II–14. Flexural Strength of Nonreinforced Brick Masonry with Age

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ABSTRACT

Nonreinforced brick masonry walls must be strong enough to support both gravity and lateral loads, both during and after construction. Allowable stress values in current U.S. masonry codes are based on 28 days or older test data. For walls under construction (less than 28 days) no values for allowable stresses are suggested. Such information, in particular flexural bond strength, would be of benefit since current failures of walls under construction due to lateral wind forces are estimated to cause an annual U.S. loss of $500,000. In addition, current bracing requirements of masonry walls under construction are either nonexistent or confusing.

Concrete and clay brick masonry prisms of Type M, S, and N mortar and with inspected and non-inspected workmanship were tested in flexure using one-third point loading method of ASTM E 518 for eleven age intervals up to 28 days. The data at 28 days was evaluated in light of existing published full-scale wall and prism data and current clay and concrete masonry allowables for tension. Functions were generated to mathematically express wall strength with time for given mortar and workmanship conditions. Design curves were then developed to provide bracing requirements for various wall types under given conditions of wind loading, mortar type, workmanship, and age.

INTRODUCTION

Masonry walls must be strong enough to support gravity and lateral loads both during and after construction. Allowable stress values in current U.S.A. masonry codes are based on 28 days or older test data. For walls under construction (less than 28 days) no values for allowable stresses are suggested. Strength variation with age, in particular flexural bond strength, would be of benefit since current failures of walls under construction due to lateral wind forces are estimated to cause an annual loss in the U.S.A. of at least $500,000. In addition, current building code bracing requirements for masonry walls under construction are either nonexistent or vague and inconsistent.

Concrete and clay brick masonry prisms of Type M, S, and N mortar and with inspected (full bed joint) and non-inspected (deeply furrowed bed joints) workmanship were tested in flexure using one-third point loading method of ASTM E518 for the eleven age intervals of 8 hours, 1, 2, 3, 4, 5, 6, 7, 14, 21, and 28 days. The data at 28 days was evaluated in light of existing published full-scale wall and prism data and current clay and concrete masonry code allowables for tension. Functions were generated to mathematically express wall strength with time for given mortar and workmanship conditions. Allowable flexural bond stresses were then developed using factors of safety currently found in existing masonry codes.

MATERIALS AND TEST PROCEDURE

Masonry prisms were constructed one wythe thick, one unit long, seven units high, in stack bond, with 3/8″ concave tooled mortar joints on one face tested down. Specimens were built outside in the summers of 1977 and 1978. They were cured under exposed southern summer conditions until their designated test date. The 1977 program was conducted at UT Austin and all specimens used Type S mortar.[1] The 1978 program was conducted at UT Arlington and specimens used both Type M and Type N mortars.[2,3] Although masonry units from different manufacturers were used for the Austin and Arlington project, the same mason built all specimens. Five replications for each test date were made for the following:

1. Inspected workmanship, clay brick, Type M and N mortar
2. Uninspected workmanship, clay brick, Type M, S, and N mortar
3. Inspected workmanship, concrete brick, Type M and N mortar
4. Uninspected workmanship, concrete brick, Type M, S, and N mortar

A total of 550 specimens were tested.

Type M, S, and N mortars were proportioned by volume according to ASTM C270 using Type I Portland cement, Type S lime, and natural masonry sand. Gradation of sand by ASTM C144 was acceptable. All mixing was done in an electrically driven pan type mixer with rotating blades on a horizontal axis. The mixing time was five minutes. The quantity of water used was determined by the experienced mason to be typical of the workability of the various mortar types currently found in construction. Initial flow and air content of each batch of mortar were determined according to ASTM C109 and C173. All mortars had a flow of approximately 118. Air contents for Type M, S, and N mortars were 5.0, 6.5, and 6.6% respectively.

Clay and concrete brick masonry units were used in construction of prisms. The clay bricks were three-hole cored nominal 4″ × 2-2/3″ × 8″ units.

The concrete masonry units were solid nominal 4″ × 2-2/3″ × 8″ expanded shale aggregate lightweight units. The average properties of five tests for each unit type according to ASTM C67 and ASTM C55 are given in Table 1.

The prism flexural test was conducted according to ASTM E518. With a span of approximately 45 inches, a five-pound, 15-inch deep channel was used for third-point loading. A uniformly distributed load induced with an air bag under pressure was not used in these tests because the one-third point loading test gives lower values of strength. To avoid localized bearing stresses, the load was transmitted through 1/4" thick leather shims as shown in Figure 1. Failures occurring outside the middle two joints were discarded and additional test specimens constructed.

TEST RESULTS

For third-point loading, the gross area modulus of rupture was determined from the following equation:

$$R = \frac{(P + 0.75\, P_s)\, L}{bd^2}$$

Where

R = gross area modulus of rupture, psi
P = test machine load reading at failure plus 5 lb. channel weight, lbs.
P_s = specimen weight, lbs.
L = span, in.
b = average specimen width, in.
d = average specimen depth, in.

ANALYSIS OF TEST DATA

The test results showing variation of average modulus of rupture with age are given in Table 2 and in Figures 2 through 5. The coefficient of variation for the inspected tests varied from 8 to 25% while for non-inspected from 10 to 30%. The scatter of test results is understandable in light of variation in materials, workmanship, and in particular, weather effects. The average maximum temperature was 96° for the 28-day period, the average minimum temperature was 75°, and the average wind velocity was 9 mph. The prisms were exposed to direct sunlight for about 10 hours per day. These conditions are typical for a brick wall during the summer months on most construction sites. Obviously better control would have resulted based on laboratory curing conditions but would not have been representative of field conditions. The average modulus of rupture showed a rapid increase in the first two- or three-day period followed by an "up and down" period which slowed to a steadier trend towards the 28-day test. Statistical corrections based on lower bound resulted in essentially the same pattern. After consideration of several possible curve fitting approaches, the following conservative method was used to obtain a reasonable mathematical function for variation of tensile strength with age. Future testing on control laboratory specimens may liberalize this approach. A linear regression line of average modulus of rupture versus age of masonry was found for each type of masonry prism. The correlation coefficient indicated that a non-linear relationship is probably better suited for the test data reported. By examination of all the prism types, the 5-day test result appears to be a relatively stable lower point. It was decided to use an exponential curve of $ft = at^b$ from the origin through the 8-hour and 5-day test values. For this region, the final exponential equation to predict ultimate average modulus of rupture uses the average of the exponential values (b) for Type M and N mortar with different coefficient values (a) for the different mortar types. The linear regression line for 5 to 28 days was slightly shifted to match the average exponential curve value at 5 days. See Figures 2 through 5.

The allowable tensile stresses in existing BIA (Brick Institute of America) and NCMA (National Concrete Masonry Association) Codes are based on 28-day full-scale wall strength tests.[4,5] For each mortar type and workmanship condition, a factor of safety can be obtained by dividing ultimate strength full-scale wall test average by the current code allowable. Assuming that full-scale wall strengths versus age would vary in exactly the same manner as prism tests, the exponential and linear regression expressions developed from prism tests were reduced by the appropriate factor of safety based on mortar type and workmanship. See Figures 2 through 5.

REFERENCES

1. "An Experimental Study to Determine the Flexure Strength vs. Age for Masonry Walls," Issam Mahmoud, M.S. Thesis, Civil Engineering Department, University of Texas at Austin, Austin, Texas, May, 1978

2. "Flexural Strength of Nonreinforced Brick Masonry Walls with Age Using Type M Mortar," Behrooz Ghomghani, M.S. Thesis, Civil Engineering Department, University of Texas at Arlington, Arlington, Texas

3. "Flexural Strength of Nonreinforced Brick Masonry Walls with Age Using Type N Mortar," Yuan-Hung Huang, M.S. Thesis, Civil Engineering Department, University of Texas at Arlington, Arlington, Texas

4. Monk, C.B., Jr.: *Transverse Strength of Masonry Walls*, Symposium on Methods of Testing Building Construction, ASTM STP 166, American Society of Testing and Materials, Philadelphia, Pennsylvania, 1954

5. Substantiation for "Specification for Design and Construction of Load Bearing Concrete Masonry," National Concrete Masonry Association, McLean, Virginia

TABLE 1—Dimensions and Physical Property of Brick

Material	Width (in.)	Length (in.)	Height (in.)	Gross Area (in.^{2})	Net Solid Area %	Initial Rate of Absorption g/min-30 sq. in.
University of Texas at Austin						
Clay	3.58	7.65	2.25	27.43	75.2	11.07
Concrete	3.63	7.71	2.25	27.98	100.0	—
University of Texas at Arlington						
Clay	3.51	7.71	2.31	27.10	80.4	18.60
Concrete	3.64	7.56	2.25	27.50	100.0	—

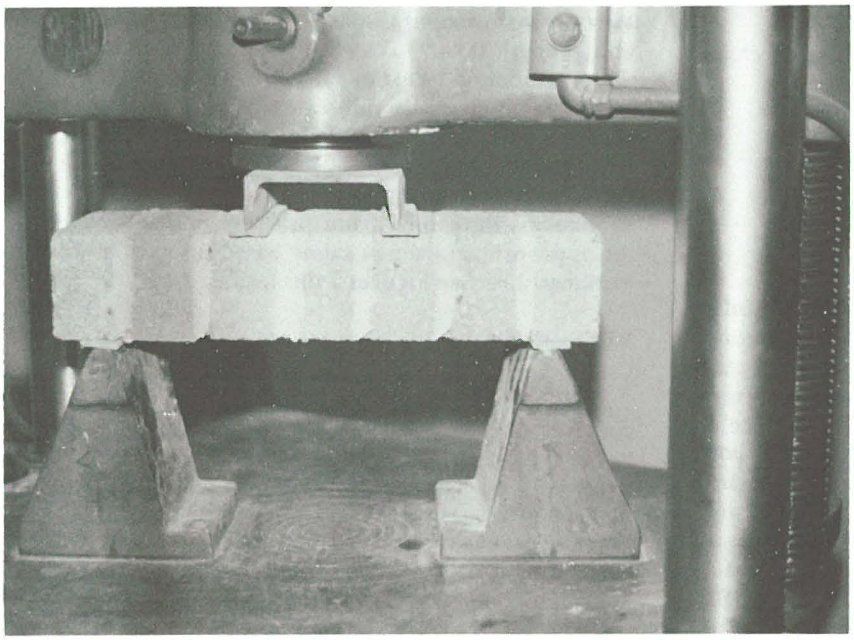

Figure 1. Prism Flexural Test

TABLE 2—Average Modulus of Rupture

	Clay Brick				Concrete Brick			
	Inspected		Non-Inspected		Inspected		Non-Inspected	
Age Days	ft psi	V %	ft psi	V %	ft psi	V %	ft psi	V %
			Type M Mortar—UT Arlington					
1/3	58.4	7.5	37.2	26.6	28.7	8.7	27.1	23.2
1	102.2	16.8	64.7	24.9	74.4	6.9	57.1	17.5
2	169.0	11.6	79.6	17.1	92.2	16.7	46.2	23.6
3	101.2	15.0	91.0	19.1	90.2	14.7	49.1	20.2
4	233.3	13.2	95.6	24.9	131.2	16.7	58.1	27.7
5	140.7	11.6	60.0	25.7	77.5	29.4	56.5	25.8
6	135.1	20.9	67.3	21.1	106.5	13.5	77.5	21.0
7	195.1	17.0	80.0	23.9	116.2	14.0	99.5	28.1
14	191.2	21.7	135.2	17.8	144.5	25.8	52.3	2.1
21	164.3	19.7	57.4	30.0	115.8	19.6	37.1	15.6
28	146.2	17.6	85.6	13.3	141.3	18.5	35.0	28.0
			Type S Mortar—UT Austin					
1/3			57	16			30	15
1			47	18			32	22
2			62	22			27	33
3			67	12			22	28
4			69	33			18	36
5			31	30			14	17
6			50	43			22	35
7			50	32			24	18
14			70	28			17	44
21			55	21			21	41
28			69	18			19	43
			Type N Mortar—UT Arlington					
1/3	36.2	14.5	25.6	15.0	19.6	19.6	20.2	16.2
1	73.4	26.3	83.0	15.8	41.4	4.7	37.6	13.1
2	110.0	16.5	50.8	8.9	46.8	13.5	30.0	10.9
3	92.8	17.9	59.5	18.6	38.0	15.8	27.6	25.7
4	123.8	13.8	69.8	9.8	69.2	5.1	55.0	14.4
5	96.6	13.0	58.5	8.5	43.2	10.5	41.0	15.1
6	105.2	13.8	62.0	4.3	53.5	2.4	44.0	16.1
7	115.8	25.5	52.8	9.3	71.4	16.4	52.8	24.2
14	46.0	17.0	53.3	20.7	78.0	19.4	32.0	15.5
21	84.3	18.4	38.5	27.6	50.0	24.3	36.0	3.9
28	148.8	9.7	43.0	9.9	48.7	40.4	23.5	15.0

ft = average modulus of rupture
V = coefficient of variation

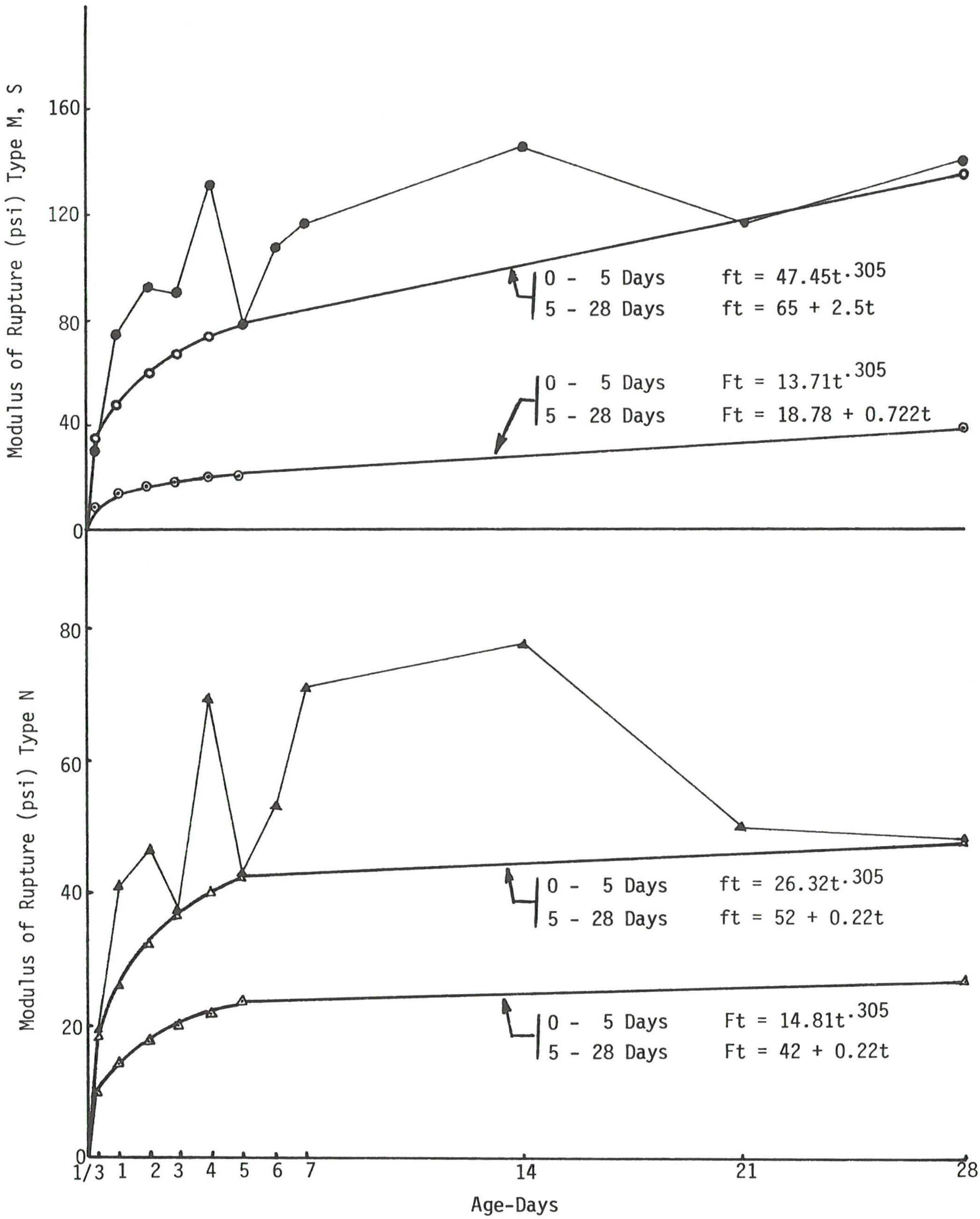

Figure 2. Modulus of Rupture-Clay Brick-Inspected

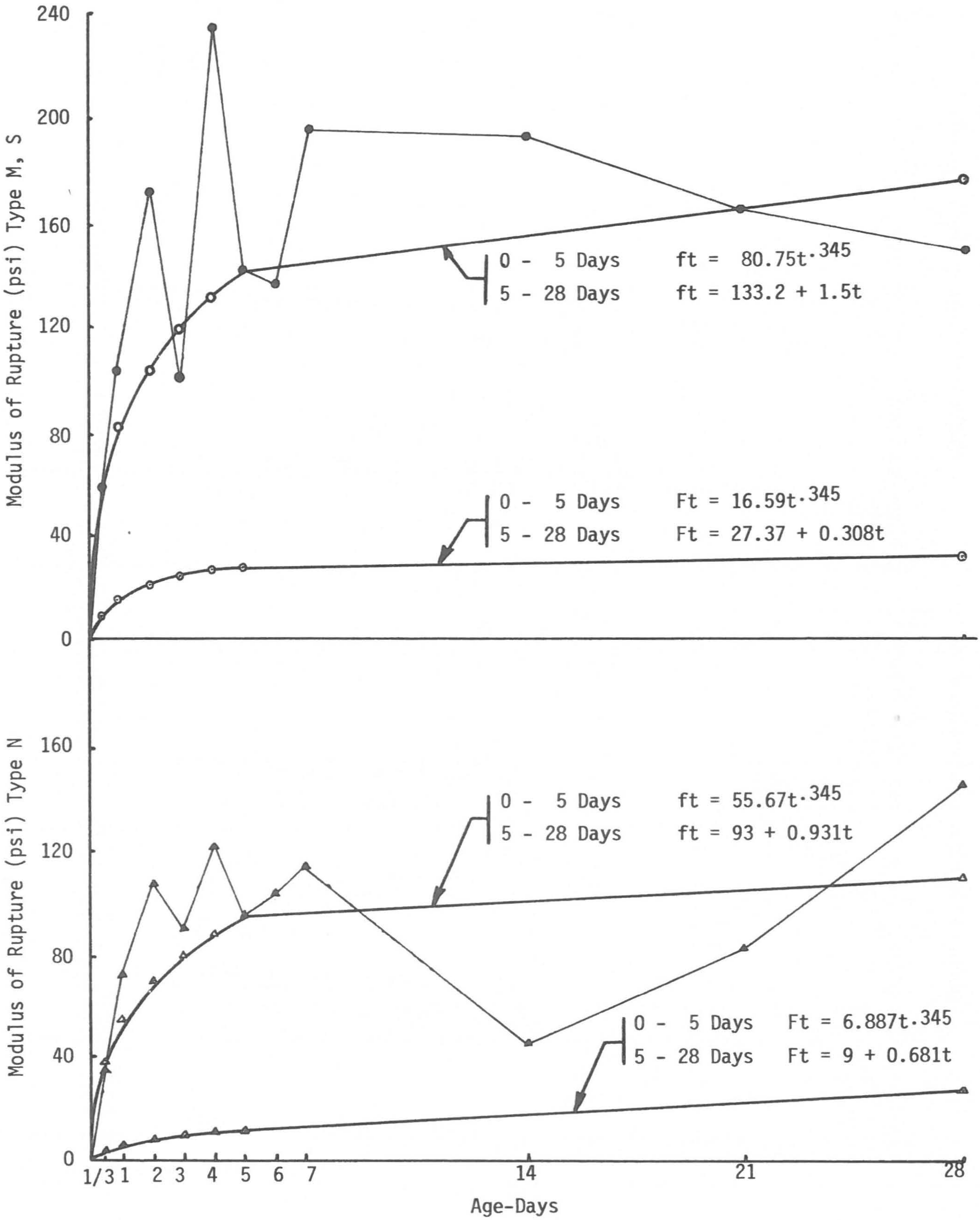

Figure 3. Modulus of Rupture-Concrete Brick-Inspected

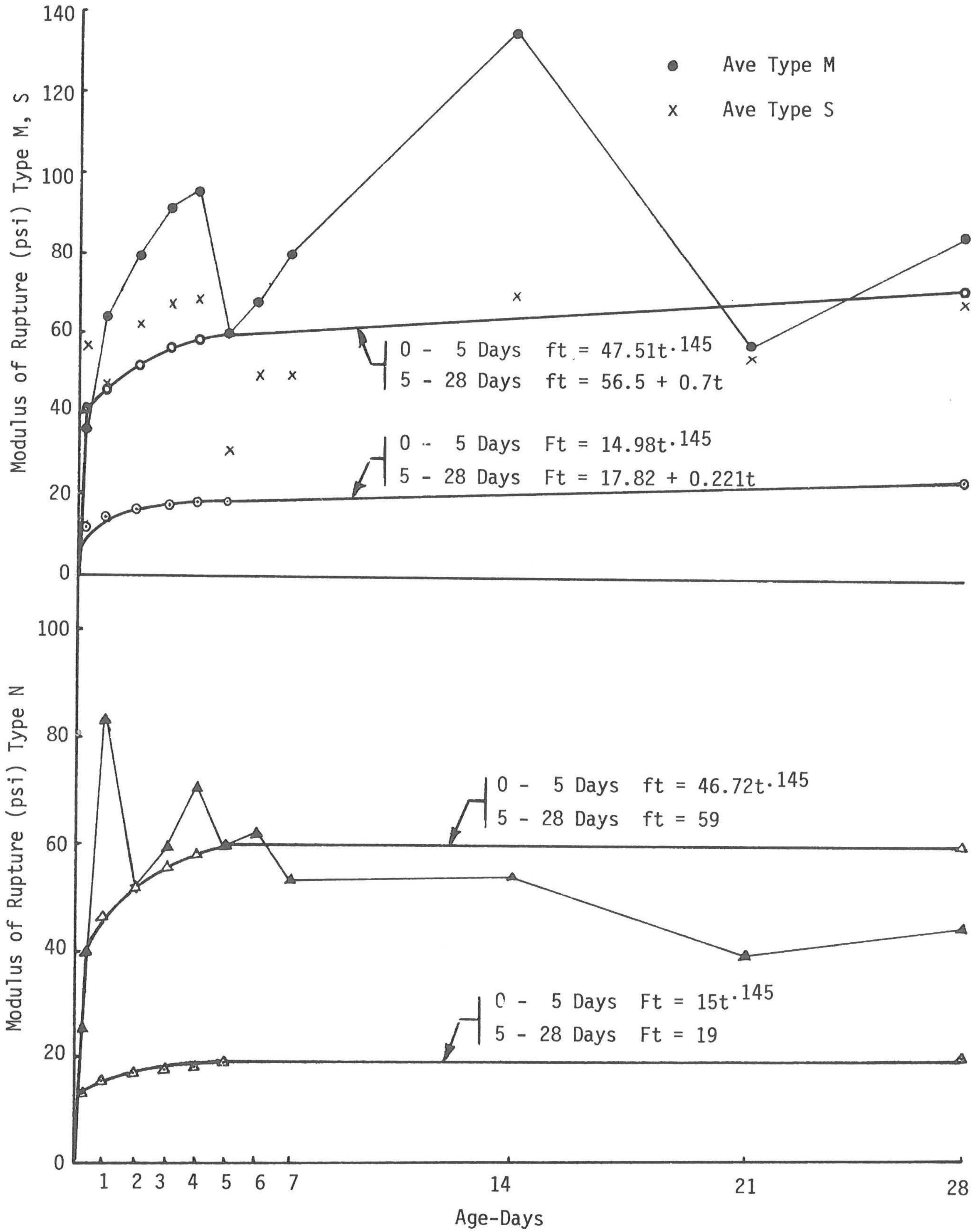

Figure 4. Modulus of Rupture-Clay Brick-Non-Inspected

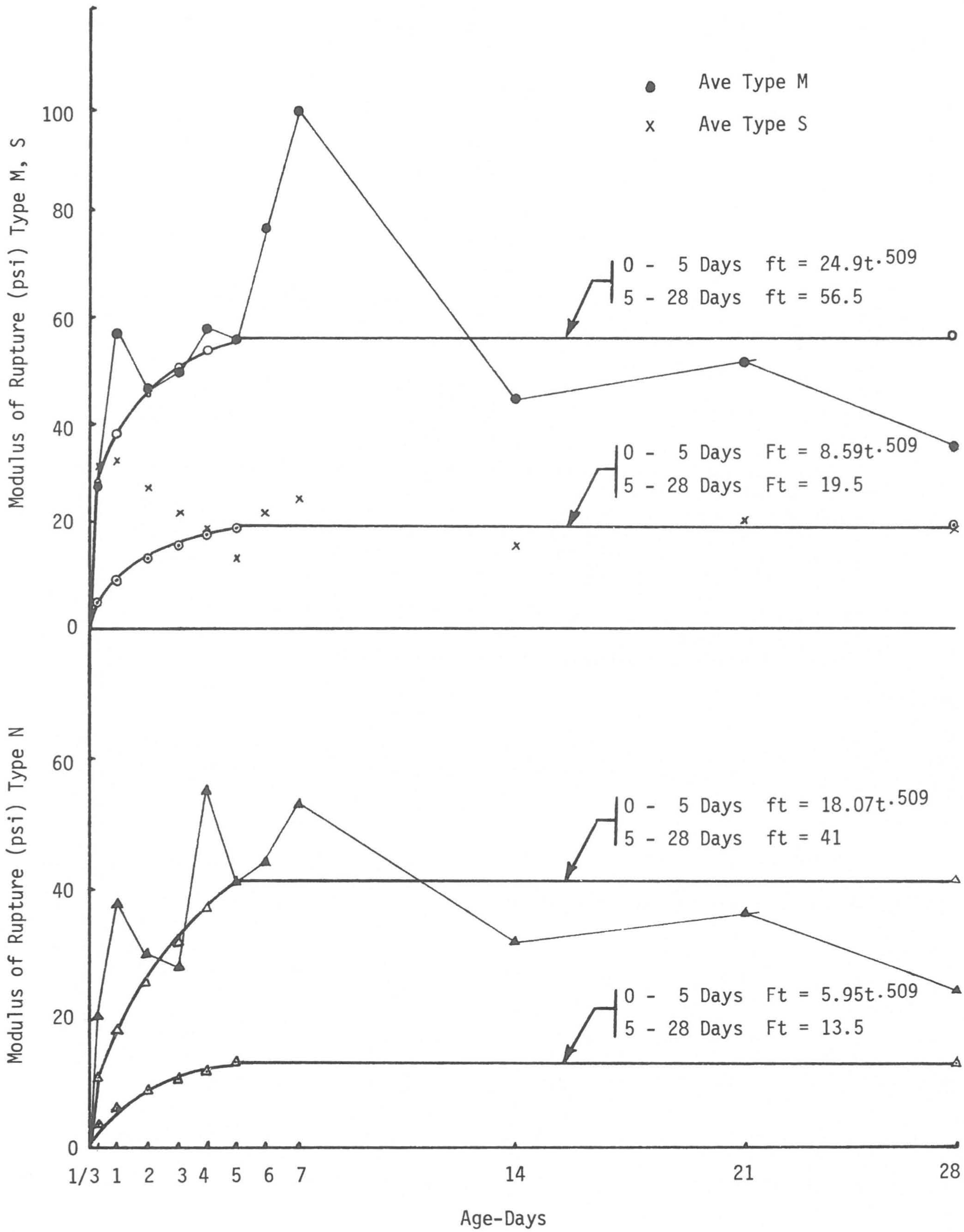

Figure 5. Modulus of Rupture-Concrete Brick-Non-Inspected