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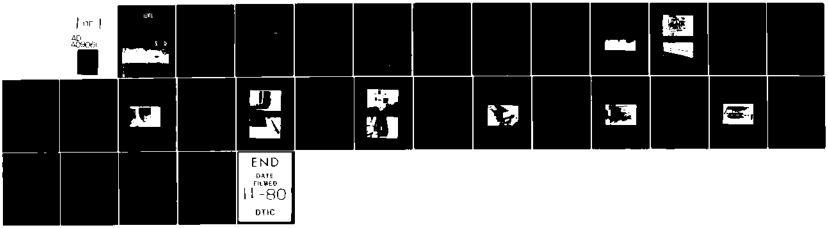

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INVESTIGATION OF DISTRESSED COMPOSITE WALLS, U. S. ARMY RESERVE ARMORY, GREENWOOD, MISSISSIPPI

by

Robert H. Denson

Structures Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1980

Final Report

Prepared for U. S. Army Engineer District, Ft. Worth
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The distressed condition of the composite walls was characterized by saturated interior wall portions and water ponding on floors. The walls were of composite design involving brick, parged bedding, and concrete masonry units, with gypsum board as a final interior covering in certain areas. Two composite and two cavity wall models were built on concrete pedestals which represented floor slabs. The models were subjected to static heads of water and water spray applications simulating rain to determine the effectiveness (continued)

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20. ABSTRACT (continued).

of each type of wall to resist water movement through the wall from the exterior to the interior. Volumes of moisture and times of migration were measured and recorded. No water migrated through the composite-wall model during the spray and static head tests. Water migrated through the veneer of the cavity wall into the cavity and drained out through a weep hole. Based on these tests, properly constructed composite walls should effectively protect against intrusion of rain.

PREFACE

This work was authorized by Intra-Army Order for Reimbursable Services (DA Form 2544) No. E87790190, dated 28 August 1979, and was conducted by the Structures Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U. S. Army Engineer District, Ft. Worth. The work was accomplished under the general supervision of Messrs. Bryant Mather, Chief, Structures Laboratory; J. M. Scanlon, Chief, Concrete Technology Division; and G. C. Hoff, Chief, Materials and Concrete Analysis Group. Other staff members actively participating in the investigation were Mr. Robert H. Denson, who prepared this report, and Ms. Donna Skipper. The project was coordinated with Mr. Roy Perkins, Ft. Worth District.

Commander and Director of WES during the preparation and publication of this report was COL Nelson P. Conover, CE. Technical Director was Mr. Fred Brown.

CONTENTS

CONVERSION FACTORS, INCH-POUND UNITS TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
mils	0.0254	millimetres
inches	2.54	centimetres
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	0.006894757	megapascals
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
gallons per minute	3.785412	litres per minute

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

INVESTIGATION OF DISTRESSED COMPOSITE WALLS, U. S. ARMY RESERVE ARMORY, GREENWOOD, MISSISSIPPI

PART I: INTRODUCTION

Background

1. On 2-3 August 1979, Mr. Roy Perkins, Architectural Section, Design Branch, Ft. Worth District, and Mr. Robert H. Denson, Structures Laboratory (SL), Waterways Experiment Station (WES), conducted an on-site investigation of the Greenwood, Mississippi, U. S. Army Reserve Armory (Figure 1). The exterior walls of this facility are of composite design of brick, parged bedding, and concrete masonry units (CMU). In certain areas, gypsum board was used as a final interior wall covering.

2. Examination of the exterior of the building revealed evidence of efflorescence (Figure 2), open mortar joints, and epoxy grout mortar joint repair at certain locations. The exterior examination was interrupted by an afternoon rain shower. When the investigation was resumed the following day, it was discovered that certain CMU surfaces of the roof parapet displayed evidence of a moisture content gradient as shown by surface discoloration and shading (Figure 3).

3. Examination of the interior of the building revealed ponded water on the floor adjacent to saturated walls in several locations. In some instances the walls had dark brown stains and streaks. In certain other locations the gypsum board was completely saturated and could be easily deformed and imprinted with only slight finger pressure. One wall in the kitchen of the building displayed evidence of moisture behind the ceramic tile facing.

4. After completion of the on-site investigation it was agreed that SL, WES, would conduct an investigation to determine the effectiveness of a composite wall construction similar to the Greenwood Armory walls to protect the interior of a structure against rainfall.

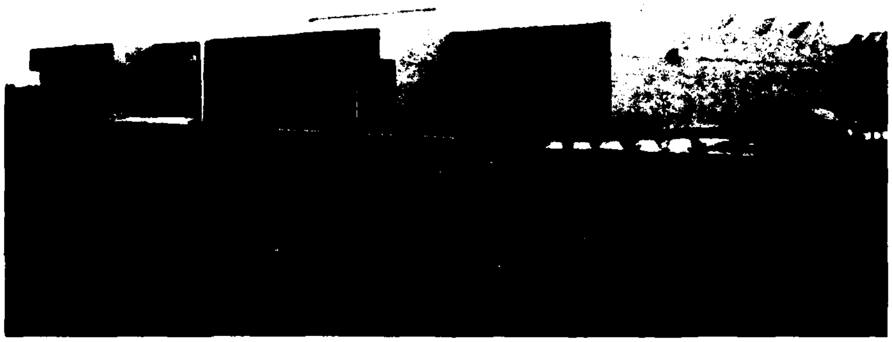


Figure 1. U. S. Army Reserve Armory, Greenwood, MS

Figure 2. Typical efflorescence on exterior wall

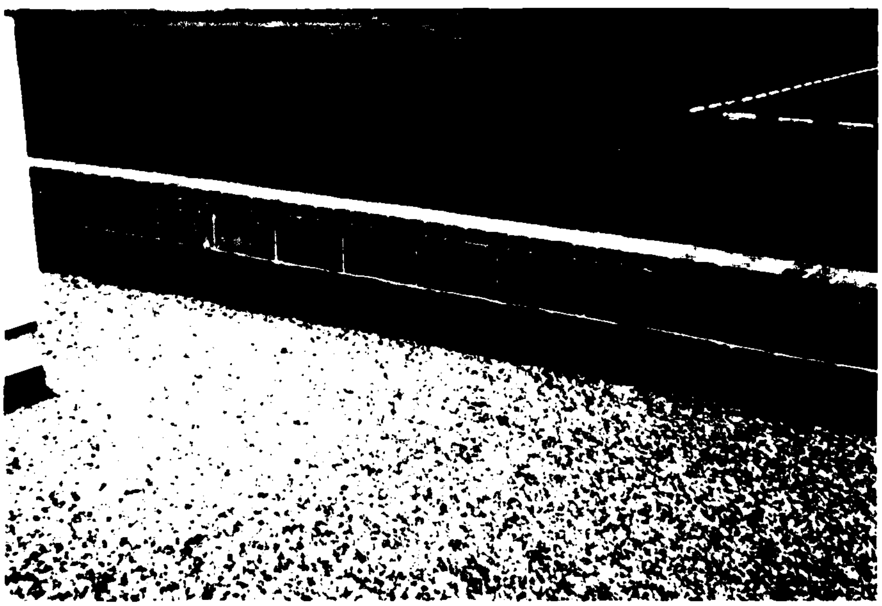


Figure 3. Rainfall effect on CMU parapet wall

Objective

5. The principal objective of the study that is reported on herein was to determine the protective effectiveness of a composite wall to resist moisture migration associated with rainfall through the wall.

Approach

6. Model composite walls were constructed and tested to develop data from which conclusions could be drawn as to the protective effectiveness of that type of wall against rainfall saturation. In addition, model cavity walls were constructed and tested in a similar manner and results compared to the composite walls.

PART II: TESTS OF MODEL COMPOSITE AND CAVITY WALLS

Materials

General

7. The Ft. Worth District provided as-built sketches of the typical exterior wall of the Armory and provided information for the dimensions and characteristics of a typical cavity wall.

Bricks

8. One hundred bricks remaining from the construction of the Armory were obtained from the project contractor. The job specifications described these bricks as being "modular size, American Society for Testing and Materials (ASTM), ASTM C 216-75 Grade SW, Type FBS." It was implied that these bricks meet those specifications since they were from the lot used for actual construction. The brick have nominal dimensions of 3-5/8-in. high by 3-5/8 in. thick by 11-5/8-in. long and have dry weights of approximately 8 lbs.

Parged bedding

9. Mortar for the parged bedding was produced as specified in ASTM C 270-73, Type M, using laboratory stock Type I cement, and fine aggregate, meeting the requirements of ASTM C 144-76.

Concrete masonry units

10. Concrete masonry units were procured from the same producer who provided the CMU for the Armory construction. The blocks have nominal dimensions of 7-5/8-in high by 7-5/8-in. thick and 15-5/8 in. long, and have dry weight of approximately 23.5 lbs.

Concrete for model floor slabs (pedestals)

11. Concrete for the model floor slabs was produced from laboratory stock Type I cement, 3/4 in. crushed limestone coarse aggregate, and manufactured limestone sand. The concrete was proportioned to achieve 3000 psi compressive strength in 28 days.

Construction of Model Walls

Composite Wall

12. Two composite wall models were constructed in accordance with Figure 4. The pedestal was 4 ft long with the model wall being four brick courses high on the exterior face and one block high on the interior (Figure 5). A collection trough was formed in the pedestal at the outer edge of the base of the blocks and was used to collect any water migrating through the bricks for measurement. One model was used for a spray test and the other for static head test.

Cavity wall

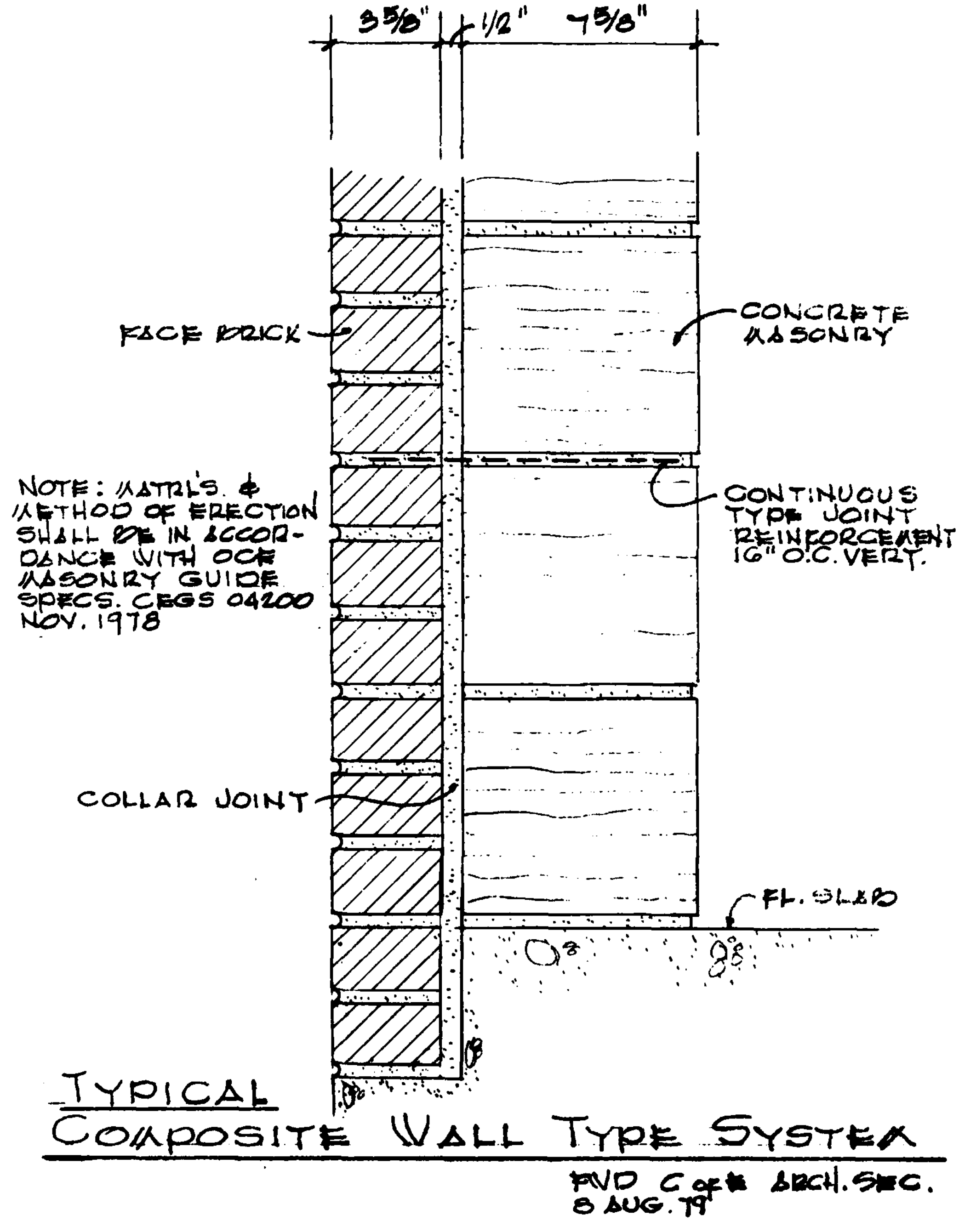
13. Two cavity wall models were constructed in accordance with Figure 6. The pedestals were 4 ft long with the model wall being four brick courses high on the exterior face and one block high on the interior (Figure 7). One model was used for the spray test and the other for the static head test.

Composite Wall Tests

Spray test

14. Once the composite wall model had been constructed, a spray bar was mounted 1 ft from the exterior face of the bricks about 3 in. below the top of the model. The spray bar was composed of a 3-ft long by 3/4-in. diameter steel pipe which had thirty-four 1/16-in. holes at 1 in. centers arranged in three rows 1/4 in. apart. A bulkhead containing the spray bar was built around the brick exterior of the model with all edges being sealed (Figure 8). A sheet of clear plastic was placed on top of the model to prevent stray moisture from entering or leaving the sprayed area. This sheet was sealed along the edges with clay and asphalt. The sides and front of the pedestal and the ends of the brick and block wall were also coated with an asphalt roofing cement. Water was sprayed for 4 hr at an approximate rate of 3.5 gpm on an area 16 in. high by 4 ft wide on the exterior face of the model. At the end of this

Figure 4


3 5/8"
1/2"
7 5/8"
FACE BRICK
CONCRETE MASONRY
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CONTINUOUS TYPE JOINT REINFORCEMENT 16" O.C. VERT.
COLLAR JOINT
FL. SLAB
TYPICAL
COMPOSITE WALL TYPE SYSTEM
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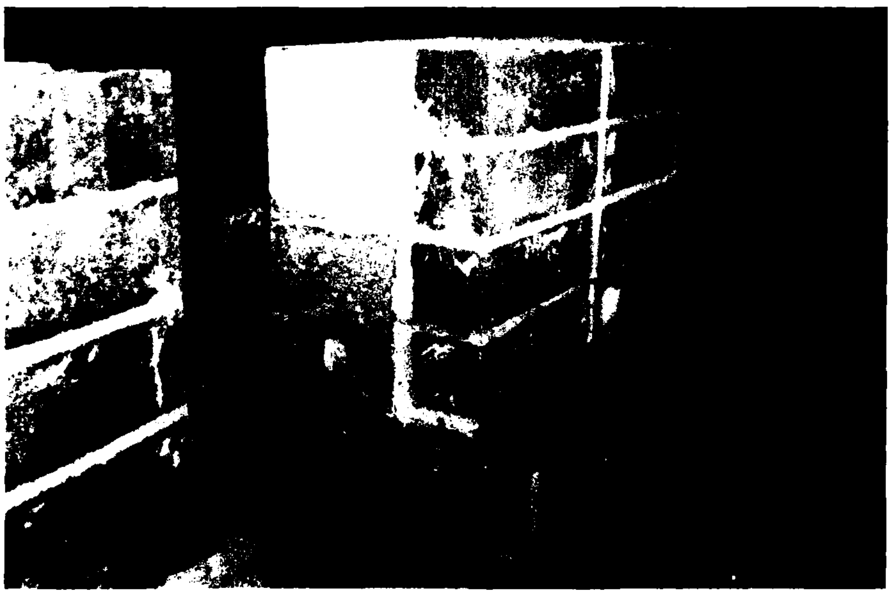
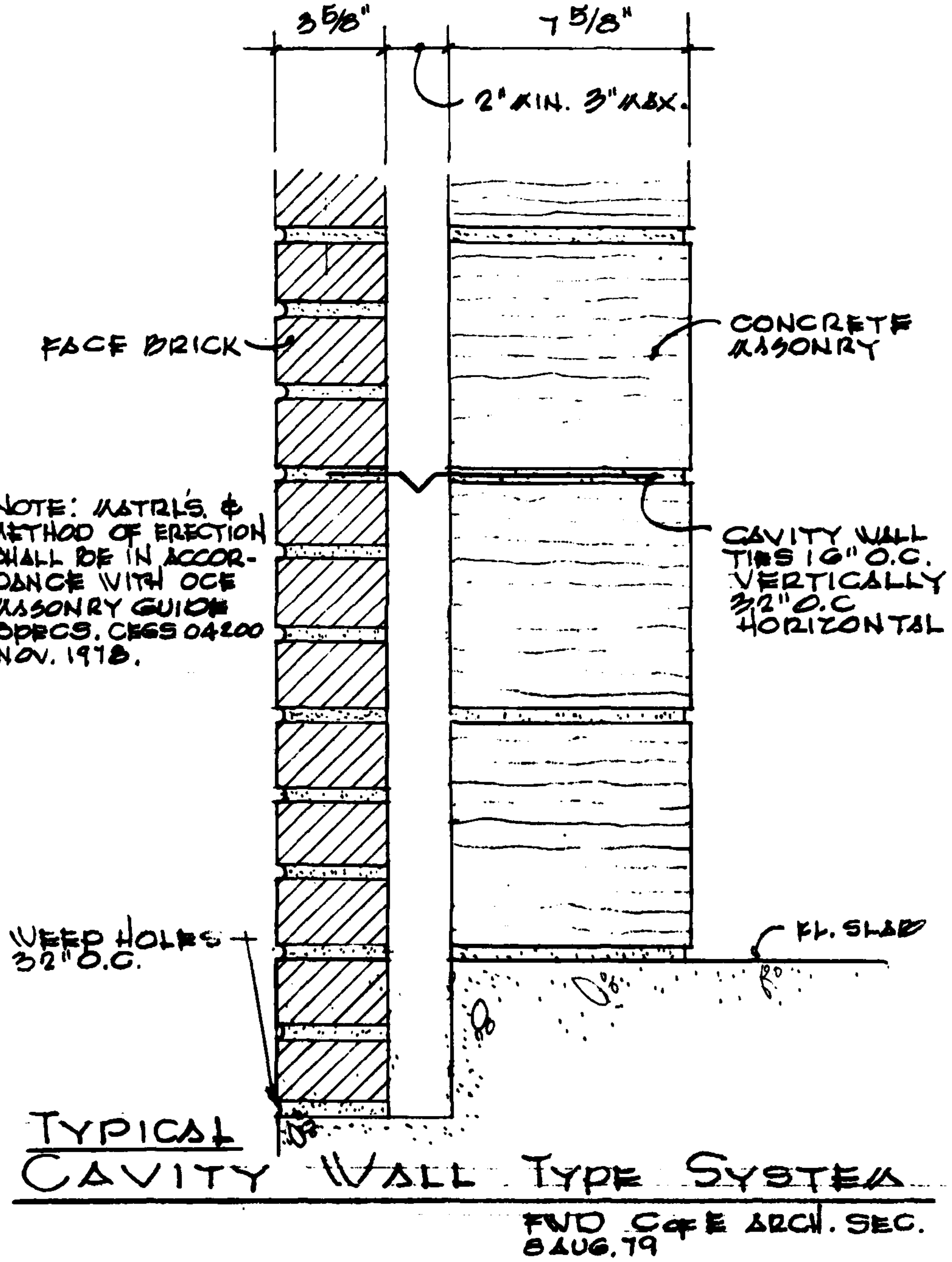


Figure 5. Composite wall model

Figure 6



3 5/8"
7 5/8"
2" MIN. 3" MAX.
FACE BRICK
CONCRETE MASONRY
NOTE: MATRL'S. & METHOD OF ERECTION SHALL BE IN ACCORDANCE WITH OCE MASONRY GUIDE SPECS. CEGS 04200 NOV. 1978.
CAVITY WALL TIES 16" O.C. VERTICALLY 32" O.C HORIZONTAL
FL. SLAB
WEEP HOLES 32" O.C.
TYPICAL CAVITY WALL TYPE SYSTEM
FWD C of E ARCH. SEC. 8 AUG. 79

Figure 7. Cavity wall model

Figure 8. Composite wall spray test

period no water had entered the walls nor was evident on the back face of the blocks.

Ultrasonic pulse velocity (UPV) test (sprayed wall)

15. The ultrasonic pulse velocity method (Figure 9) is used to generate compressional waves through a known distance in concrete and other materials.* By measuring the time of travel of the wave through this known distance, velocities through the material can be calculated by using the following relationship:

$$\text{Pulse velocity, fps} = \frac{\text{Path length, ft}}{\text{Effective time, sec.}}$$

The pulse velocity test provides a nondestructive method for determining an index of the condition or quality of the concrete through which the readings are taken. This method is used extensively in the field for determining the general quality of concrete, locating cracked and inferior concrete, and providing input to condition surveys of concrete structures. By first developing pulse velocity versus other physical property data in the laboratory for any materials in question, this method is readily adaptable for structures composed of these materials when evaluated in the field.

16. Readings were taken on the model wall before and after the spray test was conducted in order to determine if any intrusion of water produced an appreciable difference in velocities and also to estab'ish the quality of continuity of path length. Six readings (two on each block) were taken on the model. The transducers were placed in line with the web between the block cells thus avoiding the cavities in the block and at approximately the 1/3-points of the block height (Figure 10). The following results were obtained:

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* U. S. Army Engineer Waterways Experiment Station, CE, "Handbook for Concrete and Cement" CRD-C 51-72, "Standard Method of Test for Pulse Velocity Through Concrete."

Figure 9. Instruments of ultrasonic pulse velocity test method

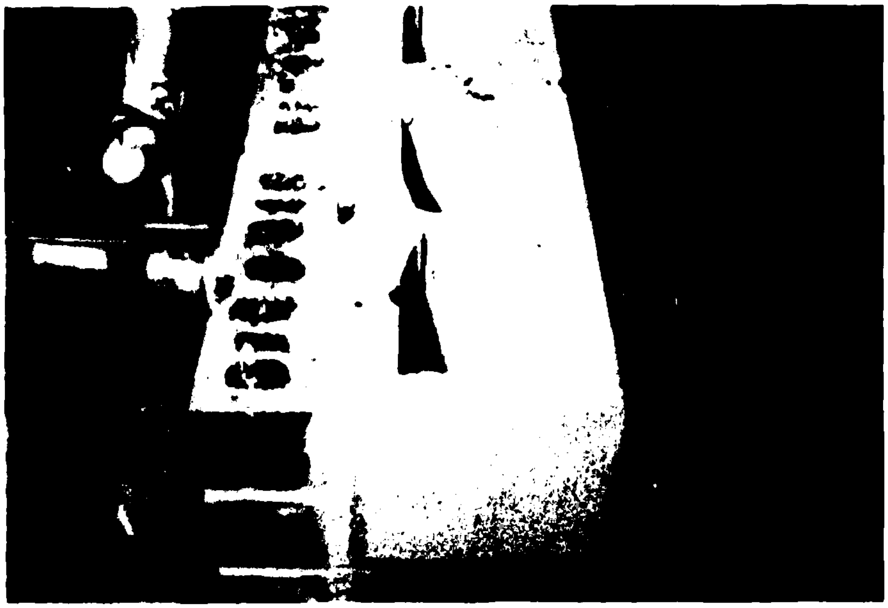

Figure 10. UPV determination - composite wall (dry)

Block/Point	UPV Dry fps	UPV Wet fps
1/A	7618	7797
1/B	7560	7797
2/A	8686	8458
2/B	8248	8458
3/A	8048	7921
3/B	7448	8048

Depending on several interrelated factors such as porosity, void ratio, and absorption, a 15 percent increase in velocities (based on "dry" velocities) is possible due to the presence of appreciable amounts of water. This is not indicated by the above readings and was further substantiated by the visual observations.

Static head test

17. A second composite wall model was constructed for use in a static head test. Clear plastic 1/4-in. thick was used to construct an inclosure for the front or exterior face of the model (Figure 11). A clear plastic bottom was placed in the enclosure above the first course of brick. The resultant head of water was 8 in. high by 4 ft long by 1-3/4 in. thick. Twenty minutes after the 8 in. head was established, water had migrated through the face and had begun seeping into the block cells. After 4 hr the water stains showed no signs of growing, no water had collected nor come through the back face of the blocks.

Ultrasonic pulse velocity (static head)

18. The UPV test method, as described in paragraph 16, was applied to this model before and after the static head test with the following results:

Block/Point	UPV Dry fps	UPV Wet fps
1/A	7804	6937
1/B	7568	6937

(Continued)

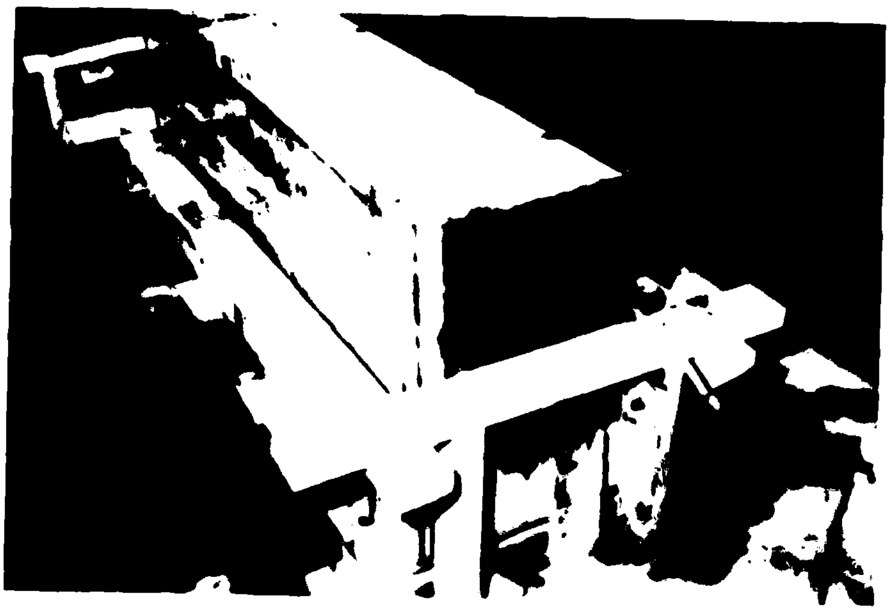

Figure 11. Composite wall static head test

Block/Point	UPV Dry fps	UPV Wet fps
2/A	8466	7797
2/B	8325	7797
3/A	7626	6750
3/B	7626	6750

The velocities through the wet material are consistently lower than through the dry material. This may indicate the presence of a discontinuity along the path length probably between the parged bedding and blocks after the dry readings were taken and during the time the plastic tank was attached. This could account for the presence of water staining on the inside of the blocks noted by visual observations.

Cavity Wall Tests

General

19. The major difference between the composite and cavity wall is the absence of the parged bedding in the cavity wall. It was decided to test the cavity wall in the same manner as the composite wall in order to make a comparison between the two and also to try to determine the effect of the parged bedding to either inhibit or assist in the migration of water.

Spray tests

20. Once the first cavity model was constructed and properly sealed, a steel pipe spray bar was mounted 1-1/2 in. from the brick much in the same manner as in the composite wall spray test (Figure 12). The pipe had thirty-four 1/16-in. diameter holes spaced 1 in. apart arranged in two rows 3/4-in. apart.

21. Water was sprayed at an approximate rate of 3.0 gpm over an area 12-in. high by 4 ft long. Four and one-half minutes after the spray was begun, water started coming from the wall cavity through the weep hole into the drain on the front of the model at an average rate of 0.03 gpm (2 ml per second) and remained constant at that rate for

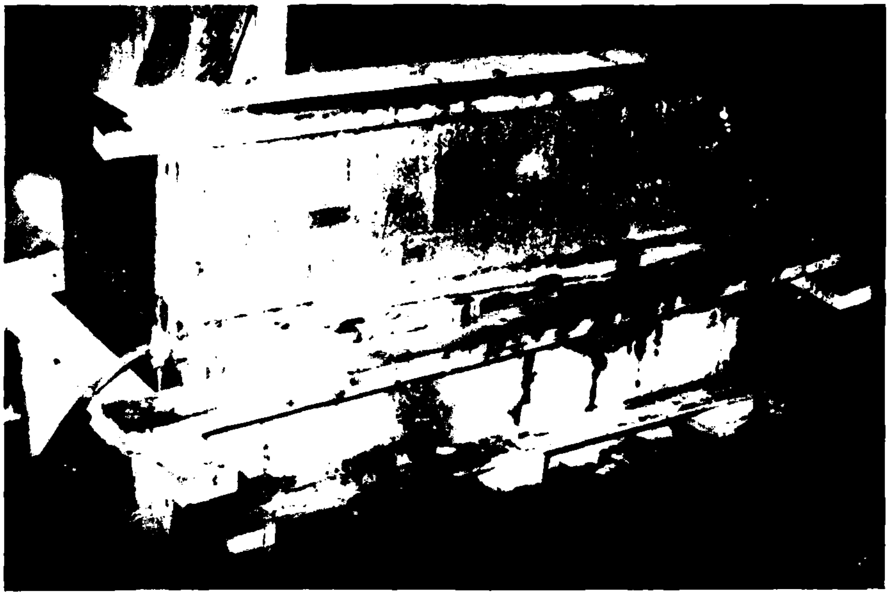

Figure 12. Cavity wall spray test

1 hr. Thirty minutes after the spray was started a 3/4-in. head built up in the wall cavity and remained constant for 30 min. There was no evidence of water migration through the blocks.

Static head test

22. A second cavity wall was constructed for use as a static head test. Sheet plastic 1/4-in. thick was placed on the sides and front and properly sealed to form an enclosure for the exterior face (Figure 13). A sheet plastic bottom was placed in the enclosure above the first course of bricks. This was done to allow water that migrates through the wall into the cavity to drain out through the weep hole.

23. As soon as the 8-in. head was established, water went through the brick veneer into the cavity and back out the weep hole. The rate of migration was approximately 0.02 gpm (1.23 ml/sec). This gradually decreased to 0.005 gpm (0.32 ml/sec) after 2 hr. No water was observed on the blocks on the interior face of the model.

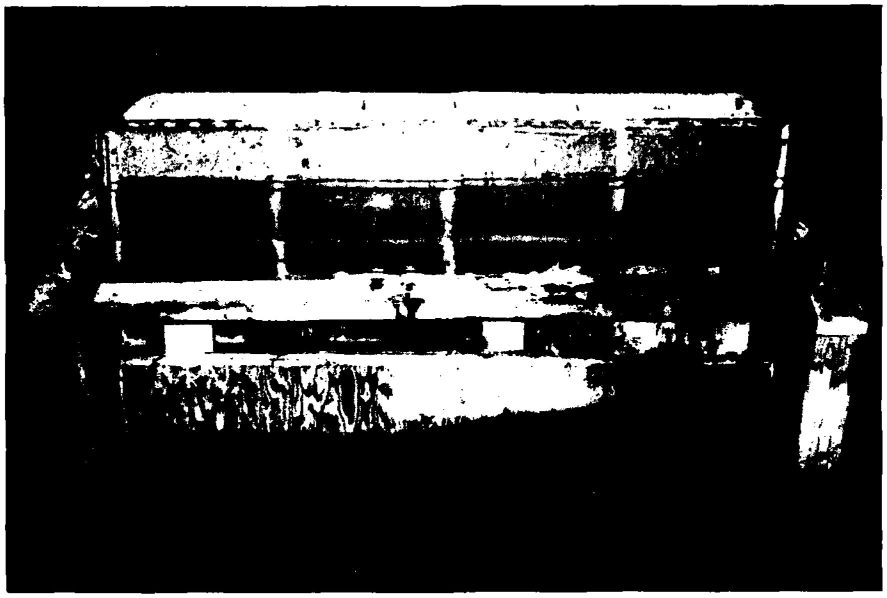

Figure 13. Cavity wall static head test

PART III: CONCLUSIONS

24. The composite-wall spray test, which simulated a constant 4-hr rainfall, showed that no water will migrate through the wall if there is no path, such as open mortar joints or cracks in bricks, for it to follow. The composite-wall static head test, which simulated a constant ponding of water against the wall such as during a flood, showed that in the case of a crack or discontinuity (as shown by the UPV test), migration will take place.

25. The small flow of water through the brick veneer of the cavity wall gave a direct comparison between the two systems. The indication was that the parged bedding was the mechanism which caused this difference of response in the two systems.

26. Based on these test results, when the integrity of the composite wall is maintained, with no open joints or cracked bricks, the wall should effectively protect the building interior against rainfall.

APPENDIX A

Record of Architect's on-site Investigation

Greenwood, Mississippi
USAR Center

Subject: Rain Penetration thru Exterior Walls and Interior Surfaces Damage.

1. An on-site investigation of subject building was conducted on 2 & 3 August 1979. Investigating personnel were:

Mr. Bob Denson - U. S. Army Engineer Waterways Experiment Station - Vicksburg Mississippi
601-636-3111 Ext. 3206

Mr. Roy Perkins FWD Arch Section, Design Branch
817-334-3414

2. The following observations were made.

a. Exterior Wall Surfaces:

(1) Brick work appeared to reflect generally satisfactory workmanship; however, there were numerous mortar joints in both head and bed joint locations showing separation of sufficient width to allow water penetration.

(2) There were numerous spot locations around perimeter of building indicating a type of epoxy grout repair to mortar joints.

(3) Efflorescence was apparent at several locations around building.

b. Interior Surfaces:

(1) Classrooms 131, 132 & 133 had water streaked walls and moisture was present on top surface of chalk board frame and on chalk rail. There was also evidence of water having ponded at base of walls.

(2) Unit Storage room 109 - All gypsum board wall surfaces were completely saturated with moisture and soft to touch.

(3) Scullery Room 113 - GSU wall above scullery sinks and counter showed discoloration in mortar joints indicating possible moisture content.

c. Roof Top:

(1) Reglet and base flashing installation at juncture of built-up roofing and parapet wall indicated contractor did not comply with contract requirements.

(2) Reglet was sealed with a cement mortar material in lieu of sealant type required.

(3) Overlapped ends of metal base flashings were not sealed.

(4) Exposed CMU surfaces of parapet above reglet showed signs of continued wetness.

3. Visual inspection of building did not provide an answer to source of water penetration nor recommended permanent fix. It is recommended that Waterways Experiment Station provide a non-destruct type test procedure on exterior wall system of subject building and under laboratory conditions, conduct tests on cavity and composite wall systems in general.

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