3317

NATIONAL BUREAU OF STANDARDS REPORT

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REPORT ON CRACKING IN CONCRETE BLOCK MASONRY CONSTRUCTION AT NAVAL SUPPLY DEPOT, MECHANICSBURG, PA.

by

J. W. McBurney

Report to
Bureau of Yards and Docks
Department of the Navy

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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1. SUMMARY AND CONCLUSIONS

The Mechanicsburg Naval Supply Depot was investigated for the purpose of determining, if possible, the cause of excessive cracking of the concrete block masonry in certain of the storehouses at this site. The method finally followed was to select the best and the worst structures from the standpoint of observed cracking and to compare them with respect to factors which are common and which are unlike. Based upon inspections, study of photographs, replies to a questionnaire answered by the Works Officer, receipt of information from various other sources and from the results of some laboratory tests on blocks and mortars, some conclusions were reached and opinions formed.

(1) The aggregate used in the manufacture of blocks used in Building 114 (the poorest from the standpoint of cracking) was largely limestone with some admixture of cinders. The blocks used in Building 904, (which was remarkably free from cracking) were made with cinders as the aggregate.

(2) Both types of block were in essential compliance with the American Society for Testing Materials and Federal Specifications for hollow load-bearing concrete masonry units with respect to strength and absorption.

(3) Linear shrinkage at nine years for the 114 block (limestone and cinders) averaged 0.035 percent. The corresponding shrinking of the 904 blocks (cinder aggregate) was 0.051 percent at age of six years.

(4) Reliable evidence was secured to the effect that Building 114 was built of block laid when about 4 days old while the block used in Building 904 has been stored at the site under tarpaulins for from 30 to 60 days. This evidence would indicate that the shrinkage of block used in Building 904 was much less than had occurred in Building 114.

(5) Examination and identification of the mortar gave no evidence of unsoundness (expansion) as a cause of cracking.

(6) Straight vertical cracks spaced at regular intervals and apparently not penetrating the concrete foundations of Building 114 and similar building, appeared to be associated with steel columns or pilasters at these locations.

(7) Irregular cracking of various patterns and associated with cracks in concrete foundations may have resulted from foundations settlement. There were more cracks in a 600 ft length of foundation of Building 114 than in the block masonry supported by this foundation.

(8) Building 904 had obviously good soil (rock) conditions. No information on soil conditions could be obtained for Building 114. An unconfirmed rumor that its site was a former bog or pond was circulated.

(9) Building 114 (600 by 200 ft) had no expansion joints in either masonry or foundations. Building 904 (400 by 200 ft) had four expansion joints.

(10) Building 114 departed widely from the recommendations given in the NBS Report 3079, "Requirements for concrete-masonry construction." Building 904 was in somewhat better agreement with these requirements. The units of 904 may be considered as having complied with the requirements for moisture content at time of laying.

(11) No evidence was obtained on the effect of dehumidification. Building 114 was dehumidified and was badly cracked, whereas Building 904 was not dehumidified and was remarkably free from cracking. There were, however, so many other differences between these two buildings that a conclusion with respect to the effect of dehumidification appears unwarranted.

2. HISTORY OF INVESTIGATION

Early in the summer of 1952, the Bureau of Yards and Docks had requested the National Bureau of Standards to investigate certain cases of excessive cracking of concrete block masonry construction used as storehouses at the Naval Supply Depot in Mechanicsburg, Pennsylvania. The Depot was visited by J. W. McBurney and C. C. Fishburn of the National Bureau of Standards on July 16, 1952, and a general inspection was made of the Depot with particular reference to the structures that exhibited cracking. Specifications covering the materials, construction and design of the masonry buildings were examined during this visit and the problem was discussed with Lt. Commander W. E. Flynn (Public Works Officer) and his aids. A set of photographs, made on June 6, 1952, and showing cracking patterns on certain of these buildings was supplied. (See Appendix A). Commander Flynn subsequently visited the National Bureau of Standards and further discussions took place. Information was also sought from various people who had contact with the Depot at the time of construction (1944-45). As would be expected some rather conflicting hearsay evidence was collected. It was decided to confine the investigation to a comparison of two buildings (Nos. 114 and 904), selected on the basis of showing the most and the least cracking. A questionnaire relating to these two buildings was prepared and submitted to Commander McRorey (Works Officer) in June 1953. A reinspection of Buildings 904 and 114 was made at that time. This questionnaire combined with Commander McRorey's answer is reproduced as Appendix B of this report. Arrangements were made for submittal of samples of block and mortar from these two buildings for laboratory examination, and they were received at the NBS in October 1953. The results are presented under Laboratory Tests.

3. GENERAL DESCRIPTION OF DEPOT

The Mechanicsburg Depot contains some 68 storehouse buildings which with four exceptions are 600 ft long by 200 ft wide. One of these buildings, 904, is located in the vicinity of the Tank Farm and is a considerable distance from the main group. This building is approximately 400 ft long by 200 ft wide and the soil conditions in the vicinity of this building appears to be different from the corresponding conditions near the main group. Of these 68 storehouses, 13 are of concrete block construction and the remainder are wood frame sheathed with asbestos-cement board on both sides and with glass windows. Up to window sill height (approximately 4 ft above floor level), the walls are either 12-in. thick concrete or 12-in. thick clay brick masonry. These wood frame structures were remarkably free from observable cracking in their masonry. Cracking appeared to be confined to the concrete block structures.

A number of these storehouses are dehumidified. Building 114 is known to be dehumidified and 904 is not dehumidified. The concrete block masonry structures are supplied with heating facilities according to available information.

4. LABORATORY TESTS

Eight concrete block from Building 114 and eight from Building 904 were received for test and examination. These specimens had been removed from various points in the walls of these buildings and were identified by numbers referring to locations photographed at the time of removal. All of the units were more or less damaged in that corners were missing and parts of the shell and webs. A selection of the five most perfect units from each sample was made and these were used for compressive strength determinations and for measuring shrinkage. The remaining specimens were broken into pieces for determining absorption.

The units selected for testing in compression were built up to give plain bearing surfaces by use of a 1:3 portland cement-sand mortar. After curing of the mortar, the bearing surfaces were shellacked and capped and tested according to the method given in ASTM Standard C140-52.

Linear shrinkage was determined on three specimens of each sample by the rapid method described in the Progress Report of the American Concrete Institute's "Physical Properties of High-Pressure Steam-Cured Concrete Block." (Journal of the American Concrete Institute, April 1953). In this method the specimens were soaked in water for 24 hr at 73 ± 3 F and then dried in an oven at a temperature of 220 to 235 F for 48 hr and then cooled in a sealed drum for 24 hr. Measurements of length change were made after soaking and again after drying and cooling using a 10-in. Whittemore strain gage.

The absorption test was made by immersing pieces of broken units free from mortar in water for 24 hr according to the method of C140-52.

The results of tests on the block from Building 114 are presented in Table 1, and for Building 904, in Table 2.

Sample 114 is in compliance with Grade A of ASTM Specifications C90-52 (Hollow Load-Bearing Concrete Units) with respect to compressive strength and absorption. Sample 904 rates Grade B in compressive strength since the average strength is 985 psi instead of 1000 psi.

From inspection together with some qualitative chemical examinations, it was established that the aggregate in block from Building 114 was predominantly limestone with some added cinders. The aggregate for Building 904 was cinders.

Examinations of the mortar were confined to determining the total content of magnesium oxide (MgO). Mortar from Building 114 contained 2.0 percent and from 914, 2.8 percent of magnesia calculated as magnesium oxide. The interpretation of these results is considered in the following section of this report (Discussion).

5. DISCUSSION

In the section History of Investigation, it was stated that Buildings 114 and 904 were selected as the extremes in degree of cracking. This section, for the most part, considers the application of available information about these two buildings with respect to factors which are common and which are unlike, with the purpose of identifying the factor or factors which may explain the differences in performance. In addition to the data presented under the section on laboratory tests, this discussion is based upon Appendix A (Observation and comments on photographs of buildings of Naval Supply Depot), Appendix B (Questions and Answers on design, construction, materials and history of buildings 114 and 904) and Appendix C (Discussion of possible causes of cracking), plus some unverified information from other sources. Appendix C was prepared on the assumption that much of the observed cracking could be ascribed to volume change of certain of the materials of construction.

Masonry Units - That laboratory tests for shrinkage showed 45 percent greater shrinkage for the units for Building 904 (slight cracking) compared with those from Building 114 (excessive cracking) was unexpected. This result appears reasonable in view of the constitution of the block (cinder aggregate for 904 and predominantly limestone for 114). A possible explanation of this paradox appears in the answer to Question 3D (Appendix B). The blocks used in 904 were 30 to 60 days old before laying and were protected at the site by tarpaulins whereas, according to reliable information, the No. 114 blocks were laid within 4 days of forming. (See discussion under "Shrinkage of units on drying" in Appendix C). It may reasonably be considered that the use of wet blocks contributed to the cracking behavior of Building 114 and that use of dried and aged block helped to minimize cracking in Building 904. Although no information is available, it is probable that values for shrinkage measured at 28 days or less after forming, would considerably exceed shrinkages determined on similar units after ageing from 7 to 9 years.

Mortar - Certain cracking patterns such as shown in figure 17 (Appendix A) might be interpreted as resulting from expansion. For this reason the soundness of the mortar was questioned on the possibility that there might be ingredients which could cause an expansion. The values for magnesium oxide reported under laboratory tests are not considered to be excessive and there is no evidence indicating that the mortars initially contained significant amounts of free magnesium oxide. The mortar for Building 114 was specified as a 1:1:6 cement-lime-sand mixture by volume and the lime was specified to be a dolomitic hydrate made by autoclaving. See Questions and Answers 7E in Appendix B. Assuming a 35 percent content of hydrated magnesia in "SuperLimoid" and further assuming the dry weight proportions of a 1:1:6 mortar to be 94:40:480, the magnesia content would calculate as 2.17 percent. The 2.0 percent result from analysis is in reasonable agreement with the above value. The 2.8 percent content of magnesia for the mortar from Building 904 would, on the assumption of a 70:240 dry weight proportion of masonry cement to sand, correspond to a 12 percent content of magnesia in the masonry cement. This is not unreasonable for the masonry cement (Brixment) in question. It should be remarked that no reports of excessive expansion attributed to either "Brixment" or the use of pressure hydrated lime have been received.

On the basis of available information the difference in behavior between Building 114 and 904 cannot reasonably be ascribed to differences in the mortars.

Foundations - A continuous vertical crack from roof through foundation is shown on the east wall of Building 4 Item 3 of Appendix A). The west wall center of Building 7 (Item 6) shows more vertical cracking in the concrete than in the masonry. The diagonal cracking in the masonry of the east wall of Building 12 near the south end (Item 7) could indicate differential vertical movement of the foundation. The vertical cracks in the foundation are compatible with such an explanation. The southwest corner of Building 13 (Item 8) on the other hand is free from foundation cracks and resembles more the cracking usually associated with volume change. A conspicuous feature of Building 114 (See Items 16, 17, and 18 of Appendix A) was the excessive vertical cracking of the concrete foundation of the east wall. A count of the number of cracks in the 600 ft length of the east wall of 114 showed a greater number of cracks in the foundation than in the masonry superstructure. Some of the foundation cracks were continuous with cracks in the masonry and other cracks were unrelated.

Photograph No. 2 made September 21, 1953, shows a fine crack in the foundation of Building 904 indicated as in the west side at about the center approximately midway between the two expansion joints (7A of Appendix B). The crack extends upward into the block masonry for four courses. This was either overlooked during the previous inspections or had developed subsequently. It is the only foundation crack in 904 as far as known.

The differences in extent of foundations cracking between Building 904 compared with Buildings 4, 7, 12, and 114 (114 being the most conspicuous with respect to foundation cracking) would indicate the possibility of foundation trouble as one of the causes of the variation in extent of masonry cracking. The rock near the surface shown in photograph 1098G (Item 20 of Appendix A) would appear to provide a good base for the footings of Building 904. A hearsay statement was received to the effect that Building 114 was in part on the site of a former pond or bog. Questions and Answers 7C (Appendix B) reports for Building 114. "North half of east wall shows additional excavation for depth of wall footings on solid earth bearings. No record of any former bog or lake." For Building 904 the record reports "solid earth and rock foundations for footings." Rerunning of levels on finish foundation walls were requested for both buildings (6C). This was done for Building 904 and no deviation of grade was found but for 114 either levels were not run originally or no records were available, hence deviations, if any, are unknown.

An argument against foundation settlement from soil conditions is the remarkable freedom from cracking of the clay-brick masonry in the general vicinity of the concrete block structures. The load on the foundations should, however, be greater for the all block super-structures in comparison with the wood frame super-structures.

Thought was given to the possibility of lateral flow of soils under loading. See Questions and Answers 3A of Appendix B. While not impossible, no evidence was provided pointing to such an action. A 2000 psi concrete was specified for the footings and foundation of Building 114 and 2500 psi for 904. No admixtures were used in either concrete. No information on source or grading of the aggregate for the 114 concrete was available. Questions and Answers 1C gives available information for 904.

Differences in reinforcement of the foundations and footings of the two buildings (2c) do not appear to be significant.

Building 904 had two expansion joints in each of the 400 ft lengths. (120 ft each from the ends). Questions and Answers 7A give the following information of Building 114: "No expansion joints in any foundation or masonry block walls," and "Insufficient expansion joints in reinforced concrete foundation walls."

Freezing did not occur at early age on either concrete. There does not appear to be any significant difference in exposures and early history.

In summary, the extent of cracking in the concrete foundations of Building 114 points to possible settlement of the foundation. Absence of expansion joints in the building might be the explanation considering volume change resulting from changes in temperature and in moisture content. See Appendix C for discussion of these factors. Movements in the concrete foundation is one of the probable contributing causes of cracking of the concrete masonry.

Design - The superior performance of Building 904 may have been helped by the concrete block masonry being two wythes in thickness, consisting of alternate reversed courses of 4-in. and 8-in. widths. Building 114 was built of a single thickness of 12-in. wide blocks. See Questions and Answers 2A of Appendix B.

The explanation of regularly spaced vertical cracks as in the north end of Building 5 (Item 5 of Appendix A and Questions and Answers 4A of Appendix B) also probably Building 9 and in the walls of Building 114 (Item 14 and Questions and Answers 2A) is that shrinkage of the blocks took place and steel columns (Building 5) or pilasters (Building 114) occur at these locations. Note also the cracks associated with anchorages on Building 114 (Items 10 to 13). It will be noted as far as can be determined from the photographs, that these straight vertical cracks do not extend down into the concrete foundations. It is considered that the location of such cracks result from design and could have been avoided by suitable control joints and horizontal reenforcement. That cracks resulting from shrinkage tend to occur when there is a change in cross section is generally recognized. Reference is made to Section 5 of the attached "Requirements for concrete-masonry construction," NBS Report 3079 (January 30, 1954).

It should be remarked that Building 114 departed widely in many respects from the requirements referred to above. Building 904 has some expansion joints and also probably complied with 3e (storage of units) of these requirements.

Effect of Dehumidifying - One of the questions asked NBS was whether dehumidifying contributed to the cracking of these concrete block constructions. Building 114 was and 904 was not dehumidified but there were too many other differences to permit selection of dehumidification as a factor in causing difference in amount and degree of cracking. With a vapor barrier on the inner face of the masonry, it is hard to see how moisture could be drawn in from the masonry. On the other hand, there might be weather conditions in which the moisture gradient was reversed. This would not seem a probable initial cause of cracking but might have something to do with continuing cracking once it had started. This is in line with the well known relation between degree of saturation and effect of freezing and thawing, other things being equal.

The conclusions from the data and observations considered in the foregoing discussion are presented at the beginning of this report.

10.1
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Table I

Laboratory examinations of concrete blocks from Building 114
Naval Supply Depot, Mechanicsburg, Pa.

Bldg.	Unit No.	Linear shrinkage	Dimensions: Wall thickness	Dimensions: Height	Dimensions: Length	Dimensions: Shell thickness	Dimensions: Web thickness	Compressive strength gross area	Absorption 24 hr cold	Absorption 24 hr cold	Weight per cu ft
		%	in.	in.	in.	in.	in.	lb/sq in.	lb/cu ft	%	lb
114	5	.0360									
114	6	.0307									
114	7	.0386									
114	4		12.15	8.00	15.70	1.75	1.28	800			
114	5		12.10	7.75	15.70	1.75	1.25	1480			
114	6		12.10	7.70	15.65	1.80	1.30	1630			
114	7		12.10	7.75	15.65	1.75	1.28	1610			
114	8		12.10	8.00	15.75	1.75	1.28	1980			
114	1								10.5	10.0	104.7
114	2								10.2	9.7	104.7
114	2								12.1	11.6	104.6
114	3								10.6	10.2	103.3
114	3								12.7	12.5	101.3
Avg		.0351	12.11	7.84	15.69	1.76	1.28	1500	11.2	10.8	103.7

Table II

Laboratory examinations of concrete blocks from Building 904
Naval Supply Depot, Mechanicsburg, Pa.

Bldg.	Unit No.	Linear shrinkage	Dimensions: Wall thickness	Dimensions: Height	Dimensions: Length	Dimensions: Shell thickness	Dimensions: Web thickness	Compressive strength gross area	Absorption 24 hr cold		Weight per cu ft
		%	in.	in.	in.	in.	in.	lb/sq in.	lb/cu ft	%	lb
904	1	.0530									
904	3	.0540									
904	5	.0461									
904	1		3.60	8.0	15.35	1.00	1.05	1170			
904	2		3.90	8.0	15.60	1.10	1.05	1020			
904	3		3.65	8.0	15.50	1.00	1.00	850			
904	4		3.75	8.0	15.45	1.00	1.05	840			
904	5		3.70	8.0	15.50	1.05	1.05	1050			
904	6								12.3	13.9	88.9
904	6								11.1	13.5	91.1
904	7								12.2	14.1	86.4
904	7								12.0	13.8	86.9
904	8								12.1	13.4	93.1
904	8								12.1	13.2	91.5
Avg		.0510	3.72	8.0	15.48	1.03	1.04	986	12.0	13.7	89.7

APPENDIX A

OBSERVATIONS AND COMMENTS ON PHOTOGRAPHS OF BUILDINGS OF NAVAL SUPPLY DEPOT, MECHANICSBURG, PA. PHOTOGRAPHS TAKEN JUNE 6, 1952.

(1) Building #3 N.E. corner, Photo 1085(G)

Cracks extending down from cantilever beams. Diagonal at top and straight without regard to mortar joints below. Diagonal and straight cracking around lintel of door.

(2) Building #4 N. end, Photo 1087(G)

Essentially straight cracks from roof to base. One crack lined up with one end of lintel over door.

(3) Building #4, East wall, Photo 1092(G)

Two cracks starting at roof. One continues through concrete. This one started as diagonal through mortar joints for first four courses below roof and thereafter goes straight. The other started straight at roof and not quite half way down started to follow mortar joints to the right in a diagonal pattern. Below, the crack continued straight in line with the straight crack above. According to the photo, the crack disappeared before reaching the concrete.

(4) Building #4, East wall N. center, Photo 1095(G)

Picture apparently shows paint failures. If there is any structural cracking it is not visible.

(5) Building #5, North end, Photo 1090(G)

Uniformly spaced straight cracks from roof to base. Horizontal joints involved only at top and in connection with openings. Resembles Bldg. #4 N. end (2) but differs in uniformity of distance between cracks. Suspect that #5 has columns or possibly abutting partitions behind these cracks.

(6) Building #7, West wall center, Photo 1080(G)

Except for cracking at ends of lintels and under sill of left of two windows, the picture shows more cracking in concrete than in masonry. Is not this wall just across the street from brickwork (600 ft) which shows no visible cracking?

(7) Building #12, East wall near S. end, Photo 1094(G)

Diagonal cracking of masonry combined with related and unrelated cracks in concrete might result from settlement with resulting vertical shear.

(8) Building #13, S.W. corner, Photo 1084(G)

The right hand crack appears to line up with the inner face of the other wall. This is a common location of cracking on masonry where volume change is occurring. The diagonal cracking to the right of the down spout and the horizontal cracking between masonry and concrete might indicate a horizontal shear. The concrete does not appear to be cracked according to this photograph.

(9) Building #14, South end, Photo 1093(G)

Cracking pattern consists for the most part of vertical lines from roof to base usually not including horizontal joints. The cracks resemble those shown in Items (2) and (5). Item (9) differs from Item 2 in being more frequent and in having vertical cracks on both sides of openings. The difference from (5) is lack of uniformity in distance between cracks and also in having more relation to openings.

(10) Building #114, West wall, Photo 1096(G)

Association of vertical cracks at roof line with anchorages of supports for permanent awning will be noted. Below the awning these cracks displace diagonally to the right and then continue down vertically with some tendency to show parallel doubling. Note the increasing displacement of the vertical cracks below the awning in relation to the cracks above from left to right. Whether the platform shows cracking associated with the masonry cracking is not distinguishable in the photograph. Compare (10) with (1). Also (11).

(11) Building #114, West wall, center, Photo 1082(G)

Another portion of the wall shown in (10). The same origin of cracks above awning is evident as in (10). The cracks differ in being more diffuse (tending to branch and give parallel cracks) and in the location of short cracks between the principal cracks at anchorages. The displacement of cracks below the awning does not appear in photograph (11).

(12) Building #114, West wall, Photo 1097(G)

Another portion of wall shown in (10) and (11). Cracking above awning corresponds in location and appearance to (11). The three types of cracking (diagonal following joints, straight vertical and diffuse) are shown in this view. The unusual feature of figure 12 is that none of the cracks above the awning extends below. The only cracks appearing below the awning are two short (6 courses) straight cracks on both sides of the large door.

(13) Building #114, West wall, Photo 1086(G)

Still another portion of the wall shown in Nos. (10), (11), and (12). The peculiarity of the pattern is (a) that two out of five cracks visible above the awning do not extend down to the awning and (b) there are only two continuous cracks below the awning. In one case a crack extends half way down from the awning and in another the cracks start half way down. In the third case, the picture does not show any continuation of the crack below the awning. This absence of cracking is along the door on the right.

(14) Building #114, S. E. corner, Photo 1099(G)

Essentially straight vertical cracks from roof to foundation. Regularity of spacing might indicate some design feature (columns). Note short cracks around ends of lintels and a few short cracks extending up from concrete foundation. If the concrete is cracked, it is not evident in the photograph.

(15) Building #114, North end, Photo 1091(G)

The origin of all vertical cracks extending from roof to foundation is with one exception the vertical offsets of the parapet. This exception is the crack midway between the two center parapet offsets. Several short cracks extend upward from the foundation. The usual vertical cracking is associated with openings.

(16) Building #114, East wall, Photo 1083(G)

This, with the exception of some cracking seen in No. (8) and above the awning in Nos. (11) and (12) shows a different type of cracking. Note (a) the parallel cracking in the two roof-to-foundation cracks; (b) the reversal of diagonal cracking to the right of the lower opening; (c) the pattern above and around the upper opening (lintel); and (d) the vertical cracking in the concrete foundation.

(17) Building #114, East wall, Photo 1081(G)

The straight vertical cracks are short (6 to 8 courses) and are confined to locations immediately below the roof and below window sills, and along the ends of lintels. Cracks otherwise follow joints. Diagonal cracking above lintels and extending down right and left (inverted V) to both ends of lintels is conspicuous. Caulking (remedy for cracking) has been applied over the entire length of the bed joint between the first and second courses of block above the lintels. A conspicuous feature of this photograph is the number of vertical cracks in the concrete foundation. A count was made of the cracks in the 600 ft length of the east wall of Building #114. The cracks in the concrete exceeded in number those in the masonry. This is the only photograph showing horizontal cracks through blocks.

(18) Building #114, East wall, Photo 1079(G)

The greater number of vertical cracks in the concrete foundation compared with the number in the block masonry will be noted. The cracking in the masonry follows a "delta" pattern (single cracks going straight and then branching into a number of parallel or diverging cracks.

(19) Building #402, N. E. corner, Photo 1088(G)

According to this photograph, the brick masonry is entirely free from cracks. This is in agreement with observation of another building having a 600 ft length of brick masonry.

(20) Excavation for Tank Farm Addition, Photo 1098(G)

This shows soil conditions in the vicinity of Building #904 which is characterized by minimum cracking.

Appendix A

APPENDIX B

Questions and Answers on Design, Construction, History and Materials of Buildings 114 and 904

Subsequent to the inspection made on July 16, 1952, by Messrs. McBurney and Fishburn, information was secured from various sources and study had been given to the photographs. The following questions are intended to provide further information and to check the correctness of information from unofficial sources. Most of these questions deal with Buildings 114 and 904 since these two buildings represented the extremes of condition when inspected in July 1952.

For convenience, Commander C. E. McCrorey's reply of July 6, 1953, is combined with the questionnaire.

A. Questions on Design

1A. Question

What are the dimensions, length, breadth, height, and thickness of masonry in 114 compared with 904?

Answer

Building 114	Building 904
Length - 602' 8"	Length - 402' 8"
Width - 202' 6"	Width - 202' 6"
Height - 26' 8 1/2" - to bottom eaves	Height - 21' 2"
Wall Thickness 1' - Height at gable	Wall Thickness - 1' 1/2"

2A. Question

Are there any differences in design (pilasters, columns, roof, partitions, etc.) between these two buildings?

Answer

Building 114

The walls are of masonry block construction - block size - 12" wide 16" long 8" thick with 3 hollow cells in each. Pilasters of masonry block 32" long and 1' wide spaced on 20' centers for side walls and 2 pilasters on end walls and fire walls - spaced 66' centers or 1/3 points of wall and backed up by exterior wall. These masonry block pilasters were reinforced by 8 - 3/4" reinforcing steel rods and cells filled with concrete - then topped off with 6 courses of brick to receive steel trusses, with the exception of the 2 pilasters in end and fire walls where the other structural steel is bearing on 12" exterior end walls and on fire walls. All interior and intermediate columns are H beam steel columns. There is no expansion provided in concrete foundation wall, masonry or roof steel.

Building 904

The walls are of masonry block construction. These masonry blocks came in two sizes, one 8" x 8" x 16" and one 8" x 4" x 16", 3 cell block and laid in alternate courses 8" x 4", then 4" and 8". The steel columns are built-in masonry side, end and fire walls. Brick masonry is used around all columns on all exterior walls and keyed in masonry block construction. Expansion joints are provided in the exterior side walls, where the 2 - fire walls join same and extend from top of concrete footing to roof. There is no expansion in ends or fire walls.

3A. Question

Describe the floors in 114 and 904 with respect to material, support and base, and relation to foundations. Could there be floor loading such that flow of soil under the floor might take place?

Answer

The floor in Building 114 is concrete throughout, laid on graded earth. The concrete was type C-1 2,000 psi 6" thick, with no reinforcing *other than over the under-floor heating ducts, which run along the entire perimeter of exterior walls. One-half inch expansion joint is provided betweeen all walls and floor slabs.

*Addendum to Spec. deleted 6x6x10 reinforcing steel in lieu of substituting 6" concrete thickness for 5" thickness with reinforcements. Suggestion made by A & E contractor and approved by ROinCC.

Appendix B

The floor of Building 904 is 6x6x10 mesh concrete throughout, laid on 6" compacted sand and gravel fill. The concrete is type F-1, 3,500 psi reinforced with 6x6 wire mesh. Expansion joint is provided between all walls and floor slabs.

4A. Question

Are the regularly-spaced cracks on the north end of Building 5 related to the presence of pilasters, columns, etc. at the location of these cracks?

Answer

The regularly spaced cracks in North wall appear 20 feet on centers where steel columns are built in masonry block walls.

5A. Question

Is there any horizontal reinforcement in the masonry?

Answer

Pencil rods only where steel columns are blocked in masonry walls.

6A. Question

What is the design of the lintels?

Answer

Building 114 has 6 12' wide x 12' high overhead door openings in each side-wall, total of 12. The end walls each have 2 overhead door openings size 12' wide and 13' high, total of 4 doors. The lintels over overhead doors on street side are 2'9" x 1' x 14' reinforced with 6 3/4" Ø rods, hooked ends, 3 top and 3 bottom and tied with 1/4" Ø rod ties 12" O.C.

The window lintels above overhead doors on street side are 1' 9" x 1' x 14' reinforced with 6 3/4" Ø rods, hooked ends, 3 top and 3 bottom and tied with 1/4" Ø rod ties 12" O.C.

The end wall door lintels are 2' 6" x 1' x 13' reinforced with 6 3/4" Ø rods, hooked ends, 3 top and 3 bottom and tied with 1/4" Ø rod ties 12" O.C.

Appendix B

The lintels over overhead doors on railroad platform side are 3' 6" x 9" x 14' reinforced with 4 3/4" Ø rods, hooked ends, 2 top and 2 bottom and tied with 1/4" Ø tie rods O.C.

The window lintels over these doors are 1' 4 1/2" x 1' x 14' reinforced with 6 3/4" Ø rods, hooked ends and tied with 1/4" Ø tie rods 12" O.C.

Type C-1 2,000 psi concrete used (Y'D Spec. 13YC).

Building 904 has 3 12' x 12' overhead doors on each side of building, total of 6, and one 12' wide x 13' 4-3/4" high overhead door in each end wall, total of 2 doors.

All overhead door lintels are 2'1/2" x 1' x 14' reinforced with 6 5/8" Ø rods, hooked ends, 3 top and 3 bottom and tied with 1/4" Ø rod ties 12" O.C.

The window lintels over these doors are 1' 4-1/4" x 1' x 14' reinforced with 4-5/8" Ø rods, hooked ends, 2 top and 2 bottom and tied with 1/4" Ø tie rods 12" O.C.

Type D-1 2,500 psi concrete used.

7A. Question

What is there with respect to expansion joints in the masonry?

Answer

Building 114

No expansion joints in any foundation or masonry block walls. Insufficient expansion joints in reinforced concrete foundation walls. Lack of horizontal reinforcing and expansion joints in masonry block walls.

Building 904

Expansion joints in foundation walls and masonry block walls from footing to roof in exterior side walls, 2 on each side 120' from end walls, (where fire walls join exterior walls). Total 4 expansion joints in entire building walls. No expansion joints in end walls or fire walls.

Appendix B

B. Questions on Construction

1B. Question

What were the dates of beginning and completing construction of 114 and 904?

Answer

Building 114 - Date started - approximately 1st week August 1944; date finished 3rd Feb. 1945.

All foundation walls and block walls completed before 6th Nov. 1944 as shown on Progress Photograph No. 59-1495. No other records available.

Building 904 - Date started - May 28, 1947; date completed 11 Jan. 1949. Concrete foundation started 24 July 1947; concrete foundation completed 15 Oct. 1947. Masonry block started 12 Nov. 1947; masonry block completed 10 Apr. 1948.

All concrete foundation walls were 2-1/2 to 3 months old before any masonry block walls were laid on same.

2B. Question

Is a log of weather conditions available for these construction periods? If so, can an abstract be furnished or made available?

Answer

Buildings 114 and 904 - Log available - can be furnished. Weather records requested from Weather Bureau.

C. Questions on Foundations, Footings, and Soil Conditions

1C. Question

What was the concrete mix used for footings and foundations for 114 compared with 904 (proportions, nature and source of aggregates, admixture if any)?

Appendix B

Answer

Concrete mix and proportions.

Building 114 - Concrete mix Y&D Spec. 13 Y.C. Type C-1 2,000 psi. Mix of aggregates - No record. No admixtures used.

Building 904 - Concrete mix Y&D Spec. 13 Y.C. Type D-1 2,500 psi. 489 lb cement - 1302 sand - 1952 - wash gravel.

Fine Aggregate Total Passing Square Openings		Coarse Aggregate Total Passing Square Openings	
3/8 in.	100%	1 1/4 in.	100%
#4	93%	1 in.	96%
#20	56%	1/2 in.	41%
#50	15%	#4	3%
#100	5.3%		

No admixtures used.

2C. Question

What was the nature and degree of reinforcement in the footings and foundations of 114 compared with 904?

Answer

Building 114 - Footing and foundation reinforcing.

Horizontal 1/2" Ø c 12" o.c.
Verticals 1/2" Ø c 12" o.c.
Footing is 1' 8" Walls are 1' 0" 2" x 4" key

Building 904 - Horizontal 3/8" Ø longitudinal, 5/8" Ø at 9" o.c.
Vertical 3/8" Ø at 18" o.c.
3/8" Ø at 12" c.c. both faces of foundation wall running horizontally.

3C. Question

Were the footings and foundations subject to freezing at early ages? At what age of the foundation was the masonry superstructure started and at what age finished?

Appendix B

Answer

Building 114 - The footings and foundations were not subject to freezing. Masonry block walls started last week of August 1944 and completed about 6th Nov. 1944.

Building 904 - The footings and foundations were not subject to freezing. Masonry block walls started 12 Nov 1947 and completed 10 Apr 1948.

Concrete footings and concrete foundation walls started 24 Jul 1947, completed 14 Oct 1947.

4C. Question

At what age was cracking of the concrete foundations of 114 first noted?

Answer

Building 114 - No record available but some time in March after north wall building 011 collapsed, 23 Feb 1945.

5C. Question

Is there any evidence of vertical shear along any of the vertical cracks in the foundations of Building 12 (see photo 1094 G January 6, 1952)?

Answer

No vertical shear apparent.

6C. Question

Were reasonably accurate levels run on any of these foundations (particularly 114) before masonry was started? If so, could levels be rerun?

Answer

Building 114 - Unknown - Levels could not be rerun.

Building 904 - Finish foundation wall levels run and no deviation of grade found.

7C. Question

According to report, Building 114 is located on the site of a former bog or lake and 904 is on bed rock close to the surface. Are these statements true?

Answer

Building 114 - From data of field books the North half of East wall shows additional excavation for depth of wall footings on solid earth bearing. No record of any form bog or lake.

Building 904 - Solid earth and rock foundations for footings.

8C. Question

Along side Building 7 (?) is a glass-transite board building with brick up to the window sills. The mortar in the brick work is reported to be Lehigh or Brixment masonry cement, and the 600-foot length of masonry is quite free from cracking. Are there any site or foundation differences between building 7 and the one described?

Answer

The type building mentioned has for exterior walls a brick curtain wall sill high with a concrete sill doweled to same. Above brick curtain wall is wood studs exterior for window framing and cement asbestos covering to eave of roof. The building is wood frame construction, with wood columns spaced 20' centers both ways, wood girders and purlins built up to receive wood deck roof. No site or foundation differences in buildings.

D. Questions on Concrete Masonry Units

1D. Question

According to report Building 114 uses either an (expanded) slag block or a 50-50 mixture of slag and limestone. What are the facts? What block is used in 904? If the record is uncertain, a laboratory examination would probably supply this information.

Answer

Unknown.

2D. Question

According to report the source of the block was York and Harrisburg and, according to one rumor, some blocks were made at the site. Is this true? Can the different sources of block be assigned to specific buildings, particularly 114 and 904?

Answer

Building 114 - Source of Block 12" x 8" x 16" hollow masonry units, York Building Products Company, York, Pa.

Building 904 - Source of Block, Harrisburg Building Units Co., Harrisburg, Pa. 8" x 8" x 16" and 4" x 8" x 16".

To our knowledge no blocks were made on Building site.

3D. Question

It has been stated that the block used in 114 was less than 4 days old at the time of laying. Is this true? What was the corresponding age at laying of the block in 904?

Answer

Building 114 - Unknown.

Building 904 - One to two months and protected at site with tarpaulins.

E. Questions on Mortar

1E. Question

The 1944-45 specifications under which 114 was built call for a 1:1:6 cement-lime-sand mortar by volume with the lime to be the Warner Company's "Super-Limoid". Was this lime actually used or was "normal" (Limoid brand) used? The date 1945 seems rather early for the commercial production of pressure hydrated lime such as "Super-Limoid". On the answer to this question would depend whether expansion of mortar is a possible factor to be considered.

Answer

Building 114 - Letter from Jamus Steward & Company and John B. Kelly, Inc., sub-contractor - Philadelphia, Pa. Mortar mix 1 - 1 - 6 for masonry construction.

Appendix B

Cement - Lehigh Portland Cement Co., Lehigh Valley Mills or Unionbridge, Md.

Lime - Super Limoid as manufactured by Warner Company from Morrisville, Pa.

Sand - Bar Sand as furnished by Warner Company from Morrisville, Pa. approved OICC letter 29th Aug 1944.

2E. Question

What mortar was specified (and used) in 904?

Answer

Building 904 - Brixment type 2 masonry cement, Louisville Cement Company of New York, Akron, N. Y.

F. Questions on Maintenance and Repair

1F. Question

What are the painting histories of 114 and 904? (Types and brands of paint and frequency of repainting.)

Answer

Building 114 - 1 of 7 Buildings
Work started 15 May 1947, completed 15 Aug 1947
Type of cement water paint Medusa, prepared dry paint mixed at job site with water - 2 coats.

Building 904 - Work started 12 Oct 1949, completed 21 Oct 1949
Type of cement water paint, Sears Roebuck & Company prepared dry paint mixed at job site with water - 2 coats.

2F. Question

Describe materials and methods for filling cracks. Does caulking material extrude from cracks? If so, at what seasons of the year (temperature and rainfall conditions)? The answer to these questions may provide information as to cyclic volume changes in the masonry.

Answer

Before paint was applied all cracks up to 3/16" were cleaned and filled with masonry caulking compound. Where loose mortar appeared and larger cracks than 3/16" were found same was raked out and new mortar replaced. Seems to push out in winter months.

3F. Question

If the caulking is renewed from time to time (time intervals), is the renewal required by failure of the material or change in the cracks?

Answer

Regular caulking compound was used at first but dried out and shrunk leaving openings. Approximately 2 years ago this was replaced with a pitch type caulking which has given no trouble up to the present time.

4F. Question

What is the nature and thickness of the vapor barrier on the inside of 114? Does this require renewal or repair? Does 904 have a vapor barrier and DH?

Answer

Building 114 - Thickness of vapor barrier ranges between 1/32" and 1/16". Primer is cutback asphalt - Flintkote #267. Sealer is Flintkote C-13-HPC stable non-flowing asphalt emulsion (non-fibrated).

Building 904 - None - No dehumidification.

G. Questions on History of Cracking

1G. Question

Can a log be furnished on the cracking history of 114? If available, give age for first appearance of cracking and subsequent changes with time, noting also any changes such as installation of DH, changes in occupancy, etc. Does there appear to be any relation between weather (seasonal or otherwise) and formation of new cracks or changes in width or extension of old cracks?

Answer

There is no log available but cracking is apparently a progressive process. However it seems as though new cracks are more noticeable in the spring which would indicate some frost action as far as the widening of the cracks is concerned. The pattern does not seem to change, regardless of changes in occupancy or installation of D/H.

2G. Question

At what age did cracking first appear on 904? Have these cracks changed with age?

Answer

Building 904 - Cracks appeared only on 1 side of concrete overhead door lintels and extend upwards. On side walls and 1 side of concrete overhead door lintels on end walls. These end wall doors are offset 2' from center line of wall and crack is in center of wall extending to top of wall and about 1/2 way down in door opening. There are no cracks in concrete foundation walls at these locations. These cracks appeared three to six months after walls were erected. The cracks are small and there is no noticeable change in same.

These solid concrete reinforced lintels weigh approximately 3,000 to 3,800 pounds each, and do not carry any appreciable superimposed loads - therefore, could be hollow thus lightening same.

APPENDIX C

DISCUSSION OF POSSIBLE CAUSES OF CRACKING

Concrete Masonry Units

Since the concrete blocks used in Building 114 and 904 are reported to include limestone and cinders as aggregates, the following discussion emphasizes the properties of these ingredients.

Shrinkage of Units on Drying

That concrete masonry units will shrink during drying is well known. The amount of shrinkage depends upon a number of factors such as (1) age of the unit (time elapsed between forming the unit and the initial measurement), (2) method of curing, (3) the degree of saturation (amount of contained water) or conversely the degree of drying, (4) the nature of the aggregate, and (5) the ratio of binder (portland cement) to the aggregate. Certain other factors such as water-cement ratio, grading of aggregate, and method of forming may have an effect on shrinkage.

Considering the above factors in order, "green" blocks (those delivered at an early age limited only by development of sufficient strength to permit handling and transportation) would be expected to give maximum shrinkage. Such blocks would not yet have developed much strength, and the portland cement would not have completely reacted with the mixing water, and the excess water would have had little opportunity to evaporate. According to Mr. Paul Woodworth, Director of Research and Development of the Waylite Company, the 1945 construction at Mechanicsburg (Building 114) was done with blocks not over 4 days old at the time of laying.

The purpose of steam curing is to speed up the reaction between water and portland cement and thus harden the blocks. The usual treatment (steam at atmospheric pressure) has little effect in drying the blocks. Pressure steam curing both accelerates strength gain and drives off moisture. There is experimental evidence that pressure steam curing reduces shrinkage by roughly one-half compared with non-pressure steam curing. The effectiveness of pressure steam curing in reducing shrinkage of concrete masonry units is strikingly shown by some data published by the Housing and Home Finance Agency (Housing Research Paper No. 25, "Relation of Shrinkage to Mortar Content in Concrete Masonry Units"). Table 6 in this paper (copy enclosed) presents values for shrinkage of cinder block cured with high pressure steam in comparison with cinder block cured by high temperature steam, high temperature steam plus 150° F drying, low temperature steam, and moist air. Drying to moisture and volume equilibrium took place at 70 and at 25 percent relative humidity on resaturated blocks. Curing with high pressure steams gave shrinkage (linear) of from 0.016 (70% RH) to 0.026 percent (25% RH) compared with 0.042 and 0.065 percent for low pressure steam cure and 0.038 and 0.062 percent for cure in moist air. The reduction in time to reach equilibrium for high pressure steam curing compared with the other types of curing was very noticeable.

The degree of saturation is what the 40 percent limit given in specifications (ASTM C90-44 and Federal Specification SS-C-621) is intended to control. Obviously, a 40 percent limit on degree of saturation at time of delivery (or sampling) has no relation to condition at time of laying the blocks in the wall if the blocks are exposed to weather subsequent to sampling. A more pertinent test would appear to be setting limits on the total shrinkage resulting from drying previously saturated specimens. British Standard BS834-1944 gives maximum permissible drying shrinkage of 0.04 and 0.06 percent for dense and lightweight aggregate blocks respectively. The corresponding limits for partition blocks (BS492 and 728-1944) are 0.06 and 0.08 percent, respectively. It is assumed that the units after laying in masonry will not resaturate to the degree resulting from total immersion for several days in water. Such subsequent saturation would occur only where very defective workmanship or design had been used in the masonry. Data are not available for determination of the relation of saturation by immersion to saturation at very early ages (shortly after "final set" of the cement, for example) in establishing volume change. Also uncertain is the choice and comparison of drying methods in these tests. Oven drying at various temperatures has been used. Preferred is drying by exposure to air of controlled low relative humidities. As an example of this type of drying, see data from Kluge, Sparks and Tuma presented as part of the discussion of effect of aggregate. Copy of this paper "Lightweight-Aggregate Concrete" is enclosed. The data in HHFA Housing Report No. 25 give comparisons of initial moisture content and shrinkage compared with moisture contents and shrinkage determined on resaturated block.

The differences in permissible shrinkage of concrete block classified as made with dense and lightweight aggregates by British Standards were given above. The data reported by Kluge, Sparks, and Tuma were obtained on cast concrete which differed from concrete used in block making principally in its higher water-cement ratio. The exposure consisted of 7 days in a fog room followed by drying in air at 70° F and relative humidity of 55 percent. Zero time was removal from the fog room. Drying continued up to 180 days. The data on a number of concretes differing with respect to aggregate are presented graphically in figure 8, and the shrinkage at 100 days in inches per foot are given in Table 4. Sand-gravel concrete had shrunk in length from approximately 0.03 to 0.06 percent at 100 days, at which time equilibrium appeared to have been reached.

The ranges reported above were on concretes differing in cement factor (sacks of cement per cubic yard of concrete). It will be noted from the data in Kluge's paper that differences in shrinkage of considerable magnitude result from differences in cement factor but there is no observable correlation between them.

A higher water-cement ratio would obviously provide more evaporable water and hence be associated with a greater total shrinkage resulting from removal of water. This is in accord with the well recognized effect of additional water on the shrinkage of mortars and concretes cast in non-absorbent molds. The method of forming of concrete block is in their favor compared with poured concretes since a relatively low water-cement ratio is used in block making. Note that the shrinkages reported in HHFA Housing Research Paper No. 25 on commercial block are very small in comparison with the shrinkage on concretes made with similar aggregates as reported by Kluge, Sparks, and Tuma.

The large initial shrinkage of concrete units is usually associated with the large initial loss of water introduced during mixing. In general, submersion for a considerable time would be necessary to recover by expansion the original volume (length) measured before drying. Reversible volume changes, small in magnitude compared with the shrinkage resulting from initial drying, take place with changes in relative humidity of the ambient air. Changes in moisture content and resultant volume changes resulting from wetting by rain are also considered to be small in magnitude unless design or workmanship are such as to permit ready entry of water into the masonry.

In summary, shrinkage of concrete masonry units (linear) may range from 0.02 to 0.15 percent or greater during the loss of water contained in units before laying in the wall. The magnitude of the shrinkage depends upon the previous history of the block and its composition.

Appendix C

For such reasons as (1) the wide range in amount of cracking (Building #114 compared with Building #904 for example), (2) variations in cracking patterns from building to building and in the same building, and (3) the reported history of continued cracking (formation of new cracks and widening of existing cracks) there is the probability that other factors may be operating in addition to the shrinkage of units heretofore discussed. The following possible factors are considered. The order of this consideration is without respect to the degree of probability of these factors.

Thermal Expansion of Concrete Masonry Units

R. E. Copeland ("The Problem of Shrinkage Cracking") reported that the coefficient of thermal expansion of typical concrete block ranged from 2.5 to 5.5 millionths inch per inch per degree F in the range 0 to 100° F. This would correspond to a length change of from 0.025 to 0.055 percent for a 100° change in temperature. Corresponding data on comparable plain concrete (expanded clay and shale or slag aggregates in 7-sack mixes) from Price and Cordon gave from 4.4 to 5.3 millionths inch per inch per degree F. (In terms of cracking, 833 millionths inch per inch equals 1 inch in 100 ft).

Expansion of Concrete Block Other Than Reversible Volume Changes Resulting From Change in Temperature and in Moisture Content

The probability of "alkali-aggregate" reactions occuring such as are assocated with certain opaline, rhyolitic, or chert concrete aggregates in the western part of the United States is low if the aggregates in the blocks are what they are reported to be. Limestone and cinders have never been reported as suspect in the alkali aggregate reaction in any of the very considerable literature on this phenomenon. On the basis of available data, alkali-aggregate expansion does not appear to be a factor in the performance of the concrete block under consideration.

Volume Changes of Mortar

Various investigators have reported values for the shrinkage of mortar. These data have, with few exceptions, been determined on specimens cast in non-absorbent molds and, in general, the earlier the age of the initial reading, the greater the shrinkage subsequently measured. The few volume change measurements which have been made on masonry (brick) indicate, however, that slight expansions (linear) take place, rather than shrinkage. See enclosed paper by McBurney on "Cracking in Masonry Caused by Expansion of Mortar" for a summary of the findings of Davis and Troxell together with a discussion of mortar shrinkage as a factor in cracking. The explanations of the discrepancy between the volume change of mortar cast in non-absorbent molds and the volume change of masonry is considered to be that mixing water is removed from mortar by contact with absorbent units while the mortar is still plastic. Since shrinkage of mortar, as with concrete block, results from removal of water, there is, under these conditions, a very low water-cement ratio at the time when the reactions of setting and hardening begin, and this small amount of water for the most part reacts with the constituents of portland cement rather than being lost through evaporation or other means for removal from the mortar.

McBurney's paper considers in detail the abnormal expansion of mortar and its consequences resulting from the presence of free magnesium oxide (MgO) in mortar. The specifications (1944-5) covering concrete block construction at Mechanicsburg call for 1:1:6 cement-lime-sand mortar by volume and require "Limoid" or "Super Limoid" made by the Warner Company of Philadelphia to be the lime. This brand of lime is understood to be a dolomitic hydrate, but the Super Limoid refers to that company's autoclaved lime. If Super Limoid were used, cracking from the use of unsound mortar ingredients can be dismissed as highly improbable. Neither does there appear to be grounds for assuming the presence of soluble sulfates which might react with mortar to cause expansion.

Foundations

One of the unverified reports dealing with the Mechanicsburg Depot was that Building 114 occupied the site of a pond or bog, and the excessive cracking of the foundation and superstructure of this building could therefore be ascribed to foundation settlement. The lack of cracking in Building 904 is correspondingly ascribed to bed rock outcropping on and near the site. See photograph No. 1098G showing excavations near Tank Farm.

Weathering

The effect of such factors in weather as temperature change and precipitation has been previously discussed in part. Freezing and thawing remains to be considered from the standpoint of this action's effect on cracking. From observations of units during laboratory freezing and thawing and of masonry exposed to natural weathering, it is concluded that one effect of repeated freezings and thawings is to open up and extend previously formed cracks. The accepted explanation of this action is that water expands about 9 percent in freezing and therefore exerts pressure, if the body during freezing is saturated with water. There is the further possibility that dehumidification may, under certain climatic conditions, reverse the saturation gradient in masonry and build up saturation beyond what would normally occur without dehumidification. In any case, the reported continuation of cracking could result either from continued action of the factors causing the original cracking or from the frost action discussed in this paragraph.

Enclosures

Housing Research Paper No. 25, "Relation of Shrinkage to Moisture Content in Concrete Masonry Units," Housing and Home Finance Agency.

R. W. Kluge, M. M. Sparks and E. C. Tuma "Lightweight-Aggregate Concrete," Reprint Title No. 45-37 of the American Concrete Institute.

J. W. McBurney "Cracking in Masonry Caused by Expansion of Mortar." 1952, Reprint American Society for Testing Materials.

NBS Report 3079, "Requirements for Concrete-Masonry Construction," (January 30, 1954).

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