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March 27, 1984

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MIDLAND ENERGY CENTER GWO 7020
ADDITIONAL INFORMATION TO JANUARY 4-6, 1984
NRC AUDIT QUESTIONS
File: 0485.16.1 UFI: 42*05*22*04 Serial: CSC-7533
0460.2 12*16
00211(S)

REFERENCE: J A Mooney to J J Harrison letter dated February 8, 1984, CSC-7292

Enclosed find the following three items of additional information to the referenced letter:

1. Errata sheet for subject letter attachment (Attachment 1)

2. Stress tabulations for remaining stages of construction after CT 1/12 [supplement to question response 3 of referenced letter]. (Attachment 2)

3. Stress and deflection tabulation for remaining unsymmetrical construction conditions after CT 1/12 [supplement to question response 8 of referenced letter]. (Attachment 3)

In addition, we are also enclosing Construction Technology Laboratories report, dated 3/6/84, evaluating crack conditions in slabs at elevation 674'6" and 704'0" in comparison to slab at elevation 685'0" (Attachment 4). This is in response to NRC inquiries raised at February 2, 1984 Stone and Webster public meeting.

JAMooney

JAM/RHW/klw

Attachments

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DSHood, USNRC
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OC0384-00011A-CN01

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DS03

CONSUMERS POWER COMPANY
Midland Units 1 and 2
Docket No 50-329/50-330

Letter Serial CSC-7533 Dated March 27, 1984

At the request of the Commission and pursuant to the Atomic Energy Act of 1954, and the Energy Reorganization Act of 1974, as amended and the Commission's Rules and Regulations thereunder, Consumers Power Company submits Additional Information to January 4-6, 1984 NRC Audit Questions, J A Mooney to J J Harrison letter Serial CSC-7533, dated March 27, 1984.

CONSUMERS POWER COMPANY

By J A Mooney
J A Mooney
Executive Manager

Sworn and subscribed before me this 29 day of March, 1984.

Barbara P Townsend
Notary Public

My Commission Expires Sept 8, 1984

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DFLewis, Bechtel
FJLevandoski, B&W
GALow, P-12-237A
DASommers, P-14-106
PPSteptoe, IL&B, Chicago
DJVandeWalle, P-24-614B
BJWalraven, P-24-517
RAWells, Midland
FCWilliams, IL&B, Washington, DC
DTPerry, Midland
NRC Correspondence File, P-24-517
UFI, P-24-511
CMS-Midland

RC DMBudzik, P-24-517A
RJErhardt, P-14-113A
LSGibson, P-24-618A
P-24-505 (Last)

ATTACHMENT 1

TABLE — 3-4

LOCATION — EAST EPA-'K' LINE WALL @ X = 102' 3"
(FIG 1-6 AREA 4) TOP ELT #9 GRP 23. Sxx

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN (10^{-6}) IN/IN	CONCRETE STRESS PSI	STRAIN (10^{-6}) IN/IN	
1 (EXISTING)	0	0	0	0	0	0					CHANGE
							(16.74) 4.0	8			TOTAL
2 (EXC. E/W8)	66	69	12	13	56	52	(22.0)				CHANGE
							(38.74) 9.3	19			TOTAL
3 (JACK E/W8)	-81	-58	-13	-11	-65	-48			(-50.4)		CHANGE
									(-11.7) -23	-6	TOTAL
4 (EXC. CT1/12)	-77	-53	-5	-3	-69	-51			(0)		CHANGE
									(-11.7) -23	-6	TOTAL
5 (JACK CT1/12)	-109	-91	-65	-64	-40	-25			(-.1)		CHANGE
									(-11.8) -23	-6	TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS SHOWN IN FIGURE 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESSES INCLUDE PRESTRESS LOAD.

TABLE — 3.5

LOCATION — EAST EPA-'K' LINE WALL @ X ≃ 102'-0"
(FIG 1-6 AREA 4) BOT ELT. # 134, GRP 23, S_{xx}

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN (10^{-6}) IN/IN	CONCRETE STRESS PSI	STRAIN (10^{-6}) IN/IN	
1 (EXISTING)	0	0	0	0	0	0					CHANGE
									(-24.5) -49	-12	TOTAL
2 (EXC E/WB)	66	69	12	13	56	52			(-29.2)		CHANGE
									(-53.7) -107	-26	TOTAL
3 (JACK E/WB)	-81	-58	-13	-11	-65	-48	(76.8)				CHANGE
							(23.1) 5.6	11			TOTAL
4 (EXC. CT1/12)	-77	-53	-5	-3	-61	-51			(-.1)		CHANGE
							(23.0) 5.5	11			TOTAL
5 (JACK CT1/12)	-109	-91	-65	-64	-40	-25	(0.2)				CHANGE
							(23.2) 5.6	11			TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS SHOWN IN FIGURE 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESSES INCLUDE PRESTRESS LOAD.

TABLE — 3.6

LOCATION — EAST EPA - 'K' LINE WALL @ x ≃ 51'-0"
(FIG 1-6 AREA 5) TOP ELT # 2 GRP 23 Sxx

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN (10^{-6}) IN/IN	CONCRETE STRESS PSI	STRAIN (10^{-6}) IN/IN	
1 (EXISTING)	0	0	0	0	0	0					CHANGE
									(-3.1) -6	-2	TOTAL
2 (EXC E/WB)	66	69	12	13	56	52	(22.2)				CHANGE
							(19.1) 4.6	9			TOTAL
3 (JACK E/WB)	-81	-58	-13	-11	-65	-48			(-46.8)		CHANGE
									(-27.7) -55	-14	TOTAL
4 (EXC. CT1/12)	-77	-53	-5	-3	-69	-51			(-0.2)		CHANGE
									(-27.9) -55	-14	TOTAL
5 (JACK CT1/12)	-109	-91	-65	-64	-40	-25	(2.6)				CHANGE
									(-25.3) -50	-12	TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS SHOWN IN FIGURE 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESSES INCLUDE PRESTRESS LOAD.

TABLE — 3.7

LOCATION — EAST EPA-K LINE WALL @ X ≃ 51'-0"
(FIG 1-6 AREA 5) BOT ELT #141 GRP 23 Sxx

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN (10^{-6}) IN/IN	CONCRETE STRESS PSI	STRAIN (10^{-6}) IN/IN	
1 (EXISTING)	0	0	0	0	0	0					CHANGE
									(-70.7) -140	-35	TOTAL
2 (EXC. E/WB)	66	69	12	13	56	52			(-42.8)		CHANGE
									(-113.5) -225	-56	TOTAL
3 (JACK E/WB)	-81	-58	-13	-11	-65	-48	(88.4)				CHANGE
									(-25.1) -50	-12	TOTAL
4 (EXC. CT1/12)	-77	-53	-5	-3	-69	-51	(0.7)				CHANGE
									(-24.4) -48	-12	TOTAL
5 (JACK CT1/12)	-109	-91	-65	-64	-40	-25			(-5.2)		CHANGE
									(-29.6) -59	-15	TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS SHOWN IN FIGURE 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESSES INCLUDE PRESTRESS LOAD.

TABLE 8-1

CALCULATED STRESSES FOR UNSYMMETRICAL CONSTR. ANALYSIS. (STAGE II FIG. 8-1)

DESCRIPTION		TENSION		COMPRESSION		REMARKS
		REBAR STRESS KSI	STRAIN $\times 10^{-6}$ IN/IN	CONCRETE STRESS PSI	STRAIN $\times 10^{-6}$ IN/IN	
WALL BELOW EL. 614'-0 ON COL. LINE 5.3 BETWEEN COL. LINES G & H (FIG. 1-1)		18.5 (2)	185			
WALL BELOW EL. 614'-0 ON COL. LINE 7.8 BETWEEN COL. LINES G & H (FIG. 1-2)		27.6 (2)	318			
SLAB AT EL. 659'-0 BETWEEN COL. LINES G & H (FIG. 1-3)		9.3 (1)	13			
EPA WALLS AREA 4 FIG. 1-6	TOP	(29.6 K/FT) 7.1	16			
	BOT			(-43.7 K/FT) -87	-24	
EPA WALLS AREA 5 FIG. 1-6	TOP	(7.0 K/FT) 1.7	4			
	BOT			(-92.0 K/FT) -183	-51	
FLOOR SLAB AT EL. 685'-0 AREA 6 / FIG. 1-6		13.6	12			

1) AVERAGE TENSILE STRESS.

2) AVERAGE SHEAR STRESS.

ATTACHMENT 2

②

AUXILIARY BUILDING UNDERPINNING - STRESSES, STRAINS, AND DEFLECTIONS DURING CONSTRUCTION

The attached Tables 3-8 through 3-16 and Figures 3-15 through 3-25 supplement similar tables and figures given in Attachment 3 of Consumers Power Company's response to the January 4 through 6, 1984, NRC audit questions (Reference 1). Tables 3-8 through 3-16 show stress, strain, and differential deflection values. In addition, the differential deflection values are shown graphically in Figures 3-15 through 3-20. The differential deflection values have been calculated for the following temporary underpinning construction stages:

1. Existing condition (load combination 1) - Figure 3-1 (see Reference 1, Attachment 3)
2. Following excavation for E/W 8 (load combination 2) - Figure 3-2 (see Reference 1, Attachment 3)
3. Following jacking of E/W 8 (load combination 3) - Figure 3-3 (see Reference 1, Attachment 3)
4. Following excavation of CT 1/12 (load combination 4) - Figure 3-4 (see Reference 1, Attachment 3)
5. Following jacking of CT 1/12 (load combination 5) - Figure 3-5 (see Reference 1, Attachment 3)
6. Following excavation of E/W 5 and CT 3/10
7. Following jacking of CT 3/10 (load combination 7) - Figure 3-21
8. Following jacking of E/W 5 (load combination 8) - Figure 3-22
9. Following excavation of CT 5/8
10. Following excavation of E/W 2 (load combination 10) - Figure 3-23
11. Following jacking of CT 5/8
12. Following jacking of CT 2/11
13. Following excavation of CT 13/15
14. Following jacking of CT 13/15
15. Following excavation of CT 14
16. Following jacking of E/W 2 (load combination 16) - Figure 3-24
17. Following jacking of CT 14
18. Following excavation of balance of soil
19. Following jacking of CT 6/7

For calculating stresses, strains, and deflections, the assumptions described in Reference 1 have been used. Differential deflections have been calculated using different models for different stages. Construction stages 6 and 7 have been analyzed using the weightless model shown in Figure 3-8 (Reference 1). Stages 9 through 12 have been analyzed using the weightless model shown in Figure 3-25, and stages 13 through 19 have been analyzed using another weightless model shown in Figure 3-26.

The stress and strain values for construction stages 7, 8, 10, and 16 have been analyzed. These stages represent the maximum and minimum values of the predicted differential deflections (Δ_1 and Δ_2) for temporary construction stages 6 through 19 as shown in Figures 3-15 through 3-20. The changes in stress and strain values as shown in Tables 3-9 through 3-16 correspond to the changes from the previous construction stages, as included in the table. For example, the change in stress and strain in stage 10 is the change between stage 8 and 10.

Conclusion

As stated in Attachment 3, Reference 1, the maximum tensile stress occurs following excavation of E/W 8 and is lower than the allowable. The tensile stresses and strains are lower in all subsequent stages.

Reference

1. Auxiliary Building Underpinning Response to January 4 through 6, 1984, NRC audit questions; CPCo Letter to NRC, Serial CSC-7292, J.A. Mooney to J.J. Harrison, 2/8/84

TABLE - 3-9

LOCATION - SLAB @ EL. 659'-0" BETWEEN COL. LINE G & H
(FIG. 1-1)

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS $(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	TENSION: REBAR STRESS KSI	TENSION: STRAIN $\times 10^{-6}$ IN/IN	COMPRESSION: CONCRETE STRESS PSI	COMPRESSION: STRAIN $\times 10^{-6}$ IN/IN	REMARKS
5 (JACK CT 1/12)	-109	-91	-65	-64	-40	-25	-9.6				CHANGE
							(4.0) 4.5 ②	6			TOTAL
7 (JACK CT 3/10)	-66	-45	-70	-70	10	24	(-2.1) -2.3				CHANGE
							(1.9) 2.2 ②	3			TOTAL
8 (JACK E/W 5)	-191	-168	-121	-120	-61	-44			(-7.1)		CHANGE
									(-5.2) -29	-8	TOTAL
10 (EXC. E/W 2)	-145	-113	-75	-73	-61	-43			(5.2)		CHANGE
									0	0	TOTAL
16 (JACK E/W 2)	-190	-173	-172	-170	-6	1			(-13.4)		CHANGE
									(-13.4) -74	-20	TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS, SEE FIG. 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESS INCLUDES PRESTRESS LOAD

TABLE - 3-10

LOCATION - WALL BELOW ELE. 614'-0" ON COL. LINE 7.8 BETWEEN G & H
(FIG. 1-2)

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN $\times 10^{-6}$ IN/IN	CONCRETE STRESS PSI	STRAIN $\times 10^{-6}$ IN/IN	
5 (JACK CT1/12)	-109	-91	-65	-64	-40	-25	-8.7				CHANGE
							27.9 ③	240			TOTAL
7 (JACK CT3/10)	-66	-45	-70	-70	10	24	1.7				CHANGE
							29.6 ③	250			TOTAL
8 (JACK B/W 5)	-191	-168	-121	-120	-61	-44	-7.3				CHANGE
							22.3 ③	207			TOTAL
10 (EXC. E/W 2)	-145	-113	-75	-73	-61	-43	7.4				CHANGE
							29.7 ③	251			TOTAL
16 (JACK E/W 2)	-190	-173	-172	-170	-6	1	-10.5				CHANGE
							19.2 ③	189			TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS, SEE FIG. 3-6
② AVERAGE TENSILE STRESS.
③ AVERAGE SHEAR STRESS.
④ VALUES IN ( ) ARE IN K/FT
⑤ EXISTING STRESS INCLUDES PRESTRESS LOAD

TABLE - 3-11

LOCATION (FIG 1-3) - WALL BELOW ELE. 614'-0" ON COL. LINE 5.3 BETWEEN COL. LINE G & H

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN $\times 10^{-6}$ IN/IN	CONCRETE STRESS PSI	STRAIN $\times 10^{-6}$ IN/IN	
5 (JACK CT 1/12)	-109	-91	-65	-64	-40	-25	-5.1				CHANGE
							26.8 ③	234			TOTAL
7 (JACK CT 3/10)	-66	-45	-70	-70	10	24	0.9				CHANGE
							27.7 ③	239			TOTAL
8 (JACK B/W 5)	-191	-168	-121	-120	-61	-44	-7.2				CHANGE
							20.5 ③	196			TOTAL
10 (EXC. E/W 2)	-145	-113	-75	-73	-61	-43	7.3				CHANGE
							27.8 ③	240			TOTAL
16 (JACK E/W 2)	-190	-173	-172	-170	-6	1	-11.8				CHANGE
							16.0 ③	170			TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS, SEE FIG. 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESS INCLUDES PRESTRESS LOAD

TABLE - 3-12

LOCATION - EAST EPA-'K' LINE WALL @ X ≈ 102'-0"
(FIG 1-6, AREA 4) TOP, ELT #9, GRP 23, S_{xx}

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN $(\times 10^{-6})$	CONCRETE STRESS PSI	STRAIN $(\times 10^{-6})$	
5 (JACK CT 1/12)	-109	-91	-65	-64	-40	-25					CHANGE
									(-11.8) -23	-6	TOTAL
7 (JACK CT 3/10)	-66	-45	-70	-70	10	24			(4.5)		CHANGE
									(-7.3) -14	-4	TOTAL
8 (JACK B/W 5)	-191	-168	-121	-120	-61	-44			(-3.5)		CHANGE
									(-10.8) -21	-5	TOTAL
10 (EXC. E/W 2)	-145	-113	-75	-73	-61	-43			(-1.3)		CHANGE
									(-12.1) -24	-6	TOTAL
16 (JACK E/W 2)	-190	-173	-172	-170	-6	1	(23.5)				CHANGE
							(11.4) 2.7	6			TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS, SEE FIG. 3-6
② AVERAGE TENSILE STRESS.
③ AVERAGE SHEAR STRESS.
④ VALUES IN ( ) ARE IN K/FT
⑤ EXISTING STRESS INCLUDES PRESTRESS LOAD

TABLE - 3-13

LOCATION - EAST EPA - 'K' LINE WALL @ X ≈ 102'-0
(FIG 1-6 AREA 4) BOTTOM, ELT # 134, GRP 23, S_{xx}

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN $(\times 10^{-6})$	CONCRETE STRESS PSI	STRAIN $(\times 10^{-6})$	
5 (JACK CT 1/12)	-109	-91	-65	-64	-40	-25					CHANGE
							(23.2) 5.6	11			TOTAL
7 (JACK CT 3/10)	-66	-45	-70	-70	10	24	(4.6)				CHANGE
							(27.8) 6.7	14			TOTAL
8 (JACK E/W 5)	-191	-168	-121	-120	-61	-44			(-31.4)		CHANGE
									(-3.6) -7	-2	TOTAL
10 (EXC. E/W 2)	-145	-113	-75	-73	-61	-43			(0.1)		CHANGE
									(-3.5) -7	-2	TOTAL
16 (JACK E/W 2)	-190	-173	-172	-170	-6	1			(-22.5)		CHANGE
									(-26.0) -52	-13	TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS, SEE FIG. 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESS INCLUDES PRESTRESS LOAD

TABLE - 3 - 14

LOCATION - EAST EPA-'K' LINE WALL @ X ≃ 51'-0
(FIG 1-6 AREA 5) TOP, ELT #2, GRP 23, Sxx

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN $(\times 10^{-6})$	CONCRETE STRESS PSI	STRAIN $(\times 10^{-6})$	
5 (JACK CT 1/12)	-109	-91	-65	-64	-40	-25					CHANGE
									(-25.3) -50	-12	TOTAL
7 (JACK CT 3/10)	-66	-45	-70	-70	10	24			(21.1)		CHANGE
									(-4.2) -8	-2	TOTAL
8 (JACK E/W 5)	-191	-168	-121	-120	-61	-44			(-36.3)		CHANGE
									(-40.5) -80	-20	TOTAL
10 (EXC. E/W 2)	-145	-113	-75	-73	-61	-43			(5.7)		CHANGE
									(-34.8) -69	-17	TOTAL
16 (JACK E/W 2)	-190	-173	-172	-170	-6	1			(8.6)		CHANGE
									(-26.2) -52	-13	TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS, SEE FIG. 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESS INCLUDES PRESTRESS LOAD

TABLE - 3-15

LOCATION - EAST EPA - 'K' LINE WALL @ X ≃ 51'-0
(FIG 1-6 AREA 5) BOTTOM, ELT #141, GRP 23, Sxx

CONSTRUCTION STAGES	DIFFERENTIAL DEFLECTION IN MILLS						TENSION		COMPRESSION		REMARKS
	$(\Delta_1)_{2E}$	$(\Delta_1)_{2W}$	$(\Delta_1)_{3E}$	$(\Delta_1)_{3W}$	$(\Delta_2)_{2E}$	$(\Delta_2)_{2W}$	REBAR STRESS KSI	STRAIN ($\times 10^{-6}$)	CONCRETE STRESS PSI	STRAIN ($\times 10^{-6}$)	
5	-109	-91	-65	-64	-40	-25					CHANGE
(JACK CT 1/12)									(-29.6) -59	-15	TOTAL
7	-66	-45	-70	-70	10	24			(-38.5)		CHANGE
(JACK CT 3/10)									(-68.1) -135	-34	TOTAL
8	-191	-168	-121	-120	-61	-44	(68.6)				CHANGE
(JACK E/W 5)							(0.5) 0.1	0			TOTAL
10	-145	-113	-75	-73	-61	-43			(-12.2)		CHANGE
(EXC. E/W 2)									(-11.7) -23	-6	TOTAL
16	-190	-173	-172	-170	-6	1			(-6.3)		CHANGE
(JACK E/W 2)									(-18.0) -36	-9	TOTAL

NOTE: ① STRESS DISTRIBUTION FOR THE EXISTING CONDITION IS AN UPPER BOUND SOLUTION AND HAS BEEN OBTAINED USING THE LONG TERM SOIL SPRINGS, SEE FIG. 3-6

② AVERAGE TENSILE STRESS.

③ AVERAGE SHEAR STRESS.

④ VALUES IN ( ) ARE IN K/FT

⑤ EXISTING STRESS INCLUDES PRESTRESS LOAD

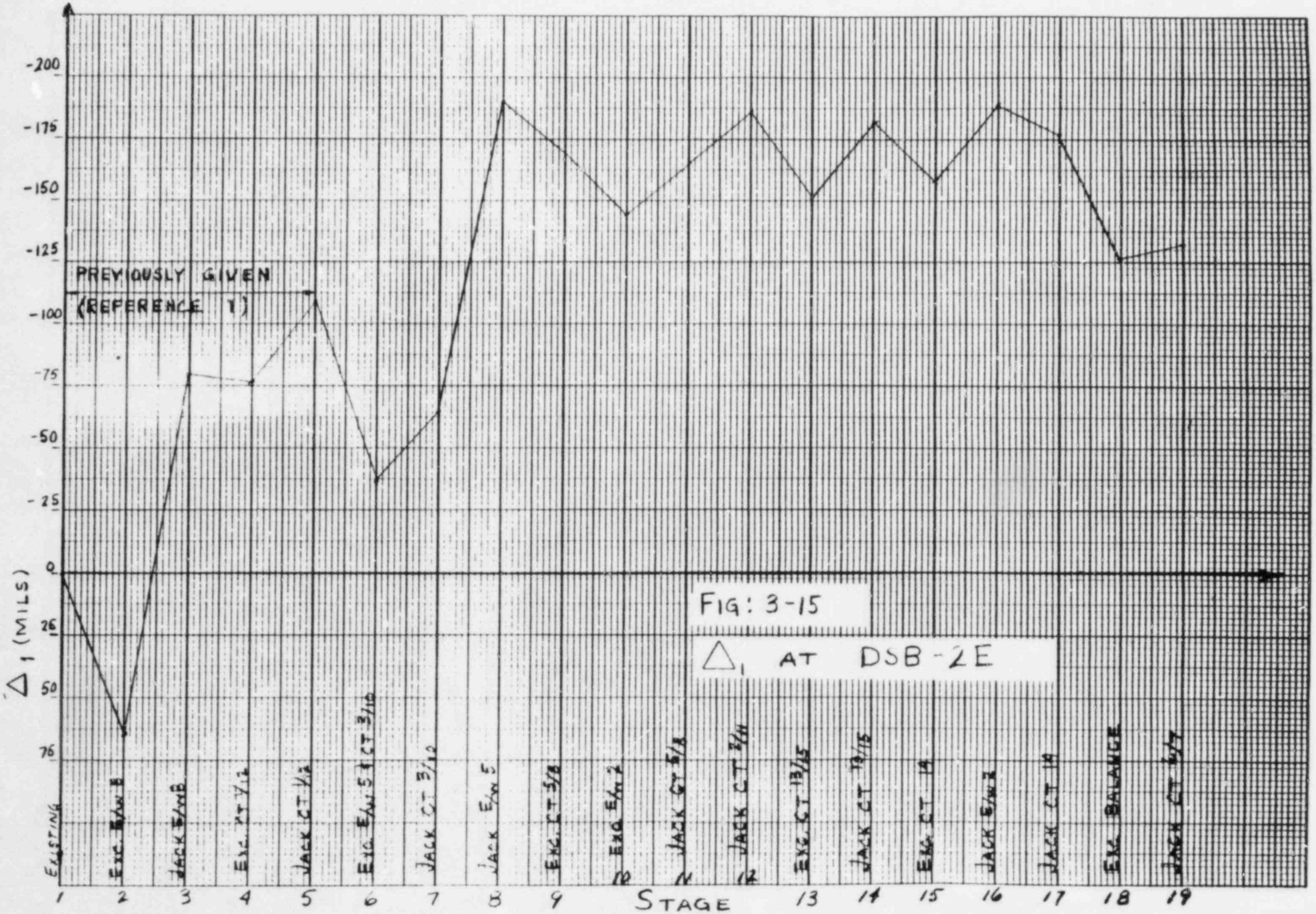
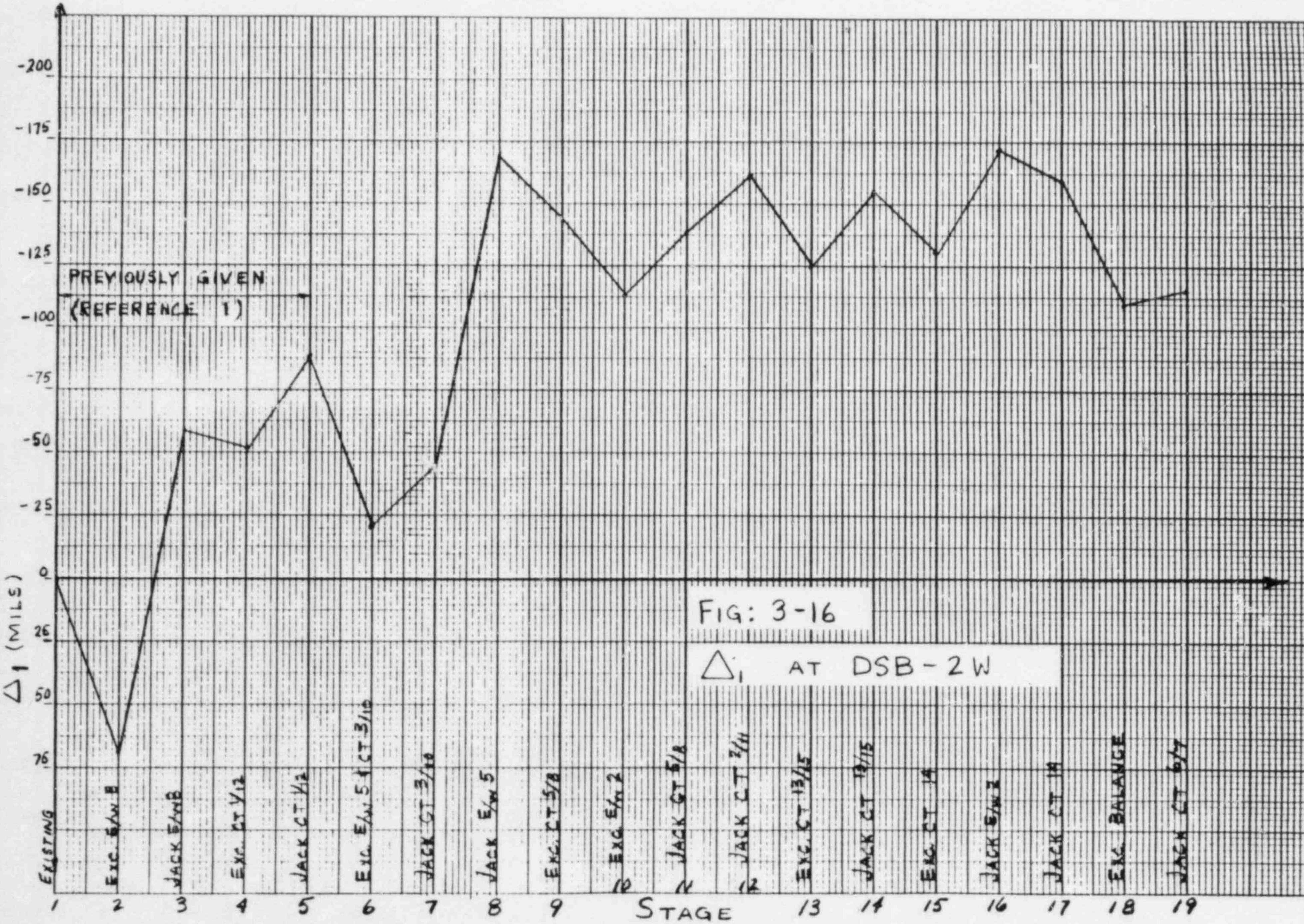


FIG: 3-15

Δ_1 AT DSB-2E



-200
-175
-150
-125
-100
-75
-50
-25
0
25
50
75
Δ_1 (MILS)
PREVIOUSLY GIVEN
(REFERENCE 1)
FIG: 3-16
Δ_1 AT DSB-2W
EXISTING
EXC. E/W 8
JACK E/W 8
EXC. CT 1/12
JACK CT 1/12
EXC. E/W 5 & CT 3/10
JACK CT 3/10
JACK E/W 5
EXC. CT 5/8
EXC. E/W 2
JACK CT 5/8
JACK CT 2/11
EXC. CT 13/15
JACK CT 13/15
EXC. CT 14
JACK E/W 2
JACK CT 14
EXC. BALANCE
JACK CT 6/7
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
STAGE

K·E 20 X 20 TO THE INCH · 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.   46 1242

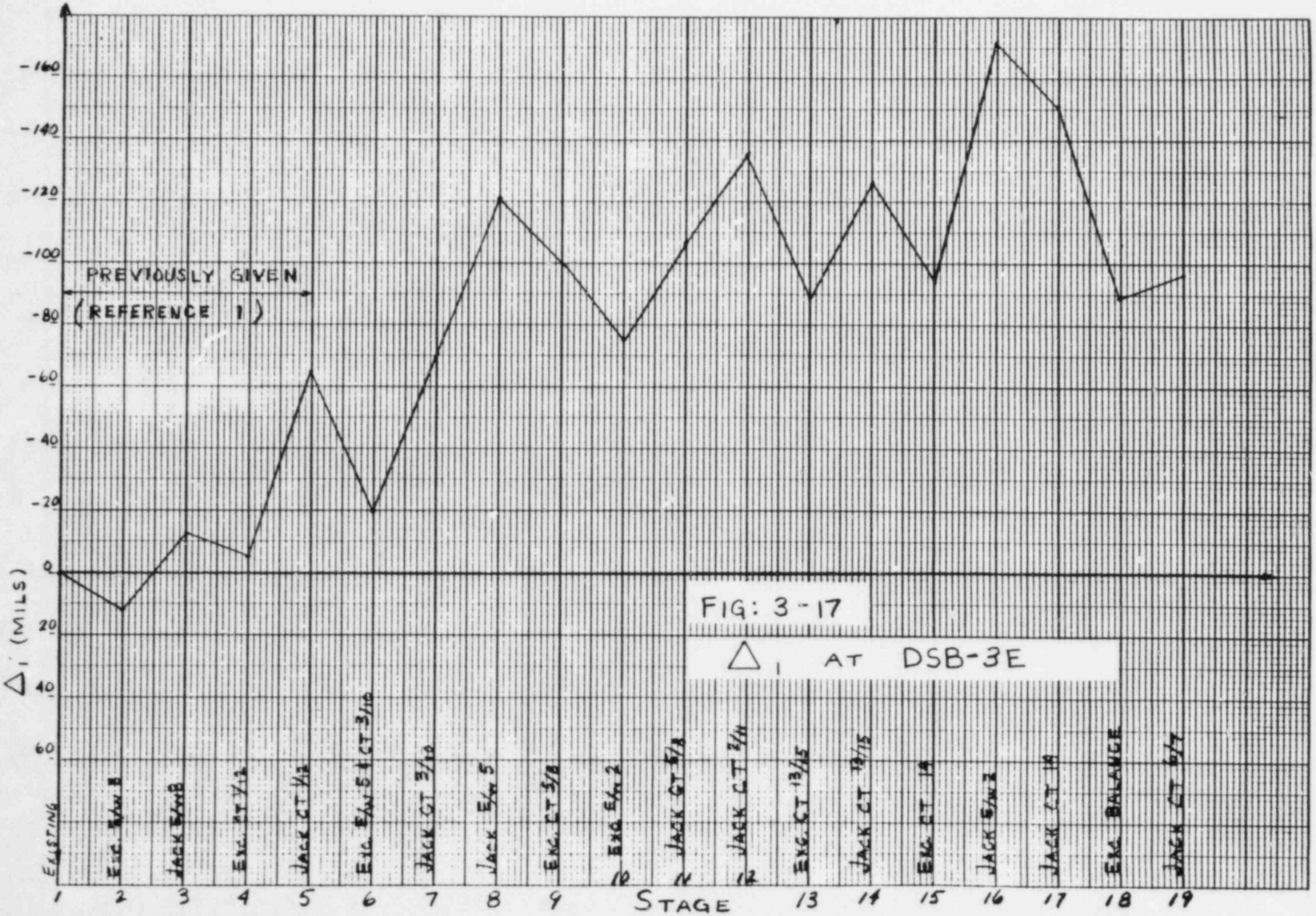


FIG: 3-17

Δ1 AT DSB-3E

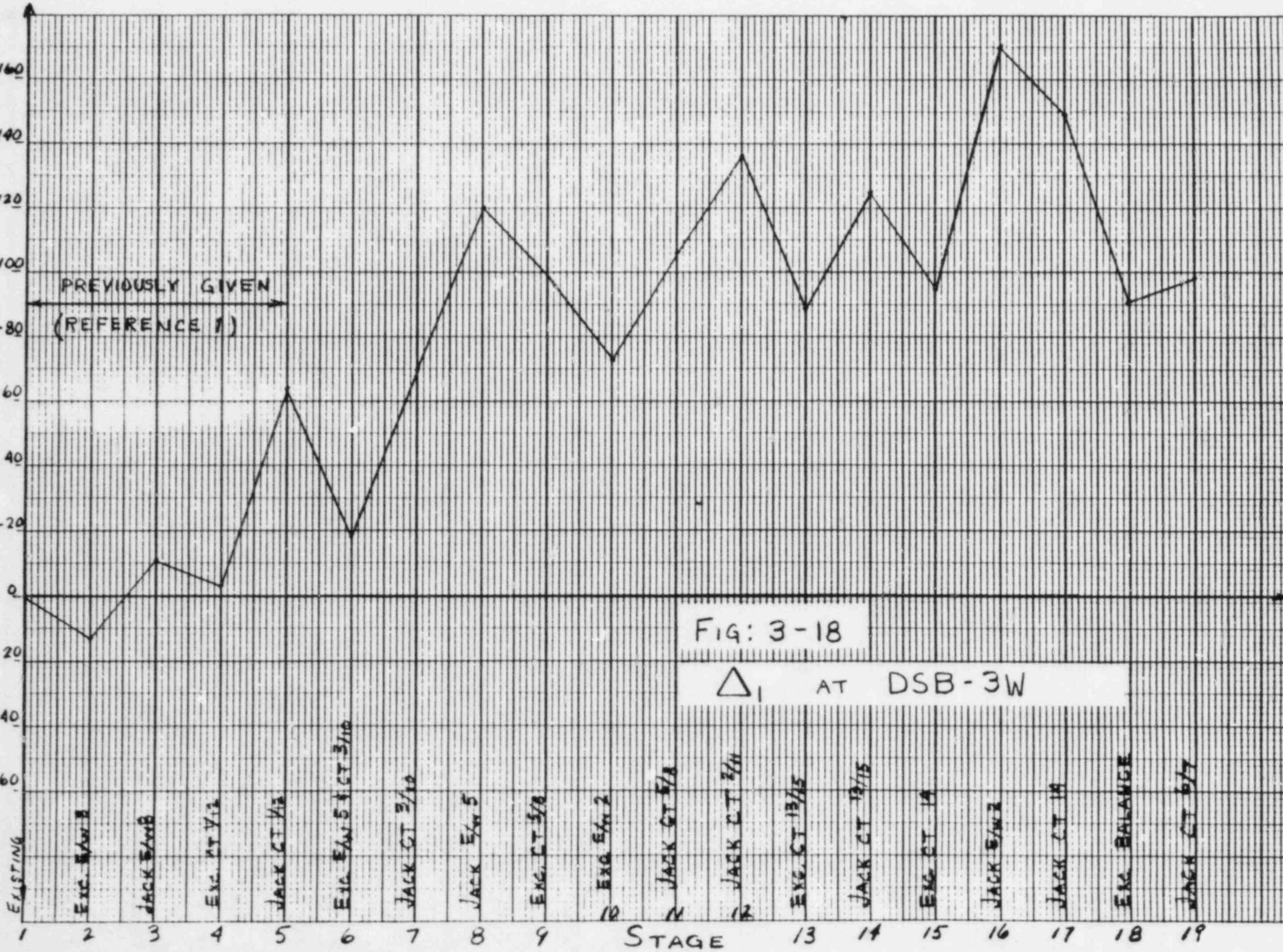


FIG: 3-18

Δ1 AT DSB-3W

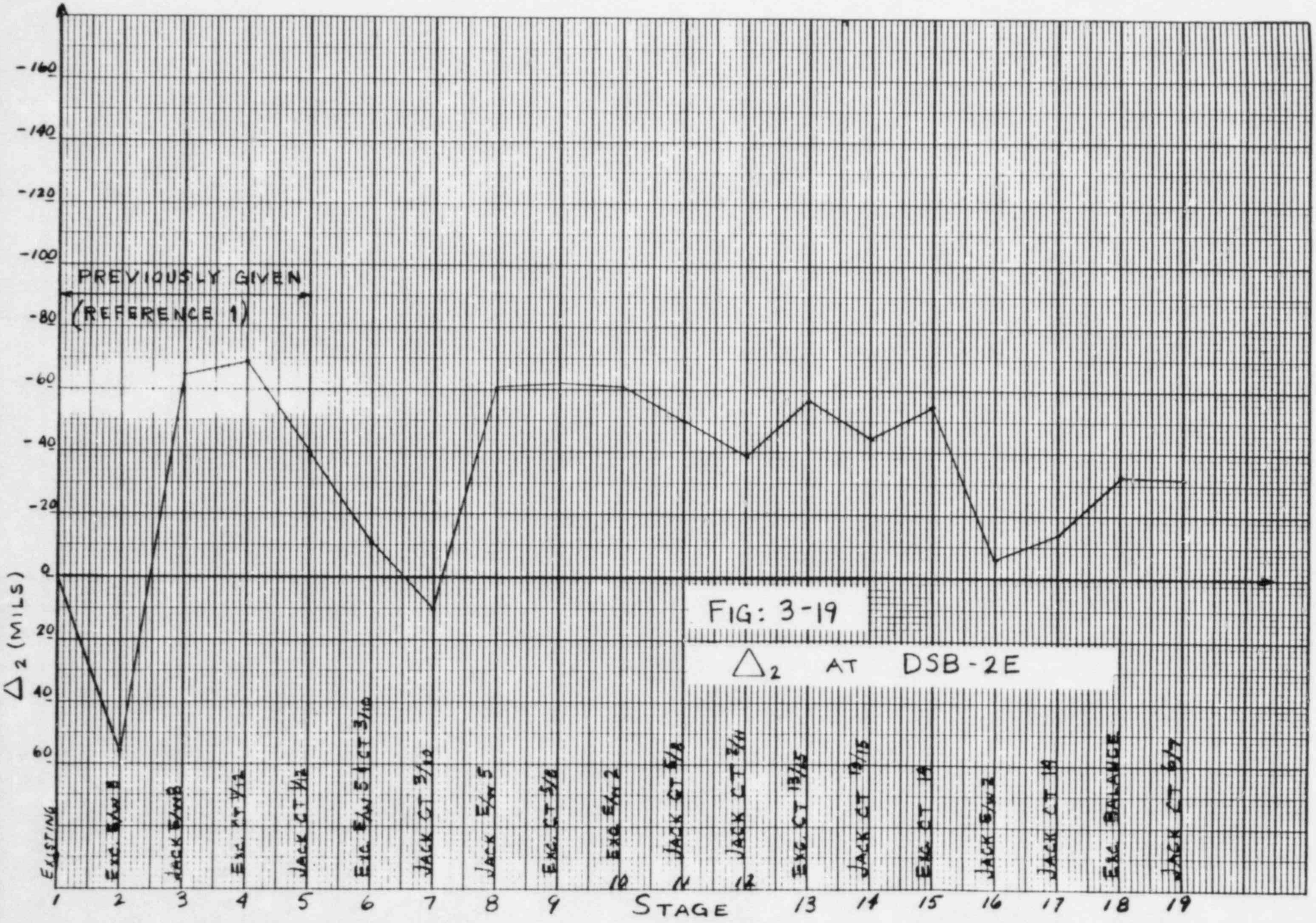


FIG: 3-19

Δ_2 AT DSB-2E

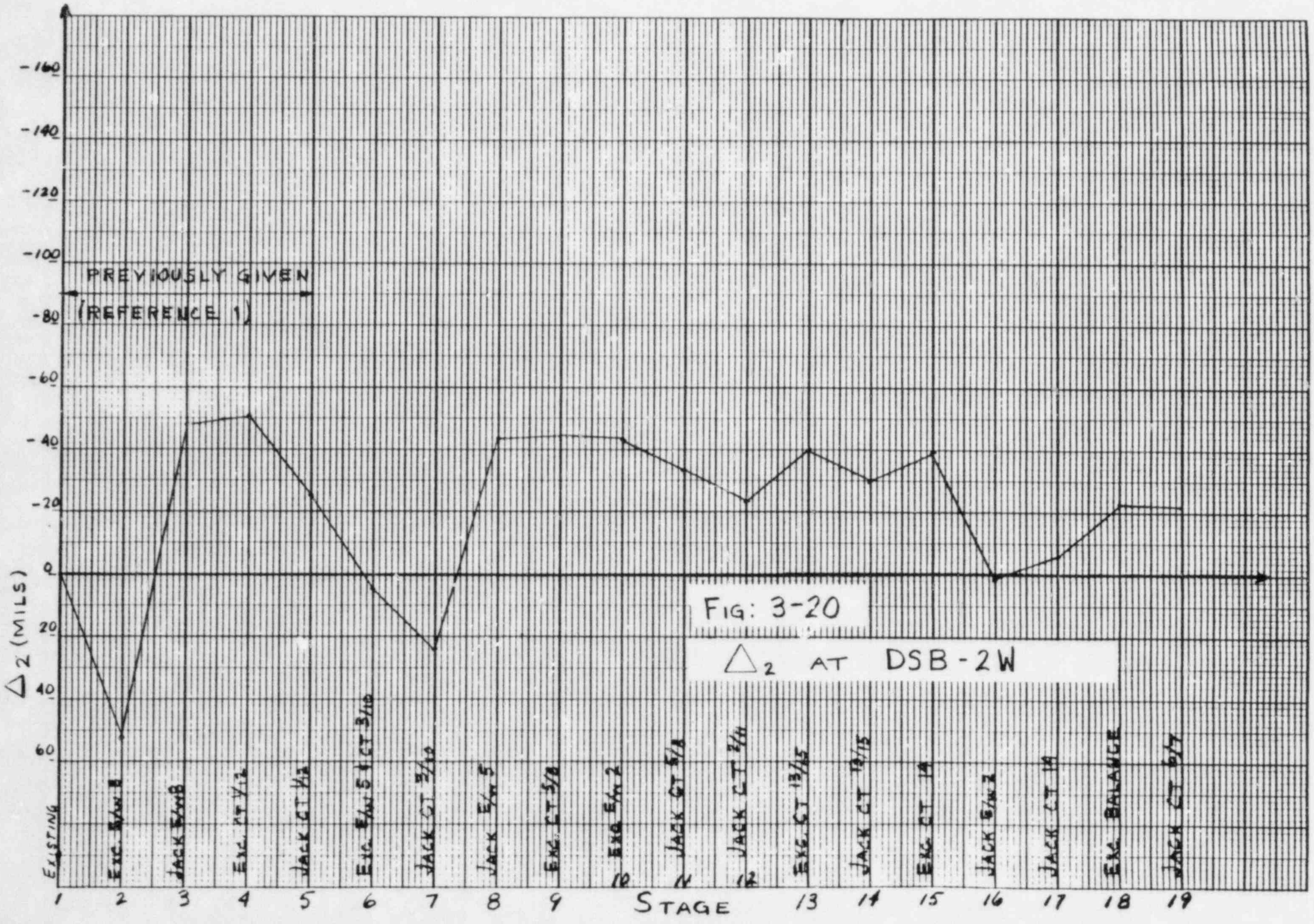


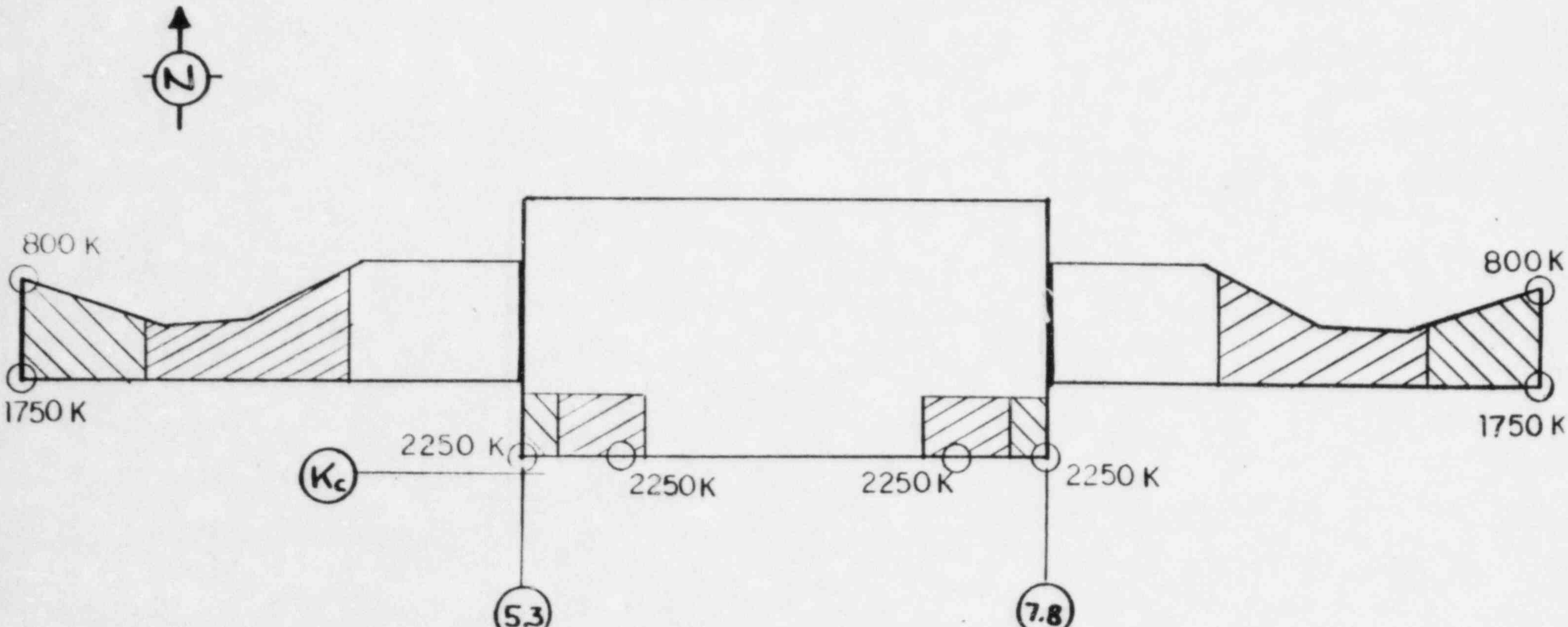
FIG: 3-20

Δ_2 AT DSB-2W

AUXILIARY BUILDING UNDERPINNING

CONSTRUCTION AREA

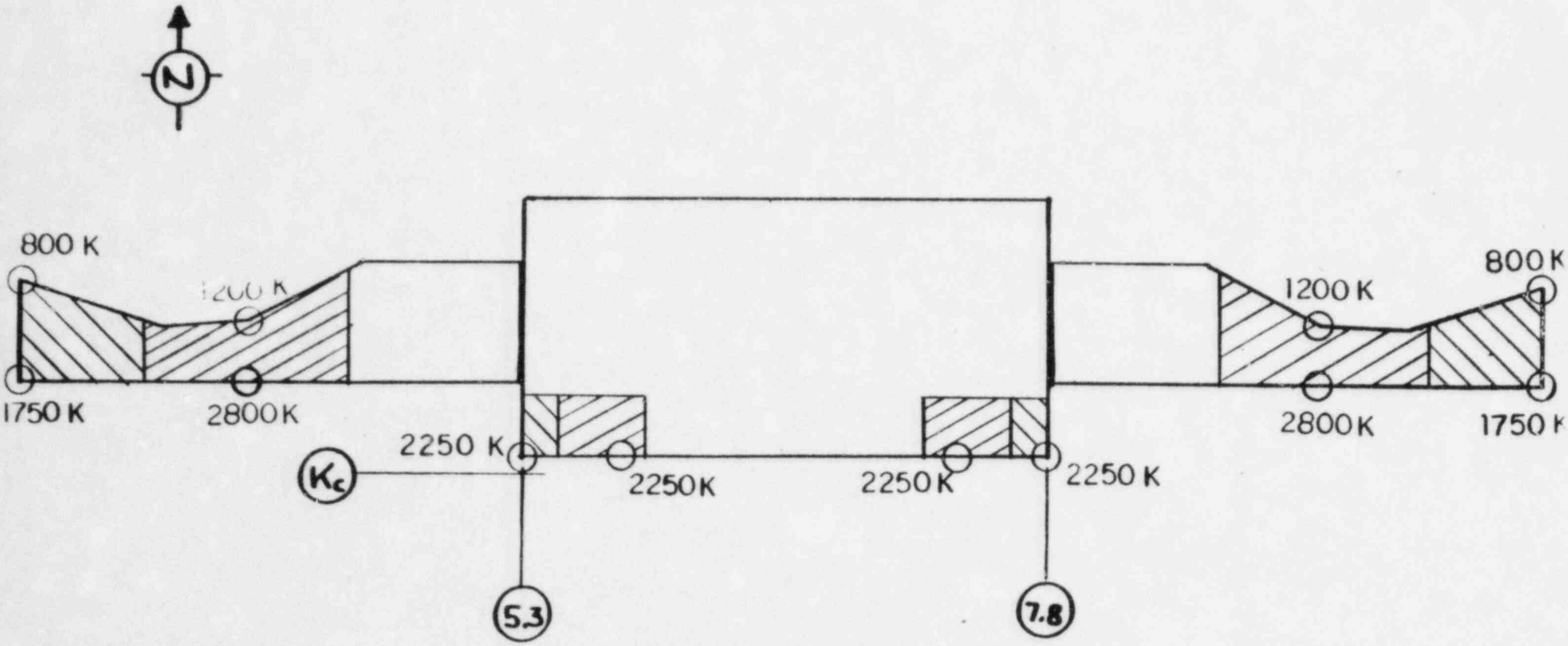
PLAN



JACKING OF CT 3/10 (LOAD COMBINATION 7)

FIGURE 3-21

AUXILIARY BUILDING UNDERPINNING
CONSTRUCTION AREA
PLAN



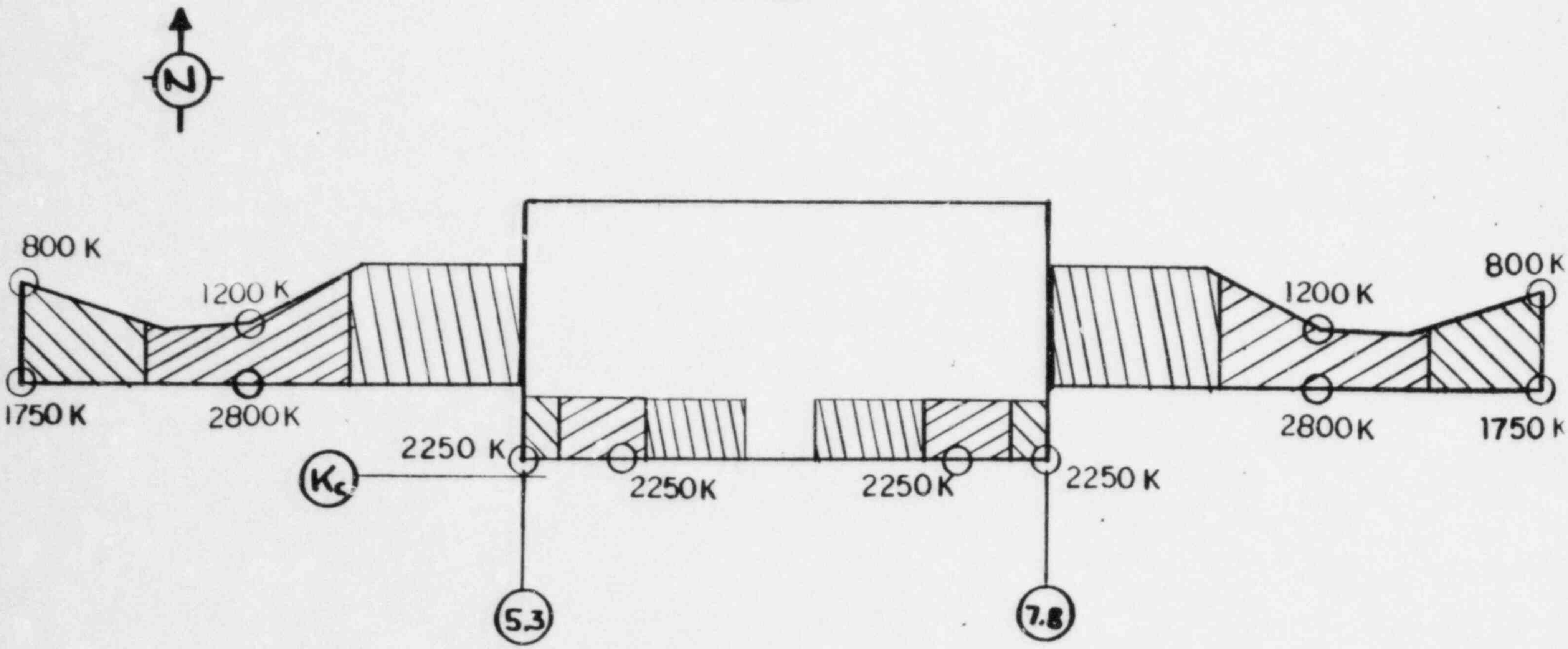
JACKING OF E/W 5 (LOAD COMBINATION 8)

FIGURE 3-22

AUXILIARY BUILDING UNDERPINNING

CONSTRUCTION AREA

PLAN



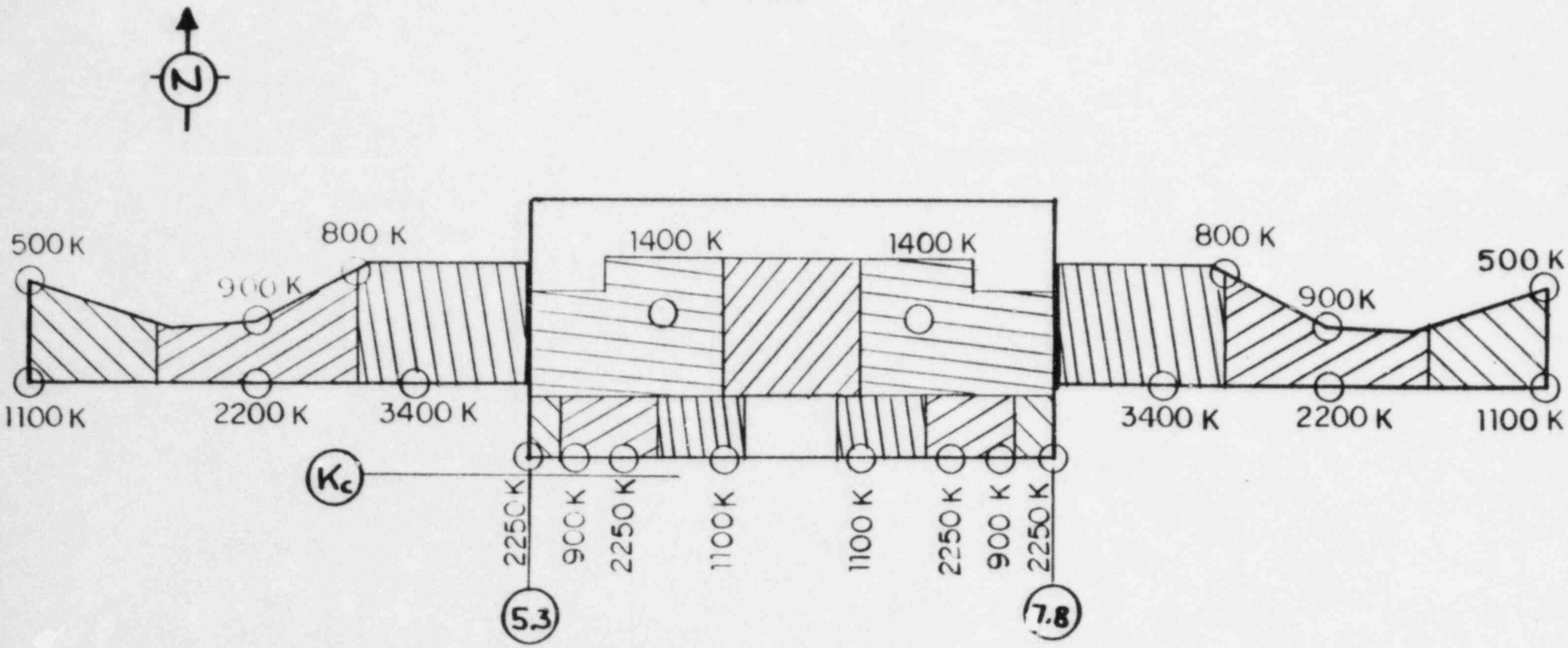
EXCAVATION OF E/W 2 (LOAD COMBINATION 10)

FIGURE 3 - 23

AUXILIARY BUILDING UNDERPINNING

CONSTRUCTION AREA

PLAN

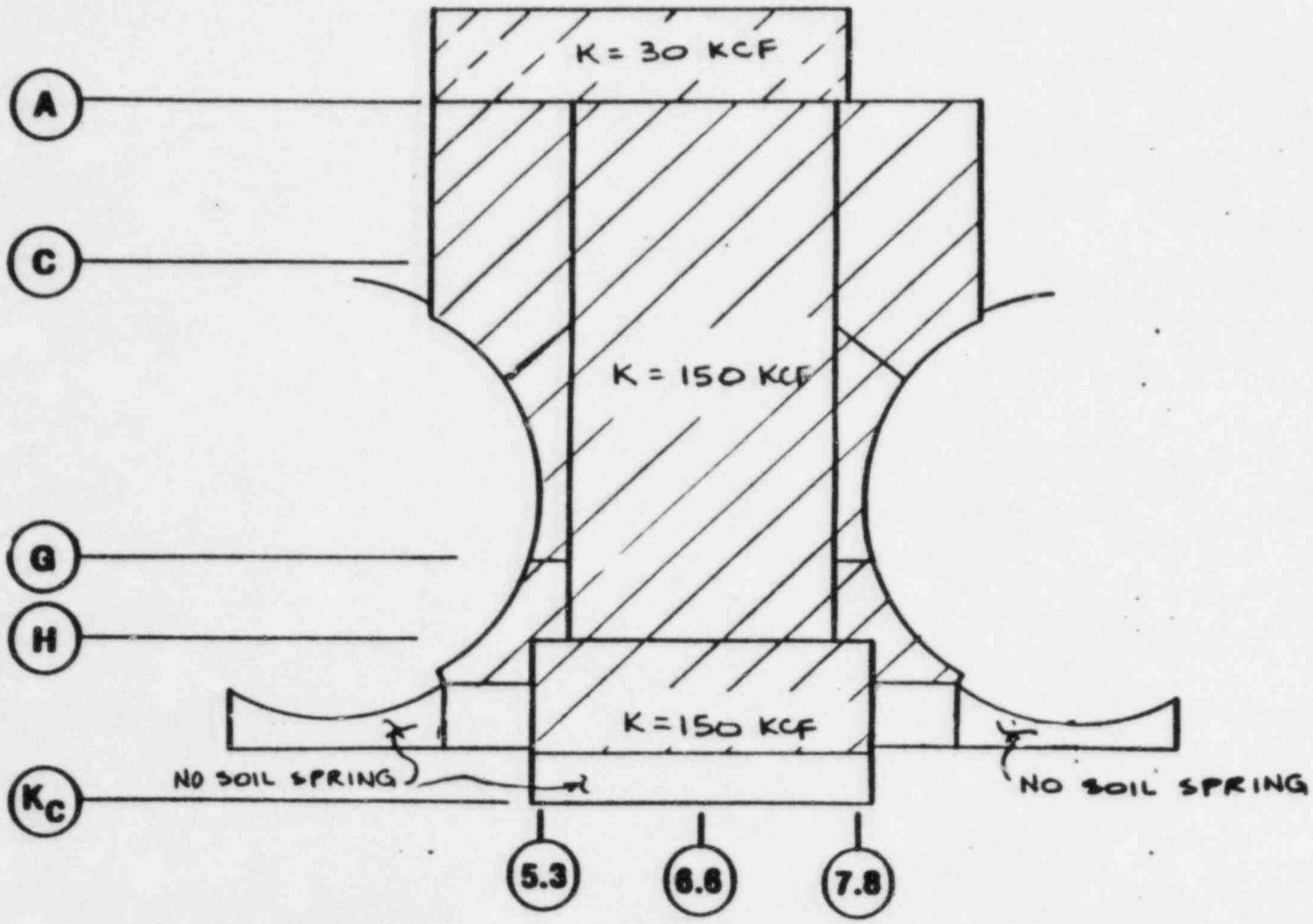


JACKING OF E/W 2 (LOAD COMBINATION 16)

FIGURE 3-24

AUXILIARY BUILDING UNDERPINNING
SOIL SPRINGS UNDER AUXILIARY BUILDING

FIGURE 3-25

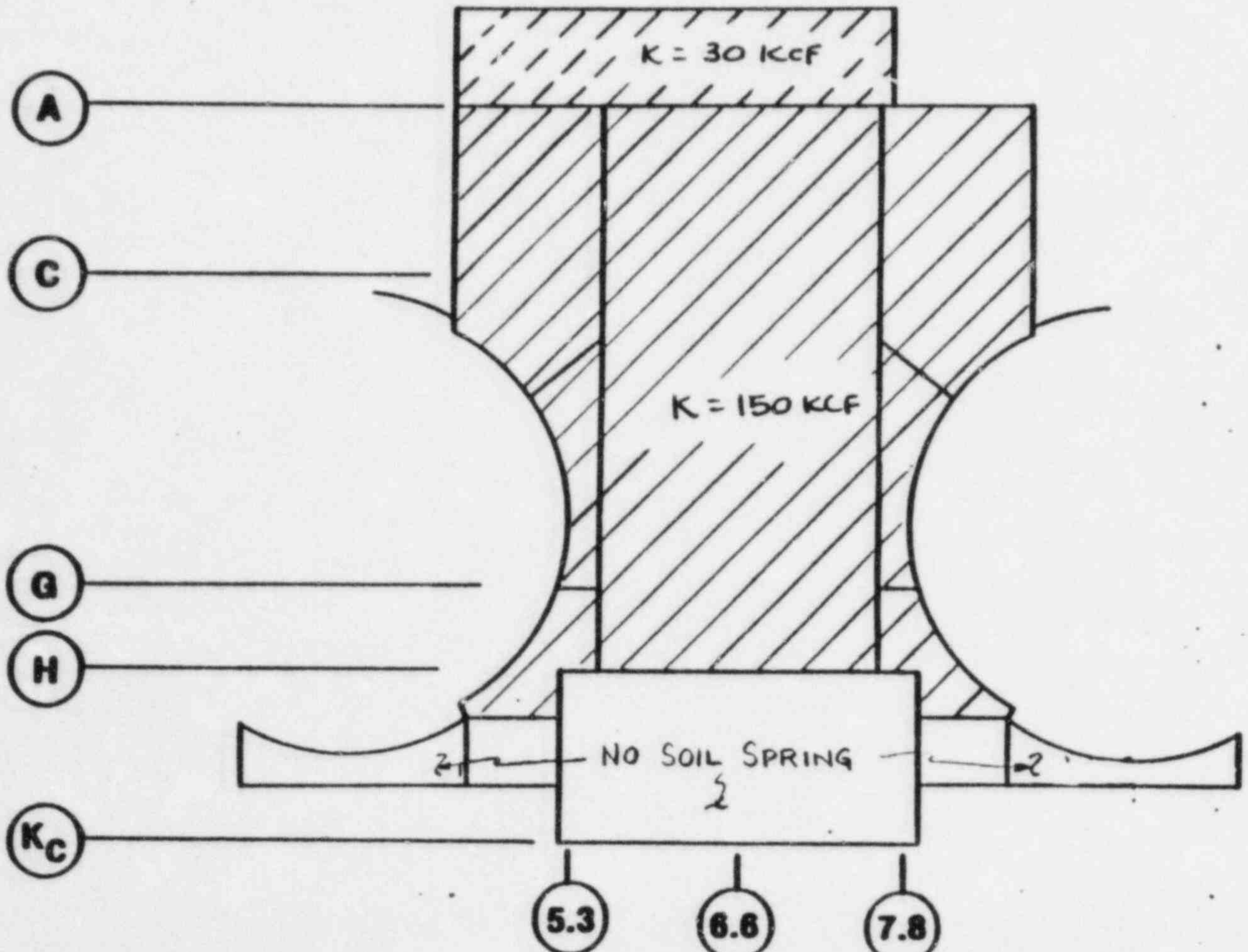


INSTANTANEOUS SOIL SUBGRADE MODULII
FOR DEFLECTION ANALYSIS

AUXILIARY BUILDING UNDERPINNING

SOIL SPRINGS UNDER AUXILIARY BUILDING

FIGURE 3-26



INSTANTANEOUS SOIL SUBGRADE MODULII

FOR DEFLECTION ANALYSIS

ATTACHMENT 3

TABLE 8-2

CALCULATED STRESSES FOR UNSYMMETRICAL CONSTR. ANALYSIS. (STAGE 21 FIG. 8-2)

DESCRIPTION		TENSION		COMPRESSION		REMARKS
		REBAR STRESS	STRAIN	CONCRETE STRESS	STRAIN	
		KSI	$\times 10^{-6}$ IN/IN	PSI	$\times 10^{-6}$ IN/IN	
WALL BELOW EL. 614'-0 ON COL. LINE 5.3 BETWEEN COL. LINES G & H (FIG. 1-1)		28.3 (2)	243			
WALL BELOW EL. 614'-0 ON COL. LINE 7.8 BETWEEN COL. LINES G & H (FIG. 1-2)		25.7 (2)	228			
SLAB AT EL. 659'-0 BETWEEN COL. LINES G & H (FIG. 1-3)		9.1 (1)	12			
EPA WALLS AREA 4 FIG. 1-6	TOP			(-19.2 K/FT) -38	-11	
	BOT	(33.6 K/FT) 8.1	18			
EPA WALLS AREA 5 FIG. 1-6	TOP			(-34.0 K/FT) -67	-19	
	BOT			(-10.2 K/FT) -20	-6	
FLOOR SLAB AT EL. 685'-0 AREA 6 / FIG. 1-6				127	35	

1) AVERAGE TENSILE STRESS.

2) AVERAGE SHEAR STRESS.

TABLE 8-3A

CALCULATED STRESSES FOR UNSYMMETRICAL CONSTR. ANALYSIS. (STAGE 32 FIG. 8-3A)

DESCRIPTION		TENSION		COMPRESSION		REMARKS
		REBAR STRESS	STRAIN	CONCRETE STRESS	STRAIN	
		KSI	$\times 10^{-6}$ IN/IN	PSI	$\times 10^{-6}$ IN/IN	
WALL BELOW EL. 614'-0 ON COL. LINE 5.3 BETWEEN COL. LINES G & H (FIG. 1-1)		8.9 (2)	128			
WALL BELOW EL. 614'-0 ON COL. LINE 7.8 BETWEEN COL. LINES G & H (FIG. 1-2)		22.5 (2)	208			
SLAB AT EL. 659'-0 BETWEEN COL. LINES G & H (FIG. 1-3)				33	13	
EPA WALLS AREA 4 FIG. 1-6	TOP			(-17.2 K/ft) -34	-9	
	BOT	(36.5 K/ft) 8.8	20			
EPA WALLS AREA 5 FIG. 1-6	TOP			(-19.6 K/ft) -39	-11	
	BOT			(-34.9 K/ft) -69	-19	
FLOOR SLAB AT EL. 685'-0 AREA 6 / FIG. 1-6				66	18	

1) AVERAGE TENSILE STRESS.
2) AVERAGE SHEAR STRESS.

TABLE 8-4

CALCULATED STRESSES FOR UNSYMMETRICAL CONSTR. ANALYSIS. (STAGE 43 FIG. 8-4)

DESCRIPTION		TENSION		COMPRESSION		REMARKS
		REBAR STRESS KSI	STRAIN $\times 10^{-6}$ IN/IN	CONCRETE STRESS PSI	STRAIN $\times 10^{-6}$ IN/IN	
WALL BELOW EL. 614'-0 ON COL. LINE 5.3 BETWEEN COL. LINES G & H (FIG. 1-1)		7.0 (2)	116			
WALL BELOW EL. 614'-0 ON COL. LINE 7.8 BETWEEN COL. LINES G & H (FIG. 1-2)		14.5 (2)	161			
SLAB AT EL. 659'-0 BETWEEN COL. LINES G & H (FIG. 1-3)				57	22	
EPA WALLS AREA 4 FIG. 1-6	TOP			(-21.8 K/FT) -43	-12	
	BOT	(5.0 K/FT) 1.2	3			
EPA WALLS AREA 5 FIG. 1-6	TOP			(-50.5 K/FT) -100.	-28	
	BOT	(29.2 K/FT) 7.0	16			
FLOOR SLAB AT EL. 685'-0 AREA 6 / FIG. 1-6				181	50	

1) AVERAGE TENSILE STRESS.

2) AVERAGE SHEAR STRESS.

TABLE 8-3

CALCULATED STRESSES FOR UNSYMMETRICAL CONSTR. ANALYSIS. (STAGE 3'2 FIG. 8-3)

DESCRIPTION		TENSION REBAR STRESS KSI	TENSION STRAIN $\times 10^{-6}$ IN/IN	COMPRESSION CONCRETE STRESS PSI	COMPRESSION STRAIN $\times 10^{-6}$ IN/IN	REMARKS
WALL BELOW EL. 614'-0 ON COL. LINE 5.3 BETWEEN COL. LINES G & H (FIG. 1-1)						
WALL BELOW EL. 614'-0 ON COL. LINE 7.8 BETWEEN COL. LINES G & H (FIG. 1-2)						
SLAB AT EL. 659'-0 BETWEEN COL. LINES G & H (FIG. 1-3)						
EPA WALLS AREA 4 FIG. 1-6	TOP			(-16.7 K/Ft) -33	-9	
	BOT	(36.2 K/Ft) 8.7	20			
EPA WALLS AREA 5 FIG. 1-6	TOP			(-23.3 K/Ft) -46	-13	
	BOT			(-31.1 K/Ft) -62	-17	
FLOOR SLAB AT EL. 685'-0 AREA 6 / FIG. 1-6						

1) AVERAGE TENSILE STRESS.

2) AVERAGE SHEAR STRESS.

ATTACHMENT 4

(4)

CTL

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March 6, 1984

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Evaluation of Cracking in Slabs at Elevation 674 ft-6 in., 685 ft-0 in. and 704 ft-0 in.

Dear Thiru:

On January 6, 1984 A. E. Fiorato and R. G. Oesterle of Construction Technology Laboratories (CTL) inspected cracks in the Auxiliary Building at the Midland Nuclear Power Plant. These cracks were located in the Control Tower floor at Elevation 685 ft-0 in. A description of the site visit, analysis of observations, evaluation of the structural effects of observed cracking, and results of an engineering evaluation of conditions that led to cracking are presented in two previous reports by CTL dated January 10 and January 30, 1984.

This letter is intended to clarify some concerns discussed during a recent site visit by W. G. Corley of CTL regarding the findings in the report of January 30, 1984. The January 30 report states that evidence did not strongly support the probability that cracking was caused by settlement of the EPA walls. Rather, results of calculations suggested that shrinkage of concrete was the primary cause of the observed cracking.

As part of the evaluation reported on January 30, 1984, a comparison was made between observed cracking at Elevation 685 ft-0 in. and at Elevation 704 ft-0 in. If cracking in the floor slab at Elevation 685 ft-0 in. was caused by differential settlement, similar cracking should be expected in the roof slab at Elevation 704 ft-0 in. However, field observations indicated similar cracking did not occur in the roof slab. Calculations made for the January 30, 1984 report show that the sum or measured crack widths along the floor at Elevation 685 ft-0 in. was comparable to expected shortening of the slab

due to shrinkage strains. Therefore, it is our opinion that the primary cause of cracking in the slab at Elevation 685 ft-0 in. was restrained volume changes due to drying shrinkage of the concrete.

This conclusion has apparently led to a concern about the observed low amount of shrinkage cracking in the roof slab at Elevation 704 ft-0 in. as well as a difference in cracking in the floor slab at Elevation 674 ft-6 in. In the following portions of this report, some of the reasons why the amount of shrinkage cracking observed at Elevations 685-ft-0 in. would not be expected at Elevations 704 ft-0 in. and 674 ft-6 in. are discussed.

PARAMETERS AFFECTING SHRINKAGE CRACKING

Shrinkage is defined as the reduction in volume of concrete independent of external load. Shrinkage is primarily related to the loss of water during the drying process. The amount of shrinkage and resulting cracking expected in a particular concrete depends on a number of parameters. Constituents of the concrete mix and the environment in which the concrete is placed both have significant influence. The resulting cracking pattern is affected by restraints imposed on the volume changes and the amount of reinforcement present within the concrete.

The following sections of this letter compare parameters affecting the roof slab at Elevation 704 ft-0 in. with those affecting the floor slab at Elevation 685 ft-0 in. Also, the parameters affecting the floor slab at Elevation 674 ft-6 in. are compared with those affecting the floor at Elevation 685 ft-0 in. The comparisons indicate why different cracking patterns should be expected in each slab.

ROOF SLAB AT ELEVATION 704 FT-0 IN.

Both the roof slab at Elevation 704 ft-0 in. and the floor slab at Elevation 685 ft-0 in. are relatively thick concrete slabs containing reinforcing bars and cast on metal decking supported by structural steel beams. However, there are significant differences in the constituents of the concrete, exposure to environment during casting and curing, restraint of volume change, and amount of reinforcing steel in these slabs. Figures 1 through 4 show relevant parameters for the two slabs.

Concrete Mix

The class of concrete used in the roof was D-2 having constituents listed in Table 9.7 of Specification 7220-C-230(Q), Rev. 25. Concrete for the slab at Elevation 685 ft-0 in. was Class C-1. Class D-2 is a higher strength concrete with a lower water-to-cement ratio and has different proportions of coarse and fine aggregates than Class C-1. Calculations indicate that, for equivalent casting and curing conditions, shrinkage volume changes in Class D-2 concrete are expected to be only 50% of volume changes in Class C-1 concrete. Therefore, with equivalent restraint and reinforcement, significantly less cracking would be expected in the roof slab than in the slab at Elevation 685 ft-0 in.

Exposure to Environment

Shrinkage is closely associated with drying of concrete. Therefore environmental conditions that increase drying also increase both the rate and total amount of shrinkage. Conditions that influence drying include temperature, relative humidity, exposure to high winds, and volume-to-surface ratio. The slab at Elevation 704 ft-0 in. was placed in two castings on October 13 and 24, 1977. The slab at Elevation 685 ft-0 in. was placed in two castings on June 14 and 17, 1977. Weather conditions during mid-October are usually significantly different than those during mid-June.

Available records of weather conditions during the time of casting of each floor and for several days after do not indicate any high winds or significant precipitation. As an indication of temperatures, the average of the recorded daily high and low temperatures from the day of the first casting to 28 days after the second casting was calculated. This average temperature was 71°F with a range of 40°F to 98°F for the slab at Elevation 685 ft-0 in. The average temperature was 46°F with a range of 14°F to 70°F for the slab at Elevation 704 ft-0 in. Drying and subsequent shrinkage strains increase with increased temperature. Therefore, the slab at Elevation 685 ft-0 in. would be expected to have higher shrinkage volume changes due to differences in ambient temperature.

The volume-to-surface ratio of the concrete also has a significant effect on the rate of drying. An increase in this ratio, which is essentially the effective thickness of the concrete, decreases the rate of drying. The slab at Elevation 704 ft-0 in.

is nominally 21 in. thick as compared to the 15-in. thickness of the slab at Elevation 685 ft-0 in. With this difference in thickness combined with the effect of difference classes of concrete, total calculated shrinkage volume change after 6-1/2 years in the slab at Elevation 704 ft-0 in. is only 36% of that for the slab at Elevation 685 ft-0 in.

Restraint

Unrestrained shrinkage volume changes do not cause stresses or cracking in concrete. Stresses and the potential for cracking result from constraints that oppose movement of the concrete as it shrinks. Stiffer constraints induce higher stresses and higher probability of cracking.

Slabs in the Control Tower are restrained from shrinkage in the plane of the slab by internal reinforcement, by the steel framing system under the slabs and by the surrounding walls. As shown in Fig. 1 and 2, for Elevation 685 ft-0 in., shrinkage movement in the east-west direction is restrained by two layers of No. 6 bars at 18 in. on center and by six W18x60 steel beams spaced at approximately 6 ft-6 in. The beams are continuously connected between the north-south walls from Column Line 5.3 to 7.8. The internal reinforcement and external beams are constraints that contribute to the potential for the observed cracks in the north-south direction.

As shown in Fig. 3 the steel framing system at Elevation 704 ft-0 in. consists primarily of beams in the north-south direction. There is no continuous external structural steel that would restrain the slab in the east-west direction. The only steel restraint in this direction would be produced by the internal reinforcement. Figure 4 shows that shrinkage in the east-west direction is restrained by two layers of No. 8 bars at 9 in. on center. The combined stiffness of external beams and internal reinforcement for the slab at Elevation 685 ft-0 in. is 35% greater than the stiffness of the internal reinforcement at Elevation 704 ft-0 in.

As shown in Section A of Fig. 4, the roof slab is restrained by walls that support the edge of the slab from below. However, Section A in Fig. 2 shows that the slab at Elevation 685 ft-0 in. is restrained by walls that extend above the slab in addition to walls that support the edge or slab from below. The edge restraint on the slab at Elevation 685 ft-0 in. is essentially

twice as stiff as the restraint on the roof slab. Therefore, because of differences of in-plane restraint from internal reinforcement, steel framing systems, and surrounding walls, less north-south cracking would be expected in the roof slab than in the slab at Elevation 685 ft-0 in.

Beams in the north-south direction under the roof slab could have restrained the slab in this direction, thereby increasing the probability of east-west cracks. However, as shown in Fig. 4, large construction openings were left in the north-east and north-west corners during casting. These openings extend 25 ft in the east-west direction. The openings relieved a large portion of the roof slab restraint in the north-south direction. This would significantly decrease the probability of east-west cracking in the roof slab, particularly in the region of the openings. The potential for east-west shrinkage cracking in the slab at Elevation 685 ft-0 in. is significantly reduced by the openings along the south edge.

Both slabs are also restrained from out-of-plane movement. Since both slabs were cast on metal decking that remained in-place, loss of moisture occurs only from the top surface. This results in differential shrinkage through the slab thickness. That is, higher shrinkage strains occur at the top surface than at the bottom. The differential shrinkage produces a curvature that tends to curl the slab downward. This downward out-of-plane movement is opposed by the steel beams below the slab. The restraint by the steel beams results in negative bending in the slab in the region directly above the beams. Negative bending causes tensile stresses in the top surface of the slab that increase the probability of cracks occurring near the supporting beams. It should also be noted that negative bending from gravity loading on the slabs acts in the same direction.

The roof slab at Elevation 704 ft-0 in. is supported in the north-south direction by twelve W36x300 beams at spacings ranging from 5 ft-6 in. to 8 ft-0 in. The slab at Elevation 685 ft-0 in. is supported in the north-south direction by four W36x300 beams at center spacings of 17 ft-6 in. to 20 ft-0 in.

Calculations indicate that the roof slab at Elevation 704 ft-0 in. would have a lower probability of cracking from negative bending than would the slab at Elevation 685 ft-0 in. This is true for

negative bending resulting from either the curling effect associated with differential shrinkage or from equivalent gravity load on the slabs. Also, if cracking did occur in the roof slab at Elevation 704 ft-0 in., the width of the crack at the top surface due to curvature in the slabs would be smaller because of the significantly shorter spans.

Reinforcement

Reinforcing bars embedded in uncracked concrete have low stresses. The uncracked concrete carries most of the stress. If the concrete cracks, stresses are transferred to the reinforcement the reinforcing bars then become active by spanning the cracks. The resulting width and spacing of cracks are highly dependent on the amount of reinforcement present in the concrete. A larger amount of reinforcement produces more closely spaced cracks with smaller crack widths.

The amount of reinforcement present in the roof slab at Elevation 704 ft-0 in. is significantly larger than the reinforcement at Elevation 685 ft-0 in. The amount of reinforcement in the top layers of the slab at Elevation 704 ft-0 in. is approximately four times the reinforcement in the slab at Elevation 685 ft-0 in. Therefore, if the slab at Elevation 704 ft-0 in. cracked, a pattern of smaller more distributed cracks would be expected as compared to the slab at Elevation 685 ft-0 in.

Summary for Slab at Elevation 704 ft-0 in.

Because of the differences in concrete mixes, environmental exposure conditions during and following casting, restraint to the slab by the surrounding structure, and the amount of reinforcement within the slab concrete, significantly less cracking from drying shrinkage would be expected in the roof slab at Elevation 704 ft-0 in. as compared to the slab at Elevation 685 ft-0 in. Considering the parameters affecting the slab at Elevation 704 ft-0 in., the observed low amount of shrinkage cracking in the areas uncovered for inspection of this slab is reasonable.

FLOOR SLAB AT ELEVATION 674 FT-6 IN.

As stated in a previous report by CTL dated January 30, 1984, an inspection of the floor at Elevation 674 ft-6 in. did not indicate cracking similar to that observed at Elevation 685 ft-0 in. Cracking in the floor at Elevation 674 ft-6 in. is generally a crazed pattern (closely spaced and narrow)

throughout the surface of the slab. However, within the crack mapping being done under Specification 7220-C-198(Q), five relatively long, distinct cracks running in the north-south direction have been identified in Submittal 7220-C-198-394-1. The crack widths are noted as either hairline or 0.005 in. Four of these five cracks are located in regions above the W36x300 floor beams.

The difference between observed cracking patterns in floors at Elevations 674 ft-6 in. and 685 ft-0-in. is not as great as the difference between the slabs at Elevations 704 ft-0 in. and 685 ft-0 in. Because the crack pattern at Elevation 674 ft-6 in. tends to mask any more distinct cracking patterns, it is difficult to state which slab has exhibited more shrinkage.

It is not the primary concern of the following discussion to state which slab would be expected to exhibit larger shrinkage volume changes. The main point is that significantly different cracking patterns would not be unexpected in the two slabs.

Both the slab at Elevation 674 ft-6 in. and the slab at Elevation 685 ft-0 in. are nominally 15 in. thick reinforced concrete slabs supported by structural steel beams. However, there are differences in the constituents of the concrete, exposure to environment during and after casting and curing, restraint to volume change, and amount of reinforcing steel in the slabs. Figures 1, 2, 5 and 6 show the relevant parameters for the two slabs.

Concrete Mix

The class of concrete indicated on the drawings and in concrete pour cards was Class C-1 for both slabs. Reports of concrete cylinder tests, though, indicate that the east half of the slab at Elevation 674 ft-6 in. was cast with Class D-1 concrete. Class D-1 is a higher strength concrete with a lower water-to-cement ratio and contain slightly different proportions of coarse and fine aggregates than Class C-1. Calculations indicate that, for equivalent casting and curing conditions, shrinkage volume changes in Class D-1 concrete are expected to be 90% of volume changes in Class C-1 concrete. Also, Class D-1 concrete will be stronger than C-1 at equivalent ages. Therefore, a somewhat different cracking pattern in the east half of the slab at Elevation 674 ft-6 in. could be expected because of the different concrete classes.

Exposure to Environment

One difference in exposure is related to the forming systems used. The slab at Elevation 685 ft-0 in. was cast on metal decking that remained in-place. Therefore, drying only occurs from the top surface. The slab at Elevation 674 ft-6 in. was cast on plywood forms that were later removed. This allowed the slab at Elevation 674 ft-6 in. to dry from two surfaces.

This difference in exposure has two effects. One effect is that, for equivalent casting and curing conditions, total calculated shrinkage volume changes after 6-1/2 years are approximately 65% larger in the slab at Elevation 674 ft-6 in. This effect would produce larger cracks in the floor at Elevation 674 ft-6 in.

With drying from both the top and bottom surfaces, there should not be any significant differential shrinkage between the bottom and top surfaces. Therefore, the curling effect and resulting negative moments at the beam locations should not be significant. This would decrease the probability of cracking over the beams in the slab at Elevation 674 ft-0 in. Also, the widths of cracks at the top surface of the slab at Elevation 685 ft-0 in. may be accentuated by the rotations associated with the curling effect. This accentuation would not occur in the slab at Elevation 674 ft-6 in. Therefore, if what would be equivalent average crack widths did occur in the slabs, a larger crack would be measured in the top surface of the slab at Elevation 685 ft-0 in.

Another difference in exposure is related to the surface finish on the slab. The slab at Elevation 685 ft-0 in. has a wood float finish which "opens" the concrete surface and allows drying. The slab at Elevation 674 ft-0 in. has a steel trowel finish. A steel trowel finish produces a dense, tight surface that inhibits drying.

The differences in finish have two effects on shrinkage cracks. The first effect is that the top surface of the steel trowel finished slab drys more rapidly than the concrete a short distance below the surface. This produces differential shrinkage strains over a shallow depth and can result in a finely distributed, crazed pattern of shrinkage cracks as observed in the floor at Elevation 674 ft-6 in. This crazed pattern tends to mask any more distinct shrinkage cracking.

The second effect of the steel troweled finish is that, with drying below the surface inhibited, the shrinkage strains take a longer time to develop. As concrete ages, there is a simultaneous increase in tensile strength and shrinkage strains. With more moisture retained in the concrete, tensile strength develops faster while shrinkage develops more slowly. This effect decreases the probability of shrinkage cracks through the thickness of the concrete. Also, if restraint of shrinkage movements is due to surrounding concrete structures, having shrinkage occurring over a longer time allows more creep strain to develop in the surrounding structure. Creep strain in the surrounding concrete would relieve some of the restraint. The net effect of a slower rate of shrinkage in the slab at Elevation 674 6 in. is to decrease the probability of cracking.

A third difference in exposure is related to the environmental conditions. The slab at Elevation 674 ft-6 in. was placed in two castings on May 3 and 17, 1977. The slab at Elevation 685 ft-0 in. was placed on June 14 and 17, 1977. Weather conditions during early May can be significantly different than those during mid-June.

Available records of weather conditions during the time of casting do not indicate any high winds or significant precipitation for either slab. As an indication of temperatures, the average of the recorded daily high and low temperatures from the day of the first casting to 28 days after the second casting was calculated. This average temperature was 71°F with a range of 40°F to 98°F for the slab at Elevation 685 ft-0 in. The average temperature was 63°F with a range of 26°F to 97°F for the slab at Elevation 674 ft-6 in. Drying and subsequent shrinkage strains increase with temperature. Therefore, the slab at Elevation 685 ft-0 in. would be expected to have higher shrinkage volume changes.

Restraint

Slabs in the Control Tower are restrained from shrinkage in the plane of the slab by internal reinforcement, by the steel framing system under the slabs, and by the surrounding walls. The restraint from the surrounding walls is nominally the same for both slabs. However, the combination of internal and external steel in the east-west direction is significantly different.

As shown in Figs. 1 and 2, the slab at Elevation 685 ft-0 in. is restrained in the east-west direction by two layers of No. 6 bars at 18 in. on center and by six W18x60 steel beams spaced at approximately 6 ft-6 in. As shown in Fig. 5, the west bay of the floor at Elevation 674 ft-6 in. contains only two W21x82 beams connected to the west wall along Column Line 5.3. The beams are located relatively close to the east-west walls at Column Lines H and K_c. There is no continuously connected restraint within the center 30-ft wide region between the north-south walls from Column Line 5.3 to 7.8. Figure 6 shows that shrinkage in the east-west direction is also restrained by two layers of No. 6 bars at 12 in. on center.

The combined stiffness of external beams and internal reinforcement for the slab at Elevation 685 ft-0 in. is approximately 50% greater than the combined stiffness at Elevation 674 ft-0 in. The effect of this difference in restraint is to increase the probability of north-south cracking in the slab at Elevation 685 ft-0 in. as compared to the slab at Elevation 674 ft-6 in.

The potential east-west shrinkage cracking in both slabs is significantly reduced by the openings along the south edge of the slabs.

Reinforcement

As stated previously in this report, if concrete cracks, the resulting width and spacing of cracks are highly dependent on the amount of reinforcement present. A larger amount of reinforcement produces, more finely spaced cracks with smaller crack widths.

Reinforcement in the east-west direction of the slab at Elevation 674 ft-6 in. is about 50% greater than that at Elevation 685 ft-0 in. In addition, there is a significant amount of reinforcement added around numerous openings in the floor at Elevation 674 ft-6 in. Also, there are two layers of seven No. 11 bars in a 4-ft strip along the south edge of the floor at Elevation 674 ft-6 in. With this larger amount of rein- forcement, a pattern of smaller, more distributed cracks would be expected in the floor at Elevation 674 ft-6 in., as compared to the slab at Elevation 685 ft-0 in.

Summary for Slab at Elevation 685 ft-0 in.

Because of the differences in forming systems, surface finishes, environmental conditions during and following casting, restraint

of the slabs by the steel framing, and the amount of reinforcement within the concrete, significantly different cracking from drying shrinkage would be expected in the floor slab at Elevation 674 ft-6 in. as compared to the slab at Elevation 685 ft-0 in. Considering the various parameters affecting the slab at Elevation 674 ft-6 in., the smaller widths and more closely spaced cracks in this slab are reasonable.

Sincerely,

Ralph G. Oesterle, Manager
Analytical Design Section

RO/rr

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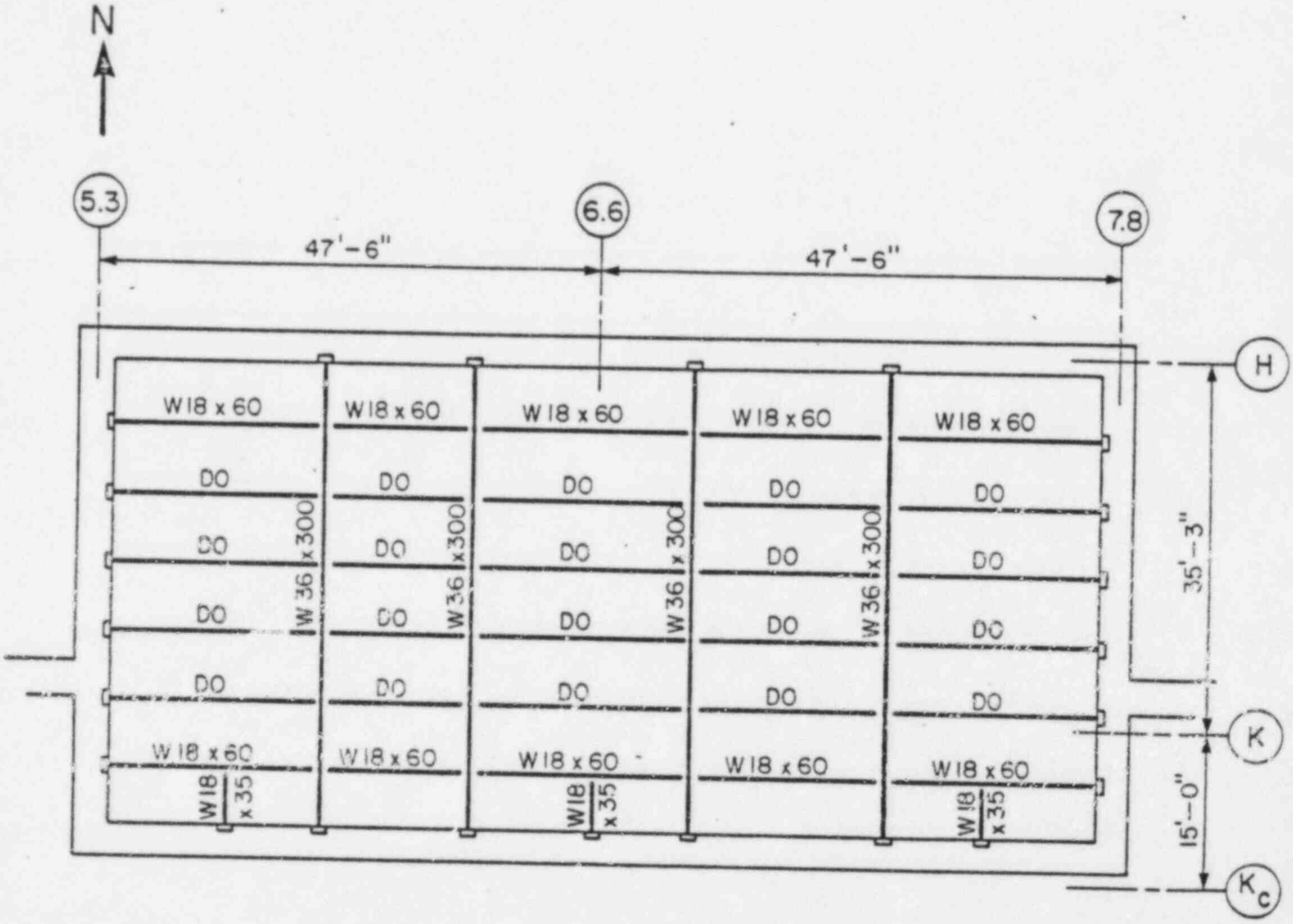
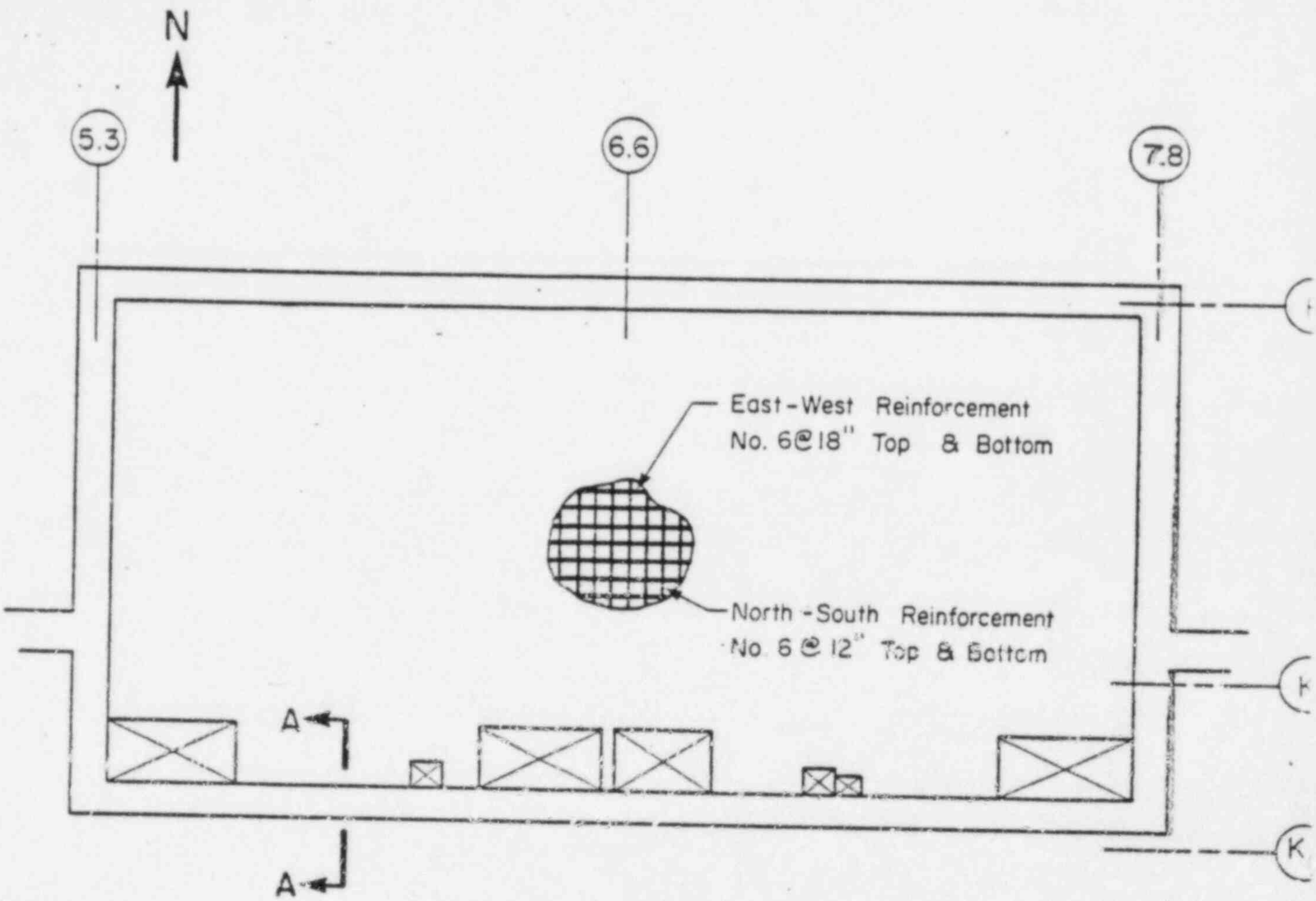
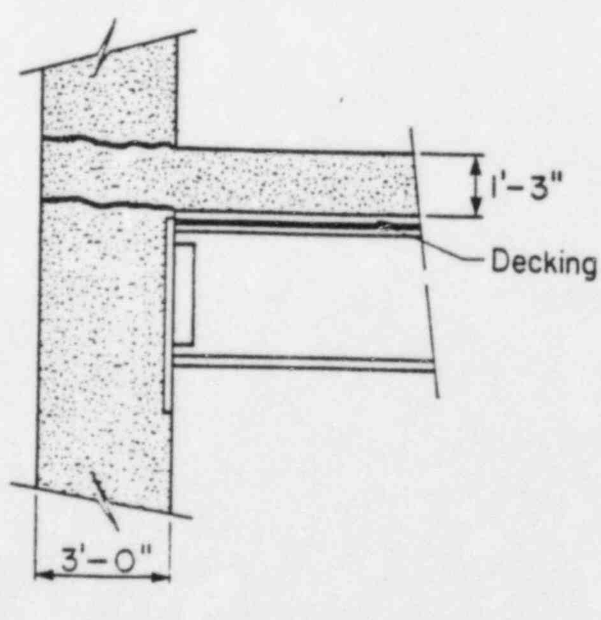


Fig. 1 Plan of Structural Steel Framing at Elevation 685 ft-0 in.



Plan @ Elev. 685'-0"

Notes:
Concrete = Class C-1
Average Temperature
During 28 days After
Casting = 71°F



Section A—A

Fig. 2 Internal Reinforcement, Openings and Concrete Information for Slab at Elevation 685 ft-0 in.