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SYNOPSIS: Heavily instrumented dams are unusual in the midwestern United States. Council Bluff Dam, Missouri, USA has an imbankment that provides monitoring by piezometers, inclinometer, settlement plates, earth pressure cells, extensometers, tiltmeters, and datum plates. The collection, evaluation, and discussion of the data and instruments give insight into embankment performance. Emphasis has been placed on monitoring after construction.

INTRODUCTION

This paper evaluates the performance of Council Bluff Dam embankment. The embankment height is 124 feet and represents the largest earthfill dam ever built by the USDA-Forest Service. Construction began in 1979 and was completed in 1981. The embankment is zoned with both a fat and lean clay zone and is anchored to steep abutment rock. The area of construction is a narrow rock canyon on the Big River in central Missouri.

Instrumentation was installed to monitor embankment performance due to the High hazard classification of the dam. Items being monitored: 1) Piping potential along the interface of the clay core and steep right abutment, 2) Piping potential around the conduit, 3) High stress around the top of the conduit, 4) Performance of all of the zones and chimney drain.

Woodward-Clyde Consultants of San Francisco, California designed the instrumentation and Shannon and Wilson, Inc. of St. Louis, Missouri installed and monitored the instruments during embankment construction. The Forest Service has done all monitoring since construction.

Instrumentation is composed of the following units: 21 piezometers, One inclinometer with settlement plates, Six sondex settlement devices, Six earth pressure cells, Six extensometers with tiltmeters, One mercury settlement device, and 22 surface monuments.

Monitoring of the instruments began immediately after installation and continues today. All of the instruments were in place by the fall of 1980. Reservoir filling began in 1981 with full pool achieved in 1984. Some instruments malfunctioned from the beginning, while others gave questionable readings, but most have performed well.

The dam has the following characteristics:

Maximum Height	124 ft
Crest Length	485 ft
Zone Embankment	285,000 CY
Dam Section -	
a) Fat Clay Core	
b) Lean Clay Core	
c) Lean Clay Blanket - Upstream	
d) Chimney Drain	
e) Drain Blanket	
Full Pool Elevation	1087 ft
Reservoir Surface Area	440 Ac
Full Pool Volume	12,640 Ac-ft
Construction Complete	1981
Reservoir Filled	1984

EMBANKMENT INSTRUMENTS

The instruments used to provide the needed information were designed as six different components. The following is a list of the components:

1. Piezometers

   Twenty-one piezometers were installed at locations shown in Table 2. These devices, model number P4KF10L or SINCO 51401, were supplied by Franz Gloetzl, D-7512 Rheinstatten, 4-Fo, West Germany. Their purpose was to monitor construction pore water pressure developed in the clay core and seepage conditions developed in the core and the foundation as the reservoir filled.

2. Slope Indicator with Settlement Plates

   A three-inch nominal diameter plastic casing was installed from the rock foundation to the top of the dam and aluminum settlement plates were placed every five feet up the casing. The inclinometer (model Digitilt 50320) and other parts of the device were supplied by Slope Indicator Co., 3668 Albion Place N, Seattle, Washington 98103. This device is used to measure horizontal and vertical movements within the lean clay core during and after embankment construction.

3. Continuous Profile Settlement Device

   This device, also called a Tube Profile Gauge, is installed to verify settlement and compressions in the embankment across and within the various zones. Two gauges are installed, one at elevation (EL) 1031.5 and another at EL 1067. At each elevation six datum plates are installed; one in the upstream random zone, one in the lean clay, and the remaining four in the fat clay core. The gauge was supplied by the Slope Indicator Company.

4. Extensometer and Tiltmeter Units

   Four units were installed on the right abutment within the steep interface between the foundation and the fat clay core to measure relative movement of the core with respect to the abutment. Tilt sensor (model SINCO 50322) and parts of the unit were supplied by Slope Indicator Company. Two piezometers were installed immediately downstream of these units to monitor changes in seepage pressure which may accompany core movement.

5. Earth Pressure Cells

   Two sets of cells were installed on the outside walls of the outlet conduit. Each set consists of three cells with one cell mounted on the top of the conduit and one cell mounted on each side of the conduit. The cells measure the total earth pressure on the conduit sections. The cells (model number E 15/25 KFA or SINCO 51482) were supplied by Franz Gloetzl. Four of the piezometers at elevation 1004 were located near the pressure cells on the side of the conduit to measure pore pressure and to detect seepage pressures near the conduit.

6. Surface Monuments

   Thirteen surface monuments were installed along the crest of the dam and on the downstream berms to check horizontal and vertical movements after initial construction. In 1984, nine additional surface monuments were installed on the upstream side of the crest. The first monuments on the crest were located toward the downstream slope.

A variety of problems occurred during installation of the instruments. All of these problems required careful embankment construction of the areas around and adjacent to the instrument. Bloomsdale Construction, St. Louis, Missouri constructed the embankment and took the necessary care to protect the instruments.

COLLECTION AND EVALUATION OF DATA

Data collection has been continuous since placement of the embankment began. During the construction phase, data collection was the responsibility of Woodward-Clyde, St. Louis, Missouri. Once the embankment was complete data collection and evaluation has been done by the Forest Service. The first four years after construction readings were taken every month except on the surface monuments, which were monitored twice each year. During 1984, it had become obvious that the structure was performing well, and the magnitude of the changes was not significant. In 1985, instruments were read quarterly and beginning in 1986 twice each year. Surface monuments have been surveyed once a year. The dam is visually inspected several times a year and is inspected for operation and maintenance annually. There is a surface water elevation monitor that records water levels daily and also initiates a response to a six-inch water elevation drop from full pool. This recorder transmits the data by radio signal to a receiver at a local office. The water level information will eventually be linked by data communication to several other office locations.

Surface Monuments

Settlement of the embankment surface is well below the maximum anticipated and increases from the abutment interfaces toward the center of the embankment. The center 1/3 (horizontally) is experiencing the greatest amount of settlement. Maximum settlement at the surface is .44 feet, which is well below the anticipated 1.2 feet. It is also apparent that the upstream edge of the dam has settled more in the last two years than the downstream edge. Settlement varies from 0 - .12 downstream and .02 - .35 upstream. Initial movement of the monuments indicated a gradual migration upstream. The second set of monuments installed in 1984 now show a reverse of this trend and instead are moving slightly downstream. As the zones are loaded by reservoir water pressures it was anticipated that downstream movement would occur.

It was not anticipated that there would be an initial upstream movement of the embankment surface. It appears that this is a function of the differential settlement of various zones that compose the embankment. Most of these zones are upstream from the surface monuments that were initially installed. Associated with analysis of the crest settlement is the information on settlement of the two downstream berms where the instrument houses are located. Readings indicate that there is very little settlement in the downstream random zone. The upstream surface monuments (installed in 1984) have settled almost twice as much as the downstream monuments in the last two years with settlement over the last three years even greater. It is apparent that the upstream fat clay and random zones have settled more than the downstream random zone and lean clay zone. It was expected that the fat clay zone would exhibit the greatest amount of settlement.

Settlement Plates

The lean clay zone experienced 68 percent of all settlement during construction. After construction, settlement has been greatest in the top 20 feet of the zone and the least in the bottom 20 feet. The zone is performing as anticipated with the middle 1/3 of the embankment experiencing the greatest settlement. Very little settlement has occurred in the lower section of the lean clay zone, while it has settled 1.24 feet in the upper area. Maximum settlement has been 2.5 feet with the maximum predicted settlement 1.2 feet. The prediction by Woodward-Clyde was based upon an analysis of five different dams with the observation stations normalized with respect to dam height. Actual settlement did exceed predicted settlement by 1.3 feet, but based upon the emperical methods used for prediction it is not a cause for concern. Seventy-nine percent of the settlement at the station that experienced the maximum occurred during construction.

Inclinometers

Information from the inclinometers indicates that minor deflections (less than .2 inches) occurred in both the downstream and upstream directions. The bottom 20 feet and top 15 feet of the lean clay zone have migrated a fraction of an inch downstream. The middle 80 feet of this zone has moved slightly upstream (maximum is about 1/2 inch). The upstream migration of most of the material in the zone is probably due to the increased settlement of the fat clay zone immediately upstream. It is more compressible and was expected to settle 2.5 times more than the lean clay zone. As the upstream face settles the lean clay core deflects slightly in the upstream direction. The very bottom of the zone has moved slightly downstream probably reflecting hydrostatic loading and is less affected by the upstream zones. The upper area is also less affected by the settlement of the upstream zones. This area is much closer to the downstream random zone and doesn't appear to be as significantly affected by upstream settlement. Once the phreatic surface reaches equilibrium most of this zone is expected to move slightly downstream. The question is whether or not all of the initial upstream movement will be overcome.

Piezometers

There are six piezometers that will never give equilibrium readings for the phreatic line. These piezometers were installed to measure pore pressures during construction and as precautions in the chimney drain and immediately downstream from the chimney drain. Two piezometers are no longer operating. It is obvious that the phreatic line has not reached equilibrium conditions. It appears that response of the foundation piezometers and the piezometers at elevation 1003 feet is good, but there is a substantial lag time in responding to actual water surface fluctuations. The piezometers at elevations 1031.0 and 1067.0 are much less responsive. It took 2 years and 10 months after first filling to get a response in the first piezometer at 1031.0 and 3 years and one month to get a reading at elevation 1067. It is difficult to draw conclusions about the phreatic line in a pre-equilibrium state, but several things have become evident.

There is a substantial lag time for the piezometers to respond within the upstream random zone and fat clay zone. It would have been useful to have them located lower in the sections. It appears that it may take 10 years or more to reach equilibrium with the phreatic surface and there may never be any readings for some piezometers.

Extensometer and Tiltmeter Units

The extensometers placed on the right abutment interface with clay zone have moved very little since 1981. Maximum movements have been less than 1/4-inch during this period. Total movement of the four extensometers has varied from 10-1/2 inches to 1/3-inch with 83 percent of the movement occurring during construction. This interface has shown very little movement since construction and is performing well.

Earth Pressure Cells

The earth pressure cells along the conduit have not functioned very well. Two of the six cells are no longer working and another is giving questionable readings. There has been a dissipation of pore pressures on the top of the conduit since construction. It is difficult to establish the trend of the pore pressures on the sides of the conduit. The two surviving cells indicate that the pressures are reasonable, but one shows that the pressure has dissipated since construction while the other has increased. Pore pressures around the conduit are in the anticipated range and in general have dissipated since construction.

CONCLUSION

Analysis of the data on Council Bluff embankment indicates that most of the parameters are as predicted. The initial upstream movement of the fat and lean clay zones is not unusual and has occurred in other dams. Stanley D. Wilson noted a similar situation on the Muddy Run Embankment in an article for Dam Engineering in 1968. Equilibrium of the phreatic surface takes many years in this type of structure, and requires a long-term commitment to monitoring.

Data collection and interpretation is important. But it is also important to recognize what constitutes a problem and to have a plan in mind should a problem occur. The designer established anticipated maximum values for the parameters being monitored. This was a great assistance and serves as a guideline for evaluation. It is also important to provide more responsive systems to evaluate potential problems. The embankment devices require time to collect information and can only be monitored periodically. They are located in specific areas and provide information only for those areas. Together, all of the data gives a good picture of how the embankment is performing. However, it is necessary to provide more responsive systems on some dams. Owners and managers of major dams need to consider these systems in view of their structure and downstream impacts.

Familiarity with instruments in a dam also identified information that would be valuable to collect but is not available. Surface movements on both the front and back crest of the embankment would have assisted evaluation from the beginning. It would also have been beneficial to locate some piezometers to better identify the pre-equilibrium phreatic surface.

LIST OF REFERENCES

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TABLE 1

DESIGN PROPERTIES OF EMBANKMENT MATERIALS

PROPERTIES	LEAN CLAY	FAT CLAY
Atterberg Limits	42	61
Liquid Limit, %	18	25
Plasticity Index		
Compaction Test (T-99)		
Max. Dry Density, PCF	109	100
Optimum Moist. Content, %	16	22
Shear Parameters		
Q-Test		
Angle of Int. Friction, Deg.	1	3
Cohesion, TSF	0.8	0.6
S-Test		
Angle of Int. Friction, Deg.	28	22
Cohesion, TSF	0	0

Note: The angle of Internal Friction for
Sand/Gravel = 30
Rockfill 36

Earth Pressure Cells
Located on Conduit

Pressure Cell	Max Antici-pated (Psi)	Actual Readings (Psi) 1981	1983	1985	1987
North Side #1	39-62	35	30	35	43
North Side #2	39-62	34	18	12	13
Top #1	117-156	150	107	51	46
Top #2	117-156	131	136	128	110
South Side #1	39-62	31	NW	NW	NW
South Side #2	39-62	36	34	NW	NW

Extensometers
Right Abutment

Extensometer	Max (Ft) Anticipated	Actual Movement (Ft.) 1981	1983	1985	1987
#1	.97	.32	.36	.36	.36
#2	1.11	.19	.23	.23	.23
#3	1.25	.87	.88	.88	.88
#4	1.39	.03	.05	.05	.05

TABLE 3

Piezometer Readings

Piezo-meter	Est.Const. Pore Pres.	Est. Full Pool Pres.	Oct. 1981	Oct. 1983	Nov. 1985	July 1987
FP1	-	46	11.1	31.1	37.1	38.7
FP2	-	41	23.5	-not working-		
FP3	-	23	13.7	16.6	23.3	23.8
FP4	-	7	19.7	15.7	17.9	17.2
P1A	78	26	0	4.2	12.8	16.8
P2A	78	26	0	x	24.8	x
P3A	77	20	0	6.4	9.8	11.3
P4A	77	20	0	4.9	9.3	11.5
P5A	-	0	0	0	0	0
P1B	-	24	---not working---			
P2B	50	20	0	0	0	0
P3B	50	7	0	0	0	0
P4B	-	0	0	0	0	0
P5B	-	0	0	0	0	0
P1C	-	5	0	2.8	7.7	8.8
P2C	25	0	0	0	0	0
P3C	26	0	0	0	0	0
P4C	-	0	0	0	0	0
PAP1	69	25	1.9	6.8	9.1	8.0
PAP2	62	25	0	6.9	8.7	8.3

Settlement Plates

Plate #	Initial Elevation (FT)	Settlement (Feet) Cumulative 1981	1983	1985	1987
1	995.53	.47	.64	.66	.68
2	1000.91	.50	.71	.70	.72
3	1006.39	.61	.95	.89	.91
4	1011.90	.93	1.33	1.36	1.37
5	1017.32	1.13	1.51	1.56	1.79
6	1022.78	1.34	1.69	1.80	1.83
7	1028.17	1.49	1.84	1.95	1.99
8	1033.55	1.59	1.95	2.04	2.09
9	1038.95	1.81	2.19	2.28	2.33
10	1044.29	1.78	2.16	2.25	2.30
11	1049.70	1.84	2.22	2.31	2.36
12	1055.08	1.97	2.35	2.44	2.50
13	1059.99	1.53	1.92	2.02	2.05
14	1065.38	1.63	2.13	2.10	2.14
15	1070.47	1.27	1.67	1.73	1.79
16	1075.83	1.18	1.57	-	1.84
17	1081.28	1.16	1.56	-	1.89
18	1086.48	1.00	1.40	-	1.92
19	1091.88	.95	1.52	-	2.04
20	1096.84	.60	1.36	-	1.84

TABLE 4

Surface Monument
Horizontal Movement

Monument #	1982	1983	1984	1985	1986	1987
1	.06D	.06D		.03D	.04D	.03D
2	.02U	.01U		.0	.01D	.00
3	.03U	.02U		.01U	.0	.01U
4	.04U	.04U		.04U	.05U	.06U
5	.04U	.04U		.05U	.06U	.06U
6	.03U	.03U		.04U	.04U	.05U
7	.02U	.02U		.03U	.02U	.04U
8	.00	.01U		.00	.01D	.00
9	.00	.00		.00	.01D	.01D
T-1						
T-2						
10				.02U	.0	.03D
11				.03U	.03U	.00
12				.04U	.03U	.03D
13				.07U	.05U	.00
14				.06U	.02U	.03D
15				.05U	.04U	.00
16				.04U	.01U	.03D
17				.01U	.0	.04D
18				.01U	.02U	.00

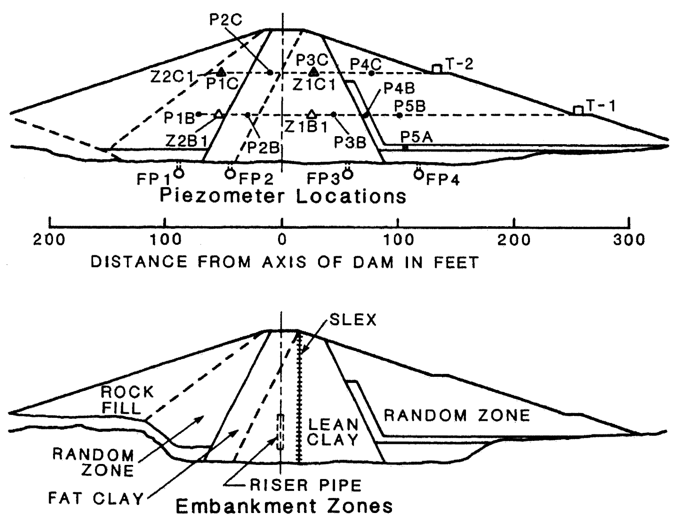
Settlement

Monument #	Initial Elevation	Settlement Cumulative (Feet) 1981	1983	1985	1987
1	1102.98	.03	.05	.01	.01
2	1103.22	.06	.25	.34	.41
3	1103.67	.09	.26	.27	.35
4	1103.87	.10	.14	.32	.44
5*	1103.75	.11	.19	.33	.43
6	1103.51	.07	.32	.36	.43
7	1103.53	.04	.03	.03	.08
8	1108.20	.03	.09	.17	.21
9	1103.08	.01	.02	.02	.01
T-1*	1065.64	+.02	+.03	.00	.01
T-2*	1031.48	+.07	+.12	+.08	.00
10**	1102.62			0	.04
11	1102.55			.06	.11
12	1102.63			.08	.26
13	1102.68			.13	.34
14	1102.43			.13	.35
15	1102.81			.10	.28
16	1102.62			.08	.24
17	1102.67			.03	.07
18	1102.75			.00	.03

* Predicted maximum settlement at Station 5 is 1.20 feet, T-1 is .3 feet, and T-2 .5 feet.

**The initial elevations for Surface Monuments 10-18 were established in 1984.

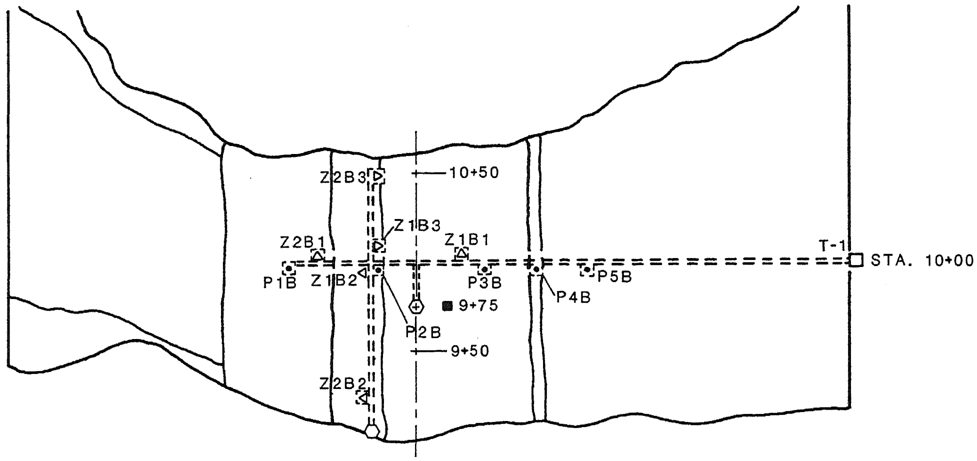
FIGURE 1: DAM SECTION STATION 10+00



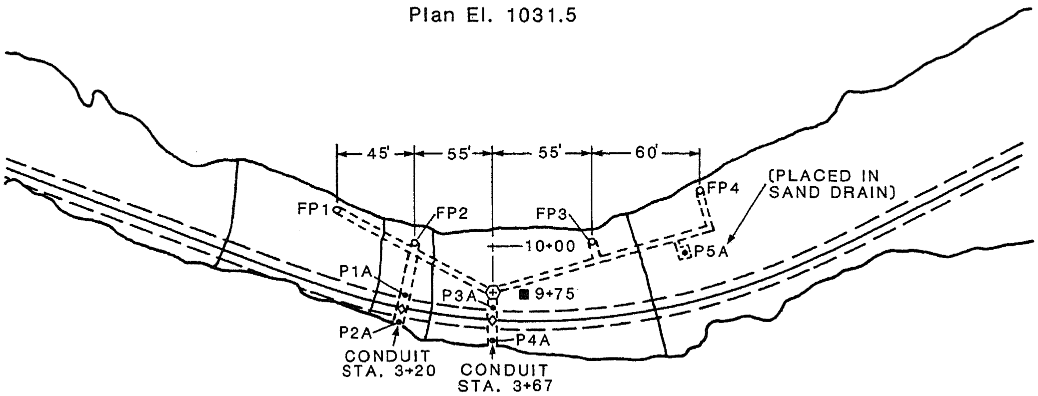
Legend: (Figures One and Two)

- o FOUNDATION PIEZOMETER (FP_)
- • EMBANKMENT PIEZOMETER (P__)
- △ TUBE PROFILE GAGE DATUM PLATE (Z___)
- ■ SLOPE INDICATOR AND EXTENSOMETER (SLEX)
- ⊕ RISER PIPE
- ◇ SET OF THREE SOIL PRESSURE CELLS (SP_)
- □ READOUT TERMINAL
- === INSTRUMENTATION TRENCH
- ○ RIGHT ABUTMENT INSTRUMENT LEADS

FIGURE 2: FOUNDATION AND ELEVATION 1031.5 INSTRUMENTS



Plan El. 1031.5



Plan El. 1004

FIGURE 3: COUNCIL BLUFF LAKE - Water Elevation Vs. Time