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PREVIOUS COMMERCIAL RCC TESTING RESULTS

LEVY NUCLEAR PLANT

Engineering & Construction Management
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Environmental Engineering & Permitting

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PROJECT NO. 07-3935

PREVIOUS COMMERCIAL RCC TESTING RESULTS
LEVY NUCLEAR PLANT
REVISION 0

PROJECT NO. 07-3935
OCTOBER 7, 2010

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PREVIOUS COMMERCIAL RCC TESTING RESULTS
LEVY NUCLEAR PLANT
REVISION 0

1.0 PURPOSE

This Report is intended to provide the reader with background information regarding prior testing performed by Paul C. Rizzo Associates, Inc. (RIZZO) as part of commercial applications of roller-compacted concrete (RCC). As discussed in the teleconference with the U.S. Nuclear Regulatory Commission (NRC) on June 8, 2010, descriptions of representative RCC test programs and results from large commercial RCC construction projects are provided herein. This information is intended to supplement the response to the NRC Request for Additional Information (RAI) 03.08.05-4 regarding the testing programs associated with the RCC bridging mat proposed for LNP 1 and 2 (LNP Bridging Mat).

This evaluation of Commercial RCC Projects serves as Phase I of the RCC Test Program, as presented on ***Table 1-1*** below. The remaining Phases of the LNP RCC Test Program are further discussed in ***Section 4.4***.

TABLE 1-1
RCC TEST PROGRAM OVERVIEW

PHASE	PROGRAM DESCRIPTION	TIME FRAME
I	Evaluation of Commercial RCC Projects	Pre-COL
II	Mix Design (At least 14 RCC mixes, 5 Bedding mixes)	Pre-COL
III	Laboratory Testing (At least 1 RCC mix, 1 Bedding mix) to Verify RCC Thermal Properties and Joint Strength	Pre-COL
IV	On-Site Test Pad to Verify Production Equipment and Contractor Methodology	Post-COL
V	Quality Control Inspection Program during Bridging Mat construction	Post-COL

2.0 PROJECT DESCRIPTIONS

Information from the Saluda Dam Remediation, the Taum Sauk Upper Reservoir Rebuild, and the Bear Creek Dam projects are presented as representative major commercial RCC design/construction projects that have direct applicability to the types of design, testing, and construction activities that will be performed at the Levy Nuclear Plant.

Brief overviews of the Saluda Dam Remediation, the Taum Sauk Upper Reservoir Rebuild, the Bear Creek Dam project, and the proposed LNP Bridging Mat are presented in the following subsections. The size of the projects is compared in ***Table 2-1***.

TABLE 2-1
RCC VOLUME COMPARISON

PROJECT	VOLUME OF RCC (CUBIC YARDS)
Saluda Backup Dam	1,300,000
Taum Sauk Upper Reservoir	2,840,000
Bear Creek Dam	76,000
LNP Bridging Mat (each)	49,500

2.1 SALUDA DAM REMEDIATION PROJECT

The Saluda Dam Remediation Project primarily consisted of the construction of a "backup dam" at the downstream toe of the existing Saluda Dam near Columbia, South Carolina. The original dam is a semi-hydraulic fill embankment dam, constructed in 1930, and impounds Lake Murray. Due to the method of construction, the dam was determined to be susceptible to liquefaction during a large earthquake event. The calculated extent of liquefaction is significant; thus, repairing the existing dam would have been difficult and costly. Therefore, RIZZO developed a remediation design consisting of constructing a backup dam at the downstream toe of the existing dam. This backup dam consists of 5,500 linear feet of rock fill berm (approximately 3.5 million cubic yards) with a center gravity dam section of about 2,300 linear feet of RCC (approximately 1.3 million cubic yards). RIZZO served as Engineer-of-Record and Construction Manager for this Project, which was completed in 2006. The completed RCC dam is shown on ***Figure 2-1***.

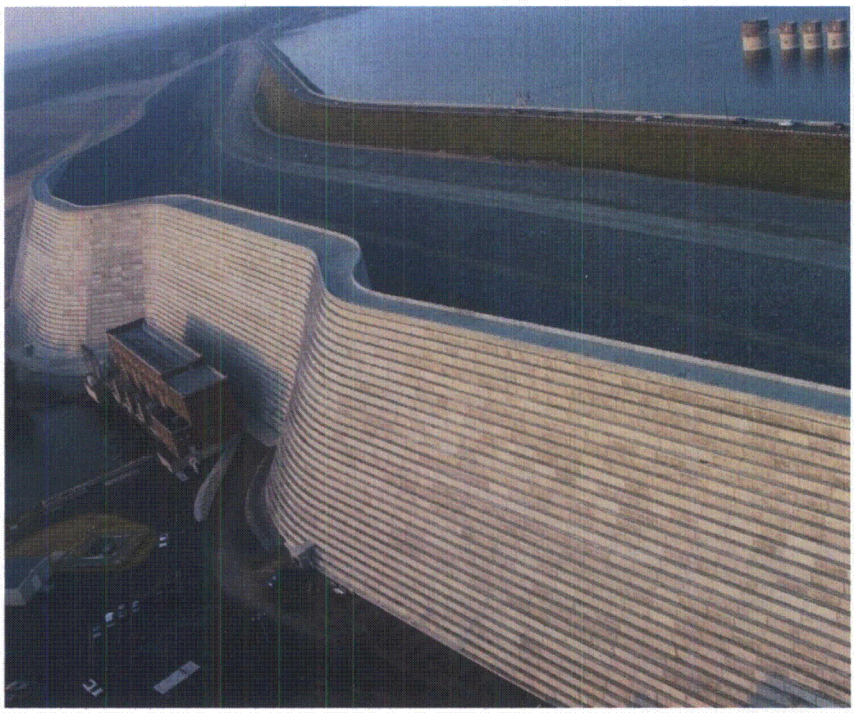

FIGURE 2-1
COMPLETED SALUDA BACKUP DAM

2.2 TAUM SAUK UPPER RESERVOIR REBUILD

The Taum Sauk Plant Upper Reservoir Dam Rebuild involved the construction of a 2.84 million cubic yard RCC dam to impound the Upper Reservoir of this Pumped Storage Project in Reynolds County, Missouri. The original rock fill embankment dam failed on December 14, 2005 after overtopping. The embankment breached over a width of about 700 feet, causing a catastrophic, uncontrolled, rapid release of water down the west slope of Proffit Mountain. RIZZO was hired by the dam owner (AmerenUE) to conduct the forensic analysis on the original dam, and later to design the replacement dam. RIZZO is the Engineer of Record for the replacement dam and acted as the Construction Manager for the rebuild. The Project, which is regulated by the Federal Energy Regulatory Commission (FERC), was completed in 2010. The completed Upper Reservoir is shown on ***Figure 2-2***.

FIGURE 2-2
COMPLETED TAUM SAUK RCC DAM

2.3 BEAR CREEK DAM

The Bear Creek Dam project involved the construction of an RCC dam at the downstream toe of the existing Bear Creek Dam in Franklin County, Alabama. The original dam is a homogeneous rolled fill embankment dam, constructed from compacted residual soil. The RCC dam was constructed to address seepage issues with the existing dam, as well as to provide a dam capable of meeting seismic and probable maximum flood demands. The RCC dam is approximately 1,200 feet long and approximately 68 feet high at the maximum section. It is comprised of approximately 76,000 cubic yards of RCC. RIZZO designed this dam and performed quality control and inspection during its construction, which was completed in 2009. ***Figure 2-3*** shows the completed Bear Creek Dam.

FIGURE 2-3
COMPLETED BEAR CREEK DAM

2.4 LNP BRIDGING MAT

The Levy Nuclear Plant Nuclear Island foundation concept consists of a RCC bridging mat, placed in 35 one-foot lifts between elevation -24 ft NAVD88 and elevation 11 ft NAVD88.

The LNP Bridging Mat is designed to replace weakly cemented, undifferentiated Quaternary and Tertiary sediments that are present between El -24 ft NAVD88 (the approximate location of a geologic unconformity) and El 11 ft NAVD88 (the lower elevation of the AP1000 Nuclear Island Basemat), thereby creating a uniform subsurface with suitable bearing capacity. The Bridging Mat will also be capable of bridging postulated karst features that are conservatively estimated to exist in the underlying Avon Park Limestone. Each Bridging Mat is anticipated to be approximately 49,500 cubic yards of RCC.

3.0 RCC MATERIALS

RCC primarily consists of aggregate, cement, fly ash, and water. The following subsections discuss the materials used in past commercial RCC projects and how past experience influenced material selection for the LNP mix design.

3.1 AGGREGATE

As shown in ***Table 3-1***, successful RCC mixes have been produced when using aggregate with high specific gravity, low absorption, and low loss to LA Abrasion. When selecting materials for the LNP mix design, this experience was incorporated by establishing a minimum specific gravity of 2.6, a maximum absorption of 1.0%, and a maximum loss to LA Abrasion of 40%.

TABLE 3-1
AGGREGATE COMPARISON

PROJECT	AGGREGATE SOURCE	ROCK TYPE	NUMBER OF STOCKPILES	SPECIFIC GRAVITY	ABSORPTION (%)	LA ABRASION (%)
Saluda	On-Site	Gneiss	3	2.65	0.6	23
Taum Sauk	On-Site	Rhyolite	2	2.62	0.7	< 20
Bear Creek	Commercial	Limestone	2	2.63	1.6	31
LNP (Targeted)	Commercial	Granite	3	> 2.60	< 1.0	< 40

Table 3-1 also indicates that past projects have used either two or three aggregate stockpiles of varying gradations. These stockpiles are then blended to meet a specified combined gradation. The specified combined gradations for the three commercial projects, as well as the targeted combined gradation for the LNP mix design, are shown in ***Table 3-2***.

The main advantage of a two stockpile system is its simplicity, as there are fewer stockpiles to maintain and blend. When the aggregate is manufactured on-site, as it was at Taum Sauk, it is possible to crush the stone to meet the specified gradation using two stockpiles. When using commercial aggregates, it is more difficult to achieve the desired gradation with just two stockpiles. This is illustrated by the combined gradation of the Bear Creek project, where two commercial aggregates were used. While the gradation is similar to that used in Saluda and Taum Sauk, it was not possible to achieve the same results, especially for the very coarse and

very fine particles. Using three stockpiles (anticipated for the Levy Nuclear Plant) allows for greater control over the combined gradation, especially when commercial aggregates are to be used.

TABLE 3-2
AGGREGATE GRADATION SPECIFICATION

SIEVE SIZE	PERCENT PASSING BY WEIGHT			
	SALUDA	TAUM SAUK	BEAR CREEK	LNP (TARGETED)
2"	99 – 100	100	100	100
1.5"	97 – 100	95 – 100	99 – 100	95 – 100
1"	80 – 90	75 – 87	91 – 93	75 – 87
¾"	67 – 78	68 – 80	-	68 – 80
½"	55 – 67	56 – 70	63 – 72	56 – 70
3/8"	48 – 60	49 – 63	-	49 – 63
No. 4	40 – 50	38 – 50	39 – 51	38 – 50
No. 8	30 – 40	28 – 38	31 – 38	28 – 38
No. 16	22 – 31	21 – 31	23 – 28	21 – 31
No. 30	17 – 25	15 – 24	-	15 – 24
No. 50	12 – 19	10 – 18	14 – 17	10 – 18
No. 100	7 – 12	7 – 13	-	7 – 13
No. 200	3 – 7	4 – 10	9 – 11	4 – 10

3.2 FLY ASH

Fly ash is commonly used in RCC to replace a fraction of the cement. This contributes to strength gain at later ages while reducing the heat of hydration generated by the mix. As described in detail in ***Sections 4.1, 4.2, and 4.3***, RIZZO has evaluated fly ash replacement ratios ranging from 0 – 80 percent in past mix designs. It has been found through testing on trial mixes that a 50% replacement ratio performs well, and the production mixes for all three commercial projects have used 50% cement and 50% fly ash.

Past mix designs have also investigated the use of both Class C fly ash and Class F fly ash, as defined by ASTM C 618. Both classes of fly ash have pozzolonic properties, but Class C ash also has cementitious properties, thereby contributing to the heat of hydration. Prior testing and experience has shown that Class F is preferable, and it is anticipated that commercial Class F fly ash will be used at the Levy Nuclear Plant.

As shown in ***Table 3-3***, pond ash was used at both Saluda and Taum Sauk. Pond ash is fly ash that has been stored in a pond to reduce environmental contamination through airborne dispersion. Although using this ash required additional handling controls during production, its use demonstrates that both commercial and noncommercial pozzolans can be used in RCC.

TABLE 3-3
FLY ASH SUMMARY

PROJECT	SOURCE	FLY ASH CLASS	REPLACEMENT RATIO (% BY WEIGHT)
Saluda	McMeekin Station Pond Ash	n/a[1]	50
Taum Sauk	Meramac Pond Ash	F	50
Bear Creek	Colbert Plant Silo Ash	F	50
LNP (Anticipated)	Commercial	F	50

[1]This ash met project requirements for pozzolanic effects, but did not meet Class F requirements for gradation, loss on ignition, and moisture content.

3.3 CEMENT

The cement used in past commercial RCC projects has either been Type I/II or Type II cement, as defined by ASTM C 150. These types of cement are preferred because they have a lower heat of hydration and, in combination with fly ash replacement, contribute less to heat generation. ***Table 3-4*** summarizes the cement suppliers used for past projects, including the cement supplier that is anticipated for use during the LNP Phase II mix design.

TABLE 3-4
CEMENT SUMMARY

PROJECT	CEMENT TYPE	SUPPLIER
Saluda	I/II	Holcim – Holly Hill
Taum Sauk	I/II	Buzzi – Festus
Bear Creek	II	National Cement
LNP (Anticipated)	II	American Cement - Pennusco

4.0 MIX DESIGN PROCESS

The mix design process is used to determine the most economical proportions of cementitious materials (Portland cement and fly ash) and water required to produce the required RCC consistency, strength, and thermal properties using the selected aggregates. A baseline mix is established and properties are varied to evaluate the effect on strength and workability. A summary of the final mixes selected from this process is provided in ***Table 4-1***. The following subsections provide more detail regarding the process by which the properties were evaluated and the mixes selected.

TABLE 4-1
FINAL RCC MIXES

PROJECT	SPECIFIED F'C (PSI)	CEMENT (LB/CY)	FLY ASH (LB/CY)	TARGET VEBE (S)
Saluda	2300	150	150	27
Taum Sauk	1500	100	100	n/a[1]
Bear Creek	2000	130	130	30

[1]The RCC used at Taum Sauk was a low paste, low strength mix. Therefore Vebe time was not specified.

4.1 SALUDA

The RCC mix design program for the Saluda Dam project consisted of four phases. Phases I, II, and III were laboratory mix designs, while Phase IV was associated with a test pad program.

The Phase I Mix Design Program began in May 2000 and concluded in May 2001 with the completion of 365 day strength testing. Phase I consisted of a total of 13 mixes with 336 test cylinders molded from those mixes throughout the week of May 15, 2000. These 13 mixes were further subdivided into four categories of mixes. Mixes from Categories 1, 2, and 4 were batched for information only and will not be discussed in detail. The 10 Category 3 mixes were the potential design mixes, batched with varying amounts of fly ash, cement, aggregate, and water. These 10 mixes are summarized in ***Table 4-2***. Note that the fly ash content for all mixes is greater than 350 pounds per cubic yard (pcy), and the fly ash replacement ratio ranges from 68 to 84 percent. These values are much higher than the fly ash content used in the final mix shown in ***Table 4-1***. The unit weights for the Category 3 mixes ranged from 145.3 pcf to 148.6 pcf.

These values were considered low, and were attributed to the high fly ash content causing an increased water demand, resulting in increased pore volume.

TABLE 4-2
SALUDA PHASE I, CATEGORY 3 RCC MIXES

MIX NO.	PHASE I MIX ID	CEMENT (LB/CY)	FLY ASH (LB/CY)	C+FA[1] (LB/CY)	WATER (LB/CY)	W/(C+FA)[2]	180-DAY COMPRESSIVE STRENGTH (PSI)
2	Mix 3(2): 162+382 (70.2)+(8.0)	162	382	544	497	0.349	3597
3	Mix 375: 75+382 (83.6)+(8.2)	75	382	457	310	0.570	840
4	Mix 3100: 100+382 (79.4)+(8.1)	100	382	482	310	0.678	2006
5	Mix 3200: 200+382 (65.6)+(7.9)	200	382	582	310	0.643	4303
6	Mix 3-.8: 162+382 (70.2)+(7.3)	162	382	544	310	0.533	3663
7	Mix 3-.4: 162+382 (70.2)+(7.6)	162	382	544	281	0.517	3749
8	Mix 3.4: 162+388 (70.5)+(8.3)	162	388	550	293	0.539	3282
9	Mix 3.8: 162+351 (68.4)+(9.6)	162	351	513	324	0.589	3421
10	Mix 3A: 150+392 (72.3)+(4.7)	150	392	542	340	0.663	3372
11	Mix 3T: 162+382 (70.2)+(8.0)	162	382	544	190	0.351	2639

[1] C+FA = Cement + Fly Ash (cementitious content)
[2] W/(C+FA) = Water-Cementitious Ratio

The Saluda Phase II Mix Design Program was undertaken to optimize the final RCC mix to be used by determining the optimum fly ash content. This was accomplished by observing the sensitivity of strength and other properties as they are affected by varying the fly ash content. The Phase II mix design consisted of texting 6 mixes, as shown in ***Table 4-3***. Note that the Phase II mixes had both a lower fly ash replacement ratio and lower fly ash content. The unit weights of these mixes ranged from 146.4 pcf to 150.6 pcf, and the water demand was reduced compared to Phase I.

TABLE 4-3
SALUDA PHASE II RCC MIXES

MIX NO.	PHASE II MIX DESIGNATION	CEMENT (LB/YD)	FLY ASH (LB/CY)	C+FA[1] (LB/CY)	WATER (LB/CY)	W/(C+FA)[2]	180-DAY COMPRESSIVE STRENGTH (PSI)
1	127+153 (54.6)+(6.1)	127	153	280	243	0.868	1775
1A	128+153 (54.4)+(5.9)	128	153	281	243	0.868	2028
2	128+256 (66.7)+(6.9)	128	256	384	271	0.706	2116
3	127+254 (66.7)+(6.0)	127	254	381	242	0.635	2443
4	125+200 (61.5)+(6.9)	125	200	325	274	0.843	1692
5	150+231 (60.6)+(7.0)	150	231	381	278	0.730	2208
6	150+231 (60.6)+(6.5)	150	231	381	258	0.677	2699

[1] C+FA = Cement + Fly Ash (cementitious content)
[2] W/(C+FA) = Water-Cementitious Ratio

As seen in the previous tables for Phase I and Phase II of the Saluda Mix Design Program, higher cementitious content mixes generally displayed high compressive strengths.

Phase III of the Saluda Mix Design Program consisted of a series of RCC Test Pads constructed in the field to establish criteria and guidance in the development of the final design parameters for the RCC Berm. Three RCC mixes were evaluated in Phase III: a 175+150 mix (175 pcy cement, 150 pcy fly ash), a 150+150 mix, and a 125+150 mix.

4.2 TAUM SAUK

The Taum Sauk Mix Design Program took place in three phases. Phase I consisted of laboratory testing and occurred in the spring of 2006. Phases II and III consisted of the field construction of test pads.

The Phase I Test Program's goal was to provide a preliminary evaluation of the material properties of the RCC mixes with both Class C and Class F fly ash provided by the client and onsite aggregate to be used. A total of 16 mixes were prepared for Phase I. As shown in ***Table***

4-4, the Phase I mixes were produced with various proportions of cement, fly ash (using both Class C and Class F), and moisture content.

TABLE 4-4
TAUM SAUK PHASE I RCC MIX SUMMARY

MIX ID	PHASE I MIX DESIGNATION	CEMENT (LB/CY)	FLY ASH (LB/CY)	C+FA[1] (LB/CY)	WATER (LB/CY)	W/(C+FA)[2]	FLY ASH CLASS
TS-5	100+0 (Neat Cement)	100	0	100	199	1.990	n/a
TS-4	150+0 (Neat Cement)	150	0	150	190	1.267	n/a
TS-6	200+0 (Neat Cement)	200	0	200	199	0.995	n/a
TS-3C	105+45	105	45	150	190	1.267	C
TS-105F	105+45	105	45	150	199	1.327	F
TS-103F	50+50	50	50	100	200	2.000	F
TS-104F	75+75	75	75	150	200	1.333	F
TS-201PA	100+100	100	100	200	200	1.000	F
TS-9	125+125 (-H2O)	125	125	250	190	0.760	F
TS-7	125+125 (Opt H2O)	125	125	250	200	0.800	F
TS-10	125+125 (+H2O)	125	125	250	210	0.840	F
TS-101F	150+150	150	150	300	210	0.700	F
TS-6C	50+50	50	50	100	199	1.990	C
TS-2C	75+75	75	75	150	190	1.267	C
TS-5C	100+100	100	100	200	199	0.995	C
TS-7C	45+105	45	105	150	199	1.327	C

[1] C+FA = Cement + Fly Ash (cementitious content)
[2] W/(C+FA) = Water-Cementitious Ratio

4.3 BEAR CREEK

The RCC Mix Design Program for the Bear Creek Rehabilitation Project consisted of two phases. Phase I consisted of a laboratory scale RCC Mix Design program, and Phase II consisted of the construction and testing of a full-scale RCC test pad.

Phase I of the RCC Mix Design Program was initiated in August 2007, and consisted of 17 trial mixes. These mixes evaluated a range of both cementitious contents, fly ash replacements, and water contents, as shown in ***Table 4-5***. Additionally, three sources of Class F fly ash were evaluated: Colbert Plant Pond Ash, Colbert Plant Silo Ash, and Cumberland Plant fly ash. Phase

I culminated in the selection of two mixes, BC 15 and BC 17, to be evaluated in a full-scale test pad in Phase II.

TABLE 4-5
BEAR CREEK RCC DESIGN MIXES

MIX ID	MIX DESIGNATION	CEMENT (LBS/CY)	FLY ASH (LB/CY)	C+FA[1] (LB/CY)	WATER (LB/CY)	W/(C+FA)[2]	FA SOURCE[3]
BC 1	130+130 Wet	130	130	260	220	0.846	CO-P
BC 2	130+ 130 Dry	130	130	260	210	0.808	CO-P
BC 3	130+130 Base	130	130	260	215	0.827	CO-P
BC 4	145+145	145	145	290	220	0.759	CO-P
BC 5	115+ 115	115	115	230	212	0.922	CO-P
BC 6	161+69	161	69	230	212	0.922	CO-P
BC 7	182+78	182	78	260	211	0.812	CO-P
BC 8	240+0	240	0	240	212	0.883	n/a
BC 9	203+87	230	87	317	225	0.710	CO-P
BC 10	104+156	104	156	260	213	0.819	CO-P
BC 11	115+115	115	115	230	212	0.922	CU
BC 12	123+123	123	123	246	214	0.870	CU
BC 13	130+130	130	130	260	215	0.827	CU
BC 14	115+115	115	115	230	212	0.922	CO-S
BC 15	130+130	130	130	260	215	0.827	CO-S
BC 16	130+130	130	130	260	214	0.823	CO-S
BC 17	145+145	145	145	290	215	0.741	CO-S

[1] C+FA = Cement + Fly Ash (cementitious content)
[2] W/(C+FA) = Water-Cementitious Ratio
[3] Colbert Pond Ash = "CO-P"; Colbert Silo Ash = "CO-S"; Cumberland fly ash = "CU"

4.4 LEVY NUCLEAR PLANT

Phase II of the LNP RCC Test Program will consist of a mix design to evaluate a range of RCC properties, including cementitious content, water content, fines content, and fly ash source. At least 14 trial mixes will be evaluated, which is consistent with the past RCC mix designs. At least one mix will be selected for further evaluation in Phase III based on strength, workability, and anticipated thermal properties.

5.0 LABORATORY TESTING DATA

The following subsections present testing data compiled from RIZZO's RCC experience. The focus of the following data is information collected during final construction, as well as the performance of construction mixes during the mix design and testing process.

5.1 COMPRESSIVE STRENGTH

Compressive strength is used as a gauge of the overall strength and durability of the RCC. As with conventional concrete, it is standard practice to overdesign RCC so that the average compressive strength exceeds the specified strength.

Figures 5-1, 5-2, and 5-3 compare the strength gain during mix design to the strength gain during production for the three commercial projects. Note that the specified strength is typically achieved before 180 days

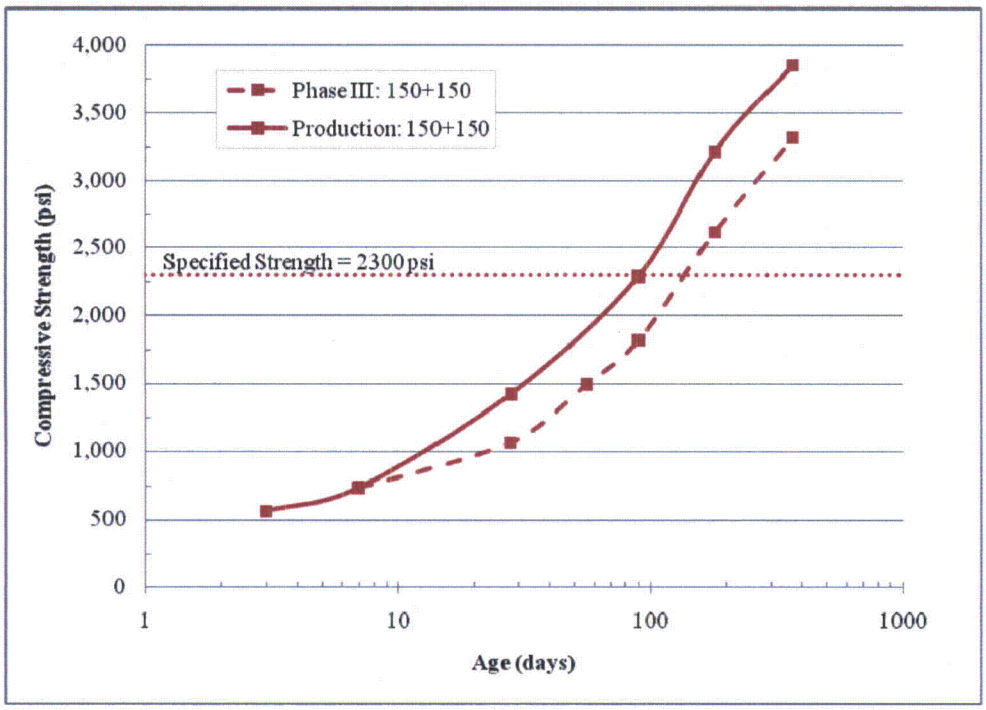

FIGURE 5-1
SALUDA STRENGTH GAIN COMPARISON

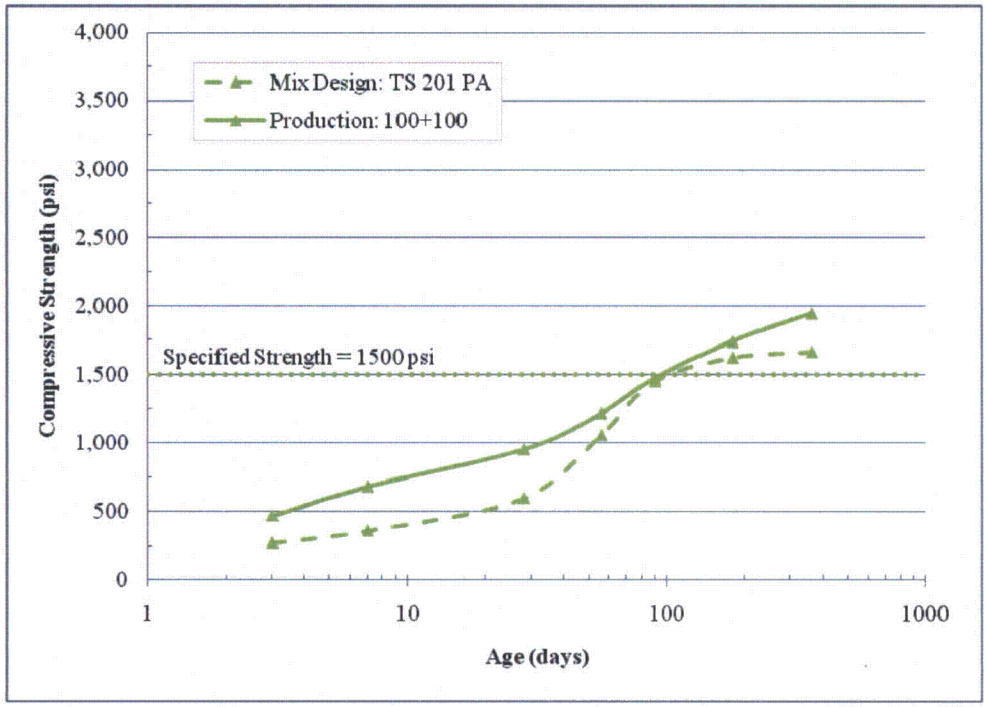

FIGURE 5-2
TAUM SAUK STRENGTH GAIN COMPARISON

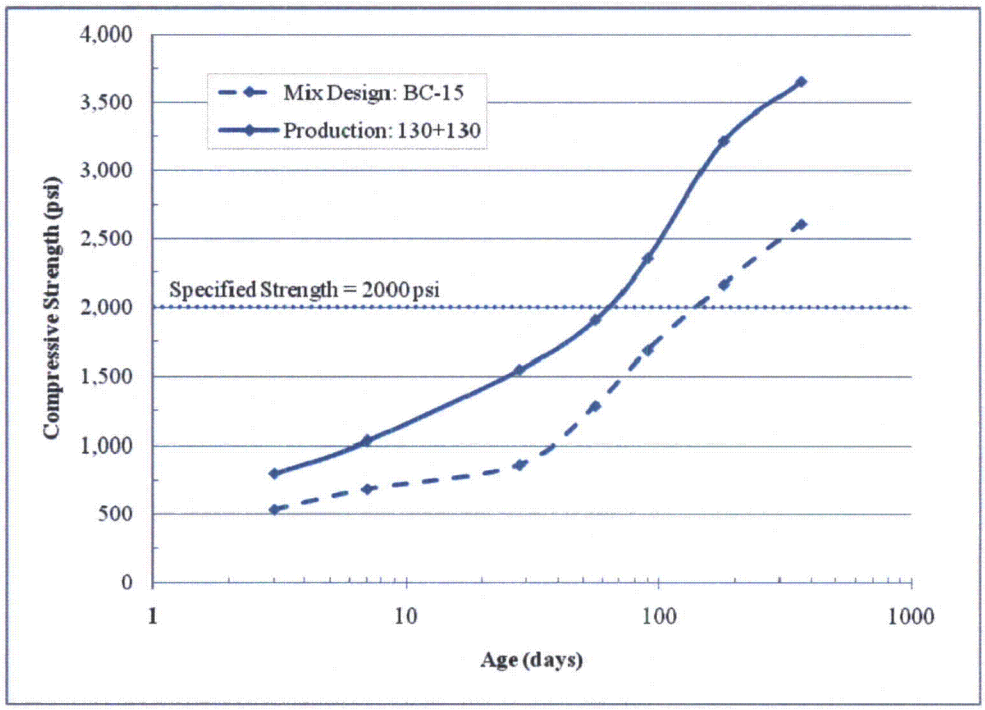

FIGURE 5-3
BEAR CREEK STRENGTH GAIN COMPARISON

5.2 SPLIT TENSILE STRENGTH

For the preliminary design of the LNP Bridging Mat, the equation from ACI 318 is used to estimate RCC tensile strength. As stated in ACI 318, for structural concrete is not to be less than 2,500 psi. According to the USACE, the tensile strength of RCC is approximately 75% of the split tensile strength. The relationship between 75% of the split tensile strength and compressive strength for Bear Creek and Saluda is presented in ***Figure 5-4***. Compressive strengths measured at Taum Sauk were generally lower than 2500 psi, so these values are not shown.

For compressive strengths greater than 2,500 psi, it is noted that the estimated tensile strength correlates well with the tensile strength predicted using the ACI equation. Therefore the ACI equation is judged to be accurate for preliminary design. Direct tension testing during Phase III of the LNP mix design will confirm that this relationship is appropriate.

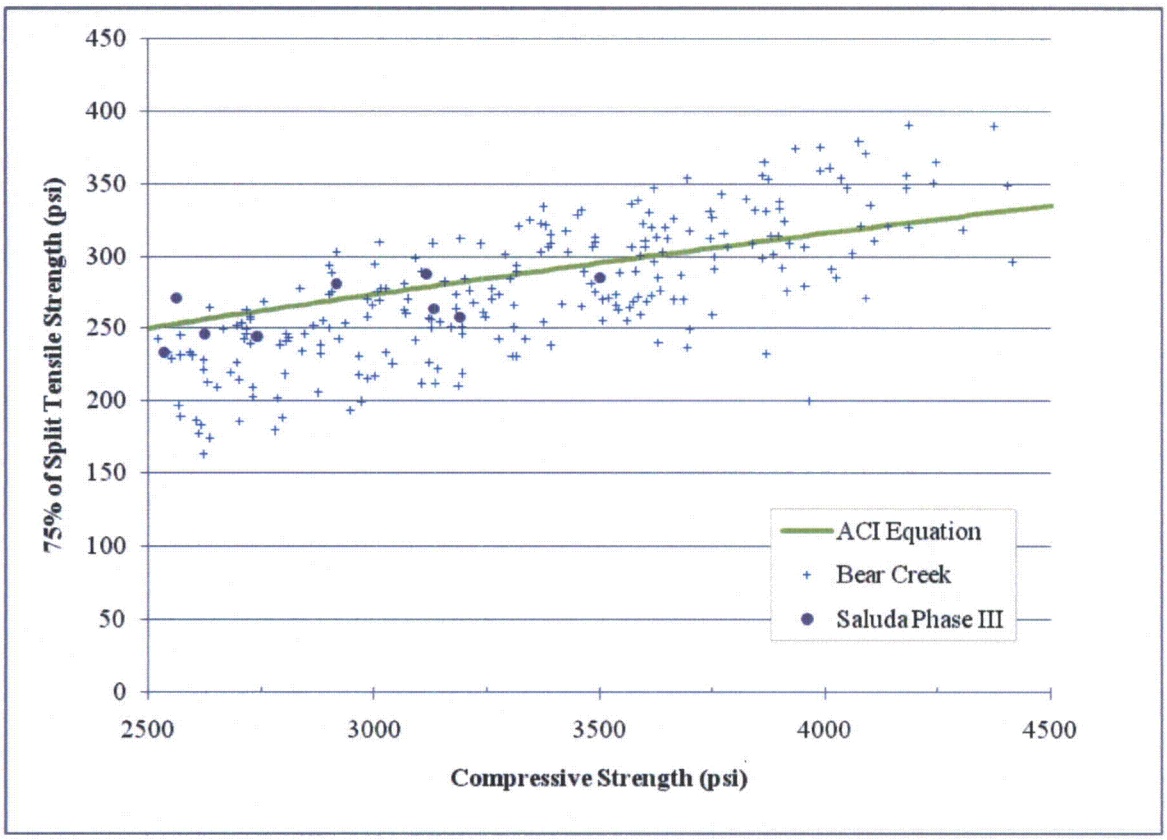

FIGURE 5-4
SPLIT TENSILE STRENGTH VS. COMPRESSIVE STRENGTH

5.3 MODULUS OF ELASTICITY

At Saluda, the secant modulus of elasticity was measured at 4 stresses during Phase III testing: 25 percent, 50 percent, 75 percent, and 100 percent of f'_c. These data were not recorded during construction at Taum Sauk and Bear Creek. ***Figure 5-5*** shows the 50 percent secant modulus from Saluda Phase III. This figure also shows the equation used for preliminary design of the Levy Nuclear Plant RCC, which is based on ACI 318. These values correlate well, and testing during Phases II and III of the LNP RCC Test Program will confirm that the ACI equation is appropriate to calculate the Young's Modulus for a design compressive strength greater than or equal to 2,500 psi.

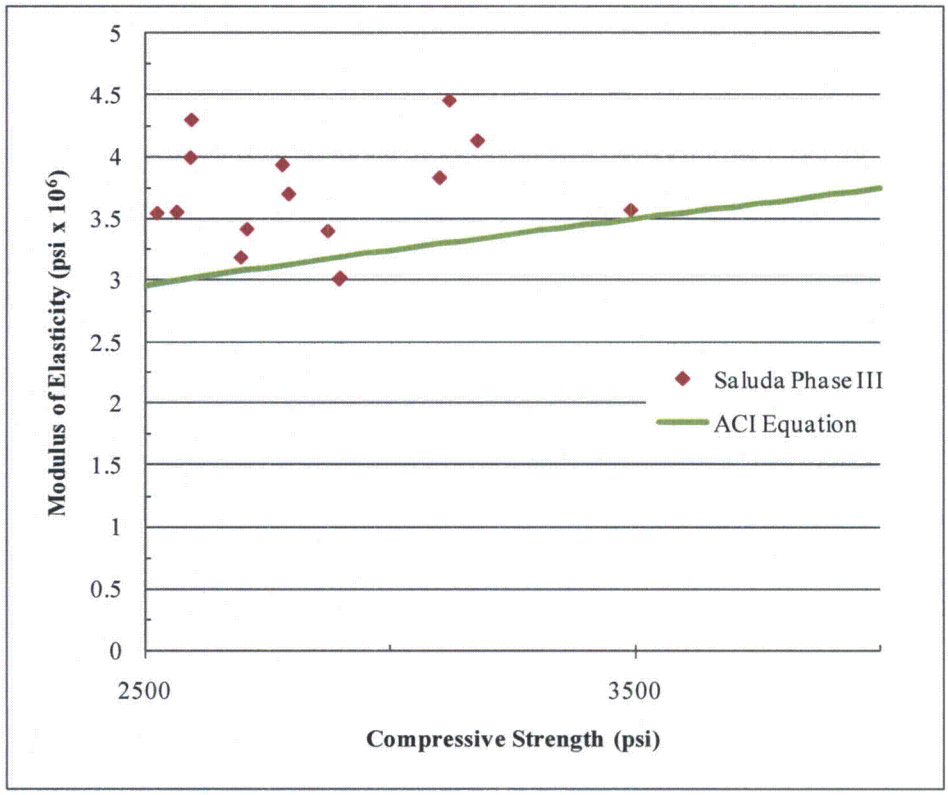

FIGURE 5-5
MODULUS OF ELASTICTY

5.4 DIRECT TENSILE STRENGTH

A limited number of cylindrical specimens were tested in direct tension after 90 days as part of the Saluda Phase II Mix Design Program. The results of this testing are presented in ***Table 5-1***, and the 90-day tensile strength is presented as a percent of the corresponding 90-day compressive strength.

As part of the LNP RCC Test Program, a much more extensive set of direct tension testing will be performed on RCC block samples, as described in the "Pre-COL Roller Compacted Concrete Testing Plan" (RIZZO, 2010).

TABLE 5-1
SALUDA DIRECT TENSILE TEST RESULTS

MIX	SAMPLE #	DENSITY (PCF)	90-DAY TENSILE STRENGTH (PSI)	90-DAY COMPRESSIVE STRENGTH (PSI)	TENSILE STRENGTH % OF COMPRESSIVE STRENGTH
1	25/28	149.2	83 [1]	1110	7.5
1A	27/28	148.9	125 [2]	1524	8.2
			122 (retest)	1524	8.0
2	26/28	149.5	140 [2]	1241	11.3
3	27/28	149.2	191	1424	13.4
4	26/28	145	152	953	15.9
5	26/28	147	168	1365	12.3
6	27/28	NR [3]	217	1649	13.2

[1] This sample was poorly compacted and had large voids.
[2] The sample failed on the concrete/platen glue line.
[3] Not Recorded

5.5 DIRECT SHEAR STRENGTH

As part of Phase III testing at Saluda, RCC blocks were saw cut from a series of test pads and tested for shear strength. These blocks were pre-cracked at the lift joint to facilitate failure in that plane, and blocks were tested at three normal stresses to obtain a shear failure envelope. The results of this testing are presented in ***Table 5-2***, and cohesion is presented both in psi and as a percent of the 2300 psi compressive strength. These results indicate that the use of either bedding concrete or bedding mortar increases the friction angle of the joint, and the use of bedding concrete increases the cohesion.

TABLE 5-2
SALUDA DIRECT SHEAR TEST RESULTS

BEDDING MIX	RCC MIX (C+FA)[1]	VEBE TOP/BOTTOM (S)	JOINT MATURITY (DEG-HR)	COHESION (PSI)	COHESION (% F'_C)	FRICTION ANGLE (DEGREES)
¾" MSA Concrete	150 + 150	25 / 33	3000	65	2.8 %	61
	175 + 150	25 / 15	1500	214	9.3 %	67
Sand Mortar	150 + 150	29 / 37	500	37	1.6 %	67
	175 + 150	33 / 37	1500	0	0.0 %	64
	175 + 150	18 / 17	3000	10	0.4 %	66
None	125 + 150	38 / 37	1500	11	0.4 %	49
	150 + 150	29 / 29+	500	81	3.5 %	49
	150 + 150	33 / 33	1500	60	2.6 %	47
	150 + 150	25 / 33	3000	46	2.0 %	45
	175 + 150	18 / 15	1500	83	3.6 %	56

[1] C+FA = Cement + Fly Ash (cementitious content)

5.6 THERMAL MEASUREMENTS

The coefficient of thermal expansion was measured during Saluda Phase III Testing. Three-inch by three-inch mortar bars were fabricated and tested in accordance with ASTM C 531. The results of these tests yielded thermal expansion coefficients on the order of 4.6×10^{-6} in/in/°F.

As part of the LNP RCC Test Program, a suite of thermal testing will be conducted to ensure accurate values are used in the final thermal analysis. Measurement of the thermal properties of the RCC will be performed as part of Phase III Testing and will include measurements of

adiabatic temperature rise, coefficient of thermal expansion, specific heat, thermal diffusivity, and thermal conductivity.

5.7 FRESH MIX PROPERTIES

The properties of fresh RCC are recorded with every RCC sample taken during both mix design and construction. ***Table 5-3*** presents the average fresh mix properties and the range experienced during construction of the three commercial RCC projects.

As a point of comparison, the preliminary baseline RCC mix at the Levy Nuclear Plant has a 20 second Vebe time and a design unit weight of 147.5 pcf. Preliminary thermal analysis has shown that the LNP Bridging Mat can feasibly be placed with RCC temperatures up to 80°F. As shown in ***Table 5-3***, these values are in the same range as previous projects.

TABLE 5-3
FRESH MIX TESTING SUMMARY

PROJECT	VEBE (S)	UNIT WEIGHT (PCF)	RCC TEMP (°F)
Saluda Average	27	149.3	61.2
Saluda Range	16 – 45	146.2 - 152.8	40 - 96
Taum Sauk Average	60 +	148.0	66.0
Taum Sauk Range	-	145.1 – 152.7	37 – 84
Bear Creek Average	32	150.1	59.0
Bear Creek Range	20 – 49	145.4 – 152.9	43 – 76
LNP (Target)	20	147.5	80

6.0 CONSTRUCTION

6.1 RCC PRODUCTION

RCC production for the Levy Nuclear Plant will utilize industry-standard means and methods, as described in the "Post-COL Roller Compacted Concrete Testing Plan" (RIZZO, 2010).

6.2 RCC TEST PADS

For past commercial projects, at least one RCC Test Pad has been constructed to evaluate contractor methods and RCC behavior. The construction of a Test Pad can serve as an effective training exercise for both the Contractor and the RCC Inspectors allowing for the establishment of effective rolling patterns and evaluation of the effectiveness of cooling measures implemented to place RCC at the specified placement temperature. An RCC Test Pad can be used to evaluate RCC lift surface preparation required at various maturities and curing conditions; placement procedures to eliminate segregation; and RCC mixing, placement and compaction including establishing effective rolling patterns and forming procedures.

Phase IV of the LNP RCC Test Program will consist of a full scale RCC Test Pad to be constructed prior to the construction of the RCC Bridging Mat by the constructor of the AP1000, as described in the "Post-COL Roller Compacted Concrete Testing Plan" (RIZZO, 2010). This Test Pad will allow the verification of Contractor equipment and methodology, as well as providing training for all personnel.

6.3 THERMAL CONSIDERATIONS

As with all engineered concretes, the thermal properties of RCC during placement are important to consider in order to prevent mass gradient thermal cracking. Therefore, the temperature of the RCC should be monitored and compared against the specifications. At Taum Sauk, for example, the temperature of the RCC at placement was not to exceed 75° F. The temperature of the RCC after placement was not to exceed 110°F.

If either of these temperature limits is exceeded, controls must be established to ensure conformance. At Taum Sauk, the RCC temperature was controlled by restricting the placement

hours during the summer and storing cool aggregates in the winter for later use during the summer. The aggregate was produced in two groups: Group I consisted of particle sizes ranging from 1 ½ in. to ¾ in., and Group 2 consisted of particle sizes less than ¾ in. The two groups were stockpiled separately and blended at the RCC batch plants. By storing aggregate in the winter, the temperature of the fine Group II aggregate from the core of the stockpile was as low as 55° to 60°F. In addition, the Contractor installed chillers to produce cool mixing water, about 50°F, to sprinkle the Group I aggregate in the summer. The temperature of the cool Group I aggregate was typically around 65°F. On site, there were five, 200-ton chillers, with a total capacity of 1,000 refrigeration tons. The temperature gain of the RCC mix from the plant to the placement area was about 5°F during hot days and long conveying times. The average temperature gain for warm days and shorter conveying times ranged from 2° and 3°F.

During summer, the RCC placement hours were reduced to control the temperature rise in the RCC. Typically, the Contractor started RCC placement at 9:00 p.m. and ended placement at 11:00 a.m. the following day. When temperatures were lower, RCC placement started at 7:00 p.m. and was extended to 2:00 p.m. the following day. In general, the Contractor was able to maintain the required average temperature of 75°F. The method used to calculate the average RCC temperature resulted in longer placement durations since low initial readings made up for a low running average. This would allow RCC placement even if the individual readings were 2° to 3°F above the average minimum placement temperature.

Depending on the results of thermal analysis and weather patterns expected at the time of placement, similar measures to control the quality of the RCC under extreme environmental conditions will be implemented for the LNP Bridging Mat. As described above, the most common measures include chilling of RCC constituents or reduction in allowable hours of placement.

6.4 PRODUCTION VARIABILITY

The coefficient of variation of compressive strength test specimens cast during construction is used to measure production variability. Coefficient of variation tends to decrease with age. The coefficient of variation of 365 day compressive strength specimens is presented in ***Table 6-1***, with control standards presented in ***Table 6-2***. These tables show that the coefficient of variation on RIZZO's previous RCC projects has ranged from good to excellent. It also demonstrates that the projected coefficient of variation of 14% for the Levy Nuclear Plant is reasonable based on past experience.

TABLE 6-1
COEFFICIENT OF VARIATION OF COMPRESSIVE STRENGTH

PROJECT	PLACEMENT METHOD	COEFFICIENT OF VARIATION (%) AT 365 DAYS
Saluda	Conveyor	10
	Trucks	16
	Trucks + Creter + Placer	13
Bear Creek	Overall	12
Taum Sauk	Overall	17
LNP	Projected	14

TABLE 6-2
RCC CONTROL RATINGS
(FROM SCHRADER 2000)

DESCRIPTION		EXCELLENT	VERY GOOD	GOOD	FAIR	POOR
Overall C of V	General Construction	0-11%	11-14%	14-18%	18-23%	> 23%
Within Batch C of V	General Construction	0-4%	4-6%	6-8%	8-10%	> 10%
Overall C of V	Laboratory Trial Batches	0-3%	3-5%	5-7%	7-9%	> 9%

7.0 CONCLUSIONS

This report presents representative RCC test programs and results from several large commercial RCC construction projects completed by RIZZO. These testing procedures and methods have been implemented by RIZZO to varying degrees on multiple other projects not discussed herein. The experience gained on these projects is directly applicable to the design, testing, and construction of the Levy Nuclear Plant RCC Bridging Mats, as described in the sections above.

This report demonstrates that the planned RCC construction at the Levy Nuclear Plant is sufficiently similar to RIZZO's previous successful RCC experience, in terms of materials selection, mix design, testing, and construction methods. Therefore we have a high level of confidence that similar results can be produced at the Levy Nuclear Plant.

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