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ATTACHMENT I-1

TO

TECHNICAL REPORT

STRUCTURAL STRESSES INDUCED BY  
DIFFERENTIAL SETTLEMENT OF THE  
DIESEL GENERATOR BUILDING

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MIDLAND PLANT UNITS 1 AND 2  
DIESEL GENERATOR BUILDING  
SETTLEMENT DATA ANALYSIS

CONTENTS

1.0 INTRODUCTION	1
2.0 GENERAL CONSIDERATION OF BUILDING SETTLEMENT AND STRUCTURAL RESPONSE	1
3.0 SETTLEMENT DATA, MEASUREMENT LOCATIONS, AND METHODOLOGY TO DERIVE ORIGINAL SETTLEMENT DATA	2
4.0 DATA ANALYSIS	4
5.0 DISCUSSION OF THE SURVEY DATA	6
6.0 CONCLUSIONS	8
REFERENCES	9

TABLES

1	Exterior Wall Settlement Data
2	Difference of Settlement Between Two Consecutive Measurement Dates of Markers for Exterior Wall
3a	Relative Displacement Along North Wall for Settlement Markers
3b	Relative Displacement Along South Wall for Settlement Markers
4a	Angle Variation for Markers 1-22-21 Along Exterior South Wall
4b	Angle Variation for Markers 21-20-3 Along Exterior South Wall
5	Result of Warpage Analysis

FIGURES

1	Derivation of Differential Settlement From Settlement Data
2	Measurement Locations
3	Settlement Along South Wall
4a	Settlement-Time Curves for South Wall
4b	Settlement-Time Curves for North Wall
5	Analysis of Angle Variation
6	Warpage Analysis
7a	Modified Settlement-Time Curves for South Wall
7b	Modified Settlement-Time Curves for North Wall
8	Differential Settlement Determination

MIDLAND PLANT UNITS 1 AND 2  
DIESEL GENERATOR BUILDING  
SETTLEMENT DATA ANALYSIS

1.0 INTRODUCTION

This report presents the analysis of the surveyed settlement data of the diesel generator building (DGB). The reported settlement data obtained between November 24, 1978, and November 19, 1979, were studied.

Section 2.0 presents a general discussion of the structural response due to differential settlement. (Differential settlement is defined as structural deformation which induces stresses, i.e., rigid body motion is not considered to be differential settlement.) As indicated in this section, an accurate settlement data set is required for structural analysis.

A description of the settlement data, measurement location, and methodology used to derive the original settlement data is presented in Section 3.0. The settlement data in a time-history form is presented in this section. The effectiveness of settlement in the time-history form is discussed.

Section 4.0 presents the four different analyses made on the original settlement data. The original data analyzed in this section do not indicate a consistent structural deformation. A further discussion of the accuracy of the settlement data is provided in Section 5.0.

Conclusions of this study are presented in Section 6.0.

2.0 GENERAL CONSIDERATION OF BUILDING SETTLEMENT AND STRUCTURAL RESPONSE

Figure 1 illustrates the building settlement data and differential settlement derived from the settlement data. The stresses induced on the structure from date i to date j are functions of the relative differential displacements and are defined as  $D_2$ ,  $D_3$ , and  $D_4$  in Figures 1b and 1c.

Figure 1a indicates that the elevation measurement is subjected to an assumed measurement error (E). The accuracy of the measured absolute total settlement is higher than the accuracy of the calculated relative differential settlement. Letting  $S_n$  be the absolute settlement of a particular measurement point, the error of total settlement is  $E/S_n$ . The error of differential settlement is  $E/D_n$ . It is obvious that  $E/D_n$  is much larger than  $E/S_n$ .

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

If  $E/D_n$  is large, the differential settlement value ( $D_n$ ) should not be imposed on the structure for the structural analysis. The absolute settlement value ( $S_n$ ), however, has a higher accuracy and, therefore, may be utilized. The soil stiffness derived from  $S_n$  may be used to determine the structural responses.

3.0 SETTLEMENT DATA, MEASUREMENT LOCATIONS, AND METHODOLOGY  
TO DERIVE THE ORIGINAL SETTLEMENT DATA

The settlement data of the DGB were obtained at different locations during different time periods. Figure 2 illustrates the locations of "scribe" and permanent "markers."

Before installation of the permanent building markers (DG markers 1, 3, and 20 through 29), settlements had been monitored by surveys on construction scribes which were elevation marks placed on the inside of the building exterior walls 3 or 4 feet above final grade. A total of 26 such construction scribes were placed between March 28, 1978, and May 12, 1978. Elevation surveys of these scribes began on July 10, 1978, and continued at weekly intervals until November 24, 1978.

The first permanent building settlement marker, DG-3, was installed May 9, 1978, marker DG-1 was installed September 9, 1978, and markers DG-20 through 29 were installed November 15, 1978. The permanent markers were installed on the outside of the building walls 1 to 4 feet above final grade and consisted of short steel rods grouted into the walls. When the surcharge was placed, these permanent markers were no longer accessible and temporary markers were set in the mezzanine floor at elevations 663.5 to 664. Temporary markers consisted of nails set in the concrete in locations generally above the corresponding permanent markers.

The settlement record included settlements monitored by the construction scribes which had occurred up to November 24, 1978. The settlement data had been calculated by assuming the settlement of a given DG marker on November 24, 1978, equal to the settlement recorded at the scribe for that particular area of the building. Beginning December 1, 1978, and up to and including March 22, 1979, only the permanent DG markers were optically surveyed. Placement of the surcharge prevented the use of the permanent markers after March 22, 1979, and temporary markers were installed to continue monitoring the settlements. The first survey of the temporary DG markers was made on March 24, 1979 (2 days after the final survey of the permanent markers), except for temporary markers DG-23 and 29 which could not be surveyed until April 9, 1979 (18 days after the final survey of the permanent markers). Temporary DG markers were surveyed during surcharge and surcharge removal until

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

00072000

September 14, 1979, according to the settlement record table. By this time, the permanent DG markers were accessible.

The procedure used to obtain and calculate the original settlement data was to:

- a. Convert the settlements of the construction scribes to the corresponding permanent markers for the period between July 10, 1978, and November 24, 1978.
- b. Set the settlements of the permanent DG markers on November 24, 1978, equal to the settlements measured by construction scribes up to that date, for the particular area of the building where a given DG marker was located.
- c. Obtain the elevations of the DG markers by optical surveys and calculate the settlement of a marker on a given day by adding the settlement of the marker on November 24, 1978, to the change in elevation of the marker between November 24, 1978, and the day of the survey. This procedure continued until March 22, 1979, when the permanent DG markers were no longer accessible.
- d. Install temporary DG markers above the level of the surcharge and obtain their elevations on March 24, 1979 (except for temporary markers DG-23 and 29 which were not surveyed until April 9, 1979). The settlements of the permanent markers on March 22, 1979, were added to the elevations of the corresponding temporary markers on March 24, 1979, to establish base elevation for the temporary markers. Because temporary markers DG-23 and 29 were not surveyed until several days after the final survey of the permanent markers, settlements of these markers between March 22 and April 9, 1979, were estimated from the behavior of nearby markers and these estimated settlements were added to the April 9, 1979, elevations to establish base elevations for these two markers.
- e. Calculate the settlements of the temporary DG markers on a given day by subtracting the marker elevation determined by surveys from the base elevation established on March 24, 1979 (April 9, 1979, in the case of markers DG-23 and 29). Settlements of the temporary markers were calculated in this manner until September 14, 1979.
- f. Obtain elevations of the permanent markers on September 14, 1979, and calculate settlements of the permanent markers on that date by subtracting the marker elevations from base elevations for the permanent

00072000

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

markers. The base elevations for the permanent markers were established for December 2, 1978, by adding the settlements which had occurred up to that date (these settlements were estimated from scribes up to November 24, 1978) to the elevations of the markers obtained from surveys on December 2, 1978.

The settlement data were plotted in Bechtel Drawings SK-C-628 and SK-C-629 (Reference 1). Figure 3 illustrates the settlement values of the south wall for several dates. The settlement data plotted in Reference 1 for permanent markers DG-20, 23, 24, 25, 26, 27, and 29 for the period from July 10, 1978, to November 24, 1978, were derived from the settlement data of the nearby scribes by taking the numerical average values. Because the structure was only partially constructed before November 24, 1978, and the structural analysis shows that the stress level is low because of high structural flexibility, data earlier than November 24, 1978, are less important and, therefore, are not considered in this study.

The reported settlements after November 24, 1978, are listed in Table 1 and are plotted in a time-history form in Figure 4. These data were originally used in the settlement and structural evaluations.

The settlement-time relation shown in Figure 4 is a better form for studying the accuracy of the survey. The presentation method used in Reference 1 and Figure 3 (i.e., the settlement-marker location relationship) is misleading. For example, the structural shapes plotted in Figure 3 are based on the premise that the structure deformed according to the reported data without considering survey accuracy.

Figure 4 reflects survey errors. A discussion of these errors is presented in Section 5.0. Section 4.0 presents numerical analyses based on the original data.

#### 4.0 DATA ANALYSIS

The settlement history data for the exterior wall settlement markers shown in Figure 2 are listed in Table 1. The data were analyzed and are presented in this section. The analyses include:

- a. Difference of settlements between two consecutive measurement dates
- b. Relative displacement along north and south walls
- c. Angle variation analysis

00072090

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

d. Warpage analysis

These analyses are discussed as follows.

4.1 DIFFERENCE OF SETTLEMENTS BETWEEN TWO CONSECUTIVE MEASUREMENT DATES

The values of  $S_i - S_j$  for all marker points on the exterior wall of the DGB as shown in Figure 2 are listed in Table 2. The negative values indicate that either the structure moved up or a potential measurement error existed. Because the structure cannot easily move up on its own weight, it is likely that negative values indicate a measurement error.

4.2 RELATIVE DISPLACEMENTS ALONG NORTH AND SOUTH WALLS

To establish a datum point, the displacements of the exterior corners are normalized to zero. The relative displacements of the interior points  $D_2$ ,  $D_3$ , and  $D_4$  as defined in Figure 1 are calculated and are listed in Table 3.

If the measurement was 100% accurate, these relative displacements should be positive, negative, or zero for differential settlement.

- a. If the relative displacement is positive or negative, the structure is undergoing differential settlement and the curvature increases or decreases.
- b. If the relative displacement is zero, the structure remains at the previous curvature.

Table 3 shows that data varies irregularly. It cannot be concluded from these data that the structure developed differential settlement in the period considered.

4.3 ANGLE VARIATION ANALYSIS

Figure 5 illustrates the method used to calculate the term called "angle." The variations, with respect to time, of "angles" between markers 1-22-21 and 21-20-3 are listed in Tables 4a and 4b.

If the measurement is 100% accurate, the angle will continue increasing or decreasing through the survey period for differential settlement or will remain constant for rigid body motion.

Observations of the angle are listed below:

00072090

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

Angle 1-22-21	from 11/24/78 to 03/22/79	relatively constant in the range of 179.941 degrees
	from 03/30/79 to 09/06/79	relatively constant in the range of 179.864 degrees
	from 09/14/79 to 08/28/80	relatively constant in the range of 179.934 degrees

Angle 21-20-3 has a pattern identical to that of Angle 1-22-21.

Based on the difference between successive reading dates, the change in angle between marker points on the exterior south wall is small with a random change in algebraic sign.

Therefore, these results show that the structure developed rigid body motion in the periods during which settlements were measured and the random change in algebraic sign of the change in angle is due to the accuracy of the measurements being taken.

#### 4.4 WARPAGE ANALYSIS

A review of the settlement data for the settlement markers on the four corners of the DGB indicates the amount of warpage the structure has attained. The method of analysis for warpage is illustrated in Figure 6. Results of this analysis are listed in Table 5.

As shown in Table 5, the warpage across the structure ( $\Sigma$ DIFD) is very small and varies with time between positive and negative values. It can be concluded from this analysis that the survey data is not accurate enough to prove that the structure has developed differential settlement (or warpage) across the corners.

#### 5.0 DISCUSSIONS OF THE SURVEY DATA

The numerical data analyses presented in Section 4.0 reveal that the reported settlement data do not identify a consistent pattern of differential settlement in the overall period considered. This warrants a further consideration of the accuracy of survey data.

There are two types of errors in the original data (see Figure 4). The first type is the erratic error that occurred in a particular marker elevation reading on a particular date. This type of error occurred most often in the period between December 15, 1978, and March 30, 1979. Considering the consistency of relative elevation of the north wall in the periods of December 2, 1978, to December 8, 1978, and January 26,

00072090

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

1979, to February 16, 1979, the inaccuracy of readings on markers DG-27 and 28 in the period from December 15, 1978, to January 19, 1979, is quite obvious. Readings from marker DG-24 on January 19, 1979, is 0.012 ft lower than the average value of January 12 and January 26, 1979. Erroneous readings are also observed on May 3, 1979, for markers DG-1, 3, 22, 24, 25, and 28. These erratic errors are clearly reflected on the settlement-time curves shown in Figure 4.

The second type of error is the systematic error that is carried over in the period from March 30, 1979, to September 6, 1979. Inspecting the relative elevation in the periods after March 30, 1979, shows that a systematic inconsistency existed between September 6, 1979, and September 14, 1979.

The systematic error during the period from March 30, 1979, to September 6, 1979, had been studied by Mr. Peter A. Lenzini of the University of Illinois (Reference 2).

Both survey data records and Mr. Lenzini's report show that on September 14, 1979, the discrepancy between temporary and permanent markers is as high as 0.017 ft at marker DG-27, 0.016 ft at marker DG-3, 0.015 ft at marker DG-28, etc. Mr. Lenzini corrected the original data and calculated the settlement relative to January 26, 1979.

As discussed in Section 3.0, the procedure to obtain and calculate the original settlement data in the period between March 24, 1979, and September 14, 1979, is to determine the base elevation for the temporary markers by adding the settlement of permanent markers to the corresponding temporary marker elevation. The base elevation is then used to calculate the settlements for the subsequent dates. This procedures indicates that the erratic error during the time to establish a base elevation can be carried through the period of temporary marker survey. Therefore, the erratic error becomes a systematic error.

Because the error may be about 0.02 ft, settlement-time curves in Figure 4 are smoothed and illustrated in Figure 7.

Based on Figure 7, the differential settlements developed in the south wall are plotted in Figure 8. It is found that as long as the comparisons are made within the period of the same measurement location, deflection is a rigid body motion (Figures 8a and 8b). When settlements of different measurement locations are compared, a higher curvature was observed (Figure 8c). This indicates the structure was developing rigid body motion and differential settlement was due to a survey error. This observation agrees with the angle variation analysis, as indicated in Section 4.3.

00072030

As indicated in Section 2.0, the absolute settlement ( $S_n$ ) has a higher accuracy than the relative settlement ( $D_n$ ). To utilize the available data, the soil stiffness derived from  $S_n$  may be used for structural analysis. This approach can minimize the effect due to survey error.

#### 6.0 CONCLUSIONS

Based on this study, the following conclusions concerning the Midland DGB settlement data are made.

- 6.1 The survey data varies up to 0.02 (erratic error) ft.
- 6.2 The existing data does not indicate a consistent pattern of differential settlement. This is proven in the differential displacement analysis, angle variation analysis, and warpage analysis.
- 6.3 Systematic errors are contained in the survey data.
- 6.4 By smoothing the settlement-time curves to correct the erratic error, the data reflect that the structure was developing rigid body motion in the period during which settlement was measured at the same locations.
- 6.5 Differential settlement is derived only when data obtained at different elevations were compared. This is due to systematic errors. Therefore, it is concluded that the structure is under rigid body motion during the period considered in this study.
- 6.6 The total settlement data has a higher degree of accuracy than the relative differential settlement values. Therefore, the soil stiffness derived from the total settlement data may be used for the structural analysis.

Because of the errors in the differential settlement values, these values should not be imposed on the structure for structural analysis.

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

00072090

REFERENCES

1. Bechtel Power Corporation, Midland Project Drawings SK-C-628 and SK-C-619, Diesel Generator Building Settlement Data
2. Peter A. Lenzini, Review of Data

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

00072090

TABLE 1  
**EXTERIOR WALL SETTLEMENT DATA\* (Ft)**

Date	1	3	20	21	22	23	24	25	26	27	28	29
781124	0.215	0.282	0.217	0.183	0.184	0.166	0.146	0.146	0.163	0.188	0.211	0.240
781202	0.217	0.295	0.238	0.195	0.188	0.167	0.146	0.155	0.178	0.202	0.226	0.249
781208	0.216	0.299	0.231	0.194	0.188	0.170	0.152	0.158	0.181	0.206	0.232	0.255
781215	0.218	0.318	0.243	0.196	0.188	0.168	0.153	0.166	0.190	0.206	0.259	0.283
781222	0.228	0.342	0.264	0.213	0.200	0.177	0.164	0.168	0.190	0.206	0.263	0.292
781229	0.229	0.350	0.272	0.219	0.204	0.177	0.159	0.168	0.190	0.206	0.264	0.299
790105	0.234	0.350	0.280	0.229	0.211	0.188	0.163	0.176	0.203	0.236	0.264	0.299
790112	0.231	0.349	0.280	0.231	0.214	0.181	0.160	0.180	0.209	0.236	0.267	0.301
790119	0.238	0.354	0.287	0.234	0.218	0.192	0.174	0.180	0.209	0.236	0.271	0.305
790126	0.234	0.356	0.280	0.227	0.210	0.188	0.164	0.180	0.209	0.236	0.261	0.303
790201	0.237	0.357	0.284	0.236	0.214	0.192	0.168	0.189	0.220	0.250	0.272	0.306
790216	0.259	0.378	0.314	0.265	0.245	0.210	0.179	0.205	0.239	0.266	0.288	0.329
790223	0.277	0.398	0.335	0.282	0.261	0.216	0.181	0.201	0.232	0.267	0.289	0.340
790302	0.280	0.428	0.366	0.305	0.274	0.225	0.182	0.201	0.232	0.267	0.312	0.364
790309	0.322	0.451	0.401	0.338	0.315	0.251	0.207	0.224	0.256	0.297	0.324	0.383
790315	0.344	0.466	0.407	0.346	0.324	0.260	0.213	0.231	0.263	0.303	0.328	0.397
790322	0.354	0.476	0.411	0.352	0.327	0.266	0.215	0.235	0.271	0.312	0.340	0.401
790330	0.349	0.495	0.425	0.369	0.337	0.270	0.227	0.255	0.305	0.342	0.371	0.426
790406	0.400	0.536	0.475	0.421	0.380	0.303	0.242	0.274	0.321	0.359	0.384	0.453
790413	0.439	0.570	0.514	0.452	0.413	0.332	0.260	0.281	0.331	0.369	0.397	0.477
790420	0.442	0.577	0.522	0.458	0.420	0.336	0.260	0.284	0.330	0.372	0.398	0.479
790426	0.454	0.583	0.526	0.467	0.424	0.345	0.268	0.289	0.335	0.375	0.404	0.486
790503	0.449	0.583	0.528	0.465	0.423	0.341	0.266	0.283	0.334	0.374	0.402	0.485
790511	0.464	0.594	0.536	0.470	0.435	0.352	0.277	0.294	0.337	0.379	0.409	0.492
790518	0.464	0.600	0.543	0.479	0.439	0.354	0.274	0.296	0.344	0.385	0.412	0.496
790525	0.464	0.598	0.541	0.477	0.439	0.352	0.274	0.293	0.340	0.380	0.409	0.494
790531	0.464	0.598	0.543	0.478	0.439	0.350	0.273	0.294	0.340	0.381	0.410	0.496
790605	0.467	0.601	0.542	0.480	0.443	0.353	0.275	0.295	0.344	0.380	0.412	0.496
790607	0.471	0.603	0.546	0.481	0.443	0.357	0.279	0.297	0.341	0.383	0.413	0.499
790615	0.473	0.606	0.549	0.485	0.446	0.359	0.281	0.297	0.345	0.386	0.416	0.503
790622	0.477	0.612	0.555	0.487	0.447	0.361	0.283	0.300	0.347	0.389	0.420	0.507
790629	0.477	0.612	0.556	0.489	0.447	0.360	0.280	0.299	0.350	0.389	0.418	0.504
790706	0.478	0.612	0.557	0.491	0.451	0.361	0.281	0.300	0.349	0.389	0.419	0.506
790713	0.482	0.615	0.557	0.490	0.453	0.364	0.287	0.302	0.346	0.388	0.420	0.507
790720	0.482	0.616	0.560	0.492	0.454	0.365	0.285	0.302	0.348	0.389	0.419	0.508
790727	0.485	0.618	0.561	0.493	0.454	0.366	0.286	0.302	0.351	0.392	0.422	0.510
790803	0.484	0.620	0.561	0.495	0.454	0.366	0.288	0.302	0.351	0.391	0.423	0.510
790810	0.486	0.620	0.564	0.494	0.457	0.369	0.288	0.304	0.352	0.392	0.424	0.512
790817	0.479	0.615	0.559	0.491	0.453	0.364	0.285	0.306	0.352	0.394	0.423	0.511
790824	0.471	0.608	0.552	0.487	0.444	0.357	0.277	0.295	0.347	0.387	0.416	0.504
790831	0.466	0.605	0.546	0.480	0.439	0.351	0.273	0.291	0.341	0.382	0.410	0.499
790906	0.462	0.602	0.546	0.478	0.439	0.349	0.269	0.289	0.341	0.380	0.410	0.497
790914	0.464	0.616	0.544	0.477	0.448	0.358	0.271	0.298	0.330	0.363	0.393	0.493
790921	0.464	0.615	0.544	0.477	0.450	0.360	0.271	0.297	0.333	0.363	0.392	0.492
790928	0.464	0.616	0.544	0.477	0.450	0.359	0.271	0.295	0.334	0.362	0.392	0.492
800206	0.458	0.616	0.536	0.467	0.441	0.348	0.265	0.291	0.326	0.365	0.395	0.491
800627	0.459	0.615	0.538	0.469	0.441	0.349	0.264	0.289	0.323	0.361	0.422	0.487
800822	0.456	0.612	0.536	0.468	0.440	0.348	0.265	0.288	0.323	0.362	0.423	0.490
800828	0.456	0.612	0.537	0.468	0.440	0.350	0.269	0.288	0.326	0.364	0.424	0.491

\*See Figure 2 for location of settlement markers.

Midland Plant Units 1 and 2  
 Diesel Generator Building  
 Settlement Data Analysis

00072090

TABLE 2

DIFFERENCE OF SETTLEMENT BETWEEN  
 TWO CONSECUTIVE MEASUREMENT DATES OF  
 MARKERS FOR EXTERIOR WALL\* (ft)

Date 1	Date 2	1	3	20	21	22	23	24	25	26	27	28	29
781124	781202	.002	.013	.021	.012	.004	.001	.000	.009	.015	.014	.015	.009
781202	781208	-.001	.004	-.007	-.001	.000	.003	.006	.003	.003	.004	.006	.006
781208	781215	.002	.019	.012	.002	.000	-.002	.001	.008	.009	.000	.027	.028
781215	781222	.010	.024	.021	.017	.012	.009	.011	.002	.000	.000	.004	.009
781222	781229	.001	.008	.008	.006	.004	.000	-.005	.000	.000	.000	.001	.007
781229	790105	.005	.000	.008	.010	.007	.011	.004	.008	.013	.030	.000	.000
790105	790112	-.003	-.001	.000	.002	.003	-.007	-.003	.004	.006	.000	.003	.002
790112	790119	.007	.005	.007	.003	.004	.011	.014	.000	.000	.000	.004	.004
790119	790126	-.004	.002	-.007	-.007	-.008	-.004	-.010	.000	.000	.000	-.010	-.002
790126	790201	.003	.001	.004	.009	.004	.004	.004	.009	.011	.014	.011	.003
790201	790216	.022	.021	.030	.029	.031	.018	.011	.016	.019	.016	.016	.023
790216	790223	.018	.020	.021	.017	.018	.006	.002	-.004	-.007	.001	.001	.011
790223	790302	.003	.030	.031	.023	.013	.009	.001	.000	.000	.000	.023	.024
790302	790309	.042	.023	.035	.033	.041	.026	.025	.023	.024	.030	.012	.019
790309	790315	.022	.015	.006	.008	.009	.009	.006	.007	.007	.006	.004	.014
790315	790322	.010	.010	.004	.006	.003	.006	.002	.004	.008	.009	.012	.004
790322	790330	-.005	.017	.014	.017	.010	.004	.012	.020	.034	.030	.031	.025
790330	790406	.051	.041	.050	.052	.043	.033	.015	.019	.016	.017	.013	.027
790406	790413	.039	.034	.039	.031	.033	.029	.018	.007	.010	.010	.013	.024
790413	790420	.003	.007	.003	.006	.007	.004	.000	.003	-.001	.003	.001	.002
790420	790426	.012	.006	.004	.009	.004	.009	.008	.005	.005	.003	.006	.007
790426	790503	-.005	.000	.002	-.002	-.001	-.004	-.002	-.006	-.001	-.001	-.002	-.001
790503	790511	.015	.011	.008	.005	.012	.011	.011	.011	.003	.005	.007	.007
790511	790518	.000	.006	.007	.009	.004	.002	-.003	.002	.007	.006	.003	.004
790518	790525	.000	-.002	-.002	-.002	.000	-.002	.000	-.003	-.004	-.005	-.003	-.002
790525	790531	.000	.000	.002	.001	.000	-.002	-.001	.001	.000	.001	.001	.002
790531	790605	.003	.003	-.001	-.002	.004	.003	.002	.001	.004	-.001	.002	.000
790605	790607	.004	.002	.004	.001	.000	.004	.004	.002	-.003	.003	.001	.003
790607	790615	.002	.003	.003	.004	.003	.002	.002	.000	.004	.003	.003	.004
790615	790622	.004	.006	.006	.002	.001	.002	.002	.003	.002	.003	.004	.004
790622	790629	.000	.000	.001	.002	.000	-.001	-.003	-.001	.003	.000	-.002	-.003
790629	790706	.001	.000	.001	.002	.004	.001	.001	.001	-.001	.000	.001	.002
790706	790713	.004	.003	.000	-.001	.002	.003	.006	.002	-.003	-.001	.001	.001
790713	790720	.000	.001	.003	.002	.001	.001	-.002	.000	.002	.001	-.001	.001
790720	790727	.003	.002	.001	.001	.000	.001	.001	.000	.003	.003	.003	.002
790727	790803	-.001	.002	.000	.002	.000	.000	.002	.000	.000	-.001	.001	.000
790803	790810	.002	.000	.003	-.001	.003	.003	.000	.002	.001	.001	.001	.002
790810	790817	-.007	-.005	-.005	-.003	-.004	-.005	-.003	.002	.000	.002	-.001	-.001
790817	790824	-.008	-.007	-.007	-.004	-.009	-.007	-.008	-.011	-.005	-.007	-.007	-.007
790824	790831	-.005	-.003	-.006	-.007	-.005	-.006	-.004	-.004	-.006	-.005	-.006	-.005
790831	790906	-.004	-.003	.000	-.002	.000	-.002	-.004	-.002	.000	-.002	.000	-.002
790906	790914	.002	.014	-.002	-.001	.009	.009	.002	.009	-.011	-.017	-.017	-.004
790914	790921	.000	-.001	.000	.000	.002	.002	.000	-.001	.003	.000	-.011	-.001
790921	790928	.000	.001	.000	.000	-.001	.000	-.002	.001	-.001	.000	.000	.000
790928	800206	-.006	.000	-.008	-.010	-.009	-.011	-.006	-.004	-.008	.003	.003	-.001
800206	800627	.001	-.001	.002	.002	.000	.001	-.001	-.002	-.003	-.004	.027	-.004
800627	800822	-.003	-.003	-.002	-.001	-.001	-.001	-.001	-.001	.000	.001	.001	.003
800822	800828	.000	.000	.001	.000	.000	.002	.004	.000	.003	.002	.001	.001

\*See Figure 2 for location of settlement markers.

Midland Plant Units 1 and 2  
 Diesel Generator Building  
 Settlement Data Analysis

00072090

TABLE 3a

RELATIVE DISPLACEMENT ALONG NORTH WALL  
 FOR SETTLEMENT MARKERS\* (Ft)

From Date	To Date	24	25	26	27	28
781124	781202	.000	-.005	-.007	-.003	.000
781202	781208	.000	.003	.003	.002	.000
781208	781215	.000	-.000	.005	.020	.000
781215	781222	.000	.007	.008	.006	.000
781222	781229	.000	-.004	-.002	-.001	.000
781229	790105	.000	-.005	-.011	-.029	.000
790105	790112	.000	-.005	-.006	.002	.000
790112	790119	.000	.012	.009	.007	.000
790119	790126	.000	-.010	-.010	-.010	.000
790126	790201	.000	-.003	-.004	-.005	.000
790201	790216	.000	-.004	-.005	-.001	.000
790216	790223	.000	.006	.009	.000	.000
790223	790302	.000	.006	.012	.017	.000
790302	790309	.000	-.001	-.005	-.015	.000
790309	790315	.000	-.002	-.002	-.002	.000
790315	790322	.000	.001	-.001	.000	.000
790322	790330	.000	-.003	-.012	-.004	.000
790330	790406	.000	-.005	-.002	-.004	.000
790406	790413	.000	.010	.005	.004	.000
790413	790420	.000	-.003	.002	-.002	.000
790420	790426	.000	.002	.002	.004	.000
790426	790503	.000	.004	-.001	-.001	.000
790503	790511	.000	-.001	.006	.003	.000
790511	790518	.000	-.003	-.007	-.005	.000
790518	790525	.000	.002	.003	.003	.000
790525	790531	.000	-.002	.000	-.001	.000
790531	790605	.000	.001	-.002	.003	.000
790605	790607	.000	.001	.006	-.001	.000
790607	790615	.000	.002	-.001	-.000	.000
790615	790622	.000	-.001	.001	.001	.000
790622	790629	.000	-.002	-.006	-.002	.000
790629	790706	.000	.000	.002	.001	.000
790706	790713	.000	.003	.007	.003	.000
790713	790720	.000	-.002	-.004	-.002	.000
790720	790727	.000	.001	-.001	-.001	.000
790727	790803	.000	.002	.002	.002	.000
790803	790810	.000	-.002	-.001	-.000	.000
790810	790817	.000	-.004	-.002	-.003	.000
790817	790824	.000	.003	-.002	-.000	.000
790824	790831	.000	-.001	.001	-.001	.000
790831	790906	.000	-.001	-.002	.001	.000
790906	790914	.000	-.012	.003	.005	.000
790914	790921	.000	.001	-.004	-.001	.000
790921	790928	.000	.002	-.001	.001	.000
790928	800206	.000	.000	.006	-.002	.000
800206	800627	.000	.008	.016	.024	.000
800627	800822	.000	.002	.001	.000	.000
800822	800828	.000	.003	-.001	-.000	.000

\*Settlement marker locations are shown in Figure 2.

Midland Plant Units 1 and 2  
 Diesel Generator Building  
 Settlement Data Analysis

00072090

TABLE 3b

RELATIVE DISPLACEMENT ALONG SOUTH WALL  
 FOR SETTLEMENT MARKERS\* (Ft)

From Date	To Date	1	22	21	20	3
781124	781202	.000	.001	-.004	-.011	.000
781202	781208	.000	.000	.002	.010	.000
781208	781215	.000	.006	.009	.003	.000
781215	781222	.000	.001	.000	-.000	.000
781222	781229	.000	-.001	-.002	-.002	.000
781229	790105	.000	-.003	-.008	-.007	.000
790105	790112	.000	-.005	-.004	-.002	.000
790112	790119	.000	.002	.003	-.002	.000
790119	790126	.000	.005	.006	.007	.000
790126	790201	.000	-.001	-.007	-.002	.000
790201	790216	.000	-.009	-.008	-.009	.000
790216	790223	.000	.002	.002	-.002	.000
790223	790302	.000	-.003	-.006	-.008	.000
790302	790309	.000	-.004	-.000	-.007	.000
790309	790315	.000	.011	.010	.011	.000
790315	790322	.000	.007	.004	-.006	.000
790322	790330	.000	-.009	-.010	-.001	.000
790330	790406	.000	.006	-.006	-.007	.000
790406	790413	.000	.005	.006	-.004	.000
790413	790420	.000	-.003	-.001	-.002	.000
790420	790426	.000	.007	.000	.003	.000
790426	790503	.000	-.003	-.000	-.003	.000
790503	790511	.000	.002	.008	.004	.000
790511	790518	.000	-.002	-.006	-.002	.000
790518	790525	.000	-.001	.001	.000	.000
790525	790531	.000	.000	-.001	-.002	.000
790531	790605	.000	-.001	.001	.004	.000
790605	790607	.000	.003	.002	-.001	.000
790607	790615	.000	-.001	-.002	-.000	.000
790615	790622	.000	.003	.003	-.000	.000
790622	790629	.000	.000	-.002	-.001	.000
790629	790706	.000	-.003	-.002	-.001	.000
790706	790713	.000	.002	.005	.003	.000
790713	790720	.000	-.001	-.002	-.002	.000
790720	790727	.000	.003	.001	.001	.000
790727	790803	.000	-.000	-.002	.001	.000
790803	790810	.000	-.001	.002	-.003	.000
790810	790817	.000	-.003	-.003	-.000	.000
790817	790824	.000	.001	-.003	-.000	.000
790824	790831	.000	.000	.003	.002	.000
790831	790906	.000	-.004	-.001	-.003	.000
790906	790914	.000	-.004	.009	.013	.000
790914	790921	.000	-.002	-.000	-.001	.000
790921	790928	.000	.000	.000	.001	.000
790928	800206	.000	.004	.007	.007	.000
800206	800627	.000	.001	-.002	-.003	.000
800627	800822	.000	-.002	-.002	-.001	.000
800822	800828	.000	.000	.000	-.001	.000

\*Settlement marker locations are shown in Figure 2.

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

00072090

TABLE 4a

ANGLE VARIATION FOR MARKERS 1-22-21 ALONG EXTERIOR SOUTH WALL

Settlement Data From Tbl 1						$\Delta$ Angle** (Deg)	
Date	1	22	21	Angle*(Deg)	Date i	Date j	
781124	.215	.184	.183	179.95467377	781124	781202	-.00884919
781202	.217	.188	.195	179.94582558	781202	781208	.00325775
781208	.216	.188	.194	179.94908333	781208	781215	-.00675774
781215	.218	.188	.196	179.94232559	781215	781222	-.00448990
781222	.228	.200	.213	179.93783569	781222	781229	.00159454
781229	.229	.204	.219	179.93943024	781229	790105	-.00159454
790105	.234	.211	.229	179.93783569	790105	790112	.01124763
790112	.231	.214	.231	179.94908333	790112	790119	-.00325775
790119	.238	.218	.234	179.94582558	790119	790126	-.00838280
790126	.234	.210	.227	179.93744278	790126	790201	-.00561142
790201	.237	.214	.236	179.93183136	790201	790216	.01725197
790216	.259	.245	.265	179.94908333	790216	790223	-.00459671
790223	.277	.261	.282	179.94448662	790223	790302	.00000000
790302	.280	.274	.305	179.94448662	790302	790309	.01018715
790309	.322	.315	.338	179.95467377	790309	790315	-.01800728
790315	.344	.324	.346	179.93666649	790315	790322	-.01517487
790322	.354	.327	.352	179.92149162	790322	790330	.01215744
790330	.349	.337	.369	179.93364706	790330	790406	-.02564049
790406	.400	.380	.421	179.90800858	790406	790413	-.00667191
790413	.439	.413	.452	179.90133667	790413	790420	.00801086
790420	.442	.420	.458	179.90934753	790420	790426	-.01971245
790426	.454	.424	.467	179.88963509	790426	790503	.00709915
790503	.449	.423	.465	179.89673424	790503	790511	.00635338
790511	.464	.435	.470	179.90308762	790511	790518	-.00150299
790518	.464	.439	.479	179.90158463	790518	790525	.00302867
790525	.464	.439	.477	179.90461349	790525	790531	-.00152588
790531	.464	.439	.478	179.90308762	790531	790605	.00492096
790605	.467	.443	.480	179.90800858	790605	790607	-.00765800
790607	.471	.443	.481	179.90035057	790607	790615	.00000000
790615	.473	.446	.485	179.90035057	790615	790622	-.00618935
790622	.477	.447	.487	179.89416122	790622	790629	-.00318718
790629	.477	.447	.489	179.89097404	790629	790706	.00767326
790706	.478	.451	.491	179.89864731	790706	790713	.00121307
790713	.482	.453	.490	179.89986028	790713	790720	.00049019
790720	.482	.454	.492	179.90035057	790720	790727	-.00618935
790727	.485	.454	.493	179.89416122	790727	790803	-.00160599
790803	.484	.454	.495	179.89255524	790803	790810	.00730515
790810	.486	.457	.494	179.89986038	790810	790817	.00322723
790817	.479	.453	.491	179.90308762	790817	790824	-.00915718
790824	.471	.444	.487	179.89393044	790824	790831	.00286360
790831	.466	.439	.480	179.89673424	790831	790906	.00969124
790906	.462	.439	.478	179.90642548	790906	790914	.02540588
790914	.464	.448	.477	179.93183136	790914	790921	.00600433
790921	.464	.450	.477	179.93783569	790921	790928	.00000000
790928	.464	.450	.477	179.93783569	790928	800206	-.00269508
800206	.458	.441	.467	179.93514061	800206	800627	-.00473022
800627	.459	.441	.469	179.93041039	800627	800822	.00323868
800822	.456	.440	.468	179.93364906	800822	800828	.00000000
800828	.456	.440	.468	179.93364906			

\*See Figure 5

\*\* $\Delta$ Angle is the angle increment between Date i and Date j.

Midland Plant Units 1 and 2  
Diesel Generator Building  
Settlement Data Analysis

00072090

TABLE 4b

ANGLE VARIATION FOR MARKERS 21-20-3 ALONG EXTERIOR SOUTH WALL.

Settlement Data From Tbl. 1						$\Delta$ Angle** (Deg)	
Date	21	20	3	Angle*(Deg)	Date i	Date j	
781124	.183	.217	.282	179.95256424	781124	781202	.02645493
781202	.195	.238	.295	179.97901917	781202	781208	-.02593613
781208	.194	.231	.299	179.95308304	781208	781215	.00495338
781215	.196	.243	.318	179.95803642	781215	781222	.00058746
781222	.213	.264	.342	179.95862389	781222	781229	.00306892
781229	.219	.272	.350	179.96169281	781229	790105	.00863457
790105	.229	.280	.350	179.97032738	790105	790112	-.00081253
790112	.231	.280	.349	179.96951485	790112	790119	.00836945
790119	.234	.287	.354	179.97788429	790119	790126	-.01285362
790126	.227	.280	.356	179.96503067	790126	790201	-.00269508
790201	.236	.284	.357	179.96233559	790201	790216	.01554871
790216	.265	.314	.378	179.97788429	790216	790223	.00647736
790223	.282	.335	.398	179.98436165	790223	790302	.00574875
790302	.305	.366	.428	179.99011040	790302	790309	.02967072
790309	.338	.401	.451	180.01978111	790309	790315	-.01978111
790315	.346	.407	.466	180.00000000	790315	790322	-.01211357
790322	.352	.411	.476	179.98788643	790322	790330	-.00886726
790330	.369	.425	.495	179.97901917	790330	790406	.01109123
790406	.421	.475	.536	179.99011040	790406	790413	.02200317
790413	.452	.514	.570	180.01211357	790413	790420	.00352478
790420	.458	.522	.577	180.01563835	790420	790426	-.01563835
790426	.467	.526	.583	180.00000000	790426	790503	.01211357
790503	.465	.528	.583	180.01211357	790503	790511	.00000000
790511	.470	.536	.594	180.01211357	790511	790518	-.00222397
790518	.479	.543	.600	180.00988960	790518	790525	.00000000
790525	.477	.541	.598	180.00988960	790525	790531	.00574875
790531	.478	.543	.598	180.01563835	790531	790605	-.00574875
790605	.480	.542	.601	180.00988960	790605	790607	.00574875
790607	.481	.546	.603	180.01563835	790607	790615	-.00574875
790615	.485	.549	.606	180.00988960	790615	790622	.00574875
790622	.487	.555	.612	180.01563835	790622	790629	.00000000
790629	.489	.556	.612	180.01563835	790629	790706	.00000000
790706	.491	.557	.612	180.01563835	790706	790713	-.00352478
790713	.490	.557	.615	180.01211357	790713	790720	.00501823
790720	.492	.560	.616	180.01713181	790720	790727	-.00149345
790727	.493	.561	.618	180.01563835	790727	790803	-.00574875
790803	.495	.561	.620	180.00988960	790803	790810	.01109123
790810	.494	.564	.620	180.02098083	790810	790817	-.00384903
790817	.491	.559	.615	180.01713181	790817	790824	-.00149345
790824	.487	.552	.608	180.01563835	790824	790831	-.00574875
790831	.480	.546	.605	180.00988960	790831	790906	.00724220
790905	.478	.546	.602	180.01713181	790906	790914	-.02702141
790914	.477	.544	.616	179.99011040	790914	790921	.00988960
790921	.477	.544	.615	180.00000000	790921	790928	-.00988960
790928	.477	.544	.616	179.99011040	790928	800206	-.00574875
800206	.467	.536	.616	179.98436165	800206	800627	.04352478
800627	.469	.538	.615	179.98788643	800627	800822	.00000000
800822	.468	.536	.612	179.98788643	800822	800828	.00222397
800828	.468	.537	.612	179.99011040			

\*See Figure 5

\*\* $\Delta$ Angle is the angle increment between Date i and Date j.

Midland Plant Units 1 and 2  
 Diesel Generator Building  
 Settlement Data Analysis

00072090

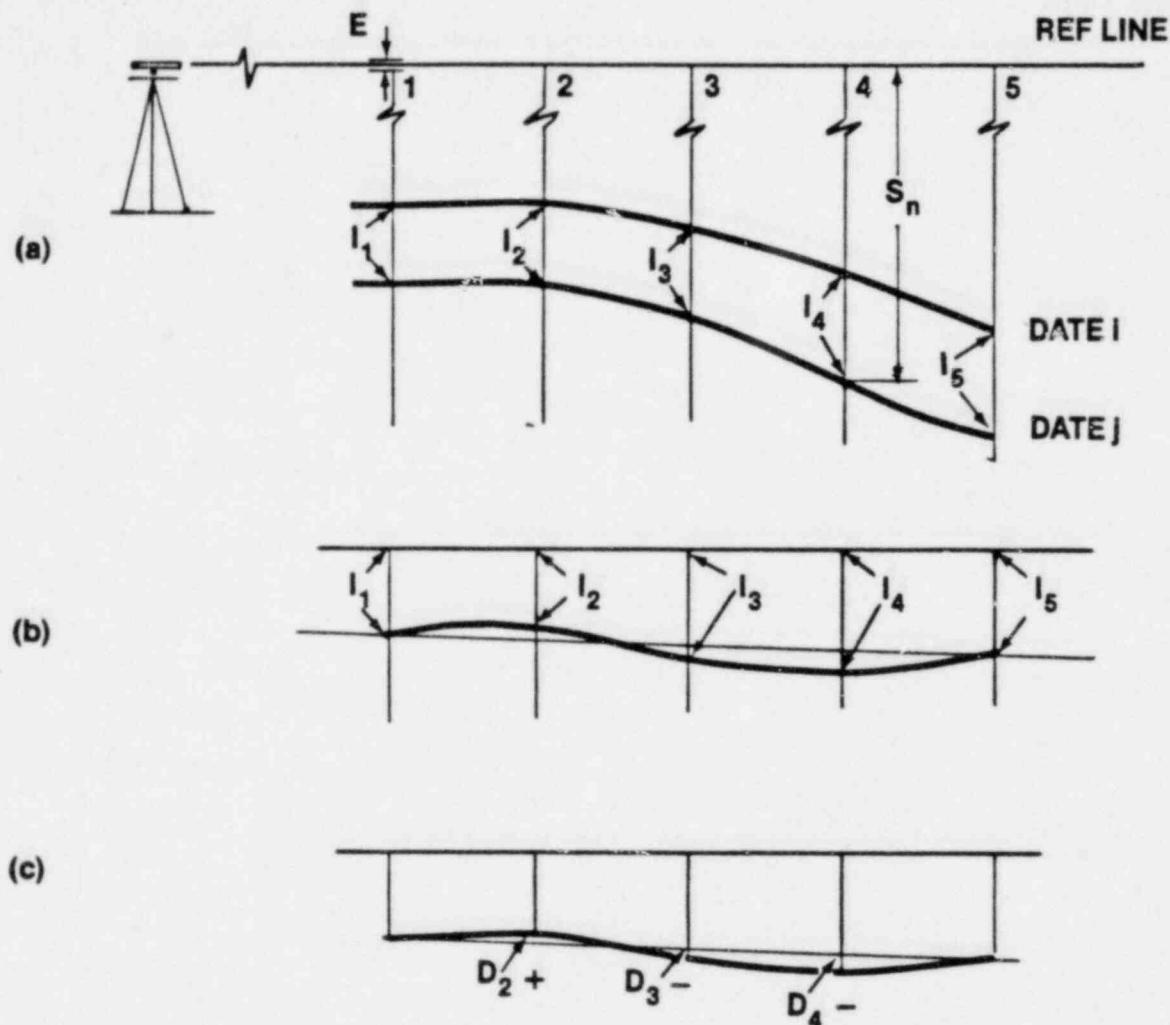
TABLE 5

RESULT OF WARPAGE ANALYSIS (Ft)

Date i	Date j	A	B	C	D	DP	DIFD	$\Sigma DIFD^*$
781124	781202	.00	.002	.013	.015	.011	.004	.004
781202	781208	.006	-.001	.004	.006	.011	-.005	-.001
781208	781215	.001	.002	.019	.027	.018	.009	.008
781215	781222	.011	.010	.024	.004	.025	-.021	-.013
781222	781229	-.005	.001	.008	.001	.002	-.001	-.014
781229	790105	.004	.005	.000	.000	-.001	.001	-.013
790105	790112	-.003	-.003	-.001	.003	-.001	.004	-.009
790112	790119	.014	.007	.005	.004	.012	.008	-.017
790119	790126	-.010	-.004	.002	-.010	-.004	-.006	-.023
790126	790201	.004	.003	.001	.011	.002	.009	-.014
790201	790216	.011	.022	.021	.016	.010	.006	-.008
790216	790223	.002	.018	.020	.001	.004	-.003	-.011
790223	790302	.001	.003	.030	.023	.028	-.005	-.016
790302	790309	.025	.042	.023	.012	.006	.006	-.010
790309	790315	.006	.022	.015	.004	-.001	.005	-.005
790315	790322	.002	.010	.010	.012	.002	.010	.005
790322	790330	.012	-.005	.019	.031	.036	-.005	.000
790330	790406	.015	.051	.041	.013	.005	.008	.008
790406	790413	.018	.039	.034	.013	.013	.000	.008
790413	790420	.000	.003	.007	.001	.004	-.003	.005
790420	790426	.008	.012	.006	.006	.002	.004	.009
790426	790503	-.002	-.005	.000	-.002	.003	-.005	.004
790503	790511	.011	.015	.011	.007	.007	.000	.004
790511	790518	-.003	.000	.006	.003	.003	.000	.004
790518	790525	.000	.000	-.002	-.003	-.002	-.001	.003
790525	790531	-.001	.000	.000	.001	-.001	.002	.005
790531	790605	.002	.003	.003	.002	.002	.000	.005
790605	790607	.004	.004	.002	.001	.002	-.001	.004
790607	790615	.002	.002	.003	.003	.003	.000	.004
790615	790622	.002	.004	.006	.004	.004	.000	.004
790622	790629	-.003	.000	.000	-.002	-.003	.001	.005
790629	790706	.001	.001	.000	.001	.000	.001	.006
790706	790713	.005	.004	.003	.001	.005	-.004	.002
790713	790720	-.002	.000	.001	-.001	-.001	.000	.002
790720	790727	.001	.003	.002	.003	.000	.003	.005
790727	790803	.002	-.001	.002	.001	.005	-.004	.001
790803	790810	.000	.002	.000	.001	-.002	.003	.004
790810	790817	-.003	-.007	-.005	-.001	-.001	.000	.004
790817	790824	-.008	-.008	-.007	-.007	-.007	.000	.004
790824	790831	-.004	-.005	-.003	-.006	-.002	-.004	.000
790831	790906	-.004	-.004	-.003	.000	-.003	.003	.003
790906	790914	.002	.002	.014	-.017	.014	-.031	-.028
790914	790921	.000	.000	-.001	-.001	-.001	.000	-.028
790921	790928	.000	.000	.001	.000	.001	-.001	-.029
790928	800206	-.006	-.006	.000	.003	.000	.003	-.026
800206	800627	-.001	.001	-.001	.027	-.003	.030	.004
800627	800822	.001	-.003	-.003	.001	.001	.000	.004
800822	800828	.004	.000	.000	.001	.004	-.003	.001

\* $\Sigma DIFD$  is the accumulated value of DIFD

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Where D<sub>2</sub>, D<sub>3</sub> and D<sub>4</sub> are determined from the following equations:

$$D_2 = [0.25(I_5 - I_1) + I_1] \cdot I_2$$

$$D_3 = [0.50(I_5 - I_1) + I_1] \cdot I_3$$

$$D_4 = [0.75(I_5 - I_1) + I_1] \cdot I_4$$

CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2

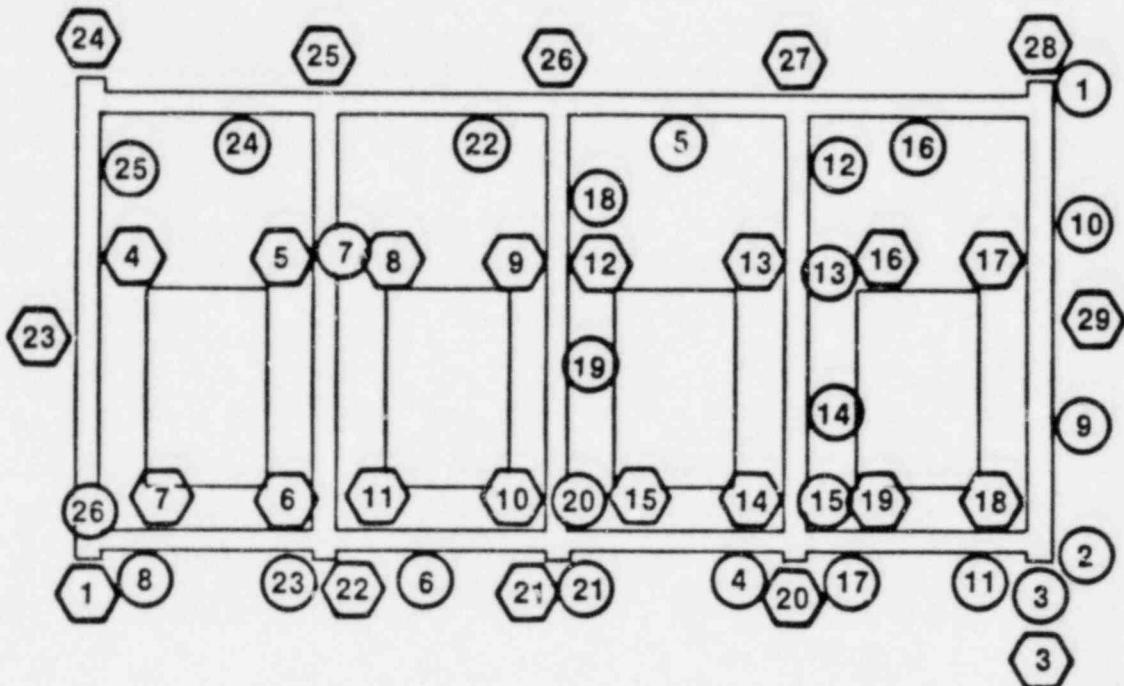
DERIVATION OF DIFFERENTIAL  
SETTLEMENT FROM SETTLEMENT  
DATA

FIGURE 1

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 MARKER  
EL 633'~ 638'

 SCRIBE

**DATA DATE**

7/10/78 - 11/24/78

**DATA DERIVATION**

Measured settlements on scribe, then converted to the equivalent settlement on marker location

12/2/78 - 3/22/79

Measured settlements directly from marker

3/30/79 - 9/14/79

Measured settlements from substituted marker inside the building on mezzanine floor el 663'

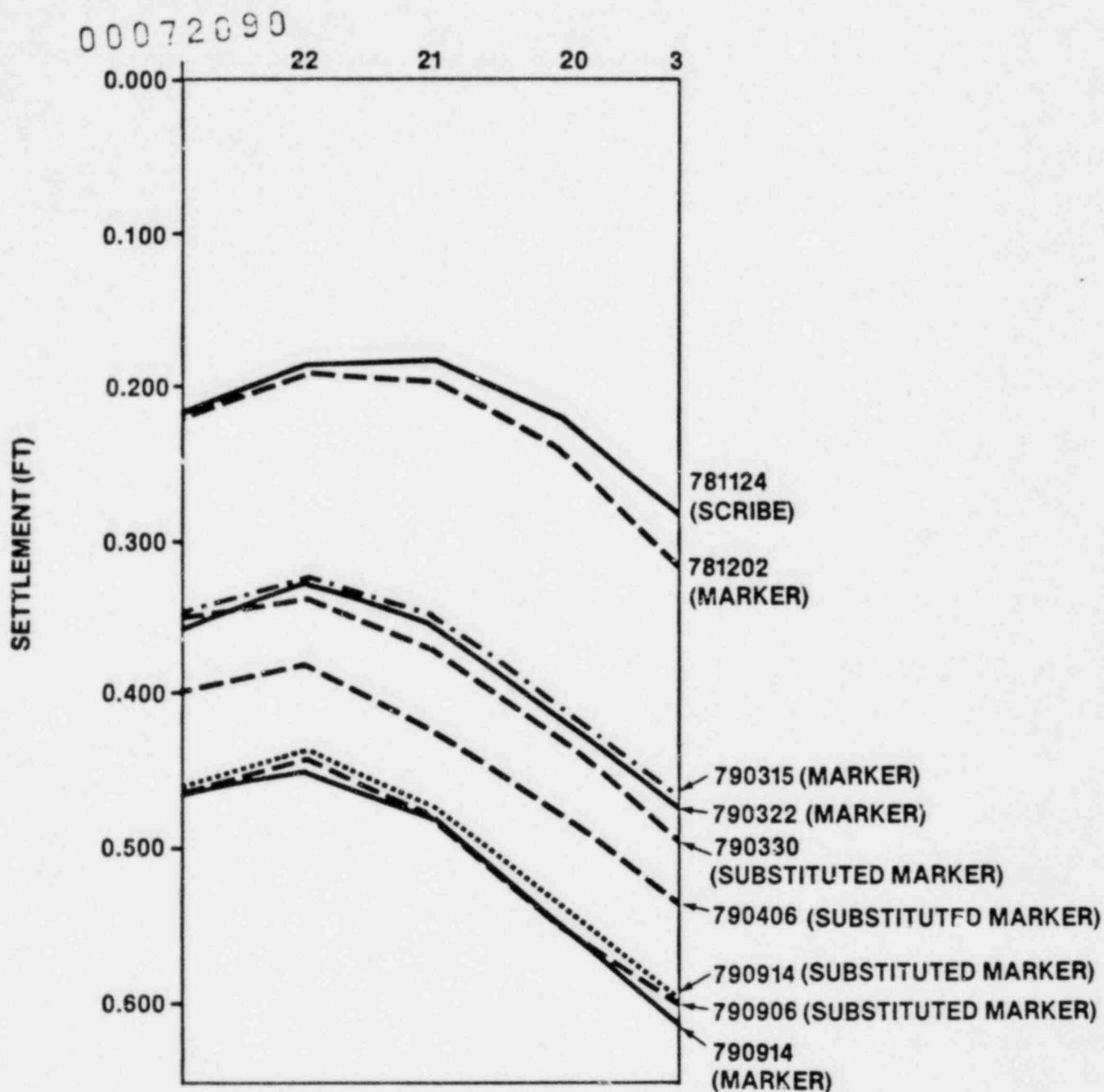
9/14/79 - Now

Measured settlements directly from marker

CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2

MEASUREMENT LOCATIONS

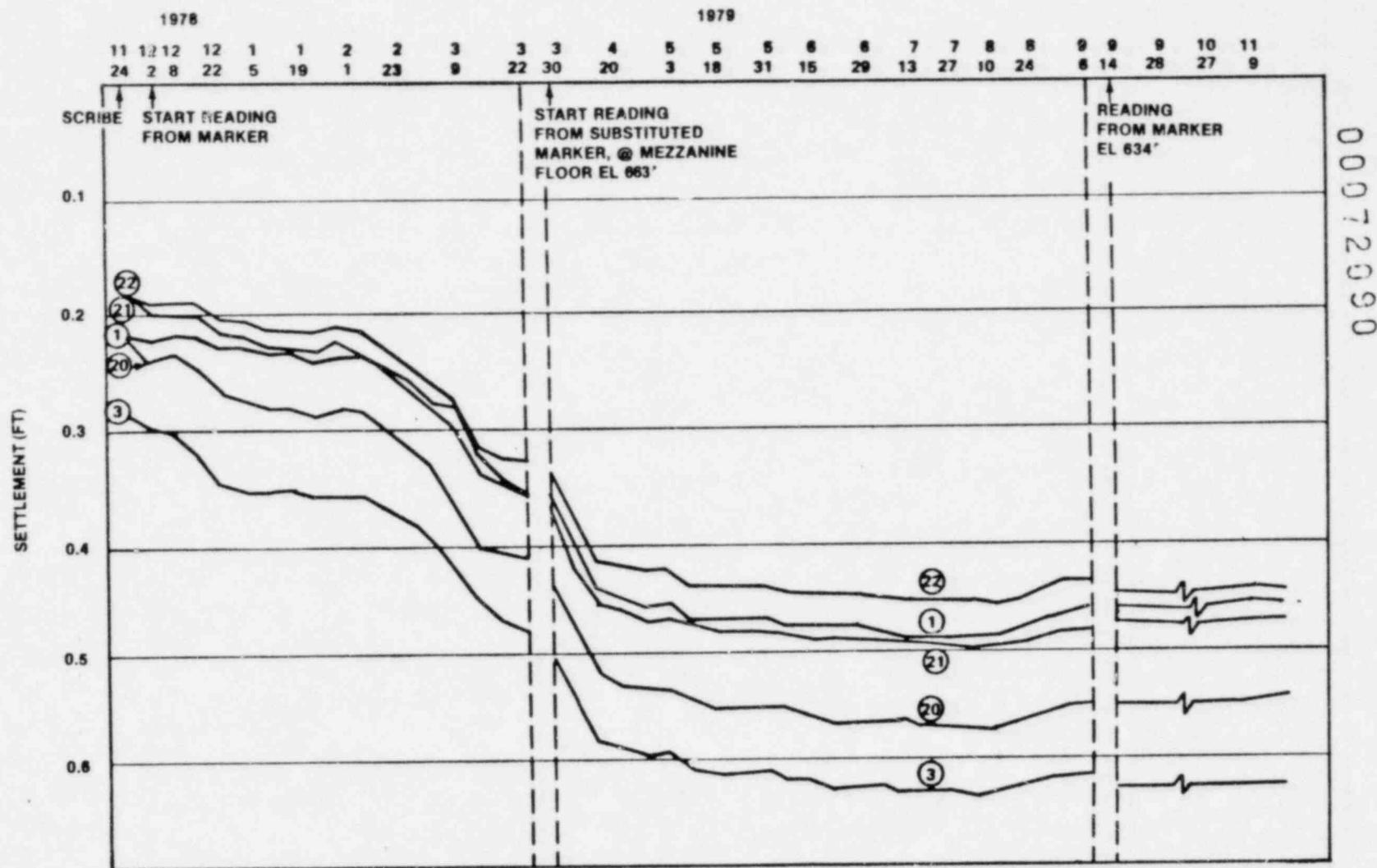
FIGURE 2



CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2

SETTLEMENT ALONG SOUTH  
WALL

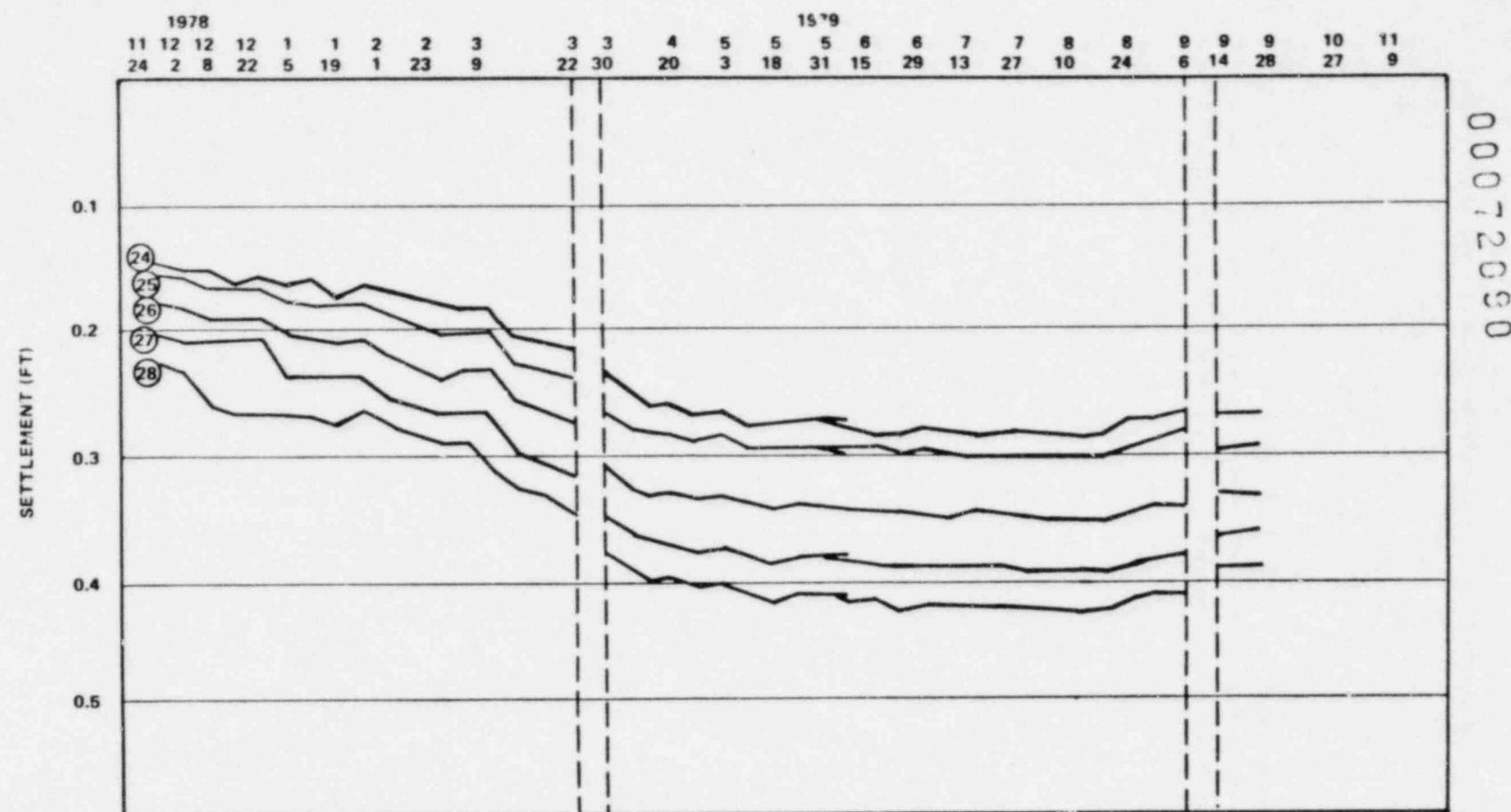
FIGURE 3



**CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2**

**SETTLEMENT-TIME CURVES  
FOR SOUTH WALL**

**FIGURE 4a**

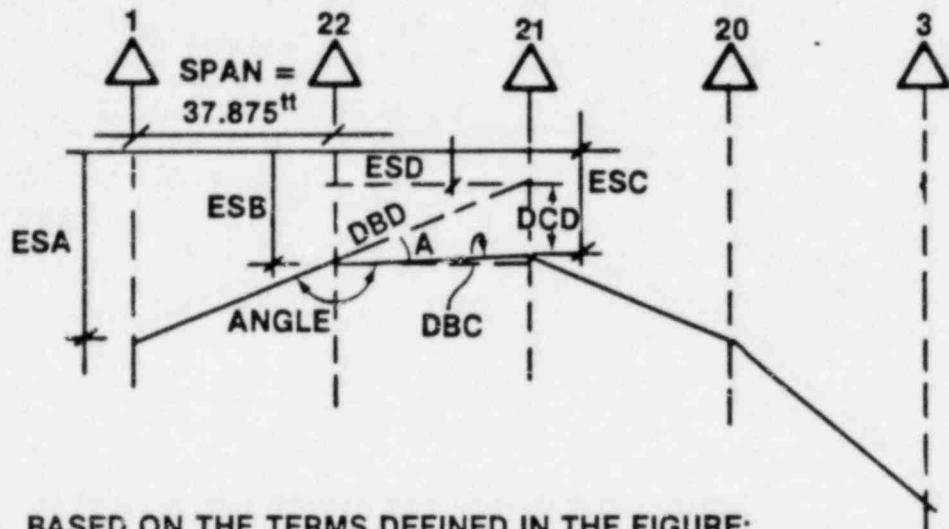


**CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2**

**SETTLEMENT-TIME CURVES  
FOR NORTH WALL**

**FIGURE 4b**

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BASED ON THE TERMS DEFINED IN THE FIGURE:

$$ESD = ESB + (ESB - ESA)$$

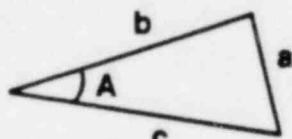
$$DBD = [(ESB - ESD)^2 + SPAN^2]^{1/2}$$

$$DBC = [(ESB - ESC)^2 + SPAN^2]^{1/2}$$

$$DCD = |ESC - ESD|$$

FROM THE TRIANGLE RELATIONSHIP

$$a^2 = b^2 + c^2 - 2bc \cos A$$



$$\therefore \cos A = (DBD^2 + DBC^2 - DCD^2) / (2DBC \times DBD)$$

$$A = \cos^{-1}(\cos A)$$

$$\therefore \text{IF } ESC \geq ESD, \text{ ANGLE} = 180^\circ - A$$

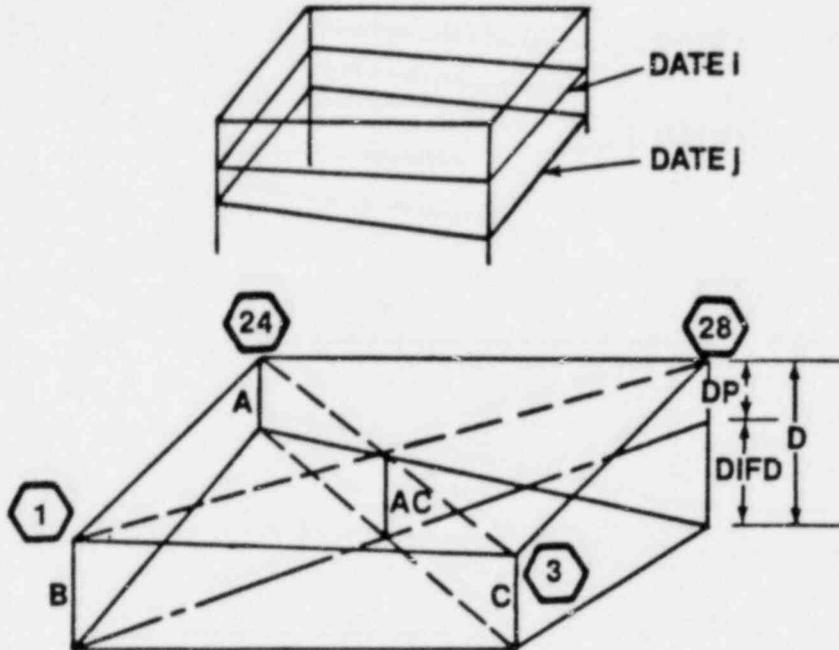
$$\text{IF } ESC \leq ESD, \text{ ANGLE} = 180^\circ + A$$

CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2

ANALYSIS OF ANGLE  
VARIATION

FIGURE 5

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$$AC = (A + C)/2$$
$$DP = AC + (AC - B)$$
$$DIFD^* = D - DP$$

IF SURVEY IS 100% ACCURATE,  
 $\Sigma$  DIFD\*\* SHOULD:

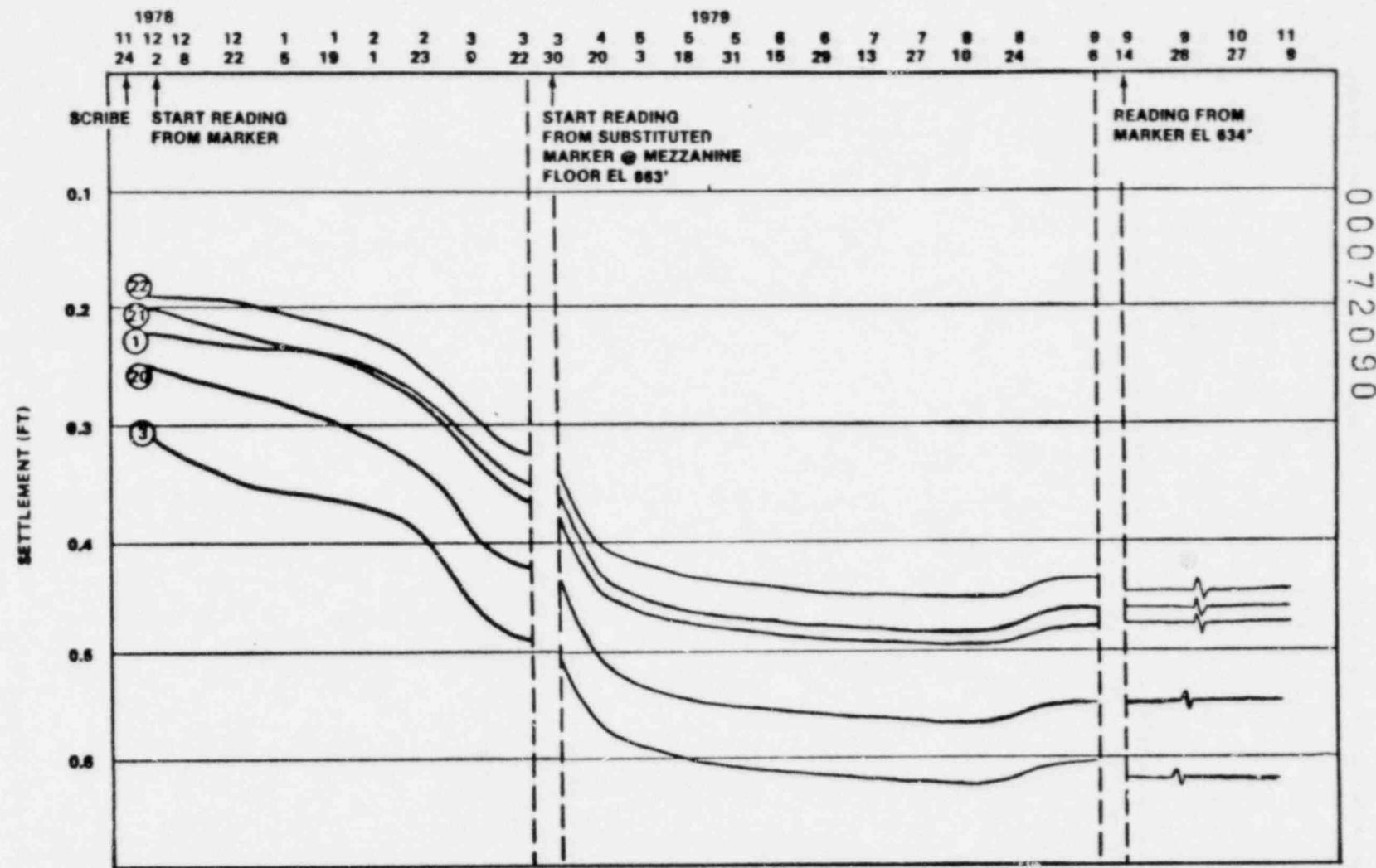
- (1) KEEP INCREASING  
(2) KEEP DECREASING }  
(3) KEEP CONSTANT - RIGID BODY MOTION      STRUCTURE UNDERGOING TWISTING

\*DIFD is the deviation of the corner from a plane which induces warping.  
\*\* $\Sigma$  DIFD is the accumulated value of DIFD.

CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2

WARPAGE ANALYSIS

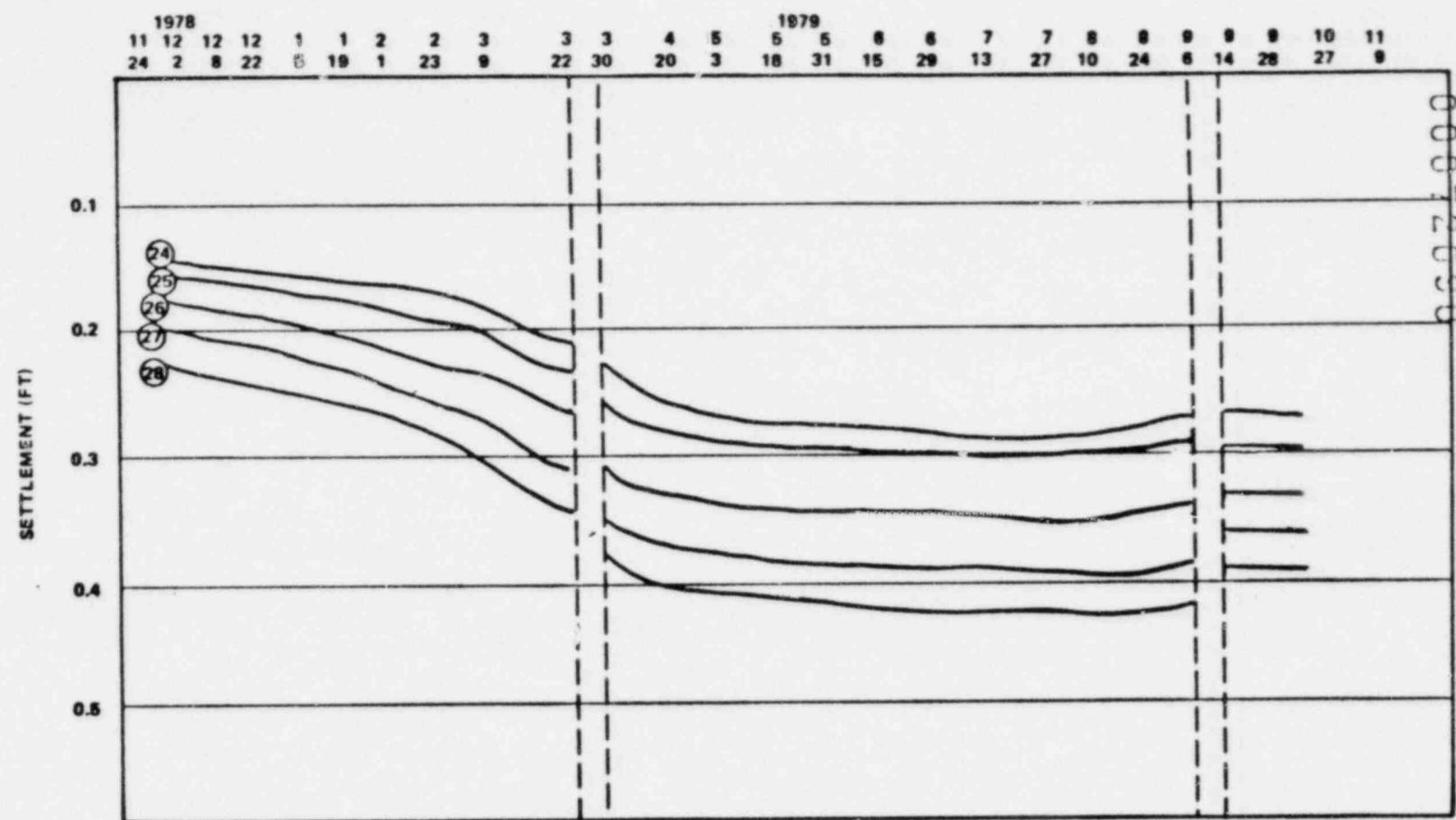
FIGURE 6



**CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2**

**MODIFIED SETTLEMENT · TIME  
CURVES FOR SOUTH WALL**

**FIGURE 7a**

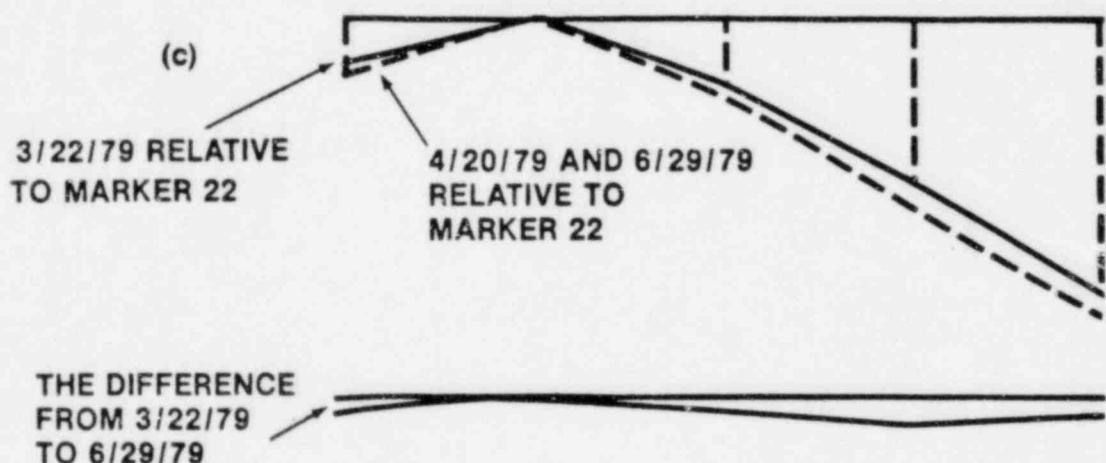
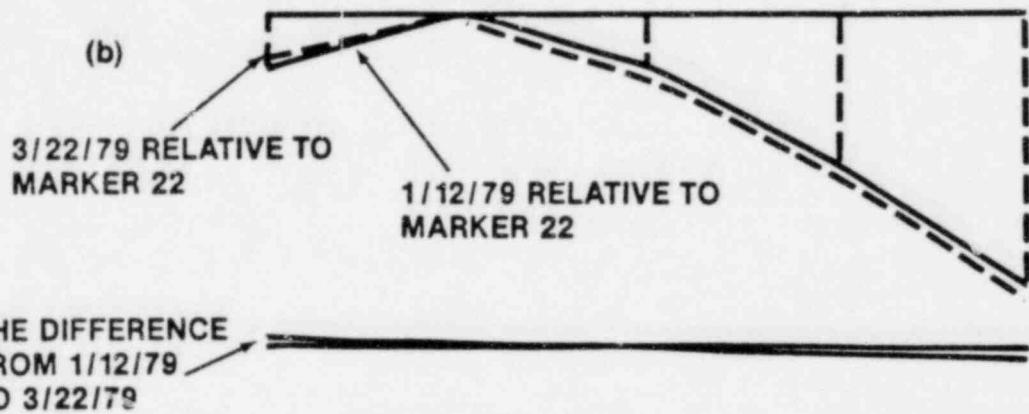
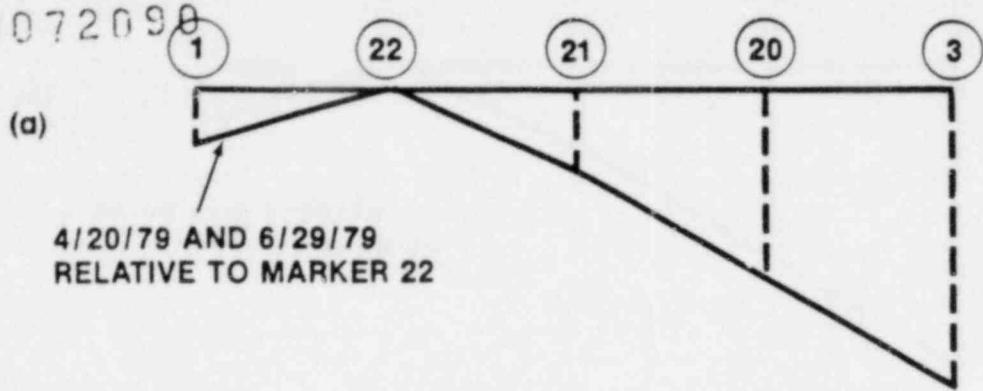


**CONSUMERS POWER COMPANY  
UNITS 1 AND 2**

**MODIFIED SETTLEMENT -  
TIME CURVES FOR NORTH  
WALL**

**FIGURE 7b**

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CONSUMERS POWER COMPANY  
MIDLAND UNITS 1 AND 2

DIFFERENTIAL SETTLEMENT  
DETERMINATION

FIGURE 8