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Evaluation of Soil-Cement Cracking
McMicken Dam
Flood Control District of Maricopa County
Contract FCD 2004C068
Work Assignment No. 1

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Work Assignment No. 1

Submitted to:

Flood Control District of Maricopa County
Phoenix, Arizona

Submitted by:

AMEC Earth and Environmental, Inc.
Tempe, Arizona

Registered Professional Engineer (Civil)
CERTIFICATE NO.
40220
BRETT A.
HOWEY
Date Signed 4-13-06
ARIZONA, U.S.A.

April 13, 2006
AMEC Job No. 6-117-001007

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April 13, 2006
AMEC Job No. 6-117-001007

Michael D. Greenslade, P.E.
Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009-6399

Dear Mr. Greenslade:

Re: Evaluation of Soil-Cement Cracking
McMicken Dam
Flood Control District of Maricopa County
Contract FCD 2004C068
Work Assignment No. 1

Transmitted herewith is the final report for the referenced project which incorporates review comments provided by the Flood Control District of Maricopa County on March 30, 2006. The report includes the findings of a supplemental investigation and analyses completed to evaluate transverse cracking of the soil cement embankment extension of McMicken Dam.

Respectfully submitted,

AMEC Earth & Environmental, Inc.

Registered Professional Engineer (Civil) Certificate No. 40220 BRETT A. HOWEY 4-13-06 Date Signed ARIZONA, U.S.A.

Brett A. Howey, P.E.
Project Engineer

Reviewed by:

Registered Professional Engineer (Civil) Certificate No. 13872 LAWRENCE A. HANSEN 4/13/06 Date Signed ARIZONA, U.S.A.

Lawrence A. Hansen, Ph.D., P.E.
Senior Vice President

c: Addressee (4)

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Registered Professional Engineer (Civil)
CERTIFICATE NO.
40220
BRETT A.
HOWEY
Date Signed: 4-13-06
ARIZONA, U.S.A.

1.0 INTRODUCTION

This report presents the findings of a supplemental geotechnical appraisal to evaluate transverse cracking of the recently constructed soil-cement extension of McMicken Dam, and the potential impact these cracks may have on the stability and safe operation of the dam. The appraisal was designed to determine if the existence of transverse cracks has any adverse impacts to the original soil cement design criteria.

The investigation described herein was authorized by the Flood Control District of Maricopa County (District) during January 2006 as Work Assignment No. 1 of Contract FCD 2004C068. The appraisal involved field data collection and crack characteristic documentation. The goals of the work assignment included characterization of the soil-cement cracking, an appraisal regarding the source of transverse cracking, and an assessment to demonstrate the stability and safety of the dam extension have not been jeopardized by the cracking. Field activities included excavation of two (2) upstream test pits at two transverse crack locations, visible crack surface cleaning and photo documentation, and crack measurement documentation.

2.0 PROJECT DESCRIPTION

The overall purpose of the McMicken Dam Fissure Risk Zone Remediation (FRZR) Project was to modify McMicken Dam in accordance with the Arizona Department of Water Resources (ADWR) requirements and to mitigate potential hazards associated with an existing fissure risk zone. The soil-cement dam extension extends from about Station 75+00 westward about 1,400 feet. The mitigation design included the construction of a new soil-cement dam extension, removal of a section of the existing McMicken Dam and construction of a basin and diversion channel. The McMicken Dam FRZR Project was designed by AMEC Earth & Environmental, Inc. (AMEC) under Contract FCD 2002C011. Construction of the McMicken Dam FRZR Project was completed by DBA Construction under contract FCD2004C010.

3.0 INVESTIGATION

The following discussion summarizes the investigation methods and data collected for this evaluation. Data was collected during two site visits occurring on February 9 and 15, 2006. Attending the February 9, 2006, site visit was Lawrence A. Hansen, Ph.D., P.E. and Brett Howey, P.E., both with AMEC. Dr. Hansen and Mr. Howey were accompanied by Michael Greenslade, P.E. and Dennis Duffy, Ph.D., P.E., both with the District. Mr. Howey conducted the February 15 site visit and was accompanied by Mr. William Leal, with the District. The approach included surficial dam crest cleaning, test pitting, and field data collection.

3.1 Dam Crest Cleaning

During the February 9, 2006, site visit the dam crest was cleaned utilizing hand tools and brooms to remove loose surficial soils to reveal the underlying soil cement cracks. Individually observed cracks were cleaned for their observable extent. On February 15, 2006, the District provided a 3,500 gallon water truck which was used to water clean the crest of the soil cement section of the dam by means of a low pressure hose and nozzle. Due to an extremely rough soil cement surface and its close proximity to a critical dam tie-in, a portion of the crest near the existing embankment and soil cement section tie-in (from Station ±0+32 to ±0+75) was not as rigorously cleaned as the rest of the soil cement section. Sufficient information regarding the presence of transverse cracks was obtained so that the lack of rigorous cleaning at this isolated location did not affect the overall objectives of the investigation nor the findings of this report.

3.2 Test Pits

Two upstream test pits (TP-1 and TP-2) were excavated by means of a CAT 446B with a 24-inch bucket, provided by the District, at two crack locations that indicated the greatest open aperture at the dam crest. TP-1 was excavated at approximately dam Station 3+26 to a depth of approximately 8 feet below dam crest with a width of approximately 8 feet. TP-2 was excavated at approximately Station 2+49 to a depth of approximately 7 feet below dam crest to a width of approximately 8 feet. Both tests pits were excavated within the upstream landscape fill soils directly adjacent to the central soil cement section. Approximately 6 inches of the outer soil cement shell was removed at each crack location. Upon completion of the field investigation, the test pits were backfilled by District personnel with the previously excavated landscape fill spoils. The test pit locations are shown on Figure 1, and photographs of the test pits are presented in Appendix A.

3.3 Data Collection

3.3.1 Dam Crest Cracks

Cracks were visually identified and documented along the crest of the soil cement dam section by Mr. Howey. Documentation included approximate station, crack type, approximate width, and crack category. Each crack was visually categorized into one of the following four different categories:

- **Category Type A** – A transverse crack crossing the entire crest of the soil cement section, shows measurable open aperture (≥ 0.1 in) and is visually observed with minor surface cleaning.
- **Category Type B** – A transverse crack crossing the entire crest of the soil cement section, shows no measurable open aperture (hairline) and is visually observed with moderate surface cleaning.
- **Category Type C** – A crack that is transverse in direction but only partially crosses the crest of the soil cement section, shows no measurable open aperture (hairline) and is visually observed only with rigorous surface cleaning.
- **Category Type D** – Longitudinal or semi-polygonal "alligator style" cracking that is confined to small areas on the crest of the soil cement section and is visually observed with moderate to rigorous surface cleaning.

Station locations of each crack were measured utilizing the District's JAMAR Technologies, Inc. digital measurement device (±1 ft per mile tolerance) installed in the District Dodge Dakota pick-up truck. Stationing for the crack location documentation commenced from the crest monument point located at the intersection of the existing embankment dam and the newly constructed soil cement section, Station 0+42. All crack locations were measured relative to this point. Use of the truck mounted digital measurement device and the difficulty in following the exact dam extension centerline introduced some distance measurement error that had to be accounted for. When crest monuments at Station 5+40 and Station 10+40 were reached during the inspection, the distance measurement device indicated Stations 5+54 and 10+33 respectively. Therefore, the field measured crack station for cracks between monuments at Stations 0+42 and 5+40 were incrementally adjusted by (-)14 feet, cracks between Stations 5+40 and 10+40 were incrementally adjusted by (+)7 feet, and cracks between Station 10+40 and the end of dam extension were adjusted by (+)7 feet. Adjustments were made such that future measurements may be correlated with the dam stationing documented on the as-built drawings. A summary of the crack documentation is included in Table 1 with select digital photographs presented in Appendix A.

3.3.2 Test Pit Cracks

The cracks in both test pits were hand cleaned by a shovel and brushed clean to fully expose the encountered cracks to depth. The depth and width of each crack was documented with digital photographs recorded at a vertical interval of approximately every 2 feet. Photographs of the test pit cracks are presented in Appendix A.

4.0 FINDINGS AND EVALUATION

4.1 Dam Crest Crack Characteristics

Seventy two (72) crack discontinuities were identified within the crest of the soil cement section from dam Station 1+00 to Station 13+22. Nineteen (19) were classified as Category A cracks, twenty six (26) as Category B, twenty (20) as Category C, and seven (7) as Category D. The predominant crack feature was transverse in nature, with a lesser amount of longitudinal or alligator type cracking. Approximately 89 percent of the observed cracks were transverse. Of the 72 cracks approximately 26 percent of them showed a measurable open aperture of greater than 0.1 inch but less than or equal to 0.2 inches. The remaining 74 percent of the documented cracks were hairline in nature.

The average crack spacing for all transverse cracks (Categories A, B, and C) was approximately one (1) transverse crack for every 59 feet of dam crest length. The frequency of cracking for Category A cracks was one (1) for every 66 feet of dam crest length. Furthermore, the frequency of Category A cracking was fairly uniform for the entire length of the soil cement dam section, independent of soil cement section height or width. A plot of crack type vs. crack location is presented in Figure 2.

4.2 Test Pit Crack Characteristics

Two cracks located at Stations 2+49 and 3+26 were identified as having the greatest crack width of those observed and were therefore selected to be investigated further by means of two test pits at the upstream side of the dam. The two cracks observed in TP-1 and TP-2 showed similar characteristics, both of which exhibited a slightly more open aperture near the dam crest and then a fairly uniform width to depth. Additionally, crack propagation was through the concrete matrix and not through the soil cement aggregate. The transverse crack in TP-1 is approximately 0.2 inches in maximum width and is near vertical spatially. The crack did appear to occasionally shift sideways vertically at a soil cement lift, but not more than 0.5 feet horizontally. Similarly, the crack observed in TP-2 is 0.15 to 0.2 inches in maximum width and was near vertical with occasional horizontal shifting in vertical alignment at a lift line, but not more than 0.5 feet horizontally. Although the two select Category Type A cracks investigated were not investigated to full depth, it may be conservatively concluded that the transverse cracks investigate at these two locations likely extend to the soil cement foundation. .

4.3 Stability

Sliding along the soil cement/Pleistocene foundation contact and overturning analyses of two typical soil-cement sections were previously completed by AMEC to evaluate the stability of the soil-cement embankment section above the soil cement apron (AMEC, 2005)[1]. The overturning analyses also determined the pressure along the bases of the sections analyzed. Calculations and analysis results determined that the factors of safety (FOS) were within acceptable limits. It is worth noting that the analyses performed assumed a unit width dam section and conservatively ignored any additional sliding resistance effect that an adjacent section of soil cement may have on the overturning and sliding stability. Inclusion of the interaction would provide for additional resistance to movement resulting in a higher factor of safety.

4.4 Soil Cement Erosion

As part of the McMicken Fissure Risk Zone Remediation (FRZR) design extensive multi-layer foundation fissure modeling was performed to assess and validate the adequacy of a soil cement section. The fissure modeling was performed by G.W. Annandale and documented in a 2005 final report (Annandale, 2005). Of greatest interest as related to the transverse cracking is that the fissure modeling was used to verify that the soil cement was non-erodible. The Erodibility Index of the soil cement was conservatively estimated and compared to the erosive power of water running through a 0.5 inch wide crack. Using the Erodibility Index method Annandale (2005) estimated the resistive strength of the soil cement to be 56 kW/m^2. A 0.5 inch crack in the soil cement was evaluated and the available stream power calculated to be 1.4 kW/m^2, which is far less than the assumed 56 kW/m^2 threshold value of the soil cement. Soil cement strength properties assumed in the Annandale analysis for erosion threshold calculations were reasonably validated with the laboratory test results previously reported by

[1] References are listed in Section 8.

AMEC (2005). The available stream power through a 0.2-inch wide crack would be less than that through a 0.5-inch wide crack.

5.0 CONCLUSIONS

AMEC has determined by thorough inspection, documentation, and design analysis review that the current extent of transverse cracking within the realigned soil cement section of McMicken Dam does not adversely impact the safe operation for the following reasons:

- Sliding and overturning stability of the soil cement section has not been adversely impacted by the presence of the transverse cracks. As discussed in Section 4.3 the stability assessment previously performed by AMEC neglected the mobilization of sliding resistance created by an adjacent section of soil cement. Furthermore, the sliding resistance that could be mobilized is greatly increased by the irregular natural of the transverse cracks at each soil cement lift.

- As discussed in Section 4.4, previous analyses performed as part of the FRZR design, and validated by laboratory testing of soil cement cores, showed that erosion of the soil cement section by flow through a transverse cracks will not occur if the crack is as large as 0.5 inches in width. None of the cracks observed by AMEC exceeded 0.2 inches in open aperture.

- The observed interaction between the soil cement matrix and its aggregate indicated crack propagation was maintained in the matrix and was not through the aggregate. The deflection of the cracks around the aggregate increases the crack surface area roughness, thus creating a more tortuous condition that will restrict crack flow.

- The observed transverse cracking is the result of the curing and shrinkage of the soil cement section post construction. Considering the regular frequency of the cracking along the soil cement section and the sequence of appearance, the cracking is not the result of isolated foundation settlement or localized earth fissuring. This conclusion is further supported by foundation cracking not being observed during inspection of the downstream TDR instrumentation trench.

- Over the next couple of years, as the soil cement section continues to cure and age, the occurrence of additional transverse cracks and alligator type cracking should be expected. Occurrence of cracking should be limited due to the release of tensile stresses by the current transverse cracking.

6.0 RECOMMENDATIONS

AMEC recommends that the District continue annual inspections of the new dam section. Observed cracks should be documented sufficiently to allow periodic trend analysis. Crack width and crack intensity data should be collected and reviewed by a qualified dam safety engineer. Any cracks that exceed 0.5 inches in width should be further investigated by means of test pits with any remedial measures identified and implemented.

7.0 ADDITIONAL OBSERVATION DOCUMENTATION

Dr. Dennis Duffy, Ph.D., P.E., Senior Geotechnical Engineer, with the District, completed an independent observation documentation memorandum, dated February 13, 2006. AMEC has included a copy of his memorandum for additional information purposes in Appendix B.

8.0 REFERENCES

AMEC Earth & Environmental, Inc., 2005, Evaluation of Soil-Cement Dam Extension, McMicken Dam, Contract FCD 2003C014, Work Assignment No. 6, report submitted to the Flood Control District of Maricopa County, AMEC Job No. 5-117-001071, October 13.

Dennis Duffy, Ph.D., P.E., 2006, Memo to file, Observations of Soil Cement Embankment at McMicken FRS, Flood Control District of Maricopa County, February 13.

Engineering & Hydrosystems, Inc., 2005, McMicken Dam Multi-Layer Foundation Fissure Modeling, prepared for AMEC Earth & Environmental, Inc. and Flood Control District of Maricopa County, FCD Contract 2002C011, PCN 202.01.31, February 17.

TABLES

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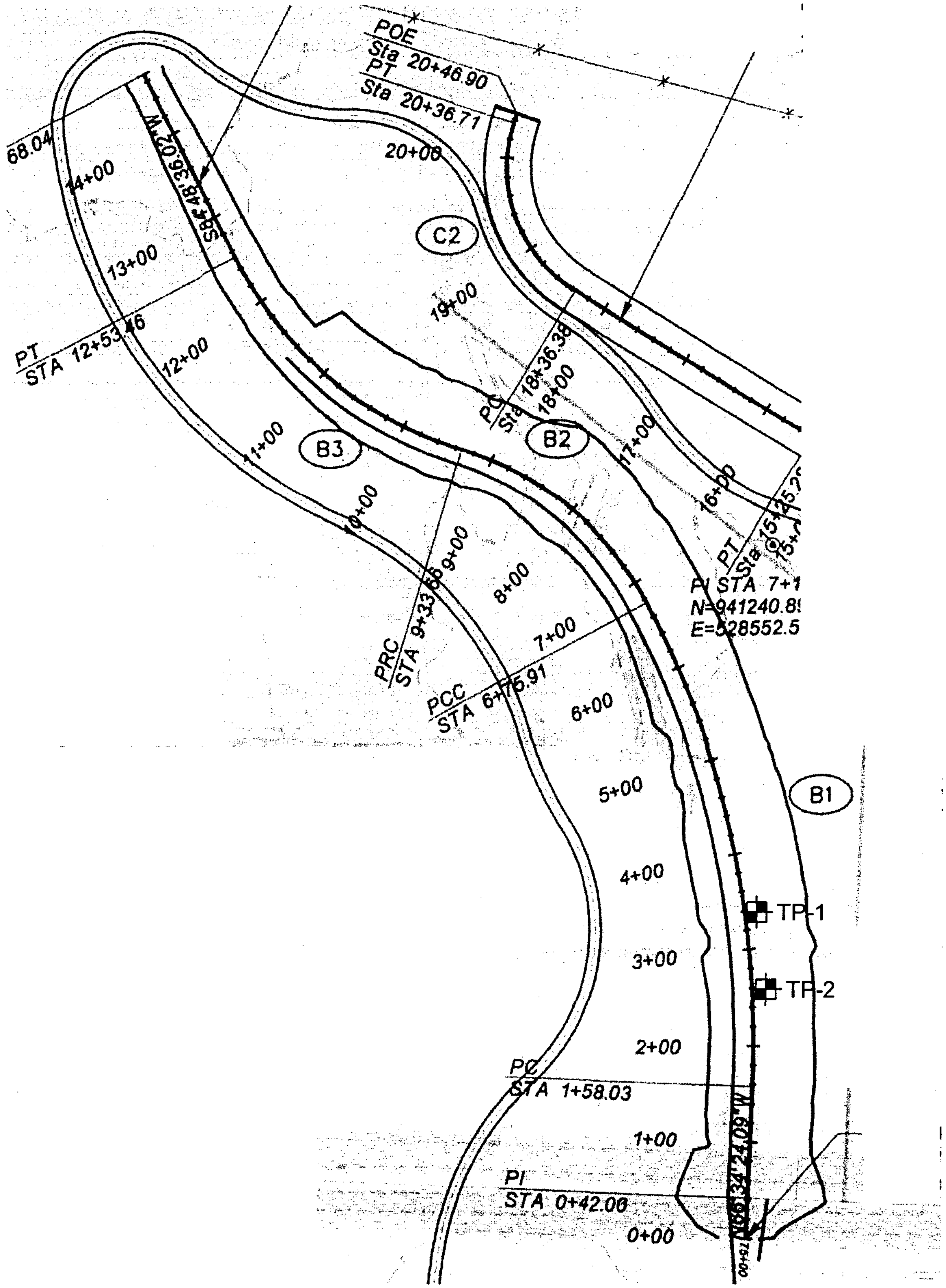
McMicken Dam
Soil Cement Crack Documentation
February 15, 2006

Dam Station (field measured)	Dam Station (adjusted)	Type	Width [in]	Category	Comment
1+00	1+00	Transverse	HL	C	
1+10	1+08	Transverse	HL	B	
1+31	1+28	Transverse	0.1 - 0.15	A	
1+46	1+43	Transverse	HL	C	
1+52	1+48	Transverse	HL	B	
1+60	1+56	Transverse	HL	B	
1+66	1+62	Transverse	HL	C	
1+80	1+76	Transverse	HL	B	
2+01	1+96	Transverse	0.1	A	
2+08	2+03	Transverse	HL	C	
2+50	2+44	Transverse	HL	B	
2+50	2+44	Longitudinal	HL	D	from Sta 2+44 to 2+49 and 5-ft from upstream shoulder
2+55	2+49	Transverse	0.15 - 0.2	A	
2+71	2+64	Longitudinal	HL	D	from Sta 2+64 to 2+71 and 4-ft from upstream shoulder
2+71	2+64	Transverse	HL	C	
2+90	2+83	Transverse	HL	B	
2+99	2+91	Transverse	HL	B	
2+99	2+91	Longitudinal	HL	D	from Sta 2+91 to 2+98and 5-ft from upstream shoulder
3+18	3+10	Transverse	HL	B	
3+35	3+26	Transverse	0.2	A	
3+46	3+37	Transverse	HL	C	
3+80	3+70	Transverse	HL	B	
3+91	3+81	Transverse	HL	B	
4+10	3+99	Transverse	HL	B	
4+24	4+13	Transverse	HL	C	
4+38	4+27	Transverse	HL	C	
4+65	4+53	Transverse	0.1	A	
5+20	5+06	Transverse	0.1	A	
5+58	5+44	Transverse	0.1	A	
5+62	5+48	Longitudinal	HL	D	from Sta 5+48 to 5+55and 6-ft from upstream shoulder
5+65	5+51	Transverse	HL	B	
5+71	5+57	Transverse	0.1	A	
5+81	5+68	Transverse	HL	C	Soil cement surface delamination in this area
5+97	5+84	Transverse	HL	C	
5+97	5+84	Longitudinal	HL	D	from Sta 5+84 to 6+01 and 5-ft from upstream shoulder
6+01	5+89	Transverse	HL	B	
6+03	5+91	Transverse	HL	B	
6+04	5+92	Transverse	HL	B	
6+07	5+95	Transverse	HL	B	
6+44	6+33	Longitudinal	HL	D	from Sta 6+33 to 6+41
6+44	6+33	Transverse	HL	B	This crack starts at the upstream and connects with crack 6+42
6+52	6+42	Transverse	HL	B	This crack starts at the downstream and connects with crack 6+33
6+56	6+46	Transverse	HL	B	
6+65	6+55	Transverse	0.1	A	
6+73	6+64	Transverse	HL	B	
7+11	7+03	Transverse	0.1 - 0.15	A	
7+42	7+36	Transverse	HL	B	
7+60	7+55	Transverse	0.1 - 0.15	A	
8+08	8+05	Transverse	0.1 - 0.15	A	
8+19	8+16	Transverse	HL	B	
8+28	8+26	Transverse	HL	C	This crack starts at the downstream side
8+34	8+32	Transverse	HL	B	
8+47	8+45	Transverse	0.1	A	
9+04	9+05	Transverse	0.15 - .2	A	
9+55	9+58	Transverse	HL	C	This crack starts at the downstream side
9+93	9+98	Transverse	0.1 - 0.15	A	
10+18	10+24	Transverse	HL	B	
10+39	10+46	Transverse	HL	B	
10+71	10+78	Longitudinal	HL	D	from Sta 10+78 to 10+84 and 6-ft from upstream shoulder
10+74	10+81	Transverse	HL	C	
10+77	10+84	Transverse	HL	C	
10+84	10+91	Transverse	HL	C	
10+87	10+94	Transverse	0.1 - 0.15	A	
11+24	11+31	Transverse	HL	C	
11+39	11+46	Transverse	HL	C	
11+74	11+81	Transverse	0.1 - 0.15	A	
12+61	12+68	Transverse	0.1	A	
12+71	12+78	Transverse	HL	C	
12+75	12+82	Transverse	HL	C	
12+83	12+90	Transverse	HL	B	
13+01	13+08	Transverse	HL	C	
13+15	13+22	Transverse	0.1	A	

Table 1.

FIGURES



LEGEND

TP-1 TEST PIT LOCATION

NORTH

JOB NO.	6-117-001007
DESIGN:	BAH
DRAWN:	GWH
DATE:	2/2006
SCALE:	N.T.S.

SITE MAP
SHOWING TEST PIT LOCATIONS

McMICKEN DAM - SOIL CEMENT CRACK EVALUATION

FIGURE 1

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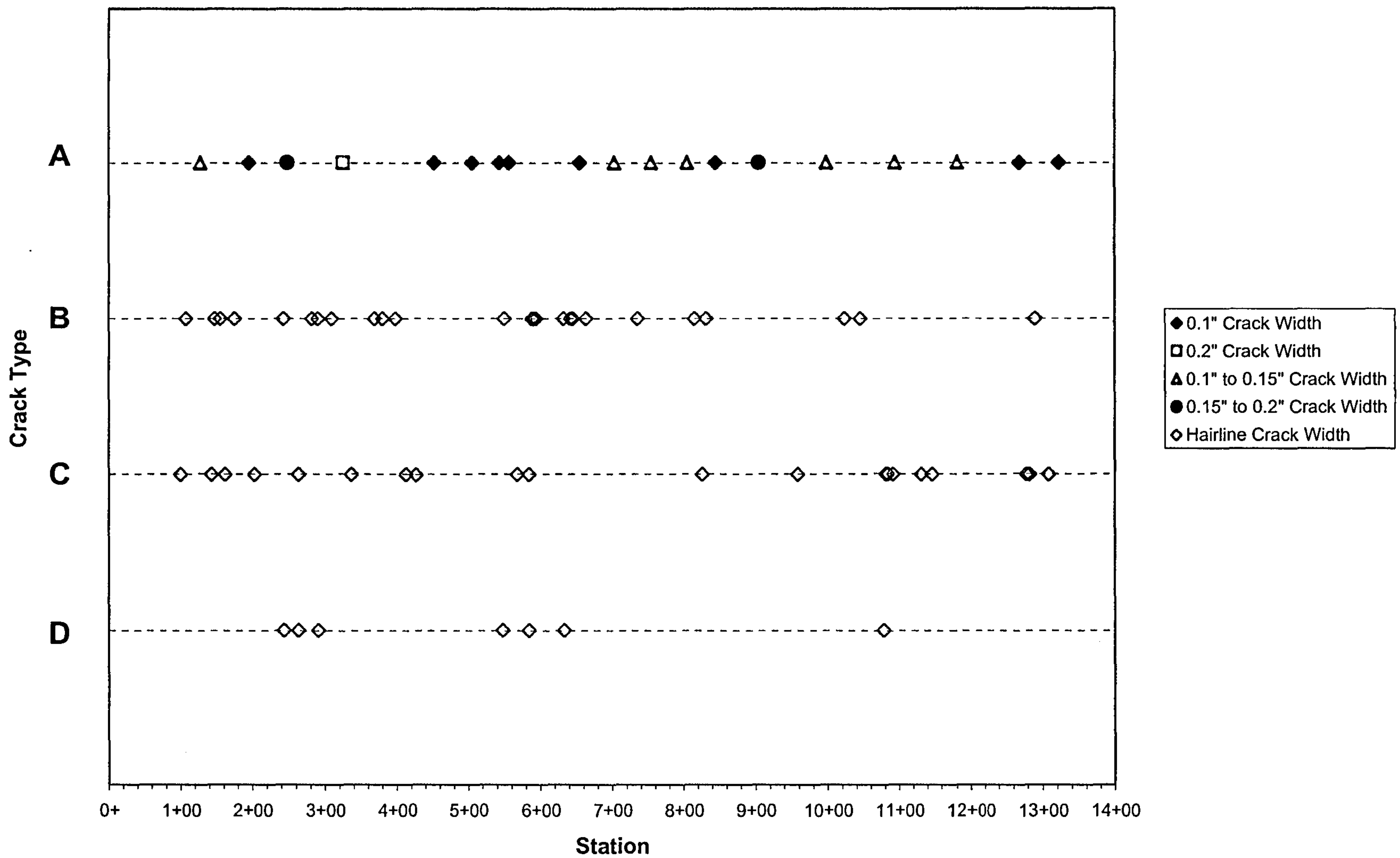
G:\Engineering Department\2006 Projects\6-117-001007 McMicken Dam FRZR Completion\Cad\Site Map.dwg

FIGURE 2.
Soil Cement Crack Type vs. Location
McMicken Dam Soil Cement Realigned Dam

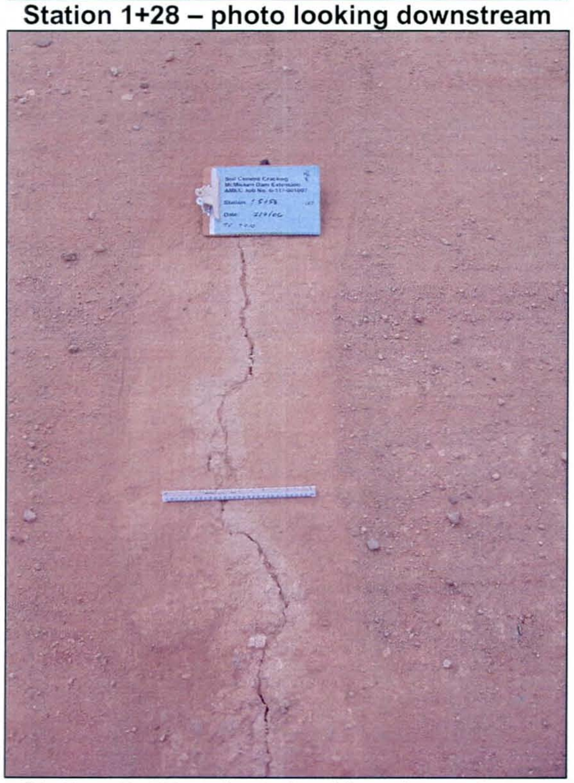


APPENDIX A

Photographs

Station 1+28 – photo looking downstream

Station 4+13 – photo looking downstream



Station 5+57 – photo looking downstream

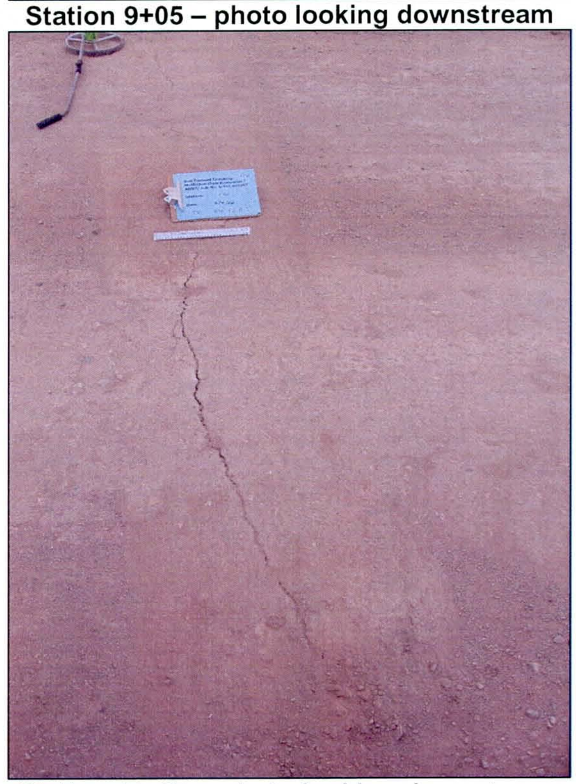
Station 7+55 – photo looking downstream

Note: Stationing shown on the blue marker in each photograph is inconsistent with the actual dam stationing. The stationing referenced in the photo description should be used for reference.

Station 8+05 – photo looking downstream

Station 9+05 – photo looking downstream

Station 10+94 – photo looking downstream



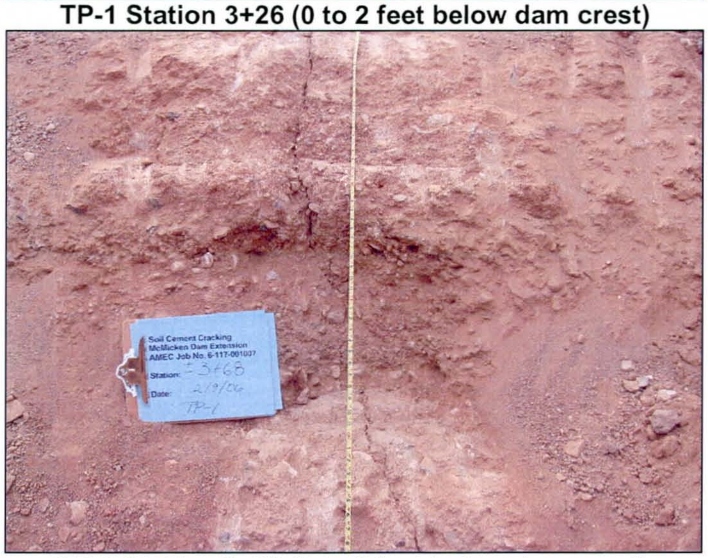
Station 11+81 – photo looking downstream

Note: Stationing shown on the blue marker in each photograph is inconsistent with the actual dam stationing. The stationing referenced in the photo description should be used for reference.

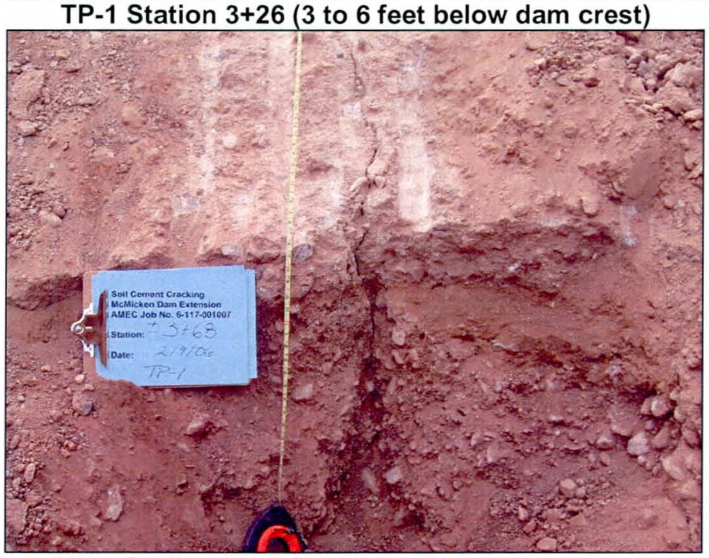
TP-1 Station 3+26 – photo looking downstream

Note: Stationing shown on the blue marker in each photograph is inconsistent with the actual dam stationing. The stationing referenced in the photo description should be used for reference.

TP-1 Station 3+26 (0 to 2 feet below dam crest)



TP-1 Station 3+26 (3 to 6 feet below dam crest)

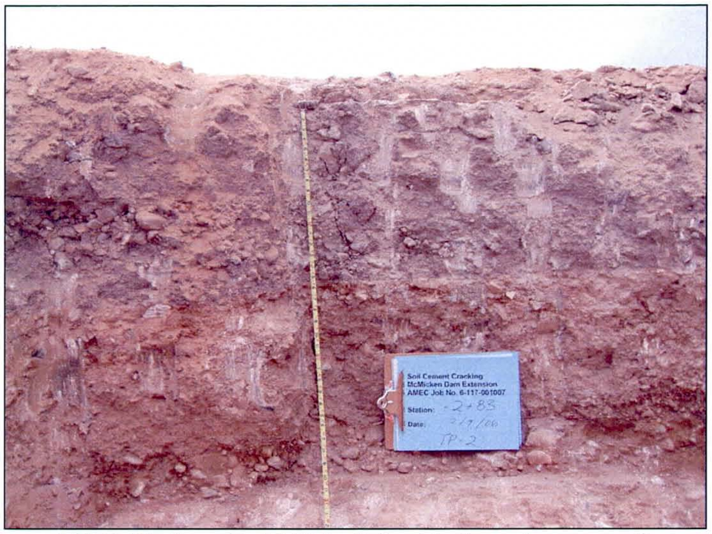


TP-1 Station 3+26 (6 to 8 feet below dam crest)

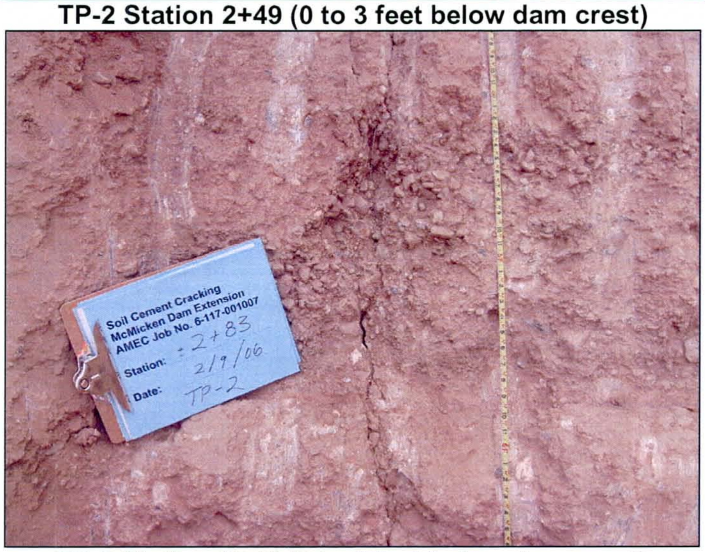
Note: Stationing shown on the blue marker in each photograph is inconsistent with the actual dam stationing. The stationing referenced in the photo description should be used for reference.

TP-2 Station 2+49 – photo looking downstream

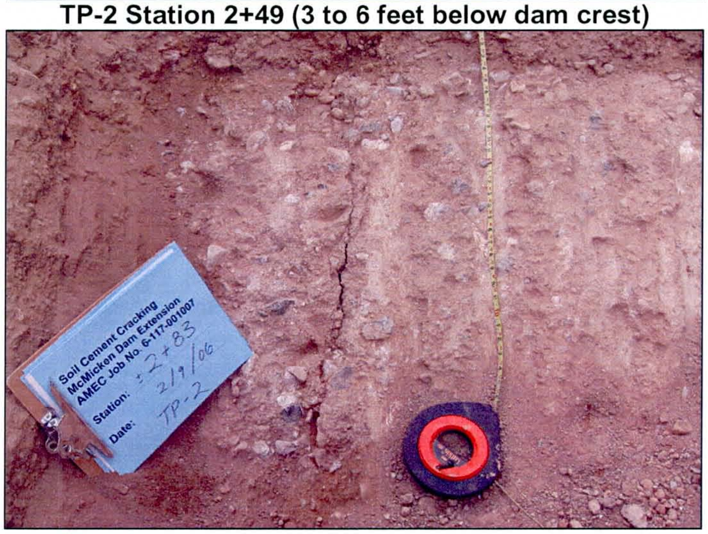
Note: Stationing shown on the blue marker in each photograph is inconsistent with the actual dam stationing. The stationing referenced in the photo description should be used for reference.



TP-2 Station 2+49 (0 to 3 feet below dam crest)



TP-2 Station 2+49 (3 to 6 feet below dam crest)



TP-2 Station 2+49 (6 to 8 feet below dam crest)

Note: Stationing shown on the blue marker in each photograph is inconsistent with the actual dam stationing. The stationing referenced in the photo description should be used for reference.

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APPENDIX B

Flood Control District of Maricopa County Memorandum

Memorandum

To: file
From: Dennis Duffy
Re: Observations of soil cement embankment at McMicken FRS
Date: 2-13-06

On 2-9-06 I visited the soil cement embankment section with Mike Greenslade My observations following from that visit are:

1. There were several types of cracks visible on the surface. There is a semi-polygonal pattern of thin cracks with approximate crack widths on the order of 1mm. The appearance of these cracks is similar to that of large dimension "alligator" cracks. This crack pattern lies primarily on the Western segment of the embankment. My impression of these cracks is that they are shallow in depth and non-continuous. These cracks are similar to the classical 120 degree angle cracks seen in many materials, plate 1.

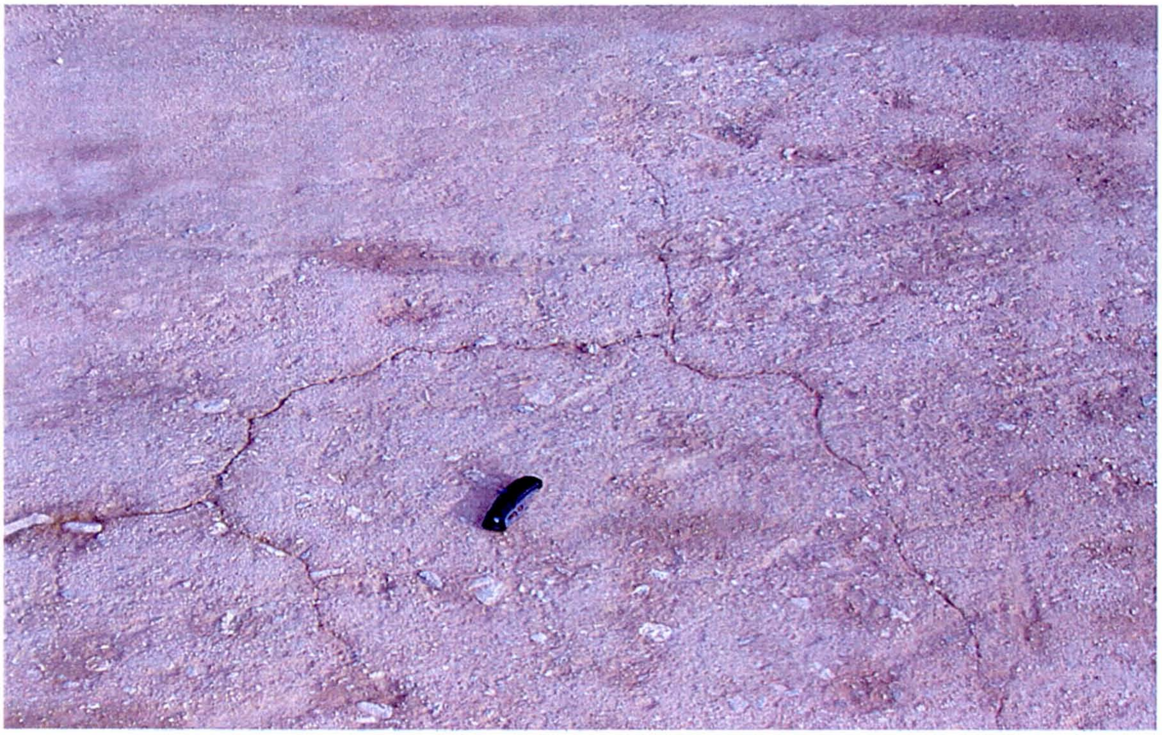

Plate 1 Polygonal crack pattern

There are two classical crack types shown in Plate 1 that are related to their respective times of cracking. The 120 degree cracking is associated with cracks developing at the same time. Cracks that terminate at a crack are formed after the terminating crack existed. The release of tensile stresses at the existing crack is believed to be the reason the later crack does not pass beyond the existing crack. In the work of Bohn, Pauchard, and Couder, (2005) the development of both crack patterns is depicted by sketch and photos. In the sketch noted by Bohn, Pauchard, and Couder as FIG. 1 the progression of crack formation, as time changes, is provided. In their FIG. 3 the 120 degree cracks in (a) form at the same time associated with a defect. The (b) image depicts the terminated cracking that develops over time.

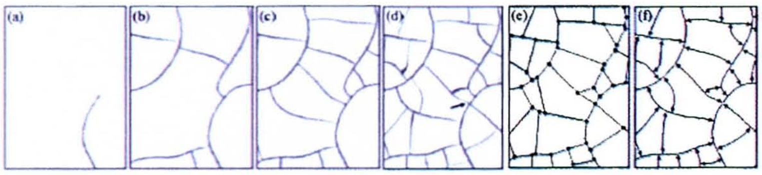

FIG. 1. (a)–(d) Photographs of the formation of a crack pattern. (e) The representation of the final pattern (d) as an embedded graph. The disks represent the nodes, the lines the edges. (f) The reconstructed cracks. The arrow heads indicate the geometrical hierarchy relation between them.

After Bohn S. Pauchard L. and Couder Y. Physical Review E. 71, 046214 (2005)

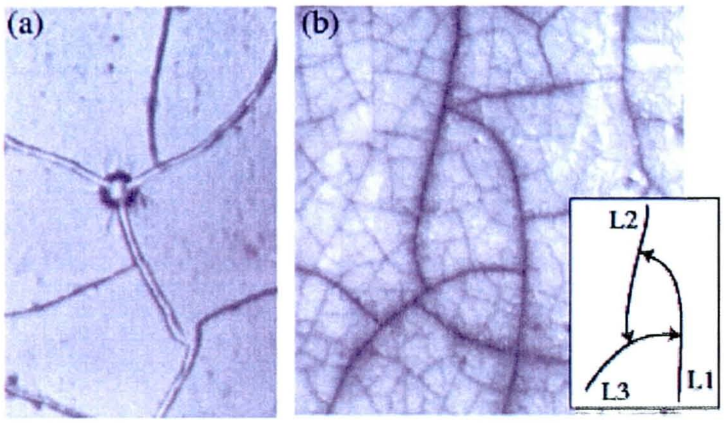

FIG. 3. Two cases where the introduced description must fail. (a) A triplet of cracks is formed at a defect of the layer. (b) Three fractures form a loop.

After Bohn S. Pauchard L. and Couder Y. Physical Review E. 71, 046214 (2005)

The cracks depicted by Bohn . Pauchard . and Couder, (2005) are seen in drying mud flats, fired ceramics, and geological structures, such as at the Concentrator Fault near Superior Arizona. The surface crack patterns found at the McMicken soil cement embankment are therefore not unique.

2. Cracks that have widths larger than 1 mm and appear to run transverse across most of the soil cement embankment crest, Plate 2. These cracks appear to persist for some depth and to have an almost constant dam axes period of less than 100 feet. These cracks appear to run across the crest as a single line with some surface widening that appears to be surface damage due to vehicle traffic.

Plate 2 transverse crack that persists across the soil cement embankment crest

3. Transverse cracks that have bifurcated and do not progress across the soil cement embankment crest as a single crack line were also detected, Plate 3. These cracks sometimes

form rectangular blocks with length to with ratios of approximately 2 or 3. These cracks appear to extend to some depth.

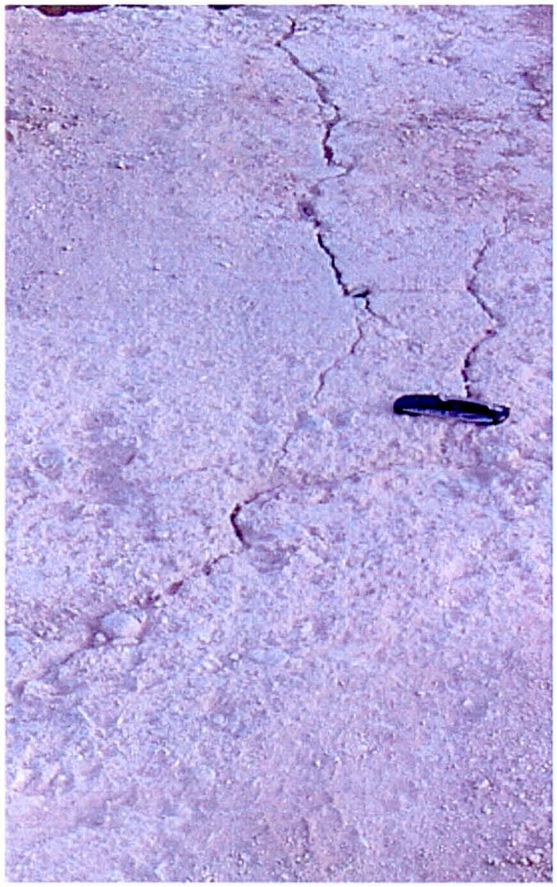

Plate 3 transverse cracks with a bifurcated crack pattern

Greenslade had trenches excavated exposing the 2nd and 3rd types of crack, Plate 4. Both types of cracks were traced to the full depth of excavation. Neither crack ran in a continuous plane from the crest to full depth, Plate 4.

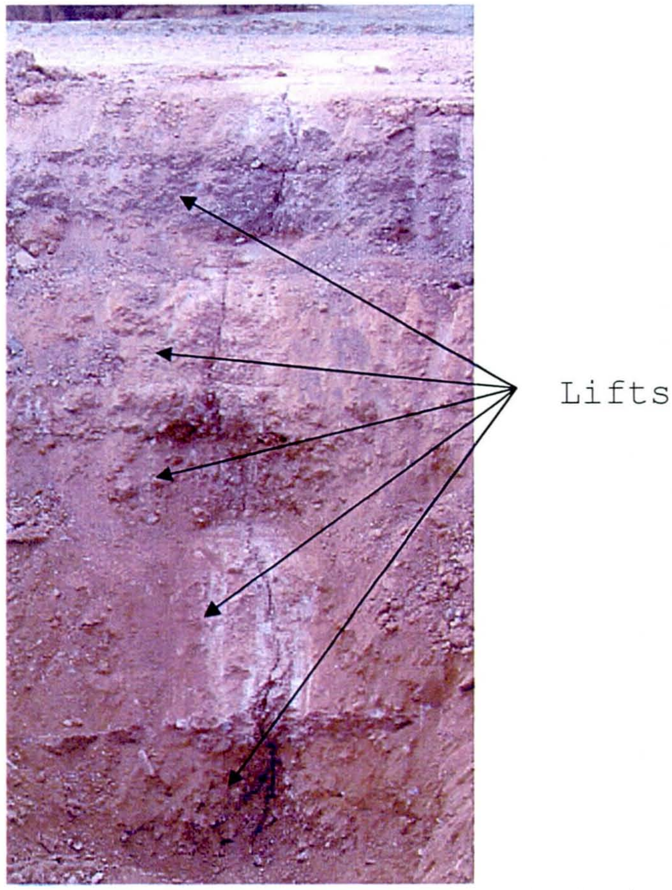

Plate 4 Lift influence on Crack offset and plainer geometry

All exposed cracks expressed offset as they traversed what appear to be lifts of the soil cement. The 3rd type of crack also split into two separate cracks in small segments of the exposure. Crack widths appeared to be essentially constant with depth. All lifts of the soil cement were visibly moist and in some areas the adjacent soil was also moist. The soil cement sections I examined were primarily granular in appearance.

A closer view of the trench shown in Plate 5 shows some additional characteristics of the soil cement, Plates 5a and 5b. In Plates 5a & 5b gouge marks from the teeth on the bucket can be seen. The gouge marks are evidence of strong resistance to abrasion. The backhoe used to make the trenches had to use impact blows with the teeth to break off chunks of the soil cement. At several times the backhoe could not develop sufficient down force to excavate the soil cement. The operator was forced to raise the bucket to maximum height and then "slam" it down to fracture the soil cement.

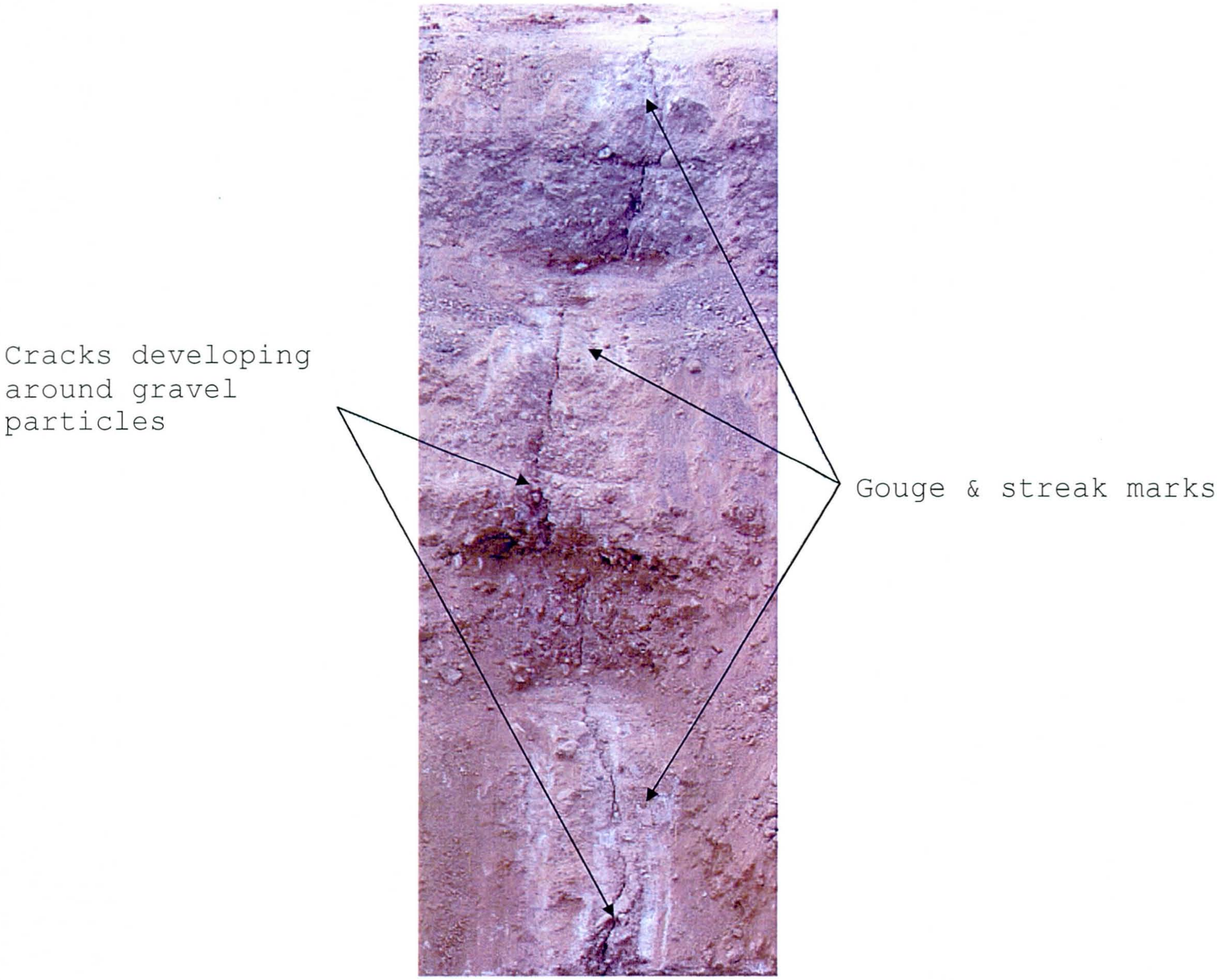

Plate 5a with gouge and streak marks from excavator teeth visible, trench 1

Plate 5b with gouge and streak marks from excavator teeth visible, trench 2

The importance of the gouge marks shown in Plates 5a and 5b, is significant. The soil cement embankment is intended, in part, to prevent embankment erosion subsequent to earth fissure formation and reservoir filling at McMicken FRS. The streak marks are clear evidence of resistance of soil cement particles to movement. Since the soil cement is insoluble to reservoir water the flow of water through such cracks will produce little if any crack erosion. In neither excavation, Plate 5a nor Plate 5b, is there evidence of layer disbanding in spite of the excavation difficulty.

An additional observation involves the interaction between the larger aggregate within the soil cement and the propagating crack. As can be seen in Plates 1 through 5 propagating cracks go around large aggregate instead of breaking through them. Unlike high strength concrete, where cracks should propagate through the aggregate, the soil cement cracks go around the aggregate. Some of the crack segments passing around aggregate are noted on Plate 4. This crack deflection around larger particles also contributes to crack surface roughness. Crack offsetting and tortuisity will increase flow boundary layer resistance and thus act to restrict crack flow, Plates 2, 3, 4 and 5.

In neither excavation was the backhoe able to produce disbanding of the soil cement layers. In spite of the impact blows of bucket teeth against the soil cement layers no disbanding was observed. This is interesting because it would be expected that reflected energy from a upper layer strike would be reflected off of an underlaying layer. This reflection of energy would tend to produce disbanding in layers of different materials. Some examples are reactive armor used on military vehicles, and explosives used in rock excavations to fragment and remove rock.

During the crack inspection efforts a water truck was used to wash off the surfical accumulation of soil. During this process the operator was instructed to direct the full stream along a transverse crack. The stream from a 2 inch diameter fire hose through a fire nozzle, set for maximum flow, was applied for 30 seconds to a crack. Plates 6 and 7 show the crack before and after the jetting action of the nozzle directed flow.

Plate 6 Soil cement crack before high pressure jet is applied

Plate 7 Soil cement crack after high pressure jet applied for 30 seconds. Pump running at full throttle with focused jet less than 8 feet away from crack

Plates 6 and 7 reinforce the belief that the soil cement embankment is not only resistant to mechanical excavation it is resistant to fluid erosion. There is no appreciable erosion of the crack seen in Plate 7. There is slight crack widening in some segments of the crack that are believed due to the removal of soil cement damaged by heavy vehicle traffic. The presence of gravel size particles in the soil overlying the soil cement are believed to be "driven" by tires into the cracks and as a result damage the sides of the cracks. It is the damaged fragments that were jetted away while the non traffic damaged segments remained at constant width under the jetting action.

I observed nothing in the excavations or exposed on the embankment surface that makes me believe that erosion of soil cement exposed to seepage should be a concern. I recommend that the surface cracks should continue to be observed. A photographic program that is based on visual changes over time would be well suited to the McMicken FRS. Four or five crack areas representing the types of cracks present today should be sufficient.