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REPORT BMS101

Strength and Resistance to Corrosion of Ties for Cavity Walls

by

Cyrus C. Fishburn

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Strength and Resistance to Corrosion of Ties for Cavity Walls

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CYRUS C. FISHBURN

ISSUED JULY 1, 1943

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly

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Foreword

Ties for cavity-wall construction are usually specified in accordance with empirical rules for a minimum thickness and a minimum spacing. This report presents data on the resistance to axial loads of wall ties and the corrosion resistance of some steel ties exposed to weathering, either when unprotected or when coated with corrosive-resistant metals, portland cement, or a bituminous paint.

LYMAN J. BRIGGS, *Director*.

Strength and Resistance to Corrosion of Ties for Cavity Walls

by CYRUS C. FISHBURN

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ABSTRACT

The resistance to axial loads of ties for cavity walls was determined by testing steel and cement-asbestos ties when they were embedded at the ends in brick masonry. Fourteen different ties and three mortars were represented in a group of about 110 specimens. The ties, with one exception, when spaced one to every 3 ft² of wall area, provided connections of ample strength to resist the usual lateral forces to which cavity walls are subjected.

The corrosion resistance of some of the steel ties was measured by exposing them when unprotected and when coated to accelerated and to outdoor weathering.

I. INTRODUCTION

The cavity wall, a form of hollow masonry-wall construction widely used in Great Britain, and to some extent elsewhere, consists of two parallel tiers of unit masonry separated by a continuous cavity about 2 in. wide. The tiers are joined by ties, usually consisting of bent steel rods or wires spaced one for each 2 or 3 ft ² of wall area. According to Fitzmaurice,[1] properly built cavity construction has two desirable features, namely, a high resistance to rain penetration and a greater heat insulation than solid walls of the same materials and thickness.

Available evidence,[2] based largely on experience, indicated that steel ties equivalent in strength to ¼-in. steel bars have adequate strength when well anchored in strong mortar. Also that galvanized iron or steel ties are likely to have a satisfactory durability for use in ordinary buildings under conditions of normal exposure. For monumental structures or for unusually corrosive conditions more resistive materials would be preferable.

The tests described in this report were made to determine: (a) the strength of ties under axial tensile and compressive loads and (b) the corrosion resistance of steel ties coated with various materials. Fourteen different types of ties and three mortars were represented in the specimens subjected to strength tests. The ties exposed to accelerated or outdoor weathering were either unprotected or coated with

[1] Principles of Modern Building, vol. 1, Walls, Partitions and Chimneys, London (1939), p. 159.

[2] Footnote 1, p. 164 to 166.

copper, zinc, portland-cement mortar, or coal-tar paint.

II. SPECIMENS

1. Materials

(a) *Ties*

The ties used in the compressive-strength specimens are illustrated and described in figure 1 and table 1, respectively. Ties 1 and 2 (fig. 1), made of copper-coated steel, are known as Copperweld nonrusting cavity-wall ties, and were donated by the Copperweld Steel Co., Glassport, Pa. Tie 1 was No. 182–30 type Z–6300. Tie 2 was No. 204–30.

Ties 3 to 8, inclusive, were made of concrete-reinforcing steel wire donated by the Pittsburgh Steel Co., Pittsburgh, Pa. They differed in thickness (No. 6, 8, or 10 gage) and in shape (table 1). Tie 8, of rectangular shape, was made of the 8-gage wire, and had the ends of the wire butted at the center of one end of the tie. The square ties 9, 10, and 11 were cut from welded wire fabric, donated by the Pitts-

Table 1.—*Wall ties*

Tie number	Kind of material	Stl. W. G.	Over-all dimensions			Type
			Length	Width	Thick-ness	
			In.	*In.*	*In.*	
1	Copperweld [a]		6	6	0.183	Z-shape.
2	do		6	6	.207	Do.
3	Steel [b]	6	6	6	.188	Do.
4	do	8	6	4	.158	Do.
5	do	8	6	6	.158	Do.
6	do	8	6	8	.158	Do.
7	do	10	6	6	.131	Do.
8	Steel [b]	8	6	4	.158	Rectangular, ends butted on 4 in. side.
9	do [b]	6	7	7	.192	Welded wire fabric, 6- by 6-in. mesh.
10	do	8	7	7	.161	Do.
11	do	10	7	7	.135	Do.
12	Steel, galvanized [c]	24	6.8	0.94	.06	Corrugated, ⅜-in. pitch.
13	Cement-asbestos board.		7	4.5	.275	I-shape, perforated at ends.
14	do		7	4.5	.134	Do.

[a] Furnished by the Copperweld Steel Co., Glassport, Pa. Tie 1 was No. 182–30, type Z–6300; tie 2 was No. 204–30.
[b] Bright basic wire made by the Monessen, Pa. plant of the Pittsburgh Steel Co.
[c] Purchased from Fries, Beall & Sharp Co., Washington, D. C.

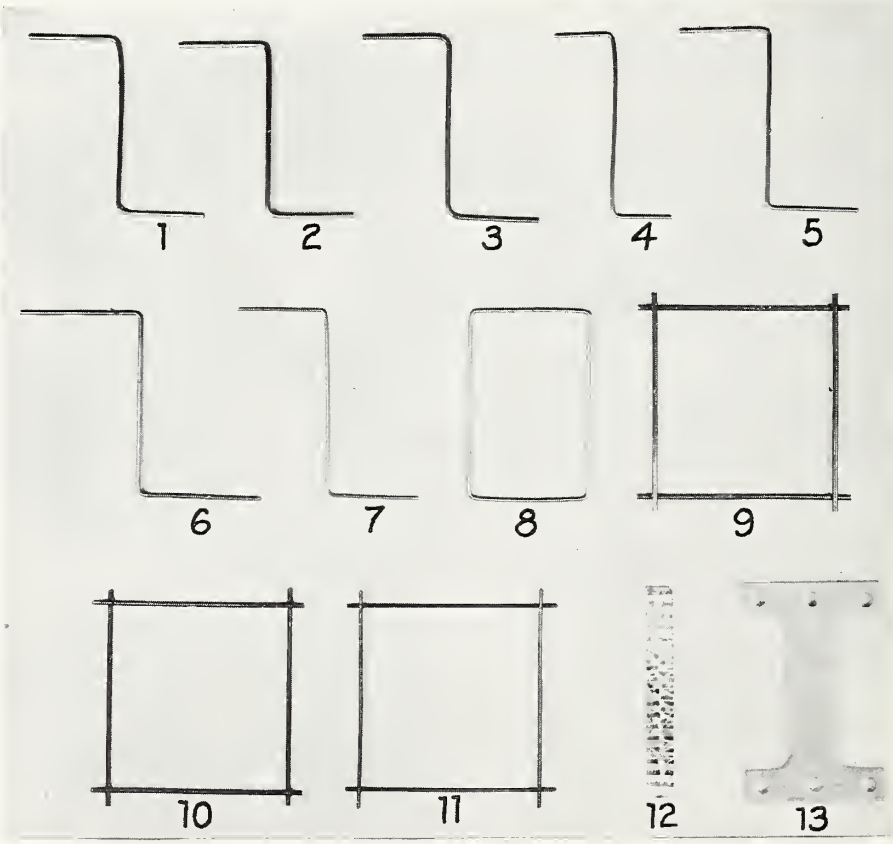

Figure 1.—*Ties for compressive-strength specimens.*

burgh Steel Co., and made at the same plant of a similar steel as that used in ties 3 to 7. The strengths of the wire in the welded fabric and of those used in ties 3 to 8 were approximately equal. The average yield strength (offset=0.2 percent) and the average tensile strength of the wires [3] were, respectively, 86,000 and 90,000 lb/in.^{2}

Tie 12 was a corrugated galvanized sheet strip of the type often used in brick veneer on wood-frame construction.

The cement-asbestos ties 13 and 14 contained six ½-in.-diameter holes, were of like shape, and were ¼ and ⅛ in. thick, respectively. The ties were cut from sheets of cement-asbestos fiber board weighing about 120 lb/ft^3. The moduli of rupture, when dry and when wet, of strips cut from the ¼-in.-thick board were, respectively, 6,850 and 3,400 lb/in.^{2} Deflection measurements made on strips 4 in. wide loaded at the center of an 8-in. span indicated that the moduli of elasticity of the strips, when dry and when wet, at loads of 0.6 the ultimate were, respectively, 2,700,000 and 1,800,000 lb/in.^{2} The tensile strength, when dry, of the ¼-in. board was 3,240 lb/in.^{2} The tensile strengths of the ⅛-in. board, when dry and when wet, were, respectively, 2,690 and 1,340 lb/in.^{2}

(b) *Brick*

The brick [4] used in the specimens were side-cut shale units made in Martinsburg, W. Va. They had an absorption of 3.1 percent during 24-hr. cold immersion. The compressive strength and the modulus of rupture of the brick were, respectively, 15,700 and 2,030 lb/in.^{2}

(c) *Mortars*

The proportions and physical properties of the three mortars, designated as mortars *H*, *M*, and *L*, are given in table 2. They differed in strength and in the relative proportions of portland cement and hydrated lime. The cementing materials were Medusa brand portland cement, which met the physical requirements of Federal Specification SS–C–191a, and Miracle hydrated lime manufactured by the G. & W. H. Corson Co., Plymouth Meeting, Pa. A sieve analysis of the Potomac River building sand used in the mortars is given in table 3.

The mortars were proportioned by weight, and mixed in a batch mixer having a capacity of 0.6 ft.^{3} The water used for tempering was adjusted in amount to give an initial flow [5] of 110 to 115 percent. Since the Miracle brand hydrated lime was highly plastic, the water retentivity of the mortars was much greater than that usually obtained with mortars containing dry lime hydrates (table 5, BMS82). Six 2-in. cubes made from each batch of mortar were cured as indicated (table 2) and tested in compression when 28 days old.

Table 2.—*Proportions and physical properties of mortars*

Properties of mortars		Mortars *H*	Mortars *M*	Mortars *L*
Proportions of cement, lime, and sand. [a]	by volume	1:0.25:3.0	1:1:6.0	1:3:12.0.
	by weight	1:0.11:2.6	1:0.42:5.1	1:1.28:10.2.
Average water content, [b] percentage by weight of dry materials.		17.7	20.4	22.5.
Compressive strength [c] lb/in.^{2}	dry cured	2,450	800	230.
	wet cured	4,450	1,330	270.

[a] Proportioning was by weight, assuming that portland cement weighed 94 lb/ft^3, Miracle brand hydrated lime 40 lb/ft^3, and that 1 ft^3 of loose, damp sand contained 80 lb. of dry sand.
[b] The initial flow of the mortars, determined according to Federal Specification SS–C–181b, was about 110 percent.
[c] Strength at age of 28 days of 2-in. cubes molded in accordance with paragraph F–4m of Federal Specification SS–C–158. Dry-cured cubes were removed from the molds when 2 days old and stored in air at 70°F until tested. Wet-cured cubes were removed from the molds when 2 days old, stored in air at 70°F in the damp closet for 5 days, and then immersed in water at 70°F until tested.

Table 3.—*Sieve analyses of sand*

U. S. Standard Sieve	Amount passing	U. S. Standard Sieve	Amount passing
	Percent		*Percent*
4	100.0	30	79.0
8	99.8	50	27.5
16	97.0	100	4.6

(d) *Cementitious and coal-tar-paint coatings*

The protective coatings applied to ties 3, 4, and 7 embedded in the weathering specimens were mortar *M*, a coal-tar paint, and a neat portland-cement paste containing 40 percent by weight of water. The paint was Eternium

[3] Tested in accordance with the Standard Methods of Tension Testing of Metallic Materials (E8–36) A. S. T. M. Standards, 1939.

[4] The brick were similar to brick *A*, described in Building Materials and Structures Report BMS82.

[5] Measured in accordance with Federal Specification SS–C–181b.

brand made and donated by the Barrett Division of the Allied Chemical & Dye Corporation, New York, N. Y. The ties treated with neat cement and Eternium paint were dipped in the coating material, and the coatings were hardened in air before the ties were placed in the specimens. The ties dipped in mortar M were immediately embedded in the specimens.

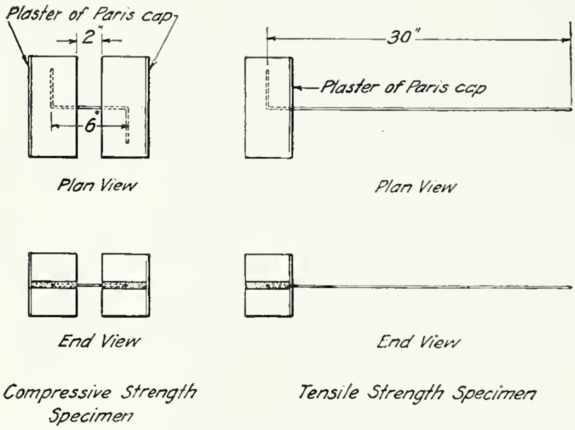

Figure 2.—*Drawing of compressive- and tensile-strength specimens, showing embedment of Z-shaped ties.*

2. Construction of Specimens

(a) *Compressive-strength specimens*

A typical compressive-strength specimen is illustrated in figure 2. A T-shaped jig was used to aline the brick in the first course of the specimens so that the distance between the brick was 2 in. The ties were alined by eye in the mortar bed, and they were covered with mortar before the upper bricks were laid. It required about 35 min. to make 30 specimens, and the mortars H and M were retempered once during this interval, if and when the mortar has stiffened to a flow of 100 percent or less. The edges of the joints were cut flush with the surfaces of the brick. The average joint thickness in specimens containing metal ties was 7/16 in., that in specimens containing cement-asbestos ties (tie 13) was 5/8 in. Joints containing mortar L averaged nearly 1/16 in. less in thickness than did the joints containing the other mortars. At least five like specimens of each kind of tie and mortar were made and tested after curing in air at 71°F for 28 days.

Figure 3.—*Outdoor-weathering specimens.*

The small (indoor) weathering specimens were placed above the wallettes after the indoor tests were completed.

(b) *Tensile-Strength Specimens*

The ties in the tensile-strength specimens were embedded at one end only (fig. 2). Five like specimens were made of each kind of mortar for ties 3 to 7, inclusive. They were stored in air at about 71° F for 28 days before they were tested.

(c) *Indoor-Weathering Specimens*

The indoor-weathering specimens were similar to the compressive-strength specimens, except that each contained two like ties. The ties used were Nos. 2, 3, 4, 7, and 12, of which the steel ties 3, 4, and 7 were either uncoated or protected by coatings of Eternium, neat cement, or mortar *M*.

(d) *Outdoor-Weathering Specimens*

The outdoor-weathering specimens, figure 3, were cavity-type wallettes. These specimens were three stretcher brick in length, five stretcher courses high, and were topped with a covering course of header brick. The cavity was 2 in. wide. Mortar *H* was used in all but the covering courses, which contained mortar *L*. Two ties were placed near the ends of the specimens in the bed joint between the first and second courses, and one tie was placed at midlength of the wall between the fourth and fifth courses. The joints were cut flush with the surfaces of the brick. The ties were of the same kind and were given the same protective coatings as those represented in the indoor-weathering specimens.

III. METHOD OF TESTING

1. Tests for Structural Strength

(a) *Compressive-Strength Test*

The ends of the compressive-strength specimens were capped with a thin coating of calcined gypsum (see fig. 2) about 2 days before they were tested. Steel loading plates containing a ½-in-wide slot were placed over the caps, and the slots in the plates were alined with the mortar joints so that no pressure was exerted directly against the joint. The specimens were loaded to failure, and the type of failure was observed. The rate of load application was about 400 lb/min.

(b) *Tensile-Strength Test*

The specimens were capped with gypsum and supported on a slotted steel plate with the end of the tie projecting through a hole at the center of the slot. A pull was exerted on the end of the tie until failure occurred, and the type of failure was observed.

2. Weathering Tests

(a) *Indoor-Weathering Exposure*

Each specimen was covered with a strip of damp burlap and was supported above heated water in a metal pan. The ends of the burlap drapings hung in the water, and the pan was fitted with a cover so that the burlap over the specimens remained moist. The temperature of the humid air adjacent to the specimens ranged between 95° and 100° F. The specimens were exposed for 180 days, and the extent of the corrosion of steel in the ties was observed.

(b) *Outdoor-weather exposure*

The specimens (fig. 3) were built outdoors at Washington, D. C., in June 1942 and exposed to the weather.

IV. RESULTS OF THE STRENGTH TESTS

1. Compressive Strength

The type of failure, the average tie stress, and the compressive strength of the specimens are listed in table 4. The specimens failed either by buckling of the ties or by crushing of the mortar against the ends of the ties. The strength of those that failed in buckling was affected by irregularities of alinement of the ties in the specimens, but it is probable that the accuracy of tie alinement was equal or better than that usually found in cavity-wall construction.

TABLE 4.—*Compressive strength of wall tie specimens* [a]

Tie number	Area of cross section	Kind of failure [b] and kind of mortar			Maximum load on specimens and kind of mortar			Maximum compressive stress in ties and kind of mortar		
		H	*M*	*L*	*H*	*M*	*L*	*H*	*M*	*L*
	in.²				*lb*	*lb*	*lb*	*lb/in.²*	*lb/in.²*	*lb/in.²*
1	0.0263	*B*	*B*	*M*	2,070	1,900	970	78,700	72,200	36,900
2	.0336	*B*	*M*	*M*	3,880	2,180	1,030	115,300	64,800	30,600
3	.0278	*B*	*Bm*	*M*	2,025	1,810	780	72,900	65,200	28,100
4	.0196	*B*	*B*	*M*	1,140	990	860	58,100	50,500	43,900
5	.0196	*B*	*B*	*M*	1,060	1,115	770	54,100	56,900	39,300
6	.0196	*B*	*B*	*M*	1,150	1,120	800	58,600	57,100	40,800
7	.0135	*B*	*B*	*Mb*	600	520	660	44,500	38,600	49,000
8	.0392	*B*	*Bm*	*M*	2,310	2,060	1,010	58,900	52,500	25,800
9	.0579	*B*	*Mb*	*M*	3,740	3,060	1,370	64,600	52,800	23,700
10	.0407	*B*	*B*	*M*	2,440	2,345	1,500	59,900	57,600	36,800
11	.0286	*B*	*B*	*M*	1,730	1,600	1,100	60,400	55,900	38,400
12	.019	*B*	*B*	*B*	70	60	90	3,700	3,200	4,700
13	.412	*B*	*Mb*	*M*	4,370	3,580	1,860	10,600	8,700	4,500
14	.201	-----	*B*	-----	------	2,065	-----	-------	10,300	------

[a] Average values obtained from tests on groups of 5 or more like specimens.
[b] Key:
B =Buckling or crushing of the tie between supports.
M =Crushing of mortar over the tie.
Bm=Predominant buckling failure with 2 or more mortar failures.
Mb=Predominant mortar crushing with 2 or more buckling failures.

(a) *Effect of shape and diameter of steel ties*

Over 90 percent of the specimens containing ties 3 to 11, inclusive, embedded in mortars *H* and *M* failed in buckling of the tie. Specimens containing mortar *H* were nearly 10 percent stronger than those built of mortar *M*. As would be expected, the ultimate stress developed in the ties was least for the single-stem ties of the smallest diameter (10 gage). The length of ear in ties 4, 5, and 6 (2, 3, and 4 in., respectively) had a slight but significant effect on the strength of specimens built of mortars *H* and *M*, but had no significant effect on the strength of those specimens that failed by crushing of the mortar (table 4). The rectangular, double-stemmed ties, sustained approximately twice the ultimate loads, as did the single-stem Z-shaped ties. Specimens containing the square tie 10, cut from welded fabric, were stronger than those containing the narrower rectangular tie 8.

(b) *Strength of specimens containing Copperweld, corrugated galvanized-steel, and cement-asbestos ties*

The ultimate stresses developed in the Copperweld ties (tie 2) embedded in mortar *H* were exceptionally high. Specimens containing these ties embedded in mortar *M* failed by crushing of the mortar, the average maximum bearing stress over the 3-in. lear length was 3,500 b/in.².

The corrugated galvanized-steel strips (tie 12) were extremely weak in compression, and care had to be taken in handling the specimens to prevent buckling of the ties before they were tested.

Specimens containing tie 13, cut from portland-cement and asbestos fiber board, sustained the greatest compressive loads of any of those listed in table 4. The mortar *M* in some specimens containing these ties was crushed against the ends of the ties, and the average maximum bearing stress of this mortar on the ties was about 2,900 lb/in.² Tie 14 approximately one-half the thickness of tie 13 buckled at the same stress when embedded in mortar *M* as did tie 13 embedded in mortar *H*.

The possibility of failure in ¼-in.-thick ties similar to tie 13, produced by a differential vertical movement between the two faces of a cavity wall, was investigated. Assuming the tie to be fixed at the inner faces of a 2-in. cavity, a modulus of rupture of 6,850 lb/in.² and a value of *E* of 2,720,000 lb/in.² (calculated from observed beam deflections at 0.6 maximum load), it was estimated that the tie may break if one support was moved vertically 0.01 in. relative to the other. The estimated vertical movement required to break a tie ⅛ in. thick was similarly estimated to be 0.02 in.

2. TENSILE STRENGTH

The tensile-strength specimens, listed in table 5, failed by crushing of the mortar under the tie, with subsequent splitting of the brick-mortar assembly, by pulling out of the tie or by tension in the tie. Many of the ties in specimens that failed by pull-out or by mortar crushing were necked, the reduction in area usually occurring at or immediately below the ear in the ties. Likewise, a partial bond failure of the tie occurred in many specimens that failed in tension of the tie or by crushing of the mortar, and the ends of the ties often slipped in the bed as much as ⅛ in.

Ties of 6- and 10-gage wire (ties 3 and 7) embedded in mortar *H* failed by pull-out; the ties of 8-gage wire, similarly bedded, failed in tension (with two exceptions), and the variation in the length of ear had but a slight effect on strength. An increase in the ear length of 8-

gage ties bedded in mortar *M* (ties 4, 5, and 6), however, did increase the strength of the specimens. All the 10-gage-wire ties (tie 7) bedded in mortar *L* pulled out of the specimen, whereas most of the specimens containing 6- and 8-gage-wire ties, bedded in this mortar, failed by crushing of the mortar.

TABLE 5.—*Tensile strength of wall tie speeimens* [a]

Tie number	Area of cross section	Kind of failure [b] and kind of mortar			Maximum load and kind of mortar			Maximum tensile stress in ties and kind of mortar		
		H	*M*	*L*	*H*	*M*	*L*	*H*	*M*	*L*
	*in.*²				*lb*	*lb*	*lb*	*lb/in.*²	*lb/in.*²	*lb/in.*²
3	0.0278	*P*	*Pm*	*M*	1, 540	1, 570	1, 210	55, 500	56, 600	43, 600
4	.0196	*T*	*P*	*M*	1, 470	1, 220	840	75, 000	62, 200	42, 800
5	.0196	*T* [c]	*Tp*	*Mp*	[d]1, 580	1, 320	800	[d]80, 600	67, 300	40, 800
6	.0196	*T* [c]	*Tp*	*Mp*	[d]1, 550	1, 420	900	[d]79, 000	72, 400	45, 900
7	.0135	*P*	*P*	*P*	890	870	540	65, 100	63, 700	39, 500

[a] Average values obtained from tests on groups of 5 like specimens unless otherwise noted.

[b] Key:

M=Crushing of mortar under tie followed by splitting of specimen.

P=Pull-out of tie.

T=Tensile failure of tie.

Mp=Predominant crushing of mortar, with pull-out failure of 2 specimens.

Pm=Predominant pull-out failure with motrar failure on 2 specimens.

Tp=Predominant tensile failure with pull-out failure for 2 specimens.

[c] Four specimens failed in tension, 1 by pull-out of the tie.

[d] Average of 4 specimens that failed in tension.

3. Discussion of Strength Data

Ties in cavity walls are intended to connect the two tiers and to serve as struts or tension members between them. Wall ties of the usual type do not have sufficient flexural rigidity to transmit shear across the cavity. Consequently, when one tier is subjected to a vertical load, only a small part of the load is transmitted to the other, and the two tiers do not exert common action under such loading.

Z-shaped ties of ¼-in. round steel bars, similar except for diameter to tie 3, were used in cavity-wall specimens subjected to impact and transverse loads;[6] ties of $\frac{3}{16}$-in. wire, similar except for diameter to tie 8, were in other cavity walls similarly tested.[7] Weakness of the individual ties did not contribute to the failure of the walls.

The strength of tie needed to assure that they would not deform excessively under lateral loading before the failure of a wall will depend upon such factors as the thickness of the tiers, the properties of the masonry materials, and the workmanship. Excepting tie 12, and assuming a tie spacing of one to each 3 ft² of wall area, the data in table 4 indicate that any combination of the ties and mortars included in the tests would provide connections of ample strength to resist the lateral forces such as wind loads to which cavity walls are usually subjected.

V. RESULTS OF WEATHERING TESTS

1. Indoor Exposure

The effects of the indoor-weathering exposure on the rusting of the ties are listed in table 6. The uncoated steel ties and those coated with neat cement or mortar were lightly rusted in 10 days or less, and most of them were severely rusted in 30 days. The cementitious coatings, especially those of the mortar *M*, did not retard rust formation, and even appeared to have had an accelerating effect on rusting. Coatings of Eternium coal-tar paint afforded some protection, but within 120 days the ties were severely rusted over portions adjacent to the inside faces of the brick. It is possible that the coatings at these points were nicked with the trowel when the mortar protruding from the joints was cut away.

The copper coatings on the Copperweld ties (tie 2) were darkened by the exposure, but no evidence of rusting of the steel beneath the copper was noted. One cut edge of one galvanized tie (tie 12) showed two very small and barely perceptible rusted spots after 180 days of exposure. A white discoloration was noted on the underside of these ties after 65 days of exposure.

The specimens were handled frequently during the exposure period, and it is possible that the high temperatures during weathering and the flexure of the ties during handling produced some damage to the coatings of Eternium paint and to those of cementitious materials.

[6] Building Materials and Structures Reports BMS23, Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick Manufacturers Association of New York, Inc., and BMS24, Structural Properties of a Reinforced Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute.

[7] Building Materials and Structures Report BMS21, Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association.

Table 6.—*Results of weathering exposure tests of coated and uncoated steel wall ties*

Tie number	Kind of tie	Kind of coating	Indoor-weathering time required for development of rust as indicated by [a] degree of rusting [b]			Outdoor-weathering time required for development of rust as indicated by [a] degree of rusting [b]		
			Light	Moderate	Severe	Light	Moderate	Severe
			Days	*Days*	*Days*	*Days*	*Days*	*Days*
2	Copperweld	Copper	-----	-----	-----	-----	-----	-----
3	Steel wire	No coating	9	45	65	7	17	25
4	Do	do	9	(c)	25	3	13	20
7	Do	do	6	25	30	5	15	30
3	Steel wire	Portland cement.	10	(c)	30	55	(c)	(e)
4	Do	do	10	(c)	30	(c)	(c)	(e)
7	Do	do	10	(c)	25	25	30	35
3	Do	Mortar *M*	(c)	6	11	30	(c)	35
3	Do	Eternium coal-tar paint.	30	45	120	35	50	(f)
4	Do	do	13	45	120	30	50	(f)
7	Do	do	30	55	70	30	60	(f)
12	Corrugated steel.	Galvanized	(d)	-----	-----	-----	-----	-----

[a] Dashes indicate no failure was noted during an exposure period of 6 months.
[b] *Light rusting* was the first visible rusting, *Moderate rusting* was the formation of a light crust or caking of rust. No visible enlargement of tie diameter; and, *severe rusting* was a thick encrustation of rust, irregular in color with a noticeable enlargement of tie diameter, and accompanied by pitting of the ties.
[c] Not noted.
[d] A white discoloration, probably of metallic salts was noted on the underside of the ties at 60 days. There was no rusting noted at 120 days. At 180 days, 2 very small rust spots were noted at 1 cut edge of 1 tie.
[e] No severe rusting noted at 70 days. At 180 days, severe rusting and cracking of the cement was noted.
[f] Moderate to severe rusting, principally at the ends of the ties, was noted at 180 days.

2. Outdoor Exposure

As can be noted (table 6) the uncoated steel ties corroded in less time when exposed to the outdoor than to indoor weathering. The cementitious coatings seemed to offer better protection to the ties when exposed outdoors than to those weathered indoors, but it is possible that rust on the ties in the outdoor-weathering specimens did not become noticeable until the corrosion of the steel had cracked the coatings. Ties coated with Eternium paint were moderately to severely rusted at points adjacent to the inner faces of the brick, after 180 days of exposure.

There was no rusting of steel in the ties coated with copper or zinc (ties 2 and 12, respectively).

VI. SUMMARY AND CONCLUSIONS

Ties for cavity-wall construction were tested in tension and compression when embedded at the ends in brick-mortar assemblies spaced to give a 2-in. cavity. Most of the ties were made of 6-, 8-, or 10-gage concrete-reinforcing steel wire, cut either from welded fabric or from coiled lengths. Other ties that were tested were Copperweld copper-coated Z-shaped steel ties, corrugated and galvanized steel strips, and I-shaped ties cut from sheets of cement-asbestos board. Three kinds of mortar were used, designated as *H*, *M*, and *L*, and mixed in the respective volume proportions of 1:0.25:3, 1:1:6, and 1:3:12.

Some of the ties coated with neat cement, mortar *M*, Eternium brand coal-tar paint, copper, or zinc, were exposed outdoors and others to artificial indoor weathering.

The following pertains to the structural strength of the specimens and to the corrosive effects on the plain and coated steel ties produced by exposure indoors to warm humid air and to outdoor weathering.

1. Compressive Strength

(a) Brick-mortar assemblies containing ties of 6-, 8-, and 10-gage steel wire embedded in mortars *H* and *M* failed by buckling of the ties; when the ties were embedded in mortar *L* the specimens failed by crushing of the mortar against the ends of the ties.

(b) Specimens built with mortar *H* that failed by buckling of the ties were nearly 10 percent stronger than similar specimens built with mortar *M*.

(c) Increase in the length of ear on Z-shaped ties, from 2 in. to 3 or 4 in., resulted in a slight but consistent increase in the strength of the specimens.

(d) Specimens containing a square tie cut from welded wire fabric of 6-in. mesh were stronger than those containing a rectangular tie 4 in. wide (of the same kind and diameter of steel wire) bent from one piece with butted, not welded, ends.

(e) **I**-shaped cement-asbestos ties with stems 1½ by ¼ in. in cross section were stronger than two-stem ties of No. 6 gage welded steel-wire fabric, 6-in. mesh.

2. Tensile Strength

(a) Z-shaped ties of 6- and 10-gage steel wire embedded in mortar *H* pulled out of the mortar beds; ties of 8-gage wire failed in tension.

(b) Most of the Z-shaped ties of the 6-, 8-, and 10-gage steel wire, embedded in mortar *M*, pulled out of the mortar beds, some of the 8-gage ties with ears 3 and 4 in. long failed in tension.

(c) Most of the specimens containing Z-shaped ties of 6- and 8-gage steel wire, embedded in mortar *L* failed by crushing of the mortar, with subsequent splitting of the brick-mortar assembly; ties of 10-gage wire pulled out of the mortar beds.

3. Corrosion of the Ties

(a) Light rust was observed on plain, uncoated steel wire during the first week of exposure, and these ties were severely rusted in about 30 days.

(b) Coatings of neat portland cement and mortar were ineffective and cracked away from steel ties that had rusted.

(c) Coatings of Eternium coal-tar paint prevented the corrosion of steel ties except where the coatings had been nicked with the mason's trowel during construction of the specimens.

(d) Zinc and copper coatings were effective in preventing the corrosion of steel ties.

Washington, February 12, 1943.

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