COMANCHE PEAK RESPONSE TEAM

RESULTS REPORT

ISAP: II.b

Title: Concrete Compression Strength

REVISION 1

Issue Coordinator ______ Date 2/27/86

Review Team Leader ______ Date 2/28/86

John W. Beck, Chairman CPRT-SRT ______ Date 2/28/86

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Concrete Compression Strength

1.0 DESCRIPTION OF ISSUE

The TRT investigated allegations that concrete strength tests were falsified. The TRT reviewed an NRC Region IV investigation (IE Report No. 50-445/79-09; 50-446/79-09) of this matter that included interviews with fifteen individuals. Of these, only the alleger and one other individual stated they thought that falsification occurred, but they did not know when or by whom. The TRT also reviewed slump and air entrainment test results of concrete placed during the period the alleger was employed (January 1976 to February 1977) and did not find any apparent variation in the uniformity of the parameters for concrete placed during this period. Although the uniformity of the concrete placed appears to minimize the likelihood that low concrete strengths were obtained, other allegations were raised concerning the falsification of records associated with slump and air content tests. The Region IV staff addressed these allegations by assuming that concrete strength test results were adequate. Furthermore, a number of other allegations dealing with concrete placement problems (such as deficient aggregate grading and concrete in the mixer too long) were also resolved by assuming that concrete strength test results were adequate.

The TRT found that the preponderance of evidence suggests that falsification of results did not occur. However, since a number of other allegations were resolved on the basis of concrete strength results, the TRT believes that action by TUEC is required to provide confirmatory evidence that the reported concrete strength test results are indeed representative of the strength of the concrete placed in the Category I concrete structures.

2.0 ACTION IDENTIFIED

Accordingly, the NRC outlined the following action: TUEC shall determine areas where safety-related concrete was placed between January 1976 and February 1977, and provide a program to assure acceptable concrete strength. The program shall include tests, such as Schmidt Hammer tests, on a random sample of the concrete in areas where safety is critical. The program shall include a comparison of the results with the results of tests performed on concrete of the same design strength in areas where the strength of the concrete is not questioned, to determine if any significant variance in strength occurs. TUEC shall submit the program for performing these tests to the NRC for review and approval prior to performing the tests.

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3.0 BACKGROUND

Falsification of concrete strength tests is alleged to have occurred between January 1976 and February 1977. Air content and slump data were reviewed by the TRT and no apparent variations were found in the the uniformity of the parameters for concrete placed during the allegation time frame. However, concrete compressive strength tests have been used by the NRC to resolve previous allegations of falsifications of slump and air entrainment tests and allegations dealing with concrete placement problems (such as deficient aggregate grading and concrete in the mixer too long). Due to the importance of concrete compressive strength tests in assessing the allegations the TRT requested that additional testing be performed by TUEC to confirm that concrete strength tests performed on the concrete in question are representative of the actual concrete strength. Therefore, TUEC implemented a program to test the concrete-at-issue for verification of acceptable strength.

4.0 CPRT ACTION PLAN

4.1 Scope and Methodology

This action plan was designed to verify the quality of the concrete-at-issue. It was proposed that the relative strengths of concrete poured during the period in question (concrete-at-issue, or CAI) and concrete poured during the six months immediately following this period (control concrete, or CC) be compared using the Schmidt Hammer test as a relative measure of strength. This time period for the CC was selected to minimize any effect of aging on the comparison of the two sets of hammer data and to provide approximately equal volumes of concrete for the CAI and CC. The Schmidt (Rebound) Hammer test, a non-destructive test, was conducted in accordance with ASTM C805-79 "Standard Test Method For Rebound Number of Hardened Concrete" (Reference 7.1). The Schmidt Hammer is essentially a concrete hardness tester which measures the rebound of a spring loaded plunger after it has struck a smooth concrete surface.

Using this indirect test of strength, those portions of the two populations of concrete that were accessible for surface testing have been compared empirically and statistically. In addition to recording the raw rebound number data and average indication for each test, statistical summaries, such as means and variances, have been computed for both CAI and CC

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4.0 CPRT ACTION PLAN (Cont'd)

populations. Both normal and unspecified (non-parametric) distributions have been considered for the populations. For the normal distribution assumption, goodness-of-fit tests of the sample data were performed.

Concrete cylinder data for the two populations have also been obtained, reviewed, and used for reference (see Section 4.4).

The two populations of average hammer indications have been compared at the tenth percentile level. The tenth percentile is selected as a point of comparison based on the American Concrete Institute (ACI) Standard 214-65, "Recommended Practice for Evaluation of Compression Test Results of Field Concrete" (Reference 7.2), which gives the general guideline that no more than one out of ten cylinder compression tests shall fall below the design strength. The population of average hammer indications for the control concrete was used to establish a tenth percentile target and the tenth percentile average hammer indications for the concrete-at-issue was then compared with this target value. Other CC target values (i.e., fractions of the CC tenth percentile) were also used for comparison. Hypotheses that the tenth percentile for the CAI is greater than or equal to various target values were tested at a minimum significance level of five percent. In addition, the significance level at which an hypothesis is just accepted was determined. A higher significance level passed indicates a greater confidence that the hypothesis is true.

4.1.1 Test Program

4.1.1.1 TUGCO Nuclear Engineering Civil Structural (TUGCO) determined the areas where concrete was placed in Category I structures between January 1976 and February 1977 (Reference 7.3).

4.1.1.2 From these areas, TUGCO determined the number of truckloads of concrete for which part of the concrete of that truckload is exposed and testable (Reference 7.3).

4.1.1.3 Each truckload identified as exposed and testable was assigned a unique number (Reference 7.3).

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4.0 CPRT ACTION PLAN (Cont'd)

4.1.1.4 Grid volumes corresponding to these truckloads were selected at random to be tested (Reference 7.3).

4.1.1.5 The concrete surface for each selected volume was prepared by Brown & Root Craft personnel for testing per ASTM C805-79. Southwest Research Institute (SWRI) personnel were responsible for inspecting and accepting the prepared surfaces before testing.

4.1.1.6 The prepared areas were tested by SWRI personnel (Reference 7.4) in accordance with ASTM C805-79.

4.1.1.7 TUGCO determined the areas where concrete was placed in Category I structures between March 1977 and August 1977 (Reference 7.3).

4.1.1.8 From these areas, TUGCO determined the number of truckloads of concrete for which part of the concrete of that truckload is exposed and testable (Reference 7.3).

4.1.1.9 Each truckload identified as exposed and testable was assigned a unique number (Reference 7.3).

4.1.1.10 Grid volumes corresponding to these truckloads were selected at random for testing (Reference 7.3).

4.1.1.11 The concrete surface for each selected grid volume was prepared by Craft personnel for testing per ASTM C805-79 and inspected by SWRI prior to testing.

4.1.1.12 The prepared areas were tested by SWRI (Reference 7.4) in accordance with ASTM C805-79.

4.1.1.13 Third-party overview consisted of review and check of activities in 4.1.1.1 through 4.1.1.5 and 4.1.1.7 through 4.1.1.11 (Reference 7.5).

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4.0 CPRT ACTION PLAN (Cont'd)

4.1.2 Sampling Plan

At Comanche Peak, concrete placement quality procedures were based on the required air content and slump tests being performed on each truckload. Test cylinders from the first truckload and every tenth truckload thereafter were required to verify quality. These procedures were based on ACI-ASME 359 and ACI 318 (References 7.6 and 7.7, respectively), which reference appropriate ASTM standards. Since the original quality control program was based on the unit of a truckload, the truckload was employed as the unit to be tested in the present quality evaluation. This is consistent with the inherent assumption in the ACI code that a truckload represents the smallest unit of concrete with uniform material properties.

Since Schmidt Hammer tests can only be performed on exposed surface area, the determination of the number of truckloads which were placed as exposed testable concrete was determined as follows:

- For slabs on grade, the number of truckloads was calculated as:

  (1' depth X Surface Area)/10 yd^3 per truck

  A depth of one foot was used, because, during placement, vibrators caused the concrete to flow and level out. Thus, only truckloads placed in the last foot of the slab would be exposed.

- For columns and walls the number of truckloads was calculated as:

  Total Volume/10 yd^3 per truck

- For suspended slabs up to 28 inches thick, the number of truckloads was calculated as:

  Total Volume/10 yd^3 per truck

  Each truckload was considered to be accessible on either surface for slabs less than 18 inches thick. For slabs between 18

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4.0 CPRT ACTION PLAN (Cont'd)

and 28 inches the total number of truckloads were distributed equally between the top and bottom halves of the slab.

- For suspended slabs between 28 and 46 inches thick, the volume of concrete was split into three equal quantities, with one third at the top, one third on the bottom and one third in the middle of the slab. The top and bottom layers were considered as exposed and testable. The middles layer was included if it could be tested from the side.

Slabs not falling into the above categories were handled on a case by case basis. For example, a portion of a thick slab on grade below the one foot depth was accessible from a tunnel and hence was included.

Of the 326 Category I concrete pours placed between January 1976 and February 1977, 103 were for seal slabs, shotcrete, grout, or concrete backfill, and are inaccessible for surface testing. Of the remaining 223 pours, 197 were found to be at least partially accessible for Schmidt Hammer testing (Reference 7.3), which corresponds to a testable CAI population of approximately 1300 truckloads. A total of 119 randomly selected truckload units was tested from this population. Table 1 gives a breakdown of the Category I concrete pours placed in the allegation time frame.

Comparable numbers of truckloads define the population of testable control concrete and the sample of the truckload units that were tested (see Table 2).

4.1.3 Concrete Cylinder Data

The 28-day cylinder strength data (Reference 7.8) were obtained from the TUGCO Records Center for the time period in question and the control concrete time frame. The data, which represents all Category I concrete pours except seal slabs, etc., were statistically evaluated and used as reference information in the hammer data evaluation. The completeness of the data list was checked by the third-party (Reference 7.5).

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4.0 CPRT ACTION PLAN (Cont'd)

4.2 Participants Roles and Responsibilities

The organizations and personnel that have participated in this effort are described below with their respective scopes of work.

4.2.1 TUGCO Nuclear Engineering Civil Structural

4.2.1.1 Scope

- Concrete population determination
- Sample selection
- Location of test areas and preparation of operational traveler
- Acquisition of 28-day cylinder data
- Assistance in evaluation of test data and preparation of Results Report

4.2.1.2 Personnel

Mr. R. Hooton	Project Discipline Supervisor
Mr. R. Williams	Supervising Engineer
Mr. C. Corbin	Civil Engineer

4.2.2 Brown & Root

4.2.2.1 Scope

- Prepare concrete test surfaces

4.2.2.2 Personnel

Craft personnel as required

4.2.3 Third-Party Activities

4.2.3.1 Scope

- Review of sample selection

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4.0 CPRT ACTION PLAN (Cont'd)

- Perform hammer tests (SWRI)
- Document tests (SWRI)
- Review test data
- Review and statistical evaluation of test results
- Preparation of Results Report

4.2.3.2 Personnel

Mr. H. A. Levin	TERA, CPRT Civil/ Structural Review Team Leader
Dr. J. R. Honekamp	TERA, Manager TRT Issues
Dr. F. A. Webster	JBA, Associate (Engineering Statistical Consultant)
Dr. D. Veneziano	MIT, Professor of Civil Engineering (Engineering Statistical Consultant)
Mr. G. Lagleder	SWRI, Manager (Testing and Inspection)

4.3 Qualifications of Personnel

Where inspections required the use of certified inspectors, qualification were to the requirements of ANSI N45.2.6 (Reference 7.9) at the appropriate level. CPSES personnel were qualified in accordance with applicable project requirements. Third-party inspectors were certified to the requirements of the third-party employer's quality assurance program and in accordance with USNRC Regulatory Guide 1.58, Revision 1 (Reference 7.10). The third-party inspectors were specifically trained to the requirements of SWRI Procedure X-FE-108-1, Revision 1 (Reference 7.11).

Other participants were qualified to the requirements of the CPSES Quality Assurance Program or to the specific requirements of the CPRT Program Plan (Reference 7.12), as appropriate.

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4.0 CPRT ACTION PLAN (Cont'd)

4.4 Acceptance Criteria

A review of the historic 28-day cylinder strength data for both time frames (see Figure 1 or Table 3) indicated that, regardless of whether falsification of data occurred during the allegation period or not, it is likely that the CAI is lower in strength than the CC. This observation is not unusual, since under normal construction processes, there is only a 50 percent chance that the concrete strength (and hammer indication) in the allegation period would be equal to or greater than that in any other comparable period. There is also a 50 percent chance that it would be less than that in any other comparable period. Therefore, the appropriate acceptance criterion was determined to be that of accepting the CAI population if the tenth percentile hammer indication was not "significantly lower" than that of the CC population. In this case, "significantly lower" means not more than about ten percent. This is based on the fact that the design strength of 4000 psi is 18.6 percent lower than the CC tenth percentile 28-day cylinder strength (see Table 3), and this change in compressive strength [illegible]1) corresponds to a relative change in hammer indication of approximately ten percent (see References 7.13 and 7.14). Thus, the hypothesis that the Schmidt Hammer indication tenth percentile for the CAI is not "significantly lower" than that of the CC was tested at a minimum statistical significance level of five percent.

4.5 Decision Criteria

Three hypothesis tests were considered for the comparison of the Schmidt Hammer data, with the understanding that the one (or ones) with the most power* would be used to test the two populations. The three test methods include:

4.5.1 Method A tests whether the tenth percentile hammer indication of the CAI is greater or equal to the target value of the CC, where both populations are assumed to be normally distributed (see Reference 7.20). Note, the target value is defined as the CC population tenth percentile or a fraction thereof.

* Power is defined as the probability of rejecting the hypothesis when it is not true. The power function gives the power as a function of disparity with the hypothesis.

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4.0 CPRT ACTION PLAN (Cont'd)

4.5.2 Method B tests whether the percentage of hammer indications in the CAI population above the target value of the CC is greater or equal to 90 percent. In this test the CC population is assumed to be normally distributed for purposes of establishing the target value (which may be defined as the tenth percentile or a fraction thereof), but the distribution of CAI hammer indications is unspecified.

4.5.3 Method C tests whether individual CAI hammer indication data values belong to the same distribution as the control concrete rebound values. No assumptions are made regarding either population distribution.

Although the power functions for these three methods are not directly comparable, Methods A and B are of similar power and are better than Method C (References 7.15, 7.20, and 7.21). Therefore, both Methods A and B were retained to compare the two populations.

Based on the sample outcomes for the two concrete populations, test statistics were computed and the hypotheses regarding the CAI population were either accepted or rejected at the 5 percent level of significance. In addition, the levels of significance at which the hypotheses are accepted were also determined.

The action identified by the NRC (Section 2.0) is considered complete now that all Schmidt Hammer tests have been completed, the results statistically analyzed, and the two concrete populations compared.

Since the comparison indicates that the CAI population of hammer indications is not "significantly lower" than the CC, no further evaluation of the CAI is necessary, nor is it necessary to calibrate the Schmidt Hammer test to concrete of known strength and age or test cores from the CAI.

5.0 IMPLEMENTATION OF ACTION PLAN AND DISCUSSION OF RESULTS

5.1 Summary of Implementation

The implementation of this action plan followed the flow chart shown in Figure 2, with the four major aspects of the program being: 1) identification of all CAI and CC Category I pours

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5.0 IMPLEMENTATION OF ACTION PLAN AND DISCUSSION OF RESULTS (Cont'd)

and surface testable truckload populations; 2) the random selection of truckloads; 3) the preparation and testing of selected areas; and 4) the test data evaluation.

Detailed descriptions of the population identification and random selection processes are contained in Reference 7.3. In summary, all Category I concrete pours in the two time frames were identified and an estimate of how many and which truckloads are surface testable was made. These estimated testable truckload populations were randomly sampled for testing with the Schmidt Hammer, their accessibility verified, and the selected accessible areas were prepared for testing.

Once the test areas were prepared, certified SWRI personnel verified the surface preparation, performed the Schmidt Hammer tests, summarized the hammer readings, determined the average hammer indication for each test area, and submitted a report (Reference 7.4) to TUGCO containing these data.

The third-party statistically evaluated the hammer data (Reference 7.16), and performed the hypothesis tests which were used to compare the two testable populations (References 7.17). A copy of the average hammer indications, as summarized from the SWRI raw data sheets, is listed in Appendices A and B of this Results Report. Cumulative frequency plots of the two sample data sets are shown in Figure 3.

In addition to the hammer data, the reported 28-day concrete cylinder strength data for both populations were obtained from the TUGCO Records Center (Reference 7.8) and statistically evaluated (Reference 7.18). Cumulative frequency plots for these two data sets are shown in Figure 1.

5.2 Data Evaluation

Before comparing the two populations using Methods A and B, the hammer data were first evaluated (Reference 7.16) by calculating mean values, standard deviations, coefficients of variation (see Table 4), and cumulative frequencies (see Figure 3). The two data sets were tested for goodness-of-fit to the normal distribution (References 7.17 and 7.19). Normality of the two populations is accepted at the five percent significance level.

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5.0 IMPLEMENTATION OF ACTION PLAN AND DISCUSSION OF RESULTS (Cont'd)

To compare the two testable concrete truckload populations, Methods A and B hypothesis tests were performed using target values of 1.0, 0.975, and 0.95 times the CC population tenth percentile value. The hypothesis that the CAI population tenth percentile is greater or equal to 1.0 times the CC population tenth percentile is rejected at the five percent significance level. The hypothesis that the CAI population tenth percentile is greater than or equal to 0.975 times the CC population tenth percentile is accepted at the five percent significance level, and is also accepted at the ten percent significance level. The hypothesis that the CAI population tenth percentile is greater than or equal to 0.95 times the CC population tenth percentile is accepted at the five percent significance level, and is also accepted at the 95 percent significance level. This means that, although there is not a high confidence that the CAI population of hammer indications is equal to or better than the CC population, there is a high confidence that the CAI is within five percent of the CC population at the tenth percentile value and therefore well within the ten percent range required by the acceptance criteria (see Section 4.4.).

The 28-day cylinder compressive strength data for the 223 Category I concrete pours (see Section 4.1.2) in the CAI time frame and comparable data in the CC time frame were statistically analyzed. The mean values, standard deviations, and coefficients of variation are listed in Table 3. These data were also ordered and cumulative frequency plots were constructed (see Figure 1). The results of the cylinder data evaluation are consistent with the Schmidt Hammer tests in that both show a slightly higher mean value and tenth percentile value for the control concrete. In fact, the cylinder data indicate that the compressive strength of the CAI is 9.3 percent lower than that of the CC at the population tenth percentile value (see Table 3). This corresponds approximately to a five percent difference in hammer indications (Reference 7.13). Thus, the results show that, not only are the compressive strengths of both the CC and CAI well above the 4000 psi design value, but that the reported 28-day cylinder data truly represents the CAI at the population tenth percentile value.

Regarding potential falsification of 28-day cylinder records, there are two general categories of interest. Of greater concern is the masking of out-of-specification concrete by recording it to be within specification. Of lesser concern is the recording of within-specification concrete when the tests

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5.0 IMPLEMENTATION OF ACTION PLAN AND DISCUSSION OF RESULTS (Cont'd)

were not performed. Neither of these two types of falsification appears to have occurred in a systematic way, since there is no obvious bimodal behavior in the hammer indication data and the shift between the CC and CAI populations for the cylinder data is consistent with that of the hammer indication data.

During third-party review (Reference 7.5) of the Schmidt Hammer test program development, some errors were found due to arithmetic, accessibility determinations, and volume modeling assumptions. A portion of these errors, if corrected, would result in fewer truckloads being included in the populations; the other portion would result in more truckloads being added to the population. However, no systematic errors were found. The total error in the CAI truckload volume is three percent underestimated. For the CC population the estimate is less than half of one percent overestimated. Considering only those truckloads which were not included in the testable populations, but should have been (i.e., were not in the population from which the sample was drawn), the error rate is about six percent for the CAI and less than one percent for the CC. The samples do not strictly represent the excluded truckloads. However, these error rates are not significant, and even if additional samples were obtained to represent the excluded truckloads, the conclusions would not be affected.

6.0 CONCLUSIONS

Although the present strength of the concrete in question has not been measured directly, based on the hammer indication data obtained, in association with the 28-day cylinder data for the control concrete, it is concluded that the tenth percentile value of the CAI testable concrete is well above the design strength of 4,000 psi. The 28-day cylinder strength data are consistent with the hammer indication data. There is no evidence that systematic falsification of cylinder data or the non-performance of required tests occurred. Finally it is concluded that the reported 28-day cylinder strength data represents the testable CAI population, thus validating the utilization of these data to address other allegations of concrete records falsification.

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7.0 REFERENCES

7.1 ASTM Committee C-9, "Standard Test Method for Rebound Number of Hardened Concrete", (ASTM C805-79), American Society for Testing and Materials, Philadelphia, PA, 1979.

7.2 ACI Committee 214, "Recommended Practice for Evaluation of Compression Test Results of Field Concrete", (ACI 214-65), American Concrete Institute, Detroit, MI, 1965.

7.3 "Test Program Development Report", CPRT File No. II.b.6.C.1, October, 1985.

7.4 "Testing to Confirm Acceptability of Concrete Strength Data for the Comanche Peak Steam Electric Station, Units 1 and 2", Final Report, Project 8478, Southwest Research Institute, San Antonio, TX, September, 1985. (CPRT File No. II.b.6.C.2)

7.5 "Third-Party Review and Verification of Sampling Activities and Procedures for CPRT Issue II.b Concrete Compressive Strength", CPRT File II.b.6.C.3, October, 1985.

7.6 ACI-ASME Committee 359, "Code for Concrete Reactor Vessels and Containments", (ACI-ASME 359-83), American Society of Mechanical Engineers, New York, NY, 1983.

7.7 ACI Committee 318, "Building Code Requirements for Reinforced Concrete", (ACI 318-83), American Concrete Institute, Detroit, MI, 1983.

7.8 "Cylinder Data", CPRT File No. II.b.6.C.1.I.

7.9 ASME Committee on Nuclear Quality Assurance, "Qualifications of Inspection, Examination, and Testing Personnel for Nuclear Power Plants", (ANSI/ASME N45.2.6-1978), American Society of Mechanical Engineers, New York, NY, 1978.

7.10 Office of Standards Development, "Qualification of Nuclear Power Plant Inspection, Examination, and Testing Personnel", (USNRC Regulatory Guide 1.58, Revision 1), U.S. Nuclear Regulatory Commission, Washington, DC, September, 1980.

7.11 "Schmidt Hammer Test on Concrete at the Comanche Peak Steam Electric Station", Nuclear Projects Operating Procedure X-FE-108-1, Revision 1, Southwest Research Institute, San Antonio, TX, January, 1985. (CPRT File No. II.b.6.A)

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7.0 REFERENCES (Cont'd)

7.12 "Comanche Peak Response Team Program Plan and Issue-Specific Action Plans", Revision 3, TUGCO, Glen Rose, TX, January 24, 1986. (CPRT File No. II.b.1)

7.13 Operating Instructions Concrete Test Hammer Types N and NR, Copyright 1977, PROCEQ, Zurich, Switzerland. (CPRT File No. II.b.11)

7.14 Attachment A of F. Webster, "Target Tenth Percentile", CPRT File II.b.4a-003, February, 1985.

7.15 F. Webster, "Slides on Data Evaluation Methods Presented at NRC-TRT Meeting of 1/7/85", Memo to File, CPRT File II.b.10-004, January, 1985.

7.16 A. Boissonnade, "Schmidt Hammer Data Statistical Evaluation", CPRT File II.b.4a-010, August, 1985.

7.17 F. Webster, "Hammer Data Hypothesis Tests", CPRT File II.b.4a-011, July, 1985.

7.18 A. Boissonnade, "Statistical Evaluation of Cylinder Data", CPRT File II.b.4a-012, August, 1985.

7.19 F. Webster, "Chi-Square Goodness-of-Fit Test of Hammer Data", CPRT File II.b.4a-013, September, 1985.

7.20 D. Veneziano, "Comparison of the Fractiles of Two Normal Populations - A Large Sample Test and Its Power", CPRT File II.b.4a-001, December, 1984.

7.21 F. Webster, "Additional Background for TUGCO-NRC Meeting of 3/6/85", CPRT File II.b.4a-008, May, 1985.

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TABLE 1

CHARACTERIZATION OF CATEGORY I CONCRETE
PLACED IN ALLEGATION TIME FRAME

	NUMBER OF POURS		NUMBER OF TRUCKLOADS	
All Category I		326		
Category I (Other Than Seal Slabs, Shotcrete, Grout, or Backfill)	223	31 SOG* 192 C,W,ES*	4,080	1780 SOG 2300 C,W,ES
Testable Category I	197	19 SOG 178 C,W,ES	1,305	315 SOG 990 C,W,ES

*SOG = Slabs on Grade
C = Columns
W = Walls
ES = Elevated Slabs

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TABLE 2

CHARACTERIZATION OF CATEGORY I CONCRETE
PLACED IN CONTROL CONCRETE TIME FRAME

	NUMBER OF POURS		NUMBER OF TRUCKLOADS	
All Category I		324		
Category I (Other Than Seal Slabs, Shotcrete, Grout, or Backfill)	291	24 SOG* 267 C,W,ES*	2,715	920 SOG 1,795 C,W,ES
Testable Category I	282	24 SOG 258 C,W,ES	2,090	353 SOG 1,737 C,W,ES

*SOG = Slabs on Grade
C = Columns
W = Walls
ES = Elevated Slabs

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TABLE 3

28-DAY STANDARD CURE CYLINDER DATA STATISTICAL SUMMARIES

	Concrete at Issue	Control Concrete
Number of Data	509	372
Mean Value	5158 psi	5441 psi
Standard Deviation	475 psi	383 psi
Coefficient of Variation	0.09	0.07
Tenth Percentile	4457 psi	4913 psi
Minimum	4047 psi	4540 psi

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TABLE 4

SCHMIDT HAMMER DATA STATISTICAL SUMMARIES

	Concrete at Issue	Control Concrete
Number of Data	119	132
Mean Value	48.57	49.14
Standard Deviation	3.13	2.87
Coefficient of Variation	0.06	0.06
Tenth Percentile	44.1	45.3
Minimum	38.5	39.7

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FIGURE 1

CAI and CC CYLINDER DATA CUMULATIVE FREQUENCIES

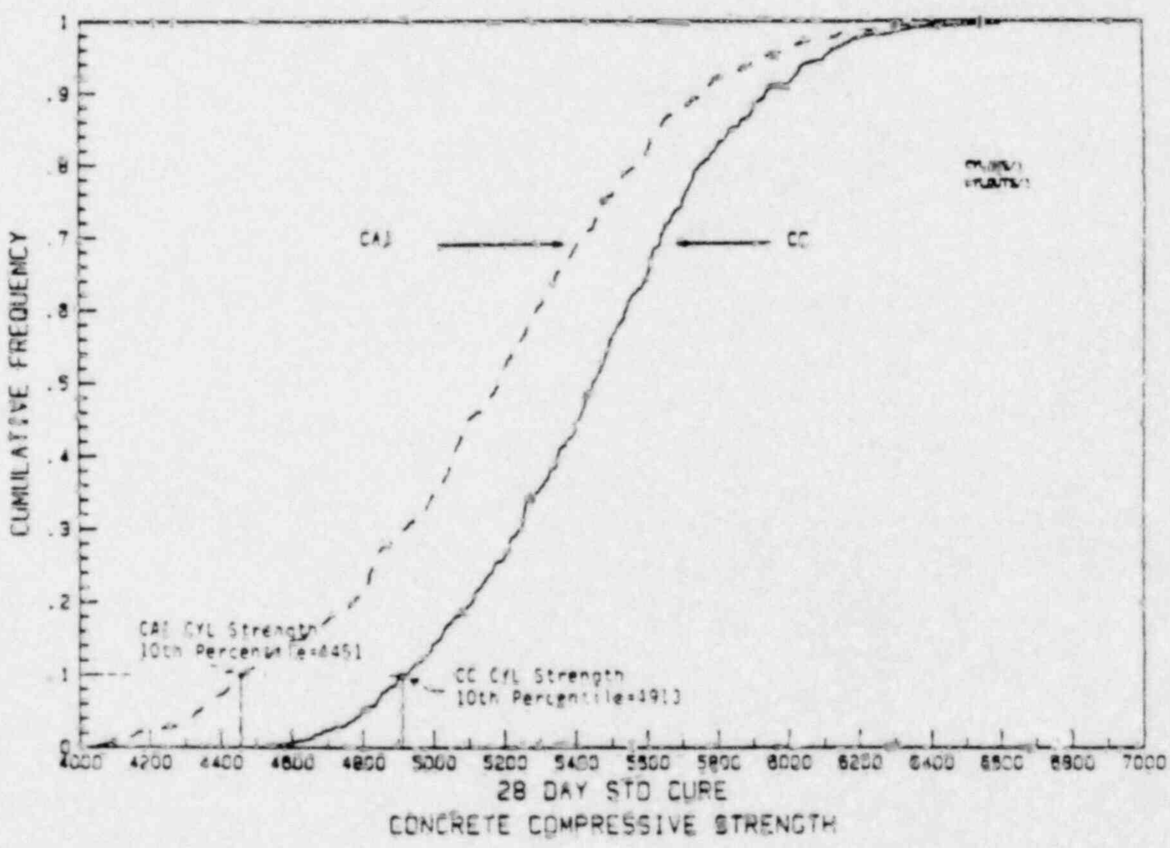

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FIGURE 2

ISSUE II.b FLOW CHART

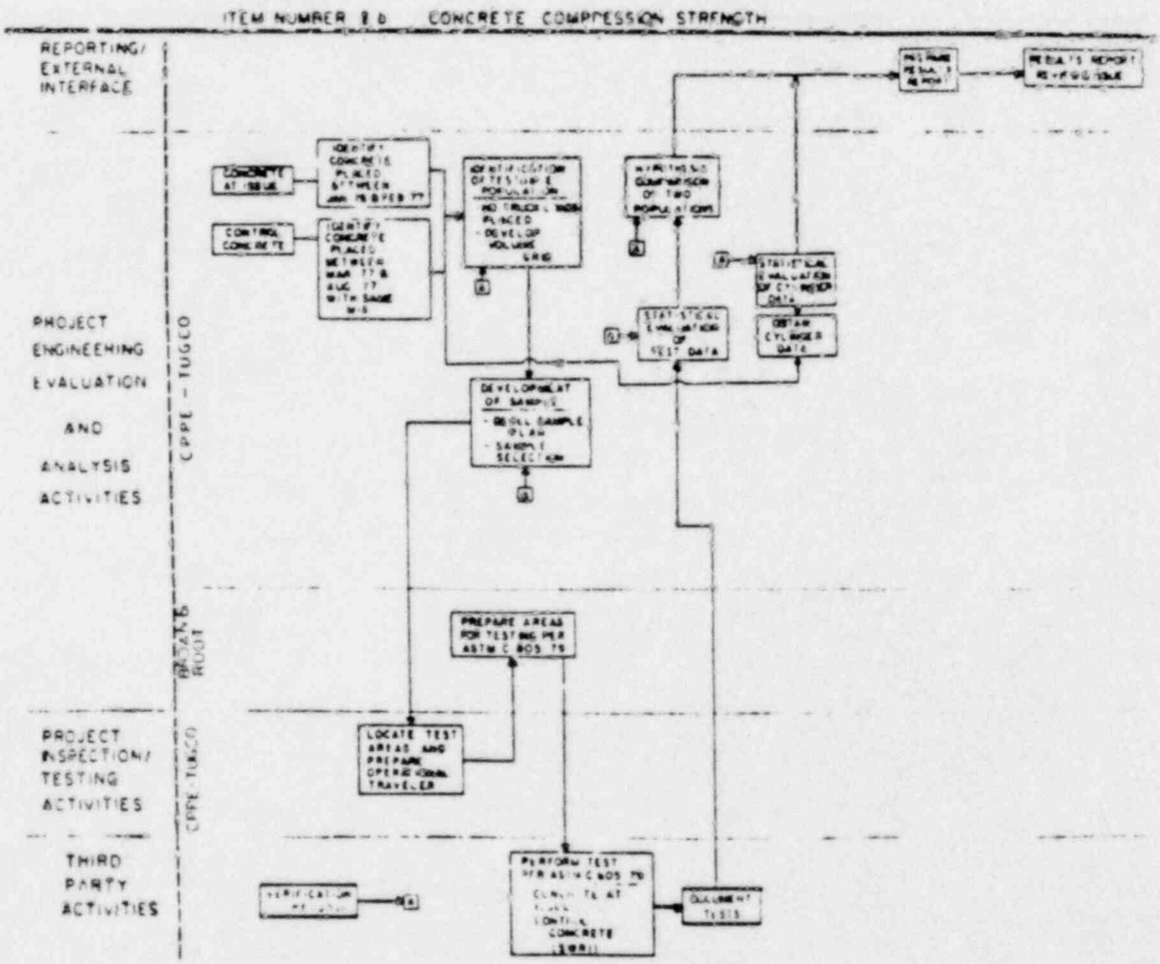

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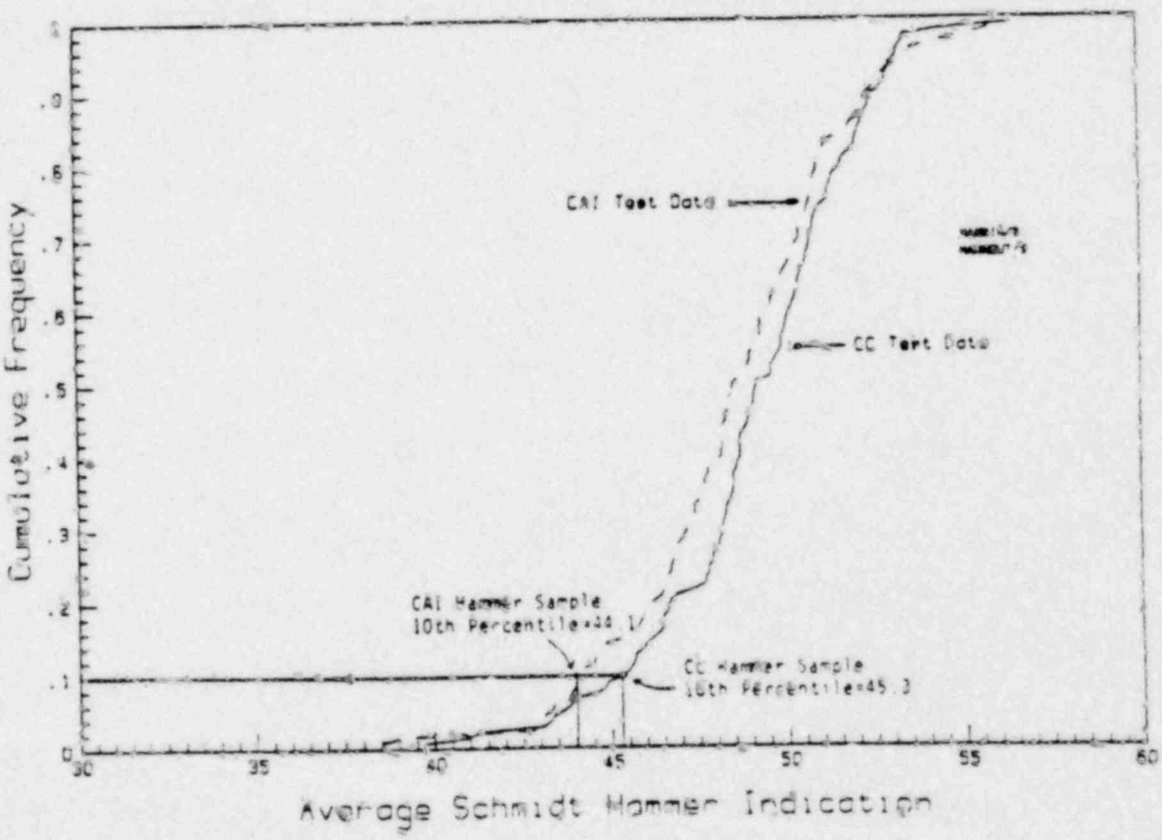
FIGURE 3

CAI and CC HAMMER DATA CUMULATIVE FREQUENCIES



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APPENDIX A

CAI AVERAGE HAMMER INDICATIONS

HAMMER TEST DATA SHEET No.	POUR PACKAGE No.- GRID AREA	TEST LOCATION	MEAN REBOUND VALUE HORIZ.	UP	DOWN
8	002-2790-004-H	TR-85-066-8904			44.38
10	002-4790-005-I	TR-85-005-8904	47.67		
13	002-4790-037-HH	TR-85-100-8704	44.0		
24	002-4792-005-B	TR-85-029-8904	38.5		
37	002-2778-002-WW	TR-85-060-8904			46.1
46	002-5778-001-D	TR-85-123-8904	43.9		
72	002-4792-008-F	TR-85-001-8904	42.9		
73	002-5778-001-Q	TR-85-079-8904	47.4		
74	002-5778-001-R	TR-85-098-8904	46.0		
76	002-5778-001-Z	TR-85-095-8904	46.6		
77	002-5778-001-AA	TR-85-096-8904	46.6		
79	002-6778-005-A	TR-84-204-8904	43.8		
80	002-2778-002-X	TR-85-056-8904			42.0
81	002-2778-002-KK	TR-85-120-8904			44.1
88	105-4785-003-C	TR-84-101-8903	48.2		
89	002-4790-016-I	TR-85-009-8904	48.3		
92	002-6778-010-A	TR-85-122-8904	48.3		
118	002-6790-001-A	TR-85-017-8904	44.6		
127	002-7792-003-B	TR-85-103-8904			44.4
128	002-2778-002-L	TR-85-119-8904			42.8
129	002-4792-018-A	TR-85-028-8904	39.1		
130	002-4790-037-O	TR-85-188-8904	44.1		
131	002-4790-037-C	TR-85-104-8904	43.0		
145	101-5805-003-M	TR-85-162-8902	49.3		
153	002-4778-001-D	TR-85-149-8904	48.2		
154	002-5778-007-C	TR-85-092-8904	49.4		
157	101-5805-003-D	TR-85-161-8902	48.4		
163	002-5790-002-A	TR-85-207-8904	47.4		
165	002-4792-003-A	TR-85-146-8904	43.0		
166	002-7792-001-P	TR-85-150-8904			46.4
167	002-4792-009-A	TR-85-191-8904	47.4		
168	002-7792-001-BB	TR-85-151-8904			45.8
169	002-5778-006-A	TR-85-099-8904	47.6		
211	105-5790-005-I	TR-85-113-8903	50.4		
214	101-5805-002-P	TR-85-160-8902	50.7		
215	101-5805-003-Q	TR-85-163-8902	49.0		
217	002-2778-002-T	TR-85-057-8904			44.4
218	002-2778-002-P	TR-85-058-8904			46.1
219	002-2778-002-Q	TR-85-059-8904			43.4
220	002-5778-001-X	TR-85-094-8904	49.9		

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CAI AVERAGE HAMMER INDICATIONS
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HAMMER TEST DATA SHEET No.	POUR PACKAGE No.- GRID AREA	TEST LOCATION	MEAN REBOUND VALUE HORIZ.	UP	DOWN
226	101-2808-004-A	TR-85-105-8902			44.3
230	101-2808-003-N	TR-85-110-8902			42.0
236	002-4790-046-A	TR-85-006-8904	44.2		
238	002-4790-037-AA	TR-85-101-8904	47.0		
239	002-5790-009-B	TR-85-091-8904	47.7		
240	002-6790-012-B	TR-85-014-8904	49.7		
248	002-4792-008-D	TR-85-192-8904	44.0		
249	002-4792-001-G	TR-85-121-8904	44.8		
262	105-5773-001-U	TR-85-329-8903	45.9		
263	105-5773-001-N	TR-85-331-8903	47.4		
264	105-5773-001-T	TR-85-328-8903	54.2		
265	105-5773-001-X	TR-85-330-8903	50.6		
266	105-7785-001-Q	TR-85-268-8903	49.3		
267	105-5773-001-KK	TR-85-341-8903	50.4		
268	105-5773-001-JJ	TR-85-342-8903	52.2		
269	105-5773-004-N	TR-85-267-8903	50.4		
270	105-4785-001-D	TR-85-269-8903	47.8		
271	105-5773-001-RRRR	TR-85-338-8903	46.2		
272	105-4773-003-B	TR-85-332-8903	49.0		
273	105-5773-001-LLL	TR-85-333-8903	52.8		
274	105-5773-001-BBBB	TR-85-334-8903	43.3		
275	105-5773-001-DDDD	TR-85-335-8903	48.7		
276	105-5773-001-NNNN	TR-85-336-8903	48.5		
277	105-5773-001-ZZ	TR-85-343-8903	52.3		
278	105-5773-001-DDD	TR-85-366-8903	47.6		
279	105-5773-001-FFF	TR-85-344-8903	50.3		
280	105-5773-001-GGG	TR-85-345-8903	56.1		
282	105-5790-001-BB	TR-85-350-8903	47.8		
283	105-5790-001-T	TR-85-339-8903	47.1		
288	105-5773-004-F	TR-85-327-8903	52.6		
289	002-2790-001-WW	TR-85-315-8904			44.0
290	002-5790-001-E	TR-85-323-8904	50.8		
291	002-2790-001-YY	TR-85-325-8904			48.4
293	002-2790-001-UU	TR-85-320-8904			45.4
294	002-4790-004-Q	TR-85-314-8904	48.2		
296	002-4790-016-A	TR-85-319-8904	51.8		
297	002-4790-026-B	TR-85-318-8904	49.3		
298	002-4790-038-C	TR-85-317-8904	50.1		
299	002-2790-001-II	TR-85-316-8904			43.3
300	002-4790-004-J	TR-85-322-8904	49.7		
303	002-7792-001-X	TR-85-353-8904			46.6

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CAI AVERAGE HAMMER INDICATIONS
(Cont'd)

HAMMER TEST DATA SHEET No.	POUR PACKAGE No.- GRID AREA	TEST LOCATION	MEAN REBOUND VALUE HORIZ.	UP	DOWN
304	002-7792-001-B	TR-85-354-8904			47.3
306	101-5805-001-T	TR-85-265-8902	50.2		
307	101-5805-001-S	TR-85-278-8902	53.6		
308	101-5805-002-V	TR-85-363-8902	51.0		
309	101-5805-002-X	TR-85-361-8902	51.9		
310	101-5805-004-N	TR-85-371-8902	53.4		
313	101-5805-004-U	TR-85-373-8902	50.8		
314	101-5805-003-X	TR-85-360-8902	50.9		
315	101-5805-005-S	TR-85-372-8902	51.2		
317	002-2785-001-KK	TR-85-368-8904	51.1		
318	002-2785-001-YY	TR-85-369-8904	53.3		
319	002-2785-001-Q	TR-85-260-8904	51.6		
320	002-2785-001-BB	TR-85-266-8904	51.1		
321	002-2785-001-SS	TR-85-270-8904	50.5		
322	002-2785-001-BBB	TR-85-263-8904	53.0		
323	002-2785-001-Z	TR-85-262-8904	52.6		
324	035-5782-003-F	TR-85-280-8906	50.8		
325	035-5782-003-C	TR-85-279-8906	49.1		
326	035-5782-001-L	TR-85-264-8906	50.9		
327	035-5782-001-I	TR-85-259-8906	49.6		
328	002-4790-038-G	TR-85-324-8904	45.7		
330	002-2790-001-R	TR-85-321-8904			45.8
333	002-5778-013-H	TR-85-358-8904	43.4		
334	002-5778-013-B	TR-85-359-8904	55.7		
370	101-5805-004-BB	TR-85-364-8902	48.5		
374	101-5805-004-FF	TR-85-362-8902	52.4		
377	101-5805-001-M	TR-85-275-8902	49.7		
378	101-5805-001-P	TR-85-276-8902	50.3		
379	101-2808-003-L	TR-85-349-8902			50.0
383	101-2808-003-E	TR-85-348-8902			45.8
390	101-2808-002-F	TR-85-370-8902			50.0
391	101-2808-002-C	TR-85-347-8902			48.5
394	002-7807-001-P	TR-85-356-8904			46.8
395	002-7807-001-W	TR-85-357-8904			47.0
396	002-7792-001-MM	TR-85-351-8904			44.8
397	002-7792-001-FF	TR-85-352-8904			44.3
398	105-5773-001-GGGG	TR-85-337-8903	55.0		
405	101-5805-005-J	TR-85-365-8902	50.0		

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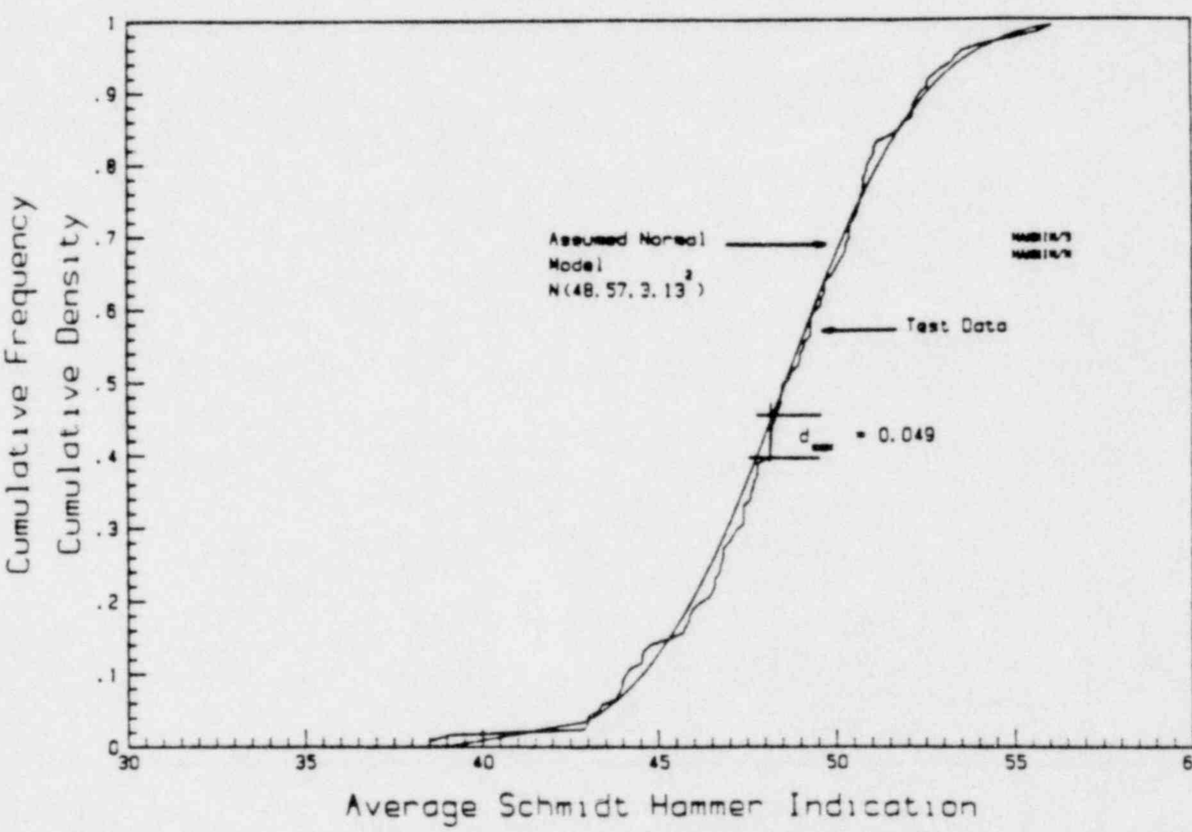
CAI AVERAGE HAMMER INDICATIONS



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APPENDIX B

CC AVERAGE HAMMER INDICATIONS

SHEET No.	CONCRETE POUR PACKAGE No.	TEST LOCATION	MEAN REBOUND VALUE HORIZ.	UP	DOWN	OTHER
15	002-7810-002-X	TR-85-078-8904			40.7	
20	002-7810-001-EE	TR-85-126-8904			42.3	
25	002-4792-007-B	TR-85-030-8904	41.3			
34	002-7810-003-DD	TR-85-127-8904			44.2	
35	105-4810-021-J	TR-85-051-8903	45.5			
54	105-4790-016-C	TR-85-038-8903	43.9			
57	101-5805-012-P	TR-85-186-8902	49.9			
96	105-4790-015-C	TR-85-114-8903	45.7			
110	105-4810-021-D	TR-85-048-8903	43.4			
115	101-5805-010-E	TR-85-169-8902	48.2			
116	101-5805-012-E	TR-85-176-8902	49.0			
124	002-5807-002-G	TR-85-157-8904	48.1			
125	002-5807-002-E	TR-85-027-8904	40.9			
137	003-4785-002-III	TR-85-200-8901	47.8			
139	003-4785-007-U	TR-85-201-8901	46.9			
140	003-4785-002-FF	TR-85-202-8901	45.6			
141	003-4785-002-O	TR-85-204-8901	43.7			
142	003-4785-002-N	TR-85-203-8901	48.6			
143	003-2810-004-E	TR-85-141-8901			46.6	
144	105-5790-002-E	TR-85-196-8903	46.2			
148	002-5810-004-H	TR-85-116-8904	45.3			
149	101-5805-012-O	TR-85-185-8902	52.1			
150	101-5805-012-K	TR-85-184-8902	49.1			
151	101-5805-006-F	TR-85-168-8902	50.3			
155	003-2810-005-D	TR-85-093-8901			49.7	
156	003-2810-002-D	TR-85-040-8901			48.4	
158	101-5805-010-G	TR-85-171-8902	48.7			
162	105-4810-021-S	TR-85-208-8903	43.9			
164	002-5810-001-GG	TR-85-019-8904	46.5			
170	201-5805-002-F	TR-85-190-8902	48.2			
171	002-5807-002-Y	TR-85-156-8904	39.7			
179	101-5805-013-U	TR-85-179-8902	50.6			
180	101-5805-012-V	TR-85-183-8902	50.6			
182	101-5805-013-BB	TR-85-180-8902	53.0			
185	105-4810-021-B	TR-85-050-8903	45.9			
186	003-4785-002-RRR	TR-85-206-8901	50.9			
187	003-4785-002-B	TR-85-205-8901	48.5			
188	101-4808-009-I	TR-85-158-8902	52.2			
191	101-4812-005-J	TR-85-135-8902	50.0			
193	105-7810-002-N	TR-85-229-8903		51.3		
194	105-7800-001-B	TR-85-210-8903			48.1	

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CC AVERAGE HAMMER INDICATIONS
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SHEET No.	CONCRETE POUR PACKAGE No.	TEST LOCATION	MEAN REBOUND VALUE HORIZ.	UP	DOWN	OTHER
199	002-7810-003-LL	TR-85-222-8904	48.5			
200	002-7810-001-W	TR-85-220-8904		53.0		
207	105-7810-001-D	TR-85-227-8903			45.6	
209	105-7810-007-A	TR-85-133-8903	52.9			
210	105-5790-002-I	TR-85-039-8903	46.4			
212	105-4810-021-I	TR-85-049-8903	49.8			
213	105-4810-021-G	TR-85-148-8903	50.7			
221	101-5805-011-G	TR-85-173-8902	49.7			
222	101-5805-011-K	TR-85-174-8902	50.8			
223	101-5805-011-L	TR-85-175-8902	52.0			
225	101-4808-004-D	TR-85-139-8902	48.5			
241	105-4790-011-B	TR-85-043-8903	47.8			
244	002-4807-002-F	TR-84-153-8904	47.7			
245	201-5805-002-D	TR-85-187-8902	53.4			
252	002-7807-002-G	TR-85-085-8904	50.4			
255	002-7807-003-A	TR-85-086-8904			46.8	
256	002-7807-002-Q	TR-85-155-8904			48.0	
257	002-4810-020-I	TR-85-020-8904	47.9			
281	105-4790-008-G	TR-85-236-8903	48.3			
284	105-4800-001-F	TR-85-235-8903	48.5			
285	105-7810-007-S	TR-85-237-8903		58.8		
286	105-5790-003-L	TR-85-238-8903	48.9			
287	105-7790-002-D	TR-85-306-8903			48.5	
292	002-7810-001-OOO	TR-85-300-8904		49.2		
295	002-7810-001-CCC	TR-85-305-8904		52.1		
301	002-5830-001-N	TR-85-312-8904	47.7			
302	035-3790-001-B	TR-85-257-8906			49.4	
305	002-5807-003-L	TR-85-242-8904	49.9			
311	101-5805-007-U	TR-85-378-8902	53.0			
312	101-5805-008-Z	TR-85-272-8902	52.4			
316	002-7810-001-WW	TR-85-301-8904		52.9		
329	002-7810-002-OO	TR-85-302-8904	49.9			
331	002-7810-003-SS	TR-85-303-8904	44.6			
332	002-4790-027-P	TR-85-258-8904	43.1			
335	002-7810-001-RR	TR-85-291-8904			49.9	
336	002-5810-001-A	TR-85-367-8904	53.2			
337	002-7810-001-I	TR-85-295-8904			43.2	
338	002-4810-015-H	TR-85-284-8904	49.1			
339	002-4810-015-M	TR-85-283-8904	50.8			
340	002-7810-002-M	TR-85-285-8904			46.1	

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CC AVERAGE HAMMER INDICATIONS
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SHEET No.	CONCRETE POUR PACKAGE No.	TEST LOCATION	MEAN REBOUND VALUE HORIZ.	UP	DOWN	OTHER
341	002-7810-003-DD	TR-85-294-8904			47.3	
342	002-5810-002-MM	TR-85-232-8904	50.7			
343	002-5810-002-S	TR-85-282-8904	48.8			
344	002-7810-003-CCC	TR-85-290-8904	44.9			
345	002-7810-003-EEE	TR-85-281-8904	47.9			
346	002-7810-003-XX	TR-85-293-8904	48.7			
347	002-4810-002-V	TR-85-233-8904	48.1			
348	002-7810-002-C	TR-85-286-8904			45.9	
349	002-4810-002-H	TR-85-288-8904	46.5			
350	002-7810-002-EE	TR-85-292-8904			44.2	
352	002-5810-014-C	TR-85-287-8904	48.6			
353	003-2810-007-H	TR-85-326-8901			46.7	
354	003-2813-002-AA	TR-85-254-8901	46.5			
355	003-2810-007-BB	TR-85-246-8901	48.2			
356	003-2810-001-M	TR-85-253-8901	48.7			
357	003-2810-002-T	TR-85-249-8901	51.3			
358	003-2810-002-VV	TR-85-248-8901	51.6			
359	003-2810-002-L	TR-85-251-8901	51.2			
360	003-2810-002-AA	TR-85-250-8901	51.2			
361	003-2810-007-CC	TR-85-247-8901	51.7			
362	003-2813-001-N	TR-85-252-8901	52.8			
363	003-2813-001-U	TR-85-244-8901	54.4			
364	003-2813-001-T	TR-85-243-8901	52.9			
365	003-2810-004-R	TR-85-245-8901			47.8	
366	201-5805-002-V	TR-85-374-8902	52.4			
367	201-5805-001-R	TR-85-377-8902	52.0			
368	003-2813-002-G	TR-85-256-8901	48.7			
369	003-2813-001-AA	TR-85-255-8901	52.2			
371	101-5805-010-HH	TR-85-376-8902	52.7			
372	101-5805-012-LL	TR-85-375-8902	53.4			
373	101-5805-009-JJ	TR-85-274-8902	51.4			
375	105-7810-001-B	TR-85-304-8903			44.3	
376	105-2810-001-D	TR-85-234-8903			48.2	
380	101-2812-001-BBB	TR-85-239-8902	50.5			
381	101-6808-008-A	TR-85-355-8902	48.4			
382	101-2812-001-OO	TR-85-241-8902	48.7			
384	101-2312-001-C	TR-85-240-8902	53.3			
385	101-4812-001-M	TR-85-309-8902	51.2			
386	101-4812-001-J	TR-85-310-8902	50.3			
387	101-4812-001-B	TR-85-311-8902	52.3			

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CC AVERAGE HAMMER INDICATIONS
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SHEET No.	CONCRETE POUR PACKAGE No.	TEST LOCATION	MEAN REBOUND VALUE HORIZ.	UP	DOWN	OTHER
388	101-4812-002-H	TR-85-307-8902	49.6			
389	101-4812-002-K	TR-85-308-8902	51.3			
392	002-5807-001-L	TR-85-346-8904	49.3			
393	002-5807-001-E	TR-85-296-8904	47.4			
399	101-5805-008-K	TR-85-271-8902				51.1
400	101-5805-009-O	TR-85-273-8902	53.2			
401	002-6807-008-A	TR-85-297-8904	51.0			
402	002-6807-009-C	TR-85-313-8904	50.2			
403	002-7807-002-O	TR-85-299-8904			47.3	
404	002-7807-002-R	TR-85-298-8904			48.6	
406	002-7810-002-A	TR-85-289-8904		47.7		

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AVERAGE SCHMIDT HAMMER INDICATION