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A COMPARATIVE ANALYSIS OF STRUCTURAL CONCRETE
QUALITY ASSURANCE PRACTICES ON THREE
FOSSIL FUEL POWER PLANT CONSTRUCTION PROJECTS

Final Report

J. H. Willenbrock, H. R. Thomas, Jr.
and J. L. Burati, Jr.

The Pennsylvania State University
University Park, PA 16802

June 1978

Prepared For

THE DEPARTMENT OF ENERGY
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ABSTRACT

The basic objective of this research effort was to perform a comparative analysis of the Quality Assurance practices related to the structural concrete phase on three fossil fuel power plant projects which are (or have been) under construction in the United States in the past ten years. This analysis identified the response of each Quality Assurance program to criteria similar to those which apply on nuclear power plant projects. The major emphasis was placed on the construction aspects of the structural concrete phase of each project. The engineering and design aspects were examined whenever they interfaced with the construction aspects. For those aspects of the Quality Assurance system which can be considered managerial in nature (i.e., organizational relationships, types of Quality Assurance programs, corrective action procedures, etc.) an attempt has been made to present the alternative approaches that were identified. For those aspects of the Quality Assurance system which are technical in nature (i.e., the frequency of testing for slump, compressive strength, etc.) an attempt has been made to present a comparative analysis between projects and in relation to the recommended or mandated practices presented in the appropriate industry codes and standards.

FOREWORD

The basic objective of this research effort was to perform a comparative analysis of the Quality Assurance practices related to the structural concrete phase on three fossil fuel power plant projects which are (or have been) under construction in the United States in the past ten years. This analysis identified the response of each Quality Assurance program to criteria similar to those which apply on nuclear power plant projects. The major emphasis was placed on the construction aspects of the structural concrete phase of each project. The engineering and design aspects were examined whenever they interfaced with the construction aspects (i.e., development of project specifications, design change procedures, etc.). For those aspects of the Quality Assurance system which can be considered managerial in nature (i.e., organizational relationships, types of Quality Assurance programs, corrective action procedures, etc.) an attempt has been made to present the alternative approaches that were identified.

For those aspects of the Quality Assurance system which are technical in nature (i.e., the frequency of testing for the slump, air, or compressive strength properties of concrete, the curing practices observed, etc.) an attempt has been made to present a comparative analysis between projects and in relation to the recommended or mandated practices presented in the appropriate industry codes and standards.

It was not possible, within the time and budgetary constraints of the research project, to consider the topic related to fossil power plants in as great a depth as was presented in the companion study entitled

"A Comparative Analysis of Structural Concrete Quality Assurance Practices on Nine Nuclear Power Plant Construction Projects" (see Ref. 1.1 in Chapter 1 of this report). The interested reader is encouraged to first examine the nuclear power plant report cited above since the explanations and analysis found in it provide a more extensive coverage of the Quality Assurance topic. It is felt that Utilities, Engineers and Constructors will be able to compare the levels of QA/QC emphasis on the two types of power plant projects with respect to structural concrete after both reports have been read.

The writers would like to express their appreciation to: (1) the people within the Fossil Power Plant Construction industry who either guided this research effort during the developmental stages or assisted during the data collection stage, and (2) the graduate students (R. Fron, P. Wilson, J. Rouland and A. Zilich) who assisted the writers in their efforts. These personnel and the firms within the industry which they represent are not cited directly in this preface or in the report in order to protect the identity of the projects that were included in the research study. The research effort could not have been completed however without the excellent cooperation which they provided.

The "Comparative Analysis" which is found in this report, represents, to a large degree, an interpretation by the writers of data which was collected as a result of countless hours of personal interviews and analysis of project documents. The majority of this effort took place from April, 1977, to December, 1977, and in general does not reflect all of the revisions to the practices observed which have been made since that time period. When

a research effort of such a magnitude is undertaken there will certainly be instances when the impressions which were obtained might have been partially inaccurate. Such a situation is unavoidable. Taken as a whole, however, it is felt that the results of the research study present a fairly reasonable interpretation of the topic which was studied. It is hoped that the report will be a valuable contribution to the Quality Assurance literature of the Fossil Power Plant Construction industry.

Jack H. Willenbrock

H. Randolph Thomas, Jr.

James L. Burati, Jr.

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CHAPTER 1

INTRODUCTION

One of the areas of power plant construction which has an impact, in terms of both the cost and duration of projects, is structural concrete. It is also one of the areas that is most directly influenced by field related Quality Assurance practices since concrete is essentially produced and placed by combining raw materials at or near the project site.

DESCRIPTION OF RESEARCH EFFORTNeed for Research: Fossil Projects

The Quality Assurance practices related to structural concrete on nuclear power plant projects are more formalized and extensive than those found on fossil fuel projects. An extensive research effort for the U.S. Department of Energy entitled "A Comparative Analysis of Structural Concrete Quality Assurance Practices: on Nine Nuclear Power Plant Construction Projects" (1) was undertaken by the writers in the Fall of 1976. In order to provide an appropriate frame of reference for that study, it was felt that a similar, but more limited, research effort on fossil fuel power plant projects was also necessary. This report summarizes those efforts.

Objective of Research: Fossil Projects

The basic objective of the research effort was to perform a comparative analysis of the Quality Assurance practices related to the structural concrete phase on three fossil fuel power plant projects which are (or have been) under construction in the United States in the last ten years. An attempt was made to analyse the practices in a fashion which paralleled the approach used in the nuclear study (1) mentioned above, although it was recognized

that a set of 18 Quality Assurance Criteria for fossil plants [similar to the 18 Criteria of 10 CFR 50 Appendix B (2)] did not exist.

The major emphasis was placed on the construction aspects of the structural concrete phase of each project. The engineering and design aspects were examined whenever they interfaced with the construction aspects (i.e., development of project specifications, design change procedures, etc.). For those aspects of the Quality Assurance system which can be considered managerial in nature (i.e., organizational relationships, types of Quality Assurance programs, corrective action procedures, etc.) an attempt has been made to present the alternative approaches that were identified. Examples of the approaches which appear to be most cost and time effective without influencing the final quality of the concrete have been cited whenever possible.

For those aspects of the Quality Assurance system which are technical in nature (i.e., the frequency of testing for the slump, air, or compressive strength properties of concrete, the curing practices observed, etc.) an attempt has been made to present a comparative analysis between projects and in relation to the recommended or mandated practices presented in the appropriate industry codes and standards. In some instances it is possible to point out practices which are "over and above" what appears to be the "average" practice and hence may be considered as unusually costly or time-consuming while resulting in only a marginal increase in quality.

Limitations of Research: Fossil Projects

It was not possible, within the time and budgetary constraints of this research project, to consider the topic from a fossil viewpoint in as great a depth as the comparative analysis of the nuclear projects (1) cited above. The interested reader is encouraged to first examine the nuclear report (1) since the explanation and analysis which is provided in that report is much

more extensive. It is felt, however, that utilities, engineers and constructors will be able to compare the levels of QA/QC emphasis on the two types of power plant projects with respect to structural concrete when this fossil report is evaluated in relation to the nuclear report.

Research Procedure

The research effort consisted of the following phases:

1. Literature review

The literature review was divided into three parts:

- a. Quality Assurance literature which commented on the practices which were being implemented on power plant projects in the last ten years as well as the regulatory environment under which they were being built.
- b. The pertinent Quality Assurance requirements, codes, standards, and guides. These essentially included Appendix B, the appropriate NRC Regulatory Guides, the ANSI standards, the ASME Boiler and Pressure Vessel Code, etc.
- c. Concrete and concrete-component related literature such as the ACI Codes and Recommended Practices, ASTM Standards, the ASME Boiler and Vessel Code, etc.

2. Identification of Nuclear Projects

The interested reader is referred to (1, pg. 1.7) for details.

3. Identification of Fossil Projects

A total of three fossil fuel power plant projects were selected for this phase of the comparative analysis. The specific details related to these projects is found in Tables 2.1 and 2.2 in Chapter 2 of this report.

It should be noted that a direct comparison between this fossil based report and the one related to Nuclear Power Plant Construction Projects (1) is

not made in either report. It is left to the reader to draw his own conclusions after both reports have been examined in detail.

4. Data Collection

The first step in the data collection phase involved the acquisition of as many of the project-related Quality Assurance documents (i.e., concrete specifications, QA programs and procedures, QC programs, inspection plans, construction procedures, etc.) which each project would make available. An analysis of these documents resulted in a questionnaire which was sent to each project in order to obtain additional information. It should be noted that since there are no formal governmental regulations with regard to QA/QC programs on fossil power plant construction projects the data which was received was often not as extensive as was found on the nuclear projects examined in (1).

Each fossil plant was visited at least twice and an effort was made whenever possible to interview representatives of each of the parties involved with the project. The level of detailed coverage was not uniform on all projects because two of the projects were essentially beyond the major concrete stage. The material presented for each of the projects in this report is therefore not complete in a number of cases. The data received was also dependent upon the availability of information on the project sites. In a number of cases, topics were not discussed, detailed information was either not supplied or not made available to the writer and interpretations had to be made.

5. Comparative Analysis

The final phase of the research effort involved a comparative analysis of the three fossil projects. The information which resulted from this comparative analysis is presented in this report as follows:

- Chapter 2 Case Studies of Three Fossil Power Plant Construction Projects
- Chapter 3 Discussion of Quality Related Criteria
- Chapter 4 Analysis of Concrete Components
- Chapter 5 Control Systems, Mass Concrete and Cold and Hot Weather Requirements
- Chapter 6 Preplacement Activities
- Chapter 7 Placement and Post-Placement Activities

Research Benefits

This report, by presenting a comparative analysis of the Quality Assurance practices related to the structural concrete phase, will surface the acceptable alternative approaches which are being implemented and indicate the generic type of problems which have occurred for the sample of projects which were studied. This information should be useful to those Utilities that will be involved with future fossil power plant projects as well as those that are currently in the design or construction stages.

OBSERVATIONS

The results which were obtained from the research study, as noted above, are presented in Chapters 2 to 7 of the report. Some of the important observations which we felt to be of particular significance are presented below.

1. On two of the fossil projects (i.e., Projects X and Y) the Utility served as its own Construction Manager. The construction phase of Project Z was managed by the same A.E. firm that was responsible for the design phase.

The direct influence of the Utility on Project X was rather significant even though the number of Utility X personnel committed to the project was not very large. Utility X personnel were placed in the key managerial positions within the field organization. They were supplemented by personnel from the AE Firm.

On Project Z the AE/CM Firm appeared to play the more significant role although there was a good deal of coordination between the small project site staff of Utility Z personnel and the AE/CM Firm personnel.

Offsite concrete batch plants were utilized on all three projects. The concrete testing responsibility was placed with an independent testing laboratory on 2 of the 3 projects. Testing on the third project was directed by the Utility.

2. It appears that all three projects had active QC programs, some parts of which clearly showed the influence of nuclear construction practices. On Project X for example, the Nonconformance Report, Corrective Action, Surveillance and Inspection Log, etc. elements were key parts of the QC program. On Project Y the Utility retained a Constructor to develop and direct a QA/QC program which would later serve as the model to be implemented on Utility Y's next nuclear project. Utility Y was therefore effectively using Project Y as a "testing ground" for the development of a more formal QA/QC program than had previously existed.

It appears that a formal QA program was developed on Project X after the QC program was operational. At the time of the project visits by the writer no formal Auditing program had been established. This element has, however, been added since the site visit. On Project Y a QA program which includes formal Audits, follow up procedures, etc. was found to be operational. It is interesting to note, however, that there is no on-site QA group; all Audits are performed by home office personnel who make periodic visits to the project. There does not appear to be a fixed schedule or minimum frequency for these Audit visits.

On Project Z both the AE/CM Firm as well as Utility Z are involved in QA activities such as Audits, Surveillances, etc. All of these QA activities are implemented through a set of well defined QA procedures.

3. It appears that the level of documentation has increased on fossil projects and now often includes a series of formalized instructions and procedures which supplement the more traditional drawings and project specifications used on construction projects. As an example, Project X has two separate quality related "Instructions" (i.e., "Performance of Field Q.C. Inspection and Surveillance" and "Development and Implementation of Inspection Point Program") which provide Quality Control guidance. The latter type of document, which was initiated by the A.E. firm, provides guidance to inspectors when they are performing shop inspections. It includes a description of the material or equipment to be inspected and the reference documents, Inspection and Test Procedures and Quality Assurance Checklists which will be required.

4. As noted in (2) above the fossil projects exhibited Nonconformance Report and Corrective Action practices which were very similar to those found on nuclear projects. On Project X for instance a formalized Nonconformance and Corrective Action procedure which includes Hold Tags, Stop Work Action and Disposition Categories has been implemented. On Project Y two different Nonconformance Report (i.e., NCR) categories (based upon criticality) are used. Class 1 NCR's are evaluated and dispositioned by a Material Review Board consisting of the Construction Manager, Project Engineer and Q.C. Supervisor. The disposition categories are: Use As Is, Repair, Rework or Reject.

5. Another aspect of documentation which bears some relationship to nuclear practices is the emphasis which is placed on the maintenance of Quality Assurance Records. All three fossil projects had specific requirements related to the development of a "historical record" for the project. Project Y's requirements included 5 separate classification designations which specified different duration conditions for the maintenance of records in the "historical file".

6. Chapter 4 of this report presents a rather extensive analysis of the requirements which are found on each of the three fossil projects with regard to the concrete components (i.e., cement, aggregates, water, ice and admixtures) which are used in the production of concrete. Several comments of a general nature can be made.

a. There appears to be an extensive reliance on references to existing ASTM, ACI, etc. documents in the project specifications when the concrete component properties are defined. It is interesting to note that very little mention was made of problems involved with these requirements. It appears that "engineering judgment" is still extensively used in fossil plant construction when these requirements are evaluated in the field.

b. Statistical concepts related to the "Quality Control of Construction Materials" were not used on the fossil projects in the research study. The techniques of random sampling, evaluation of both the mean and standard deviation of material properties, etc. were not being implemented. This appears to be an area which should be examined in more detail by the industry.

6. There do not seem to be as many problems on fossil projects with regard to the definition of "Mass Concrete" and the interpretation of "Cold and Hot Weather" conditions as was found on the nuclear projects. This may be due to the fact that "engineering judgment" on the part of the QC inspector is often applied in those situation where problems have arisen.

Concrete placements on fossil projects are also generally not as congested from a reinforcement point of view as they are on nuclear projects. The use of Cadwelding also appears to be limited so the problems associated with this process on nuclear projects do not carry over into fossil projects.

7. The level of involvement of the QC inspectors on the fossil projects was not as extensive as found on some of the nuclear projects. Although concrete checklists which evaluated some of the attributes associated with concrete

placements were utilized, the impact on the overall concrete phase was more in line with the practices found on conventional construction. Very little mention was made of problems associated with formwork tolerances, cleanliness, requirements (with regard to both formwork and reinforcing steel), or changes in concrete properties due to pumping or curing conditions. On one of the projects (i.e., Project 2) it was noted that concrete is delivered to the placement location in a dry state. Mixing water is metered and mixing of the concrete components occurs after the truck arrives at the site.

8. The concrete placement practices which were in existence on the three fossil projects are reviewed in Chapter 7 of this report. Placement, consolidation and curing practices as they were defined in the project specifications are presented.

REFERENCES

- 1.1 Willenbrock, J. H., Thomas, H. R., Burati, J. L., "A Comparative Analysis of Structural Concrete Quality Assurance Practices on Nine Nuclear Power Plant Construction Projects," Research Report to U.S. Department of Energy, The Department of Civil Engineering, The Pennsylvania State University, University Park, PA, June 1978.
- 1.2 Atomic Energy Commission, "Code of Federal Regulations, 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, D.C., 1969.

CHAPTER 2

CASE STUDIES OF THREE FOSSIL POWER PLANT CONSTRUCTION PROJECTS

This chapter contains case studies of the three fossil plants which were visited during the course of the research. Each of the case studies is divided into the following sections: (1) Project Organization, (2) Quality Assurance Program, (3) Quality Control Program, (4) Summary.

These case studies can be used as reference points for each of the three projects when reading the other chapters of the report. Table 2.1 provides some of the basic information about the projects and Table 2.2 defines the responsibility of each of the parties involved.

Table 2.1 Basic Fossil Project Data

Project	Fuel	Construction Permit		%Complete Concrete	Commercial Operation
X	oil	Unit #1	1974	89%	1982
		Unit #2	1974	33%	1984
Y	coal	Unit #3	1973	55%	1979
Z	coal (Mine mouth)	Unit #3	1973	100%	1977

Table 2.2 Division of Responsibilities on Fossil Projects

Project	X	Y	Z
Owner	Utility X	Utility Y	Utility Z
Engineer	Independent A/E	Independent A/E	Independent AE/CM
Construction Mgr.	Utility X	Utility Y	Independent AE/CM
Concrete Const.	Independent Constr.	Independent Constr.	Independent Constr.
Batch Plant Operation	Independent concrete supplier with off-site batch plant	Independent concrete supplier with off-site batch plant	Independent concrete supplier with off-site batch plant
Concrete Testing	Independent testing lab	Utility Y	Independent testing lab

CASE STUDY - PROJECT XProject Organization

On this project, as noted in Table 2.2, Utility X acts as the Construction Manager, thereby providing the necessary overview while at the same time retaining the decision making responsibility over all activities. Figure 2.1, which illustrates the flow of responsibility on the project, indicates that a Project Manager who is located at Utility X's home office has been placed in direct charge of Project X. He is able to maintain a full appreciation for the project's scope and stage of construction through frequent visits to the site and a close interface relationship with Utility X's functional departments.

All engineering services are performed by an independent A.E. firm who works closely with the Utility X's Project Department regarding the preparation and design of all systems, engineering drawings and specifications. The A.E. firm provides the design experience, while Utility X provides the management and coordination services required during the construction phase. An independent Testing Firm has been retained for the project with the requirement that copies of all of the documents which are generated must be sent to Utility X.

A separate contract was placed by Utility X for the operation of the concrete batch plant. The concrete supplier is responsible for the production and delivery of concrete and the receipt and testing of incoming material. There is also a Utility X Quality Control representative at the Batch Plant who performs spot surveillances and inspections.

The interface contact between the A.E. firm and Utility X is distributed throughout the project by the Project Manager, Resident Engineer, Field Engineers, Quality Control Engineers as well as by the individual Contractors' Superintendents and their subordinates.

Figure 2.1 Project X Organization

Quality Assurance Program

The only formal Quality Assurance Program pertaining to Project X is the one which is incorporated by the Batch Plant Concrete Supplier. It is essentially independent of Utility X's control, except for the fact that monthly Quality Assurance Reports are prepared and sent to Utility X for review and concurrence.

Although Utility X, as of the summer of 1977, had no formal Quality Assurance Program, their Quality Assurance Department recently completed an audit of the total Quality Control program.

Quality Control Program

The only site Quality Control Program is the one which is under the direction of Utility X. As shown in Figure 2.1, this program is under the control of the Utility X's Project Manager who has contact, thru Utility X's

Construction Manager, with the Field Quality Control Supervisor and his subordinate engineers and field inspectors.

Some of the areas of activity covered by the QC Program are:

a. Performance of Field QC Inspections and Surveillances:

This activity covers all construction areas with regard to extent and frequency. The level of importance of various areas and the requirements of the program are determined by the Quality Control, Construction and Management Supervisory personnel. This activity incorporates the use of checklists, drawings, specifications, Bill of Materials, etc.

b. Issuance of Nonconformance Reports:

Nonconforming situations are identified when Non-Conformance Reports (i.e., NCR's) are initiated. A master log of NCR's is maintained as a means of follow-up and control to insure that corrective action is taken in an appropriate period of time. A hold tag is used to flag material which should not be used because of a non-conformance.

c. Documentation and Resolution of QC Non-Conformances:

The Non-Conformance Report (NCR) is used by the Quality Control Unit to notify the Field Engineer (FE) and other applicable personnel of an existing problem, and to specify the suggested corrective action. The FE must send a reply when corrective action has been taken.

d. Follow up of the Non-Conformance Report:

An "Outstanding Non-Conformance Report" summary sheet is issued weekly. The summary sheet serves as a reminder to the Field Engineer and Quality Control Unit that Non-Conformances still exist and that the final resolution date may have expired. The "Report of Outstanding Non-Conformances" (i.e., RONC) highlights the NCR's that have been open for more than thirty (30) days with no acceptable commitment for resolution.

e. Issuance of Work Stoppage:

Work Stoppages will occur when a Non-Conformance of a critical nature exists (i.e., one which could cause injury, loss of life, or serious irreparable damage to equipment/material if further work were performed).

The responsible personnel capable of work stoppage authorization are:

Resident Engineer
Field Engineer
Coordinating Engineer
Field Quality Control Supervisor
Field Quality Control Inspector
Project Engineer
Construction Manager
Project Manager

f. Establishment and Maintenance of QC Files:

The Field Quality Control Group is responsible for the development and maintenance of a Quality Control File. The Field Quality Control Supervisor (FQCS) is responsible for determining if a document merits retention by the QC Unit.

g. Maintenance of a Surveillance Log:

A surveillance log is maintained up to date by all Quality Control Inspectors when they are performing an inspection and/or surveillance of any phase of construction.

h. Development and Implementation of the Inspection Point Program:

The Inspection Point Program consists of a series of inspection guides initiated by the A/E firm as an aid to inspectors while performing shop inspection. It consists of a description of the material/equipment, reference documents, Inspection and Test Procedures and an A.E. Quality Checklist.

Summary

Project X is unique in that even though the Utility X management group is small as compared to other projects, it is still able to observe and retain approval responsibility for all activities before they are performed. This

concurrence role also provides Utility X with the ultimate control of project costs. When difficulties and problems arise, Utility X has first hand knowledge of the situation.

With regard to the project organization, the strategy of Utility X has been to supplement its organization with personnel who are on loan from the A.E. firm. In this manner, Utility X and the A.E. firm are able to work together rather closely throughout the design and construction period. This interrelationship is also operative in the Quality Control Unit. Utility X supplies the management skills and the A/E Firm supplements the owner's experienced staff. There is really only one organization employing both Utility X and A/E personnel with Utility X in control.

CASE STUDY - PROJECT Y

Project Y is the third of a three unit Fossil Plant project. Units #1 and #2 have been in commercial operation, respectively since 1975 and 1976.

Project Organization

As noted in Table 2.2, Utility Y is acting as the construction manager of the project. Utility Y, in conjunction with an A.E. firm and a General Contractor (G.C. firm) (who is responsible for the concrete phase of the project) organizes all site activities from the design through to the construction stages.

Figure 2.2 indicates the division of responsibility for Project Y. A Project Y Project Manager, who reports directly to the President of Utility Y coordinates all of the activities at the home office as well as the project site. Utility Y's Construction Department, which is located on the project site, is under the supervision of a Project Y Superintendent of Construction, who reports to the Project Y Project Manager. The Project Y Superintendent is responsible for all of the construction work on the site. All approvals and problems are administered through his office. He is provided with current information about project activity by the individual heads of the functional departments who are

involved with the various phases of construction.

Utility Y does not have its own formal QA/QC Program for the construction phase. It has retained the GC firm to develop and direct the total QA/QC effort at the project site. The GC Firm's Chief of Quality Assurance, who reports to both the management of Utility Y as well as the management of the GC firm, has the freedom to identify and obtain correction of quality related problems, and when necessary bring them to the attention of management for corrective action.

The AE firm performs all of the required engineering work which includes the design of all systems and components, preparation of the engineering drawings and specifications, and procurement of some of the permanent and temporary plant equipment. The interface between the A.E. and G.C. firm is passed on throughout the project through a stepping process or line diagram. It is the responsibility of the home office management personnel to make sure that the site personnel are aware of the project direction. This direction is transmitted both verbally and in writing to explain the current areas of priority and concern.

A separate contract was placed by Utility Y with a concrete supplier for the operation of an off site batch plant. The concrete supplier is responsible for the production and delivery of concrete and the receipt and the testing of incoming concrete material and components.

There is no permanent QC representative at the batch plant; inspection is done on a periodic basis by Utility Y's testing laboratory inspector. The frequency of inspections is left up to the engineering judgment of the testing laboratory inspector. The concrete batch plant operates under its own independent Quality Assurance Program, one which was developed by the concrete supplier.

Figure 2.2. - Project Y Organization

Quality Assurance Program

The Quality Assurance Program for Project Y was developed by the G.C. firm after the Quality Control Program had been developed in response to the need to establish an orderly system for the documentation of the observations of the QC inspectors.

There is no onsite Quality Assurance Department. The personnel who perform audits are permanent home office employees of the G.C. firm who are only at the site for the duration of the audit. There appears to be no scheduling frequency of audits; the scheduling is determined as a result of the findings of previous audits.

The contractor to be audited is given prior notice of the visit. After the audit, a formal letter stating the findings of the audit is sent to the audited contractor and other interested parties. The contractor must review the letter and comment on it. The letter evaluates the performance of the contractor with regard to the contract responsibilities which he has been delegated. Thirty working days are designated as the contractor's review and comment period.

Quality Control Program

A contractor Quality Control Program was implemented on Project Y as a stepping stone for both the Utility Y and the G.C. firm towards a Nuclear Power Plant which they will be involved with in the near future. It was felt that if a QC Program could be successfully implemented on a Fossil Plant, that many of the bugs could be identified and remedied before a formal QA/QC Program for nuclear work was needed.

Utility Y accepted the proposal for such a program when it was recommended by the GC Firm because it was felt that such a program would provide tighter controls and quality documentation than normally found on fossil projects.

Utility Y is thus assured to a greater degree that construction is being performed in accordance with the appropriate project specifications and work procedures.

Summary

Utility Y requires concurrence on all construction activities and documentation. Since they are the construction manager, they are well informed of daily site activities. It appears, however, that Utility Y personnel are unable to exercise full day to day responsibility. They cannot, for instance, stop a concrete placement. The steps which are required to take corrective action when problems occur are very time consuming since only the A.E. firm Engineering Department and QC department of the G.C. firm have authority to issue work stoppage during surveillance and inspections. This creates a problem when Utility Y's personnel, while performing a surveillance, observe a non-conformance. They must waste valuable time approaching their superiors and informing them of the difficulty when the error could possibly have been corrected immediately if they had the necessary authority to stop work.

CASE STUDY - PROJECT Z

Project Organization

As noted in Table 2.1, Project Z is the third unit of a three unit Fossil Plant; the first and second units have been in operation since the early 70's. Figure 2.3 illustrates the levels of responsibility and the interface relationships on Project Z through the design and construction stages. Utility Z has the responsibility to assure that Unit 3 will be designed, fabricated and constructed in accordance with applicable codes and specifications to assure operation with the highest regard to safety and reliability. Utility Z's Senior Site Representative oversees all activities on behalf of the utility. His assistants filter all the necessary information through his office for

review and comment so that he is aware of all of the activities being performed.

The Field Construction Engineer is the second in command. He also monitors all field work being performed by the contractors and subcontractors. The Accounting Department is concerned with final decisions on approvals submitted by the AE/CM firm. The group tightly controls all expenses, materials, and equipment at the site.

The Cost Engineer maintains an up-to-date analysis of the cost of the project with respect to material, equipment and component costs. The Planning and Scheduling Department incorporates Utility Z's ideas into the planning and scheduling deadlines. The AE/CM receives this schedule and organizes the work forces and schedules to meet these deadlines.

The AE/CM firm has been retained to perform the engineering design and construction work which includes the responsibility for preparing design specifications and drawings used in the procurement, fabrication, erection and installation of systems, structures or components. The same firm has been retained as Construction Manager (CM) and in this capacity is responsible for planning and managing all site construction activities.

Figure 2.3 illustrates the interfacing relationships between Utility Z and the AE/CM firm. Utility Z informs the AE/CM firm of its opinions and the general direction they believe the project should take. Personnel from both organizations maintain a close working relationship in order to implement a project direction which is agreeable to all parties concerned.

Utility Z, because of its responsibility to assure that Project 2 is designed, fabricated and constructed in accordance with applicable codes and specifications, has required that all contracts specify that a quality assurance program is required. This program must cover all phases of equipment

Figure 2.3 Project 2 Organization

procurement, fabrication, erection, installation, construction and start-up for each individual contractor.

A separate contract was placed by the AE/CM Firm for an off-site batch plant with a concrete supplier who is responsible for the production and delivery of concrete.

Quality Assurance Program

The AE/CM Quality Assurance Program for Project Z complies with Utility Z's overall Assurance Program. This program provides for review of engineering specifications, construction and testing procedures to insure that necessary quality requirements are included. Quality Assurance surveillances of contractors is also performed to insure that the specific requirements of the Utility Z's QA Program are met. The Quality Assurance Program is established and implemented under the direction of the Utility's Manager of Quality Assurance. This Manager of QA has the responsibility for establishing and implementing the quality assurance program through the coordination and direction of all necessary quality assurance requirements.

The AE/CM Firm implements Utility Z's QA Program by means of detailed, approved procedures covering the areas of project operations, construction management operation, and quality assurance surveillance of site construction as well as pre-purchased equipment.

The Quality Assurance Program is implemented by the following five functional groups: (1) Engineering and Design, (2) Construction Management, (3) Materials Engineering and Quality Compliance, (4) Procurement and (5) Project Management. The responsibilities of each of the functional groups is shown in Figure 2.4.

During the design phase the AE/CM Firm's Quality Compliance Engineering Group (a take off of Quality Control) reviews the firm's prepared drawings

Figure 2.4. - AE/CM Quality Assurance Program for Project Z

and specifications for the inclusion of quality assurance criteria prior to submittal for the owner's approval. After acceptance, this same Engineering Group reviews and evaluates the programs and procedures of manufacturers and performs quality assurance surveillances for conformance during the construction phase.

Quality Control Program

The site Quality Control effort on Project Z is under the direction of the AE/CM Firm's Quality Assurance Department.

During the manufacturing and fabrication stage, the Quality Compliance group performs quality assurance surveillances on systems, components and equipment built to Design Specifications. Any deviations require the firm's Project Engineer's approval prior to the release for shipment. The AE/CM firm's Project Engineer obtains approval from Utility Z's Project Engineer when necessary.

The AE/CM Firm's Quality Assurance Group obtains and maintains all documentation required by the quality assurance program. These documents and records are turned over to Utility Z upon completion of the project. This same group monitors all site quality activities throughout the construction phase.

Summary

This project is controlled differently than Projects X or Y because one independent firm acts as both Architect-Engineer and the Construction Manager. The Quality Assurance Program, however, is under the direction of Utility Z and is based on their requirements. Utility Z, in order to maintain close contact with construction activities, has its own QA Engineer on site who performs audits and surveillances and confers frequently with the AE/CM Firm's QA Group about site activities.

As previously mentioned all correspondence is distributed through the Utility's Senior Site Representative. It should be noted, however, that only the AE/CM Firm's Construction Superintendent has the authority to stop work on the project. This could cause a problem if someone other than the Construction Superintendent observes problems or non-conformances while performing site surveillances or audits. Such a person cannot stop work, he must waste valuable time going to his superiors and informing them of the difficulties.

CHAPTER 3

DISCUSSION OF QUALITY RELATED CRITERIADESIGN CONTROL

On power plant projects, it is the responsibility of the Utility to establish measures for the identification and control of all design interfaces, coordination and organization. Engineering and design must be correctly translated into specifications, drawings, procedures, and other applicable instructions with the specific objective of getting the project completed with adequate assurance of quality throughout the life of the project.

On the three fossil plants in the research study, the major source of responsibility for Design Control was delegated to the QA/QC program and the responsible parties that implemented these programs.

Project Y

On Project Y, the independent A. E. Firm prepared specifications applicable to the design portion of the project which were responsive to Utility Y's requirements. Quality Assurance and Quality Control, through continuous surveillances and audits, monitored the adequacy and control of Utility Y's Quality Program.

The Chief of Quality Assurance for Utility Y communicates directly with the A. E. firm's Quality Assurance Manager on Quality related matters and policy while directing the Quality Assurance Program for Project Y. Design control is achieved by auditing the A. E. firm's Quality Assurance Programs, operations, and design and procurement activities.

Each contractor is responsible for reviewing the specifications prior to acceptance and bidding. Once he has accepted them, it is

expected that he will perform according to them in an adequate fashion. The A. E. firm is responsible for conducting audits to ensure this fact.

Utility Y is responsible for the plant during commercial operation. It has therefore chosen to maintain a plant operations force at the project site to observe the construction work while it is being performed.

Because authority is delegated to the contractors, Utility Y requires that each contractor have a QC Program that is auditable and subject to verification and approval prior to the award of a contract.

Prior to the execution of the contract, the parties involved informally discuss the specifications which must be followed once the contract is accepted. The contract is signed after all problems and difficulties are resolved.

Project X

The uniqueness of this project rests with the fact that Utility X only has a small supervisory staff assigned to the project. This staff, however, is in charge of all the functional units. They observe and approve all activities before they are performed. This provides Utility X with ultimate control of all project costs, as well as control over the design phase. When difficulties and problems occur, Utility X has first hand knowledge.

The A. E. firm supplies the specialty needs which Utility X does not have. For example, in the Quality Control Department, both Utility X and A. E. firm personnel work together. Utility X supplies the management skills, the A. E. firm supplements the owner's expertise. Only one, not two separate organizations, exists with Utility X possessing ultimate control.

The responsibilities of the functional units which assist in

in Design Control are:

1. Project Engineering - this unit closely monitors the project engineering work. The function of the Field Coordinating Engineer for the A. E. firm is to coordinate and resolve engineering problems as they occur, as well as to maintain good communication with his firm's Home Office Engineering Department.
2. Project Construction - this section has three main functions:
 - (1) to act as the construction manager for the Home Office,
 - (2) to provide the direction for construction contractors and
 - (3) to provide quality control of installed work.
3. Field Construction - the role of this unit is to direct all construction activities. Field engineers are used to perform most of the contractor management activities and generally are assigned to a particular area of the project.
4. Field Quality Control - this unit's main function is to monitor and inspect all field activities for the owner's concurrence. This group is independent, maintains a good working relationship with Field Construction, and reports to the Construction Manager.
5. Construction Test and Start Up - this group is composed mostly of experienced operating personnel from generating stations. Their role is to supervise turnover of systems and, ultimately the whole plant, from construction to the operating department.
6. Cost Control and Scheduling - this group has three main functions, cost control, scheduling and accounting. Cost control is developed through estimating, forecasting and

control of charges. The A. E. firm's estimating specialty is helpful here, because reference can be made to past projects and case histories in order to develop estimated costs.

Scheduling is performed by Utility X's engineers who receive their scheduling procedures through directives from the project home office.

Accounting is administered by Utility X, with the A. E. firm providing lower level help. In this way, as the level of work changes, the manpower can be adjusted to match the level. It should be recalled that Utility X supplies the unit heads while the A. E.'s personnel fill in wherever specialties are required.

7. Contract and Project Services - this group relies generally on home office supervision and control. Procurement, Contract Administration and General Project Services are the responsibility of the Utility X's home office personnel. They are deliberately independent of the project site in order to act as a form of "check and balance" with no interference received from the field. This function also aids Utility X in maintaining control of the project cost and procurement activities.

In summary, the A. E. firm has no formal Quality Control Program, however, they have a few employees involved in Utility X's QC Program. The purpose here is to supplement the experience and expertise required by Utility X.

Overall, the program is achieving what it was designed to, control by Utility X and expertise by the contractor, with open communication to resolve all differences.

Project 2

On Project 2, the A. E. firm issues bid inquiries which include specifications, drawings and other instructions as appropriate. Quality assurance design control requirements are also incorporated into the documents. All bids are analyzed to ensure that Quality Assurance programs and procedures are provided as required.

The A. E. firm, through its Engineering and Design Groups, has the responsibility for the preparation of the design specifications and drawings used in the procurement, fabrication, erection and installation of systems, structures or components. During the design phase the A. E. firm's Quality Compliance Engineering group reviews designated A. E. prepared design specifications for the inclusion of Quality Assurance related criteria prior to submittal for Client's approval. The A. E. firm also has the responsibility of performing quality related surveillances and audits that are felt to be necessary by the Quality Control Engineers.

The A. E. firm's Project Manager enforces the A. E. firm's contractual obligations. To do this, he directs, monitors and controls the A. E. firm's operations on the project, including adherence to, and satisfaction of, the Quality Assurance program and procedures. He periodically assesses the performance and effectiveness of quality control and quality compliance personnel working on the project. He is promptly notified of any failures to satisfy quality design control requirements and nonperformances related to the Quality Assurance program and procedures. He will consult, as appropriate, with Utility 2's Project Manager upon learning of a deficiency and will then initiate both preventative and remedial action.

Utility A only receives an up-to-date report of the coverage of

inspections performed by the A. E. firm after a particular contractor's work is completed. Utility Z is, however, informed of major difficulties in an expeditious manner. Utility Z's QA group monitors only those activities which are identified on the project schedule as ones which require close attention and coverage by the owner.

INSTRUCTIONS, PROCEDURES, AND DRAWINGS

All construction projects typically include some form of documented material related to the activities which are to be performed. Documented instructions, procedures, or drawings, which included appropriate acceptance criteria for verifying the quality of work which was performed were examined on each of the three fossil plants in the research study.

As an example, the areas covered by Quality Related Procedures on Project X include:

1. Field QC Inspection and Surveillance
2. Adequacy of Tools and Instruments Used in Construction
3. Surveillances of Material/Equipment Receipt, Handling and Storage
4. Surveillances of Material/Equipment Storage
5. Non-Conformance Report Initiation
6. Quality Control Hold Tags
7. Resolution of QC Non-Conformance
8. Follow-up of Non-Conformance Reports
9. Verification and Documentation of the Qualifications of Skilled Workmen
10. Work Stoppages
11. Establishment and Maintenance of QC Files
12. QC Tentative Surveillance Schedule (Material/Equipment in Storage)
13. Surveillance Logs
14. Development and Implementation of an Inspection Point Program

The general areas covered by Construction Procedures on the projects pertain to project operations, construction management operation, and Quality Assurance surveillance of equipment and site construction. Specifications include all codes, acceptance standards, Quality Assurance requirements and provisions for document retention.

These instructions, procedures and drawings provide the Quality Assurance and Quality Control Groups, as appropriate, with a guide for verifying the quality of the work which is performed. This verification can essentially be performed by an independent organization in order to assure the owner as well as the contractor of the quality of work being performed on the project.

INSPECTION

An inspection program related to the construction activities verifies conformance with the previously documented instructions, procedures, and drawings. Such inspections are often performed for each work operation in order to assure quality. The inspections should be performed by individuals other than those who performed the activity being inspected.

Project X

On Project X, inspections are performed by the Utility X's Quality Control unit, as well as by the Quality Control inspectors employed by the individual contractors and subcontractors. Instruction governing the latter type of activities were unavailable at the time of the site visits.

Two sets of instructions have been developed by Utility X's Quality Control unit. One set provides instructions for performing inspections or surveillances of Project X, the other is directed toward the implementation of an Inspection Point Program. An example of these instructions

is provided below:

1. Performance of Field QC Inspection and Surveillance

This procedure provides a general guide for performing inspection and/or surveillance of equipment, material, and installation work performed during construction. Coverage with regard to extent and frequency will be based on the available QC unit manpower, relative importance, and risk level of the item. These decisions are made by the Quality Control, Construction, and Management supervisory personnel. Inspection and/or surveillance incorporate the use of applicable standards (i.e., checklists, drawings, specifications, Bills of Material, etc.). Basic skills of the trade, good workmanlike practices, safety, good house-keeping, and other unwritten standards also provide some of the basic criteria which are evaluated.

Preplacement, Placement and Post Placement inspections are performed with checklists which contain pertinent questions and requirements which serve as reminders of inspection and surveillance points that must be checked for compliance.

A Surveillance Log is also maintained by Utility X's Quality Control Group. It is a record of items which have been inspected. Each item which is monitored is listed and noted as being satisfactory or unsatisfactory. Each inspector's Surveillance Log also serves as the supporting document for the issuance of an NCR.

The breakdown of Field Responsibilities with regard to inspection activities are:

1. The Field Quality Control Clerk is responsible for the maintenance of the QC checklist file.
2. The Field Quality Control Inspector is responsible for the performance of inspection and surveillance of construction activities

within his particular discipline.

3. The Field Quality Control Supervisor is responsible for ensuring that adequate inspection and surveillance of construction activities are performed. He assigns Field Quality Control Inspectors to the task of inspection and surveillance of construction activities.

2. Development and Implementation of Inspection Point Program

This procedure covers the development and implementation of the Inspection Point Program beginning with the receipt of the individual Inspection Point Programs from the A. E. firm through the completion of the shop inspections.

The program essentially provides an inspection guide initiated by the A. E. firm to aid Utility X and their inspectors while performing shop inspections. It includes a description of the material, equipment, reference documents, Inspection and Test Procedures and the A. E. firm's Quality Assurance Checklists.

The breakdown of field responsibility with regard to this program is:

1. The Inspection Point Program Coordinator (the Field Quality Control Clerk) is responsible for the distribution of the required copies of the Inspection Point Program to appropriate personnel and must follow up on any delays in the Inspection Point Program approval cycle.
2. The Inspector is responsible for the approval or rejection of the work and the preparation of an inspection report which documents the results of the inspection.
3. The Responsible Engineer, the Test Department Inspector (if applicable), and the Production Department Inspector, are

responsible for a thorough review of the Inspection Point Program.

4. The A. E. firm is responsible for originating the Inspection Point Programs, incorporating Utility X's comments into the Inspection Point Programs and resolving any IPP discrepancies with the Quality Control group.
5. The Supervisor Field Quality Control is responsible for the overall implementation of this procedure and a review of the Inspection Point Program.

As mentioned earlier in this report, Utility X has also engaged an independent individual Testing Firm to perform inspections and Qualification Tests on the concrete portion of the project. The work of that firm includes:

1. Inspection of concrete batch plant operations (including quality control at the batch plant, verification of batching quantities, performing checks on the moisture corrections and scale accuracy determinations, the time of mixing, the amount of water which is added to the concrete, etc.).
2. Inspection of concrete placement operations (including field sampling and testing of concrete slump, air content, unit weight and temperature, and the casting of concrete cylinders for compressive strength tests).
3. Inspection of reinforcing steel in place.
4. The operation and control of a site laboratory which performs the following tests:
 - a. Concrete cylinder tests.
 - b. Testing of other items as directed by the Resident Engineer.
 - c. Documentation of sampling and testing work.
 - d. Testing and analyzing fine and coarse aggregate and cement for concrete.

Project Y

On Project Y, inspections are performed by: (1) the A. E. firm Quality Assurance/Quality Control Group, (2) the individual contractors and subcontractors and (3) the Utility Y construction group.

Utility Y's construction group is divided into the following specialty areas: Structural Steel, Mechanical, Electrical, and Civil. The heads of these areas perform visual inspections of the work being performed and keep the Project Superintendent informed of all activities related to Project Y.

A second series of observations are performed by the A. E. firm's Quality Control Group acting independently of that firm's Construction Department. They perform audits and surveillances and maintain a log of all surveillance activity and findings. Surveillances may be performed at any time with a frequency which is determined by past and previous findings. Checklists are used to aid the inspector in his field inspection activities, and act as a permanent record of the inspection.

Inspections are performed in accordance with the A. E. firm's Quality Assurance Manual which includes a specific procedure entitled "Inspection and Test Status Control." This procedure describes the controls that are applied to identify the status of inspections and tests.

All inspections are conducted in accordance with the code, drawings, specifications, procedures, standards and instructions issued by the Engineer of Utility Y. All results are recorded and maintained in a permanent history file by the Quality Control Department.

A tagging system is used during the inspection of materials, equipment, etc. This system uses the following types of tags: (1) An "Accept tag" which indicates that the material has been identified and conforms to the quality requirements, (2) A "Hold tag" that

indicates that all requirements have not been met and the items cannot be used until the problem has been resolved, and (3) A "Reject tag" which indicates that the material does not meet the technical requirements and cannot be used. Each possible rejection is reviewed by the QC Supervisor and others to determine the appropriate disposition.

Project Z

On Project Z, inspections are performed in a similar fashion to those on Project Y. The individual contractors and subcontractors perform their own inspections according to their own Quality Programs.

Recorded inspections and surveillances are performed by the Quality Control Inspectors as stipulated in the Quality Assurance Manual. These inspectors check that the contract documents, and other related material adhere to the project requirements. NCR's are developed whenever non-conformance is identified. All records are maintained in an historical file and are turned over to Utility Z when the project is completed.

It should be noted that the discussion related to Project Z is extremely short since material related to the inspection program on Project Z was not provided to the writer during the project site visits.

NONCONFORMING MATERIALS, PARTS OR COMPONENTS

In the construction industry, measures must be taken to prevent the occurrence of nonconforming materials, parts or components. The measures usually include procedures for the identification, documentation, segregation, disposition, and notification of nonconformances to the organizations. Such items are reviewed and accepted, rejected, repaired or reworked in accordance with documented procedures.

Project Z

On Project Z, as noted earlier, the Site Quality Compliance Group monitors the inspection, documentation and performance of construction activities to assure compliance to the specifications, codes, and standards. Any deviations or nonconformances discovered are reported to Utility Z and satisfactorily resolved.

Surveillances and audits are generally performed to provide checks on the Quality Assurance Program. The A. E. firm also investigates contractor activities to ensure conformance to specifications and engineering requirements.

A checklist is prepared prior to a concrete placement and completed by the area Quality Control Inspector. This list governs all of the phases of a placement, from preplacement through curing. It documents all of the drawings, specifications and procedures related to the particular placement. After completion of the list, it is filed and acts as documented proof of the quality of the placement. If nonconformances occur, they are documented by number on the related checklist and distributed to the parties responsible for the resolution of the deficiency or nonconformance.

Project X

On Project X, a nonconformance report is written if deviations from the design specification occur. This report provides proof of the identification of the problem and remains active until the deficiency is corrected, approved for construction, and finally signed off with Utility X's concurrence. All NCR's are filed and maintained by Utility X's QC Group.

Utility X's Quality Control Manual discusses all aspects of the

verification of Construction Quality, from Field QC Inspection and Surveillance to the Initiation of Non-Conformance Reports. The responsibilities for the issuance of Non-Conformance Reports on Project X are:

1. The QC Inspector is responsible for determining when a nonconformance exists and for filing the Non-Conformance Report to ensure that the person(s) responsible for corrective action are notified of each existing non-conformance.
2. The responsibility of the Field Quality Control Supervisor is to ensure that QC Inspectors are performing adequate surveillance; that the NCR's are properly completed and that distribution will be made to the person(s) responsible for corrective action.
3. The Project Accountant is responsible for determining if the nonconformance justifies a "Hold Payment" approval.
4. The QC Clerk is responsible for maintaining the NCR Master Log and for the actual distribution of the Non-Conformance Report.
5. The Field Engineer, upon receipt of an NCR, is responsible for notifying the contractor involved of the existing nonconformance and overseeing the rectification of same. Because of the nature of some nonconformances it may also become necessary for the Resident Field Engineer to order all related work to be stopped.

Project Y

On Project Y, all nonconformances which require corrective action are dated, documented and filled out by the QC Supervisor. A copy is forwarded to Utility Y. After being notified that corrective action has been taken, the QC Supervisor again inspects the NCR for conformance and approval for construction.

Instructions for the processing of NCR's are provided in the A. E. firm's Quality Assurance Manual. NCR's are categorized as follows:

NCR Class 1 - A nonconformance in a technical requirement which has a bearing on safety, installation, operation or performance.

NCR Class 2 - A nonconformance that is nontechnical and has no bearing on safety, installation, operation or performance.

Copies of undispositioned NCR's are sent to the A. E. firm's Project Engineer and Construction Manager. A Master File of all NCR's is maintained by the QC Supervisor.

Class 1 NCR's are evaluated and dispositioned by a Material Review Board (MRB) consisting of the Construction Manager (Chairman), Project Engineer and the QC Supervisor or his representative. Class 2 NCR's are generally processed by the QC Supervisor meeting individually with the Material Review Board members. The Material Review Board acts as quickly as possible on all NCR's. The MRB, when reviewing either Class 1 or Class 2 NCR's, carefully evaluates the nonconformance and its cause, decides and documents the needed corrective action to prevent recurrence and takes disposition action on the nonconformance (i.e., "Use-as-is," "Repair," "Rework," or "Reject"). The Project Engineer obtains the required technical actions on NCR's from the Design Agent in accordance with Standards and Procedures. The dispositioned NCR is signed by all MRB members indicating their approval of the actions taken.

The Project Engineer obtains Utility Y's concurrence on NCR's affecting Utility Y's materials and the "Authorized Inspector Agent's" concurrence on NCR's affecting construction.

Follow up and verification of the effectiveness of corrective action on NCR's is the responsibility of the QC Supervisor. Any action is noted

on the QC master file NCR. The QC Supervisor must also prepare a bi-weekly NCR Summary Report that summarizes actions taken and indicates significant and recurring nonconformance trends. This report is forwarded for review to the Chief of Quality Assurance and Project Manager for the A. E. firm. It is used by the QA organization to determine the need for internal audits or other management actions.

The master copy of the NCR is maintained by the QC Supervisor, a copy is forwarded to the supervisor responsible for correcting the nonconformance.

CORRECTIVE ACTION

The identification of significant conditions adverse to quality, the cause of the condition, and the corrective action to be taken are generally documented and reported to appropriate levels of management on all power plant projects. This method maintains control of the quality throughout the construction phase.

Project Y

On Project Y, after an audit is performed and nonconformances or deficiencies are identified, action is taken to document and correct the problems. A final report is written and a follow-up audit is performed when the corrective action has been completed.

The corrective action available to the Quality Control Supervisor is:

1. Issue a "Stop Work Order" if further work would increase the severity of the nonconformance or cause the nonconformance to become undetectable.
2. Tag the nonconforming part with a "hold" tag and, if possible, segregate the material to a controlled nonconforming material

area (such as a locked cage or a roped off area marked with signs clearly stating that the enclosed material shall not be used until properly cleared for further work).

3. Issue a Non-conformance Report giving particular attention to the identification, description and cause of the nonconformance.
4. Obtain the immediate corrective actions, which are required in order to maintain work quality.

Design changes as requested by the field, are handled by specific procedures developed by the A. E. firm. This procedure establishes a systematic method for Project Engineering to process and control requests for design information or design changes which require action or approval by Utility Y or the Design Agent. The scope of this procedure includes all field requested design changes and the necessary documentation to assure compliance with Utility Y requirements. When the need for design changes occurs due to drawing errors, discrepancies, interferences, field errors, omissions or problems with constructability, it must be brought to the attention of the Project Engineer or the appropriate Discipline Engineer, who must verify the need for the change.

The division of responsibility on Project Y, with regard to Design Changes is:

1. The Project Engineer is responsible for coordinating design change action with Utility Y's field construction staff.
2. Utility Y responds to all requests for design change and interacts with the Design Agent as necessary on requested changes.
3. The QC Supervisor is responsible for providing internal audits, as specified in the QAM, to assure compliance.

Project Z

On Project Z, the A. E. firm's Engineering and Design Group is responsible for establishing the course of action with regard to deviations from the design and construction specifications and associated drawings. Engineering and Design, as appropriate, coordinate actions with Utility Z and the A. E. firm's Quality Compliance group before finalizing the recommendations regarding deviations.

During the site installation stage, the A. E. firm's Site Quality Control Inspectors are directly responsible for the performance of receiving inspection on all procured material and equipment and for inspection of site construction activities. Any deviations from the approved standards, procedures, specifications, drawings and applicable codes are reported immediately to the A. E. firm's Resident Engineer for corrective action. If the responsible construction contractor does not take action to correct such deviations, the A. E. firm's Resident Engineer recommends to the A. E. firm's Construction Superintendent (after advising Utility Z's Project Engineer and Resident QA Representative) that work should be stopped on the specific item under consideration until such time as satisfactory corrective action is taken. The A. E. firm's Construction Superintendent is the only site representative that has the authority to stop work on the project. The A. E. firm's construction and installation specifications state that only the A. E. firm's Construction Superintendent has the authority to stop work on a portion or the whole of the contract when the Contractor is not performing his work in accordance with the contract. Such stoppage remains in force until compliance with the contract has been assured,

Project X

On Project X, the Quality Control Manual of Utility X indicates the delegation of authority for implementing corrective actions regarding deficiencies or nonconformances. When a nonconformance of a critical nature exists, a responsible person has the authority to stop work until such a time as the nonconforming condition is corrected.

"Critical Nature" refers to a condition which may cause injury, loss of life, or serious irreparable damage to equipment/material if further work is performed. The responsible personnel that can stop the work are: (1) Resident Engineer (RE), (2) Field Engineer (FE), (3) Coordinating Engineer (CE), (4) Field Quality Control Supervisor (FQCS), (5) Field Quality Control Inspector (FQCI), (6) Project Engineer (PE), (7) Project Manager (PM), and (8) Construction Manager.

The Field Quality Control Inspector is responsible for determining when a nonconformance exists and stopping work promptly when he feels the nonconformance is of critical nature. He must notify the FQCS and the FE immediately after stopping work. He issues an NCR in order to document the nonconformance which necessitated a work stoppage and works with the FE to resolve the nonconformance which created the work stoppage.

The Field Quality Control Supervisor must immediately notify the Resident Engineer when a nonconformance is of such a nature as to consider having all related work stopped. It is also his responsibility to ensure that Quality Control Inspectors are performing adequate surveillance; and that the NCR's are properly completed and distributed to the person(s) responsible for corrective action.

The Field Engineer is responsible for stopping work promptly after discussion with responsible personnel if a nonconformance is of a

critical nature. He must also work with the FQCI and the contractors to resolve nonconformances which created a work stoppage.

The QC Inspector in cases involving incorrect or damaged materials must determine from the nonconformance report whether or not to recommend payment for the nonconforming item. The QC Inspector may recommend that the "Hold Payment" option be considered. The final decision with regard to this option is made by the Project Accountant based on cost, terms of the contract, extent or nature of damage or nonconformance, etc., after he contacts the Project Engineer, Construction Manager and Project Management.

QUALITY ASSURANCE RECORDS

On a fossil project, a sufficient number of records must be maintained in order to furnish evidence of all activities affecting quality. The records generally include operating logs and results of reviews, inspections, tests, audits, monitoring of work performance, and materials analysis. All records must be identifiable and retrievable.

Project X

On Project X, the Field Quality Supervisor of Utility X is responsible for determining if a document merits retention by the Quality Control Unit. The Field Quality Control Clerk is responsible for maintaining the Quality Control Files.

All documents are received on a continuous basis and reviewed by the responsible parties for comment prior to QC filing. The list of documents filed for Project X include:

1. Progress Reports
2. Bills of Material
3. Quality Control Related Correspondence

4. Specification and Addenda, Revisions to the Specification
5. Sample, Blank and Completed Checklists
6. Concrete Cylinder Data
7. Certification of Concrete Plant Inspection
8. Field Report of Concrete Inspection
9. Inspection Point Program

A surveillance log is maintained up to date by all Quality Control Inspectors when performing an inspection and/or surveillance of any phase of construction. A record of items which have been inspected for conformance to drawings, specifications, Bills of Material, purchase orders, etc., is maintained by each QC Inspector. Each item which is monitored will be listed and noted "satisfactory" or "unsatisfactory." Each inspector's Surveillance Log serves as the supporting document for the issuance of an NCR.

Project Y

On Project Y, a current up-to-date record is maintained to provide objective evidence of the quality of the fabrication and installation. Requirements and responsibilities for record preparation, acceptance, distribution, retention, access rights and storage are included on the project QA Manual.

All Quality related records are retained in accordance with the following designations:

<u>Designation</u>	<u>Duration and Responsibility</u>
"A"	Permanent retention, controlled and filed by QC.
"B"	Filed for the life of project by QC.
"C"	Filed for the life of project by the Project Engineer
"D"	Filed for the life of project by the Purchasing Agent.

DesignationDuration and Responsibility

"E"

Filed for the life of project by the Material Control Supervisor

"F"

Filed for the life of project by the Lead Pre-Op Engineer.

Utility Y or its agent has access to all Quality Control documents and records. All records, upon completion of the project, will be transferred to Utility Y in accordance with Utility Y instructions.

All records are indexed, filed and maintained in facilities that provide a suitable environment to minimize deterioration or damage to prevent loss. The A. E. firm's Quality Control Group maintains the file but the Owner receives copies of everything documented and filed.

A list of the Quality Assurance Records appears below:

1. Field Design Change Requests
2. Purchase Requisitions, Orders and Change Orders
3. Audits of Vendors, Surveillances
4. Approved Vendor Lists
5. Material Certification, Welding Records
6. Receiving Inspection Reports
7. Nonconformances
8. Calibration Records
9. System Verification
10. Requests for Corrective Actions
11. NCR Summary Reports
12. Audit Reports, internal and external

Project 2

On Project 2, a Quality Assurance Control File must be maintained by the A. E. firm's Quality Control Group. This record represents a permanent

historical file of the quality achieved during the construction phase. It is turned over to the Owner upon completion of the project. A list of the required documents and instructions was not available when the writer visited the project site.

AUDITS

Audits are performed to verify compliance with all aspects of quality during the construction phase of a project. Usually these audits are performed under the Quality Assurance/Quality Control Program. They generally are carried out in accordance with written procedures or checklists by appropriately trained personnel not having direct responsibilities for the areas being audited. All results are reviewed and placed into the permanent historical file of the plant.

Project Y

On Project Y, the A. E. firm performs the auditing function based on the Auditing and Corrective Action Procedure found in the Quality Assurance Program. The A. E. firm performs audits on the activities of contractors and subcontractors. The A. E. firm itself is audited by Utility Y's Quality Assurance Group.

All problems discovered during the auditing process are distributed to the Project Superintendent for Utility Y's review and comment. These problems are then discussed with the proper disciplines for corrective action.

These audits are performed by permanent home office personnel familiar with the project. Since the A. E. firm does not have an onsite QA staff.

On Project Y, the following three levels of auditing are performed:

(1) Internal audits which consider field activities, (2) External audits which consider offsite subcontractors and vendors, and (3) home office audits.

Internal Audits. The QC Supervisor plans and implements the internal audit program. Both scheduled and unscheduled audits are performed. The management personnel involved in the activities to be audited are notified not later than one day before the audit. Unscheduled audits are also performed when deemed necessary by the QC Supervisor. All audits are conducted and prepared in accordance with the pre-planned procedures and checklists found in the Quality Assurance Manual.

External Audits. These audits are performed by the QC Supervisor and his staff. Utility Y's site personnel assist the QC Department with this function. Most of the audits are not formally scheduled, they are conducted as deemed necessary.

As a minimum, an audit must contain the following information:

1. The Organization to be Audited
2. The Date of the Audit
3. The Scope of the Activities to be Audited
4. The Audit Team Members
5. The Key Persons to be Contacted
6. The Findings and, Supportive Discussion
7. An Audit Summary

Audit reports may also include:

1. Recommendations for additional actions which could improve quality
2. A statement of areas that were not audited

All findings are discussed with the appropriate QC personnel. A copy of the report finding is sent to the proper discipline, with a request for a corrective action response.

Home Office Audits. These audits are conducted on an unscheduled, as-needed basis. The same procedure and minimum requirements for external audits also apply in this case.

Project X

On Project X, audits are performed under the direction of the Utility X's Quality Control Program to verify and document the performance of each contractor, vendor and manufacturer. Prior to being asked to bid, the Owner or his representative will sometimes audit the contractor or subcontractor. After acceptance, the contractor is responsible for strict conformance with the contract and design specifications. Utility X's Quality Control Unit frequently monitors construction activities for conformance.

Utility X's Quality Control Supervisor has the right to inspect:

(1) the sources of materials, (2) the plans for the layout and operation of materials storage, (3) the design of concrete batching and mixing equipment, (4) the proposed quality control system, and (5) the equipment for transportation of concrete to the points of delivery.

Activities that require tighter controls than stipulated by Utility X's representatives have specific check off lists which are completed by the Quality Control Engineer during his inspection or audit.

They are later filed for Documentation Control, Verification and Retention.

Project Z

On Project Z, all auditing is performed by Utility Z's Quality Assurance personnel. They are assisted by the A. E. firm's Quality Compliance Group. An up-to-date record is required and maintained in a permanent historical file which is turned over to Utility Z when the project is completed.

The purpose of the audits performed by the A. E. firm's Quality Compliance Group is to assure Utility Z and itself that the applicable specifications, procedures and codes are being met. Some items which are auditable under the Quality Compliance Program are:

1. Batch Plant Equipment
 - calibration of scales.
 - truck cleanliness
 - truck mixing blade wear
 - truck drum counter
 - conveyors
2. General Batching Operation

Qualification tests are also performed and filed to assure compliance with quality requirements, and to assure that the concrete meets the applicable specifications, procedures and codes. The tests performed are also auditable under the QC Program.

Utility Z's Quality Assurance Group is structured in accordance with the A. E. firm's Intensified Quality Compliance Program. The QA representative performs audits to assure that the applicable specifications, procedures and codes are being met and applied appropriately. He monitors the inspection, documentation and performance of the prime contractor

and visually observes the operations of subcontractors.

Subcontractors on the project also maintain their own inspection and audit programs in order to locate deficiencies and correct them prior to the audits being performed by both Utility Z and the A. E. firm.

CHAPTER 4

ANALYSIS OF CONCRETE COMPONENTSINTRODUCTION

The requirements for high quality concrete for a power plant can be quite large. Due to their nature, projects of this type require materials of the highest quality to insure the integrity of the structures. The components which are used in the production of concrete must be of acceptable quality if the finished product is to be acceptable. This chapter investigates the specification limits and testing requirements imposed upon the materials which are used to produce concrete on the projects which were studied. Specification limits are compared with the requirements of applicable codes and standards which govern the production of concrete as well as on a project-by-project basis. One point which should be kept in mind while considering this comparative analysis is that the requirements for high quality concrete are essentially the same, whether the concrete is used on a power plant or is used in some other application.

CEMENT

In the power plant construction industry cement is required in large quantities. It's not uncommon for a single unit fossil plant to require approximately 50,000 tons of cement. It appears that since the production of cement occurs in a controlled environment, the quality of the product does not contribute greatly to problems encountered during construction.

As can be seen in Table 4.1, the fossil plants use both Type I and Type II cement. Type I is generally used in concrete construction not requiring special properties, while Type II is used in concrete areas exposed to moderate sulfate action in those situations where moderate heat of hydration is required.

Table 4.1.--Testing Requirements for Portland Cement

Project	X	Y	Z
Cement Type	I ^a	I, II	II
Reference ASTM C150	✓	✓	✓
Optional Tests	-	Physical Chemical	-
Additional Requirements	Mortar Cubes 3 day--3000 7 day--4000	b	d
In-Process Testing Frequency	Sealed Silos ^e	c	d
Retesting	-	Cement stored 3 months	d
Max. Cement Temperature at Delivery	140°F	165°F	d

^aCement shall be Type I, unless otherwise called for in the Contract Documents.

^bWater or calcium sulfate, or both, may be added in amounts such that the limits shown in Table 1 of ASTM Specification 150 for sulfur trioxide and loss-on-ignition shall not be exceeded.

^cAll tests are to be performed in accordance with the current issues of ASTM C109, C114, C115, C150, C151, C183, C185, C186, C191, C204, C226, C266, C451, C452, C465.

^dInformation unavailable during site visit.

^eCement is received by rail, and inspected as each car is received.

Material Qualification

All of the projects in the fossil plant study stipulate that cement will meet the requirements of ASTM C-150. In addition to the standard tests specified in ASTM C-150, Project Y also requires some of the optional chemical requirements.

Only Project X imposed any additional requirements on the cement beyond those stipulated in C-150. The additional requirements relate to the mortar cube specimen strengths. Project X requires mortar cube strengths of 3000 psi at 3 days, and 4000 psi at 7 days. ASTM C-150 on the other hand requires 1800 psi at 3 days, 2800 psi at 7 days with an optional requirement of 4000 psi at 28 days for Type I cement. The ASTM requirements for Type II cement are: 1500 psi at 3 days, 2500 psi at 7 days with an optional requirement of 4000 psi at 28 days.

Receiving Inspection

As can be noted from Table 4.1, most of the projects place a maximum allowable delivery temperature on the cement with none of the projects reporting severe problems as a result of the requirement. It appears that if the temperature was exceeded, the entire truck was removed from the site.

None of the projects stipulate special delivery temperature requirements in the specifications for cement delivered while cold weather conditions prevail. There are also no provisions in any of the specifications which consider the cooling of the cement during its retention time in the storage silos at the project site.

Rejection of cement for delivery temperature in the 140°F range may be a questionable practice in view of the fact that changes in cement temperature have significantly less effect on the final concrete temperature than changes in either water or aggregate temperature. Referring to Figure 4.1, it can be seen that, holding all other factors constant, a reduction in aggregate

temperature of 20°F produces a decrease in the concrete temperature of about 16°F . On the other hand, a reduction in the cement temperature from 175°F to 125°F produces a reduction in the concrete temperature of approximately 5°F . This clearly indicates that the temperature of the aggregate and the mixing water are far more important factors than the cement temperature.

In-Process Testing

All of the projects studied require periodic testing of the cement in order to verify that the cement being supplied to the projects meets the specifications. On Project X, the cement supplier ships cement by rail, and performs the testing on each rail car.

In addition to this periodic testing, all of the projects require the supplier to furnish certified copies of mill test reports showing the chemical composition of the cement in order to verify that the cement being furnished is in accordance with the specifications.

When the cement is delivered in packages, the words "Portland Cement", the type of cement, the name and brand of the manufacturer, and the weight of the cement contained therein must be plainly marked on each package. When the cement is an air-entraining type, the words "Air Entraining" must be plainly marked on each package. Similar information must be provided in the shipping documents accompanying packaged or bulk cement. All packages are to be in good condition at the time of inspection.

The only project that stipulated additional retesting for cement was Project Y, where retesting is required if the cement is stored over three months. On Project X, cement is ordered sufficiently far in advance to accommodate the Batch Plant. Storage is not a problem on these projects because cement is used so rapidly that rarely does it remain in storage for over three months.

Figure 4.1.--Influence of Temperature of Concrete Ingredients
 on Concrete Temperature (Source: ACI 305-72)

On Project X, a sealed silo is used after cement is delivered to the Batch Plant. These silos conform to the requirements of the National Ready Mixed Concrete Association (NRMCA), and are checked periodically for conformance. The silos are completely sealed for weather protection and the prevention of contamination.

AGGREGATE

There are extensive aggregate testing programs in effect on all of the projects studied. In order to assure that aggregate of acceptable quality is being furnished, there are two phases to these aggregate testing programs. The first phase, qualification testing, is performed only once at the beginning of the project. The second phase, material verification, (also referred to as periodic or in-process testing) is performed throughout the concrete production phase of the project. Qualification tests are usually complete before any concrete is placed at the project site. The material verification tests are performed throughout the project to assure that aggregate which is received at the site is of the same quality as the material which was originally qualified. A comparison and discussion of the material qualification and material verification systems employed on the projects in this research study is presented below.

Material Qualification

On all of the projects studied, more than one aggregate supplier is qualified in the event that a second source is required (i.e., if the primary source is unable to supply the quantity of material, or has difficulty meeting specification requirements). In lieu of the lost production time which could be involved in such situations, the extra expense involved in qualifying a secondary aggregate source is probably justifiable.

Table 4.2, provides a comparison of the qualification test requirements for the projects in the research study. Whenever the project specifications indicate requirements similar to ASTM C33, a check mark is shown; exceptions are shown under their proper subscript.

As can be noted from Table 4.2, all projects studied have essentially adopted the ASTM C33 requirements. Projects X and Z have a few exceptions. The exceptions require tighter restrictions but do not appear to be unreasonable.

Material Verification

In-process testing verifies that the quality of material being received during the construction phase is of the same quality as the material which was originally qualified. The tests performed on concrete aggregates are in accordance with "Standard Specification for Concrete Aggregates, ASTM Designation C33".

During construction, aggregates are sampled as they are delivered to the mixer. Records of tests which have been made on proposed aggregates are furnished to the Engineer, in advance of the work to be performed, for his evaluation regarding suitability. The frequencies and interpretation of tests performed on the projects are subject to his "engineering judgment". This approach is considerably different than the practices observed on nuclear power plant projects where very little "engineering judgment" is permitted (i.e., a "literal interpretation" approach is followed).

It is the writer's opinion that this area is worth investigating in more detail. An analysis to determine the effect of engineering judgment on the quality of the concrete on a fossil plant versus that on a nuclear plant should be performed. The use of engineering judgment in the projects studied did not seem to create any serious difficulties in the construction areas.

Table 4.2.--Aggregate Qualification Tests

Project		X	Y	Z
Reference in Specifications		C-33 ^a	C-33	C-33 ^a
Test	ASTM			
Material finer than #200	C-117	✓	✓	✓
Soundness	C-88	✓	✓	✓
Abrasion	C-131	✓	✓	✓
	C-535	✓	✓	✓
Organic Impurities	C-40	✓	✓	✓
Mortar Strength	C-87	✓	✓	✓
Fineness Modulus	C-125	✓	✓	✓
Clay Lumps	C-142	✓	✓	✓
Coal and Lignite	C-123	✓	✓	✓
Unit Weight	C-29	✓	✓	✓
Alkali Reactivity	C-227	✓	✓	✓
	C-586	✓	✓	✓
Potential Reactivity	C-289	✓	✓	✓
Petrographic Examination	C-295	✓	✓	✓
Compressive Strength	C-39	✓	✓	✓
Fine and Coarse Aggregates	C-136	✓	✓	✓
Volume Change of Cement-Aggregate	C-342	✓	✓	✓
Resistance of Concrete	C-666	✓	✓	✓
Sampling Aggregates	D-75	✓	✓	✓

^aASTM Standard Specifications. Exceptions:

1. The use of blast-furnace slag shall not be permitted.
2. The ASTM C40 standard colorimetric test for organic impurities shall be used, and sands producing a color darker than standards shall be rejected. Deviation from this rule will be permitted only upon written approval of the Engineer in each instance.
3. Grading limitations as given in ASTM C33 shall be superseded by the requirements of Table A of the Concrete Specifications.
4. Aggregates tested for abrasion in accordance with ASTM C131 shall lose not more than 40 percent after 500 revolutions.

One point which should be noted, particularly as it applies to the area of aggregate gradation, is the indicated lack of application of statistical concepts and the lack of recognition of the natural variability of materials on the projects in the research study. None of the projects utilized a formal or informal random sampling plan. Multiple sampling techniques were not employed to reduce the variability involved in estimating the population central tendency. It is suggested that a formal random sampling process based on multiple samples taken from the day's production would provide a much better description of the true properties of the materials being sampled, and may alleviate the necessity for the high frequency of testing which is currently taking place. Employing statistical concepts to determine the properties of construction materials may seem radical to the fossil construction industry, but such techniques have been employed in the highway industry for a number of years. Many state highway agencies have developed statistically based specifications and acceptance plans for such construction materials as aggregates, portland cement concrete, bituminous concrete and soils excavation and embankment (4.1). The incorporation of these statistical concepts into fossil project specifications is certainly a promising area for future research.

One area where statistical concepts could readily be employed in fossil construction is in the area of aggregate gradation. Most of the specifications studied base acceptance of aggregate gradation on the results of a single gradation analysis. Concerning this subject, the ACI Manual of Concrete Inspection states:

"It must be recognized that aggregates, particularly coarse aggregates, vary considerably within stockpiles and bins; hence the significance of any single test is limited. Each new analysis should be averaged with at least two immediately preceding analyses of the same material to obtain a more representative analysis of its general run on which to base mix adjustments or to determine if grading requirements are met."

This approach is commonly referred to as a "running average" or "moving average" approach. ACI 304, "Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete", recommends the use of a running average of from 5 to 10 gradation tests for the purpose of both quality control and mix proportioning.

Material Storage

The storage requirements on all projects were the same, they essentially stated:

"All fine and coarse aggregates shall be stored separately and in such manner as to prevent the inclusion of foreign materials."

On Projects X and Y, the aggregate is separated by individual bins, and designated according to material size in order to aid in the prevention of segregation and contamination. On both projects, a front-end loader is used to stockpile the aggregate. The aggregate is dropped into the bins from the loader, through a distance which is short enough to prevent segregation.

There are basically three methods for removing material from a stockpile: a clamshell, a front end loader, or a conveyor belt operating in a tunnel below the pile. Two of the projects in the study, X and Y, use the front-end loader to transport material from the stockpiles to the batch plant conveyor. Of the three methods mentioned, "Use of an end-loader is the least desirable method, as this machine usually removes gravel from the periphery of the pile, near the bottom, causing the gravel to flow down the slope, with resulting segregation." (4.2) This potential for segregation has not appeared to present any difficulties on the projects which were studied.

Care should be taken in the storage of aggregate because improper stockpiling practices can lead to problems with the aggregate. Problems associated with the stockpiling of aggregate include segregation mentioned above, accumulation of fines, and variation in moisture content. ACI 304, "Recommended Practice for

Measuring, Mixing, Transporting, and Placing Concrete", includes techniques for handling and storing aggregates to minimize problems of segregation and indicates that incorrect stockpiling methods can cause segregation, aggregate breakage, and excessive variation in gradation.

During the site visit to project Z, the writer was unable to visit the Batch Plant to observe their method of storage but was informed by personnel at the project that the material was separated adequately to prevent segregation or contamination.

WATER

Water initiates the chemical reactions that produce the binding properties of the portland cement. Generally speaking, water from any source of domestic water supply may be used for mixing and curing concrete. Small amounts of impurities in the mixing water can be tolerated with no detrimental effects on concrete quality. Impurities concentrated in sufficient quantities can, however, have an appreciably harmful effect upon the strength or durability of the concrete in service (4.3). Certain other compounds may cause unattractive discoloration in concrete surfaces, efflorescence (movement of salts to the surface), and excessive corrosion of reinforcing steel. Due to these potentially harmful effects, water for use in concrete on Fossil plants must be qualified and periodically tested in a fashion similar to the other concrete components.

Material Qualification

All of the projects incorporate ACI-318, "Building Code Requirements for Reinforced Concrete," into their specifications. With respect to water for mixing or curing of concrete or for processing concrete aggregates shall be free from any injurious amounts of acid, alkali, salts, oil, sediment or organic matter.

Project Y expands upon this requirement by stating that the water shall be usable by a community for drinking purposes. The source of water is drinkable well water located at the project site and approved by an Independent Testing Firm. The capacity required and obtained is 300 gallons per minute. Testing of water quality is performed every three months. To date, there have been no difficulties with water quality. The average temperature of the well water is from 55°F to 90°F, with little variation in water temperature during each day's operation.

On Project X, all water supplied and used for construction is obtained directly from the nearby city water facility. Water used must not contain more than 100 parts per million (i.e., ppm) of dissolved solids and not more than 100 ppm chloride ion content. The aggregate, sand and water are to be combined in the same amounts as in the concrete mix, and not contain a total soluble chloride ion content of more than 250 ppm when water is extracted from the combination after being thoroughly mixed, unless the Project Engineer issues a documented written deviation.

Since the water is obtained directly from the Municipal City Water supply, little testing is performed on-site; direct reliance is based on daily testing performed by the City Health Department on Water Quality. The theory is that water pure enough for human consumption is more than adequate for construction use. Therefore, any documentation required is referred to the city's records on water quality.

There is a very wide variation in the chemical tests which are required on the various projects. This in part stems from the various interpretations of quantitative statements which appear in the codes, such as "water shall be free from injurious amounts of oils, acids, alkalis, salts, organic materials, or other substances that may deleteriously affect concrete." A statement

such as this places the burden on each individual specification writer to determine what limits are acceptable and unacceptable. This difficulty is, no doubt, an outgrowth of the fact that codes and standards are developed by committees, and it is inherently difficult to get a group of people to agree upon quantitative values.

ICE

On all projects studied, the requirements for water also refer to the use of ice. There is no difference between ice and water with regard to the quality or construction requirements. The water for making ice is subject to the same testing requirements and frequencies as is the regular mixing water.

One area of concern on the projects was the question of how much ice could be used in the mix. ACI 305, "Recommended Practice for Hot Weather Concreting", states that "use of ice as part of the mixing water is highly effective in reducing concrete temperature," but places no limits on the amount of ice which may be substituted for mixing water.

In project specifications, it was unclear as to the amount of ice that could be used to replace water. The statements used generally stated that a part of the mixing water may be replaced with crushed or flaked ice. With the concern over high heat of hydration temperatures in some of the massive concrete placements on power plant projects, it is probably advisable to clearly state in the specifications that 100% ice substitution is acceptable if such a condition is indeed acceptable.

ADMIXTURES

There are many different types of chemical admixtures currently being promoted and sold for inclusion into concrete. Admixtures are usually employed

to modify the properties of concrete to make it more suitable for a particular application. Some of the reasons for which admixtures are used are: to increase workability, to reduce water-cement ratio (W/C), to accelerate or to retard setting time, to accelerate strength development, and to improve resistance to weathering. Admixtures which were encountered on the projects include air-entraining and water-reducing agents. In addition to these chemical admixtures, some of the projects used a pozzolan (i.e., fly ash) to replace a portion of the cement in the mix.

Project X

On Project X, the water-reducing densifiers can be added to all concrete with a required ultimate compressive strength equal to or greater than 3000 psi at 28 days. The quantity to be added, the controlling temperatures, and the method of mixing are to conform to the manufacturer's recommendations for use of their particular products. Chemical admixtures for concrete are to conform to the requirements of ASTM C94. No calcium chloride or similar products are to be used.

The air entrainment agent used is verified by the Project Engineer, and is to conform to the requirements of ASTM C260, in order to produce entrained air within the following limits:

<u>Nominal Maximum Size of Coarse Aggregate--inches</u>	<u>Total Air Content Percent by Volume</u>
3/8	7-9
1/2	6-8
3/4	5-7
1	4.5-6
1-1/2	4.5-5.5
2	4-5

All testing (both Qualification and In-Process) is performed by an Independent Testing Firm.

Project Y

On Project Y, the Owner's Superintendent must approve in writing, the use and the amounts of admixtures. The admixtures must also conform to the requirements and test provisions of Specification ASTM C494.

One of the admixtures used is a Water Reducing Agent (WRA) manufactured in liquid form. An average of about 26 ounces of WRA are used per cubic yard. A volumetric dispenser (interlocked into the controls to make discharge automatic) is used. Calibration is performed every 90 days by the Batch Plant QC Site Manager.

The admixture is added after all ingredients are in the central mixer. The admixture is purchased in 55 gallon drums and is stored in a heated trailer. Testing is performed in accordance with ASTM C494.

Fly ash is used on Project Y as an addition to the concrete mix. The mix design requirements state that minimum cement and fly ash content for structural concrete will be dependent upon the total unit water content and water cement and fly ash ratio as follows: A maximum of 5 1/4 gallons of water per bag of cement and fly ash for air entrained concrete; a maximum of 6 1/2 gallons of water per bag of cement and fly ash for non-air entrained concrete.

The source for fly ash is an independent supplier. All testing is performed at the mill and certification is verified by a letter of compliance and spectrographic analysis. Fly ash is tested every 100 tons, in accordance with ASTM C311 and C618. It is stored in a 350,000 lb. capacity silo and is handled in the same manner as cement.

Air entraining admixtures (an average of about 12 ounces per cubic yard) are also used on Project Y. According to the mix design, air entrained concrete shall be used only where specified on drawings. The air content for all air entrained concrete shall be 5% plus or minus 1%. The air content for all non-air entrained concrete shall be not less than 1/2% or more than 2%.

The type and brand of air entrainment used is manufactured and shipped in 55-gallon drums. The agent was tested and approved by the AE Firm's home office. The admixture is protected from freezing by providing storage in a heated trailer and requiring that all lines must be drained at night.

Discharge is automatic, with controls being interlocked into the control equipment. The air entrainment admixture is added with water into the concrete mixer to insure adequate mixing.

Project 2

On Project 2, both Pozzolith and Plastiment Water Reducing and Retarding Admixtures are used. Both were first approved by the Project Engineer, and must conform to the requirements of ASTM C494.

The conditions for usage of one or the other are:

- (1) for all placements of 200 cu. yd. or greater;
- (2) for all placements when the daily ambient temperatures exceed 85°F; and
- (3) for all on grade and superstructure floor slabs.

Admixtures are to be accurately measured and added to the mix according to the manufacturer's directions and ASTM Specifications.

"Pozzolith" when used, is added as a powder premixed with water in accordance with the manufacturers' recommendations under the direction of the Engineer and according to the schedule given below:

Maximum Daily Temperature:

Above 90°F -- 0.35 lb. of Retarder Pozzolith per bag of cement

90°F-70°F -- 0.25 lb. of Retarder Pozzolith per bag of cement

Below 70°F -- 0.25 of Normal Pozzolith per bag of cement.

"Plastiment", when used, is added in liquid form under the direction of the Engineer and according to the schedule given below:

<u>Maximum Daily Temperature</u>	<u>Fluid Ounces/Bag of Cement</u>
Above 85°F	4
85-65°F	3
65-48°F	2
Below 48°F	None

Air-Entraining Agents

Air-entraining agents are used on all three of the projects in the research study. Air-entraining agents have been employed in the production of concrete for many years. Many advantages as well as disadvantages are claimed with regard to their usage. Some of the advantages are: increased workability, reduced bleeding and segregation, and increased durability. Some of the disadvantages are reduced strength and inconsistency of the concrete mix. These advantages and disadvantages, along with their applications to power plants, are discussed in this section.

Probably the most widely used argument for the use of air entrainment is the improved durability which it imparts to the concrete. This improved durability centers primarily around an improved resistance of air-entrained concrete to the action of freezing and thawing. Much research has been conducted which indicates that entrained air greatly increases the freeze-thaw resistance of concrete. In research conducted by PCA, the conclusion reached was that air entrainment is an important requirement of frost-resistant concrete and that adjustments in either the chemical composition of cement, fineness of grinding, or methods of manufacture have relatively little effect on increasing frost resistance of concrete as compared to air entrainment (4.4). The ACI Guide for Use of Admixtures in Concrete states that the primary purpose of air entrainment in concrete is to provide a high degree of resistance to the disruptive action of freezing and thawing and of de-icing chemicals (4.5). It

would seem that this feature of entrained air would make the use of an air-entraining agent advisable for power plant construction, particularly in concrete which will be exposed to cycles of freezing and thawing.

On the other hand, it can be argued that the use of entrained air for increased freeze-thaw resistance is not necessary for power plant projects in all cases. Tuthill (4.6) states that in mild climates, in unexposed portions of the structure in any climate, in exposed portions of structures not subject to saturation in any climate, and in portions of structures composed of such concrete with a W/C approaching 0.40, no air entrainment is required for the sake of durability.

ACI 211 has prepared a graded table which can be used for guidance when determining air content requirements (4.7). This table bases air content requirements on three exposure conditions: mild, moderate, and severe. A portion of this table is included in this report as Table 4.3. For most power plant applications, the concrete will probably fall in the moderate or mild exposure conditions. ACI 211 states that if a member is not continually wet and will not be exposed to de-icing salts, lower air content values (such as those given for moderate exposure) are appropriate even though the concrete is exposed to freezing and thawing temperatures.

As noted above, another advantage attributed to entrained air is an increase in the workability of the concrete. It has been estimated that the addition of 5 percent of air can increase the slump of a mix by 1/2 to 2 inches (4.8). However, Tuthill (4.6) observes that the concrete mixes commonly used in nuclear construction are usually rich, well sanded and have relatively small maximum size aggregate. He goes on to state that for mixes such as these, purposeful air entrainment is not needed for the sake of workability.

Table 4.3.-- Approximate Air Content Requirements for
Different Nominal Maximum Sizes of Aggregates (from ACI 211)

	Nominal Maximum Size of Aggregate					
	3/8"	1/2"	3/4"	1"	1 1/2"	2" ^a
Recommended average ^b total air content, percent for level of exposure:						
—Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0
—Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0
—Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0

^a The slump values for concrete containing aggregate larger than 1 1/2 in. are based on slump tests made after removal of particles larger than 1 1/2 in. by wet-screening.

^b Additional recommendations for air content and necessary tolerances on air content for control in the field are given in a number of ACI documents, including ACI 201, 345, 318, 301, and 302. ASTM C 94 for ready-mixed concrete also gives air content limits. The requirements in other documents may not always agree exactly, so in proportioning concrete consideration must be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

A disadvantage of the use of air entrainment is the corresponding reduction in strength which can accompany its use. Since the entrained air increases workability, some of the water can be left out while maintaining, or actually improving, the workability. This decreased W/C helps to compensate for the strength loss associated with the entrained air. Investigations by Blanks and Cordon (4.8) show that in the cases where the reduction which could be effected in the water content through air entrainment were small (such as rich mixes, particularly where the maximum aggregate size was large) there was a reduction in both the flexural and compressive strength. Tuthill (4.6) states that in the rich mixes commonly used in nuclear construction, air entrainment is likely to reduce strength as much as 5 percent for each percent of entrained air. This reduction can result in the need for increased cement content in order to reach the required strength levels. This additional cement can add to the heat of hydration problems in massive sections. Tuthill goes on to state that the use of entrained air increases the problem of maintaining uniform slump and increases the variation in the strength of test cylinders. For these reasons, on one tunneling project which used water-reducing agents, air-entraining agents were not used and it was found that workability was sufficient and that 28-day strengths were increased by 17 percent (4.9).

Experiences of the fossil projects in the study support the observations of Tuthill concerning the indiscriminate use of air entrainment. The specifications generally require across-the-board use of air entrainment in all concrete mix designs. Furthermore, the required air content of all classes of concrete is frequently the same value.

Due to problems discussed above, and the fact that much concrete on fossil projects is not subjected to freeze-thaw action, it must be questioned whether entrained air is necessary for all fossil project concrete. The

unnecessary use of air-entraining agents adds another element of variability to the concrete production process. This increases the likelihood of rejecting concrete and also requires the added expense of additional testing. Where air entrainment is necessary, guidance should be taken from the ACI recommendations. This will assure uniformity in requirements and prevent unnecessarily restrictive specification limits which do little to improve the concrete quality. Air content requirements should be dictated by the exposure conditions of the concrete. ACI Committee 211 has recommended an approximate air content requirement of 2.5 percent for 1-1/2 inch maximum size aggregate concrete in mild exposure conditions. It may be possible to achieve air contents in this range without the use of an air-entraining agent. Widely used water-reducing agents contribute to workability and may add 1 or 2 percent air to the concrete. In view of this fact, and the fact that on many fossil projects flyash and high cement mixes which improve workability are used, the use of air-entraining agents solely to improve workability may be a questionable practice.

Water-Reducing Admixtures. The addition of a water-reducing admixture to a concrete mix reduces the water requirements necessary to maintain the same workability.

Tests show that the slump loss of concrete containing water-reducing admixtures is usually slightly greater than for comparable concrete without the admixture (4.5). Hersey (4.10) has noted that water-reducing or set-retarding admixtures, when used with high or moderately high alkali cements, may cause a slump loss and false set of concrete when used in the normal batching sequence.

As noted previously in the discussion on air-entraining admixtures, water-reducing admixtures may contribute to the air content of the concrete. Water reducers of the lignosulfonate variety usually produce some air-entrainment, whereas water reducers of the hydroxylated carboxylic acid type normally do

not entrain air (4.5). In the amounts normally used, lignosulfonates may entrain 2 to 6 percent air in concrete (4.3). Due to the other potential benefits, the use of water-reducing agents in lieu of air-entraining agents should be seriously considered. This elimination of the use of air-entraining agents when possible should decrease the variability of the concrete production by eliminating a component of variability from the process.

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CHAPTER 5

CONTROL SYSTEMS, MASS CONCRETE, AND COLD AND HOT WEATHER REQUIREMENTSINTRODUCTION

The material presented in this chapter addresses areas which affect the overall concrete operation, including: preplanning requirements, mass concrete and cold and hot weather requirements.

PREPLANNING REQUIREMENTS

The successful placement of quality concrete requires preplanning on the part of field engineering in order to insure that the proper documents are being used, adequate equipment and materials are available, and necessary coordination is done with all the parties involved. The actions taken to insure that adequate preplanning is accomplished vary from site to site. It should be noted that QC involvement in the preplanning phase varies considerably because the implementation of a Quality Program is dependent upon the contractual relationship which each Utility has with the Prime Contractor.

On two of the projects (i.e., Projects X and Z) there was no information available regarding detailed formal work plans of the type that are prepared for individual concrete placements although it should be recognized that some form of preplanning must be performed on all projects if the construction phase is to progress in an orderly fashion. There were field construction procedures available for special activities. For routine concrete placements, inspection and monitoring was performed against the project specifications.

On Project Y, all operations were performed in accordance with field work procedures which were considered to be a part of the overall QA program. All records were maintained on file along with a description of the conditions related to preplacement, placement and curing acceptance. Field Work Standards,

which: (1) establish controls for concrete placement, and (2) establish surveillance and inspection requirements to assure that all work complies with Owner and A/E specifications, were also used.

MASS CONCRETE

Many of the placements on fossil power plant projects are massive and require special attention. The principal technical problem peculiar to mass concrete is the probability of high tensile stresses resulting from the heat generated by the hydration of cement associated with subsequent differential cooling. It has been recognized throughout the industry that the ACI Code does not adequately address the subject of mass concrete where the members are heavily reinforced. The provisions of ACI 207, "Mass Concrete for Dams and Other Massive Structures"; and ACI 301, "Specifications for Structural Concrete for Buildings," were developed as a result of experience gained from placing mass concrete on unreinforced gravity dams. As a result, many of the suggested practices are not applicable to fossil plant construction. This is evident from the fact that the slump for mass concrete is limited to a maximum of 2 inches. Also, aggregates as large as 6 inches are used in dam construction, however, aggregates in excess of 1 1/2 inches are seldom used in fossil construction.

Mass concrete is defined in ACI 207 as "any large volume of cast-in-place concrete with dimensions large enough to require that measures be taken to cope with the generation of heat and attendant volume changes to minimize cracking." There are many factors which influence whether or not a structure may require special attention. These factors include weather conditions, the volume-surface ratio, rate of hydration, temperature and mass of surrounding materials, functional effect of surface cracking, etc. ACI 301 further

states that "in general, the critical size may be more than $2\frac{1}{2}$ feet in the least dimension, but the requirements of each project should be evaluated on their own merits".

The practice of defining mass concrete by comparing the least dimension to a critical size limit is a satisfactory approach on a dam where the geometric configuration is "orderly". On a fossil structure, many of the placements are irregular in shape and have unique confinement characteristics. The establishment of a critical size limit may lead to problems since there may be large placements where non-mass practices should be employed. On the other hand, there may be small structures which should be characterized as mass concrete.

The project requirements for massive and non-massive concrete are given below:

1. On Project X, mass concrete is defined as all slabs or footings which have a cross-sectional area greater than 30 square feet, with a depth from 1 to 4 feet.
2. Both Projects Y and Z state that there is no major difference between a massive and non-massive pour. Both are handled in the same manner with similar inspections, controls, and documentation.

The establishment of a critical size is a simple approach to defining mass concrete, however, it is not without problems. The use of a 36-inch limit, as defined by ACI 301, is considered to be an example of quoting the code without giving adequate consideration to whether the provisions are applicable. Although there are many aspects discussed in ACI 207 which should be applied to fossil construction, there are a number of features which separate fossil construction from dam construction. The difference in the size of the aggregate used and the shape characteristics were mentioned above.

Another characteristic important to mass concrete on fossil plant projects is the influence of the reinforcement on consolidation and temperature dissipation. Many of the questions regarding the behavior of mass concrete in heavily reinforced sections have not been answered, and it appears that the industry should further investigate this subject.

COLD WEATHER CONCRETING

The primary objective with regard to cold weather concreting practices is the establishment of a procedure that will assure, despite freezing weather, that strong and durable concrete will be produced. This section of the report indicates how cold weather conditions are defined and identifies the temperature restrictions which are placed on the fresh concrete.

On Projects X and Y, concrete is placed during cold weather in accordance with the requirements of ACI 306, "Recommended Practice for Cold Weather Concreting". This recommended practice suggests that cold weather conditions exist when the mean daily temperatures are below 40°F. Under these conditions, concrete should be placed at the temperature indicated in Table 5.1 (which is table 1.4.1 of ACI 306). Project Z does not comply with this requirement. That project, although reference is not made to ACI 306, defines Cold Weather in the same manner as ACI 306. The only requirements related to Cold Weather conditions in the project specifications are:

"When cold weather conditions are in effect, no concrete shall be placed until satisfactory provisions have been made for protection and to maintain the ambient temperature at minimum of 45°F and maximum of 65°F for at least 10 days after placing. In addition, the following steps shall be taken:

TABLE 5.1—EFFECT OF TEMPERATURE OF MATERIALS ON TEMPERATURE OF VARIOUS FRESHLY MIXED CONCRETES^a

Line			Very thin sections				Thin sections				Moderately massive sections				Massive sections			
1	Approximate maximum size rock, in. (mm)		2½ (10)				1½ (38)				3 (76)				6 (152)			
2	Approximate percent sand		40				35				30				25			
3	Weight of sand for batch, lb (kg)		1200 (544)				1100 (499)				1000 (454)				900 (410)			
4	Weight of coarse aggregate for batch, lb (kg)		1800 (820)				1600 (726)				1400 (635)				1200 (544)			
5	Weight of water for batch (total), lb (kg)		300 (135)				250 (113)				200 (90)				150 (68)			
6	Weight of cement for batch, lb (kg)		600 (272)				500 (225)				400 (180)				300 (135)			
7	Minimum temperature fresh concrete as placed deg F (deg C)		55 (13)				50 (10)				45 (7)				40 (4.5)			
8	Minimum temperature fresh concrete as mixed, for weather,* deg F (deg C)	Above 30 F (-1 C)	60 (15.5)				65 (13)				60 (18)				45 (7)			
0 to 30 F (-18-1 C)		65 (19)				60 (15.5)				55 (13)				60 (10)				
Below 0 F (-18 C)		70 (21)				65 (18)				60 (15.5)				55 (13)				
11	Minimum temperature of materials to produce indicated temperature of freshly mixed concrete, deg F (deg C)	Cement†	35 (1.5)	15 (-9.5)	15 (-9.5)	-10 (-23.5)	35 (1.5)	15 (-9.5)	15 (-9.5)	-10 (-23.5)	35 (1.5)	15 (-9.5)	15 (-9.5)	-10 (-23.5)	35 (1.5)	15 (-9.5)	15 (-9.5)	-10 (-23.5)
12		Added water	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	140 (60)	
13		Aggregate water‡	40 (4.5)	30 (3.4)	31 (10.5)	32 (17)	37 (3)	35 (35)	47 (8)	37 (14)	35 (13.5)	39 (32)	47 (6)	32 (12)	34 (11)	105 (40.5)	48 (4.5)	49 (8.5)
14		Sand	48 (4.5)	32 (3.4)	31 (10.5)	32 (17)	37 (3)	35 (35)	47 (8)	37 (14)	35 (13.5)	39 (32)	47 (6)	32 (12)	34 (11)	105 (40.5)	48 (4.5)	49 (8.5)
15	—	Coarse aggregate	48 (4.5)	32 (3.4)	31 (10.5)	32 (17)	37 (3)	35 (35)	47 (8)	37 (14)	35 (13.5)	39 (32)	47 (6)	32 (12)	34 (11)	105 (40.5)	48 (4.5)	49 (8.5)
16	Temperature mixed concrete, deg F (deg C)		60 (15.5)	65 (18)	65 (18)	70 (21)	65 (18)	60 (15.5)	60 (15.5)	65 (18)	60 (15)	65 (18)	65 (18)	60 (15.5)	65 (18)	60 (15)	60 (15)	65 (18)
17	Maximum allowable gradual drop in temperature throughout first 24 hr after end of protection, deg F (deg C)		50 (28)				48 (22)				50 (17)				50 (11)			

*For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place

Cement temperature has been taken as the same as that of average air and of unheated materials

The amount of free water in the sand has been assumed equal to one-quarter the amount of the mixing water.

Coarse aggregate is assumed to be surface dry and free of ice.

^a Reproduced from ACI 306-66, Recommended Practice for Cold Weather Concreting

- a. Frozen or frost covered surfaces, against which concrete is to be placed shall be covered and heated before start of placement of concrete, to remove all frost and raise the temperature of the surfaces to above freezing. Checks shall be made to insure that frost has been removed from soil to its full penetrated depth.
- b. The operation of protection equipment and the removal of forms shall be handled in such manner that the surface concrete shall not be subjected to a differential in temperature of more than 25° F, as determined by observation of ambient and concrete surface temperature indicated by suitable thermometers."

Lines 8-10 of Table 5.1 indicate the minimum temperatures of the concrete when mixed so that when the concrete is placed the concrete temperatures will not fall below those given on line 7 of Table 5.1. These are, of course, general guidelines and it must be recognized that ACI 306 represents generally acceptable approaches for all types of placements from sidewalks to apartment buildings. The conditions on each type of project are different, and the change in temperature is dependent on many factors (including travel distance from the batch plant to the point of placement, duration of delays encountered at the discharge point, the combined effect of temperature and wind, etc.). Thus, it appears that the batch plant operator should be given the freedom to deviate from the suggested batching temperatures in Table 5.1 in order to satisfy the placing temperature requirement. However, there is no evidence that any freedom to deviate is provided on any of the projects in the research study.

HOT WEATHER CONCRETING

The primary concern during hot weather concreting is the rapid rate of evaporation of water from the concrete surface. If the rate of evaporation exceeds the rate at which water bleeds to the surface of the freshly placed concrete, then precautions must be taken to prevent plastic shrinkage cracks

and subsequent drying of the concrete which can seriously impair its strength and durability. Unlike cold weather, which affects concrete operations when the temperature approaches freezing, hot weather is difficult to define in terms of temperature alone. ACI 305, "Recommended Practice for Hot Weather Concreting", defines hot weather as any combination of high air temperatures, low relative humidity, and wind velocity tending to impair concrete quality by causing excessive evaporation. ACI 305 suggests that precautions should be taken when the evaporation rate is expected to approach 0.2 pounds per square foot per hour. Figure 5.2 is reproduced from ACI 305 in order to illustrate how the rate of evaporation can be evaluated. It should be readily apparent that the only factor over which there is any control is the placement temperature of the concrete. For the example calculation shown, an evaporation rate of 0.12 pounds per square foot per hour can be anticipated for the atmospheric conditions established and a concrete temperature of 60°F. If the concrete temperature rises 20° to 80°, the evaporation rate will triple to 0.36.

Projects X and Y both reference ACI 305, "Recommended Practice for Hot Weather Concreting". On Project Z, Hot Weather conditions are considered to be in effect whenever the dry bulb temperature is above 85°F and is expected to go higher. Before concrete is placed, the contractor must indicate all protection for the entire curing period. These methods are subject to Engineering Firm approval. In addition the following steps are taken:

- a. When hot weather conditions are in effect, the concrete shall be placed in the forms and consolidated to its final state within 30 minutes of the time it leaves the mixer.
- b. During hot weather conditions, the height of lifts in structures of large concrete volume shall be reduced, as necessary, or other means employed as approved by the Engineer, to reduce the heat of hydration

Fig. 5.2 — Effect of concrete and air temperatures, relative humidity, and wind velocity on the rate of evaporation of surface moisture from concrete. This chart provides a graphic method of estimating the loss of surface moisture for various weather conditions.

in the interior of the mass. Extreme care shall be taken to prevent crack formation in areas of restraint due to concrete shrinkage.

It should be noted that no major problems associated with either Cold or Hot Weather Concreting conditions or requirements were uncovered during the writer's project site visits.

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CHAPTER 6

PREPLACEMENT ACTIVITIESINTRODUCTION

This chapter discusses those activities which are defined as preplacement activities. The discussion will concentrate on four major areas, namely (1) formwork, (2) reinforcement, (3) cadwelding, and (4) delivery systems. Where applicable, a discussion of the relationship of Quality Control in preplacement activities will be presented. It is important to keep in mind that the implementation of a Quality Control/Quality Assurance program is not a legal requirement on Fossil Plant Construction, but one of personal judgment, decision, and implementation by the Utility. Its purpose is to evaluate and monitor the quality of construction from the preliminary design stage through the commercial operation of the plant.

QUALITY CONTROL INVOLVEMENT

Quality Control Inspectors are generally involved in preplacement activities on a surveillance or monitoring basis and on a limited inspection basis. This involvement on each of the three projects will be discussed below; in doing so reference will be made to concrete preplacement inspection documents.

Project X utilizes a very detailed checklist which incorporates: (1) Reference documents (including specifications, plans and drawings, applicable codes and standards), (2) Batch plant operations, (3) Preplacement activities, (4) Placement activities, (5) Form removal, (6) Finishing, (7) Repairs, and (8) Curing. One of the times when the inspection checklist is used is during the final preplacement inspection. When all items have been checked to the satisfaction of the inspector, the Concrete Status Report is signed which denotes that the placement can be started.

If during the course of in-process surveillances, the QC inspector identifies unsatisfactory work being done, the contractor is verbally notified. If the work can be corrected on the spot, then no further action is taken by QC, except to check the area later for correction and conformance. If the item cannot be corrected immediately or within the same day, a nonconformance report (NCR) is completed, (with the attribute in question being identified as unsatisfactory) and forwarded to the contractor for disposition. A final check is later performed (using the original checklist) on the areas previously in non-conformance.

On Project Y, a Concrete Placement Inspection Checklist which assists the QC Inspector is provided in the applicable QC Instruction. This is similar although not as detailed as the checklist used on Project X. Further detail is maintained, however, through the use of surveillance logs. There were no problems observed with regard to the checklist during the project site visits, and it appears to be serving its purpose well.

The identification, documentation and resolution of NCR's on Project Y are handled in the same manner as on Project X, and therefore will not be discussed.

On Project Z, the Quality Assurance efforts are implemented by the Utility's own forces. Audits, surveillances, and monitoring of construction activity are performed according to the AE Firm's formal "Intensified Quality Compliance Program" for compliance to codes, specifications, and standards. The majority of the Utility Z QA group's time is spent in the performance of audits and the evaluation of past audits.

The AE Firm's Quality Control Group is responsible for surveillances and conformances during the construction phase of operation. The QC Inspectors maintain a surveillance log for all their field activity, and issue non-conformance reports (NCR's) on items not in conformance with codes, specifications

or contract agreements. These NCR's are maintained in a history file for documentation and control. Access can be easily attained for any follow-up action on all NCR's.

The writer was unable to obtain a more detailed knowledge of the QA/QC programs due to the recent reorganization of office personnel which had taken place on Project Z. It was mentioned, however, during a general discussion with QC Site Personnel that the QC Inspectors also used Checklists on Project Z.

As noted above, the major difference between the three projects is the method of recording objective evidence (i.e., documentation) rather than the items which are inspected. One approach provides the inspector with a detailed attribute list; each of these attributes must be initialled as the specific item is satisfactorily completed.

Although the attributes checked on each project are generally the same, there is considerable difference in the degree of guidance and the verification requirements which are given to the QC Inspector. This difference ranges from very limited documentation to very detailed instructions and attribute lists. The basic philosophy behind this latter approach may be that the inspector is unskilled or at best semi-skilled, and of course, unmotivated and thus cannot be trusted to do a totally adequate job of inspection without the aid of a very detailed set of instructions. This approach works quite well when there is a minimal level of confidence in the capabilities of the inspection staff, but could have opposite effects on a highly trained staff. For skilled inspectors, a detailed checklist approach could stifle inspector productivity and motivation.

FORMWORKTolerances

On all of the projects studied, the standard which provided guidance with respect to formwork tolerance was ACI 301, "Specifications for Structural Concrete Buildings". The tolerances for building construction, as given in ACI 301, are presented in Table 6.1. ACI 347, "Recommended Practice for Concrete Formwork", is also used for guidance and agrees with ACI 301 for buildings; it also provides a degree of flexibility for special structures such as canal linings, bridges, mass structures, and tunnel linings. The recommended tolerances for mass structures are also presented in Table 6.1. It should be noted that for some elements, the tolerances are more stringent and for others they are less stringent.

In a structure as complex as a fossil power plant, flexibility in the specifications is essential if the quality control program is expected to operate in a cost-effective manner. However, the amount of flexibility should be controlled to the degree where it provides the maximum benefits at the minimum cost.

Another question which was discussed during site visits was the difficulty of meeting the ACI tolerance requirements. Very few NCR's were issued on the three projects. This fact may not, however, reflect the difficulty with meeting these requirements. It is felt that the relaxation of ACI requirements may be in order since the ACI code establishes minimum requirements for ordinary commercial reinforced concrete structures. ACI Committee 318 has stated that for special structures, the provisions of the ACI Code shall govern where applicable. There are many within the industry that feel that fossil power plants qualify as special structures and are only governed by applicable provisions of the code rather than the code in its entirety.

Table 5.1.--Formwork Tolerances

		ACI 301 & 347 Building Structures	Mass Structures
Vertical Surfaces and Control Joint Grooves			
Variation from plumb:	in 10 feet	1/4	1/2
	in 20 feet	1/4	3/4
	40 ft. or more	1/2	1 1/4
	but not more than	1	
Horizontal Surfaces and Horizontal Grooves			
Variation from level:	in 10 feet	1/4	1/4
(slab soffits, ceilings, and beam soffits)	in 20 feet	3/8	
	40 ft. or more	3/4	1/2
Exposed lintels, sills, and horizontal grooves)	in 20 feet	1/4	1/4
	40 ft. or more	1/2	1/2
Position of Walls, Columns and Partitions			
Variation in location:	in 20 feet	1/2	1/2
	40 ft. or more	1	3/4
Buried Construction:	in 20 feet		
	40 ft. or more		
Floor and Wall Openings and Sleeves			
Variation in size:	plus	1/4	
	minus	1/4	
Variation in location:	plus	1/4	
	minus	1/4	

(continued)

Table 6.1.--(continued)

Dimension of Members			
Variation in cross-section of columns, beams; thickness of walls, slabs:	plus	1/2	1/2
	minus	1/4	1/4
If dimension exceeds two feet:	plus		
	minus		
Footings, Pits and Sumps			
Variation from dimensions:	plus	2	2
	minus	1/2	1/2
Misplacement or eccentricity: (Z)		2 ^d	2 ^d
Reduction in thickness: (Z)		5	5

^aDimensions in inches unless otherwise noted

^bProposed revision to project specifications

^cBut not to exceed 1/2 of 1 percent of opening dimension in direction of misplacement

^dBut not more than 2 inches

Lewis H. Tuthill, a well-known concrete expert and consultant has stated:

"Accordingly, tolerance values should be judged on their merit or necessity in each case. ACI 347 and ACI 301 are well considered guides but should not be mandatory if wider tolerances are adequate or narrower tolerances really worthwhile. It should be noted that ACI/ASME, Section III, Division 2 (ACI 359), CC4342, says, 'The tolerances for the placement of reinforcement shall be specified in the Construction Specifications'."

In specifying tolerances, it should be remembered that more exacting tolerances than needed increase construction costs. In view of the fact that there are different levels of criticality within a fossil plant, a possible solution is the evaluation of each placement. Critical and non-critical areas can thus be reviewed, and tolerances developed on an individual basis.

Cleanliness

Very little is said in ACI 301 regarding cleanliness of forms except that the forms should be thoroughly cleaned of all dirt, mortar, and foreign matter and shall be coated with a form release agent. Each of the three fossil project specifications reference ACI 301 and state that forms should be designed and engineered accordingly. The only other reference to form cleanliness is found in project quality control procedures where phrases such as "properly cleaned" or "cleaned as completely as possible" are often used. To facilitate cleaning, inspection, and placement, access openings are generally permitted in columns and walls. The interpretation of cleanliness is a qualitative attribute and therefore is a matter of engineering judgment on the part of the inspector. In most cases, this responsibility has been administered satisfactorily since most projects have not experienced any difficulties with regard to cleanliness.

Inspection Activity

A review of the QC procedures on the three projects indicates that, in general, the same attributes are checked by the inspector. As noted earlier

the primary difference is in the method of documenting the results. A comparison of the procedures and attribute lists also indicates that there are four major areas that are inspected on each project. These are: (1) surface preparation and coating, (2) cleanliness, (3) joint tightness, and (4) alignment, grade, and tolerances.

On Project X, all construction activities are subject to surveillance by the Owner's Quality Control Group. All contractors and subcontractors perform their own quality inspections for conformance with construction procedures and specifications. The QC group performs their surveillances with a Field Checklist. This list, which is six pages long, is taken to the placement site by the QC Inspector and completed there. The list is very complete since it references the governing specifications, drawings and other required documents. Other sections included are Preplacement, Placement and Curing activities. It is the writer's opinion that the list is very informative and accurate. After being completed, the list is maintained on file as a reference citing that the verification of quality has been performed.

On Project Y, most of the control of formwork is based on engineering judgment. The personnel employed in the QC department appear to have many years of experience on construction sites. A general type specification is used; specific decisions are the responsibility of the Field Engineer or his subordinates. As an example, the average time for concrete curing before forms are removed is three days; deviations from this time are decided individually, depending on the placement itself and its level of classification.

The Project Engineer is responsible for the design of all forming systems including materials, shoring, bracing, allowable loadings, etc. All verification of installation is the responsibility of the Field Engineer. All lines and grades for construction are established based on tolerances indicated in

the specification, code, procedure, or by the Area Engineer. As previously mentioned, engineering judgment plays an important part in decisions which are made. Any specific deviations must be processed by means of a Field Design Change Request by the Owner or Design Agent. The scope of this procedure includes all field requested design changes and the necessary documentation which is needed to assure compliance with owner requirements.

REINFORCEMENT

With regard to reinforcement on the projects studied, it is generally stated in the construction specifications that all reinforcement is to be cleaned free from excessive rust, mill scale, grease, dirt, and other substances capable of destroying bond before placement. It is also stated that all reinforcement must be accurately and securely placed. All reinforcement except wire fabric must consist of deformed bars which conform to the requirements of ASTM A615-72 entitled "Specifications for Deformed Billet Steel Bars for Concrete Reinforcement". All wire fabric reinforcement must conform to the requirements of ASTM A185-72 entitled "Specification for Welded Wire Fabric for Concrete Reinforcement".

Long-term storage of reinforcing steel can cause problems when the cleanliness attribute is applied. ACI 301 specifies that reinforcement should be free of mud, oil, or other materials which can adversely affect bond. Reinforcement with rust or mill scale is acceptable without cleaning or brushing, provided the weights and dimensions of a cleaned sample are not less than required by ASTM. It is further stated in the commentary to ACI 318 that research has shown that a normal amount of rust actually increases bond, and normal rough handling generally removes rust which is loose enough to injure bond.

The effect of rust and scale on the bond characteristics of reinforcing bars has for instance been studied by Kemp et. al. (6.1). An experimental program was established to provide information on bond characteristics of ASTM A432 bars with a broad range of scale and rust conditions. The principal parameter in the tests was the bar surface condition. It was concluded that the bond characteristics of deformed reinforcing bars with deformations meeting ASTM A305 specifications do not appear to be adversely affected by varying degrees or types of surface rust or mill scale, provided the weight of the bar meets the minimum ASTM requirements. The deformation dimensions appear to govern bond characteristics; the rusted bar should meet the ASTM requirements in this regard. The test data indicated that the current bond requirements of ACI 318 were quite conservative, especially with respect to smaller bars, and that concrete strength appears to control the overall bond behavior to a much greater extent than does the surface condition of the bar.

The problem of rust has also been studied by the Bureau of Reclamation (6.2) and Gilkey et. al. (6.3) with similar results being reported. The latter report stated that two-year air rust samples which had a thick coating of rust lost less than 5 percent weight upon cleaning. Unless deliberate action is taken to produce a special surface, it appears that bars would have to rust in water or air for an extraordinarily long period before a cleaned sample of maximum overweight bar would be rejected on the basis of not passing a weight or deformation height test. In addition, it would be impossible to maintain these heavy coatings with normal handling on site, and any removal of this delicate surface would improve bond resistance significantly.

On the three projects in the research study, no extreme difficulties were cited with regard to reinforcing tolerances or cleanliness.

Reinforcement-Tolerance Relationship. The inter-relationship between formwork tolerances, reinforcing tolerances and concrete cover requirements adds another degree of complexity to fossil plant concrete construction. On a number of projects, it has been stated that reinforcement placing tolerances were difficult to achieve because of the fabrication tolerances allowed. Many of the areas are heavily congested and there may be interferences with embedments. In such areas, the fabrication tolerances may use up all of the allowable placement tolerances. This is also related to formwork tolerances through the minimum cover requirements.

DELIVERY SYSTEMS

The methods used to deliver concrete are generally the same for all types of construction. Differences do occur in the sizes, type and percentages of each piece of equipment which is used. On all three of the projects, QC inspectors as well as Field Supervisors and Inspectors performed regular checks and inspections on equipment to be used prior to a "sign off" of the placement pour card.

Project X

On Project X, concrete is delivered to the placement area by 10 cubic yard-capacity transit agitating trucks. Concrete loads are limited to 9 cubic yards and mixed at the batch plant. The trucks are inspected yearly as required by the state regulations, up-to-date checklists are kept on file. Water carried by the concrete trucks can be added to the mix as required, provided that the amount does not exceed the mix design specifications. The amount of allowable water is printed on the batch tickets to aid in maintaining specification limits.

The number of trucks furnished, operated and maintained is handled on a placement by placement basis with a maximum time period of availability for production being three consecutive eight-hour shifts. Concrete delivery

schedules are submitted in advance in order to allow sufficient time for the scheduling of the required number of trucks. A 12 hour advance notice is required for placements up to 200 cubic yards. A 24 hour notice is required for larger placements. The resident engineer determines the order of priority of concrete delivery on-site, whenever the demand for concrete exceeds the plant capacity.

Massive concrete pours require constant communications between plant and field in relation to supply, operations and testing.

The specification limits differ with respect to temperature and slump because mixes are designed to better control temperature and placement.

Auxiliary delivery systems include 4" to 5" portable pumps, 1 to 5 cubic yard buckets, chutes, Georgia buggies, and conveyors. The majority of concrete appears to be placed with pumps and chutes whenever possible, or even directly from the truck.

Project Y

On Project Y, the systems used for delivery of concrete are: 10 cubic yard mixer trucks, 1 to 5 cubic yard buckets (with size depending on the location and size of placement), 4" to 5" portable concrete pumps, Georgia buggies and conveyor systems. As a specification requirement, all systems used for the delivery of concrete must have a sufficient number of qualified back-up support systems.

Most placements are directly from the truck into buckets when clearances permit, otherwise pumps are used. If pump failure occurs, a back-up pump must be supplied within an hour, in order to avoid the creation of a cold joint. A supply of Georgia buggies are maintained in case a reserve pump cannot be obtained. To date, no problems or difficulties have occurred with concrete placements. Approximately 90% of concrete is delivered by crane and buckets

with the remaining 10% by pumps. Georgia buggies and conveyors are used only as an emergency back-up source. It should be noted that if a pump is used, the mix design of the concrete is altered to allow a larger amount of sand as an aid in overcoming pipe friction.

Project 2

On Project 2, concrete is delivered to the placement dry, in a 10 cubic yard mixer truck. After arriving at the placement discharge location, metered water is added and mixing occurs. Both the water-meter and the counters on each truck are periodically inspected. Checklists are maintained on file. Water added at the placement is limited to the design mix requirements, although generally subject to engineering judgment. The inspector can approve the concrete as it is placed based on the consistency of the concrete as it enters the placement. However, as mentioned earlier, air and slump tests are periodically performed with the results recorded and filed.

Delivery systems also include 4" to 5" portable pumps, 1 to 5 cubic yard central-bottom-dump buckets, chutes and conveyors. These systems are adapted for delivering concrete of the required consistency and plasticity without segregation or loss of slump. All concrete must be placed in the forms within thirty (30) minutes after the addition of water to the cement and aggregate when hot weather conditions prevail, or within forty-five (45) minutes at other times, unless authorized otherwise by the Project Engineer.

Another requirement specifically mentioned in the contract specifications relates to cleaning of equipment. Project 2's specifications state that "All equipment used for transporting and placing of concrete shall be maintained in clean condition, and all buckets, hoppers, chutes, and other equipment are to be thoroughly cleaned after each period of placement."

The inspector must exercise engineering judgment when he interprets the definition of "clean" as it refers to the equipment. During the writer's site visits, no problems with the delivery systems mentioned above were observed.

CADWELDING

On those fossil plant projects which were studied, cadwelding was rarely used except for tying together the Cooling Tower foundations. The topic will therefore not be discussed in this report.

REFERENCES

- 6.1 Kemp, E. L., Brezny, F. S., and Unterspan, J. A., "Effect of Rust and Scale on the Bond Characteristics of Deformed Reinforcing Bars," ACI Journal, Proceedings, V. 65, No. 9, September 1968, pp. 743-756.
- 6.2 USBR, A Manual for the Control of Concrete Construction, U.S. Department of the Interior, Bureau of Reclamation (6th edition), 1956.
- 6.3 Gilkey, H. J., Changerlin, S. J., and Beal, R. W., "Bond Tests on Rusted Bars," Proceedings, Highway Research Board, V. 19, 1939, pp. 149-154.

CHAPTER 7

PLACEMENT AND POSTPLACEMENT ACTIVITIES

This chapter discusses some of the activities which occur during the concrete placement and postplacement phases. The role of the Quality Control/Quality Assurance program will be highlighted wherever appropriate.

PLACEMENT ACTIVITIESProject X

On Project X, all contractors and subcontractors perform placement inspections in order to insure conformance with the design specifications. Often surveillances are performed and documented by the Quality Control group. Concrete conveying and placing, formwork and the tools used, and the details of construction must be in accordance with ACI 318-71 entitled "Building Code Requirements for Reinforced Concrete".

With regard to testing requirements, cylinders are generally made every 100 yds. while slump measurements are made every 50 yds. Cylinders are also made by the supplier on all rejected trucks.

The specification requirements on Project X state:

1. Before any concrete is placed, the entire placing program consisting of equipment, layout, proposed procedures and methods shall be submitted to the resident engineer for acceptance, and no concrete shall be placed until the resident engineer's approval has been received.
2. Where the foundations or concrete structures are placed on earth, the subgrade supporting the concrete shall be level and trimmed to the lines and dimensions excavated, free of debris and organic material, and thoroughly compacted to produce a firm base. Prior to placing the concrete, the subgrade shall be thoroughly dampened. Immediately prior to placing concrete, there shall be no standing water or puddles on the subgrade.
3. Concrete shall not be placed until the placement site has been examined by the resident engineer.

4. The concrete shall be handled from the mixer to the place of deposit as rapidly as practical, and by methods which will prevent separation and loss of ingredients. It shall be deposited in the forms in approximately horizontal layers a maximum of 2 feet thick as nearly as practical in its final position, so as to minimize rehandling. It shall be thoroughly compacted by means of vibrators, and thoroughly worked around reinforcing and into all spaces to be filled. Vibrators shall be employed under experienced supervision. Precautions shall be taken not to over-vibrate to the point that segregation results.
5. Spouting or chuting concrete into place will be permitted under conditions that will prevent segregation. The slope of chutes shall not be steeper than 1 vertical to 2 horizontal and, at the point of discharge from the chutes, a hopper shall be provided that will cause the concrete to drop vertically into the place of deposit. Concrete shall not be allowed to drop freely more than four feet. Separation of concrete aggregates will be cause for rejection of the chuting equipment. Aluminum chutes, hoppers, and pipe shall not be used.
6. Metal or wood screed bars shall be used so as to ensure even uniform slabs of proper thickness, allowance being made for settlement of concrete. Aluminum tools, screeds, or pipe shall not be used.
7. Concrete shall not be deposited during rain unless adequately protected. Newly-placed concrete shall be protected from rain until it has hardened sufficiently so that it will not be damaged.

Project Y

On Project Y, all placement activities are performed according to standards and procedures. Some of the procedures used on this project include:

Field Work Procedures (related to Concrete Placement). These procedures detail the surveillance and inspections required to assure that all work complies with the owner's requirements and design agent's specifications.

Responsibilities of Field Personnel (Contractor and Owner) and Quality Control are stipulated in this procedure. Some of the major areas covered are: placement methods, check-off lists for verification of Quality Assurance, delivery of concrete during placement as well as inspection and surveillance activities, etc.

Field Work Procedures (related to Embedments). These procedures establish methods, tolerances and inspections for all miscellaneous embedded material,

as well as the responsibility of field personnel governing the implementation of this procedure.

Field Work Standards (related to Concrete Placement). These are the standards which the AE Firm uses in their construction practices. Topics discussed in this standard are: the implementation of the standard, the documents required, deviation and field change requests, special weather effects, the specified curing period and the placement checkoff lists which are required.

Some of the technical requirements which appear in the above documents are:

- a. Concrete be thoroughly worked around the reinforcement and around embedded fixtures and conduits and into the corners of the forms. Special care must be taken to rod along concrete surfaces which are to be exposed. All proposed changes that may occur must be first approved by the Owner's Superintendent before they are performed. Concrete must be handled from the mixer to the place of final deposit as rapidly as possible in order to prevent separation or loss of ingredients.
- b. Concrete shall not be allowed to drop freely more than 4'. Where the drop exceeds 4' a chute or tight tube must be used. Concrete may be dropped into forms vertically for a distance of not more than 30' through a tight tube. The bottom of the tube must not be more than 3' above the plastic surface.
- c. If for any reason the concreting is stopped, the greatest care must be taken to stop the work at such a point that the joints formed will not weaken the member structurally. Such construction joints shall be made only on approval of the Owner's Superintendent and shall be true, straight joints.
- d. The requirements for consolidation during placement activities are:
 - . Concrete, during and immediately after depositing, shall be thoroughly consolidated to maximum subsidence, without segregation, using approved mechanical vibrators.

- . All areas shall be vibrated uniformly.
- . Vibrators shall be inserted vertically at close enough intervals so that the zones of influence overlap.
- . Vibration shall not be continued in any one spot to the extent that pools of grout are formed.
- . The vibrator shall be inserted to the full depth of the layer being treated. When concrete is being placed in layers, the tip of the vibrator shall extend approximately 4" into the underlying layer.
- . Vibrators shall not be used to move concrete horizontally.
- . Frequency of vibrators to consolidate mass concrete shall not be less than 6000 rpm when immersed in the concrete for vibrating heads larger than 4" diameter. The minimum frequency of vibrators with heads 4" or less in diameter shall be 7000 rpm.

Project 2

On Project 2, the major requirements for concrete placement are:

a. Before any concrete is placed, the entire placement program, consisting of equipment, layout, proposed procedures and methods shall be submitted to the Engineer for approval. No concrete shall be placed until the Engineer's approval has been received.

b. The control of placement shall begin at the mixer discharge. Concrete shall be discharged by a vertical drop into the middle of the bucket or hopper. This principle of a vertical discharge of concrete shall be adhered to throughout all stages of delivery until the concrete comes to rest in the structures.

c. Concrete shall, in all cases, be deposited as nearly as practical directly in its final position, and shall not be caused to flow in a manner which will cause segregation. For locations where direct placement is not possible, and in narrow forms, the Contractor shall provide suitable drop chutes and "elephant trunks" to confine the concrete in movement.

d. Concrete placed in restricted forms by wheelbarrows, buggies, cars, short chutes or hand shoveling shall be subject to the requirement for vertical

delivery of limited height to avoid segregation and shall be deposited as nearly as practical in its final position to avoid segregation due to rehandling or flowing.

e. Concrete shall not be placed until the forms, the cleaning of rock or concrete surfaces, reinforcing steel and embedded parts in place have been inspected and approved by the Engineer.

f. Bedding planes shall be approximately horizontal, except in dams or other structures where inclined beds may be required on a downward slope of about 1 vertical to 10 horizontal in an upstream direction. In such a case the placement shall proceed in an upslope direction.

g. Concrete shall be compacted with mechanical vibrating equipment until the concrete has been consolidated to the maximum practicable density, is free of pockets of coarse aggregate, and fits tightly against all form surfaces and embedded materials.

. Vibrators shall be the internal or immersion high-frequency type, with speeds of not less than 6000 revolutions per minute when immersed in the concrete. Vibrators shall be used in sufficient number of units and power of each unit to properly consolidate all concrete.

. Vibrators shall be inserted in a vertical position at intervals of about 2 ft., depending upon the mix, the equipment used, and continued experience on the job. Vibrators shall be withdrawn slowly.

. In placing concrete in layers which are advancing horizontally as the work progresses, great care shall be exercised to insure adequate vibration, blending and welding of the concrete between the succeeding batches.

. The vibrator shall penetrate the layer being placed and also penetrate the layer below while the under layer is still plastic to insure good bond and

homogeneity between the two layers and prevent the formation of cold joints.

. Care shall be taken to prevent contact of vibrators against reinforcement steel after the start of initial set. Vibrators shall not be permitted to contact the forms of finished surfaces.

. The use of form attached vibrators shall not be permitted without specific authorization of the Engineer.

. The use of surface vibrators will not be permitted under ordinary conditions. However, for thin slabs such as highways, runways and similar construction, surface vibration by specially designed vibrators may be permitted upon approval of the Engineer.

SLUMP OF FRESH CONCRETE

There are three primary attributes of fresh concrete that are typically verified at the point of discharge into the placement; namely, slump, temperature and air content. Although the reasons for rejection of concrete on each project were not available in a quantifiable form it was generally agreed that the highest rate of rejection was due to slump. ACI 301 allows a slump of 4 inches with a 1-inch tolerance for individual batches provided the average of the ten (or less) most recent batches tested is less than the 4 inch maximum. A maximum slump of 2 inches, with the same allowable 1-inch tolerance, is given for mass concrete.

Specification writers should recognize the inherent variability of slump measurements, and in particular that occasional batches may exceed the slump limits without having a detrimental effect on quality. This understanding is reflected in the 1-inch tolerance provided by ACI 301. The underlying danger, however, in the ACI Code approach appears to be the development of an acceptance criterion solely based upon an average slump value. Although the concept is sound, it can have an adverse effect on quality by encouraging

the placement to begin with batches having slumps on the low side of the preferable range, merely to provide low numbers which can be averaged with higher values that may appear later.

The slump requirements for Projects X and Y are provided in Tables 7.1 and 7.2. It is evident in the Project Y case that very little recognition of the variability of slump is provided. On Project X this variability is recognized. In addition it should be noted that on Project X slump requirements are considered to be dependent upon the design strength as well as the size of the aggregate and the type of member in which the concrete is placed.

POSTPLACEMENT ACTIVITIES

The Postplacement requirements are indicated in the general specifications for each project. They specify that a curing compound is required, and stipulate differences in temperature requirements (as was previously discussed in requirements for "Hot and Cold Weather Concreting").

The curing temperature requirements for the three projects are:

a. Project Z - Concrete shall be maintained above 50°F and in a moist condition for at least the first 7 days after placing, except that high-early-strength concrete shall be so maintained for at least the first 3 days. Other curing periods may be used if the specified strengths are obtained. For concrete containing a pozzolan, the curing time shall not be less than fourteen (14) days.

b. Project X - At no time should the temperature change at the surface of the concrete be greater than 5°F in any hour or be greater than 40°F in 24 hours.

c. Project Y - Temperature isn't mentioned except in the "Requirements for Hot and Cold Weather Concreting". Instead, reference is made to the number of days formwork must be in place after concrete placement, in order to achieve

Table 7.1.--Slump Requirements for Project X

<u>Portion of Structure</u>	<u>Slump in Inches</u>	<u>Maximum Size of Coarse Aggregate Based on Square Screen Openings</u>
Rainforced footings	2-1/2:- 1/2, + 1	1-1/2 in.
Substructure walls	2-1/2:- 1/2, + 1	1-1/2 in.
Supporting slabs, beams, and reinforced walls	3:- 1/2, + 1	3/4 in.
Building piers	3:- 1/2, + 1	3/4 in.
Mats	2-1/2:- 1/2, + 1	1-1/2 in.
Transformer foundations	2-1/2:- 1/2, + 1	1-1/2 in.

Table 7.2.--Slump Requirements for Project Y

<u>Class Concrete</u>	<u>Size of Aggregate</u>	<u>Maximum Allowable Slump</u>
A--3000 psi	1-1/2"	4.0
A--3000 psi	3/4"	4.5
B--4500 psi	1-1/2"	4.0
B--4500 psi	3/4"	4.5
C--3000 psi	1-1/2"	3.5
C--3000 psi	3/4"	3.5
D--2000 psi	1-1/2"	4.0
D--2000 psi	3/4"	4.0

*Size of aggregate dependent on Pour Placement-Type of Structure

a proper curing period. In the specification it states:

"All concrete surfaces shall be protected against loss of surface moisture for at least seven days after being placed, and high-early strength concrete shall be cured for at least the first 3 days.

Other areas discussed in the project specifications are the detailing of finished concrete work, the patching and repairing of concrete surfaces, and the moist curing of placements. These areas are performed utilizing the "Engineering judgment" acquired on past projects. The specifications don't specifically detail the performance standards but specify that all activity, practices and methods performed are to be approved by the Project's Head Engineer. The consensus of a general statement included on all specifications is: "All fillings shall be tightly bonded to the concrete and shall be sound, free from shrinkage cracks after the fillings have been cured and dried. All materials, procedures and operations used in the curing and repair of concrete, and also the finish work shall be subject to the approval of the Engineer."