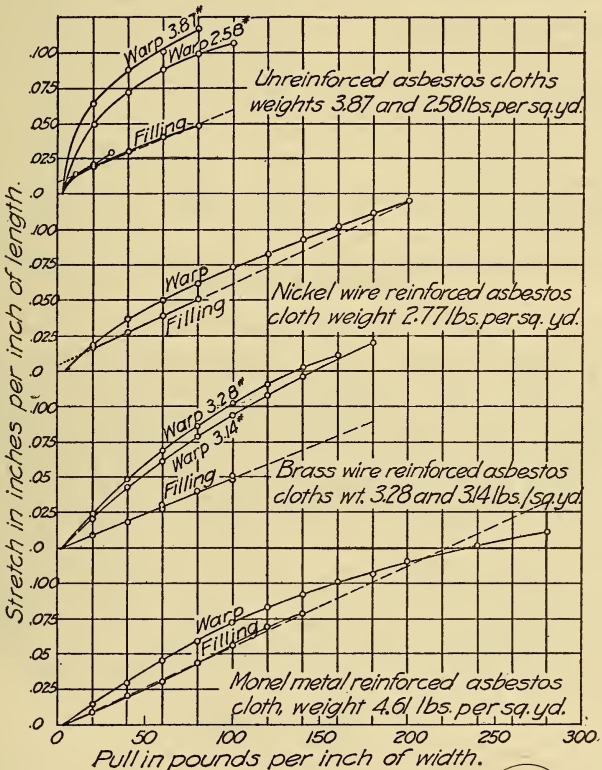

FIGURE 12.—*Stretch of asbestos cloths.*

cubic foot of air through each square foot of area. Samples 7, 8, and 12 passed about twice as much, and the other samples passed quantities ranging from 7 to 35 times as much air under the same conditions. Painting with two coats of suitable fillers reduced the permeability, at 2 lb./ft.^{2} pressure, to 1½ cubic feet per minute, which is considered satisfactory for service in theater curtain installations.

The paint used on curtain *F* was found to be effective for the purpose. Many paints other than those used would, undoubtedly, be suitable for filling the cloth. However, casein or other pliant binder to prevent cracking and dusting is essential with the more open cloths.

TABLE 5.—*Analyses of asbestos cloths*

Sample no.	Kind of cloth	Weight	Reinforcing metal	Extracted by ether	Carbon in residue of fibers	Cotton in fibers computed	Cotton in cloth computed
		lb./sq. yd.	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Plain chrysotile	2.44	None	1.9	1.60 1.68	3.6 3.8	3.7
2	Brass reinforced	3.05	25.0	1.2	1.875 1.875	4.2 4.2	3.2
3	Plain crocidolite (African blue)	2.29	None	.2	.135 .135	.3 .3	.3
4	Monel reinforced	4.31	39.8	1.5	1.64 1.68	3.7 3.8	2.25
5	Nichrome reinforced	3.06	27.1	1.0	1.84	4.1	3.0
6	do	5.21	16.3	.5	1.70 1.70	3.8 3.8	3.2
7	Plain (curtain *C*)	2.53	None	.7	1.09	2.5	2.5
8	Monel metal reinforced (curtains *D* and *E*)	4.61	23.4	.6	1.15 1.03	2.6 2.3	1.87
9	Brass reinforced (curtain *E*)	3.25	34.3	1.1	1.12 1.04	2.50 2.35	1.59
10	Nickel reinforced (curtain *F*)	2.77	28.9	.4	.83	1.86	1.32
11	Brass reinforced (curtain *F*)	3.14	35.6	.3	1.06	2.4	1.54
12	Plain	3.87	None	.7	1.09	2.5	2.5

3. TESTS FOR SOLUBLE AND CARBONACEOUS MATERIALS IN ASBESTOS CLOTHS

The test apparatus for the determination of the carbon content of the various asbestos cloths after the ether-soluble content had been extracted was like that described in vol. 22, part I, of the Proceedings of the American Society for Testing Materials, pp. 580–582, and the carbon content of the extracted fibers was determined by the standard combustion method described on page 578 of the same volume.

The results of the determinations are given in table 5. All carbon on the extracted residue of the fiber has been considered as derived from cotton in the proportion of 445 parts carbon to 1,000 parts cotton. No determination was made of the composition of ether-extracted materials, but they were presumably oils and greases from the wire-drawing and fiber-spinning processes. The crocidolite (African blue) asbestos had very little ether-soluble and carbonaceous substances. All the samples were of low cotton content.

VI. CONCLUSIONS

The surveys of curtain installations and the tests reported herein have led to the following observations with respect to the several types of curtains and their effectiveness. Recommended requirements for curtain installations have been formulated.[6]

1. FIRE RESISTANCE

The purpose of the fire-resistive curtain is to close the proscenium opening against the passage of fire and smoke into the auditorium in dangerous or alarming amounts. The single-ply asbestos cloth curtain as found in many installations might screen stage fires from the audience under the less severe conditions, but unless supplemented by effective vents above the stage would permit ready flow of smoke and gases into the auditorium. They would show glow quickly if subjected to flames. Drafts and light winds lift the botton from the floor and moderate air pressures or winds might tear them from their

[6] Copies of "Recommended Requirements for Theater Proscenium Curtains" may be obtained by application to the Bureau of Standards, Washington, D.C.

mountings. None were adjudged to give adequate closure when exposed to severe fire or draft conditions.

Proscenium openings can be adequately closed against severe fires for periods of 15 minutes with a curtain composed of two plies of 3¼ pound wire-reinforced asbestos cloth with positive separation between the plies, such as in test curtain *F*, and of sufficient strengh to resist the pressures encountered under fire conditions.

Steel curtains of the types tested form effective barriers against fire for one half hour or more and do not glow or pass smoke and gases in objectionable amount during this period.

Asbestos, although incombustible, is seriously injured by high temperatures. Only wire-reinforced asbestos cloth should be used for structures exposed to fire and where strength and integrity are essential. Asbestos cloths having wires of nickel or nickel alloys spun in the yarns were found to have higher strength at high temperatures than those having brass wires. Cloths used for theater proscenium curtains need filling to prevent the flow of smoke through the weave. Mixtures of casein and sodium silicate were found to be more suitable as a vehicle for the paint used for this purpose than animal glue which has been much used but which gives off quantities of dark smoke when exposed to fire.

2. OPERATING MECHANISM

Whatever the type of proscenium curtain, the mechanism for operating it should be both simple and reliable. The better devices for emergency lowering operate without the use of power sources other than gravity, and some of them operate in the same manner for the regular lowering of the curtain. As a part of this mechanism there should be some device for automatically closing the curtain when the temperature of any large part of the stage exceeds some predetermined safe limit.

The frictional resistance of some of the curtains on which observations were made was very high. The descent of the single-ply asbestos cloth curtains was arrested by very slight pressures. Heavy bottom battens or positive means of hauling the curtains down would be required to close them when subjected to heavy drafts or wind. Except for small curtains, guides having little friction were indicated as necessary for reliable operation under conditions that may occur with fire.

Whatever the type of curtain or operating mechanism, reliable means of ventilation for the discharge of flame, smoke, and gases are necessary to the safety of the audience in the event of serious stage fires.

VII. ACKNOWLEDGMENTS

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