TECHNICAL REPORT 88104

NEW HAMPSHIRE YANKEE

INVESTIGATION OF CONCRETE CRACKS IN THE SOUTH WALL OF THE SERVICE WATER COOLING TOWER

SEABROOK STATION

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184 High Street
Boston, MA

1.0 INTRODUCTION

This report summarizes the results of a study to determine if cracks observed in the south wall of the Seabrook Station Service Water Cooling Tower result from concrete shrinkage or from some other cause. The approach taken is to analyze the wall for tension stresses caused by shrinkage strain while accounting for the sequence in which the wall was constructed. A pattern of predicted cracks is then drawn by assuming cracks to form perpendicular to the principal stress directions. If the analytically derived crack pattern closely follows the existing pattern, it can reasonably be concluded that the cracks were caused by shrinkage and not by some other mechanism.

2.0 ANALYSIS

Specifically, the portion of wall under consideration is that portion which forms the south wall of the cooling tower basin between elevations 22'-0" and 44'-0" (see Figure 31). The analytical model includes the entire 301 foot length of wall, 22 feet high with the base fixed at elevation 22'-0". This height is used because the wall was constructed in five sections, each 22 feet high. By the time additional construction took place, nearly all shrinkage had occurred. The wall has been divided into five sections corresponding to each concrete placement, with the cold joints numbered 1 to 4 (see Figures 1 and 31). This area was constructed over a four month period, with the dates of installation shown in Table 1.

The analysis was carried out using the ANSYS Engineering Analysis System. The wall model consisted of 490 plane stress elements and 610 nodes (see Figures 2 to 10). Elements in Figures 3 to 10 are shown in a reduced plot to provide additional detail. Five separate analyses were performed where each analysis represents a particular phase. The models for each phase consist of the wall sections in place at that time (e.g., Phase 3 model includes Sections 1, 2, and 3). Final stresses and displacements are obtained at the end of each phase by summing results from previous phases. To illustrate, the stress for Element 63 at the end of Phase 3 is given in equation form below:

$$\sigma_{63,3(\text{end})} = \sigma_{63,1} + \sigma_{63,2} + \sigma_{63,3}$$

element ____| |____phase

In each analysis concrete shrinkage strains are simulated by imposing a temperature differential on each wall section. The relationship for concrete shrinkage versus time is taken from Reference 1, equation 1.10.2. The shrinkage strain is equated to thermal strain which leads to the appropriate

temperature values. These temperatures are shown in Table 2. Constraint equations between the sections are imposed to provide connectivity for each phase after Phase 1.

The applied temperatures and constraint locations for each phase are tabulated below:

PHASE	APPLIED Δ T (°F) SECTION NUMBER 1	2	3	4	5	LOCATION OF IMPOSED CONSTRAINTS
1	-101					None
2	- 9	-68				Cold Joint 1
3	- 2	- 7	-21			Cold Joints 1 & 2
4	- 3	-14	-38	-49		Cold Joints 1 & 2
5	- 30	-56	-86	-96	-145	Cold Joints 1, 2, 3 & 4

3.0 RESULTS

Deformed shapes of the wall due to shrinkage are shown in Figures 11 to 19. The effect of individual phases are shown in Figures 11 to 15 while Figures 16 to 19 show the combined effect at the end of each phase. To plot crack directions, a tensile stress of 500 psi was selected as a threshold for crack initiation (Ref. 1). This limit was compared to the stress from the end phase results. Elements with a maximum principal stress of 500 psi or greater were plotted (see Figures 20, 22, 24, 26 and 28). These were then overlaid on the principal stress plots (Figures 21, 23, 25, 27 and 29 and Figures 1A to 5A). Beginning with Phase 1, crack patterns were drawn perpendicular to the principal stresses within those elements with stress greater than or equal to 500 psi (see Figure 30). Once a crack pattern was drawn, say for the end of Phase 2, it was not changed, even though the principal stress directions changed at the ends of later phases. This presumes that a crack will form the first time the concrete tensile stress is 500 psi. Comparing Figure 30 to the actual crack pattern, Figure 31, it is observed that the predicted cracks are remarkably close to the actual. This includes some reversals in direction, such as both sides of cold joint 1; and some cracks with kinks, seen at the left side of cold joint 2.

4.0 CONCLUSIONS

The analysis demonstrates that the derived crack pattern induced by concrete shrinkage very closely follows the existing pattern of fine hairline cracks.

This analysis provides additional confirmation that the existing pattern of hairline cracks in the north and south walls occurred during construction as a result of the normal concrete curing process.

5.0 REFERENCE

1. Wang, C-K and Salmon, C.C., Reinforced Concrete Design, Harper & Row, 3rd ed., 1979.

TIMING OF CONCRETE POURS

PHASES 1 THRU 5

PHASE	POUR DATE	Δ* DAYS	Σ DAYS FROM 1	Σ DAYS FROM 2	Σ DAYS FROM 3	Σ DAYS FROM 4
1	05/04/79					
		79	79			
2	07/23/79					
		31	110	31		
3	08/24/79					
		6	116	37	6	
4	08/30/79					
		18	134	55	24	18
5	09/18/79					

*Assume 30 days/month

TABLE 1

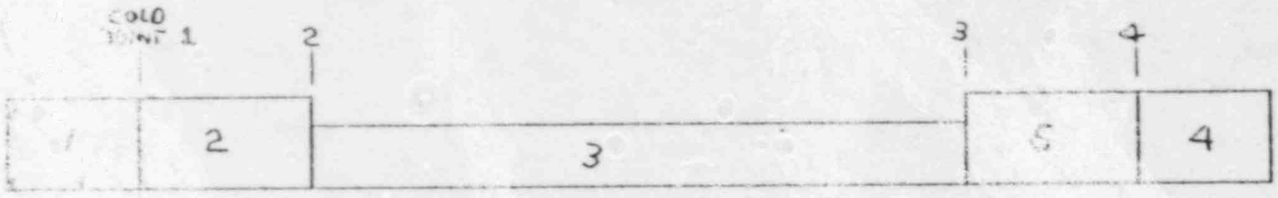
TEMPERATURE CALCULATIONS

END PHASES

PHASE		END PHASE 1	END PHASE 2	END PHASE 3	END PHASE 4	END PHASE 5
1	Σ Days	79	110	116	134	∞
	Total T*	-101	-110	-112	-115	-145
	Δ T	-101	- 9	- 2	- 3	- 30
2	Σ Days		31	37	55	∞
	Total T*		- 68	- 75	- 89	-145
	Δ T		- 68	- 7	- 14	- 56
3	Σ Days			6	24	∞
	Total T*			- 21	- 59	-145
	Δ T			- 21	- 38	- 86
4	Σ Days				18	∞
	Total T*				- 49	-145
	Δ T				- 49	- 96
5	Σ Days					∞
	Total T*					-145
	Δ T					-145

* Total T = $145.45 \frac{t}{t + 35}$

TABLE 2



ANSYS 4.3

FEB 22 1988

10:59:57

PLOT NO. 2

PREP7 ELEMENTS

ORIG

ZV=1

DIST=1987

XF=1808

YF=132

EDGE

FULL MODEL - BOUNDARIES

FIGURE 1

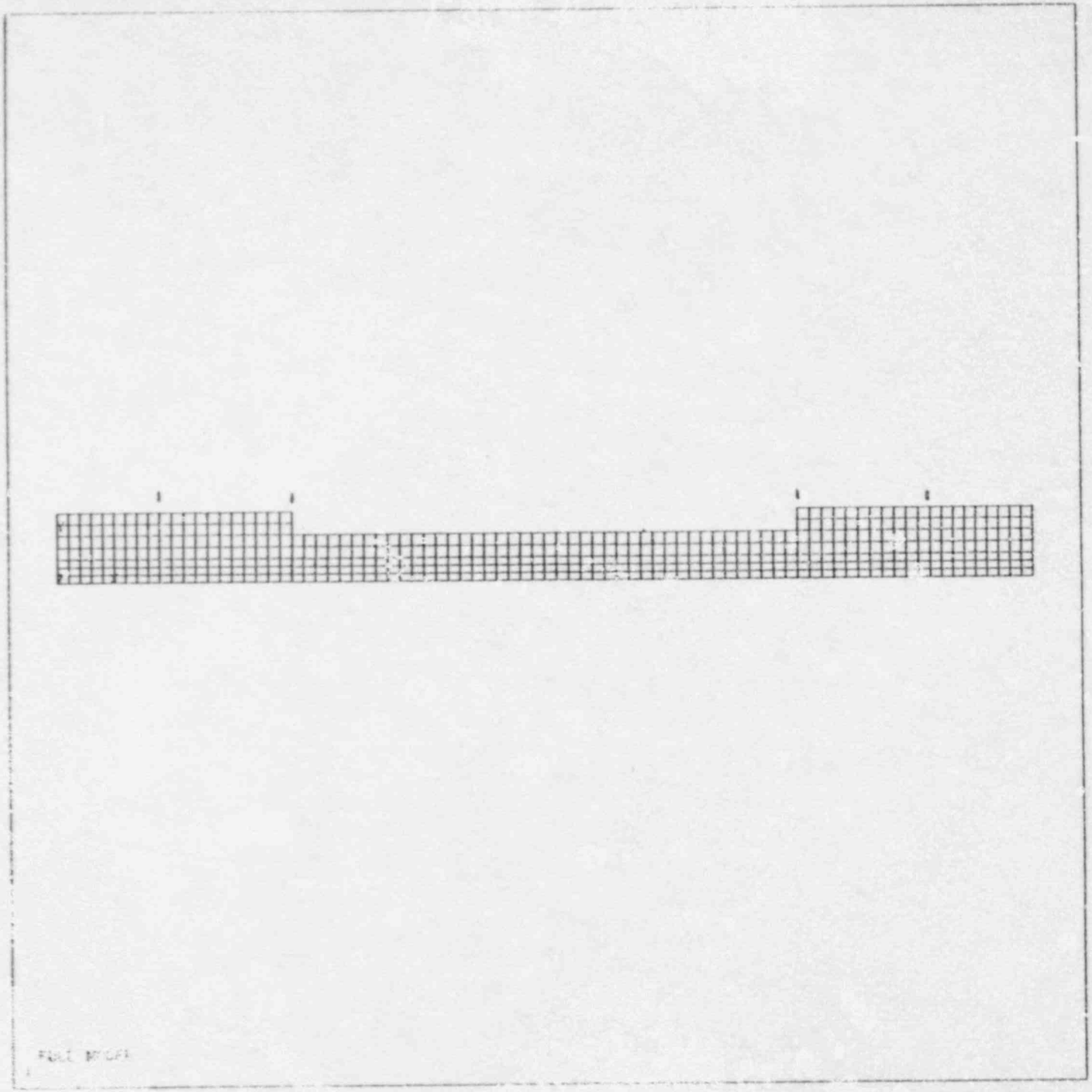
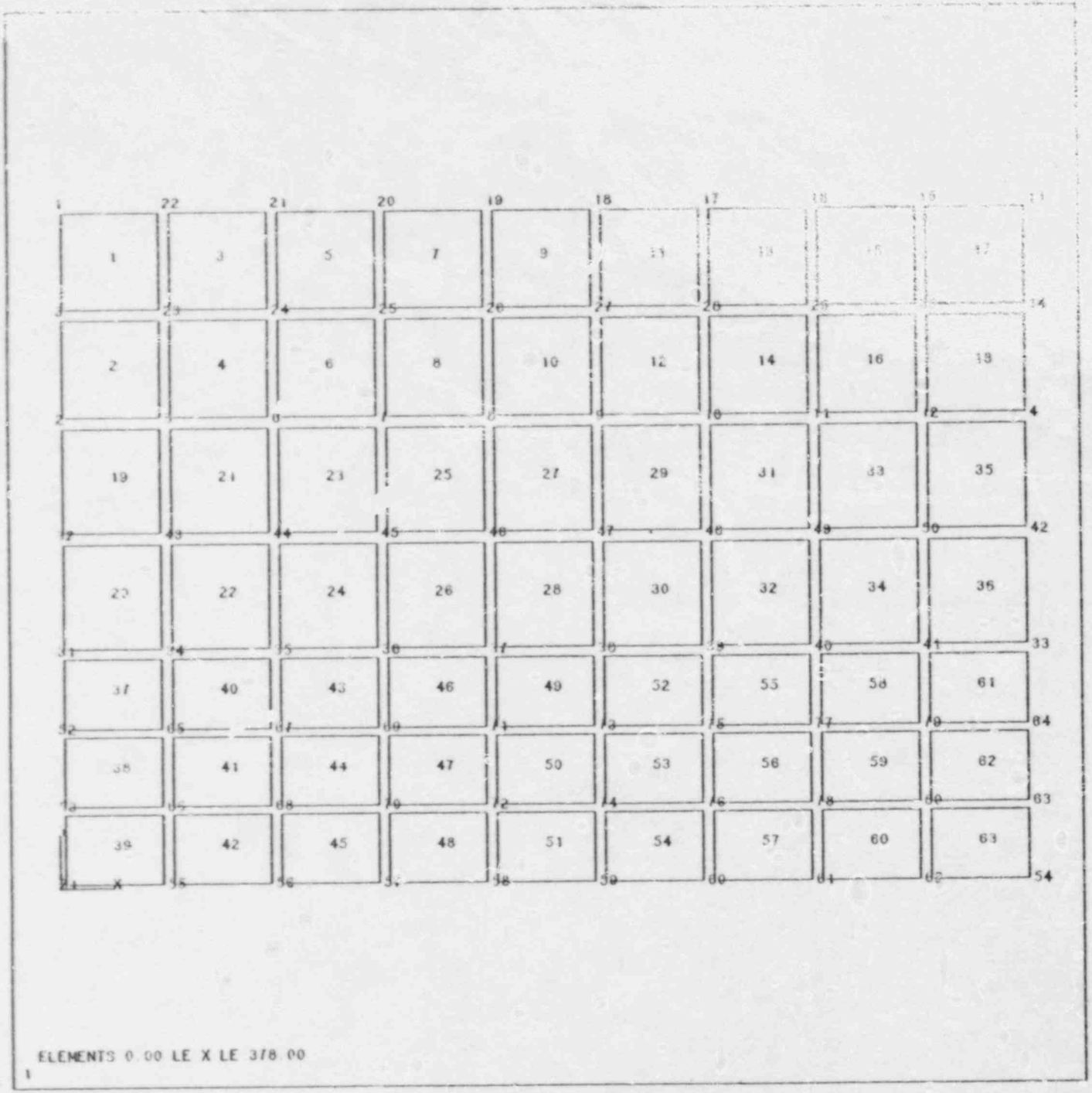

ANSYS 4.3
FEB 22 1988
10:58.05
PLOT NO. 1
PREP7 ELEMENTS
ORIG
ZV=1
DIST=1981
XF=1806
YF=132

FIGURE 2



ORIG

ZV=1

DIST=208

XF=189

YF=132

FIGURE 3

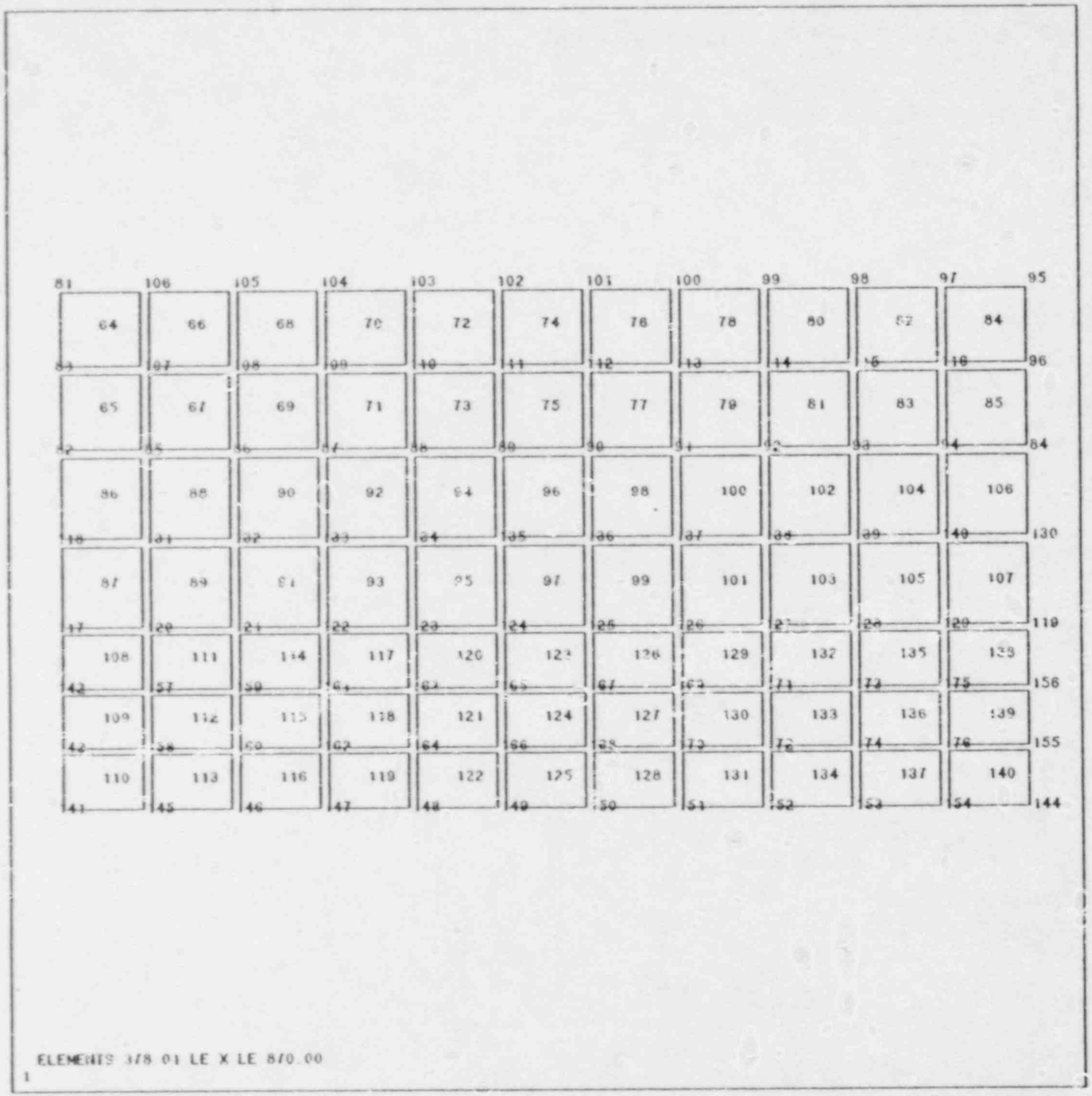
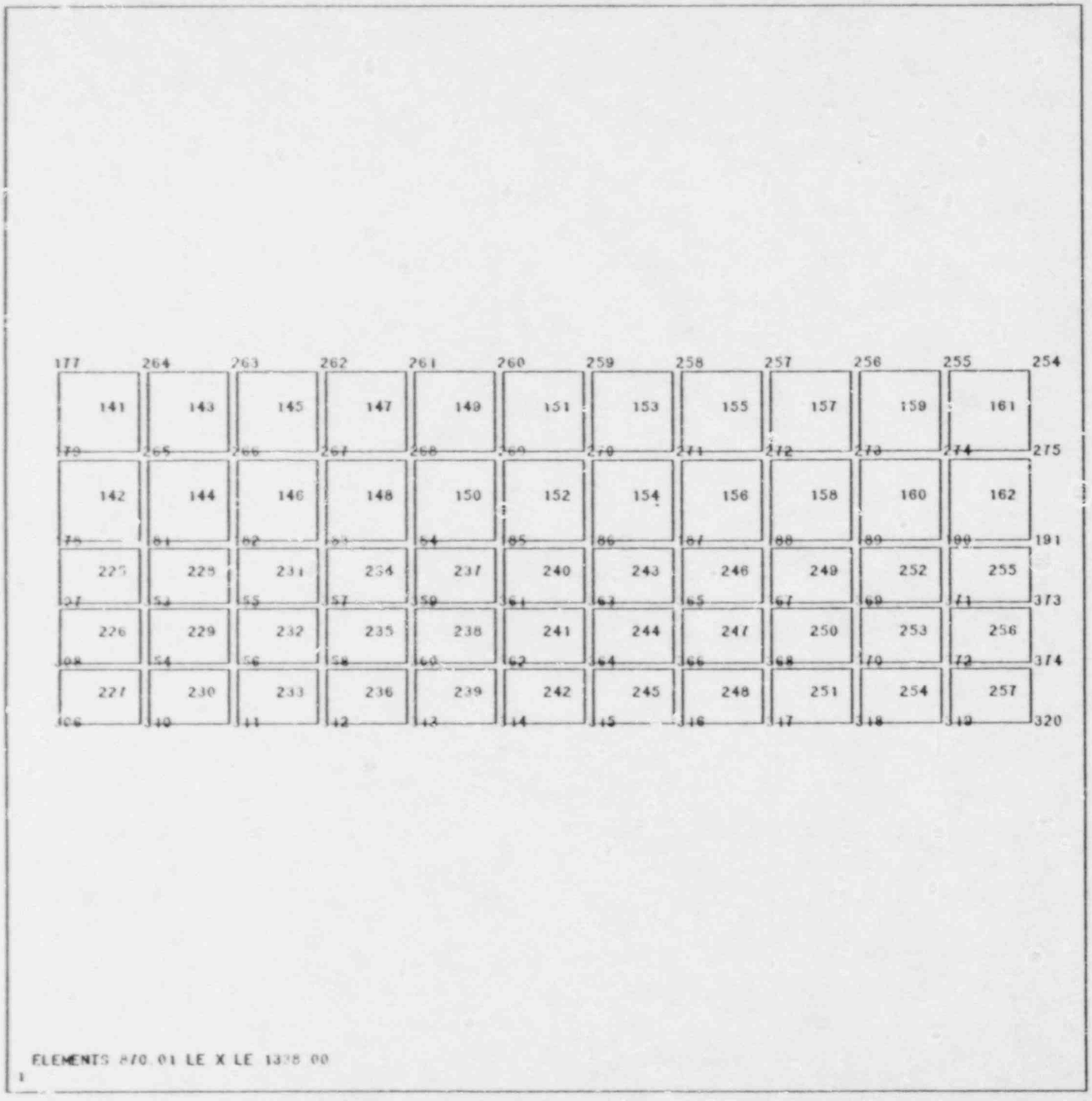

ANSYS 4.3
FEB 22 1988
11:03.23
PLOT NO. 5
PREP7 ELEMENTS
NODE NUM
ELEM NUM
ORIG
ZV=1
DIST=271
XF=624
YF=132
ELEMENTS 378 01 LE X LE 870.00

FIGURE 4



ANSYS 4.3

FEB 22 1988

11:05:16

PLOT NO. 6

PREPT ELEMENTS

NODE NUM

ELEM NUM

ORIG

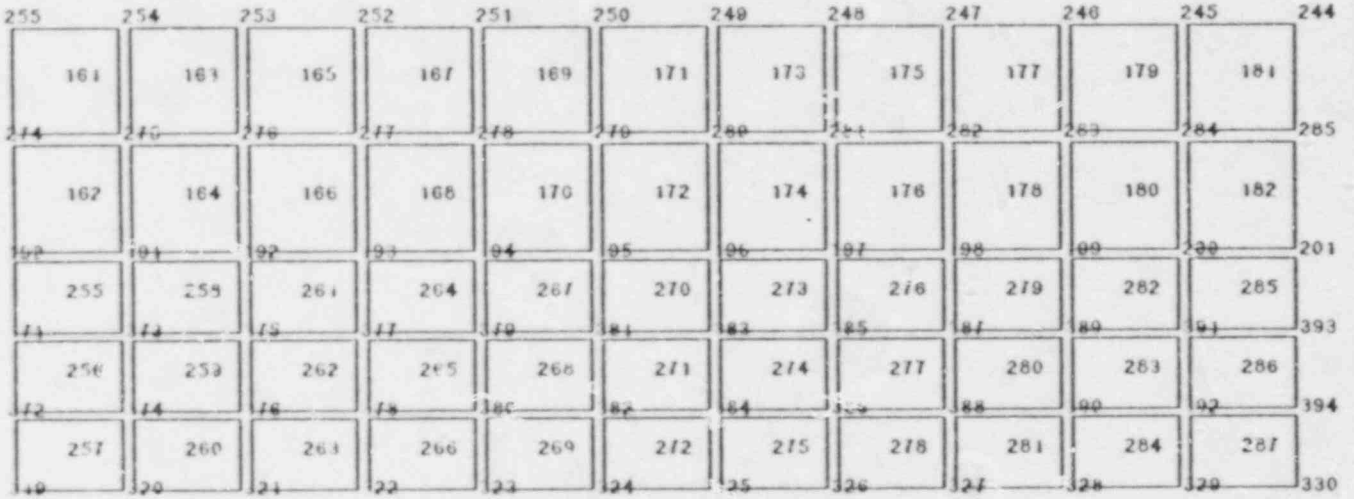
ZV=1

DIST=270

XF=1115

YF=80

FIGURE 5



ELEMENTS 1338.00 LE X LE 1806.00

1

ANSYS 4.3

FEB 22 1988

11:14:41

PLOT NO. 11

PREPT ELEMENTS

NODE NUM

ELEM NUM

ORIG

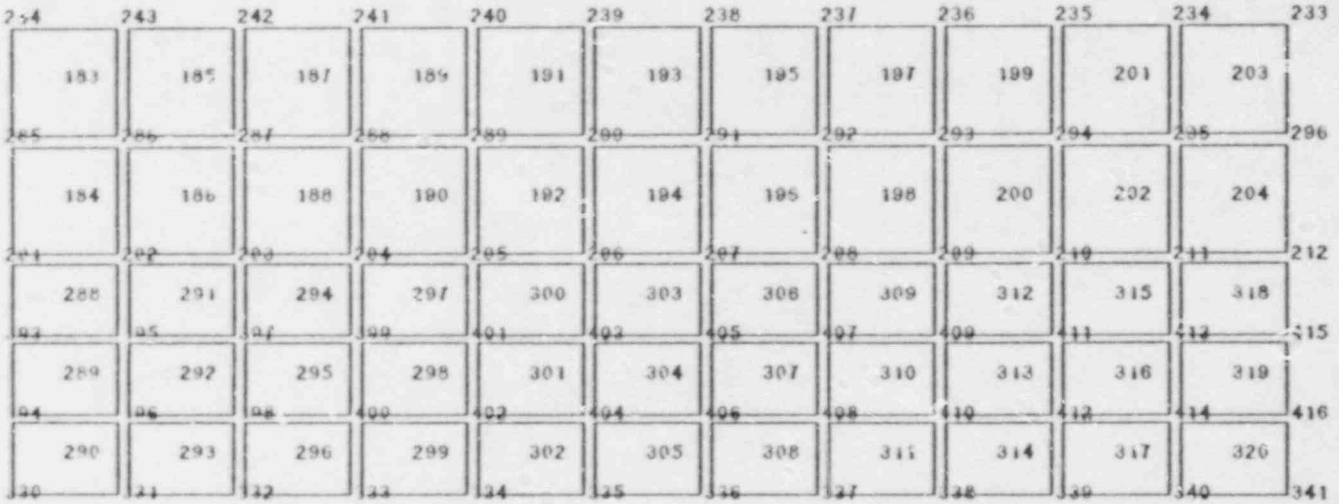
ZV=1

DIST=270

XF=1561

YF=00

FIGURE 6



ELEMENTS 1806.00 LE X LE 2274.00

ANSYS 4.3

FEB 22 1988

11:09.19

PLOT NO. 8

PREP7 ELEMENTS

NODE NUM

ELEM NUM

ORIG

ZV=1

DIST=270

XF=2051

YF=80

FIGURE 7

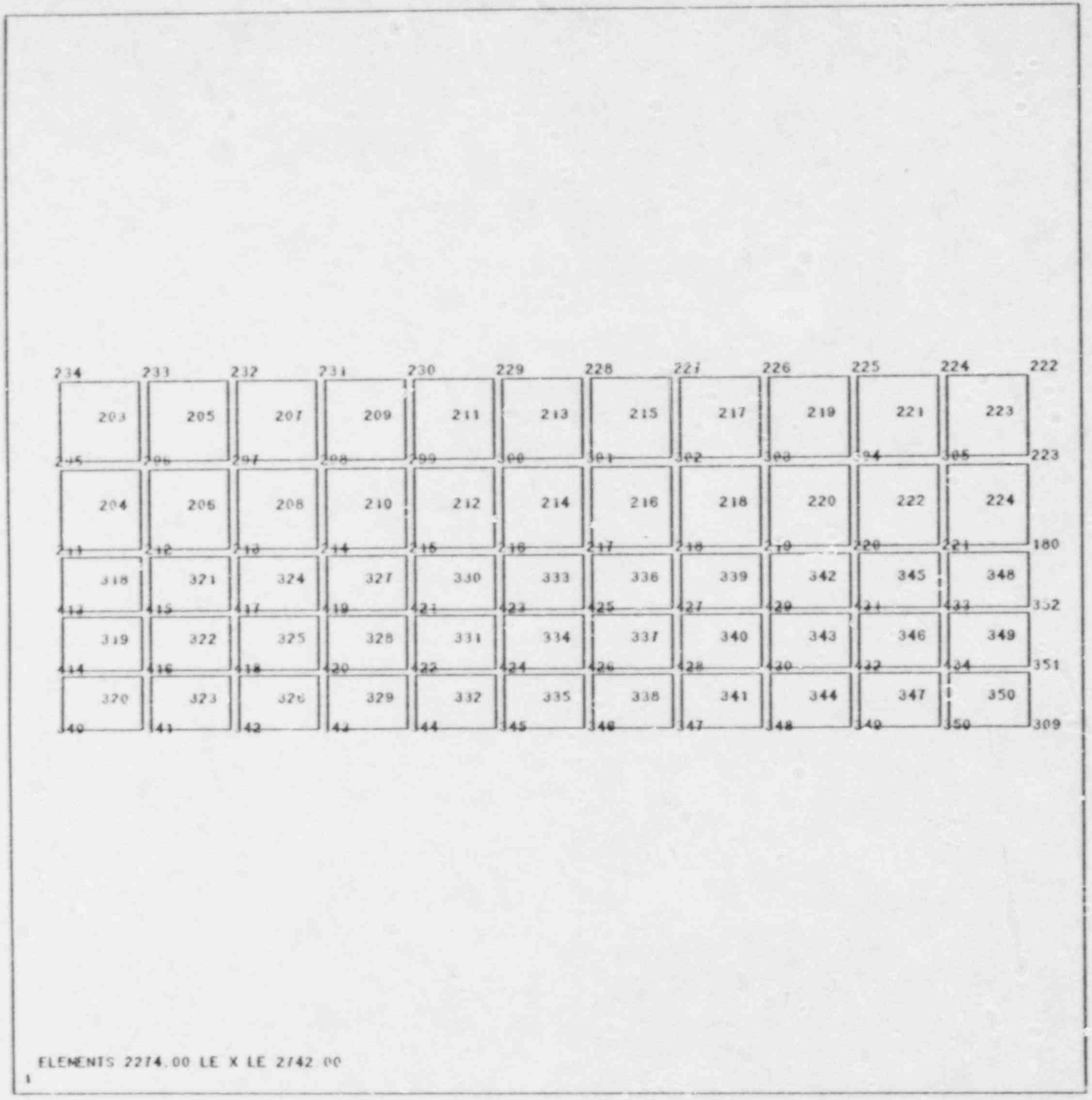

234 233 232 231 230 229 228 227 226 225 224 222
203 205 207 209 211 213 215 217 219 221 223
204 206 208 210 212 214 216 218 220 222 224
318 321 324 327 330 333 336 339 342 345 348
319 322 325 328 331 334 337 340 343 346 349
320 323 326 329 332 335 338 341 344 347 350
ELEMENTS 2274.00 LE X LE 2742.00
1
ANSYS 4.?
FEB 22 1988
11:13:26
PLOT NO. 10
PREP7 ELEMENTS
NODE NUM
ELEM NUM
ORIG
ZV=1
DIST=270
XF=2497
YF=90

FIGURE 8

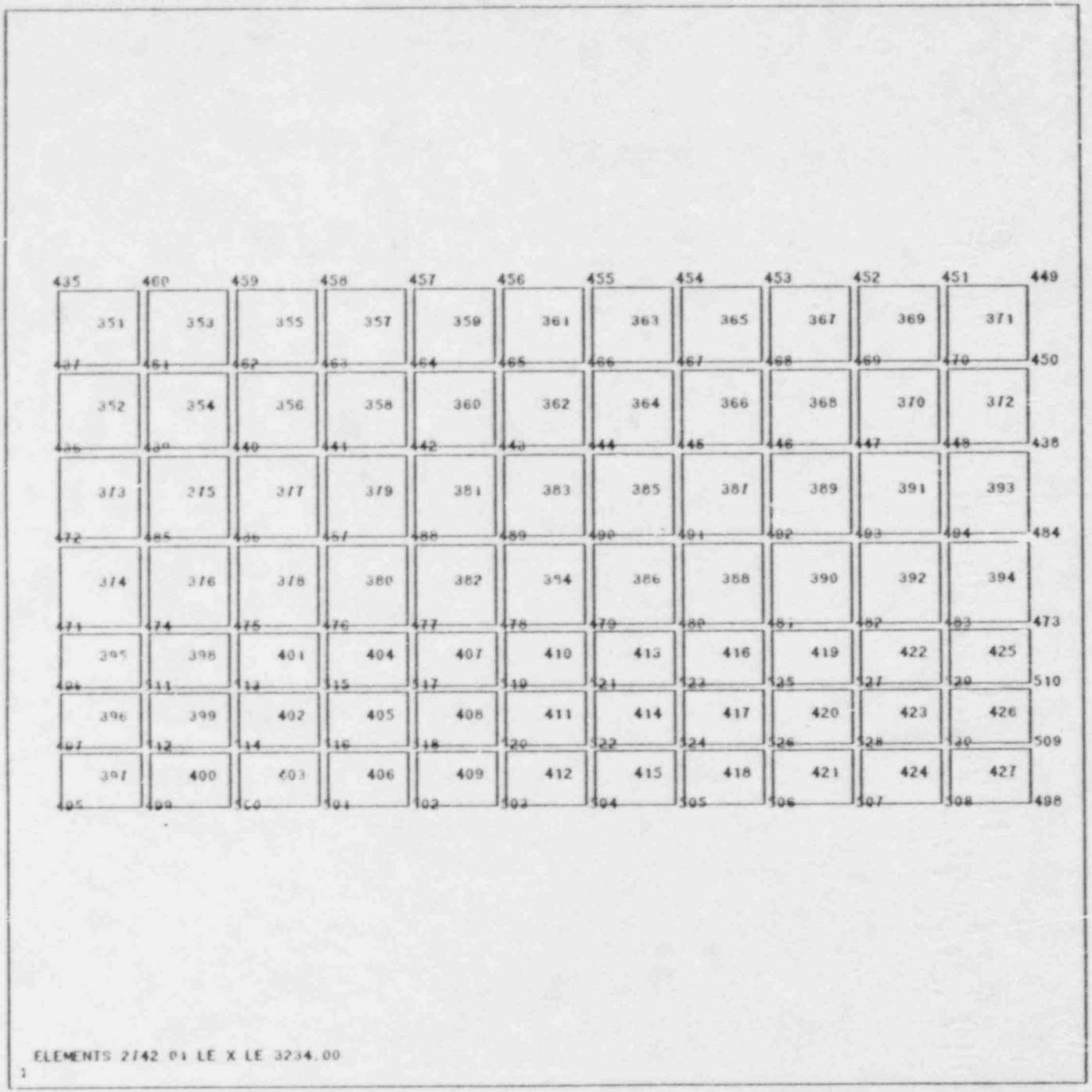

435 460 459 458 457 456 455 454 453 452 451 449
351 353 355 357 359 361 363 365 367 369 371
450
352 354 356 358 360 362 364 366 368 370 372
438
373 375 377 379 381 383 385 387 389 391 393
484
374 376 378 380 382 384 386 388 390 392 394
473
395 398 401 404 407 410 413 416 419 422 425
510
396 399 402 405 408 411 414 417 420 423 426
509
397 400 403 406 409 412 415 418 421 424 427
498
ELEMENTS 2742 01 LE X LE 3234.00
1
ANSYS 4.3
FEB 22 1988
11:15:59
PLOT NO. 12
PREP7 ELEMENTS
NODE NUM
ELEM NUM
ORIG
ZV=1
DIST=271
XF=2988
YF=132

FIGURE 9

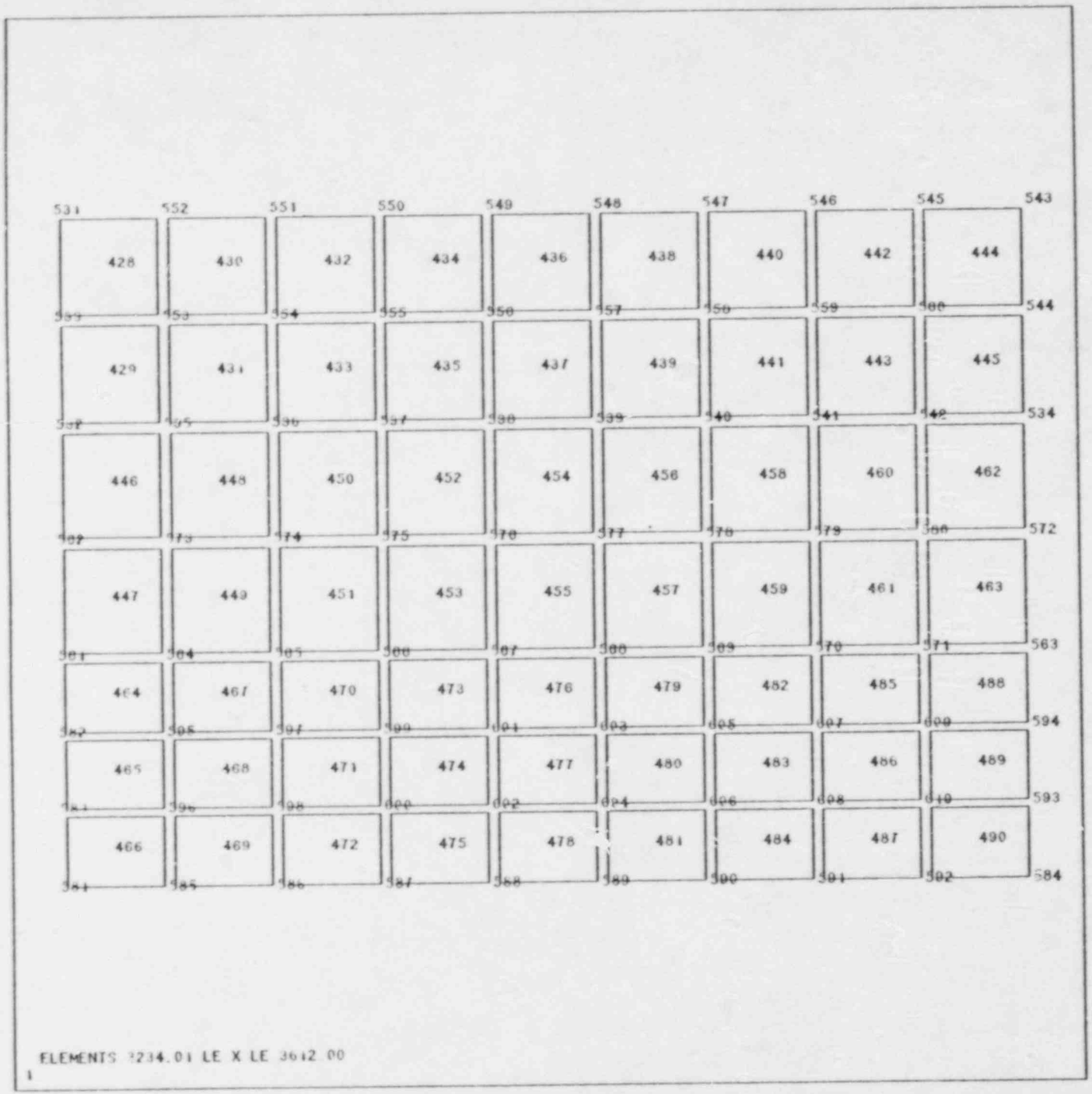
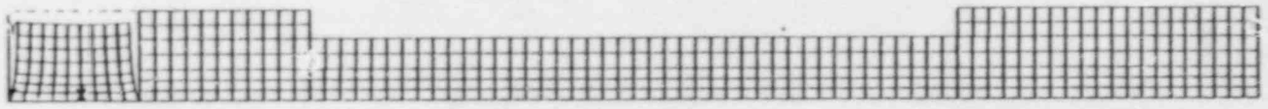

ANSYS 4.3
FEB 22 1988
11:17:29
PLOT NO. 13
PREP7 ELEMENTS
NODE NUM
ELEM NUM
ORIG
ZV=1
DIST=208
XF=3423
YF=132
ELEMENTS 3234.01 LE X LE 3642.00

FIGURE 10



ANSYS 4.3

FEB 22 1988

11:37:17

PLOT NO. 2

POST1 DISPL.

STEP=1

ITER=1

ORIG

ZV=1

DIST=1987

XF=1806

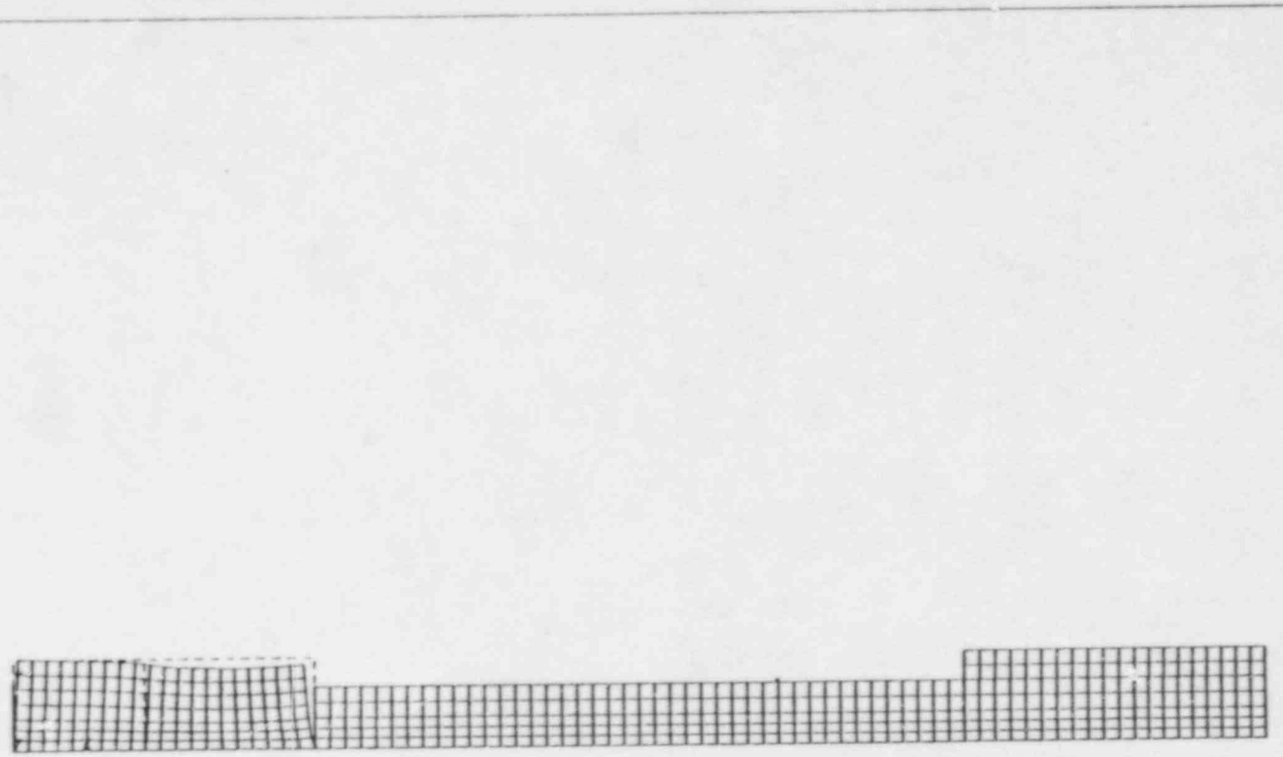
YF=132

DMAX=.179

DSCA=250

PHASE 1 DAY 0 TO DAY 79

FIGURE 11

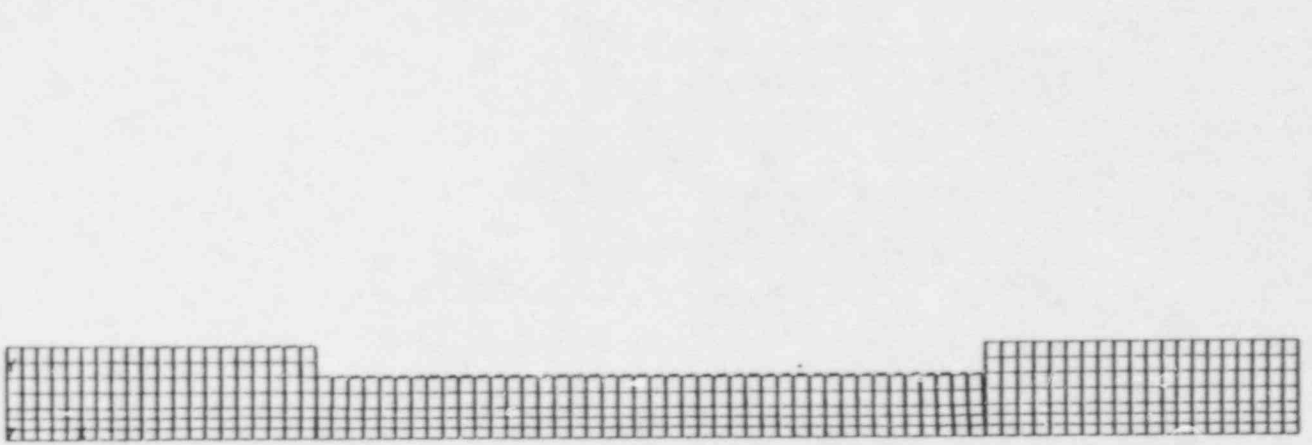


ANSYS 4.3
FEB 22 1988
11:38.04
PLOT NO. 3
POST1 DISPL.
STEP=2
IIER=1

ORIG
ZV=1
DIST=1987
XF=1806
YF=132
GMAX=.141
DSCA=250

PHASE 2 DAY 79 TO DAY 110

FIGURE 12



PHASE 3 DAY 110 TO DAY 110

1

ANSYS 4.3

FEB 22 1988

11:40.32

PLOT NO. 4

POST1 DISPL.

STEP=3

ITER=1

ORIG

ZV=1

DIST=1987

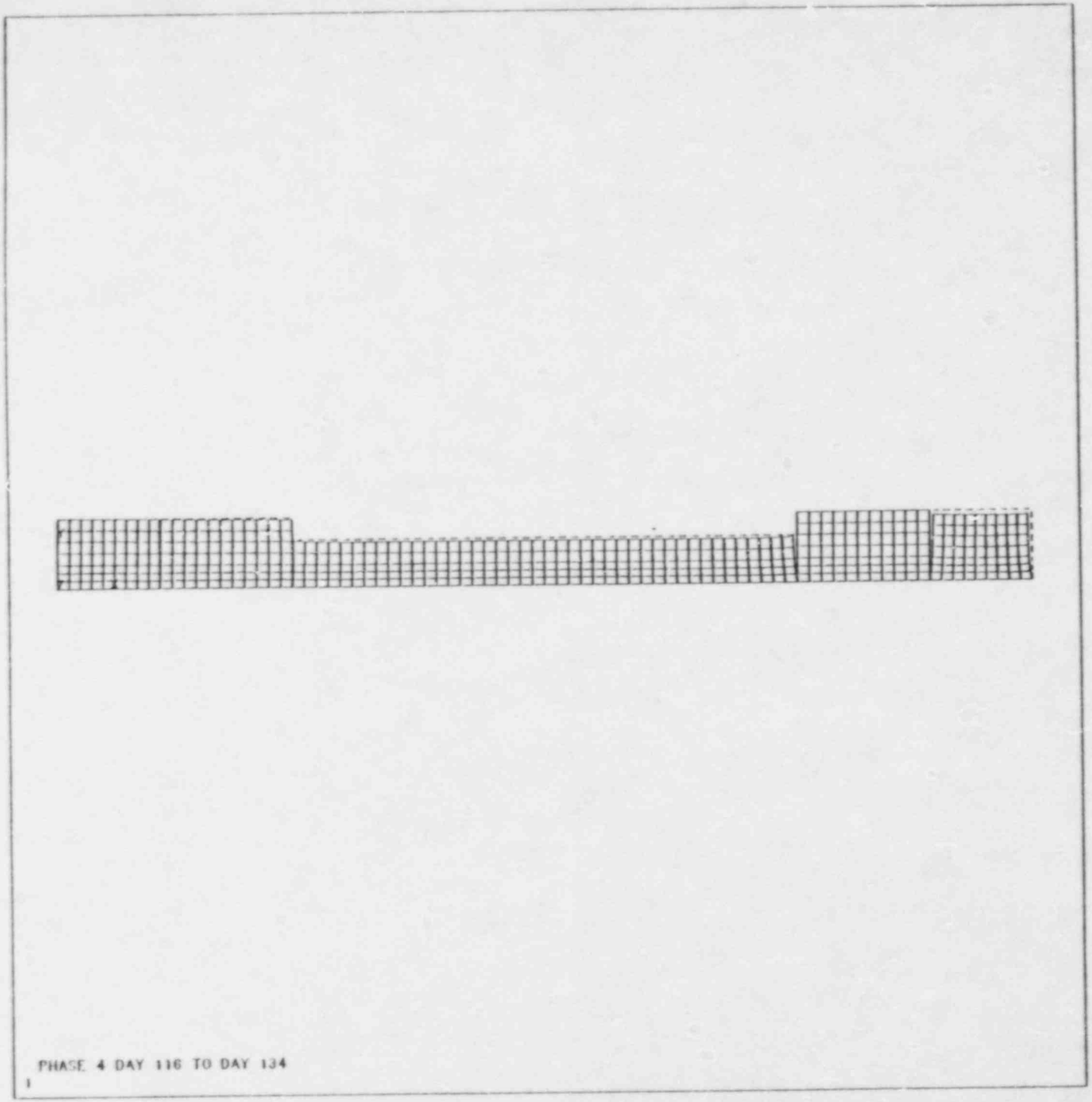
XF=1806

YF=132

DMAX=.0344

DSCA=250

FIGURE 13

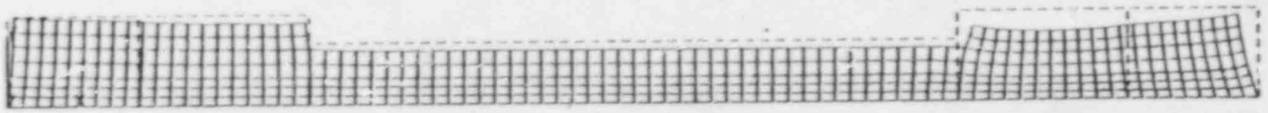


ANSYS 4.3
FEB 22 1988
11:42.56
PLOT NO. 5
POST1 DISPL.
STEP=4
ITER=1

ORIG
ZV=1
DIST=1987
XF=1836
YF=132
DMAX=.087
DSCA=250

PHASE 4 DAY 116 TO DAY 134

FIGURE 14



PHASE 5 DAY 134 TO TODAY

1

ANSYS 4.3

FEB 22 1988

11:45:20

PLOT NO. 6

POST1 DISPL.

STEP=5

ITER=1

ORIG

ZV=1

DIST=1987

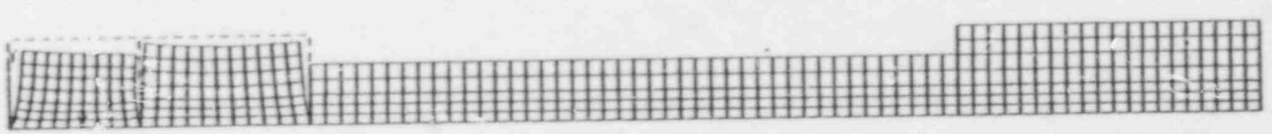
XF=1806

YF=132

DMAX=.257

DSCA=250

FIGURE 15



ANSYS 4.3

FEB 23 1988

10.12.59

PLOT NO. 4

POST1 DISPL.

STEP=9999

ITER=1

ORIG

ZV=1

DIST=1987

XF=1806

YF=132

DMAX=.215

DSCA=250

END PHASE 2

1

FIGURE 16

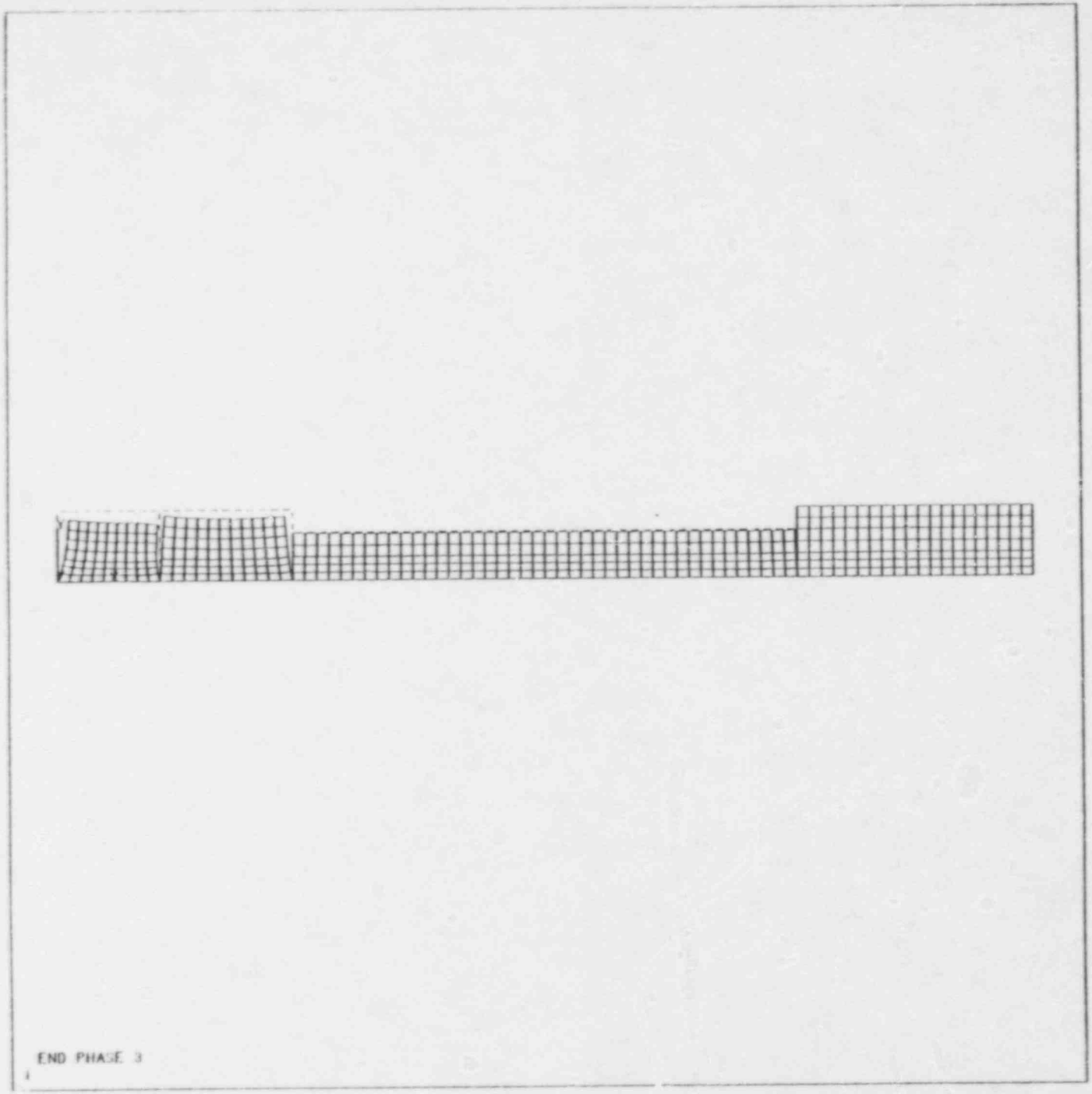
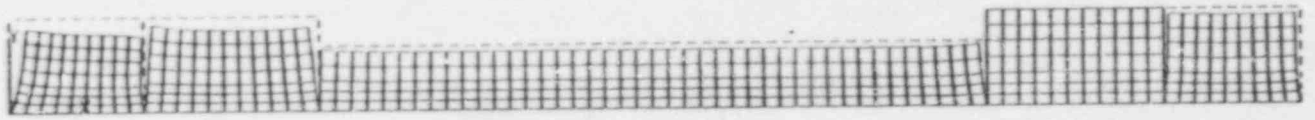

ANSYS 4.3
FEB 23 1988
10:15:52
PLOT NO. 5
POST1 DISPL.
STEP=0999
ITER=1
ORIG
ZV=1
DIST=1987
XF=1806
YF=132
DMAX=.222
DSCA=250
END PHASE 3

FIGURE 17



ANSYS 4.3

FEB 23 1988

10:18:24

PLOT NO. 6

POST1 DISPL.

STEP=9999

ITER=1

ORIG

ZV=1

DIST=1987

XF=1806

YF=132

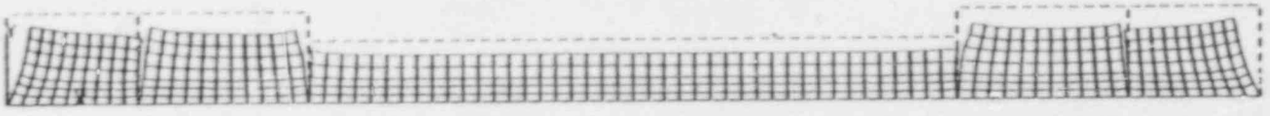
DMAX=.235

DSCA=250

END PHASE 4

1

FIGURE 18

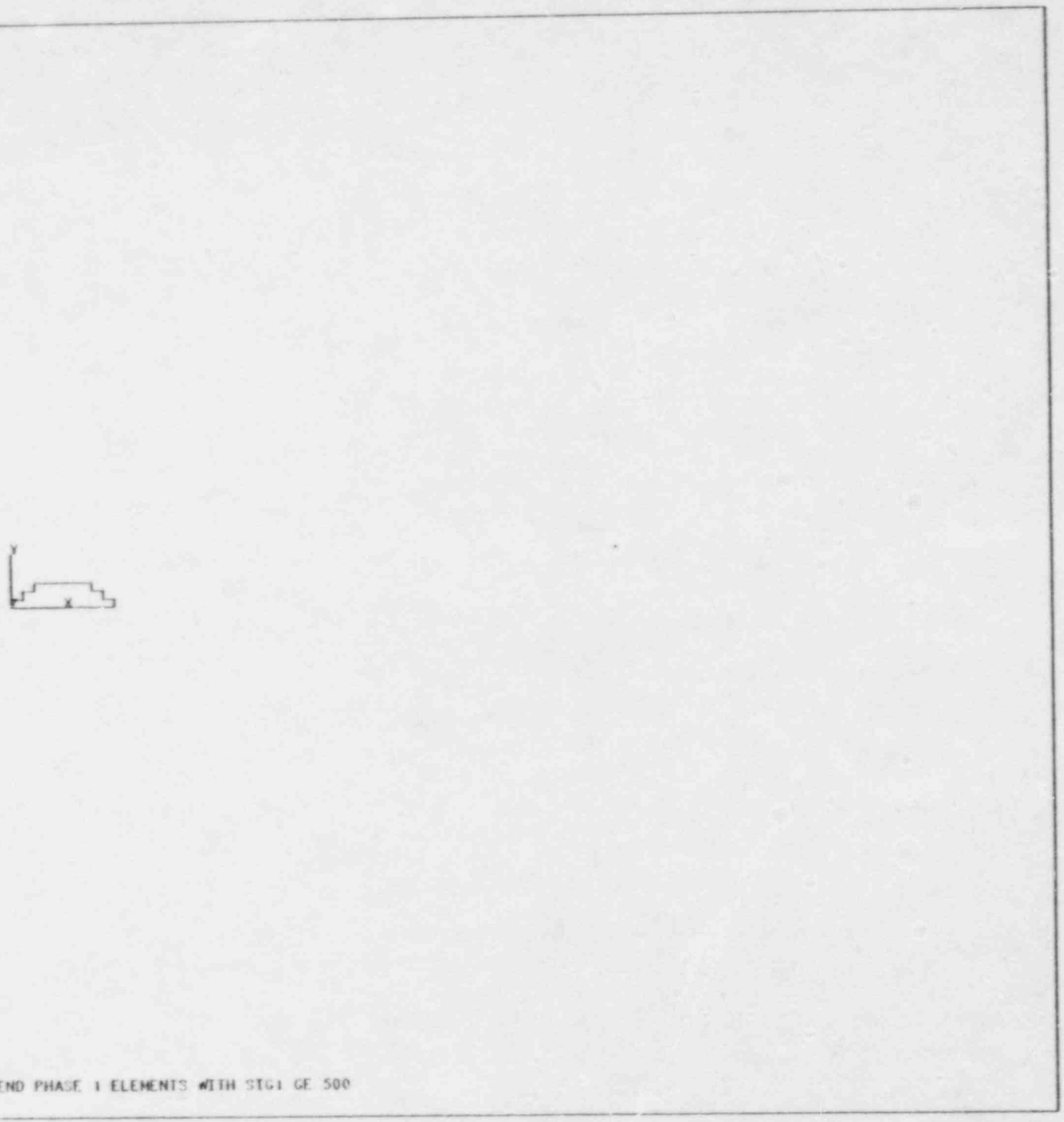


ANSYS 4.3
FEB 23 1988
10:21:09
PLOT NO. 1
POST1 DISPL.
STEP=0999
ITER=1

ORIG
ZV=1
DIST=1987
XF=1806
YF=162
DMAX=.33
DSCA=250

END PHASE 5

FIGURE 19



ANSYS 4.3

MAR 1 1988

16.33.10

PLOT NO. 1

POST1 ELEMENTS

ORIG

ZV=1

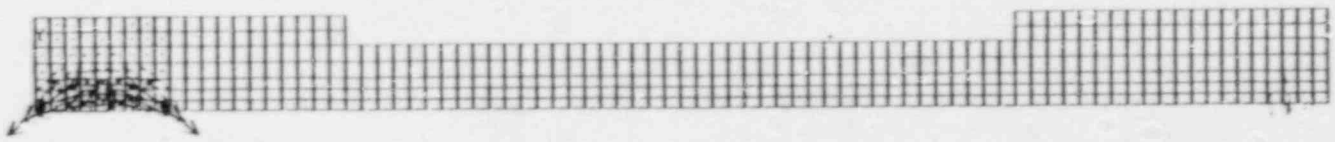
* DIST=1987

* XF=1806

* YF=132

EDGE

FIGURE 20



PHASE 1 DAY 0 TO DAY 79

1

AMSYS 4.3

/EB 22 1988

15:19.59

PLOT NO. 1

POST1 VECTOR

STEP=1

ITER=1

PDIR

SIG1=2184

ELEM=63

ORIG

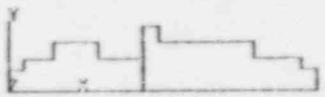
ZV=1

DIST=1987

XF=1806

YF=132

FIGURE 21



END PHASE 2 ELEMENTS WITH SIG1 GE 500

1

ANSYS 4.3

MAR 1 1988

16:34:51

PLOT NO. 2

POST1 ELEMENTS

ORIG

ZV=1

DIST=1987

XF=1806

YF=132

EDGE

FIGURE 22

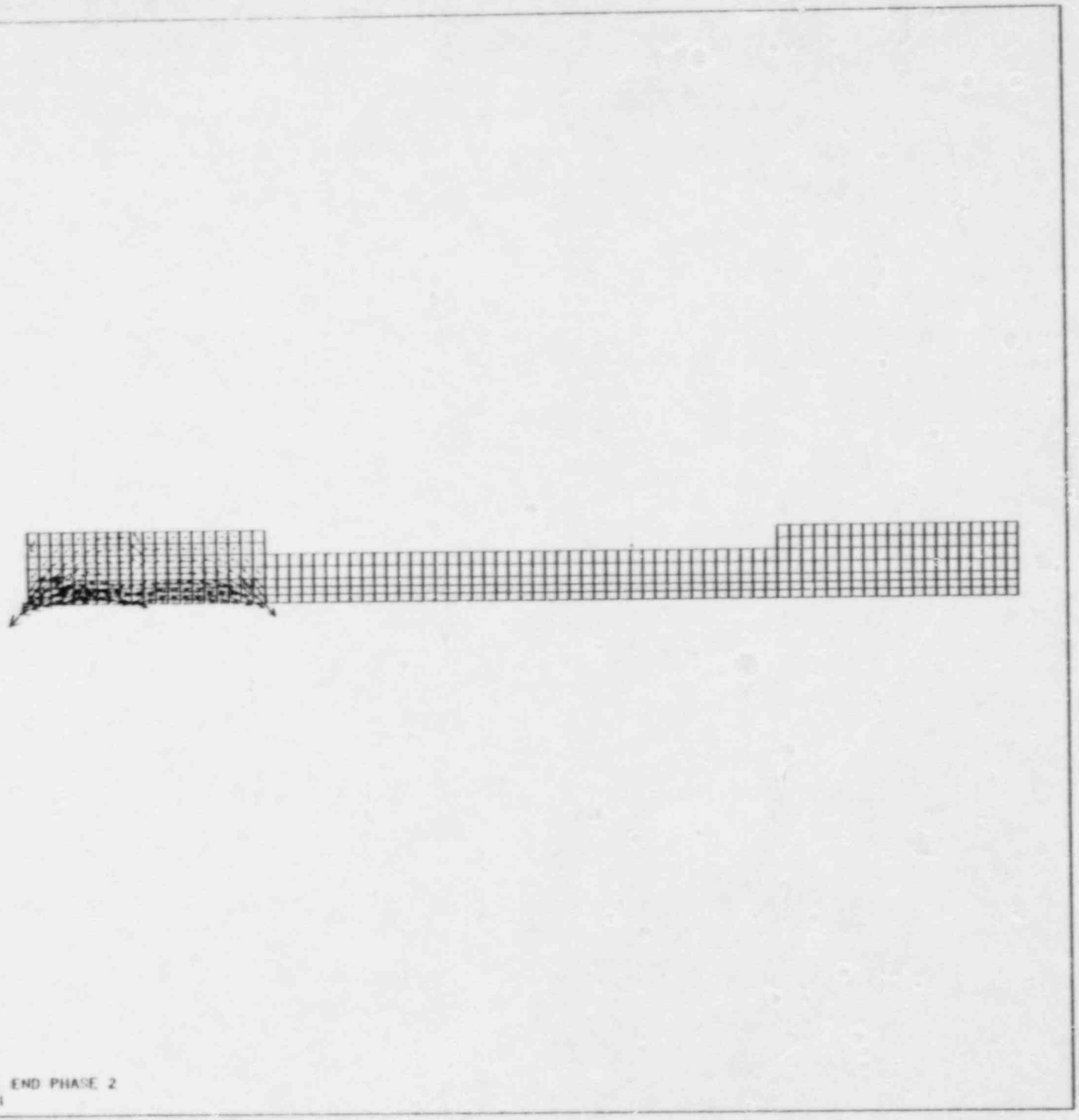
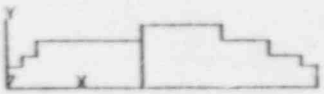

ANSYS 4.3
FEB 23 1988
9.45:38
PLOT NO. 1
POST1 VECTOR
STEP=9999
ITER=1
PDIR
SIG1=2837
ELEM=39
ORIG
ZV=1
DIST=1987
XF=1806
YF=132
END PHASE 2
1

FIGURE 23



END PHASE 3 ELEMENTS WITH SIG1 GE 500

ANSYS 4.3

MAR 1 1988

16:37:03

PLOT NO. 3

POST1 ELEMENTS

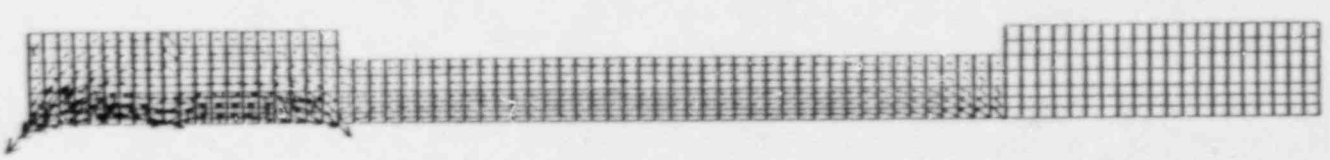
ORIG

ZV=1

- DIST=1987
- XF=1806
- YF=132

EDGE

FIGURE 24



ANSYS 4.3

FEB 23 1988

9:49:18

PLOT NO. 2

POST1 VECTOR

STEP=9999

ITER=1

PDIR

SIG1=2958

ELEM=39

ORIG

ZV=1

DIST=1987

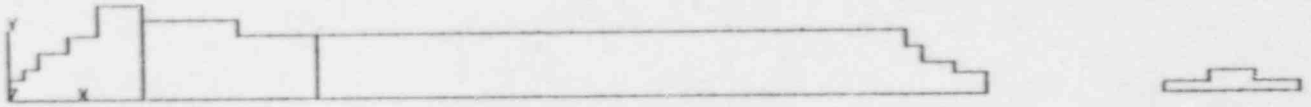
XF=1806

YF=132

END PHASE 3

1

FIGURE 25



ANSYS 4.3

MAR 1 1988

16:38:58

PLOT NO. 4

POST1 ELEMENTS

ORIG

ZV=1

- DIST=1987
- XF=1806
- YF=132

EDGE

END PHASE 4 ELEMENTS WITH SIGI GE 500

1

FIGURE 26

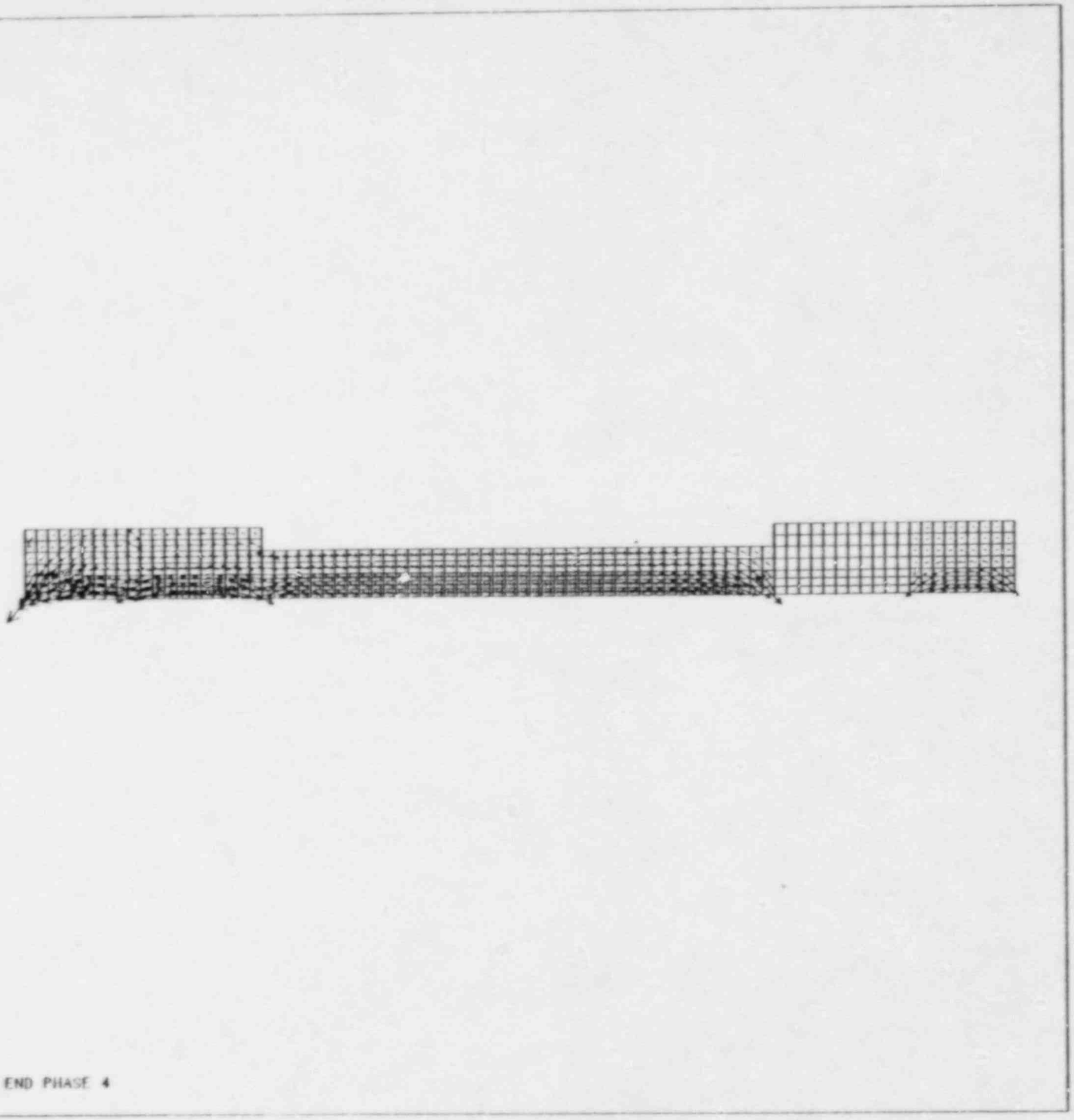

ANSYS 4.3
FEB 23 1986
9.55.09
PLOT NO. 3
POST1 VECTOR
STEP=0909
ITER=1
PDIR
SIG1=3172
ELEM=39
ORIG
ZV=1
DIST=1987
XF=1806
YF=132
END PHASE 4

FIGURE 27

ANSYS 4.3

MAR 1 1988

16:41:17

PLOT NO. 5

POST1 ELEMENTS

ORIG

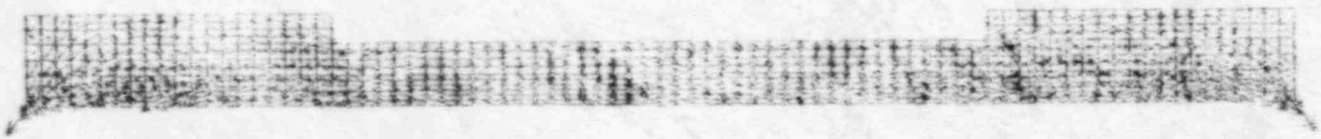
ZV=1

- DIST=1987
- XF=1806
- YF=132

EDGE

END PHASE 5 ELEMENTS WITH SIG1 GE 500

FIGURE 28

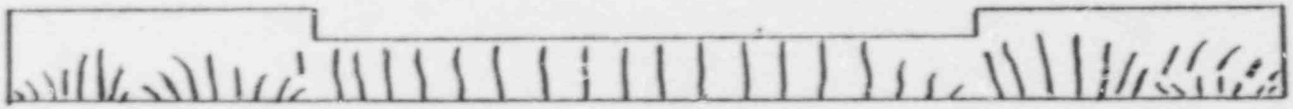


ANSYS 4.3
FEB 22 1988
15:34:20
PLOT NO. 1
POSTN VECTOR
STEP=NSUB
ITER=1
*DIR
STG1=4020
ELEM=400

OPTN
ZV=1
DIST=1387
XF=1806
YF=132

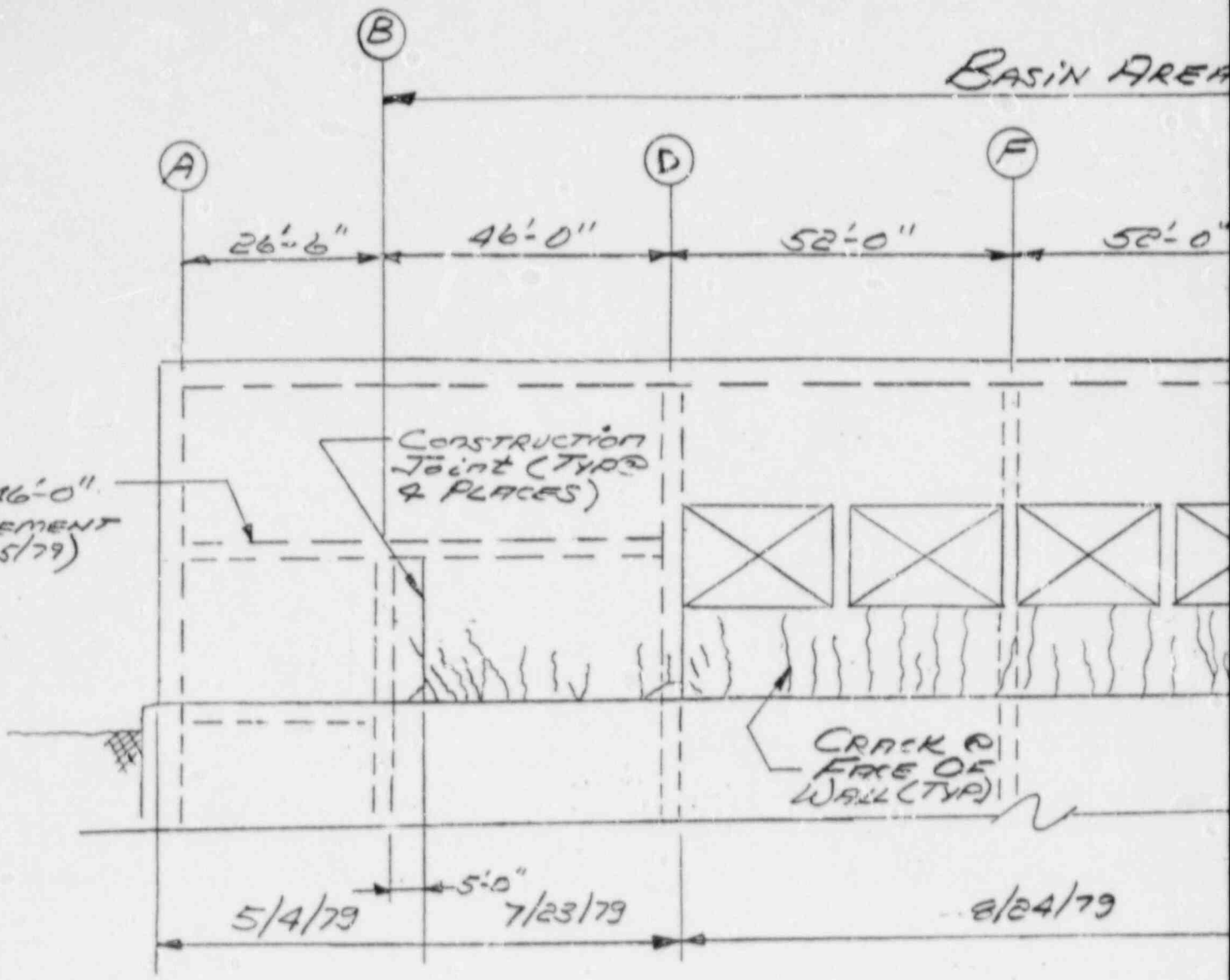
END PHASE 5

FIGURE 29

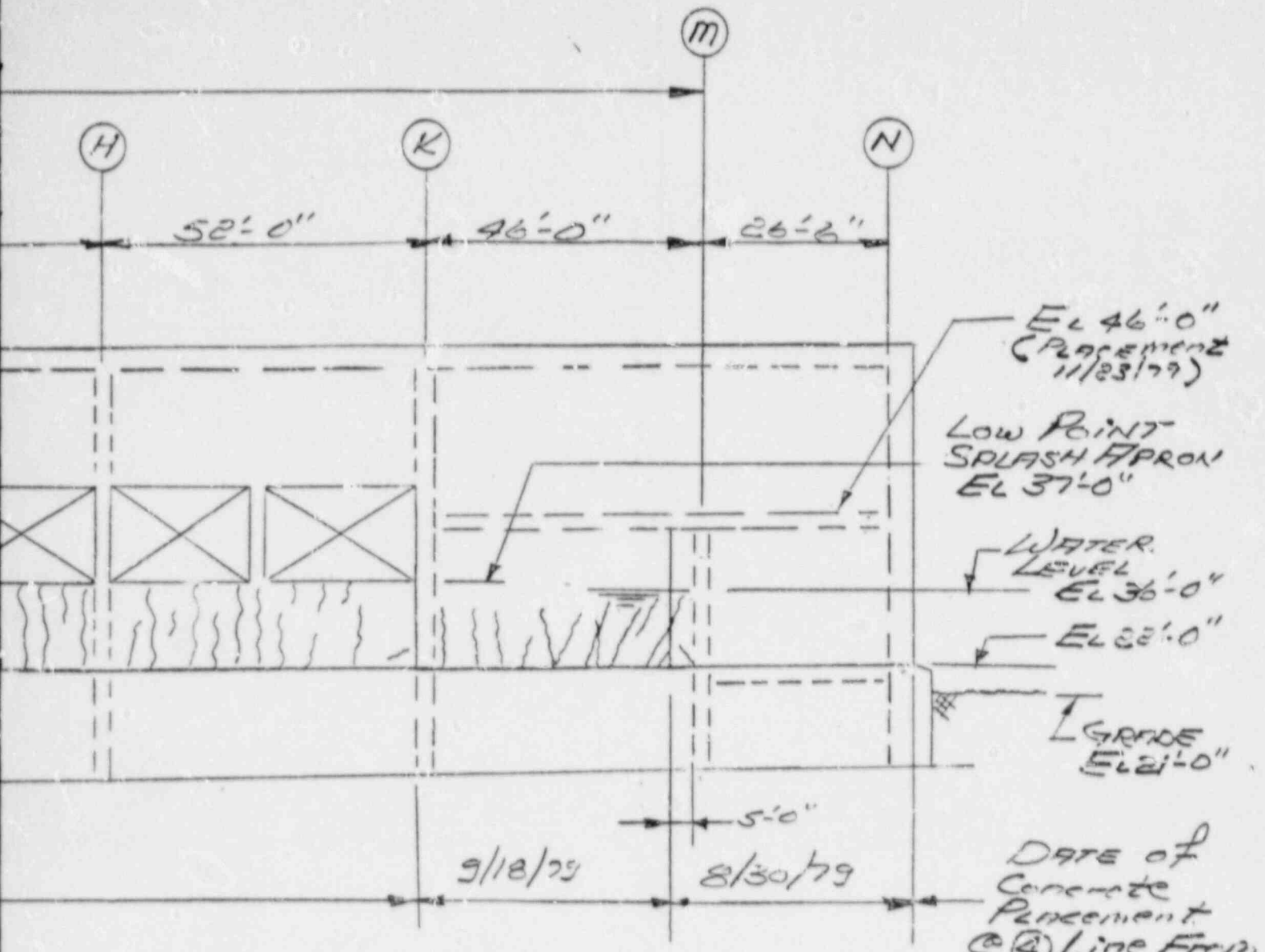


PREDICTED CRACK PATTERN

FIGURE 30



ELEVATION SC



TH WALL

SERVICE WATER COOLING TOWER
SOUTH WALL

FIGURE 31

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