MOISTURE VARIATION

Three Rivers Levee Improvement Authority **4-5-07**

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Introduction

This technical memorandum serves as a supplement to the previously submitted Construction Documentation Report (CDR) for the Three Rivers Levee Improvement Authority (TRLIA) levee repair project. This memorandum has been prepared in response to a USACE review comment concerning a number of field tests that did not meet the acceptance criteria for optimum moisture content variation, found in section 3.2.3.5 of the CDR. Particular attention was placed on material that was placed dry of the optimum moisture content, as discussed herein. This memorandum includes revised analysis of the QC field compaction moisture data, with accompanying assessments and conclusions regarding the suitability of the placed fill materials. An in-depth analysis of the laboratory compaction curves and field density tests has been performed to better illustrate the as-constructed conditions. The QC manager, Sierra Testing Laboratories, has provided three letters (one for each phase of work) dated 30 March 2007, confirming the updated data and affirming that the construction activities met the design objectives.

Similar analysis of the quality assurance (QA) field compaction moisture data is included in the attached memo titled “Statistical Analyses of QA Moisture Content Data” (Kleinfelder 2007), prepared by the QA manager Kleinfelder, Inc. Kleinfelder has also provided a letter, dated March 30, 2007, regarding their field observations during construction and including an affirmation that the construction activities met the design objectives.

Revised Statistical Analyses of QC Compaction Data

Purpose of Revisions

Revisions to the construction QC data summaries and statistical analyses have been completed following closer inspection of the field and laboratory compaction data. Revisions have been based on:

- Updated QC Data Sets.
- Exclusion of Aggregate Base (AB).
- Exclusion of Random Fill.

The reasons for these data changes are presented below. A discussion of the revisions to the statistical analysis is presented in the next section.

Quality Control Updates

Sierra Testing Laboratories reviewed the QC data sets and found several errors with the referencing of field density tests and laboratory compaction curves, as noted in their letters dated 30 March 2007. Updated data tables were issued and included in the statistical analysis.

Exclusion of Aggregate Base and Random Fill

In the original analysis, moisture content was erroneously examined regardless of fill type and location. Upon further inspection of the specifications and the test data, it was determined that field density data for both aggregate base and random fill were included in the analyses. The specifications do not include moisture content requirements for these two material types. Aggregate base was used on the levee crown, outside of the levee prism and above the design levee crown elevation. Random fill was used for seepage berms along the Bear River North Levee (BRNL) and for ditch fill along the Western Pacific Interceptor Canal (WPIC). The following statistical analysis does not include aggregate base or random fill materials.

Revised QC Statistical Analysis

Phase 1

Revisions to Phase 1 statistical analysis include the removal of test results for the AB placed on the levee crown. This resulted in the removal of 8 samples. The QC data was updated to reflect inconsistencies in the laboratory curve data and the corresponding field density tests. Incorrect curves were used for 20 field density tests.

Phase 1 data included two material types; existing levee material and imported impervious fill material. Table 1 shows a breakdown of the material types and the corresponding moisture variation tests that did not meet the specifications. Though the number of tests was even for the two material types, two thirds of the test results on the dry side of optimum occurred in the existing sandy levee material. Due to the sandy nature of the existing levee material, it was decided that the sandy material placed dry of optimum would not have a significant affect on the compacted engineering properties. (Note that all existing levee materials did meet the density requirements). For this reason, focus has been placed on the clayey impervious fill material.

Table 1 - Phase 1 Moisture Tests Summary

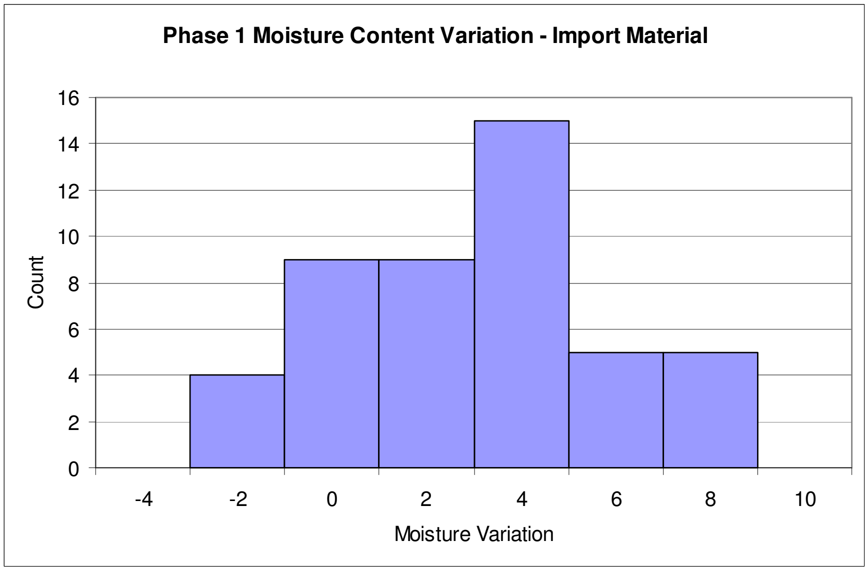
MOISTURE VARIATION – PHASE 1					
Phase 1	**# Tests**	**Tests Outside of Specified Range**	**% Tests Outside of Specified Range**	**Tests Below Specified Range**	**% Total Tests Below Specified Range**
All Tests	94	41	43.62%	18	19.15%
Impervious Fill	47	19	40.43%	6	12.77%
Existing Levee Material	47	22	46.81%	12	25.53%

After revising the statistical analysis and focusing on impervious material, the number of test results located outside the moisture variation specification decreased from 43 to 19, as shown in Table 2. Of these 19 tests, 6 lie below the specified range. This amounts to roughly 13% of the total tests. Figure 1 shows the data distribution. Note that the data is skewed to the wet side of optimum moisture content.

Table 2 - Revised Statistical Analysis for Phase 1

MOISTURE VARIATION – PHASE 1		
Value	**Old Data**	**New Data**
Number of Samples	102	47
Minimum	-3.3	-3.3
Maximum	9.8	7.6
Mean	1.4	1.9
Standard Deviation	2.8	2.7
Total Tests Not Meeting Requirements	43	19
Tests Below Specified Range	18	6

Figure 1- Distribution of Phase 1 Moisture Variation



The majority of the samples not meeting moisture variation requirements, including the 6 samples that lie below the specified range, were taken from the upper 3 feet of the reconstructed levee in the zone of freeboard. Material in this region of the levee is not as integral to the stability and performance as the material within the levee embankment, as discussed in Kleinfelder's letter dated 30 March 2007.

Phase 2

Revisions to Phase 2 statistical analysis included the removal of test results for the AB placed on the levee crown as well as random fill used for Bear River seepage berms and WPIC ditch fill. Repeated tests were also removed where material was removed and replaced due to failing compaction tests. Material placed outside of the levee prism as backfill for Pump Station #6 and for the construction of maintenance roads was also removed. Four samples were added for the WPIC extension completed in February 2007. This resulted in the net removal of 374 samples. Table 3 shows the breakdown of the data removed from the statistical analysis with the corresponding feature.

Table 3 - Summary of Data Removed

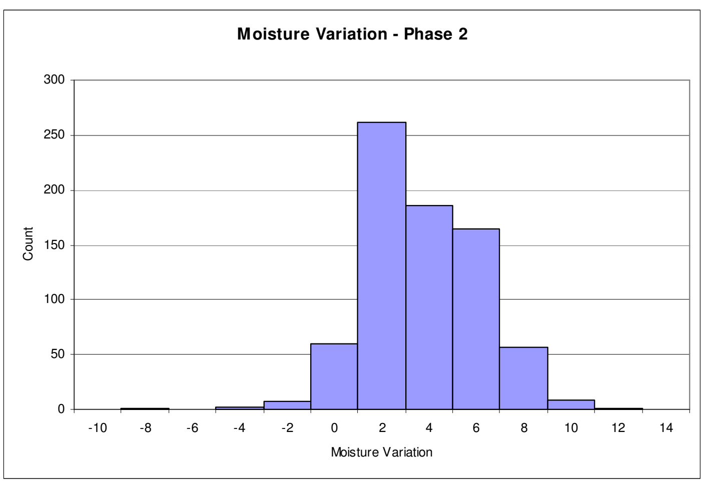
Feature	WPIC	Bear River	ODB	Total
Random Fill	74	30	-	104
Aggregate Base	58	-	-	58
Failed Tests	11	8	-	19
PS #6	-	181	-	181
Maintenance Road	-	2	10	12
Total	**143**	**221**	**10**	**374**

The QC data was updated by Sierra Testing Laboratories to reflect inconsistencies in laboratory curve data and the field density test results, as referenced in their letter dated 30 March 2007. As noted in Table 4, the number of test results not meeting the specifications for moisture variation decreased from 767 to 421. Of these 421 tests, 9 lie below the specified range. This amounts to roughly 1% of the total tests. One of these 9 tests was located in the freeboard zone. Figure 2 shows the data distribution. Note that the data is skewed to the wet side of optimum moisture content.

Table 4 - Revised Statistical Analysis for Phase 2

MOISTURE VARIATION – PHASE 2		
Value	**Old Data**	**New Data**
Number of Samples	1119	749
Minimum	-6.2	-9.5
Maximum	11.9	10.8
Mean	2.6	2.7
Standard Deviation	3.1	2.4
Total Tests Not Meeting Requirements	767	421
Tests Below Specified Range	95	9

Figure 2 - Distribution of Phase 2 Moisture Variation



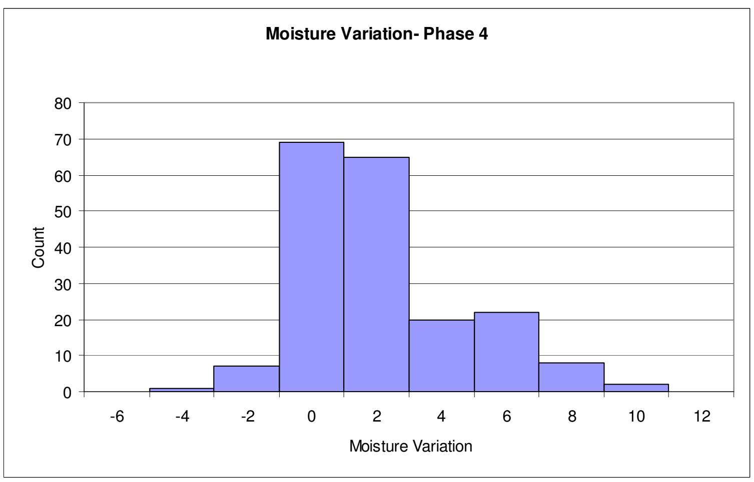
Phase 4

The revisions to the Phase 4 statistical analysis included an update of the QC data to reflect inconsistencies in laboratory curve data and the field density test results as referenced in their letter dated 30 March 2007. As noted in Table 5, the number of test results not meeting the specifications for moisture variation decreased from 104 to 57. Of these 57 tests, 6 lie below the specified range. This amounts to roughly 3% of the total tests. One of these 6 tests was located in the freeboard zone. Figure 3 shows the data distribution. Note that the data is skewed to the wet side of optimum moisture content.

Table 5 - Revised Statistical Analysis for Phase 4

MOISTURE VARIATION – PHASE 4		
Value	**Old Data**	**New Data**
Number of Samples	194	194
Minimum	-8.6	-4.3
Maximum	9.3	9.2
Mean	0.8	1.1
Standard Deviation	3.36	2.60
Total Tests Not Meeting Requirements	104	57
Tests Below Specified Range	37	6

Figure 3 - Distribution of Phase 4 Moisture Variation



Summary

With the above-mentioned revisions, the statistical data for moisture variation changed significantly. Table 6 shows a summary of the revised QC analysis. According to the new analysis, the percentage of test results located below the specified moisture content is roughly 2% of all tests, or 21 samples out of 990. Of the 21 dry samples that were below the optimum moisture range, 8 were located in the freeboard zone. Approximately 50% of the total tests were above the specified moisture content range.

Table 6 - Summary of Revised Analysis

MOISTURE VARIATION SUMMARY					
Phase	# Total Tests	Total Tests Not Meeting Requirements	% Total Tests Not Meeting Requirements	Number of Tests Below Specified Range	% Total Tests Below Optimum
1	47	19	40.43%	6	12.77%
2	749	421	56.21%	9	1.20%
4	194	57	29.38%	6	3.09%
Total	990	497	50.20%	21	2.12%

Analysis of the QA data for moisture variation for Phase 1, 2 and 4 was completed by the Construction Quality Assurance manager (Kleinfelder) and can be found in the attached memorandum titled "Statistical Analyses on QA Moisture Content Data" (Kleinfelder 2007).

Evaluation of QC Laboratory and Field Data

Laboratory compaction curves were created using ASTM D 1557 per the construction specifications. The resulting moisture-density curves were used to calculate the maximum dry density and optimum moisture content upon which the field density tests were based. Each curve represented one or more field density tests.

In order to illustrate the field conditions a range of laboratory moisture-density curves were selected based on the number of field tests corresponding to each curve and the overall nature of the respective field results. Three curves were taken from Phase 1 and included 62 field density tests, or roughly 66% of the test results. 25 curves were taken from Phase 2 and included 351 field density tests, or roughly 47% of the test results. 5 curves were taken from Phase 4 and included 36 field density tests, or roughly 19% of the test results. Significantly more laboratory curves were completed for Phase 4, resulting in fewer field density tests per curve and consequently lower percentage of test results examined.

The corresponding field density results were plotted on the moisture-density curves and are included in this report. The optimum moisture content range, compaction requirement and zero air voids (ZAV) curve were also plotted. Some notable trends throughout the data set are;

- The laboratory curves met expectations regarding shape and trends.
- The field density tests were generally clustered to the wet side of optimum moisture content.
- Some field density results were located above the ZAV curve, signifying a testing anomaly or inconsistent test result. These were generally the samples with the highest moisture content.

- Some field density results were located above the moisture density curve, signifying an inconsistent test result.

The following sections discuss specific features and significant findings for each phase of work, along with a selection of moisture-density curves. The remaining curves selected for this report can be found in the enclosed attachment.

Phase 1

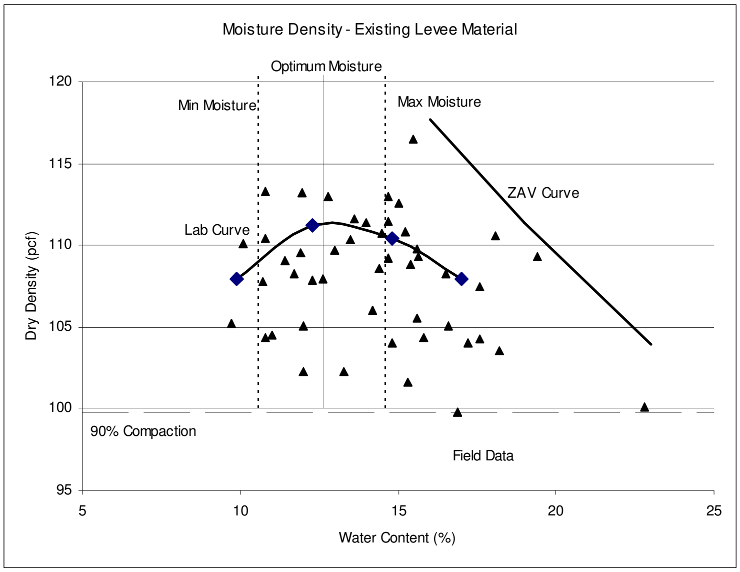
Of the 3 moisture-density curves examined for Phase 1, two represented imported material and one represented the existing levee material discussed above. The breakdown of each curve and the quantity of field density tests they represent is included in Table 7.

Table 7 - Curve Summary for Phase 1

SUMMARY OF CURVES – PHASE 1	
Curve No.	**No. of Field Tests**
1	47
2	9
3	6
Total	**62**

The field density tests for the existing levee material (Curve No. 1) show a wide scatter of data that include many tests above and below the specified range. Figure 4 shows this laboratory curve. Several data points are located above the laboratory curve. Due to the sandy nature of the material, the test results for existing levee material were not included in the updated statistical analysis.

Figure 4 - Laboratory Curve for Phase 1 Existing Levee Material



Phase 2

Of the 25 curves examined for Phase 2, 8 came from the WPIC, 13 from the BRNL, and 4 came from the Olivehurst Detention Basin (ODB). The breakdown of each curve and the quantity of field density tests they represent is included in Tables 8 through 10.

Table 8 - Curve Summary for Phase 2 WPIC

SUMMARY OF CURVES – PHASE 2 WPIC	
Curve No.	**No. of Field Tests**
24	21
26	6
27	35
31	41
32	17
33	15
236	14
Total	**163**

Table 9 - Curve Summary for Phase 2 BRNL

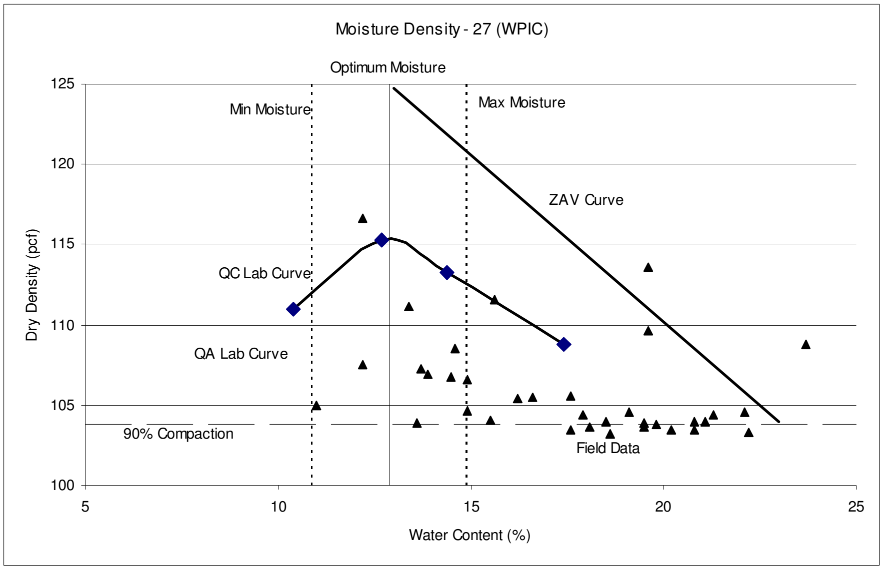
SUMMARY OF CURVES – PHASE 2 BRNL	
Curve No.	**No. of Field Tests**
10	2
16	9
18	11
23	8
31	11
32	7
68	24
69	9
87	9
90	15
99	12
102	19
110	7
Total	**143**

Table 10 - Curve Summary for Phase 2 ODB

SUMMARY OF CURVES – PHASE 2 ODB	
Curve No.	**No. of Field Tests**
13	5
14	17
24	12
46	11
Total	**45**

The WPIC moisture-density curves had a small number of tests that were located outside of the ZAV. Figure 5 shows the curve for WPIC 27, which has two points in this region. There are several possible sources for this error, such as incorrect laboratory-field correlation or errors in the testing procedure. WPIC 27 represents 35 field density tests over 6000 feet of levee, so variability is expected.

Figure 5 - Laboratory Curve for WPIC 27



The BRNL and ODB laboratory curves did not have significant issues other than those already mentioned above. The selected curves for these two levee reaches, along with the remainder of the WPIC curves, are included in the enclosed attachment.

Phase 4

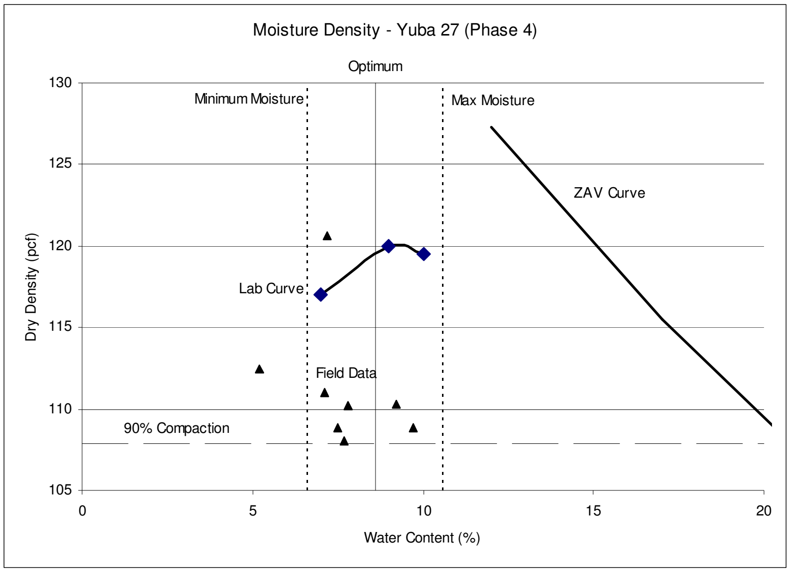
For the Phase 4 analysis, 5 laboratory curves were selected that represented the most field density tests, in this case all curves with more than 6 tests. The breakdown of each curve and the quantity of field density tests they represent is included in Table 11.

Table 11 - Curve Summary for Phase 4

SUMMARY OF CURVES – PHASE 4	
Curve No.	**No. of Field Tests**
27	8
98	6
109	6
131	9
160	7
Total	**36**

The Phase 4 laboratory curves did not have significant issues other than those already mentioned above. The curve for Yuba 27 is shown below. Yuba 27 represented the most field density tests of all the curves for Phase 4. This particular figure shows the majority of the tests passing the optimum moisture content requirements, with the exception of one test that is on the dry side and another that lies above the compaction curve. The remaining curves are included in the enclosed attachment.

Figure 6 - Laboratory Curve for Yuba 27



Conclusions

With the inclusion of updated QC data tables and the exclusion of material that was not applicable to the moisture content requirement, the statistical analysis for optimum moisture content for Phases 1, 2, and 4 of the TRLIA levee repairs project has been revised. The revised QC data has been prepared by Sierra Testing Laboratories, and in their letter from a registered engineer dated 30 March 2007 they have stated that the project "has been constructed and tested in general accordance with the plans and specifications and with the standard care and practice of the area for similar construction".

The revised statistical analysis shows that the instances of moisture contents being too dry of the specified moisture range occurred in a relatively low percentage of overall tests (less than 2%). As noted by the Construction Quality Assurance manager Kleinfelder in their 30 March 2007 letter, many of the dry of optimum portions of the impervious fill occurred above the design water surface elevation. The remaining failed tests represent a significantly smaller portion of the total tests taken.

The statistical analysis indicates that about half of the moisture-density tests showed moistures that were above the specified range. As was discussed by Kleinfelder in their 30 March 2007 letter, the Quality Assurance field personnel, who were on site full time during fill compaction, allowed the contractor to place the material wet of optimum to achieve the desired engineering properties. QC and QA testing data has confirmed that, while all placed material met the density requirement, many were wet of optimum. No evidence of pumping or yielding was observed by the QC or QA inspectors during compaction. All compacted materials were accepted by the QA inspectors in the field.

An in-depth examination of laboratory moisture density curves and in-field density tests also revealed some minor discrepancies (e.g., moisture density data points that plotted outside the Zero Air Voids curve) that should be expected from large earthwork projects. The variability of the field test method inherently leads to anomalies in the results that can lead to these discrepancies. These discrepancies represent a very small percentage of the total tests completed.

Field observations during construction of the levee repairs were performed full time by qualified QC and QA personnel. These independent inspectors observed the compaction activities and found no significant departure from accepted construction standards. Considering the recommendations of field personnel and representatives of the QC and QA program, it is our opinion that the moisture content variation is not a concern and that the degree of compaction and associated engineering properties of the levee fill materials meet the design intent of the levee repairs.