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Technical aspects of a total quality assurance plan for an electric utility.

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TECHNICAL ASPECTS OF A TOTAL QUALITY ASSURANCE PLAN FOR AN ELECTRIC UTILITY

by

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ABSTRACT

In recent years there has been felt within the electric utility industry increasing pressures for tighter control measures on quality. These pressures have been exerted both from within and outside the organization. From the outside has come a public demand for greater reliability, an increased environmental compatibility, and governmental requirements for quality control measures to assure safety in nuclear generating plants. From within the organization has come increased desires to reduce costs since cost reductions realized in the sixties based upon promoting load growth to foster lower unit costs through increased plant sizes are no longer feasible. These cost reductions can be realized, at least partially, through a quality assurance program. Such a program emphasizes doing the job correctly the first time thereby reducing the costs of scrap and rework and improving reliability while maintaining schedules by reducing the number and severity of delays created by quality problems.

In a recent EEI survey questionnaire of 23 utilities, those reporting that they had a quality assurance

program (five reported that no quality assurance group existed in their company) described mainly a system of inspections. It is granted that inspection is a necessary function, but in applying highly inspector oriented quality assurance programs, the inspector soon becomes responsible for the quality of the work being inspected rather than those performing the work. This type of quality control organization is mainly aimed at corrective action and provides little information aimed at preventing quality problems before they arise.

To be effective, it becomes necessary to have an inspection section to match the work force since for every work function an inspector is required to assure a quality job. This can be seen to be an uneconomical approach if an alternate can be found which successfully places the responsibility for quality on the vendor of materials, the builder of utility projects and/or the designer without sacrificing quality, costs or schedules.

The intent of this thesis is to provide a workable quality assurance plan for the unique operations of an electric utility. The approach will be to concentrate on a particular quality sub-system, namely the transmission sub-system, emphasizing the technical aspects of design, materials, and construction. It will provide a method of auditing these three areas and a feedback system for meeting quality assurance goals. It will then be shown that the basic philosophies of the transmission sub-system can be applied to other sub-systems although the technologies will be different and that with some planning these quality sub-systems can be integrated to form a total quality system.

INTRODUCTION

EVOLUTION OF QUALITY CONTROL AND ASSURANCE

Quality control and assurance methods have long been a necessity in manufacturing industries. Prior to the close of the nineteenth century, one worker, or at most, a very small number of workers, was responsible for manufacture of the entire product. Under this system, labeled operator quality control, each worker had total control over the quality of his work.

With the coming of large scale manufacturing processes of our modern factory concept in the nineteen hundreds, many men performing a similar task were grouped together. A foreman who supervised the group then assumed responsibility for the quality of the group's work. This is known as foreman quality control.

During World War I, the complexity of the manufacturing system increased involving larger numbers of workers reporting to each production foreman. The first full-time inspectors appeared on the scene to relieve the foreman of some of his quality responsibility. This then became a system known as inspection quality control.

About the time of World War II, the tremendous mass production requirements necessitated a fourth step of quality control. This phase was an extension of the inspection phase and was aimed at making the big inspection organizations more effective. Inspectors were provided with new tools such as statistical sampling techniques and control charts. This phase was called statistical quality control and contributed such things as sampling inspection and control limits or warning signals.

The necessity of removing quality control from the shop floor and permitting business management to attack the really big quality control problems resulted in the present goal of <u>total quality control systems</u>.

Quality control as applied throughout the electric utility industry has not necessarily followed the manufacturing industries in these extensive changes. This is attributable to a number of factors unique to electric utilities. The fact that the product - electric power - must be generated the instant it is used has had a dominant influence on every phase of the business. The establishment of "franchised areas" for electric utilities has influenced the competitive nature of the industry. The emphasis in the past on increasing the use to permit reduction of costs through the lower unit cost of larger machines has created tremendous growth in the electric utilities production requirements in generation, transmission and distribution facilities. It is interesting to note, however, that in light of present day pressures it is generally recognized that the "growth cycle" has reached saturation and, in fact, public conservation of electricity is now being promoted by electric utilities.

Standards of service have long been maintained at a high level by electric utilities. Good reliability has been maintained by limiting the number and duration of interruptions. Good quality of service has been maintained by a high degree of attainment of standard voltage and frequency. Economy of production has been attained through the use of generator allocation and proper load division.

In view of these high standards of performance what then can total quality assurance bring to the electric utility? For transmission lines which are in service 98% of the time during a year, is it necessary or economically feasible to increase this percentage to 99 or 100%? Is this the intent of a total quality control program? These are questions which can reasonably exist in the minds of utility managers when considering a proposed improvement in the corporate quality control system.

ELECTRIC UTILITY NEED FOR QUALITY ASSURANCE

A parallel quality control evolution can be seen within the electric utility industry. This industry has also felt a growth in its production requirements in the generation and transmission of electric power to meet the public demand. It therefore certainly becomes easy to see that the increased complexity of the electric utility industry contributes to its need for total quality control.

Other needs besides complexity have developed. One is a result of increasing cost pressures and the resulting necessity to get the most from the construction dollar by doing both the engineering job and the construction job right the first time. By concentrating on this, it is possible to eliminate the need for costly rework and/or delays while obtaining the maximum intended reliability.

Safety pressures, legislation, and the desire to provide the safest working conditions for personnel and safe operation for the public also promotes the idea of doing the job right the first time to avoid delays and unfortunate situations during construction and during operation for the life of the facility. Total quality assurance as applied to the electric utility industry must be involved in the engineering, purchased material, and construction systems involved in developing the utility facilities which have the high degree of reliability and quality. The need is generally not to improve this quality level but to provide assurance that this level will be met by each project. Also, each discipline working on the project must meet its responsibilities towards reaching that quality level, thereby reducing the costs and increasing the productivity of the utilities manpower. Basically what is being said is that total quality assurance will be involved with the preventive aspects of control. It will seek out problem areas, pinpoint their cause and feed back this information to those who can effect the necessary changes to prevent these problems from occurring on future jobs.

It is this philosophy which will take the electric utility beyond the inspection quality control method which was concerned mainly with correcting deviations found in the construction phases of the project and contributed little towards preventing these same deviations from occurring over and over again on other projects. This, in effect, is the means for reaching the goal presented previously of getting the job of quality control out of the shop and permitting business management to cope with the big quality problems.

ELEMENTS OF TOTAL ASSURANCE

DESIGN ASSURANCE AND CONTROL

In the manufacturing industry the primary objective, identified as the aim of new design control, is that of analyzing newly designed products for possible quality troubles before production begins. Through this objective, the purpose of new design control - integrated quality planning for new products - can be accomplished.

Accomplishment of this new objective is normally sought through:

1) Matching product planning to customer requirements.
2) Reviewing specifications of components and part requirements to assure completeness and tolerance limits.
3) Assuring adequate pre-production testing is used.
4) Applying past experience with similar products to judge consumer likes and dislikes.
5) Applying past experience of quality problems created by previous designs.

In a product oriented industry, it has been found that there must be a difference in the approach to new design control for mass production manufacture versus job shop production. Job shop production is that type of manufacture where only one or a few products are to be made for a given design. The approach to mass production concentrates on pilot runs and sampling procedures while job shop production is involved with the establishment of quality performance based on similar previous designs.

Certainly for application of new design control to the electric utility industry, it is feasible and necessary to analyze newly designed facilities as was the case in the manufacturing industries, for possible quality problems before construction of the facility begins. As in the manufacturing industry, accomplishment of this objective can be sought through: (1) matching designs to the requirements of those who will be constructing the facilities, and (2) applying past experience with similar facilities to avoid quality problems created by previous designs.

Another application of new design control which will be particularly unique to electric utility design work is the following. Many of the utilities projects are concerned with facilities which essentially use existing engineering and manufacturing know-how. Because this is true, various standard design and criteria have evolved for this type of facility. It is therefore possible and highly profitable, from the standpoint of preventing quality problems, to review designs for new projects to see if these new designs match the established design criteria for past facilities.

This type of approach will not be possible to the same extent for facilities which are being designed on a research and development oriented basis. These facilities contain new design criteria and standards and, therefore, the quality assurance activities must make extensive use of such techniques as environmental testing and reliability analysis. Another difference will be in the approach to in-house versus contracted design for electric utility facilities. The basic difference in this case is that the in-house quality system has been defined, reshaped and tuned over a long period of time and a large number of projects, whereas the contracted engineering firm must prove to the utilities satisfaction that they have a system for turning out project designs which have the desired quality characteristics. Further, whatever can be added to the contractor's quality system based on the quality experience of the utility must be determined and incorporated into the contractor's system. It also may be necessary to perform in-depth reviews of design plans to ensure that they meet the various needs of the construction forces. Also, in-process reviews of the design efforts may be advisable to see if the contractor is following the quality system which has been set up for the project design. New design control will be aimed at locating quality problems in the design prior to construction of the facilities. It will provide information so that not only can the designs for projects reviewed be revised to eliminate the quality problems but also the cause for the deviation from quality standards will be determined so that information can be provided for eliminating the cause and thereby preventing recurrence of these problems on future jobs. It is this type of information which can truly make an impact on the economics of utility capital construction and is lacking in the inspection oriented systems prevalent within electric utilities today. By these means, the causes of quality problems will be made visible to utility managers so that they may be eliminated.

This discussion of new design control has been based upon information gathered from the quality control experience in the manufacturing industries, with some emphasis on the needs and applications to utilities. Specific application to electric utilities will be discussed in the following section. The intent of the discussion was to establish the justification for design review of utility projects.

PURCHASED MATERIAL CONTROL

The second element of total quality assurance of particular applicability to the electric utility industry is that of purchased material control.

Incoming material control is an extremely important subject for the electric utility with its necessarily heavy capital investment in materials. Materials range from the generator and its associated equipment representing several millions of dollars to the meter on a customer's building which is relatively inexpensive but which is purchased in very large quantities.

The purpose of incoming material control is to assure that materials of the proper quality will be available for use during construction and for maintenace of the facilities. It aims to reach this objective without spending unnecessary inspection dollars and without "trusting to luck" that incoming material will be acceptable when used in various facilities. The elements which may exist in any purchased materials system are:

1) Review of quality requirements.
2) Formal classification of characteristics.
3) Establishment of quality levels.
4) Development and documentation of acceptance plans and procedures.
5) Development of disposition routines for non-conforming material.
6) Development of effective vendor certification programs.
7) Establishment of inter-vendor contacts.
8) Development of vendor servicing programs.
9) Conducting of incoming inspections and tests.
10) Development of effective feed-back systems.
11) Development of an effective Purchased Material Control audit.
12) Development of Special Quality Studies.

13) Establishment of tools for measuring the overall effectiveness of the purchased material control sub-system.

The relative importance of each of these elements will vary with the particular sub-system for which the material will be purchased along with the nature and complexity of the material itself. In other words, any or all of the above may be applicable to a generation project while perhaps only a few are applicable to materials used for distribution projects. It is interesting to note at this point that there are individuals in the utility industry who have, in the literature, indicated a need for "certified" or "approved" vendors. They have stressed the need for an effective purchased material control system and in this system they have ranked quality as being the most important of all the elements of purchased material. However, the methods whereby the quality of the material is to be determined has often been based on opinions, on operating characteristics, on the ease of construction, or matching the design intent. The feed-back systems for obtaining this information are often ineffective and the information gathered is quite often late, fragmented, inaccurate, and/or incomplete. The main reason for these problems is because little consideration has been given to providing in some manner or other the necessary elements of work outlined above. A practical discussion of the application of an incoming materials control system will be discussed later in the section covering the transmission line sub-system.

PRODUCT CONTROL (PROJECT CONSTRUCTION ASSURANCE)

It was pointed out previously that a difference existed in a basic need for quality control and assurance for the product in an electric utility when contrasted to a manufacturing firm. This difference was based upon the idea of competition for the customer's acceptance of a product, which requires a manufactured product to meet certain quality standards. We must not sell this realm of product quality completely short as having no value to the electric utility. The utility needs to have public respect for the overall quality and reliability of its entire system to preserve its position with the public. It is also valuable in helping to justify the necessity for rate changes.

The situation in which the electric utility finds itself however may create financial problems of a more subtle form than that of losses or public mistrust. Returning to the fact that the operation of transmission lines are 98% reliable, it is possible that quality problems in the transmission system may become so routine that they are reflected in increased planned costs "just to be safe" or their costs have been built in by basing estimates on past job experience.

One distinction which has been made in the manufacturing industry concerning product quality control is that of job-lot versus high quantity production. Job-lot production is that type in which only a limited number of products are to be manufactured for a particular production set-up and run. An unfortunate carry-over from early successes of statistical sampling of articles produced in large quantities was that "the quality control jobs are essentially tools for mass production."

In the electric utility, production is mainly on a job-lot basis. Therefore product quality assurance must be centered around controlling the production process rather than controlling the product as would be applicable in mass production. By controlling the processes for a job-lot production scheme we can make the most effective contribution towards final product quality assurance. What processes should be controlled and methods for providing assurance that processes are being properly controlled will be discussed in the next section for a transmission line quality system. This, it is hoped, will provide a practical example for application of a total quality control system to the electric utility industry.

SUB-SYSTEM DESIGN FOR FUTURE TOTAL SYSTEM INTEGRATION

In the resolution of the question of scope of the total quality assurance system it will be necessary to return to the need which was identified as leading to this present day quality control approach. This was stated as a need for management to identify and solve the really big quality problems. In terms of the electric utility, the question naturally arises, what managers and what needs. To identify quality assurance needs it seems reasonable to look at the electric utility product. Naturally the product is electricity and in most utilities the overall goal is to provide usable energy to the public, safely and efficiently. In trying to identify needs from this goal it soon becomes recognized that the scope of the needs are too broad to diagnose and find ways of meeting them. It is therefore necessary to further break down these products to identify needs.

There are many sub-systems within the total organizational system of an electric utility. Each of these sub-systems generates "products" which contribute to the overall product of the utility, namely saleable electricity. For instance, the transmission subsystem must be capable of designing and constructing, whether internally or through the use of contracted forces, a transmission system which is capable of meeting the corporate goal. In order to make this contribution, the transmission design quality sub-system must provide the means for assuring that plans issued for construction meet the needs of those who will construct the facilities, the needs of those who will operate and maintain the facilities, the requirements of the system planners to maintain reliability, frequency and voltage and, in general, the requirement of providing reliable electric service, safely and economically. Similarily, the construction forces who will build the transmission line must meet certain needs and requirements as do the designers of transmission line plans. The construction forces are required also to meet the needs of those who will operate and maintain the line, they must carry out the intent of the design, and they must provide workmanship which will create reliability and quality in the line.

It is apparent that in order to perform its job, the construction force must be supplied with materials whose design and production are consistent with the quality and reliability requirements of the transmission line on which they will be installed. We have thus defined the three sub-systems of the transmission sub-system and further defined the main quality objectives of the sub-systems of engineering design, materials, and construction.

In order to provide integration of these various utility sub-systems it is necessary that the utility have each of its components define clearly their quality policy; for instance, the Engineering Department of the electric utility must provide a clear definition of its quality requirements. Each of the various engineering sections can then define their quality requirements to meet and match those required by the department. Everything which is then done towards building quality into a design will be done in such a fashion that it meets the quality requirements of the department. This will allow utility management to determine if excessive quality dollars are being spent in one section where it may not be required and further may identify a lack of quality responsibility in other sections which might make increased contributions towards overall quality. These documents which we have discussed are quality policies. The quality policy for each of the engineering sections must be developed to integrate with one another so that the department quality policy can be attained. This information must be completed by each of the departments within the utility so that quality policies will be developed within the engineering design and will cover purchased materials. Further discussion of the quality policies will be carried out in the section dealing with the transmission quality sub-system.

TRANSMISSION LINE QUALITY ASSURANCE SUB-SYSTEM

In previous sections, we have discussed total quality assurance in a general manner pointing out some needs and parallels within the electric utility industry versus the manufacturing industries where to date, most of the application of quality assurance methods have been applied and upon which most of the literature to date has been written. We have recognized the need to further subdivide the application of total quality assurance into one of the sub-systems within the utility to make a realistic attempt at illustrating its application. It is certainly a well known fact that in the application of any total system it is basic to start with a particular sub-system in applying the new system. The approach taken should be that of designing the sub-system so that it will integrate with other sub-system designs either existing or proposed so that the total system will be worth more than the sum of its individual parts in meeting corporate goals. The following information will be provided for the transmission line quality assurance sub-system and will be separated into the three critical components previously identified: design, materials, and construction. The objective is to give specific examples of how such a system can be applied to the transmission line component.

TRANSMISSION LINE DESIGN QUALITY ASSURANCE

As a means of setting the main criteria or objectives for the quality assurance sub-system for transmission line design, the following list of objectives has been developed from the previous general discussion of quality assurance and its application to the electric utility.

1) Reduce the amount of design rework required in issuing a construction plan.
2) Assure that plans issued for construction are correct and complete so that construction delays and rework are reduced.
3) Provide a system that will develop information aimed at identifying problems, determining causes and eliminating the causes.
4) Move beyond the inspection quality control schemes which are now prevalent in electric utilities as a means of promot-

ing preventive action rather than purely corrective actions.

5) Do not hinder the system from meeting in-service schedules or keeping costs to a minimum; in fact, enhance these systems wherever possible.

Generally the transmission line design section is set up to some degree according to the following simplified organization chart.

Design Section Head
|
Supervising Engineers
|
Working Engineers

The creation of a construction plan generally involves design work based on standard design criteria, line structures, and structure framing. This work is completed by the design engineers. The first-line supervisors are generally involved in designs by providing sources of expertise; however, they are generally responsible for providing a review of the project upon completion of the design work and prior to issuing the plans to construction forces.

The necessity of injecting the work 'generally' in the above discussion provides another reason that the quality system must be carefully defined by each section who makes a contribution to the overall quality of electric service. As was pointed out in the previous section this is known as the section quality policy. It will enhance and support the corporate quality goals and will spell out in detail what the section intends to do to insure that the quality of its product meets the level set forth in the quality policy. In other words, the quality policy will describe the procedure and the system for achieving the quality required to match the corporate goals.

In the case of the transmission design section, the policy will contain a discussion of the procedure described above for the creation of a construction plan for a transmission line. In addition, the following components of a transmission line design quality system should be included in a design section quality policy:

1. A definition of the quality standards to be maintained in the design of transmission

lines.

2. The contribution that these quality standards will make to the overall company quality level.

3. Definition of major assignments of responsibility and authority for determining quality requirements and evaluating the quality risk situation.

4. Allowable span lengths based on the structure wind loading and for preventing contact under galloping conductor conditions.

5. Conductor sag and maximum tension including special situations (dead-end spans, broken conductor clearances, off set clippings, etc.)

6. Structure mechanical loading calculations.

7. Electrical design parameters which are normally included as a part of standard structure framings for each class of voltage used by the utility.

It is now appropriate to look at the design system from the standpoint of measuring the quality of designs issued for construction.

Certainly those who are involved in the actual construction of the facilities can provide valuable feedback concerning problems created by the design features along with suggested improvements. This feedback must be maintained and strengthened where necessary by providing accessible channels for getting this information to those in design who can effect any advisable changes on a system level. It will be recognized that some of the problems created may not be seen as problems or may be deemed as unsolvable by field personnel due to a lack of understanding of design principles and criteria. It is this type of situation which leads to the suggestion that an outside audit group should be formed to provide an integration of the quality efforts of both design and field personnel. This audit group must have the necessary design and construction knowledge to perform their job. Their job would be to provide audits of the design system as well as the construction system to provide information concerning the causes of problems arising from one or the other systems or perhaps from the lack of integration of the two systems. It is this idea of auditing the systems that will provide the means of preventive action which is necessary to effect real savings while assuring the desired quality level. The audit would be based on finding problems either created in the field or in the design plans themselves and then determining the cause of the problem through the quality plan discussed previously. The problems could be due to not performing design work according to the quality plan, a deficiency in the plan itself or simply oversights by designers, drafting personnel, etc.

The design section must, of necessity, have within its organization certain checks and balances to assure that design plans meet desired quality levels. These checks and balances, within the design section itself, will normally consist of reviews of the design plans by senior men within the design group. The function of the audit group concerning these appraisals is to determine their effectiveness through their audits. The auditors must be free from production pressures and would not be a part of the normal production progression. This fact will allow more in-depth reviews and audits by these persons concerning the impact of design plans on efficiency and workability for the construction forces as well as whether or not design plans match the original design criteria. Design audits by personnel with this background and free from production pressures can uncover many hidden problems within the design system which would be routinely accepted or often overlooked due to the standardization of engineering procedures and specifications. It is intended at this point to give actual examples of how the design system audits can provide this type of information which would not be available from any other production oriented source. Previously we listed seven of the requirements of the transmission design system which must be met by each plan issued for construction. The following are some actual case studies of these technical aspects in an attempt to show specific examples of how a quality audit by an external group can provide useful information to the designers. Generally it is felt, from the information at hand, that a design review by a quality audit group is a new approach, especially for electric utilties. For this reason, I will attempt to give some of these specific examples. The first example will be for the design element of conductor sags and maximum tensions. The audit of conductor sags and tensions is quite complicated since the proper choice of sags and tensions considers its effect on ground clearances, support clearances, insulator swing clearances, conductor loading, conductor separation, line economy and operation, conductor vibration fatigue, permanent stretch, elastic stretch, and structural and equipment stresses. Normally within a transmission line design section, standard conductor sizes are used for the various voltage levels for which lines are constructed. Further, for each of these standard conductors, sag charts, and templets have been prepared for various ruling spans and maximum design tensions. Using the design ruling span, the most economical type of construction can be determined for each line from various criteria. The construction possibilities existing are single wood pole structures, wood pole "H" frame structures, steel poles, or steel towers. After the type of line is chosen, then the sag chart to be used is determined by matching the sag chart ruling span to the line ruling span as closely as possible. Assuming that a sag chart has been selected for a particular type line to be built, we can now examine some of the possible problems which could be determined by the use of an outside audit group. For this case, a normal conductor structure configuration as shown in Figure 1, page 33 has been selected for this line. This would probably be a standard configuration for certain classes of voltages for an electric utility. Assume, also, that a ruling span of 450 feet has been selected with a maximum tension not to exceed 7407 pounds. It can also be assumed that this is a standard sag chart normally used by the utility for this standard type structure framing. The profile at a particular point of the line is of the nature of that shown in Figure 2, page 34.

For reasons of economics and/or asthetics, the structure locations are selected as shown also in Figure 2, page 34. It has been decided, in this instance, to span the gorge rather than set poles within the gorge. This will provide a number of desirable effects such as elimination of some poles, less road building for construction equipment, less right of way clearing. This represents a normal type of decision faced by design engineers in the course for the planning for a transmission line in many areas of the country. Because of the transverse wind load on the structures at each end of the gorge, it is necessary

FIGURE 1

TYPICAL STRUCTURE CONFIGURATION

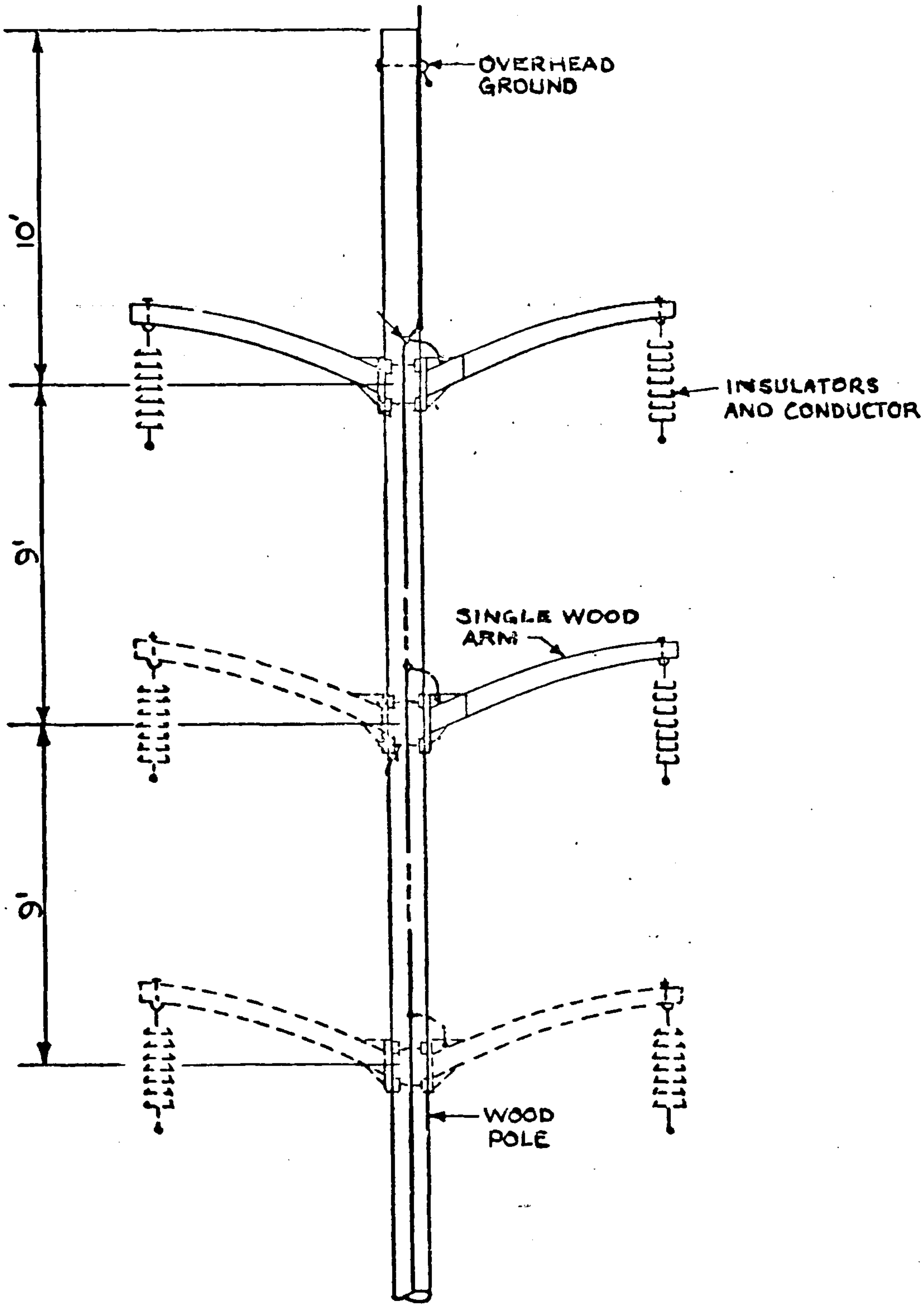
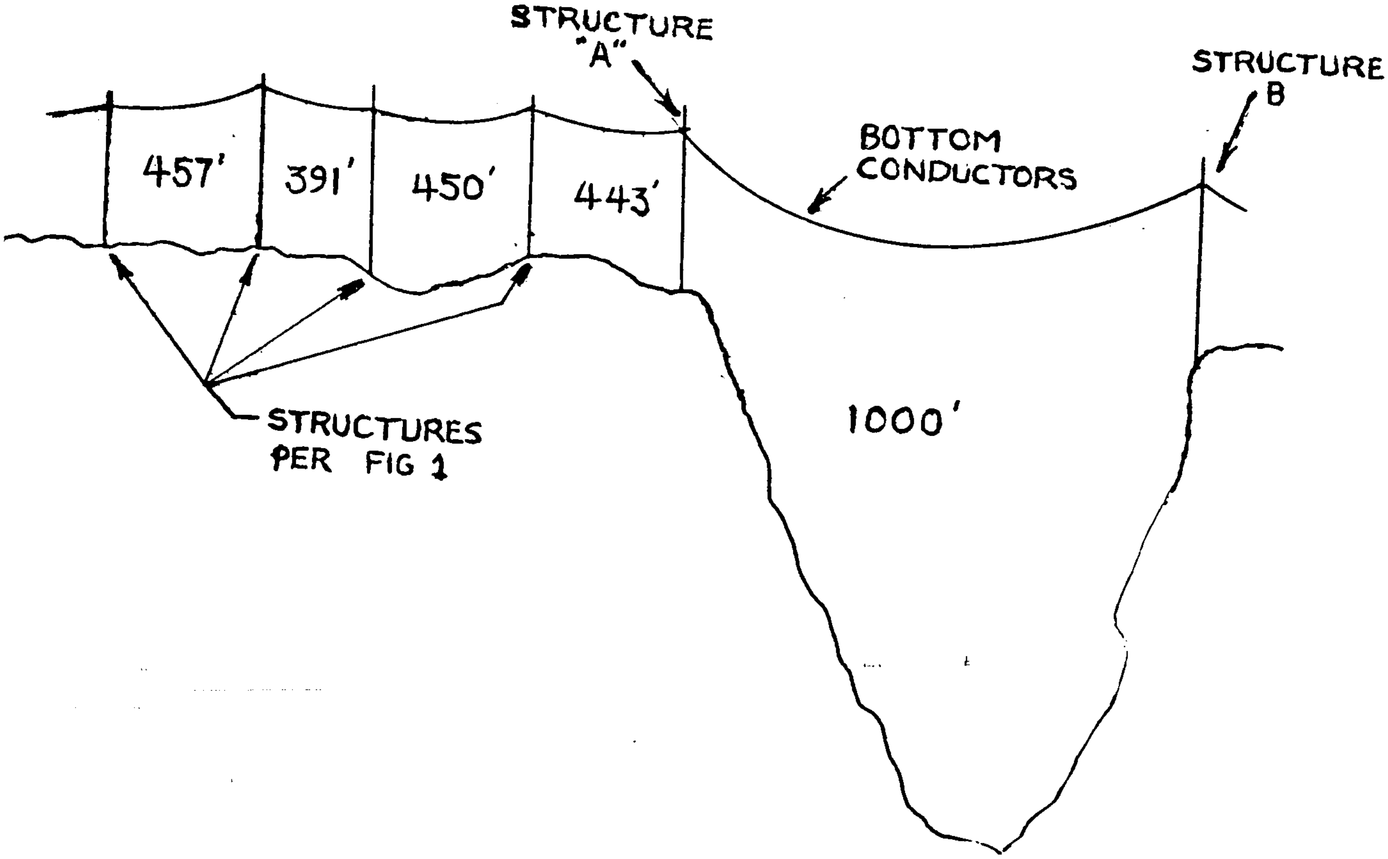


FIGURE 2

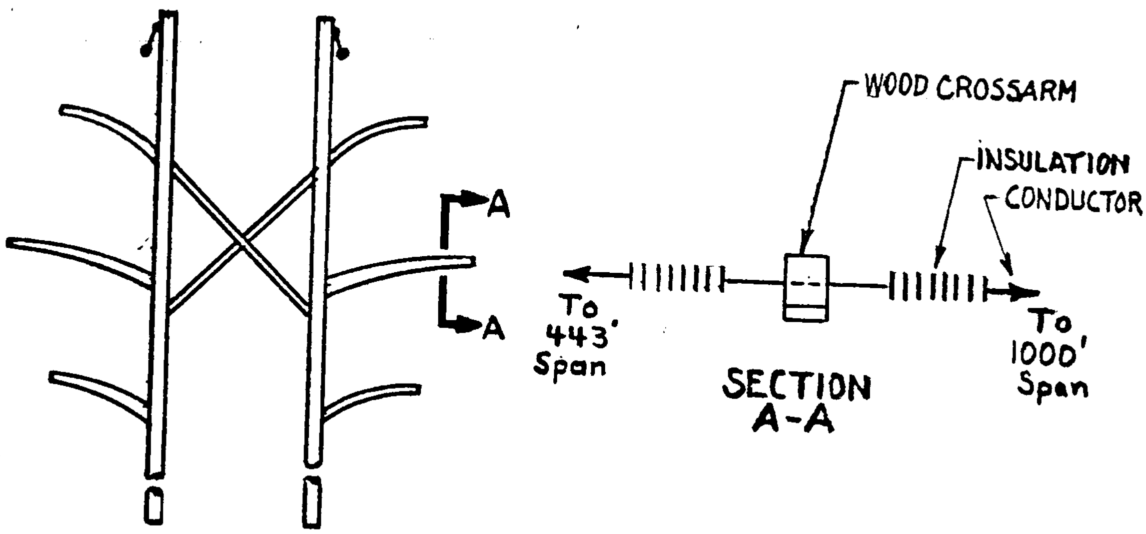
EXAMPLE TRANSMISSION LINE
PROFILE VIEW



to provide a means of support which will be different from the standard structure selected for this line. It is assumed that the design engineer has recognized this and has provided for a structure as shown in Figure 3, page 36 for each end of the gorge. It is this type of situation where the application of design audits can yield some interesting information. A few of the observations which can be made concerning this particular instance along with the methods used to analyze the situation are shown below. First, make use of a sag-tension computer program to look at some of the various sags and tensions encountered under conditions of changing temperature, ice loading and wind loading. Also, through the use of this computer print out, it will be determined whether or not the approximate parabolic equations used to compute the sag charts used by construction forces will create any problems in either clearances or tension differences for the conductor which actually assumes the shape of the catenary curve. See Tables 1 & 2, pages 37 & 38 for the complete computer print-outs for this particular case.

The standard sag chart as normally specified

FIGURE 3



Configuration of Structures A & B Showing Conductor Tie.

TABLE 1

CONDUCTOR SAG AND TENSION TABLE

556.5 KCMIL 24/7 ACSR SAG AND TENSION SAMPLE RUN
CONDITION NO. 8-BARE NO WIND -RESTRICTED TO -5.1
LIMITING - A) INITIAL LOADED TENSION AT 0. DEG. F. NOT TO EXCEED 9500. LBS.
CONDITIONS - B) INITIAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 6610. LBS.
- C) FINAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 4063. LBS.
GOVERNING LIMITATION CODE *1 - CONDITION A
*2 - CONDITION B
*3 - CONDITION C WITH CREEP
*4 - CONDITION C WITHOUT CREEP
THE EFFECT OF TEN YEARS OF CREEP IS CONSIDERED IN ALL FINAL CALCULATIONS
MAXIMUM LOADING CONDITION AT 1.0 INCHES ICE 8. LBS. WIND

		1.0 ICE 8WIND		BARE NO WIND		BARE NO WIND		BARE NO WIND		BARE NO WIND		BARE NO WIND		BARE NO WIND	
		0. DEG. F.		0. DEG. F.		-20. DEG. F.		20. DEG. F.		32. DEG. F.		40. DEG. F.		60. DEG. F.	
SPAN		TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG
FT		LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT
413.	INIT	8719.	9.0	4651.	3.3	5314.	2.9	4927.	3.8	3683.	4.2	3470.	4.4	3000.	5.1
*1	FIN	8719.	9.0	3610.	4.2	4314.	3.5	3066.	5.9	2798.	5.5	2643.	5.8	2323.	6.6

CONDUCTOR SAG AND TENSION TABLE

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CONDITIONS - B) INITIAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 6610. LBS.
- C) FINAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 4963. LBS.
GOVERNING LIMITATION CODE *1 - CONDITION A
*2 - CONDITION B
*3 - CONDITION C WITH CREEP
*4 - CONDITION C WITHOUT CREEP
THE EFFECT OF TEN YEARS OF CREEP IS CONSIDERED IN ALL FINAL CALCULATIONS
MAXIMUM LOADING CONDITION AT 1.0 INCHES ICE 8. LBS. WIND

		1.0 ICE 8WIND		BARE NO WIND		BARE NO WIND		BARE NO WIND		BARE NO WIND		BARE 4 LB WIND		BARE 9 LB WIND	
		0. DEG. F.		80. DEG. F.		100. DEG. F.		120. DEG. F.		257. DEG. F.		0. DEG. F.		60. DEG. F.	
SPAN		TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG
FT		LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT
413.	INIT	8710.	9.0	2621.	5.8	2322.	6.6	2088.	7.3	1403.	10.0	4745.	3.5	3599.	5.9
*1	FIN	8719.	9.0	2079.	7.4	1889.	8.1	1751.	8.8	1405.	10.9	3758.	4.4	2969.	7.2

CONDUCTOR SAG AND TENSION TABLE

556.5 KCMIL 24/7 ACSR SAG AND TENSION SAMPLE RUN
CONDITION NO. 8-BARE NO WIND -RESTRICTED TO -5.1
LIMITING - A) INITIAL LOADED TENSION AT 0. DEG. F. NOT TO EXCEED 9500. LBS.
CONDITIONS - B) INITIAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 6610. LBS.
- C) FINAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 4963. LBS.
GOVERNING LIMITATION CODE *1 - CONDITION A
*2 - CONDITION B
*3 - CONDITION C WITH CREEP
*4 - CONDITION C WITHOUT CREEP
THE EFFECT OF TEN YEARS OF CREEP IS CONSIDERED IN ALL FINAL CALCULATIONS
MAXIMUM LOADING CONDITION AT 1.0 INCHES ICE 8. LBS. WIND

		1.0 ICE 8WIND		BARE 25 LB WIND		0.5 ICE NO WIND		0.5 ICE 4 WIND		NESC HEAVY		OPT ICE 8 WIND		1.0 ICE 0 WIND	
		0. DEG. F.		60. DEG. F.		32. DEG. F.		0. DEG. F.		0. DEG. F.		32. DEG. F.		32. DEG. F.	
SPAN		TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG	TENSION	SAG
FT		LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT	LBS	FT
413.	INIT	8719.	9.0	5479.	7.9	5284.	6.4	6178.	5.9	6626.	6.5	4636.	5.8	7491.	8.8
*1	FIN	8719.	9.0	4986.	8.7	4683.	7.3	5630.	6.5	6177.	7.0	3935.	6.6	7221.	9.2

TABLE 2

CONDUCTOR SAG AND TENSION TABLE

556.5 KCMIL 24/7 ACSR — SAG AND TENSION SAMPLE RUN
CONDITION NO. 8-BARE NO WIND -RESTRICTED TO -5.1
LIMITING - A) INITIAL LOADED TENSION AT 0. DEG. F. NOT TO EXCEED 9500. LBS.
CONDITIONS - B) INITIAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 6610. LBS.
- C) FINAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 4063. LBS.
GOVERNING LIMITATION CODE *1 - CONDITION A
*2 - CONDITION B
*3 - CONDITION C WITH CREEP
*4 - CONDITION C WITHOUT CREEP
THE EFFECT OF TEN YEARS OF CREEP IS CONSIDERED IN ALL FINAL CALCULATIONS
MAXIMUM LOADING CONDITION AT 1.0 INCHES ICE 8. LBS. WIND

SPAN		1.0 ICE 8WIND 0. DEG. F.		BARE NO WIND 0. DEG. F.		BARE NO WIND -20. DEG. F.		BARE NO WIND 20. DEG. F.		BARE NO WIND 32. DEG. F.		BARE NO WIND 40. DEG. F.		BARE NO WIND 60. DEG. F.	
FT		TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT
413.	INIT	8719.	9.0	4651.	3.3	5314.	2.9	4027.	3.8	3683.	4.2	3470.	4.4	3000.	5.1
*1	FIN	8719.	9.0	3610.	4.2	4314.	3.5	3066.	5.9	2798.	5.5	2643.	5.8	2323.	6.6

CONDUCTOR SAG AND TENSION TABLE

556.5 KCMIL 24/7 ACSR — SAG AND TENSION SAMPLE RUN
CONDITION NO. 8-BARE NO WIND -RESTRICTED TO -5.1
LIMITING - A) INITIAL LOADED TENSION AT 0. DEG. F. NOT TO EXCEED 9500. LBS.
CONDITIONS - B) INITIAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 6610. LBS.
- C) FINAL UNLOADED TENSION AT 0. DEG. F. NOT TO EXCEED 4963. LBS.
GOVERNING LIMITATION CODE *1 - CONDITION A
*2 - CONDITION B
*3 - CONDITION C WITH CREEP
*4 - CONDITION C WITHOUT CREEP
THE EFFECT OF TEN YEARS OF CREEP IS CONSIDERED IN ALL FINAL CALCULATIONS.
MAXIMUM LOADING CONDITION AT 1.0 INCHES ICE 8. LBS. WIND

SPAN		1.0 ICE 8WIND 0. DEG. F.		BARE NO WIND 80. DEG. F.		BARE NO WIND 100. DEG. F.		BARE NO WIND 120. DEG. F.		BARE NO WIND 257. DEG. F.		BARE 4 LB WIND 0. DEG. F.		BARE 9 LB WIND 60. DEG. F.	
FT		TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT
413.	INIT	8710.	9.0	2621.	5.8	2322.	6.6	2088.	7.3	1403.	10.0	4745.	3.5	3599.	5.9
*1	FIN	8719.	9.0	2079.	7.4	1889.	8.1	1751.	8.8	1405.	10.9	3758.	4.4	2969.	7.2

CONDUCTOR SAG AND TENSION TABLE

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*3 - CONDITION C WITH CREEP
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THE EFFECT OF TEN YEARS OF CREEP IS CONSIDERED IN ALL FINAL CALCULATIONS
MAXIMUM LOADING CONDITION AT 1.0 INCHES ICE 8. LBS. WIND

SPAN		1.0 ICE 8WIND 0. DEG. F.		BARE 25 LB WIND 60. DEG. F.		0.5 ICE NO WIND 32. DEG. F.		1.5 ICE 4 WIND 0. DEG. F.		NESC HEAVY 0. DEG. F.		OPT ICE 8 WIND 32. DEG. F.		1.0 ICE 0 WIND 32. DEG. F.	
FT		TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT	TENSION LBS	SAG FT
413.	INIT	8719.	9.0	5479.	7.9	5284.	6.4	6178.	5.0	6624.	6.5	4636.	5.8	7491.	8.8
*1	FIN	8719.	9.0	4986.	8.7	4683.	7.3	5630.	6.5	6177.	7.0	3935.	6.6	7221.	9.2

would be based upon a parabolic equation which is of the form $S = \frac{WL^2}{8T}$.

S = Sag in feet
L = Span length in feet
T = Tension in pounds
W = Conductor Weight in pounds per foot

Thus at a given temperature, say 60°F, the sag for spans other than the ruling span (in our example 450') can be computed by

$$S_x = S_{450} \frac{(L_x)^2}{(450)^2} \cdot \quad \text{(See Appendix A)}$$

This assumes that the shape of the curve which the conductor takes is a parabola but in actuality, the shape is that of a catenary curve.

Using the standard sag chart for a 413' ruling span gives a sag of 5.1' for the conductor at 60°F with no ice or wind for the spans to the left of structure "A" (See Figure 2, page 34). The calculated ruling span for these spans is 413', the ruling span being that span which could be used for computation purposes to replace all of the suspension spans to the left of structure "A" and still give equivalent conductor tensions.

Using a computer program which makes use of the exponential catenary curve equations to compute tensions under various loading conditions, the sag of 5.1' at 60°F is used as input data to the program and the sags and tensions at various other conditions are computed as shown in Table 1, page 37.

For the 1000' span, the sag to be used by the field forces is normally computed using the parabolic equations which gives at 60°F:

$$S_{1000} = S_{413} \frac{(L_{1000}^2)}{(L\ 413^2)} = (5.1)\frac{(1000^2)}{(\ 413^2)} = 30'$$

The use of this equation assumes also that the tension remains constant.

By using the sag of 30' at 60°F as input to the computer program, the actual tensions and sags which will be encountered in the 1000' span under various loading conditions are calculated according to the more accurate catenary equations.

The actual output is shown in Table 2, page 38. Comparing some of the values to National Electric Safety Code requirements and also to the values computed for the 413' adjacent ruling span gives the following results.

The National Electric Safety Code requires that the maximum loading condition for the conductor be limited to 50% of its ultimate strength. For the conductor used, this 50% value is 11,900 lbs. For code purposes the tension encountered is shown on the computer print-out as NESC heavy and the final tension is found to be 6892 lbs., well within limits. It is noted however that the tension at 1" radial ice loading is 11,113 lbs. and general recommendations for good line design recommend that maximum design tensions be limited to 50% of ultimate strength which in this case is exceeded.

Additional insights into possible operating problems can be gained by comparing actual tensions in the 1000' span versus those in the 413' ruling span for various loading conditions. At 1" ice loading, the tension in the 1000' span will be 11,113 lbs. compared to 8719 in the 413' ruling span, a tension difference of 2394 lbs. which must be supported by each crossarm of structure "A". For crossarms of the type shown, ultimate strengths near 1000 lbs are common and it is usual to apply a safety factor of 2 when determining allowable loadings.

It can also be seen that under conditions of low temperatures and bare (no ice) conductor that the situation is reversed and at -20^{o}F, the tension in the

413' span is 5314 lbs. while that for the 1000' span is only 1360, a difference of 2154 lbs. in a direction opposite to that seen at 1" ice loading.

Concerning maximum conductor sag conditions, the parabolic equation would indicate that under loading conditions of 257°F conductor temperature, the sag would be of the order of 59' in the 1000' span. The catenary calculation shown on the computer output gives an actual sag of only 42.8' for this condition allowing possible savings of 15' of structure heights at each end of the gorge while still maintaining required ground clearances.

The specific example is relatively unimportant in itself other than to point out that the audit performed on design plans should be performed by someone who is knowledgable in the design methods, criteria, and tools in order to make in-depth analyses to locate discrepancies which would lead to poor quality.

The real question to be resolved in the above example is the cause of the problem. It may be related to the training of the engineer involved. It may be caused by a lack of specific guidelines for line designs. It is apparent that the design review performed on the project was ineffective but the question of guidelines for performing design reviews may be important for this case. The discrepancy may be the result of only a specific lack in existing guidelines. In any case these procedures (training, design, design review) must be a part of the design group's quality program and it is their effectiveness which is the subject of the audit. In other words, what is being promoted is a somewhat unique approach to design control not only for utilities but for manufacturing firms as well. Past design audit systems have dwelt mainly in checking to see if the quality system was in fact applied to design documents. The method used was to see if applicable guidelines were used, if design personnel had received specified training, if proper intials were in place on design documents indicating that these documents had received specified design reviews, etc. These audits fail miserably in providing information concerning the effectiveness of these guidelines, the design reviews, or personnel training programs.

Audits now performed by various groups to assure conformance to the 18 criteria contained in Title 10, Code of Federal Regulations 50, Appendix B which covers requirements for Quality Assurance for the Licensee of a nuclear power plant are aimed at determining whether or not the prescribed programs, work instructions, manuals, etc. are being followed. It is important, for instance, in the area of design control that someone's initials appear on the design calculations for safety related equipment indicating that the calculations have been reviewed. There is no measure of the effectiveness of either the review or the original calculations.

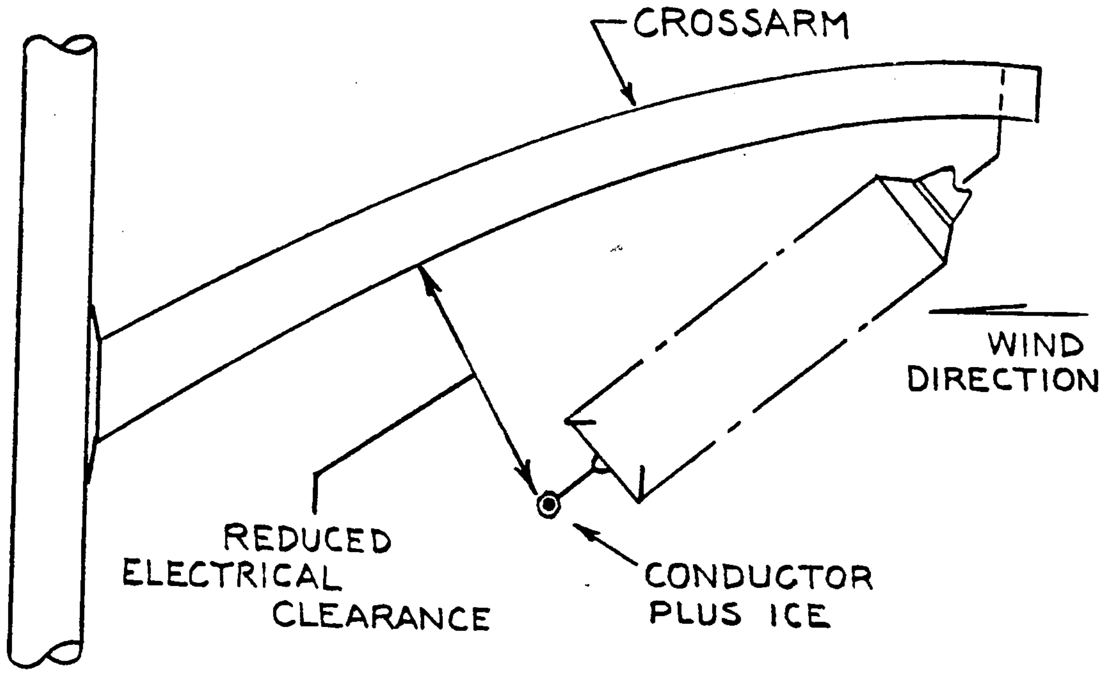
A second example, covering the area known as "insulator swing" will be used to further indicate the use of the system on proposed here.

"Insulator swing" is the effect at a suspension support of the loading on a conductor caused by ice and wind in combination which tends to reduce electrical clearances from conductor to ground. Figure 4, page 45 shows what occurs when wind loading is applied to a conductor at a suspension point.

The wind loading on both the conductor and the insulators tends to swing the conductor closer to the supporting structure. Under conditions of icing in combination with wind loading, there is a condition where

FIGURE 4

INSULATOR SWING



the amount of ice on the conductor will maximize the amount of swing for a given wind loading. This is based on the fact that for increasing amounts of ice on a given conductor, both the weight of the conductor plus ice and the wind loading on the conductor plus ice are increasing. The weight of conductor plus ice tends to stabilize the conductor while the increasing cross section created by increasing the amount of ice on a given conduction tends to increase the effect of a given wind velocity to produce swing.

It is found, by differentiating and maximizing the swing equation, that the optimum amount of ice for a 12 pound per square foot wind velocity is given by

$$T = \frac{-2.488D + \sqrt{19.904W_c - 6.1901D^2}}{4.976}$$

where

T = ice thickness in inches

D = conductor diameter in inches

W_c = weight of conductor in pounds per foot.

Using this equation it is then possible to compute the optimum ice loading to maximize insulator swing for the given wind condition and given conductor. When this is found, the catenary curve for this condition is identified and can be used in conjunction with a line profile to design each structure such that the spans involved will create enough conductor weight on the insulators to prevent undesirable amounts of swing for maximum swing conditions. The job of the transmission designer then becomes one of maintaining, for each structure, a proper ratio between horizontal and vertical span lengths for optimum ice conditions.

This is not a simple, straight forward operation since the transmission designer is also designing to meet other criteria (ground clearance, support loading, etc.) at the same time as he is trying to meet the swing requirements. Therefore, he is constantly trading off, varying structure heights, changing structure locations, changing structure framings in order to meet all required design criteria while at the same time keeping the economics in balance.

Since this particular aspect is an area easily identified as a potential problem area, it is an area where an outside auditor, armed with a knowledge of design and the proper design tools can make a contribution. If it is found that line design plans are being issued with structures which have insulator swing problems, then a change in the design system is probably desirable since the reliability of the line will suffer. Auditors, as utilities have been familiar with them based on the nuclear quality assurance programs, would not identify such a design problem because the problem has no correlation with the fact that the plan would show that the design was reviewed by someone else in the design group and therefore the design control system was implemented. The key here is that the audit group can measure both the effectiveness of system implementation and the effectiveness of the system itself in addition to assuring that the design control system was implemented.

It can be seen, from the above examples, the types of information that can be obtained from impartial design audits. It also shows that one of the most important tools for the auditor is the use of the computer to save valuable time in the technical analyses. Since the location of quality problems on design plans is only part of the auditing groups function, the more readily these can be located and analyzed, the more time will be left for discovering and suggesting means for elimination of the causes of these quality deviations.

Also of major importance to the performance of the effective and productive design audits is the ability of the auditor to locate possible problem areas. It can be seen that for a transmission line design which makes use of standard structures and standard conductor size sags and tensions, that it is impractical to compute the loadings for instance for each structure on the line.

What is necessary for a productive audit is that the auditor be capable of rapidly determining which of the structures on the line will have a maximum loading or generally, the limiting conditions of the design criteria. Once the most heavily loaded structures on the line have been pinpointed, detailed loading analyses of these structures can be carried out with the knowledge that if these structures meet the design criteria spelled out in the transmission design section quality policy, that each of the other structures on the line will also be within the design limitation.

Techniques for maximizing the productivity of design audits will be discovered as the auditor gains experience. These techniques are only limited by the ingenuity of the auditor and his supervisor. For the newly formed audit group, it is essential that as these techniques are developed, and that they be documented for use not only within the audit group but also within the design group itself for effectively assuring that plans issued meet the design intent.

The information gathered from design control audits, of course, is valuable for the particular job involved as far as initiating timely corrective action; however, the ultimate goal of the Quality Assurance Audit group is to prevent errors from occurring. The feedback of these observations then will be slanted towards providing information to designers and their supervisors to allow more effective use of design talent and more effective in-house design reviews prior to issuing of engineering plans.

The fact that the person within the design section did not foresee the possible problems inherent in these examples is of little importance when compared to the review technique which might be improved to prevent recurrence of this and similar problems.

In essence then, although particular jobs are being audited to locate particular problems, the ultimate outcome must be an audit of the quality system. If this is not the case, then the audit group only duplicates the efforts of the in-house design reviewers.

TRANSMISSION LINE PURCHASED MATERIAL CONTROL

Just as the transmission line design assurance system was designed for placing the primary responsibility on quality for those persons responsible for performing the engineering work, the material system will be designed to place the responsibility for quality on the vendor of the materials. Under an inspection quality program, it becomes the responsibility of the utility to check each piece of material received to determine whether or not it is usable on the transmission line system. This in effect relieves the vendor of his quality responsibilities and the utility takes over the problem of assuring that materials of the desired quality are delivered to the job site. The primary purpose of a purchased material quality evaluation and control procedure is to establish a format so that the utility can be reasonably assured of consistently receiving quality materials, and equipment at desired cost. The following steps are suggested as a nucleus for an effective purchase material quality evaluation and control procedure.

1. Require vendors to submit a survey of their quality control system or

their quality manual if one is already available.

a. The purpose of this step is to provide information to utility personnel as to whether or not the vendor has the equipment, personnel, and an adequate quality system for producing the required material at the required quality level. This information can be reviewed by both design and quality assurance personnel by evaluation technical requirements and quality control requirements respectively.

2. Establish a uniform vendor visit and rating procedure.

a. The vendor visit is made to verify that the information provided in the quality control manual submitted by the vendor is actually being carried out into the day to day manufacturing process. The vendor visit can consist of design personnel again reviewing technical requirements and quality assurance personnel reviewing quality control requirements.

3. Identify important quality characteristics.

   a. The purpose here is to provide the vendor with a knowledge of those characteristics which must be met in order for the material to be useful to the utility. It is an indication of those characteristics which if inspection were carried out by utility, would be cause for rejecting the material. It is intended that these "musts" be made visible by highlighting them so that the vendor will be in a position to assure that each of the "musts" are met prior to shipping material to the utility. If each of these "musts" are met when the material is received then the construction project can proceed without costly delays. This is actually a process of classifying the quality characteristics which are found in a material specification. It is a process of determining which of the quality characteristics are critical, which are major and which are minor. It should not be construed as meaning that only the critical characteristics must be met. It is an indication that, if each of these critical characteristics are met, the material will be usable by the utility for its project. The major and minor characteristics will consist of those characteristics which if found not to be consistent with requirements, can be " made right by the vendor " without causing undue project delays.

4. Establish vendor certification.

   a. The vendor submits objective evidence that the critical quality characteristics determined in step three have been met. It is this vendor certification which places the responsibility for quality in the hands of the vendor, who inspects his product against the predetermined quality characteristics and reports the results of this comparison to the utility with shipment of the material. Vendor certification reduces the necessity for the utility to provide inspection for each piece of material that it receives.

5. Verification of vendor certification.

   a. The purpose of this certification is to provide assurance that the vendor's quality data is accurate and reliable. This can be done using standard sampling techniques which incorporate reduced sample size as the utility's confidence in the vendor increases. The verification of vendor certification will concentrate on those critical characteristics that were determined in step three but will also provide a measure of the quality with respect to the major and minor characteristics.

6. Establish an effective feedback system.

   a. The information system must be designed so that quality problems will be reported to the proper persons in a timely manner so that quality of material and equipment on future shipments will be improved and the necessary corrective action can be taken for the material which is found to be defective. This quality information can be generated by those persons providing the verification of step five, those responsible for handling and storing materials, those who are making use of materials in the construction phases, and those who are responsible for failure reports on system operation.

7. Maintain a supplier evaluation report.

   a. All data concerning the vendors ability to satisfy needs and wants of the customer is maintained for evaluation purposes when placing future orders. This will consist not only of information as to the suppliers quality but also history of his ability to meet delivery dates, price, service, etc.

It is felt that in most organizations it will not be necessary to provide heavy increases in manpower to put such a system as described above into operation. Certainly there is a need for personnel with a strong quality control/assurance background to provide the expertise required in steps one and two. For the remaining steps in the proposed material system, it is felt that the various personnel involved in handling and using the material in their normal work can provide the necessary functions if they are provided with effective guidelines by the utility quality assurance personnel. It appears that the time savings gained by eliminating the necessity for double inspection and hopefully through the reduction of project delays will pay for the time spent by these personnel in the material quality program.

Some of the benefits to be realized by placing the responsibility for quality on the vendor include:

1) Improved quality of materials and equipment.
2) Reduction of duplication of effort in material handling and checking.
3) Reduction of the costs associated with reworking faulty material and equipment.
4) Reduction of costly delays during construction of facilities.
5) Maintenance of production schedules through reduction in rejected materials and equipment.
6) Development of a better sense of vendor quality responsibilities.

This material system would be directly applicable to the more important materials of the transmission line function. These materials might include:

1) Steel poles
2) Tower steel
3) Conductor
4) Wood products
5) Special and/or new materials for the system.

Perhaps for some of the minor equipment used such as guying material, bolts, and hardware that only a portion, or perhaps none, of the above steps will be deemed necessary based on expected return for effort expended.

This material program as designed for the transmission line system is equally adaptable to materials for any type of project to be undertaken by the utility. The possible exception to this are those items of material which would be associated with a nuclear generation project and are covered by the Atomic Energy Commission quality assurance guidelines for promoting the safety of nuclear plants. In this situation, the magnitude of documentation required to maintain safety standards during plant operation has in most instances required a third party architect/engineer who performs the actual work, but the philosophy of the material system still remains intact. In fact, for the utility with QA experience, it is possible to maintain the QA function for nuclear installations in-house.

TRANSMISSION LINE CONSTRUCTION QUALITY ASSURANCE

The underlying principles of the design and material quality systems which places the responsibility for quality on the designers and the vendors will be applied to those performing the work under the construction quality assurance system. These responsibilities and the procedures for meeting them should be spelled out in a transmission line construction quality policy similar to that proposed for the design section. The proposal made here is to provide a quality assurance audit group, the same group responsible for design audits, to perform the function of determining and feeding back information concerning how well the construction quality control system is performing. Just as was done for the design audits, specific examples of the type of information to be provided by the audits will be given. Certainly for quality assurance purposes, it is valid to review the construction workmanship for quality level within its own right. However for purposes of this thesis, it is intended that the examples given will relate to the construction personnel's obligation to match the intent of the designer. This is done neither to intimate that areas such as construction workmanship, drawing control, test procedures, work instructions, etc., are not important areas for the audit group to review nor to propose that these areas are not a part of the Total Quality Assurance System.

The first example to be examined is that of the use of clipping offsets. Clipping refers here to the act of removing a sagged transmission conductor from the sagging blocks and fastening it into its final position in the conductor clamp. Clipping offsets are required when the transmission line is in steeply sloping terrain and the difference in tension across the sag block is more than can be supported by the sag block friction force. When this occurs, the conductor tends to "run" in a down hill direction after it has been sagged but before the clipping operation. In order to compensate for this, clipping " offsets" are often specified which give the constructor distances at each sag block by which the conductor must be moved prior to clipping in order to pull it "back up hill" to its required position.

Offset clippings for the example being considered were specified for sag sections along the line between dead ends. However in applying the offsets, construction forces sagged and clipped in the length of only a portion of the "sag section" defined by the design. This is an error which negates the design intent. The theory is that for a given sag section, offsets are roughly proportional to the difference between high and low sag points. It can be seen by an auditor with design background that by changing the sag section, the clipping offsets will not only be incorrect but may, under certain conditions, be applied in the wrong direction.

Clearly what is required here is a review of the work instructions (if any are issued) to provide the field forces with procedures for meeting the modern design intent. This example also points out the need for a general review of important work instructions to see that they are responsive to present day requirements.

It is entirely possible that the work instructions exist and are appropriate, in which case, the supervision or the training program may be suspect. In either event, a corrective action system must be designed to analyze what is going wrong within the quality system which would cause this critical deviation.

The second example, which follows, will serve to point out another aspect of a total quality assurance program which, if neglected, can create quality problems which are not clearly visible to those persons either building or designing particular facilities.

Consider the case where a transmission structure is to be located within a substation facility. Particular interest is directed to the grounding of this structure. Standard grounding for a transmission structure is generally of a light duty type, typically of the magnitude of 3/8" steel, or No. 6 copper. On the other hand, grounding for substation structures may be of the order of two No. 4/0 conductors. For safety purposes, the general rule is not to leave any metal structures within the yard ungrounded so that potential differences will not exist between an ungrounded structure and the station grounding system during fault conditions. The magnitude of fault currents in modern substations is sufficient to burn off a 3/8" steel transmission connection and thereby leave the structure not only ungrounded but possibly remotely grounded when overhead ground wires are used as lightning protection on the transmission line. Thus, during a recurrence of fault conditions, the substation grounding system can rise to dangerous potentials relative to the remotely grounded transmission structure.

The important point to recognize from this example is that everyone involved in this project probably met the criteria involved in their aspects of the job; however, a quality problem was created. It is necessary, therefore, to create a positive system for interface control in both the design and construction phases.

The identification of a problem of this sort requires an overall viewpoint backed by sufficient technical background to understand the intent and basis for grounding standards and their limitations. Without a technically oriented audit function it is not hard to imagine this problem going unnoticed indefinitely. For management, the reporting of this type of item should trigger a number of thoughts concerning the overall interface control system.

NEW DESIGN REVIEWS

New design reviews from a quality standpoint present unique problems which differ from the reviews of design, materials and construction discussed to this point. The design work to be done on a project of this nature is so highly developmental that little can be extrapolated from past experience to determine acceptable quality. This is not to say that the control of quality should be abandoned. Too often this has been the case and there are so many quality related failures that designers are unable to isolate and analyze design engineering problems. Quality evaluations conducted during the design and development stages are especially important to assure that well conceived programs are established early and that the required quality is established and maintained.

As an example for the transmission sub-system of new design, assume that a utility has committed to build a UHV line (1000 KV or above). For a project of this nature, it will be necessary for the design group to identify the unique design bases. For a UHV line these will be:

1) Corona effects limitation such as audible noise, television interference, radio noise, and corona loss.

2) Electrostatic effects, importantly, the electric fields set up at the surface of the earth.

3) Insulation requirements to meet requirements of lightning overvoltages, switching transients, and the steady power-frequency voltages.

4) Mechanical vibration of UHV conductor bundle, especially sub-conductor oscillation limitations in the complex UHV conductor bundle.

A second requirement for the design group is to establish measures to assure that the design bases are correctly translated into specifications, drawings and instructions. This will include such design items as:

1) Insulator string lengths

2) Conductor to tower air gap

3) Minimum phase-to-phase spacing

4) Midspan clearance to ground

5) Tower heights

6) Span lengths

7) Conductor bundle configuration

These measures will be of the form of a designer's manual to provide the actual designer of the UHV line with guidelines which, when followed, will result in a line design which meets the original design criteria. The preparation of this guideline will necessitate consultation with the personnel who will be involved with the job of constructing the line. This will allow inputs to the design manual which will result in a design which is "constructable" while still meeting the design criteria. It will also provide the construction management with an insight of any unique construction requirements so that they can be aware of new erection procedures which may be required.

A third requirement for the design group is to provide a course of action which will assure that the appropriate quality standards are specified and included in the design documents. The intent here is to identify the unique situations encountered during the process of locating towers along a selected line route. Where deviations must be made to standard design due to terrain, environmental considerations, etc., these deviations should be sufficiently noted so that due consideration can be given as to whether they sufficiently meet the design criteria. An example of what is being said here might serve to clarify the intent.

As is often the case in line designs, there may occur, in the tower locating phase of design, a location where the standard tower configuration is deemed unsuitable. Perhaps for some reason, typically some environmental considerations, it is more advisable to install self-supporting steel poles rather than the standard latticed steel tower. The intent here is to recognize this as a deviation from standard and to allow for a review to see that the original design criteria have been met. Has the conductor configuration changed due to the non-standard structure? If so, what effect does this have on phase-to-phase spacing or corona limitation requirements? The course of action taken by the design group must assure that these questions are asked and answered. For new designs, it is not sufficient to assume that the line designer alone bears responsibility for meeting design criteria in unique situations. By providing a system for identifying these special situations as they occur, then the step of design verification becomes more meaningful in that the person within the design group providing this verification has a well defined starting point.

A fourth consideration which is extremely important in the new design situation is that of design changes. In transmission line design, there are bound to be changes required after design drawings are issued. These may be imposed by right-of-way difficulties, field suggestions, etc. What is important here is that a procedure be adopted which will assure that any changes are subject to the same design control measures as applied to the original design. Too often, design changes fail to meet the original design criteria because of a lack of attention to the design change system.

The quality assurance groups involvement in new design control should be:

1) Become familiar with the new design criteria for the project.

2) Contribute in planning the design control procedures to assure that design criteria are met.

3) Monitor application of the procedures to assure that they are completed as planned.

4) Provide insights as to the effectiveness of the systems in meeting their intent to allow upgrading where required.

5) Provide an end-of-line audit of the design, apart from production pressures, to measure how effectively the critical aspects of the design criteria have been translated in the design documents.

In passing, it is interesting to consider the possibility of reviewing existing design controls for standard designs in the light of the above proposal for new design control. It may provide some insights to those considering a more modern approach to design control for "standard" transmission line designs.

It is felt that it is not necessary to adjust the material control system as previously outlined for new design projects. The system as outlined is not dependent on the material being reviewed. What is important is to provide a system which will assure that applicable design criteria which are to be met are suitably referenced in procurement documents in order to assure adequate quality. It will also be necessary to completely define test requirements in the light of unique procedures and acceptability limits. These test procedures must:

1) Describe the test techniques where they are peculiar to UHV materials
2) Establish acceptance limits
3) Provide verification means

It will also be necessary to define, as above, any unique inspection requirements to determine conformance to procurement document specifications. This is in addition to the test requirements which determine if a material is suitable for use.

Generally, by applying the system for material quality assurance outlined previously, with audits performed as required to determine application and effectiveness, the materials for new design systems can be assured to meet desired quality levels. Past data for supplier quality conformance on standard designs will provide starting points for applying the seven steps previously outlined.

The construction phases of the quality assurance program for new designs must provide means for assuring that:

1) Unique procedures are spelled out in a manner which provides the constructor with the means for meeting design intent.
2) Qualitative and/or quantitive acceptance criteria for determining that unique construction activities have been satisfactorily accomplished.
3) An inspection program which provides trained personnel verifying conformance to both design specifications and construction procedures.
4) Adequate training to assure adequate performance of special processes required by and unique to the UHV line.

Basically, the requirements are to provide the means for assuring that those quality requirements which are new and are unique to UHV designs are effectively controlled so that the final product will meet the design intent without undue delays caused by incomplete or non-existent construction procedures.

Again, as in design, the quality assurance groups involvement should be to contribute to planning construction procedures, audit application of procedures for completeness and effectiveness, provide an end-of-line audit to assure that critical aspects of design are met in the final product.

USE OF AUDIT INFORMATION TO ASSURE QUALITY

It should be obvious to the reader at this point that is is not the job of the quality assurance group to assure that each and every aspect of a given transmission line is correctly completed. This responsibility rests with the designers and the builders of these facilities. The mission of the quality assurance section is to provide information which will aid those groups to control the quality of design and construction.

Previously, the example was used concerning the grounding of transmission facilities within a substation area. What should be the feedback involved with that audit finding? There are a number of considerations involved which will dictate the type of feedback and level to which the feedback should be directed. There are a number of persons who would be interested in this finding. These are:

1) The designer to correct the specific problem (i.e., by increasing the capacity of the ground wire).

2) The transmission design section head

to indicate possible problems in:

a. The design review system

b. The design procedures covering grounding

c. Omissions in the training program for designers

3) The engineering department head to identify weaknesses in the procedures covering design interface control or possibly the complete lack of these procedures.

The important point to be noted in this feedback is that the thrust should be to relate actual problems, whether they be in the design, materials, or construction phases, with the intent to identify weaknesses or ineffectiveness in the procedures used to control quality. This is the real way to control quality--by strengthening the quality control procedures.

An important distinction should be made at this point between the nuclear quality assurance audits as required by the Atomic Energy Commission in 10CFR50, Appendix B and the audits proposed in the sub-system described in this thesis. The audits for nuclear projects concern themselves with "verifying compliance with all aspects of the quality assurance program". This audit concerns itself with determining that each of the steps involved in the design, material procurement, and construction of safety related components is identified, procedures are written, and work is done as specified in the procedures. It is a true system audit and is based on preparation of a complete, highly documented quality control system which, if followed to the letter, will result in components which carry with them a high degree of assurance of meeting quality requirements.

In the case of safety-related nuclear components, this is certainly justifiable. The new design control discussed previously for a UHV line would approach this concept. However, for the day-to-day projects, it is felt that the information to be gained from the audits as proposed, i.e. identification of actual quality problems, will provide a more meaningful assessment of how well the system is working than would the system audits required in a nuclear project. In more practical terms, the audit as proposed would concern itself, for example, with the effectiveness of a design review rather than simply determining that design reviews were in fact performed and documented.

The feedback provided in conjunction with audits of the construction phases will be tailored as shown in the design audits. Again the intent is to provide opportunities for immediate corrective action concerning the specific problem identified and to allow system analysis to prevent recurrence of similar problems by isolating and correcting the cause.

The feedback system for material quality was discussed in the preceding section. As indicated, the objective was to use the information gained in the pre-award audit (quality program review and the quality program implementation review) and in the verification of vendor certification to gain corrective action for the quality problems on specific material, preventive action at the vendor's shop to eliminate these problems on future shipments, and to provide structured input to Materials Information Systems on vendor quality levels.

It should be noted from the use of this information and from the philosophy of the material control system as outlined in the preceding section that the emphasis on control of material is at the source. It is accomplished by close product-quality relationships between the vendors quality assurance group and their counterpart in the electric utility. Receiving inspection, though recognized as very important, is a supplement to this relationship rather than the whole of purchased material control.

CONCLUSION

The keys to effective use of the transmission line quality sub-system are contained basically in the following philosophies which, in the writer's opinion, have been carried throughout this proposal.

First the responsibility for quality has been placed with those doing the work. Designers, constructors, and material vendors are liable for accomplishing the quality objectives in their respective portions of the total job. These responsibilities are delineated in the corporate and departmental quality policies and the means for meeting them are spelled out within work instructions and procedures. For the electric utility transmission line sub-system, this amounts to writing down how a job is to be done, often merely by referencing existing procedures and work instructions. The purpose is to clarify for each person who affects the overall quality of the project what his responsibilities are and how he is to meet them. A secondary objective is to provide a basis for quality improvement by identifying weaknesses in these procedures.

The second key to success is that information must be generated in a fashion which promotes preventive actions as well as corrective action. The feedback system must provide those in management with information tailored for their use in changing or adding to the quality system when such action is deemed advisable.

The design of the transmission quality subsystem as proposed here has led to four basic requirements:

1) Identify those activities affecting quality in design, purchased materials, and construction.

2) Identify the controls used to insure that these activities have been effectively performed.

3) Organize a Quality Assurance Section to assist in formulating one and two above and also to audit the design, materials purchasing and construction functions. The audits are aimed at verifying compliance with and the effectiveness of one and two above.

4) Organize a feedback system to enable management in the area audited to act on the audit information.

Generally the first two requirements are already in place for the utility and all that is needed to complete an effective QA program is the formation and training of the personnel necessary to provide regular and orderly examination of the quality program.

To this point, the transmission sub-system has been discussed as an entity. In this discussion, we have become involved in discussing one interface, namely that of transmission and substation design (See page 64). As these interfaces are identified and the quality requirements are defined for the sub-system under study, this will provide a natural starting point for additional sub-systems.

As these additional quality sub-systems are formalized, progress in the various disciplines can be increased since parallelisms can be developed based upon the essence of the quality sub-systems already in operation.

Basically, in structuring these additional sub-systems, their interfaces, and their organizational and functional locations, the quality assurance audit group by this time should be in a position to provide guidance by separating concepts from contents, and applying the analysis of the concepts to the real world represented by the quality sub-systems already in operation. By this means, a Total Quality Assurance System will be developed which integrates the efforts within each subsystem towards overall quality and eliminates duplication of quality functions.

This is not to say that the approach to be taken to a Total Quality Assurance System should be one of implement now, integrate later. Rather, to be effective, the starting point must rest with top utility management. This requires the formulation and approval of a "Corporate Quality Assurance Manual". This manual will define the corporate quality goals and will identify the functions affecting quality and place responsibilities for carrying out these functions. This manual will be structured as management sees the organization at the time when the manual is prepared and will serve as the gross design for the total system. As the detailed system design is carried out as for the Transmission Sub-system, the gross design will probably be revised as more logical or economical means are discovered for meeting the corporate quality assurance goals. The gross design, in this case the Corporate Quality Assurance Manual, provides the framework for the sub-system detailed design work and in so doing, provides the means for assuring that these sub-systems will be integrated to meet the quality goals of the utility.

One of the most important questions to be asked of a Total Quality Assurance System is that concerning cost savings to the public. At this point, there are few hard facts that can be used to point out the overall effects of a systems approach to quality on the customer's electric bill. One limited study has been made on the effects of corrective action only. This study is based upon the findings of a quality audit group (three persons) and involved the areas of substation and transmission facilities design and construction. The dollars estimated are quite conservative and are further tempered with a judgement on the probability that the deviations would have been discovered prior to placing the facility in service. The results of this study based upon savings in rework, scrap, sacrifice in reliability, construction delays, and more economical construction indicated a total dollar savings of $150,000 during the period of one year.

It must be remembered that this study included the work of a quality assurance group working in only two areas and did not reflect any intangibles such as safety and preventive actions. This was purely corrective measures which assured that these portions of the job were done correctly the first time. The real savings to be realized through a Total Quality Assurance System will be found in:

1. Avoiding duplication of effort through identification of responsibilities,
2. Avoiding "emergency" situations by seeing that the job is done right the first time,
3. Avoiding unnecessary double and triple checking by developing a system in which management will have a high level of confidence that design and construc-

tion will be done in such a manner as to meet quality and reliability goals,

4. Avoiding construction delays through systematic job planning so that capital investments produce revenues as scheduled. This involves integrating quality requirements into the planning - scheduling - construction process.

The culmination of these developments (improving profitability and productivity) will be that total quality assurance - the basis for quality - engineering professionalism - will take its place as the newest of the major technological and managerial areas that make fundamental contributions to those electric utilities that grow, prosper, and contribute to general economic well-being. Total quality assurance in technical action is the future for the quality assurance man and his function within an electric utility. It is a future that, with proper application of effort, will be a productive one for the prosperity of the utility and its customers, and for the optimum utilization of resources in the economy as a whole.

APPENDIX A

DISCUSSION OF RULING SPAN

The ruling span for an overhead electric line may be considered as a design span that assures the best average tension throughout a line between conductor fixed dead-end points with suspension spans of non-uniform span lengths. The actual tension under both loaded and unloaded conditions may be greater or less than the ruling span tension, depending upon the sequence of various span lengths, ground slope, loading conditions, etc.

The ruling span for a given line is determined by the following equation:

$$\text{Ruling Span} = \sqrt{\frac{S_1^3 + S_2^3 + \ldots + S_n^3}{S_1 + S_2 + \ldots + S_n}}$$

where S_1, S_2, S_n are the first, second and the nth span length between dead-ended structures.

For the transmission line under examination in the example, the ruling span for the entire line was determined to be 450 feet. The conductor sag for a 450 foot span was determined by catenary methods to be 6.05 feet at a temperature of 60^{o}F to give a maximum tension of 7407 pounds at design basis conditions.

Referring to Figure 2, page 34, the line section to the left of structure "A" consists of eight suspension spans to a fixed dead-end point, four of which are shown.

The ruling span for this line section has been computed to be 413 feet by the ruling span equation as shown below:

$$\sqrt{\frac{383^3+376^3+455^3+369^3+457^3+391^3+450^3+443^3}{383+455+369+457+391+450+443}}$$

The sag which actually will be installed in a 413 foot span at 60°F using a 450 foot ruling span sag chart is, by the parabolic equation, equal to:

$$6.05\,\frac{(413)^2}{(450)^2} = 5.1 \text{ feet}$$

The actual tensions in this ruling span, which is used as an equivalent span to replace the eight spans to the left of structure "A" in Figure 2 have then been computed for various loading conditions (see Table 1, page 37). These sag and tension conditions are those which will exist if the conductor is installed in the eight spans to the left of structure "A" using a sag chart based upon a 450 foot ruling span.

This same reasoning is used to compute sags and tensions in the 1000 foot span however since this span contains dead-ends at both structures "A" and "B" (see Figure 3, page 36), the ruling span is the same as the actual span of 1000 feet.

BIBLIOGRAPHY

Books

Feigenbaum, A. V., Total Quality Control Engineering and Management.
New York, Toronto, London: McGraw-Hill Book Co., Inc., 1961

Fyffe, David E., Manufacturing Studies - Quality Control.
Schenectady: Manufacturing Education, General Electric, 1968-1969

Johnson, L. Marvin, Quality Assurance Program Evaluation.
Whittier, CA: Stockton-Doty Trade Press, Inc., 1970

Public Documents

Office of the Federal Register National Archives and Records Service General Services Administration, Title 10 Code of Federal Regulations Part 50, Appendix B.
Washington: U.S. Government Printing Ofc., 1974.

Articles

Zadina, Egon J., What QA Means to Utilities. Electrical World, September 15, 1973, p. 80.

Lee, W. S., Utility Managements Role in Quality Assurance. Electric Light and Power, E/G Edition, August, 1973, p. 28.

Peters, J. T., That Vital Commodity, Quality. Public Utility Fortnightly, May 10, 1973, p. 33.

Montague, J. T., Supplier Evaluation Program Emphasizes Total Value. Transmission and Distribution, February, 1973., p. 36.

Lummis, J., Fischer, H. D., Jr., Practical Application of Sag and Tension Calculations to Transmission Line Design.
IEEE Transactions on Power Apparatus and Systems, June, 1955.

Unpublished Material

Lehman, R. F., "Pennsylvania Power and Light Co. 138 KV Line Design Manual", September 1, 1972.

Emery, R. L., Personal Interviews and Various Writings on Electric Utility Quality Assurance. 1971-1974.

Computer Program

Alcoa Sag and Tension Program as Revised for Time Sharing Option by Pennsylvania Power and Light Co.

BRIEF BIOGRAPHY

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