Target: 90.25 - 382 Osaka Army Arsenal

Mission 224 26 June 45

Wing Bombing: 73, Aircraft Airborne 120 (4 Gps)
Aircraft Bombing Primary 109

Tons Airborne: 841.0
Tons Released over target 758.0

Type Bombs: AN M66 2000lb
Type Fuzing Nose .025 , tail, .025

Altitude of Release: Low 17400
High 29060

Type Bombing: Visual 0
Radar 109

Aiming Points: 2

Axis of attack 43 degrees true

Remarks: Strike reports should bob bursts and fires immediately North West of Castle, and about 2000 yards South of target.

No Strike Report No Damage Assessment.

Mission 286 24 July 45

Wing Bombing: 73 Aircraft Airborne 170 (4Gps)
Aircraft Bombing 35

Tons Airborne: 1190.0
Tons Releaed over target 216.0
Type Bombs AN M66 2000lb
Type Fuzing Nose, .025 Tail, .025
Altitude of Release: Low 19900'
High 20800'
Type Bombing: Visual 35
Radar 0

Number Squadrons Bombing: 4
Aiming Points: 2

Axis of attack 43 degrees true
Visual Hits 146
Bombing accuracy

0' to 1000'	1000' to 2000'	2000' to 3000'
28 - 19%	28 - 19%	20 - 13.8%

Roof area of target 5,020,400 sq ft

Destroyed or Da-ged	226,400 sq ft	4.5%
Gutted	218,500 sq ft	4.4%
Minor	68,600 sq ft	1.3%
Total	513,500 sq ft	10.2%

Removed or Destroyed to date
989,800 sq ft - 19.7%

Remarks: 199 A/C Bombed Kawana City

Mission 326 14 Aug 45

Wing Bombing 73rd Aircraft Airborne 161 (4Gps)
Aircraft Bombing Primary 145

Type Bombs AN M66 2000lb
AN M65 1000lb
Type Fuzing Nose, .025, tail, .025
Tons Airborne: 644.0 - AN M66
160.5 - AN M65

Tons Released over target: 570.0 AN M66
136.5 AN M65

Altitude of Release Low 22100'
High 25100'

Type Bombing: Visual 145
Radar 0
Aiming Points 2
Axis of attack 43 degrees
Formations Bombing 16
Visual hits: 544
Computed Hits: 288
Bombing Accuracy

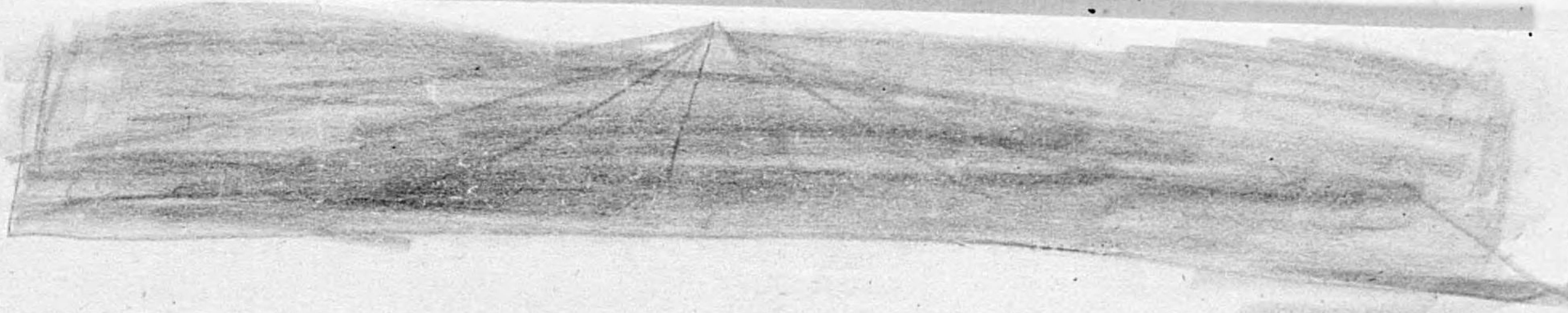
0' to 1000'	1000' to 2000'	2000' to 3000'
216 - 26%	405 - 48.7%	165 - 19.8%

Roof area of target 5,020,400 sq ft

Destroyed or damaged	494,907 sq ft	9.8%
Gutted	1,125,793 sq ft	22.4%
Minor	617,038 sq ft	12.3%
Total	2,237,739 sq ft	44.5%

Removed or destroyed to date

3,223,288 sq ft 64.3%



~~AIRBURST (ADD NOTE)~~ ✳ ~~(1) [illegible]~~

CRATER 2,000-LB. BOMB ~~[illegible]~~

CRATER 1,000-LB. BOMB ~~(2) [illegible]~~

UNEXBLODED BOMB ~~[illegible]~~

LOW ORDER DETONATION ~~(3) [illegible]~~

POSSIBLE LOW ORDER DETONATION

OK

✳ BOMBS WHICH WERE ACTIVATED BY ROOFS OR OTHER CONCRETE OBJECTS ABOVE GROUND LEVEL AND WHICH DETONATED BEFORE CONTACT WITH THE GROUND.

382 add to table 4/19/46

Bldgs Marked structural on Dwg; not in table (before rev)	old no	Bldgs Added ~~to table (Rev)~~ ~~Duplic.~~	Area of Bldg
F 43 ✓	52	~~45~~ *	5040
~~60~~			
~~72~~			
F ✓ 74 ✓	none		9900
F ✓ 82 ✓	95	82	31,080
F ✓ 84A ✓	108	84A	6440
F ✓ 92 ✓	32A		6160
~~S ✓ 93~~	115	chk. not wood 93 } add to table	~~35,000~~
~~S ✓ 94~~	116	chk. not wood 94	~~14,000~~
F 96 ✓	225, 78+		3920
S ✓ 101 ✓	124		3080
~~[illegible]~~			
S ✓ 116 ✓	186, 187		4200
S ✓ 117 ✓	184, 185		4760
~~[illegible]~~			
S ✓ 128 ✓	none ~~137~~		9000
S ✓ 130 ✓	72	~~130~~	11,200
S 131 ✓✓	74	~~131~~	9000
S 132 ✓✓	73	~~132~~	15000
F 143 ✓✓	130	~~143~~	5880

5,040
9,900
31,080

6,440
6,160.
3,920

5,880
15,000
6,000

31,000
3,600

3,090
4,200
4,760

9,000
11,200
9,000

15,000
2,000
4,500

3,150

F

S

			Area of bldg
F✓ 154 ✓	none		15000
S✓ 157 ✓	1&2	T57	2000
F✓ 159 ✓	1&6		6000
F 160 ✓		T60	31,000
S 161 ✓			4500
F 162 ✓			3600
S 163 ✓			3150

~~The following buildings were also ~~damaged~~ structurally damaged by H.E bombs. Details are unavailable ~~in the~~ (~~because the buildings were not shown on drawings available in Japan~~), because they were not considered in detail, of sufficient importance to survey, or because they had been ~~were~~ burned.~~

~~Following buildings burned~~

~~Following buildings structurally damaged~~

F - Wooden buildings destroyed by fire : 43 (5,040 sq ft); 74

S - Wood Frame construction 100% structurally Damaged

THESE BLDG. ~~#s~~ ARE MARKED STRUCT.
BUT DO NOT APPEAR
ON THE SHEETS.

# 43	~~145~~
	154
68	157
72	159
74	160
82	161
84A	
92	
93	
94	
96	
101	
109	
116	
117	
121	
128	
130	
131	
132	

P. NO 100A IS NOT ON THE DRAWING

84A

Arsenal - Bldgs destroyed by fire

92

74

161

96

128

Bldgs ~~destroyed~~ structurally dam - not fire

116~~3~~

117

note make separate sheet on

382 Superf. Damage

Bldg 60	70% N.S.D.	Bldg 85	80% ✓
33	75% ✓ N.S.D.		
32	50% N.S.D		
31	15% ✓		
6	10% N.S.D		
10	100% ✓		
15	50% ✓		
68, 69, 70	100% ? ✓		
76, 77, 78	25% N.S.D		
101	75% N.S.D.		
112	70% N.S.D.		
120	70% ✓		
135	90% N.S.D.		
129	10% N.S.D.		
128	10% N.S.D.		
140	85% N.S.D.		
141	5% N.S.D.		
~~58~~ 57	80% N.S.D.		
26	50% ✓		
20	20% ✓		
~~65A~~ 60	70% N.S.D.		
61	50% N.S.D		
62	50% N.S.D.		

RESTRICTED

OSAKA ARMY ARSENAL

TABLE G

THE FOLLOWING WOODEN BUILDINGS WERE COMPLETELY DESTROYED BY EITHER PRIMARY OR SECONDARY FIRE FROM 4,000 POUND H. E. RAIDS.

BUILDING NUMBER	DAMAGED BUILDING AREA IN SQ. FT.
~~45~~	~~[illegible]~~
~~129~~	~~11,200~~
~~130~~	~~11,200~~
~~[illegible]~~	~~73,920~~
~~[illegible]~~	~~75,600~~
82 ✓	31,080
84A ✓	6,440
~~93~~ ✓	35,000
~~94~~ ✓	14,000
143 ✓	5,880
~~109~~	9,800
157 ✓	1,960
160 ✓	37,240
92 ✓	
74 ✓	
161 ✓	
96 ✓	

RESTRICTED

116 ✓ } structurally damaged ~~damaged~~, but not fire
117 }
~~[illegible]~~
132 ✓

NEW NUMBERS

CHECK ON # [redacted] ← NEW NUMBERS

92A	28
[redacted]	16
[redacted]	[redacted]

92A OLD

SUPERFICIAL DAMAGE %'s (NEW NUMBERS)

100% SUPERFICIAL ALREADY MARKED

~~2A~~		~~59~~
~~5~~		~~61~~
~~39~~		~~81~~
~~62~~		~~96~~
~~25~~.		~~106~~
~~CAR YARD B~~		~~1A & 125~~
~~85~~		~~127~~
~~86~~		~~152~~
~~133~~	~~70~~	~~10~~
~~78~~	~~75~~	~~11~~
~~80~~	~~60~~	~~68~~
~~81~~	~~76~~	~~71~~
~~48~~	~~79~~	~~95~~
~~146~~	~~99~~	~~113~~
~~145~~	~~114~~	~~112~~
~~47~~	~~15~~	~~110~~
~~18~~	~~156~~	~~100~~
~~21~~	~~108~~	~~139~~
~~12~~	~~79A~~	~~153~~
~~10~~	~~103A~~	~~52~~
~~33~~		~~106~~
~~64~~		~~98~~
~~1~~		~~111~~

23 - 75%
22 - 50%
21 - 15%
17 - 10%
6 - 50%
134 - 25%
135 - 25%
136 - 25%
~~[illegible]~~
89 - 70%
97 - 70%
105 - 90%
141 - 10%
140 - 10%
142 - 85%
147 - 5%
45 - 30%
46 - 80%
14 - 50%
~~[illegible]~~
60 - 20%

100% STRUCTURAL

~~2~~
~~82~~
~~109~~
~~113~~
~~112~~
~~111~~
~~139~~
~~143~~
~~43~~
~~15~~
~~11~~
~~67~~
~~67A~~
~~61~~
~~91~~
~~93~~
~~131~~ ✓
~~83~~ ✓
~~132~~ ✓
~~101~~
~~102~~ ~~103~~
~~150~~ [redacted] + ~~116~~ + ~~143~~
~~[illegible]~~ + ~~[illegible]~~ + ~~13~~ + ~~123~~

NO DAMAGE → 4 ←

[redacted]

NOT ON DRAWINGS

[redacted]

~~[illegible]~~

~~145~~ 1#

6800

NEW NUMBERS

$\frac{3}{12} = \frac{1}{4}$

149	92A
79A	~~103~~
~~15~~	~~16~~

65A & 82A

$\frac{15}{50} = \frac{3}{10}$

super

% OF TOTAL FLOOR AREA

23 - 75%		
22 - 50%		
21 - 15%		
17 - 10%		
6 - 50%		
134 - 25%		
135 - 25%	14 - 50%	
136 - 25%	16 - 50%	
89 - 20%	60 - 20%	
97 - 60%	156 - 40%	157
105 - 90%	58 - 70%	158
141 - 10%	97 - 60%	92
140 - 10%	149 - 20%	122
142 - 85%		
147 - 5%		
45 - 30%		
46 - 80%		
14 - 50%		
75 - 80%		
~~60 - 20%~~		
21 - 15%		

100%

100%

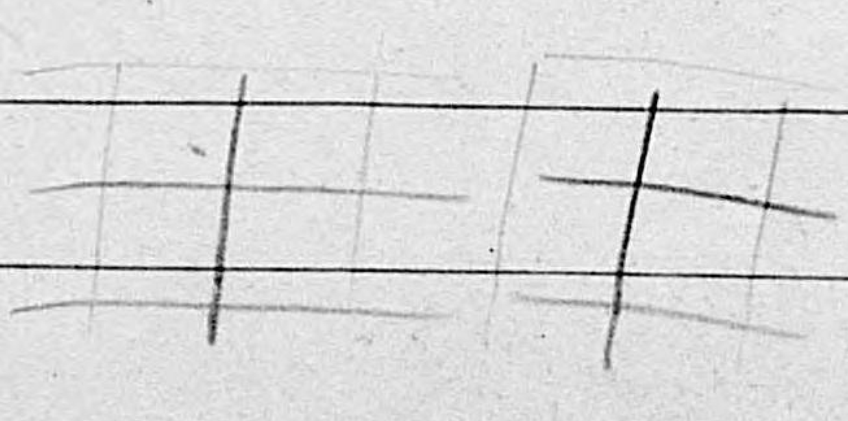
100%

100%

100%

#155 & 52

153 _	OK 148	100% S	82A _	X ?	100% S
154 _	OK 149	" "	83 _	X 67A	100%" STRUCTURAL
152 _	OK 146	" "	84 _	X 75	80% S
151 _	OK 145	" "	87 _	X 69	100% STRUCTURAL
130 _	X 143	100% STRUCTURAL	65 _	OK 59?	100% SUPERFICIAL
51 _	OK. 42	100% S	66 _	X ~~OK~~ 60	20% SUPERFICIAL
52 _	X 43	100% STRUCTURAL	67 _	OK 61	100% SUPERFICIAL
56 _	X 45	30% S	105 _	OK 81	100% SUPERFICIAL
57 _	X 46	80% S	113 _	OK. 90	100% S
37 _	X 28 OK	100% S	114 _	X 91	100% STRUCTURAL
NOTE [illegible] 38 _	X 29 OK	" "	115 _	X 93	100% STRUCTURAL
26 _	X 14	50% S	125 _	X 101	" " "
17 _	X 15	100% STRUCTURAL	126 _	X 102	" " "
29 _	~~OK~~ X 16	20% S	136 _	OK X 106	100% S
22 _	OK X 12	100% S	147 _	OK ~~[illegible]~~ 124 & 125	"
21 _	X 11	100% STRUCTURAL	147A 151 _	~~OK~~ ? 127	" "
2 _	OK 50	100% S	150 _	X 1	100% STRUCTURAL
3 _	X	NOT ON DRAWING	149 _	X 150	" " "
58 _	OK 53	100% S	158 _	OK 152	100% SUPERFICIAL
65A _	X ?	70% S	165 _	156	NO DAMAGE
79 _	OK. 64	100% S			
80 _	OK, 66	" "			
82 _	X 67	100% STRUCTURAL			



OLD NUMBERS

92A	100	65A	82A
26 ✓	136 ✓	145 ✓	61 ✓
27 ✓	133 ✓	143 ✓	81 ✓
25 ✓	78 ✓	42 ✓	90 ✓
24 ✓	80 ✓	43 ✓	91 ✓
23 ✓	79A ✓	45 ✓	93 ✓
22 ✓	89 ✓	46 ✓	101 ✓
21 ✓	97 ✓	28 ✓	102 ✓
17 ✓	87 ✓	29 ✓	106 ✓
3 ✓	137 ✓	1A ✓	124 ✓
4 ✓	109 ✓	15 ✓	125 ✓
5 ✓	105 ✓	16 ✓	127 ✓
6 ✓	113 ✓	12 ✓	150 ✓
39 ✓	112 ✓	11 ✓	151 ✓
62 ✓	121 ✓	50 ✓	152 ✓
73 ✓	123 ✓	53 ✓	156 ✓
Coal Yard O ✓	141 ✓	64 ✓	
85 ✓	140 ✓	66 ✓	
86 ✓	139 ✓	67 ✓	
82 ✓	142 ✓	67A ✓	
83 ✓	147 ✓	75 ✓	
134 ✓	148 ✓	69 ✓	
135 ✓	149 ✓	59 ✓	
	146 ✓	60 ✓	

superficial = X
structural = S

89 70% X oh	111 100% X oh	133 100% X oh	155 100% S oh
90 100% X oh	112 100% X oh 100% S	134 25% X oh	156 100% X 90% X oh
91 100% S oh	113 100% X oh 100% S	135 25% X oh	157 100% S oh
92 100% S oh	114 100% X oh	136 25% X oh	158 100% X oh
93 100% S oh	115 100% X oh	137 oh	159 100% S oh
94 100% S oh	116 oh	138 oh	160 100% S oh
95 100% S oh	117 oh	139 100% X oh 100% S	COAL YD. A. oh
96 oh	118 oh	140 10% X oh	COAL YD. B. 100% X oh
97 60% X oh	119 oh	141 10% X oh	79 A 100% X oh
98 100% X oh	120 oh	142 85% X oh	67 A 100% S oh
99 100% X oh	121 100% S oh	143 100% S oh	103 A 100% X oh
100 100% X oh	122 oh	144 100% S oh	
101 100% S oh	123 100% S oh	145 100% X 100% S oh	
102 100% S oh	124 100% X oh	146 100% X 100% S oh	
103 100% S oh	125 100% X oh	147 5% X oh	
104 oh	126 oh	148 100% X oh	
105 90% X oh	127 100% X oh	149 20% X oh	
106 100% X oh	128 oh	150 100% S oh	
107 oh	129 oh	151 100% S oh	
108 oh	130 100% S oh	152 100% X oh	
109 100% S oh	131 100% S oh	153 100% X oh	
110 100% X oh	132 100% S oh	154 100% S oh	

#74 struct.

bomb 49 ~~struct~~ bldg #161 ADD TO LEGEND

#96 struct

[redacted]

~~58 super~~

#116 struct

#117 struct

#128 struct.

[redacted]

#32 100% SUPER

OK

~~#74 100% STRUCT.~~

~~# 96 100% " "~~

~~#58 100% SUPER~~

~~#116 100% STRUCT.~~

~~#117 " " " "~~

~~#128 100% STRUCT.~~

~~#32 100% SUPER~~

ORIGINATE BLDG. #161

AT THE LOCATION OF BOMB #49.

STRUCT

~~58 - 100% SUPER~~ STRUCT.

32 - 100% Super.

STRUCT

superficial = X

structural = S

1	oh	23	75% X oh	45	30% X ?	67	100% S oh
2	oh	24	100% X oh	46	80% X oh	68	100% X oh
3	100% S oh	25	100% S oh	47	oh	69	100% S oh
4	oh	26	100% S oh	48	oh	70	oh
5	100% X oh	27	100% S oh	49	oh	71	100% X oh
6	50% X oh	28	100% X oh	50	100% X oh	72	100% S oh
7	oh	29	100% X oh	51	100% S oh	73	100% X oh
8	oh	30	100% X oh	52	100% X oh	74	oh
9	oh	31	oh	53	100% X oh	75	100% X — ~~80%~~ X oh
10	Oh	32	oh	54	oh	76	100% X oh
11	100% X 100% S oh	33	oh	55	oh	77	25% S oh
12	100% X oh	34	oh	56	oh	78	100% X oh
13	oh	35	100% X oh	57	oh	79	100% X oh
14	50% X oh	36	oh	58	70% X oh	80	100% X oh
15	100% S oh	37	oh	59	100% X oh	81	100% X oh
16	100% X oh	38	oh	60	20% X / 100% X } oh	82	100% S oh
17	10% X oh	39	100% X oh	61	100% X oh	83	100% S oh
18	oh	40	oh	62	100% X oh	84	100% S oh
19	oh	41	oh	63	oh	85	100% X oh
20	oh	42	100% X oh	64	100% X oh	86	100% X oh
21	15% X oh	43	100% S oh	65	oh	87	100% X oh
22	50% X oh	44	oh	66	100% X oh	88	Ok

33 + 47

TARGET # 382
OSAKA ARSENAL

36 ✓OK 26-27	100% STRUCTURAL			
35 ✓OK 25 -	100% S	78 _ X 136	25% S	
34 ✓OK _ 24	100% S	75 _ ✓OK 133	100% S	
33 [redacted] X 23	75% S	97 ✓OK 78	"	"
32 _ X 22	50% S	100 ?	100% S	
31 _ X 21	15% S	99 ✓OK 80	"	"
6 _ X 17	10% S	101 _ X 79A	75% S	
10 _ X 3	100% STRUCTURAL NOT ON DRAWING	102 _ X 79A	100% S	
13 _ X 4	NO DAMAGE	112 _ X 89	70% S	
14 ✓OK 5	100% S	120 _ X 97	70% S	
15 _ X 6	50% S	111 ✓OK 87	100% S	
47 ✓ 39	100% S	103 _ X 132	100% STRUCTURAL	
92 ✓OK 62	100% S	134 _ 109	100% STRUCTURAL	
92A _ X ?	100% S	135 _ X 105	90% S	
93 ✓OK. 73	"	"	144 X 113	100% STRUCTURAL
68 ✓OK Gal Yard B	"	"	145 _	NOT IN DRAWING
69 ✓OK "	"	"	143 _ 112	100% STRUCTURAL
70 ✓OK "	"	"	CHECK? FROM [illegible] ✓OK 121	100% STRUCTURAL
94 ✓OK 85	"	"	156 ✓OK. 123	OK " "
109 ✓OK 86	"	"	129 _ X 141 K	10% S
95 _ X 82	100% STRUCTURAL	128 _ X 140	10% S	
106 _ X 83	" " " "	127 _ 139 K	100% STRUCTURAL	
76 _ X 134	25% S	140 _ X 42	85% S	
77 X 135	" "	OK 141 _ X 142 OK	5% S	

100% superficial

~~[illegible]~~ (20) — 12 ✓

~~[illegible]~~ (27) — 50 ✓

~~25~~ (25) — 53 ✓

24 ✓ — 64 ✓

5 ✓ — 66 ✓

39 ✓ — ~~[illegible]~~

62 ✓ — 59 ✓

73 ✓ — 61 ✓

6(1) 45 B" ✓ — 81 ✓

85 ✓ — 90 ✓

86 ✓ — 106 ✓

133 ✓ — ~~116~~ ✓ 124 & 125

78 ✓ — 127 ✓

80 ✓ — 152 ✓

87 ✓

~~[illegible]~~ (A) STRUCTURAL

148 ✓

~~144~~ CHECK IN NOTE BOOK.

146 ✓

145 ✓

42 ✓

28 ✓

29 ✓

15 MONTHS

16 MONTHS

$7\frac{1}{2}$

$9\frac{1}{2}$

$1\frac{1}{4}$

$1\frac{1}{4}$

$18\frac{1}{2}$

19 POINT AS OF JULY 30

81A

84A ✓ STRUCTURAL NOT ON SHEETS

~~103A ✓ ON SHEETS~~

~~67A ✓ ON SHEETS~~

~~104A # 161 UNKNOWN~~

~~84A~~ ✗ 84A DO NOT ADD TO LEGEND

OFFICE → 103A ADD TO LEGEND

UNKNOWN → 67A " " " "

UNKNOWN 81A ADD TO LEGEND

UNKNOWN 161 ADD TO LEGEND

161 - UNIDENTIFIED

67A - " "

81A - " "

103A - OFFICE "

5 1/4" x 2"

U.S. STRATEGIC BOMBING SURVEY

~~USSBS~~

OSAKA ARMY ARSENAL

OSAKA, JAPAN

BOMB & DAMAGE PLOT FIG. #

			#43✓	#72✓
			# [redacted]	#74✓
			#68✓	[redacted]
3 - OK	53 OK	84 OK	127 OK #84A?	#82✓
5 - OK	59 OK	85 OK	133 OK	#92✓
6 - OK	60 OK	86 OK	139 OK 100A?	#93✓
11 SEC. I - OK	61 SEC. A OK	87 OK	144 OK	#94✓
11 SEC. II - OK	61 SEC. B OK	90 OK	145 OK	#96✓
12 - OK	61 SEC. C OK	91 OK	146 OK	#101✓
14 - OK	[redacted]	95 OK	148 OK	#109✓
15 - OK	64 OK	97 OK	149 OK	#116✓
16 - OK	66 OK	98 OK	150 OK	#117✓
21 - OK	67 OK	99 OK	151 OK	#121✓
23 - NO	67A OK	100 OK	152 OK	#128✓
24 - OK	69 OK	100A ✓	153 OK	#130✓ #131✓
25 - OK	71 OK	102 OK	155 OK	#137✓ #143✓
26 - OK	73 OK	103 OK	156 OK	154✓
27 - OK	75 OK	103A OK	158 OK	157✓
28 - OK	76 OK	106 OK		159✓
30 - OK	77 OK	110 OK		160✓
35 - OK	78 OK	111 OK		161
42 - OK	79 OK	112 OK		
45 - OK	79A OK	113 OK		
50 - OK	80 OK	114 & 115 OK		
51 OK	#81 OK 81A OK	123 OK		
52 OK	83 OK	124 & 125 OK		

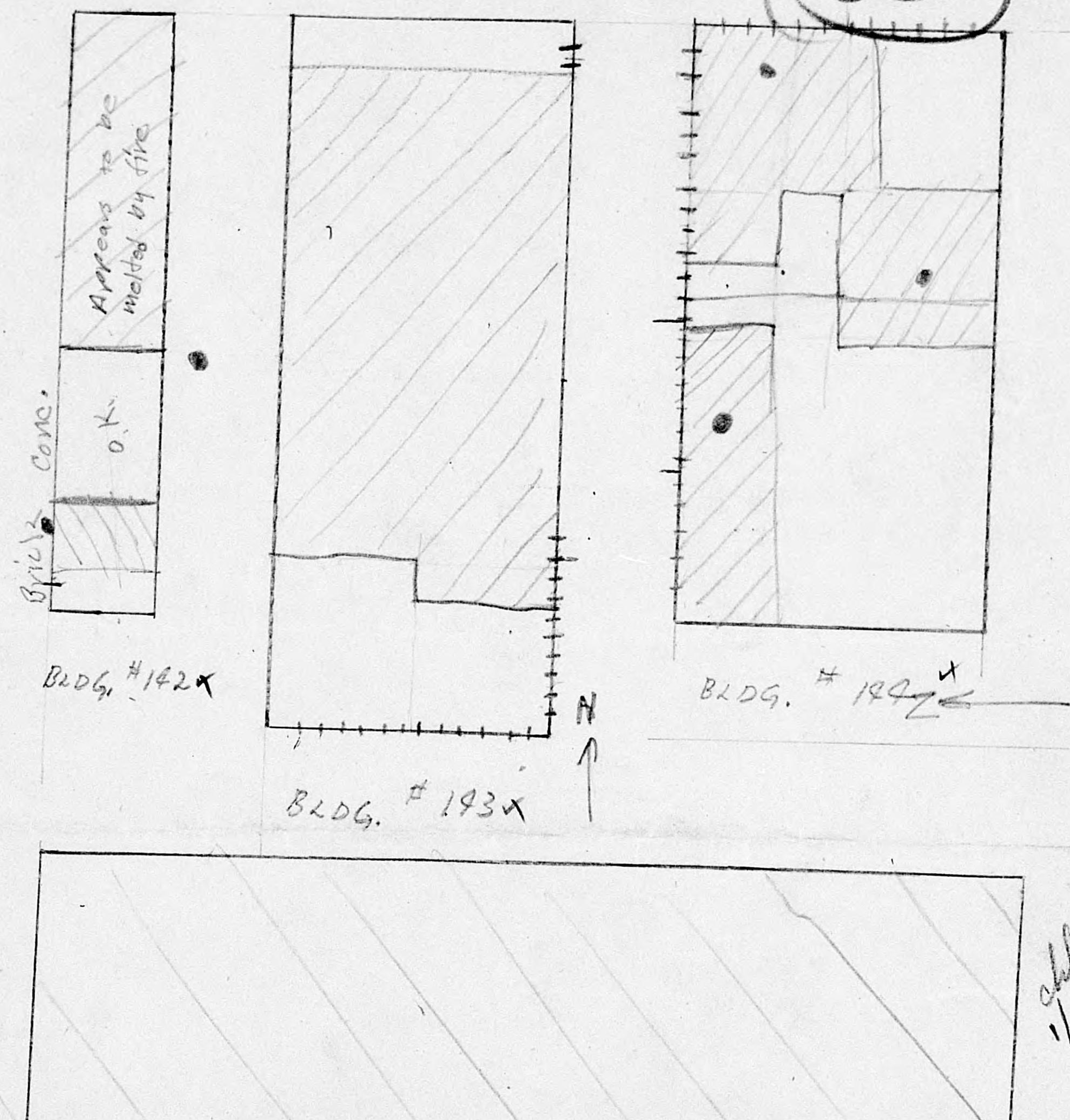
W TARGET #382

(d)

U. S. STRATEGIC BOMBING SURVEY

USSBS File

APO 234, c/o Postmaster
San Francisco, California



chk 1/22/46 RB

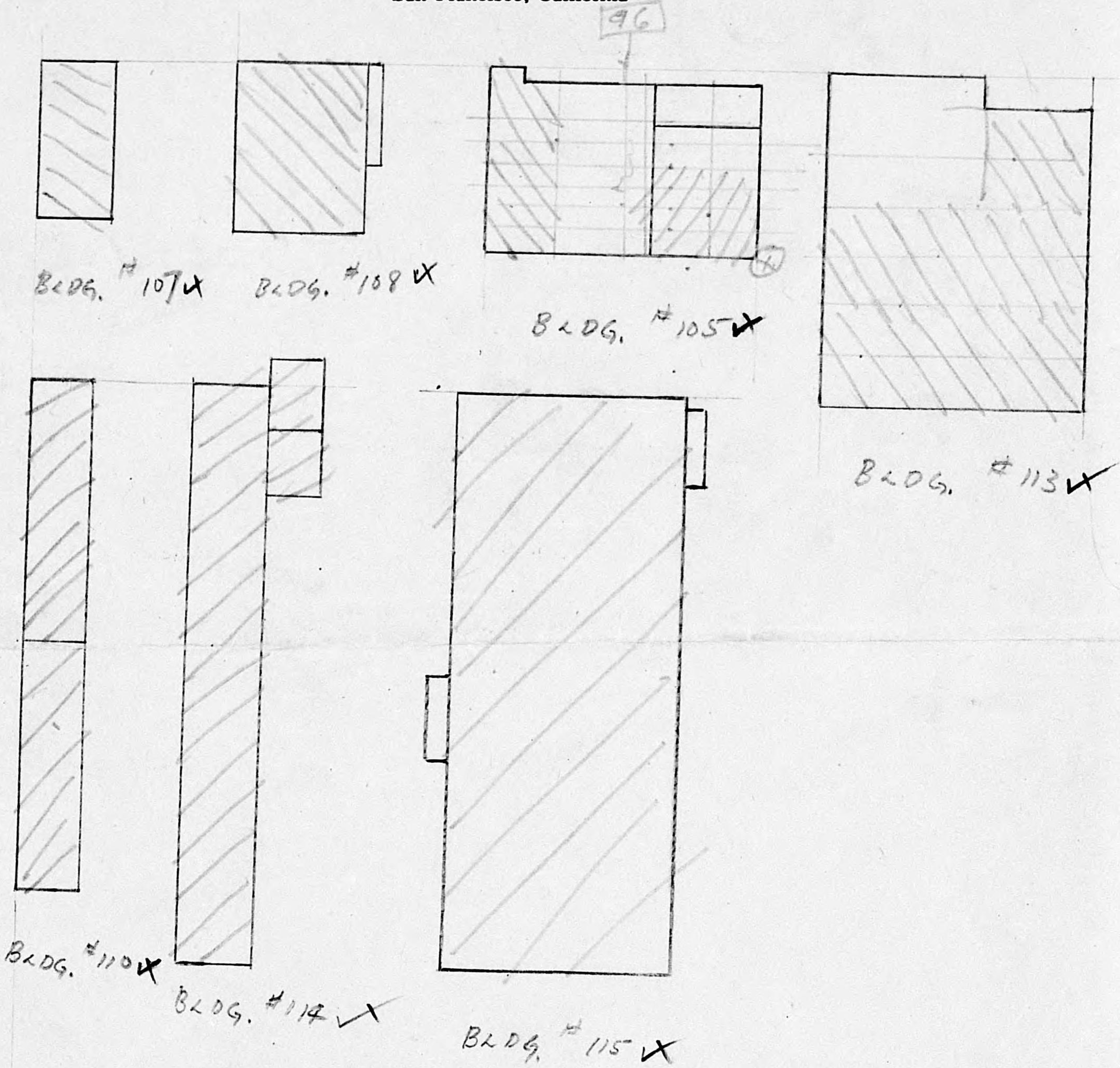
BLDG. #142
" #143
" #144
" #145

TARGET #382

U. S. STRATEGIC BOMBING SURVEY

APO 234, c/o Postmaster
San Francisco, California

USSBS
File



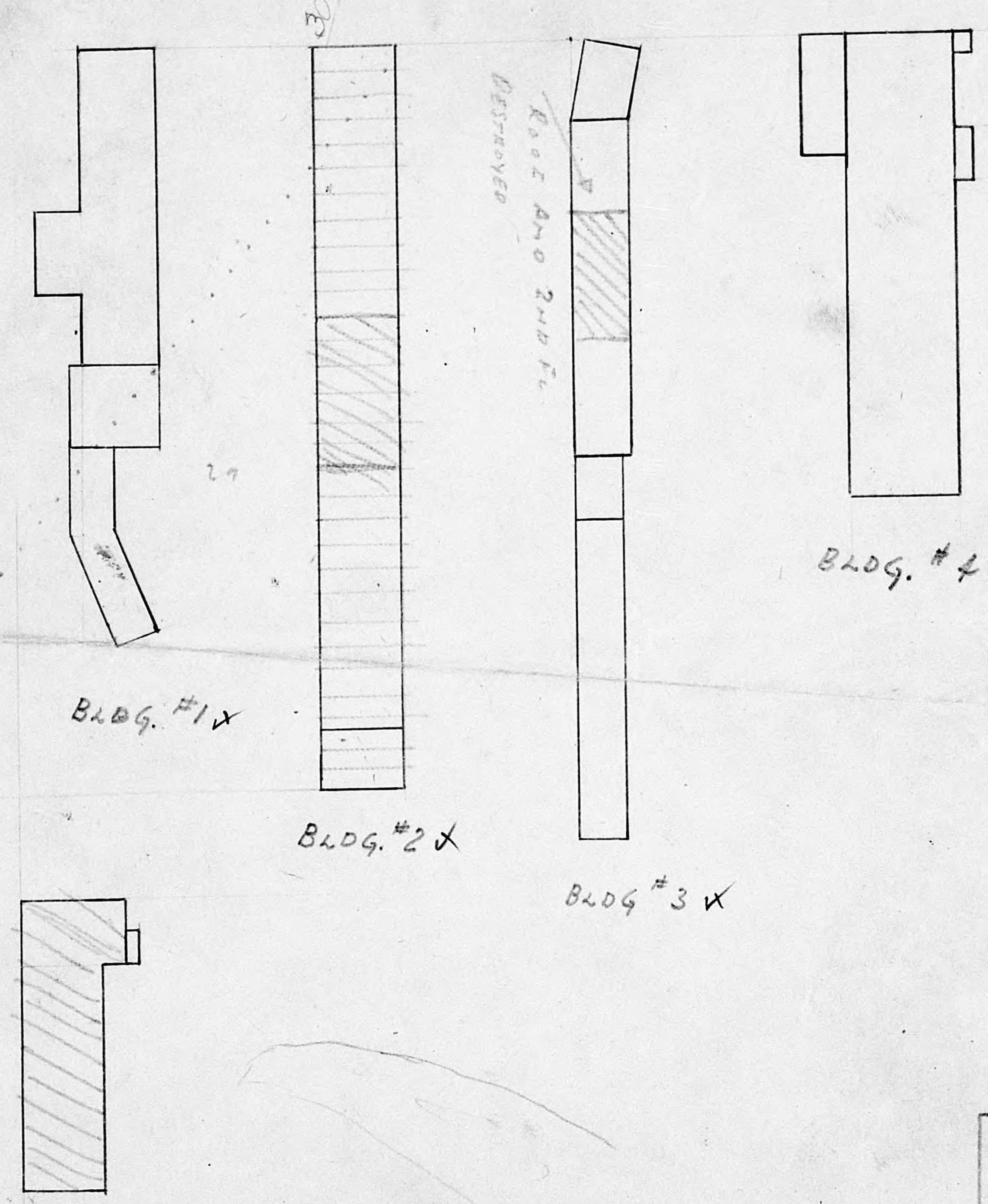
chk 1/22/46
RBM

TARGET # 382

U. S. STRATEGIC BOMBING SURVEY

APO 234, c/o Postmaster
San Francisco, California

USSBS
File



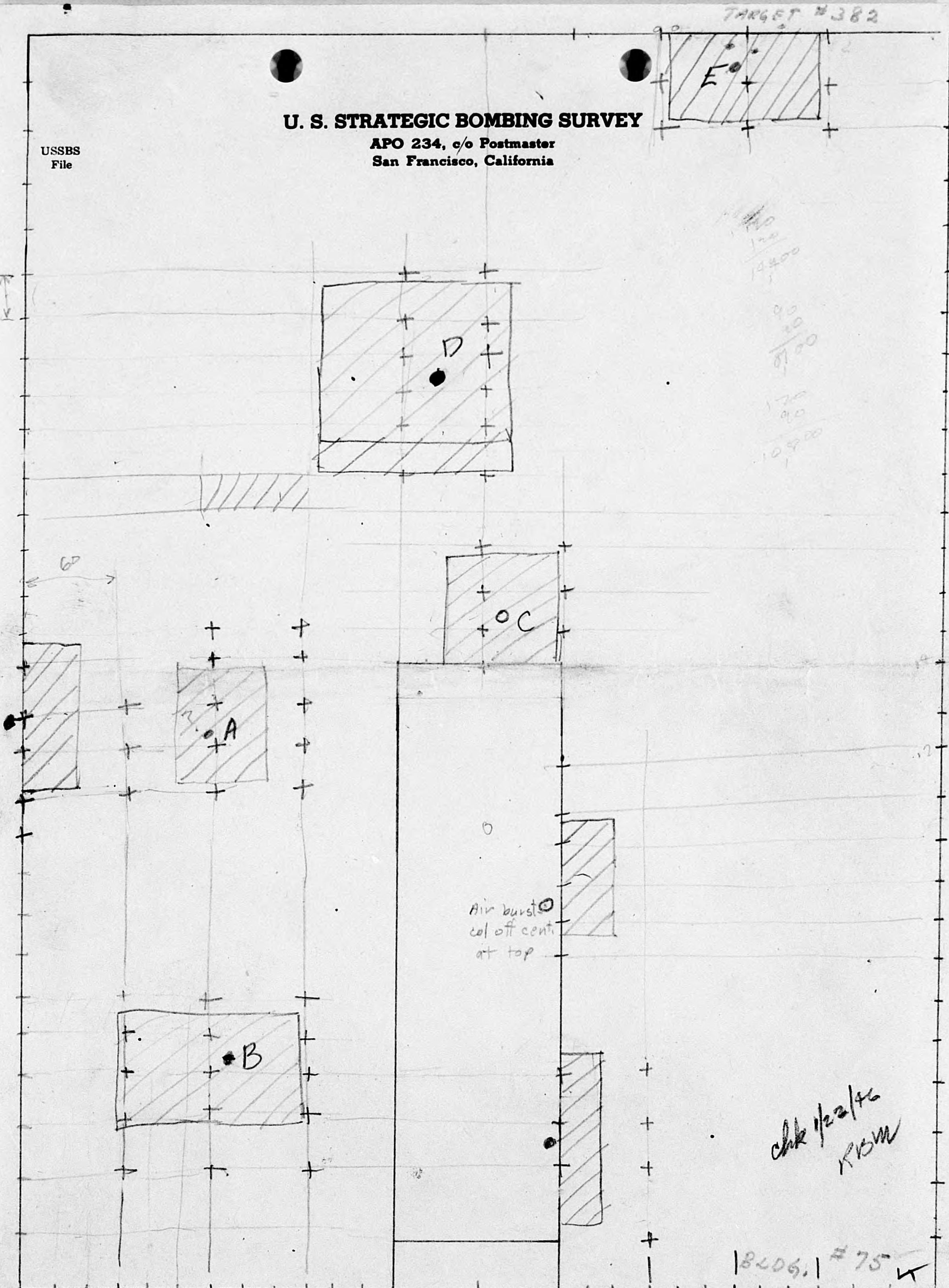
BLDG. #1
" #2
" #3
" #4
" #5

Chk 1/22/46
RBM

USSBS File

U. S. STRATEGIC BOMBING SURVEY

APO 234, c/o Postmaster
San Francisco, California

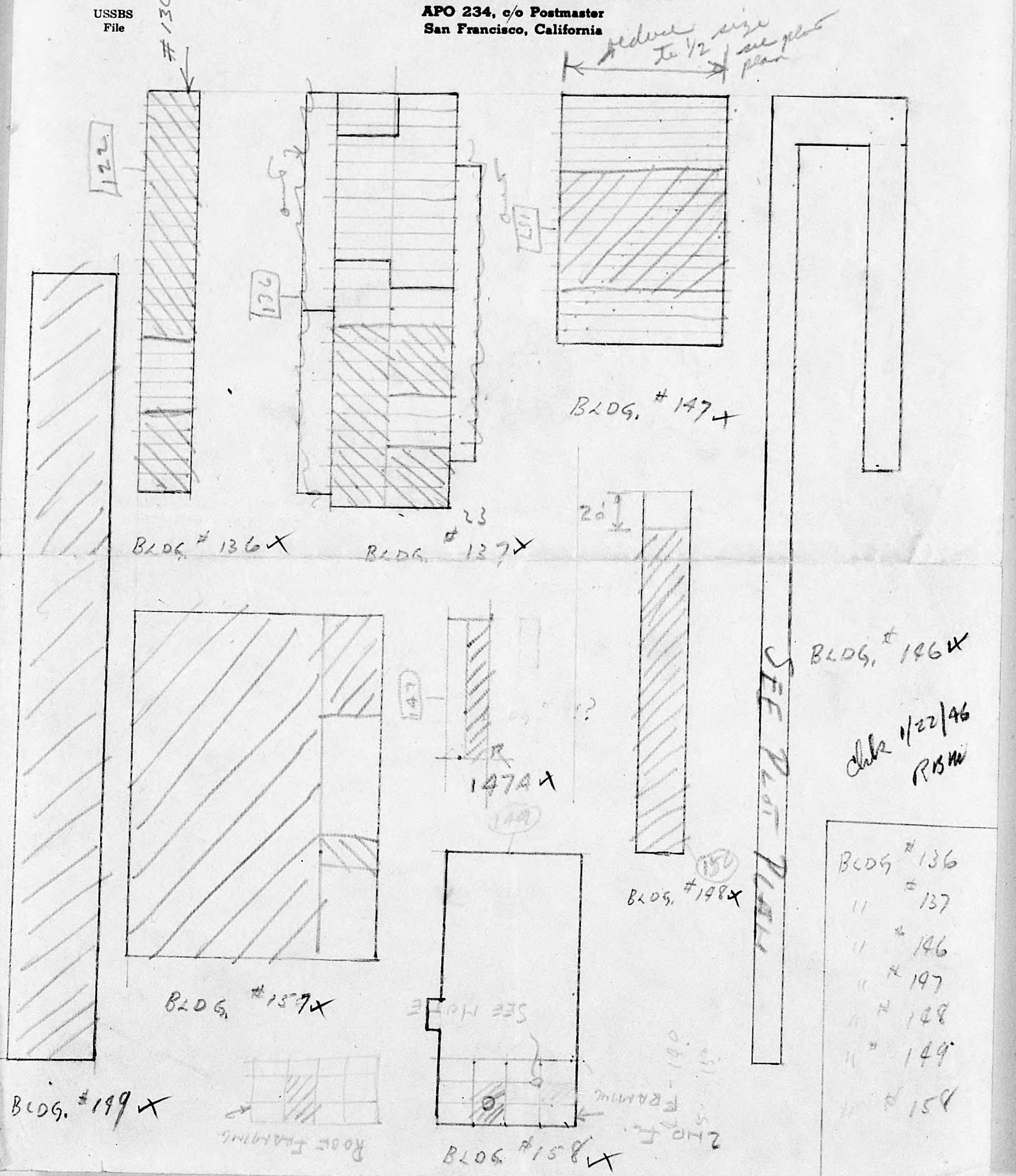


B

TARGET #382

USSBS
File

U. S. STRATEGIC BOMBING SURVEY
APO 234, c/o Postmaster
San Francisco, California

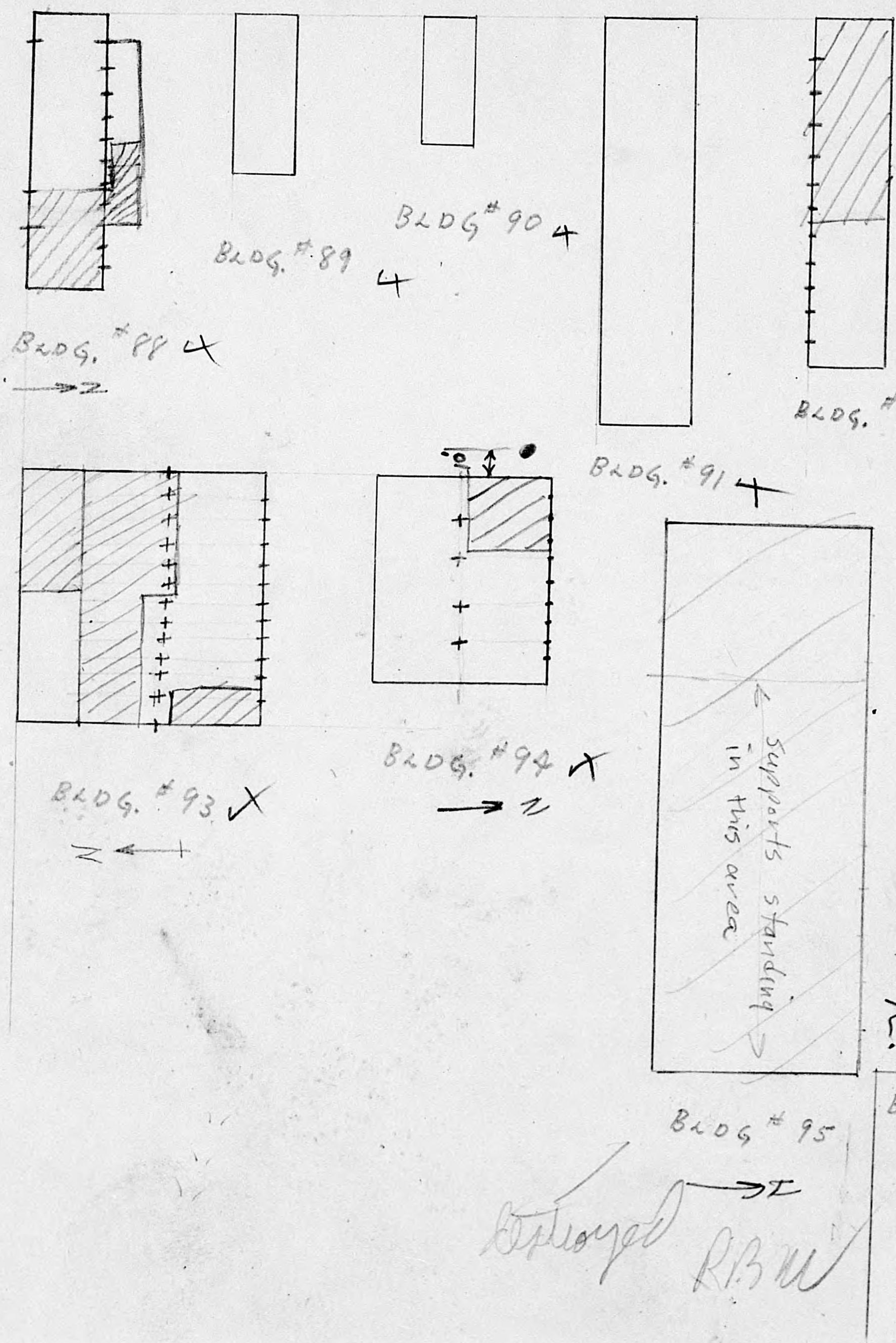


TARGET #382

U. S. STRATEGIC BOMBING SURVEY
APO 234, c/o Postmaster
San Francisco, California

USSBS
File

(12 BAYS)



chk 1/23/46 RBW

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TARGET #382

U. S. STRATEGIC BOMBING SURVEY
APO 234, c/o Postmaster
San Francisco, California

USSBS
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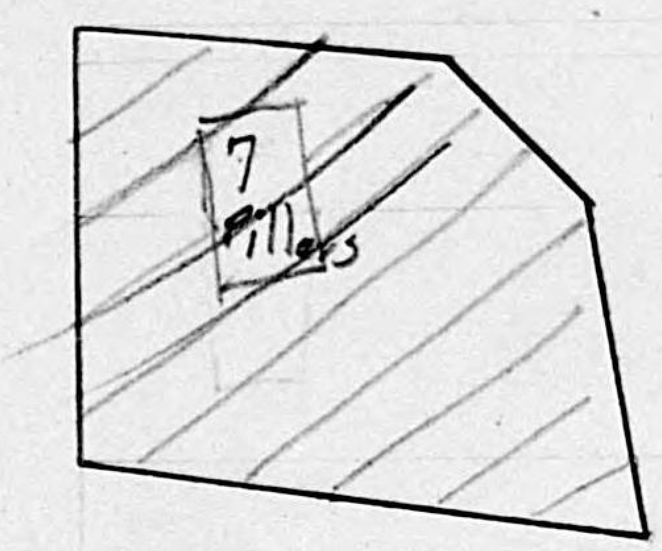

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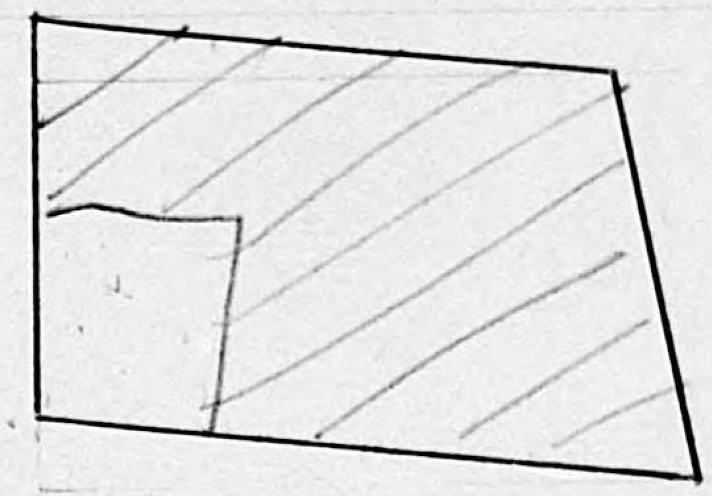

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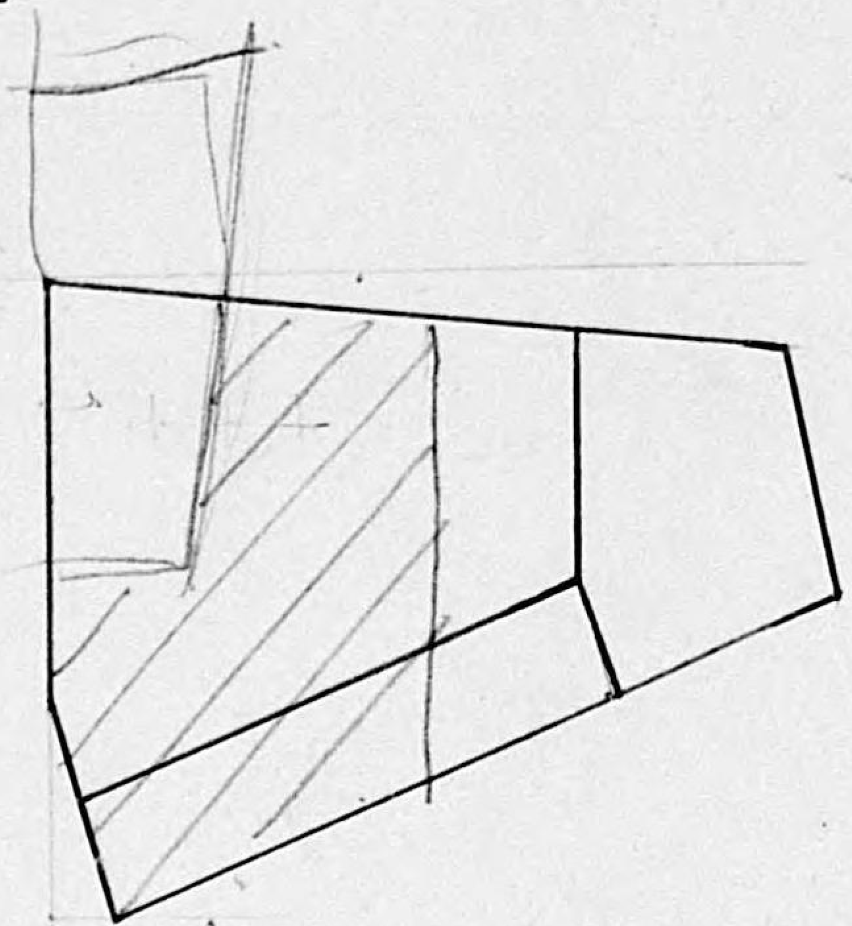

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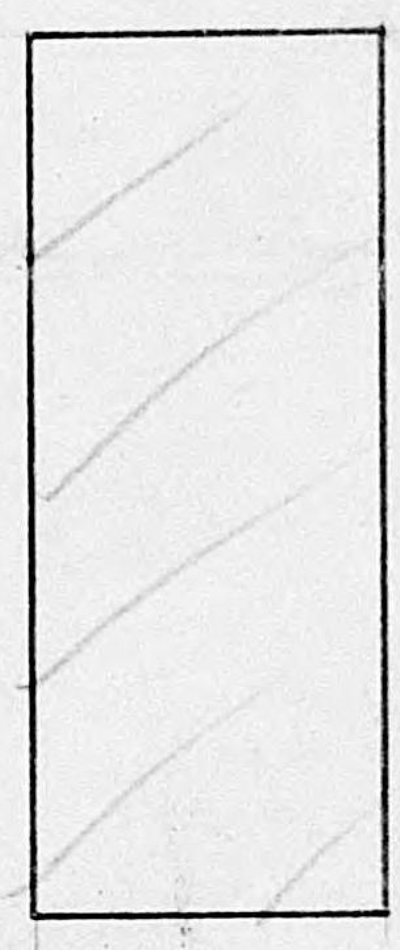

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chk 1/22/46
RBW

BLDG. #68 ✓
" #69 ✓
" #70 ✓
" #71 ✓
" #72 ✓

TARGET #382

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USSBS
File

BLDG. #74 x

BLDG. #73 +

file 1/22/46

BLDG. #73
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TARGET #382

USSBS
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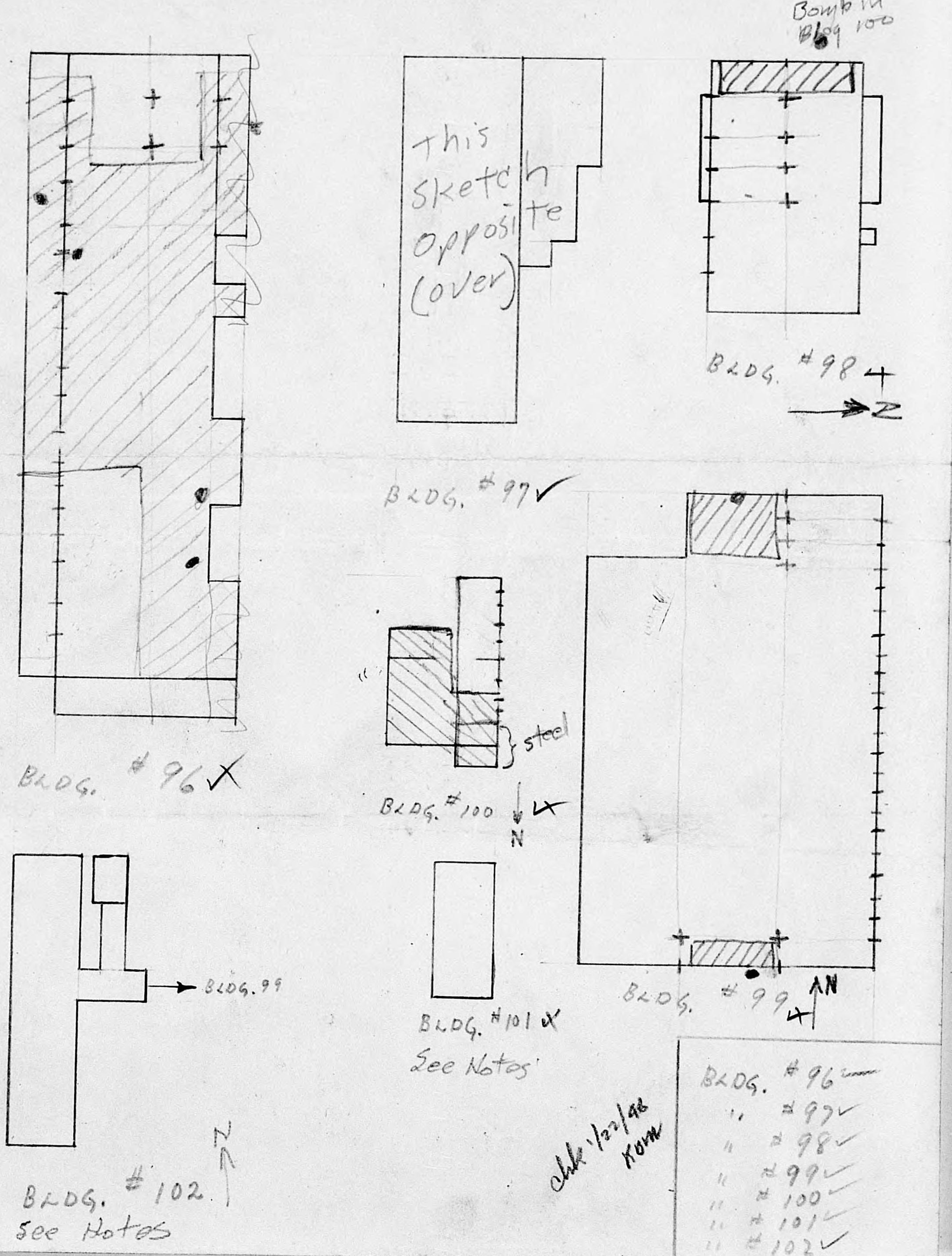

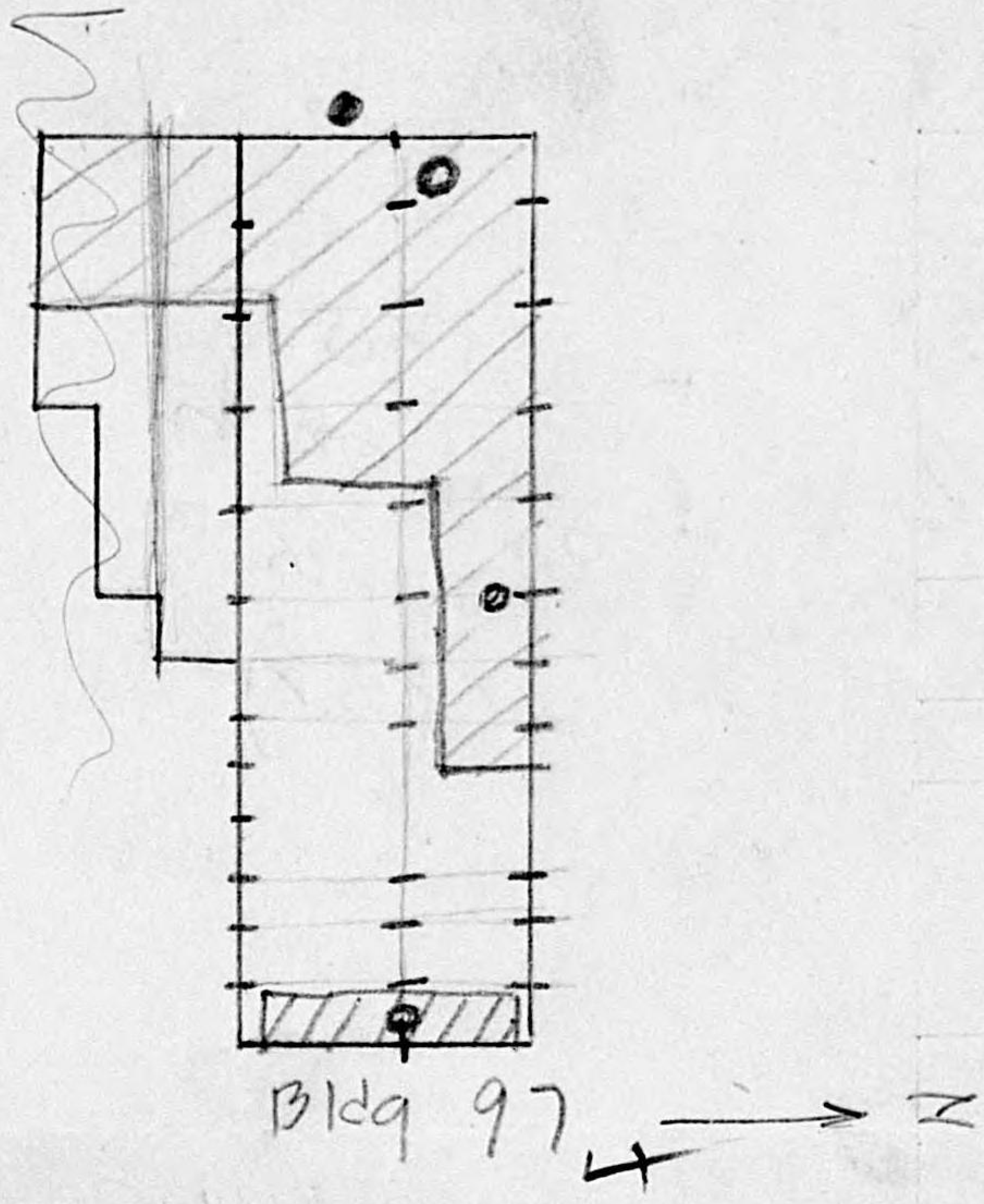
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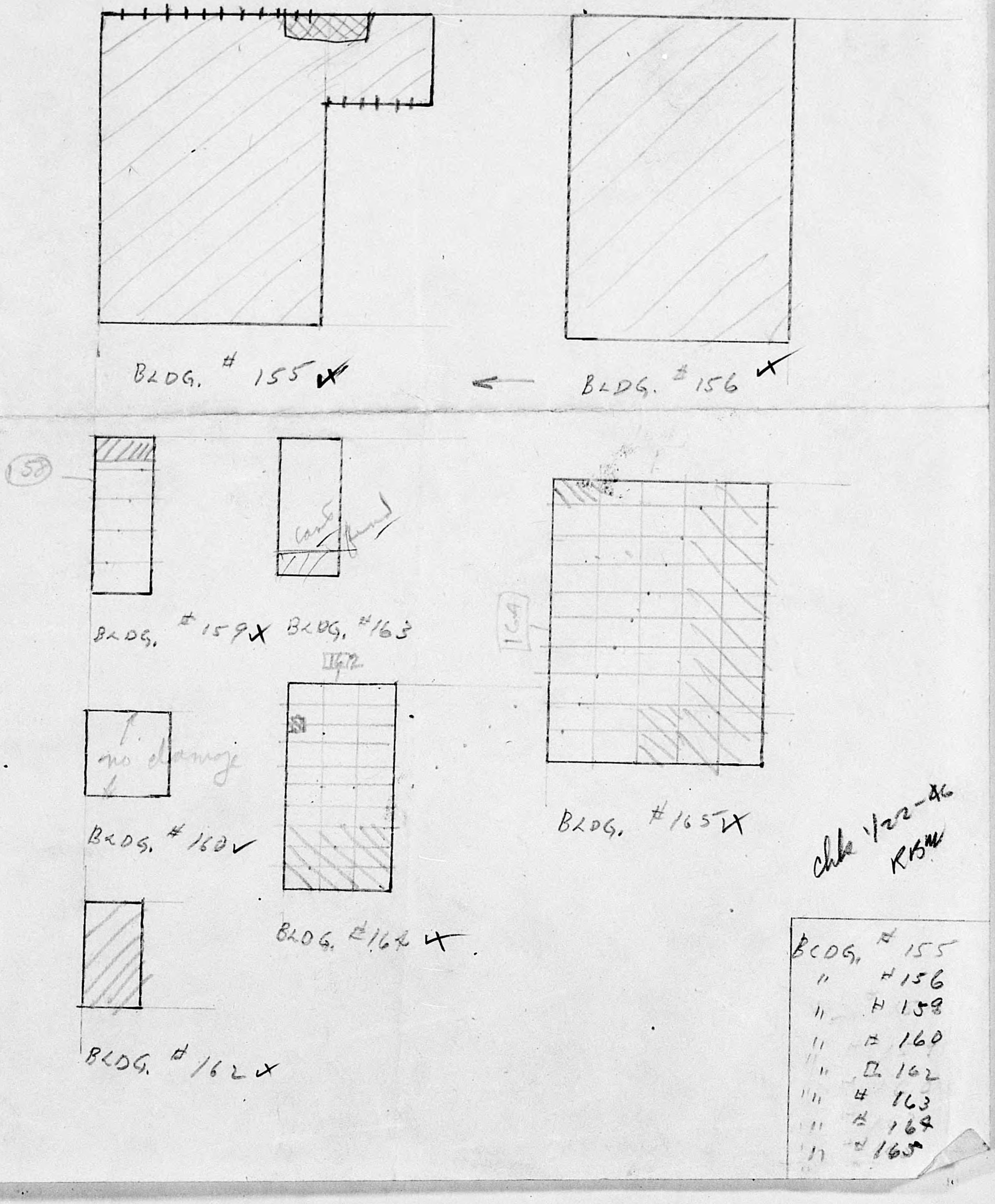

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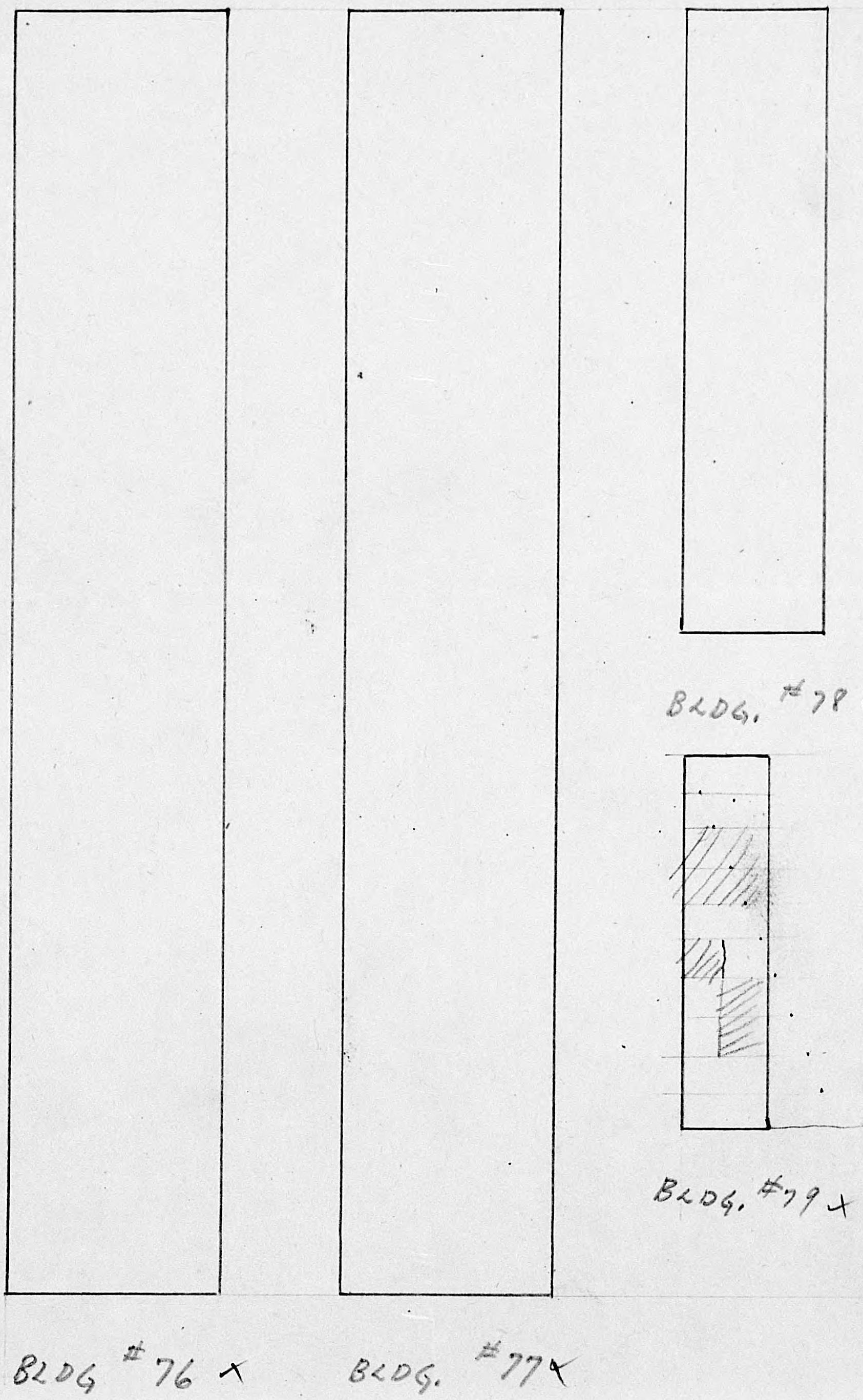

chk 1/22/46
RBW

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TARGET #382

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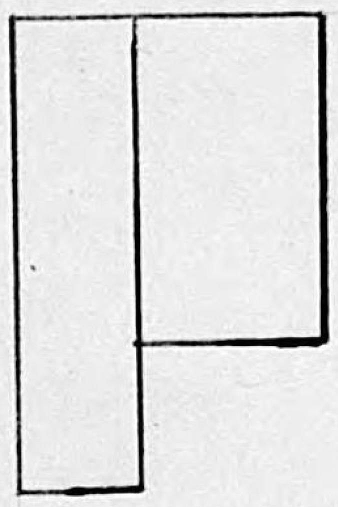

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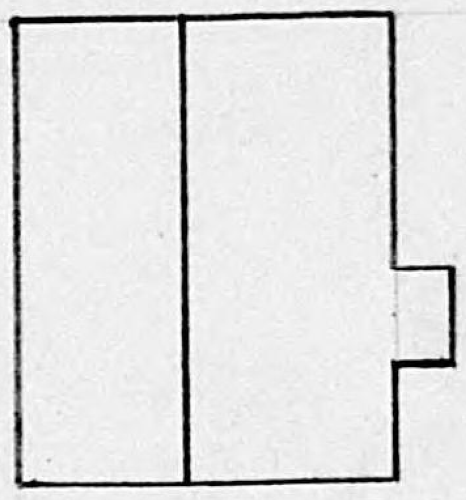

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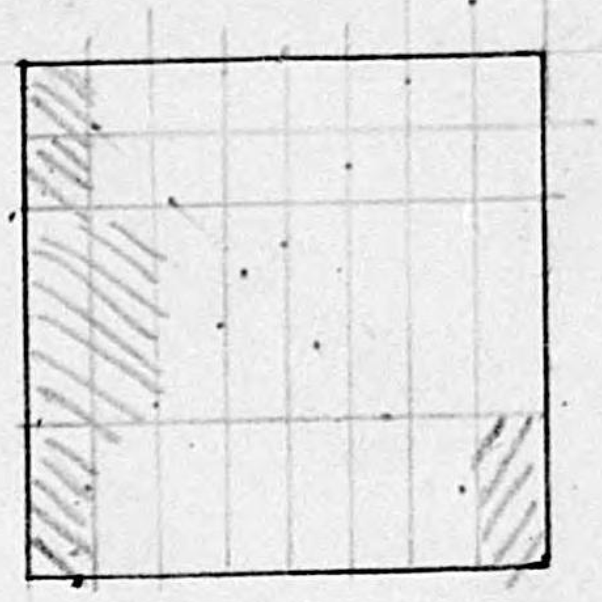

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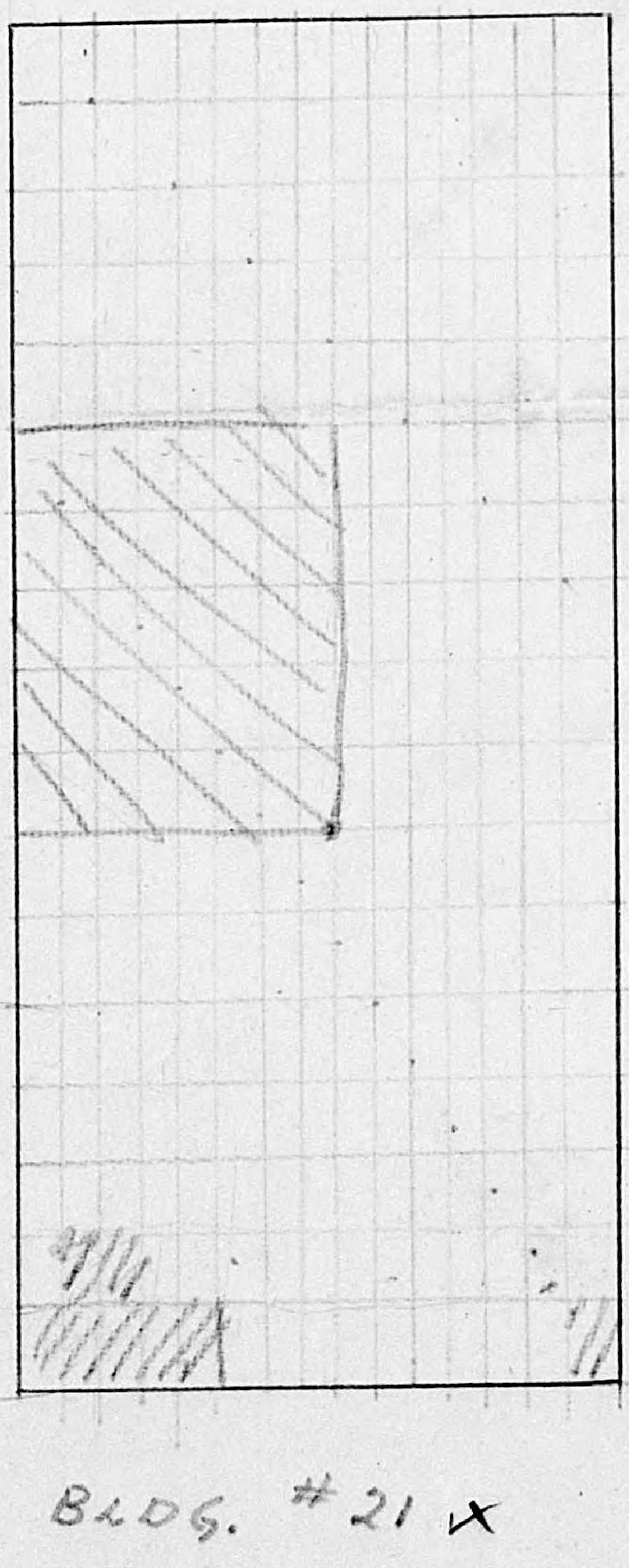

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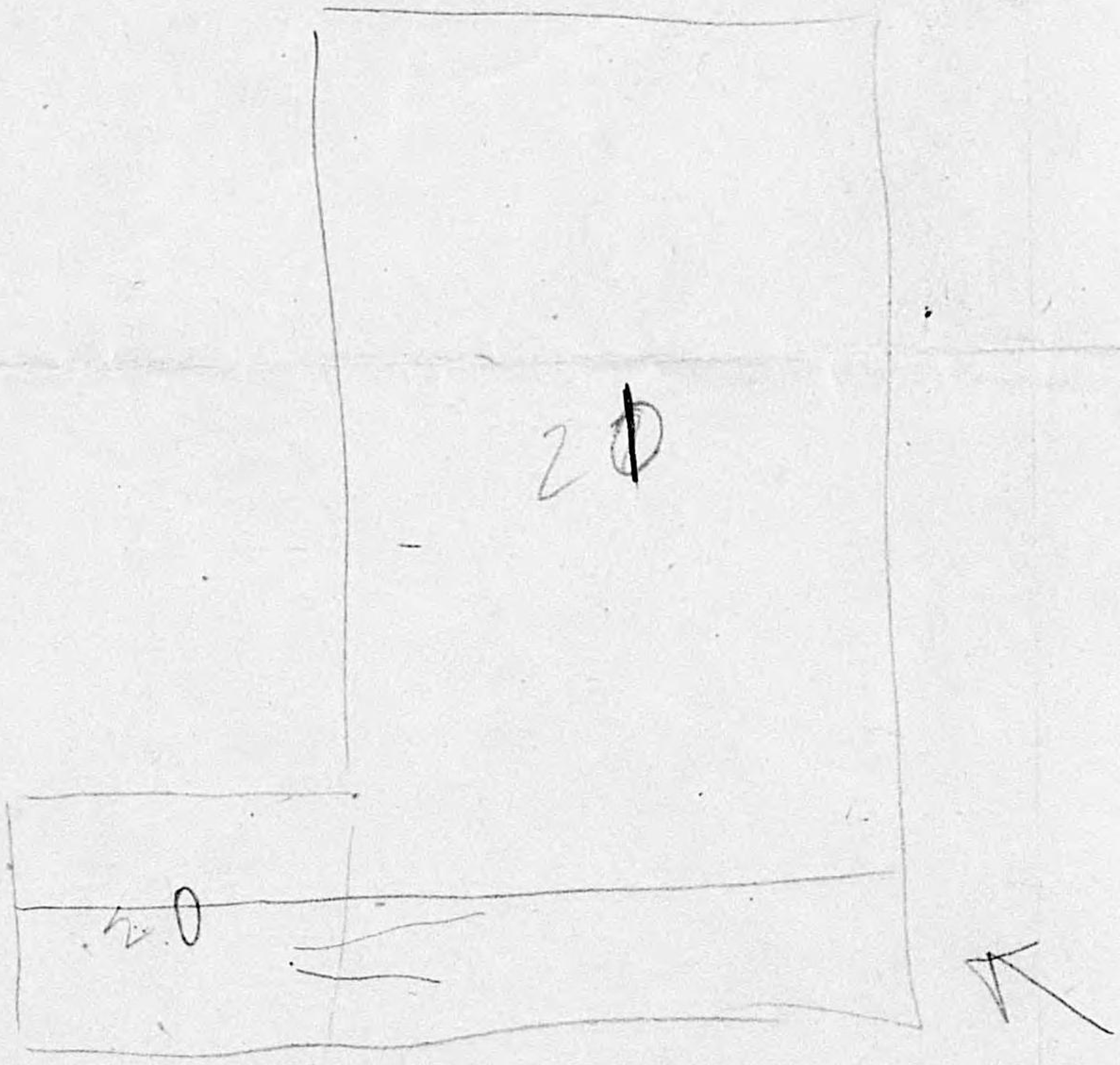

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TARGET # 382

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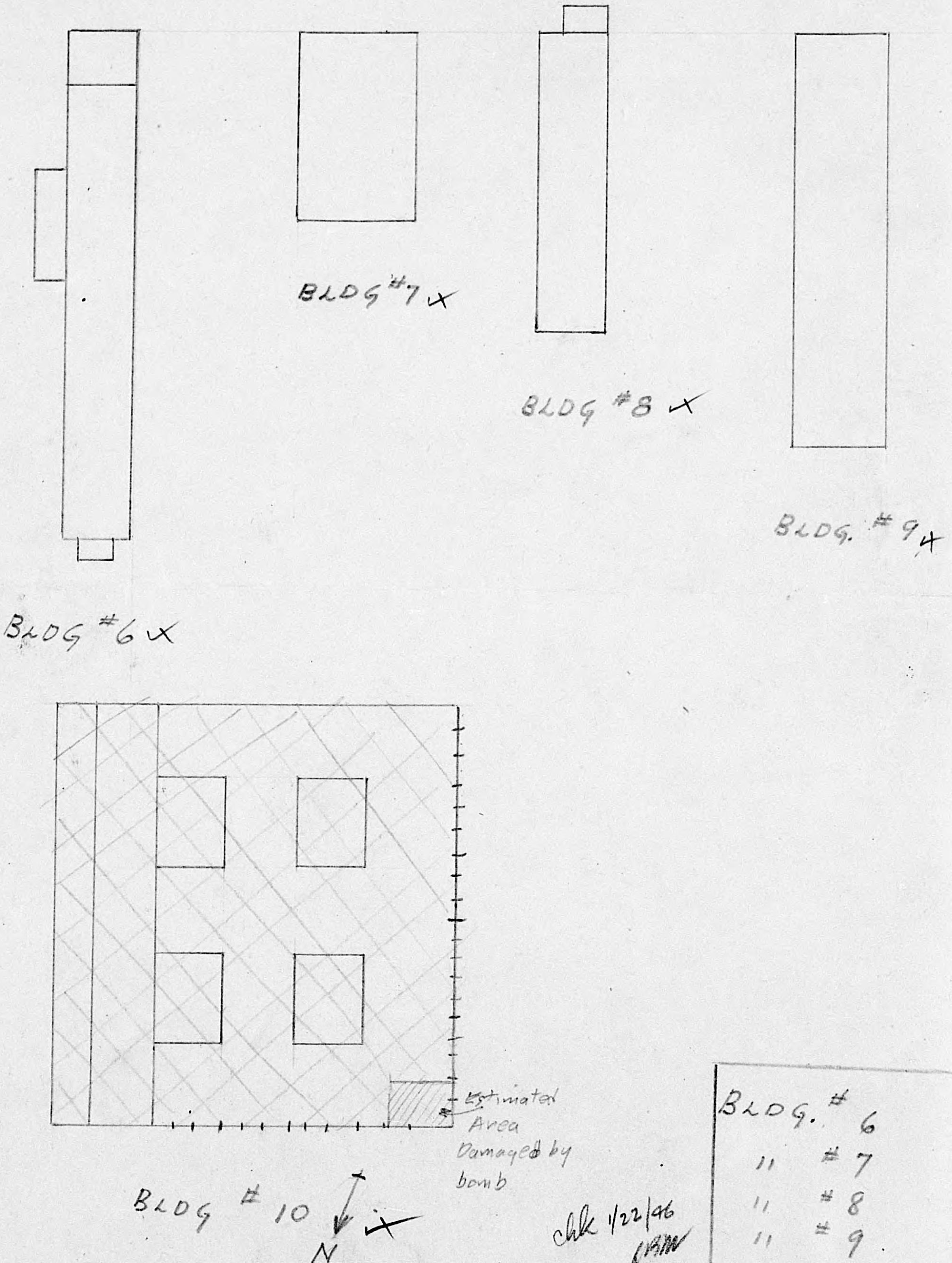
San Francisco, California



BLDG. # 6
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chk 1/22/46
JAM

TARGET #382

U. S. STRATEGIC BOMBING SURVEY

APO 234, c/o Postmaster
San Francisco, California

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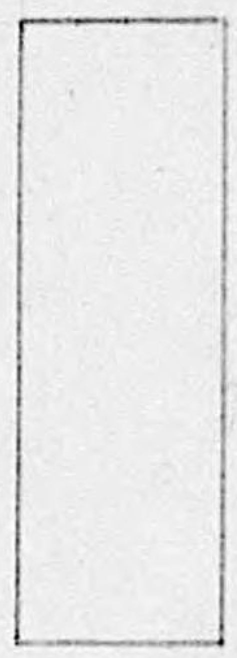

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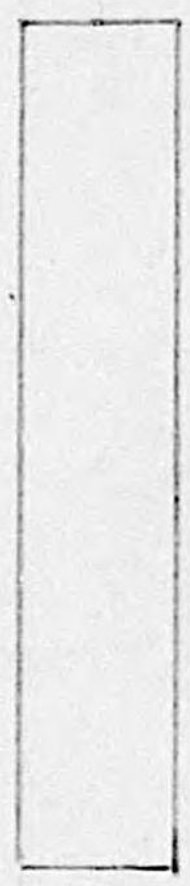

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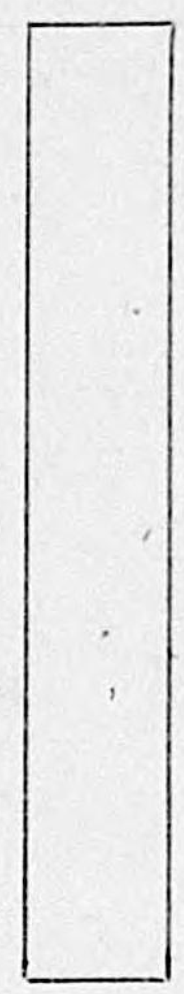

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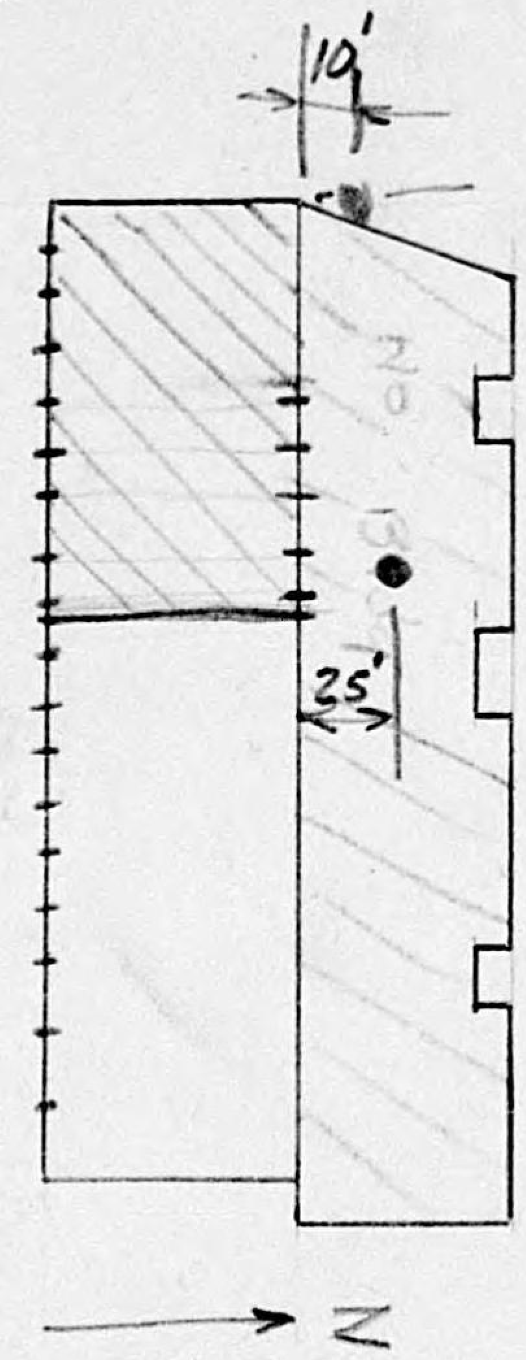

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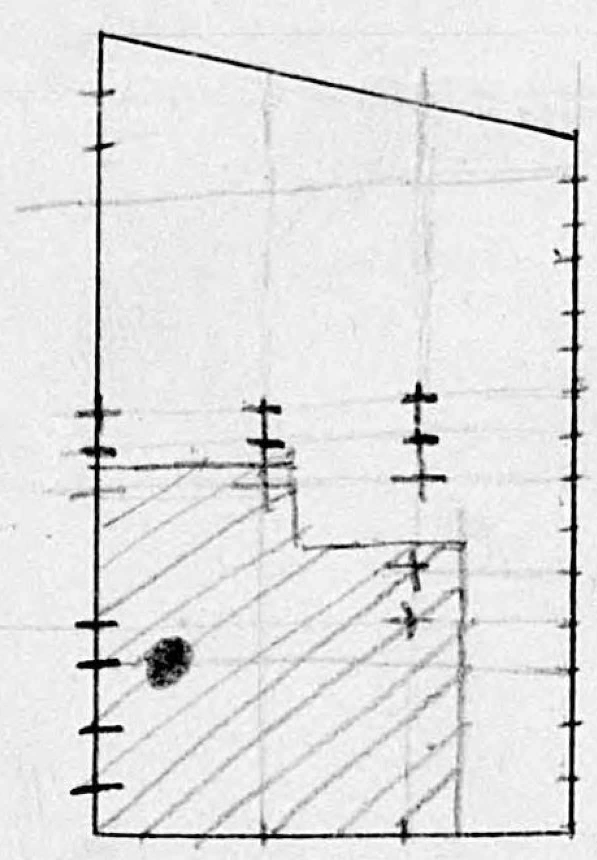

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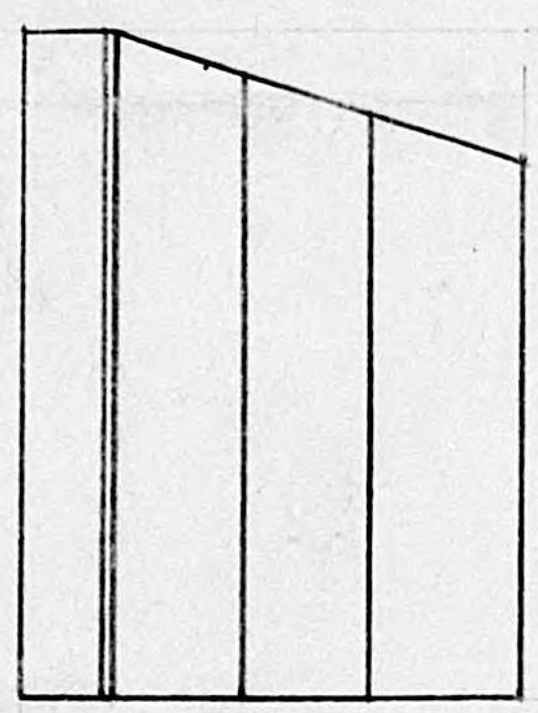

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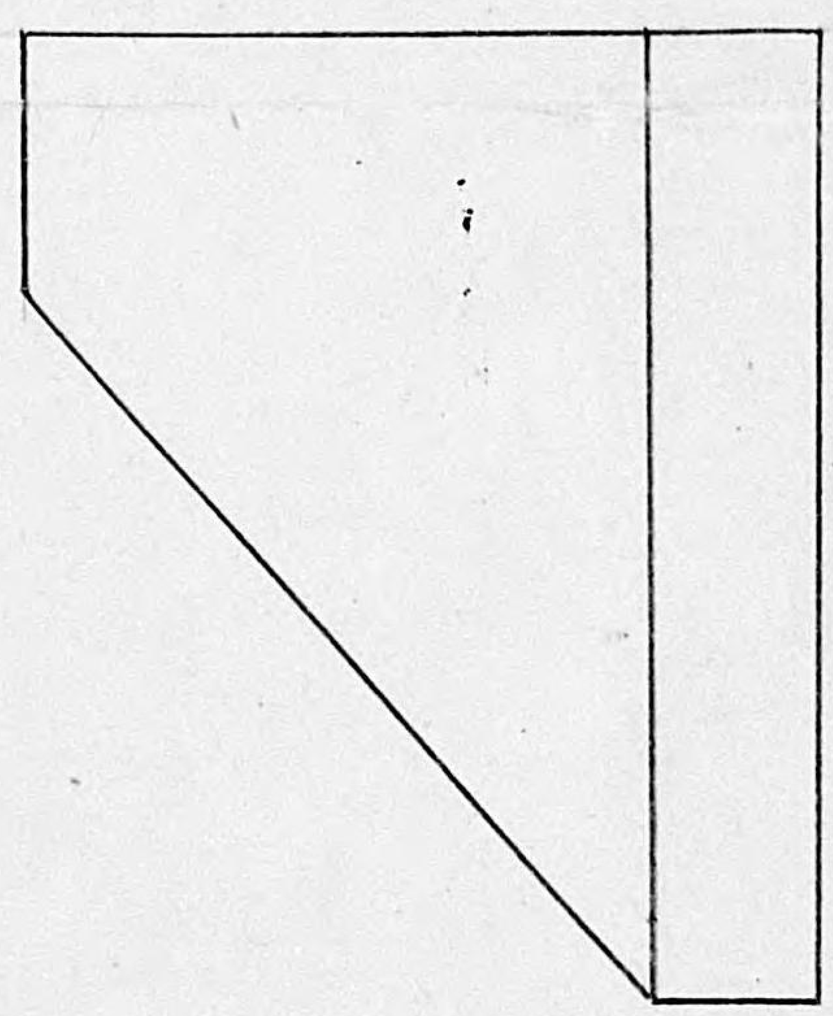

BLDG. #17 ✓

BLDG. #11
#12
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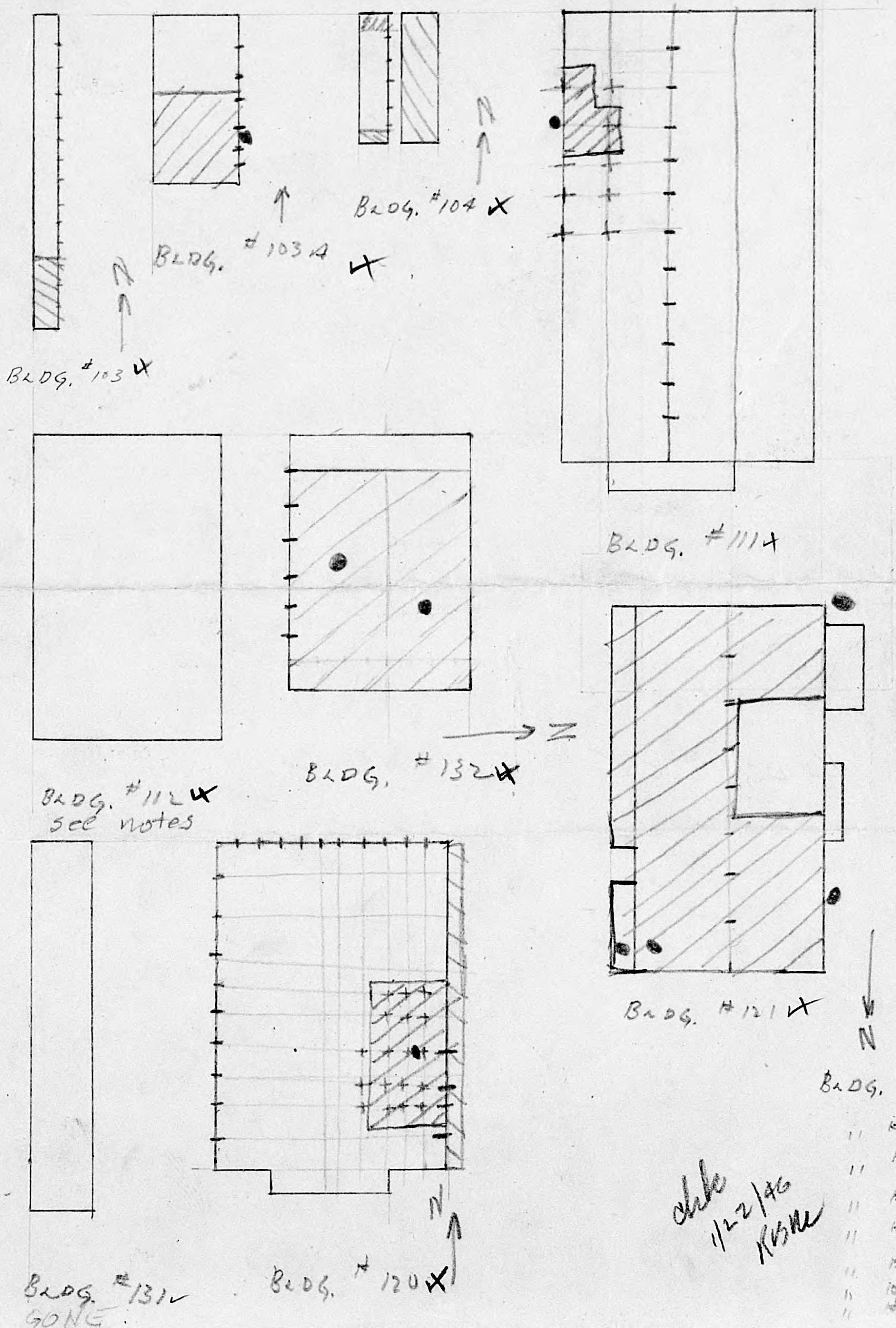

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" #111 ✓
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" #121 ✓

chk
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RBK

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APO 234, c/o Postmaster
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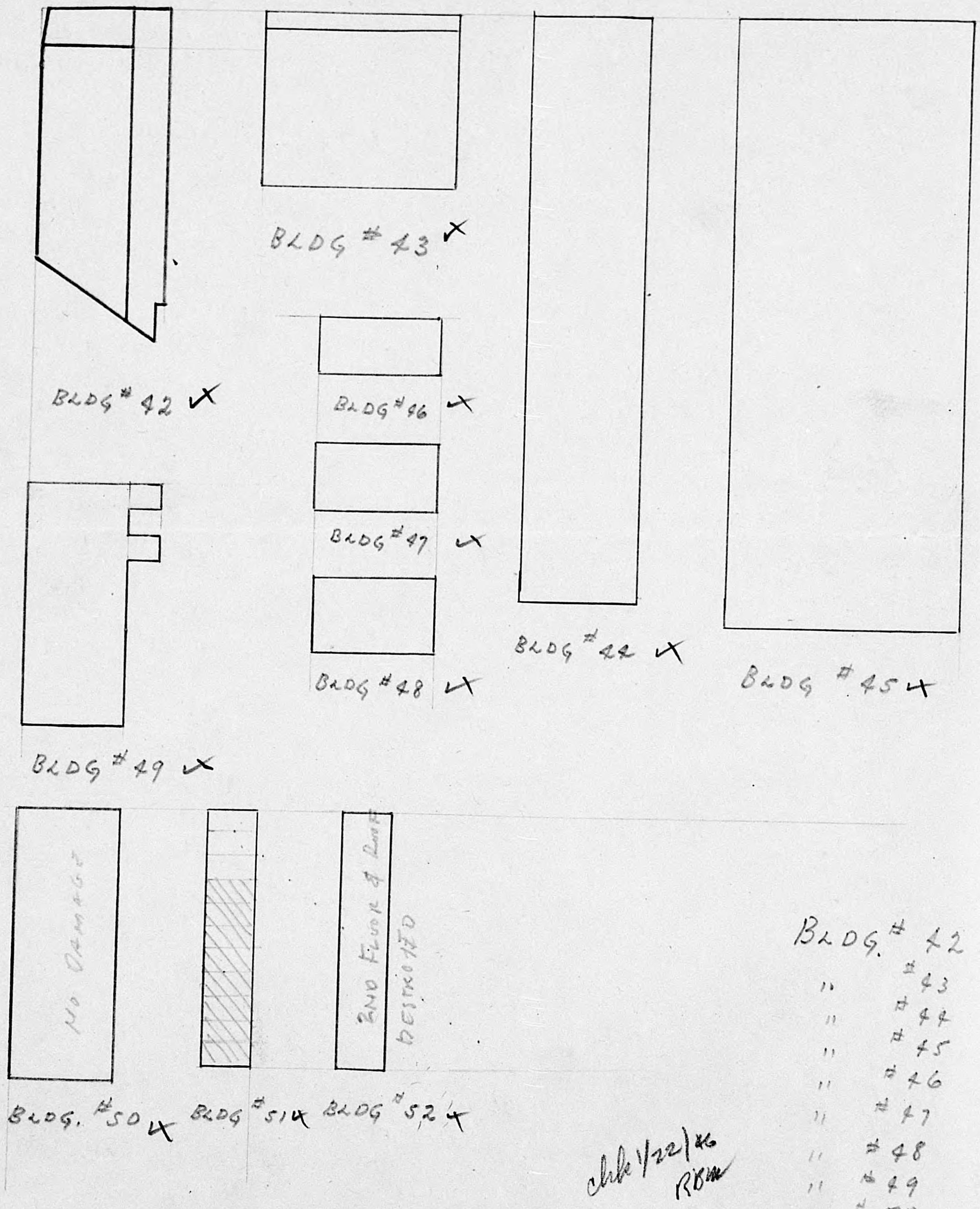

BLDG. #42
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" #47
" #48
" #49
" #50
" #51
" #52

chk 1/22/46
RBM

TARGET # 382

U. S. STRATEGIC BOMBING SURVEY

APO 234, c/o Postmaster
San Francisco, California

USSBS
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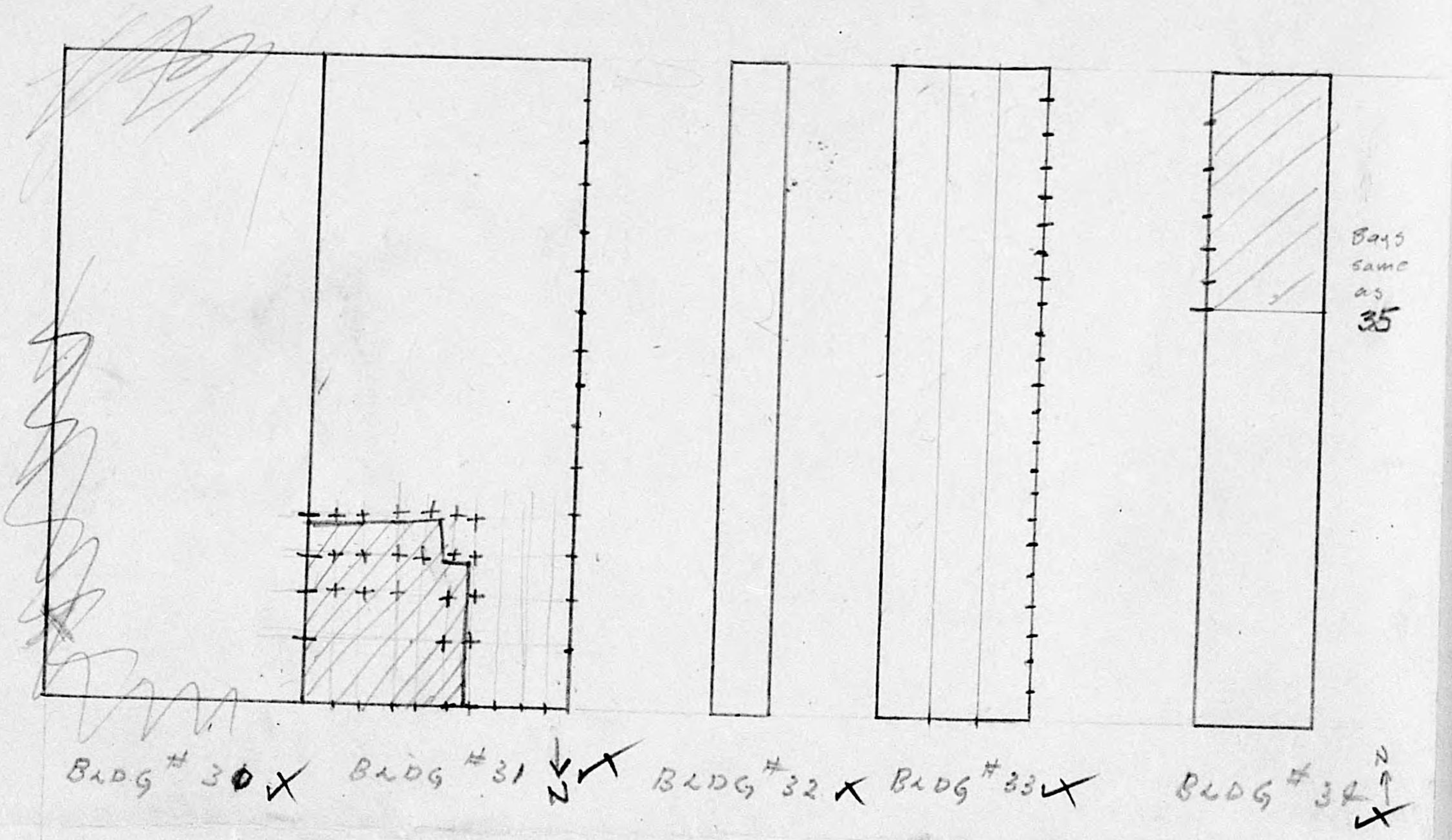

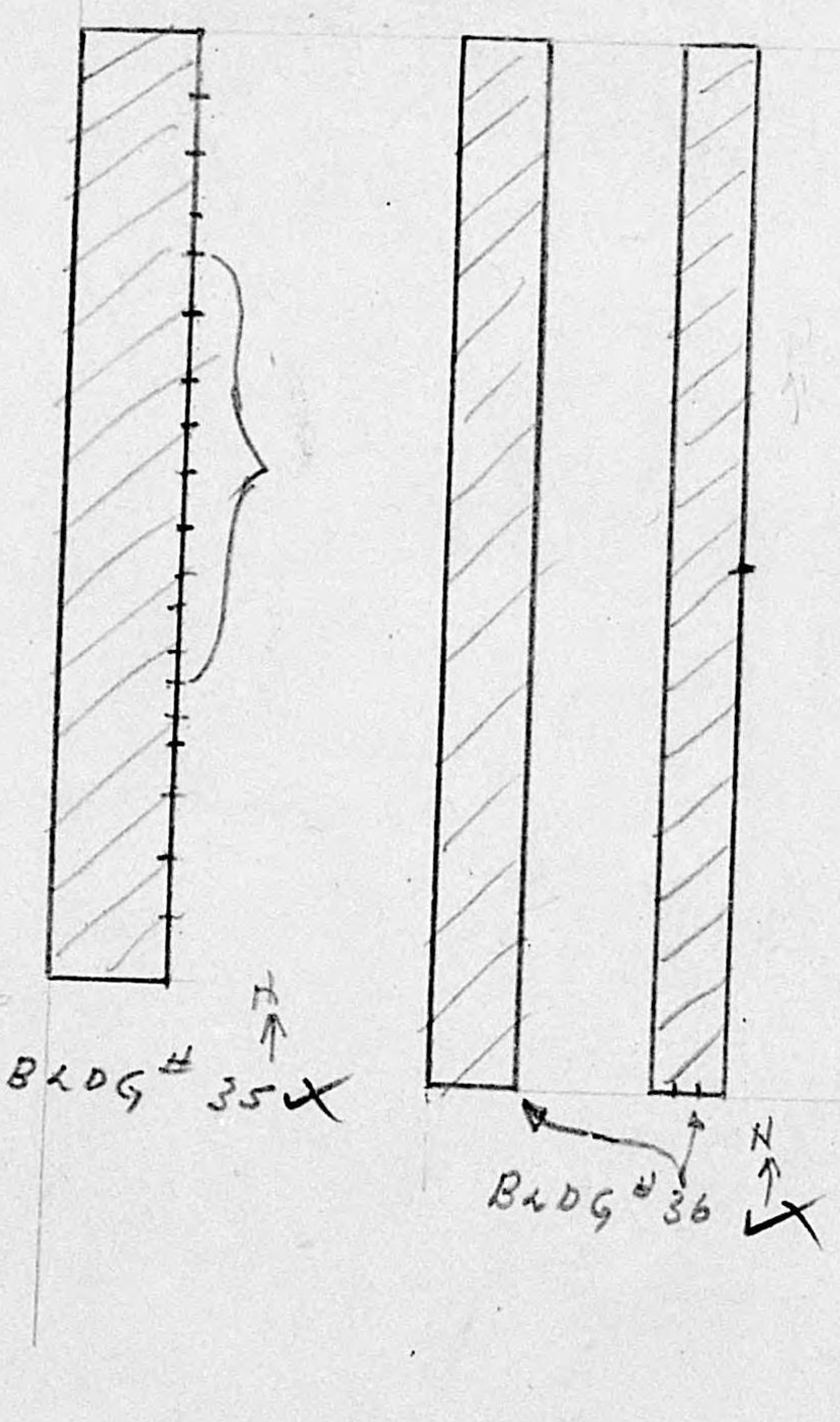

Chk. 1/22/46
RBM

BLDG # 30
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" # 33
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TARGET #382

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USSBS
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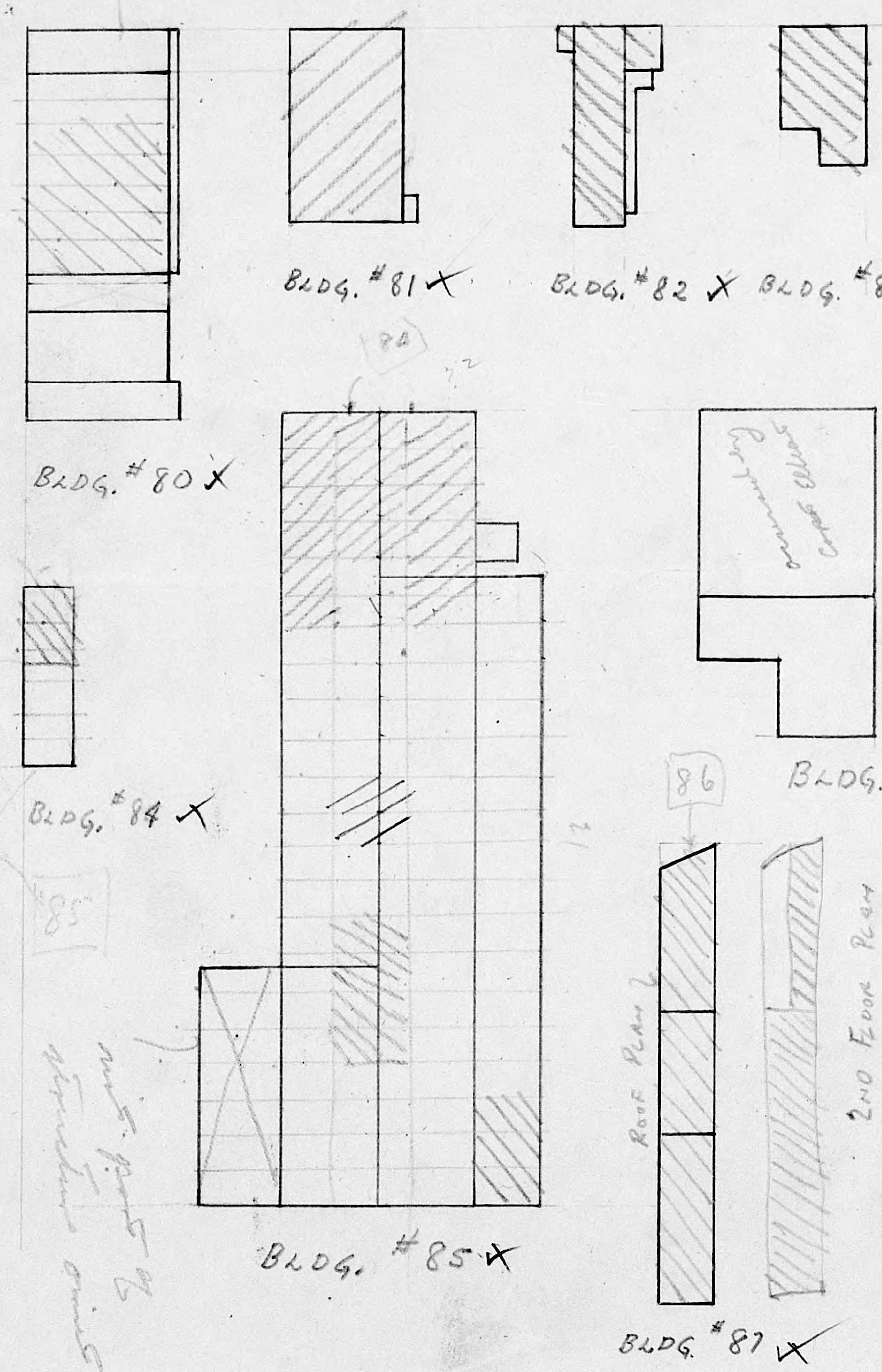

chk 1/22/46
RBW

BLDG. #80
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" #83
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TARGET # 382

U. S. STRATEGIC BOMBING SURVEY
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San Francisco, California

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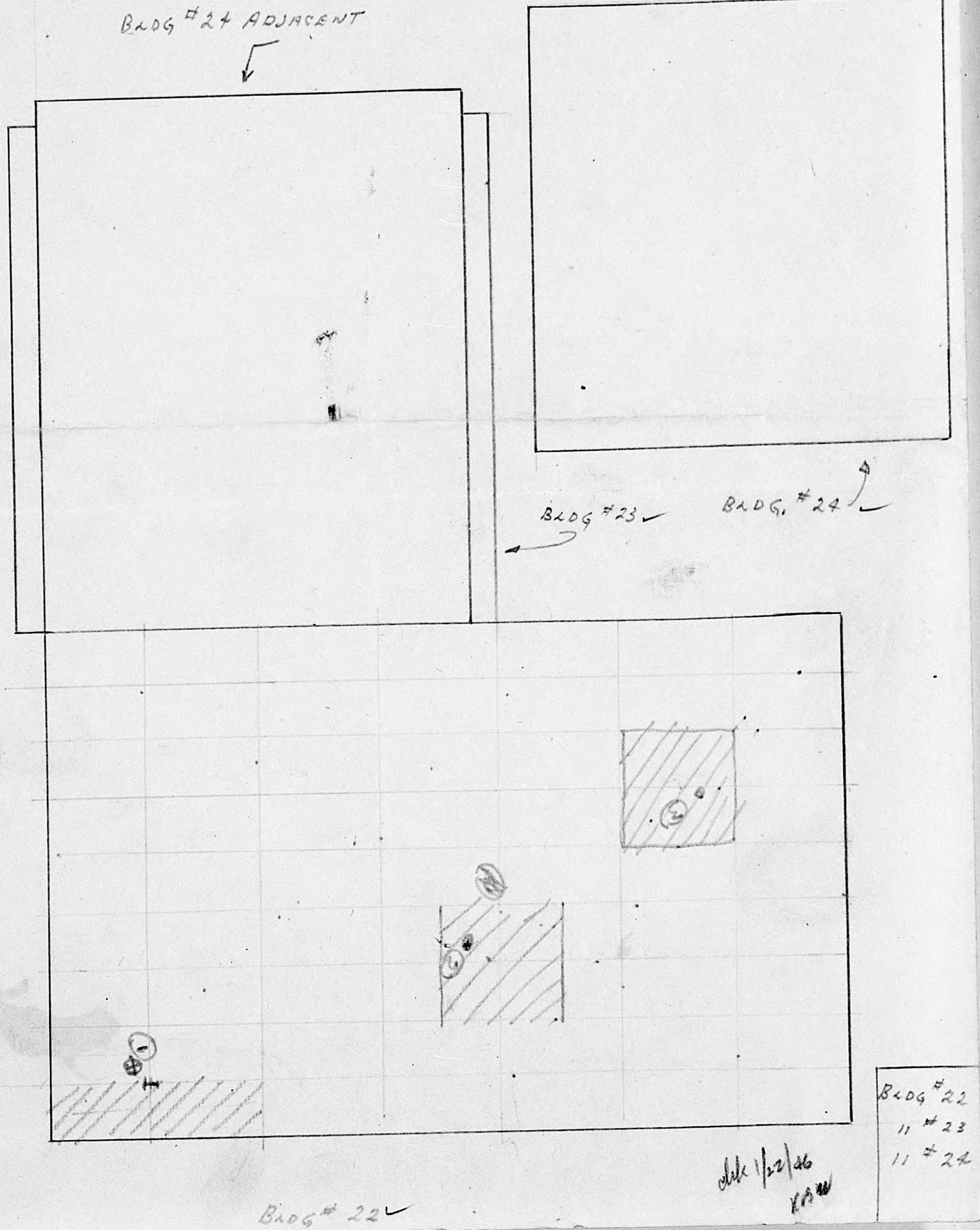

TARGET #382

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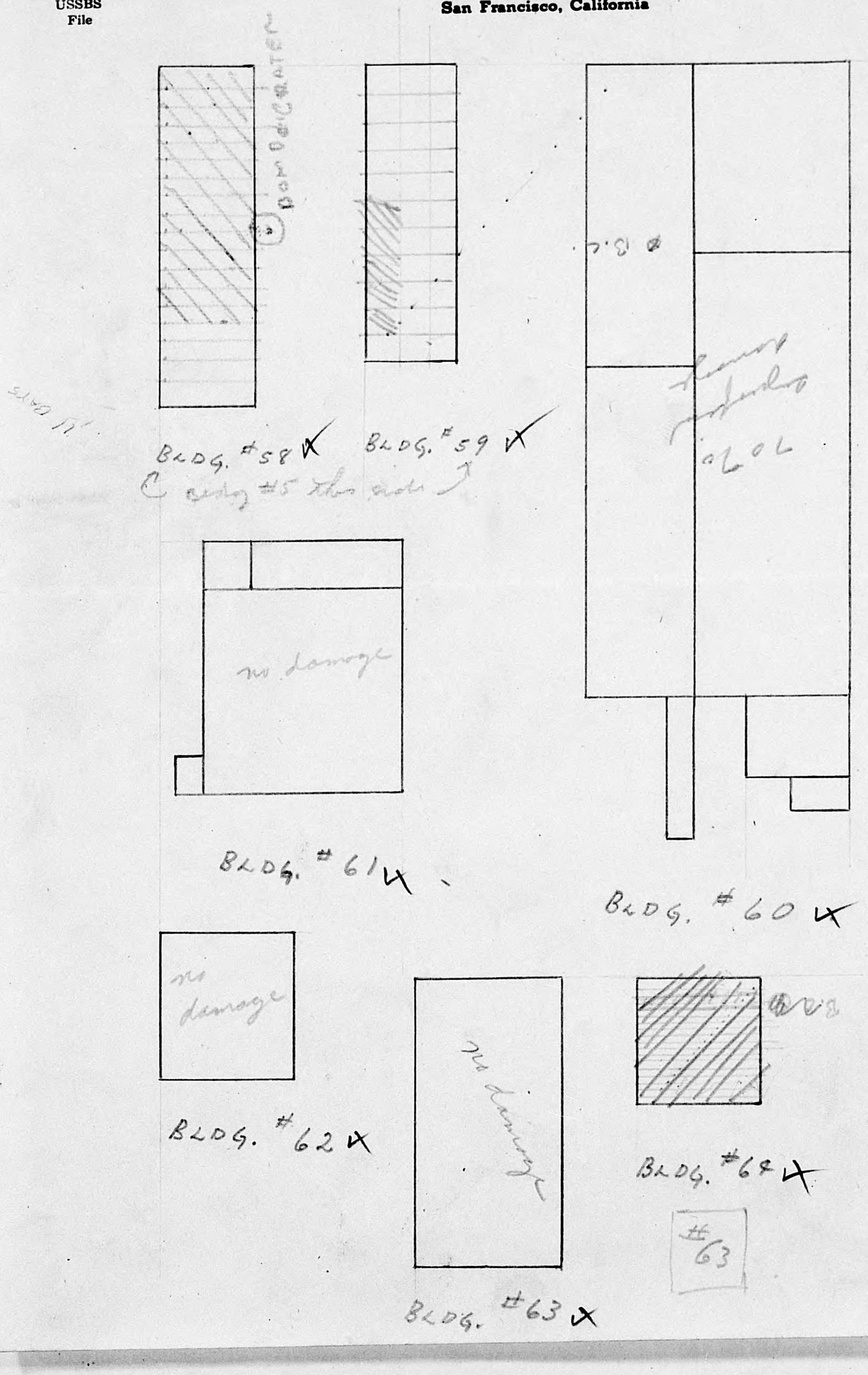

chkd 1/22/46 KBW

BLDG. #58
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" #60
" #61
" #62
" #63
" #64

TARGET #382.

USSBS
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U. S. STRATEGIC BOMBING SURVEY

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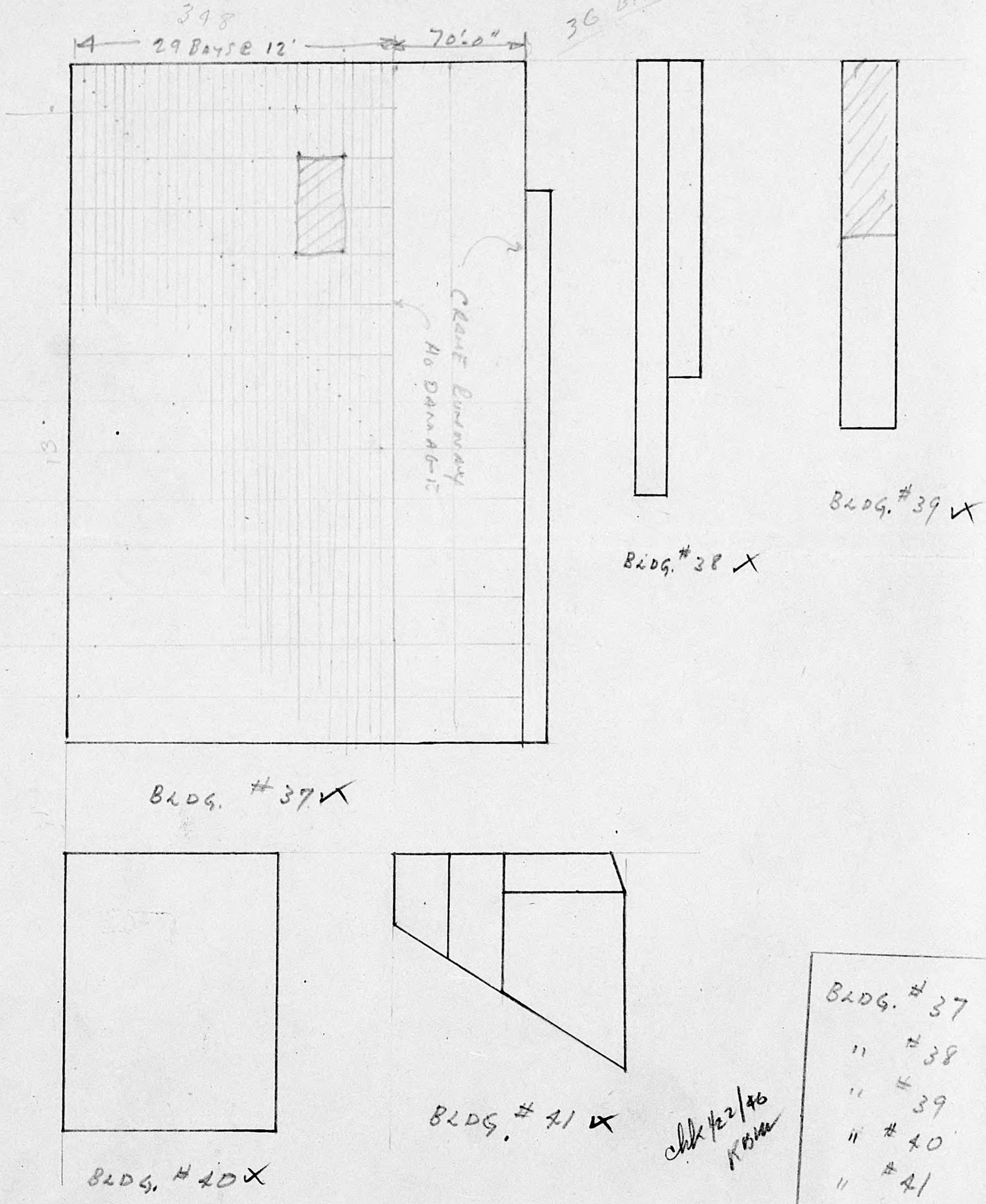

chk 4/22/46
KBM

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TARGET #382

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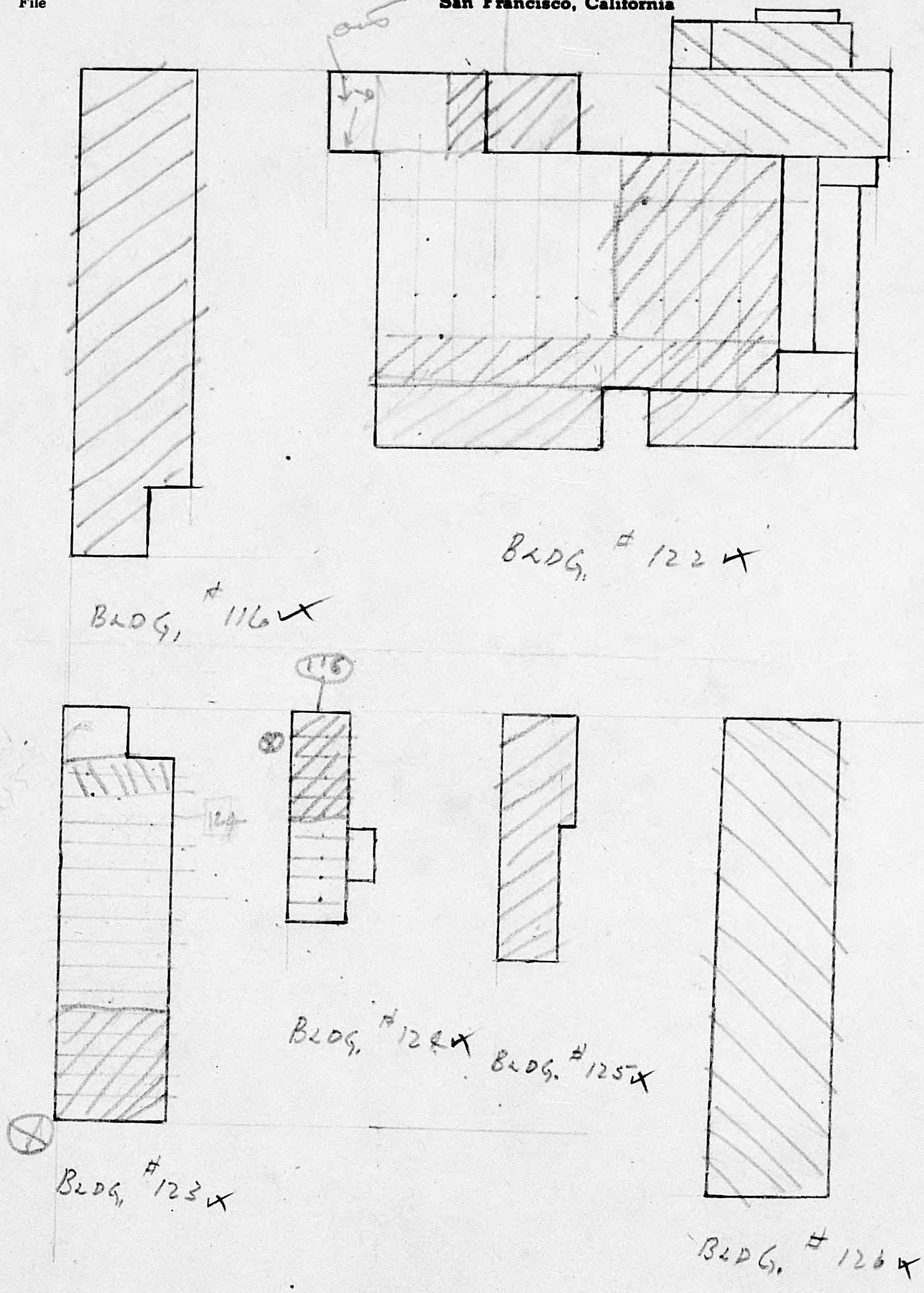

chk 1/22/46

BLDG. #116
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" #125

TARGET #382.

USSBS
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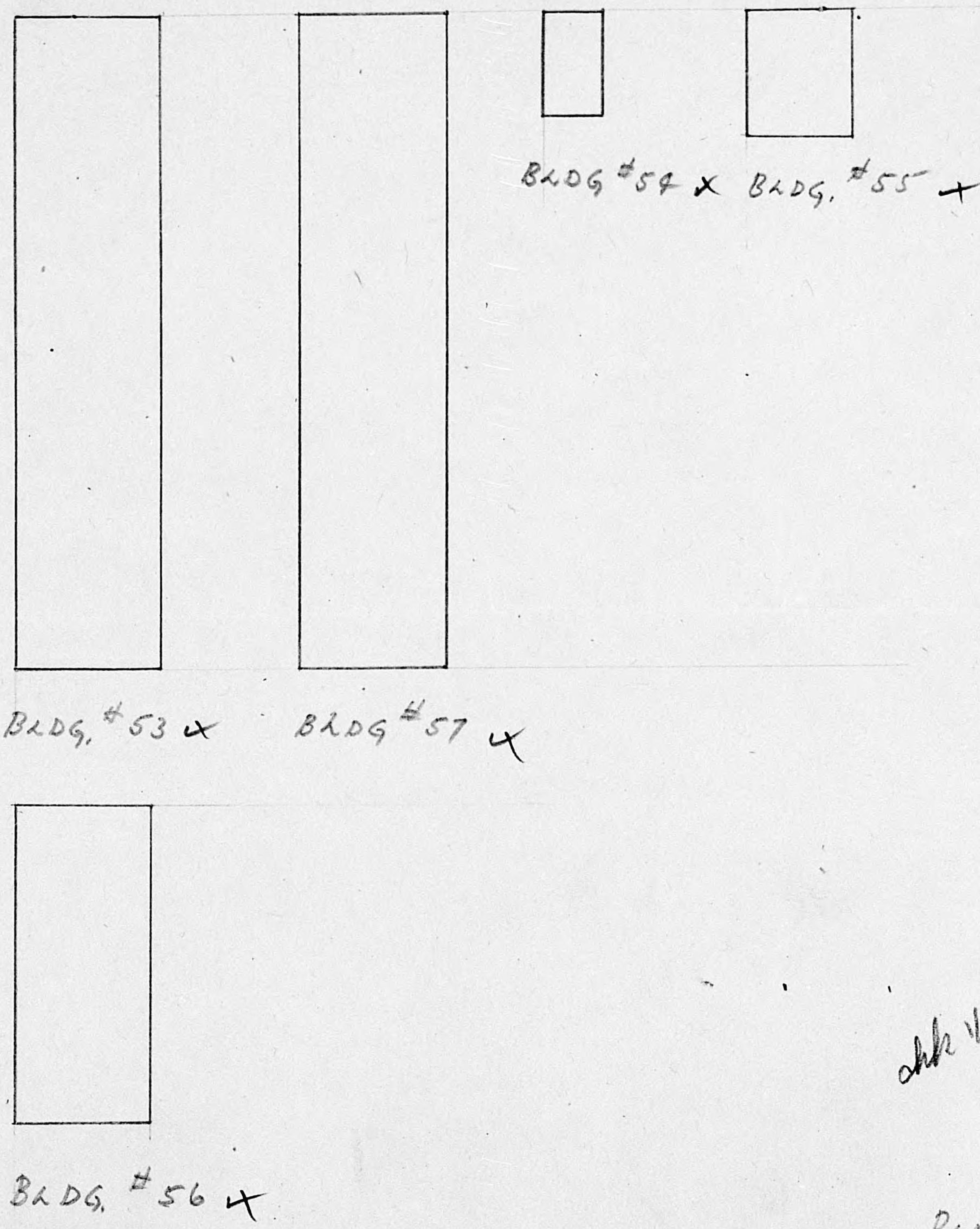

chk 1/22/46
KBW

BLDG. #53
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" #55
" #56
" #57

TARGET #382

U. S. STRATEGIC BOMBING SURVEY
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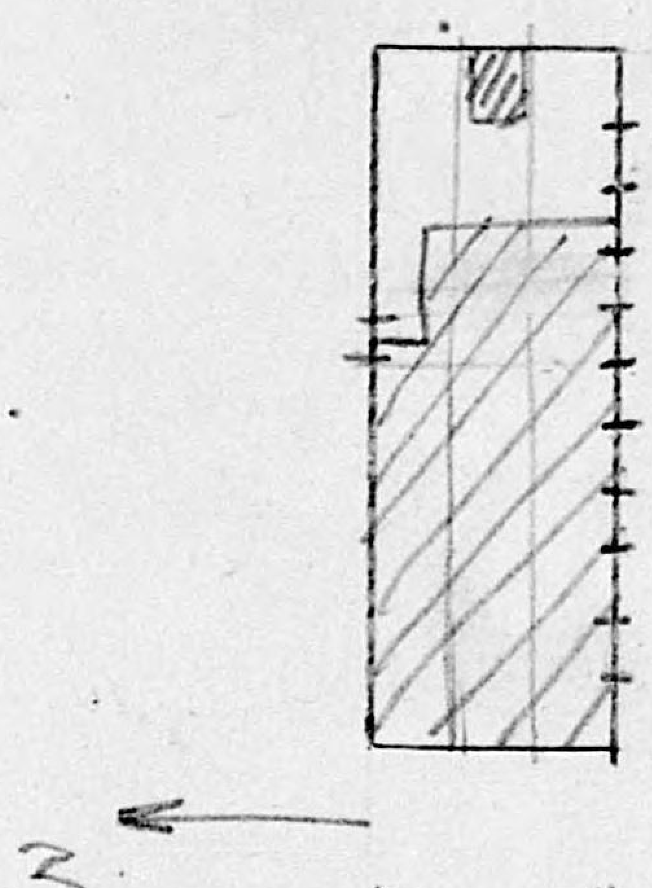

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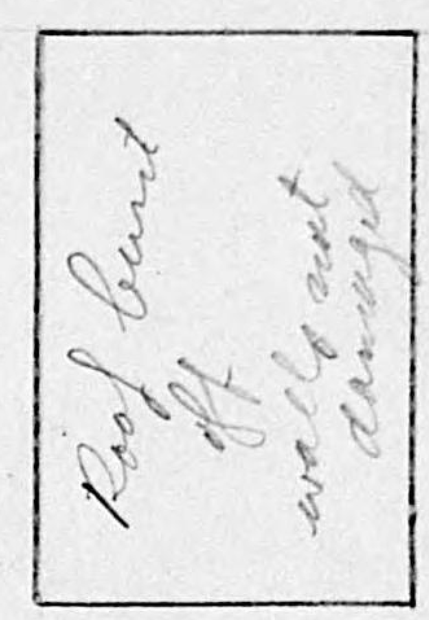

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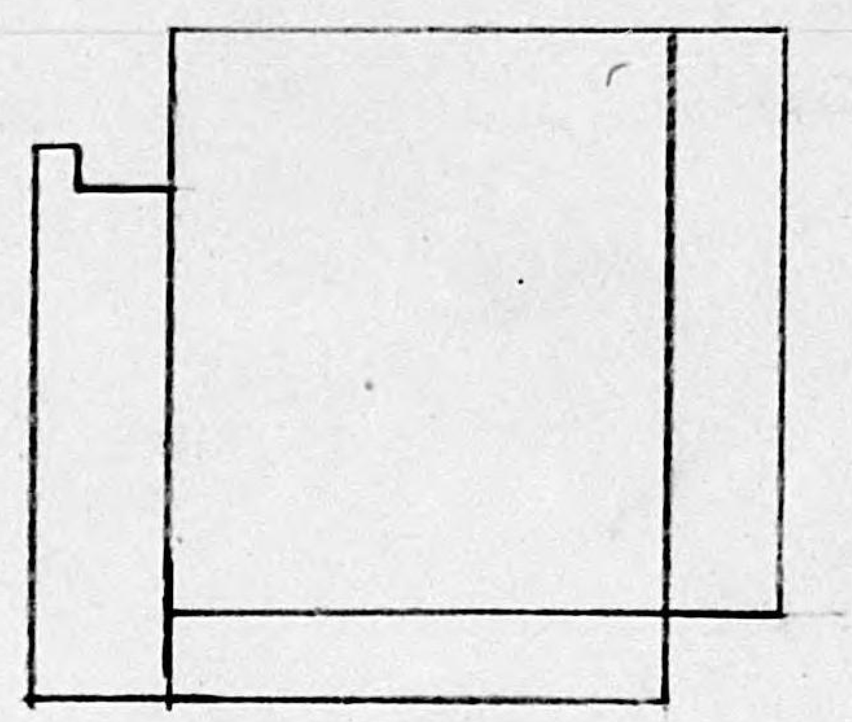
see notes



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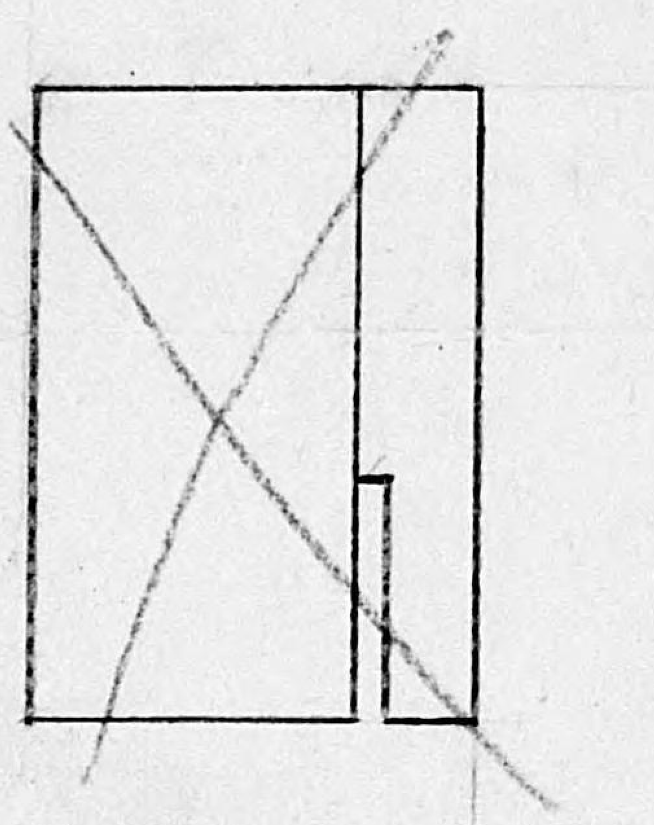

~~BLDG. #135~~

chk 1/22/46
RHW

TARGET # 382

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chk 1/22/46
RBM

BLDG. #25
" #26
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" #28
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TARGET #382

USSBS
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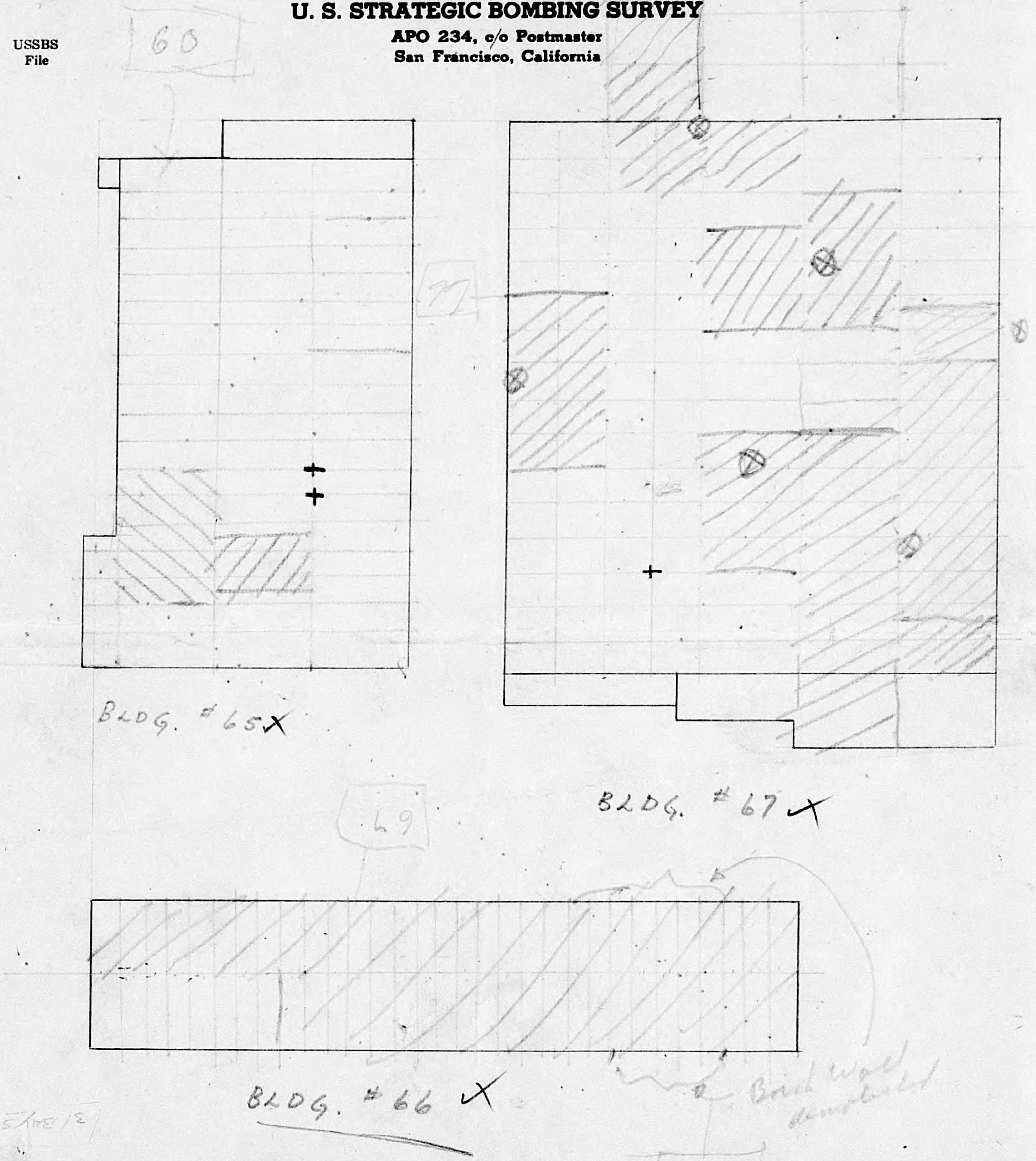

BLDG. #65
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RBM

TITLE: PDD REPORT 75

(DOUBLE SPACE PRELIMINARY DRAFT)

CHAPTER VII

THE ATOMIC BOMBS

A. FOREWORD

1. The advent of the atomic bomb opened up an entirely new field in the study of the destructive power of aerial weapons. Much data relative to the characteristics and effectiveness of conventional high-explosive and incendiary bombs had been collected and evaluated as a result of experiences gained in the European theatre, so that the AAF was able to make remunerative and effective attacks on Japanese targets. But there was an entirely new and revolutionary weapon which possessed the usual characteristics of blast, many times more powerful, and also introduced new elements - heat and radiation. The study of the effects of the atomic bombs on Hiroshima and Nagasaki with respect to physical damage to structures and their contents, utilities, and transportation has been a fascinating one, as well as one fertile in information which will be of inestimable value to planners in many fields of endeavor.

2. One of the purposes of this Division was to establish in proper perspective the relationship of the atomic bomb to other weapons by comparisons of relative effectiveness. All in all, the atomic bomb was so much more destructive for its size and weight than any other known bomb that any attempt to minimize it would be not only futile but impossible. It is believed, however, that the colorful and dire predictions of early observers, predictions based on cursory and incomplete study, can be toned down considerably in the light of current, available information. For example, it is interesting to note that the wasted

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areas of Hiroshima and Nagasaki did not differ materially, at least in outward appearances, from those of Japanese cities ravaged by incendiary attacks, such as Tokyo. And in Germany the ruins of such cities as Hamburg and Essen, attacked by both high-explosive and incendiary bombs, differed only in profile because of the type of construction, but the results achieved were the same - total damage; but how these cities got that way as compared with Nagasaki and Hiroshima is still another matter which ~~will be~~ is discussed in the following pages and in the final report on the European Theatre (PDD Report 68).

3. In many respects, the type of physical damage caused by the atomic bomb was not unusual and was what might well be expected, considering the established physical laws governing the effects of blast pressures. But the degree and extent of this kind of damage ~~was~~ were so widespread that many new factors will have to be considered in future calculations. In other respects, the heat generated by the atomic bomb explosion exceeded the limit of ordinary human comprehension. To those of us who are accustomed to thinking only in terms of weather temperatures, the millions of degrees centigrade at the bomb's core represents an astronomical figure; and even the 3,000° to 9,000° centigrade temperature estimated to have hit the atomic areas is fantastic. Its effects, however, definitely establish the stark reality of the situation, leaving no doubt in the observer's mind. Likewise, free neutrons and high-frequency radiations such as gamma rays were something new, at least in warfare. Their effects on the human body and on soil and vegetation are the subject of another Division of the Survey. ~~but some information will be found in this report respecting types of construction~~

and, other obstacles which gave entire or part protection against radiation effects.

4. Study and further experimentation will together point to what is to be done in the future to counteract the effects of the atomic bomb. In the meantime any and all information regarding the bomb's characteristics, behavior, and effects on life, morale, industry, business, utilities, and all aspects of economic endeavor is extremely important to military and civilian planners in their efforts to evaluate the bomb and to provide efficacious counter measures.

5. This report makes no attempt to pass judgment on the over-all effectiveness of the atomic bomb, its purpose being solely to give as complete a summary as possible of the physical damage suffered by the stricken cities as a result of both the direct and indirect effects of the atomic forces. (The complete story of Hiroshima will be found in PDD Report 69, and of Nagasaki in PDD Report 70). Résumés of findings on damage to buildings of all existing types - industrial, commercial, and residential - are included herein, together with certain conclusions concerning the relative degrees of resistance inherent in the several types to the direct and indirect results of the atomic bomb. Likewise, building contents vulnerability and degree of damage in relation to types of construction are discussed. Considerable space is devoted to fire since it resulted from both direct and indirect causes and was the source of a large proportion of the physical damage. Other subjects studied and reported on are: damage to machine tools, utilities, bridges, stacks, and services.

B. PRE-ATTACK CONDITIONS

1. Hiroshima

a. The City. Hiroshima, located in the southwestern area of the principal Japanese island of Honshu and at the northwestern corner of the [redacted] Inland Sea, was an important, modern, administrative, communications, and military center. The seventh largest city in Japan, it had had a wartime peak population of 380,000, but, as the result of several evacuations, that figure had been reduced to an estimated 245,000 by 6 August 1945, the date of the atomic-bomb attack. The city had developed on the delta of the Ota River and spread over seven finger-like islands formed by six river channels. Except for four small, rocky formations, only one of which was as much as 220 feet high, the delta was uniformly flat and about 10 feet above sea level. The evenly exposed area stretched 6,500 feet in all directions from the heart of the city, so that within the city boundaries there were approximately 26.5 square miles.

b. Built-upness. Densely built-up areas (over 40 per cent of plan area) or moderately built-up areas (20 to 40 per cent of plan area) extended for 23,000 feet on the north-south axis and 17,000 feet on the east-west. Around the central core of the city in a concentric area with a minimum radius of 6,000 feet occurred the greatest density of dwellings and wood-frame structures. In addition, there were located in this area many wall-bearing brick buildings and fewer steel-frame structures which were representative of the post-1923, earthquake-resistant design. Interspersed among these buildings were the low, flimsily-built shops, dwellings, and offices of typical Japanese wood design and construction.

c. Use. The central area of 6,000-feet radius comprised the principal commercial section of the city, together with large parts of the residential and military sections, but there were no industries of appreciable size nearer than 8,900 feet to the city center, the main industries being located mostly on the eastern perimeter of the city or on the southern tips of the islands. Seventy-five per cent of the 245,000 inhabitants at the time of the attack were in the congested 4-square-mile city center, which gave a population density of 46,000 persons per square mile.

d. Vulnerability. It can readily be seen from the foregoing, that Hiroshima had no natural barriers to protect it from the widespread effects of the atomic bomb, and that fact coupled with population density, flimsy construction, and building congestion, made it a choice target for maximum results.

e. Pre-Attack Sequence. The air-raid "alert" (first audible public warning) was sounded at 0720 on 6 August 1945. It was the general policy in Japan at the time not to give the air-raid "alarm" unless planes appeared in force, and, as only three aircraft were seen in the sky, the "all clear" (release-from-alert) was sounded at approximately 0740, whereupon the people resumed their customary daily tasks and practically no one was in shelters. Because of the time of day, many residences had fires for the purpose of cooking meals; most of the industrial workers were already at the factories; and many professional men and commercial employees were on the way to their offices or businesses, so that traffic was comparatively heavy. Thus the scene was set with all conditions favorable for maximum casualties and damage when the bomb exploded in the air shortly after 0800.

2. Nagasaki

a. The City. Nagasaki was located on the western coast of Kyushu island. It lay on a narrow coastal strip encircling a long, narrow bay and extended up two river valleys, one to the north (Urakami), the other to the northeast (Nakashima), the two being separated by a mountain spur. An important industrial city, its greatest population during the war had been 288,000 but it had dropped to 262,000 on 9 August 1945, the date of the atomic-bomb attack.

b. Built-upness. The main residential and commercial districts were intermingled in the two river valleys. The metropolitan area of the city comprised about 35 square miles, of which only 3.8 square miles constituted the heavily built-up portion. Seventy per cent of the latter was 30 per cent or more built up. Population density in the 3.8-square-mile area was in the neighborhood of 79,000 per square mile.

c. Use. Unlike the situation in Hiroshima where the large industries were on the fringe of the city, the industrial zone of Nagasaki was located in the Urakami River valley which averaged three-quarters of a mile in width; the Nakashima valley contained the main commercial and residential areas.

d. Vulnerability. Compared with Hiroshima, the topographical features of Nagasaki with its intervening hills offered protection from widespread blast effects of the atomic bomb, and also served to prevent fire spread. This statement is confirmed by the fact that, although the bomb exploded over Nagasaki was reported to have been more powerful and was detonated closer to the ground. The damage was less widespread but of greater intensity within the afea affected. On the other hand, the density of population, the typical flimsy construction, building congestion and concentration of industry in one valley were all factors favorable to effective atomic-bomb damage.

e. Pre-Attack Sequence. The USAAF had been sending reconnaissance planes in small numbers over the Nagasaki area daily for several weeks prior to 9 August. The "alert" would be sounded and, pursuant to local variations of shelter procedure, the aged, sick, women, children and others not engaged in essential activities went to shelters. There they would wait expectantly, but nothing would happen. This was repeated day after day, not once but several times. On the day immediately preceding the atomic-bomb attack, people had been in the shelters for two hours to no purpose, and were then released. A spirit of carelessness developed and it proved to be their undoing. On the ninth of August, a small flight (2 planes) to which the people had become accustomed appeared over the city - just other reconnaissance ships. The "alert" was sounded. Why bother going to shelter? Nothing would happen. The "alarm" howled on the sirens, to be followed in a short time by the "releast-from-alarm" which merely confirmed the belief

TITLE: PDD REPORT 75

(DOUBLE SPACE PRELIMINARY DRAFT)

of the population that there was no danger. And then at 1102 came the catastrophic detonation.

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① ATOMIC BOMB FINAL

C B. THE ATTACKS

1. The first atomic bombs to be used for military purposes, dropped on the ill-fated cities of Hiroshima and Nagasaki, inaugurated not only a totally new concept of aerial warfare, but provided a basis for the analysis of bomb damage and effects on a plane which had not been heretofore considered. For the first time, in each of these two cities, instead of studying the damaging effects of a number of missiles on individual structures, there were to be considered entire blocks of buildings wholly or partly demolished, some having the appearance of having been flattened as though by a giant hand — widespread areas of destruction and desolation measured in square miles rather than in square feet or acres; and large, fire-swept urban areas, all resulting from the air burst of one bomb.

2. The first atomic bomb was dropped on Hiroshima at 0816 hours 6 August 1945; the second on Nagasaki at 1102 hours 9 August 1945. The two attacks were made under somewhat similar circumstances, both as to weather, which was clear over both targets, with winds of low velocities, and as to the ground conditions in each of the cities. Both had been subjected to previous high-explosive attacks, which had caused relatively little damage; the residents had become accustomed to the presence of reconnaisance planes over their cities; no large groups of planes had been reported to indicate that any large-scale attacks were imminent; air-raid alarms had been sounded, then cancelled; few persons were in shelters; defense and protective forces were not fully manned; and in neither instance were either the citizens or responsible military and government officials in any way prepared for the sudden, violent, catastrophic onslaught from the skies.

3. The Hiroshima bomb detonated approximately 2,000 feet above the ground; the one at Nagasaki at an altitude of about 1,700 feet. The explosion in both cases was characterized by a blinding flash, followed by an intense heat wave

and crushing blast pressures. Scientists estimated that the detonation of the atomic bomb, lasting only a millionth of a second, created a ball of fire hotter than the center of the sun (70,000,000° C), and released radiations ranging from beyond the infra-red, through the visible spectrum, and into the ultra-violet and gamma rays. The Nagasaki bomb was reported to be an improved and more powerful version of the weapon used in the Hiroshima attack, and was detonated at a slightly lower altitude. The results, however, although indicative of more intense forces, were not as numerous nor as widespread because of the configuration and topographical features of Nagasaki.

C. EFFECTS

The results of the atomic bomb explosions which immediately paralyzed the facilities and lives of two cities were of considerable variety and in many instances as spectacular as the bomb itself. Outstanding among these were the extreme distances at which blast damage occurred; the wide area of total damage; the ignition and scorching of combustible materials and the searing of noncombustibles at great distances.

1. Buildings. In Hiroshima there were approximately 60,000 of an estimated total of 90,000 buildings over an area of 9.5 square miles totally or heavily damaged. Dwellings and structures of Nagasaki were demolished throughout an area of 1.8 square miles, or within a radius of 5/8 mile from Ground Zero, and other structures suffered various degrees of damage within a 2½-mile radius. Superficial and minor damage was experienced up to 8 miles at Hiroshima, and as far as 12 miles at Nagasaki.

2. Machine Tools. Machine tools in Hiroshima were totally or heavily damaged throughout an area exceeding four square miles. In Nagasaki various degrees of damage to machine tools extended up to 6,500 feet from Ground

Zero. The degree of damage and the number of machine tools affected depended largely on the types of structures in which they were housed. Damage resulted from blast effects, debris, fire, and exposure to the elements.

6. 3. Bridges. The [redacted] timber [redacted] bridges [redacted] in both cities were the most heavily ~~suffered total~~ [redacted] ~~or heavy~~ damaged by blast and fire. Those of steel and concrete were affected to a ~~smaller~~ lesser degree, and heavy concrete bridges were the least affected of any. Some steel bridges were collapsed, and others were structurally damaged. [redacted] At Hiroshima, [redacted] in many cases, bridges which were not seriously damaged could not be utilized because of masses of debris from adjacent buildings which clogged the approaches.

d 4. Stacks. Reinforced-concrete stacks were found to be generally resistant to blast effects, only four of approximately 30 within 6,000 feet of Ground Zero having been damaged in Nagasaki. All steel and brick stacks within the same area were totally damaged. In Hiroshima, 45 per cent of all stacks within a radius of 1.6 miles were damaged beyond use.

e 5. Public Utilities. All public utilities were damaged and completely disrupted. Both cities were temporarily without transportation, electricity, communications, gas, water, and sewers. Within a period of several days, however, some of these services, such as railroad and street railway transportation, electric power, and water supply, were available to a limited degree in certain areas, mostly for essential use.

X 6. Fire. Fires, [redacted] caused by radiant heat from the detonation of the bomb, as well as by electrical short circuits and as a result of inflammable debris falling on or upsetting open-flame devices, accounted for large areas of damage in both cities. An area of 4.4 square miles was burned over in Hiroshima, and in Nagasaki approximately one-third of the densely built-up area (3.8 square miles) was swept by ~~fire~~ flames. Fire defenses in both cities were considerably limited, as the initial bomb blast

(4)

had seriously crippled the fire-fighting organizations, damaging equipment and killing or injuring personnel.

D. DAMAGE TO BUILDINGS

1. Building Types. Buildings in both Hiroshima and Nagasaki ranged from modern, reinforced-concrete structures and steel-frame industrial buildings to wood-frame buildings and the typical Japanese dwellings which were entirely of wood construction except for tile roof covering. Some of the commercial buildings were of reinforced concrete of excellent material and earthquake design. Those of multi-story construction and aseismic design were usually heavier and stronger than similar type structures in the United States. Quality of concrete and workmanship varied considerably, however, and there were some buildings found of sub-standard design and construction. There were other buildings of load-bearing brick-wall construction, and some which had reinforced-concrete frames. The industrial-type buildings were generally of steel-frame construction, single-story, having either saw-tooth or monitor-top roofs. These buildings were usually covered with corrugated-asbestos or corrugated-metal roofing and siding. Despite the encouragement of Western construction practices and the adoption by the Japanese government of aseismic design for large buildings, the shortage of critical building materials and the lack of enforcement of the building code resulted in the prevalence of wood-frame and wood-pole construction over all other types in every city. The wood-frame buildings, for the most part, comprised dwellings, combination shop-dwellings, and small commercial and industrial buildings. Typical wood buildings in Japan had light frames, relatively heavy roofs supported by slender columns, and poorly designed joints. Buildings of this type were, of course, highly vulnerable to fire and blast.

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and up to a maximum of 11,000 ft. in Nagasaki.

2. Extent of Damage.

a. <u>Structural Damage.</u> widespread Structural damage was found in ~~both cities~~ Hiroshima up to between 6,000 and 7,000 feet from Ground Zero. The area of damage ~~were~~ in Nagasaki, however, was not as uniform as it was ~~not uniform, however, and varied more in Nagasaki than~~ in Hiroshima. The bomb ~~at Hiroshima~~ detonated over the center of ~~the city~~ where the land was level; at Nagasaki, ~~the bomb~~ detonated over a valley away from the center of the city and the blast travelled along the valley in both directions. ★INSERT In comparing the

INSERT

The ~~scale~~ degree of damage at Nagasaki was greater than at Hiroshima, although the actual area in which damage occurred was smaller. At Nagasaki 30.7 percent or 1.8 square miles of the built-up area of the city suffered structural damage. In Hiroshima, 69 per cent of the city's buildings over an area of 9.5 square miles were totally or heavily damaged.

~~the bomb detonated over a section~~ containing the most strongly built structures in the city. Although the degree of damage in both cities decreased as the distance from

~~(1) Reinforced Concrete Buildings. The strongly built, heavy, multi-story, reinforced concrete and concrete-frame buildings~~

Ground Zero increased, the rate of decrease was not uniform in similar types of buildings. This lack of uniformity resulted largely from the differences in design and quality of workmanship in similar types of buildings. Further, it was often impossible to obtain a reliable estimate of the damage which might have been expected at various distances from the point of detonation when there ~~either~~ was an insufficient number of buildings of the same general types exposed to the effects of the bomb at similar distances from Ground Zero.

(1) <u>Reinforced-Concrete Buildings</u>. The strongly built, heavy, multi-story, reinforced-concrete and concrete-frame buildings were by far the most resistive [redacted] to the blast effects of the atomic bomb. These buildings were heavily damaged only in an area relatively near the point of bomb detonation. A much higher percentage of buildings of similar construction but of lighter materials and inferior design was totally or heavily damaged at greater distances. At Nagasaki, 9.5 per cent of the floor area of reinforced-concrete buildings in the area between 2,000 and 3,000 feet from Ground Zero, the majority of which were of excellent material and earthquake-resistive design, was totally or structurally damaged. In the area between 4,000 and 5,000 feet from Ground Zero, however, 56 per cent of the buildings of this type, but of lighter construction, suffered total or heavy damage. Differences between the physical characteristics of the terrain and types of construction in the two cities, and possibly differences between the forces created by the two detonations accounted for variations in extent of structural damage to this type of building. Equivalent blast effects were found in Nagasaki over greater areas. Structural damage to reinforced-concrete buildings in that city occurred within an area of 0.43 square mile, compared with an area of 0.05 square mile of similar heavy damage in Hiroshima. It is believed that more widespread damage to this type of building would have resulted from detonation of the atomic bomb at a lower altitude without seriously affecting the extent of damage to other classes of buildings.

(2) Steel-Frame Buildings. Single-story, light, steel-frame industrial buildings were heavily damaged throughout areas of approximately equal size in both cities. Damage to structures of this type covered an area of 3.4 miles at Hiroshima; 3.3 miles at Nagasaki. There were no heavy, steel-frame buildings in Hiroshima, and damage to this class of structures could be studied only at Nagasaki where structural damage extended over an area of 1.8 square miles. Steel-frame buildings covered with corrugated-asbestos siding and roofing generally suffered less structural damage than those buildings having corrugated-iron or sheet-metal covering. The blast effects immediately ripped off or crumbled the asbestos material, leaving no wide surfaces exposed, against which damaging blast pressure could be exerted and transmitted to the framework. Metal siding, however, transferred pressure to the structural members, causing distortion or general collapse.

(3) Load-Bearing Brick-Wall Buildings. Buildings of load-bearing brick-wall construction were extremely vulnerable to blast and therefore suffered heavily from the effects of the atomic bomb. Multi-story brick buildings, which were studied only at Hiroshima, were structurally damaged within an area of 3.6 square miles. Single-story brick buildings were damaged in the same city within an area of 6 square miles, and within an area of 8.1 square miles in Nagasaki. In Hiroshima, collapse or serious cracking of walls occurred in buildings having 24- to 27-inch walls up to 3,700 feet; and in buildings having 9-inch walls, similar damage was inflicted up to 8,200 feet from Ground Zero. In Nagasaki 100 per cent of the floor area of the brick

buildings up to 3,000 feet from Ground Zero suffered total or heavy structural damage. Between 3,000 and 7,000 feet, over 75 per cent of the floor area of those studied was similarly damaged, and various degrees of structural damage extended as far as 11,000 feet from Ground Zero. Many of the brick buildings which were heavily damaged at great distances from Ground Zero were set somewhat apart from other structures and consequently had little shielding from blast.

(4) Wood-Frame Buildings. Wood-frame industrial and commercial buildings in Hiroshima were structurally damaged up to 7,300 feet from Ground Zero, and within an area of 8.5 square miles. In Nagasaki, buildings of similar construction were structurally damaged within a radius of 10,000 feet from Ground Zero, or within an area of 9.9 square miles. These buildings were generally of inferior construction and design. Supporting members and columns ~~and members~~ were easily buckled by blast pressure on roofs, leading to mass distortion and collapse of framework. Structural damage to wood-frame buildings as a result of blast generally extended well beyond the area of fire damage. Wood-frame and all-wood domestic buildings in Hiroshima were totally or heavily damaged throughout an area of 6 square miles; in Nagasaki, throughout an area of 7.5 square miles.

(5) Mean Areas of Effectiveness (MAE's). No great significance can be attached to the areas of structural damage to any one type of building without considering the total area of the buildings of that type exposed to the blast. A better estimate of the bomb's effectiveness against structures of certain types can be obtained by computing the mean areas of effectiveness (MAE's) and making comparisons at the two cities on that basis. To obtain a sufficient number of buildings with structural damage for comparison in the two cities it was necessary to group various buildings of the same or similar type of construction. These groups lack the greater refinement of classification which is found in the data for high-explosive bombs. The categories of buildings compared at Hiroshima and Nagasaki, however, were essentially the same and reacted similarly to blast. The mean areas of effectiveness of the atomic bomb for structural damage around Ground Zero and the radii of the MAE's for the different classes of buildings in both cities are shown in Table 1. To find the MAE's for the various building categories the annular-ring method was used, except for wood dwellings in Group 8. The MAE's for the latter group were computed by the average-circle method. The MAE's comprehend structural damage caused by blast alone, fire and blast combined, and fire alone. The following paragraph of this section (paragraph 3) indicates the percentages of damage resulting from these causes. In comparing MAE's at Hiroshima with those at Nagasaki, it should be understood that the figures are for two bombs whose heights of detonation differed by some 15 per cent, and that the Nagasaki bomb was reported to have been an improved

TABLE 1
MEAN AREAS OF EFFECTIVENESS (MAE'S) FOR
HIROSHIMA AND NAGASAKI

Building Group	Description of Building Type	Total Floor Area to Limit of Structural Damage (1000's of sq ft)	Total Floor Area of Structural Damage (1000's of sq ft)	Mean Area of Effectiveness (square miles)	Radius of Mean Area of Effectiveness (feet)
(1) Hiroshima Nagasaki	Multistory, earthquake-resistant buildings only	597 ----	34 ----	0.03 ----	500 ----
(2) Hiroshima Nagasaki	Multistory, steel- and reinforced-concrete-frame (Including earthquake- and non-earthquake-resistant buildings)	637 694	54 121	0.05 0.43	700 2000
(3) Hiroshima Nagasaki	One-story, heavy, steel-frame	---- ~~1060~~ 1138	---- ~~569~~ 436	---- 1.8	---- 4000
(4) Hiroshima Nagasaki	One-story, light, steel-frame	94 741	51 ~~485~~ 484	3.4 3.3	5500 5400
(5) Hiroshima Nagasaki	Multistory, load-bearing brick-wall	189 ----	158 ----	3.6 ----	5700 ----
(6) Hiroshima Nagasaki	One-story, load-bearing brick-wall	283 390	169 ~~254~~ 246	6.0 8.1	7300 8500
(7) Hiroshima Nagasaki	Wood-frame, industrial-commercial	523 1475	154 ~~1084~~ 1126	8.5 9.9	8700 9400
(8) Hiroshima Nagasaki	Wood-frame domestic	---- ----	---- ----	6.0 7.5	7300 8200

and more powerful version of the atomic bomb dropped over Hiroshima. A comparison of the building groups for which there were data for both cities indicated the more powerful Nagasaki bomb produced larger mean areas of effectiveness. The MAE for Group 2 of Hiroshima is about 10 per cent of that for Nagasaki. Some of the buildings in Group 2 at Nagasaki, however, were more vulnerable to blast because of their position on or near the ridge of the valley. Group 4 has about the same value for both cities, perhaps explained by the relative greater extent of shielding by other buildings at Nagasaki. The MAE for Group 6 at Hiroshima is about 75 per cent of that for Nagasaki. The MAE for Group 7 at Hiroshima is about 85 per cent of that for Nagasaki. In Group 8, the MAE for Hiroshima is 80 per cent of that for Nagasaki. The MAE's at Hiroshima and Nagasaki for Group 7 are larger than those for Group 8 because the buildings in the latter group were better constructed and probably more shielded from the blast. The extent of structural damage by blast to the different types of buildings, as well as the MAE for each type, is shown graphically in Figures 1 through 5. For almost every category of buildings the fraction of damage was greater for Nagasaki than for Hiroshima at corresponding distances from Ground Zero.

b. Superficial Damage. Superficial damage, consisting of the stripping of wall and roof covering, and the removal of light partitions, window glass and frames, extended to as far as 8 miles from Ground Zero in Hiroshima and up to 12 miles at Nagasaki. In addition to the 30.7 per cent of the built-up area of Nagasaki which suffered structural damage there was an additional 9.3 per cent which was superficially damaged, roof stripping and disturbance of roof tile having been found as far as 69,000 feet from Ground Zero. Wall and roof stripping was found at Hiroshima up to 22,000 feet, and glass breakage was reported beyond 37,000 feet. There were instances in which corrugated-asbestos siding and roofs were stripped from steel-frame buildings without damage to the structural framework. There were other buildings where evidence indicated the initial damage by blast was superficial, but subsequent fire had resulted in structural damage through warping and softening of steel supporting members. Cases of this nature, however, were relatively uncommon. This type of damage, while not as important nor as spectacular as building collapse and heavy structural damage, extended the effectiveness of the bomb by exposing machinery, tools, and supplies to the elements, and by making more difficult the work of clearance and the restoration of necessary shelter for victims of the attacks.

3. Causes of Damage. The structural damage to buildings in both cities was due to blast alone, blast and fire combined, and fire alone. INSERT Superficial … lted from blast. There … [illegible] tile and …

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Since the limits of structural blast damage to buildings extended beyond the burned-over areas, except for multi-story steel- and reinforced-concrete-frame buildings, it is believed that in most cases buildings which suffered mixed damage were structurally damaged by the initial blast, and subsequent fires merely intensified the damage.

city, on close inspection, to separate blast-damage areas from fire-damage areas. There was no evidence found of earth-shock damage to buildings.

a. Blast. The largest percentage of structual damage attributed to blast alone was almost 85 per cent, and occurred in the heavy and light, steel-frame buildings.

b. Blast and Fire. About 75 per cent of the structural damage in the reinforced-concrete and the load-bearing brick-wall buildings was due to blast plus fire. For single-story, light, steel-frame buildings, 20 per cent of the structural damage was due to blast plus fire.

c. Fire. Only in load-bearing brick-wall buildings and industrial and domestic wood-frame buildings was there structural damage caused by fire alone, and this was less than 10 per cent of the total structural damage for these building categories. Twenty-five per cent of the structural damage to multi-story, earthquake-resistant buildings was due to fire alone. For multi-story steel- and reinforced-concrete-frame buildings, both earthquake- and nonearthquake-resistant, 15 per cent of all structural damage was due to fire alone. Less than five per cent of the structural damage to multi-story, load-bearing brick-wall class was due to fire alone.

4. Characteristics of Damage.

a. Blast. The atomic-bomb detonations were characterized by far-reaching, crushing blast effects. The blast effects produced were uniform and essentially those of a conventional high-explosive weapon, though on a much larger scale. Instead of producing localized effects, entire buildings were crushed or distorted as units over a wide area. The effect of the atomic bomb on buildings was usually that of a powerful push which shoved them over or left them leaning. Buildings near Ground Zero, where the blast pressure was almost vertically downward, were crushed or, in some instances, had their roofs blown in with relatively little damage to walls. At greater distances, they were exposed to both vertical and horizontal forces, thereby suffering damage both to roofs and walls facing the blast. At considerable distances, the pressure was principally in a horizontal direction and the major portion of the damage occurred to walls facing the blast. Blast damage in Hiroshima spread almost uniformly in all directions from Ground Zero, resulting in an approximately circular area of devastation. The area of damage at Nagasaki was not as regular nor as evenly spread. Due to the topographical formation at this city, the blast effects were confined principally to the valley, resulting in a comparatively long, narrow, irregular area of destruction, the fringe of which was at greatly varying distances from Ground Zero. The blast effects were most striking at Nagasaki, where concrete buildings had their sides facing the detonation stove in like boxes. Long lines of steel-frame factory sheds, over a mile from Ground Zero, leaned their skeletons away from the explosion. Strongly-built steel members were bent and twisted, and roofs of reinforced-concrete buildings were crumpled and collapsed. At Hiroshima, although similarly characteristic damage was experienced, the more strongly-built reinforced-concrete structures of that city were damaged only relatively near the point of detonation, and beyond that area their burned-out, but otherwise undamaged, structural frames stood amidst the twisted steel skeletons and rubble which marked the locations of brick and steel-frame buildings.

(1) Negative Phase. The negative phase of the atomic-bomb detonation, which occurred during the period immediately following the passing of the initial, positive blast wave, at which time below-atmospheric pressures existed,

and resulted in characteristic damage such as glass and window shutters, and occasionally, ~~xx~~ plaster wall covering, being blown out toward the blast. Damage of this nature, however, was relatively uncommon and all significant damage to buildings occurred during the positive phase when the pressure was greater than atmospheric.

(2) Shielding. Some buildings were shielded from the direct effects of the bomb blast by others, and therefore suffered less damage than comparable structures at the same distance from Ground Zero. At points near Ground Zero there was little or no shielding because of the height of the buildings, which was limited to 100 feet by the Japanese building code, and the height of detonation of the bombs. Shielding played a more important role in Nagasaki, where hills divided the city, and, as a result, more than one-half the residential units escaped serious damage.

(3) Reflection and Diffraction. Reflection and diffraction effects were observed in both Hiroshima and Nagasaki. Diffraction was evidenced by damage in locations where shielding should have afforded some degree of protection had the blast wave travelled in a straight line. It is considered that this phenomenon was responsible for a considerably increased proportion of damage in both cities. There was evidence of reflection of blast in the damage to parapet walls on the side away from the bomb while

parapet walls facing the detonation remained undamaged. In these cases it appeared likely that the blast wave reflected from the roof surface reinforced the blast impinging directly upon the wall.

b. Fire. Fires were ignited by the radiant heat of the atomic-

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b. Fire. Widespread fire damage may also be described as a characteristic result of the atomic bomb explosions. Fires were ignited by the radiant heat of the atomic-bomb detonation within a radius of 3,000 feet from Ground Zero at Nagasaki, and up to 4,000 feet at Hiroshima. The majority of these fires started in dwellings and other buildings of combustible construction or containing combustible material, and in the debris created by the blast. Other fires which reached major proportions were started over wide areas in both cities by secondary causes, or as an indirect result of bombs blast, such as debris knocking over or falling on open-flame devices and ignition of combustible building material or debris by electrical short circuits. Fire damage effects were more intense and greater in proportion to other types of damage in Hiroshima than in Nagasaki. The causes and extent of fire damage are discussed in detail in another section of this chapter.

of 6,500 feet from Ground Zero. Damage up to 6,000 feet varied between 5 and 10 per cent of the total, except in wood-frame buildings and in these the damage was 95 per cent. Damage to auxiliary equipment and plant utilities amounted to 45 per cent, being of lighter construction and presenting larger surface areas to the blast. Damage to machine and building contents, as in the case of other types of weapons, was less than damage to the buildings. The extent and kind of damage to machinery depended almost entirely on the construction of, and the degree of damage sustained by, the buildings in which they were contained.

a. Reinforced-Concrete Buildings. No reinforced-concrete buildings in Nagasaki were structurally damaged or had their contents damaged beyond 4,700 feet from Ground Zero. Within ~~this~~ that distance, however, 86 per cent of the machine tools sustained damage. Damage to small tools amounted to 45 per cent. Raw materials and semi-finished products sustained 10 per cent damage. There were no reinforced-concrete shop buildings in Hiroshima.

b. Steel-Frame Buildings. The maximum range for damage to industrial steel-frame structures in Nagasaki was 5,600 feet. In those buildings 21 per cent of the machines and 36 per cent of the equipment sustained damage of ~~various~~ varying degrees. Small tools sustained damage amounting to 65 per cent. A relatively small number of tools was damaged in buildings of similar construction in Hiroshima, although 42 per cent of the total floor area was structurally damaged. This may be explained by the fact that the blast caused mass distortion of the steel frame without tearing loose heavy structural members, and wall and roof sheathing debris was light. The major portion of machine damage occurred in buildings which burned.

c. Brick Buildings. At Hiroshima, 28 per cent of the machine tools housed in load-bearing brick-wall buildings were damaged. All machine tools in one building which was burned out were heavily damaged. There were no machine tools in this type of building in Nagasaki.

d. Wood-Frame Buildings. Only 3 per cent of the machine tools in wood-frame buildings damaged by blast were heavily damaged at Hiroshima. All machine tools in buildings which burned were seriously damaged. At Nagasaki, 95 per cent of the machine tools in this type of structure suffered damage. These buildings, however, were utilized only as temporary auxiliary machine shops for industrial plants and their importance from an industrial standpoint was relatively small.

2. Causes of Damage. The principal causes of damage to machine tools and building contents were fire, debris, and weather exposure. Because of the differences between Hiroshima and Nagasaki in the housing of machines, the locations of their industrial plants in relation to the points of detonation, and the fact that a larger area of Hiroshima was affected by fire, the causes of damage to machine tools and equipment varied considerably in the two cities in buildings of comparable types.

a. Reinforced-Concrete Buildings. There were machine tools housed in buildings of this type in Nagasaki only. Debris, in the form of collapsed parts of the buildings, was the major instrument of damage in this type of structure and accounted for 80 per cent of the total damage to machine tools; fire accounted for 9 per cent; and weathering effects, 11 per cent.

b. Steel-Frame Buildings. Blast, debris, and lateral movement of structures caused 70 per cent of the machine-tool damage at Nagasaki; 27 per cent of the damage was ascribed to weathering effects; and fire accounted for only three per cent. At Hiroshima, moderate initial damage to machine tools in buildings of this type resulted from blast, but in the burned-over section of the city, there was almost total damage to machinery by fire. In buildings outside the fire area there was some exposure damage.

c. Brick-Wall Buildings. Machine tools were found in this type of structure only in Hiroshima. Debris caused serious damage to only 5 per cent of the machine tools in these buildings although 30 per cent of the total floor area was structurally damaged. In those buildings which burned because of the combustibility of building material and contents, 23 per cent of the machine tools were seriously damaged by fire.

d. Wood-Frame Buildings. At Nagasaki 54 per cent of the machine-tool damage in wood-frame buildings was due to exposure to the elements. Fire damage accounted for only 10 per cent of the damage, and debris and mass movement of the structures accounted for 26 per cent. The most serious damage to heavy machines was the overturning and fracturing of machine castings. Blast and a combination of blast, fire, and debris accounted for 10 per cent of the machines. In Hiroshima, debris caused total or heavy damage to only three per cent of the machine tools in these buildings, although 64 per cent of the total floor area was structurally damaged by blast. Serious damage resulting from debris was caused only by falling overhead shafts and pulleys. Mass movement of buildings caused some damage, but the major portion of damage was due to fire which burned buildings and their contents.

F. DAMAGE TO BRIDGES

1. Types and Construction of Bridges

a. Hiroshima. There were 81 important bridges scattered over the entire city of Hiroshima, ranging from 260 to 15,600 feet from Ground Zero. These served not only for local transportation needs but also as over-crossings for the city's services and utilities. Of those studied, the 39 highway bridges, comprising 14 timber, 15 concrete, and 10 of steel construction, were most numerous as a class. There were nine street railway bridges, most of which were in the heart of the city, consisting of two timber, one reinforced-concrete, and six steel bridges. The six railroad bridges, of strongly-built, steel construction, were, as a class, most distant from Ground Zero. There were four pedestrian bridges of timber, and seven bridges (4 timber and 3 steel) which served as aqueducts and over-crossings for utilities. The bridges in general were designed to carry lower loadings than comparable structures in the United States. The design, construction, and materials appeared to be inferior to United States standards, except for the steel-plate-girder bridges and steel-truss aqueducts.

b. Nagasaki. The 35 bridges studied at Nagasaki, all within 7,650 feet of Ground Zero, were used to span either the main body of the Urakami River or its tributaries. They were of relatively short span as nowhere did the width of the river exceed 240 feet. The maximum length of a single span was 120 feet. There were 16 reinforced-concrete bridges of the T-beam type; three curved-chord, steel-truss bridges; two of stone-arch construction; one reinforced-concrete arch; six plate-girder bridges; two timber bridges; one of wood-and-concrete construction; one of wood-and-steel construction; and three bridges of reinforced concrete and structural steel. These bridges covered a wide variety of types but none was outstanding or original in design.

2. Extent and Causes of Damage. Of the 35 bridges at Nagasaki, at distances varying from 300 to 7,650 feet from Ground Zero, four were totally or heavily damaged by blast or fire and six others sustained some degree of structural damage. At Hiroshima, 17 bridges were totally or heavily damaged, and 10 others suffered degrees of damage ranging from displaced and distorted decks and minor structural members to broken railings, curbs, posts, and copings. In terms of deck area, 33 per cent of the 19 timber bridges and four per cent of the 23 steel bridges were totally damaged by blast and fire. None of the 15 concrete bridges suffered total damage. Proximity to Ground Zero did not seem to affect the heavily-built concrete bridges seriously, possibly because of the mass of the bridges and the vertical action of the blast in the direction of their greatest strength, the design of bridges being such as to resist heavy

vertical loads. Bridges of less mass but farther from Ground Zero were damaged by displacement which resulted in distortion and failure of members. Plate-girder bridges do not possess large mass, and offered relatively greater surfaces to the blast. Wood bridges were particularly vulnerable to the atomic bomb, sustaining total damage by fire and blast, in Nagasaki up to 5,760 feet from Ground Zero, and in Hiroshima, up to 4,670 feet from Ground Zero. Steel railroad bridges in Hiroshima, being most distant from Ground Zero (5,580 to 8,480 feet), completely escaped damage except for radiant heat effects which to a minor degree on five bridges discolored the paint on girders facing Air Zero.

a. Blast. At Nagasaki two steel-plate-girder railroad bridges, one 840 and the other 900 feet from Ground Zero, were displaced and suffered heavy structural damage as a result of blast. One timber bridge was totally demolished by blast, 5,760 feet from Ground Zero. Two bridges, one of steel and concrete, the other concrete, 1,950 and 2,330 feet from Ground Zero, respectively, had spans blown off. In addition, the decks of the remaining spans of the steel-and-concrete bridge were blown 150 feet away. Four concrete bridges from 300 to 1,710 feet from Ground Zero sustained lateral displacement from one to eight inches as a result of blast. Blast damage to six other concrete bridges at Nagasaki at distances from 750 to 3,750 feet from Ground Zero ranged from displacement of deck and spalling of concrete girders to demolished railings. At Hiroshima, two steel, street railway bridges 1,000 and 4,670 feet, respectively, from Ground Zero were heavily damaged by blast. One steel highway bridge, 1,190 feet from Ground Zero, was totally collapsed. Five concrete (4,270 to 6,450 feet from GZ) and five steel highway bridges (260 to 7,600 feet from GZ) were damaged in extent ranging from distorted decks to superficial damage, such as blown-off railings and trim. Flood and typhoon were credited with damaging 9 timber, 7 concrete, and 3 steel bridges at Hiroshima between 17 September and 5 October 1945. It is considered probable that blast-loadings from the atomic bomb had weakened some of these bridges and left them in a vulnerable condition.

b. Fire. At Hiroshima five timber highway bridges were structurally damaged by fire. One timber pedestrian bridge 4,760 feet from Ground Zero was completely consumed by fires which spread from adjacent areas. No bridges at Nagasaki were structurally damaged by fire alone. Superficial damage in the form of burned ties was sustained by a steel railroad bridge 1,650 feet from Ground Zero at Nagasaki.

c. Blast and Fire. One timber bridge in Nagasaki, 5,460 feet from Ground Zero, was completely demolished by blast and fire. At Hiroshima, one timber street railway bridge 4,670 feet from Ground Zero was totally damaged. In addition one steel and four timber bridges, used as aqueducts and over-crossings at Hiroshima, totally collapsed as a result of blast and fire, and two other steel bridges were structurally damaged. These seven bridges # carried water mains, telephone wires, and low- and high-pressure gas mains.

G. DAMAGE TO STACKS

1. Types of Stacks. Stacks in both Hiroshima and Nagasaki were for the most part of reinforced-concrete, brick, and steel construction. Reinforced-concrete stacks were the most numerous; those of brick construction were second; and steel stacks were in the minority. The average height of all stacks was less than 70 feet. There were few over 100 feet, the highest in Hiroshima being 120 feet. Several other types were in use, such as vitrified-tile and asbestos-pipe, but these were not considered worthy of study.

a. Reinforced-Concrete Stacks. Concrete stacks were generally well designed and were sufficiently strong to withstand heavy wind-loads, as well as the effects of earth tremors. Mediocre quality of workmanship, however, was reflected in the lack of care in placing reinforcing steel and the varying thickness of concrete. One-course brick lining was used in many concrete stacks, usually to a height of 10 to 15 feet.

b. Brick Stacks. Stacks of brick construction, especially those of octagon shape, were usually well designed and well built. Materials and workmanship were good. The smaller, square-shaped brick stacks, however, were generally built too light and many required bracing with angle iron or steel straps.

c. Steel Stacks. Stacks of this type, comprising the smallest number of all types observed, followed no apparent design standards. Sections of some were lap welded; others had riveted joints. The chief weakness of this type stack lay in methods of anchorage, which were usually ineffective in safeguarding against overturning. The advantages in the use of these stacks were the economy and ease of construction and the fact that, even when knocked down, they could be quickly repaired on the ground and re-erected in one piece by crane.

2. Cause and Extent of Damage. It was considered that all damage sustained by stacks resulted from blast effects of the atomic bomb inasmuch as there was no evidence such as spalled concrete, vitrified brick, or oxidized steel to indicate any portion of the damage was caused by fire. In both cities there were numerous apparently undamaged stacks left standing while the buildings they served had been reduced to wreckage. At Hiroshima, within a radius of 8,700 feet

from Ground Zero, 15 per cent of the concrete, 50 per cent of the brick, and 70 per cent of the steel stacks were damaged to such an extent as to render them unusable without almost complete rebuilding. At Nagasaki, only four out of approximately 30 concrete stacks were damaged within 6,000 feet of Ground Zero. Two of these stacks, moreover, had been very close to high-explosive bomb hits during an attack prior to the atomic bomb explosion and it was possible that this circumstance might have contributed to the failure of the stacks. All brick and steel stacks within the same area were totally or heavily damaged. Stacks of reinforced-concrete construction proved most resistant to blast; brick was highly vulnerable; and steel stacks were the most easily damaged. The mean areas of effectiveness of the atomic bomb against reinforced-concrete, brick, or steel stacks at Hiroshima were computed to be 0.3, 2.7, and 4.1 square miles, respectively; the mean effective radii being 1,625 feet, 4,900 feet, and 6,050 feet. In view of the similarity of design and construction of stacks in the two cities, these figures should be applicable in no lesser degree to the stacks in Nagasaki. The amount of damage to concrete stacks in both Nagasaki and Hiroshima was almost negligible compared to the amount of damage to buildings within the same areas. The resistance of concrete stacks to blast effects of the atomic bomb might be attributed to a number of factors, such as structural flexibility, minimum exposed surface, fire-resistive qualities, vertical angle of blast, and, in some instances, partial shielding by intervening buildings.

IV. PUBLIC UTILTIES.

1. General. All public services and utilities in both Hiroshima and Nagasaki sustained damage as a result of the atomic bomb attacks, and were disrupted in whole or in part for varying lengths of time. As both cities were virtually paralyzed by the sudden, widespread destructive effects of the detonations, the demand for services fell off as sharply as the supply. Despite the extent of damages and the chaotic conditions prevailing immediately following the attacks, some of the more vital services such as street railway, railroad, water, and electricity were restored to minimum levels within periods ranging from 24 to 72 hours in an effort to facilitate emergency rescue and clearance and to provide some measure of relief for the stricken populations.

2. Transporation.

a. Street Railway and Bus Service. Hiroshima depended almost entirely upon the street railway system and busses for passenger transportation within the city and to outlying districts, since it contained ~~such~~ a small number of private vehicles. Nagasaki, ~~although~~ having no busses, depended heavily on ~~their~~ street railway system for urban transportation. ~~Their~~ double-track system carried a daily load of 77,000 ~~consumers~~. Of the 123 street railway cars in Hiroshima, 20 per cent were damaged by fire and 45 per cent by blast. Fire damaged 21 per cent and blast 26 per cent of the motor busses. Both cars and busses were ignited by radiant heat within 1,500 feet of Ground Zero. Damage varying from total to slight was sustained by cars up to 12,500 feet from Ground Zero. Buses were damaged up to 5,500 feet from Ground Zero. In addition to the loss of rolling stock, there was a total of 11.4 miles of overhead transmission system damaged by blast and fire. This included wood and steel poles and transmission cable, from 4,500 to 8,000 feet from Ground Zero. There was no damage to trackage except ~~that which~~ was carried by bridges.

Disruption of the entire electrical system resulted from fire and blast damage to converter stations as far as 6,400 feet from Ground Zero. The bomb which detonated over Nagasaki resulted in damage, both by fire and blast, to 70 per cent of that city's street-railway cars within 10,000 feet of Ground Zero, and five per cent of the total trackage. The system was further crippled by damage to 50 per cent of the trolley wire, electric power lines, and sheared and overturned steel power-line supports. It was estimated that 200,000 man hours would be required to repair Nagasaki's street railway system.

b. Railroad. Hiroshima's intercity transportation was provided by the government railroad system, comprising the double-track Sanyo Main Line, together with classification yards, repair facilities, transit sheds and stations, and a single-track line, with intermediate stations within the city, to the deep-water harbor at Ujina. The average passenger rate per month was 1,824,960 persons; average freight tonnage amounted to 9,300 tons. Railroad facilities at Nagasaki consisted of a single-track line within the city, connecting it with Tosu Junction. There were three secondary stations within the city and the main Nagasaki Station, at which the line terminated. The system served primarily as transportation for passengers within the urban area and to the suburban sections. Railroad stations in both cities suffered either total or heavy structural damage from blast and fire within 7,000 feet of Ground Zero. Classification and repair facilities at Hiroshima between 8,000 and 10,000 feet from Ground Zero were superficially damaged. All communications and signal systems were either heavily damaged, or rendered inoperable because of damage to communications buildings. Rolling stock was more heavily damaged at

Hiroshima, where 13 per cent of the freight cars, 93 per cent of the passenger cars, and 75 per cent of the electric cars were damaged by blast and fire up to 6,800 feet from Ground Zero. Rolling stock at Nagasaki sustained comparatively slight damage, caused primarily by blast. More important track damage occurred at Nagasaki, where crossties, ignited by flaming debris, burned intermittently for distances of 10,000 to 15,000 feet and buckled the steel rails. Further rail damage resulted through the displacement by blast of three bridges. Emergency repair work, however, permitted resumption of limited traffic after 48 hours. Although no damage was sustained by trackage or bridge crossings in Hiroshima, adjacent fires and blast debris on the tracks prevented utilization of some sections for a period of several days.

3. Wire Communications. The telephone and telegraph facilities of Hiroshima and Nagasaki sustained widespread damage as a result of the atomic bombings. One of the most serious consequences of the crippling of these utilities was the ensuing delay in organizing emergency relief and adequate rescue work in the two cities. The overhead wires and cables of the transmission systems, as a result of their exposed positions, were the hardest hit. At Hiroshima approximately 80 per cent of the overhead system was damaged by fire and blast. The damaged portion of the system comprised over 27 miles of cable and approximately 92 per cent of a total of 7,451 wood poles carrying overhead lines. Poles were damaged by blast at 4,500 feet from Ground Zero, and burned at 6,500 feet; cable was stripped from hangers at 8,000 feet. At Nagasaki

approximately 50 per cent, or 57 miles, of the aerial cables and open wires of the telephone system were heavily damaged, and 15 per cent, or 19 miles, of the open wires of the telegraph system sustained damage in varying degrees. The two exchange buildings at Hiroshima, one 2,000 feet and the other 3,300 feet from Ground Zero, were damaged and 100 per cent and 50 per cent, respectively, of the equipment contained in ~~each of~~ these buildings, sustained total damage by fires resulting from short circuits. Nagasaki lost 60 per cent of ~~their~~ its 4,891 subscribers' telephone sets as a result of the attack. The subsurface system~~,~~ comprising underground transmission cables, being the least exposed to the effects of fire and blast, suffered the smallest amount of damage. Cables and conduits were vulnerable, however, at bridge crossings and at exit points to the overhead system. Damage at these locations, although limited in extent, was sufficient to put approximately 80 per cent of Hiroshima's subsurface system out of service. Within nine days, 35 pairs of subsurface cable had been returned to service, being restricted entirely to prefectural and military needs. At Nagasaki, 10.8 per cent, or approximately 16 miles, of the underground cable system was heavily damaged. As a result of the bomb effects at Nagasaki, wire communications were partly paralyzed for a week.

4. Electric Power

a. Power Supply. Hiroshima was furnished electric power by the hydroelectric plants of the Nippon Electric Company through two substations and by a steam-electric plant of the Chugoku Electric Company through seven substations. Power was transmitted by overhead lines from the hydroelectric plants to the substations at# 110 kv; from the steam plant at 55 kv. The substations of the Chugoku Company transformed from 22 kv to 3.3 kv for consumer distribution, except for several large industries and the street railway company which received power at 22 kv and transformed it to their own requirements. The 22-kv distribution was transmitted by both overhead and subsurface systems. Daily power consumption in Hiroshima was 80,000 kw for lighting and 170,000 kw for heating and motor energy. The electric supply system at Nagasaki, within the area affected by the atomic bomb, comprised eight transformer stations, two switch stations, and one small generating plant. The capacity of the power transformers was 86,500 kw which supplied 40,842 residential and 949 industrial consumers prior to the attack. The majority of their transmission lines was carried on steel towers and concrete standards.

b. Damage. At Hiroshima 70 per cent of the 3.3-kv overhead and feeder system was damaged by fire and blast. Of a total of 7,000 poles in use, 4,000 wood and 27 steel-lattice poles were damaged by blast and fire, and wires were blown from the poles by blast as far as 8,000 feet from Ground Zero. Concrete poles were not damaged. Of the remaining undamaged 30 per cent of the system, only 90 per cent was usable as some sections beyond the damaged area could not be supplied with electricity due to lack of connections to substations. No damage was sustained by the 22-kv subsurface system. In Nagasaki 32.4 per cent of the 66-kv open transmission lines sustained total damage. Of 76 steel towers eight were totally damaged, and four concrete standards of a total of 30 were demolished. In addition, heavy damage was inflicted upon Nagasaki's distribution system, which suffered the loss of 27.7 per cent of a total of approximately 134 miles of feeder lines; 24 per cent, or 1,491, of a total of 6,107 poles; and 27.6 per cent, or 483, of a total of 1,750 transformers. Damage to transformer substations and heavy equipment, although severe, was relatively light compared to that sustained by the overhead transmission and distribution systems. One substation at Hiroshima was heavily damaged by blast and fire 2,400 feet from Ground Zero, and another substation and a steam-electric plant, 7,700 feet from Ground Zero, were heavily damaged by fire which spread from adjacent areas. As a result of the damage to these two substations it was necessary to distribute the areas they served among the remaining substations. Four substations were slightly damaged at 5,500 feet and beyond; three substations were undamaged. At Nagasaki, three of a total of eight transformer stations sustained heavy damage to bus structures, insulators, and steel racks. Primary heavy equipment was only slightly damaged at these stations.

5. Gas Supply System. Storage facilities of the gas supply system in both cities, consisting of large gas holders, were the most vulnerable to the blast effects of the atomic bomb. The two gas holders in Hiroshima, located 6,500 feet from Ground Zero, having capacities of 316,000 and 211,000 cubic feet, respectively, were damaged when the crowns of the tanks were torn by blast and the released gas ignited. Of the three gas holders at Nagasaki, one located 3,000 feet from Ground Zero was completely demolished by a low-order detonation after being struck by the blast wave, and the other two, 6,600 feet from Ground Zero, had their tops collapsed and sustained heavy structural damage. Total equipment damage at the producing plants was slight. The electrical switchboard and recording meters at the Hiroshima plant were heavily damaged, but there was no loss of other equipment. The retorts and producing equipment at the two coal-gas plants in Nagasaki were affected by blast only to a minor degree. Damage to mains occurred for the most part at bridges and over-crossings. Branch and feeder lines were most heavily damaged at points where they entered buildings and plants within the areas affected by blast and fire. The total

effects of the damage to holders, pressure regulators, mains, and pipe lines were sufficient completely to disrupt the gas supply systems at both Hiroshima and Nagasaki, and restoration of service would have required repairs extending over a period of several months.

6. Water Supply. Both Hiroshima and Nagasaki had water supply systems that served their domestic and commercial needs and had always proved adequate for peacetime use. Hiroshima maintained a system capable of furnishing 20,000,000 gallons of filtered water a day. Water was pumped from the Ota River to a large reservoir from which it flowed to the distribution system. Pressure within the distribution system was maintained by three booster pumping stations. Nagasaki was supplied with water from four reservoirs located within 16,000 feet of Ground Zero. There were four systems with emergency interconnections in operation, each supplied by a different reservoir. Booster stations and pumping equipment in each of the two cities were damaged only slightly: in Hiroshima a pump motor was burned out because of falling debris, metering equipment in one station was heavily damaged, and several wood-frame buildings which housed equipment sustained structural damage; at Nagasaki meters housed in wooden structures and the electric installation for pump equipment suffered slight damage. By far the most crippling damage was sustained by distribution pipes and mains. Mains were broken in both cities by displacement of bridges, and additional breaks in Hiroshima's mains were attributed to falling debris. There was no debris damage at Nagasaki, but failure of 12-inch mains three feet below grade occurred as a result of uneven displacement of soil caused by oblique blast pressure. The buried mains in Hiroshima were undamaged. Branch and distribution lines in both cities

were heavily damaged by collapsing structures and the heat from burning buildings which melted the pipes. As a result of the damage to the mains and pipes and the consequent leakage and loss of pressure, the supply systems of both Hiroshima and Nagasaki, already taxed to the limit by wartime requirements, were rendered almost useless for fire-fighting purposes within a short period after the attack. Fire-fighting forces therefore relied principally upon bucket brigades which utilized water from domestic wells, water courses, and static tanks. After closing off the supply to those areas where leakage was greatest and to those sections where there would be no demand, sufficient emergency repairs were made within 24 to 36 hours to provide a limited amount of service to meet a portion of the populations' needs.

7. Sewer System. Although the other public utilities in Nagasaki and Hiroshima were roughly comparable in many respects to those in American cities of the same size, the problem of sewage disposal was entirely different. Human excrement was not included in the sewage, but was collected by the city from the residential areas and sold to farmers at a nominal price as a substitute for natural or artificial fertilizer, which Japan lacked. The sewer systems, therefore, were maintained primarily for the disposal of domestic waste water and surface drainage. The sewer system at Nagasaki consisted entirely of open trenches and was not considered worthy of study. Hiroshima disposed of 80 per cent of ~~their~~ its residential waste water by the use of short laterals to the Ota River; the remaining 20 per cent was carried through branch pipes to the sewer mains. Drainage waters flowed into the river through the mains, which also served as storm sewers, and through open flumes. Because the height of the river prevented gravity flow

during flood stages, 14 pumping stations had been installed in the system to dispose of waste and surface drainage. The equipment in six of these stations within a 5,200-foot radius of Ground Zero was heavily damaged by blast and subsequent fires at the time of the atomic bomb attack, and electric motors in two other stations which were damaged by blast were burned out as a result of falling debris. Damage to the electric substations which powered the pump equipment rendered the undamaged stations inoperative. There was no damage to mains or flumes. Damage to the pumping stations, which was not considered serious at the time, later assumed greater significance as seasonal rains caused floods which seriously delayed repairs of other utilities in Hiroshima which utilized subsurface systems and manholes.

J. FIRE

1. Vulnerability. The cities of Hiroshima and Nagasaki were both heavily built up, with combustible buildings of Japanese domestic types predominating. Nagasaki was the more congested because of the limitations on expansion placed on it by the surrounding hilly terrain, and its streets were generally narrower. Of the 13-square-mile built-up part of Hiroshima 68 per cent was 27 per cent or more built up (percentage of roof area to total ground area, excluding parks, fields, rivers and prepared fire breaks), whereas 70 per cent of the 3.8-square-mile built-up area of Nagasaki was 30 per cent or more built up. Probably more indicative of the greater congestion in Nagasaki is the fact that most of the population of 230,000 persons lived in an area of 3.3 square miles, compared to 245,000 persons in 9.9 square miles in Hiroshima. (Only residential areas built up more than 5 per cent were considered.) Except

for one light shower in each city, the weather had been dry for a period of three weeks in Hiroshima and for ten days in Nagasaki prior to the atomic bomb attacks. At the time of the attacks, there was a southeast wind of about 2½ miles per hour in Hiroshima, and a light southwest wind (probably not in excess of 5 miles per hour) in Nagasaki.

2. Fire Protection

a. Fire Departments. Both Hiroshima and Nagasaki were poorly prepared to combat a conflagration of large-scale proportions, although preparations had been made in both cities to combat mass indendiary attacks. Private fire equipment had been augmented and citizens had been given limited instructions and training in handling incendiary bombs. On the other hand, the public fire departments, which had proved adequate in controlling normal peacetime fires, had not been improved. In fact, in Nagasaki the professional fire-fighting personnel had been reduced 40 per cent. Even in peacetime, however, Nagasaki placed more reliance on auxiliary fire-fighting equipment and personnel than did Hiroshima. Interurban assistance at both cities was quite limited because there were few near-by towns or cities of any size. Industrial plant fire departments, including equipment and personnel, were poor by American standards for cities of comparable size.

b. Water Supply. Both cities had combined domestic and fire-service water systems. Water pressure in the central part of each city was normally 40-45 pounds per square inch, but in some places pressure was as low as 5-15 pounds per square inch. Nagasaki had a reservoir capacity of 740,000,000 gallons compared to 4,500,000 gallons in Hiroshima. The water at Hiroshima, however, was pumped from the Ota River, providing an inexhaustible supply, and 20,000,000 gallons of filtered water could be furnished daily. Water flowed to the cities by gravity, booster pumps furnishing the pressure for some areas. Sizes of water mains and branch lines were comparable in the two cities. Most of the hydrants in both cities were of the below-ground type.

c. Fire Breaks. The Ota River and its six branches divided Hiroshima into nine distinct areas. These river courses and 41,000 feet of fire lanes, which had been prepared by removing combustible buildings on one or both sides of fairly wide streets, provided the city with probably the most extensive network of fire breaks per square mile of any city in Japan. An elaborate system of fire breaks, totalling 55,000 linear feet, had also been cleared in Nagasaki to augment the natural fire breaks provided by Nagasaki Bay and the Urakami and Nakashima Rivers.

3. Start of Fires.

a. Hiroshima. The explosion of the atomic bomb at Hiroshima started hundreds of fires almost simultaneously throughout the heavily built-up city center. The original fires were most numerous within 4,000 to 5,000 feet from Ground Zero, since the buildings in this area were closer to the center of heat, there were more of them, and a larger percentage was collapsed by blast. The temperature at the center of the bomb explosion was of extreme intensity (estimated at 70,000,000° C), but the closest point on the ground was 2,000 feet away and the highest building was less than 100 feet high. Although the heat had largely dissipated before reaching ground objects, the temperature at Ground Zero probably was in excess of 3,500° C for a fraction of a second. Apparently this flash heat started numerous fires only in easily ignitible materials such as dark cloth, thin paper, and dry-rotted wood, principally within 4,000 feet of the center of the explosion (3,500 feet from Ground Zero). Most of the initial fires, however, were started by secondary sources of ignition, such as kitchen charcoal fires, electric short circuits, and industrial process fires, through the collapse of combustible buildings and in debris created by blast.

b. Nagasaki. The Nagasaki bomb was more powerful than the Hiroshima bomb and was detonated ~~300 feet closer~~ somewhat nearer to the ground. For these reasons the intensity of the heat at Ground Zero exceeded that at Hiroshima, and, in proportion to the amount of combustible materials exposed, radiant heat from the Nagasaki bomb is believed to have started more fires. In addition, there were hills within 2,000 feet of Ground Zero which placed buildings, trees, and other objects on them closer to the point of detonation, and directly exposed a greater proportion of the interiors of the buildings to radiant heat from the bomb. Wooded hillsides 1,000 to 2,000 feet west of Ground Zero in Nagasaki were ignited by radiant heat. In both cities exposed, vitreous roof tiles were blistered, granite was spalled and roughened, and wood, asphalt, and asphalt-painted surfaces were flash burned at various distances from Ground Zero depending upon their susceptibility to flash heat.

4. Fire Spread. There was a relatively small amount of fire spread in both cities beyond the areas in which the original fires were ignited by radiant heat from the bomb and secondary sources. A fire storm, including both wind and rain, developed in Hiroshima soon after the start of the original fires. The wind, which blew from all directions toward the burning area, reached a maximum velocity of 30 to 40 miles per hour about two to three hours after the explosion. Light and heavy rain fell intermittently over the north and west parts of the city. The fire storm was a decisive factor in limiting fire spread in directions away from the city at the fire perimeter. The high winds were caused by the fires drawing in a fresh supply of oxygen over the flat terrain, and the rain resulted from the condensation of moisture on particles of hot carbon which had been blown northwestward by the light, natural, southeast wind.

Although a distinct fire storm did not develop in Nagasaki, the velocity of the southwest wind, directly up the bay between the hills, had increased to about 35 miles per hour when the conflagration had become well established, probably about two hours after the explosion. About nine hours after the explosion the wind had shifted to the east, but its velocity had diminished to 10 to 15 miles per hour. The southwesterly wind is believed to have assisted in stopping fire spread to the south on both sides of the bay, and the shift of the wind to the east may have limited fire spread in the Nakashima River valley. No rain was reported to have fallen over the city. The long, narrow shape of the Urakami River valley and the hills which lined both sides of it were not as conducive to development of a fire storm as the broad flat terrain of Hiroshima. There was a natural tendency for the fires to sweep up the hills, which they did, and to draw a fresh supply of air from the south up the center of the narrow area formed by the river and the sites of noncombustible industrial plants on its east bank, varying in width from 500 to 2,000 feet, which extended from just southwest of Ground Zero all the way south to the bay. Apparently the narrow area acted as a funnel through which a fresh supply of air from the south could reach the burning areas on each side of the Urakami River, and this accounted for the great increase in wind velocity from the southwest. Except in Nagasaki where the fires swept up the hills on both sides of the Urakami Valley, there was no evidence of a general advancing front to the conflagration in either city. At Hiroshima, however, there was some fire spread beyond 5,000 feet from Ground Zero in built-up areas outside the periphery of the original fires. A large proportion of the burned-over areas in both cities resulted from the spreading and merging of the original fires. In Hiroshima most of the fire had burned itself out or had been extinguished in the fringe area about 12 hours after the explosion. In

Nagasaki most of the fires had died out or were under control about 19 hours after the explosion. Isolated fires continued to burn and smoldering persisted over a large part of the burned-over areas in the two cities for three or four days. In fact, grain in three warehouses in Hiroshima burned for several weeks.

5. Fire Fighting

a. Effort. Almost no effort was made to fight the conflagrations within the areas finally burned over except in a few reinforced-concrete buildings where the occupants remained or where people took refuge. At Hiroshima the fire wind blowing toward the city from all directions was a major factor in checking fire spread at the perimeter. In both cities, the more sparsely built-up areas, some of the wider streets, and a limited amount of fire fighting assisted in stopping fire spread at the perimeter. Fire breaks at Hiroshima were ineffective because the original fires were ignited on both sides of them, but at Nagasaki man-made fire breaks (9,000 and 11,000 feet southeast of Ground Zero) combined with bucket-brigade activity stopped the spread of fire at two locations.

b. Difficulties Encountered. Within 5,000 feet of Ground Zero in all directions at Hiroshima, a large proportion of the serious casualties occurred. Thousands of persons were killed immediately by the explosion and additional thousands were injured, many critically. Approximately 70 per cent of the public fire department apparatus was immediately out of service, and over 80 per cent of the "on-duty" firemen were killed or incapacitated. Almost none of the "off-duty" firemen, who would normally be available, reported for duty. Thus the public fire department had been dealt an instantaneous, paralyzing blow from which it could not recover. The streets were blocked by demolished buildings and their contents, debris covered a majority of the underground hydrants, and the general confusion was enormous. Even if the fire department had remained intact, the general situation within 5,000 feet of Ground Zero would have been a hopeless one from the beginning. At a few places on the fire perimeter the public fire department performed some effective work but its efforts played a minor role in the over-all fire-fighting task. The most effective fire fighting was done by the civilian populace, aided by soldiers who were quartered in the area, who formed bucket brigades and passed buckets of water from tanks, open drainage ditches and rivers. One 16-inch water main was broken by the collapse of the bridge which carried it; the booster pumping stations were damaged by blast; and large numbers of small feed lines were broken by the collapse of the buildings they served. An immediate reduction of water pressure in the system resulted. Later in the day the distribution system in the center of the city was shut off. The reservoir did not run dry and lack of water in the public water system apparently had no effect on the fire situation. It would have failed, no doubt, if a heavy demand had been placed on it. In Nagasaki, extensive and serious blast damage to buildings and casualties to persons was limited to within 7,000 feet of Ground Zero in the Urakami Valley. The Nakashima Valley was shielded from the blast by 900-foot hills 6,000 feet southwest of Ground Zero. Consequently the public and volunteer fire departments escaped with only 35 per cent of their personnel killed or injured and 20-per-cent total damage to their pumping engines. These losses were light compared to those at Hiroshima. Except for minor casualties, the fire-fighting organization beyond 7,500 feet south and southeast of Ground Zero remained intact. The fire chief dispatched two pumping engines from the main fire station (9,500 feet southeast of Ground Zero) to combat the fires to the north, and dispatched men to establish liaison with the volunteer fire departments as telephone communications had been disrupted. One truck penetrated to the vicinity of the gas works, 6,500 feet south of Ground Zero, arriving there about 10 minutes after the explosion, but it could not go farther because streets were obstructed by debris and buildings in the area to the north were in flames. This truck returned to the main fire station to assist in fighting fires in that vicinity. The public and volunteer fire departments fought against spread of fire within the area between 8,000 and 11,000 feet south of Ground Zero on the east side of Nagasaki Bay and in the area between 6,000 and 8,000 feet south of Ground Zero on the west side of the Urakami River, although seriously handicapped by decreasing water pressure in the city water system which finally became so low as to be useless for fire-fighting purposes within 18 hours after the explosion. The blast caused five breaks in a 12-inch cast-iron main three feet below grade in a reclaimed area within 2,000 feet of Ground Zero by unevenly depressing the soil, and caused six additional major breaks, four of them by displacement of bridges which carried the pipes. Another contributing factor to the failure of the water supply was the breakage of several thousand service pipes resulting from collapse of buildings by blast or damage by fire. As in Hiroshima, bucket brigades utilizing water from tanks, wells, and water courses were most effective in limiting fire spread in fringe areas.

6. Extent and Cause of Fire Damage

a. Areas Involved. In Hiroshima a roughly circular area of 4.4 square miles was completely burned over. In Nagasaki an irregularly shaped area of 0.9 square miles was burned over on both banks of the Urakami River and on the north bank of the Nakashima River. There were few combustible buildings and fire-resistive buildings with combustible contents remaining unburned within the burned-over areas in both cities. The most distant extremities of the burned-over areas were 10,200 feet to the north and east from Ground Zero in Hiroshima,

(40)

and 11,200 feet to the south from Ground Zero in Nagasaki. The shape and position of the fire pattern in each city ~~was~~ were the result of the location of the bomb burst and the characteristics of the terrain and built-up areas.

b. Radiant Heat Ignition ~~and Fire Spread~~. The ability of radiant heat from the atomic bombs to ignite combustible materials ~~at distances of 2,000 feet and more and 1,700 feet and more, respectively, at Hiroshima and Nagasaki~~ was of much interest. In both cities fire-resistive buildings with combustible contents were selected for study because these buildings suffered ~~there was~~ less structural damage ~~to~~ and had fewer casualties ~~in, these buildings, and, as a result,~~ to that better visual and ~~spoken~~ oral evidence could be obtained. In Hiroshima, it was established that radiant heat from the bomb was the probable cause of initial ignition in 20 per cent of the fire-

Comparable figures were not available for Nagasaki. It has been estimated, however, that in Nagasaki 90 per cent of all initial fires in fire-resistive buildings within 4,000 feet of Ground Zero might be attributed to radiant heat; in comparison, only about 30 per cent of such fires in similar buildings in Hiroshima within 4,000 feet of Ground Zero were caused by radiant heat.

[illegible]

~~distances from Ground Zero buildings in Nagasaki were actually 300 feet closer to the center of heat (point of detonation of the bomb), and were even closer in many cases because they were located on hillsides, and, in addition, there was less shielding by roofs and floors of the interiors of buildings on the hillsides.~~

c. Fire Spread

Despite the fact that radiant heat ~~from the bomb~~ started more fires in fire-resistive buildings in Nagasaki than in Hiroshima, a higher percentage of the buildings in Hiroshima was affected by fire and sustained more extensive fire damage, evidently as a result of fire spread. In Hiroshima a large proportion of the fire-resistive buildings comprised offices, banks, stores, and warehouses which were located in congested, combustible areas, whereas similar structures in Nagasaki were principally school, college, and institution buildings, most of which were in groups or set off by themselves and not closely exposed to congested, combustible areas. In Nagasaki all of the 31 fire-resistive buildings which sustained fire damage were within or adjacent to the burned-over area and within 4,000 feet of Ground Zero, whereas in Hiroshima only 69 per cent, or 40 buildings, were within 4,000 feet of Ground Zero. In order to demonstrate that there ~~evidently~~ was more fire spread to fire-resistive buildings in Hiroshima than in Nagasaki, the following comparison is presented:

Fire -Resistive Buildings	Nagasaki	Hiroshima
No. of bldgs within or adjacent to burned-over area and within 4,000 ft of GZ	37	41
No. of bldgs involved by fire within 4,000 ft of GZ	31	40
Percentage of bldgs involved by fire within 4,000 ft of GZ	82	98
Percentage of total floor area burned within 4,000 feet	52	89
Percentage of bldgs involved in fire within or adjacent to entirely burned-over area (max. dist. 6,500 ft from GZ)	--	91
Percentage of total floor area burned within 6,500 ft from GZ	--	72

d. ~~e.~~ Effect of Exposure Distance on Fire Spread. In Hiroshima a special study of exposure distances at 107 burned and 23 unburned fire-resistive, noncombustible, and combustible buildings, and 8 burned and 7 unburned combustible bridges within or adjacent to the burned-over area led to the conclusion that there was a relationship between incidence of fire in the buildings and bridges and their distance from burned exposing buildings. Fire definitely failed to spread by exposure to only one fire-resistive and one noncombustible building among the 107 buildings which were burned. The study is summarized as follows:

Combustibility Classification	Average distance(+) from nearest exposing bldg from which fire spread may have occurred	No. of Cases	Average distance(+) from nearest exposing bldg from which fire spread did not occur	No. of Cases
Fire-resistive bldgs/	20	57	90	7
Noncombustible bldgs/	5	7	30	5
Combustible bldgs/	20	41	40	13
Average for all bldgs/	20	105	50	25
Combustible bridges	35	8	70	7

(A similar study was not conducted in Nagasaki).

At Hiroshima studies were also made which established a relationship between probability of fire spread and built-up density, and another between probability of fire spread and exposure distances ~~was established~~ for the conflagration. The results indicated that there was a rapid increase in probability of fire spread as built-up density increased above 12 per cent and as exposure distances decreased below 50 feet; and that there was a comparatively small return in immunity from fire spread among combustible buildings averaging one and a half stories with a decrease in built-up density below 12 per cent and an increase in exposure distance above 50 feet.

e. Contributive Effects of Blast to Fire Damage. Within the areas finally burned over in both cities, the bomb blast rendered most buildings of all fire classifications extremely vulnerable to spread of fire by exposure by breaking all glass and blowing in or damaging fire shutters, stripping wall and roof sheathing, and collapsing walls and roofs. Likewise, it left practically all