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SESSION A

Introduction

Leere Seite
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Page vide

Quality Assurance – A Critical Review

Assurance de la qualité – Appréciation critique de la situation

Qualitätssicherung – Eine kritische Bestandesaufnahme

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SUMMARY

The paper is a short review of the current status of quality assurance as applied in the field of civil engineering structures. It discusses the range of current applications both formal and informal and highlights some of the findings of the 1983 IABSE Workshop on this topic.

RÉSUMÉ

La contribution traite des formes d'applications actuelles, formelle et informelle, de l'assurance de la qualité dans la construction. Il présente quelques résultats de l'atelier AIPC 1983 sur le même sujet.

ZUSAMMENFASSUNG

Der Beitrag befasst sich mit den gegenwärtigen formellen und informellen Anwendungsformen der Qualitätssicherung im Bauwesen und stellt einige Ergebnisse des IVBH-Workshops des Jahres 1983 zum gleichen Thema vor.

1. INTRODUCTION

Most engineers agree on what they mean by "stress", in spite of the fact that this is a complex abstract notion. The same cannot be said of "quality assurance"! Views differ as to what quality assurance is, whether it is always of benefit and whether it involves anything that is actually new. The overall aims of the Tokyo Symposium are to pool experience of quality assurance in civil and structural engineering so that the benefits and pitfalls can be more widely known.

The aim of this paper is to examine the concept of quality assurance, to discuss its applications to date and to comment on its future role. In particular, emphasis will be placed on those aspects which are considered to be controversial. An important component of this review will be the findings of the IABSE Workshop held at Rigi in 1983 [1]. This will be supplemented by a review of British thinking on this subject [2] and the the author's own opinions.

How better to start than by asking some questions? For many readers, the answers may seem obvious, to others some of the questions may seem irrelevant, but with certainty there will not be general consensus. Part of the reason for this is that the term quality assurance is semasiologically immature. One aim of the Tokyo Symposium could be to work towards a set of agreed answers. The list is not exhaustive and no attempt is made to answer the questions explicitly or in detail:

- What is quality assurance?
- Is quality assurance new; what are its origins?
- Is it applicable to all civil engineering projects?
- Should quality assurance be considered an integral part of the design-construction process, or is it or should it be separate?
- What are the elements and tools of quality assurance?
- How should it be planned and managed?
- How should quality assurance schemes be modified according to the size and nature of the project?
- Who benefits from quality assurance?
- Is it meaningful to talk of its disadvantages?
- How can the essential features of quality assurance best be communicated to the profession?

2. WHAT IS QUALITY ASSURANCE?

Let us attempt a definition. In a narrow sense, quality assurance is the process of reviewing the quality of a product (in our case a civil engineering structure or works) to assess whether it fulfils the needs of the client and, if not, taking the necessary corrective action. This definition will be considered again below.

The process may be undertaken consciously and deliberately, or unknowingly. For example, the primitive nomadic tribes of parts of central Africa still build huts from branches and leaves, to keep out animals and provide basic shelter. These rudimentary buildings need to be strong, efficient in their use of materials and meet a number of other requirements. These "builders" are probably totally unaware of the concept of quality assurance; and yet it can be argued that they practise it - their survival depends on it. Each new structure is built using the collective experience of previous generations and each is "checked" during construction against a set of known but unwritten rules.

For quality assurance to be successfully applied requires, as a minimum, an understanding of what the essential and desirable attributes for the product or structure should be. In current British engineering usage the word "quality" in the term "quality assurance" can be interpreted as "fitness for purpose". For each structure, therefore, it is necessary to determine those attributes a structure must have for it to be fit for purpose. These may be termed "performance requirements".

The word "assurance" seems more difficult but is strictly correct, coming from "ad + securus" - "to make safe from or against risks". It is interesting to note that, as in "life assurance", quality assurance does not aim to eliminate the source of the various hazards (premature death in the case of life assurance) but employs a strategy or strategies to overcome the effects of the hazards if and when they occur.

Quality assurance in its current usage, therefore, has a broader meaning than simply that of assuring the quality of the final product, as used in the initial definition above. It has developed quite naturally to mean, inter alia, the verification of the processes that give rise to the final product, together with any monitoring that is necessary during the life of the product to assure continued satisfactory performance. For civil engineering structures, quality assurance can therefore be thought of as:

> "The design and controlled application of a set of product and process verification procedures, both prior to completion of the structure and during service, to ensure fitness for purpose with an appropriately high probability."

For short it might be better described as "performance assurance", (P.A. perhaps!).

It should be noted that the concept of probability needs to be included in the above definition since there will still be many residual uncertainties affecting the engineer's ability to predict the performance of the structure during its design life, even for structures subject to the highest standards of quality assurance. Moreover, the separate attributes or performance requirements which the designer wishes the structure to have may need, for economic reasons, to be associated with different probabilities of not being achieved.

It has been agreed [1] that quality assurance for civil engineering structures should cover all phases of a structure's life from the initial planning stages right through to de-commissioning. What is less clear, however, is the extent to which the process of "quality assurance" can logically be separated from the design and construction process itself.

To return to the African tribesman: in this case, the building process and the quality assurance process are intimately linked and are carried out by the same person, but at the same time the "builder" and the "checker" are in some sense "ego" and "alter-ego". This is the basis of so-called "self-control" or "self-checking", which is the most basic form of quality assurance. A better example of the "self-checking process" is demonstrated by the person who first designs, then builds and finally test-flys a small aeroplane. He has a strong motivation to get it right! There are equally poignant examples in the field of civil engineering. On very small projects, therefore, it is clear that quality assurance is an integral part of the design-construction-use process; but what happens when the project or structure becomes larger or more complex?

Formalised quality assurance programmes started in the manufacturing industry, e.g. [3], as an extension of product quality control procedures and have shown considerable growth in areas such as the design and operation of nuclear power plants, e.g. [4], and more generally, e.g. [5]. Similar developments have taken place in many countries. However, with the exception of its involvement in the nuclear, offshore and petro-chemical industries, the civil engineering profession has been relatively slow in taking up quality assurance in a formal way. There are a number of reasons for this. First, the civil engineering profession is different from the manufacturing industry in that it is generally involved with one-off structures. Second, the construction industry is typically conservative and employs a large pool or relatively unskilled labour. Third, some poor experience with formalised quality assurance has been counter-productive. There are undoubtedly other reasons also.

3. FORMALISED QUALITY ASSURANCE IN CIVIL ENGINEERING

The need for formalised quality assurance arises partly for safety reasons, partly to control the flow of information, and partly for reasons of organisation and management.

As mentioned above, formalised approaches to quality assurance have been developed to the greatest extent in the nuclear and offshore industries - the common factors being that projects are of great complexity, involve many people from different disciplines, require high levels of investment and are such that the consequences of a major structural or other system mal-function could be serious from economic, environmental, as well as from human, standpoints.

In all these industries, the initiative to introduce formal quality assurance procedures has almost certainly come from the process engineering side rather than from structural engineers. However, in a structure such as a tension-leg oil-production platform, the structural system and the oil production system are so closely interrelated that separate treatment of the two would be foolish.

3.1 The need for a formal approach

For each sub-task that goes to make up a complete programme of work (whether it is part of design or construction), there are at least five activities that need to be undertaken:

- to decide how to do the task and how it relates to other tasks
- to decide how to check that the task has been correctly carried out
- to carry out the task itself
- to check that the task has been done correctly, and finally
- to make, as necessary, any corrections, modifications or repairs (e.g. corrections to calculations, drawings and specifications; modifications to various procedures in the construction process; repairs/modifications to parts of the completed structure; and/or, amendments to the control and checking procedures)

It is suggested that these distinct activities are always required for a successful project. In the short-term, success might still be achieved without some of the checking stages, but in the long-run such omissions are likely to lead to disaster.

In the design and construction of a relatively small structure, the number of sub-tasks is relatively small and can be envisaged by a single person. As the size of the project becomes larger (or more particularly, as the rate of expenditure increases) this is no longer possible and a sharing of responsibility becomes essential.

One way of doing this is to subdivide the work into a series of manageable parts in a linear fashion. An alternative approach is to create a parallel operational management structure in which one branch undertakes the active, physically creative work, whilst the other serves in a more passive, checking role. The latter approach can be thought of as formalised quality assurance and can be considered to be the more desirable. It is interesting to note that the two types of organisational structure have their parallels in system reliability analysis.

In situations where formal quality assurance procedures are applied, the five activities listed above are likely to be undertaken as follows: the first is the responsibility of the main engineering team, but the procedures will need to be agreed with those responsible for quality assurance; the third will also be carried out by the main engineering team; the second and fourth are part of quality assurance; and the last depends on the nature of any error found. When the sub-task itself is essentially a checking procedure (e.g. the making and testing of concrete cubes or cylinders) this remains the responsibility of the appropriate engineering team. The parallel activity for the quality assurance staff is to devise procedures to check whether the former is being correctly carried out and whether the appropriate action has been taken in the case on non-compliance.

For smaller construction projects where there is no formal quality assurance organisation, or where the q.a. functions are carried out by the same group of engineers, there is a greater risk that one or more of the five activities is overlooked. None is trivial.

In conclusion, and as agreed at the the Rigi Workshop [1], the increasing need for emphasis of formal methods of quality assurance stems from:

- the increasing complexity of engineering structures
- the increasing complexity of engineering project organisation
- the increasing public awareness of, and concern for, the safety and serviceability of structures
- the increasing costs of maintenance and repair.

4. FACTORS AFFECTING QUALITY OR STRUCTURAL PERFORMANCE

Many factors affect the quality and performance of structures and it can be argued that within economic limits each should be taken into account in quality assurance.

These sources of influence can be roughly divided into those parameters which exhibit random behaviour and which can be monitored statistically (e.g. many material properties and loads) and those uncertainties in behaviour or loading which occur as a result of a gross error being made at some stage during the design-construction-use process. The former, provided they are resistance parameters, may be made the subject of quality control measures (e.g. material properties).

Gross errors occur for a number of reasons and can be classified according to the stage in the design-construction-use process at which they occur and according to whether they induce "failure" in a mode which could have been reasonably predicted [6]. They are generally less amenable to statistical analysis since they tend to form a non-homogeneous population. However, there is no reason why they should not be included in probabilistic models of structural behaviour, see e.g. [6]. Nevertheless, it is clear that quality assurance can provide effective control against only those types of gross error which can be foreseen. It is of almost no value when the profession as a whole is unaware of a phenomenon or a combination of circumstances which may cause failure or inadequate performance. Fortunately these circumstances are rare. Most failures (in general, failures to meet performance requirements) occur for reasons that are well understood.

A topic related to the occurrence of gross errors is data control - the handling, storage and communication of numerical data and other information. The possibility exists for incorrect actions or decisions to be taken because of incorrect information. The potential for this increases with the size of the project and the number of personnel involved. On very large projects, the amount of information required for the successful completion of the project is enormous - specifications, drawings, revised drawings, material test certificates, results of non-destructive tests on the partially completed structure, variation orders, minutes of meetings, as well as all the documentation necessary for the financial and labour control, together with many other categories of information. On a recent large project known to the author, approximately 200,000 non-destructive tests were made and reported on alone, each requiring subsequent action.

What is important is to be able to sort the essential information from the non-essential in a reliable way. The creation of a system which will enable this to be done comes within the scope of quality assurance. There would appear to be considerable potential for computerised data bases in this context.

5. SOME FURTHER COMMENTS

Partly because of the large amount of effort that has to be put in to information handling, quality assurance is often <u>seen</u> by outsiders as a purely paper exercise with few real benefits. However, with the types of quality assurance schemes that are now being introduced by some major companies [7] this does not seem a likely outcome. The introduction of formalised quality assurance has given an opportunity for revisions of management structure and a better definition of roles. Nevertheless, without personal motivation, individual staff may perform as badly under one scheme as another.

Unfortunately, controlled experiments to determine the relative overall advantages of various methods of project management and quality assurance (formalised or informal) do not seem to be practical.

Finally, two further criticisms. First, many current quality assurance schemes seem to operate within the rather narrow limits of existing codes. This seems far too restrictive and not sufficiently far-sighted as many design problems arise at the interface between codes. Second, there is a hint in some quality assurance documentation, that the purpose of the exercise is the collection sufficient information to prove that the structure is fit for purpose. Is the prospect of possible future litigation the real driving force?

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Quality Assurance: Basic Data from European Experience

Assurance de la qualité: résultats de l'expérience européenne

Qualitätssicherung: Ergebnisse aus europäischer Erfahrung

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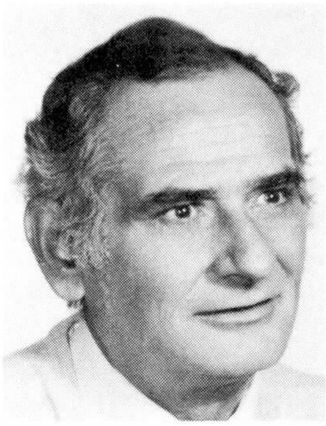

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SUMMARY
In the last decade a new mentality in the construction field has spread all over Europe. Differences between the traditional and the present approach are shown, as well as the various stages considered today in the building process. Quality assurance measures to prevent technical and human errors are briefly described.

RÉSUMÉ
Une nouvelle mentalité s'est installée depuis 10 ans dans le domaine de la construction, partout en Europe. L'auteur montre les différences entre les approches traditionnelles et nouvelles du processus de construction, ainsi que les différentes étapes considérées aujourd'hui. Il décrit les mesures prises pour éviter les erreurs techniques et humaines.

ZUSAMMENFASSUNG
Seit 10 Jahren breitet sich eine neue Grundeinstellung im Bauwesen Europas aus. Die Unterschiede zwischen dem traditionellen und dem heutigen Ablauf des Bauprozesses sowie die heute betrachteten Stufen werden erläutert. Massnahmen gegen technische Fehler und menschliches Versagen werden kurz beschrieben.

1.- INTRODUCTION

A new mentality in the construction field is spreading all over Europe since ten years ago. Tables 1 and 2 concerning basic and practical aspects show the main differences between the traditional and the present approach.

The new approach is applied in major projects and slowly moves towards medium projects. Operative methods for application of this philosophy are not yet available in a systematic way.

2.- THE BUILDING* PROCESS

The building process is considered as a set of activities going from NEED to USE. It starts from an user's need and ends in an user's satisfaction. The starting point and the arriving point being the same, the process is not linear but circular or, rather, spiral. The cause-effect mentality moves to a network mentality. The main stages in the process and their concern with quality are shown in Table 3.

3.- QUALITY ASSURANCE MEASURES (QAM)

At each stage (Table 3) a set of QAM are taken. The aim of these measures is to clarify situations, to identify responsibilities and to prevent technical and human errors.

Appropriate lists of QAM are not yet consolidated. A simple example of QAM lists dealing with stages A,B,E and H is offered in Table 4. Lists dealing with stages C, D and F are not presented because their length.

4.- PREVENTIQN OF TECHNICAL ERRORS

Measures against technical errors constitute Quality Control Systems and are applied in all stages of the building process. In Europe, quality control practices are in general satisfactory as far as materials and execution is concerned but they have to be improved in the field of planning and design.

Non-industrially produced materials are normally sampled and tested at the job.

Industrially produced materials are divided in two cathegories:

a) Non-traditional materials for which a standard does not exist. They are covered by an AGREMENT system, sponsored by UEAtc. Certificates are automatically convalidated from one country to another in western Europe.

b) Traditional materials are those covered by a standard. These materials are submitted to CERTIFICATION SCHEMES on national basis. The harmonization of national standards is a dificult task but this problem is expected to be overcome in some years, at least in the frame of the European Economic Community.

As far as Execution is concerned, contractors submit their own QA Programs describing the systems they follow to ensure the execution control. Some european Codes describe different levels of execution control and, in some cases, they are related with different values of partial safety coefficients. A formalized QA Manual for Contractors is under preparation within CEB (Comité Euro-international du Béton).

*) Building = Any construction

TABLE 1.- BASIC ASPECTS

	TRADITIONAL APPROACH	PRESENT APPROACH	REMARKS
The Building* process	DESIGN CONSTRUCTION	The same, plus: PLANNING AND USE	Simultaneous consideration of all stages Mutual influences
Reasoning	LINEAR	NET-WORK	Causes and effects interact each other
Requirements	SAFETY SERVICEABILITY DURABILITY ECONOMY AESTHETICS	The same, plus: AMBIENT ADEQUACY . . . . . ACCESIBILITY . . . . REPLACEABILITY . . . . . . ADAPTABILITY . . . . DESTRUCTIBILITY	- Community is taken into account - Inspection areas - Elements may have different life spans Easy replacement facilities without interrupting the function - Function varies with time. Reasonable degree of functional adaptability - Eventual demolition is taken into account in the design
Actions concept	LOADS AND IMPOSED DEFORMATIONS (Mechanical concept)	The same, plus: ENVIRONMENTAL ACTIONS (Physical-Chemical concept)	Designer's concern for Safety extended to Durability (Life time aspects)
Safety concept	DESIGNER CALCULATES FOR CODIFIED ACTIONS (Passive concept)	DESIGNER IDENTIFIES RISKS AND RESPONDS TO EACH ONE. (Active concept)	- Risks are either avoided, or neutralized through design, or accepted beforehand - Hazard Scenarios and Safety Plans are prepared by the designer

* Building = Any construction

TABLE 2 - PRACTICAL ASPECTS

		TRADITIONAL APPROACH	PRESENT APPROACH	REMARKS
Main concern		NEW STRUCTURES	EXISTING STRUCTURES	Increasing consideration to life time aspects
Leading parameters		MONEY TIME	The same, plus: QUALITY	Quality is focussed from the starting of the process
Parameter to be optimized		CONSTRUCTION COST	LIFE TIME COST	Life time cost includes construction cost and operating costs, e.g.: - maintenance (inspection,cleaning) - repair in case of damages - energy consumption - administration, guards, security
Emphasis in		EXECUTION	PLANNING and DESIGN	Earlier decissions involve stronger consequences
CONTROL OF	Materials	Acceptance tests at job	Quality certified beforehand (Certification Schemes)	- A Certification Scheme requires: a) a previous approval b) a production control, and c) an external inspection of b)
	Execution	Engineer controls Contractor	Contractor controls himself under the Engineer's supervision	
	Design	Exceptional	Fundamental	- For Execution, the previous approval refers to the Contractor's QA Program
Care for		TECHNICAL ERRORS	The same plus: ORGANIZATIONAL AND PERSONAL ERRORS	Quality Control extended to Quality Assurance

TABLE 3 — STAGES IN THE BUILDING* PROCESS

STAGE	ACTIVITY	GOAL	REMARKS
A	IDENTIFICATION OF THE NEEDS	TO FOCUS quality	Is a building* the best solution for the needs?
B C	PLANNING OF PROJECT PREDESIGN	TO DEFINE quality	Performance requirements
D	DESIGN	TO SPECIFY quality	Technical solutions
E	PLANNING OF CONSTRUCTION	TO OFFER quality TO DECIDE quality	- Preparation of basis for tender - Offers presentation: specific parameters - Decision
F	CONSTRUCTION	TO PRODUCE quality TO CONTROL quality	- Planning of execution - Execution
G	DELIVERY	TO VERIFY quality	- Building quality - Quality of documentation
H	USE	TO KEEP quality	- Maintenance - Periodical inspections

* Building = Any construction

(Source: CEB Task Group I|3 "Quality Assurance Program")

TABLE 4 - QUALITY ASSURANCE MEASURES

STAGE A - IDENTIFICATION OT THE NEEDS	STAGE B - PLANNING AND PROMOTING
- Description of actual and updated needs - Description of possible solutions to satisfy the needs - Justification that building is the best solution - Formal recording of who is responsible for the decision	- Appointement of the Project Manager - Investigation of actual requirements of the owner - List of authorities to be consulted - Description of restrictions (cost, time, legal; social, environmental, ambient impact) - Description of soil conditions

STAGE E - PLANNING OF CONSTRUCTION	STAGE H - USE
- Checking the design and fulfilling the lacunae - Preparation of basis for tender, including quality requirements and criteria to evaluate the offers - Assesing of contractors proposals for quality assurance - Consideration of the effect of a failing firm (bankruptcy) - Choice of the contractor	- Consideration if Commissioning is necessary - Application of the Utilisation Manual - Application of the Inspection Manual - Recording of changes and modifications

Source: CEB Task Group I|3 "Quality Assurance Program"

5.- PREVENTION OF HUMAN ERRORS

Human behaviour has to do with personal and organizational errors. It concerns all stages of the building process and is recognized as the main source of construction failures. In human behaviour the relevant variables are not numerical but literary as they have to be described with words and can not be described with figures: the level of professional knowledge, the degree of severity of an inspector, etc, are simple examples.

Literary variables can be mathematically studied by means of the fuzzy sets theory but practical engineers are not in a position of waiting for results from research experts. For the moment being, the best tools to be used in this field are cheking lists, event trees, fault trees and similar manegement technics. At the IABSE workshop of Rigi (1983) the human factor was deeply discussed; in the following, a simple methodology to deal with it is offered, based in studies carried out by BLAUT.

A.- Any task at any stage is considered to be divided in two phases:

a) Planning of the task
b) Execution of the task

B.- In the planning phase of a task, the following aspects must be assessed by means of appropriate check-lists (each check-list develops the underlined word):

1.- The goodness of the task definition
2.- The necessary means to carry out the task
3.- The necessary knowledge to carry out the task
4.- The quality of human communication between the participants
5.- The level of motivation of the participants

C.- The quality of the result depends on these five parameters, listed from less to more importance. Granted that the task is well defined, the influence of parameters 2, 3, 4 and 5 is recognized to follow the symbolic formula:

$$\text{Quality of Task} = (\text{Means}).\ (\text{Knowledge})^2.\ (\text{Communication})^3.(\text{Motivation})^n$$

were n can take values higher or lower than zero, thus leading either to a great quality or to a null quality.

D.- Check-lists for each parameter can be prepared with different degrees of complexity. As an example, two short lists concerning communication and motivation are shown in Tables 5 and 6.

E.- During the task execution the same ideas apply.

6.- RESEARCH IN PROGRESS

At present, much research is progressing in Europe on the field of Quality Assurance, mainly on national levels. As far as international level is concerned, the following bodies should be mentioned:

- Joint Committee on Structural Safety (JCSS), in the safety field. See IABSE Reports, Volume 35 "General Principles on Quality Assurance of Structures" 1981.

- IABSE, in the structural field. See IABSE Reports, Volume 47 "Workshop at Rigi: Quality Assurance within the Building Process", 1983.

- Comité Euro-international du Béton (CEB), in the concrete field. See Bulletin nº 157 "Quality control and quality assurance for concrete structures", Prague 1983.

- European Organization for Quality Control (EOQC), Section for Construction Industry, in the general construction field. See Proceedings of Symposia in Madrid 1976, Madrid 1979, Torino 1982 and Brussels 1985.

TABLE 5.- CHECK-LIST TO ASSESS THE GOODNESS OF COMMUNICATION
1.- Have all participants a clear description of the aim?
2.- Had all participants the opportunity to know each other?
3.- Had all participants the opportunity to add their own ideas?
4.- Were the various tasks clearly assigned to each participant?
5.- Are participants frenquently informed about the running of the work?
6.- Does each participant receive regularly a positive or negative evaluation about his/her work?
7.- Are critics and suggestions from participants accepted?
8.- Do all participants receive a feed-back about the results achieved?

TABLE 6.- CHECK-LIST TO ASSESS THE GOODNESS OF MOTIVATION
1.- Were all participants selected according to their knowledge and experience?
2.- Were and will be the real needs of participants (Maslow, Herzberg) taken into account?
3.- Are the participants well conducted by their inmediate superior?
4.- Are all chiefs giving a good example to the members of their teams?
5.- Are all chiefs taken care of their own motivation?