Report SCEGIT No. 82-107

INTERFACE BONDING OF SHOTCRETE REINFORCED BRICK MASONRY ASSEMBLAGES (VOLUME 2, Appendices)

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APPENDIX A

INTERVIEWS WITH LOCAL MASONRY EXPERTS

APPENDIX A-1

Mr. Snipes, Architect, BIA

Conversation Date: 7/2/81

Key words: block, brick masonry, structural tile, three (3) hole core brick, metal ties, header ties, multi wythe brick wall, poor mortar, low lateral resistance

Mr. Snipes is an employee of the Brick Institute of America. Snipes started work in industry in 1947. Recalling from that era, Snipes commented that a lot of 8 in. block masonry with 4 in. brick facades were used. Some structural clay tile was also used with the brick facades. Prior to WWII, structural clay tile was used more commonly. In the early 1900's, the buildings were built with multiple wythes of brick masonry, using headers to the wythes together. Primary examples of 16" to 24" thick unreinforced brick masonry buildings are in Underground Atlanta and South of Marietta Street in Atlanta. Solid molded brick was utilized in a number of these buildings. In the last 25 years, metal ties have been used extensively, while rowlock bricks are primarily used for decoration.

APPENDIX A-2

Mr. Hudgins, President of Hudgins & Company,
Demolitian Contractors since 1982

Conversation Date: 6/23/81

Key Words: core brick, linch stucco, square hole brick

Mr. Hudgins has been with Hudgins and Company since 1954. Hudgins has demolished almost every type of structure common to the Southeast excluding petro chemical plants. During his span at Hudgins and Company, Mr. Hudgins remarked, he could not recall seeing any buildings that they demolished, made of hollow core brick that were built before 1940's. He reported that all masonry buildings built before the 40's, at least those that Hudgins and Company were contracted to demolish, were solid brick masonry.

Another comment that is of interest to this project is, as Hudgins reported, "a one inch stucco surface applied to masonry has beefed up the walls incredibly. Contractors, like ourselves, have noted that the stucco has provided an increased resistance to lateral and inplane forces."

Hudgins also note that once in a while a masonry building from the 20's to 40's contained bricks that had double rows of square cores, though this was not seen very often.

APPENDIX A-3

Prof. Willis E. Moody, Professor in the School of Ceramic Engineering

Conversation Date: 6/18/81

Key Words: sulfate attack, water media, air media, sea coasts, time effects, sulfate attack on sewer pipes, carbonic acid attack

Sulfate attack on brick masonry and any cement products is of concern, Moody remarked. Significant deterioration of strength of a cement product can occur when it is exposed to sulfate attack. Exposure to sulfate attack from 50 to 100 years, which is not uncommon, can literally destroy any physical strength inherent of the cement product. Moody stated that sulfate attacks concrete or cement products through generally two medias, air and water. Along sea coast the use of sulfate resistant cements to retard ground water sulfate attack is common practice. Moody did not know of any reports on the subject of "time effects on masonry bonds," but recommended reports on sulfate attack on sewer pipe as a possible reference.

Another time affected chemical reaction, Moody remarked, is the carbonic acid attack on brick and mortar. Moody state that this reaction required significant time to cause appreciable damage, two to three hundred years.

APPENDIX A-4

Dr. Joseph L. Pentecost, Academic Director of Ceramic Engineering

Conversation Date: 6/18/81

Key words: hollow core bricks, solid bricks, solid soft mud bricks, construction ease, production ease

In the last 50 to 75 years various types of brick were produced some of which were types of hollow core brick. Of these various types of hollow brick, Pentecost stated, masons predominately used the three hole large core brick. Among the reasons were, the ease of which the brick can be split and broken in half. This core brick is lighter and easier to lay than the traditional solid brick. Manufacturers, according to Pentecost, preferred to produce the core brick over the solid brick because it was easier to produce. The core brick dried, fired and cooled much quicker than the solid brick yielding to higher production with minimal costs.

Solid brick were used from 100 to 500 years ago. Solid end cut bricks were predominantly used. From 100 to 150 years ago, solid soft mud bricks were used. Many houses now standing in Atlanta as Dr. Pentecost remarked, are of the latter type. The solid soft mud brick is extremely weak according to today's standards. The soft mud bricks were molded in wetted or greased wooden cases. These soft mud bricks could be identified by their characteristic scar marks, due to the wood cases, and their soft surfaces.

APPENDIX A-5

Prof. Arnall T. Connell, Professor for the College of Architecture

Conversation Date: 6/22/81

Key words: large core brick, small core brick, double row core brick

Today, Prof. Connell stated, the predominate brick used is the large core bricks. The brick has three cores, approximately 1½ inches in diameter. The bricks are light and easy to use.

An example of the use of small core brick is Prof. Connell's home. He stated that it was built in approximately 1927. Some solid bricks were used in conjunction with the core brick. The small core bricks had cores that were about 1/2 to 3/4 inches in diameter, with generally three cores to a brick.

Another predominate core brick was a double row core brick. Prof. Connell was not sure when it was used. The brick has two rows of fire cores, 1/2 to 3/4 inches in diameter.

APPENDIX A-6

Mr. James Camp, Production Manager, Chattahoochee Brick Company

Conversation Date: 7/9/81

Key words: large core, solid brick

According to Mr. James Camp, an employee of Chattahoochee for more than twenty years, Chattahoochee had been making core brick for only the past 10 to 20 years. In 1970 they began production of the large core brick, 1½ inch cores.

He reported that they never produced any of the double row square 10 hole bricks.

In 1955 when Mr. Camp started work with Chattahoochee, only solid bricks were produced.

APPENDIX A-7

Mr. William E. Edwards, Semi Retired Structural Engineer

Conversation Date: 7/7/81

Key words: hard burn, solid brick, slag cement, flemish bond, clay tile, brick veneer, metal ties, header bonds

Mr. William E. Edwards is a semi retired structural engineer. He has been a practicing engineer in the Atlanta area for a number of years. Mr. Edwards founded William E. Edwards Structural Engineering Inc., located in Atlanta.

For the time period around the 1920's, Edwards recalled that the majority of large brick buildings were backed up by a clay tile structural system. Those buildings that were totally brick were, as Edwards stated, multi wythe unreinforced load bearing brick masonry buildings. The walls might range from 4 to 8 wythes of solid brick. The hard burn brick was commonly used. The type of mortar used was a type of slag cement, lime, and sand. The mix used was 1, 1, and 4 to 6, respectively. The resulting mortar was extremely weak. When Portland cement was introduced into the market and used in the production of mortar, Edwards noted, a problem developed with cracking through the brick rather than at the joint. Edwards felt that the new cement was too strong for masonry use.

Edwards stated that it was common to use a flemish or header bond on every 6th course in the 1920's. The flemish or header bonds were used to tie wythes of brick together. Edwards also noted that metal ties also were used in the 20's but not very often. At times corrugated iron ties were used. These ties would fail under subsequent rusting causing at times the spaulling off of wythes of brick.

Bricks from the 1920's were standard 2 5/8 x 8 x 4 inch, solid, red clay brick. It was not until recently, Edwards remarked, that hollow core bricks were used.

During the conversation Edwards recalled a consulting job of his where he was to design and construct an annex to a church south of Atlanta. The church, built around the 1900's, had mortar made of lime and sand. Edwards said that the mortar was so weak and deteriorated that he could scrape out an entire bed joint with little effort. The mortar at that state was a fine powder with little to no structural capacities.

APPENDIX B

DESIGN, CONSTRUCTION AND MATERIAL PROPERTIES FOR 46 SPECIMENS

APPENDIX B.1

SPECIMEN DESIGNS

Figure B.1 shows the basic nominal sizes of the specimens that were used in this investigation. There were 17 specimens with a nominal size of 3 ft. by 3 ft. made of old brick, three specimens with a nominal size of 3 ft. by 3 ft. made of new brick, 15 specimens with a nominal size of 4 ft. by 4 ft. made of old brick, and eight specimens with a nominal size of 2 ft. by 6 ft. made of old brick. Table B.1 is a listing of the variations of the number of wythes, surface condition, and shotcrete layer thickness for the 46 specimens used in this research.

The nominal size of 4 ft. by 4 ft. is being used becaused it is called for in the ASTM E519 test for "Diagonal Tension (shear) in Masonry Assemblages" (11). The 3 ft. by 3 ft. nominal size is being used for comparison with the 4 by 4 specimens. It was anticipated that the 3 by 3 specimen size could replace the cumbersome 4 by 4 specimens. The 2 ft. by 6 ft. specimens was used to investigate the flexural aspects of the retrofitting process.

The variation of the number of wythes of brick among the nominal size groups was for the investigation of the actions between wythes of brick and/or the wythes of brick and its shotcrete treatment.

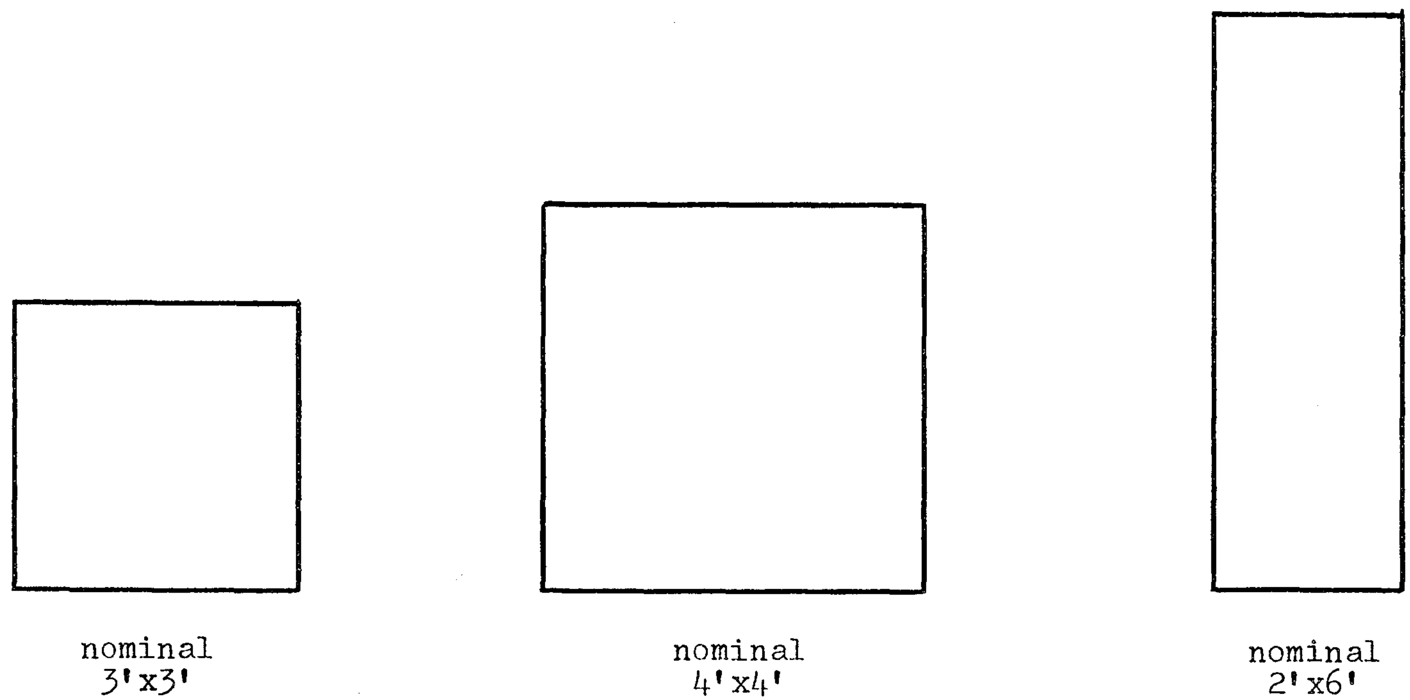


Figure B.1 Nominal Sizes of Specimens.

Table B.1 Experimental Models.

Specimen Number	Specimen Size	Number of Wythes	Surface Condition	Shotcrete Treatment	Type of Reinf.	Type of Dowels
1	3x3	1	dry	-	-	-
2	3x3	1	dry	-	-	-
3	3x3	1	dry	-	-	-
4	3x3	1	wet	3"	w.w.f.	-
5	3x3	1	wet	3"	w.w.f.	-
6	3x3	1	wet	3"	w.w.f.	-
7	3x3	1	epoxy	3"	w.w.f.	-
8	3x3	1	epoxy	3"	w.w.f.	-
9	3x3	1	epoxy	3"	w.w.f.	-
10	3x3	1	dry	3"	w.w.f.	-
11	3x3	1	dry	3"	w.w.f.	-
12	3x3	1	dry	3"	w.w.f.	-
13	3x3	1	wet	$\frac{1}{2}$"	e.m.	$\frac{1}{4}$" t
14	3x3	1	wet	$\frac{1}{2}$"	e.m.	$\frac{1}{4}$" t
15	3x3	1	wet	$\frac{1}{2}$"	e.m.	$\frac{1}{4}$" t
16	4x4	1	dry	-	-	-
17	4x4	1	dry	-	-	-
18	4x4	1	dry	-	-	-
19	3x3	2	dry	-	-	-
20	3x3	2	dry	-	-	-

Table B.1 (Continued)

Specimen Number	Specimen Size	Number of Wythes	Surface Condition	Shotcrete Treatment	Type of Reinf.	Type of Dowels
21	4x4	2	dry	-	-	-
22	4x4	2	dry	-	-	-
23	4x4	2	wet	3"	w.w.f.	-
24	4x4	2	wet	3"	w.w.f.	-
25	4x4	2	wet	3"	w.w.f.	No. 3 @ 16"o.c.
26	4x4	2	wet	3"	w.w.f.	No. 3 @ 16"o.c.
27	4x4	2	wet	3"	w.w.f.	No. 3 @ 32"o.c.
28	4x4	2	wet	3"	w.w.f.	No. 3 @ 32"o.c.
29	4x4	2	wet	$\frac{1}{2}$" one side	e.m.	$\frac{1}{4}$" t
30	4x4	2	wet	$\frac{1}{2}$" one side	e.m.	$\frac{1}{4}$" t
31	4x4	2	wet	$\frac{1}{2}$" both sides	e.m.	$\frac{1}{4}$" t
32	4x4	2	wet	$\frac{1}{2}$" both sides	e.m.	$\frac{1}{4}$" t
33	2x6	2	wet	3"	w.w.f.	No. 3 @ 16"o.c.
34	2x6	2	wet	3"	w.w.f.	No. 3 @ 16"o.c.
35	2x6	2	wet	3"	w.w.f.	No. 3 @ 32"o.c.
36	2x6	2	wet	3"	w.w.f.	No. 3 @ 32"o.c.
37	2x6	2	wet	$\frac{1}{2}$" one side	e.m.	$\frac{1}{4}$" t
38	2x6	2	wet	$\frac{1}{2}$" one side	e.m.	$\frac{1}{4}$" t
39	2x6	2	wet	$\frac{1}{2}$" both sides	e.m.	$\frac{1}{4}$" t
40	2x6	2	wet	$\frac{1}{2}$" both sides	e.m.	$\frac{1}{4}$" t

Table B.1 (Continued)

Specimen Number	Specimen Size	Number of Wythes	Surface Condition	Shotcrete Treatment	Type of Reinf.	Type of Dowels
41	3x3	1	dry	-	-	-
42	3x3	1	dry	-	-	-
43	3x3	1	dry	3"	w.w.f.	-
44	3x3	1	dry	3"	w.w.f.	-
45	3x3	1	wet	3"	w.w.f.	-
46	3x3	1	wet	3"	w.w.f.	-

w.w.f. welded wire fabric
e.m. expanded metal lath
No. 3 Number 3 rebar with a hook
$\frac{1}{4}$" t $\frac{1}{4}$" threaded rod with washers and nuts

The surface condition variations, used on the 3 by 3 specimens, was for the investigation of bond between the brick masonry and the shotcrete treatment. It was anticipated that the surface dry bond strengths would be much lower than that for the wet and epoxy surface conditions.

The variation of the thickness was used to investigate the load capacity of the specimens as a function of the shotcrete treatment thickness. It was anticipated that the thicker treatment would allow a higher load capacity yet the thin treatment would insure that at least the full capacity of the brick masonry would be reached.

APPENDIX B.2

SPECIMEN CONSTRUCTION

The old solid soft bricks used for the construction of the specimens were purchased from the Atlanta Wrecking and Salvage Company. The bricks came from the Atlanta Civic Center which was constructed between 1928 to 1932 and demolished by the salvage company in 1981. The new bricks used for the construction of the new brick specimens were donated by Mr. J. W. Stallinger of the Bricklayers and Allied Craftsman Local 8 Labor Union. The masons were apprentices from the Local 8 Union, their time was donated for the construction of the masonry assemblages.

The construction of the brick masonry specimens started on Monday, August 17, 1981, and ended on Wednesday, August 26, 1981. It took place on Cherry Street behind the grounds building on the Georgia Tech campus.

Construction began at mid day on the 17th. Four to six apprentice masons worked each day. The author, and two to three other student employees assured that the masons had enough mortar and brick at hand at all times. Each morning the author and another student would set up water hoses, mortar mixer, other necessities, and obtained from 500 to 900 bricks from the salvage company. Table B.2

Table B.2 Construction Log.

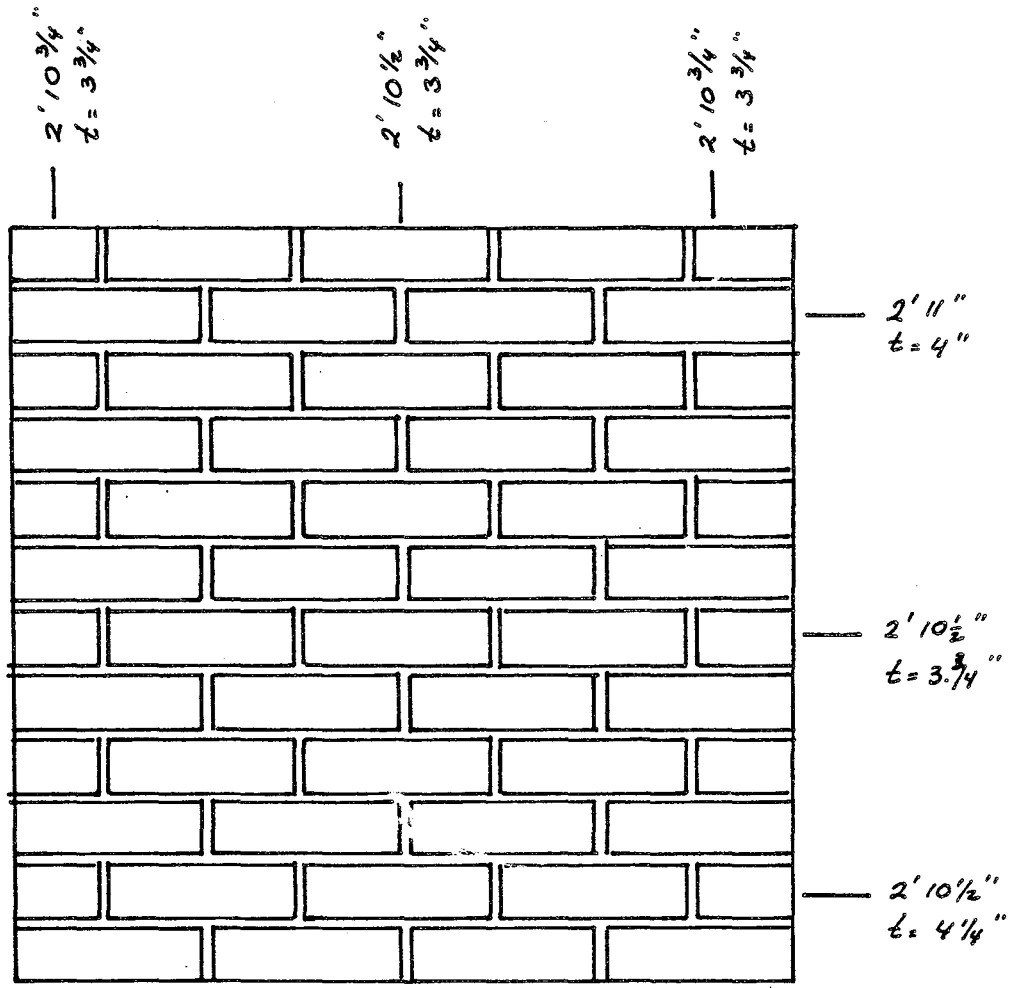
Work day Number	Date	Specimens Started	Specimens Completed
1	Aug. 17	1 to 6	1 and 2
2	Aug. 18	7 to 15 29 to 32	3 to 6 7 to 15*
3	Aug. 19	21 to 28	29 to 32
4	Aug. 20	16 to 20	21 to 28
four day weekend			
5	Aug. 24	41 to 46	16 to 20
6	Aug. 25	33 to 40	-
7	Aug. 26	-	33 to 40

* specimens 9 to 11 fell and were rebuilt

Starting Date : Monday August 17, 1981

Completion Date : Wednesday August 26, 1981

SPECIMEN NO. 1
1 WYTHE (12 COURSES)

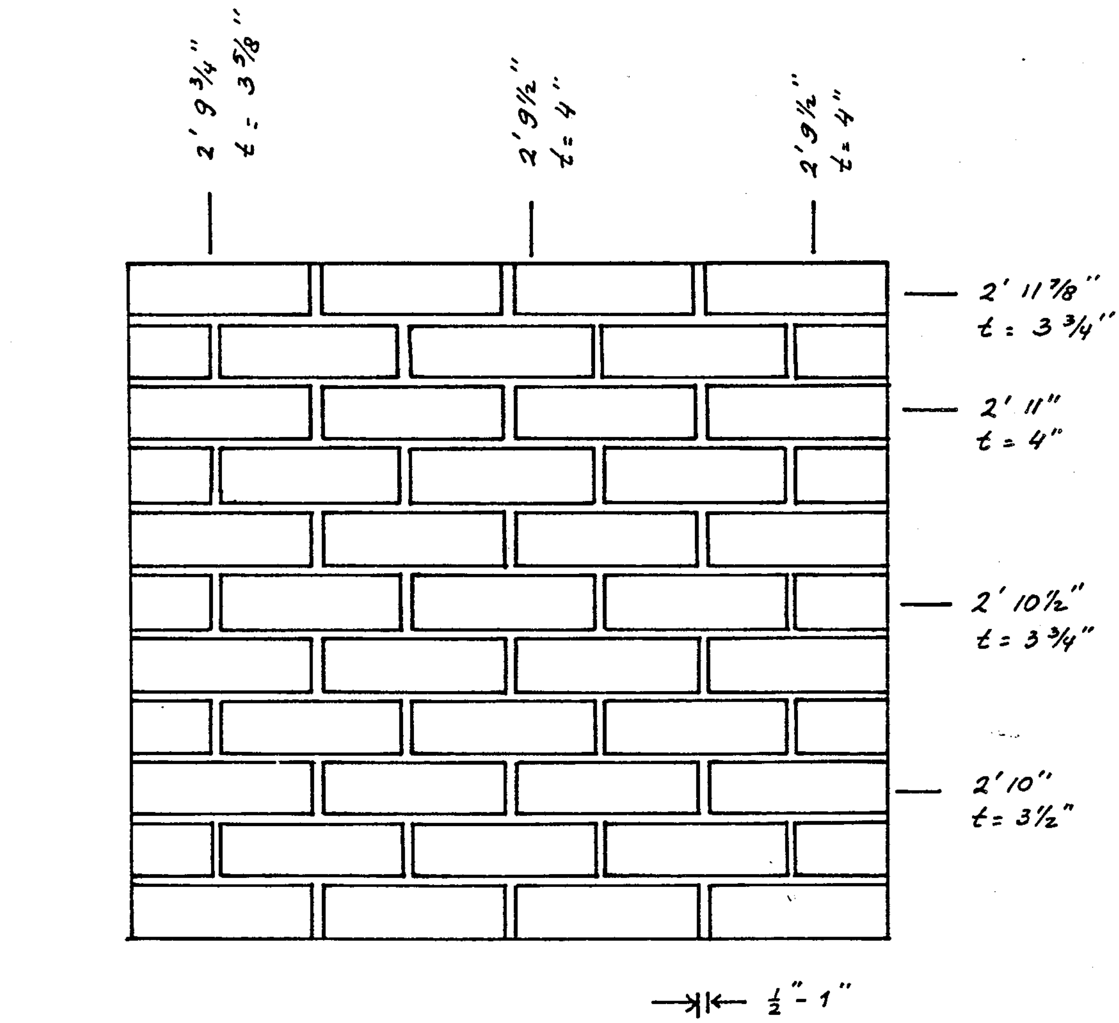


REMARKS :

b = 2' 10 5/8"
h = 2' 10 5/8"
t = 3 7/8"
BED JOINTS 1/2" - 3/4"
HEAD JOINTS 1/2" - 3/4"

Figure B.2 Specimen 1

SPECIMEN # 2
1 WYTHE (11 COURSES)

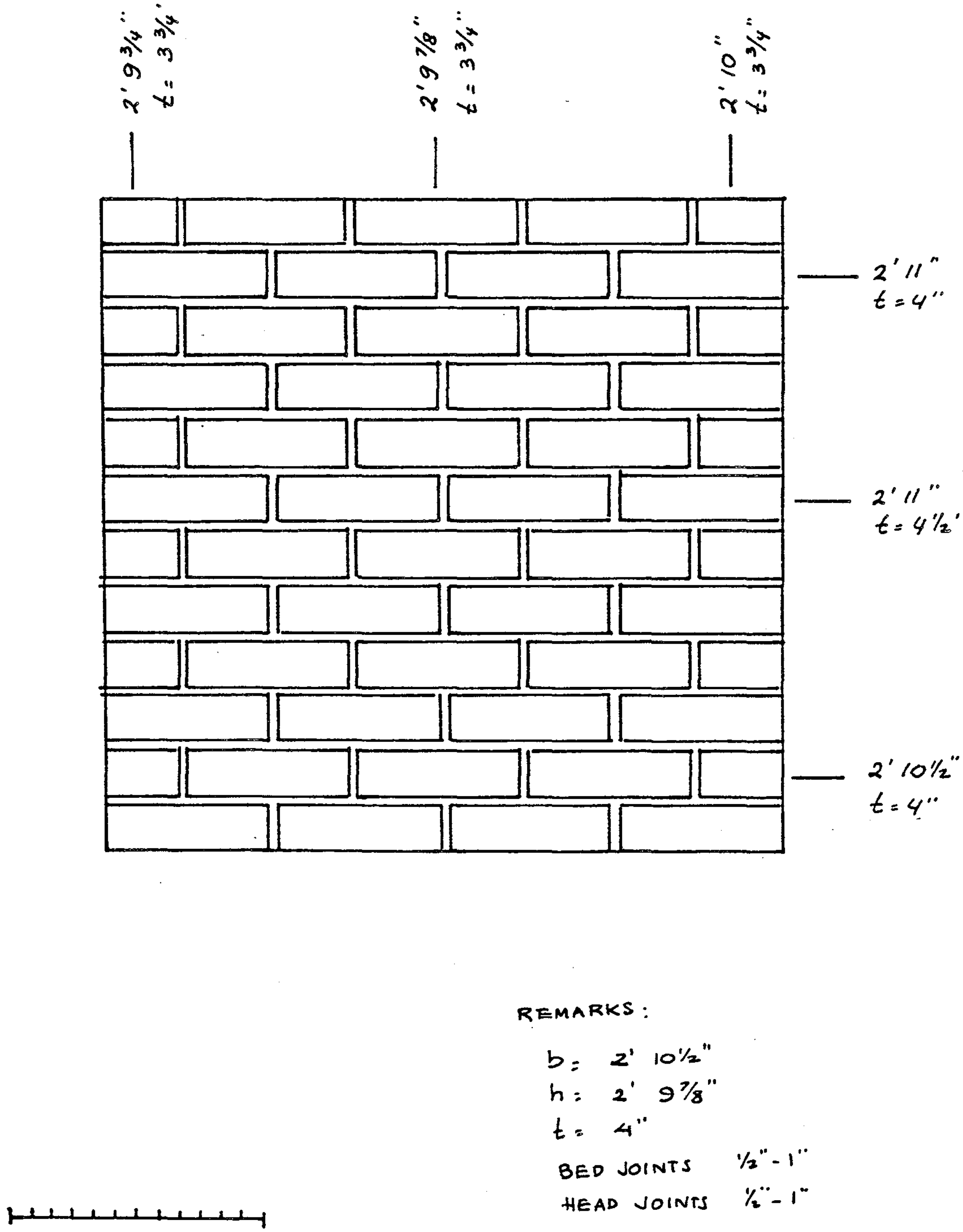


REMARKS:

b = 2' 10 4/5"
h = 2' 9 3/5"
t = 4 2/5"
BED JOINTS 1/2 - 1"
HEAD JOINTS 1/2 - 1"

Figure B.3 Specimen 2

SPECIMEN NO. 3
1 WYTHE (12 COURSES)

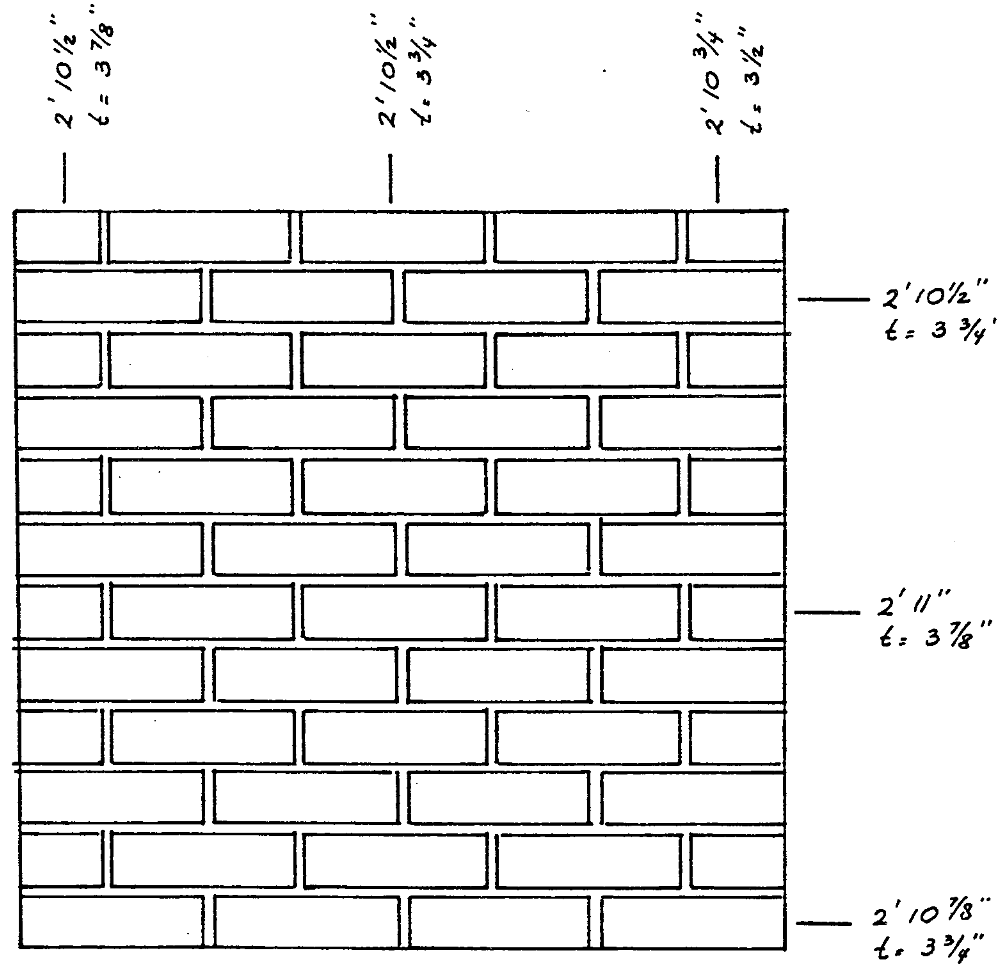


REMARKS:

b = 2' 10 1/2"
h = 2' 9 7/8"
t = 4"
BED JOINTS 1/2" - 1"
HEAD JOINTS 1/2" - 1"

Figure B.4 Specimen 3

SPECIMEN NO. 4
1 WYTHE (12 COURSES)



REMARKS:

$b = 2'\ 10\frac{4}{5}''$

$h = 2'\ 10\frac{3}{5}''$

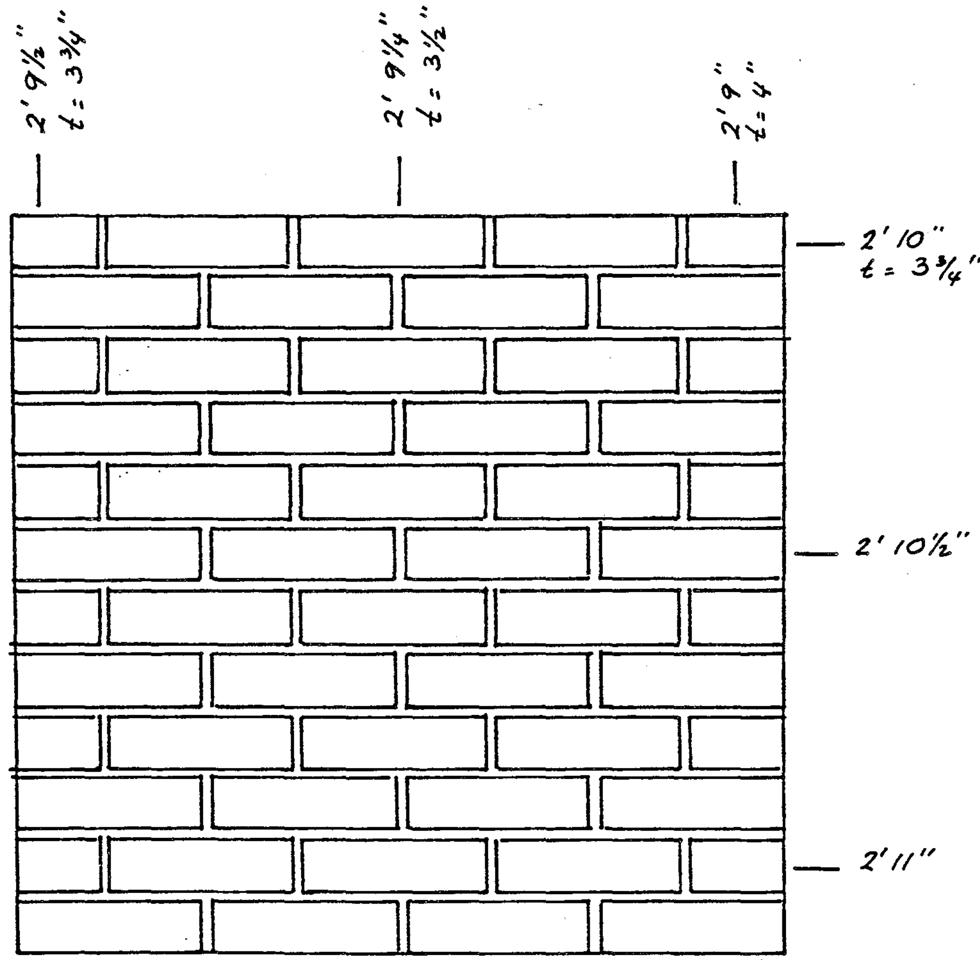
$t = 3\frac{3}{4}''$

BED JOINTS ½" - ¾"

HEAD JOINTS ½" - ¾"

Figure B.5 Specimen 4

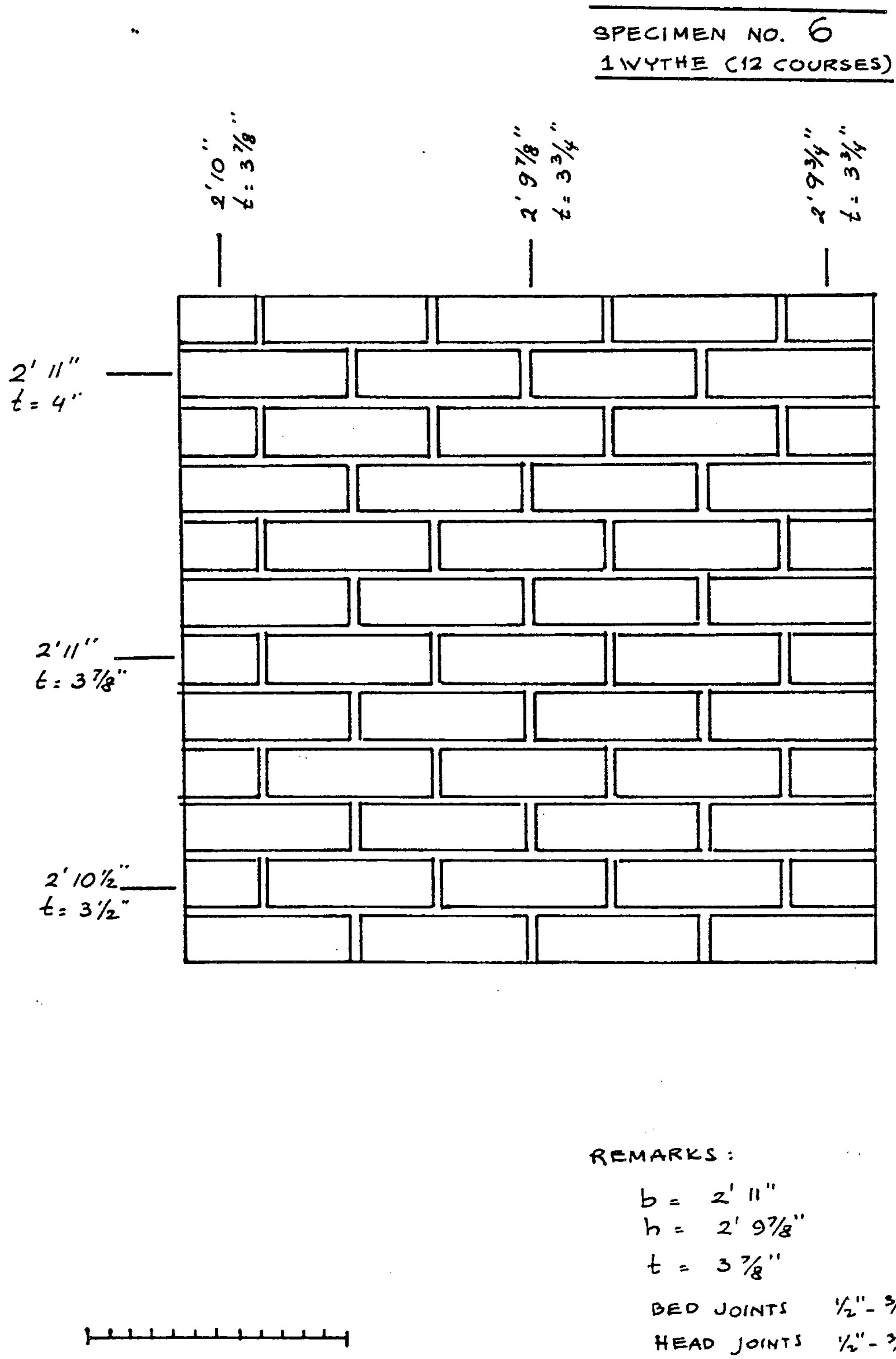
SPECIMEN NO. 5
1 WYTHE (12 COURSES)



REMARKS :

b = 2' 10½"
h = 2' 9¼"
t = 3¾"
BED JOINTS ½" - ¾"
HEAD JOINTS ½" - ¾"

Figure B.6 Specimen 5

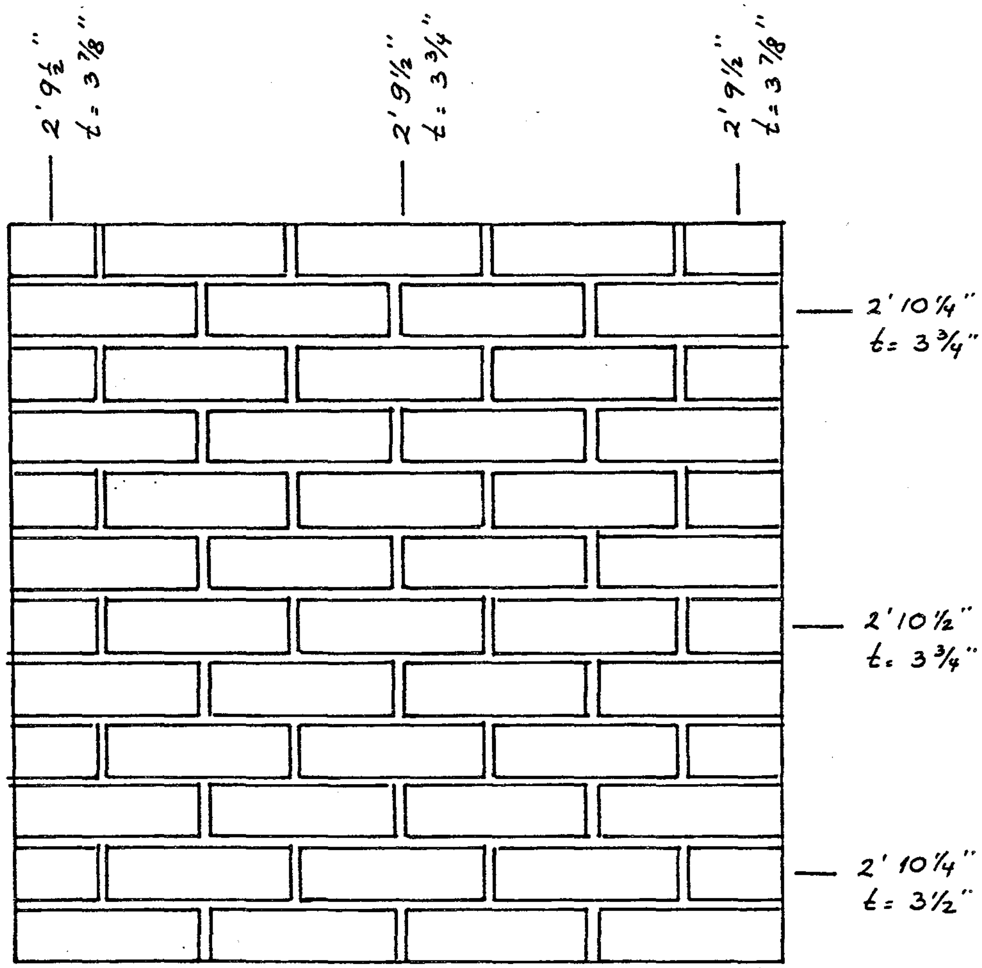


REMARKS:

b = 2' 11"
h = 2' 9 7/8"
t = 3 7/8"
BED JOINTS ½" - ¾"
HEAD JOINTS ½" - ¾"

Figure B.7 Specimen 6

SPECIMEN NO. 7
1 WYTHE (12 COURSES)



REMARKS:

b = 2' 10 3/8"

h = 3' 7/8"

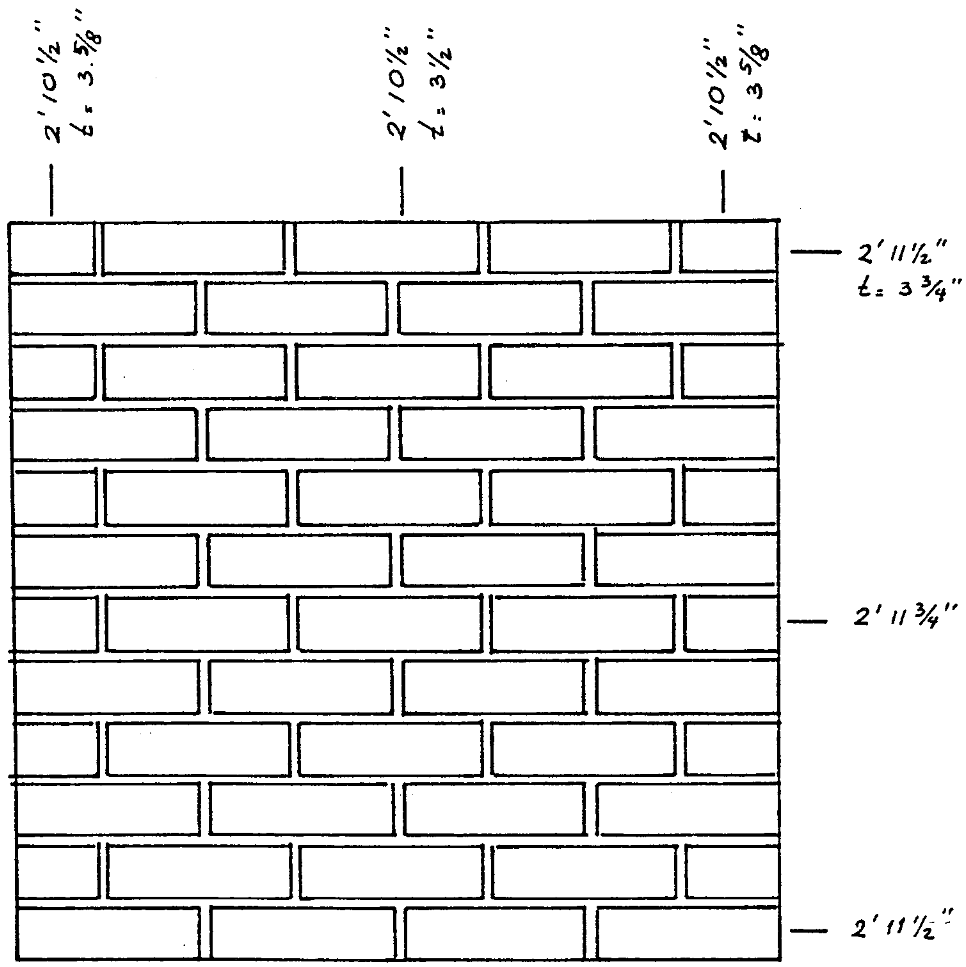
t = 3 3/4"

BED JOINTS ½" - ¾"

HEAD JOINTS ½" - ¾"

Figure B.8 Specimen 7

SPECIMEN NO. 8
1WYTHE (12 COURSES)

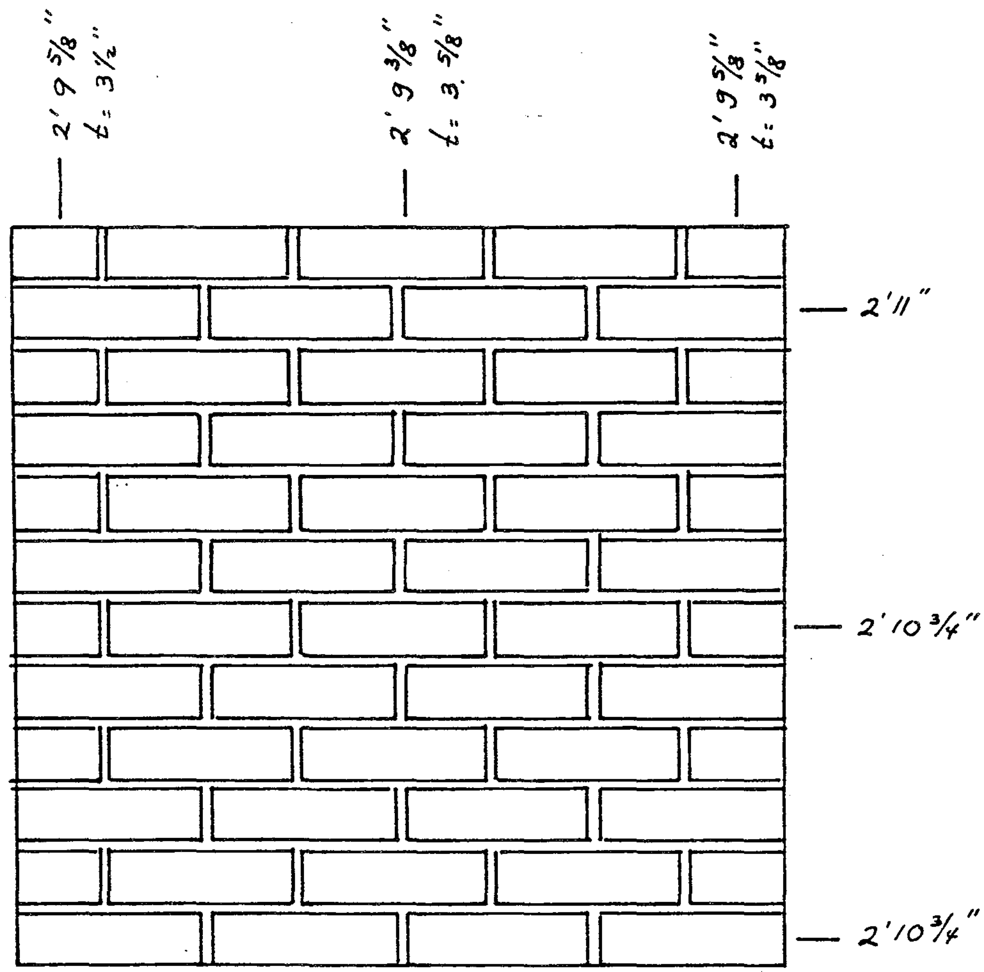


REMARKS :

b = 2' 11 3/5"
h = 2' 10½"
t = 3 5/8"

BED JOINTS ¾" - 1¼"
HEAD JOINTS ½" - 1"

Figure B.9 Specimen 8



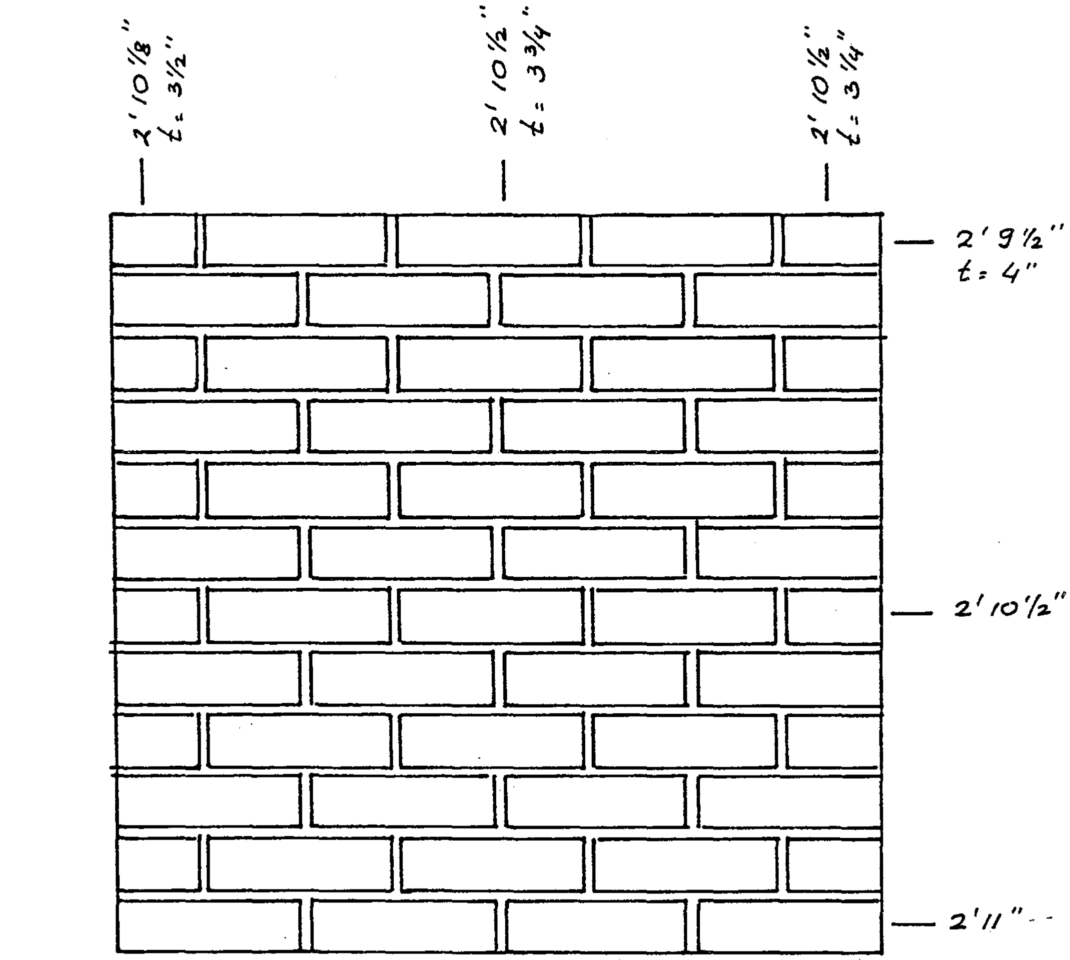
REMARKS:

$b = 2'\ 10\ 4/5''$
$h = 2'\ 9\ 1/2''$
$t = 3\ 3/5''$

BED JOINTS 1/2" - 3/4"
HEAD JOINTS 3/4" - 1 1/4"

Figure B.10 Specimen 9

SPECIMEN NO. 10
1 WYTHE (12 COURSES)

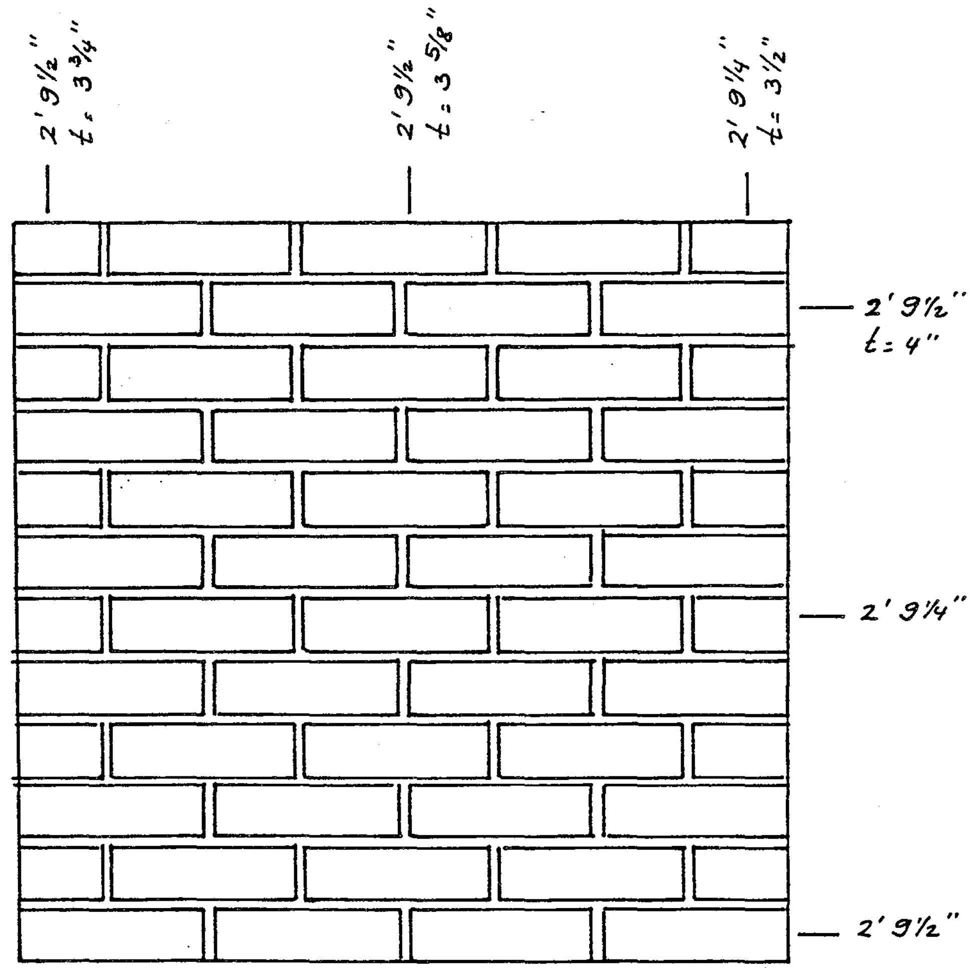


REMARKS :

b = 2' 10 3/8"
h = 2' 10 3/8"
t = 3 3/4"
BED JOINTS 1/2" - 3/4"
HEAD JOINTS 1/2" - 3/4"

Figure B.11 Specimen 10

SPECIMEN NO. 11
1 WYTHE (12 COURSES)

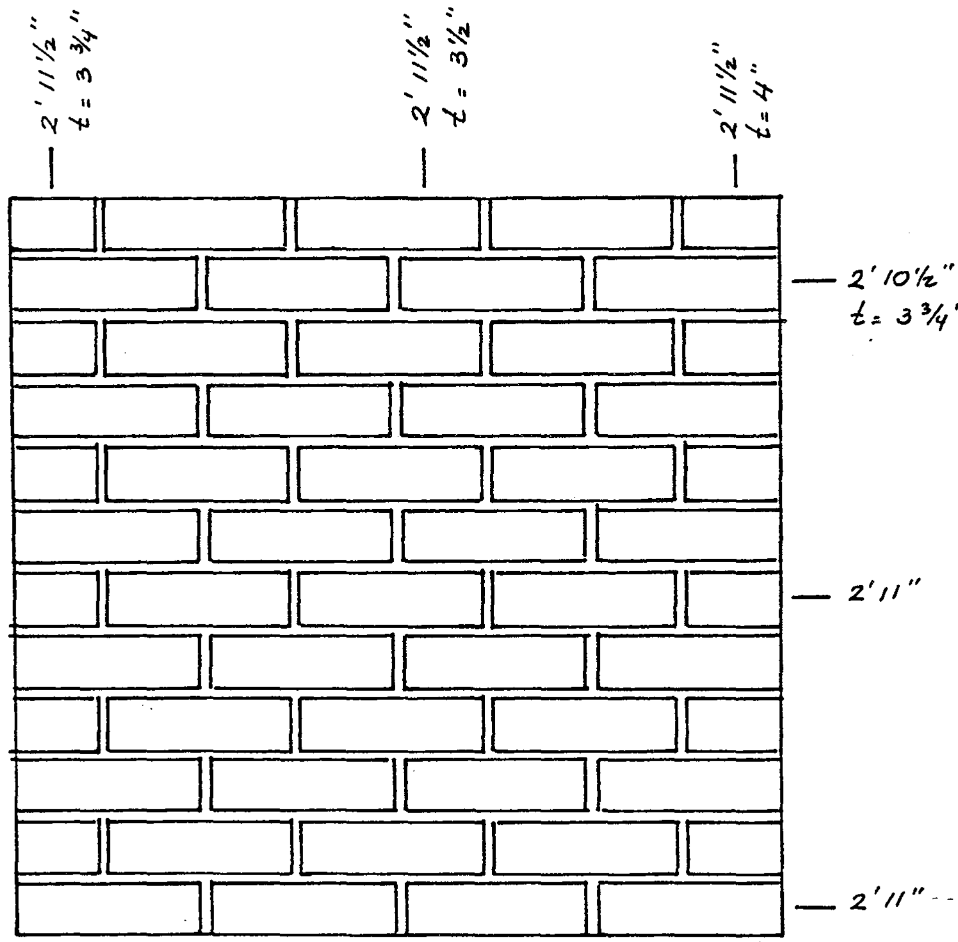


REMARKS:

b = 2' 9⅖"
h = 2' 9⅖"
t = 3¾"
BED JOINTS ½" - ¾"
HEAD JOINTS ½" - 1"

Figure B.12 Specimen 11

SPECIMEN NO. 12
1 WYTHE (12 COURSES)

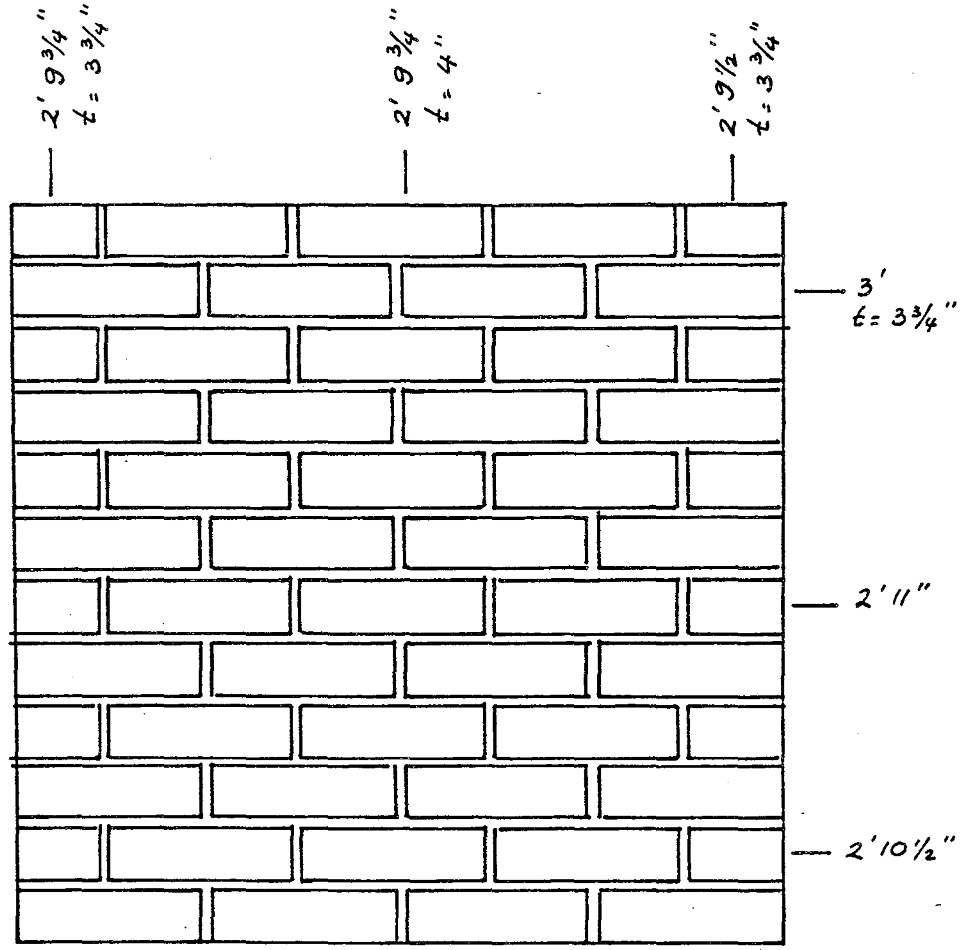


REMARKS :

b = 2' 10⅘"
h = 2' 11½"
t = 3¾"
BED JOINTS ½"-1"
HEAD JOINTS ½"-1"

Figure B.13 Specimen 12

SPECIMEN NO. 13
1 WYTHE (12 COURSES)

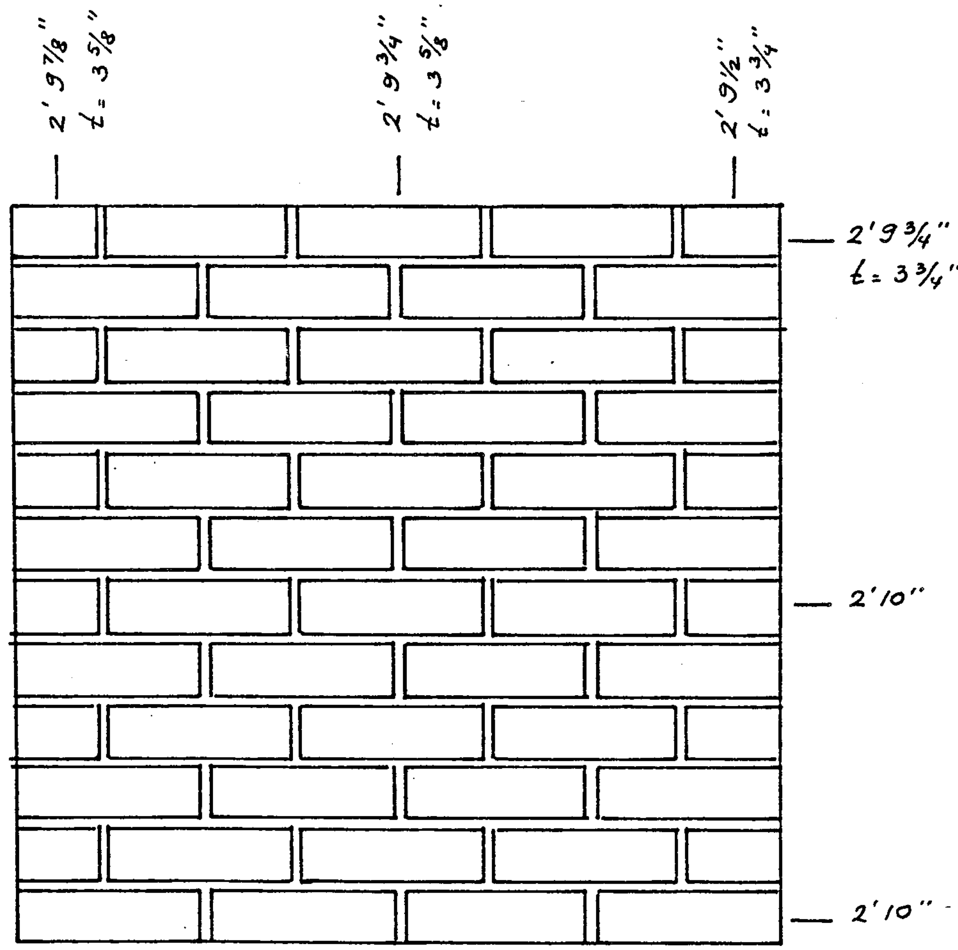


REMARKS:

b = 2' 11 1/5"
h = 2' 9 5/8"
t = 3 7/8"
BED JOINTS 1/2" - 3/4"
HEAD JOINTS 1/2" - 1"

Figure B/14 Specimen 13

SPECIMEN NO. 14
1 WYTHE (12 COURSES)

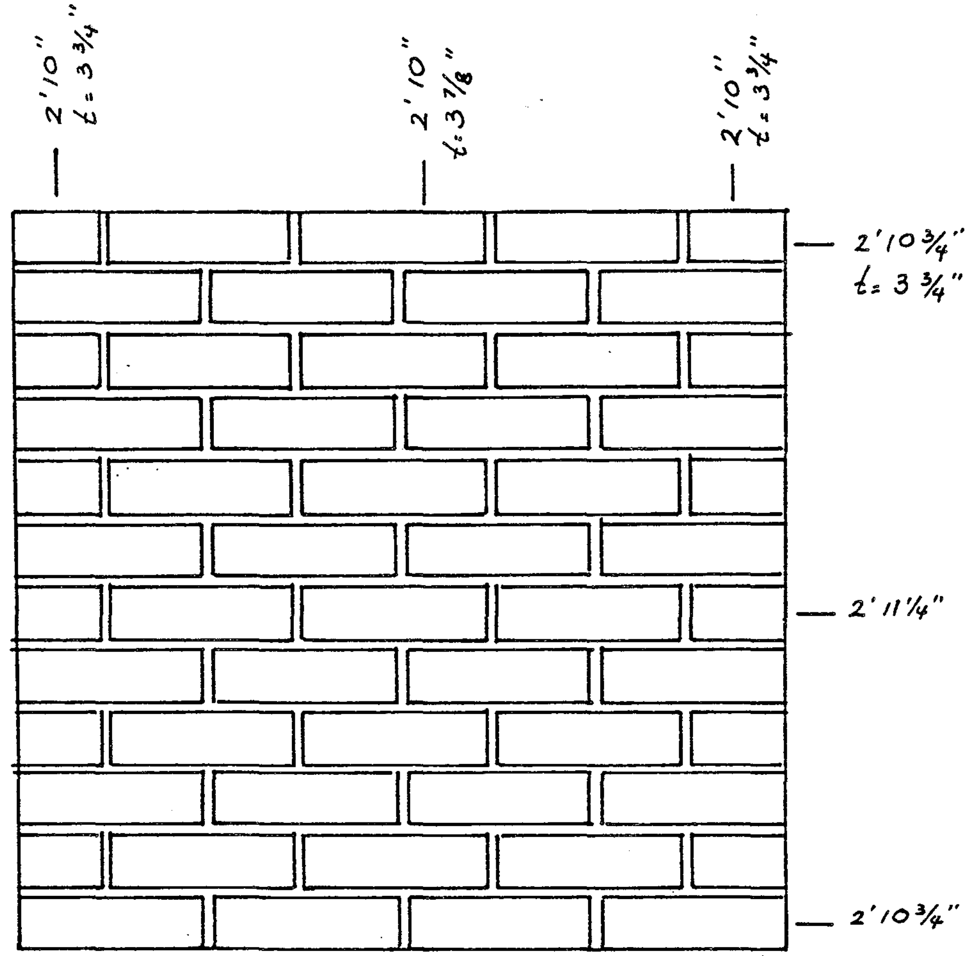


REMARKS:

b = 2' 10"
h = 2' 9 3/4"
t = 3.7"
BED JOINTS 1/2" - 1"
HEAD JOINTS 1/2" - 1 1/4"

Figure B.15 Specimen 14

SPECIMEN NO. 15
1 WYTHE (12 COURSES)

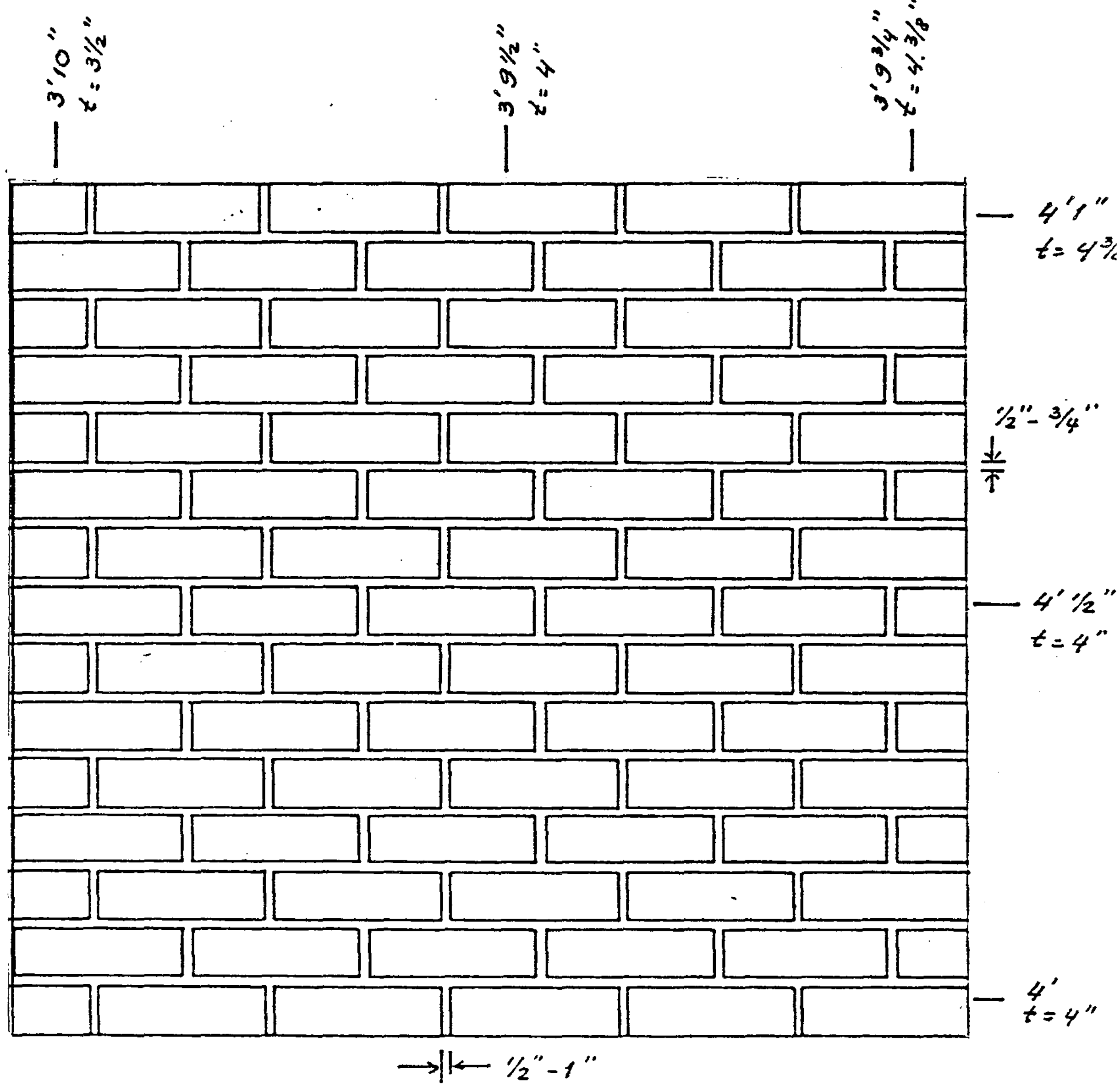


REMARKS:

b = 2' 10 3/8"
h = 2' 10"
t = 3 3/4"
BED JOINTS 1/2" - 3/4"
HEAD JOINTS 1/2" - 1"

Figure B.16 Specimen 15

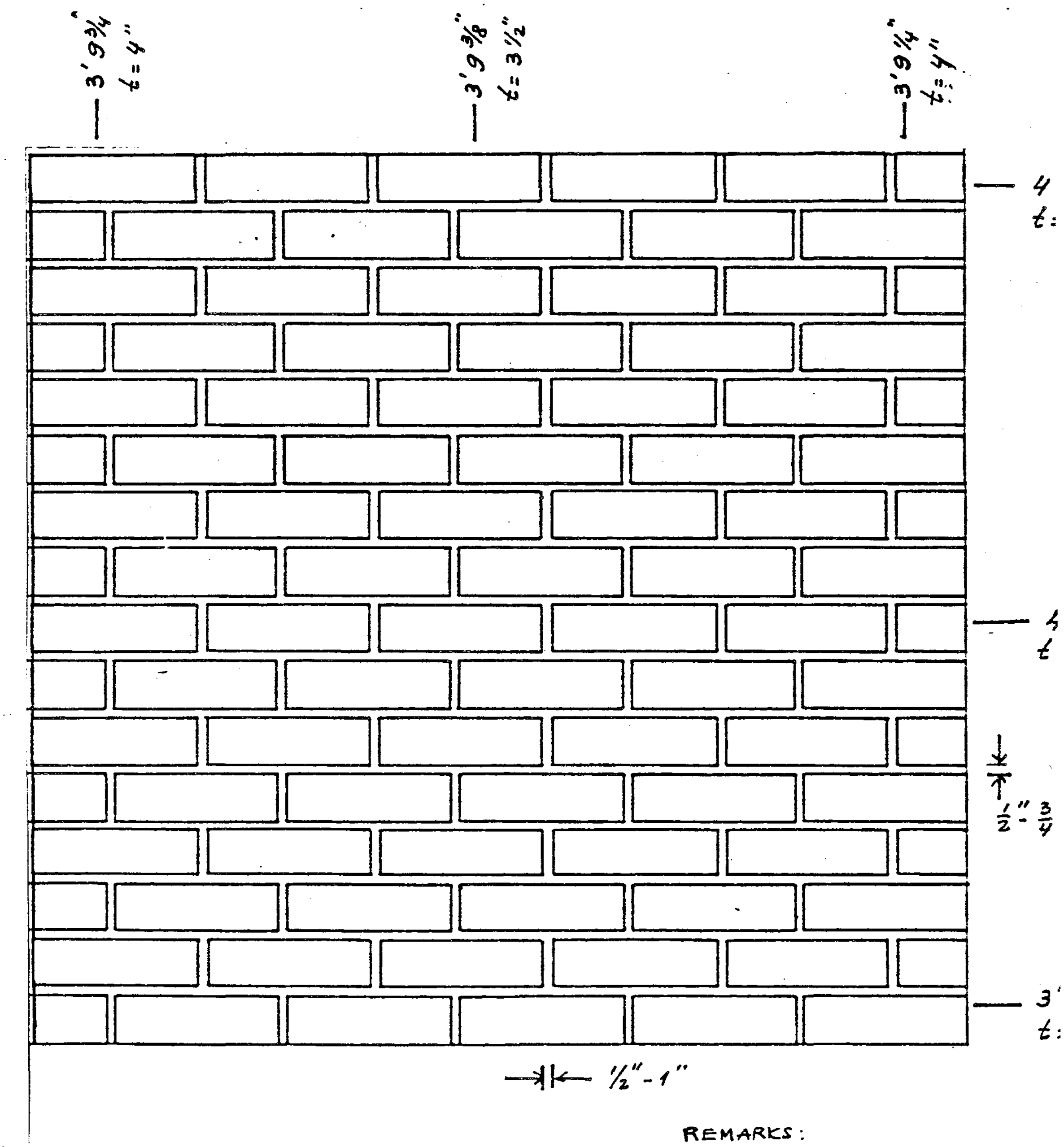
SPECIMEN NO. 16
1 WYTHE (15 COURSES)



REMARKS :
b = 4'½"
h = 3'9¾"
t = 4"
BED JOINTS ½" - ¾"
HEAD JOINTS ½" - 1"

Figure B.17 Specimen 16

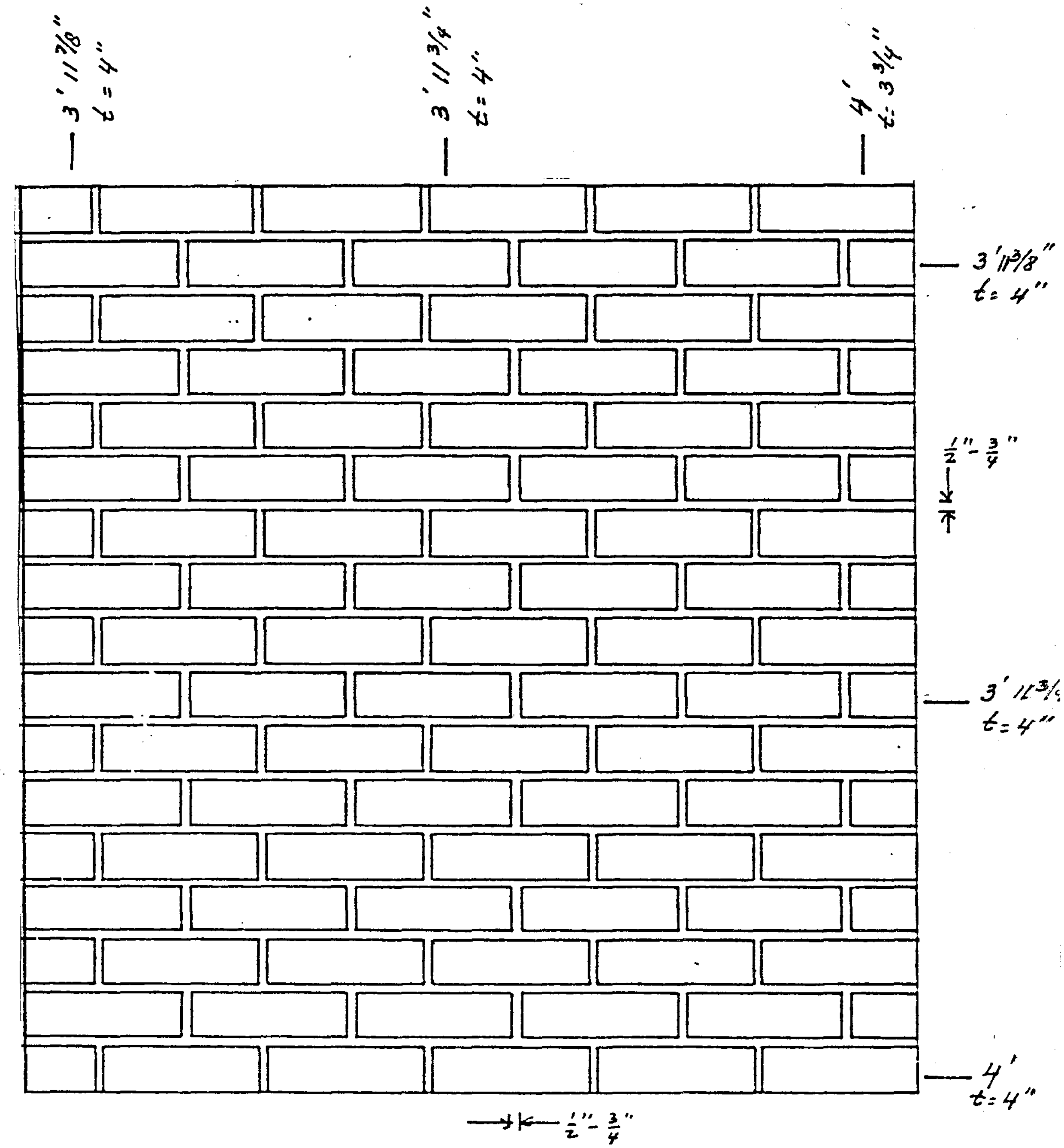
SPECIMEN NO. 17
1 WYTHE (16 COURSE:



REMARKS:
b = 4' ¼"
h = 3' 9½"
t = 3.8"
BED JOINTS ½" - ¾"
HEAD JOINTS ½" - 1"

Figure B.18 Specimen 17

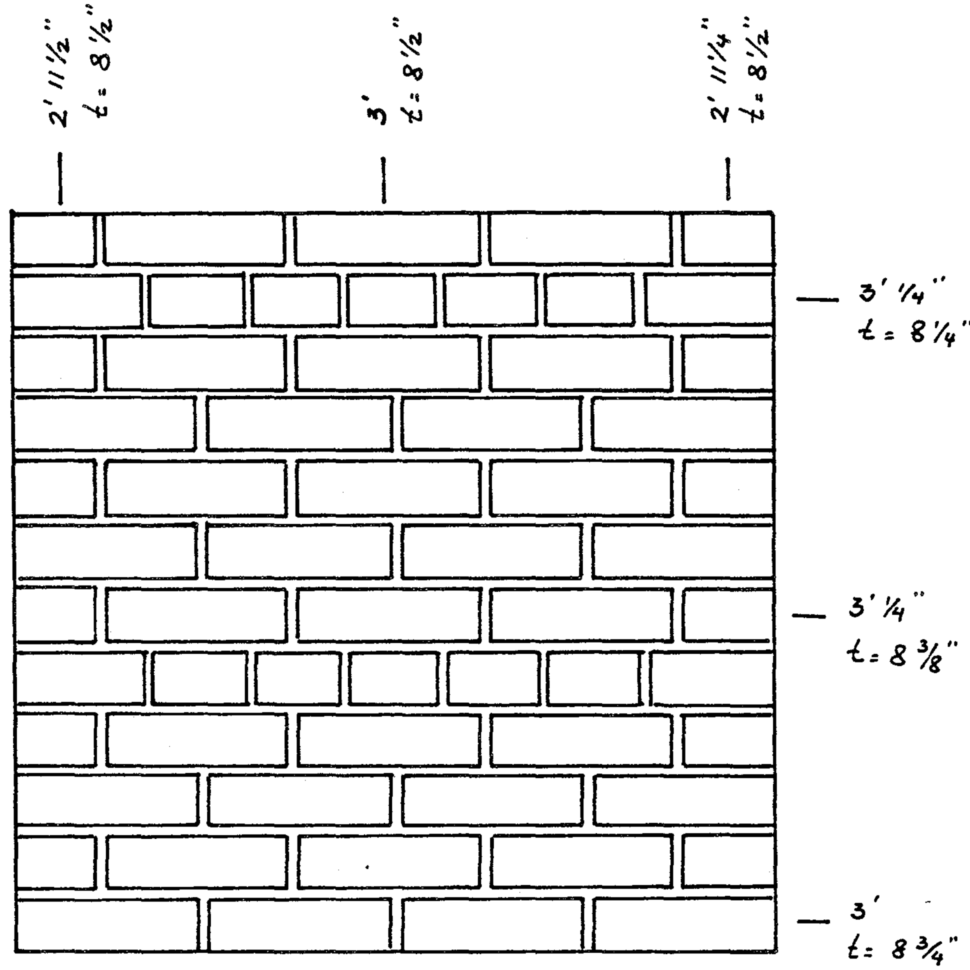
SPECIMEN NO. 18
1 WYTHE (17 COURSES)



REMARKS:
b = 3' 11.7"
h = 3' 11.8"
t = 3.96"
BED JOINTS 1/2" - 3/4"
HEAD JOINTS 1/2" - 3/4"

Figure B.19 Specimen 18

SPECIMEN NO. 19
2 WYTHES (12 COURSES)



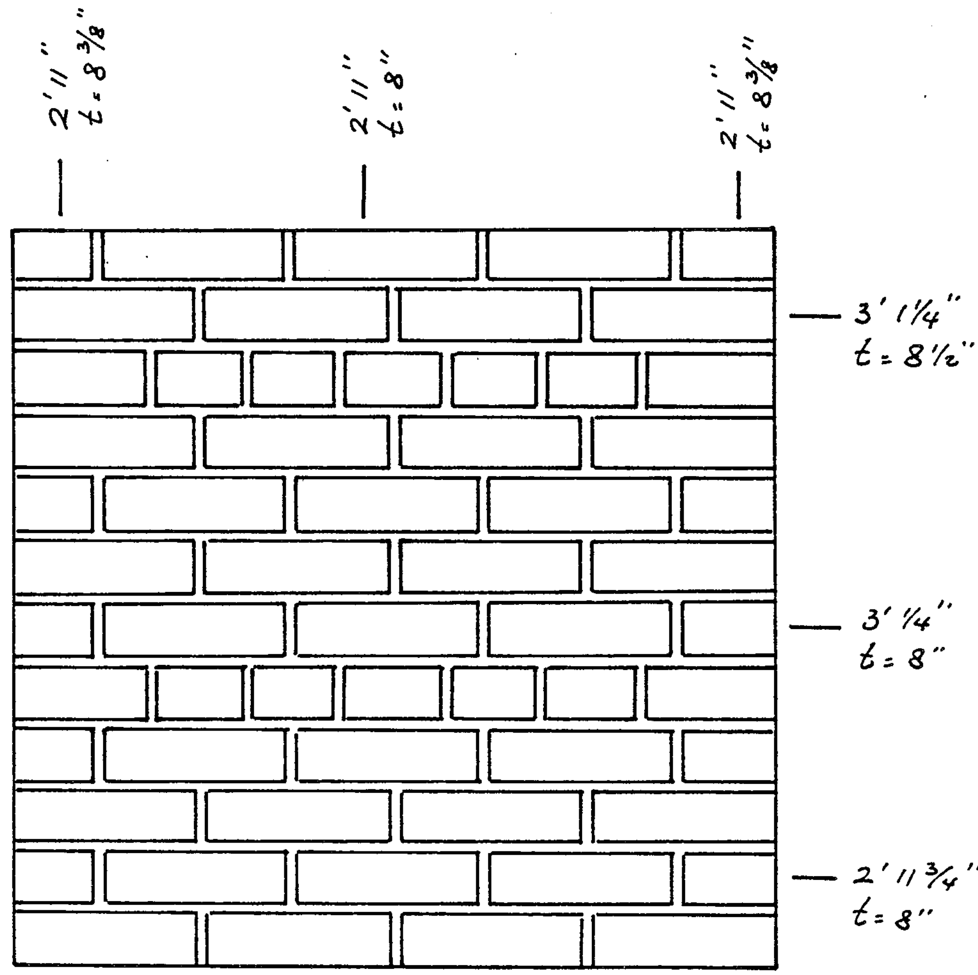
REMARKS:

b = 3' ⅕"
h = 2' 11⅗"
t = 8½"
BED JOINTS ½" - 1"
HEAD JOINTS ¾" - 1¼"
HEADERS:
COURSE NO. 5 & 11.

Figure B.20 Specimen 19

SPECIMEN NO. 20

2 WYTHES (12 COURSES)



REMARKS:

b = 3' 2/5"

h = 2' 11"

t = 8.2"

BED JOINTS 1/2" - 1"

HEAD JOINTS 3/4" - 1 1/4"

HEADERS:

COURSE NO. 5 & 10.

Figure B.21 Specimen 20

SPECIMEN NO. 21.
2 WYTHES (16 COURSES)

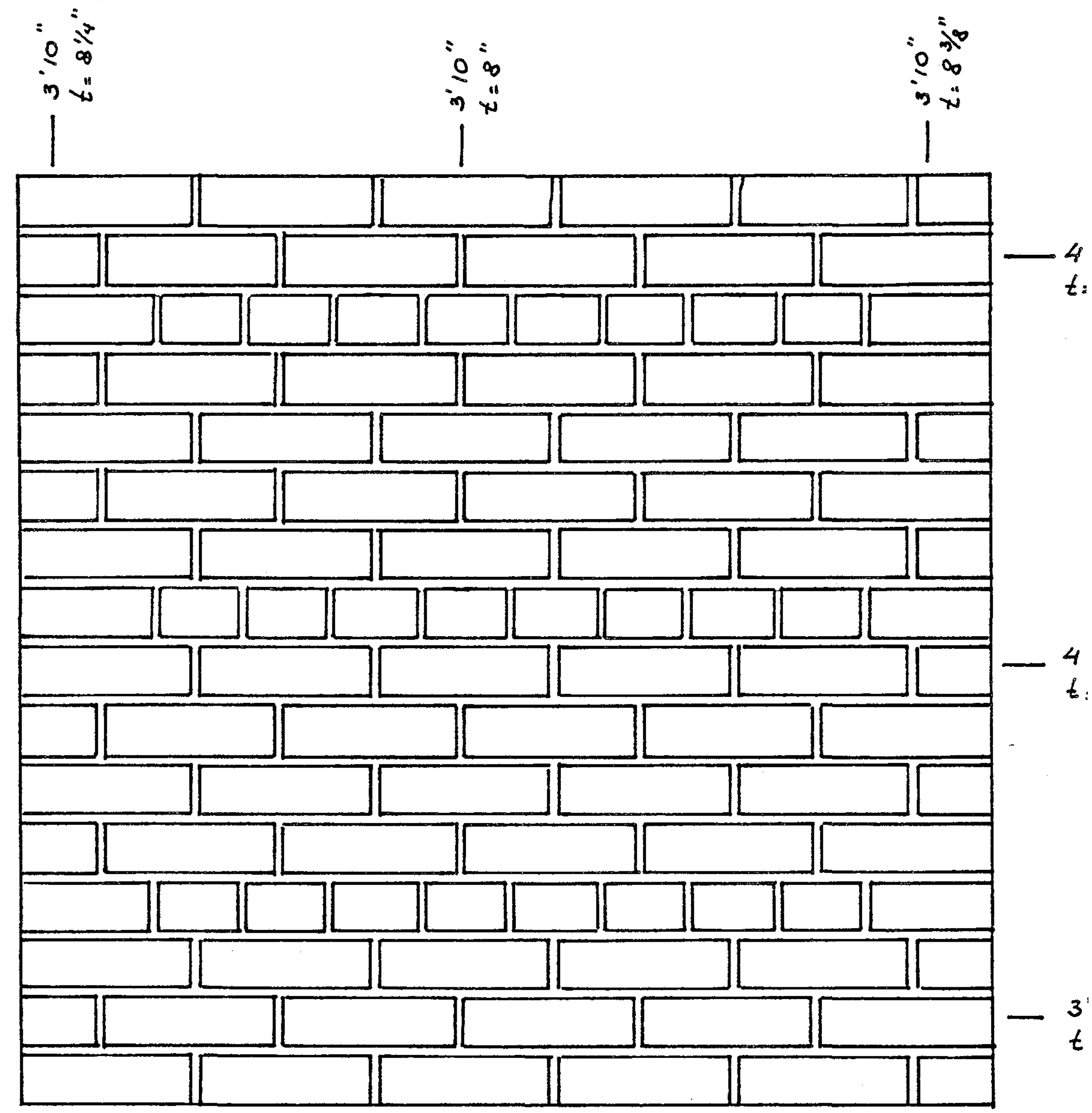


Figure B.22 Specimen 21

REMARKS:

b = 4' 1/5"
h = 3' 10"
t = 8 1/5"

BED JOINTS 1/2" - 3/4"
HEAD JOINTS 1/2" - 3/4"
HEADERS:
COURSE NO. 4, 9 & 14.

SPECIMEN NO. 22
2 WYTHES (16 COURSES)

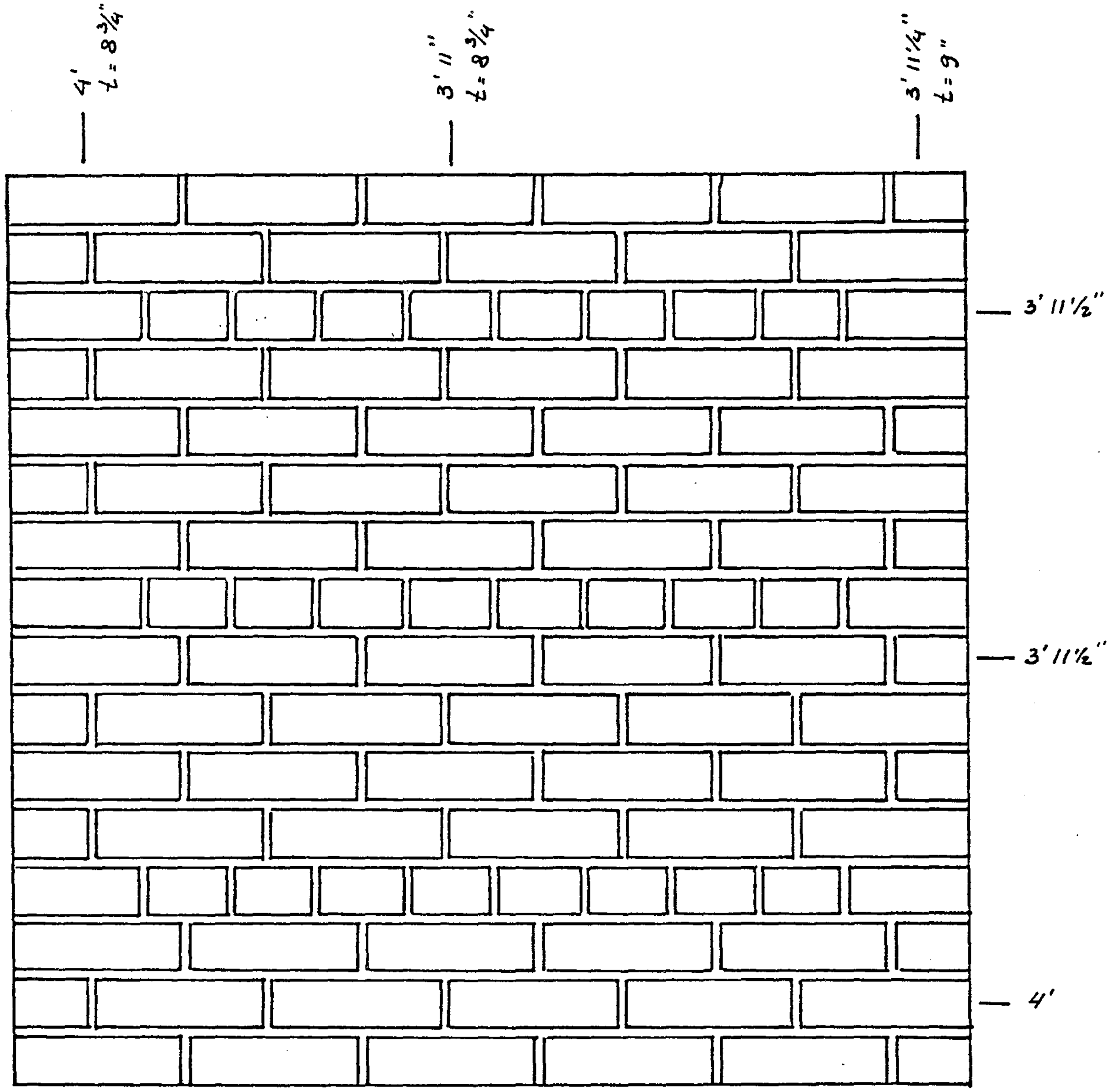


Figure B.23 Specimen 22

REMARKS:

b = 3' 11⅝"

h = 3' 11½"

t = 8.8"

BED JOINTS ½"-1"

HEAD JOINTS ½"-1"

HEADERS:
COURSE NO. 4, 9 & 14

SPECIMEN NO. 23
2 WYTHES (15 COURSES)

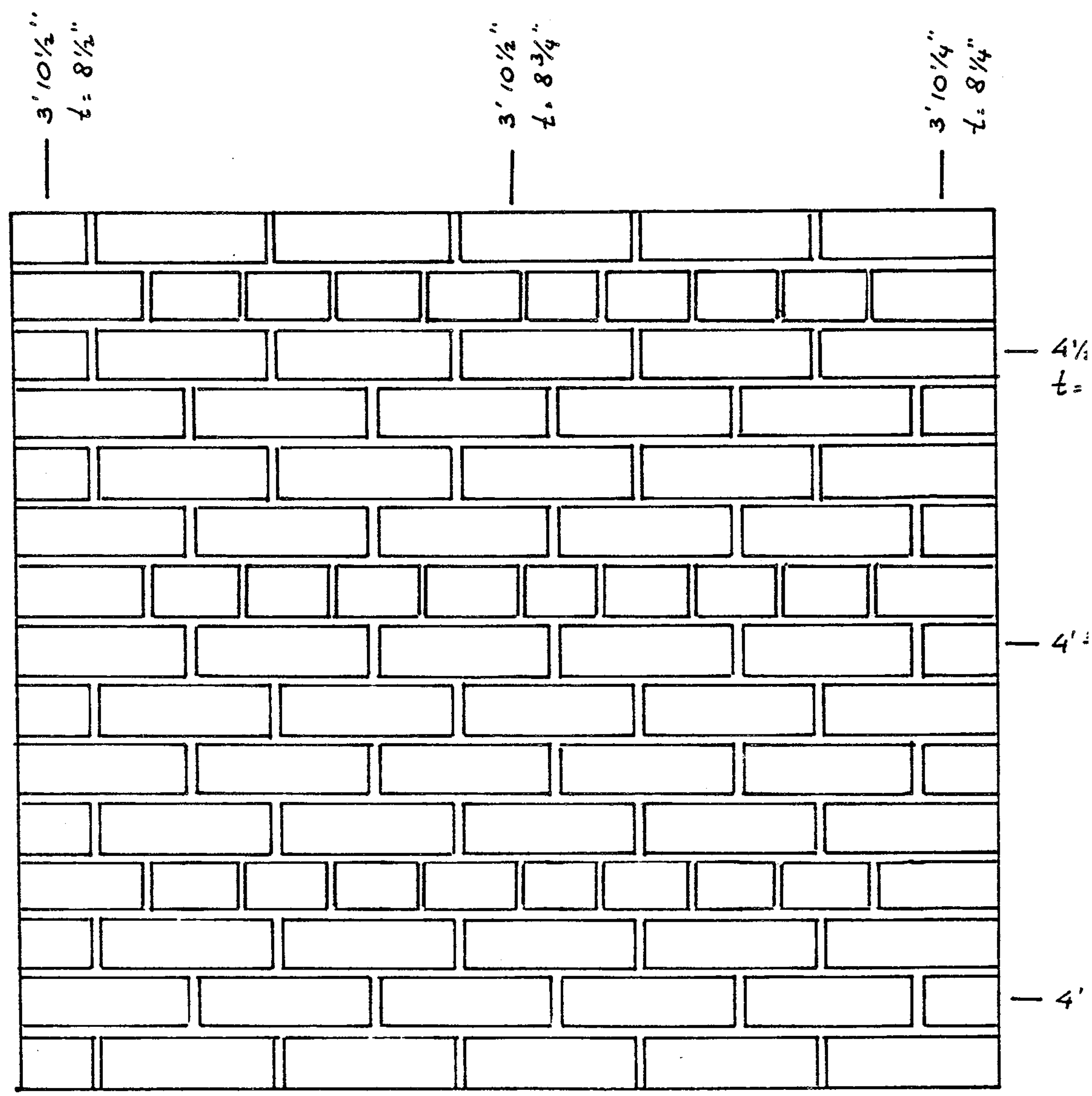
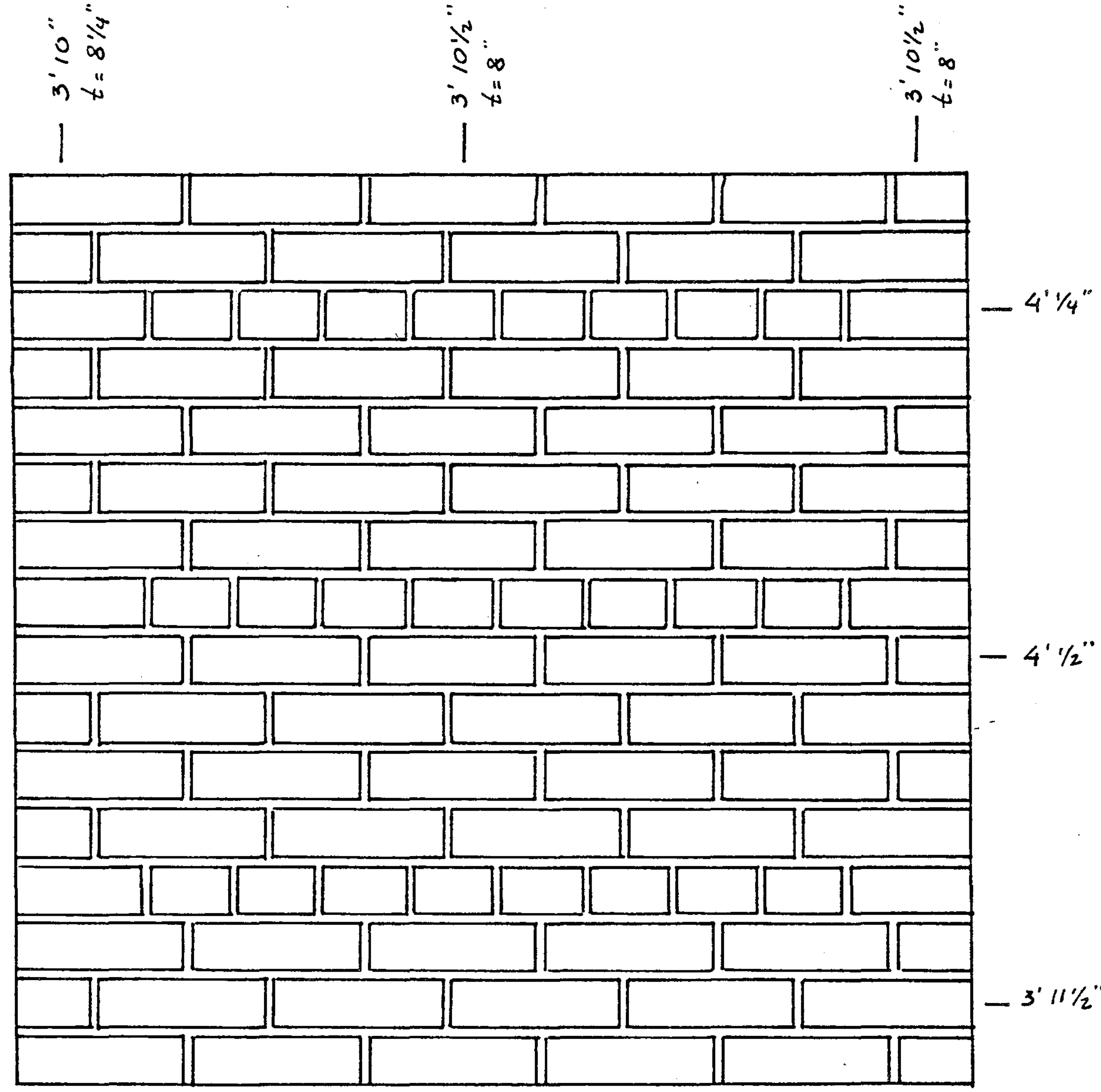


Figure B. 24 Specimen 23

REMARKS:
b = 4' 2/5"
h = 3' 10 2/5"
t = 8.4"
BED JOINTS ½"- 1"
HEAD JOINTS ½"- 1"
HEADERS:
COURSE NO. 4, 9, & 14

SPECIMEN NO. 24
2 WYTHES (16 COURSES)

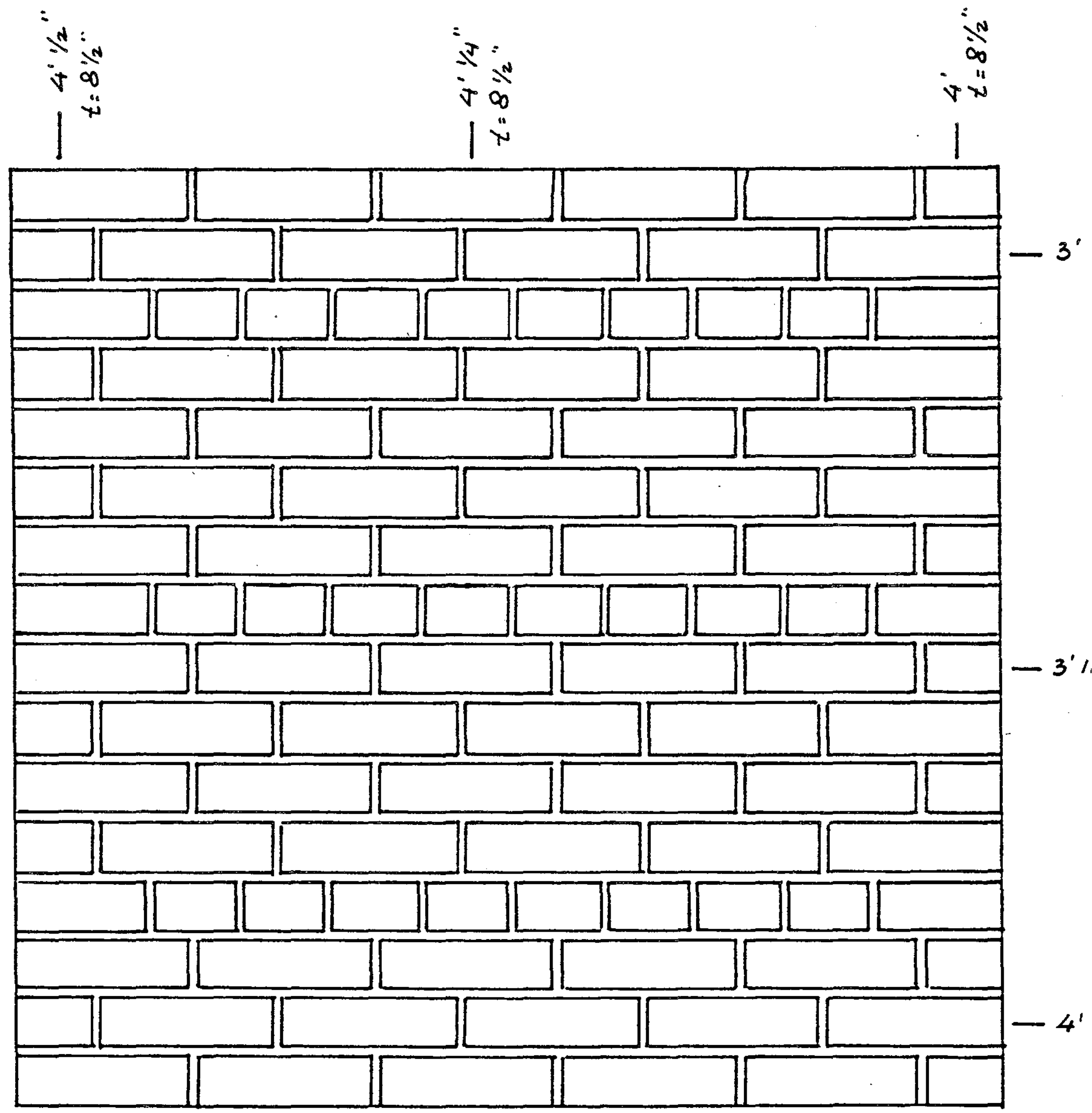


REMARKS:

b = 4' 1/10"
h = 3' 10 3/8"
t = 8.1"
BED JOINTS 1/2"-1"
HEAD JOINTS 1/2"-1"
HEADERS:
COURSE NO 4, 9 & 14.

Figure B.25 Specimen 24

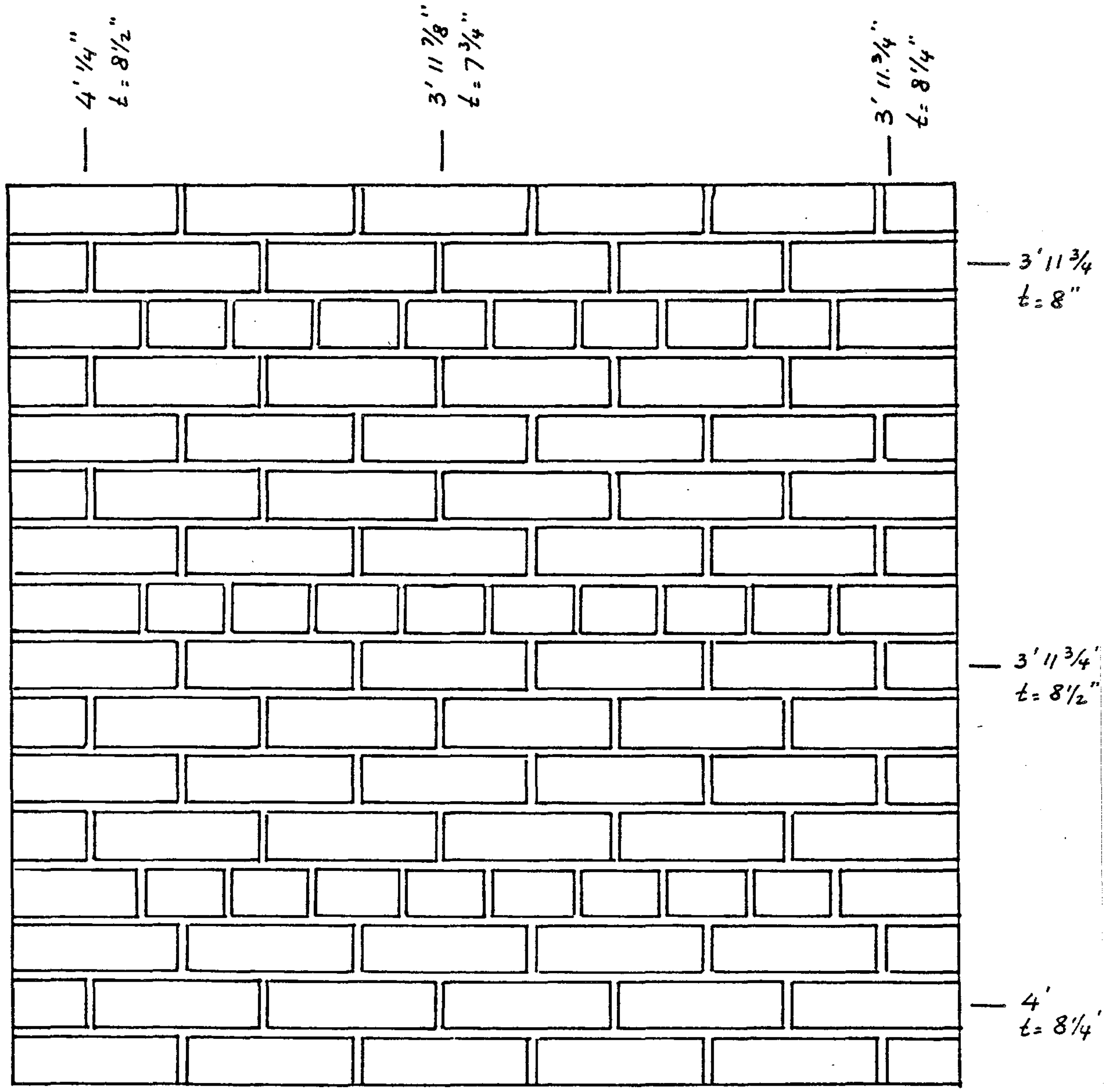
SPECIMEN NO. 25
2 WYTHES (16 COURSES)



REMARKS:
b = 3' 11 3/4"
h = 4' 1/4"
t = 8 1/2"
BED JOINTS: 1/2" - 1"
HEAD JOINTS 1/2" - 1"
HEADERS:
COURSE NO. 4, 9 & 14.

Figure B.26 Specimen 25

SPECIMEN NO. 26
2 WYTHES (17 COURSES)



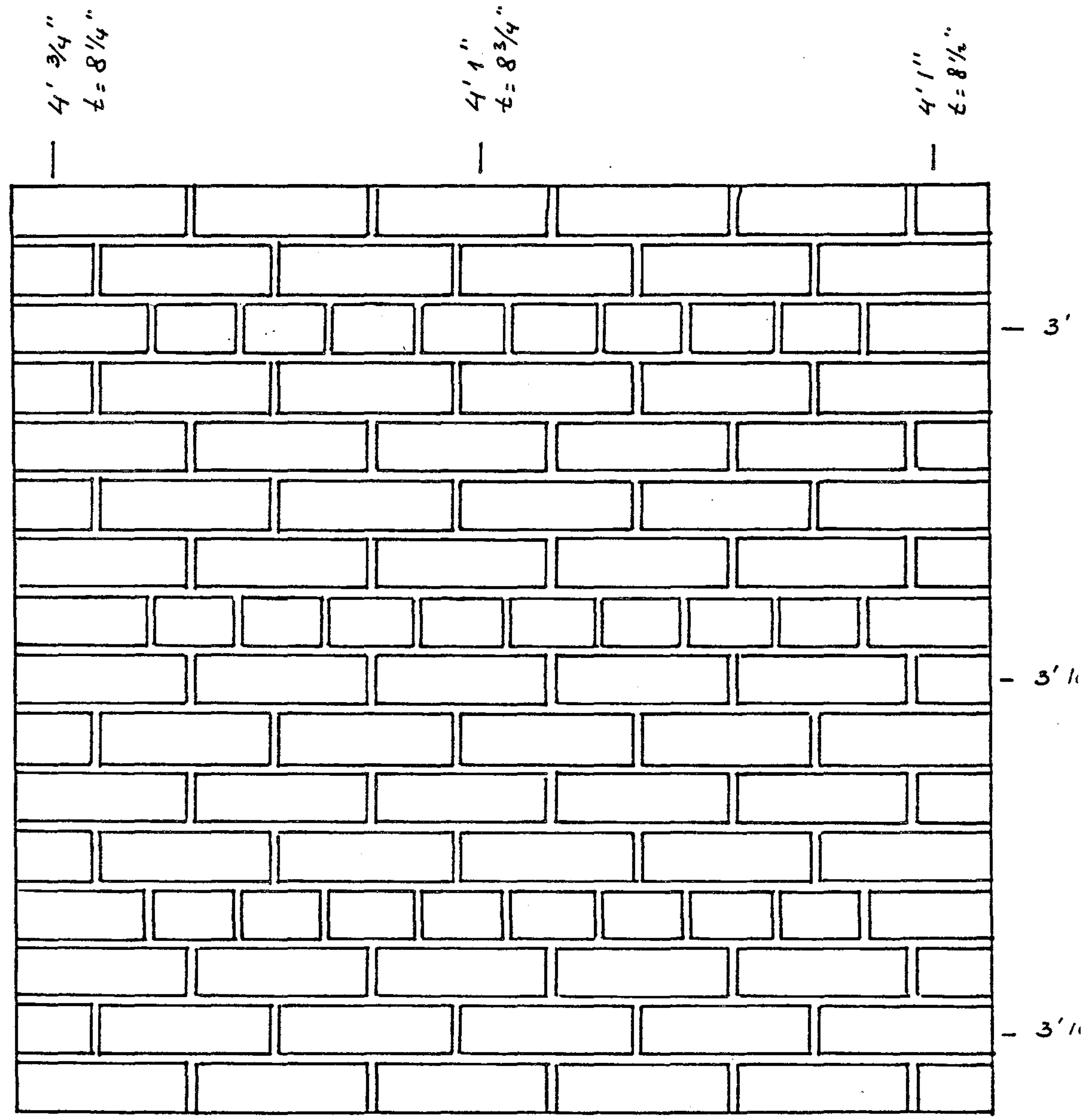
REMARKS:

b = 3' 11 3/4"
h = 3' 11.96"
t = 8.2"
BED JOINTS 1/2" - 3/4"
HEAD JOINTS 1/2" - 3/4"
HEADERS:
COURSE NO. 4, 9 & 14.

Figure B.27 Specimen 26

SPECIMEN NO. 27

2 WYTHES (17 COURSES)



REMARKS:

b = 3' 10 5/8"

h = 4' 1"

t = 8.5"

BED JOINTS 1/2"-3/4"

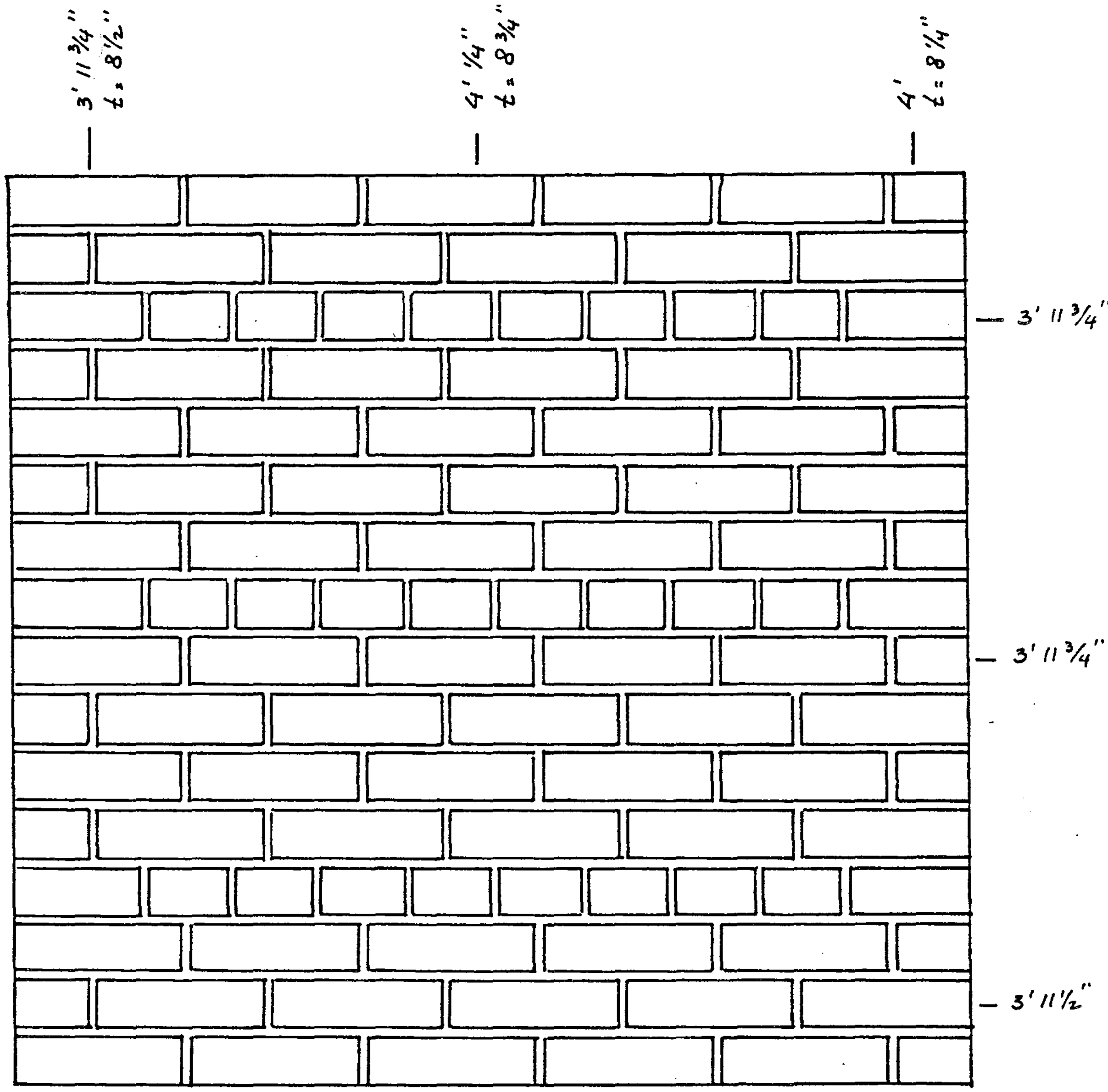
HEAD JOINTS 1/2"-1"

HEADERS:

COURSE NO. 4, 9 & 15

Figure B.28 Specimen 27

SPECIMEN NO. 28
2 WYTHES (16 COURSES)

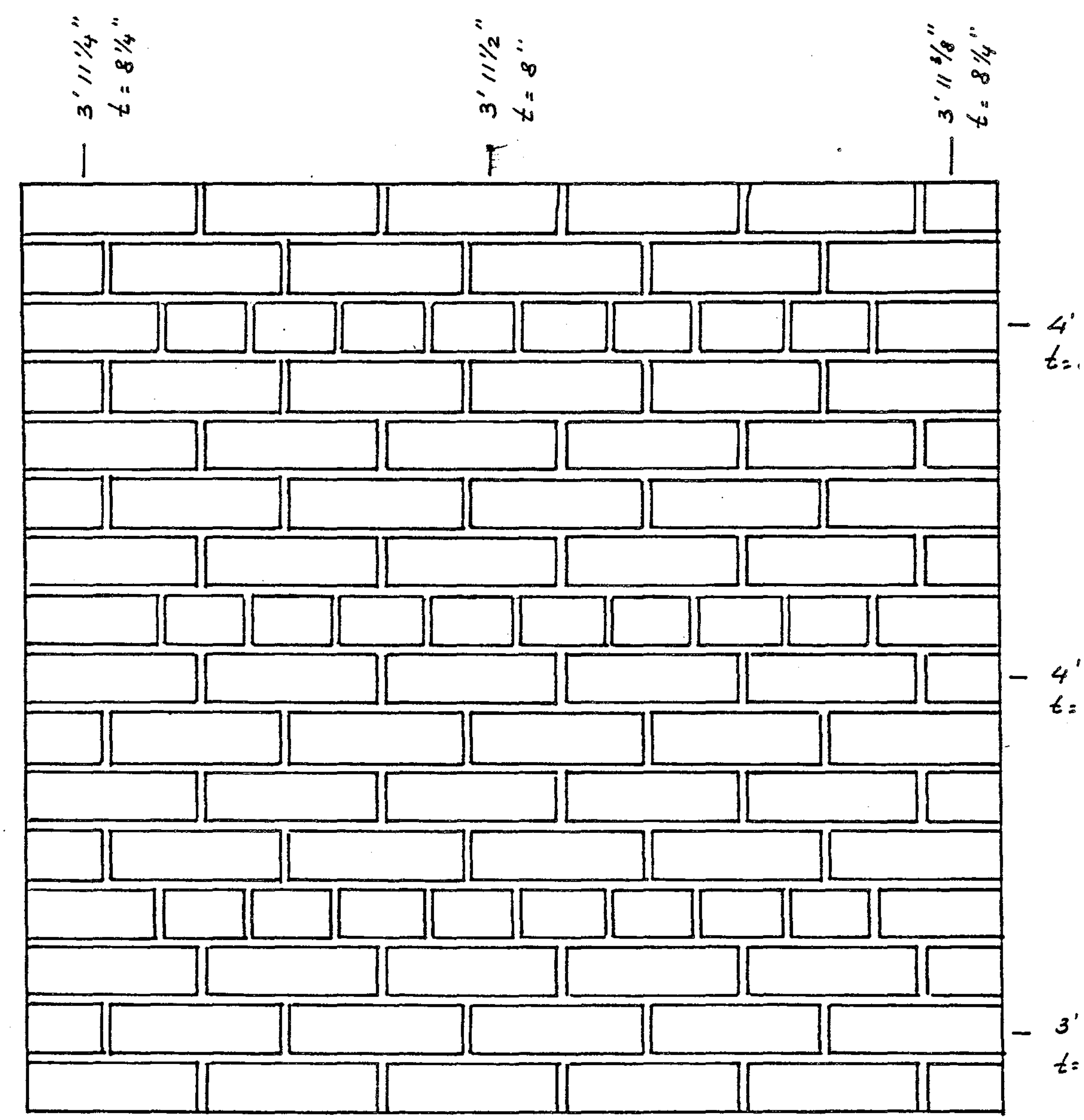


REMARKS:
b = 3' 11 5/8"
h = 4'
t = 8 1/2"
BED JOINTS 1/2"-1"
HEAD JOINTS 1/2"-1"
HEADERS:
COURSE NO. 4, 9 & 14

Figure B.29 Specimen 28

SPECIMEN NO. 29

2 WYTHES (16 COURSES)



REMARKS:

b = 4'

h = 3' 11⅜"

t = 8.08"

BED JOINTS ½"-1"

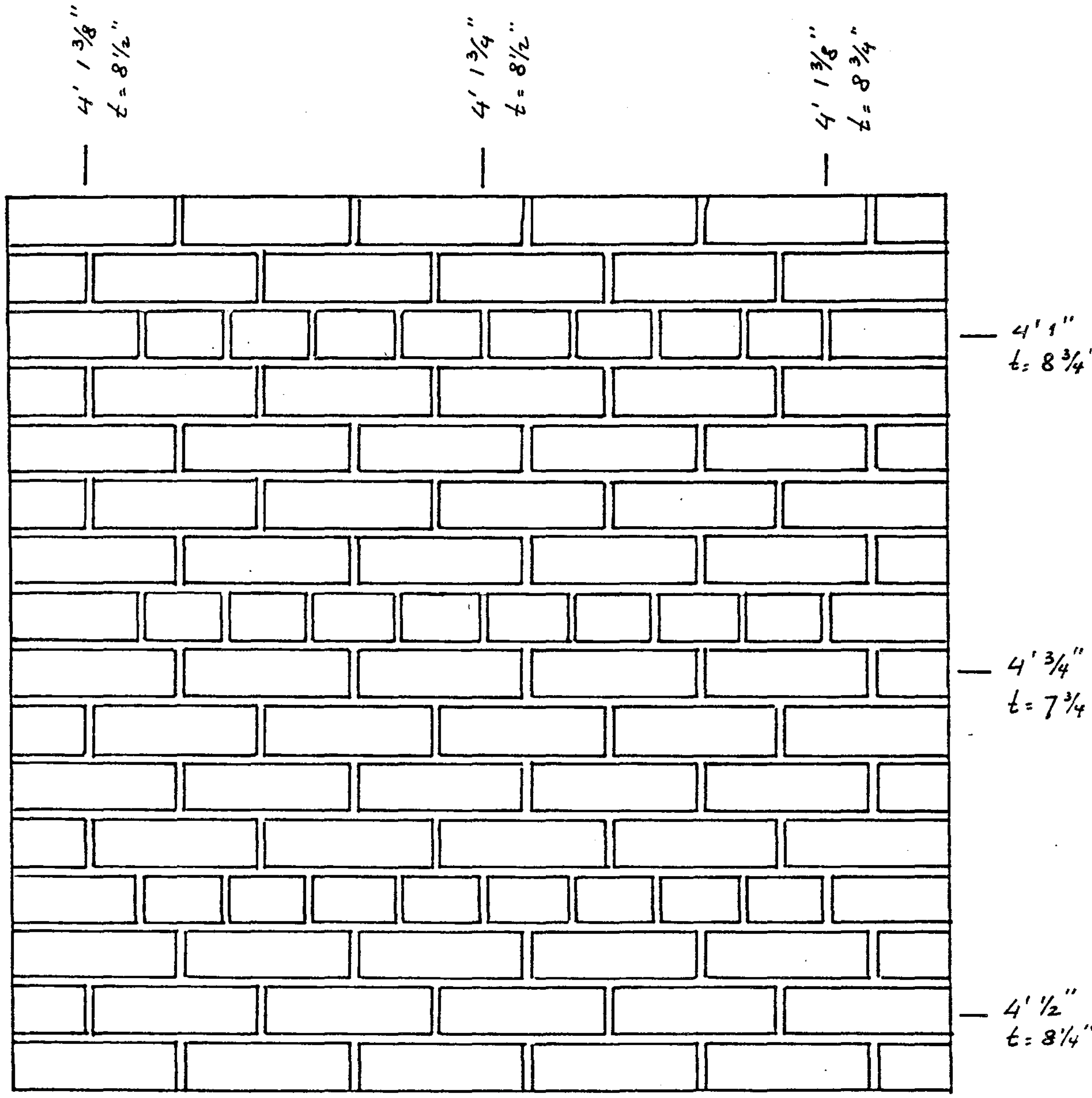
HEAD JOINTS ½"-1"

HEADERS:

COURSE NO. 4, 9 & 14

Figure B.30 Specimen 29

SPECIMEN NO. 30
2 WYTHES (16 COURSES)

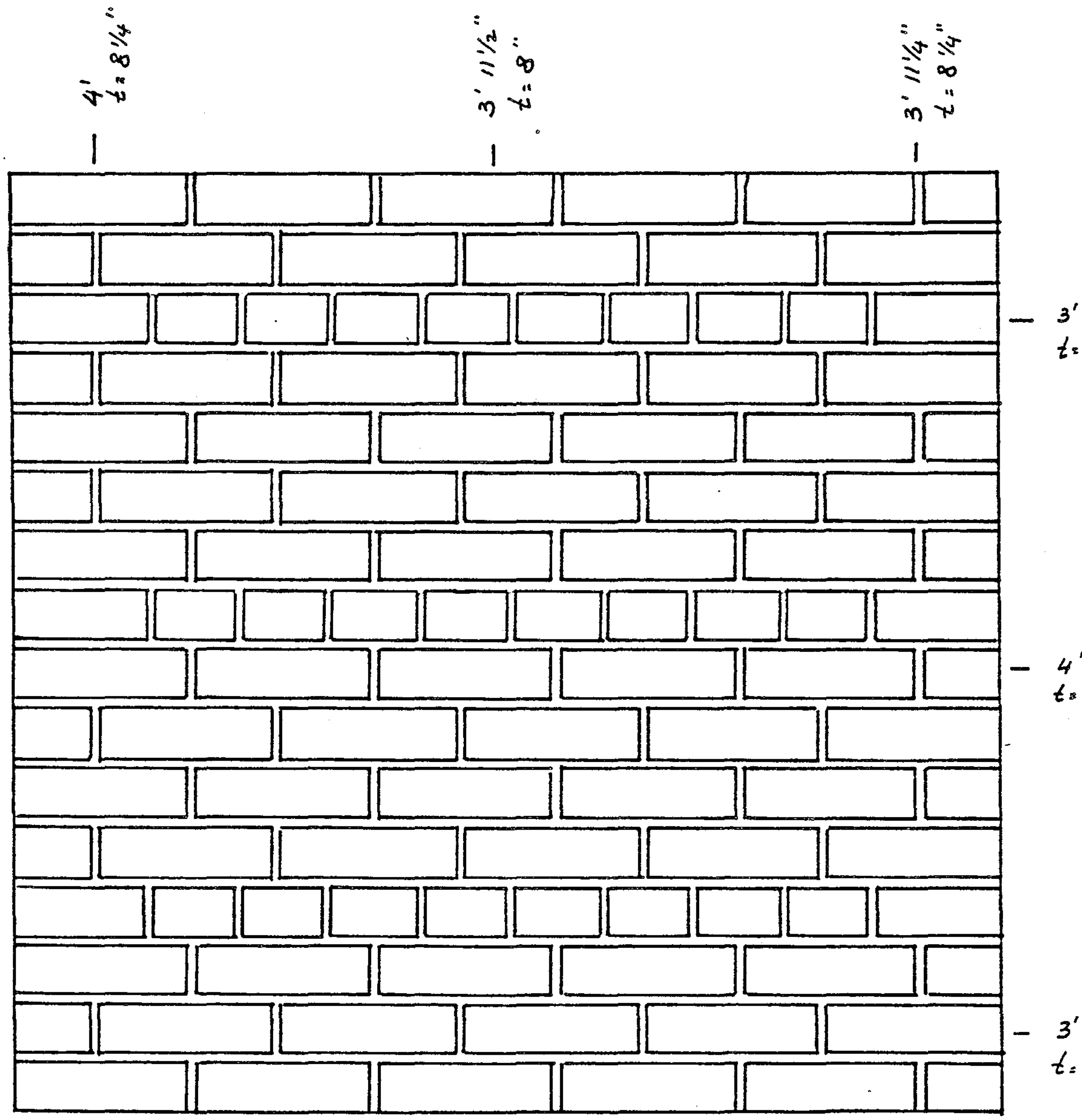


REMARKS:

b = 4' 3/4"
h = 4' 1½"
t = 8.42"
BED JOINTS ½"- 1"
HEAD JOINTS ½"- 1"
HEADERS:
COURSE NO. 4, 9 & 14

Figure B.31 Specimen 30

SPECIMEN NO. 31
2 WYTHES (17 COURSES)

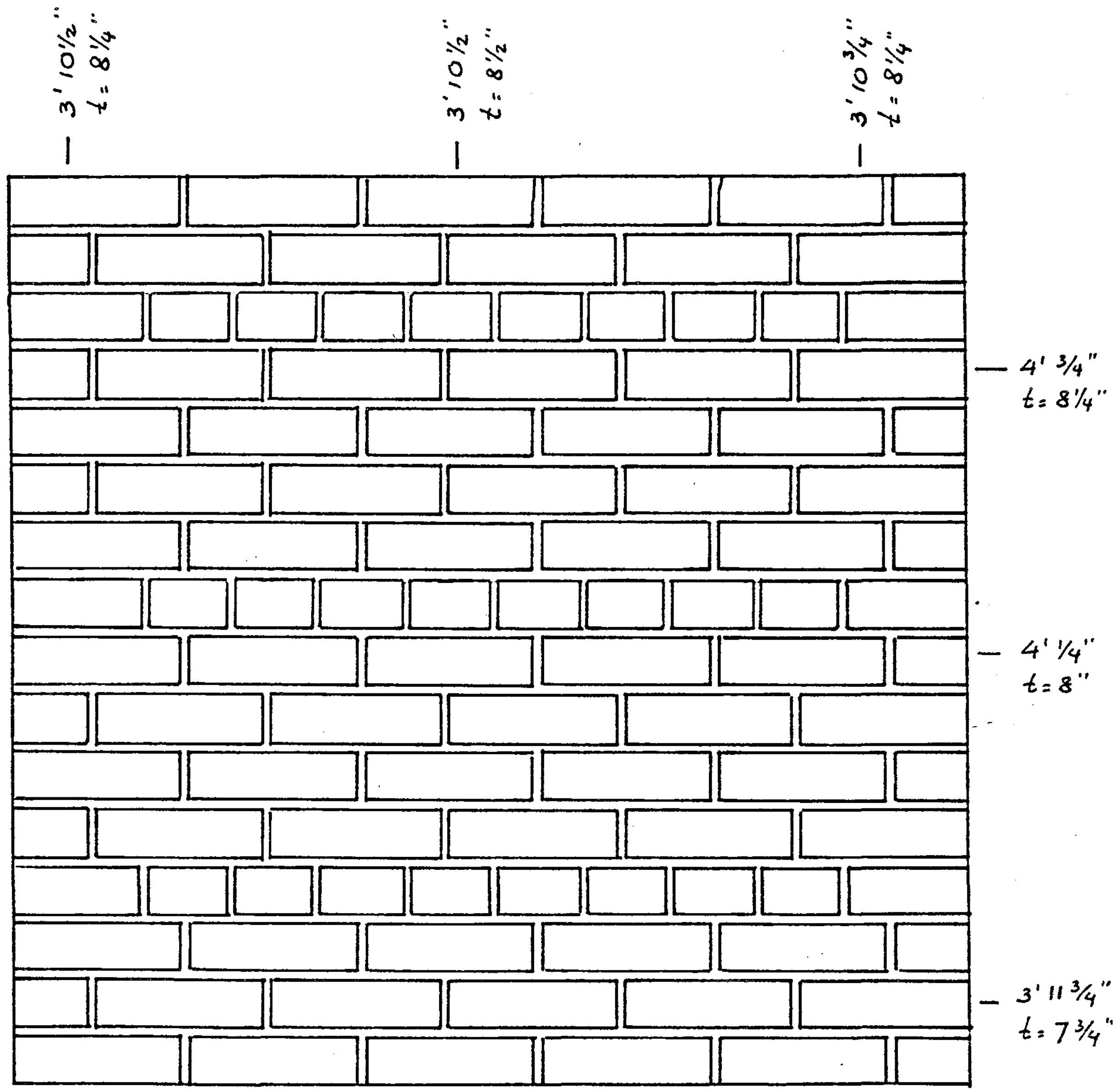


REMARKS:

b = 3' 11 3/5"
h = 3' 11 3/5"
t = 8.04"
BED JOINTS ½"-1"
HEAD JOINTS ½"-1"
HEADERS:
COURSE NO. 4, 9 & 14

Figure B. 32 Specimen 31

SPECIMEN NO. 32
2 WYTHES (16 COURSES)



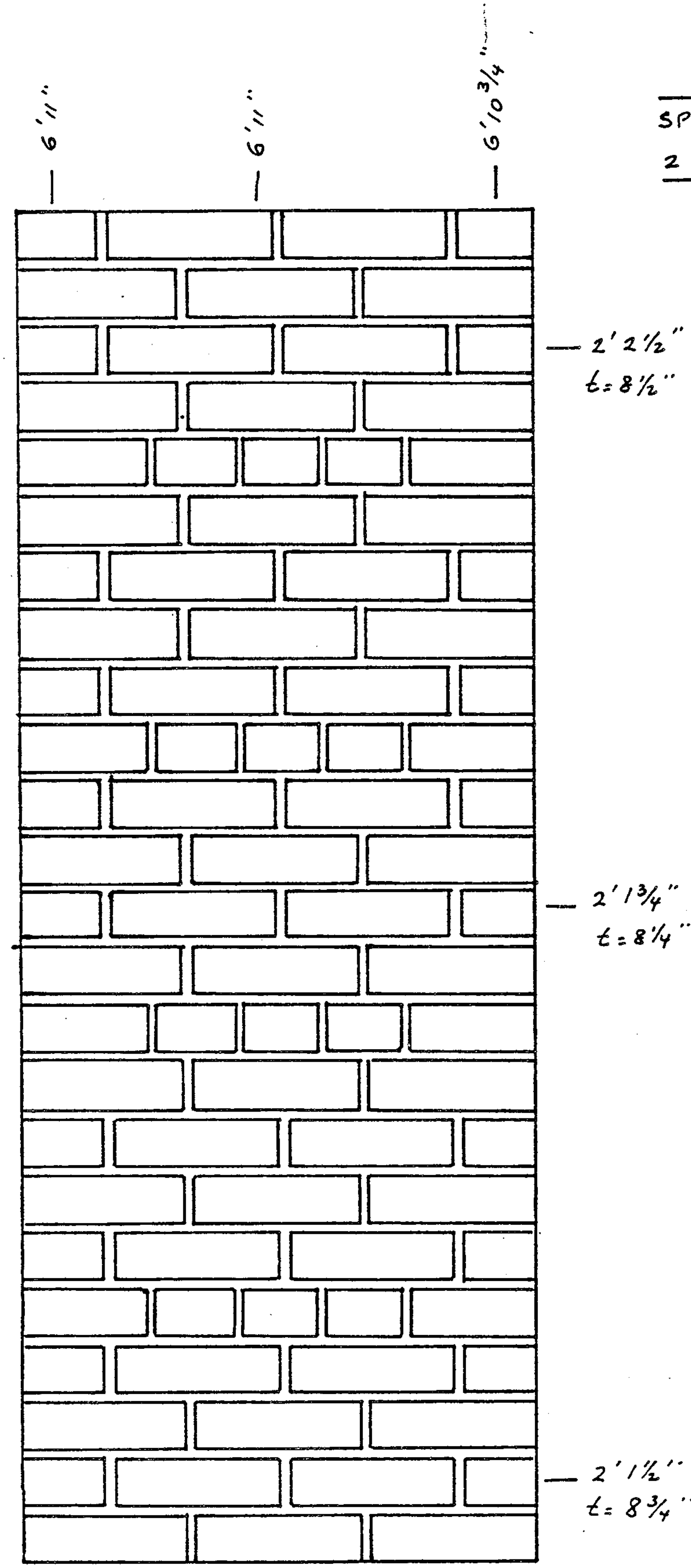
REMARKS:

b = 4' ¼"
h = 3' 10⅗"
t = 8.2"
BED JOINTS ½"-1"
HEAD JOINTS ½"-1"

HEADERS:
COURSE NO. 4, 9, 14

Figure B. 33 Specimen 32

SPECIMEN NO.
2 WYTHES (24 COURSES)

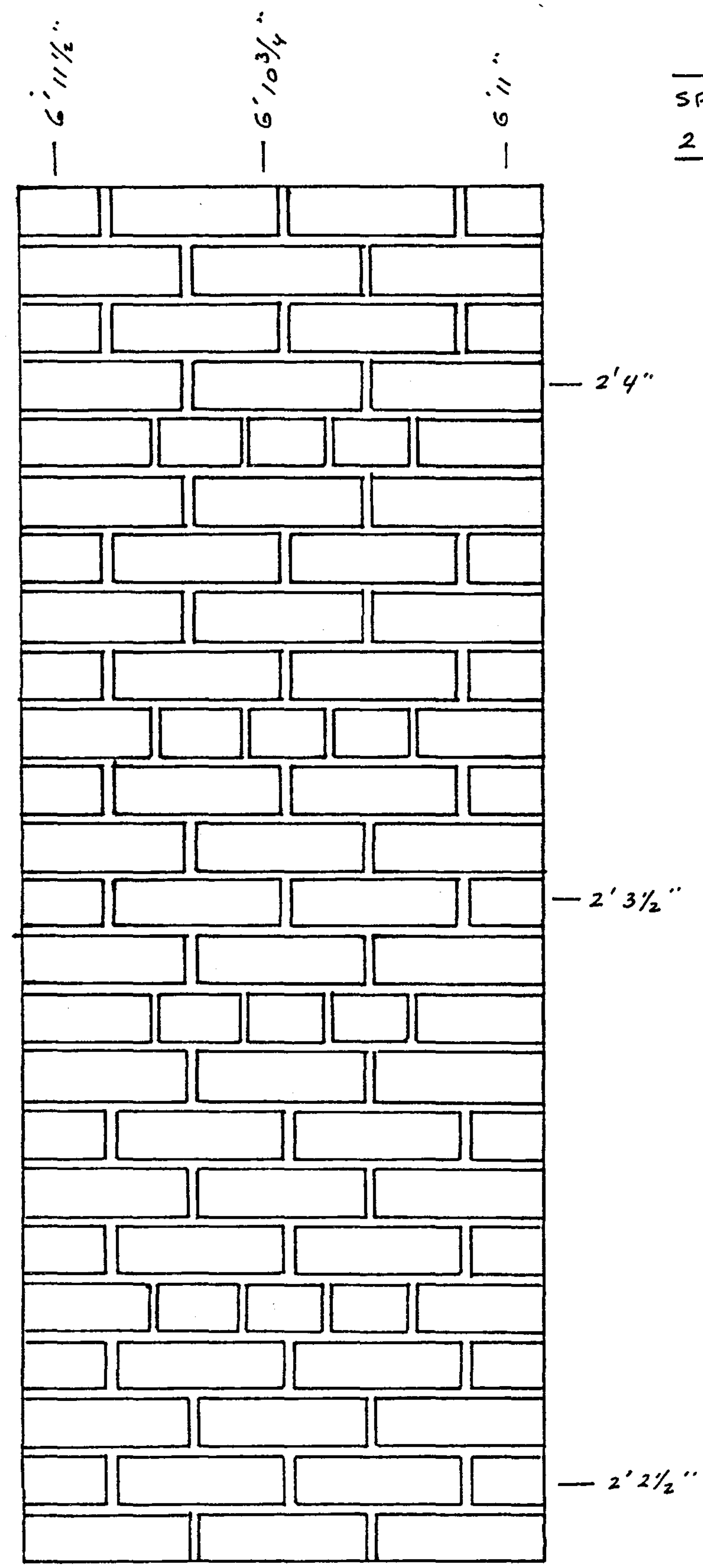


REMARKS:

b = 2'2"
h = 6'11"
t = 8 1/2"
Bed joints 1/2"-1
Head joints 1/2"-
Headers:
Course #
6, 14, 20

Figure B.34 Specimen 33

SPECIMEN NO. 34
2 WYTHES (23 COURSES)

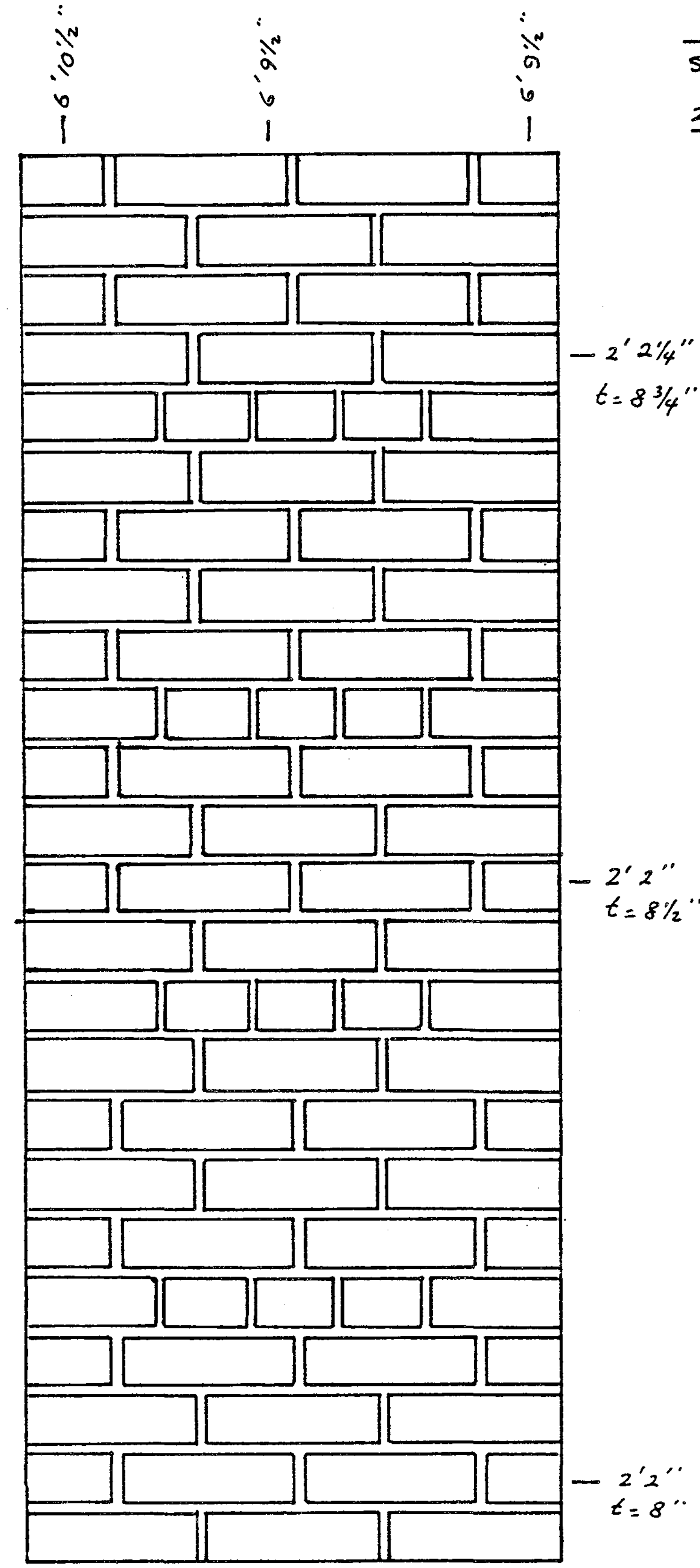


REMARKS:

b: 2' 3 3/10"
h: 6'11'
Bed joints: ½"-1"
Head joints: ½"-1"
Headers: course #: 6, 11, 16, 21

Figure B.35 Specimen 34

SPECIMEN NO. 35
2 WYTHES (23 COURSES)

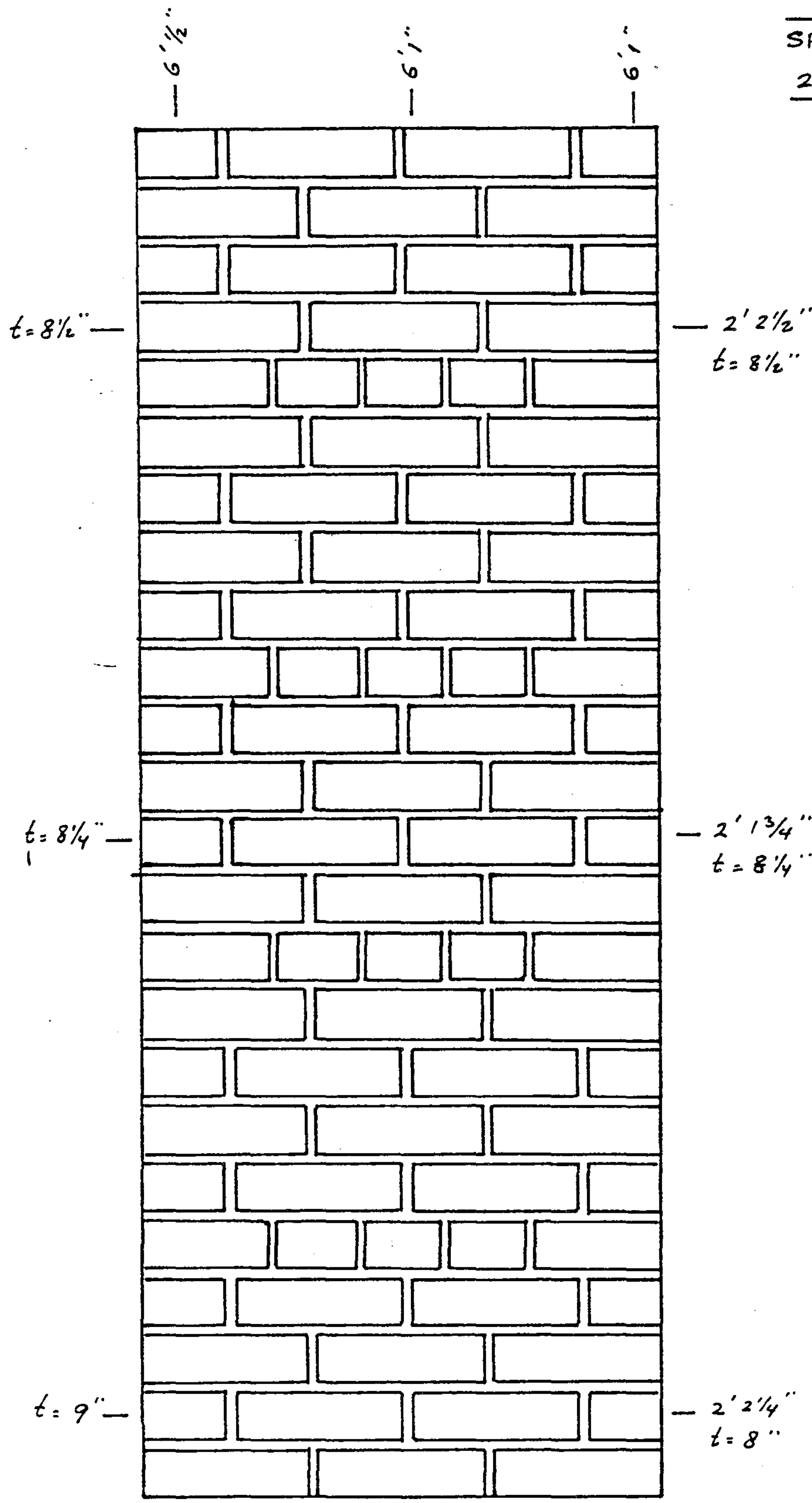


REMARKS:

b: 2' 2¹⁄₁₀"
h: 6' 9⁴⁄₅"
t: 8 ⅖"
Bed joints ½"-
Head joints ½"-
Headers:
Course #
5, 10, 15, 2?

Figure B.36 Specimen 35

SPECIMEN NO. 36
2 WYTHES (24 COURSES)

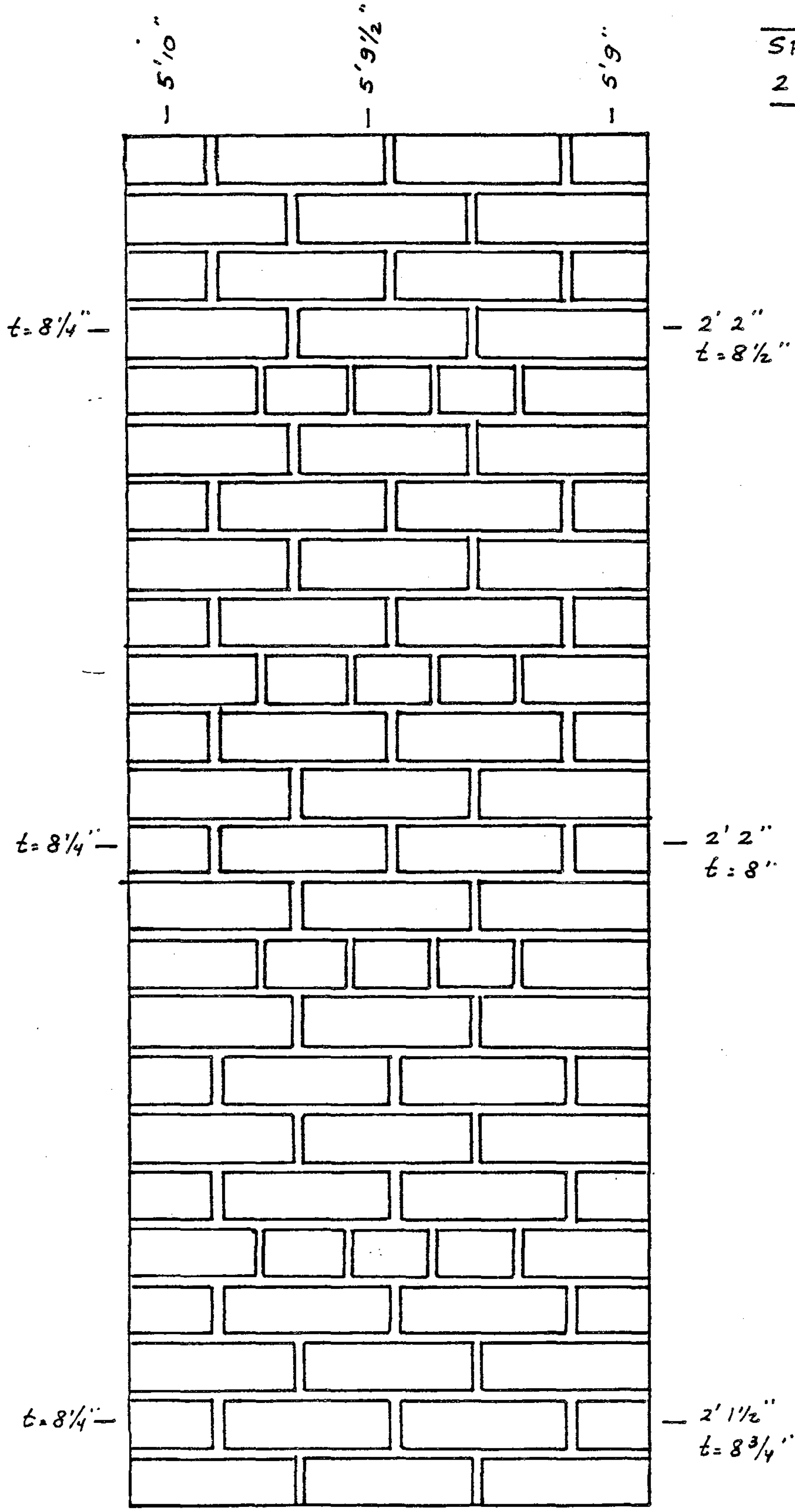


REMARKS:

b = 2' 2⅕"
h = 6' ⅘"
t = 8 ⅖"
Bed joints ½-1"
Head joints ½-1"
Headers:
Course #
5, 10, 15, 22

Figure B.37 Specimen 36

SPECIMEN NO. 3
2 WYTHES (24 COURSES)

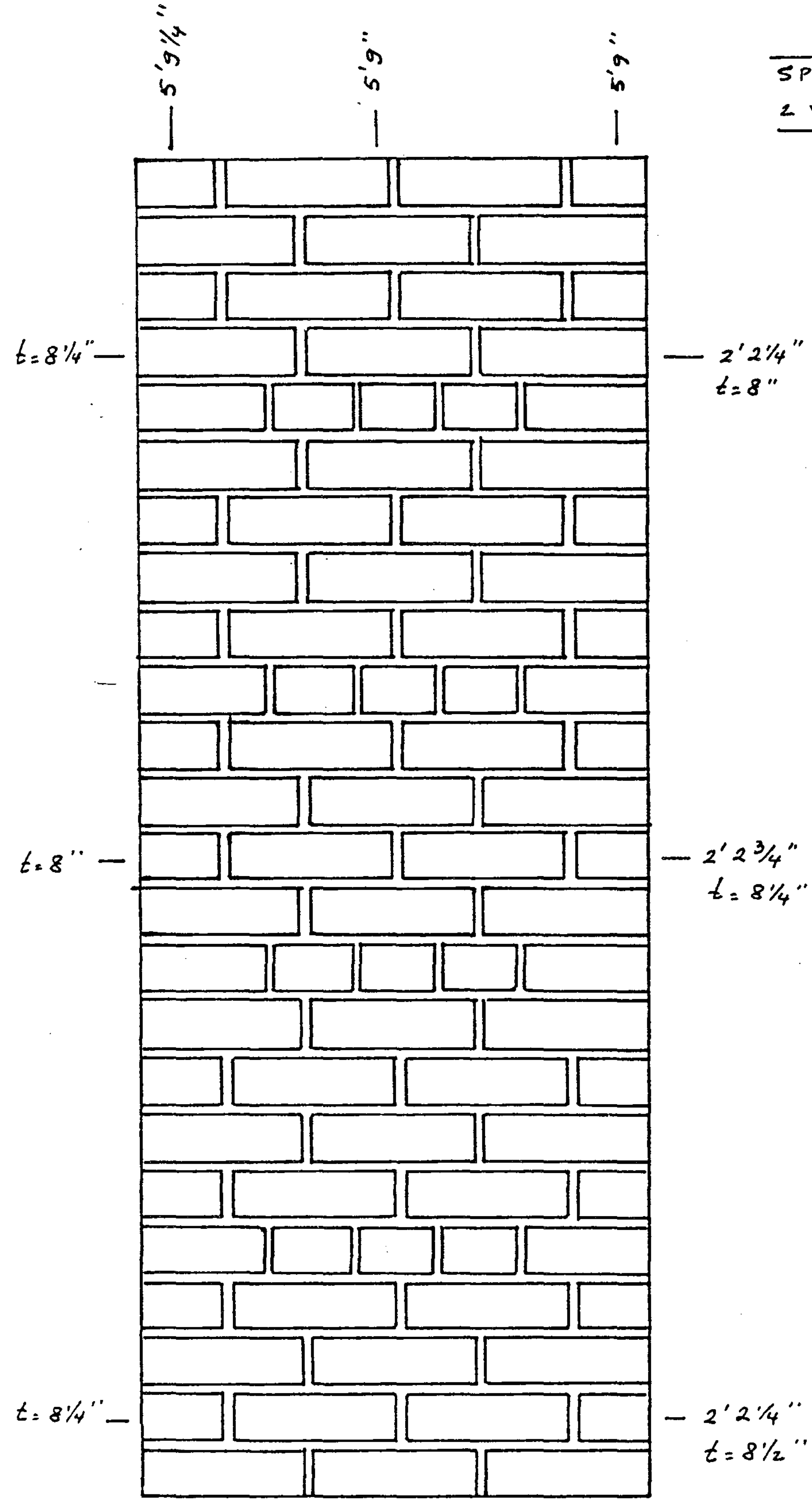


REMARKS:

b = 2' 1⅘"
h = 5' 9½"
t = 8 3/10"
Bed joints ½"-1
Head joints ½"-1
Headers:
course #
5, 10, 15, 20

Figure B.38 Specimen 37

SPECIMEN NO. 38
2 WYTHES (24 COURSES)



REMARKS:

b= 2'2⅖"
h= 5'9"
t= 8⅕"
Bed joints ½"-1"
Head joints ½"-1"
Headers:
Course #:
6,10,15 & 20

Figure B.39 Specimen 38

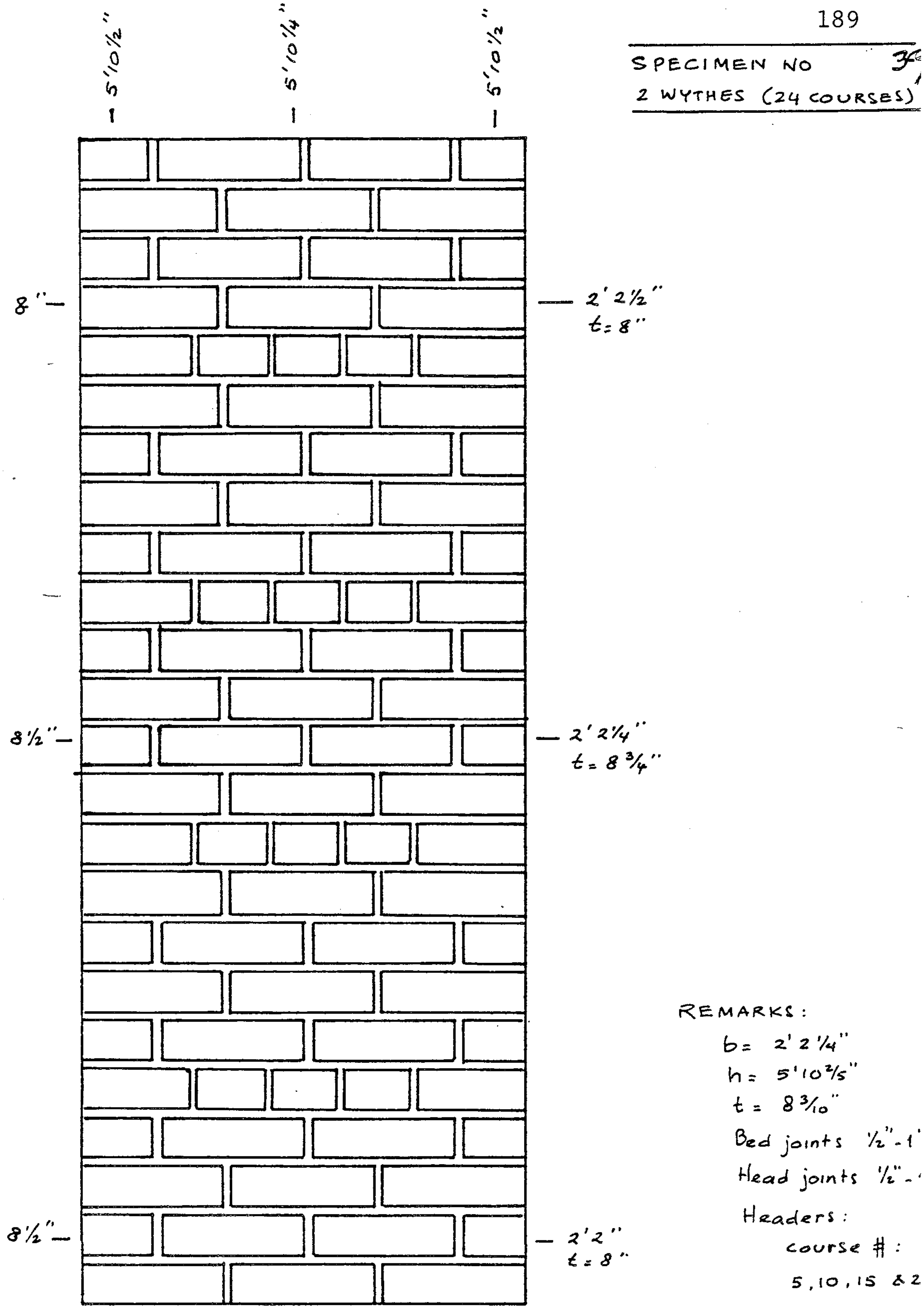
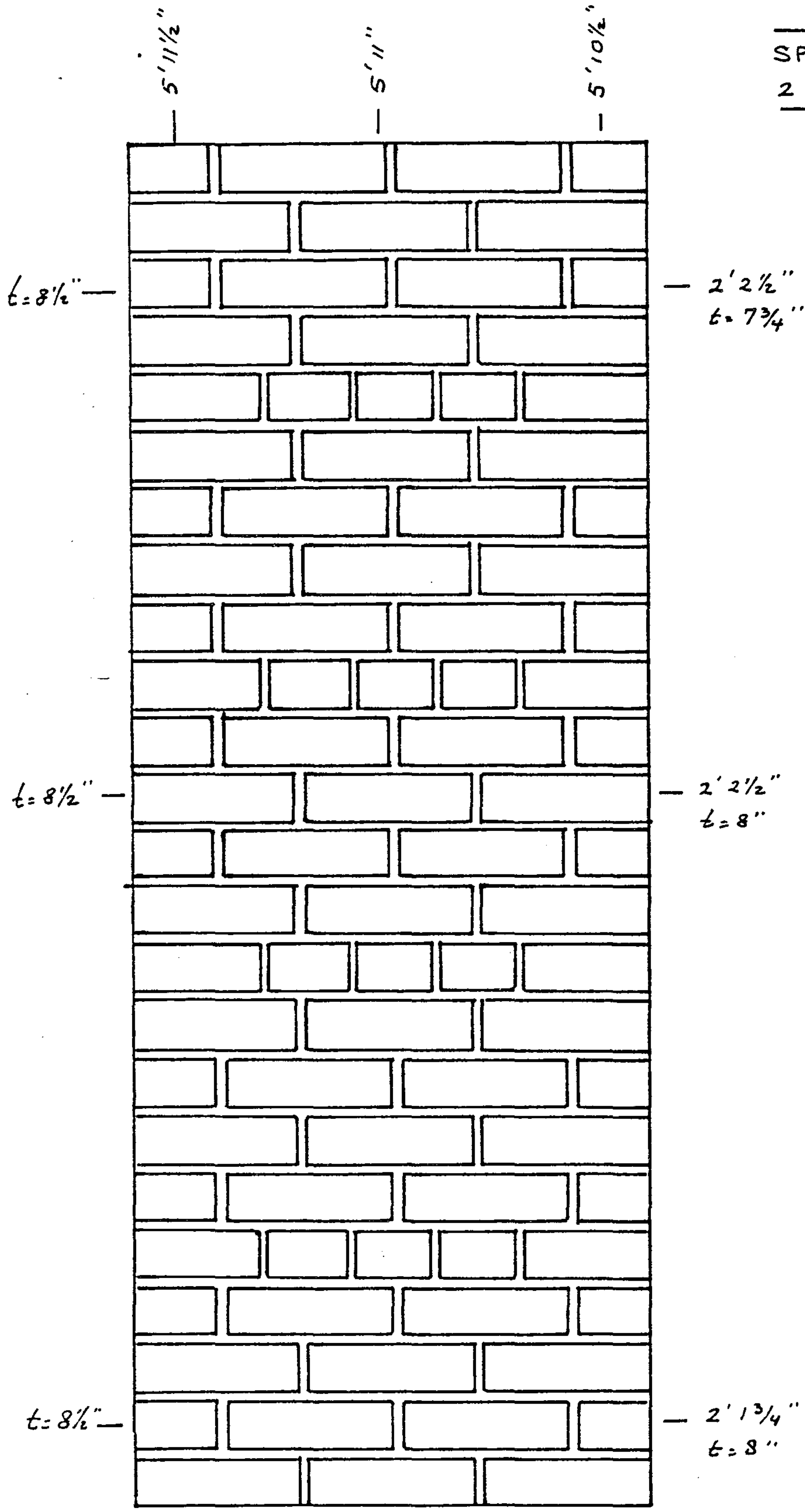


Figure B.40 Specimen 39

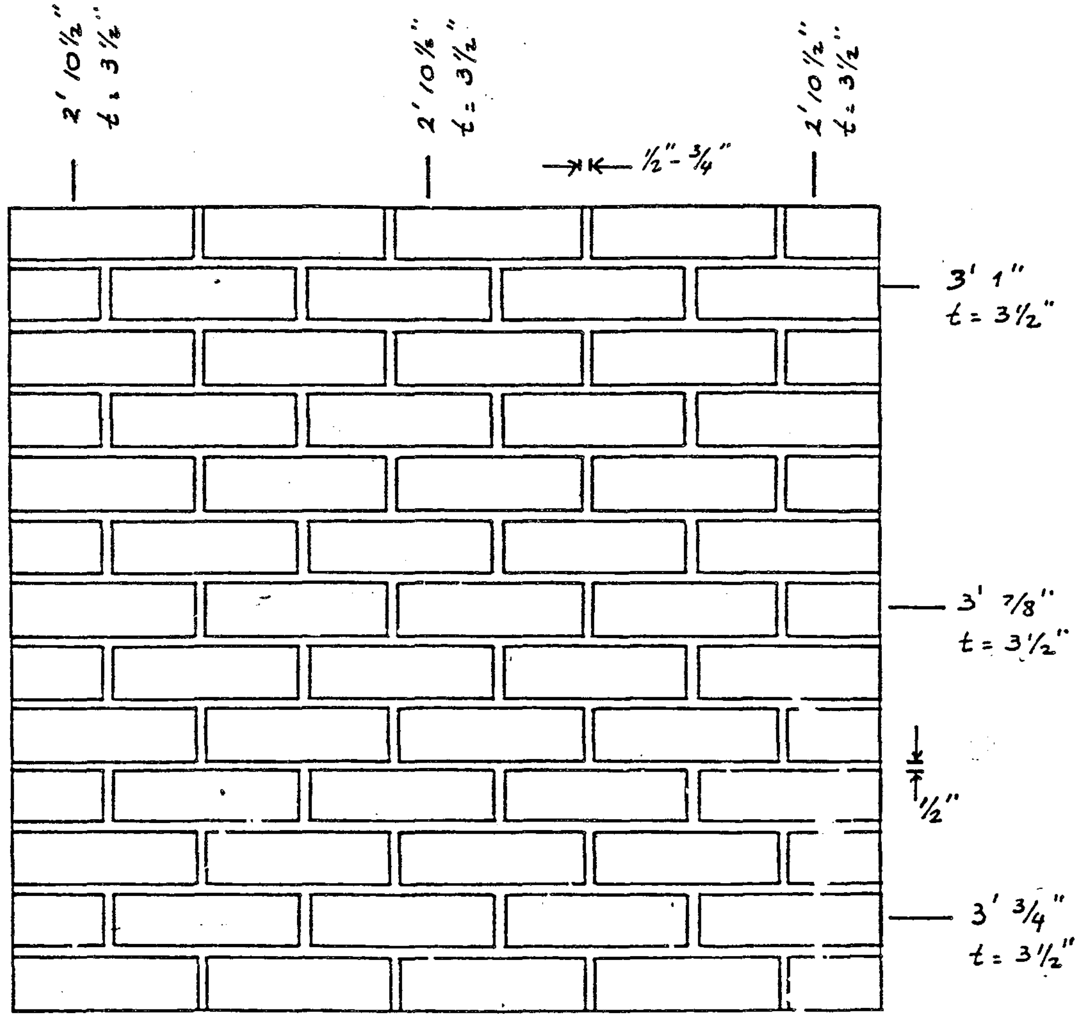
SPECIMEN NO. 40
2 WYTHES (24 COURSES)



REMARKS:
b= 2'2¼"
h= 5'11"
t= 8⅕"
Bed joints ½"-1"
Head joints ½"-1"
Headers:
Course #:
5, 10, 15 & 20

Figure B.41 Specimen 40

SPECIMEN NO. 41
NEW BRICK
1 WYTHE (13 COURSES)



New Brick
1 wythe (13 courses)

REMARKS:

b = 3' ⅞"

h = 2' 10½"

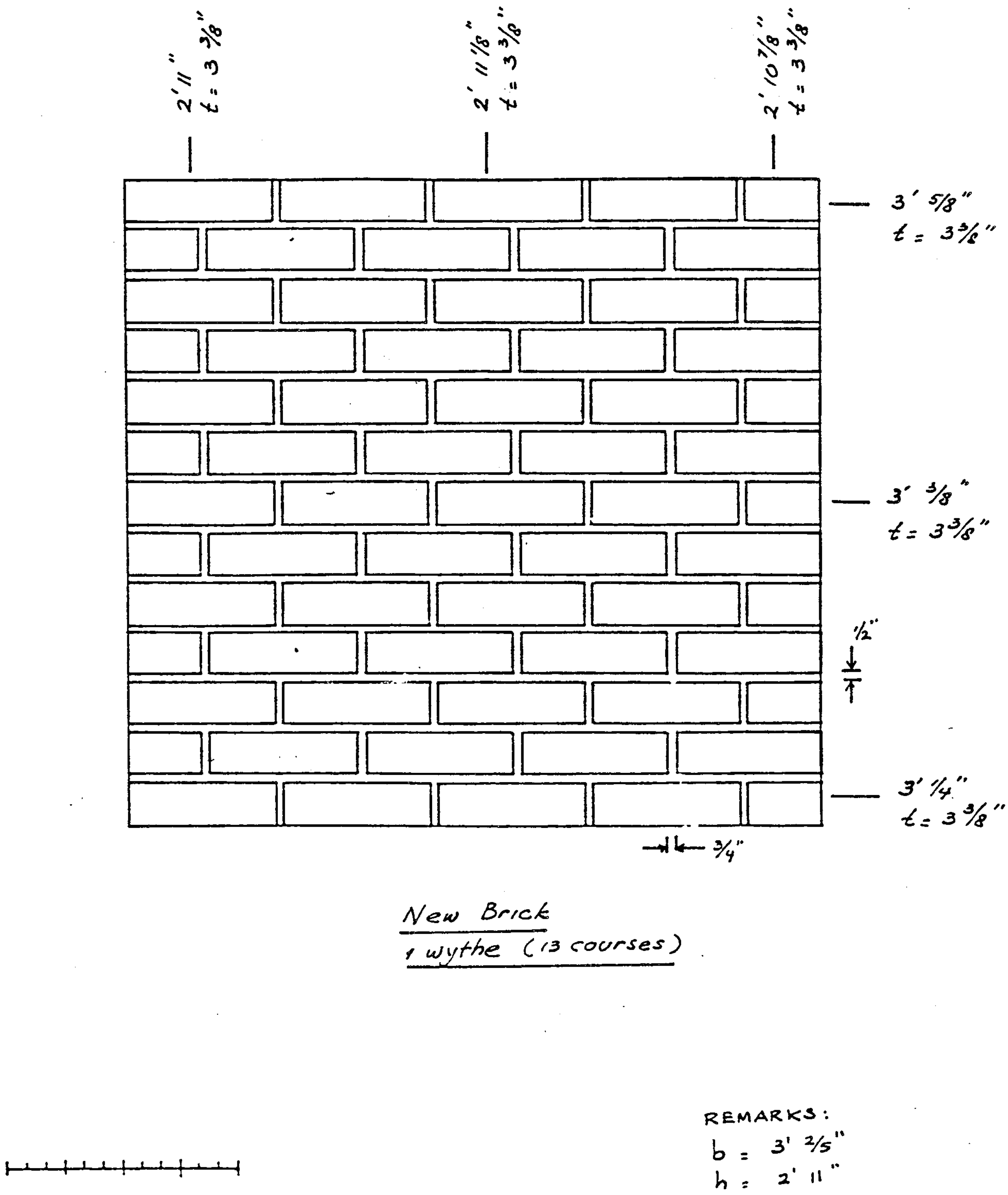
t = 3½"

BED JOINTS ½"

HEAD JOINTS ½" - ¾"

Figure B. 42 Specimen 41

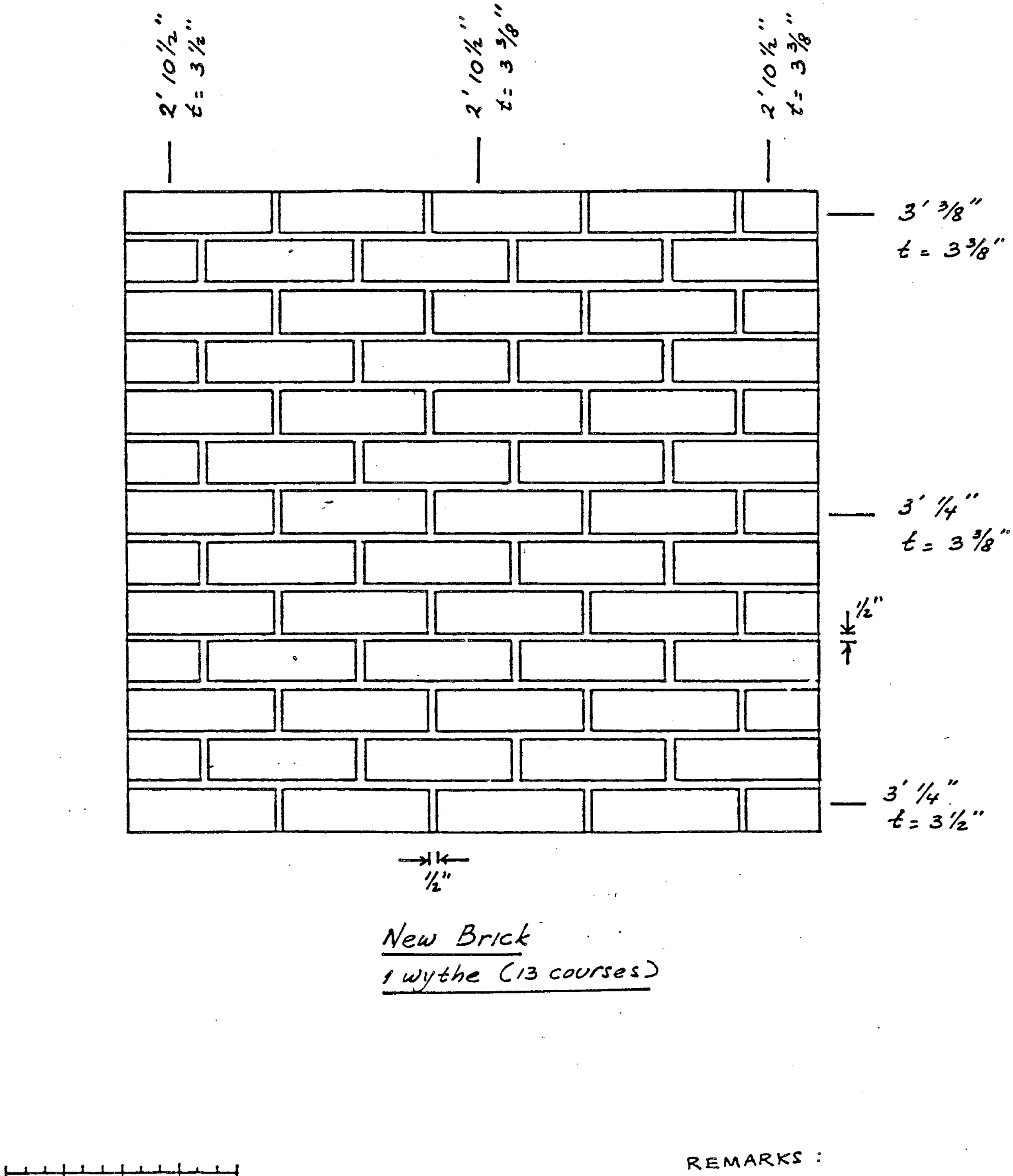
SPECIMEN NO. 42
NEW BRICK
1 WYTHE (13 COURSES)



REMARKS:
b = 3' 2/5"
h = 2' 11"
t = 3 3/8"
BED JOINTS 1/2"
HEAD JOINTS 3/4"

Figure B.43 Specimen 42

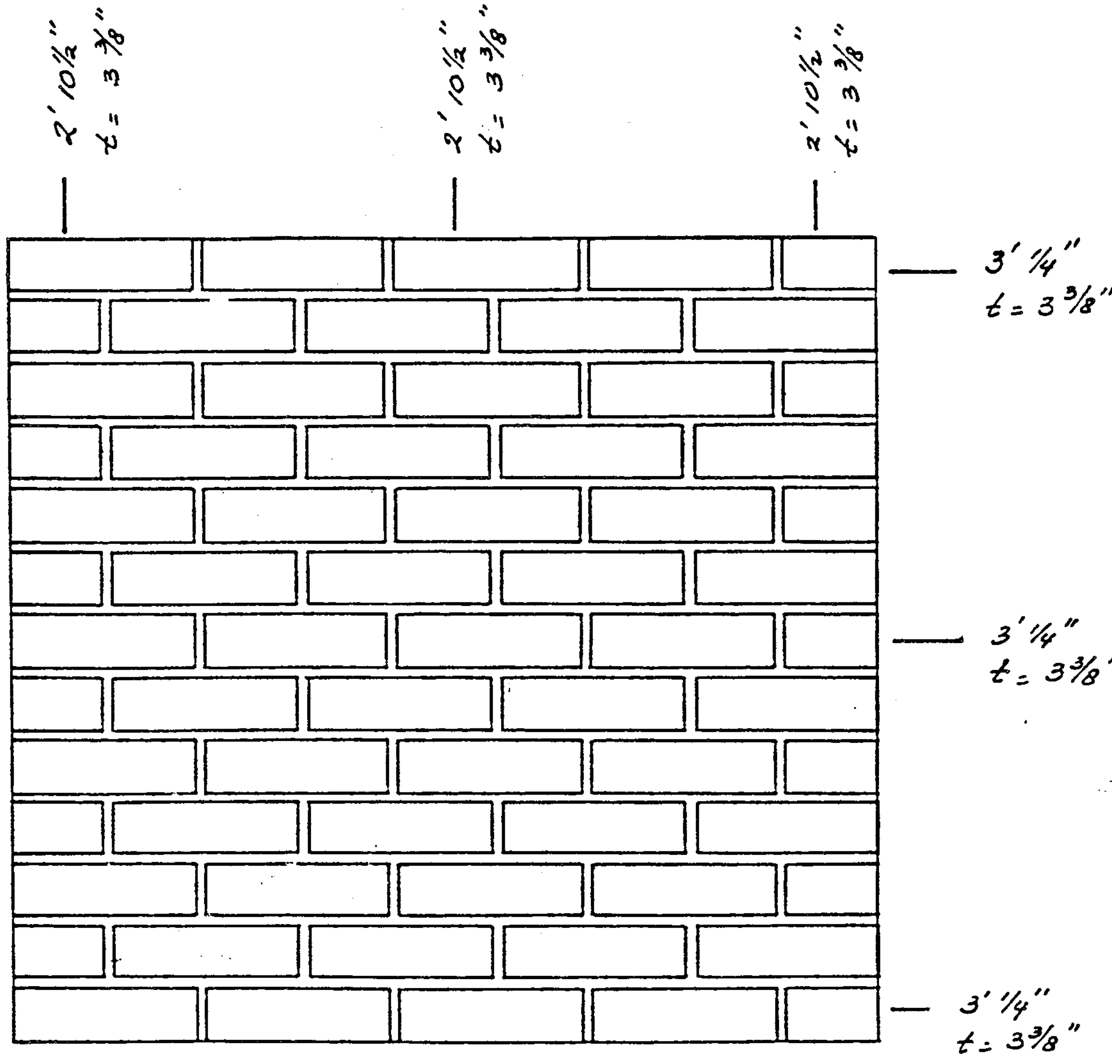
SPECIMEN NO. 43
NEW BRICK
1 WYTHE (13 COURSES)



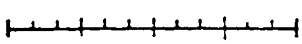
REMARKS:
b = 3' ¼"
h = 2' 10½"
t = 3 2/5"
BED JOINTS ½"
HEAD JOINTS ½"

Figure B.44 Specimen 43

SPECIMEN NO. 44
NEW BRICK
1 WYTHE (13 COURSES)



New Brick
1 wythe (13 courses)

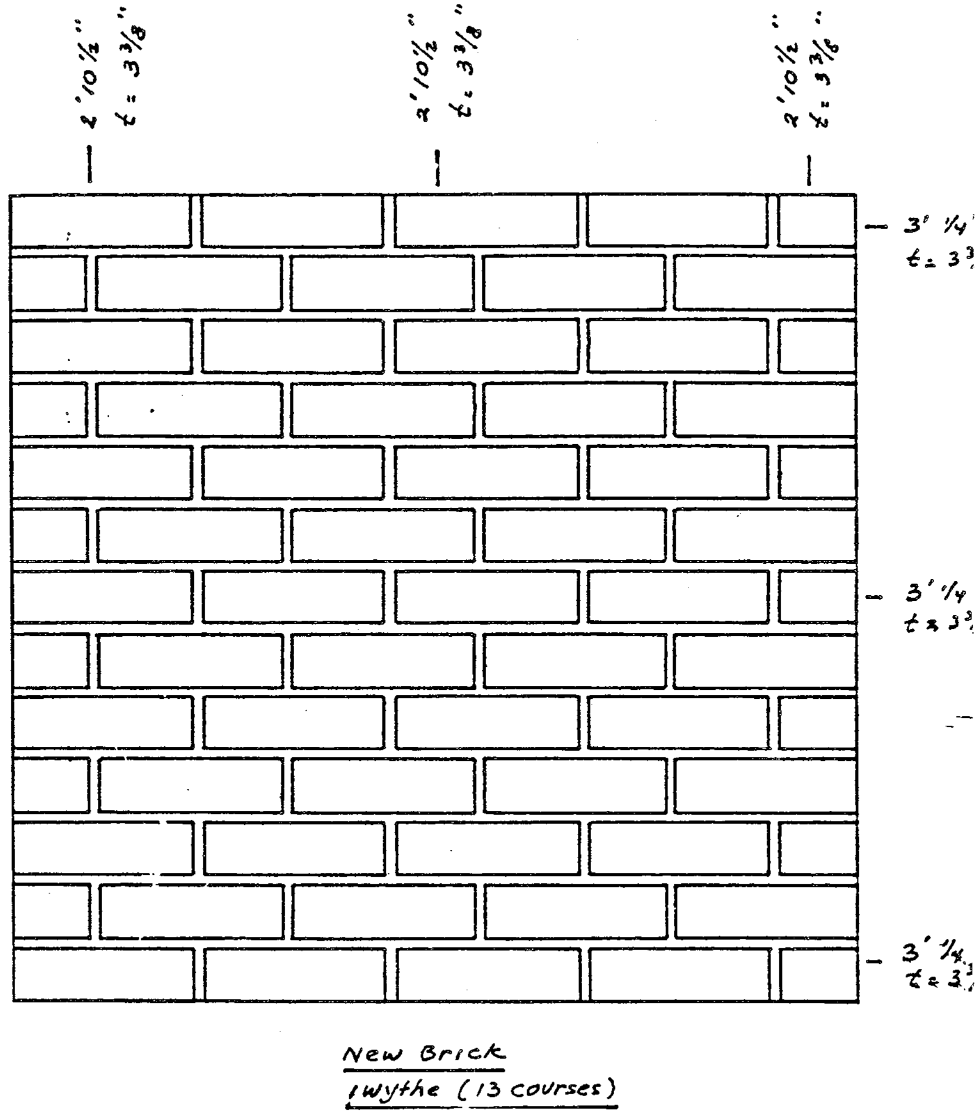


REMARKS:

b: 3' ¼"
h: 2' 10½"
t: 3⅜"
bed joints: ½"
head joints: ½"

Figure B.45 Specimen 44

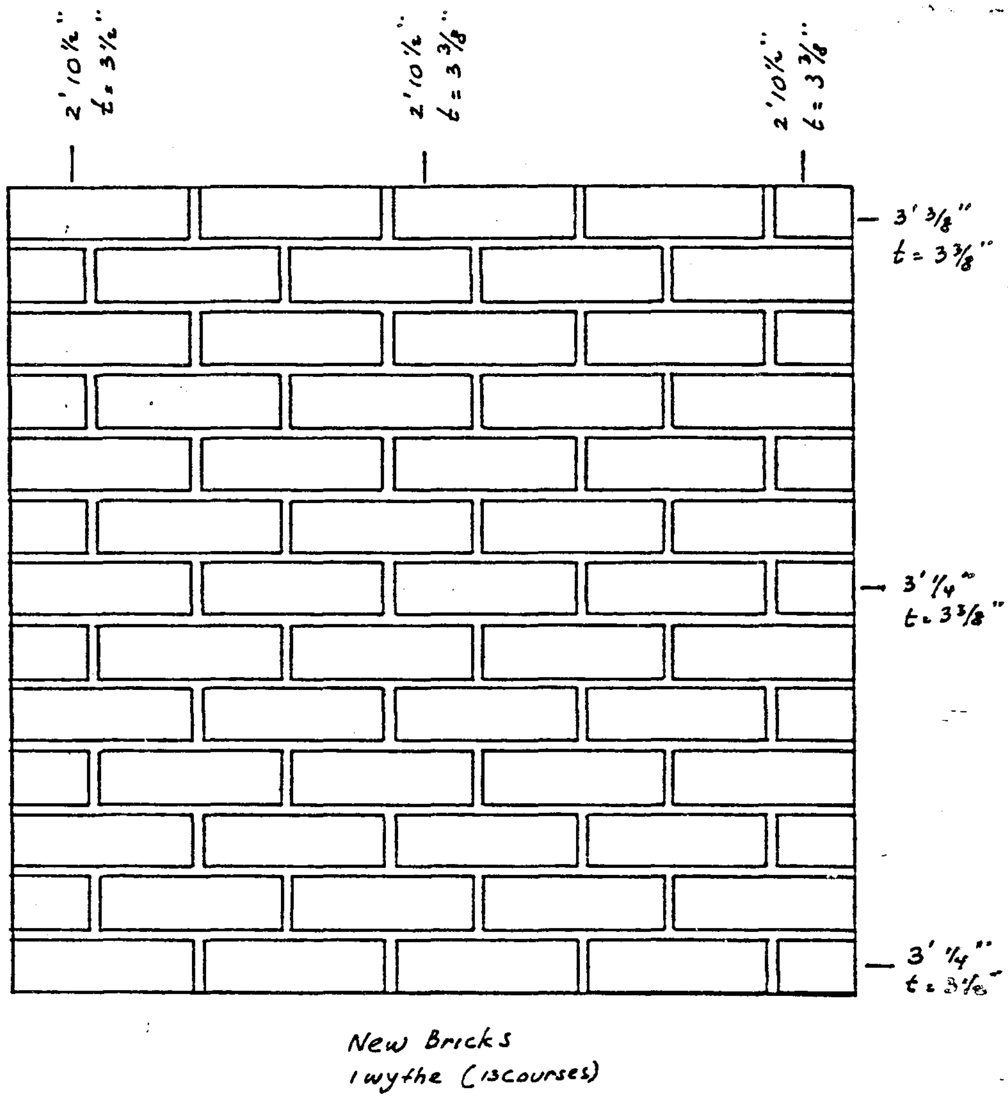
SPECIMEN NO. 45
NEW BRICK
1 WYTHE (13 COURSES)



REMARKS:
b = 3' ¼"
h = 2' 10½"
t = 3 ⅖"
BED JOINTS ½"
HEAD JOINTS ½"

Figure B.46 Specimen 45

SPECIMEN NO. 46.
NEW BRICK
1 WYTHE (13 COURSES)



REMARKS:

b = 3' ¼"
h = 2' 10½"
t = 3⅖"
BED JOINTS ½"
HEAD JOINTS ½"

Figure B.47 Specimen 46

is the construction log containing the starting and finishing dates for each brick masonry assemblage.

In general, the construction procedures were the same for all 46 specimens. They were built on wood platforms that were leveled and supported by bricks, allowing a fork lift to pick them up at a later date (Fig. 2.2.2). The specimens were grouped such that when shotcreted later, the nozzleman would be allowed to shoot a continuous row of specimens. Plywood separators were placed between specimens to create a barrier between specimens. The procedures included a full bed, head, and collar joint, non raked or struck joints, and dimensions as close to the suggested dimension as possible. The 3 by 3 specimens generally ran one inch to 2 inches shy of 36 inches in length and height. The 4 by 4 specimens between 1 inch shy to 1 inch over 48 inches in length and height, and the 2 by 6 specimens between 1 inch shy of 6 feet high and 2 inches over 24 inches wide. Figures B.2 to B.47 show the dimensions of the specimens prior to the shotcreting.

Prior to construction the bricks were not soaked because the specimens were to model a poorly built masonry wall in which the bricks were usually not soaked. The author observed that the masons were providing full bed joints, three quarters to a full head joint and a full collar joint. The author also noted that all masons would add extra water to the mortar to retain workable mixes, and would at times use mortar scraps. However, this practice was limited. Header joints were designed to be on every sixth course such that each double wythe specimen would have a minimum of two header courses; however, due to a mix up in communication with the apprentice masons, the headers were placed every 5th course. Figures B.2 to B.47 show the resulting sizes and header positions for the specimens.

The author and the student employees mixed the mortar for the masons. The mix used was 1 part Magnolia Mortar mix to 3 parts sand and enough water to produce a workable mix. The masons determined the required workability. A 2 cubic foot concrete mixer was used to mix the mortar. The water was taken from a water tap near Cherry Street.

Mortar cubes were collected as often as time permitted. The six cube mold was oiled prior to each use. The cubes were kept covered for one day while in the mold, then placed in the moisture room for testing at a later date. Also at random the author requested an apprentice to build a masonry pier made of two bricks with a full bed joint between them. These samples were allowed to set uncovered overnight. On the next day, they were placed in the moisture room for testing at a later date.

Figure B.48 shows an apprentice mason putting the finishing courses of brick of a 4 ft. by 4 ft. double wythe specimen. Figure B.49 illustrates the typical construction

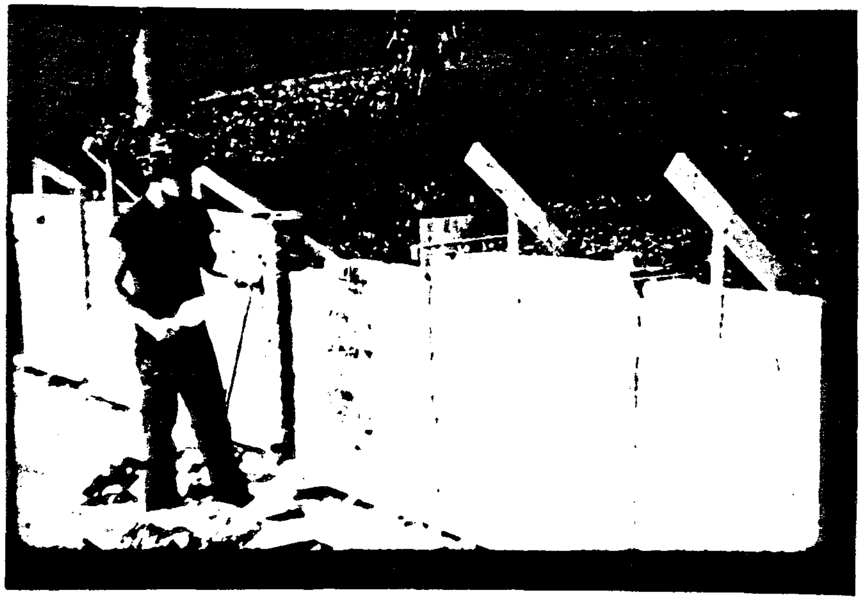


Figure B.48 View of Construction of 4 by 4 Double Wythe Panels.

Figure B.49 Construction of 2 by 6 Panels.

of the specimens. A 2 ft. by 6 ft. specimen was being constructed in Fig. B.49. Figures B.50 and B.51 show three types of finished brick masonry specimens. Figure B.51 shows finished 4 ft. by 4 ft. double wythe specimens while Fig. B.51 shows a 3 ft. by 3 ft. double wythe and a 4 ft. by 4 ft. single wythe brick masonry assemblage. Figure 2.2.3 shows the specimens on Cherry Street where they were built.

The next step in the construction of the specimens was the drilling of dowel holes in the double wythe masonry assemblages. The dowles were used to tie the brick wythes together so that both wythes would act together with the shotcrete. The size of dowel and subsequent reinforcing used in a particular specimen depended on the thickness of the shotcrete skin. The 3 inch shotcrete treatment allowed the use of hooked #3 reinforcing bar as dowels and 6 x 6 - W3.5 x W3.5 welded wire fabric; however, the one-half inch treatment restricted the dowel sizes; one-fourth inch diameter threaded rods were used because they easily fit through the expanded metal reinforcing. Washes and nuts anchored the expanded metal to the rods. Figures B.52, B.53, B.54, and B. 55 show the doweling schemes used in construction of the specimens.

Holes with a slightly larger diameter than the dowel diameter were drilled into the walls. The oversized holes, 3/4 inch diameter for the 3/8 inch dowel and 3/8 inch

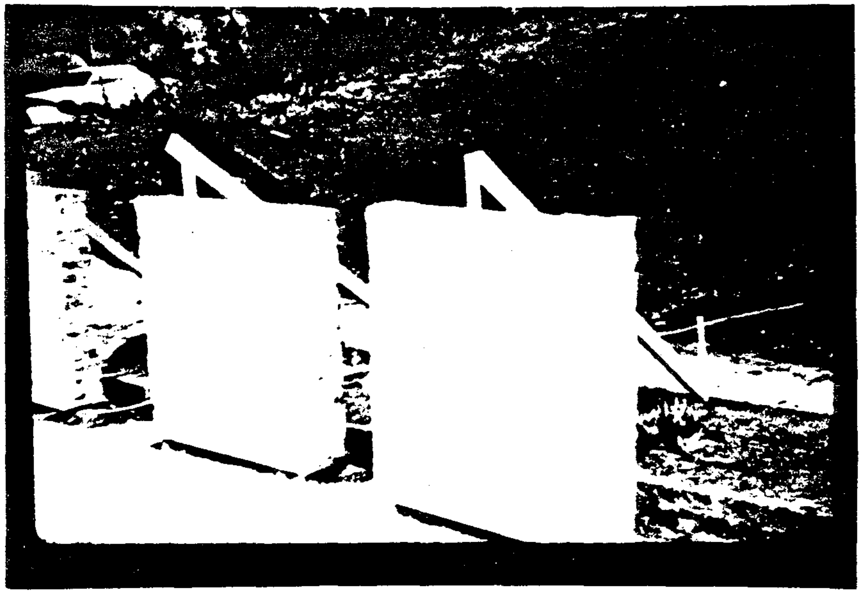


Figure B.50 View of 4 by 4 Double Wythe Specimen.

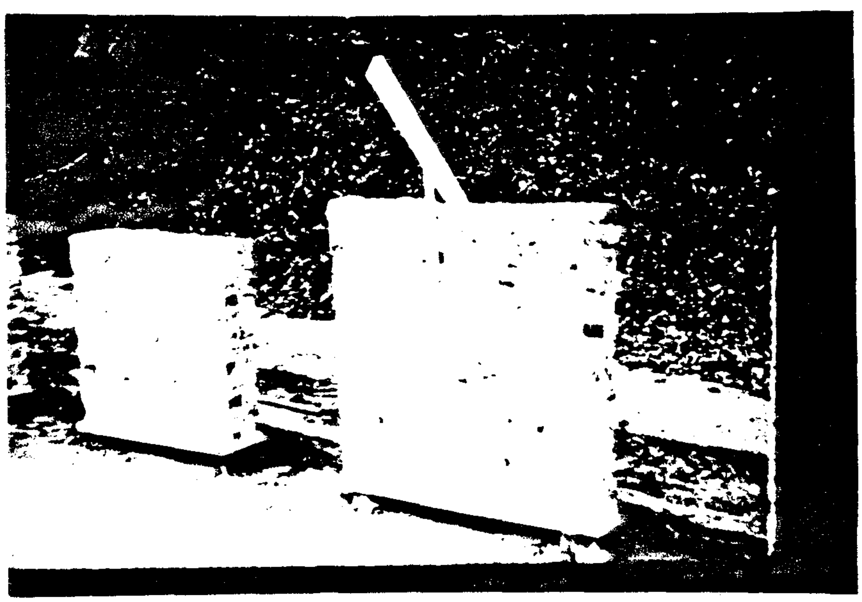


Figure B.51 View of a 3 by 3 Double Wythe and 4 by 4 Single Wythe Specimen.

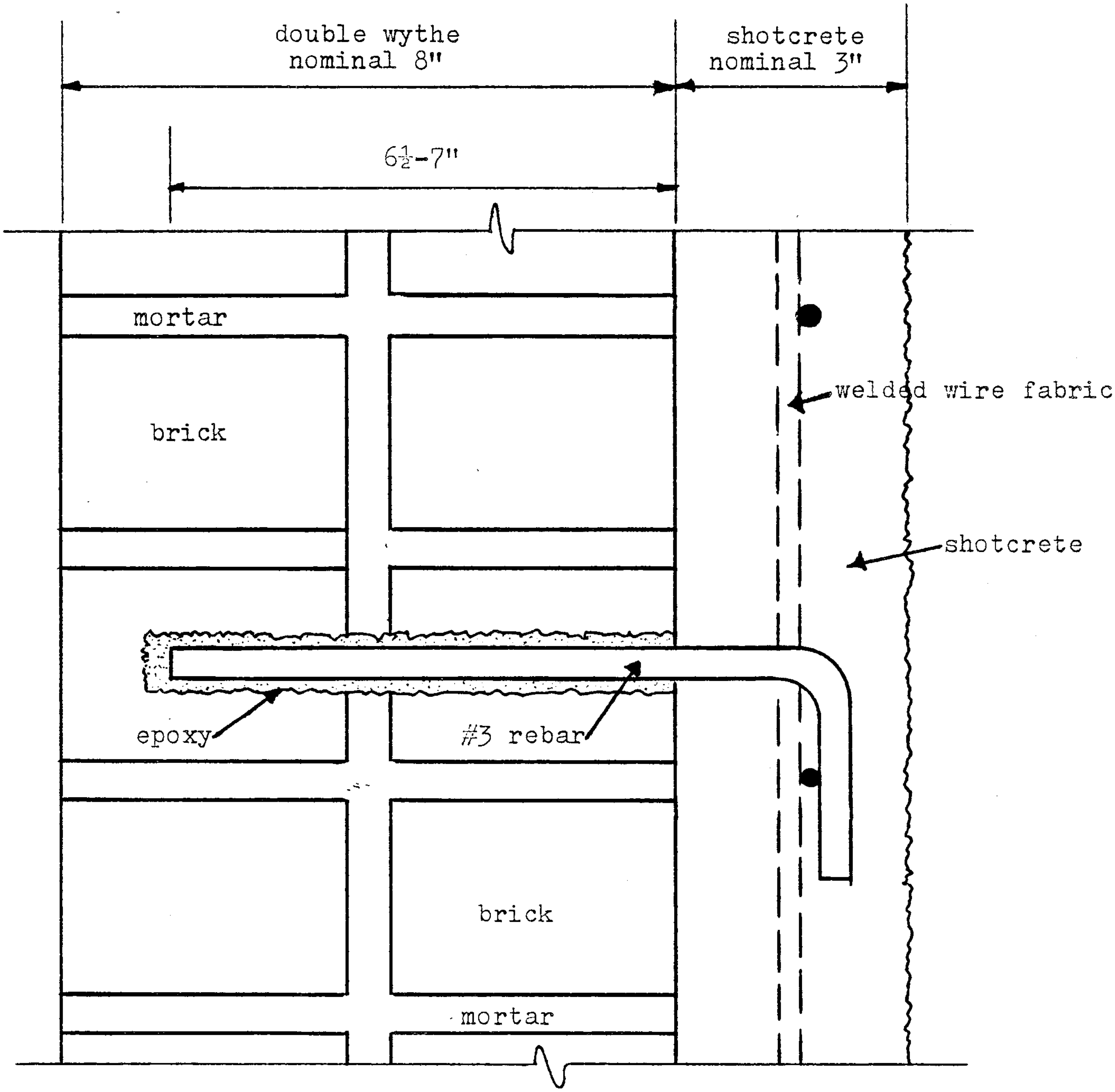


Figure B.52 Section of 3/8 inch Dowel With Hook in Double Wythe Wall with 3 inches of Shotcrete.

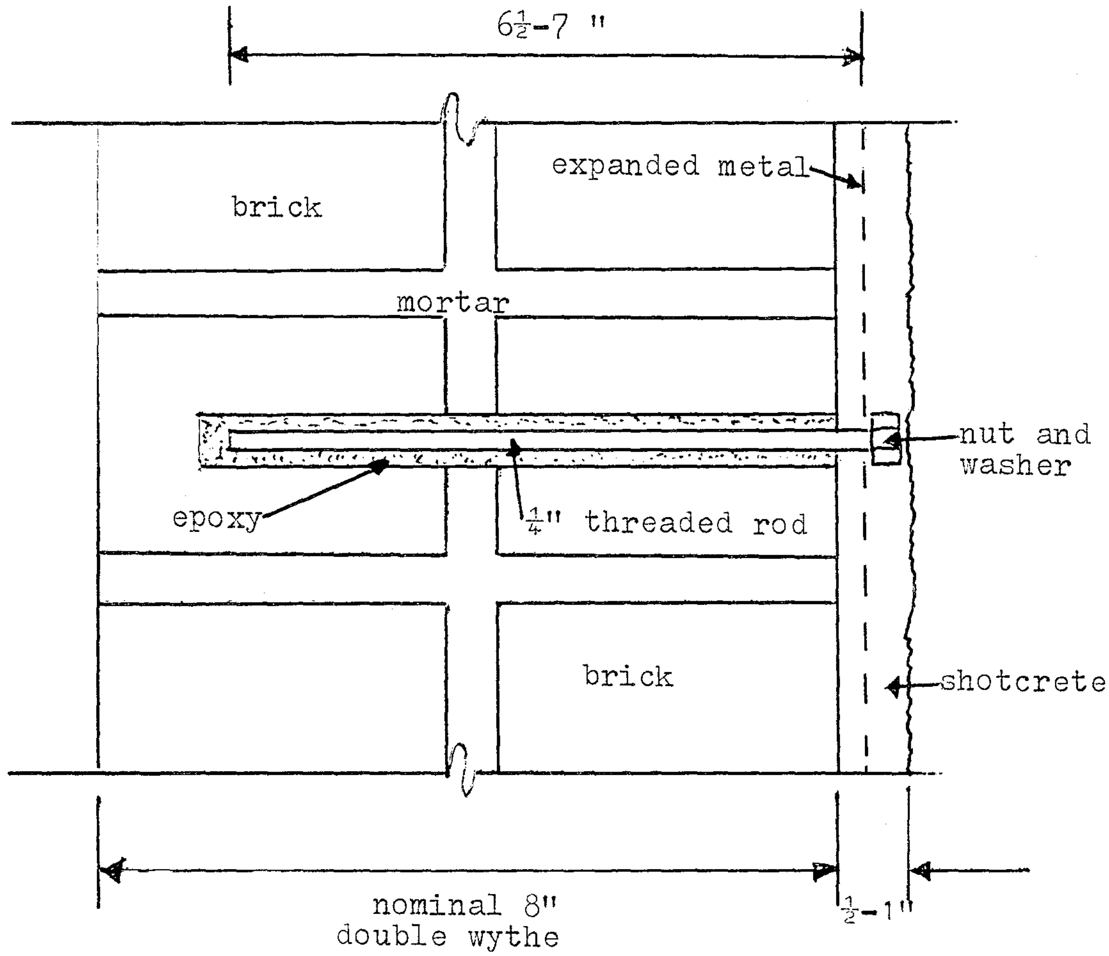


Figure B.53 Section of 1/4 inch Threaded Rod Dowel in Double Wythe Wall with 1/2 to 1 inch of Shotcrete.

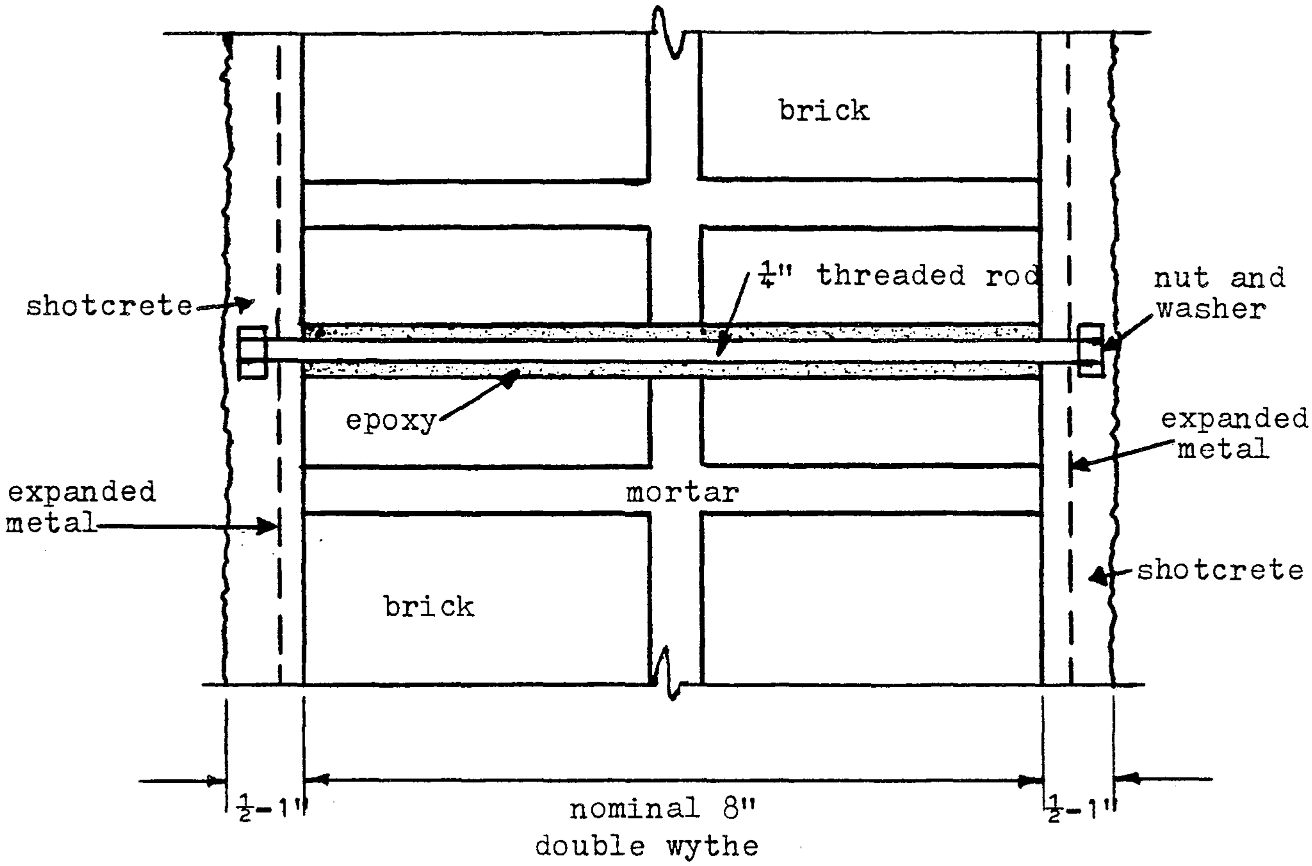


Figure B.54 Section of 1/4 inch Threaded Rod Dowel in Double Wythe Wall with 1/2 to 1 inch of Shotcrete.

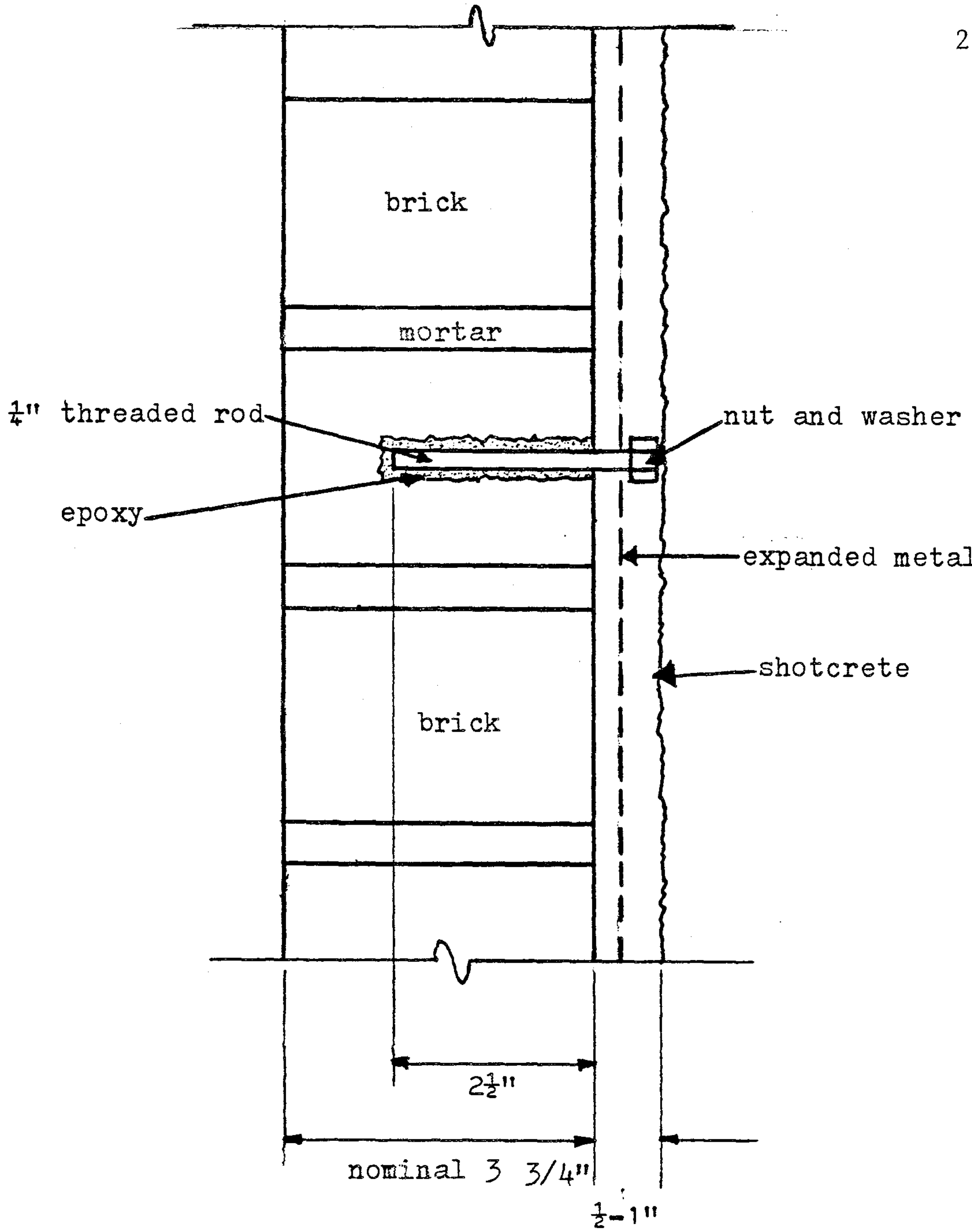
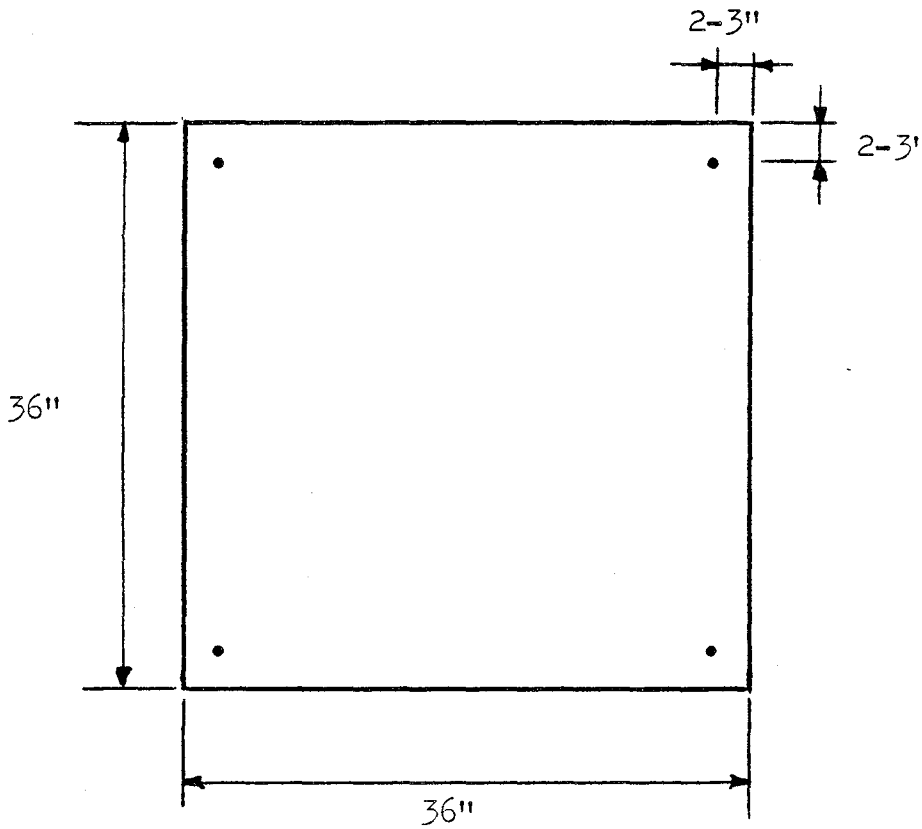


Figure B.55 Section of 1/4 inch Threaded Rod Dowel in Single Wythe Wall with 1/2 to 1 inch of Shotcrete.

diameter for the 1/4 inch threaded rods, were used to allow for clearance around the dowels for the epoxy that was used to bond the dowel in place. The depth of the holes was a function whether the specimen had shotcrete treatment on one or both sides of the panel and whether the panel had one or two wythes of brick. Double wythe walls with shotcrete on one side both had 6½ to 7 inch deep holes for doweling. Figure B.52 is a section of a typical double wythe wall with No. 3 reinforcing bar dowels with 1 3/10 inch radius hooks and 3 inches of shotcrete. Figure B.53 shows a section of a typical double wythe wall with 1/4 inch treaded rod and 1/2 to 1 inch of shotcrete on one side. Double wythe walls with 1/4 inch treaded rods and shotcrete on both surfaces, as illustrated in Fig. B.54, had holes drilled all the way through the section. Holes 2½ inch deep were drilled into the single wythe specimens in which 1/4-inch diameter threaded rods were epoxied (Fig. B.55).

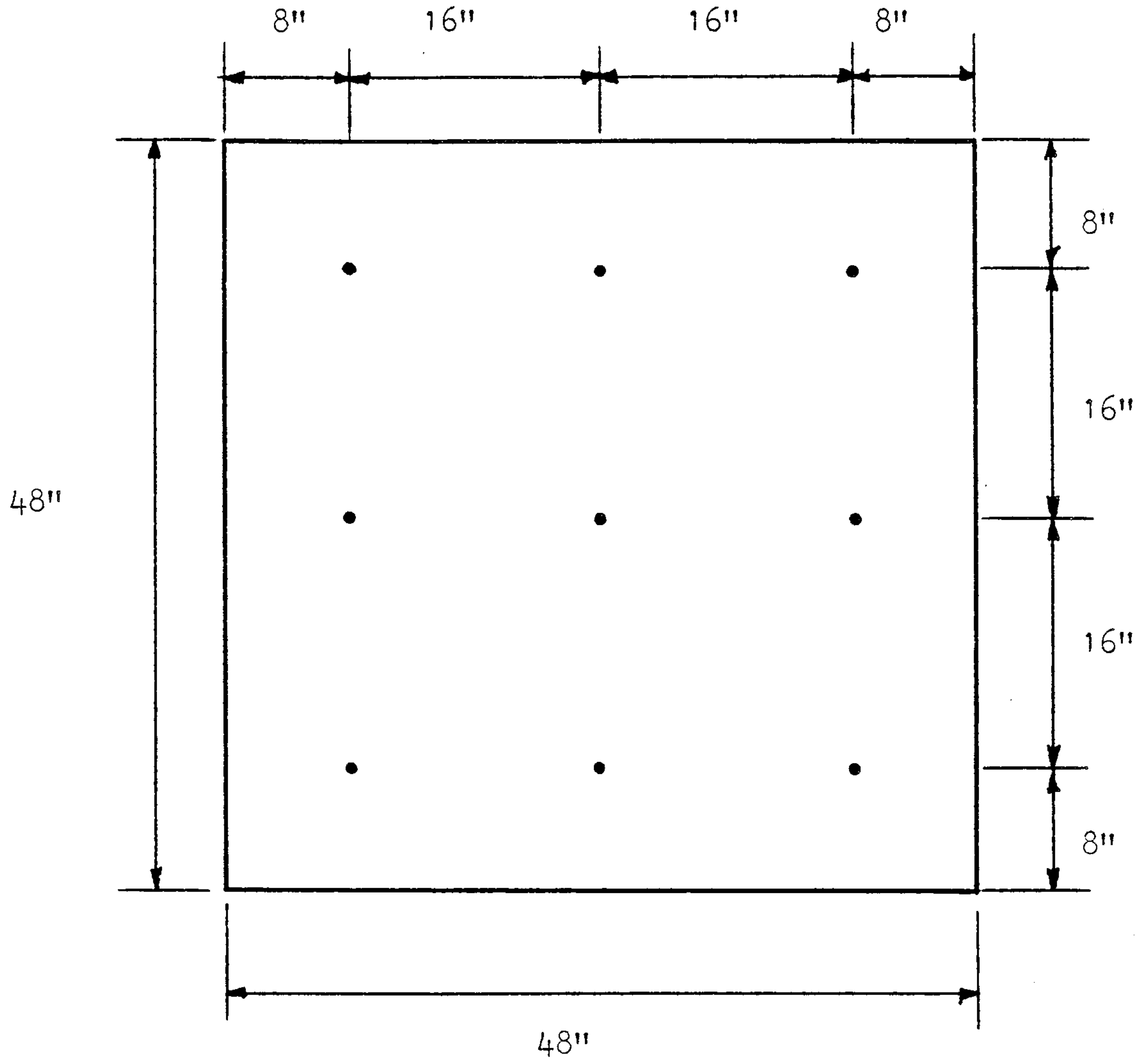
A rotary hammer with a cement bit and a large power drill with a masonry bit were used to drill the holes in the specimens. The rotary hammer worked best for drilling the larger holes; however, if excessive force were exherted during drilling, the back brick of a double wythe was either pushed out or failure at the bed joint was caused.

The dowel holes were drilled according to the diagrams in Figs. B.56 to B. 62. At times, however, the holes were not drilled according to the diagrams in Figs. B. 56 to



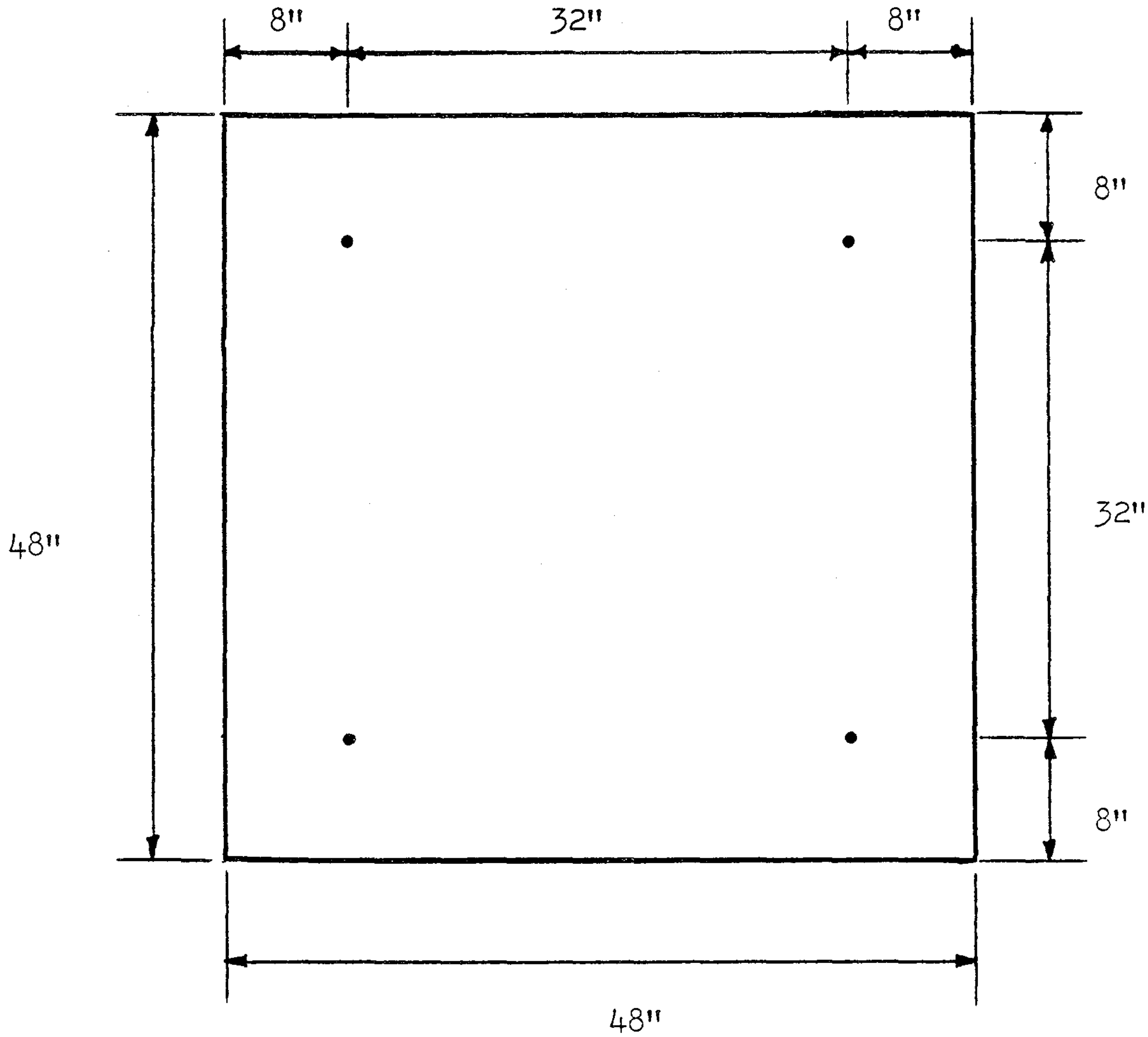
#13, 14, 15 ¼" treaded rod, 2½" deep
reinforcing: expanded metal

Figure B.56 Dowel Positions for Specimens 13, 14, and 15.



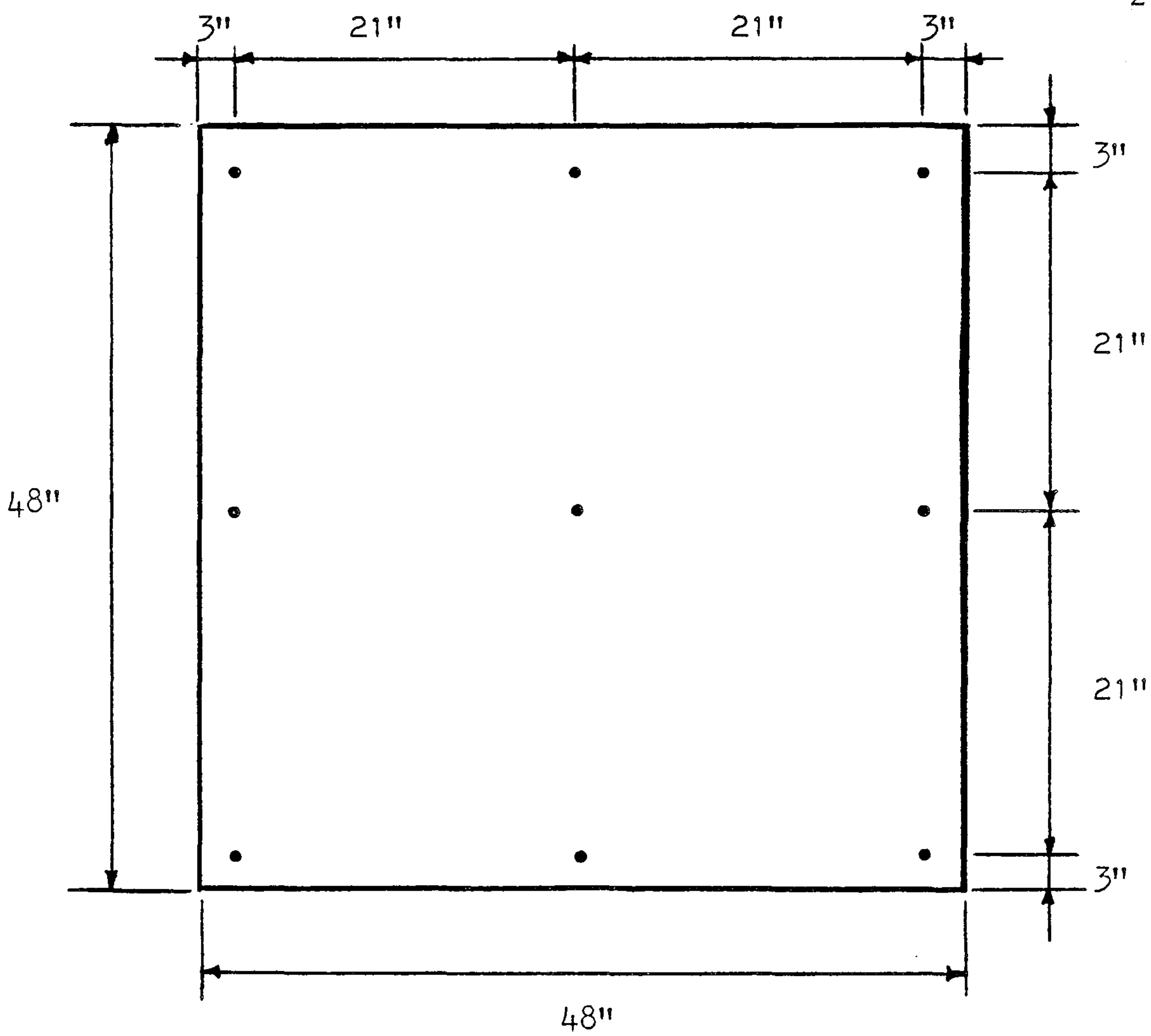
#25,26 #3 rebar with hook, 6½" deep
reinforcing: welded wire fabric

Figure B.57 Dowel Positions for Specimens 25 and 26.



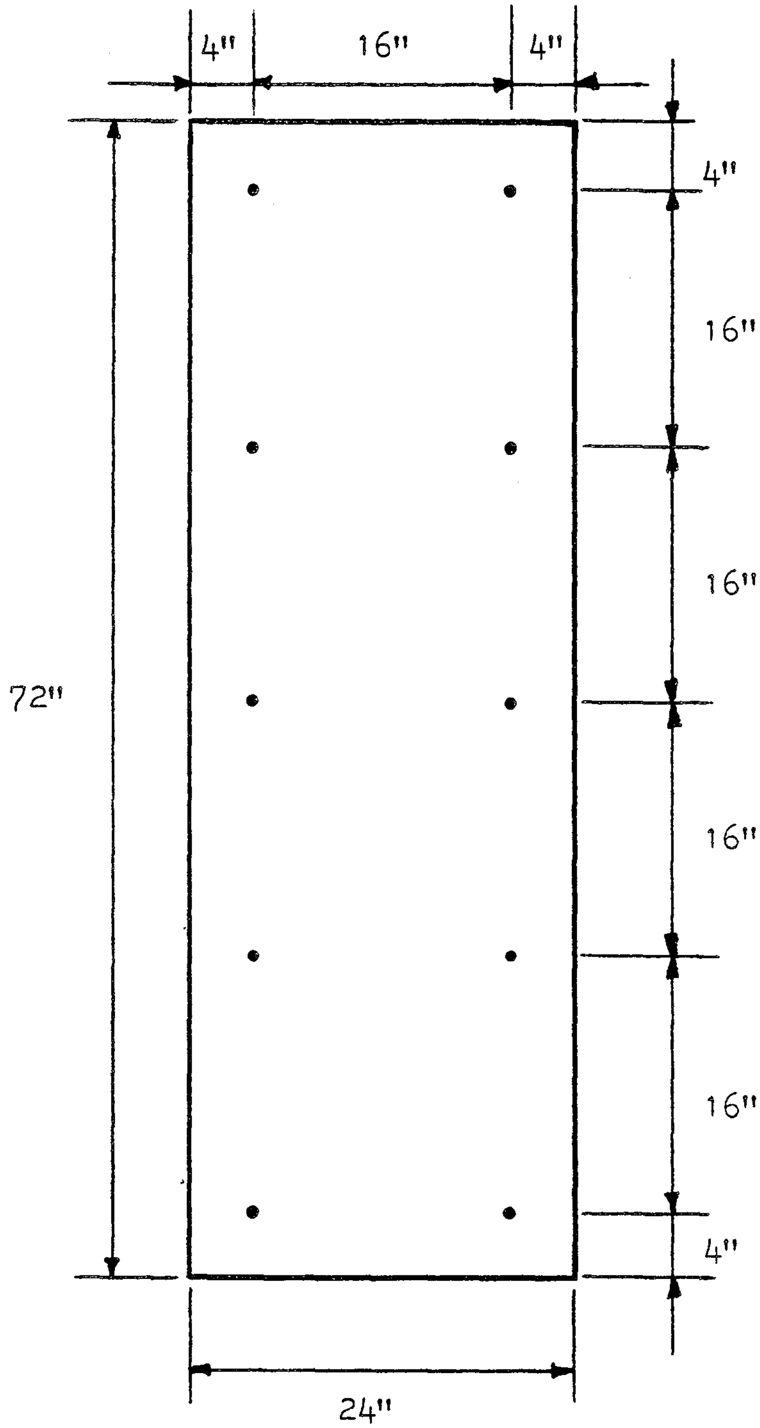
#27,28 #3 rebar with hook, $6\frac{1}{2}$" deep
reinforcing: welded wire fabric

Figure B.58 Dowel Positions for Specimens 27 and 28.



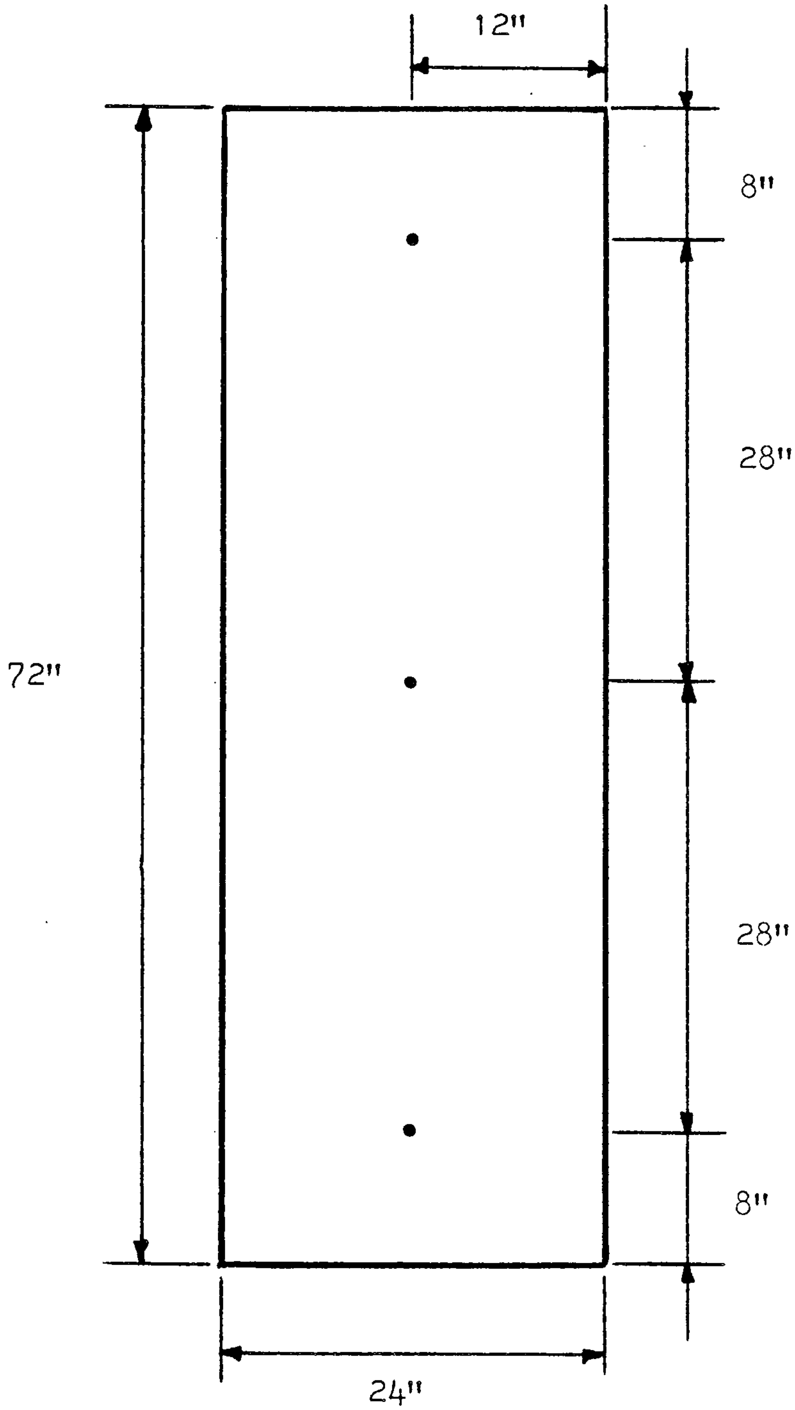
#29,30 $\frac{1}{4}$" threaded rod, $6\frac{1}{2}$" deep
#31,32 $\frac{1}{4}$" threaded rod, thru
reinforcing: expanded metal

Figure B.59 Dowel Positions for Specimens 29, 30, 31, and 32.



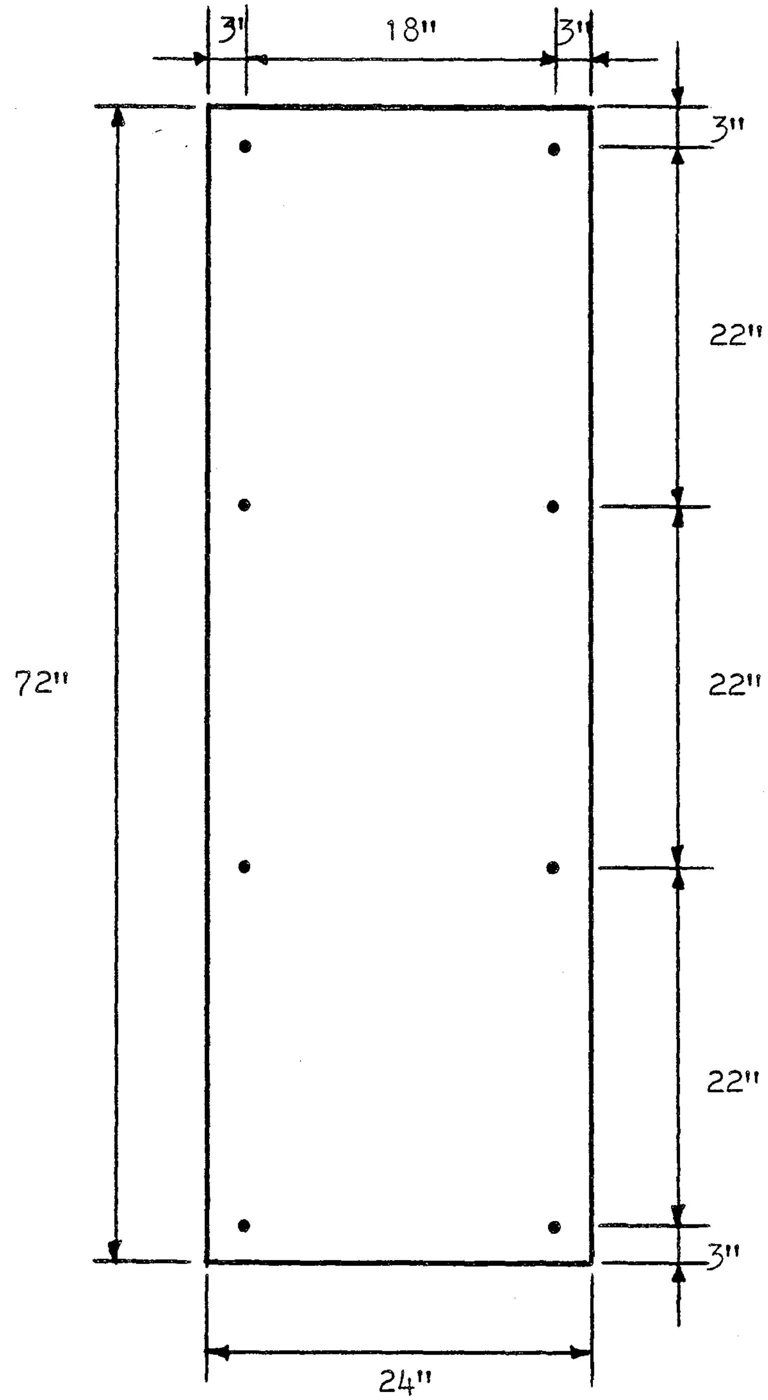
#33,34 #3 rebar with hook, 6½" deep
reinforcing: welded wire fabric

Figure B.60 Dowel Positions for Specimens 33 and 34.



#35,36 #3 rebar with hook, 6½" deep
reinforcing: welded wire fabric

Figure B.61 Dowel Positions for Specimens 35 and 36.



#37,38 ¼" threaded rod, 6½" deep
#39,40 ¼" threaded rod, thru
reinforcing: expanded metal

Figure B.62 Dowel Positions for Specimens 37, 38, 39, and 40.

82

B.62. Some holes were moved up, down, or to the side to prevent placing rows of holes in the weak bed joints.

After all the holes were drilled, the depths and positions of the holes were checked. The holes were cleaned out with a high velocity stream of water sprayed into the hole, flushing the drill debris out. The holes were cleaned out so that an adequate bond between the dowel, epoxy and brick could be assured.

The next process was to epoxy the dowels into the appropriate holes. When the No. 3 dowels were placed, it was necessary to put the welded wire against the specimen prior to placement of the dowels. Otherwise, with the dowels in place, the fabric could not be manipulated around the lengths of the dowel hooks. The epoxy that was used to grout the dowels was Sikadur 31 Hi-Mod Gel.

Empty caulking tubes with hose extensions were used to place the epoxy into the empty dowel holes. The epoxy was mixed with a paint mixer powered by a drill, then placed into the caulking tube. A six-inch length of three-quarters inch diameter tube was fixed to the tip of the caulking tube for the epoxy injection. To insure that the entire hole was filled with epoxy, the tube was inserted all the way to the end of the hole (Fig. B.63). The epoxy was then pumped in while drawing the tip of the hose out of the hole, filling it entirely. Immediately a dowel was eased into the epoxy-filled hole as is illustrated in Fig. B.64.

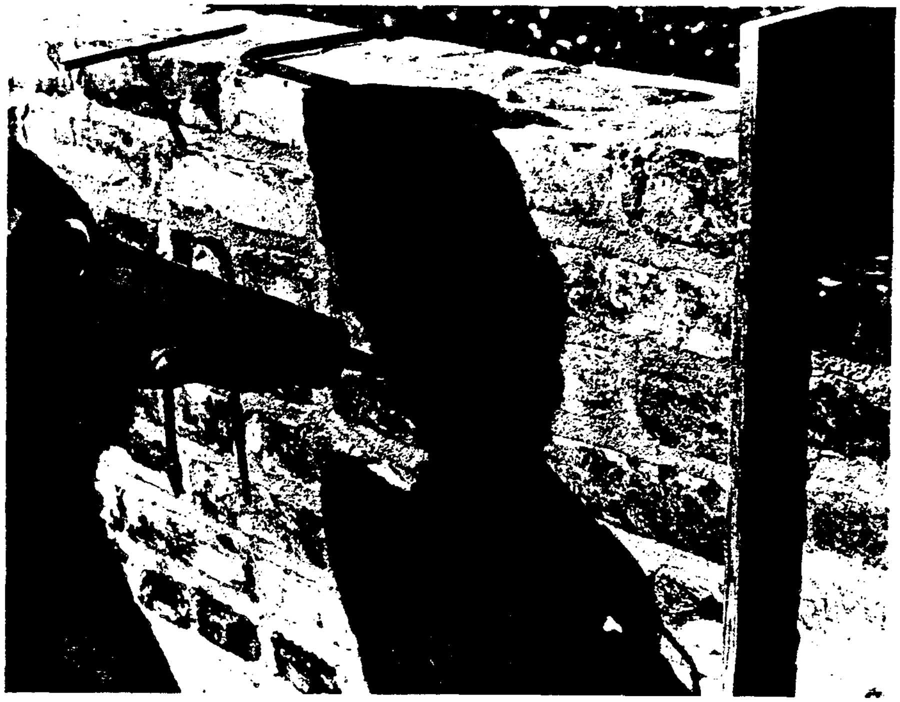


Figure B.63 View of Epoxy Being Placed in a 3/8 inch Dowel Hole.

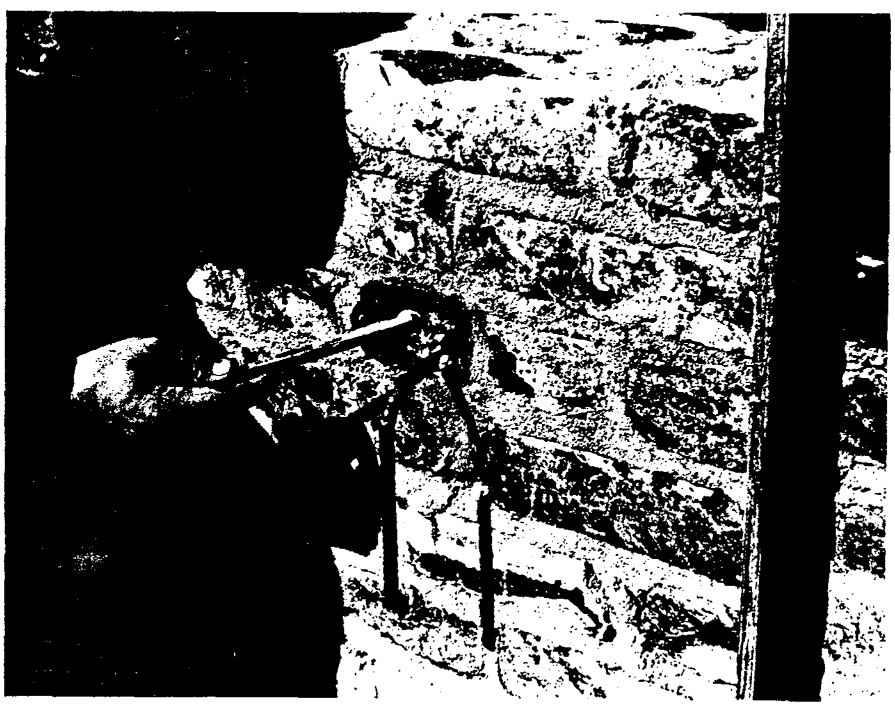


Figure B.64 Pushing a Dowel into an Epoxied Hole.

The best results occurred when the dowel was turned slowly while pushing it in. A slight amount of epoxy was displaced by the dowel but this was scraped up and spread onto the next dowel before insertion. Figure B.65 shows a dowel grouted into the specimen.

The 3/8 inch holes were at first epoxied in a similar way; however, an alternative method proved to be more effective. That alternative method was to cut the end of the caulk tube off at its tip to fit snugly in the 3/8 inch hole. The epoxy then was forced into the hole. If the hole passed through the entire section, the epoxy could be seen coming out the other side indicating that it was full. To assure that the holes were full, the author put his finger on the other end of the hole to create a back pressure. If the epoxy oozed around the finger, the hole was considered full. For the holes that were not all the way through, the author was assured that the hole was full when the epoxy oozed back around the tip of the tube. Because of the short pot life of the epoxy, four to five holes were filled; then the threaded rods were placed. The tips of the threaded rod that were to be exposed for the nuts were covered with tape to assure that the tips would not be covered with epoxy. The rods were slowly pushed into the epoxied hole. The best results occurred when the excess epoxy was coated on the rod, and when the rod was rotated while being pushed into the hole. After the epoxy hardened,

Figure B.65 Epoxy Grouted Dowel in Place.

86

the tape could be removed and then the mesh, washers and nuts could be installed. The nuts were tightened until the washer was flush up against the mesh. For the rods that were to pass all the way through the specimen, both ends were taped. While pushing these through the author put his finger on the back side so the epoxy would not escape. Again, after hardening the tape on both ends would be removed. The grey duct tape gave the best results.

Reinforcing steel was cut to fit the specimen size. Some of the steel was placed during the doweling (Fig. B.65). The expanded metal was very easy to place. The precut pieces were held against the surfaces, where a threaded rod was the metal was adjusted so the rod tip could pass through. A washer and nut was then placed on the threaded rod and tightened down snug. All the other reinforcing steel for the non doweled specimens was placed just prior to shotcreting.

After all doweling and associated reinforcing was done, form work around the specimens was built. The form work was made out of oiled plywood, some of which was placed between specimens to create the barrier, and positioned such that the edge would be the correct thickness of shotcrete. The form work made it easy to keep track of the thickness of the shotcrete treatment and to create plane edges.

Just prior to shotcreting, the specimens were numbered and labeled with the type of surface condition and the type of shotcrete treatment that that particular specimen was to receive.

On the morning of the shotcreting, the specimens that were to be saturated were continuously soaked with water. Figure 2.2.8 shows the specimens being saturated with water. The wetting would proceed until the specimen was treated. The epoxy enhanced surfaces were coated with Sikadur epoxy just prior to the placement of the shotcrete treatment because the epoxy had a short pot life.

Shotcreting started on September 30, 1981 and finished on October 1, 1981. Western Waterproofing Company, Inc. of Norcross, Georgia were the subcontractors who performed the shotcreting. They were contracted to supply labor and materials for dry-mix shotcrete (gunite) application for approximately 480 square feet of 3 inch thick shotcrete and approximately 480 square feet of one-half to three-quarters of an inch thick shotcrete. The supplier was required to provide a standard 4000 psi shotcrete mix.

One week prior to the treatment date, Western Waterproofing delivered the fine aggregate used in the mix, and the gasoline powered air compressor to the site. The aggregate was a riverbed sand from the Chattahoochee River.

On September 30, 1981 the crew came early in the morning with the pneumatic gun, an Allentown Penumatic Gun, Model N-O with steel wheels and a capacity of three-quarters to one and one-half cubic yards per hour. The gun used a

88

keeping the nozzle at about 90 degrees from the plane of the surface being treated. The nozzleman kept the nozzle about 8 to 10 feet from the surface, and shot the mixture at about a 45° angle when he was applying the treatment at the intersection of two planes such as the corner where the wall and the plywood forms met. As shown in Figs. 2.2.6 and 2.2.7, the nozzleman assured that the nozzle was kept at 90° to the plane of the surface. In Fig. 2.2.6, the nozzleman was holding the nozzle high, while in Fig. 2.2.7, the nozzleman held the nozzle low assuring that the nozzle was 90° to the plane of the surface being treatd. The nozzleman appeared to keep a consistent mix throughout the entire process. A plasterer from the Georgia Tech Physical Plant was on hand to assure that surfaces were flat and smoothed out; however, the nozzle produced such a good surface on the specimens that the plaster was not needed. The plasterer did, however, float the 4 by 4 specimens that received a one-half inch treatment as shown in Fig. B.66. The nozzle man produced a highly acceptable surface.

The 3-inch thick treatment was applied in two lifts. The nozzleman would shoot about one-half the thickness of the treatment and then let it cure for a while. Figure 2.2.12 shows a view of the first lift of shotcrete. Specimens 23 to 28 and 4 to 12 were allowed to set overnight before the second layer was applied. The surfaces of the specimens that were allowed to cure for one day were wetted down

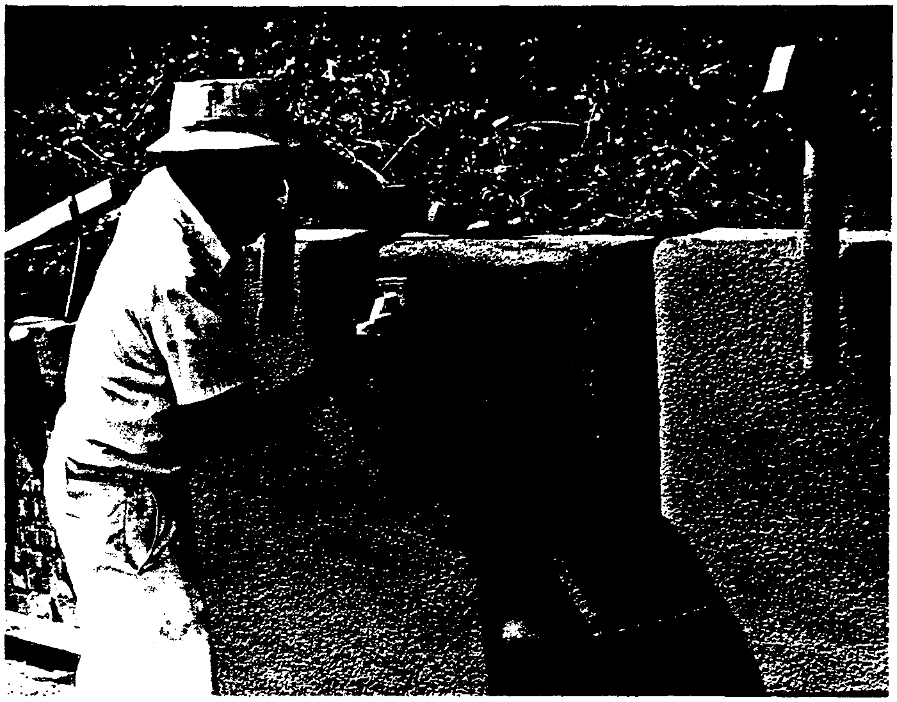


Figure B.66 Plaster.

Figure B.67 Covering Specimens with Moisture Barrier.

prior to the second treatment insuring a better bond between the first and second lifts.

Just prior to shooting the epoxy interface enhanced specimens, the 2-part Sikadur Gel epoxy was mixed using a paint-mixer and power drill as illustrated in Fig. 2.2.9. The epoxy was brushed on the brick surface as shown in Fig. 2.2.10 and then the shotcrete was applied as in Fig. 2.2.11.

The author noted that the insitu shotcrete was of high quality. The rebars were fully coated with shotcrete and only limited segregation was observed. A large percentage of rebound occurrred when first applying the treatment to a specimen. However, this allowed the rich grout to form at the surface interface. The rebound diminished upon the build up of the thickness. The impact of subsequent layers of the treatment served as an efficient means of compacting the underlying layers of shotcrete. For the top coat, the nozzleman stood back just a little further than normal and sprayed a flash coat. This finish is termed a gunned finish and was quite appropriate for the intended research. The finished surface of the shotcreted specimens is shown in Fig. 2.2.13.

Upon the completion of a row of specimens, an asphalt impregnated paper moisture barrier was placed on the exposed surface or like a glove over the entire specimen. The moisture barrier as shown in Fig. B.67 was used to help reduce the evaporation of water from the shotcrete.

Two weeks later, the specimens were moved via a forklift to the area around the structures lab. The forks of the lift were slid under the specimen in the gap provided by the brick supports. A light chain was wrapped around the specimen for safety purposes. Only one large specimen could be transported at once, while two to three of the small samples were moved together. The single wythe samples that were not treated with shotcrete were banded with metal straps prior to moving. This insured that the samples would not break when moved. Some of the specimens were exposed to all weather while others were placed inside due to limited storage space.

APPENDIX B.3

MATERIAL PROPERTIES

Sections of No. 3 reinforcing bars that were used as dowels were turned down on a metal lathe and tested in tension in an Instron testing machine. Figure B.70 illustrates a typical stress strain plot for the dowels under tension. The mean yield stress for the six specimens tested was 47.2 ksi with a standard deviation of 44 ksi and a range from 42.4 ksi to 53.7 ksi.

Sikadur 31 Hi-Mod Gel, a high-solids, 2-component, epoxy-resin system was used to grout the dowels into the walls. The Sikadur epoxy was used because it is a unique, high modulus, moisture-insensitive, structural adhesive that is used for vertical and overhead bonding and embedment. Sikadur 31 Hi-Mod Gel cures under dry, can't dry, and saturated surface dry conditions. The epoxy meets ASTM C-881 specifications.

Details on the material properties for the brick, sand, mortar welded wire fabric and shotcrete are presented in Section 2.4 of the main text of this report.

APPENDIX C

GENERALIZED EQUIVALENT WIDTH USING FINITE ELEMENTS

A generalized finite element analysis was done for the nominal 3' by 3' and 4' by 4' specimens. Figures C.1 and C.2 show the models used. The element sizes used were 3" square, isoparametric quadratic quadralaterals from the GTSTRUDL program. The 3" by 3" elements were used because of their ease of automatic generation and the fact that the boundary conditions were 6" bearings. The thickness of the elements used was 1", allowing easy interpretation.

The purpose for running the finite element analysis was to investigate the general trend of the stresses under inplane loading of a specimen, as that in the ASTM E519-74 test (11). The stress contours were to be used to approximate an effective width of the specimen for future analysis. Principal stresses were not accessible on the library version of GTSTRUDL, thus the nominal and shear stresses were utilized. The nominal and shear stresses were used because they would have the same general trend as the principal stresses.

Four combinations of Poissons ratio and the Modulus of Elasticity were run. The loads for each case were kept constants. Poissons values were 0.30 and 0.17 while the Modulus of Elasticity had values of 3.6E6 psi and 1.1E6 psi. First the 3 by 3 model was run for the four combinations of Poissons ratio and E. From the results, the variation of Poissons ratio had little effect on the stresses at the nodes, a percent variation between nodal stresses of less

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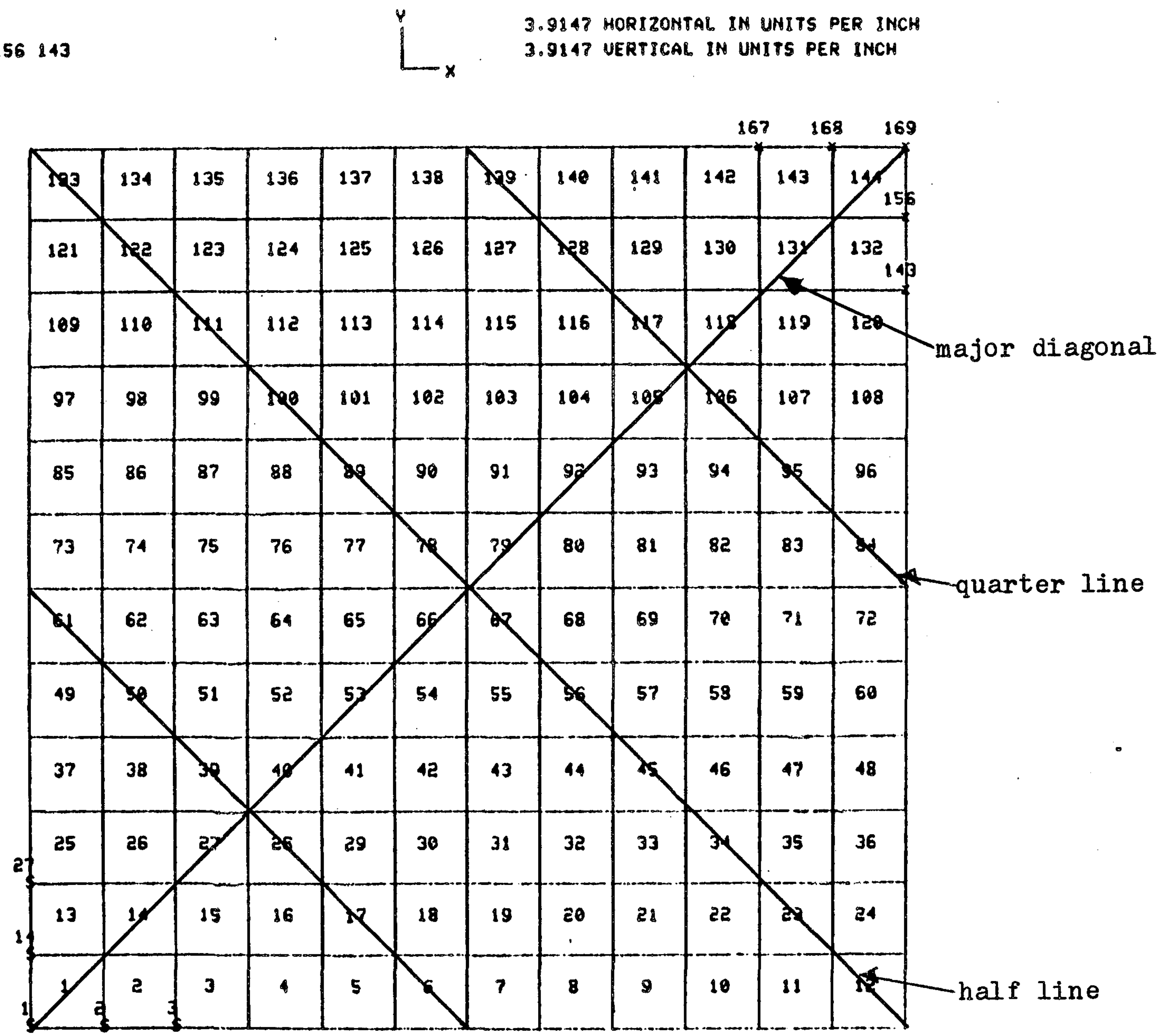

3' by 3'
Finite Element
GTSTRUDL
3" square elements
IPLQ elements

Figure C.1 3 ft. by 3 ft. Finite Element Model.

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? L SUP
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5.2197 HORIZONTAL IN UNITS PER INCH
5.2197 VERTICAL IN UNITS PER INCH

4' by 4'
Finite Element
GTSTRUDL
3" square elements
IPLQ elements

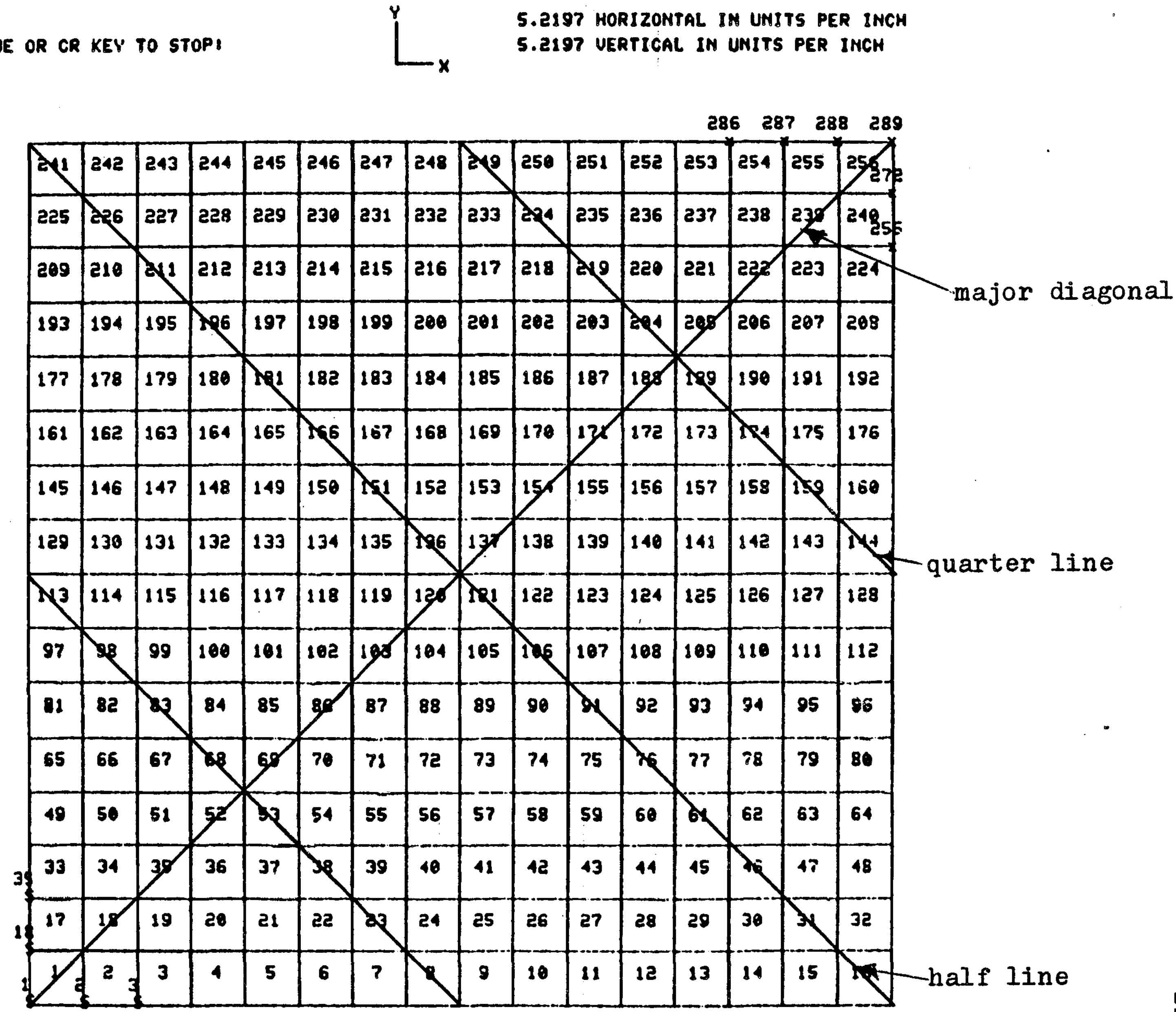


Figure C.2 4 ft. by 4 ft. Finite Element Model.

than 2.0%. Because of the small variation of stresses, the finite element analysis on the 4 by 4 model was only performed for the case of E = 3.6E6 psi, Poissons = 0.17, and loading P = 20 kip.

Using the Textronix plotter, stress contours for the two models were plotted for each set of variable combinations. Figures C.3 to C.7 show the shear stress contour plots produced for all cases. Next a plot of the stresses at the half and quarter lines were produced by hand. Figures C.1 and C.2 show the half and quarter lines. Figures C.8 and C.9 show the plots of the shear stresses at the half and quarter lines.

To approximate an equivalent width for future analysis, the areas of the stress plots were approximated with a rectangular stress block. The maximum shear stress for the rectangle was equal to the largest shear stress on the stress plot. The width of the rectangle was calculated such that the resulting area of the rectangle equal the area of the shear stress plot. Figures C.8 and C.9 show the resulting widths for the 3 by 3 and 4 by 4 models at the half and quarter lines. The resulting widths were for the 3 by 3, 14.6 in. and 21.7 in. at the quarter and half lines, and for the 4 by 4, 18.4 in. and 28.4 in, respectively. The average of the quarter and half line widths was used as the equivalent width. The resulting equivalent width for the 3 by 3 was 18.1 in. and for the 4 by 4 it was 23.4 in. The ratio of equivalent width to the nominal size of the

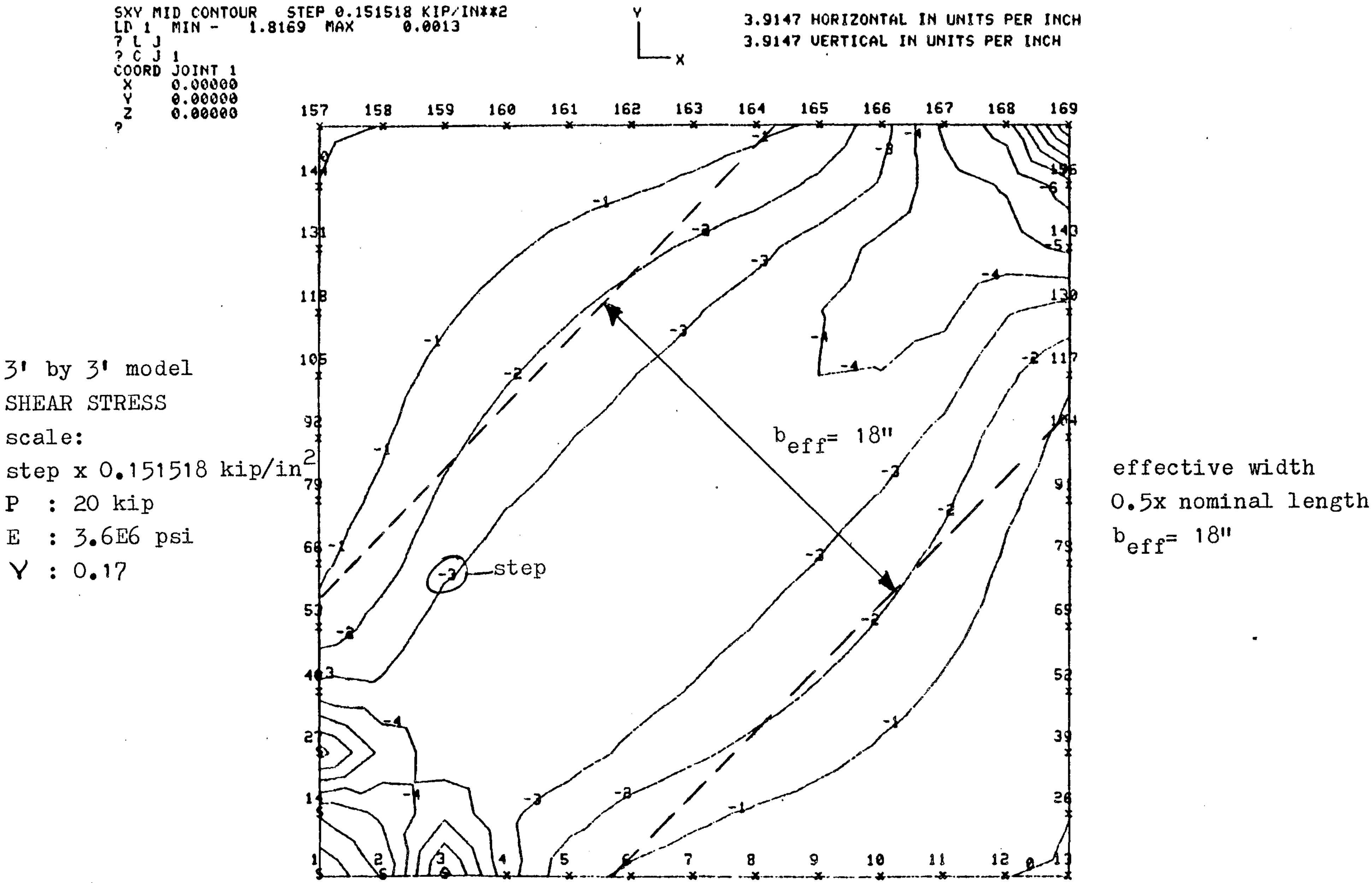


Figure C.3 Shear Stress Plot for 3 by 3 Model
P = 20k, E = 3.6E6 psi, and ν = 0.17.

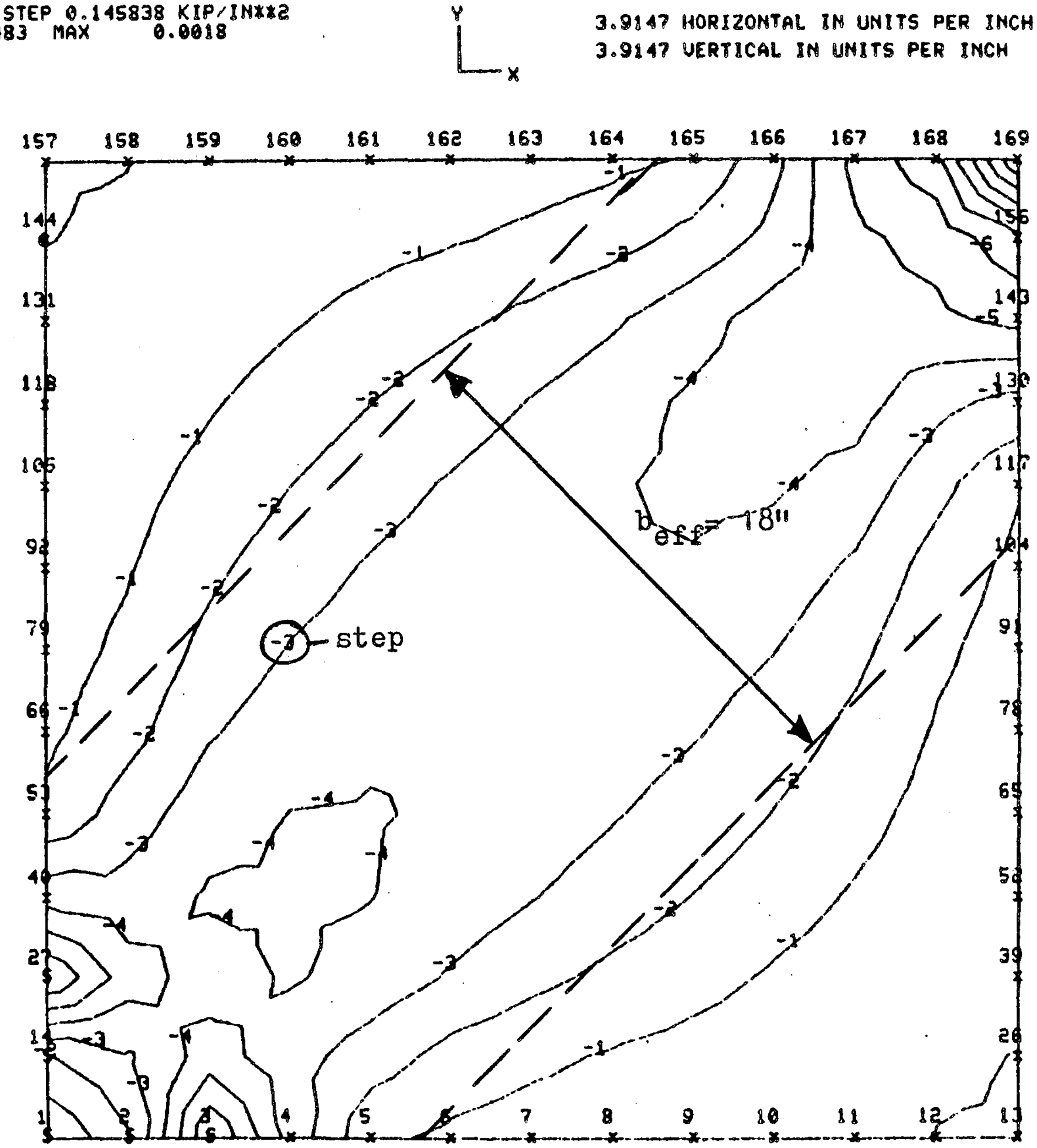
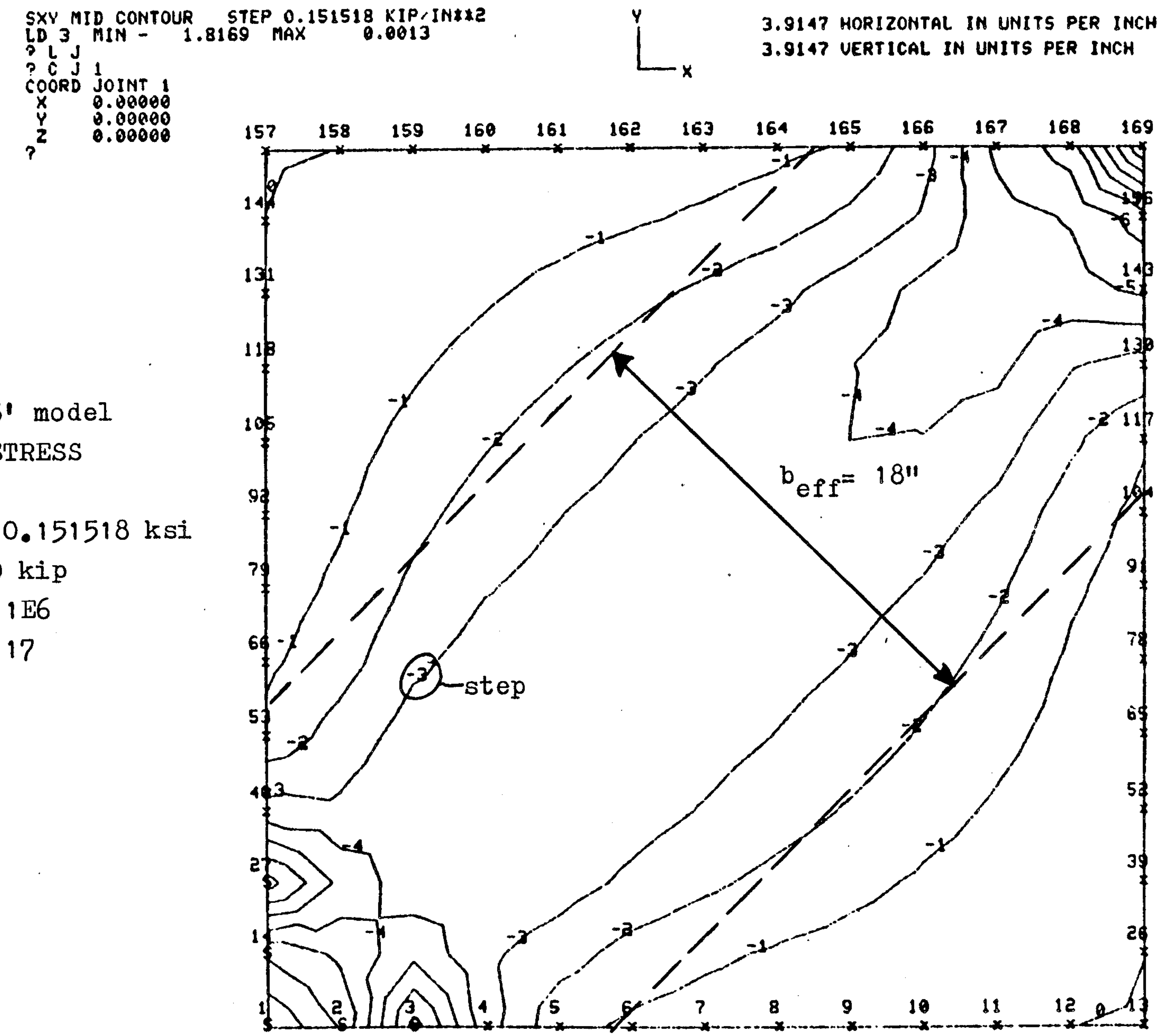


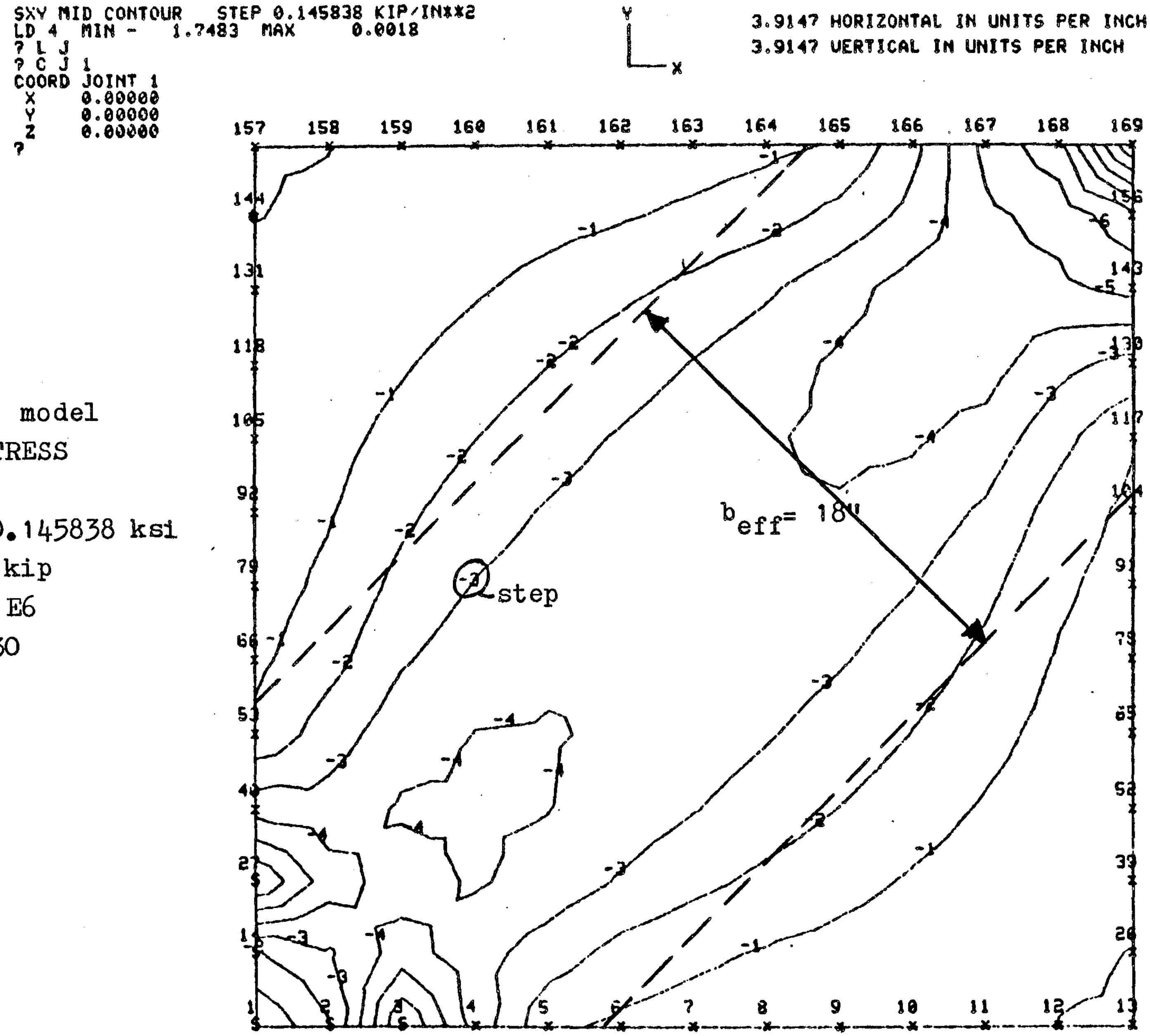
Figure C.4 Shear Stress Plot for 3 by 3 Model, P= 20k, E = 3.6E6 psi, and ν = 0.17.



3' by 3' model
SHEAR STRESS
scale:
step x 0.151518 ksi
P : 20 kip
E : 1.1E6
ν : 0.17

effective width
0.5x nominal length
b_{eff}= 18"

Figure C.5 Shear Stress Plot for 3 by 3 Model,
P = 20k, E = 1.1E6 psi, and ν = 0.17.



3' by 3' model
SHEAR STRESS
scale:
step x 0.145838 ksi
P : 20 kip
E : 1.1E6
ν : 0.30

effictive width
0.5x nominal length
b_{eff} = 18"

Figure C.6 Shear Stress Plot for 3 by 3 Model, P = 20k, E = 1.16E6 psi, and ν = 0.30.

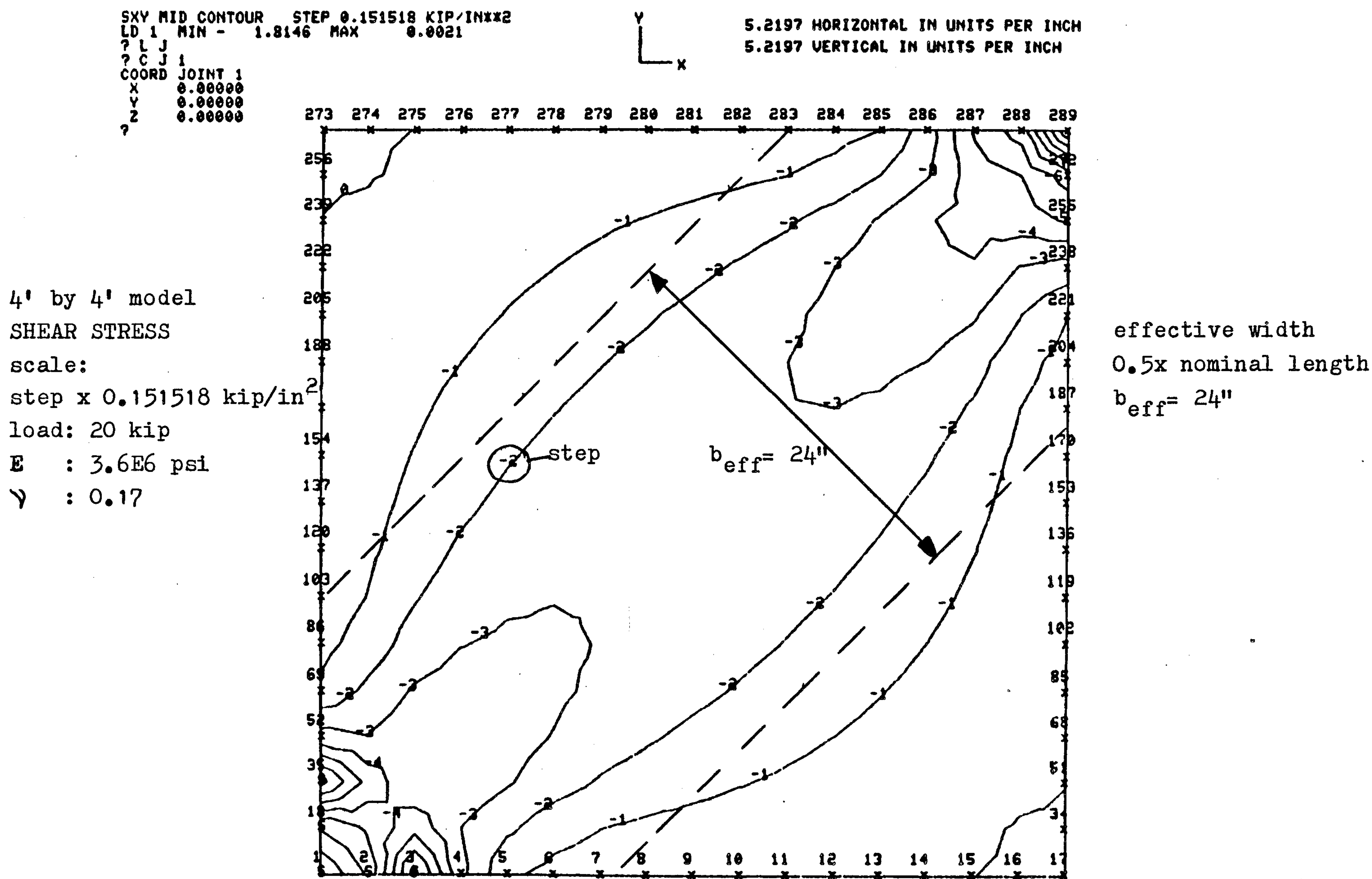


Figure C.7 Shear Stress Plot for 4 by 4 Model, P = 20k, E = 3.6E6 psi, and $\nu = 0.17$.

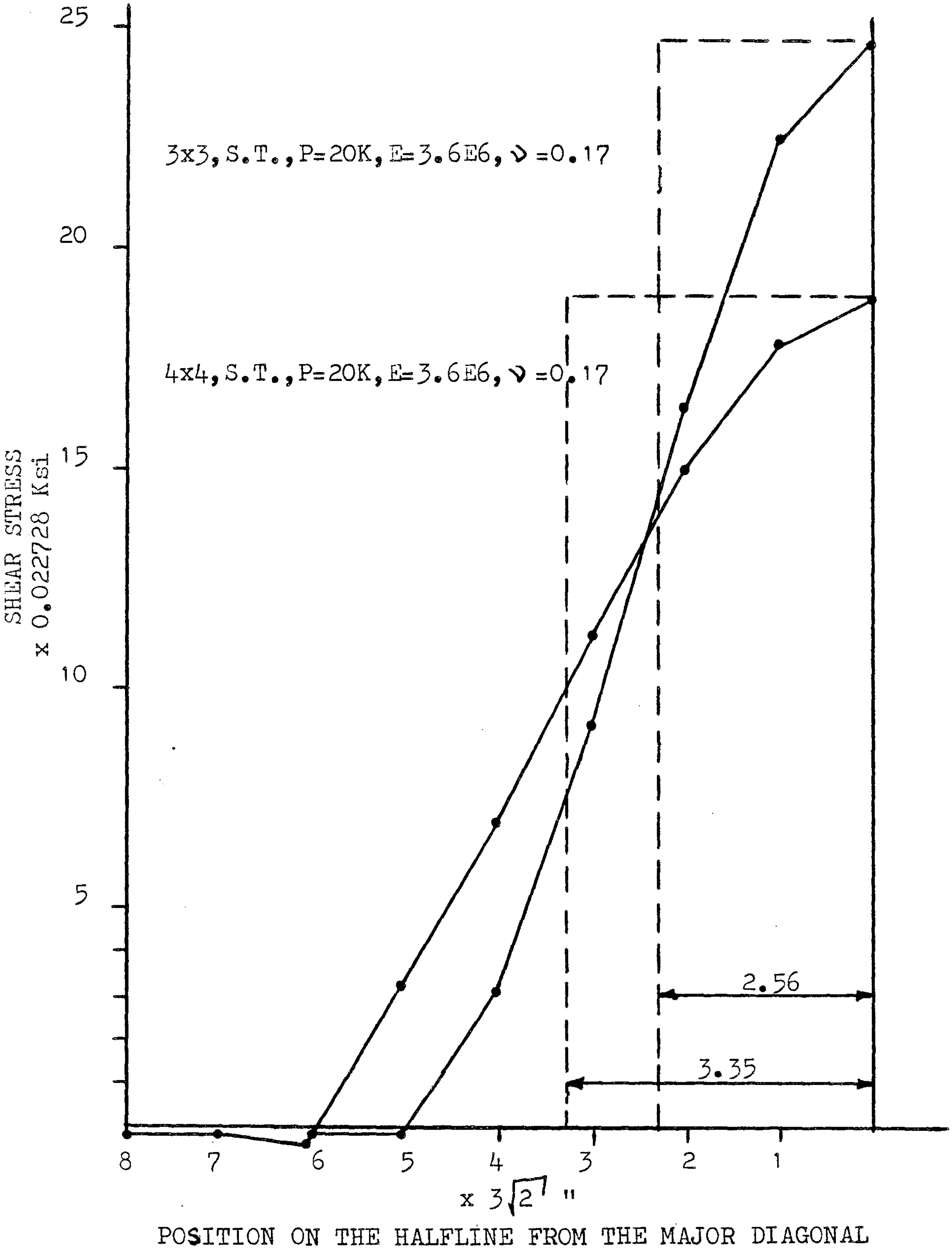


Figure C.8 Half Line Shear Stress Plot.

104

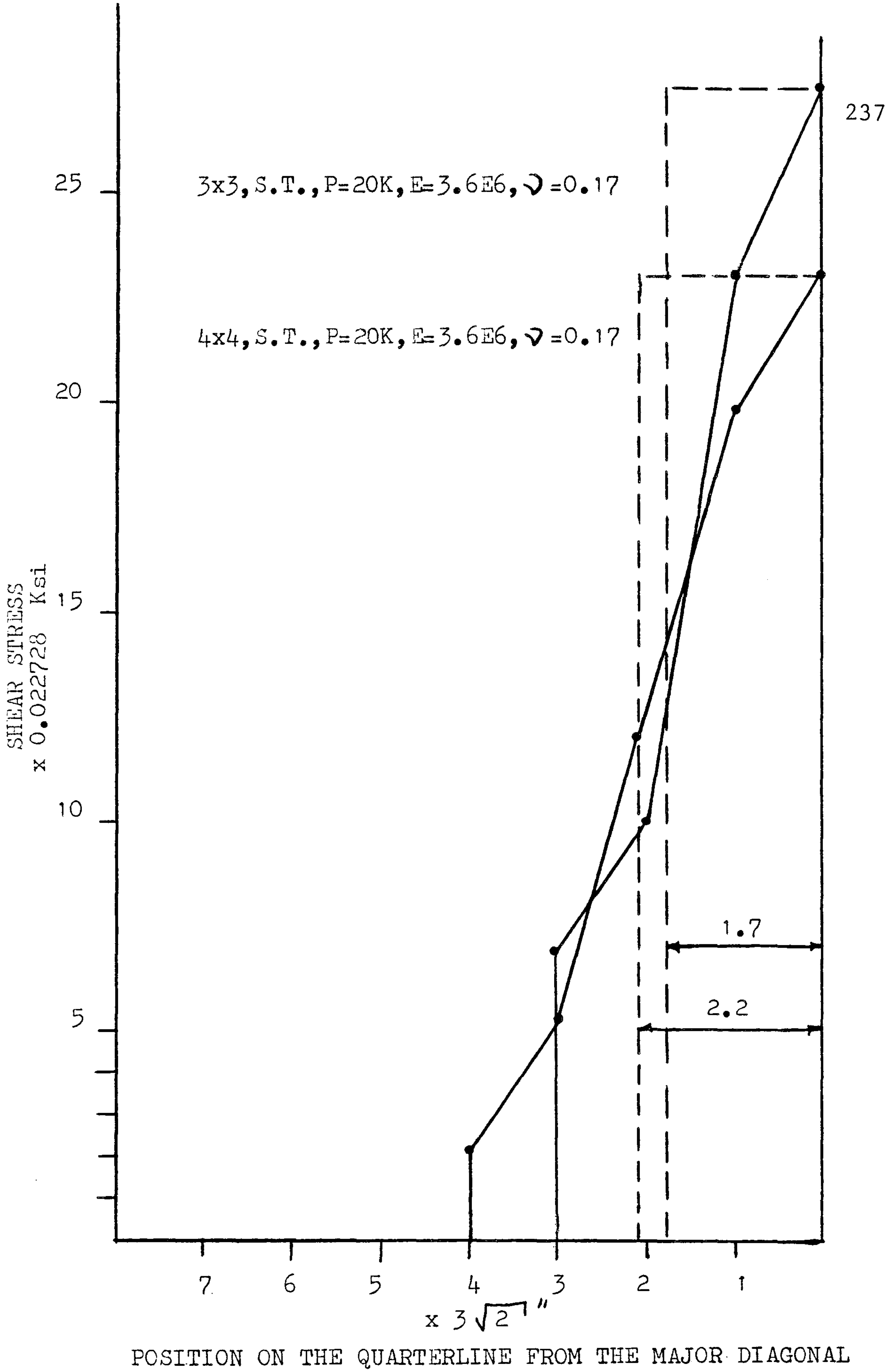


Figure C.9 Quarter Line Shear Stress Plot.

specimen was 0.503 and 0.488 for the 3 by 3 and 4 by 4 models, respectively. A value of 0.50 for the ratio of equivalent width to nominal size is an adequate approximation. The approximated equivalent width was equal to 0.50 times the nominal size of the square panel. Figures C.3 to C.7 show the equivalent (effective) widths (b_{eff}) suggested.

APPENDIX D

PLOTS FOR SPECIMENS C-1, W-1, E-2, D-3

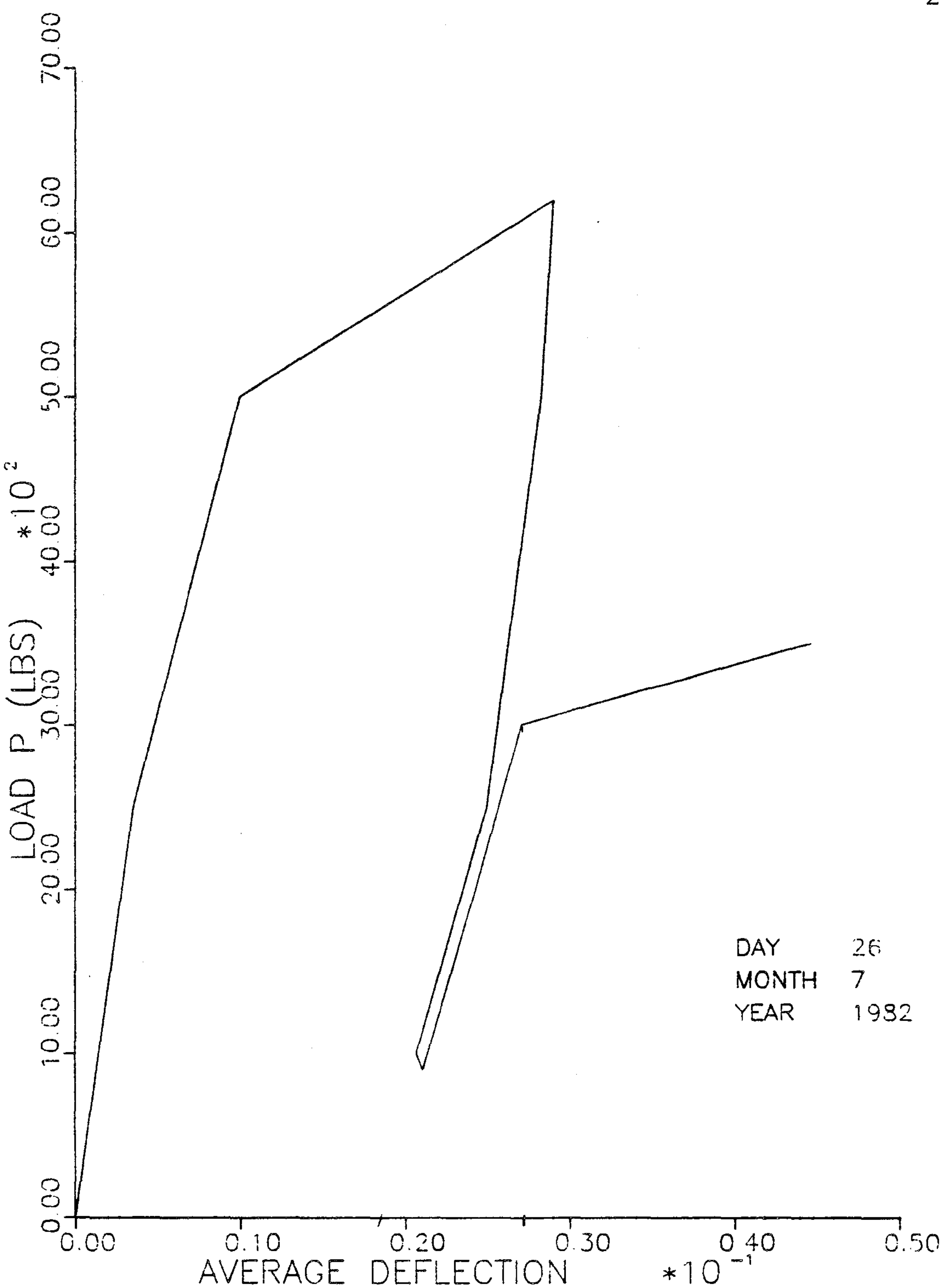


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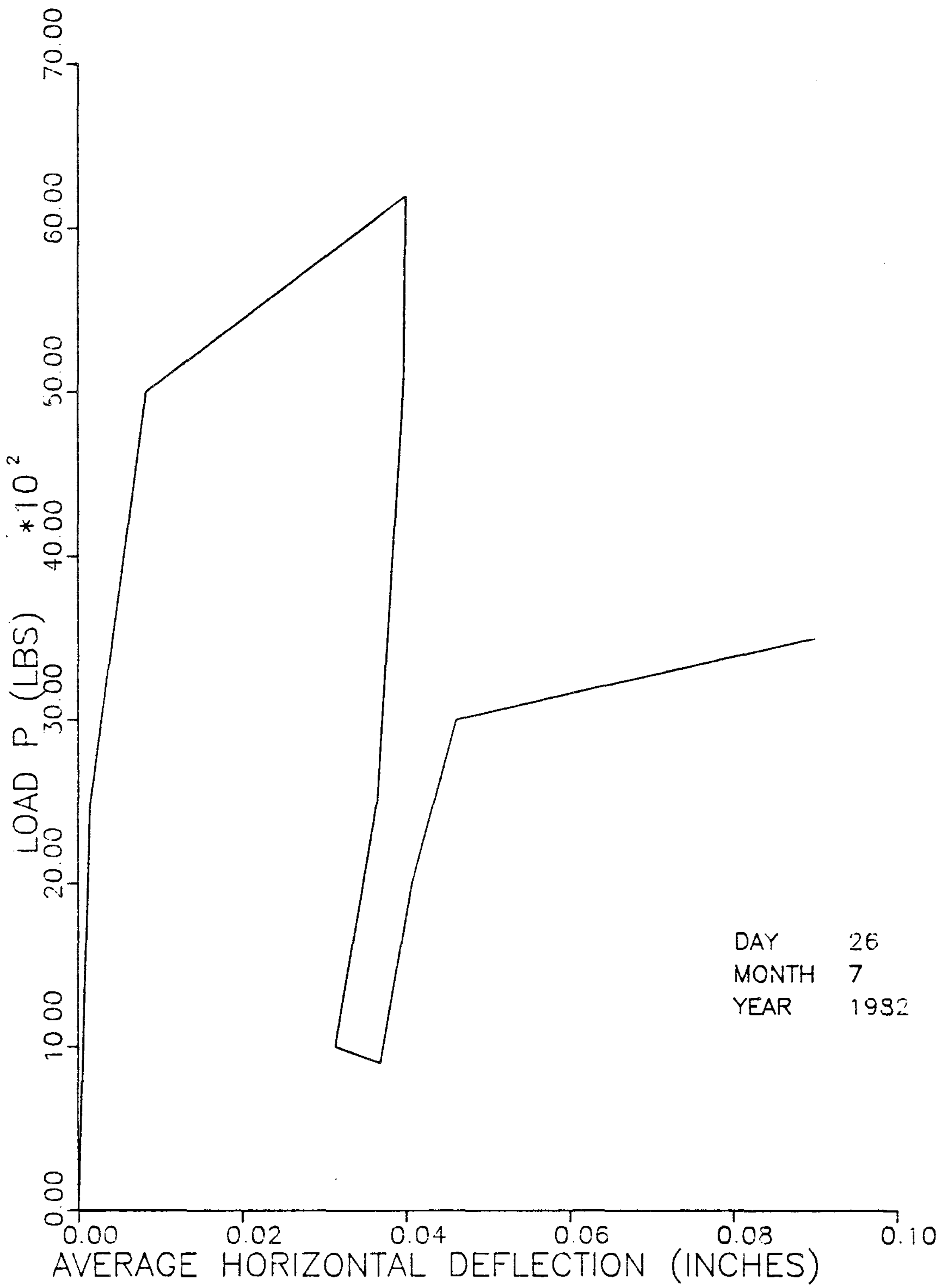
Figure D.1 Load vs Average Deflection (C-3)



3

Figure D.2 Load vs Average Horizontal deflection (C-3)

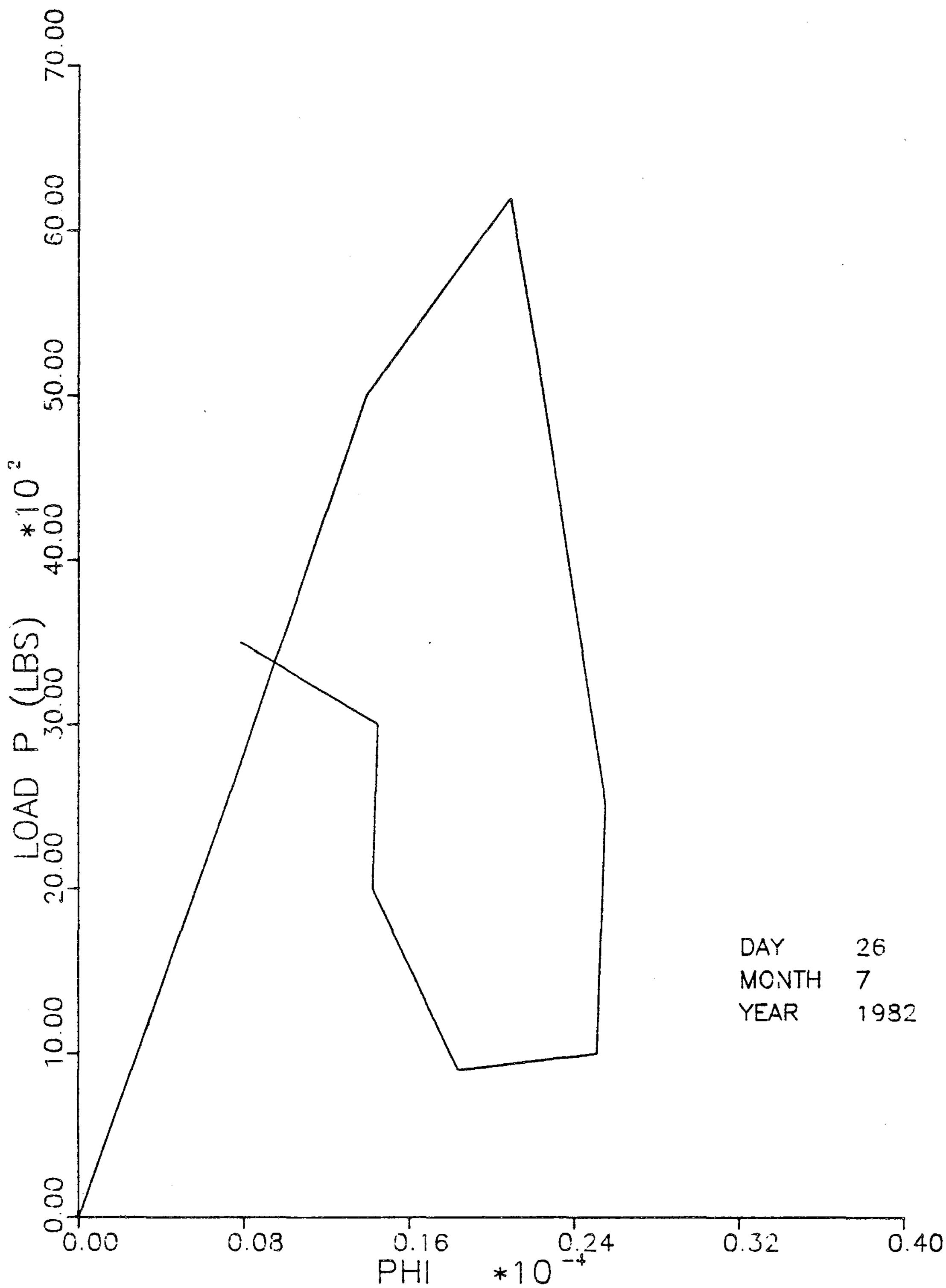


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Figure D.3 Load vs Phi (C-3)

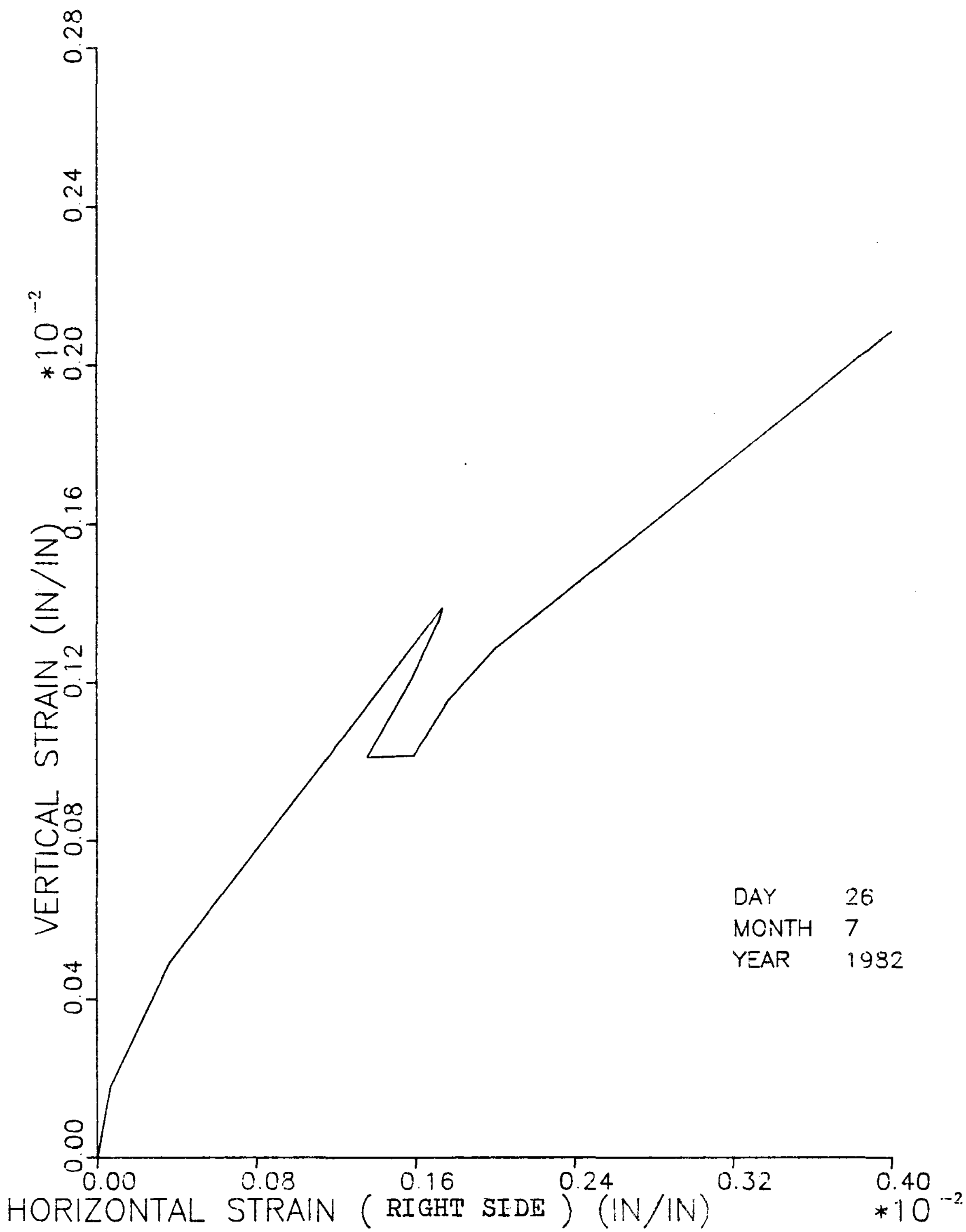

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Figure D.4 Vertical Strain vs Horizontal Strain Right Side (C-3)

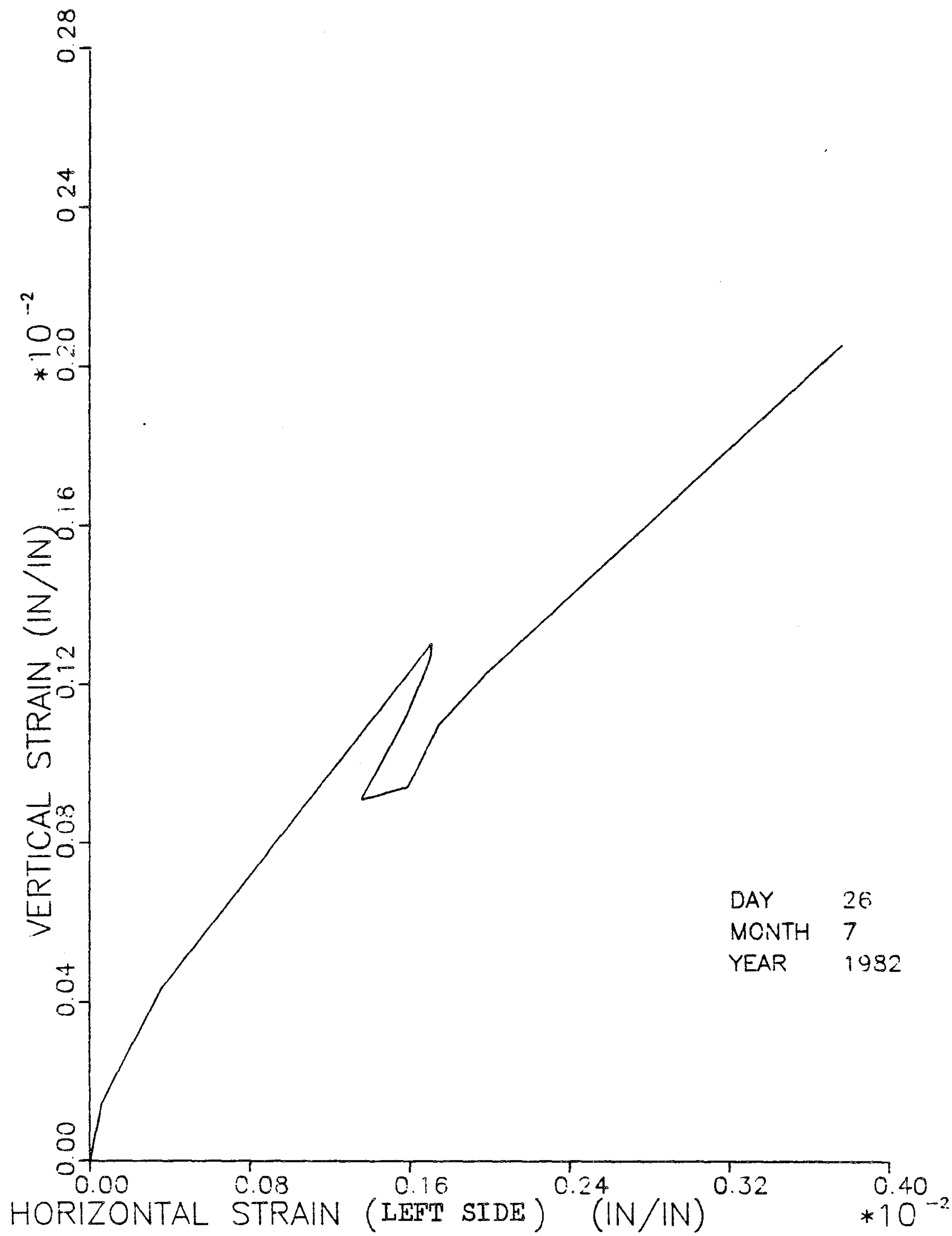

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Figure D.5 Vertical Strain vs Horizontal Strain Left Side (C-3)

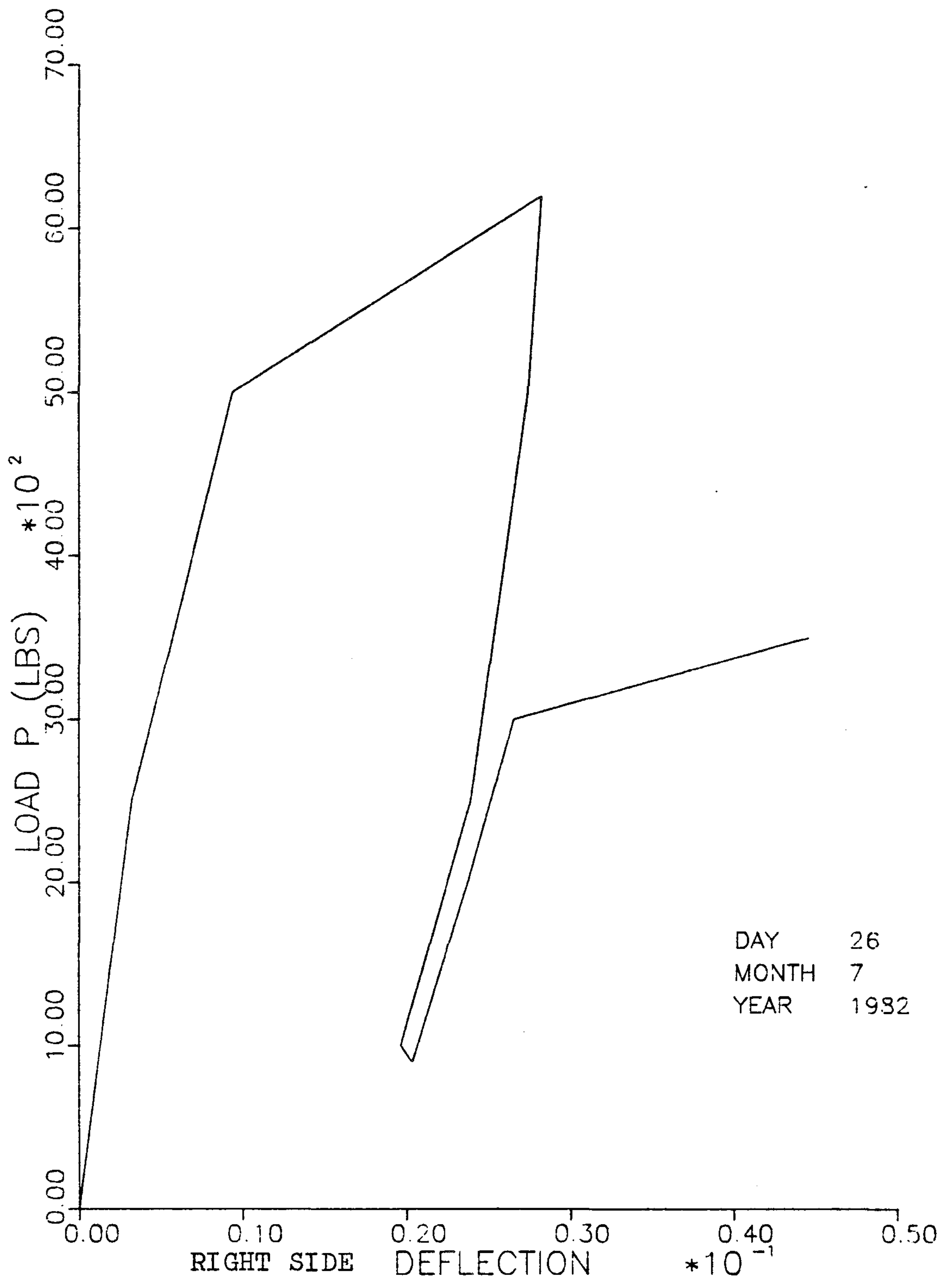

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Figure .6 Load vs Right Side Deflection (C-3)

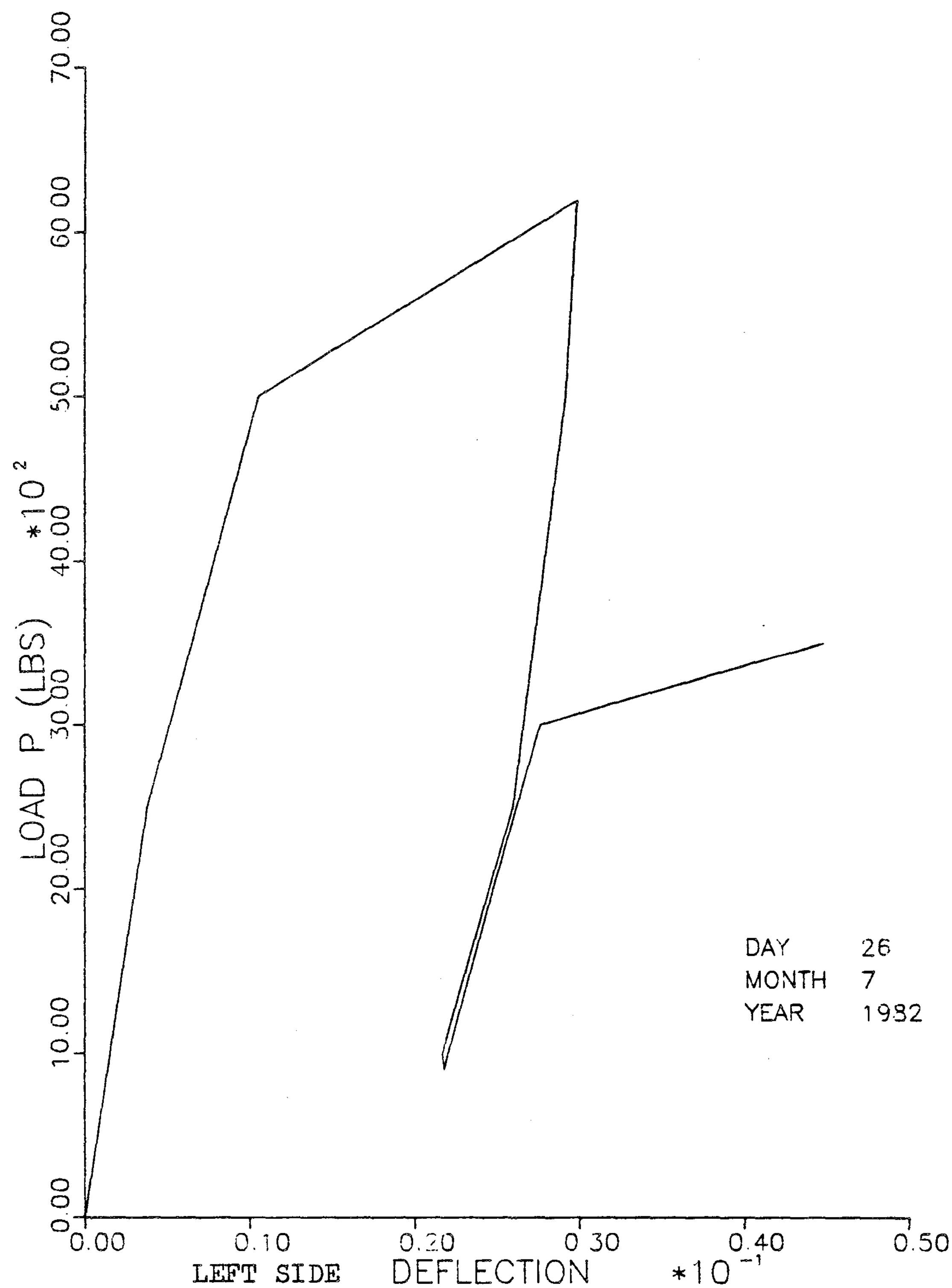

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Figure D.7 Load vs Left Side Deflection (C-3)

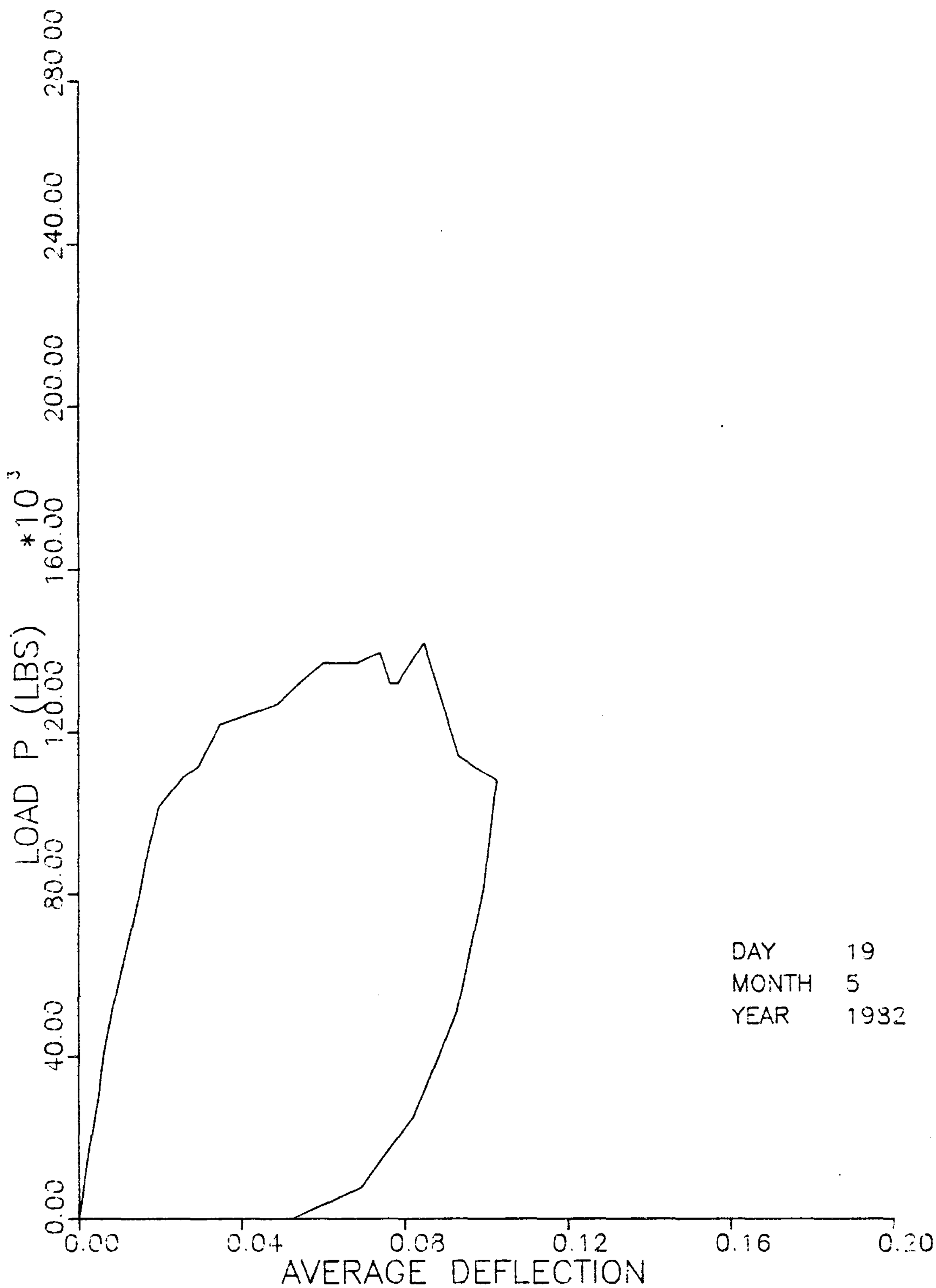

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Figure D.8 Load vs Average Deflection (W-1)
First Half-Cycle

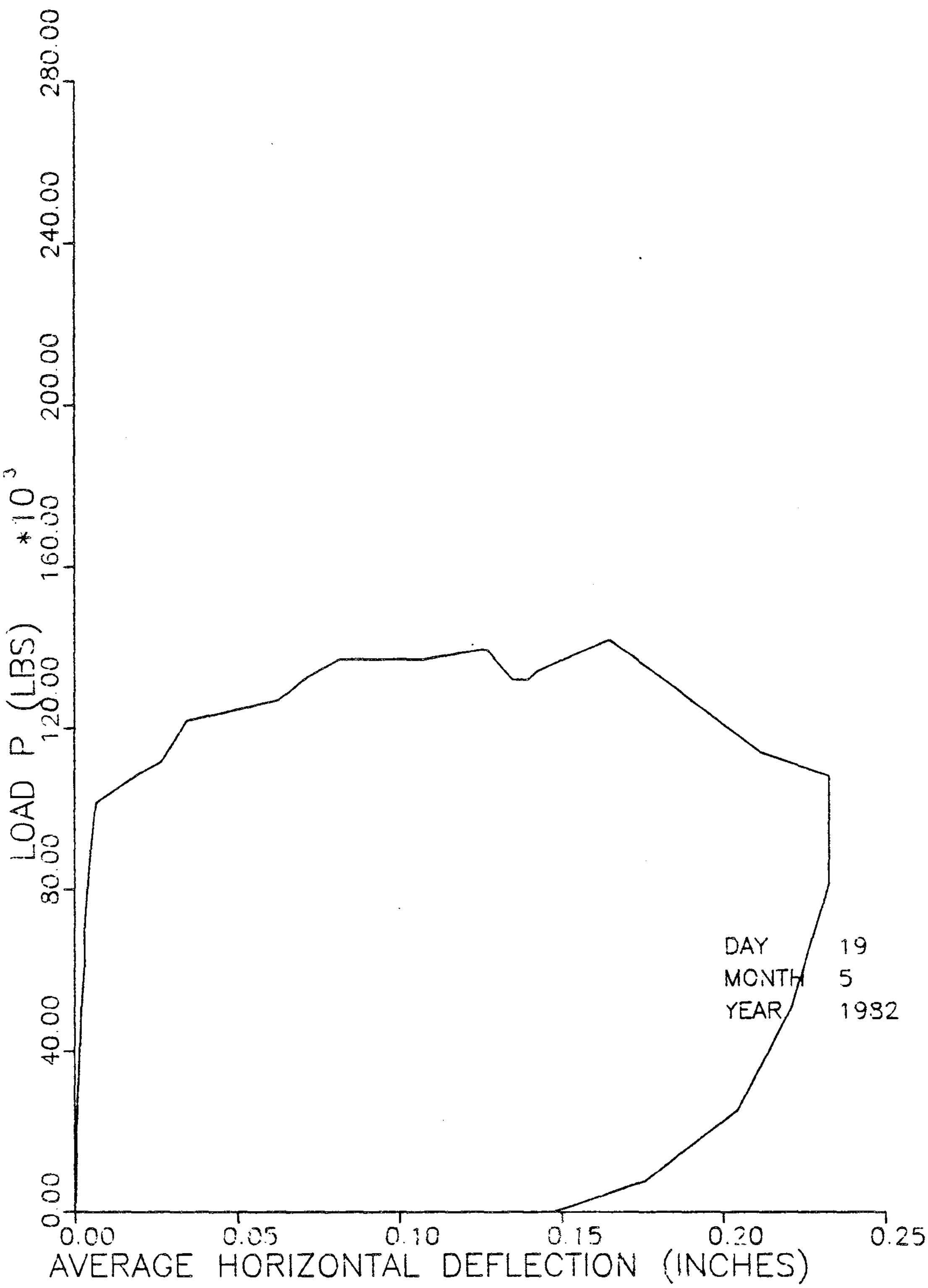

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Figure D.9 Load vs Average Horizontal Deflection (W-1) First Half-Cycle

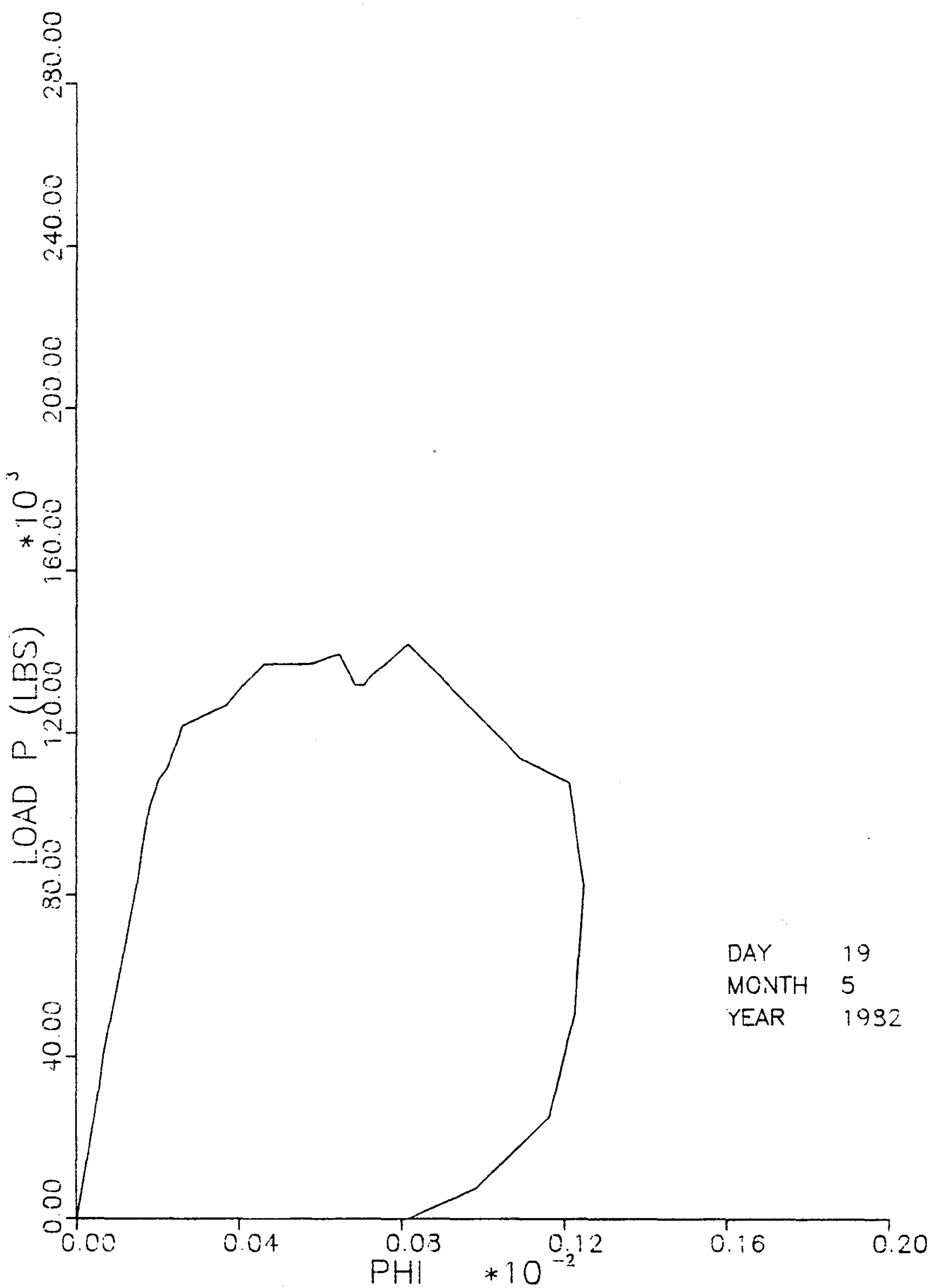

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Figure D.10 Load vs Phi (W-1)
First Half-Cycle

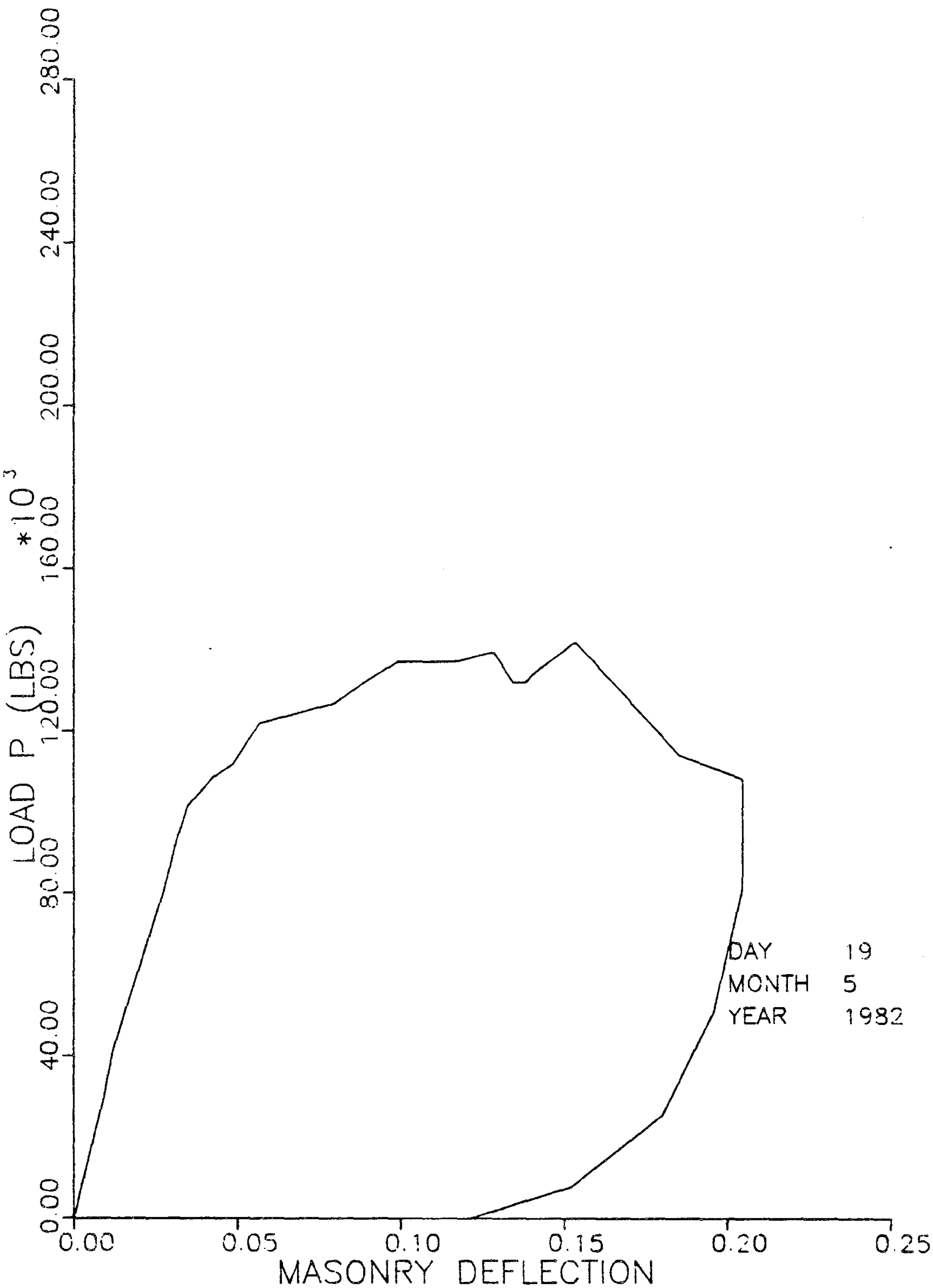

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Figure D.11 Load vs Masonry Deflection (W-1)
First Half Cycle

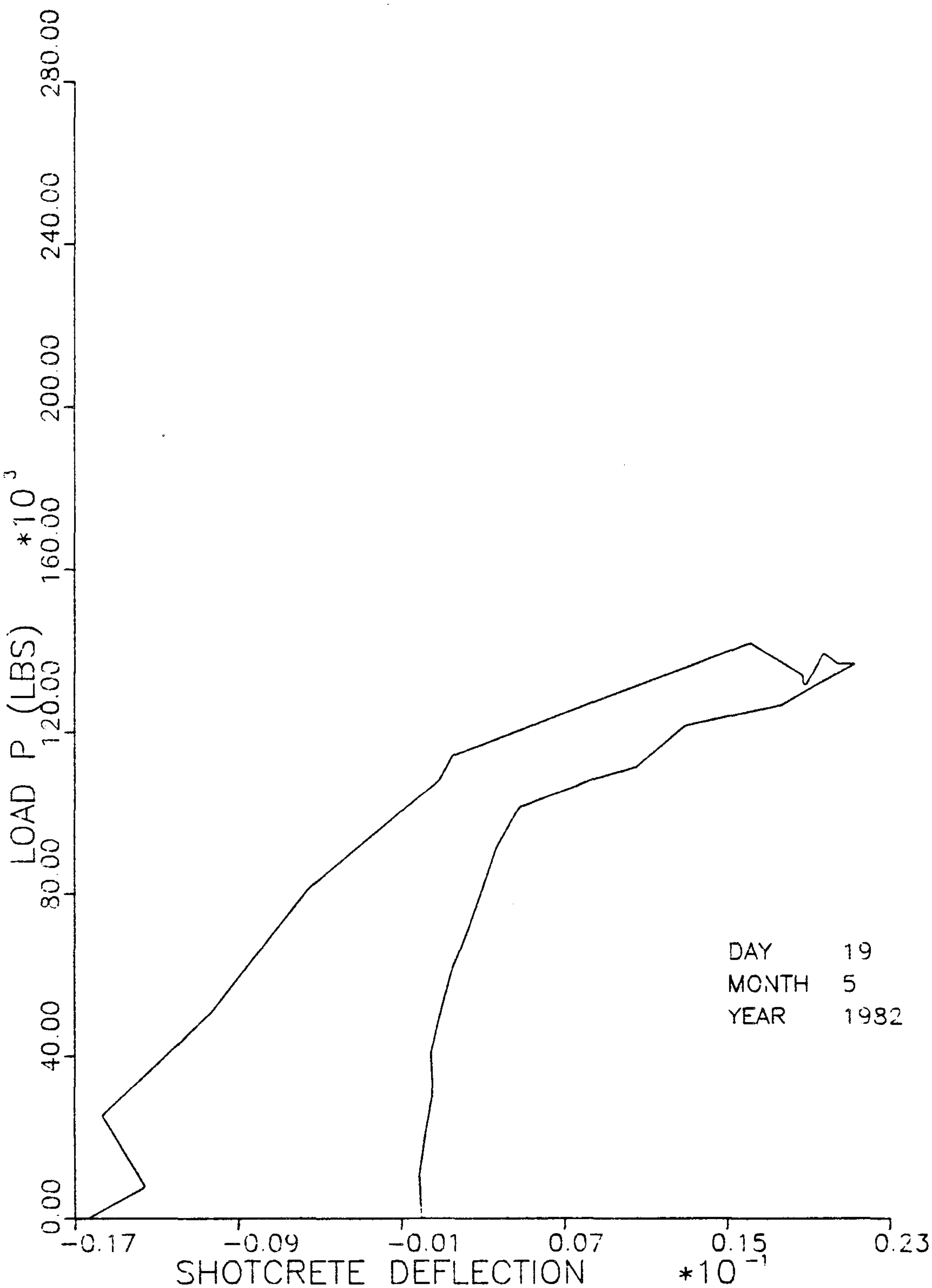

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Figure D.12 Load vs Shotcrete Deflection (W-1)
First Half-Cycle

4

Figure D.13 Vertical Strain vs Horizontal Strain Masonry Side (W-1) First Half-Cycle

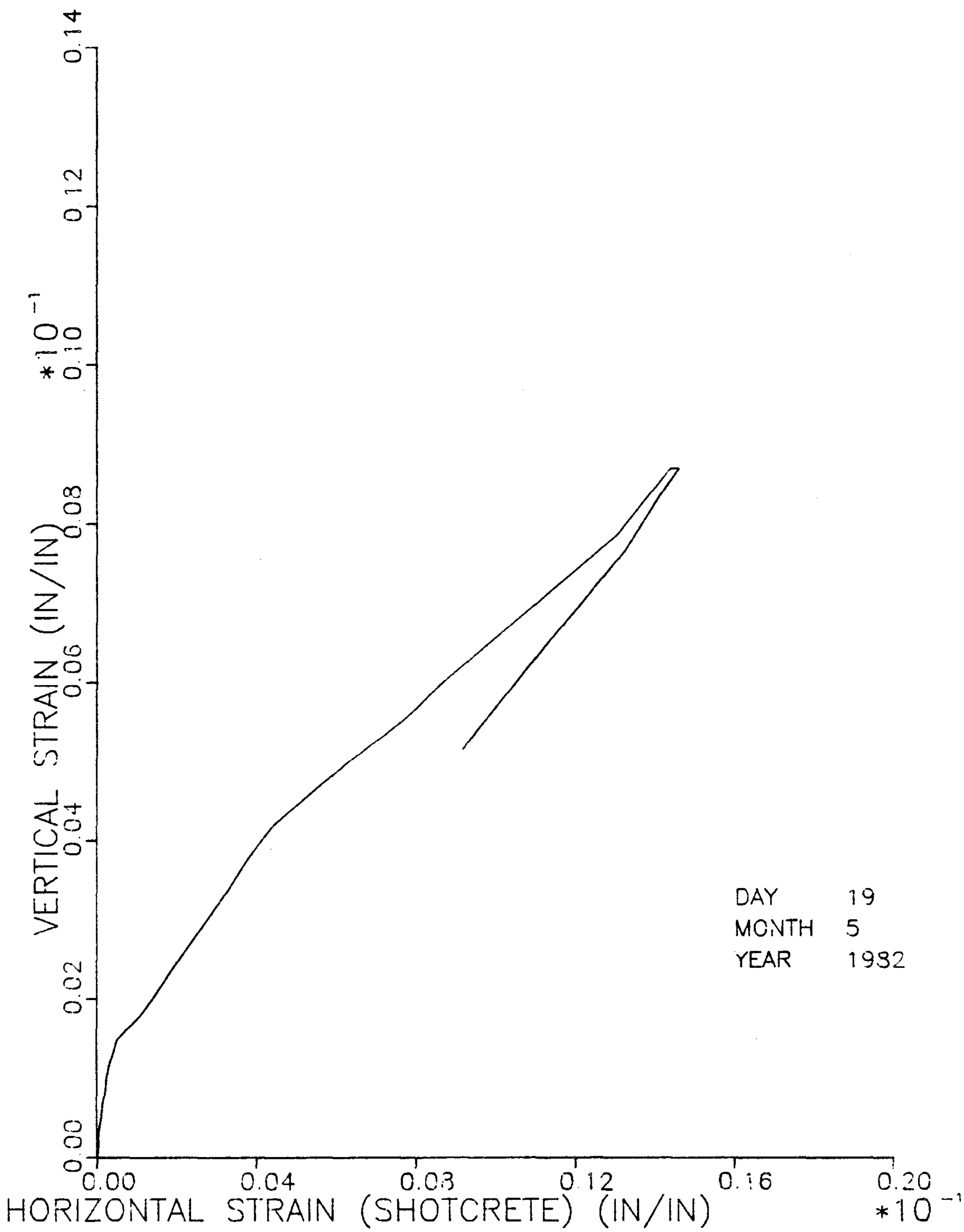

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Figure D.14 Vertical Strain vs Horizontal Strain Shotcrete Side (W-1) First Half-Cycle

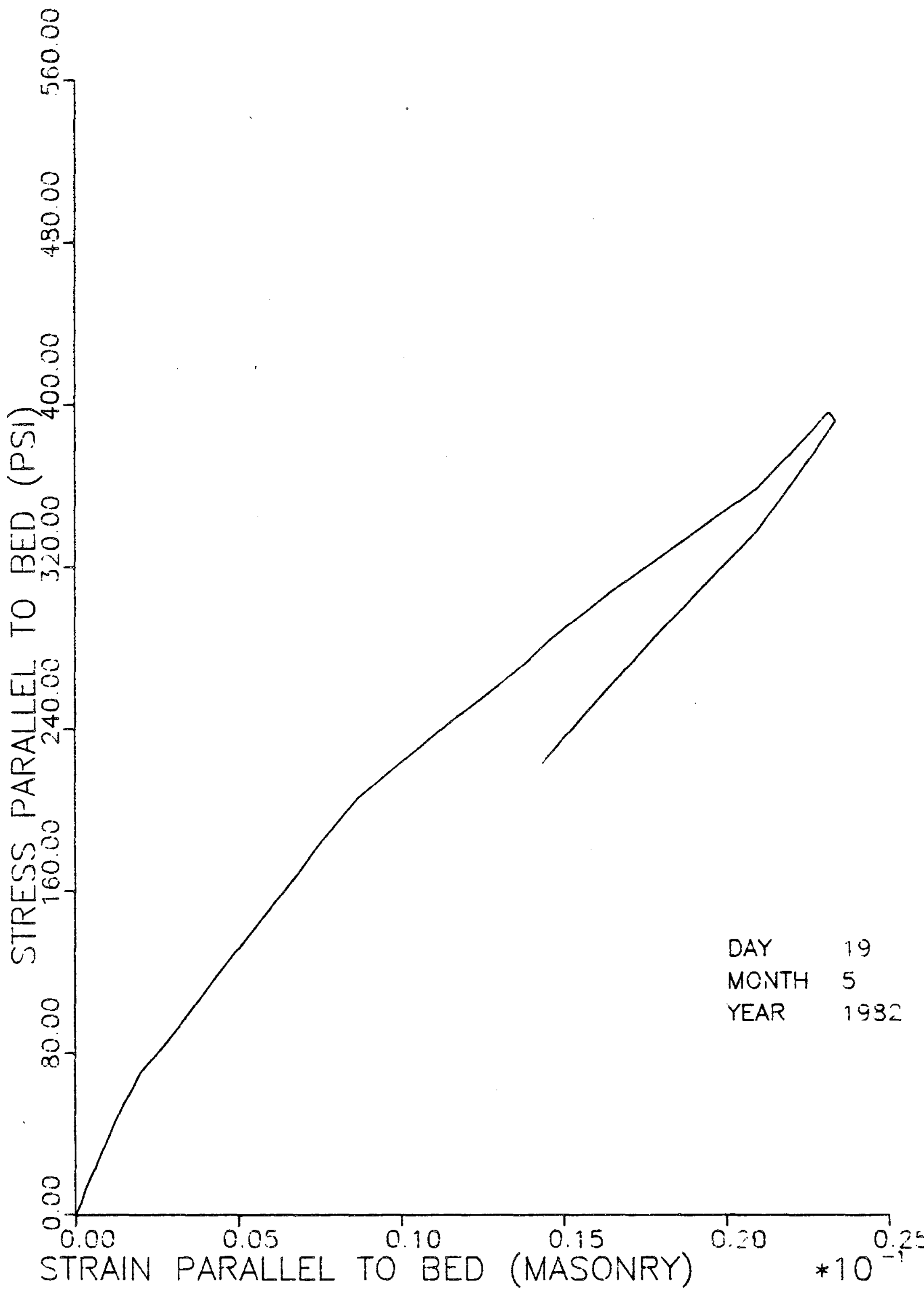

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Figure D.15 Stress vs Strain Parallel to the Bed on the Masonry Side (W-1) First Half-Cycle

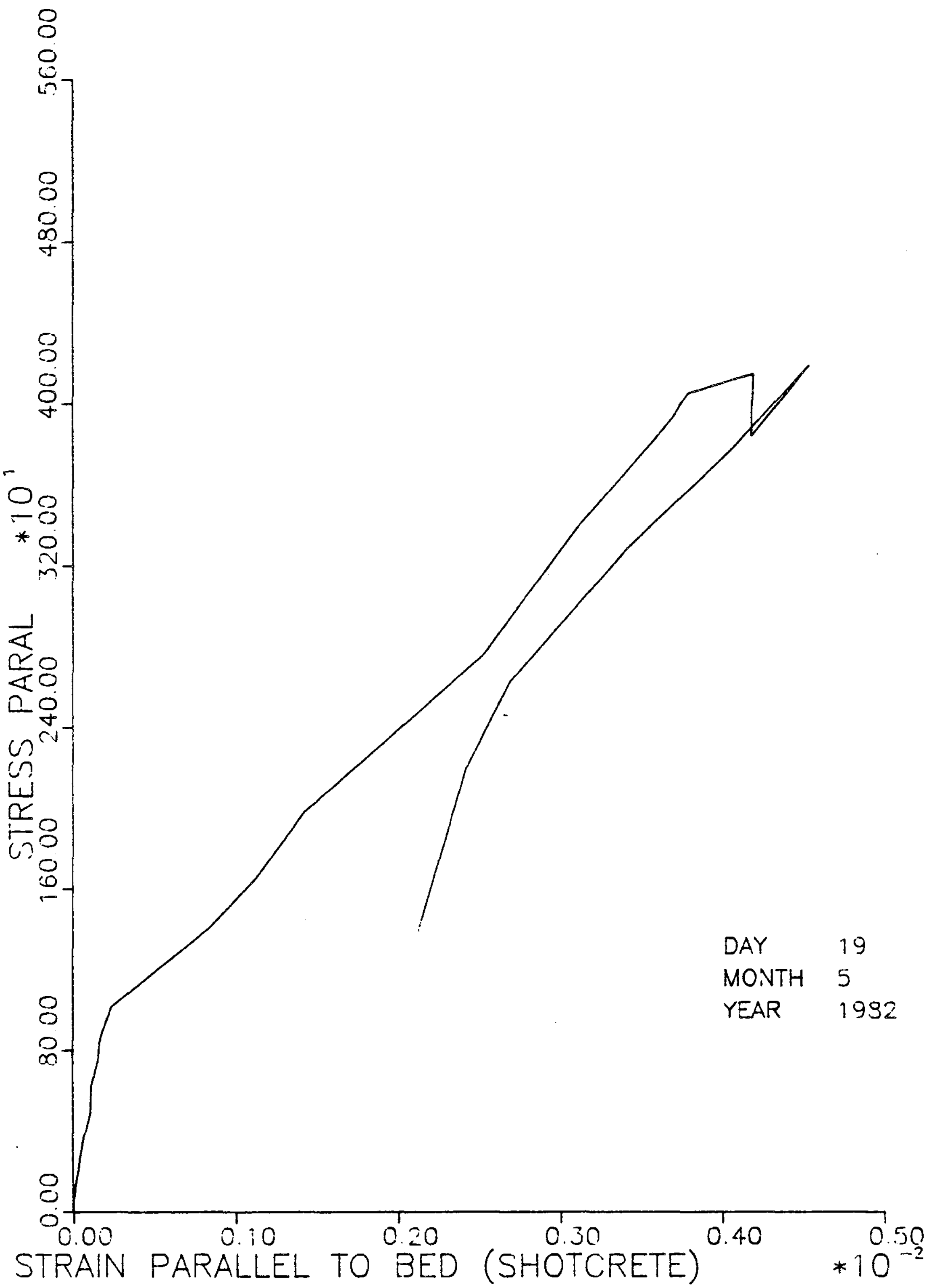

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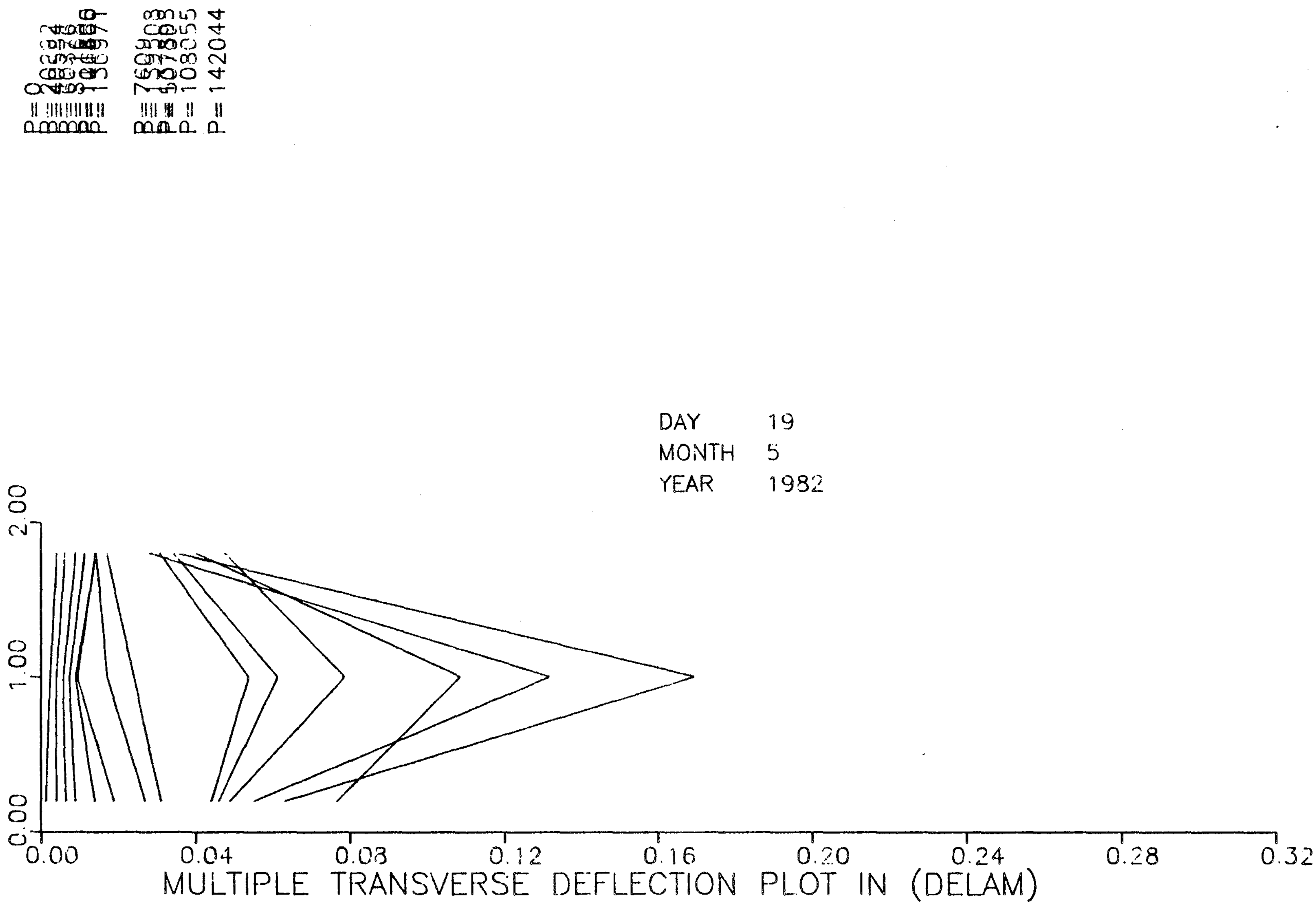
Figure D.16 Stress vs Strain Parallel to the Bed for the Shotcrete Side (W-1) First Half-Cycle



4 Figure D.17 Delamination Plot First Half-Cycle (W-1)

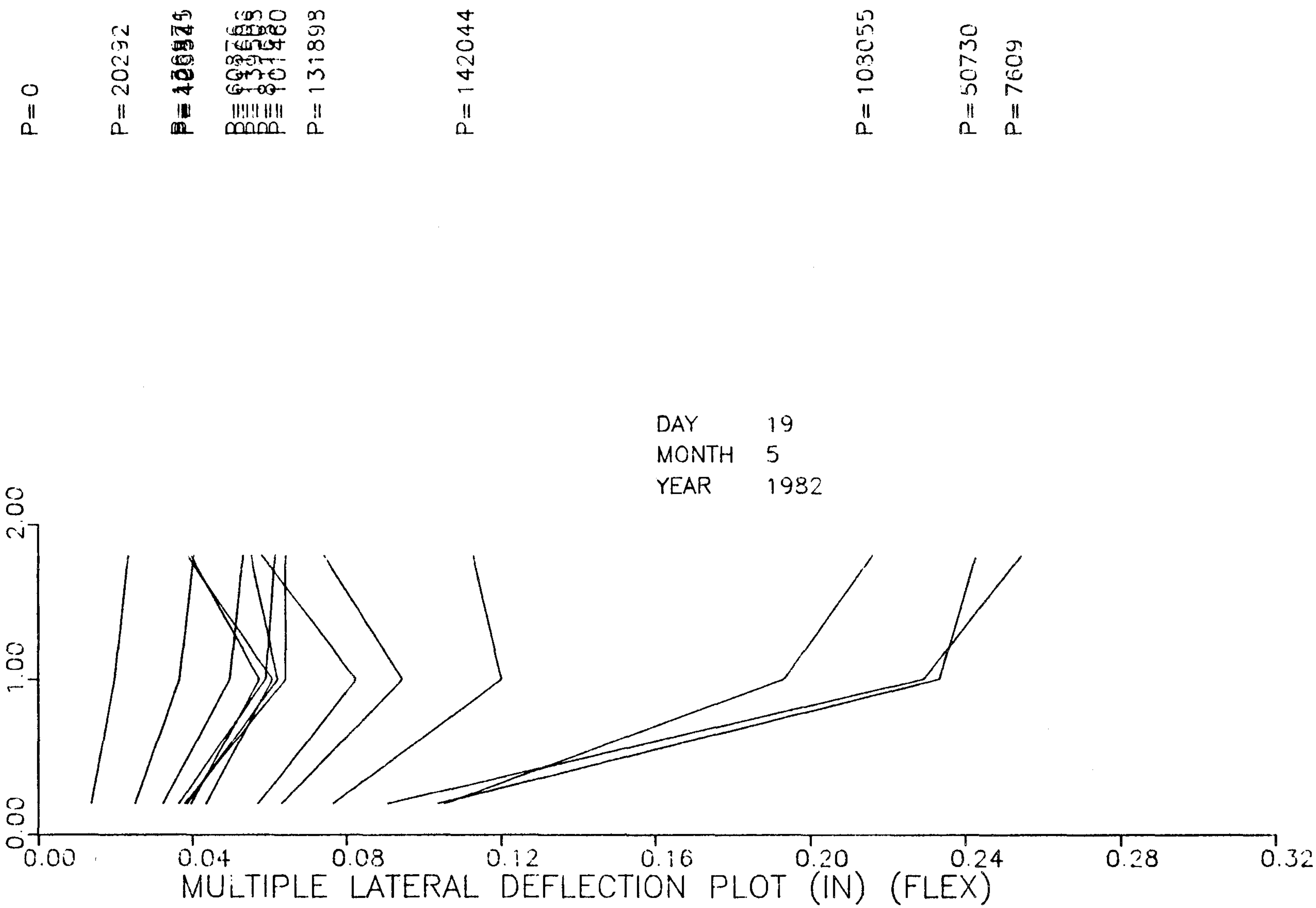


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Figure D.18 Flexure Plot First Half-Cycle (W-1)

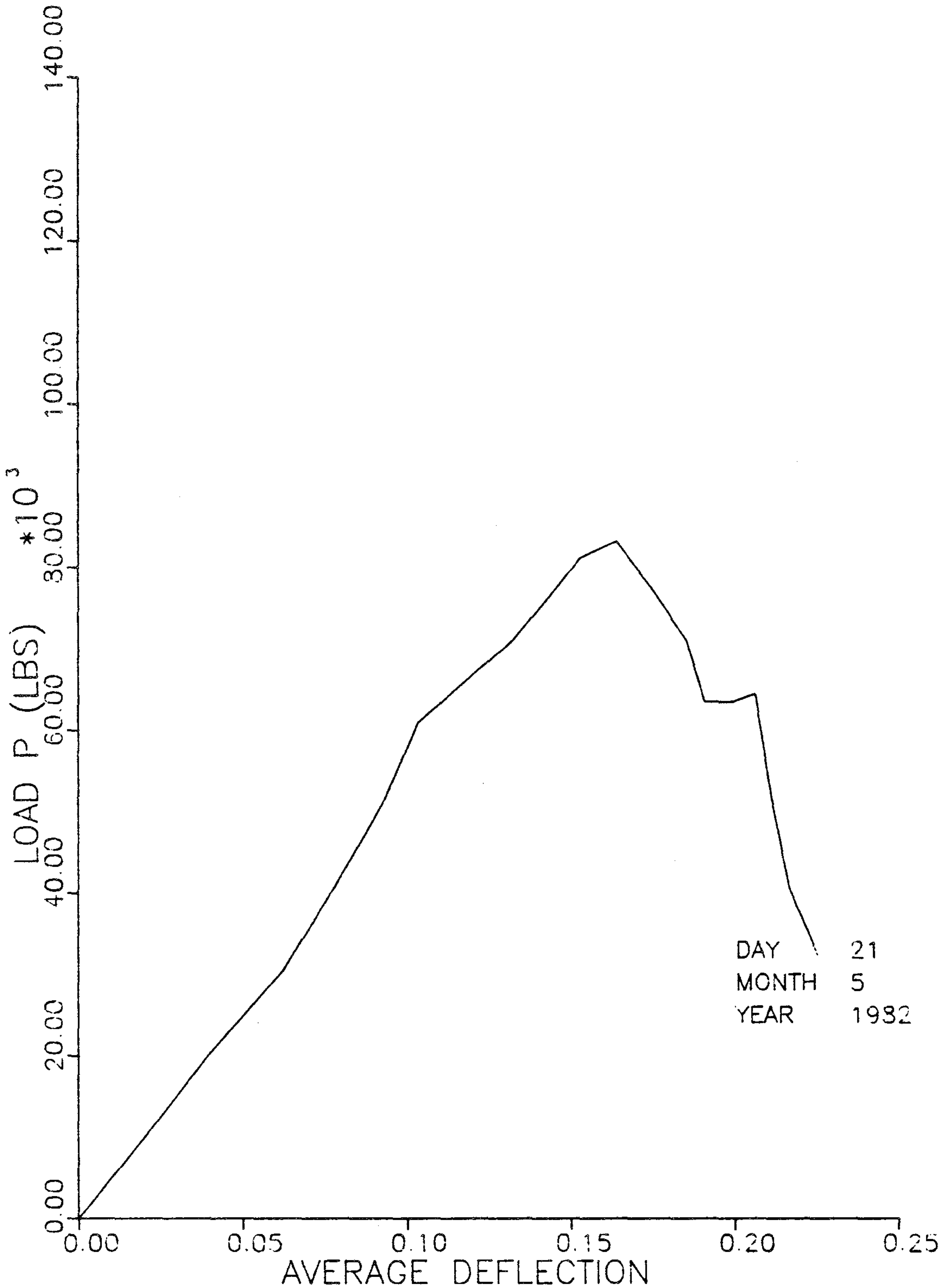

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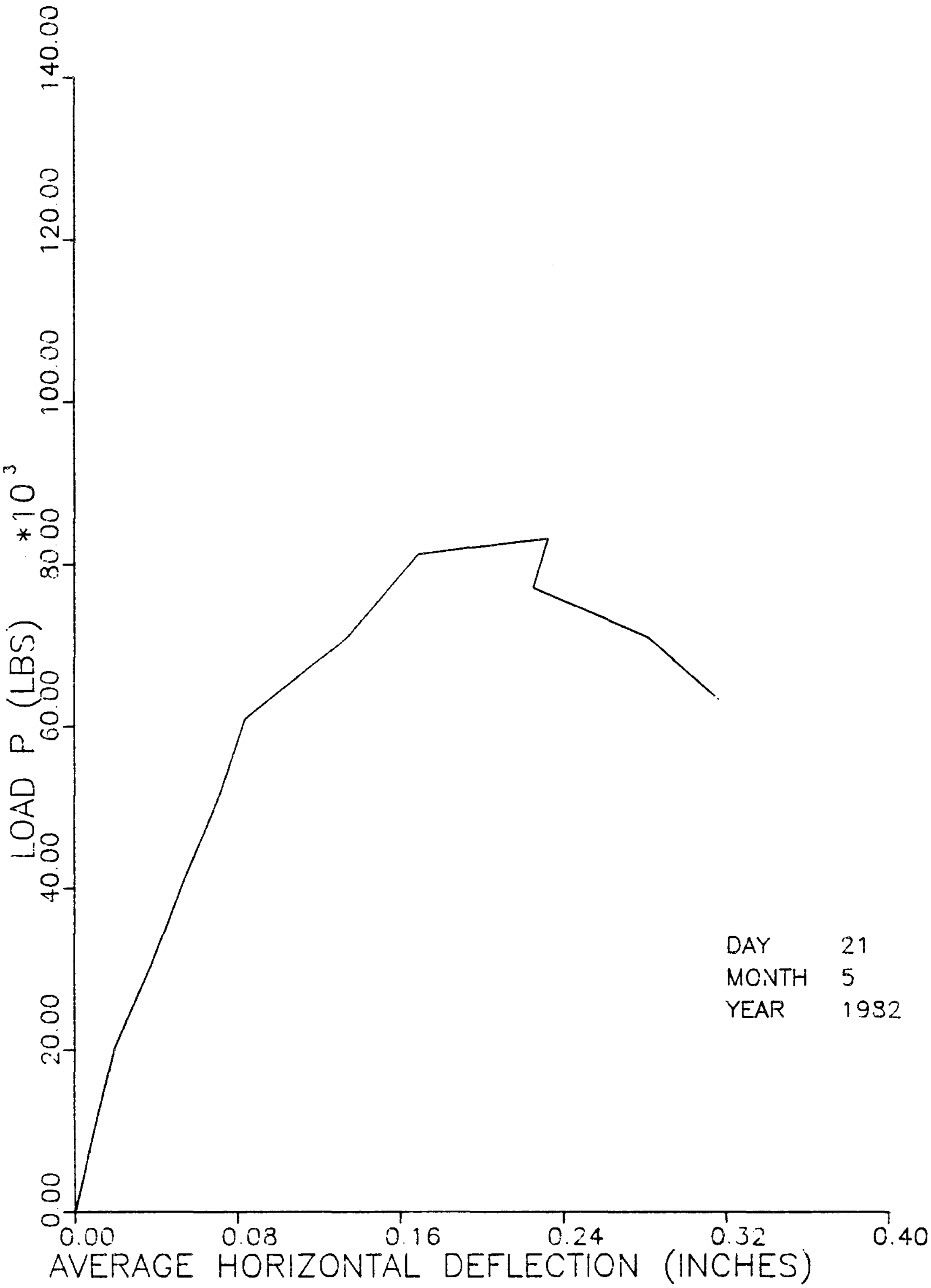
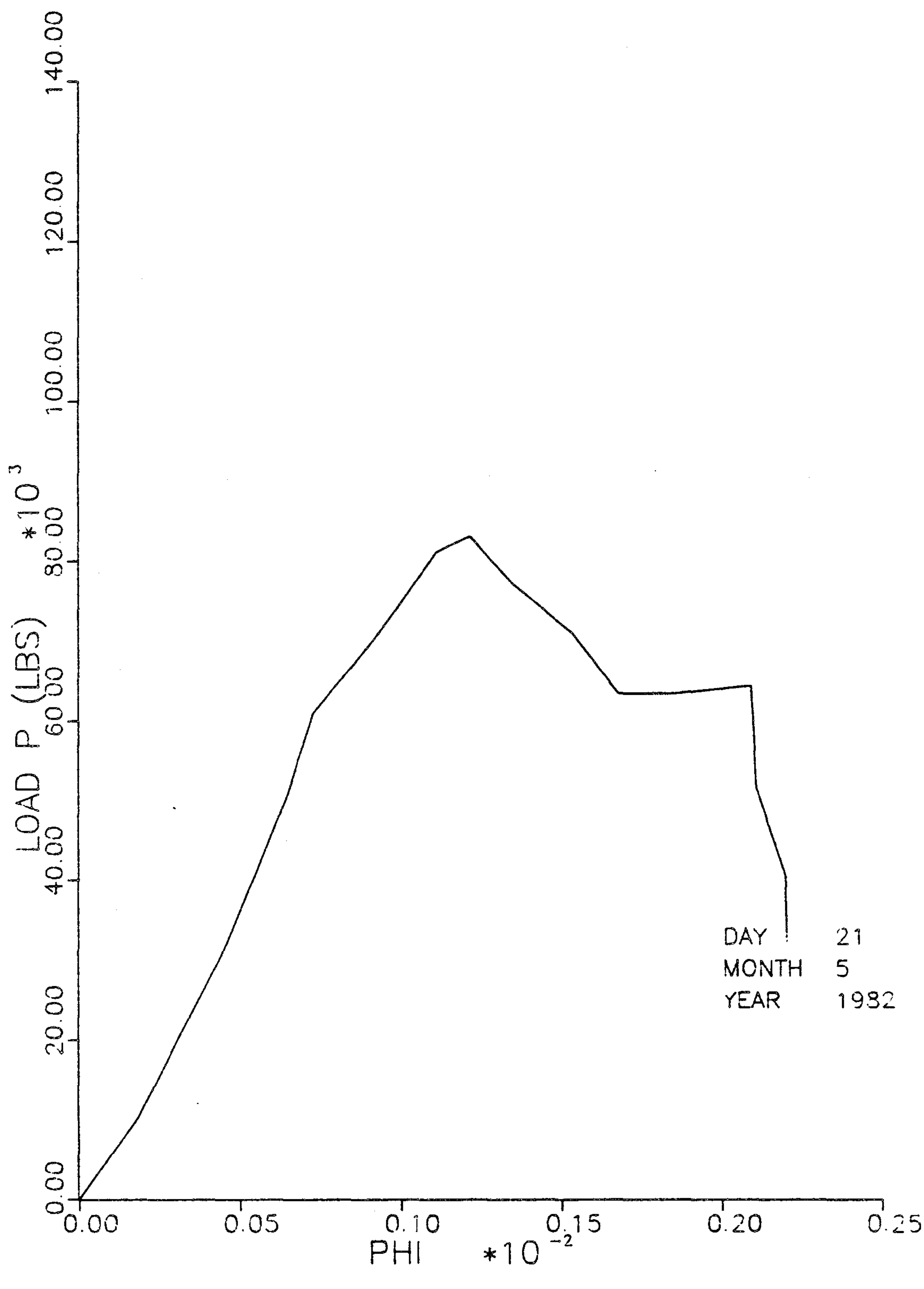
Figure D.19 Load vs Average Deflection
Second Half-Cycle (W-1)



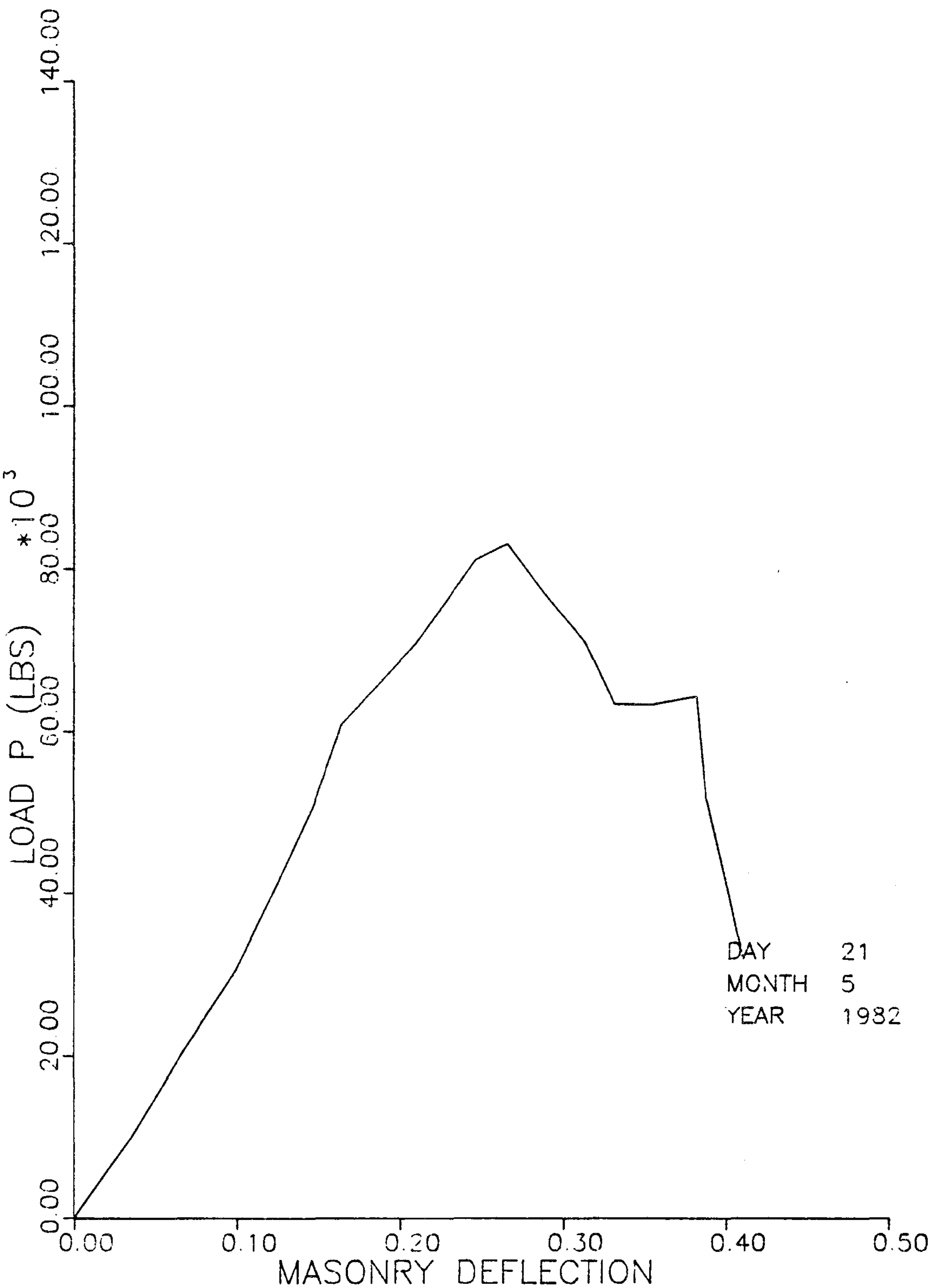
49

Figure D.20 Load vs Average Horizontal Deflection
Second Half-Cycle (W-1)



49

Figure D.21 Load vs Phi Second Half-Cycle (W-1)



49

Figure D.22 Load vs Masonry Deflection
Second Half-Cycle (W-1)

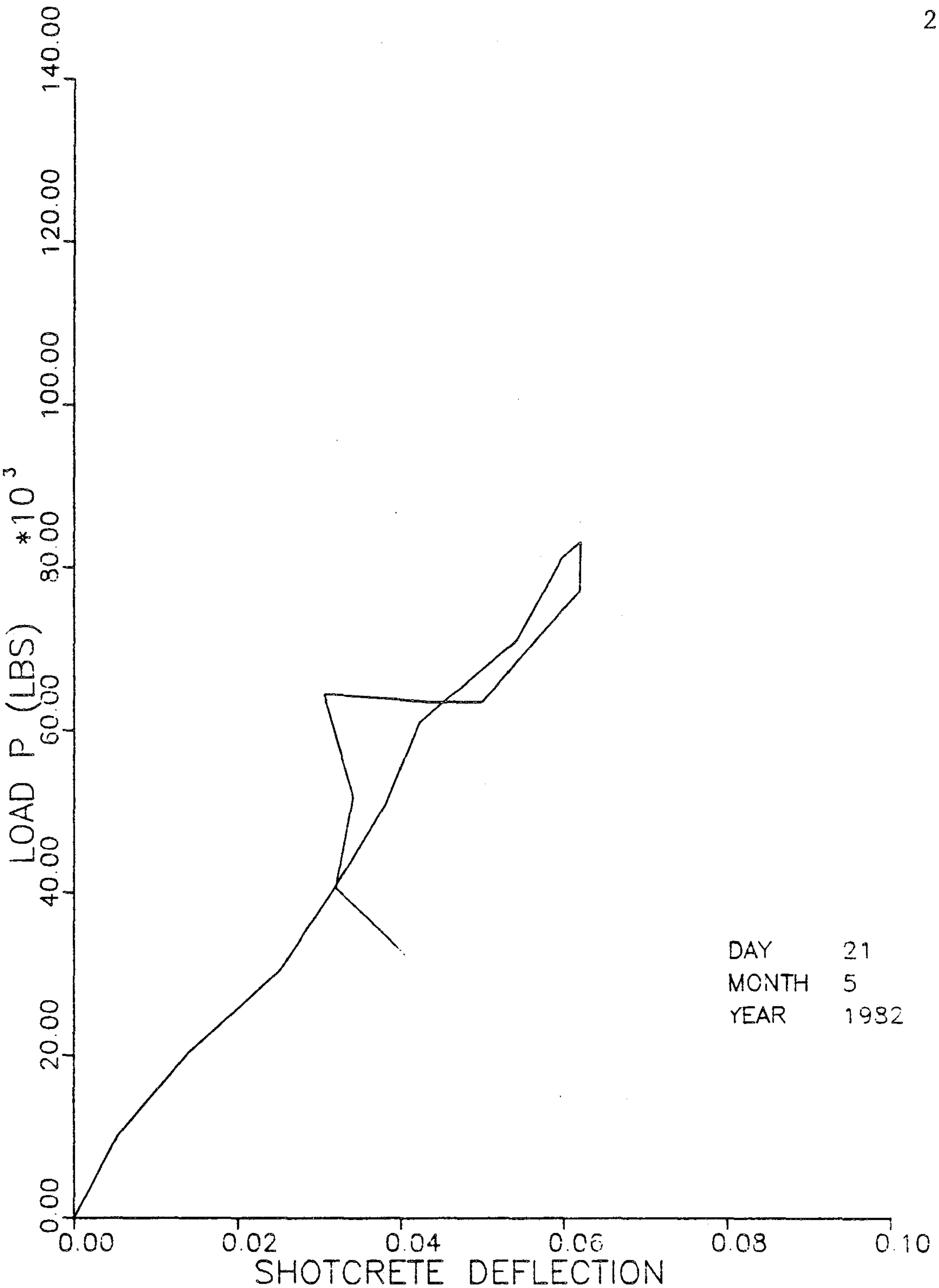


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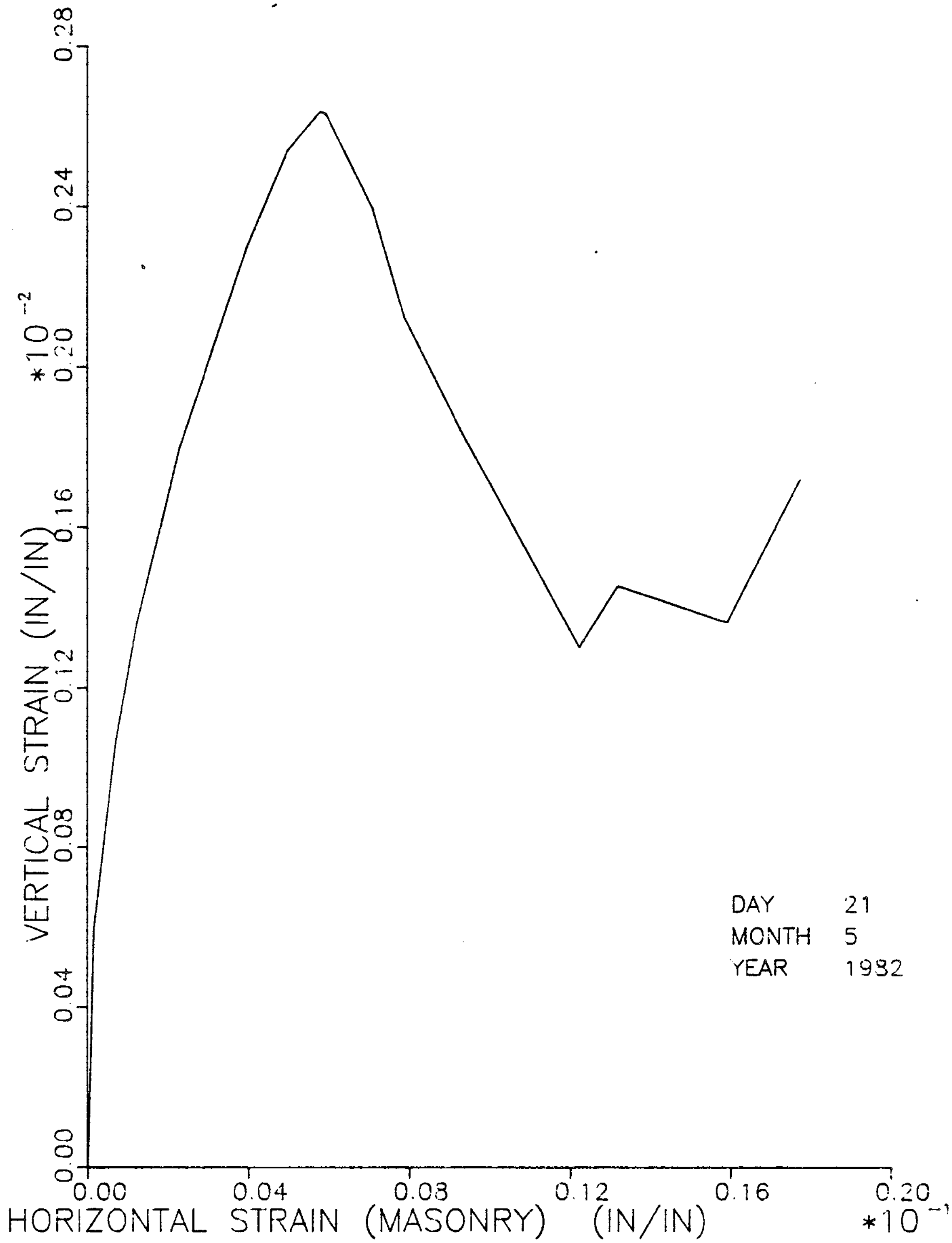
Figure D.23 Load vs Shotcrete Deflection
Second Half-Cycle (W-1)



49

Figure D.24 Vertical vs Horizontal Strain
Masonry Side Second Half-Cysle (W-1)

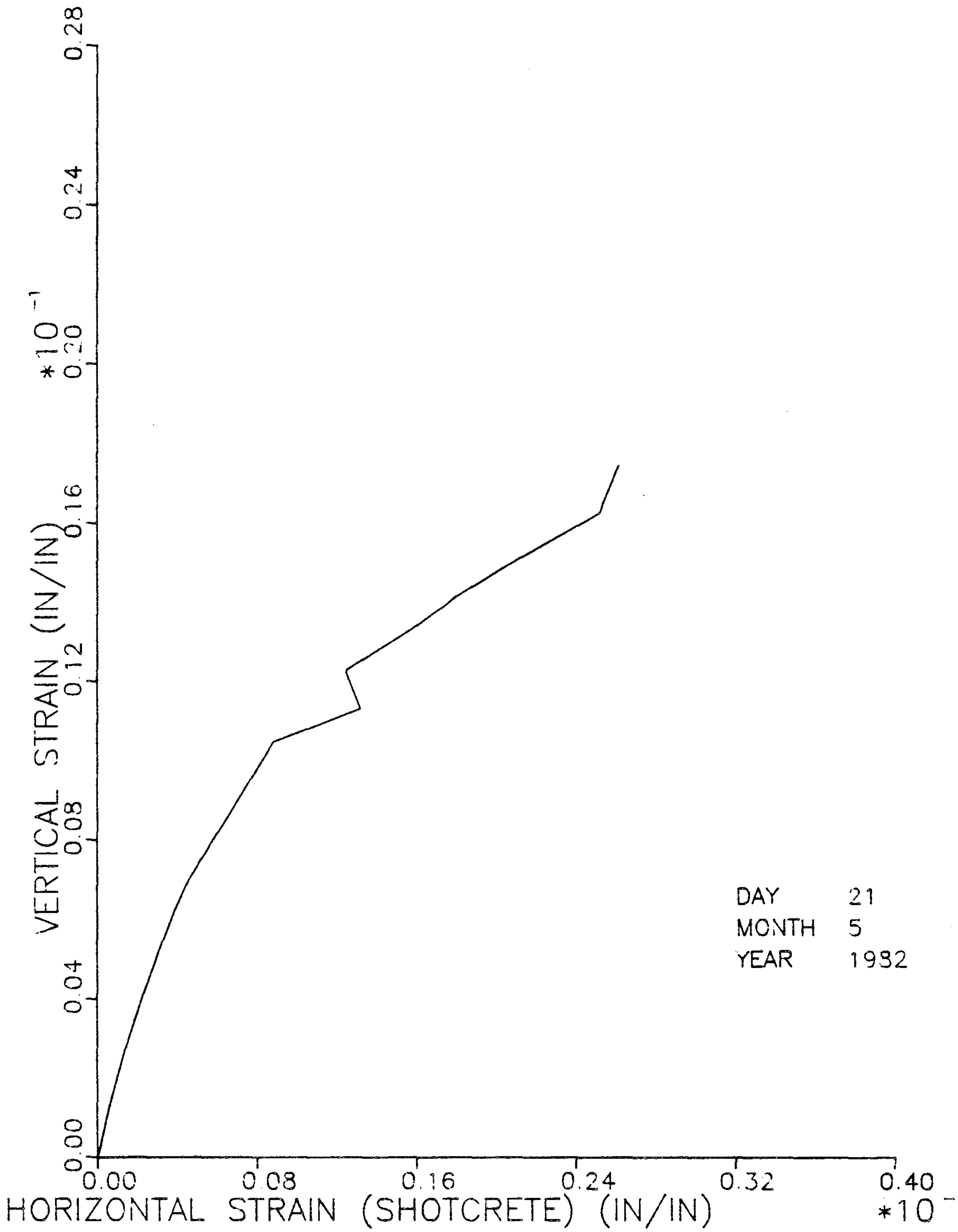


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Figure D.25 Vertical vs Horizontal Strain
Shotcrete Side Second Half-Cycle (W-1)

132

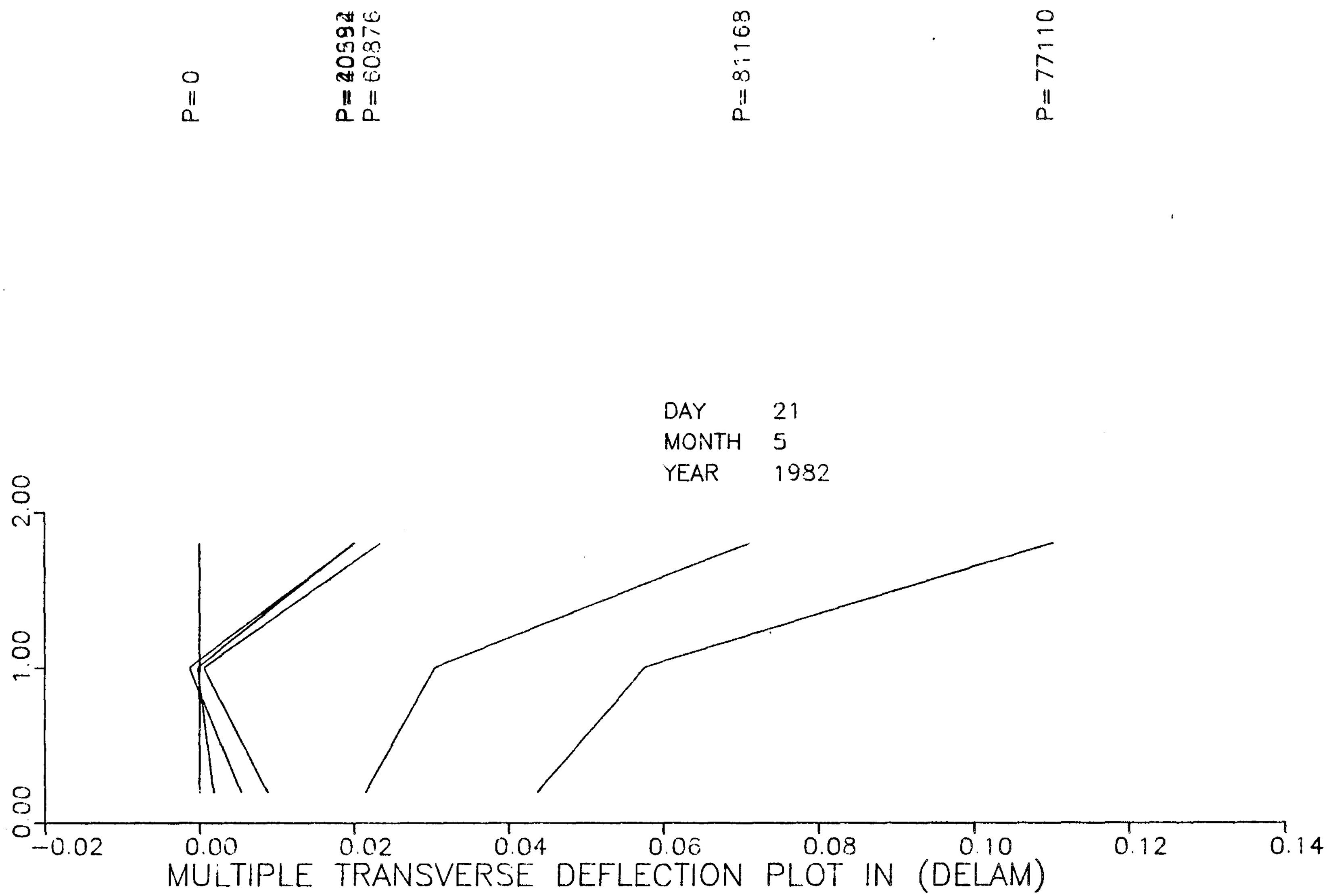

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Figure D.26 Delamation Plot Second Half-Cycle (W-1)

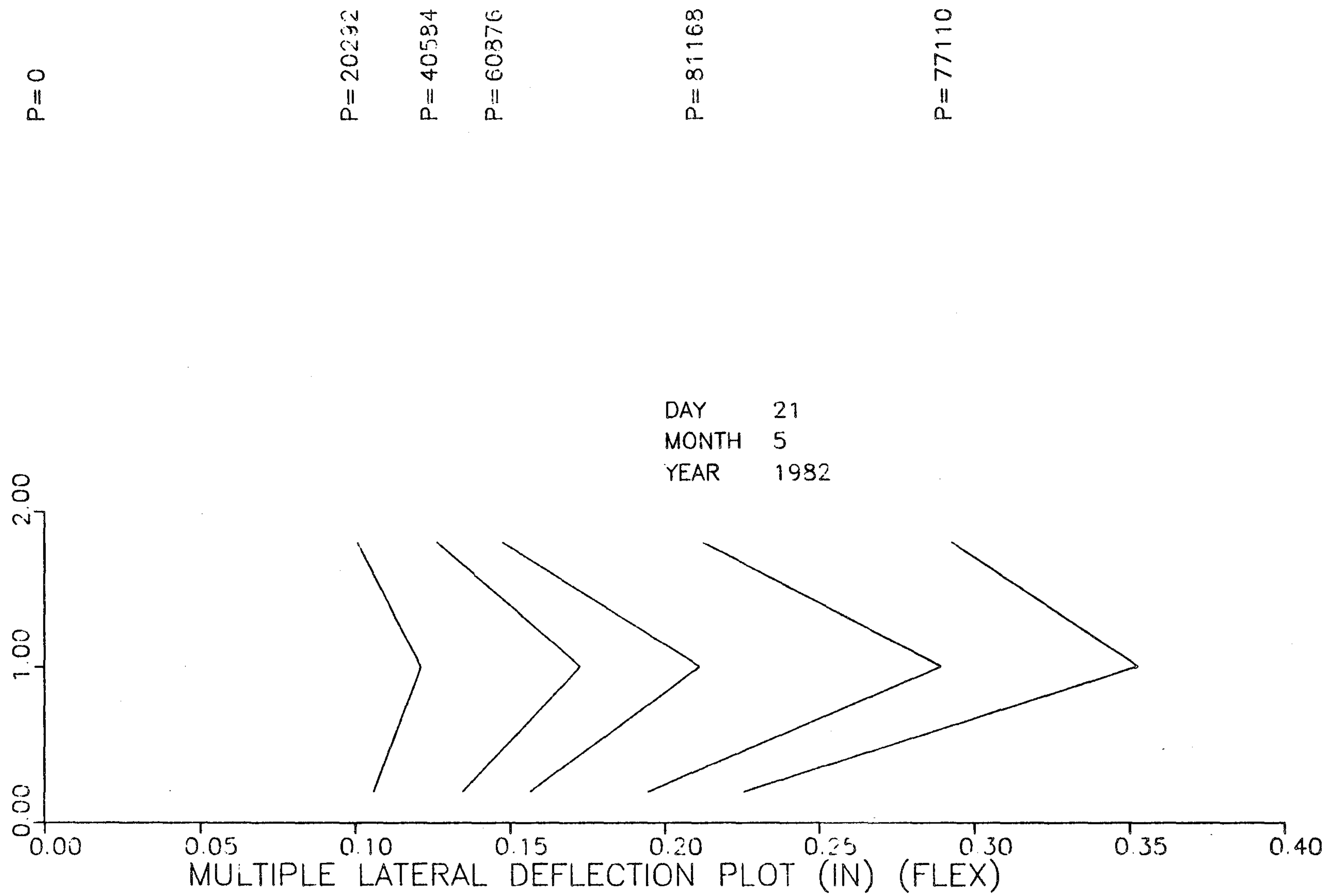

Figure D.27 Flexure Plot Second Half-Cycle (W-1)

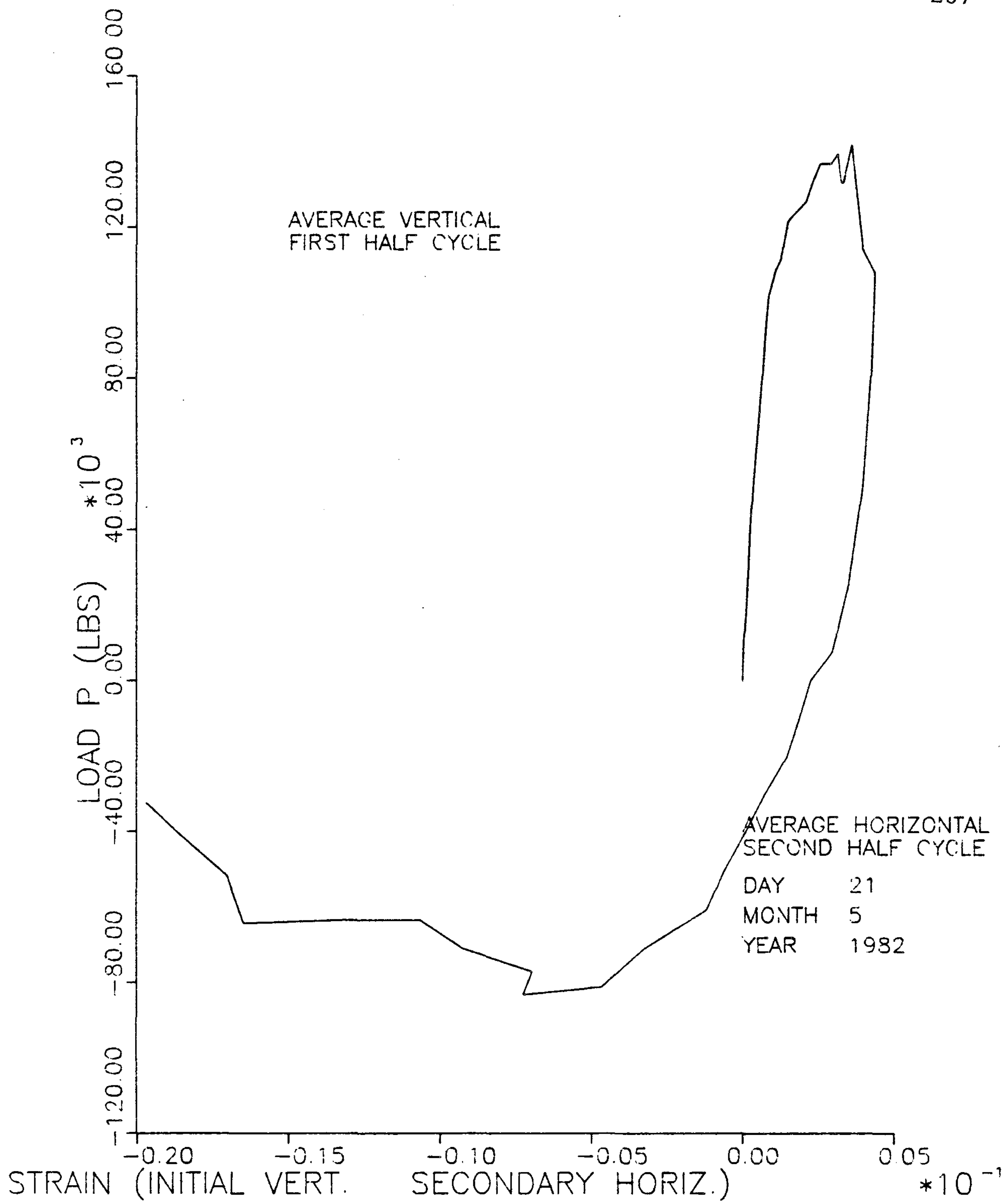

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Figure D.28 Hysteresis Plot (W-1)

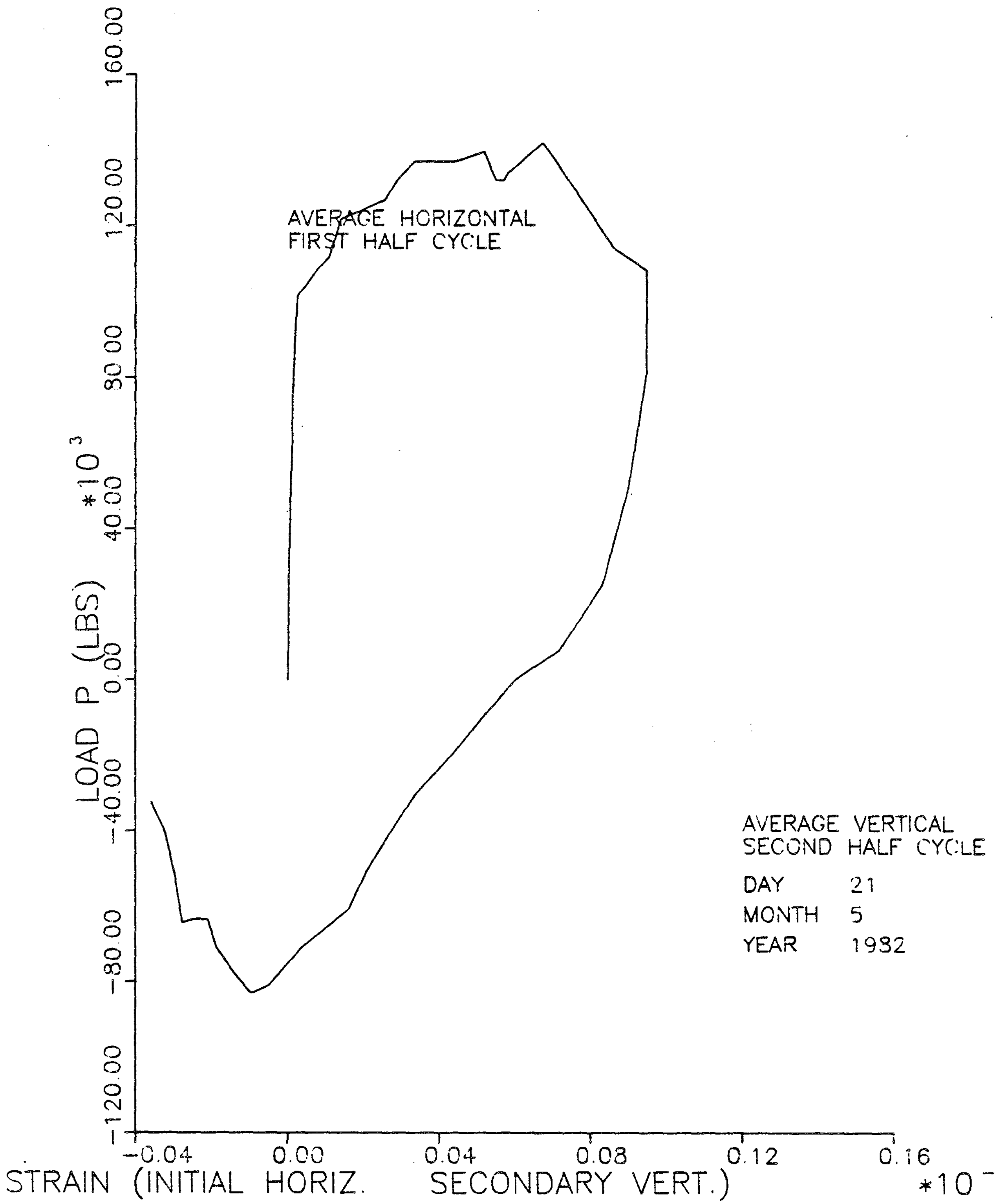

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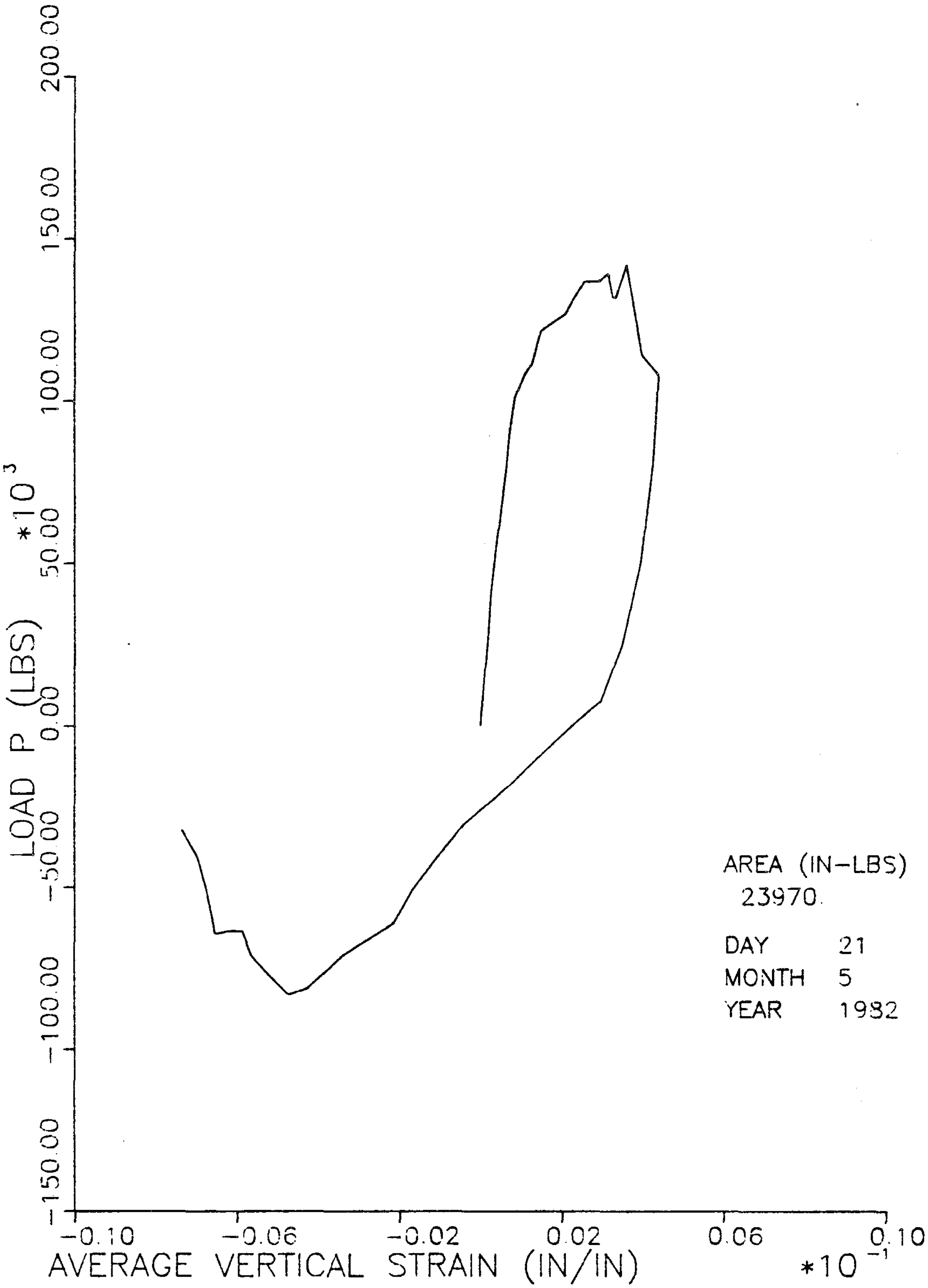
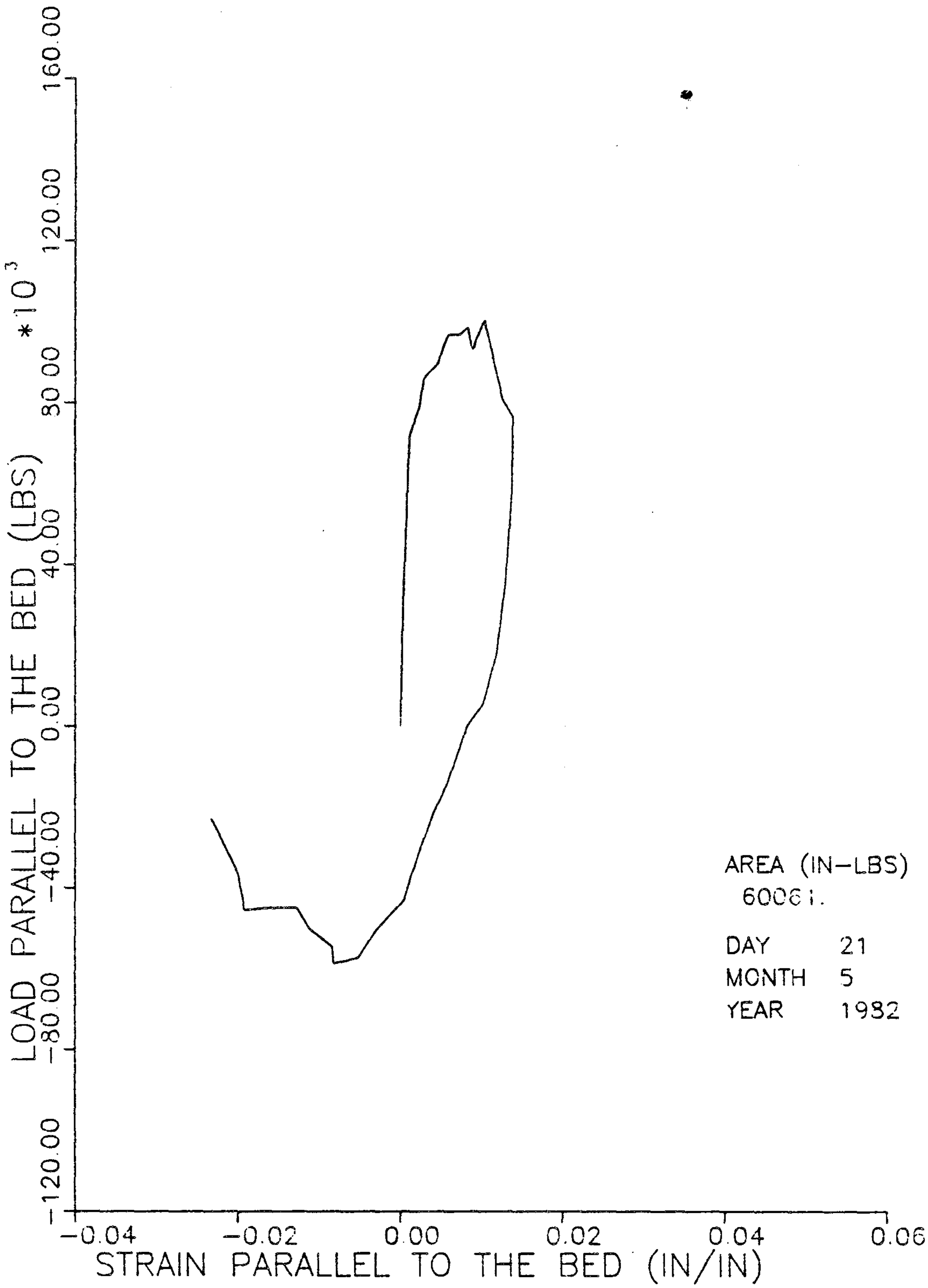
Figure D.29 Hysteresis Plot (W-1)



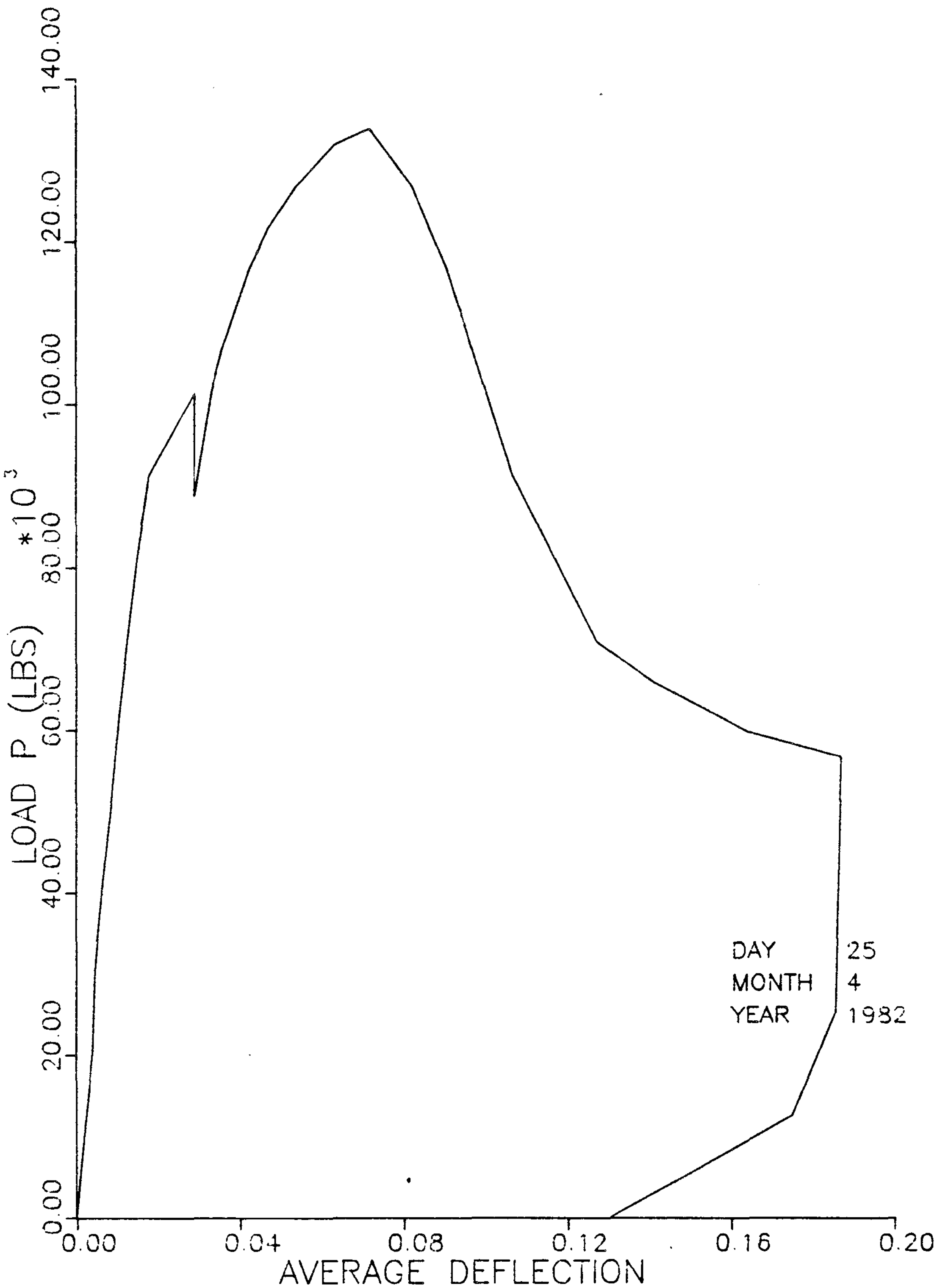
49

Figure D.30 Vertical Hysteresis Plot (W-1)



49

Figure D.31 Parallel to the Bed Hysteresis Plot (W-1)



8

Figure D.32 Load vs Average Deflection First Half-Cycle (E-2)

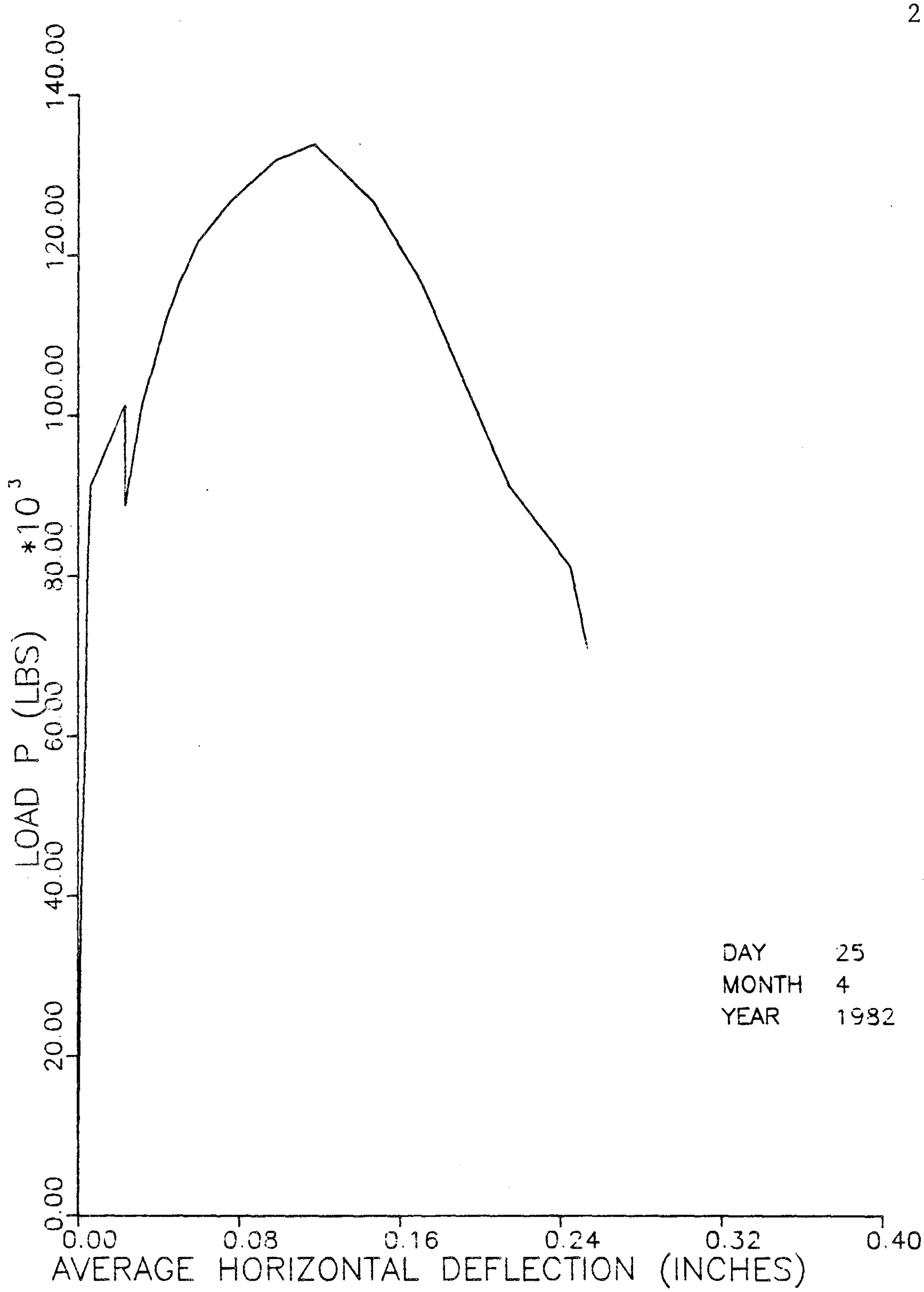


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Figure D.33 Load vs Average Horizontal Deflection
First Half-Cycle . (E-2)

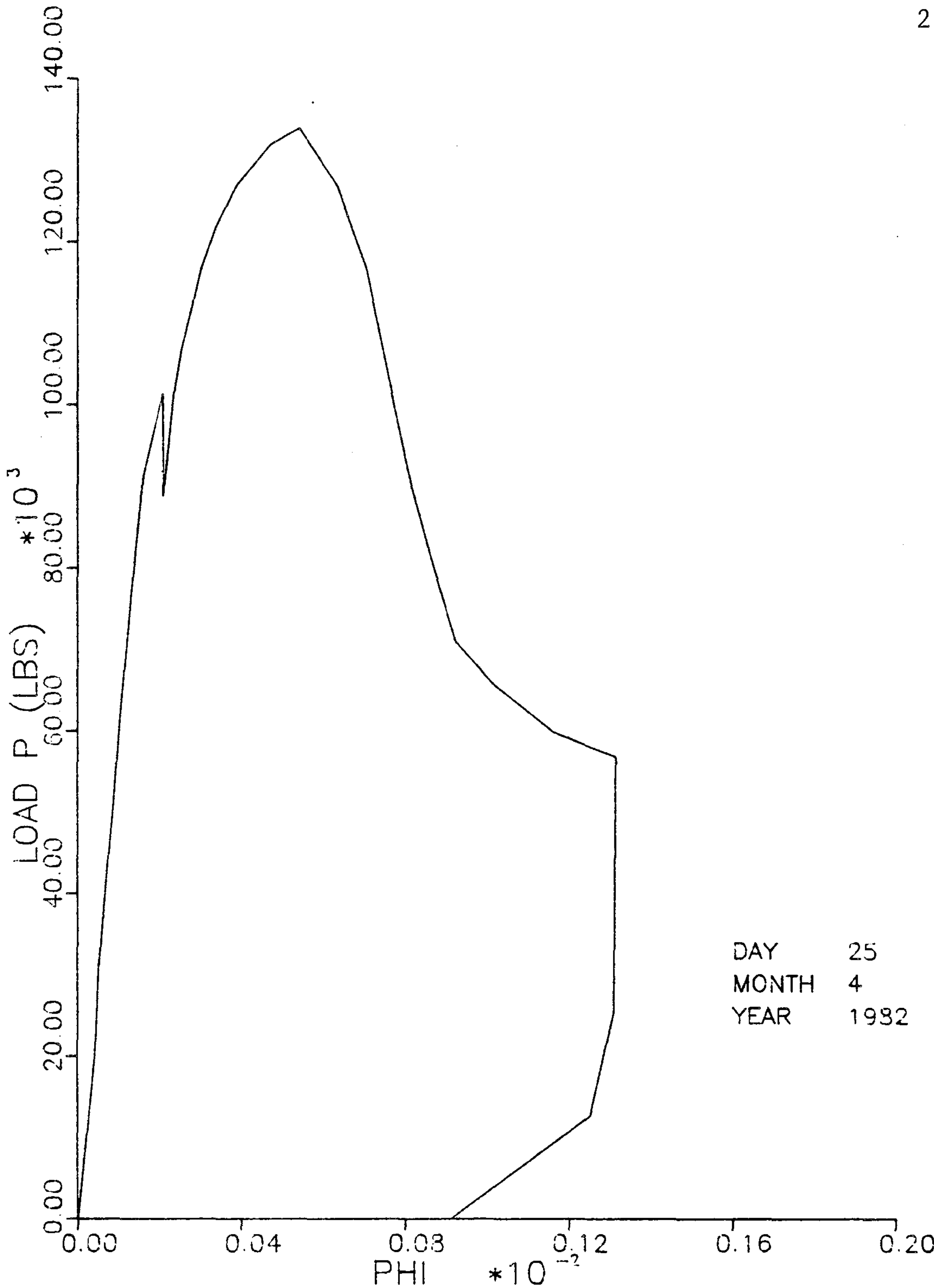

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Figure D.34 Load vs Phi First Half-Cycle (E-2)

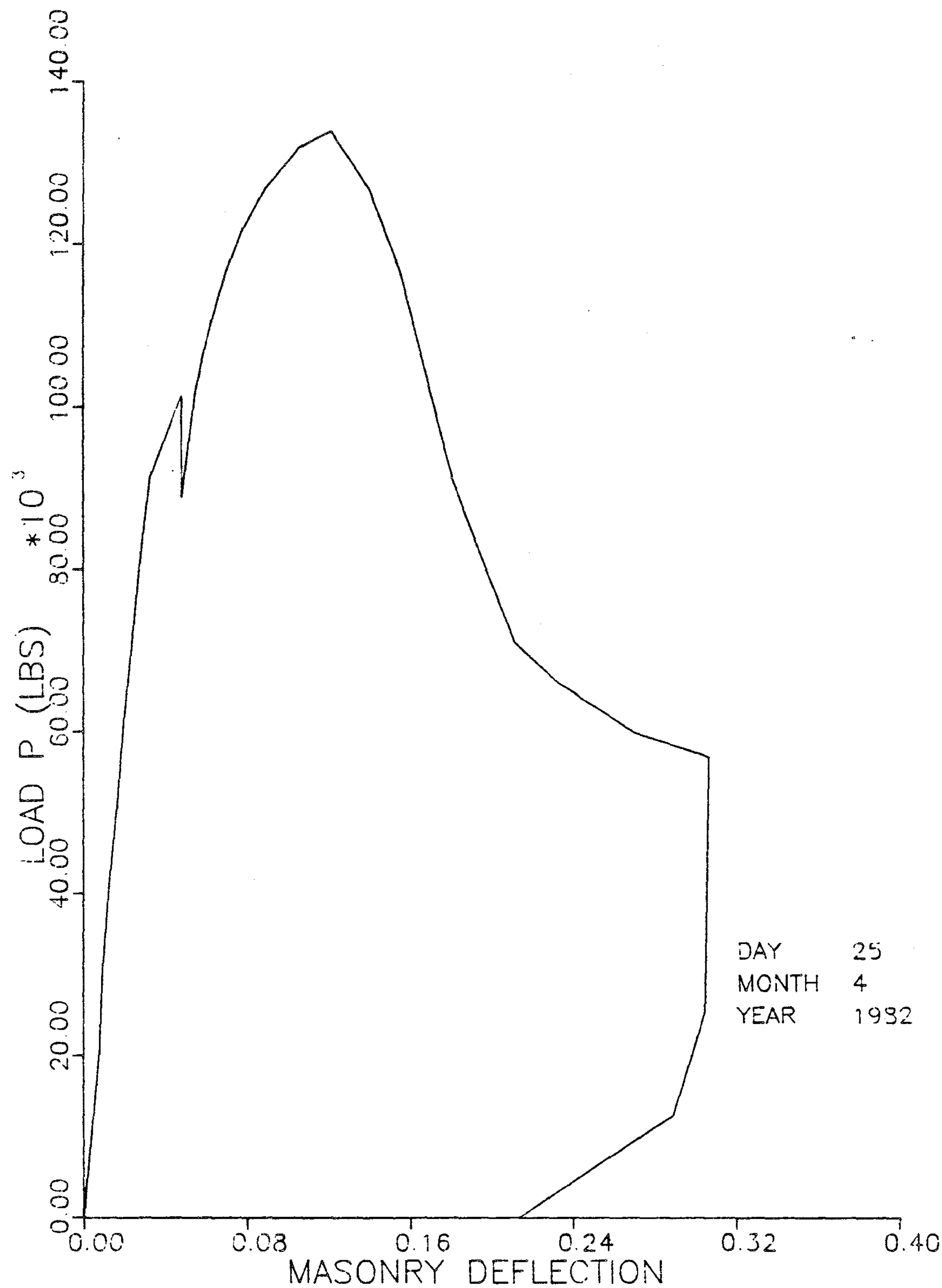

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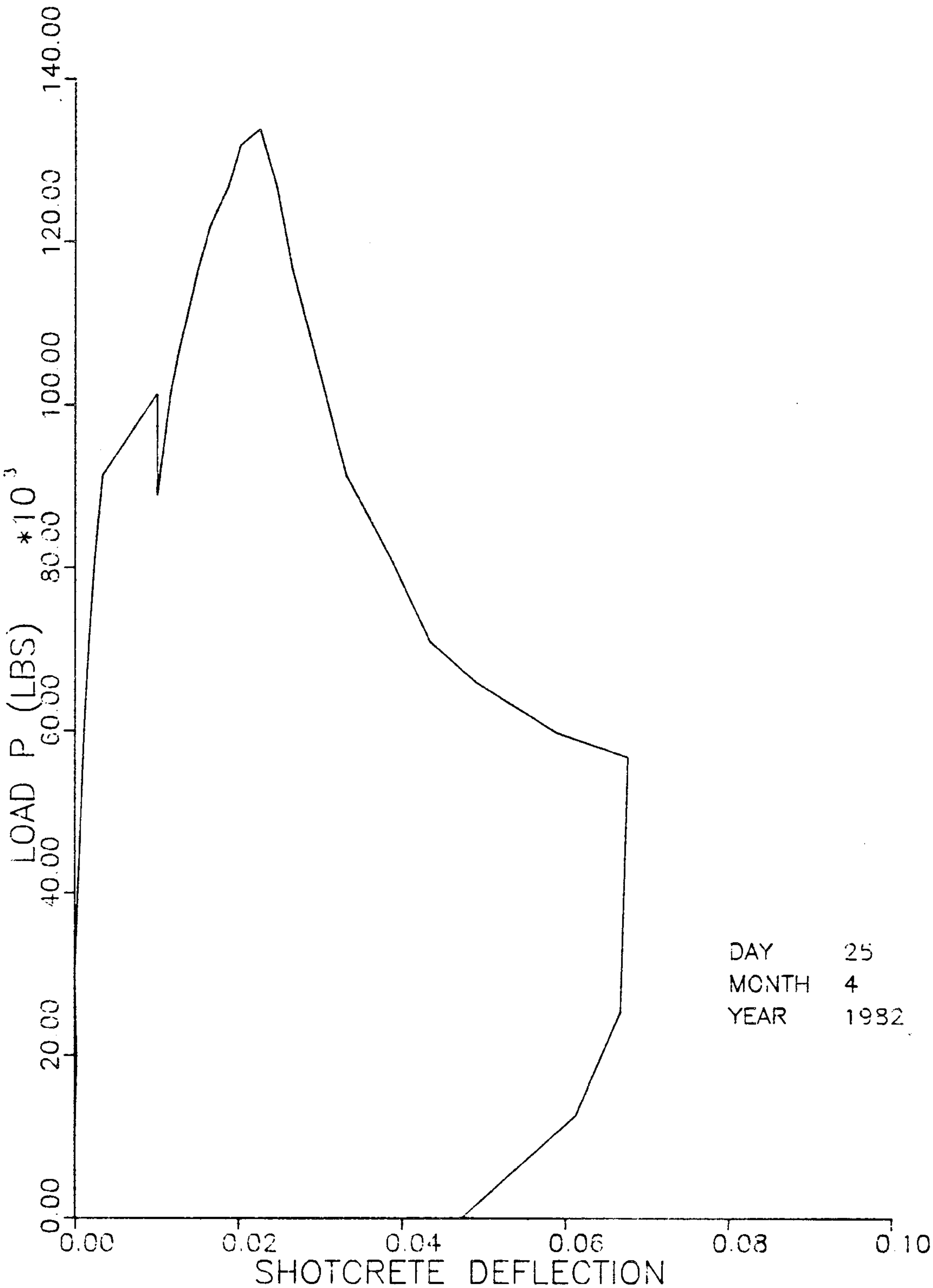
Figure D.35 Load vs Masonry Deflection First Half-Cycle (E-2)



8 Figure D.36 Load vs Shotcrete Deflection First Half-Cycle (E-2)

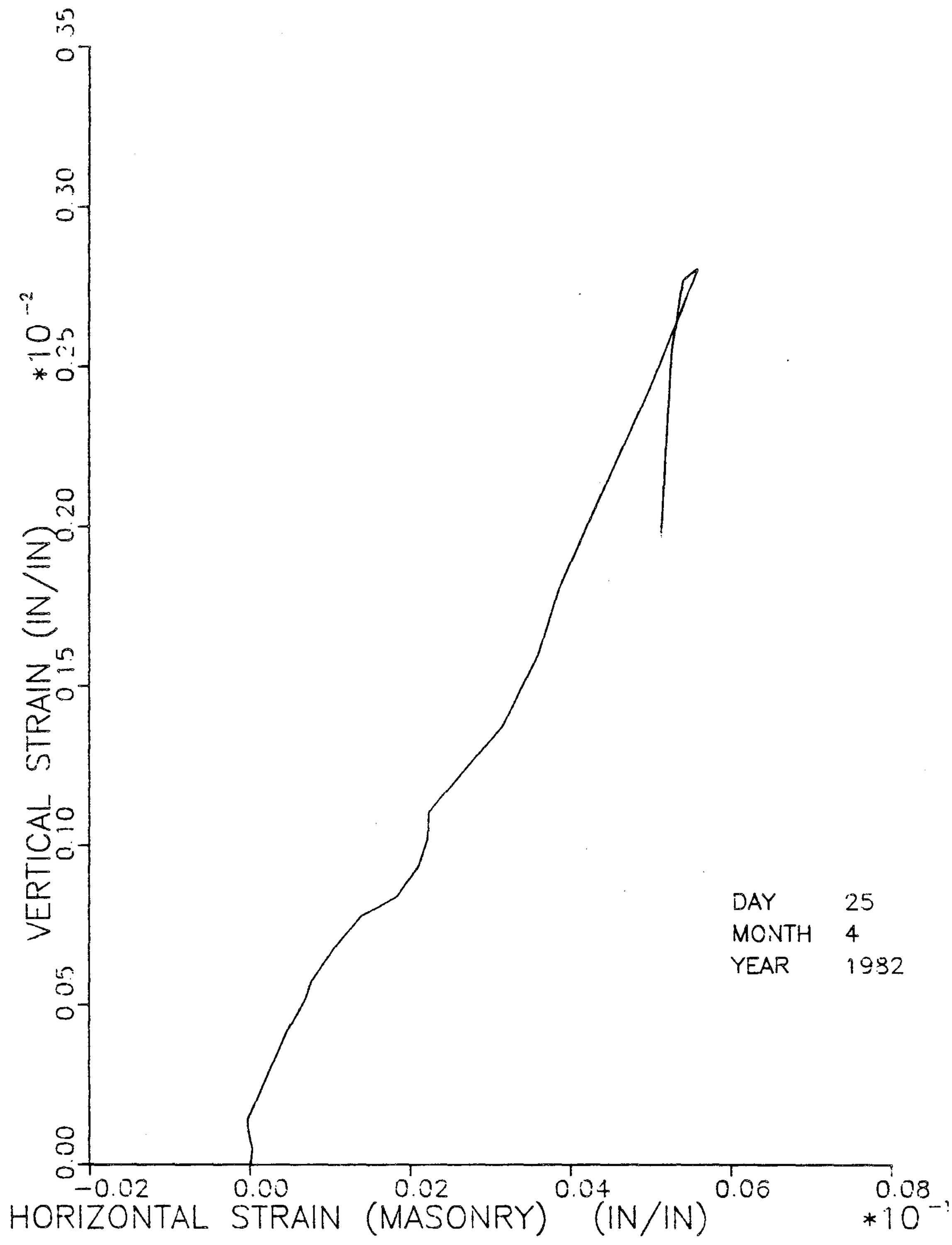


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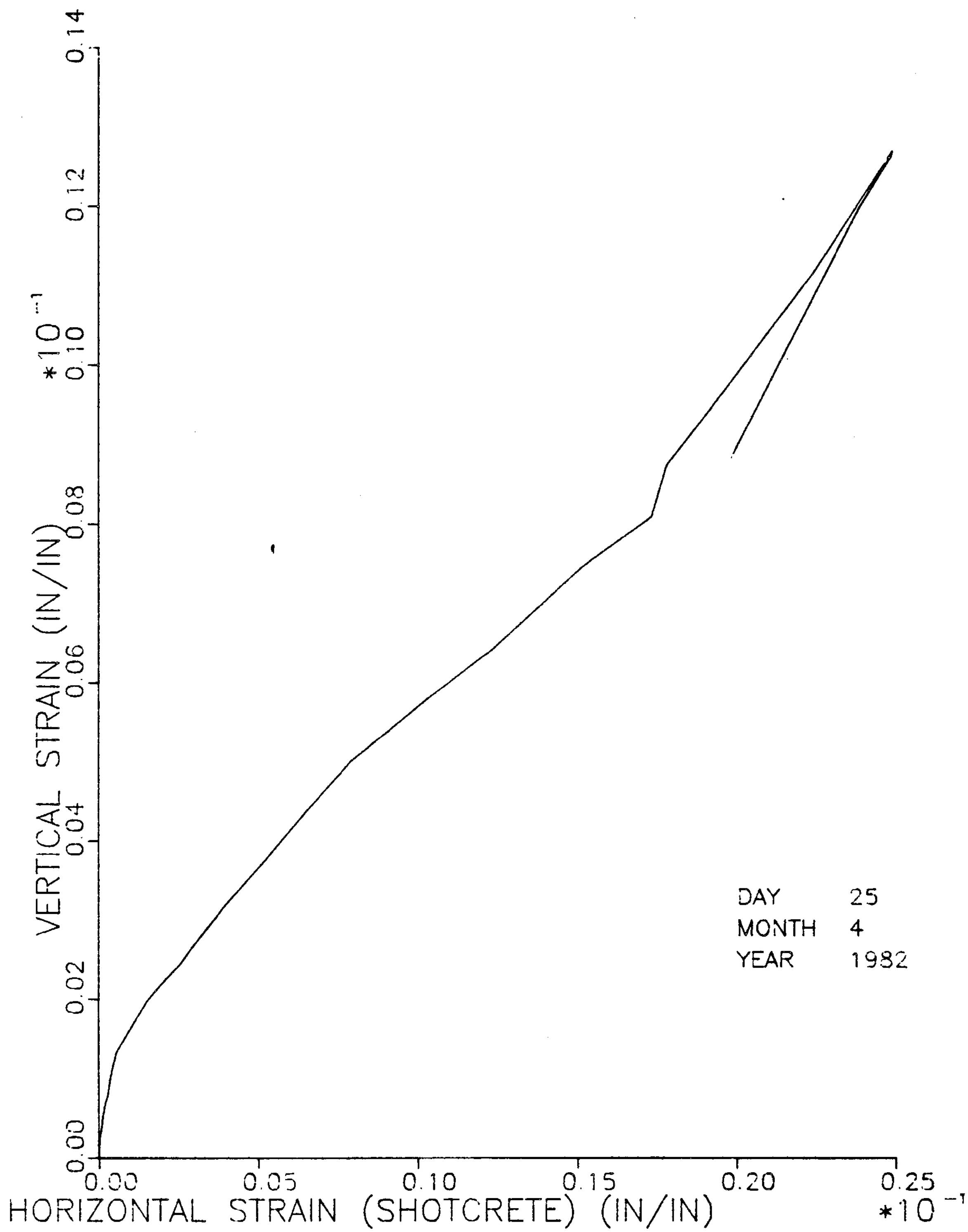
Figure D.37 Vertical vs Horizontal Strain Masonry Side First Half-Cycle (E-2)

144



8 Figure D.38 Vertical vs Horizontal Strain Shotcrete Side First Half-Cycle (E-2)

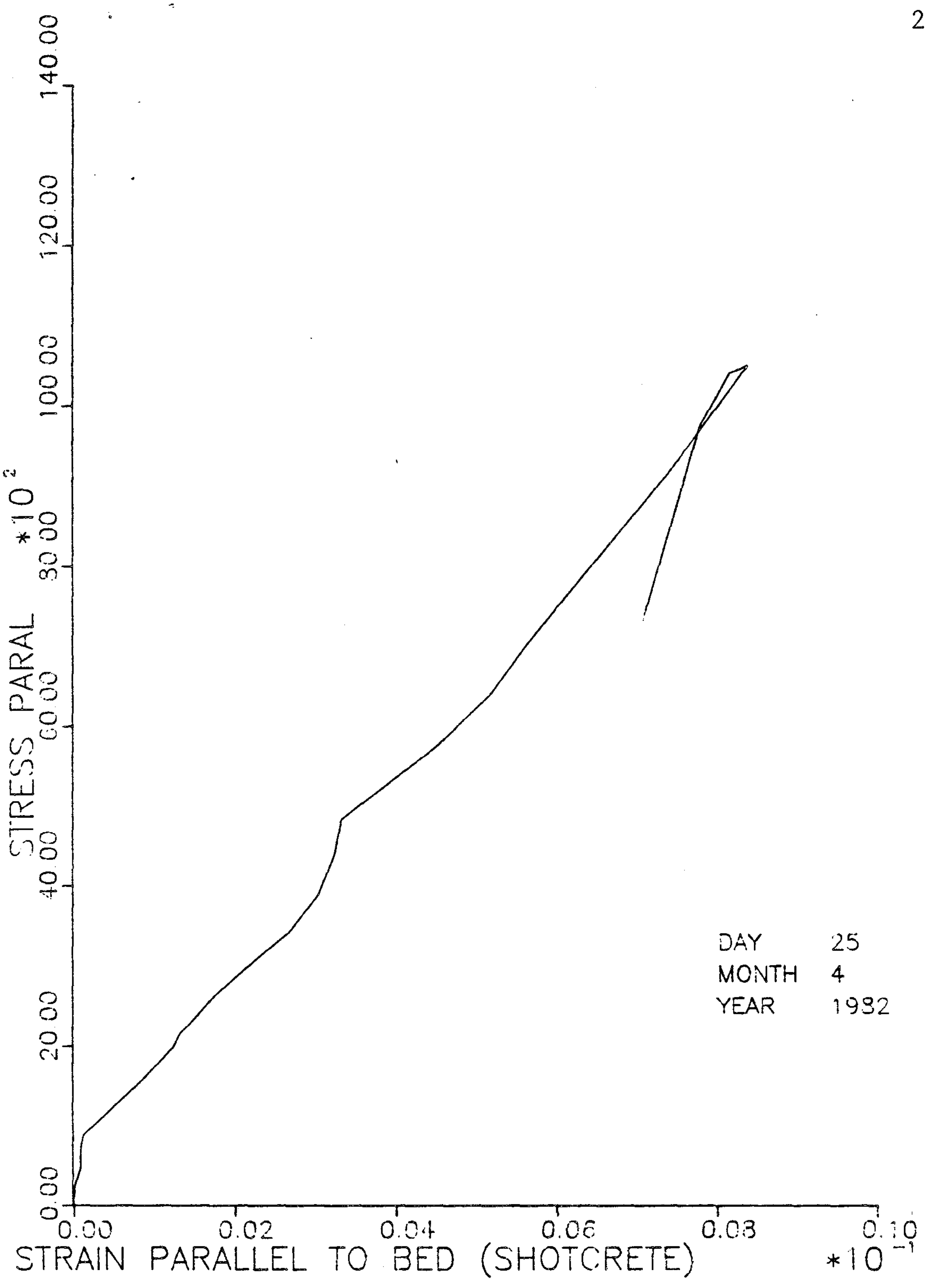
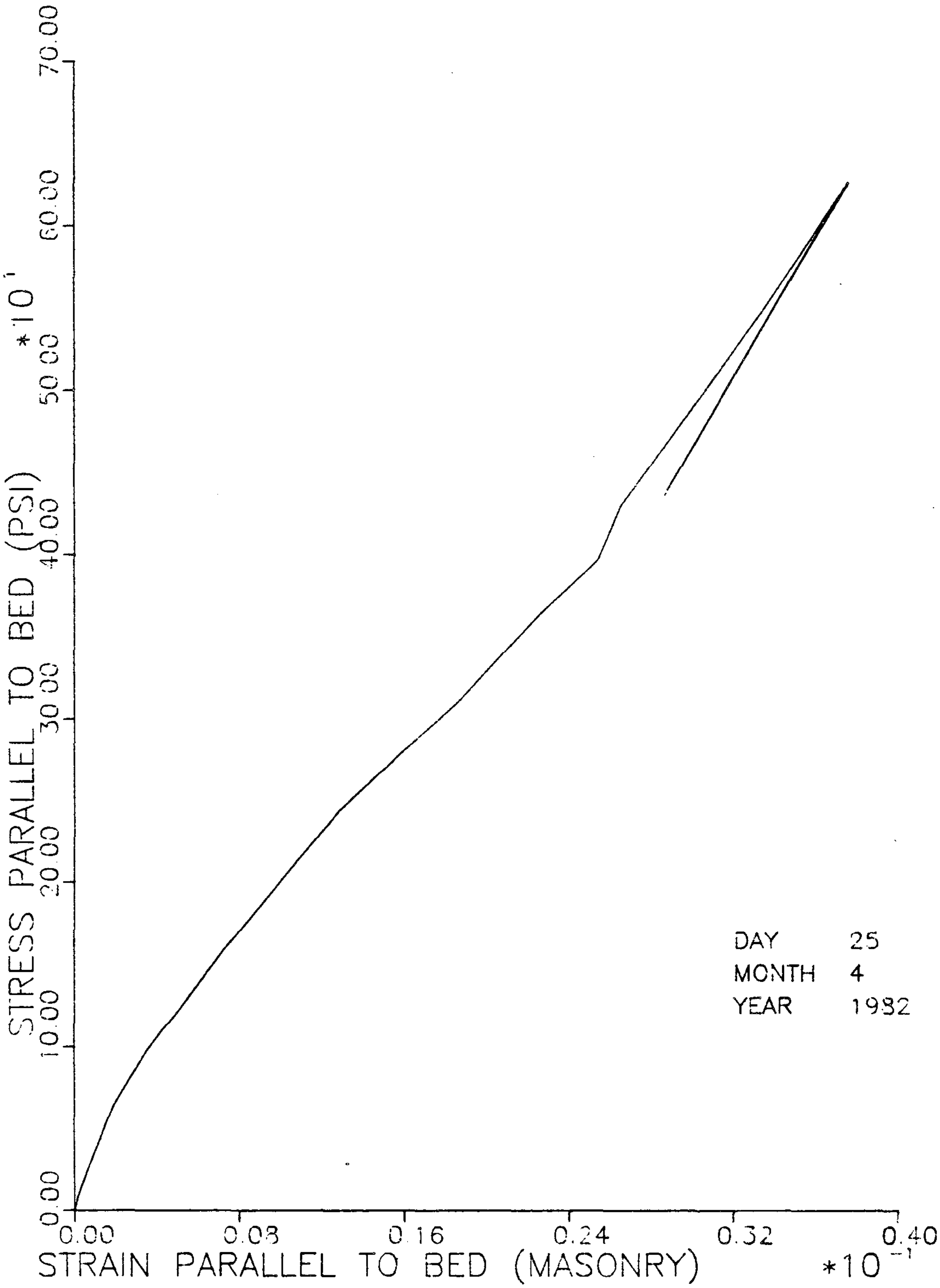


Figure D.39 Stress vs Strain Parallel to the Bed Shotcrete Side First Half-Cycle (E-2)



8 Figure D.40 Stress vs STrain Parallel to the Bed Masonry Side First Half-Cycle (E-2)

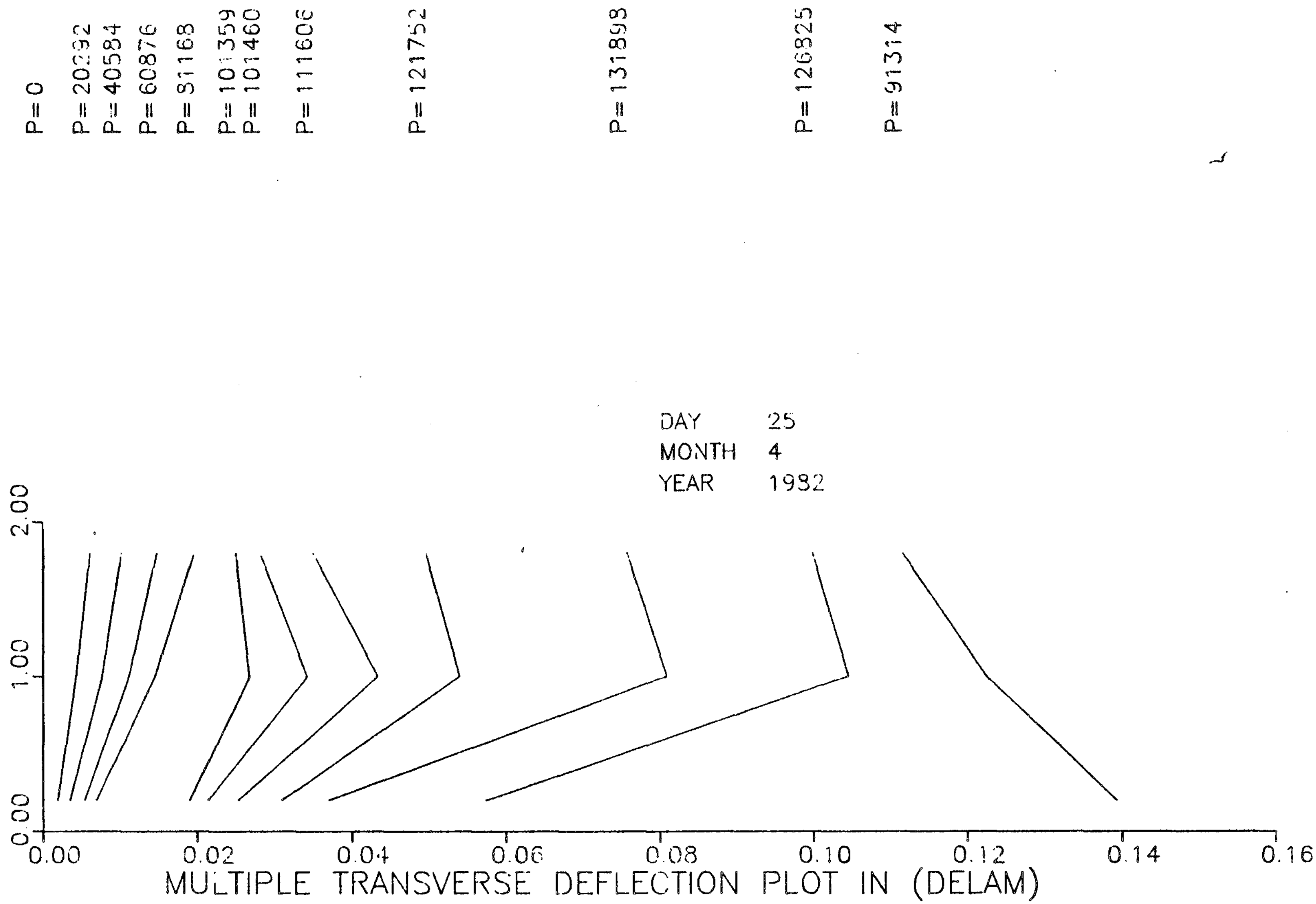


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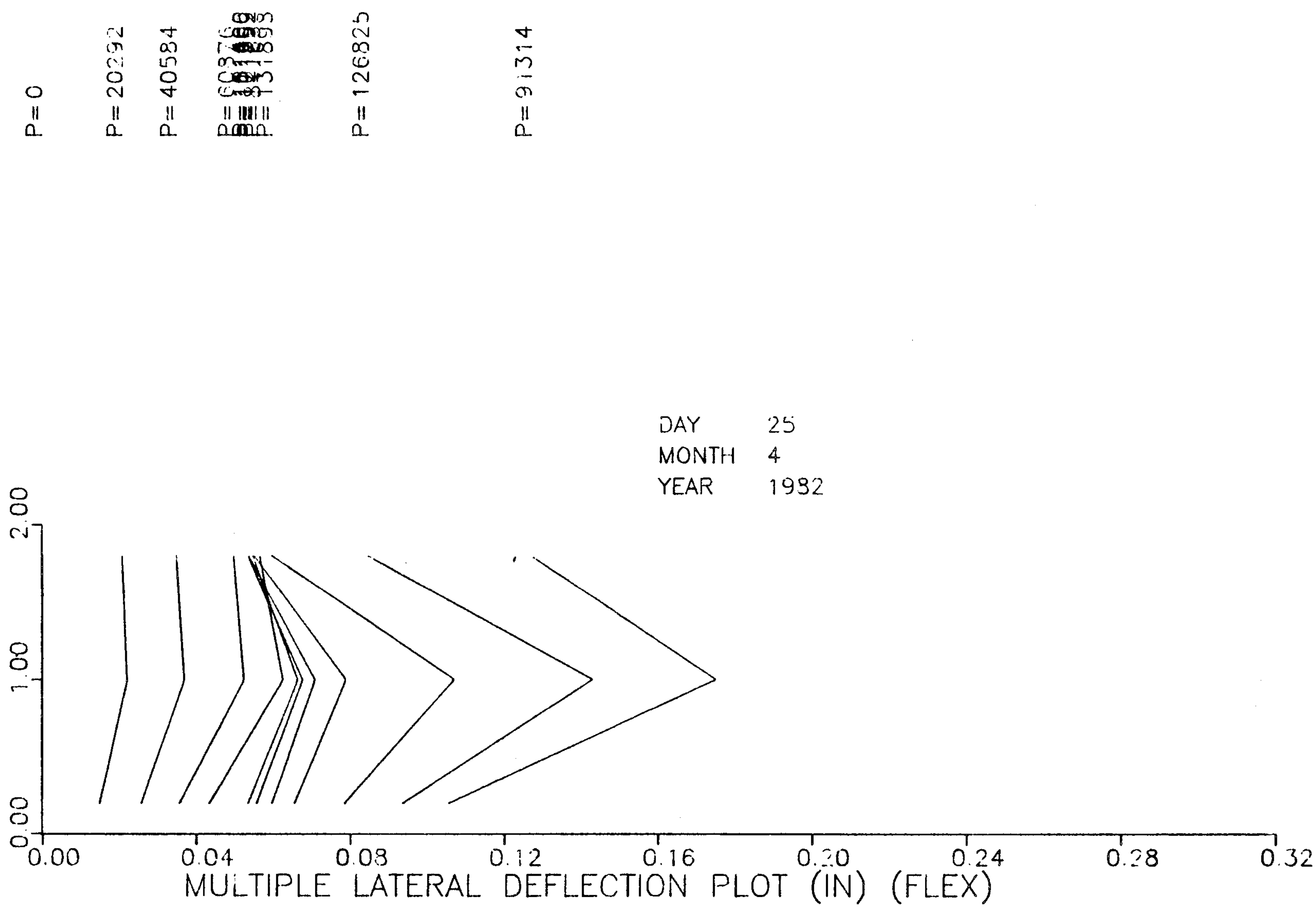
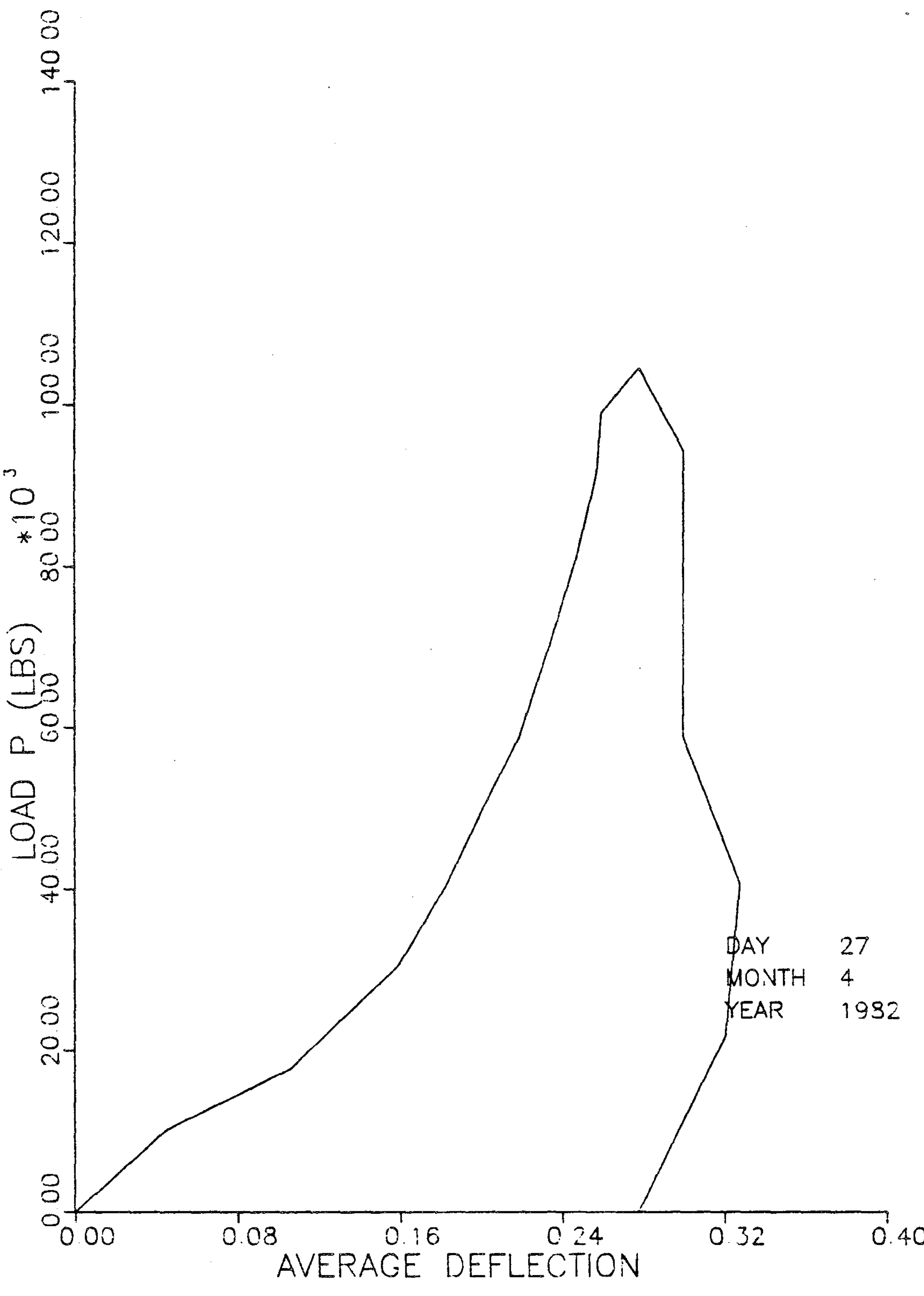
Figure D.41 Delamination Plot First Half-Cycle (E-2)

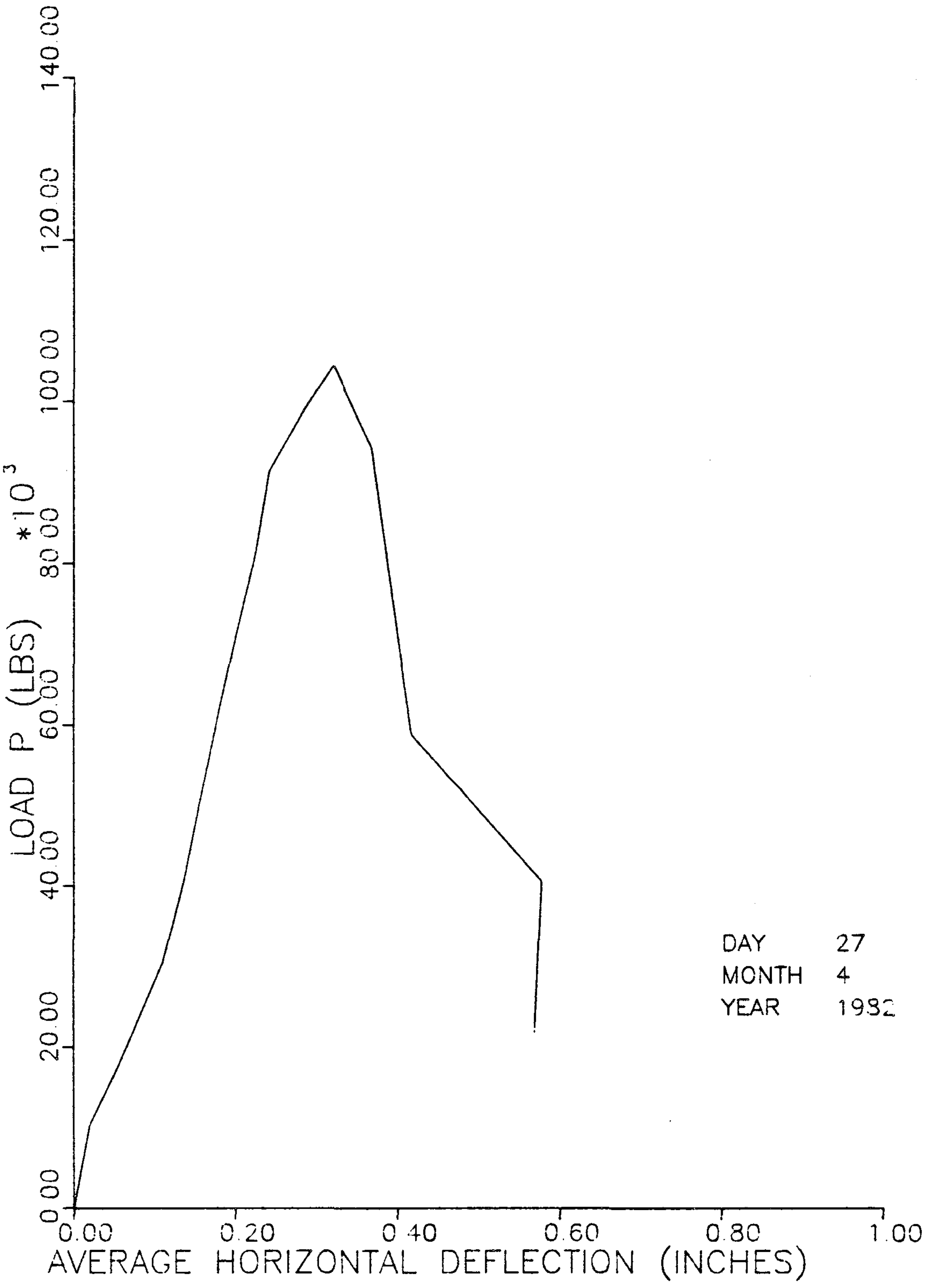


8 Figure D.42 Flexure Plot First Half-Cycle (E-2)

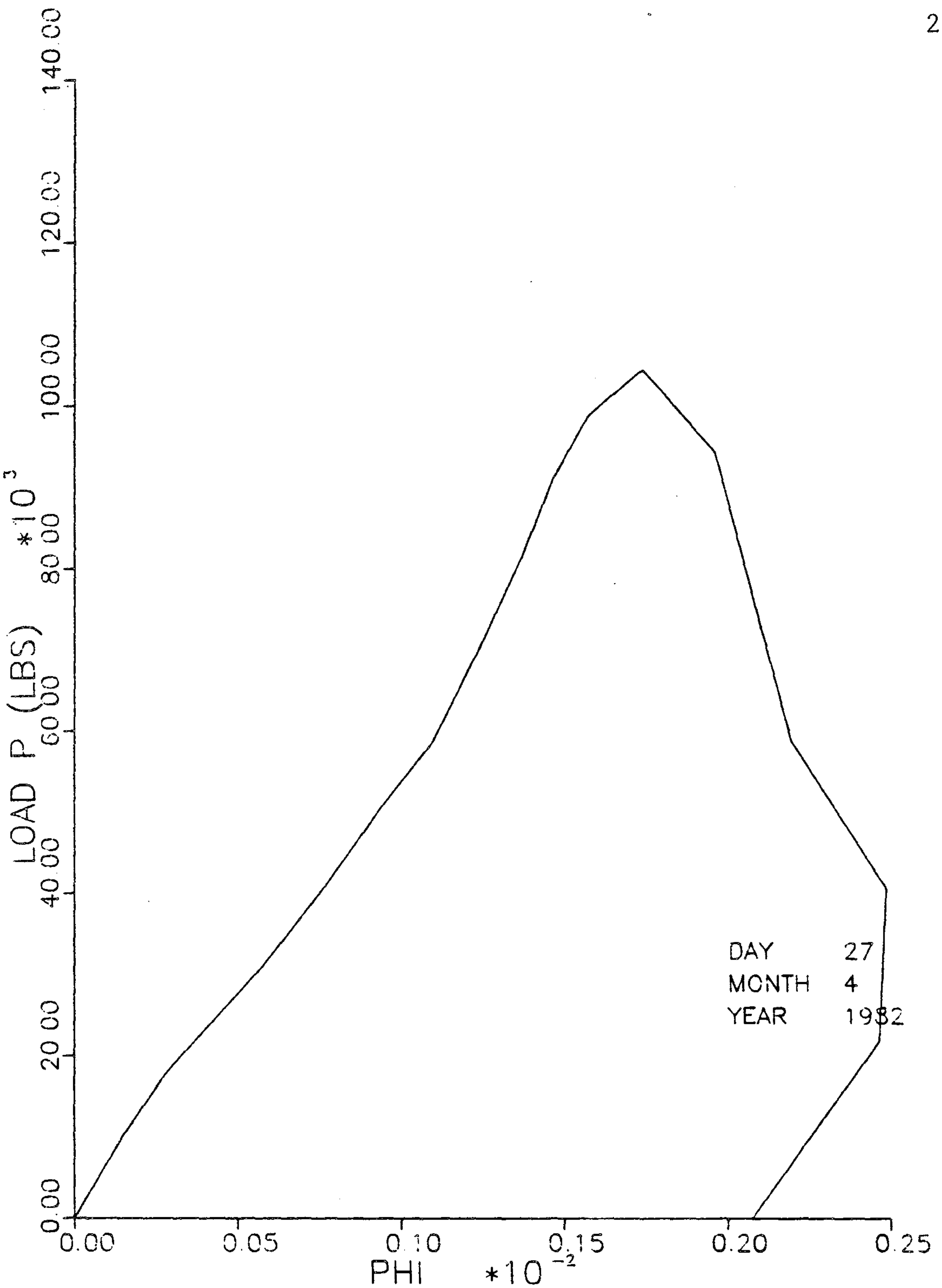


89

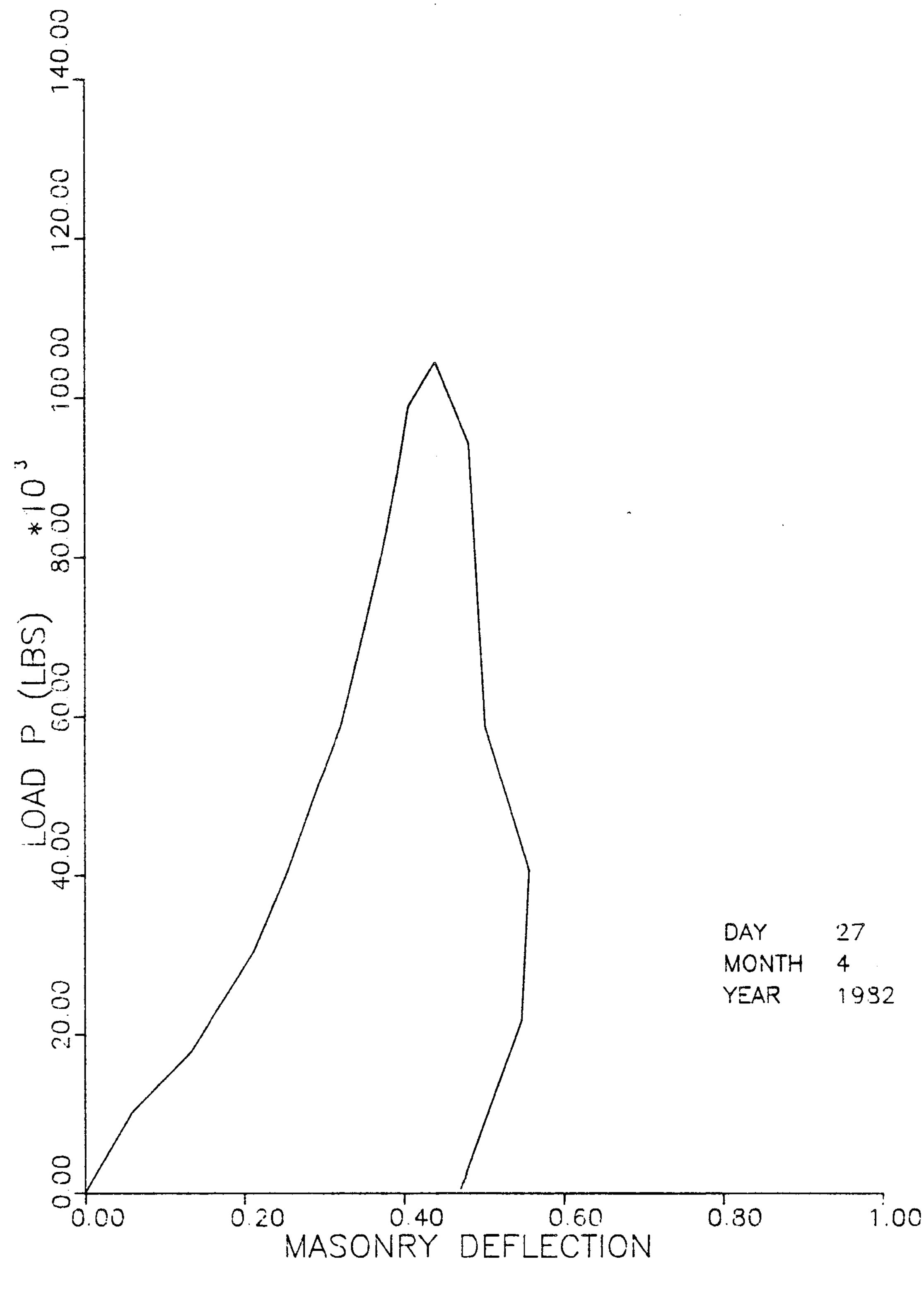
Figure D.43 Load vs Average Deflection Second Half-Cycle (E-2)



89 Figure D.44 Load vs Average Horizontal Deflection Second Half-Cycle (E-2)



89 Figure D.45 Load vs Phi Second Half-Cycle (E-2)



89 Figure D.46 Load vs Masonry Deflection Second Half-Cycle (E-2)

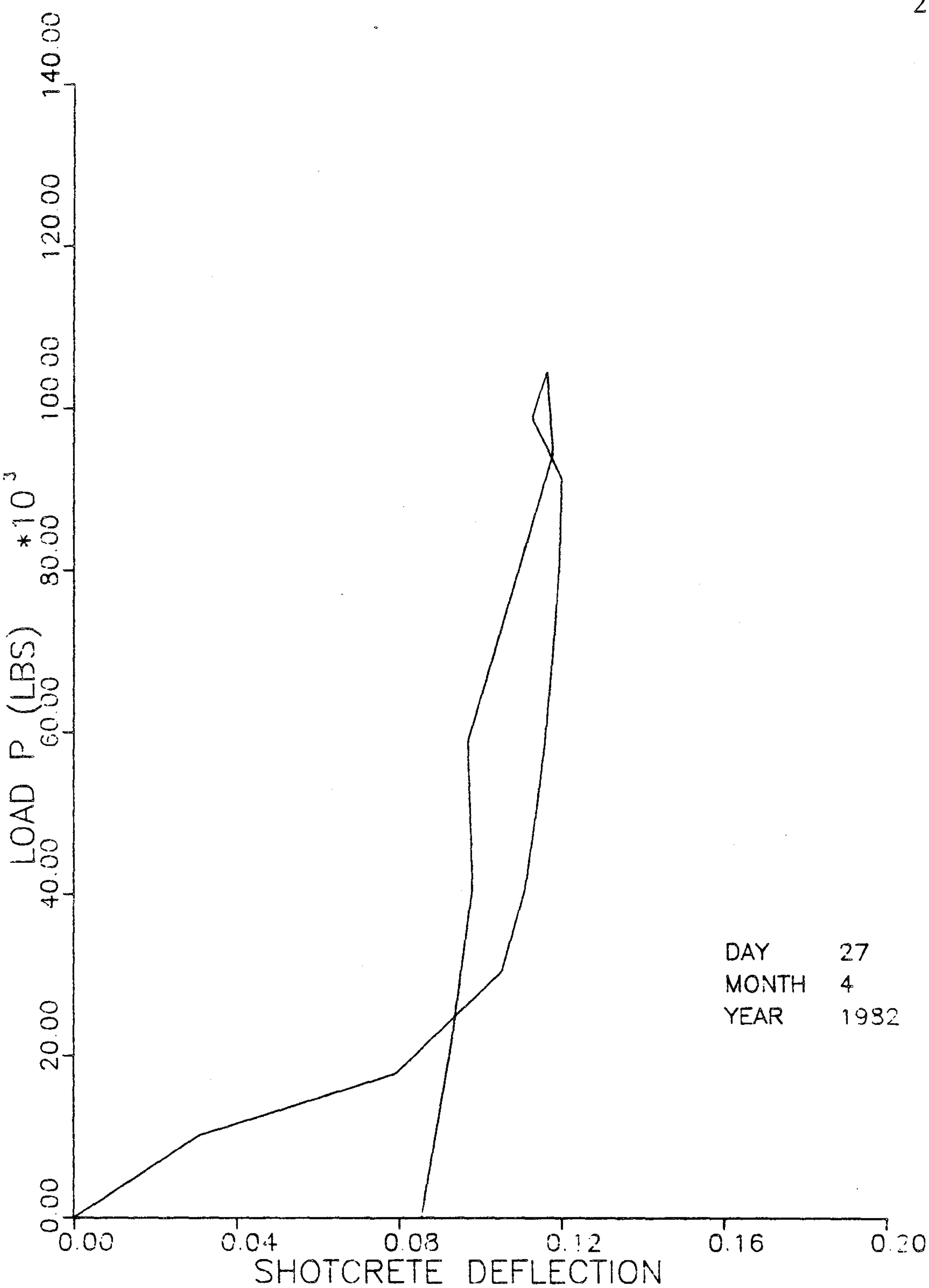


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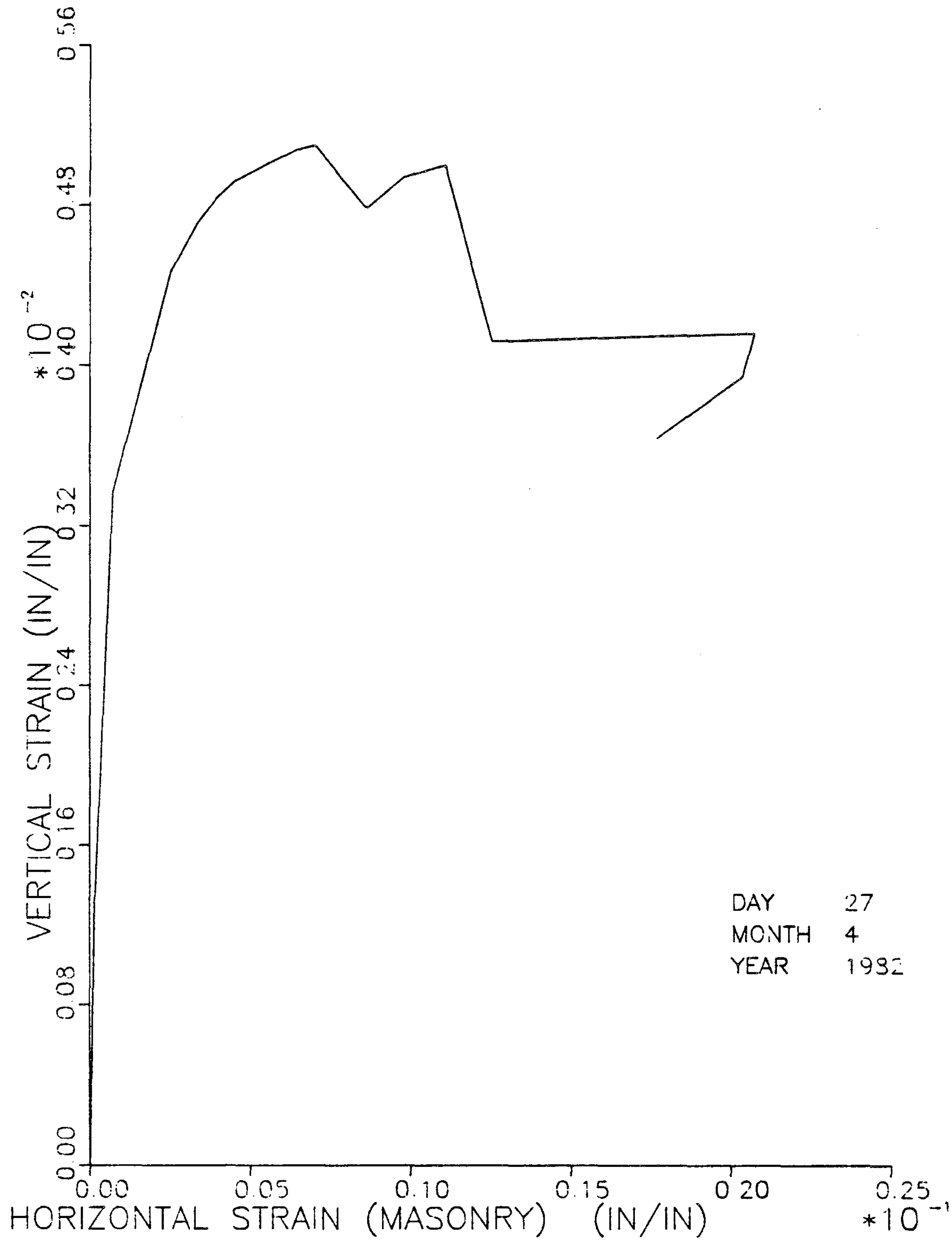
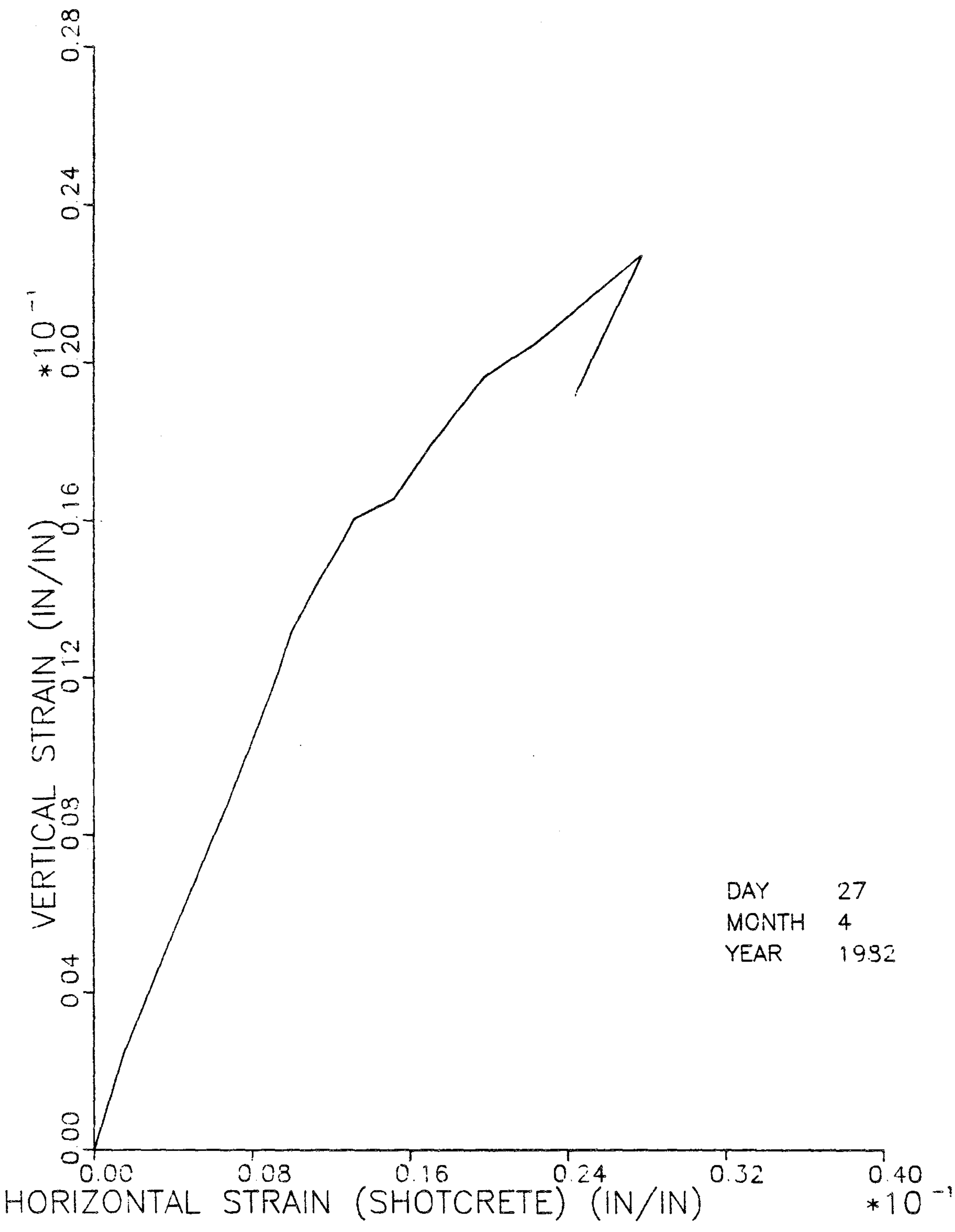
Figure D.47 Load vs Shotcrete Deflection
Second Half-Cycle (E-2)



89 Figure D.48 Vertical Vs Horizontal Strain Masonry Side Second Half-Cycle (E-2)



89 Figure D.49 Vertical vs Horizontal Shotcrete Side Second Half-Cycle (E-2)

156

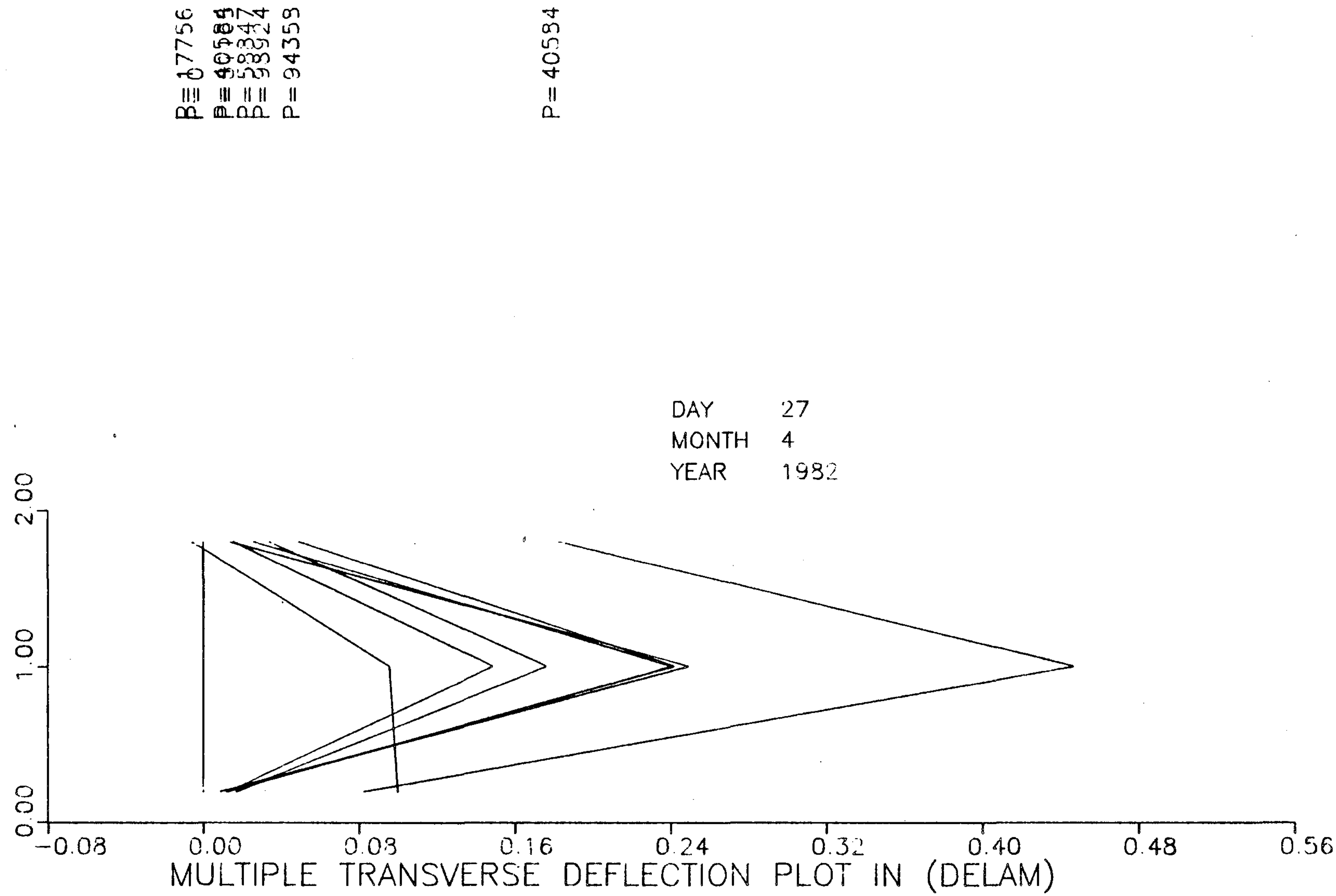


Figure D.50 Delamination Plot Second Half Cycle (E-2)

89

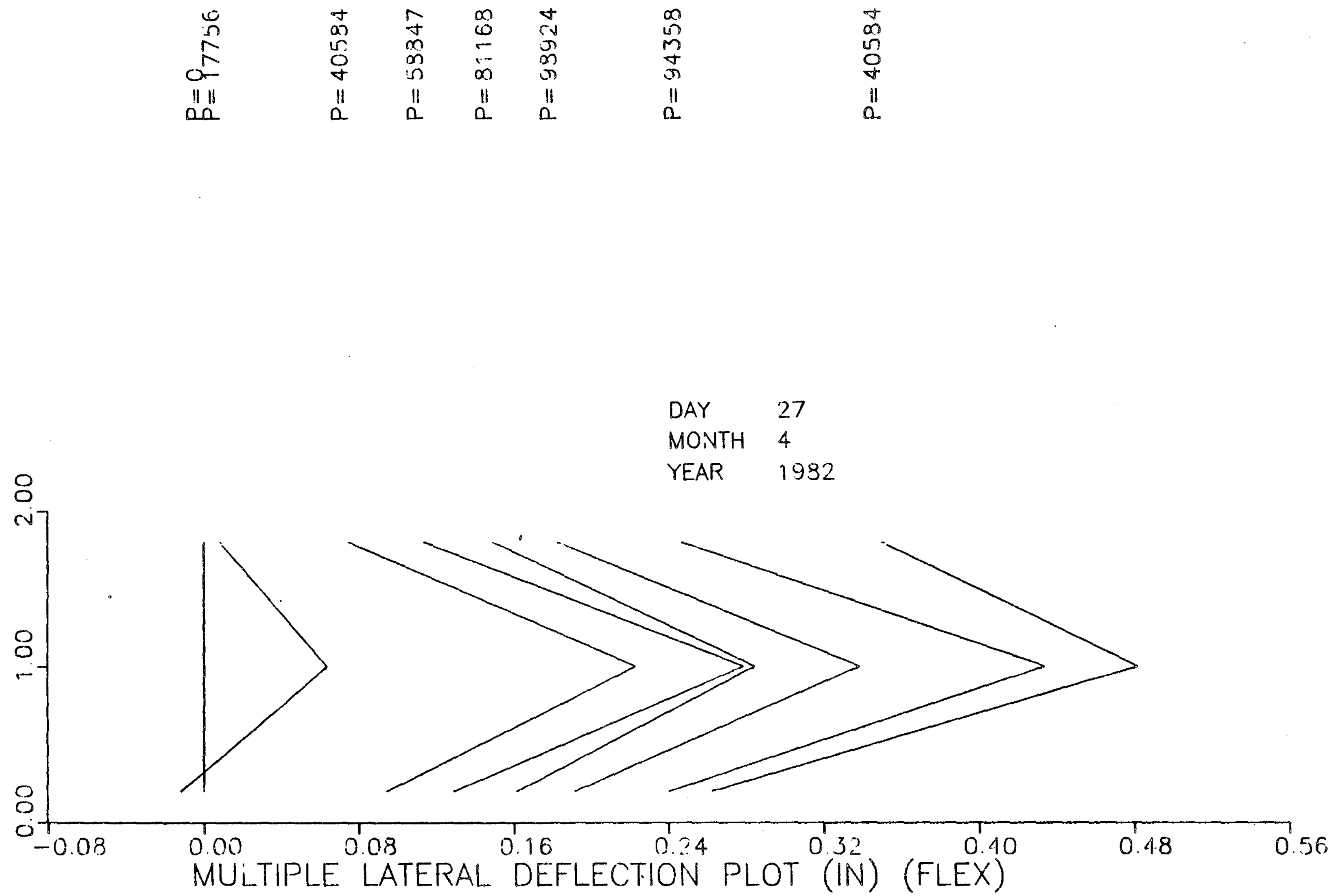


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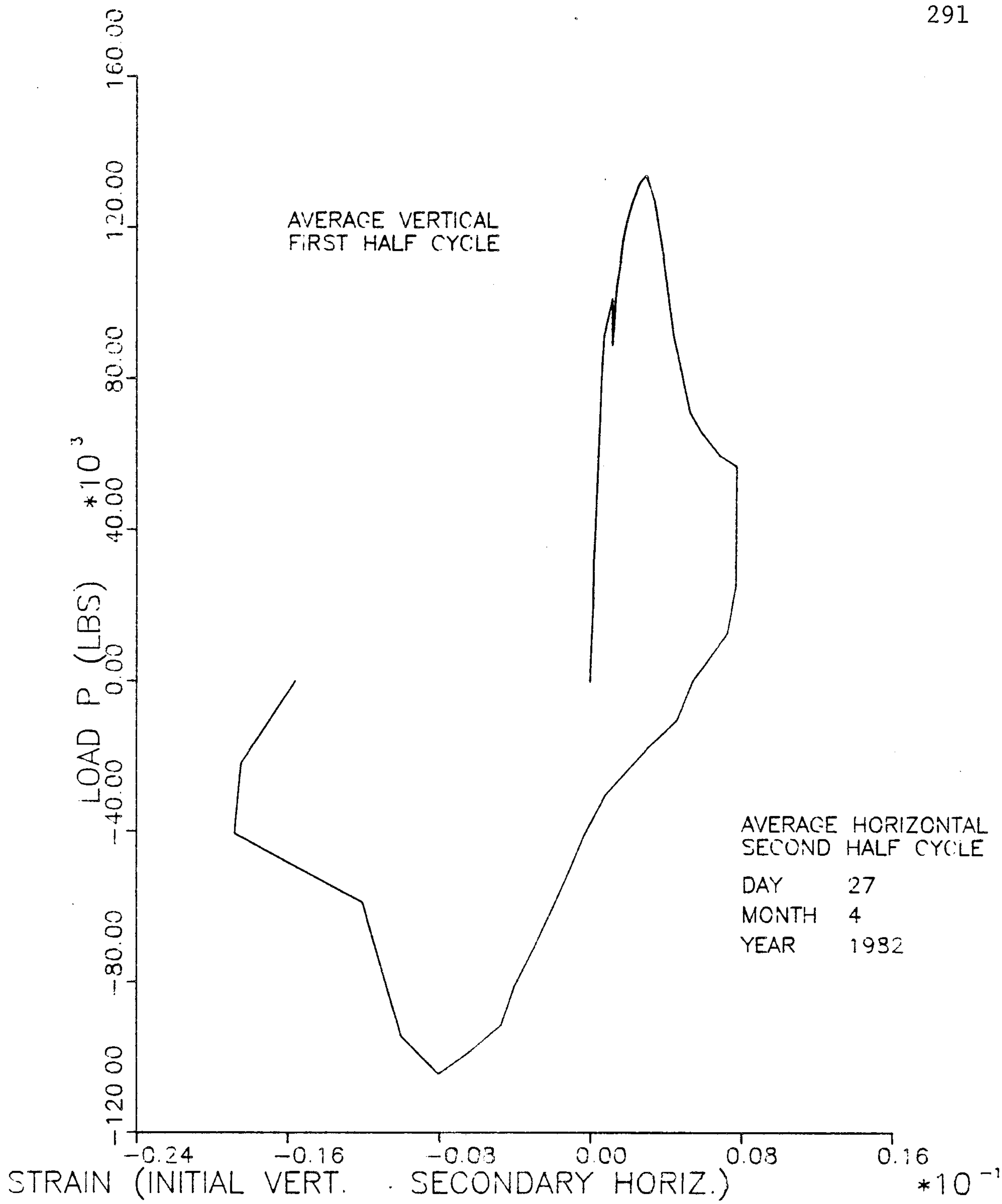
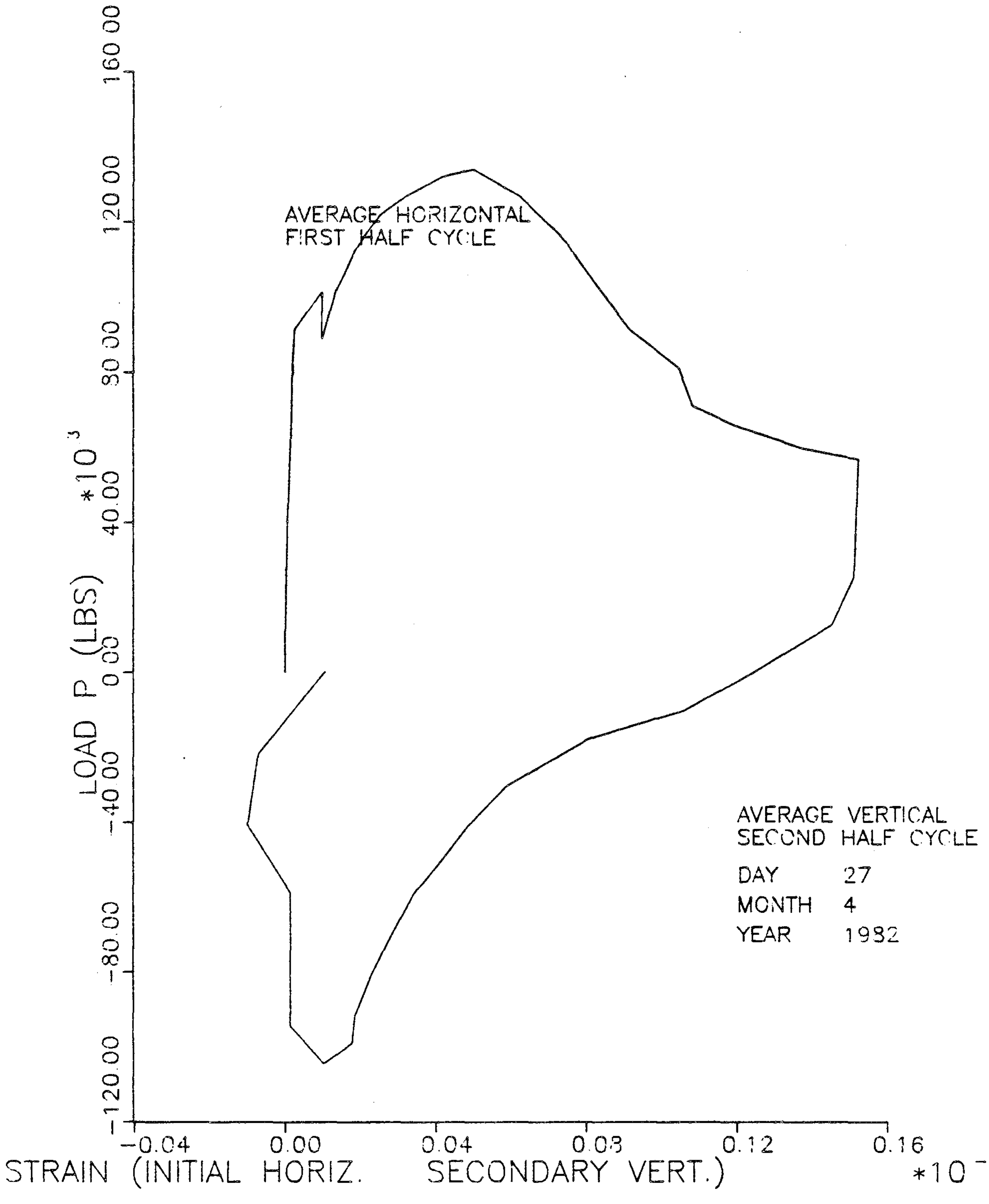
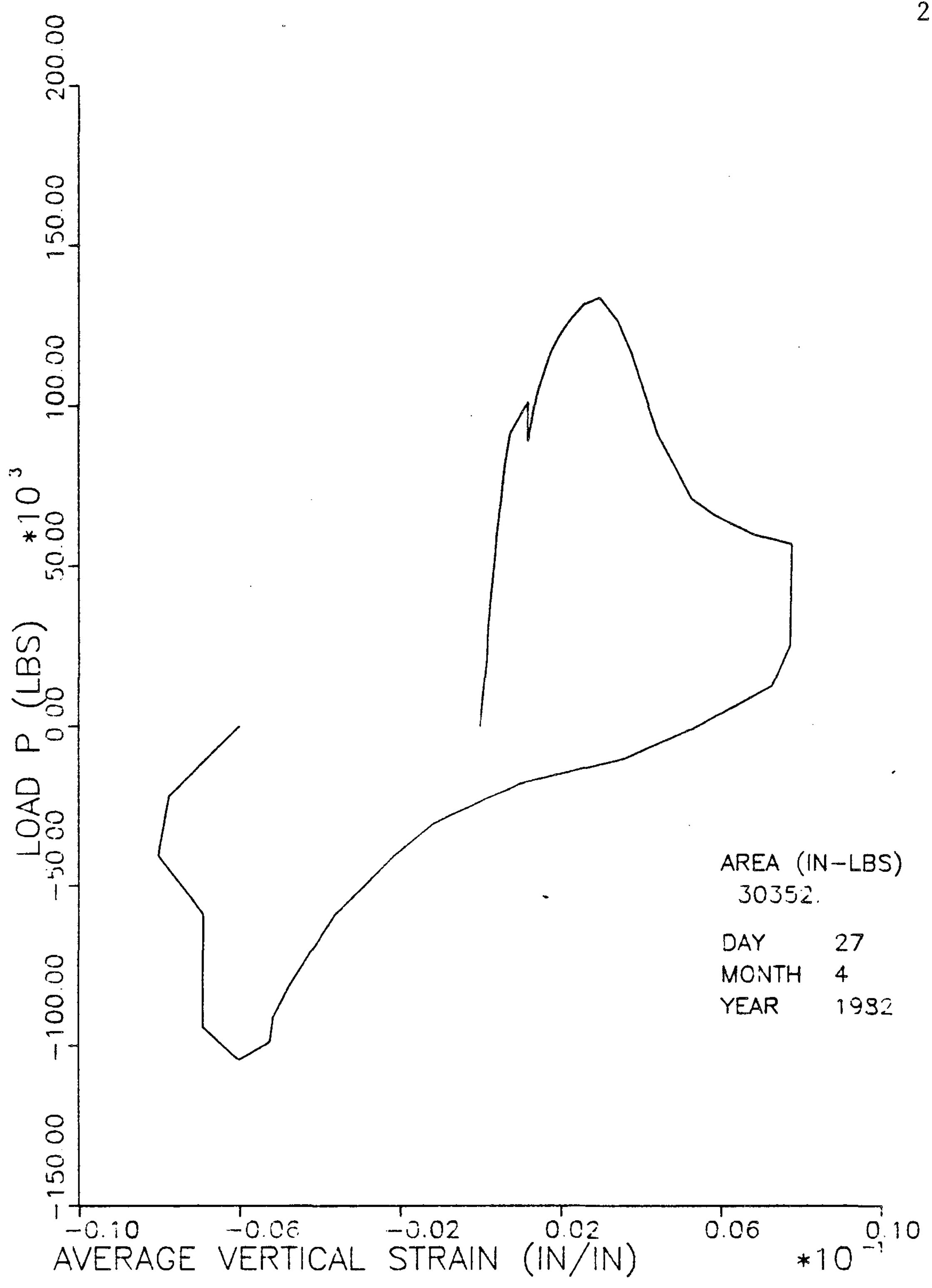
Figure D.51 Flexure Plot Second Half-Cycle (E-2)



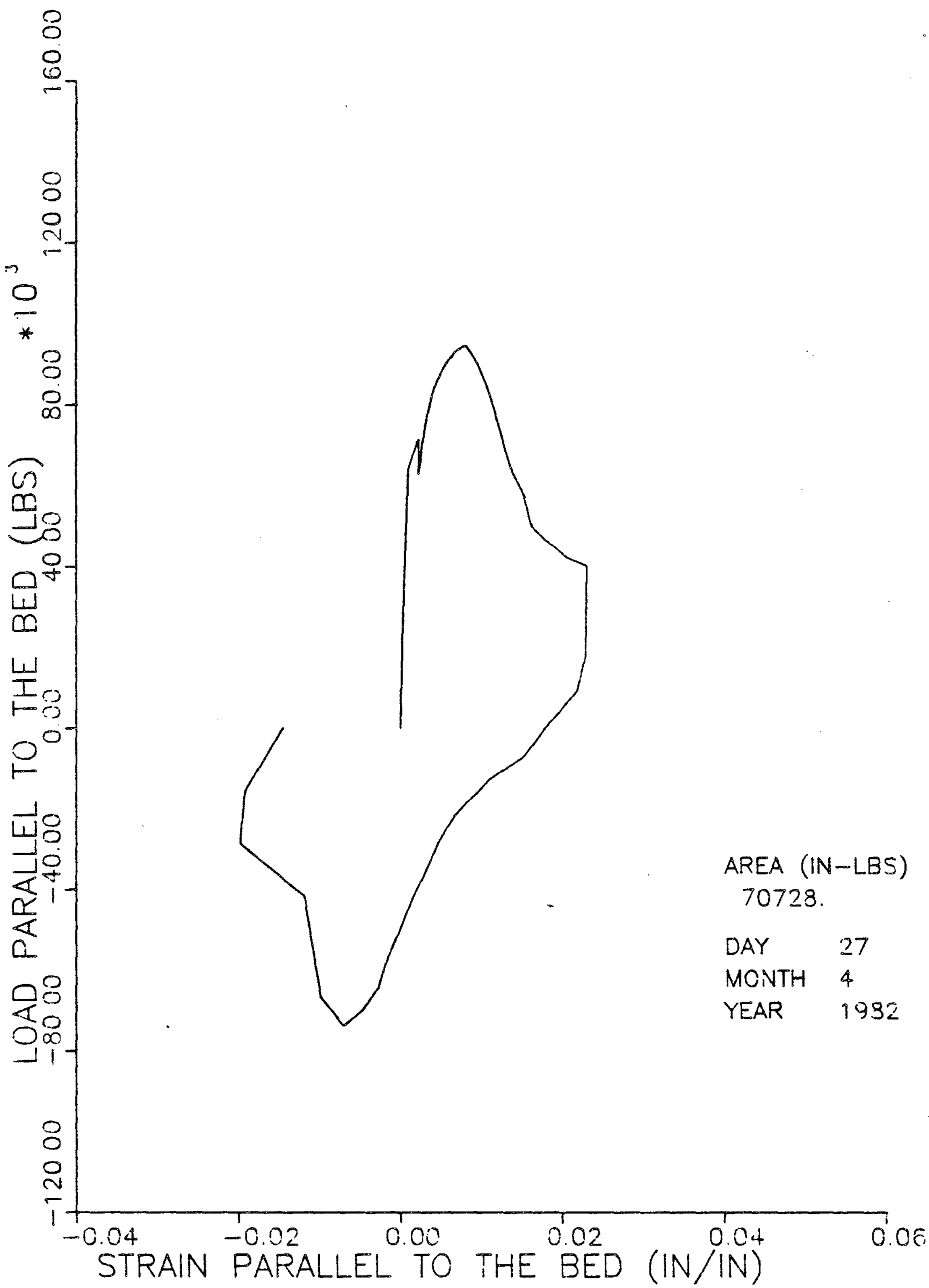
89 Figure D.52 Hysteresis Plot (E-2)



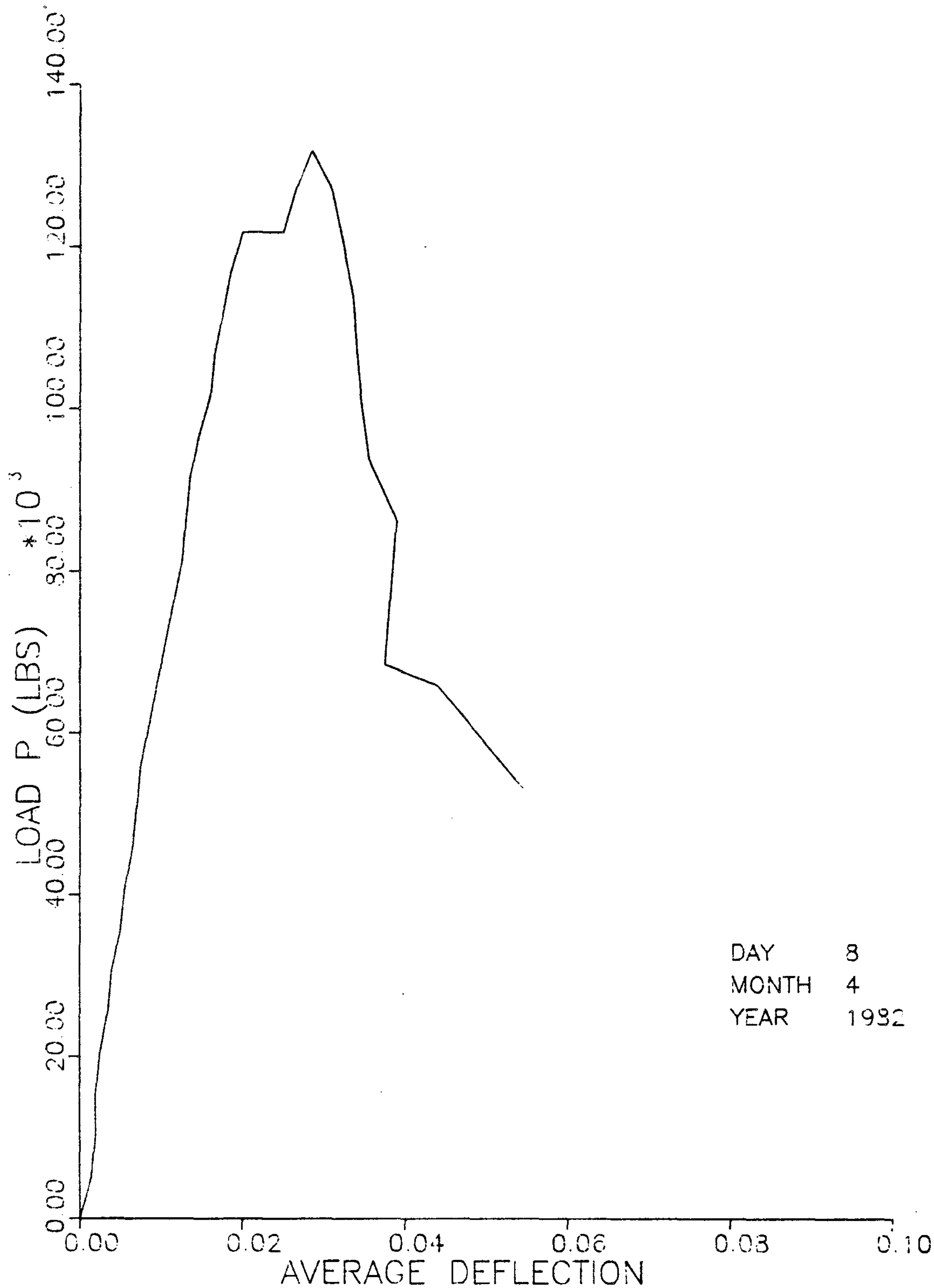
39 Figure D.53 Hysteresis Plot (E-2)



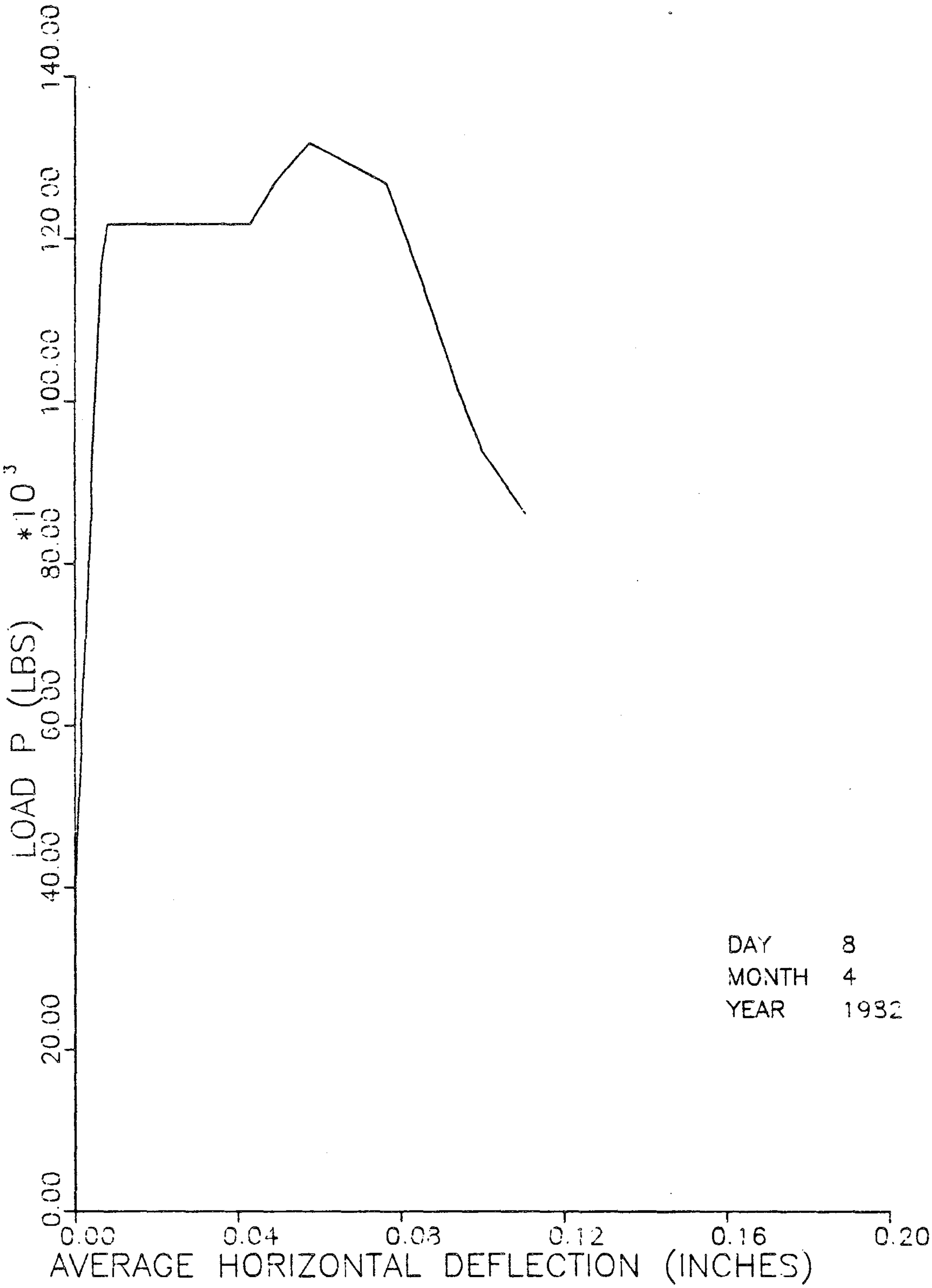
89 Figure D.54 Vertical Hysteresis PLot (E-2)



89 Figure D.55 Parallel to the Bed Hysteresis Plot (E-2)

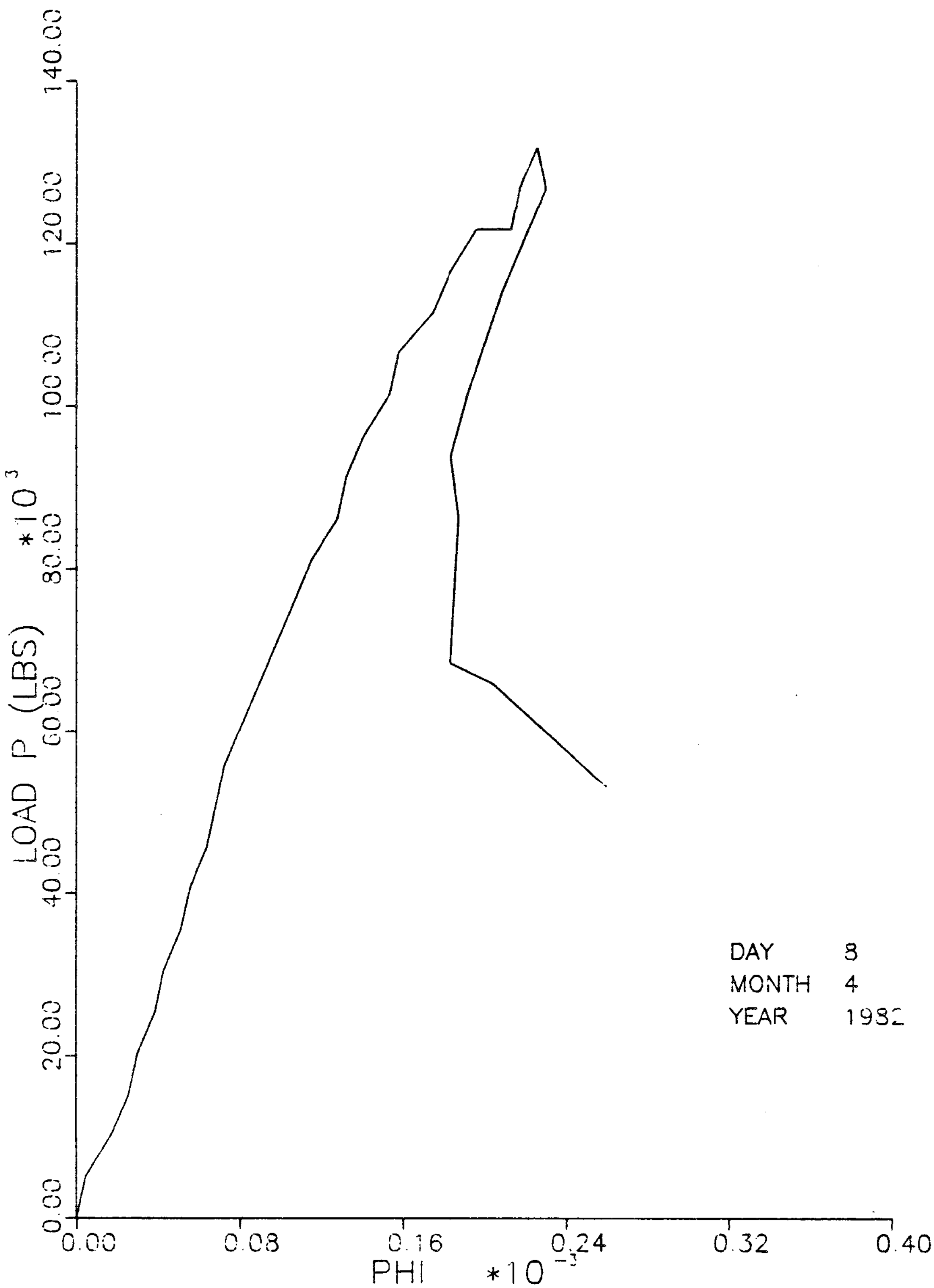


12 Figure D.56 Load vs Average Deflection First Half-Cycle (D-3)

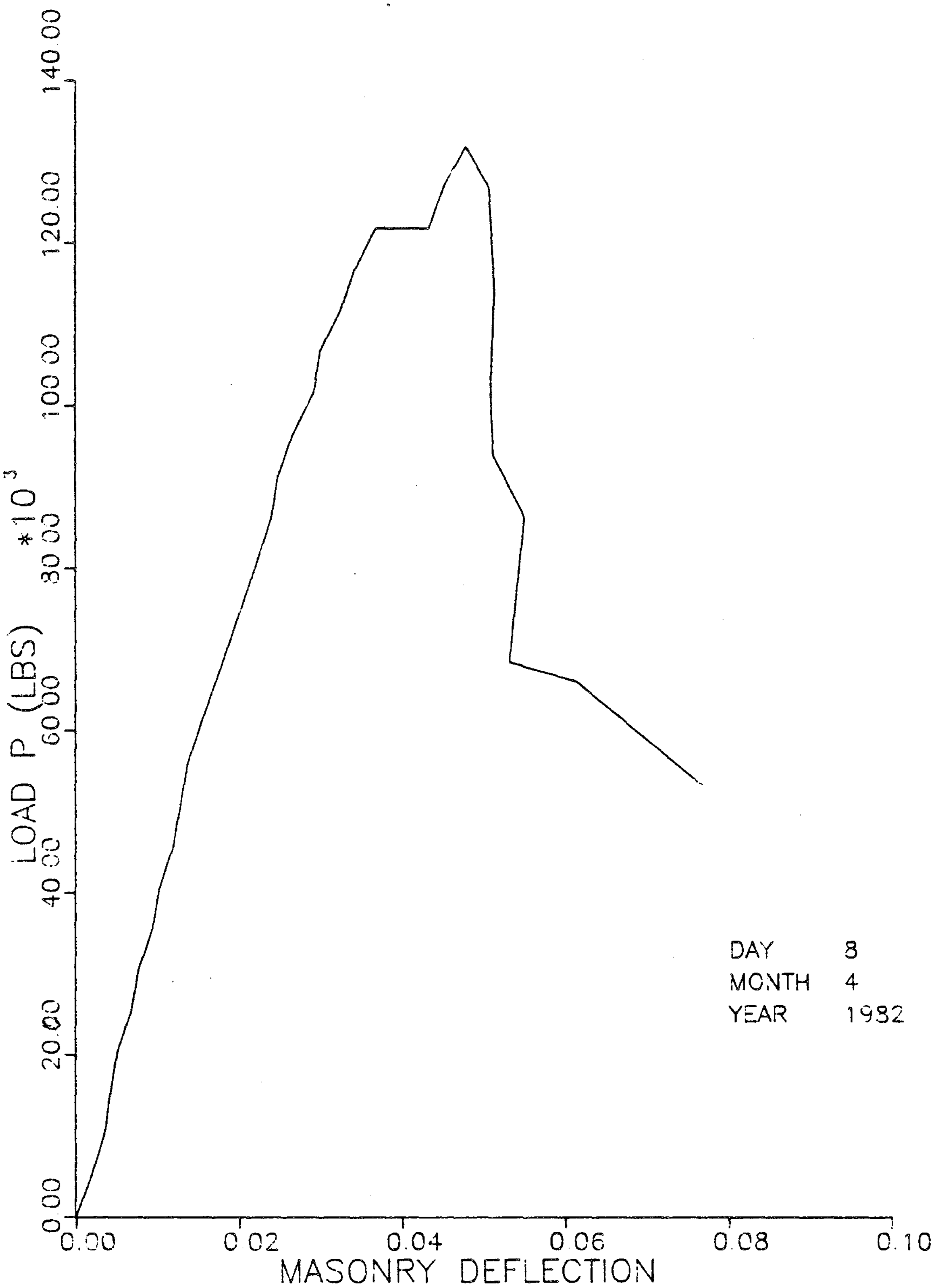


12 Figure D.57 Load vs Average Horizontal Deflection First Half-Cycle (D-3)

164

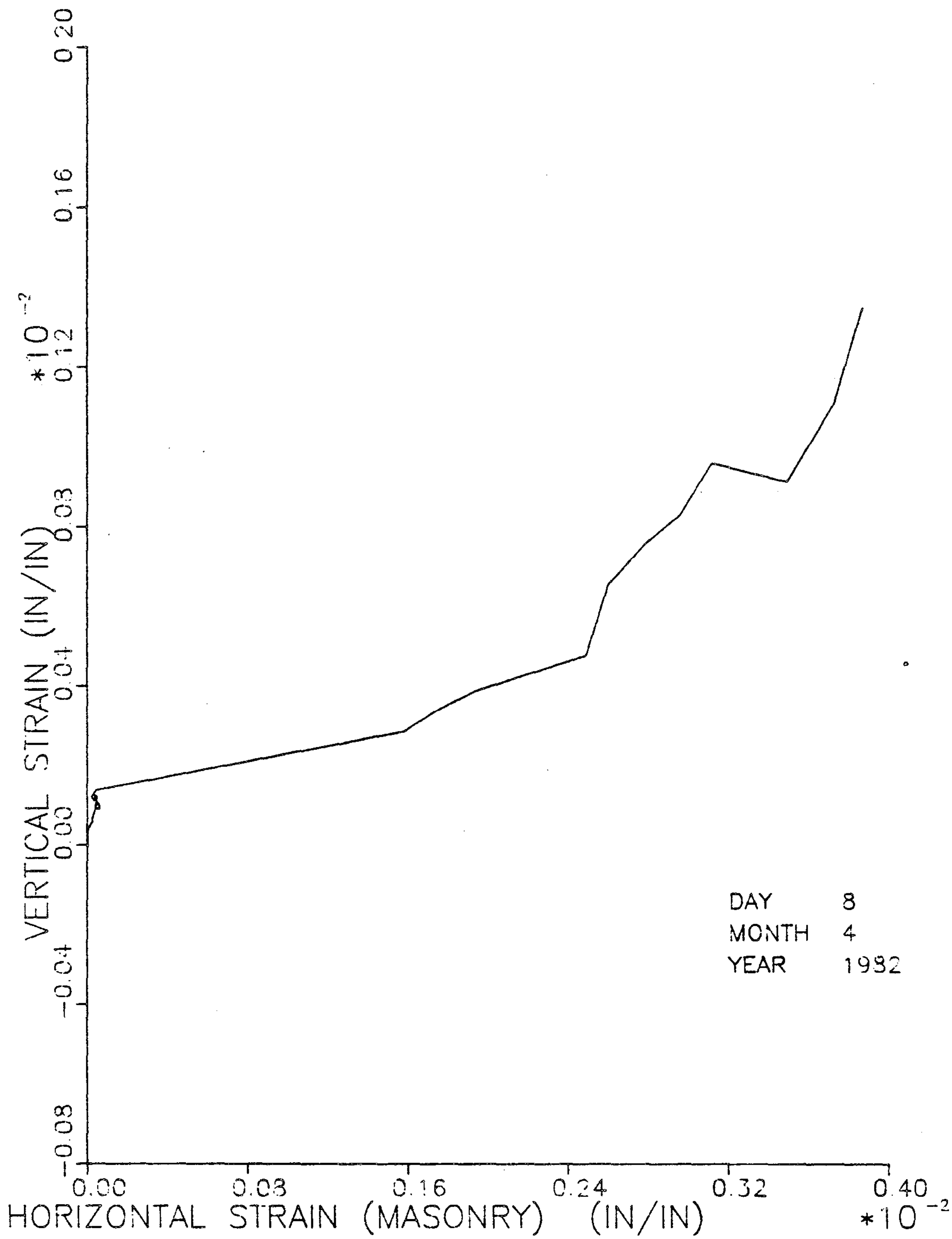


12 Figure D.58 Load vs Phi First Half-Cycle (D-3)

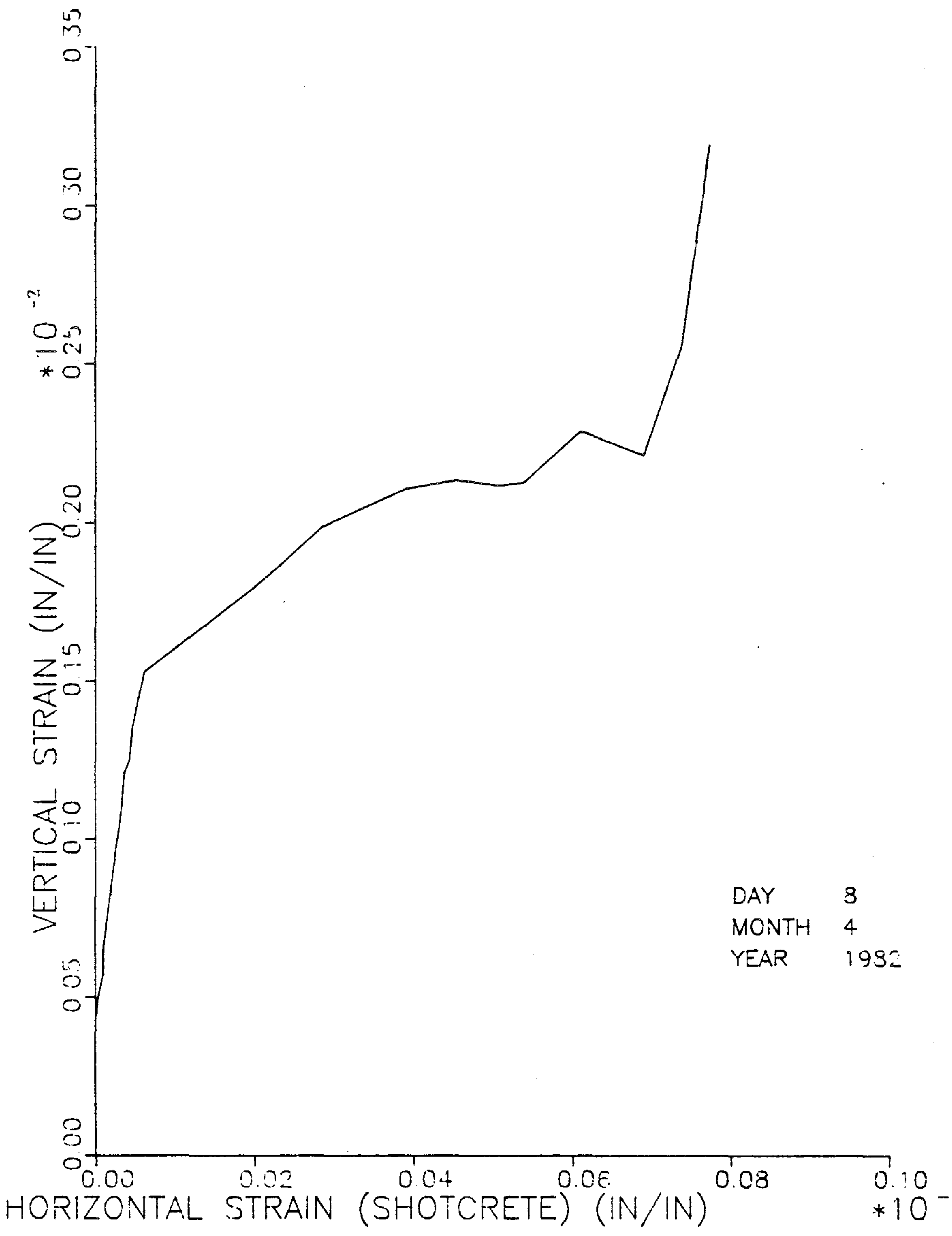


12 Figure D.59 Load vs Masonry Deflection First Half-Cycle (D-3)

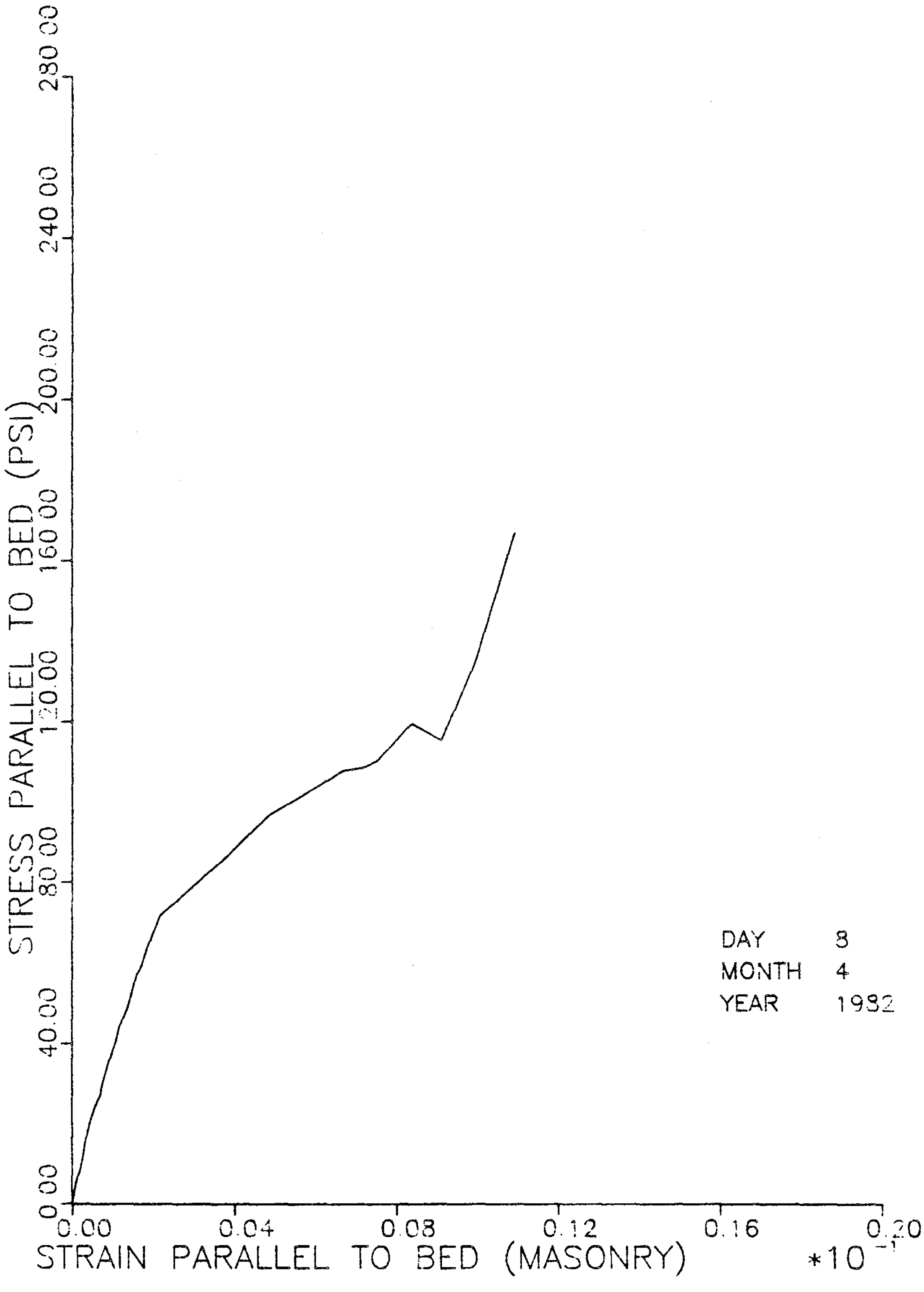
12 FigureD.60 Load vs Shotcrete Deflection First Half-Cycle (D-3)



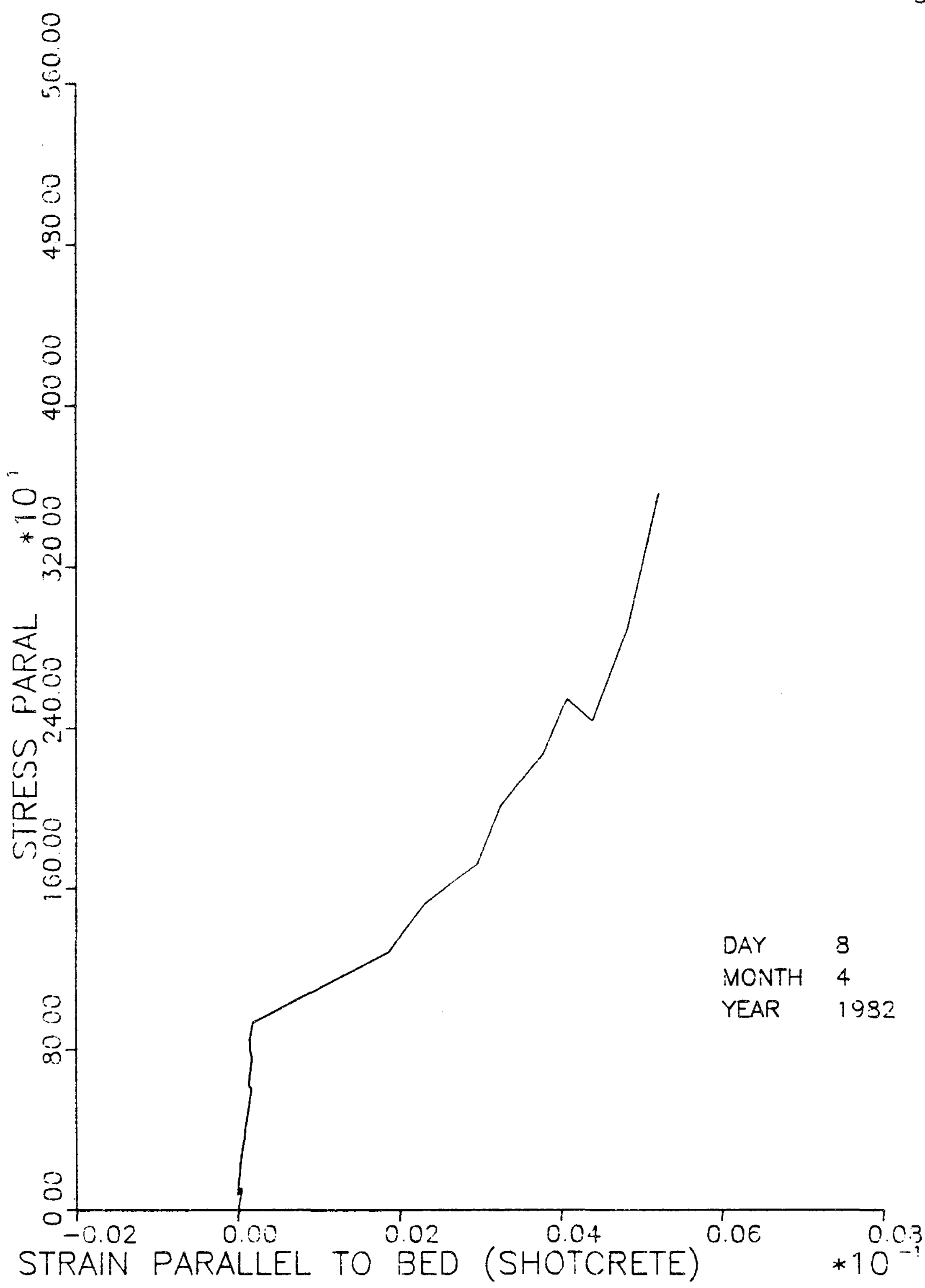
12 Figure D.61 Vertical vs Horizontal Strain Masonry Side First Half-Cycle (D-3)



12 Figure D.62 Verticah vs Horizontal Strain Shotcrete Side First Half-Cycle (D-3)



12 Figure D.63 Stress vs Strain Parallel to the Bed Masonry Side First Half-Cycle (D-3)



12 Figure D.64 Stress vs Strain Parallel to the Bed
Shotcrete Side First Half-Cycle (D-3)

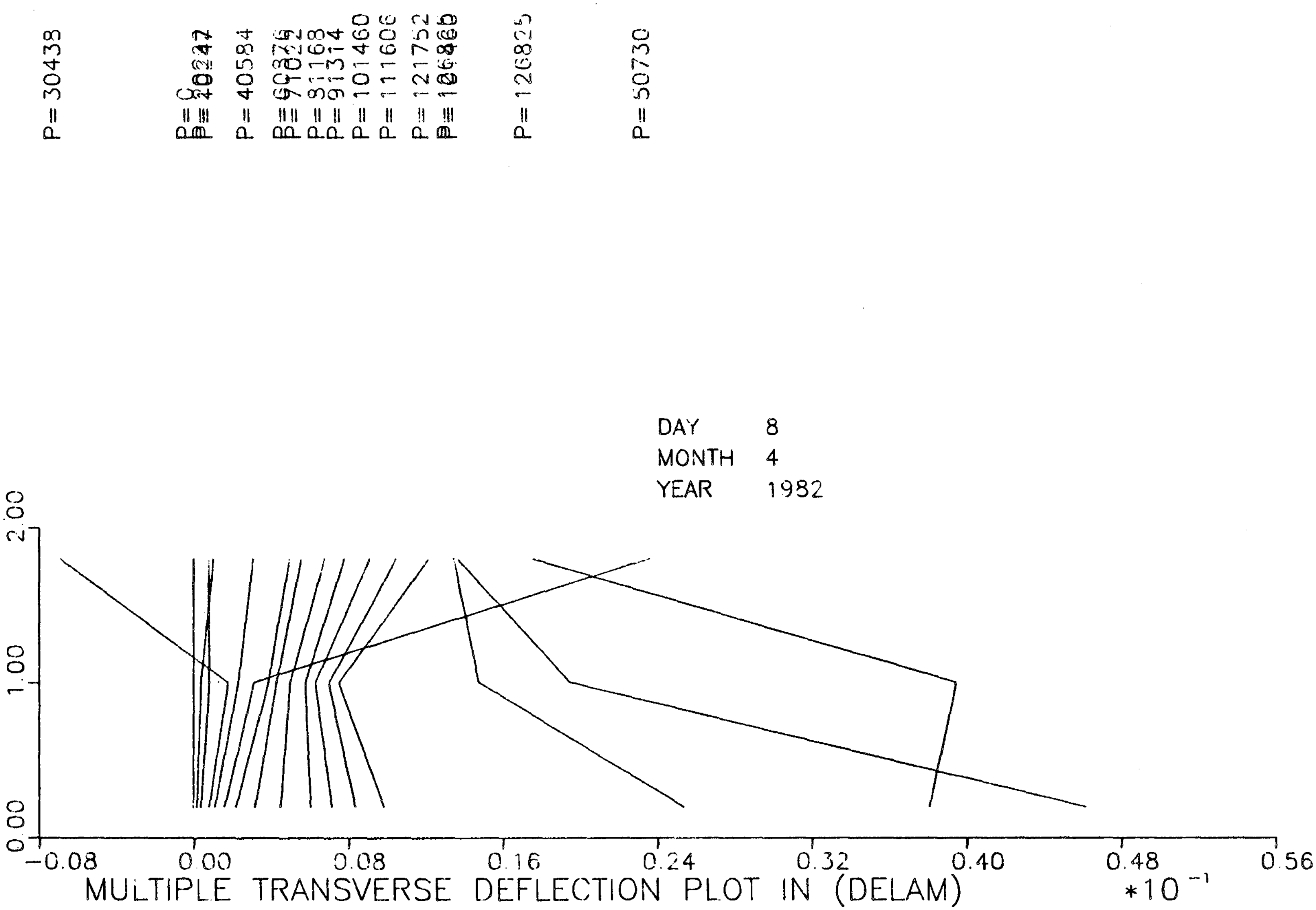


Figure D.65 Delamination Plot First Half-Cycle (D-3)

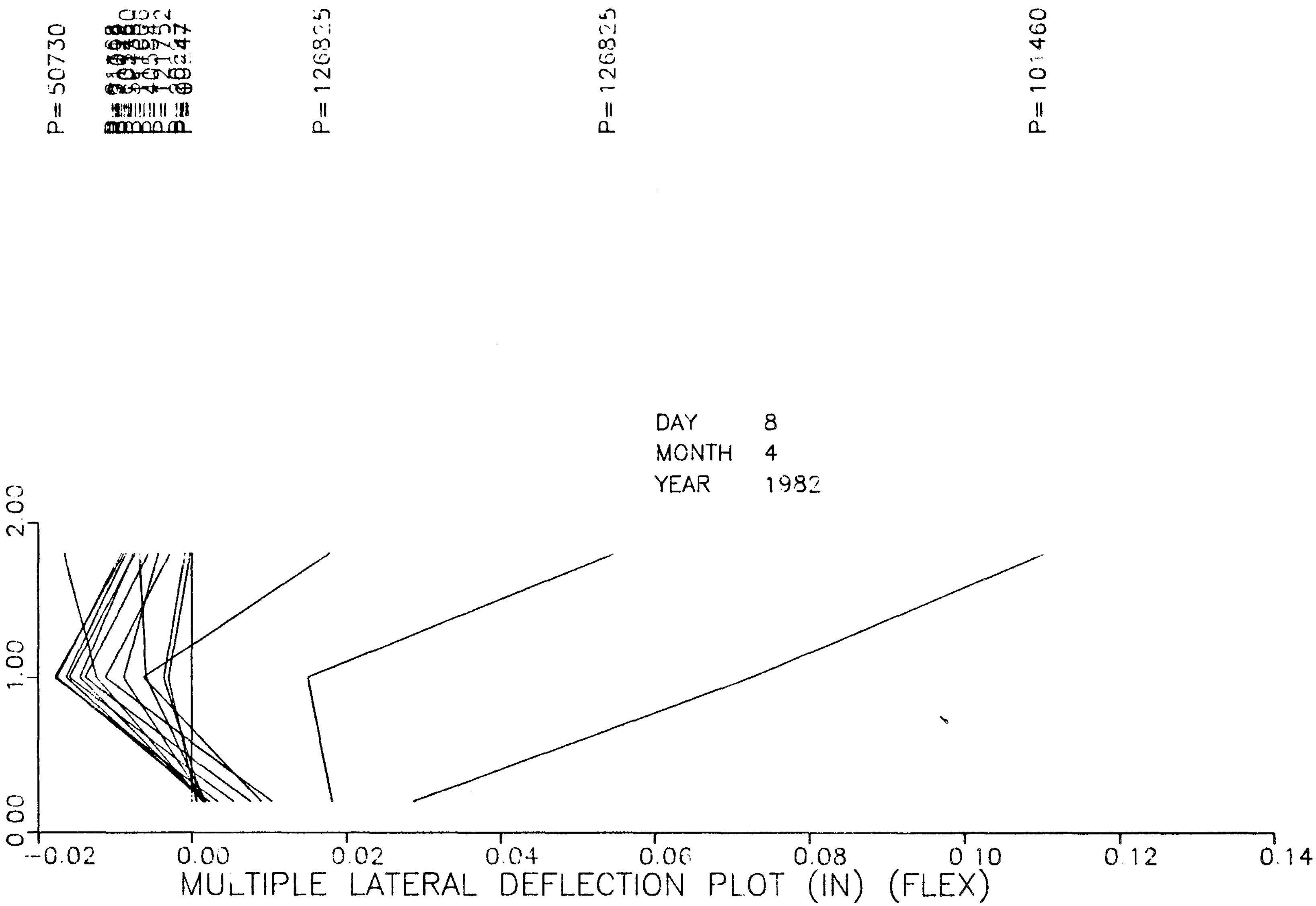
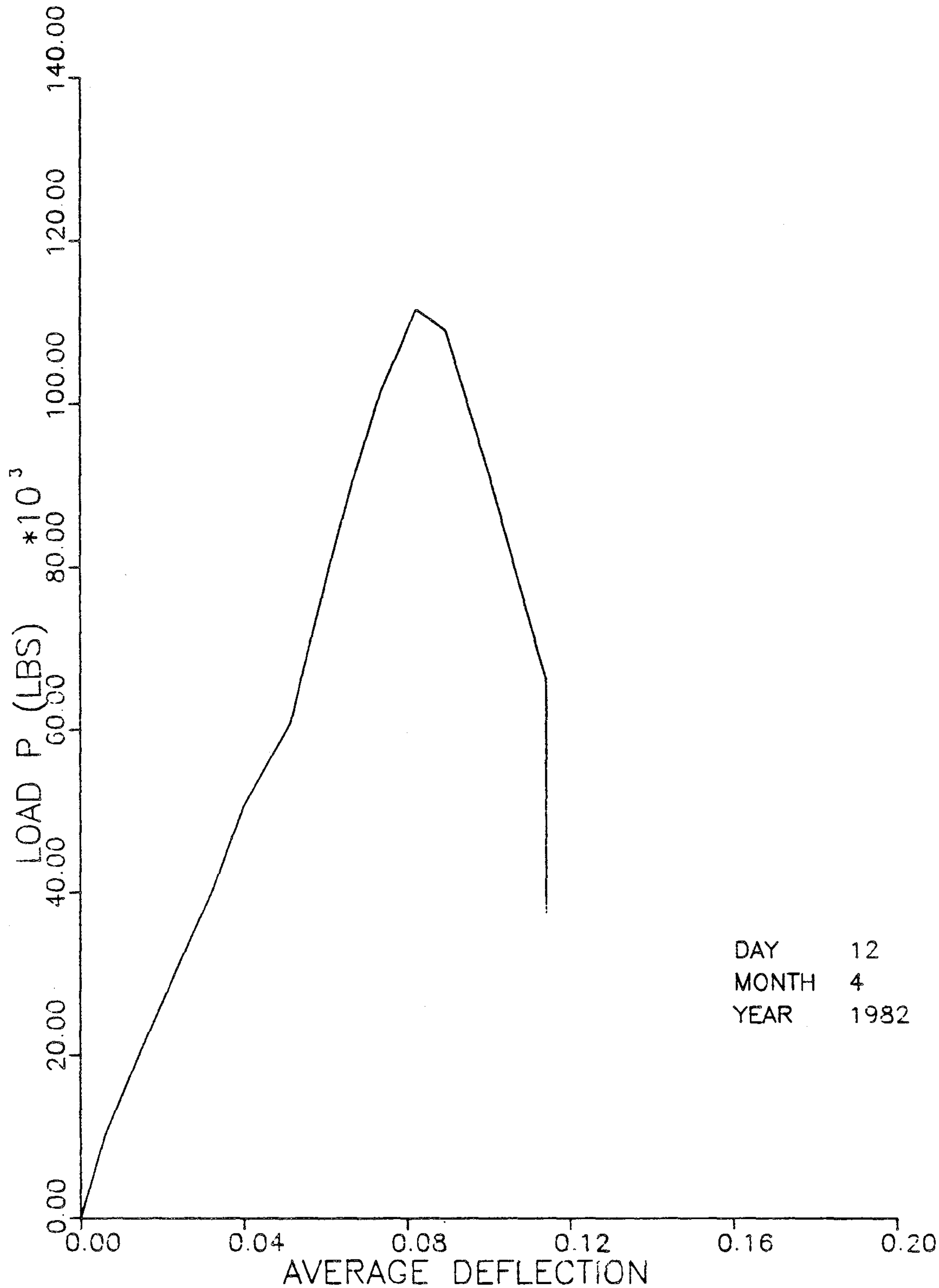
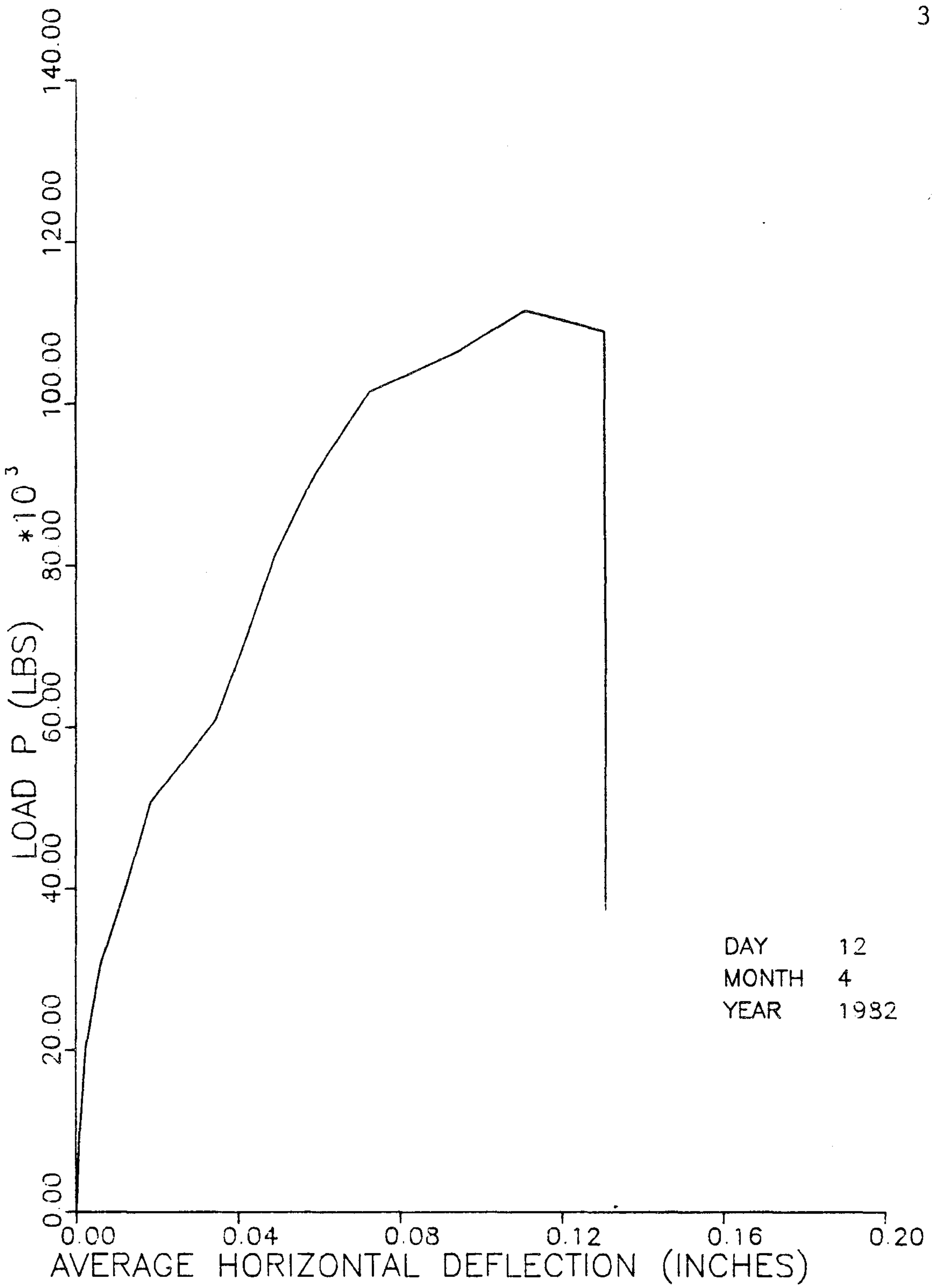


Figure D.66 Flexure Plot First Half-Cycle (D-3)

12

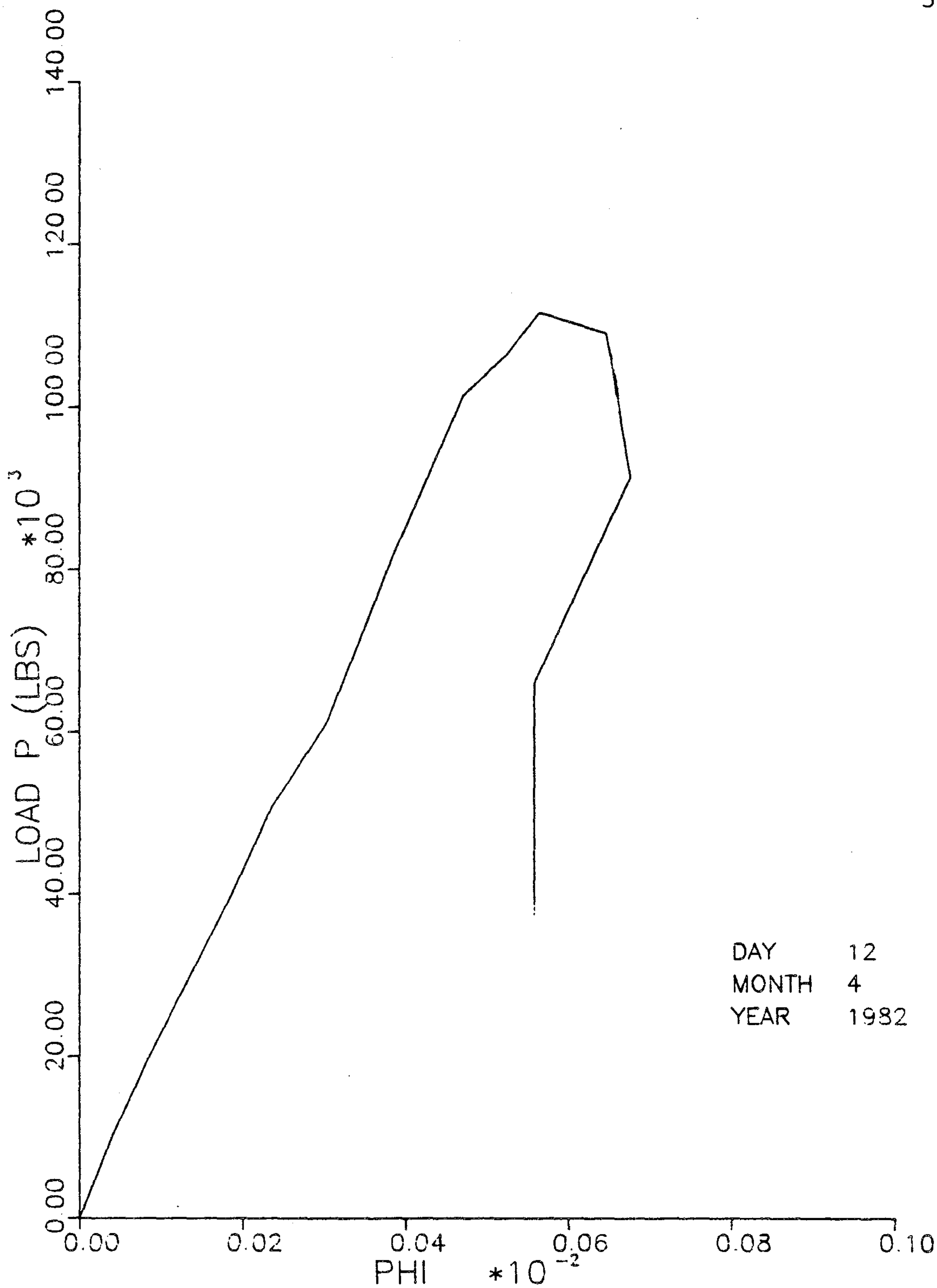


129 Figure D.67 Load vs Average Deflection Second Half-Cycle (D-3)

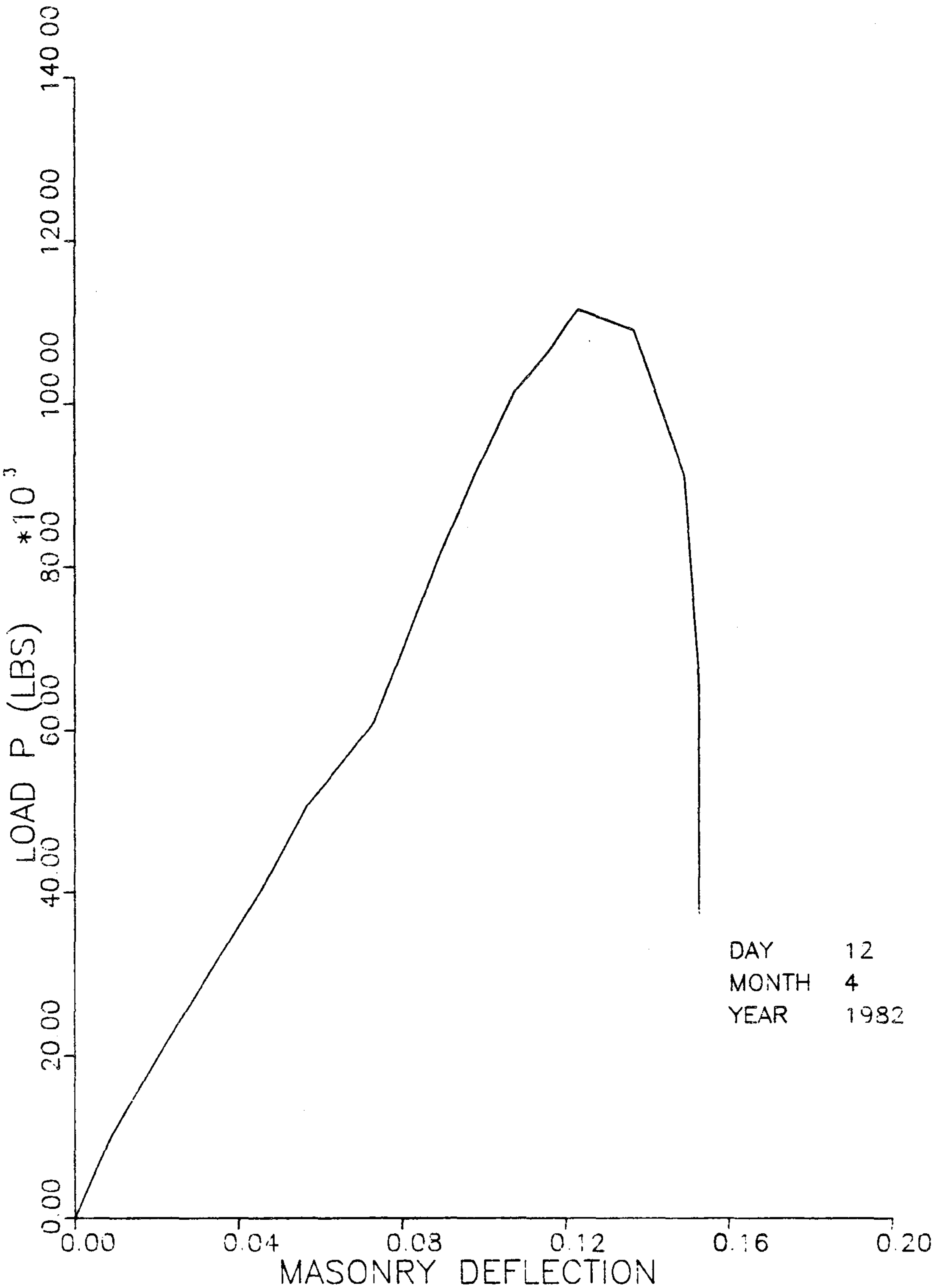


129

Figure D.68 Load vs Average Horizontal Deflection
Second Half-Cycle (D-3)



129 Figure D.69 Load vs Phi Second Half-Cycle (D-3)



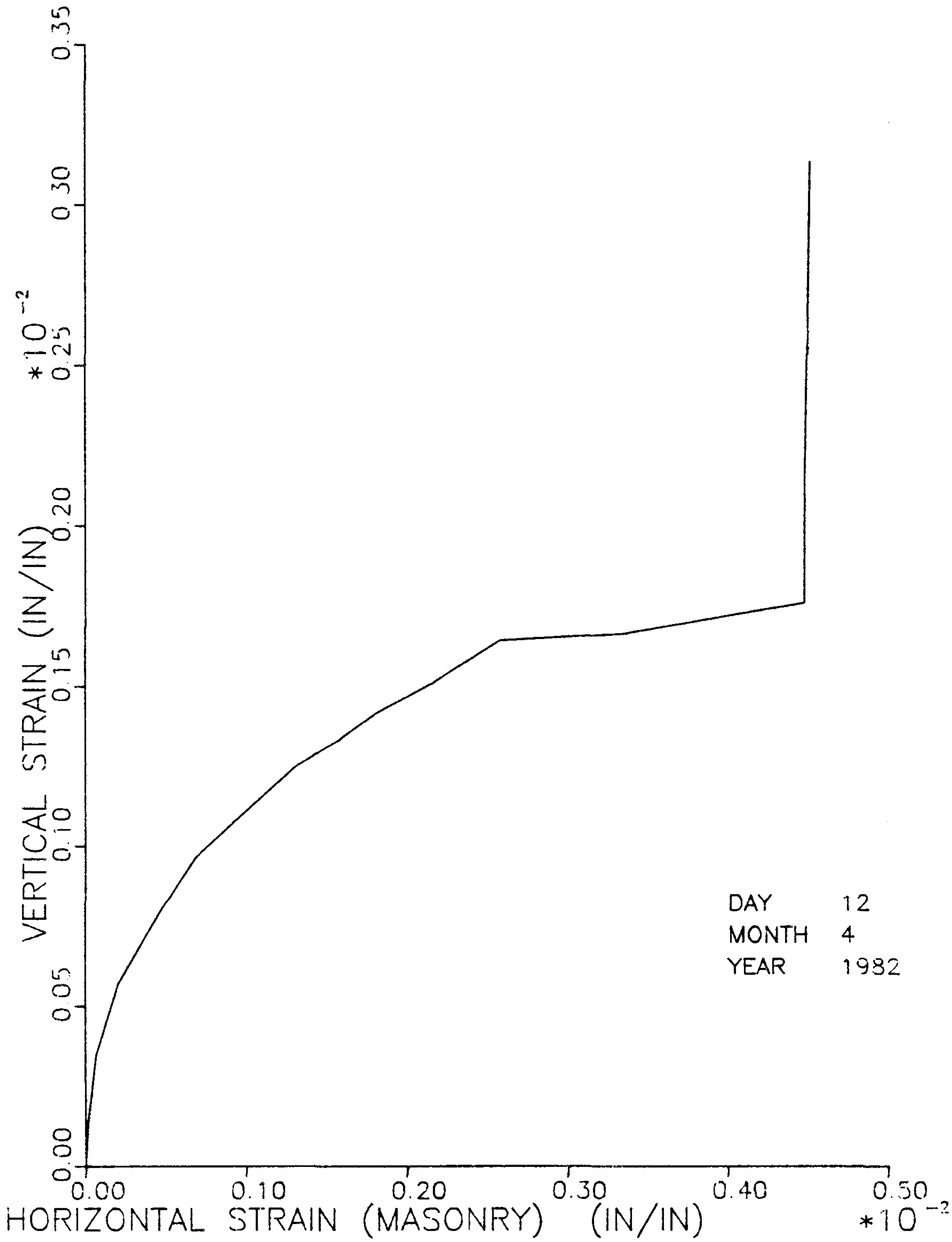
129

Figure D.70 Load vs Masonry Deflection Second Half-Cycle (D-3)

129

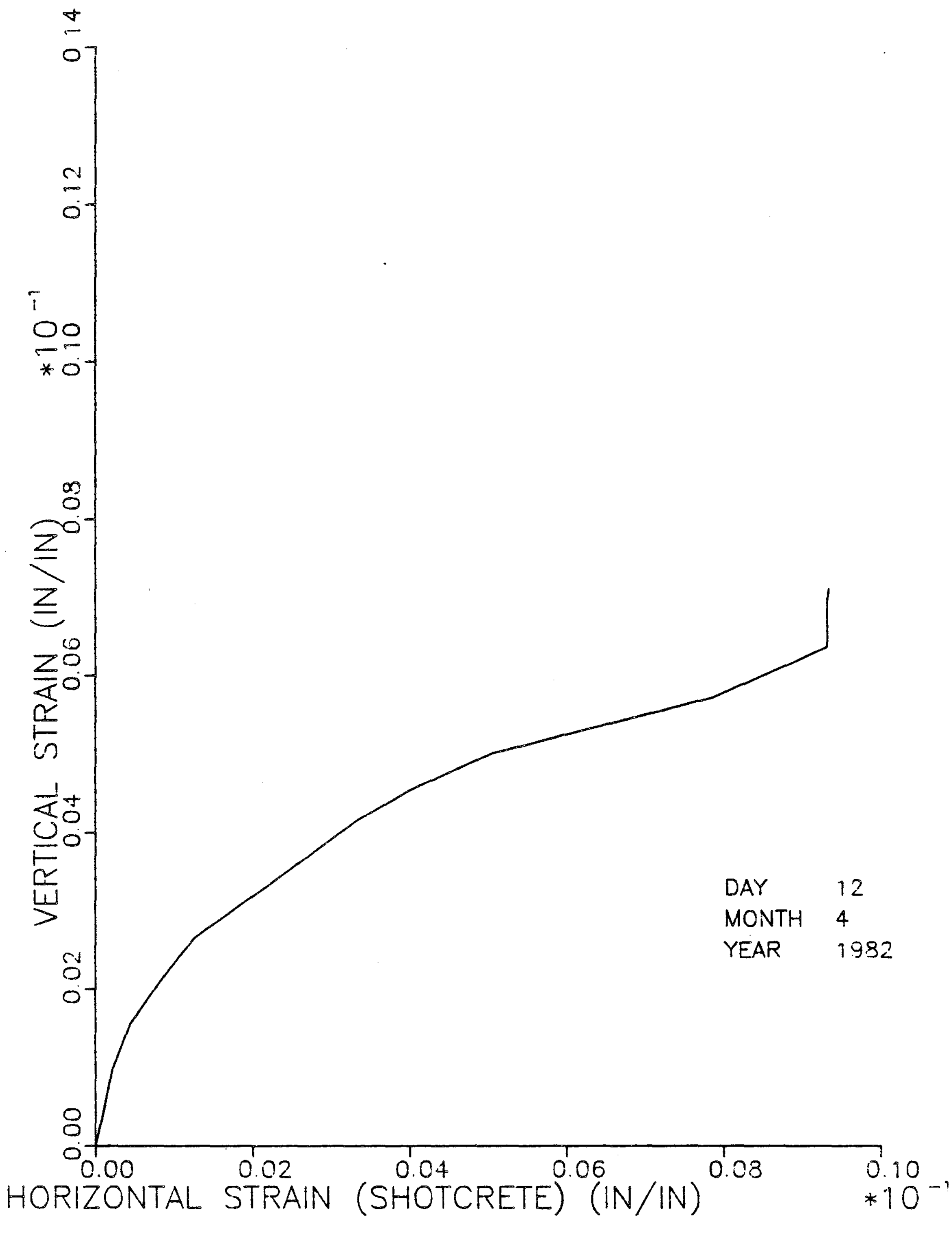
Figure D.71 Load vs Shotcrete Deflection Second Half-Cycle (D-3)

178

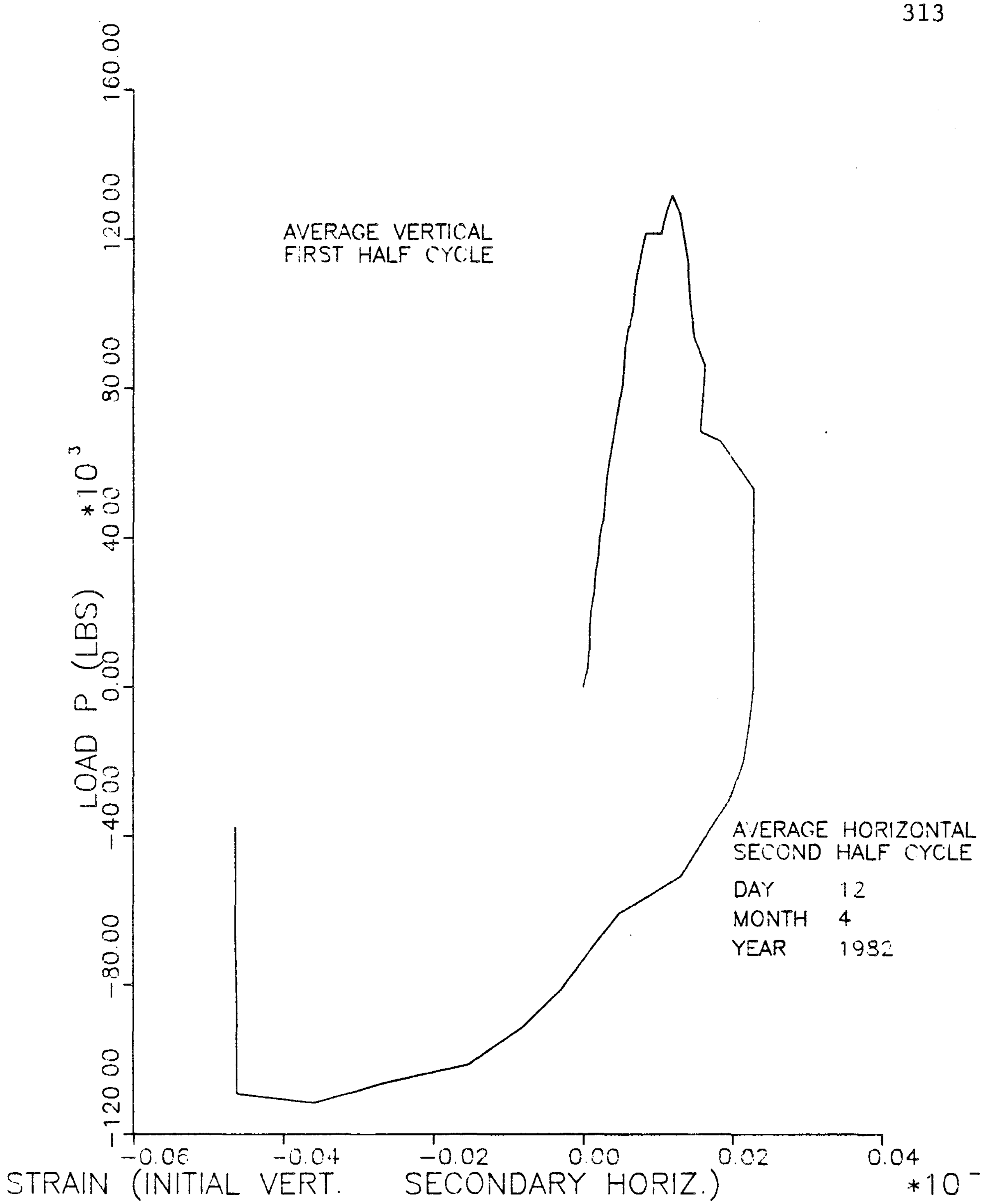


123

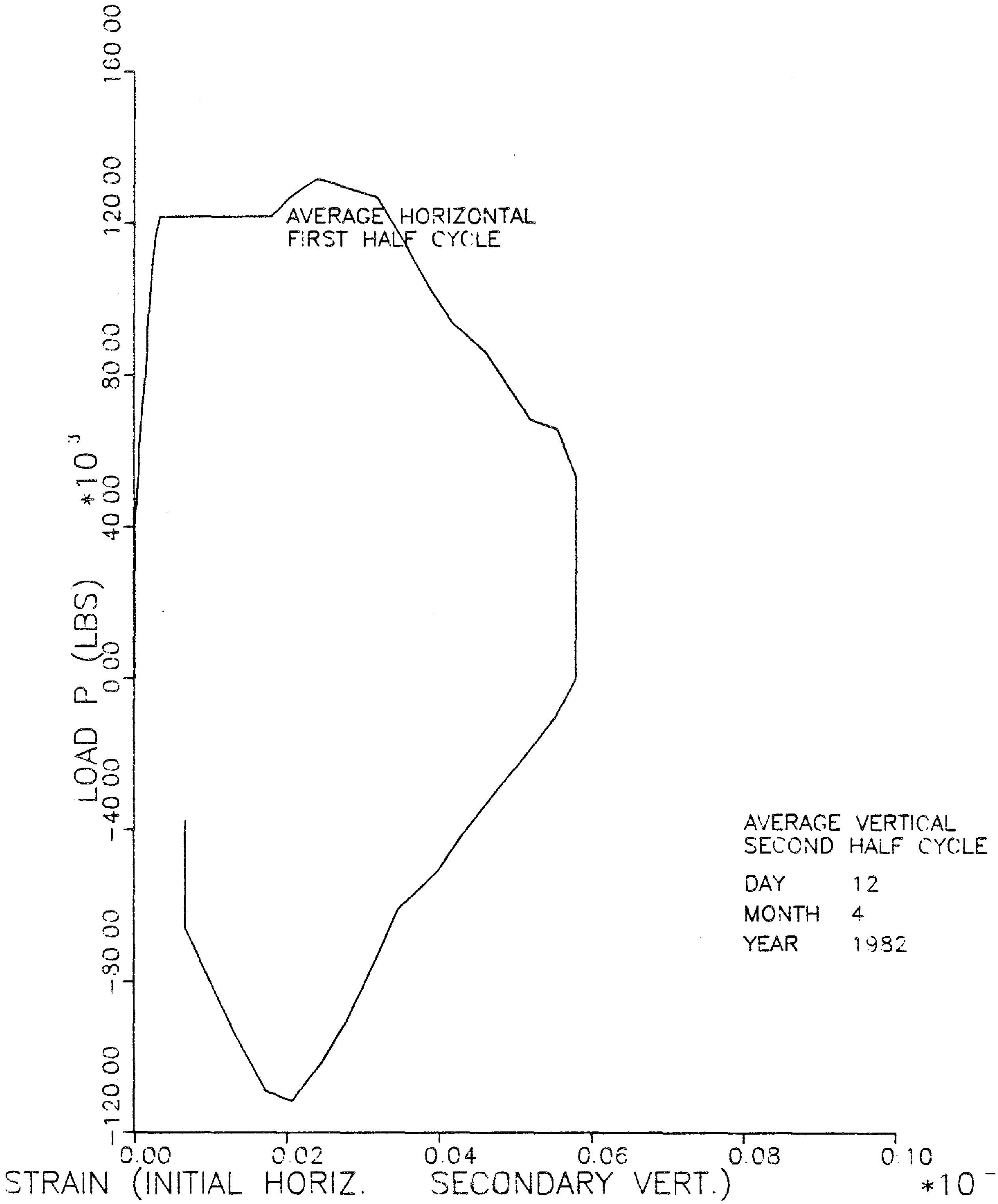
Figure D.72 Vertical vs Horizontal Strain Masonry Side Second Half-Cycle (D-3)



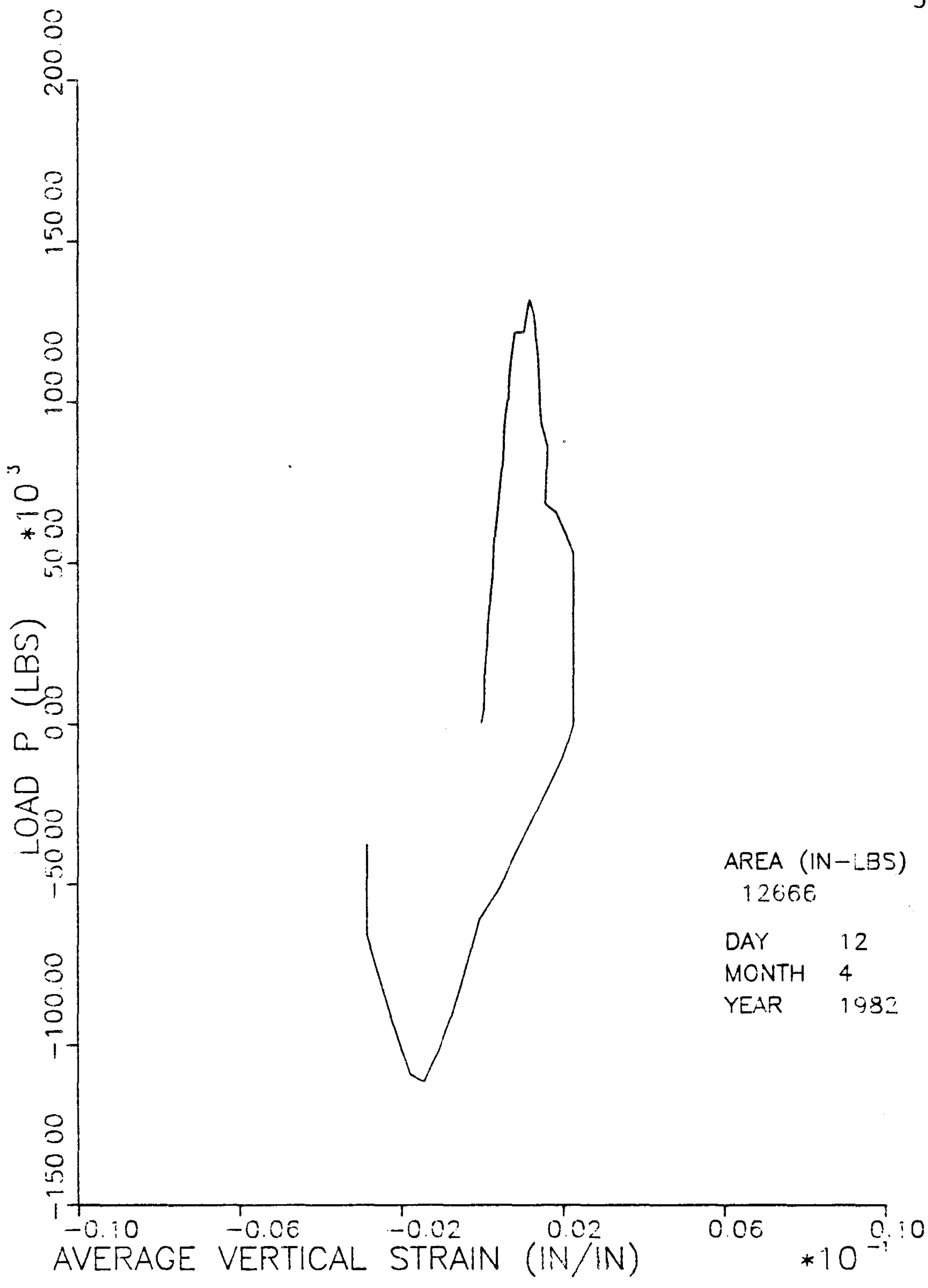
129 Figure D.73 Vertical vs Horizontal Strain Shotcrete Side Second Half-Cycle (D-3)



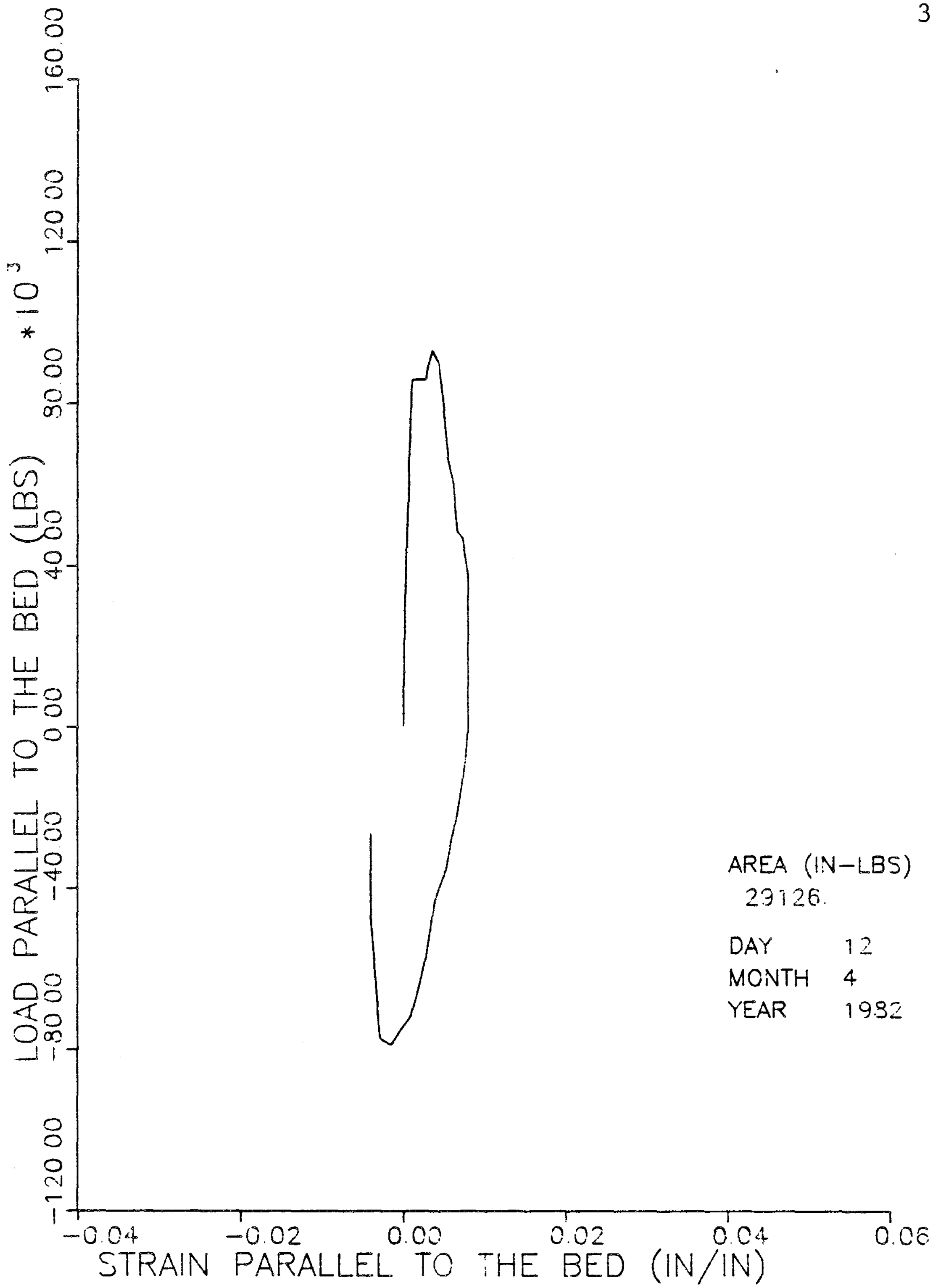
129
Figure D.74 Hysteresis Plot (D-3)



129 FigureD.75 Hysteresis Plot (D-3)



123 Figure D.76 Vertical Hysteresis Plot (D-3)



123

Figure D.77 Parallel to the Bed Hysteresis Plot (D-3)