Workshop Summary

Résumé des résultats de l'atelier

Zusammenfassung der Ergebnisse des Workshops

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SUMMARY
This workshop summary is an attempt to summarize the main currents of discussion, the most important arguments and the agreements and definitions reached. What cannot come through this summary is an impression of the intensity, openess and sophistication of the discussions at Rigi which certainly will be remembered by everybody who attended the workshop. To give the overall conclusion: Quality Assurance in the overall building process is necessary. It should be seen in the application of a comprehensive set of measures and activities aimed at assuring quality. However, "paper tigers" should be vigorously avoided.

RESUME
Ce résumé des résultats de l'atelier est une tentative de synthèse des courants principaux de discussion, des arguments les plus importants et des accords et définitions obtenus. Ce qui ne peut apparaître au travers de ce résumé, c'est l'intensité, l'ouverture, la franchise et le haut niveau des discussions de l'atelier, lesquelles resteront certainement en mémoire de tous les participants. Le résultat principal de l'atelier peut être brièvement résumé: l'assurance de la qualité dans le processus de la construction est une nécessité. Il s'agit là de l'introduction et de l'application d'un paquet adéquat de mesures et d'actions propres à promouvoir la qualité. En tout état de cause, il faut absolument éviter de produire des "tigres de papier".

ZUSAMMENFASSUNG
Diese Zusammenfassung der Ergebnisse des Workshop ist ein Versuch, den Inhalt der Diskussionen, die wichtigsten Argumente und alles, was an Konsens von Auffassungen und Definitionen erreichbar war, festzuhalten. Was nicht zum Ausdruck kommen kann, sind die Intensität und Offenheit sowie das hohe Niveau der Gespräche auf dem Rigi, die den Teilnehmern sicher in guter Erinnerung geblieben sind. Das Hauptergebnis hier in aller Kürze: Qualitätssicherung im Bauprozess ist nötig. Es geht dabei um die Einführung eines geeigneten Paketes von Massnahmen und Aktivitäten, das geeignet ist, Qualität zu fördern. Die Entwicklung von "Papiertigern" ist dabei jedoch mit allen Kräften zu verhindern.

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1. Introduction

This introduction to the workshop summary is perhaps the most appropriate place to address the very intriguing question posed in the Introductory Report by Turkstra, Allen, Knoll, namely "are we not trying to cure a healthy patient?", since if this question is clearly answered in the affirmative further discussion would appear to have only marginal relevance to the real world. The fact that the workshop drew attendance from a broad range of people with interests in the building process (contractors, consultants, regulatory agencies, researchers, teachers) and the intensity and seriousness of discussions at the workshop are in itself a measure of the concern felt about quality achievement in practice. Quality Assurance in the overall building process is necessary. It was pointed out repeatedly, however, that quality should not be associated only with structural collapse as distinct from long term behaviour as then the answer to the question probably approaches "yes". In practice, there are many difficulties with durability, structural serviceability and the quality and performance of non-structural components in buildings - mostly unreported to the public at large. It was felt that the incidence of these problems differs from country to country and from project to project, but that clear-cut reasons for this could not yet be given.

It is apparent that the answer to the above question is dependent to a degree upon the definition or meaning attached to the term "Quality Assurance" and to its individual components "Quality" and "Assurance". How to define these terms in a meaningful way occupied many minds during the workshop. In Section 2 below some of the considerations of importance to this aim are noted. Also discussed are some factors which influence quality and quality assurance and a number of techniques and terms of relevance to quality assurance.

In Section 3 of this report, the more specific findings of the workshop related to application in practice, regulatory requirements, education and research needs are described.

The general purpose of the workshop summary is to attempt to summarize in a reasonably organized and coherent fashion the main currents of discussion, the most important strands or arguments, including those at variance with mainstream thinking, and the consensus views and definitions reached. Clearly, such a task cannot be undertaken in a manner which is completely satisfactory to all participants, the personal views of the writers must intercede consciously or unconsciously.

The summary report has been based largely on the written summaries prepared at the conclusion of each group session by the relevant group reporter, together with the final summaries from each group. Each member of the editorial committee then prepared a selected part of this summary report for review by each of the other committee members. The final version then was harmonized, rearranged and partly rewritten by an even smaller editorial group. It is hoped that some degree of objectivity in reporting has been achieved with this difficult task. It must also be kept in mind that the catalogue of concepts having to do with quality assurance is altogether not consolidated. If the reader and former attendant to the workshop therefore may find his thoughts reflected in words and ways not quite coincident with what he is used to, the editorial committee asks leave until, hopefully in the near future, such a bank of clear and distinct concepts may come into existence. Finally, the responsibility for errors must be taken by the editorial group.

2. Elements of Quality Assurance

2.1 About Definitions

"To define always involves a contradiction. You cannot discuss a subject if you do not define it beforehand, but you cannot define until you dominate the subject." (A.G. Meseguer, 1983)

This fundamental contradiction was evident during the workshop. Several attempts were made to define "Quality" and "Quality Assurance" because many participants felt that to not do so would inhibit progress. Reference was made to definitions given elsewhere, but none of these seemed to eliminate all objections. Nevertheless, there was considerable agreement about the concepts involved in defining these key words, and these are discussed in some detail below. It was also felt that a premature definition, not fully based on all considerations, could well lead to a lack of useful progress through the possible misunderstanding or false leads that might be created.

2.11 Building Process

The building process comprises the following phases: planning, design, construction, use, maintenance, possible repair or alteration and demolition. It can be viewed as a network system and includes all decisions and activities leading to the creation or assembly of the building or other structure. During the building process the quality of that product is affected by all the events making up the building process.

2.12 Quality

Quality, according to the Oxford dictionary, is "degree of excellence, relative nature or kind or character of something". For pragmatic engineers, this is not very helpful, since other, undefined terms are introduced. What can be said about "quality" in terms of the building process?

Quality may be associated with different subjective meanings related to the various parties involved in the building process. For the owner of a building, its quality might imply ability to satisfy a given need (e.g. raise income from rental without incurring high maintenance charges). It is evidently a largely subjective concept since level of income, maintenance costs, etc. and hence profit are only partly comparable to baseline commercial yardsticks.

This view of quality corresponds with the concept sometimes espoused by other industries "Quality is what the client wants" - a fairly vague statement, as in most cases he does not know precisely what he wants, but with hindsight may tell you precisely what he did not want. And what is wanted by the client might very well not coincide with the requirements of the later owner and user.

For the designer, every design is an attempt to satisfy the clients requirements within a set of constraints. Quality of the design then would be the degree of satisfaction in relation to all constraints and requirements related to the intended use of the building or other structure.

For a contractor, quality is likely to be related to the degree to which the building meets the specified contract requirements.

To a large degree, quality is referenced against externally defined criteria, but also with subjective components to judge the relevance and/or adequacy of the specified requirements.

Another view of quality is that which might be held by the direct users of the building or structure. They are interested in the degree to which it is suitable for its current use. This is again a partially subjective viewpoint, which would encompass the perceived safety of the structure, its serviceability (e.g. deflections, vibrations) and would also include the standard and performance of the interior (elevators, doors, windows, wall finishes, floor coverings, ceilings, lighting, ventilation, temperature, etc.) including operational features (e.g. energy consumption).

A final but very important view is that of the public at large, the neighborhood and passers-by, who are affected by the building or structure in more indirect ways. To these groups, partly represented by public or building authorities, the measure of quality of a structure relates to the extent to which they are affected by its existence, or its construction.

How to unite these different but partly overlapping viewpoints is not at all clear with the result that it was doubted whether it is practicable or even desirable to strictly define "quality" in its broadest sense. A more useful approach might be to leave the definition of quality to the specification of the specific operational and performance requirements to be met for each particular project.

2.13 Quality Assurance

Dictionary definitions of "assurance" refer to "formal guarantee" or "positive declaration", but those meanings relate only partly to the needs of the construction industry at large. It was finally agreed at Rigi that quality assurance requires a system of positive action to attain the desired quality.

The term "Quality Assurance" therefore encompasses all measures necessary to ensure compliance with the set of given quality objectives and constraints. Quality assurance thus must include consideration of organizational, motivational, legal and other relevant matters and must take into account all aspects of quality. It is important to understand that quality assurance is more than quality control, with which it is sometimes confused.

These concepts are not new and quality assurance measures can be considered to have been implicitly applied within all successful projects in the past. However, need for increased emphasis on quality assurance, its planning and its implementation arises from:
- increasing complexity of engineering structures
- increasing complexity of engineering project organization
- increasing public awareness of and concern for safety and serviceability of structures
- increasing costs of maintenance and repair.

A number of proposals for a formal definition of quality assurance with respect to the building process were considered. The definition most favoured derives from the JCSS document [1] and was largely agreed upon:

"The function of quality assurance is to ensure that all activities influencing the final quality of a structural system
- are based on clearly defined fundamental requirements together with operational and environmental conditions
- are correctly carried out by competent personnel and in accordance with previously elaborated plans which include clearly defined responsibilities

and that this is verified by means of appropriate documentary evidence."

It was also agreed that these definitions should not lead too far towards a formalized, documentary system of quality assurance which might very well be counterproductive and turn out to be the "paper tiger" introduced in the Introductory Note by Bosshard. In fact, the fear of excessively formalized, bureaucratic quality assurance programs was raised many times during the workshop. It was felt that the quality assurance program instituted for a particular project should be in keeping with the size of the project, its importance and its potential for violating the quality requirements of any of the parties involved. In particular, it is evident that the simple adoption of formalized systems of quality assurance such as employed in the aerospace industry, in the nuclear industry, or in the defence industries is not appropriate for the normal building project.

2.2 Factors which influence Quality and Quality Assurance

Throughout the workshop many factors were mentioned which participants felt should be taken into account in the context of quality assurance. The most important of these factors are discussed below.

2.21 Legal Framework

It was noted that national legal systems may exert a certain influence over the attainment of quality. In countries with Anglo-Saxon legal systems, the respective responsibilities of designers and design checkers are presently in a state of flux. This uncertainty and the potential threat it implies, can affect the way different parties see their respective roles and responsibilities and hence can affect quality.

As noted in the Introductory Note by Turkstra et al., the lack of legal constraint can be detrimental to quality; it can also (as in France) lead to others (e.g. insurance companies) taking on a pseudo-legal role.

It was considered that in the past engineers have not participated sufficiently in formulating the legal constraints under which they operate. Another aspect is the increasing entry of the legal profession into the settlement of disputes, the greater tendency to seek legal redress, etc.

2.22 Contractual Arrangement

Contractual arrangements have a decisive influence on the organization of the building process and on technical specification. Codes and standards are often components of contractual agreements. Certain types of contractual arrangements may be preferable with respect to achieving the design performance requirements without gross errors and deficiencies in communication but this depends on the size of the project. It must be kept in mind that contractual provisions largely determine the incentives of the parties, in particular corporate parties. This will be dealt with in more detail below.

2.23 Insurance

It was suggested in the Introductory Note by Turkstra et al. that the safety net provided by insurance might be a disincentive to careful work. However, one could imagine that organizations relying on such an approach would quickly become known and might incur very high premiums. On the other hand, organizations may attempt to reduce their insurance premiums through specific safety programs, which often might be conducted in co-operation with the insurance companies.

The involvement of insurance companies in this type of activity has made useful contributions through the systematic collection of data and the publication of common hazard situations (e.g. in the field of fire protection).

2.24 Experience

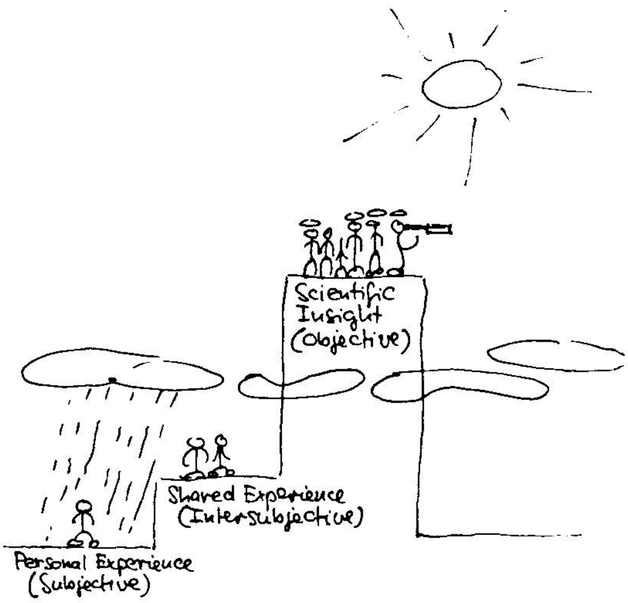
Experience has traditionally formed the main basis of engineering knowledge and exists in very diverse forms such as:

- Personal experience of engineers. This is mostly communicated from person to person, or not at all, for various reasons.
- Codes and standards. To a degree these represent collective past experience and are approximations to a general level of quality acceptable to society.
- Literature. This source of experience is strongly biased towards accounts of successes and those of major failures. More mundane cases, successful or other-

wise, are seldom recorded.

- Depositories of failure accounts. These are kept at insurance companies, state administrations and in some specialized research centres. Efforts have begun recently to make some of this data accessible.

The major problem with experience is the difficulty of its effective communication. Engineers rely mainly on their own personal stock of experience, which is often too narrow a base. However, it is well known that everybody learns mostly from his own errors and mistakes, if at all.



Cartoon by W. Bosshard (Rigi 1983)

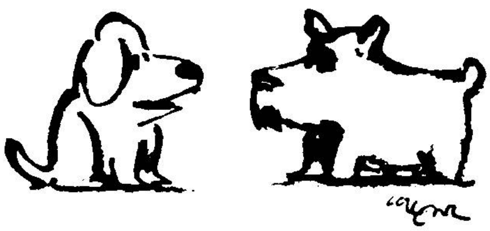
2.25 Common Sense

Common sense can be seen as a factor influencing quality assurance through the subjective input it supplies as a substitute for formalized objective knowledge or experience. This applies particularly to systems of high functional complexity, such as the building process and related quality assurance.

2.26 Errors

All gross errors are of human origin (see Introductory Note by Melchers, Baker, Moses) and are basically initiated by specific individuals. However, in the case of damage it is often difficult to trace the individual concerned because, simultaneously, several aspects, activities and/or individuals are involved in the building process. At best, a "hierarchy" of blame can be established.

Errors with major consequences often have significant effect on subsequent quality assurance programs, becoming then part of "experience". However, not all errors are revealed and may even be deliberately hidden, thus eluding possible action through quality assurance.



"I attribute it to human error. But then I attribute *everything* to human error."
Cartoon from The New Yorker, 1979

2.27 Motivation, Incentives and Working Conditions

Motivation emerged by general consensus as one of the single most important factors governing efficiency and economy of quality assurance. This is almost self-evident since no quality assurance procedure can be executed without human individuals preparing it, implementing it, and acting it out. It is clear that the thoroughness of most quality assurance procedures, formalized or not, depends directly on the attention paid to the tasks by the individuals concerned. Experience in other industrial fields (e.g. automobile manufacturing) shows that motivation has a strong influence on the attention given to job tasks and hence, to error detection, error correction and the quality of product produced. There appears to be no reason for suggesting that a similar situation does not hold in the building process (see [1] and others).

2.3 Tools for Quality Assurance Planning

Some basic tools and techniques used in quality assurance planning are considered briefly below.

2.31 Hazard Scenarios

The hazard scenario approach is probably the most general and effective tool in handling quality assurance problems. A hazard scenario is defined by one so-called leading hazard assigned to a given stage in the building process and by considering all other companion effects as associated hazards. In this approach, it is assumed that the leading hazard has become fully "active" and the hazard scenario is explored with respect to its development in time, its hazard potential, its likelihood of occurrence and the measures which could be taken to counteract it. This approach relies to a large extent on the imaginative capacity of the person who uses it.

It should be mentioned that leading hazards and accompanying hazards are not restricted to conventional hazards from the natural and man-made environments, but also comprise hazards arising from human unreliability, errors, omissions, misunderstandings, gaps in information flow, etc. in the planning, design, construction and use of buildings and other structures.

Clearly, the building process gives rise to a great variety and multiplicity of hazard scenarios, since at each stage of the process each of the many possible hazards can be taken as the leading hazard. The difficulty with the hazard scenario approach is then to abstract from all possible hazard scenarios the relevant ones. Imagination and common-sense, however, will help to immediately make this selection and reduce hazard scenarios to be analyzed to a reasonably small number. The application of brainstorming techniques in small groups of well chosen experts may broaden imagination considerably. Other formal techniques mentioned below may be helpful in defining and exploring hazard scenarios.

2.32 Event Trees

Event trees attempt to trace the development of events to their possible consequences, allowing for each possibility to be traced whenever there are choices possible. Event trees are a powerful tool for exploring hazard scenarios and its hazard potential. The first event at the root of the event tree is taken as the leading hazard becoming effective. As is the case of the hazard scenario approach, event-tree techniques require imagination and discipline in the people using it.

2.33 Fault Trees

Fault trees are a formalized procedure in which the events necessary to lead to a given fault are traced out. The emphasis is on the given fault or failure event and how it may arise. In a sense fault-tree analysis is the inverse of event-tree analysis.

2.4 Types of Control

2.41 Self Control

Control or checking of one's own work is the most basic element of quality assurance. It depends directly on the attention given to the work in hand. For the conscientious worker, free association of ideas and thoughts during off-work hours can touch on aspects which escaped attention in the confines of the work environment.

Self control is mostly informal, or of very simple form (e.g. using checklists). The nature and the efficiency of self control depends on the working habits, the motivation and incentives of the individual.

2.42 Internal Control

Checking the work of one's associates working within the same office or company is the basis of internal control. It is a relatively cheap and effective means of control since the checking occurs early in the production process and potentially expensive errors can be detected before resources are committed.

Internal control may result from personal initiative or may be established by the office or company management. Internal control may be required by an external body (e.g. the client).

2.43 External Control

External checking of work may be required as a formal activity (e.g. by Prüf-Ingenieur, building authorities or other offices or consulting engineers), but in many cases results from the activities of the next participant in the building sequence and has considerable potential for the timely detection of errors. Attention is called to the aspects of independence and effectiveness of external control.

2.44 Check Lists

A check list is a list of sub-tasks which, ordinarily, should be performed to achieve a larger task. If the overall task and its components are well defined and independent of the precise input data, the check list can be potentially all-embracing and complete (e.g. check lists for pilots). More commonly, however, the check list is merely an "aide-memoire" to help the user focus on matters potentially of importance. Since it is impossible in such cases to foresee all possible variations in input, check lists are usually not complete, and should not be considered as such.

Whether a check list is used, and how well it is used, depends on the organization, and the incentives and motivation which exist. Equally, there is the potential danger that a check list may be used as a substitute for clear thinking about the problem in hand.

3. Applications and Needs

3.1 Implementation of Quality Assurance

3.11 General

This section is concerned with the implementation of quality assurance into the offices and companies involved in building activities and within the building process itself. Apart from giving some recommendations of a more general nature, the workshop succeeded in identifying problems, rather than finding ready-to-implement solutions. Because of shortage of time, some aspects such as liability and guarantee regulations, contractual arrangements and efficiency of external control could not be discussed in notable detail.

3.12 Business Concerns Versus Quality Assurance

It was considered essential that account should be taken of the various business interests of the parties involved in the building process, when promoting the implementation of quality assurance. In this respect, it should be acknowledged that offices and companies are legitimately interested in their business profit and may only be concerned about quality and professional ethics in second place, a view which, however, was regarded as too negative by some participants. Nevertheless, these financial influences definitely deserve attention as they do represent the major incentives to corporate participants.

It was emphasized that various factors and conditions favourably affecting quality are also important features of advanced management policy, which is - by definition - strictly oriented towards maximizing the business profit of a company. Thus the motivation of staff to produce quality requires a strong concern of all employees for their work and a preparedness to share responsibilities. This will generally result in increased productivity as a by-product. Other important aspects are adequate allocation of responsibilities, tasks and duties, clear information flow paths as well as adequate project scheduling.

3.13 Tendering and Awarding

Quality provisions, in excess of the standard provisions, for ensuring quality and for detecting human errors in the various stages of the building process have to be paid for explicitly. If contracting involves a tendering procedure, it is important that the client specifies his quality expectation, so that the tenderers can base their bids on this expectation. However, it may be difficult for the client (and even his consultant) to describe his quality expectation comprehensively in terms of a catalogue of specifications. The introduction of quality classes as defined in Norwegian and Swiss standards were considered to provide some aid to the client for describing his quality expectation. Comprehensive guidelines for assessing tenders are difficult to devise, but it was considered important that some criteria should be given. These criteria could support the personal judgement of the client (or his consultant) and could also give some assistance to the tenderer. A possible basis for the elaboration of criteria is given by the following list known as the "18 Principles Universal Model":

1. Organization
2. Quality Assurance Program
3. Design Control
4. Procurement Document Control
5. Instructions, Procedures and Drawings
6. Document Control
7. Control of Purchased Material, Equipment and Services
8. Identification and Control of Materials, Parts and Components
9. Control of Special Processes

10. Inspection
11. Test Control
12. Control of Measuring and Test Equipment
13. Handling, Storage and Shipping
14. Inspection, Test, and Operating Status
15. Nonconforming Materials, Parts or Components
16. Corrective Action
17. Quality Assurance Records
18. Audits

3.14 Formalized Methods of Quality Assurance

Formalized methods received considerable attention during the workshop. There was consensus that formalized quality assurance can be overdone and then becomes counterproductive. It may not be compatible with creative work and thinking and may discourage initiative.

This points towards a separate optimization problem in a subspace of parameters which have little to do with the cost function usually employed as a workhorse for optimization among conflicting relative requirements. Research into the principles of management may eventually reveal the whereabouts of a reasonable middle road between a free-for-all non-organization on the one hand, and an exaggerated paper tiger of quality assurance on the other hand. The coordinates of that road will vary widely and will depend on the particular building process and the required product.

Various measures belonging to formalized quality assurance were discussed such as
- elaboration of detailed information flow paths
- detailed control plans
- extensive identification systems for documents
- verification by quality assurance experts
- special job description per project
- checklists and detailed operation descriptions
- extensive documentation procedures
- formal application of planning aids, such as hazard scenarios and logic trees.

It was felt to be of essence that given the diversity of the construction industry, such procedures are recognized as open-ended and incomplete by the user. They must therefore include statements to that effect, forcing the user to reflect beyond the letter of the program, corresponding to Murphy's law in the form: If you think you checked everything, obviously you have overlooked something.

A few very general conclusions emerged:

- All formalized quality assurance procedures must be suited to the case of application or be adapted as necessary. For example, hazard scenario exercises concerning conceptual decisions must be performed at the earliest stage of the building process, since as time progresses some options may no longer be possible and conceptual errors will then be carried forward, if it is no longer possible to correct them. Conversely, more detailed procedures cannot be employed at the early stages of the building process and must be postponed until sufficient information becomes available.

- Formalized procedures include the danger of being used for "satisfaction", inducing the belief that if the letter of the regulation has been followed, then everything will be alright. The testing of concrete cylinders is an example where large numbers of documented tests tend to give the impression that the job was followed closely, whereas there may be very little relation between the properties of the concrete delivered to the site and the quality of the structure being built. The mere quantity of documentation may then distract from the need to check other, possibly more important, features. It may even mask the absence of some components of quality assurance or control.

- Formalized quality assurance is a tool and must be instituted and used as such in a judicious manner. "Tuning" to the requirements of each situation is of the essence.
- It may be concluded, that the issue is not to decide "pro or con" formalized methods, but to arrive at an appropriate degree of formalization in each individual case.
- Where highly formalized quality assurance is considered to be necessary, detailed quality assurance plans should be specified jointly by the client, the designer, the contractor, the building authority and possibly other participants.

3.15 Quality Assurance Experts and Departments

The appointment and the activity of professional quality assurance experts belong to the group of formalized provisions discussed in the preceding section. Because of the importance of quality assurance departments in other industries, their possible efficiency for the construction industry should be studied.

To some extent, knowledge and independence are incompatible in the context of checking. Groups inside companies performing certain tasks will generally command detailed knowledge but no independence, whereas external quality assurance managers or audit experts will usually have more independence but less knowledge. In the sense of a compromise, it may be assumed that quality assurance departments - if reporting directly to the managing board - are just sufficiently independent and knowledgeable as well.

Various aspects deserve attention:

- Small firms can generally not afford to appoint staff members to work exclusively on quality assurance matters.
- The qualification requirements for an ideal quality assurance expert are extremely high (personal and professional). Even large firms can hardly afford to remove their best staff from the actual production or project organization and entrust them exclusively with quality assurance tasks.
- The tasks of quality assurance experts may range from the checking of documents for construction, site inspections, supervision of critical phases of the work and providing technical advice, to the (internal) auditing of organizational matters, data collection, education programs etc. This means, that there are "technical" quality assurance tasks on the one hand and more or less "organizational" tasks on the other hand.
- Certain technical tasks could be allocated to staff members who remain in the actual working process and are only entrusted with additional duties. In their particular quality assurance function they are directly related to the managing board. Only the organizational - auditing - tasks are allocated to exclusive quality assurance experts or are even performed by the managing board or the principal himself. This approach may prove to be efficient and also agreeable for small firms.

It is clear that the manner in which quality assurance functions are implemented into the organization of a firm is the responsibility of the company management. It should be their concern, that detailed knowledge and independence become sufficiently compatible concepts with regard to their organization of quality assurance functions.

3.16 Motivation and Working Conditions

As mentioned in section 3.12, a person's or a group's motivation is strongly influenced by the quality of management. Some relevant positive motivating factors

are:
- financial benefits
- status improvement or promotion
- appreciation
- added responsibility
- professional satisfaction
- intellectual interest or challenge

while some negative factors include:
- poor management
- insufficient or uninteresting work
- poor working environment
- insufficient rewards (salary, etc.).

Some factors to be considered in the actual working environment include:
- suitable working hours
- absence of disturbing factors such as noise, visual distraction through glare or flickering effects, heat, cold, vibrations, smell
- team spirit and socially-pleasing atmosphere.

The effect of negative incentives such as the threat of degrading or diminishing any of the above-mentioned positive factors, appears to be of doubtful value, especially when applied on an individual basis. Such approaches have been found useful only in strongly hierarchical organizations (e.g. military).

The presetting of personal incentives by management, if taken to its extreme, could be perceived as manipulation, which will be resented and therefore counter-productive. This may be especially so with high-level creative workers whose readiness and ability to deliver ideas (and design in its true sense), are especially sensitive to coercion in all its forms. It may also hamper inspired and circumspect performance in checking objectives.

Nevertheless, it was recognized that there are many cases where well-thought-out incentive and motivation schemes have yielded excellent results. The Japanese example was mentioned many times in this connection. The success of such measures also enhances the reputation of the company and bestows it with the longer term benefits gained from performing a good job. Hence, motivation properly applied works not only for the quality of the product, but also for the company and its workers.

Finally, it is worthy of note that little use has been made in civil engineering of some of the accepted ideas and research results in areas such as engineering psychology and psychology of organizations. This should be rectified.

3.17 Optimization

A functional optimization of quality assurance procedures is presently quite removed from any knowledge beyond informal commonsense. It was generally recognized that optimality can only be a relative matter, dependent very much on the criteria and constraints inherent in any one situation. In practice it appears that people "satisfice", that is, are tempted to meet constraints and requirements in a pseudo-fashion in order to minimize trouble for themselves, without necessarily seeking an optimum solution with respect to the work itself.

Research on the efficiency of quality assurance has yet to begin, one possible starting point being the collection and analysis of professional opinions on the subject.

3.18 A Possible Initiative

Most organizational set-ups can be shown to have areas of weakness or a number of weak points. This is also true of the building process and a basic step for assuring quality is the identification of these areas of weakness. Studies have

have shown [15] that these tend to be the same in most countries, but it is desirable that each country tries to identify its own weak points on a national basis and seeks methods for overcoming these problems in the most effective way. This requires the attention of all parties involved in the building process (promoters, owners, designers, material producers, users, authorities). As an example of this kind of analysis, cf. [5].

Implementing quality assurance by strict reference to generally acknowledged areas of weakness will ensure that the procedure devised are potentially useful.

3.2 Guidance Documents Related to Quality Assurance

3.21 General

Guidance documents should conform to a given basic framework - set-up by law or by professional bodies - which defines the elementary rules governing the "building game". These rules must also include minimum requirements concerning the professional competence of the participants in the building process. Within the limits defined by this framework, guidance documents provide the required information. All guidance documents reflect past experience.

Since the interest of the different parties involved in the building process may differ, their experiences are likely to be biased to some degree. Guidance documents are required to transform subjective experience into objective guidance. Consequently, they should represent a consensus view of the state of the art prepared under participation of all parties involved in the building process. As such, guidance documents can be seen as a rational and comprehensive presentation of formalized knowledge and experience prepared for the profession.

It was generally accepted that guidance documents should be prepared not only for technical guidance but also on matters relating to quality assurance. However, a distinction between conceptual and operational documents seems necessary.

Conceptual documents serve the purpose of defining the basic logical approach and laying down appropriate basic principles. Since these documents are primarily addressed to national and international code writing committees, they do not provide any direct advice for practical design and construction. On the contrary, they are intended to guide the preparation and drafting of operational documents. These - being directly addressed to the parties involved in the practical planning, design, construction and use of structures - must contain all the information which is required for practical implementation.

It was agreed at Rigi that guidance documents related to organizational aspects should be clearly distinguished from those treating technical aspects. Technical information itself must be operational in order to guide the practical engineering work. However, organizational information in guidance documents should be limited to principles only; one of the main reasons being that organizational aspects are often the subject of contractual agreements between the partners in the building process.

Guidance documents are required to use quality in an objective meaning embracing safety (protection of life and property), serviceability (functional requirements), durability, appearance, etc. This may call for the notion of performance requirements and requests from society (represented by building authorities) as well as from the owner and the user to clearly define what is required from a particular structure. Furthermore, it requires the engineering profession to assign unequivocal technical criteria related to these requirements and to develop consensus rules for the practical assessment of structural behaviour.

3.22 Principles of Quality Assurance in Guidance Documents

Six basic principles of quality assurance which should affect the formulation of guidance documents resulted from the discussions at Rigi:

a) All building activity requires a certain minimum standard of professional competence of the people involved, adequate time to perform the activity and reasonable remuneration.

The lack of time during planning, design and execution of engineering works, insufficient remuneration and insufficient professional competence have been identified as frequent causes of structural damage and failure. It was felt that society and/or the profession should set adequate legal and professional rules and minimum conditions, outside which no building activity should take place.

b) All intuitive and formalized activity related to quality assurance must be based on adequacy and should not inhibit creativity.

This requirement includes the need for adequacy of all quality assurance measures and a warning against over-formalization. It also emphasizes intuition, creativity and competence of the persons responsible. It was felt that creative intuition may often be an important complement to rational thinking.

c) Quality assurance is necessary in any building process.

This basic requirement does not necessarily mean the application of formalized quality assurance planning but emphasizes the need for explicit concern with quality assurance.

d) Quality assurance is required during the entire building process.

This comprises not only the planning, design and construction phases, but also use, inspection, maintenance, possible repair and final demolition. This means that concern for quality should start at the beginning of the planning process and should not end with the completion of construction but should continue during the entire service life of the structure.

e) All efforts related to quality assurance should be judged on the basis of total life time costs.

Deficiencies in the quality of past construction activities often go back to the fact that decisions had been solely based on construction costs and not on total life time costs. These include expenditures for maintenance, repair and possibly reconstruction. Any optimization of building costs as well as the estimation of appropriate efforts for quality assurance should be referred to the total life time of the building or structure.

f) Guidance documents should acknowledge the importance of the human factor.

Conditions should be such that all persons involved in the building process can develop their full professional competence, creativity and ability for co-operation.

3.23 Organizational Aspects in Guidance Documents

Quality assurance is largely related to organizational aspects of the building process. A distinction is to be made between the organization within the usual parties involved in the building process (client, owner, design offices, contractors, material suppliers, building authority) and the organization of a given building project. Provisions with respect to organization and information flow should reflect the structure of the decision-making process and observe the interactions between all parties involved, the allocation of responsibilities, tasks and duties, the identification of inspection and control tasks and finally appropriate documentation.

3.24 Inspection, Control and Compliance Criteria in Guidance Documents

Principles of quality assurance include the specification of inspection, control and acceptance criteria. Control normally requires that the quality which is to be controlled can be quantified in measurable terms. Hence, guidance documents should define quality in form of technical criteria and measurable parameters whenever possible. Compliance criteria and rules applied in the case of non-compliance are constituent elements of any control.

3.25 Differentiation of Quality Assurance Measures

Guidance documents on quality assurance should differentiate between the various components of the buildung process and give directions for the allocation of the total effort for quality assurance. Criteria for this should include considerations with respect to the social and economic importance, the degree of exposure to environmental and/or accidental actions, the sensitivity of the structure to adverse phenomena or human errors, and the efficiency and type of the quality assurance measures to be taken.

3.26 Guidance Documents should allow for Development and Innovation

Guidance documents might inhibit development and innovation if they are too restrictive. Therefore, not only is the continual up-dating of these documents of greatest importance but also the preparedness of regulatory bodies to allow for deviations and exceptions. "Escape clauses" must be included.

In connection with the up-dating of guidance documents, considerable importance should be attached to the conclusions reached from the study of case histories of structural damage.

With regard to new developments and decision making in general, there was some discussion as to who will have to bear the risk which is inherent in exceeding any of the limits set by experience. Although it has become clear that ideally those who profit from any new development (e.g. the owner if the quality/cost relation will be improved and/or the contractor if his position on the market becomes stronger, etc.) should bear the risk, it was realized that actual legal practice does not follow this obvious logic.

3.3 Education with Regard to Quality Assurance

3.31 General

The adoption and development of more formalized methods of quality assurance within the building process, as discussed in this Workshop, requires a more systematic approach to the educational aspects of the subject than has been practiced hitherto. In this context, education is interpreted in its broadest sense and includes:
- formal education of professional engineers
- training of others involved in the building process
- the general dissemination of ideas and information.

It involves both initial training and continuing education during a person's professional career or working life, and is applicable in some way to all persons involved in the building process.

It must be recognized that education takes many forms and that different approaches may be necessary according to the nature of the information to be communicated and the characteristics of the group of persons for whom it is intended. In the following, the educational requirements for various groups of people with regard to quality assurance matters are discussed.

3.32 Educational Requirements

a) Client/Owner:
   The client ordering a structure should be made to understand that quality is one of his primary values and that an appropriate standard of quality must be incorporated in the specifications for each structure. This does not occur

just by chance. Owners should be made aware of the consequences of insufficient quality in terms of the increased likelihood of high maintenance and repair costs during the life of the structure. They should also understand that the optimum extent of formal quality assurance measures depends on the size and character of the project and that for large projects there tends to be negative correlation between the expenditure on quality assurance and the overall long-term cost of the work. For very small projects, the use of an extended guarantee system covering the cost of any necessary remedial works may, however, be better than any formal quality assurance measures.

Because of the great variety of clients, information concerning the importance of quality assurance cannot be disseminated collectively and it belongs to the project engineer or consulting engineer appointed by the client to brief him in the most appropriate way. Owners or companies who are responsible for a number of structures built over a period of time also have the opportunity to gain by experience from the various quality assurance schemes used on different projects. However, this experience may be lost or not even recognized unless there is a group of people within the company capable of extracting the necessary information, i.e. the effectiveness of different systems of quality assurance will not be appreciated if the concept of quality assurance itself is not properly understood by the client or owner.

b) Professional Engineers:
One criticism of formal engineering education is that emphasis is mainly placed on those subjects which are well understood and fully developed, e.g. structural analysis. Formalized quality assurance is a relatively new subject within civil engineering and is as yet poorly developed. Since it is concerned with the inadequacies of structural performance and the inadequacies of the processes of design and management, and possibly because it does not yet have (and may never have) a rigorous mathematical basis, it tends to be largely ignored in the current training of professional engineers.

Because of its importance, there is a need to incorporate quality assurance/ quality control concepts into the curriculum of civil engineering courses. A draft curriculum is given in an Appendix to this workshop summary. Time must be made available for such material to be introduced into university and other curricula but this will only be possible if quality assurance can be shown to be effective in practice. One approach would be to include it in an indirect way - for example, in the context of finding a solution to durability problems. This has already been shown to be an effective approach. In addition, short courses on quality assurance matters could be offered to professional engineers. Professional and technical organizations should share this responsibility.

Since many examples of structural malperformance are the result of gross human errors, the subject of quality assurance must include the study of human behaviour under different working conditions in addition to structural behaviour and structural pathology. Furthermore, the teaching of structural safety should start with the concept of gross errors and progress towards formal reliability theory, rather than vice-versa. It should be recognized and taught that most quality assurance problems are open-ended and may have many possible solutions.

c) Technicians and other workers in the building process:
Whereas the education of professional engineers takes place mainly during the early stages of their careers, the education and training of construction workers is seen as taking place partly during the construction project itself.

High standards of quality (i.e. absence of gross human errors) depend to a large extent on individuals having an appropriate attitude to work and having the motivation to do a good job and to undertake an appropriate degree of self-checking (self-control). This motivation can be engendered only if senior personnel concerned with the construction process have some understanding of human behaviour. It is therefore necessary that a sufficient number of senior personnel have been trained for this role.

A further task for the informal, on-site, education of technical staff is to make them aware of the implications of their work and the likely effects of any errors, together with its relationship to the project as a whole. It is suggested that on all large projects, regular site meetings are held, involving all levels of personnel involved in the building process, to discuss quality. These should aim to:
- examine problems that have arisen
- discuss problems that have to be overcome.

It is recognized that the constraints of time and cost which exist on all construction projects make the allocation of the necessary time for such meetings difficult - particularly when the planned schedules have been disrupted for some reason; however, these circumstances could just provide occasions when the discussions of quality requirements for the project is likely to be most beneficial.

Larger companies also have the possibility to provide regular education and training programs for engineers and other staff.

3.33 Closure

To summarize, there is a need for all persons involved in the building process to be aware of quality assurance. The specific educational requirements for different groups within the building process, however, vary. All persons should be made aware that to some extent quality assurance procedures are incomplete, and that individual self-control is of the greatest importance.

3.4 Research on Quality Assurance

3.41 Data Collection

Data collection has so far been limited to a number of isolated and relatively limited exercises (see bibliography to Introductory Note to this workshop by Melchers/Baker/Moses). It has also mostly been concentrated on the acquisition of the physical and, more recently, on some organizational parameters. Little attention has been paid to the human ingredients.

Efforts to acquire data with emphasis on human factors and to prepare them appropriately must be reinforced with due regard to the needs identified by research and practice. No format exists today to be used readily as a tool for systematic data collection, except for the limited questionnaires which were employed on the above mentioned occasions. Adequate tools must be developed along with the data collection, and the entire endeavour is perceived as a learning process, with the development of tools and the acquisition of data working hand in hand for continuous improvement.

An important source of information is seen to exist in the personal experience of older engineers who have lived through a number of scenarios where errors were initiated and later detected and rectified, sometimes after lengthy periods of perpetuation. In this case, where things turned out well after all, many of the traditional obstacles preventing disclosure of some details would not exist and we could learn from successes. Also, the human side of the scenario would probably be much easier to obtain in these cases. Methods to make this source of information available should be developed.

Data collection should be coordinated on an international level, in order to arrive eventually at an amount of material on quality assurance which is commensurate with the scope of the problem, i.e. the large number of its parameters.

The feasibility of collecting experience from practice (in particular negative experience) and using it for the technical community benefit, has an important ethical component. For this and other deeper reasons, the preparation of an International Code of Ethics in Construction would be highly appreciated as guidance. This code would protect society as well as professionals and would facilitate the spreading of useful information.

3.42 Modelling, Formal Representations

Both the building process and the error history in a given scenario, must be represented by appropriate models to be used for computer processing of data. The high degree of complexity of the quality assurance problem, in particular because human factors provide a major contribution, virtually requires the combination of the theoretical/experimental as well as the empirical/observational approaches of science. Like the methods employed in medical research, theory and practice must go hand in hand intimately, in order to improve learning and understanding.

Once sufficient data is available in codified form, a "template" type of approach is seen as a promising method. Information on the particular properties of a construction process, e.g. a project as perceived during its conceptual stage, would provide a "template"; i.e. a fixed pattern of organization, technical parameters and eventually human factors such as data on personnel, incentives, etc. as visualized at this stage. The data processing system would then receive this "template" and search for all experience in the data pool which answers to the same or a sufficiently similar description. This is much like the methods presently applied by medicine, for diagnostic and therapeutic purposes. Through variation of some optional parameters (e.g. contractural relationships) optimization of quality and quality assurance would then become possible through trial and error procedures using the data processor.

A number of models derived from different fields have been proposed (Rackwitz, Introductory Note to this workshop; [3], [4]). They all appear quite rudimentary at this time and must be developed and refined to become useful tools. They all reflect in some measure the relationships and parameters making up the building process. A global analysis would have to assemble them into a comprehensive system model.

The following features belong to the essence of the problem and must be properly represented in a model:

- Diversity of parameters. Some of them are quantifiable, such as most physical parameters. Some are of fuzzy character, such as parameters having to do with human involvement. Some are of discrete character, e.g. the number and position of parties in the building process.
- The multi-dimensional network character. An intimate understanding of it imposes difficulties on the powers of visualization of the human brain which is not used to thinking in networks but has a strong tendency to reflect linearly along series of associations.
- The multi-disciplinary character of the problem which involves such diverse fields as engineering, mathematics, semantics, law, sociology, psychology, management, etc.

Perhaps the first form a model of the building process will take is a simple consistent description which should be as complete and as clear as possible. Hopefully, it can be transformed subsequently into a format accessible to treatment by more strictly scientific methods such as statistics, etc.

3.43 Terminology, Semantics, Logical Structure of the Building Process and Quality Assurance

For analytical and communications purposes, a number of terms, concepts and interrelationships must be clarified and their limits determined. First of all, clarification of the following items is seen to be urgently needed:
- quality (or performance)
- quality assurance
- quality control
- checking methods
- gross error
- motivation, incentives, working environment

Some of these terms have been extensively used in other fields and can probably be adapted quite easily. However, the uniqueness of the construction industry requires close examination of them all.

A clear set of definitions related to tasks, responsibilities and the parties involved in the building process is needed as well. As different organizational structures exist in different countries, such definitions should be prepared for international guidance.

3.44 Motivation and Incentives

Some work on this important matter has been performed in related fields of industry and hopefully adaptation of methods and results to the construction industry will be quite straightforward. The help of professionals from the human sciences such as sociologists and psychologists etc. is required.

3.45 Optimization of Quality Assurance

The elimination of errors should be performed by the most efficient and most economic means. In practice, very few attempts have been made to tackle the problem of optimization of quality assurance measures, mainly because of the lack of appropriate models for human errors. The cost-benefit relationship in principle can be expressed as follows:

$$\max(B-C) = \max(B-C_O-C_{QA}-C_{CORR}-C_E)$$

where:

B = total benefit of good quality product
C = total cost
C_O = initial cost excluding quality assurance
C_{QA} = cost of quality assurance procedures
C_{CORR} = cost of corrections
C_E = cost of effects of residual errors (not discovered and corrected in time)

With B and C_O invariant relative to quality assurance, this reduces to

$$\min C_Q = \min(C_{QA} + C_{CORR} + C_E)$$

where C_Q represents the quality related costs.

This rather trivial relationship becomes less so when one looks a little closer at the terms relating to quality assurance and corrections. Since every defect as soon as it is initiated tends to grow in importance while it is being perpetuated, progressively increasing the cost of the eventual correction up to the cost associated with failure, it can be concluded that quality assurance must take place as early as possible. However, errors introduced later on will then go uncorrected which reveals the conclusion as false. What then about doing both, extensive early as well as late checking? This of course is incompatible with the optimization C_Q. In most practical cases, resources reserved for quality assurance are quite limited and quite rigidly so. The general target is to find the most effective application in time and organizational set-up within the im-posed limits to C_{QA}. This then is not trivial at all and has so far not been accessible to quantification or any other type of systematic interpretation.

In cases where resources for quality assurance are more or less unlimited, such as in the building of nuclear-power plants, total checking is carried out, as a virtual "solutio in extremis". This is so because the controlling factor in that industry is fear an agent so potent that it largely offsets the meaning of cost-benefit relationships. One is tempted to detect a considerable amount of "satisfiction" (from Latin satis = enough, fingere = to pretend, to deceive. Also "ficticious") in overly lengthy and extensive quality assurance procedures, where they are not applied in an inspired manner. The cost-benefit relationship then appears in a changed form with a "satisfiction" term (B_S) added as a ficticious benefit from quality assurance:

$$\min C_Q = \min(C_{QA} - B_S + C_{CORR} + C_E)$$

and with the "satisfiction" relationship:

$$B_S = C_{QA}$$ (the more I spend for quality assurance the better is my conscience ...)

the optimization degenerates to:

$$\min C_Q = \min(C_{CORR} + C_E)$$

with the obvious but wrong conclusion that quality assurance should be as early and as extensive as possible. This is not a true optimization but will lead to exaggerated costs for quality assurance and resources will be spent on trivia to feed paper tigers.

References

1. ICSS General Principles of Quality Assurance. IABSE Reports of the Working Commissions, Vol. 35, 1981.
2. HUSE E.F. and BOURDITCH J.L., The Human Behaviour in Organitazions.
3. LIND N., Models of Human Error in Structural Reliability. Structural Safety. Elsevier Science Publishers, Amsterdam, 1983.
4. KNOLL F., Human Error in the Building Process, A Research Proposal. IABSE Journal J 17, 1982.
5. The quality of building in Spain - Present situation and recommendations. Istituto Torroja, P.O. Box 19002 Madrid.
6. KORMAN A.K., Psychology in Industry and in Organizations.
7. KUHLMAN A., Einführung in die Sicherheitswissenschaft. Friedrich Vieweg und Sohn, Verlag, TUV Rheinland, 1981.
8. McCORMICK E.J., Human Factors in Engineering. McGraw Hill Book Company, New York, 1964.
9. MEISTER D., Human Factors in Reliability. In W.G. Ireson, Reliability Handbook, McGraw Hill Book Company, New York, 1966.
10. HOLDING P.H. (Ed.), Human Skills. John Wiley and Sons, Chichester, 1981.
11. HELANDER M. (Ed.), Human Factors Ergonomics for Building and Construction. John Wiley and Sons, New York, 1981.
12. HARRIS H. and CHANEY F.B., Human Factors in Quality Assurance. John Wiley and Sons, New York, 1969.
13. DRURY C.G. and FOX J.G. (Eds.), Human Reliability in Quality Control. Taylor and Francis Ltd., London, 1975.
14. LAUFER L. and JENKINS G.D., Motivating Construction Workers. ASCE, J. Constr. Div., Vol. 108, No. C04, Dec. 1982.
15. CEB Bulletin No. 157, Quality Control and Quality Assurance for Concrete Structures, Paris 1983.

Appendix

Prosposal for a Curriculum of a University Course on Quality Assurance and Quality Control in Structural Engineering

1. INTRODUCTION

During the discussions within the Workshop the fact was emphasized that education towards "Quality Assurance" is urgently needed but cannot be found in most Structural Engineering Curricula either at university level or at intermediate levels of technical education. Much time - perhaps too much - is spent on technical and scientific matters that are of no direct relevance to quality and quality assurance of structures.

Ideally, teaching quality assurance should be adequately included in all university courses because then the relevance of the topic would be obvious. In order to accelerate the introduction of quality assurance and related concepts, an attempt is made here to draft a university course on Quality Assurance and Quality Control in Structural Engineering, hoping that such a proposal will assist university teachers to introduce and teach such courses at their schools.

2. AIMS

The aims of the proposed university course "Quality Assurance and Quality Control in Structural Engineering" are in very general terms

- Making students aware of the problem linked with the building process, from the first step in planning, through design, execution, use, up to the demolition of structures.
- Preparing an overall framework, into which facts and information from other fields of engineering education (Structural Mechanics, Finite-Element Analysis, structural courses on steel, timber, reinforced and prestressed concrete, bridges, buildings, etc.) can be adequately placed and seen in their respective place and importance.
- Introducing the students into fields generally neglected in engineering education, such as organizational aspects, psychological implications, motivation of people, etc.

The course proposed here should be considered as a first step towards education in Quality Assurance, but in a very broad context.

3. PLACE WITHIN OVERALL CURRICULUM

A course on Quality Assurance and Quality Control in Structural Engineering would best be placed in about the 5th semester. At that stage of education, the student is aware of some of the problems an engineer is faced with. By then he has some basic knowledge of engineering mechanics and of the theory of the strength of materials. Finally, he may feel the need for a framework into which he can put all the information that - with increasing speed - is delivered to him in various courses by many different professors in various divergent sets of terms and terminologies.

The course certainly cannot be placed in say the first three semesters. It may be placed later than in the 5th semester, but with decreasing effect and utility for the student.

4. TIME TO BE ALLOCATED

It seems possible to present the contents of the course proposed here within one semester. Two hours a week would be necessary and would therefore lead to about 24 lectures of one hour each. This does not allow for exercises which - if additional time is available - would assist in the understanding of the subject.

5. CONTENTS

The contents of the course can be outlined as follows:

1 Purpose and function of structures; environment of structures; building process and people involved; requirements and hazards.
Notions: safety, reliability, serviceability, durability, economy, ambient adequacy ... to be introduced.

2 Measures towards quality in general; hazard identification: the concept of hazard-scenario thinking; risk analysis; planning of measures; safety plan as an example.

3 Influences on structures: loads, forces, induced deformations; problems of numerical representation.

4 Resistance of structural parts; problems of numerical representation.

5 Problems of linking influences on structures to structural resistance; safety and serviceability conditions, limit state equations, design variables and design values; simple examples.

6 Formats for safety and serviceability verification; possibilities, deficiencies, pros and cons ; future trends.

7 Influence of errors and measures against human errors; case studies.

8 Effects and efficiency of control and checking; planning of control; control plans.

9 Organizational aspects in the struggle for quality; function charts; allocation of responsibilities and duties; information flow.

10 Effects of and influences on human behaviour; motivation theory; psychological effects, etc.

Most of the concepts given above are discussed in more detail elsewhere in this workshop summary.

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