Total Quality Management for Construction

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Abstract: Traditional approaches to quality control in the construction industry are inadequate and should be replaced with the Total Quality Control concept implemented through the Quality Control (Q.C.) Circle as developed in Japan and currently in wide use throughout the manufacturing industry. The term "total quality control" is defined, and four total quality control principles are set forth on the basis of this definition. The evolution of quality control is traced from the nineteenth century to today to explain the decline in quality standards and to illustrate the need for a new approach. Unique characteristics of the construction industry are described as they relate to the Q.C. circle concept. Implementation of this concept will result in higher quality, lower costs, and increased productivity in the construction industry.

Introduction

Attainment of acceptable levels of quality in the construction industry has long been a problem. Great expenditures of time, money and resources, both human and material, are wasted each year because of inefficient or nonexistent quality management procedures. The manufacturing industry has developed total quality management concepts, first applied in Japan and in recent years used in the United States, which have produced many positive effects including increased productivity, decreased product cost and high levels of product reliability. These concepts, implemented through the "quality control circle," are also applicable to the construction industry.

This paper summarizes a research effort to review the evolution and basic concepts of total quality management and to apply these concepts to the construction industry through use of the quality control circle. As an initial effort, broad in scope, its objective is to stimulate interest in research. This research could prove beneficial in many ways to the construction industry as it has in the manufacturing industry. A continuation of this research is being carried out at Furukawa Laboratory, Kyoto University, investigating the integration of time, cost, quality and safety into a comprehensive management model for construction.

A review of the evolution of quality control in the manufacturing industry demonstrates shortcomings of historical approaches to quality control in today's industry and shows the need for a definition of total quality control. Although there are significant differences between construction and manufacturing, quality control systems in the two disciplines have evolved in a similar manner. The study of quality control evolution in manufacturing provides useful insight into how traditional

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Note.—Discussion open until November 1, 1985. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on August 8, 1984. This paper is part of the *Journal of Construction Engineering and Management*, Vol. 111, No. 2, June, 1985. ©ASCE, ISSN 0733-9364/85/0002-0117/$01.00. Paper No. 19767.

J. Constr. Eng. Manage., 1985, 111(2): 117-128

construction quality control has evolved, because although the history of quality control in construction is not well documented as in the manufacturing industry, its evolution has many parallels with that of manufacturing.

Flow diagrams of traditional quality control and total quality control systems are presented and provide the basis for comparison of the two.

The quality control (Q.C.) circle is an integral part of a total quality control program. Evolution of the Q.C. circle's application in Japanese industry shows not only what it is, but also how effectively it can be used. Unique characteristics of the construction industry can cause special problems in implementing Q.C. circles on the project site; however, with commitment and involvement of management and supervisory personnel, effective Q.C. circle activity can be initiated.

The results of implementing a successful total quality management program will be increased productivity, decreased cost, and greater product reliability. Initial costs to bring the program on line should be recovered very rapidly by the increase in productivity and decrease in scrapping, reworking, and repairing of faulty materials and workmanship.

Evolution of Quality Control

Evolution of the quality control concept can effectively be traced by studying its development in the manufacturing industry, which parallels that of the construction industry. There is extensive documentation on quality control in the manufacturing of various construction materials. Other articles deal with segments of comprehensive quality control programs such as the monitoring function (12). Some articles give broader treatment to comprehensive quality control programs in specialized areas such as the nuclear power industry (8,23). However, general trends in the evolution of quality control are much more extensively documented for the manufacturing industry than for the construction industry.

There have been five stages in the evolution of quality control (18):

1. *Craftsman quality control* was inherent in manufacturing up to the end of the nineteenth century. During that time, one craftsman, or at least a very small number of craftsmen, were responsible for the manufacture of a complete product, and each craftsman exclusively controlled the quality of his work.
2. *Foreman quality control* occurred during the industrial revolution when the large-scale modern factory concept developed. During this stage, many craftsmen performing similar tasks were grouped together and supervised by a foreman, who then assumed responsibility for the quality of their work.
3. *Inspection quality control* evolved during World War I when the manufacturing system became more complex. Because a large number of craftsmen reported to each production foreman, full-time inspectors were required. This era peaked in the large inspection organizations of the 1920s and 1930s, which were separately organized from production and large enough to require superintendents.

4. *Statistical quality control* flourished during World War II when tremendous mass production was necessary. In effect, this step was a refinement of the inspection step and resulted in making the large inspection organizations more efficient. Inspectors were provided with statistical tools such as sampling and control charts. In 1924, W. A. Shewhart of Bell Telephone Laboratories developed a statistical chart for the control of product variables, marking the beginning of statistical quality control. Later in the same decade, H. F. Hodge and H. G. Roming, both of Bell Telephone Laboratories, developed the concept of acceptance sampling as a substitute for 100% inspection; this was considered the most significant contribution of statistical quality control.

5. *Total quality control* evolved in the early 1960s in a four-phase process. A dramatic increase in user quality requirements resulted in increasing customer demand for higher-quality products, leading the manufacturer to recognize the inadequacy of existing in-plant quality practices and techniques. These all contributed to excessive quality cost due to such items as inspection, testing, laboratory checks, scrapping and reworking imperfect products, and customer dissatisfaction. These problems highlighted the dual quality challenge: Providing significant improvement in the quality of products and practices while at the same time, effecting substantial reductions in the overall cost of maintaining quality. Statistical quality control could never meet the challenge; thus, a totally new concept was developed based upon the principle that in order to provide genuine effectiveness, control must start with the design of the product and end only when the product has been placed in the hands of a customer who remains satisfied (11).

The total quality control approach that grew in Japan during the 60's was based upon techniques developed by American industrial consultant Dr. W. Edwards Deming. "Many observers credit them [Deming's techniques] with the emergence of 'Japan Inc.' as a dominant force in world markets (17)."

The words "quality control" and "quality assurance" mean different things to different people at different times. Barrie and Paulson (5) define quality assurance as an all-encompassing term of which quality control forms a part. Hester (12) uses quality assurance to indicate activities performed by the owner or agents in monitoring quality control programs established and administered by others. Thus he sees quality assurance as a part of the quality control program.

To eliminate confusion, total quality control will be used in this paper to mean "an effective system for integrating the quality-development, quality-maintenance, and quality-improvement efforts of the various groups in an organization so as to enable production and service at the most economical levels which allow for full customer satisfaction" (10).

This definition prompts the establishment of four total quality control principles (18):

1. Quality control is not the responsibility of any one person or department; rather, it is everyone's job. It includes the craftsman, the manager, and the president of the company.

2. Instead of the "it shall not pass" philosophy of the historical inspection activity, the theme of total quality control is "make it right the first time."

3. Quality control is responsible for assuring quality at optimum costs.

4. The prototypal quality control person is not to be seen as an inspector but as a quality-control engineer, with background in the applicable technology and with training in statistical methods, inspection techniques, and other areas for improving and controlling product quality.

Quality Control in the Construction Industry

While the evolution of quality control in construction is parallel to that of the manufacturing industry, many dissimilar characteristics distinguish the two industries. These differences, some of them significant, must be considered when applying a manufacturing quality control program to construction:

1. Almost all construction projects are unique. They are single-order, single-production products.
2. Unlike other industries, which usually have a fixed site with similar conditions for production, construction production sites are always unique.
3. The life-cycles of construction projects are much longer than in any other production industry, so that projects evolve according to time and circumstances throughout the life-cycles.
4. There is no clear, uniform evaluation standard in overall construction quality as there is in manufactured items and materials; thus, construction projects usually are evaluated subjectively.
5. Since construction projects are a single-order design product, the owner usually directly influences the production.
6. The project participants—owner, designer, general contractor, subcontractor, material-supplier, etc.—differ for each project (1).

Because of these distinguishing characteristics, the construction industry has generally been considered so different from other industries that quality control procedures that work effectively in a mass production industry have not been considered suitable for the construction industry. Consequently, quality control throughout the construction industry has not evolved to the total quality management level attained in other industries.

Only in the past few years have major American contractors begun to recognize and adapt to construction the total quality control principles previously mentioned that have been employed successfully in manufacturing. Hawaiian Dredging initiated a program based upon quality control circles in January, 1980 (20). In 1982, Brown and Root, Inc. undertook a program to train employees and work with subcontractors to implement total quality control procedures throughout the company. Other major contractors including Bechtel and Parsons are also working in this direction. As an indication of the growing interest in total quality control in construction, a National Conference on Quality Assurance in

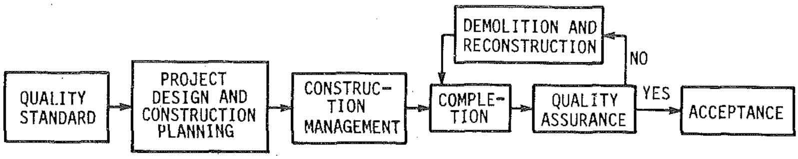

FIG. 1.—Typical Construction Project Quality Control Flow Chart

the Building Community, dealing with a variety of concerns, was held in Dallas, Texas during July, 1983.

Fig. 1 represents a typical, traditional construction project quality control flow chart (4). Project design and construction planning are carried out based upon a standard derived from relevant codes, owner requirements, and design company standard practice. Construction is then managed to conform to this composite standard as interpreted by the constructor. Quality assurance via owner, designer, or building authority, or a combination, occurs after completion, and in some cases, after partial compensation. This process results in the following trends:

1. Quality is designed into and evaluated for each individual project *each time*. Except for some specialized areas of construction such as nuclear power plants and interstate road construction, there is no comprehensive quality policy employed to establish quality assurance for the entire industry or large segments of the industry.
2. No feedback system exists for reexamining quality control work. Correction only occurs when the owner, designer, or building authority points out defects in the project. This makes quality evaluation difficult.
3. As a result, it is difficult to establish a data collection system to build an information base that could lead to early identification of defects. Since post-completion correction of unacceptable work on a construction project is damaging to a company's or an individual's reputation, or both, the defect that occurs during construction is usually corrected or concealed before top level management or the owner discovers it. Thus, lack of information means no change in procedures, and allows the defect to reoccur during the next project.
4. No mechanism exists for practical implementation of standards. This is not only because too many standards exist, but also because there are no efficient means for inputting new information and, thus, maintaining relevant standards.
5. No system exists to manage quality throughout the design/construction process. While a "construction management" block appears in Fig. 1, it is only the execution of the construction plan, and does not contain a quality management component.

Even though we recognize that the construction industry differs in many ways from other industries, the problems occurring in construction quality control are believed to have the same basis as those in other industries, namely, improper concept identity (2). We should change the concept of quality control from "controlling quality" to "controlling management for quality." This would result in using an integrated qual-

J. Constr. Eng. Manage., 1985, 111(2): 117-128

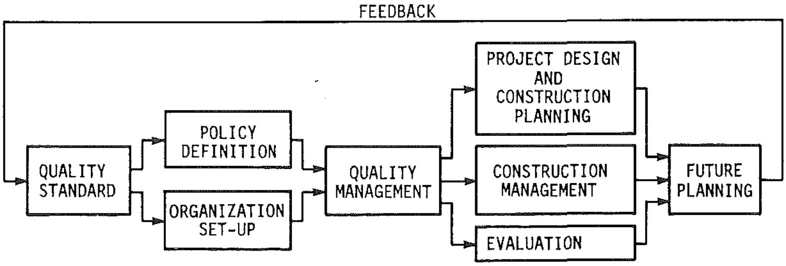

FIG. 2.—Total Quality Control Flow Chart

ity standard, based upon current industry-wide experience, to define policies and organization to manage quality. Policies are defined for quality, for the control of quality, and for management of the quality control system.

The organization created to implement the policies must have well-defined responsibilities and authority. In construction, failure can result from malfunction on the part of constructor, designer, or even owner. In most cases, however, it is the result of a combination of actions in several or all of these areas. The organization for implementing quality control is extremely important because the nature of a construction project is to have diverse entities, each potentially contributing to an action resulting in failure. The quality management organization must, therefore, have the ability to deal effectively with all parties involved.

A quality control flow chart (see Fig. 2) demonstrates the following characteristics for a properly organized quality control program in the construction industry:

1. The quality standard is derived from a current data base created through feedback from previous projects, providing a more uniform and comprehensive standard.
2. Design and planning, construction and evaluation phases are integrated through the quality management system.
3. Defects are identified and corrected early.
4. Feedback expands the quality data base to eliminate repetition of the identified defects.

Education, information and analysis, standardization, and the statistical approach all have been utilized separately in the traditional construction project. Effective unification of these activities through the concept of total quality control is essential to improved quality (3).

Evolution of the Quality Control Circle

Again, study of the manufacturing industry provides a historical context for the quality control circle.

Prior to the industrial revolution, craftsmanship was the primary concern of the individual craftsman and constituted a major source of quality assurance for buyers. The practice of craftsmanship has changed extensively, owing principally to three factors (13):

1. The factories of the industrial revolution transferred work from the village craftsman to the factory employee. The factory worker was thereby deprived of such functions as product design and marketing. What remained was only the function of manufacturing.

2. Factory work typically was divided into numerous specialized operations. As a result, the typical worker performed a highly repetitive task that comprised only a tiny part of building an entire product.

3. The Taylor system (21) went further by separating work planning from execution. As a result, the workers were left only with the job of executing plans prepared by someone else, usually industrial engineers.

These changes have caused a loss of pride in workmanship and a decline in the spirit of craftsmanship which once prevailed among workers. The implication is that while workers once were self-motivated to care about quality, this self-motivation has been lost.

Throughout most of the twentieth century, the major thrust of company motivation of workers has been to attain improved productivity. The Taylor system has been a basic model for such concepts in the United States. Because the Taylor system is, inherently, a poor motivator for quality (14), and because at the same time demand for quality has continued to grow, the attainment of acceptable quality has become progressively more difficult. As a result, a new area of research has evolved, seeking innovative forms of motivation that could stimulate worker contribution to quality and that could be built into the basic motivation structure of the company.

The worker study team is one of these new approaches. It encourages workers to participate in training programs for solving departmental problems. The most outstanding application of the worker study team concept is that of the "quality control circle" (Q.C. circle). To cover the history of the Q.C. circle, it is necessary to start with its origin in Japan, where it was nourished and grew to maturity prior to spreading to other nations.

The start of the Q.C. circle in Japan is generally attributed to a project begun in 1961 by the editors of the Japanese magazine, *Quality Control*, which in one issue sponsored a symposium on "some problems facing the shop foreman." From this symposium, two conclusions were drawn: First, there was a need for a quality control publication which was more "down to earth," closer to the shop floor than existing publications; second, foremen lacked opportunities to air their opinions outside of the factory. The editorial board of *Quality Control* thereupon set up a discussion session on "the duties of the shop foreman in quality maintenance" as part of the annual quality control conference held in November, 1961, and invited shop foremen to join the panel. Next, a magazine for shop people, called *The Foreman and QC* (first issued in July, 1962), was designed to promote education and training at the first level of shop supervision. Its price was set low enough to make it attractive to first-level supervisors and workers who would have to purchase it with their own money. In addition to the new magazine, a group activity called "Q.C. circle" (6), organized by workers in similar positions and led by foremen or supervisors, was developed. Its primary purpose was to:

J. Constr. Eng. Manage., 1985, 111(2): 117-128

1. Enhance the first level supervisor's leadership and management capability through self-development.
2. Include the worker level, with everyone participating, through Q.C. circle activities. This attempted not only to raise the workers' morale, but to put the quality control activities into first-level operation, and with this action, improve the quality-sensing, problem-sensing, and improvement-sensing abilities of the working person.
3. Provide an effective chain of quality control for the whole company, which would: Function in the work place as a core for executing principles from upper-level managers; take root in management activities; and accomplish quality assurance (7).

The Q.C. circle movement has grown extensively since its inception. A decade after its inception, registered circles (a registration administration has been set up by FQC magazine) numbered over 40,000 with a combined membership of over 400,000. Unregistered circles outnumber registered circles by an order of magnitude. The Japanese estimated that by 1977, the total number of Q.C. circles had reached more than one-half million, with a membership of about seven million (16).

The number of problems solved is even more impressive, since a circle, once it is under way, deals with an average of three problems per year. The cumulative total of completed problem discussions during the first decade of the movement was approximately 5,000,000. The money saved per problem continues to vary remarkably; however, the average reported at Q.C. circle conventions is about $5,000 per problem. The impact of the Q.C. circle movement on Japanese quality and the economy undoubtedly has been immense (15).

Quality Control Circle in Management of Construction Projects

Integration of Q.C. circle activities in the construction industry as part of a total quality control program can lead to benefits just as it has in the manufacturing industry.

Q.C. circle activities in the manufacturing industry are located primarily in the factory, but also extend to management, accounting, and other departments. In the construction industry, the construction site is equivalent to the factory floor. Successful Q.C. circle activities on the construction site play a crucial role in assuring quality, delivery, and safety, and minimizing construction costs. As they extend to the design, administration, management, and accounting areas, quality control becomes a company-wide and an industry-wide activity.

Since Q.C. circle activities above the production or trade levels are similar in both manufacturing and construction, further consideration in this paper will concentrate on Q.C. circle activities used on the construction site. These activities are affected by the unique characteristics of the construction industry. These characteristics, reviewed earlier in this paper, present several situations that cause difficulty in implementing Q.C. circle activities on the job site:

1. Various trades are involved in the same area at the same time.

J. Constr. Eng. Manage., 1985, 111(2): 117-128

2. Construction tasks change daily, very often requiring replacement or shifting of tradespeople.

3. Following the completion of the project, the project-team will be dispersed and the valuable team spirit, developed with much effort, will vanish.

4. Highly dispersive tendencies among the tradespeople, resulting from the traditional pattern of individualism, lead to natural rejection of others' opinions (15).

These problems make it more difficult to form Q.C. circles in the construction industry than in the manufacturing industry, to select discussion topics, and to bring Q.C. circle activities into play.

To initiate Q.C. circle activities within the existing conditions of the construction field, the project superintendent must provide effort and leadership. Therefore, clear understanding of the Q.C. circle and total commitment to the activity by the superintendent will be critical factors for a successful Q.C. circle.

In fact, it is important for all supervisory and management people, from project managers to field engineers, to try their best to encourage the Q.C. circle activity by introducing case studies of Q.C. circles, by teaching total quality management principles, and also by participating in circle presentations. Efforts by field staff to support, cooperate, and instruct are essential to successful Q.C. circle activities. After the Q.C. circle is operational for a time, the attitudes among the tradesmen should have progressed from "let's try it and see," to "I'm becoming involved," and finally to "I am committed to this activity."

Experience has indicated that the quality control activities for the field office staff of general contractors should not be separate from the Q.C. circle activities at the trades level. Many cases show that groups have been set up by engineering staff and have succeeded in improving work progress. Two ways to take advantage of the special character of the construction industry are through self-development and reciprocal-development between and among construction people at all levels of the industry. This should extend to business, design, construction and all other areas. The designation "Q.C. circle" as such may not be important to the construction industry; the "small group activities" approach, however, appears to be a major factor for quality management in construction.

Result of Implementing Total Quality Management

It is well documented that whereas other industries are showing positive growth in productivity, the construction industry is one of only two sectors in the economy actually showing negative growth in productivity for many years (22). In addition, the output of the construction industry today is significantly different from what it was in the past. Construction styles have changed considerably due to the development of increasingly larger-scale as well as more complicated projects. In addition to these, higher standards of living have created a need for the construction industry to evaluate its performance in light of the requirements for safety and comfort. Construction now also must meet stringent health

J. Constr. Eng. Manage., 1985, 111(2): 117-128

and environmental standards, and those involved in the building process must cope with extensive regulatory apparatus.

In the past, concern for quality in the construction industry has been a relatively insignificant consideration. The impact of this quality factor has, therefore, had little effect on construction productivity, and we recognize that past efforts to improve productivity are not sufficient to meet the strict quality requirements of today's society. We conclude that the next step in this industry must be to consider how the quality factor influences the construction project and how total quality management can profit the industry, since all previous efforts made without quality consideration have not increased productivity.

In other industries, the increased concern for consumer protection and the emphasis on production reliability have provided the impetus for management to create an effective system for quality control. Past experience has told us that managers initially may tend to view the enhanced quality control systems as burdensome. However, this attitude soon gives way to approval when it is shown that major cost savings occur. Two factors contribute to these cost savings:

1. A cost-effective quality program which sets up inspections and tests at strategic locations provides early detection and correction of product or processing deficiencies that will forestall and avoid scrap, rework, and repair, as well as customer complaints.
2. A quality-controlled product is a more saleable product. As the constructor's reputation for conformance with specifications at reasonable prices improves, customer acceptance and product marketability will grow.

Profit from a quality control program is realized as a result of producing a better product and reducing quality-related costs. These costs can be broken down into four categories: Cost of defect prevention; cost of appraisal; cost of in-house failure; and cost of customer complaints. A regular quality control program will usually mean some increase in prevention and appraisal costs, but these will be more than offset by a sharp drop in in-house failures and customer complaints.

Little published data have been found for quality-improvement costs in the construction industry. The experience of Hawaiian Dredging (20) does provide one specific case in which "changes in procedures, which cost nothing to implement, saved $8,000.00." Again looking to the manufacturing industry for information, quality-related costs for the American manufacturing industry at the beginning of the 1970s reached 10% of the sales dollar in numerous organizations. It was estimated that a level of 15% would be reached by the early 1980s unless management took action to curb this spiral (19).

A major value of quality control is the early discovery of nonstandard conditions. Faulty processes must be eliminated to prevent a defective product from continuing in the production stream, eventually causing major problems. When quality control is managed effectively, it will then follow that a good product will be produced at relatively low cost, thereby creating an effective, hidden "sales force" for the producer. Quality, cost, and productivity thus are interrelated. Quality is raised and costs are lowered, while at the same time productivity is enhanced (9).

Conclusions

Traditional approaches to quality control in the construction industry are inadequate to meet the needs of today's projects and today's society. Development of a total quality control approach has proven highly successful in the manufacturing industry. The time has come to adapt total quality control principles used successfully in the manufacturing sector to meet similar needs in the construction industry, and to develop new means of providing the high level of quality essential in today's and tomorrow's construction projects. Implementation of total quality control based upon the quality control circle concept can lead to fulfillment of stringent quality requirements, while at the same time providing cost savings, increased productivity, and greater product reliability.

Appendix.—References

1. Araki, M., *Kensetsugyō TQC nyūmon*, 1st Ed., Vol. 2, Shokokusha Publishing, Tokyo, Japan, 1980, p. 55.
2. Araki, M., *Kensetsugyō no TQC nyūmon*, 1st Ed., Vol. 2, Shokokusha Publishing, Tokyo, Japan, 1980, p. 59.
3. Araki, M., *Kensetsugyō no TQC nyūmon*, 1st Ed., Vol. 2, Shokokusha Publishing, Tokyo, Japan, 1980, p. 60.
4. Asakaoru, T., *Kensetsugyō no TQC*, 1st Ed., Vol. 3, Tokyo, Japan, 1979, pp. 32–33.
5. Barrie, D. S., and Paulson, B. C., Jr., *Professional Construction Management*, 2nd Ed., McGraw-Hill, New York, N.Y., 1984, p. 313.
6. Beardsley, J., *Quality Circles*, 1980, p. 27.
7. Beardsley, J., *Quality Circles*, 1979, p. 28.
8. Burati, A. M., Thomas, H., Randolph, J. R., and Willenbrock, J. H., "Nuclear Construction Quality Assurance Systems," *Journal of the Construction Division*, ASCE, Vol. 107, No. CO2, June, 1981, pp. 349–360.
9. Enrick, N. L., *Quality Control for Profit*, Industry Press, Inc., 1977, p. 34.
10. Feigenbaum, A. V., *Total Quality Control*, McGraw-Hill, New York, N.Y., 1961, p. 12.
11. Feigenbaum, A. V., *Total Quality Control*, McGraw-Hill, New York, N.Y., 1961, p. 22.
12. Hester, W. T., "Alternative Construction Quality Assurance Programs," *Journal of the Construction Division*, ASCE, Vol. 105, No. CO3, Sept., 1979, pp. 187–199.
13. Juran, J. M., *Quality Planning and Analysis*, McGraw-Hill, New York, N.Y., 1981, p. 149.
14. Juran, J. M., *Quality Planning and Analysis*, McGraw-Hill, New York, N.Y., 1980, p. 158.
15. Katsudo FQC editor committee, *Kensetsugyō no QC circle*, 1st Ed., Nikakugiren Publishing, Tokyo, Japan, 1981, p. 25.
16. Katsudo FQC editor committee, *Kensetsugyō no QC circle*, 1st Ed., Nikakugiren Publishing, Tokyo, Japan, 1981, p. 28.
17. McComb, D. W., *Watch, Mind and Combine the P's and Q's, Graduating Engineer*, McGraw Hill, New York, N.Y., Jan., 1984.
18. Nai-Yuan, C., "The Application of QC Circle to Quality Control in the Management of Construction Projects," thesis presented to Colorado State University, in 1982, in partial fulfillment of the requirements for the degree of Master of Science.
19. *Quality Management and Engineering Magazine*, Vol. 12, No. 3, p. 11.
20. Seltz-Petrash, A., "Workers as Managers Boost Productivity," *Civil Engineering*, ASCE, Oct., 1980, pp. 121–125.

J. Constr. Eng. Manage., 1985, 111(2): 117-128

21. Taylor, *Scientific Management*, 1947.
22. *U.S. Industrial Outlook*, annual government document, 1982, pp. 424–425.
23. Willenbrock, J. H., and Shepard, S., "Construction QA/QC Systems: Comparative Analysis," *Journal of the Construction Division*, ASCE, Vol. 106, No. CO3, Sept., 1980, pp. 371–387.