Monitoring of Bridge Abutment Walls at SR 33 Over East State St. (Athens, OH)

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for the
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and the
U.S. Department of Transportation
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16. Abstract

District 10 personnel of Ohio DOT recently noticed signs of deterioration (such as backfill infiltration, wall cracking) on the bridge abutment walls existing under the S.R. 33 bridge over East State St. in Athens, Ohio. A research project was conducted by the ORITE researcher to monitor possible rotational movements of the abutment walls for two years, which included the period before, during, and after the rehabilitation work. A tilt-meter station was established in the lower section of each of the ten abutment wall panels. Additional measurements were also taken manually at the top of the abutment walls to detect wall movements. Both the tilt-meter and manual measurements were taken monthly from December 2004 to November 2006. Visual inspections were conducted at the project site a few times during the project. In addition, cone penetration test (CPT) sounding was performed in October 2004 to gather high-resolution subsurface data of the highway embankment soil behind the abutment walls existing on the north side of East State St.

The tilt-meter and manual measurements collected during the project showed that all the abutment walls remained stable during the two-year period. Initial visual inspection revealed that each panel had at least one vertical crack running through the wall. Subsequent visual inspection detected no new cracks on the abutment walls. The CPT sounding data indicated that wet and soft soil layers were present in some parts of the embankment fill. Based on the findings of the project, implementation plans were presented to address rehabilitation work and future monitoring issues.

17. Key Words **highway bridge, abutment wall, field performance, monitoring, instrumentation, rotation, CPT, visual inspection, rehabilitation.**	18. Distribution Statement **No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.**

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

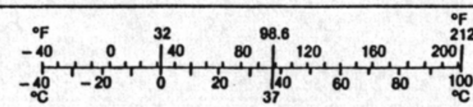
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

Monitoring of Bridge Abutment Walls at SR 33 Over East State St. (Athens, OH)

Final Report

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CHAPTER 1: INTRODUCTION

District 10 personnel of Ohio DOT recently noticed various signs of possible movements on the bridge abutment walls existing under the SR 33 bridge over E. State St. in Athens, Ohio. In this field project, a researcher from the Ohio Research Institute for Transportation and the Environment (ORITE), Ohio University, received a research contract to monitor the performance of the abutment walls at the above site for two years, relying on a modern sensor and visual inspection techniques. The ORITE researcher utilized a highly sensitive tilting measurement system (Digi-Tilt) developed by Slope Indicator (Seattle, WA) to record the rotational movements of each wall panel monthly. This system was used many times in previous research projects and proven to be reliable. In addition, CPT (Cone Penetration Test) sounding was performed at three locations on the Rt. 33 embankment. The CPT sensor readings (tip resistance, sleeve friction, and pore pressure) provided information on the type and quality of soil and the depth to water table that exist behind the north abutment wall. Throughout the duration of the project, ODOT personnel were informed frequently on the status of the abutment wall monitoring program. The data accumulated during the project assisted Ohio DOT District 10 Office to decide the type and extent of the rehabilitation measures appropriate for the site.

Figure 1.1: Project Site Area (SR 33 over E. State St. – Athens)

CHAPTER 2: METHODOLOGY

2.1 PROJECT TASKS

Activities under the research project consisted of the following seven tasks:

Task 1: Make a reconnaissance trip to the site. Examine the existing site conditions and start developing details of the project plan.

Task 2: Secure supplies.

Task 3: Perform CPT sounding of embankment soil fill behind Forward Abutment Walls, at locations recommended by ODOT District 10.

Task 4: Establish tilting monitoring stations on the abutment walls.

Task 5: Perform initial data collection (tilting measurements, initial visual survey).

Task 6: Continue collecting data once a month.

Task 7: Prepare and submit a draft final report.

2.2 VISUAL INSPECTIONS

Prior to the installations of the tilting monitoring stations on the wall panels, the ORITE researcher conducted the initial visual inspection of the abutment wall panels. The inspection was conducted to document the location and dimensions of major cracks and other distress conditions that the wall panels were exhibiting in hand sketches and digital photographs. The visual inspection was performed again a mid way through and near the end of the project.

2.3 TILT ANGLE MEASUREMENTS

During the fall of 2004, tilting measurement stations were established at the site. Initial site visit identified a total of five large panels on each side, underneath the northbound and southbound bridges, between the curved wingwalls. One station was set up per wall panel on each side of East State Street. Thus, a total of ten (10) tilt angle measuring stations were established at the site (illustrated in Figure 2.1).

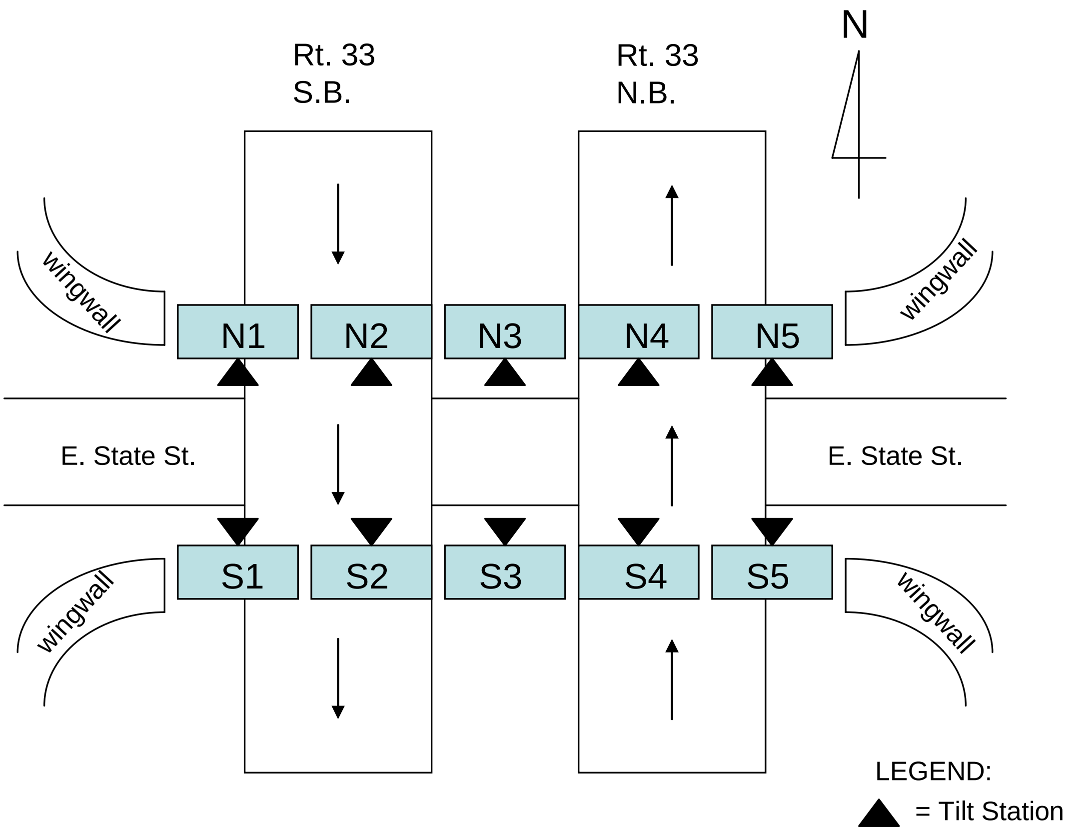
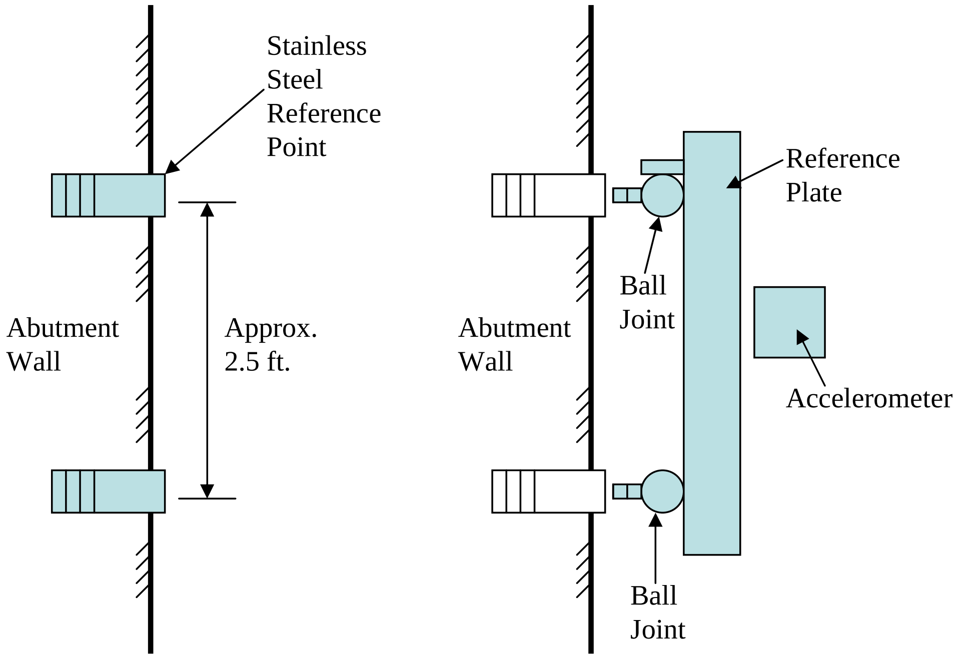


Figure 2.1: Layout and Identifications of Abutment Wall Panels

At each monitoring station, the abutment wall tilting was measured with an accelerometer (Digi-Tilt Tiltmeter by Slope Indicator, Seattle, WA). This system was used many times in previous research projects related to highway bridges and proven to be reliable. The tilt-meter sensor has a range of $\pm$ 30˚ and a sensitivity of 0.003˚. At each monitoring station, two stainless steel reference points will be grouted 2-inch (51 mm) deep into the wall approximately 2.5 ft (0.76 m) apart vertically. To take tilting measurements, a stainless steel ball joint is screwed into each reference point, a reference plate is held against the ball joints, and the accelerometer is positioned on the side of the reference point. Figure 2.2 illustrates the field set-up. Figure 2.3 shows a few components of the system (tilt-meter, cable, and read-out box). Figure 2.4 shows the reference plate attached to one of the abutment walls.



(a) Grouted Reference Points (b) Positioning of Plate & Sensor

Figure 2.2: Field Set-Up for Abutment Wall Tilt Measurement (1 ft = 0.3 m)

Figure 2.3: Digi-Tilt Sensor and Readout Device

Figure 2.4: Reference Plate Attached to Wall Panel

Each measurement consisted of two readings that were taken on the positive and negative sides of the tilt-meter. Once the positive (+) and negative (–) readings were obtained, the angle of tilt (θ) from the true vertical direction could be calculated by:

$$\theta(rad.) = \sin^{-1}\left[\frac{(+\,\mathrm{Re}\,ading) - (-\,\mathrm{Re}\,ading)}{40{,}000}\right] \tag{2.1}$$

The tilt sensor reading had the following sign convention:

Positive (+) reading ----- Wall is rotating away from the backfill behind it.
Negative (–) reading ----- Wall is rotating into the backfill behind it.

After taking the readings, the ball joints, the reference plate, and the accelerometer were all removed from the wall. A flat-head bolt was screwed into the reference points to protect their threaded holes.

2.4 FIELD MEASUREMENTS AT TOP OF ABUTMENT WALLS

In addition to the tilt-meter measurements taken in the lower section of each abutment wall panel, a set of manual measurements were taken at the top of the abutment walls. These measurements were possible, because a joint gap existed between two adjacent wall panels and the wall facings were not perfectly aligned at the top of the walls. As illustrated in Figure 2.5, the readings 1 through 8 were used to monitor changes in the joint width between the abutment walls. The readings a through h were used to monitor the rotational movements of the abutment walls (see Figure 2.5). Due to accessibility problem, no measurements were taken at the joints between abutment walls N1 and N2, N4 and N5, S1 and S2, and S4 and S5. These additional field measurements provided indications of possible movements taking place in the upper section of the walls. If the abutment wall moves as one rigid body, there will be a correlation between the tilt-meter readings taken in the lower section and the manual joint measurements taken at the top.

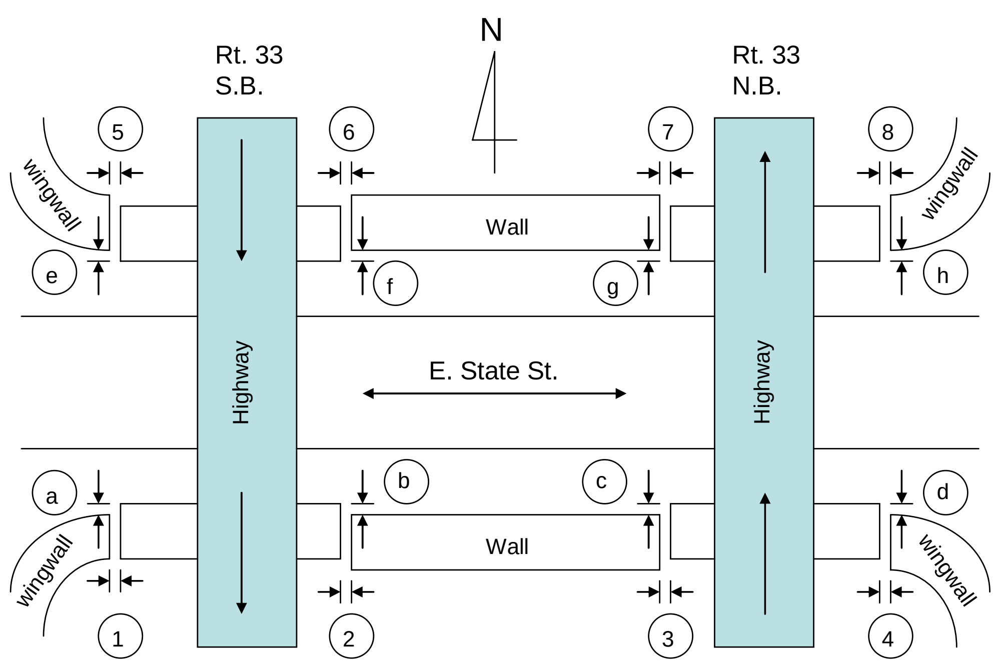


Figure 2.5: Additional Joint Measurements Taken at Top of Walls

Figure 2.6: Taking Joint Measurements at Top of Abutment Wall

2.5 SITE VISITS AND PROJECT COORDINATION

The tilting measurements and the joint measurements at the top of the walls were taken monthly, except during the first 30-day period (in which five sets of readings were recorded). The recording of the readings was continued into the fall of 2006, going through the bridge rehabilitation work (March to Sept. 2006). In addition to monitoring the abutment wall movements, CPT (Cone Penetration Test) sounding was performed at three locations on the Rt. 33 embankment in Oct. 2004. Sensor (tip resistance, sleeve friction, and pore pressure) readings recorded during the CPT sounding provided information on the type and quality of soil that exists behind the north abutment wall. All the data collected at the site were kept in a project binder located in the office of Civil Engineering Dept., Ohio University. ODOT personnel were informed monthly on the status of the abutment wall monitoring program.

2.6 CPT INVESTIGATIONS

Cone penetration test (CPT) is a field test method, in which a 1.75-inch (44.5-mm) diameter steel shaft with a 60˚ conical tip is hydraulically pushed into the ground to collect various subsurface data (see Figure 2.7). This technology, developed originally in Europe, is becoming a premier subsurface exploration method in North America for the fields of geotechnical engineering, earthquake engineering, and environmental engineering.

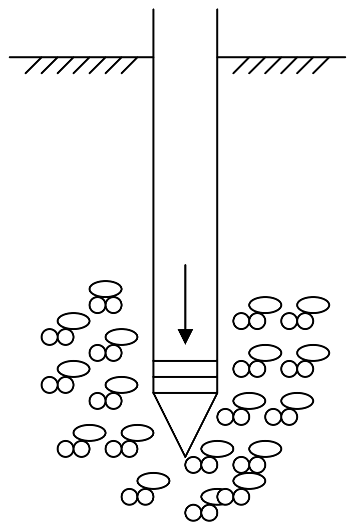


Figure 2.7: CPT Penetration

The CPT method has a number of advantages over the conventional SPT (standard penetration test) method. The sensors integrated in the CPT probe can provide much higher resolution subsurface data (at least one set of readings per second or 0.8-inch or 20-mm penetration depth). In the data collected during the CPT sounding, drained, partially drained, and undrained penetrations can be easily distinguished. The readings are displayed on the computer screen in real time for instant review. The data are already in the form suitable for plotting and further analysis. The CPT method produces no spoil and thus causes less ground disturbance.

Each CPT sounding results in a standard CPT log. The standard log consists of plots that correlate tip stress, sleeve (friction) stress, friction ratio, and pore water pressure readings to the penetration depth. The definitions for these CPT-related technical terms are given below:

Tip Stress COR (q_c) = Force acting against the conical tip, divided by the total projected area of the tip and corrected for pore water effect. Measured by strain gages installed on main shaft. See Figure 2.8.

[Note] The correction is required especially for saturated weak clayey soils to make sure that the tip stress is always at least as large as the pore pressure. This measurement may be mainly a reflection of the relative density of the material in front of the tip.

Sleeve Stress (f_s) = Side friction force acting over the sleeve, divided by the total surface area of the sleeve. Measured by strain gages installed on the sleeve. See Figure 2.8.

[Note] Cohesionless soils should exert little side friction force on the sleeve, while a measurable friction force should develop while penetrating through any cohesive soil.

Friction Ratio COR (R) = Ratio of sleeve stress (f_s) divided by the corrected tip stress (q_c).

$$R(\%) = \frac{f_s}{q_c} x100 \qquad (2.2)$$

SBT = Standardized (normalized) friction ratio. Based on the following formula:

$$SBT(\%) = \frac{f_s}{q_c - \sigma_{v0}} x100 \qquad (2.3)$$

where σ_{v0} = effective overburden stress.

[Note] The lower this ratio is, more cohesionless (or granular) the soil should be.

Pore Pressure (u) = Pore water pressure measured by a pressure transducer housed inside the cone assembly. Cavity leading to the transducer is located right behind the conical tip. See Figure 2.8.

[Note] This reading should reflect the hydrostatic pressure (that increases linearly with depth) while penetrating through any permeable zone below the groundwater table. Excess pore pressure, that is much larger than the hydrostatic pressure, tends to develop while penetrating through any zone of low permeability.

Class. FR = Soil behavioral classification based on a chart published by Robertson (1990) – see Figure 2.9.

[Note] One drawback of the CPT is that it recovers no physical soil samples during the penetration process. Thus, the likely soil type at any penetration depth is estimated by matching the set of collected readings to one of the behavioral patterns exhibited by various soil types.

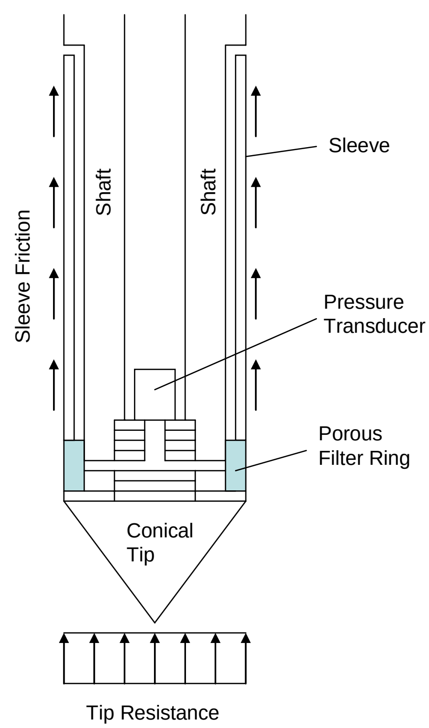


Figure 2.8: CPT Probe Schematics

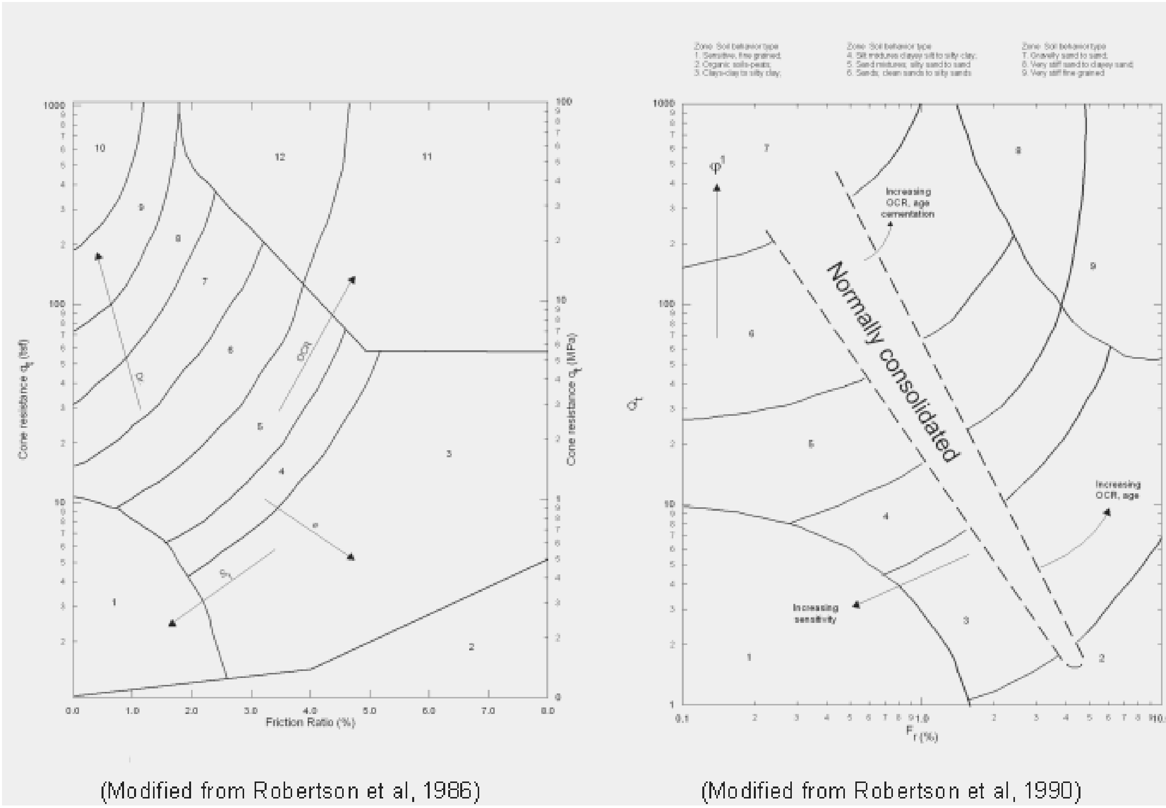


Figure 2.9: Soil Behavioral Classification Chart

In the classification chart (Figure 2.9),

Soil Type 1 = Fine-grained soil, sensitive

Soil Type 2 = Organic soil (ex. peat)

Soil Type 3 = Silty clay to clay

Soil Type 4 = Silt mixture (clayey silt)

Soil Type 5 = Sand mixture (silty sand, sandy silt)

Soil Type 6 = Sand (clean sand to silty sand)

Soil Type 7 = Gravelly sand

Soil Type 8 = Sand to clayey sand, very stiff

Soil Type 9 = Fine-grained soil, very stiff

According to Sanglerat (1972), presence of highly compressible (or weak) soil layers is generally marked by low tip resistance stress (q_c) values. A criterion suggested by him for identifying a weak layer is:

$$q_c < 145 \text{ psi (or 10 tsf or 10 bars or 1 MPa)} \qquad (2.4)$$

According to Robertson and Campanella (1988), presence of saturated soil layers may be easily identified during the CPT tests. A saturated layer reads the equilibrium hydrostatic pore water pressure if it is a granular soil layer and relatively high pore water pressure (above the equilibrium hydrostatic pressure) if it is a clayey soil layer.

CHAPTER 3: RESEARCH RESULTS

3.1 CPT SOUNDINGS

The CPT investigations took place on Oct. 20, 2004. A total of four CPT soundings were planned. However, only three of them were completed. Figures 3.1 and 3.3 show color photographs taken during the field work. The following presents the photographs and CPT sounding results as well as brief information on each CPT sounding:

CPT Hole #1: Location = Sta. 808+60 (furthest from the bridge north retaining walls).
Color Photograph: See Figure 3.1.
CPT Log: Shown in Figure 3.2.

Figure 3.1: CPT Probe Pushed into Ground at Hole #1

[Notes]

- Encountered stiff materials from 0’ to 10.0’ (0 to 3.1 m) depth.
- Soil (mostly clayey silt) soft and wet from 10.0’ to 36.0’ (3.1 to 11.0 m) depth.
- Encountered a very stiff layer at 38.0’(11.6 m); started lifting the truck (end of penetration).
- Encountered no apparent water table.

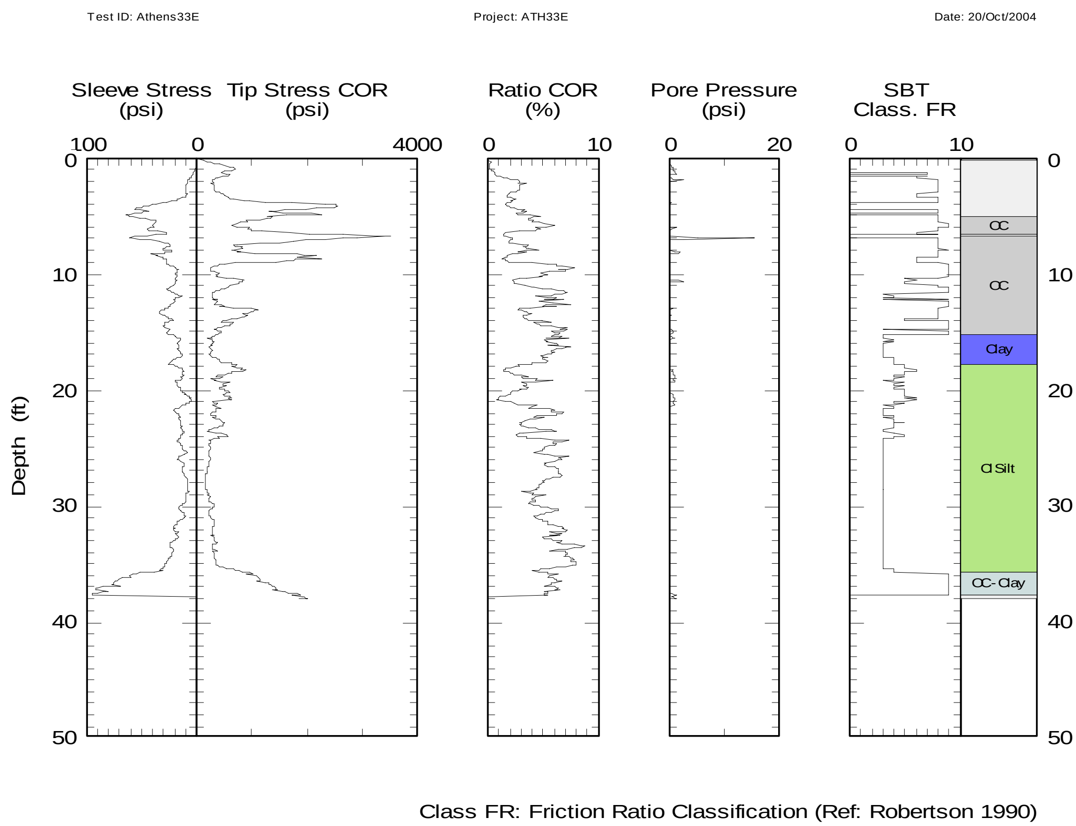


Figure 3.2: Standard CPT Log for CPT Hole #1 @ Sta. 808+60

CPT Hole #2: Location = Sta. 812+60 (2nd furthest from the bridge north retaining walls).

Photograph: See Figure 3.3.
CPT Log: Shown in Figure 3.4.

Figure 3.3: CPT Probe Pushed into Ground at Hole #2

[Notes]

- Hit a large boulder at 9.7' (3.0 m).
- Managed to reach a depth of 11.5' or 3.5 m (end of penetration).
- Soil overall dry in this hole.

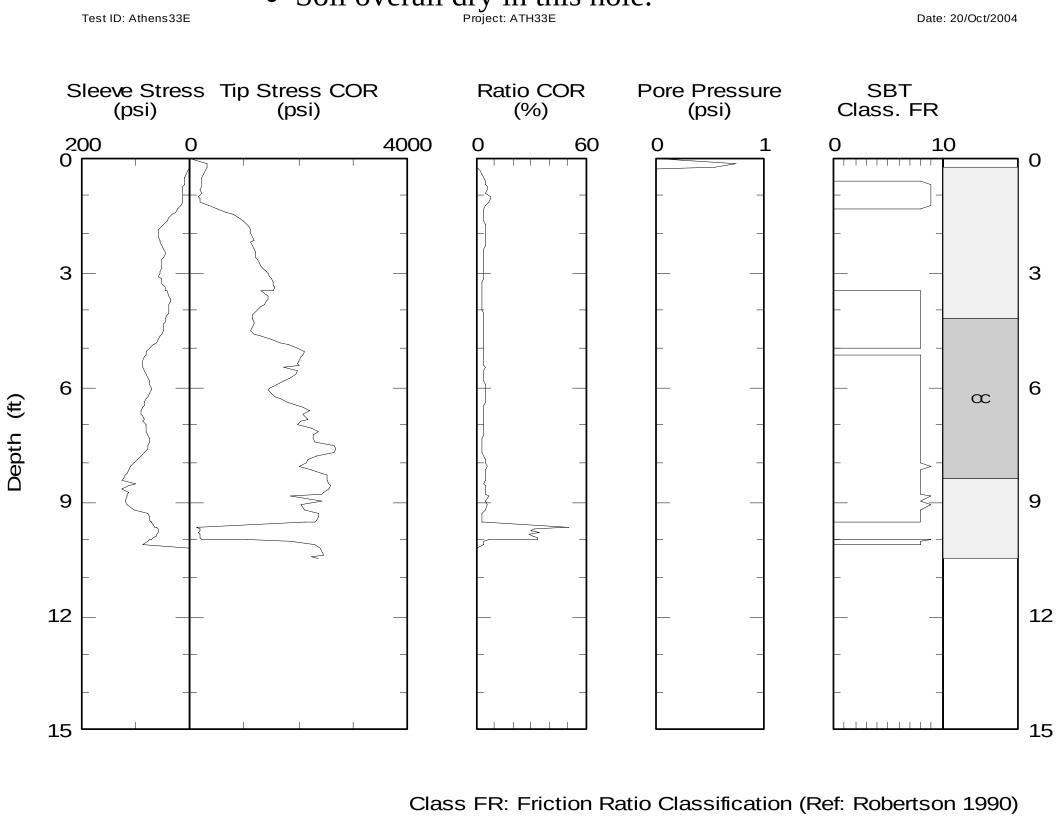


Figure 3.4: Standard CPT Log for CPT Hole #2 @ Sta. 812+60

CPT Hole #3: Location = Sta. 816+60 (2nd closest to the bridge north retaining walls).
Photograph: None.
CPT Log: Shown in Figure 3.5.

[Notes]

- Soil soft and wet from 8.0' to 20.0' (2.4 to 6.1 m).
- Encountered a very stiff layer at 27.0'(8.2 m); started lifting the truck (end of penetration).

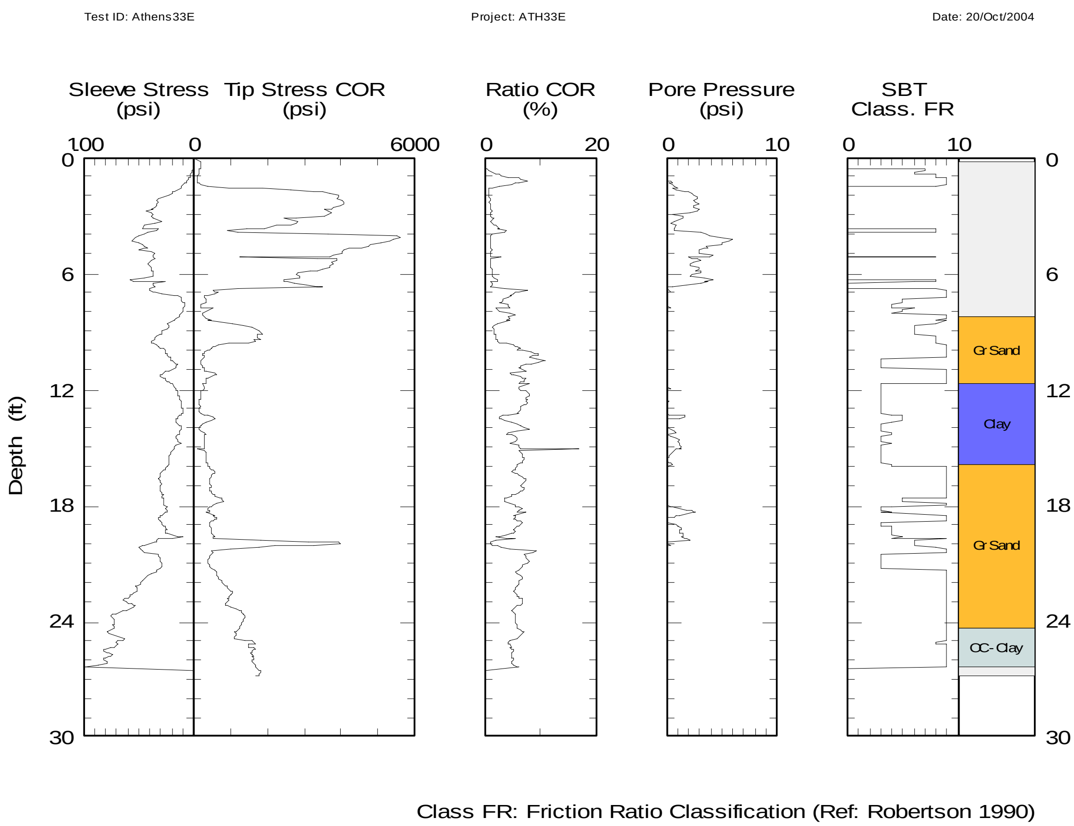


Figure 3.5: Standard CPT Log for CPT Hole #3 @ Sta. 816+60

CPT Hole #4: Location = Sta. 820+60 (Closet to the bridge north retaining walls).

[Note]

- Could not perform the CPT sounding at this location, because the cored hole was too close to the guardrail.

[Note] According to ODOT District 10 personnel, the depth from the top of pavement to the top of original ground (or bottom of the fill) may be about 17 to 19 ft (5.2 to 5.8 m) in Hole #1, 2 to 5 ft (0.6 to 1.5 m) in Hole #2, and 8 to 13 ft (2.4 to 4.0 m) in Hole #3.

3.2 FIELD VISUAL INSPECTIONS

According to the initial site visit, some of the panels had cracks that were slightly wider than hairline cracks. Also, a sign of backfill infiltration existed at some of the panel joints that had opened up slightly. Contrary to the initial speculation, no major horizontal cracks were detected anywhere in the lower half of the walls. Figures 3.6 through 3.22 present digital pictures taken at the project site on Dec. 6, 2004. Most of the panel facing had at least one crack running almost vertically. Signs of soil infiltration were visible at the construction joints between Panels N-2 and N-3, Panels N-3 and N-4, and Panel N-5 and NE Wingwall.

Figure 3.6: General View of Panel S-1 and SW Wingwall

Figure 3.7: General View of Panel S-1

Figure 3.8: General View of Panel S-3

Figure 3.9: General View of Panel S-4

Figure 3.10: General View of Panel S-5

Figure 3.11: Cracked Sidewalk on North Side of E. State St.

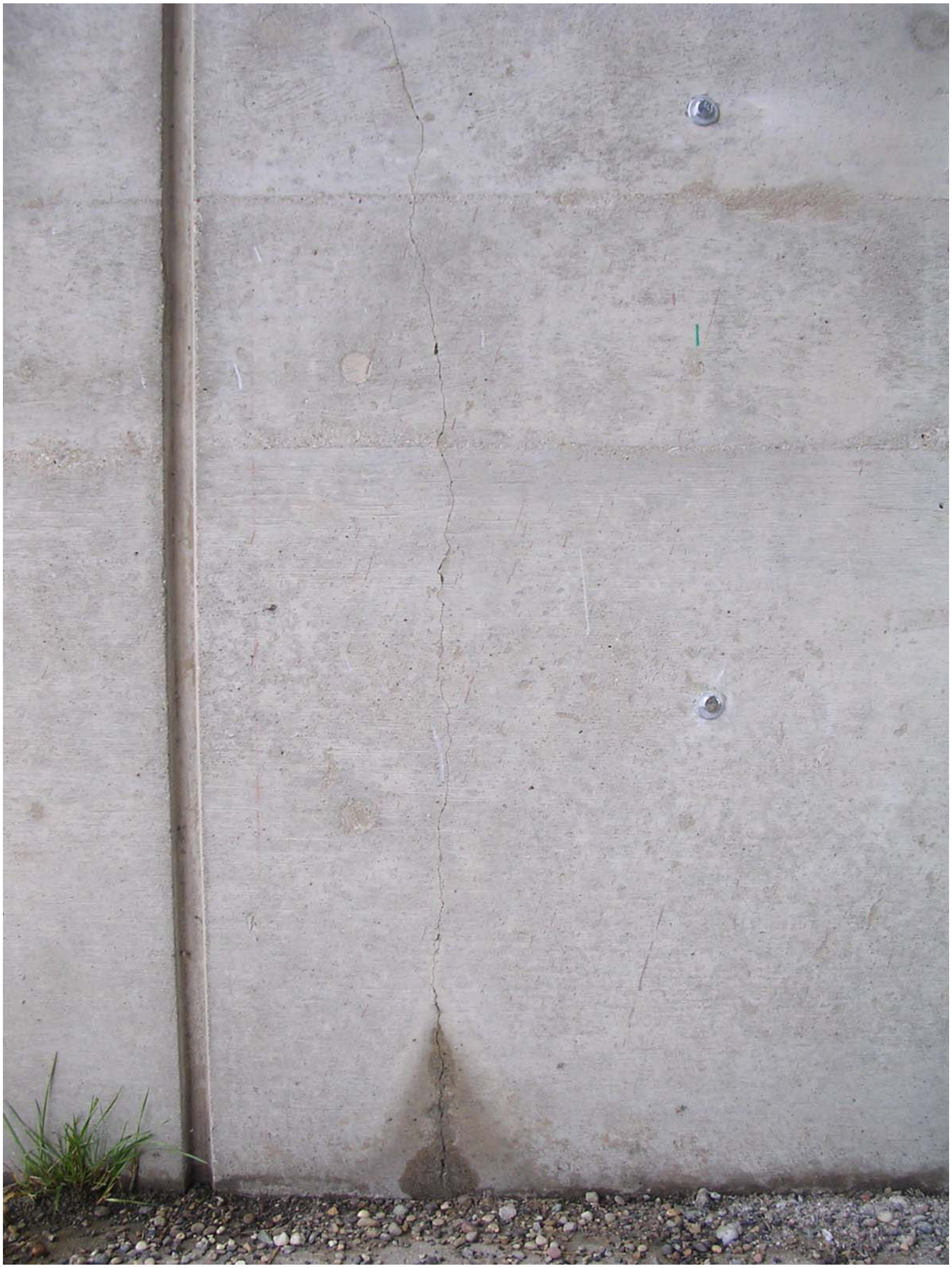


Figure 3.12: General View of Panel N-1

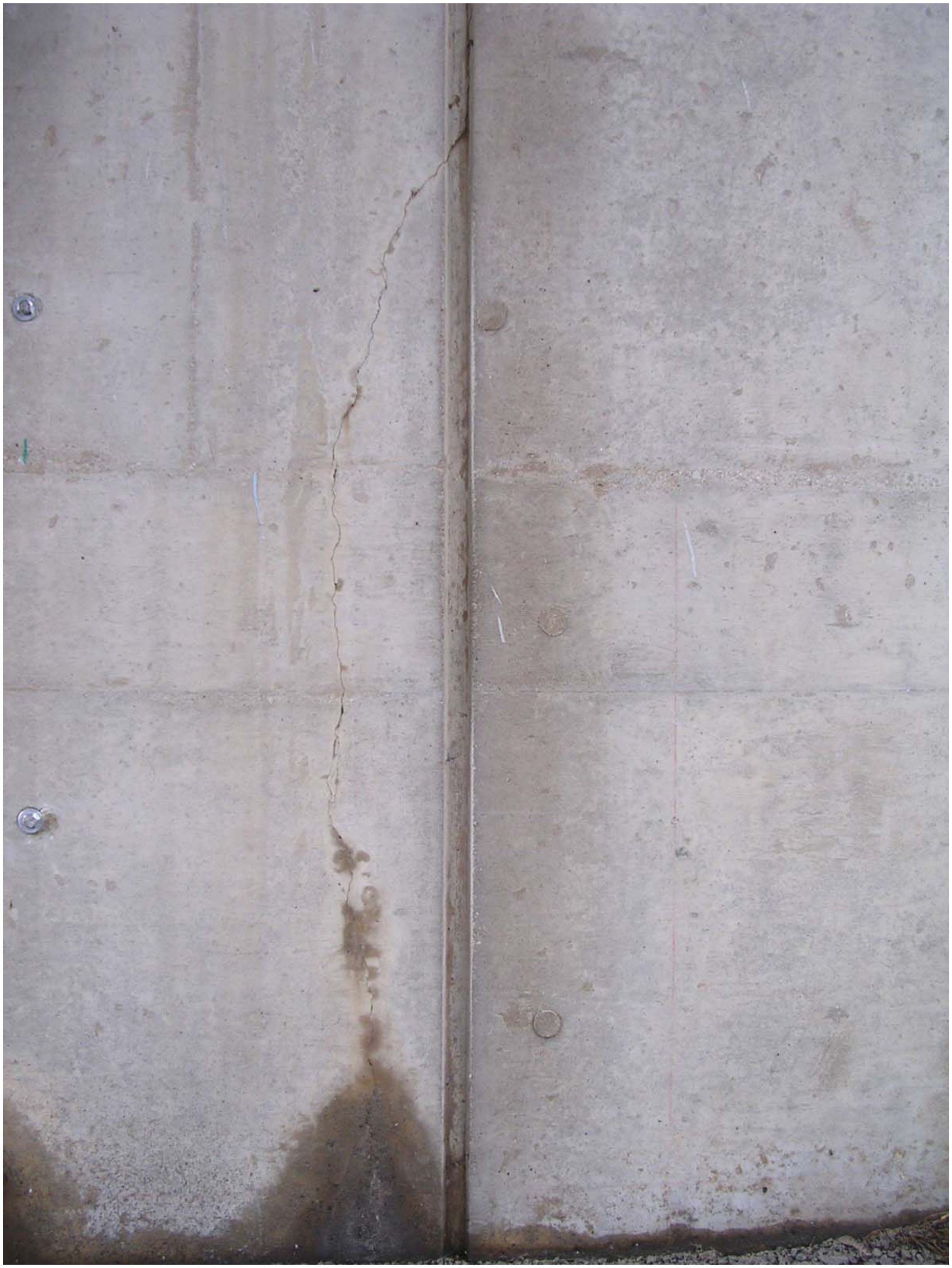


Figure 3.13: General View of Panel N-2

Figure 3.14: Signs of Soil Infiltration Between Panels N-2 and N-3

Figure 3.15: General View of Panel N-3

Figure 3.16: Signs of Soil Infiltration Between Panels N-3 and N-4

Figure 3.17: General View of Panel N-4 (Photo A)

Figure 3.18: General View of Panel N-4 (Photo B)

Figure 3.19: General View of Panel N-5 (Photo A)

Figure 3.20: General View of Panel N-5 (Photo B)

Figure 3.21: General View of Panel N-5 (Photo C)

Figure 3.22: Signs of Soil Infiltration Between Panel N-5 and NE Wingwall

The visual inspections conducted on April 25 and August 16, 2006 identified no new cracks on the abutment wall panels at the site. And, those cracked that were detected in the initial period of the project appeared to be unchanged in terms of their length and width dimensions.

3.3 TILT-METER READINGS

The initial tilt-meter readings were taken on Dec. 1, 2004 (the date when the tilting measurement stations were established). Beyond this date, thirty (30) additional sets of the tilting measurements were recorded. Tables 3.1 and 3.2 list all the tilt sensor readings taken during the project. The computed tilt angles are shown in Table 3.3. Figures 3.23 and 3.24 plot the tilt angles versus elapsed time.

Table 3.1: Tilt-Meter Readings Taken for North Side Abutment Walls

Date	Tilt-Meter Readings for Wall Panel:									
	N1		N2		N3		N4		N5	
	+	−	+	−	+	−	+	−	+	−
12-01-04	-215	180	-166	139	-72	37	-69	37	-154	117
12-08-04	-216	183	-167	135	22	-56	-66	36	-151	122
12-10-04	-213	181	-163	131	14	-42	-64	34	-150	123
12-17-04	-233	233	-163	122	8	-50	-72	29	-155	113
12-27-04	-212	232	-164	128	15	-49	-75	37	-156	120
01-07-05	-213	184	-164	133	21	-54	-73	40	-153	121
01-25-05	-208	179	-162	128	NA	NA	-70	36	-153	122
01-30-05	-213	178	-168	135	25	-59	-75	40	-156	122
02-15-05	-214	175	-166	132	23	-58	-73	38	-156	122
03-21-05	-211	180	-164	131	22	-53	-71	39	-154	122
04-19-05	-215	179	-167	129	23	-62	-75	35	-157	121
05-16-05	-210	180	-163	134	24	-55	-70	40	-152	123
06-13-05	-210	177	-160	129	26	-58	-72	40	-155	123
07-07-05	-213	180	-162	128	29	-61	-70	37	-151	121
08-09-05	-208	175	-163	131	27	-61	-69	35	-160	120
09-14-05	-206	184	-160	139	26	-55	-67	40	-149	123
10-19-05	-208	176	-161	127	27	-61	-68	37	-151	120
11-16-05	-209	179	-160	130	26	-62	-69	38	-152	116
12-16-05	-215	176	-163	127	25	-62	-72	33	-154	118
01-20-06	-214	176	-164	132	27	-58	-70	38	-152	122
02-15-06	-212	179	-165	130	23	-58	-74	36	-154	120
03-16-06	-210	178	-161	129	26	-59	-70	36	-154	120
04-03-06	-209	176	-167	132	28	-60	-70	40	-150	121
04-19-06	-206	180	-159	134	29	-56	-68	40	-148	123
05-17-06	-205	181	-158	132	29	-56	-70	45	-147	121
06-12-06	-210	178	-160	130	31	-59	-67	39	-151	118
07-14-06	-204	182	-155	131	33	-56	-61	36	-144	121
08-16-06	-209	176	-158	129	28	-63	-65	28	-148	120
09-19-06	-216	178	-155	124	30	-61	-63	31	-145	114
10-20-06	-210	174	-158	125	29	-63	-65	31	-149	115
11-21-06	-212	173	-161	122	27	-65	-69	28	-152	113

Table 3.2: Tilt-Meter Readings Taken for South Side Abutment Walls

Date	Tilt-Meter Readings for Wall Panel:									
	S1		S2		S3		S4		S5	
	+	−	+	−	+	−	+	−	+	−
12-01-04	-344	302	-92	53	100	-137	-116	78	-209	172
12-08-04	-246	220	-88	57	99	-132	-118	88	-205	176
12-10-04	-250	218	-89	57	105	-135	-115	84	-208	177
12-17-04	-263	210	-100	57	98	-137	-120	79	-235	172
12-27-04	-254	219	-99	63	98	-134	-120	84	-212	177
01-07-05	-260	226	-99	64	100	-124	-120	85	-219	188
01-25-05	-255	219	-99	64	NA	NA	-118	85	-225	194
01-30-05	-254	215	-102	63	98	-134	-120	86	-212	178
02-15-05	-255	216	-102	64	98	-131	-120	87	-212	176
03-21-05	-249	221	-97	69	101	-130	-118	87	-210	180
04-19-05	-259	212	-105	60	96	-136	-125	85	-218	176
05-16-05	-249	222	-89	66	102	-129	-118	89	-208	180
06-13-05	-240	225	-97	70	109	-128	-120	89	-210	178
07-07-05	-335	299	-98	64	103	-135	-122	90	-213	181
08-09-05	-252	218	-100	63	103	-138	-123	90	-213	181
09-14-05	-265	235	-99	70	107	-134	-119	93	-210	183
10-19-05	-252	222	-90	66	102	-130	-118	88	-210	179
11-16-05	-250	219	-98	63	103	-133	-119	86	-210	177
12-16-05	-252	218	-101	66	99	-135	-120	86	-212	178
01-20-06	-250	220	-100	67	102	-132	-119	89	-210	180
02-15-06	-255	217	-101	66	98	-133	-123	88	-214	177
03-16-06	-250	220	-98	68	102	-130	-120	89	-208	177
04-03-06	-248	218	-100	68	99	-129	-122	92	-204	175
04-19-06	-244	217	-96	68	99	-130	-118	92	-199	174
05-17-06	-245	220	-95	70	106	-129	-114	90	-197	173
06-12-06	-245	214	-95	64	105	-132	-118	87	-199	168
07-14-06	-239	210	-86	57	106	-131	-109	83	-193	167
08-16-06	-246	204	-93	69	98	-139	-111	74	-197	160
09-18-06	-242	209	-88	56	106	-136	-108	78	-194	163
10-20-06	-247	207	-94	53	99	-140	-116	75	-202	161
11-21-06	-250	208	-95	56	100	-138	-116	77	-203	165

Table 3.3: Tilt Angles of Abutment Wall Panels

Date	Tilt Angle (deg.) for Wall Panel:									
	N1	N2	N3	N4	N5	S1	S2	S3	S4	S5
12-01-04	-0.566	-0.437	**-0.156**	-0.152	-0.388	**-0.925**	-0.208	0.339	-0.278	-0.546
12-08-04	-0.572	-0.433	0.112	-0.146	-0.391	-0.668	-0.208	0.331	-0.295	-0.546
12-10-04	-0.564	-0.421	**0.080**	-0.140	-0.391	-0.670	-0.209	0.344	-0.285	-0.552
12-17-04	**-0.668**	-0.408	**0.083**	-0.145	-0.384	-0.678	-0.225	0.337	-0.285	-0.583
12-27-04	**-0.636**	-0.418	0.092	-0.160	-0.395	-0.678	-0.232	0.332	-0.292	-0.557
01-07-05	-0.569	-0.425	0.107	-0.162	-0.392	-0.696	-0.233	0.321	-0.294	-0.583
01-25-05	-0.554	-0.415	NA	-0.152	-0.394	-0.679	-0.233	NA	-0.291	-0.600
01-30-05	-0.560	-0.434	0.120	-0.165	-0.398	-0.672	-0.236	0.332	-0.295	-0.559

02-15-05	-0.557	-0.427	0.116	-0.159	-0.398	-0.675	-0.238	0.328	-0.297	-0.556
03-21-05	-0.560	-0.423	0.107	-0.158	-0.395	-0.673	-0.238	0.331	-0.294	-0.559
04-19-05	-0.564	-0.424	0.122	-0.158	-0.398	-0.675	-0.237	0.332	-0.301	-0.564
05-16-05	-0.559	-0.425	0.113	-0.158	-0.394	-0.675	-0.222	0.331	-0.297	-0.556
06-13-05	-0.554	-0.414	0.120	-0.160	-0.398	-0.666	-0.239	0.339	-0.299	-0.556
07-07-05	-0.563	-0.415	0.129	-0.153	-0.390	**-0.908**	-0.232	0.341	-0.304	-0.564
08-09-05	-0.549	-0.421	0.126	-0.149	-0.401	-0.673	-0.233	0.345	-0.305	-0.564
09-14-05	-0.559	-0.428	0.116	-0.153	-0.390	-0.716	-0.242	0.345	-0.304	-0.563
10-19-05	-0.550	-0.413	0.126	-0.150	-0.388	-0.679	-0.223	0.332	-0.295	-0.557
11-16-05	-0.556	-0.415	0.126	-0.153	-0.384	-0.672	-0.231	0.338	-0.294	-0.554
12-16-05	-0.560	-0.415	0.125	-0.150	-0.390	-0.673	-0.239	0.335	-0.295	-0.559
01-20-06	-0.559	-0.424	0.122	-0.155	-0.392	-0.673	-0.239	0.335	-0.298	-0.559
02-15-06	-0.560	-0.423	0.116	-0.158	-0.392	-0.676	-0.239	0.331	-0.302	-0.560
03-16-06	-0.556	-0.415	0.122	-0.152	-0.392	-0.673	-0.238	0.332	-0.299	-0.551
04-03-06	-0.551	-0.428	0.126	-0.158	-0.388	-0.668	-0.241	0.327	-0.307	-0.543
04-19-06	-0.553	-0.420	0.122	-0.155	-0.388	-0.660	-0.235	0.328	-0.301	-0.534
05-17-06	-0.553	-0.415	0.122	-0.165	-0.384	-0.666	-0.236	0.337	-0.292	-0.530
06-12-06	-0.556	-0.415	0.129	-0.152	-0.385	-0.657	-0.228	0.339	-0.294	-0.526
07-14-06	-0.553	-0.410	0.127	-0.139	-0.380	-0.643	-0.205	0.340	-0.275	-0.516
08-16-06	-0.551	-0.411	0.130	-0.133	-0.384	-0.644	-0.232	0.340	-0.265	-0.511
09-18-06	-0.564	-0.400	0.130	-0.135	-0.371	-0.646	-0.206	0.347	-0.266	-0.511
10-20-06	-0.550	-0.405	0.132	-0.138	-0.378	-0.650	-0.211	0.342	-0.274	-0.520
11-21-06	-0.551	-0.405	0.132	-0.139	-0.380	-0.656	-0.216	0.341	-0.276	-0.527

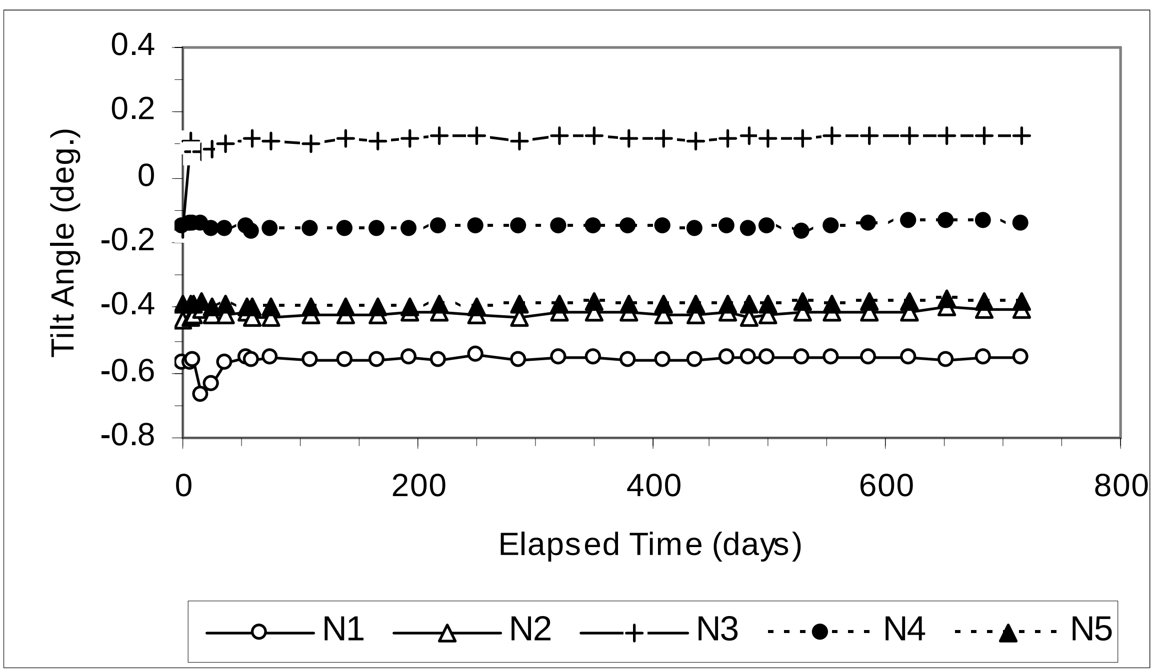


Figure 3.23: Changes in Tilt Angles vs. Time (North Side)

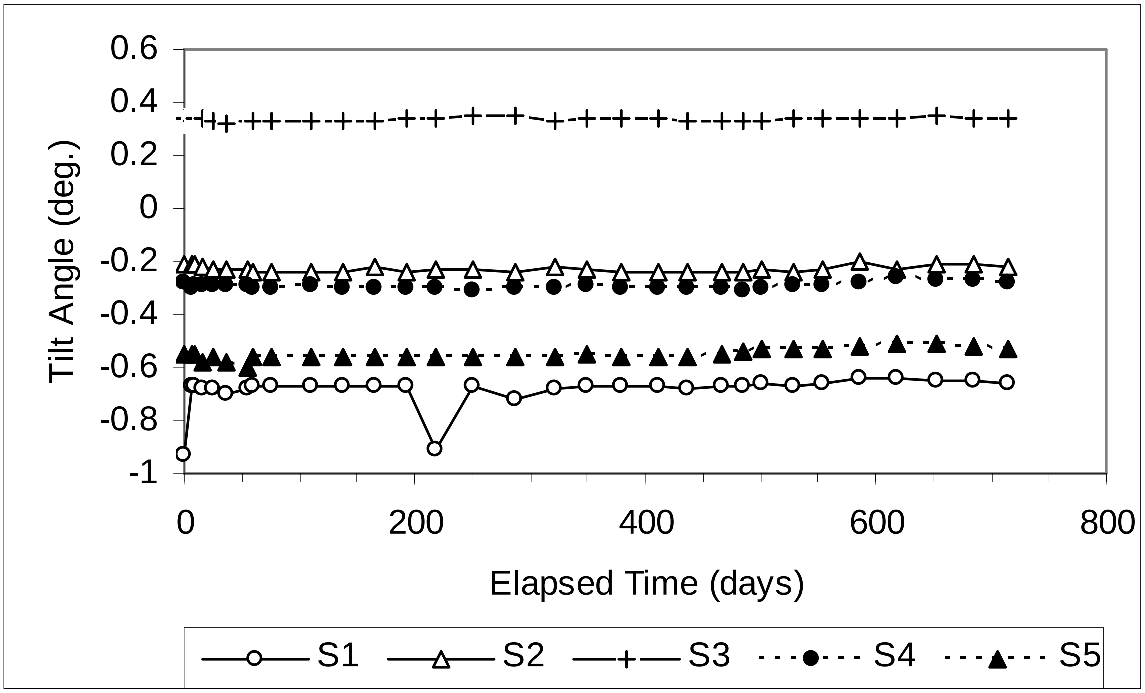


Figure 3.24: Changes in Tilt Angles vs. Time (South Side)

According to these tables and plots, the vertical positions of wall panels N-2, N-4, N-5, S-2, S-3, S-4, and S-5 changed little during the monitoring period (Dec. 2004 to April 2006). Wall Panel N-1 experienced about 0.1° rotation toward the backfill in the second half of December 2004. Since then, it has rotated back close to the original position and remained stable for more than 15 months. Wall Panel N-3 has been stationary, except during December 2004 in which it experienced about 0.2° rotation away from the backfill. Wall Panel S-1 rotated about 0.25° away from the backfill in December 2004. It experienced some movements again in July 2005. Since then, it has changed its position very little.

3.4 MEASUREMENTS TAKEN AT TOP OF ABUTMENT WALLS

The initial rotational measurements were taken at the top of the abutment walls on Dec. 10, 2004 (9 days after the tilting measurement stations were established). Beyond this date, fourteen (14) additional sets of the measurements were recorded. Table 3.4 lists all the measurements taken during the project. The initial measurements of the joint gap were taken at the top of the abutment walls on July 7, 2004 (about 7 months after the tilting measurement stations were established). Beyond this date, twenty-three (23) additional sets of the measurements were recorded. Table 3.5 lists all the measurements taken during the project. Figures 3.25 and 3.26 plot these measurements versus elapsed time.

Table 3.4: Rotation Measurements Taken at Top of Abutment Walls

Date	Rotation Measurement (in mm):							
	a	b	c	d	e	f	g	h
12-10-04	**64**	NA	NA	**64**	**76**	NA	NA	**76**
02-15-04	NA	3	3	NA	NA	11	20	NA
03-21-05	71	4	3	71	65	12	20	90
04-19-05	67	3	3	73	61	13	22	87
05-16-05	70	6	5	71	64	14	21	88
06-13-05	70	3	4	74	63	12	20	87
07-07-05	69	3	0	71	59	10	18	86
08-09-05	67	3	0	71	65	11	20	87
09-14-05	68	4	2	74	61	12	18	89
10-19-05	70	5	3	71	62	12	18	87
11-16-05	69	2	0	72	60	11	18	88
12-16-05	69	3	3	72	62	12	19	88
01-20-06	68	4	2	73	63	12	20	87
02-15-06	68	4	3	71	64	14	22	89
03-16-06	68	3	2	70	63	11	21	85
04-03-06	64	3	2	70	62	9	20	86
04-19-06	67	3	0	66	62	12	19	86
05-17-06	67	3	0	68	63	12	21	84
06-12-06	65	4	0	66	59	16	20	82
07-14-06	67	7	6	66	62	13	19	84
08-16-06	63	9	8	65	62	10	19	83
09-19-06	65	10	7	62	60	9	18	82
10-20-06	65	7	7	67	63	9	18	82
11-21-06	67	7	9	66	61	11	19	86

[Note] Refer to Figure 6 for the locations where these measurements were taken. 1 in = 25 mm.

Table 3.5: Joint Gap Measurements Taken at Top of Abutment Walls

Date	Joint Gap Measurement (in mm):							
	1	2	3	4	5	6	7	8
	No measurements were taken prior to July 2005.							
07-07-05	26	27	25	24	25	29	29	27
08-09-05	27	27	26	25	26	30	29	28

09-14-05	27	27	26	27	26	30	30	29
10-19-05	30	28	28	27	28	31	30	30
11-16-05	29	28	27	27	27	31	31	30
12-16-05	30	29	28	27	29	31	31	30
01-20-06	28	29	28	26	26	30	30	30
02-15-06	28	28	27	25	27	30	30	28
03-16-06	28	28	28	28	27	30	30	30
04-03-06	28	28	27	26	26	30	29	30
04-19-06	28	28	28	27	27	29	30	28
05-17-06	28	29	28	28	28	30	31	30
06-12-06	28	29	27	26	25	30	30	29
07-14-06	27	28	26	25	25	30	29	26
08-16-06	27	27	26	26	25	29	30	28
09-19-06	27	27	27	25	26	28	29	28
10-20-06	28	27	27	27	27	28	30	29
11-21-06	29	30	29	28	28	30	31	30

[Note] Refer to Figure 6 for the locations where these measurements were taken. 1 in = 25 mm

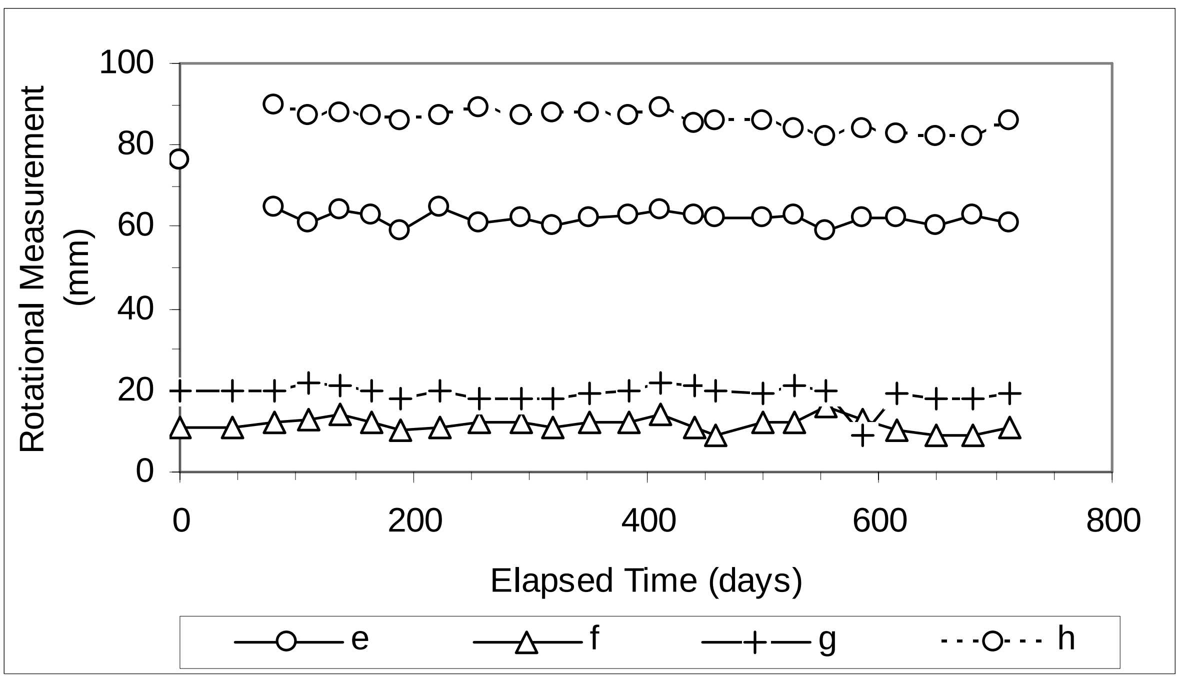


Figure 3.25: Changes in Rotational Measurements (North Side)

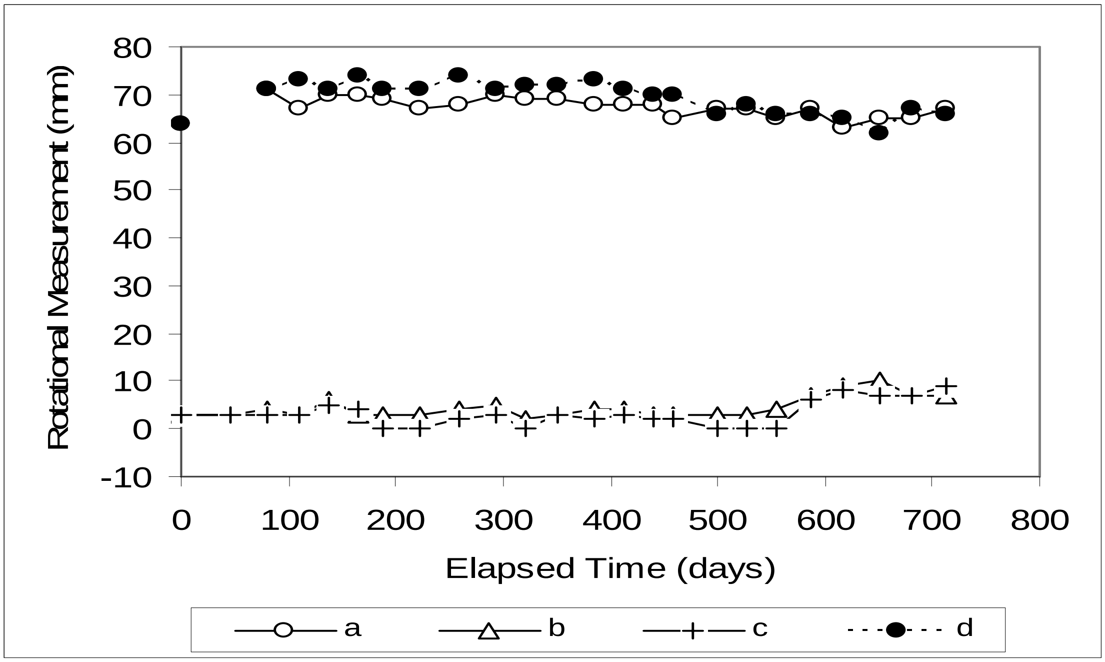


Figure 3.26: Changes in Rotational Measurements (South Side)

According to Table 3.4 and Figure 3.25, there might have been some rotational movements on Wall Panels S1, S5, N1, and N5. Table 3.5 and Figure 3.26 show that the joint openings changed very little between July 2005 and April 2006.

3.5 ADDITIONAL PROJECT INFORMATION

In the spring of 2006 the rehabilitation work started at the bridge site in full scale. The ORITE researcher continued to take readings while the rehabilitation project was under way. A conversation with the field ODOT personnel indicated that the rehabilitation work would involve:

- Reconstruction of the 4-ft (1.2-m) section of the bridge deck at both ends so that the deck will become the semi-integrated type (i.e., will be tied to the approach slabs), including slotted drain pipe right next to the top of the abutment wall
- Installation of horizontal drain pipes into the embankment just behind the abutment walls (to drain seepage water)

The deck reconstruction work began from the week of March 10, 2006. The installations of the horizontal drain pipes started at the end of March 2006. Slotted PVC pipes (1.5-inch or 38-mm diameter, schedule 80) were used as the drain pipes. They were inserted into the highway embankment from the west side in sets of three at 50 to 75 ft (15.2 to 22.9 m) spacing (see Table 3.6 for plan details).

Table 3.6: Horizontal Drain Pipes Installation Plan

Station	No. of Pipes	Elevation at Outlets	Notes
819+00	3	657.85 ft (200.51 m)	North of the bridge structure.
819+75	3	653.42 ft (199.16 m)	North of the bridge structure.
820+25	3	652.91 ft (199.01 m)	North of the bridge structure.
820+75	3	649.65 ft (198.01 m)	Directly north of the north abutment wall panels. Pipes drain the area behind Wall Panels N-1 through N-5.
822+25	3	647.60 ft (197.39 m)	Directly south of the south abutment wall panels. Pipes drain the area behind Wall Panels S-1 through S-3.
822+75	3	647.16 ft (197.25 m)	South of the bridge structure.

At each location, the middle pipe was inserted perpendicularly to the centerline of the roadway, while the other two were inserted at 10° off from the right angle. This arrangement was made to drain a larger area at each station. The slopes of the drain pipes varied from 4 to 6%. Figures 3.27 through 3.31 present photographs of the horizontal drain pipe installation work.

The rehabilitation project was completed during the first week of September 2006. The last action taken by the Contractor was the reconstruction of the sidewalk on the north side of East State Street and installation of drainage channel along the edge where the abutment wall and the new sidewalk meet.

Figure 3.27: PVC Pipes Used as Horizontal Drains

Figure 3.28: Horizontal Drain Pipe Installation Process

Figure 3.29: General View of Drain Pipes Installed at Sta. 819+75

Figure 3.30: General View of Finished Drain Pipe Installation Work

Figure 3.31: Reconstruction of Bridge Deck End Section

Figure 3.32: Construction of Sidewalk on North Side of E. State St.

CHAPTER 4: SUMMARY AND CONCLUSIONS

4.1 PROJECT SUMMARY

District 10 personnel of Ohio DOT recently noticed signs of movements on the bridge abutment walls existing under the S.R. 33 bridge over E. State St. in Athens, Ohio. In this research project, the abutment wall panels existing at the bridge site in Athens, Ohio were monitored for possible rotational movements for two years by a researcher from Ohio University. A tilt-meter station was installed in the lower section of each wall panel. A sensitive tilt-meter instrument (Digi-tilt by Slope Indicator, Seattle, WA) was utilized to measure the degree of tilting each wall panel was experiencing over the course of the project. Also, manual measurements were taken at the top of the walls to supply additional data concerning the possible wall movements. As a separate activity, cone penetration test (CPT) sounding was conducted through the highway embankment material, in the vicinity of the bridge structure, to collect detailed information related to the type and quality of soil and the depth to water table that exist behind the north abutment wall.

4.2 CONCLUSIONS

The initial site visit identified a total of ten (10) abutment wall panels – five (5) on each side of East State Street. One or two major cracks were observed running vertically on each panel, and signs of soil infiltration were also noted at some wall joint sections on the north side of East State St. Contrary to the initial speculation, no major horizontal cracks were detected anywhere in the lower half of the walls.

The CPT soundings conducted on Oct. 20, 2004 provided high-resolution information on the subsurface conditions existing within the highway embankment at three locations behind the north abutment walls. Relatively soft and wet soils were encountered in CPT Holes #2 and #3, while silty clay soil in CPT Hole #1 was mostly dry.

The tilt-meter readings collected during the project showed that most of the abutment wall panels had remained stable over the two-year period. Only the abutment wall panels N-1, N-3, and S-1 experienced small rotational movements initially. The manual measurements taken at the top of the abutment walls suggested that the abutment wall panels N-1, N-5, S-1, and S-5 might have moved slightly during the initial period. The visual inspections conducted on April 25 and Aug. 16, 2006 identified no new cracks on the abutment wall panels at the site. And, those cracks that were detected in the initial period of the project appeared to be unchanged in terms of their length and width dimensions. These facts along with the tilt-meter and manual measurements that have been accumulated over the past two years point out that these bridge abutment walls have been very stable during the life of the current project (which also included the abutment wall performance in the post-rehabilitation work period).

4.3 RECOMMENDATIONS

The site conditions observed during the first year of the current project suggested the following remedial actions to be taken by ODOT: water-proving the abutment wall front faces; complete reconstruction of the end sections of the bridge deck; installation of upgraded drainage system under each end section of the bridge deck; complete reconstruction of the sidewalk on the north side of East State Street; installation of drain gutter along the edge of the sidewalk on the north side of East State Street; and filling of the joint gaps existing between abutment wall panels. Most of these remedial actions were taken during the actual rehabilitation project, which lasted from March to September of 2006.

CHAPTER 5: IMPLEMENTATIONS

Based on the site conditions observed, the rehabilitation work being completed, and the data collected during the current project at the SR 33 bridge over E. State St. in Athens, Ohio, the following implementation plans are recommended by the author:

- There is no need to perform major reconstruction or rehabilitation work on the abutment walls. The tilt-meter readings compiled over two-year period indicated that the walls had been stable throughout all four seasons and inclement weather conditions quite some time.
- Additional horizontal drains may need to be integrated into the existing embankment structure. The horizontal drains installed during the summer of 2006 appear to have very limited capability to drain the embankment soils.
- The gap existing between the wall panels should be filled with suitable durable joint material to prevent further loss of backfill soil.
- There will be no need to keep monitoring the movements of the abutment walls with tilt-meter system in the future. The bridge and wall structures should be inspected occasionally by the ODOT District personnel. The sensor monitoring should be resurrected only if additional signs of possible wall movements are detected.

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