Measures against errors in the building process
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MEASURES AGAINST ERRORS IN THE BUILDING PROCESS

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PREFACE

Human error is the cause of most structural failures in buildings. This report describes strategies and procedures that can be used to minimize the probability of structural failure due to human error.

The translation was done because of the interest of DBR/NRC in the area of structural safety and performance and because the study of human error and its control is an important new direction for research.

The Division of Building Research is grateful to Mr. Robert Serré for translating the report and to Mr. Ulrich Stiefel of ETH-Zurich and to Dr. D.E. Allen of this Division for checking the translation.

Ottawa,
July 1983

C.B. Crawford,
Director.

FOREWORD

Buildings are becoming more and more complex from a safety point of view, and the building industry provides a greater variety of possibilities. As a result, the traditional safety strategy, largely based on experience, is coming under question. Furthermore, structural failures that have occurred in recent years have supported the need for a renewed scientific approach to safety problems in the building industry. This awareness has resulted in research work throughout the world, including Switzerland, aimed at applying to structural safety the same line of reasoning found applicable in other technological fields, thereby providing a rational basis for the safety of buildings and structures.

The findings of such research indicate that human behaviour plays an essential role in cases of damage, and that it is indispensable to incorporate human factors into a comprehensive safety strategy. The purpose of this report is to bring together the required elements.

On the basis of an analysis of 800 structural failures that was carried out at our Institute, this report provides a systematic description of possible sources of error, and proposes suitable preventive measures. These may be used directly in individual cases. The lines of reasoning outlined here should be very useful in defining optimal safety strategies. It is my hope that this report will produce beneficial results in the field of building practice.

The present report is derived from a more comprehensive research project sponsored at our Institute by the Commission for the Advancement of Scientific Research of the Swiss Federal Department of Economics. We wish to extend our sincere thanks to the Commission for its support.

Zurich, January 1982 Prof. J. Schneider

SUMMARY

The predominant cause of structural damage is human error. A systematic procedure against human error must therefore be included in an overall safety concept for structures, (that is, for the life of structures from design to utilization), and must without doubt occupy a distinct place in the field of structural engineering. This report, which is divided into 5 parts, deals with this problem by identifying the individual sources of human error, and decribes possible countermeasures. The question of which particular countermeasure would be most effective in a given situation is not explored.

Section A of the report introduces both the important factors necessary for the classification of the individual countermeasures, and the interrelationships of these factors to be considered. Feed-back from previous experiences, (in particular from near failures or from actual failures), as well as the aims and influence of research are also considered. The following sections of the paper are based on the two possible methods of error prevention: errors can be avoided by eliminating their sources, or, with appropriate controls, errors can be detected in time and subsequently corrected.

Section B describes the sources of error in the technical procedures of the building process and measures for avoiding them. The measures described lead to a clear continuity and an ordered relationship between the individual components of the various phases in the life of the structure, that is, the planning, design, construction and utilization phases. Section B however does not concern itself with the people involved and their behaviour.

Section C deals with the sources of error in the organization and management sector of the building process assuming "error-free" technical procedures and "error-free" behaviour of the people concerned. The proposed measures should result in a clear definition of the task of each person involved, a distinct set of boundaries for jurisdiction and responsibility, and a frictionless cooperation between the people concerned.

Section D finally looks at the sources of error resulting from human behaviour assuming "error-free" technical procedures and "error-free" organization and management. The measures described improve the capability and motivation of those involved, reduce disturbing influences, and guard against both intentional and unintentional misbehaviour.

Section E is devoted to the timely detection and correction of errors. Controls and, if necessary, corrections are essential since the complete elimination of the sources of errors is not always possible or feasible. The measures described are essentially the proper use of control principles, control plans, control and correction directives, check lists and check reports.

The measures for error prevention described in this paper should be viewed primarily under the heading "Safety of Structures". Nevertheless, those dealt with in sections C, D and E in particular, are quite generally applicable against errors in the field of structural engineering.

RÉSUMÉ

Dans la construction, les fautes représentent la cause prédominante des désordres dans les structures. Une méthode systématique pour contrer les erreurs doit donc être considérée comme un élément important d'un concept intégral de sécurité pour les ouvrages et les méthodes d'exécution. Le rapport, qui est divisé en cinq chapitres, démontre la nécessité d'un tel procédé en identifiant les différentes sources d'erreurs et en présentant certaines mesures qui permettent de les réduire. Le rapport n'aborde pas la question du choix d'une contre-mesure dans une situation donnée.

La partie A traite des facteurs intervenant dans la classification des différentes mesures contre les fautes et des rapports qu'il faut considérer entre les facteurs. On y traite également de l'expérience que l'on peut tirer des incidents et des accidents antérieurs ainsi que des devoirs et de l'influence de la recherche. Les chapitres suivants sont développés à partir de deux possibilités principales permettant de supprimer les fautes: on peut éviter les fautes en supprimant leurs sources ou on peut les détecter à temps par des contrôles systématiques et les corriger.

La partie B traite des sources et de l'élimination des erreurs intervenant au cours du déroulement de la construction. Les mesures proposées assurent un déroulement systématique des différentes étapes intervenant lors des périodes de préparation, de planification, d'exécution et d'utilisation des ouvrages et ceci sans tenir compte des personnes concernées et du comportement humain.

La partie C traite des sources de fautes intervenant au niveau de la gestion et de l'organisation de la construction. Il est supposé que le déroulement de la construction et le comportement des participants sont exempts de fautes. Les mesures proposées doivent permettre de poser clairement les problèmes, de distribuer les tâches, de délimiter d'une manière univoque les compétences et les responsabilités, d'informer et enfin d'assurer une bonne collaboration entre les personnes concernées.

La partie D traite exclusivement des sources de fautes découlant du comportement humain moyennant l'hypothèse que le déroulement technique et l'organisation de la gestion de la construction sont exempts de fautes. Les mesures proposées servent à augmenter le rendement et l'engagement des participants, à réduire les causes de dérangement et à agir contre le comportement erroné conscient ou inconscient des participants.

La partie E traite de la détection en temps voulu des fautes et de leur correction. Les contrôles et le cas échéant les corrections sont nécessaires étant donné que l'élimination complète des sources de fautes n'est pas possible et même pas raisonable. Les mesures proposées consistent pour l'essentiel dans l'application systématique des principes de contrôle, des plans de contrôle; des directives pour les contrôles et les corrections, des "checklistes" et des rapports de contrôle.

Les mesures décrites dans le présent travail ont été analysées dans le cadre du concept "sécurité des ouvrages". Celles qui sont contenues dans les parties C, D et E sont efficaces d'une manière générale contre les fautes qui se produisent dans le génie civil.

CONTENTS

PART A

INTRODUCTION

MEASURES AGAINST ERRORS IN THE BUILDING PROCESS

by M. Matousek

A 1. Starting point and purpose

Within the framework of a research project carried out at the Institute for Structural Engineering of the Swiss Federal Institute of Technology, 800 cases of structural failures were investigated in an effort to define the problem of safety in building [58]. The results confirmed a long-held intuitive feeling that only a small part of the problem of safety in buildings is covered by traditional safety research as it strives to develop better and better techniques of assessing the reliability of structures. Ensuring safety means avoiding hazards. It is obvious, however, that certain hazards are often integrated within designs, and knowingly accepted as risks. Moreover, there is a whole range of so-called residual hazards which, in practice, must be attributed exclusively to errors made by those who take part in the building process. These include objectively unknown, subjectively unrecognized, and disregarded hazards, as well as hazards that are not prevented because of unsuitable or wrongly applied measures. These residual hazards, which actually are due to errors, and the accepted risks are the causes of damage. The results of damage analysis provide a clear indication of this: 25% of the cases of damage and 10% of the amount of damage are due to accepted risk, while 75% of the cases of damage or 90% of the amount of damage are due to human error (figure A-1).

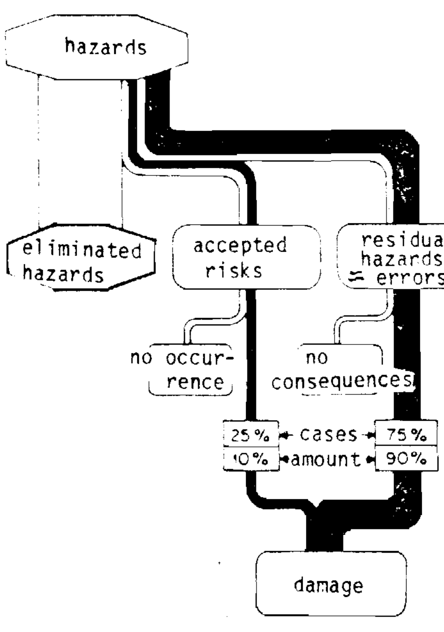


Figure A-1. Causes of damage [58]

These results are not surprising. Almost all the safety strategies used today place major emphasis on unfavourable influences such as wind or corrosion. The human factor is more or less overlooked. Human beings are considered error-free, at least implicitly, although in practice every case of damage shows the contrary. This limited view could be justified as long as the effects of errors are relatively small in comparison with those of unfavourable influences. As technology develops, however, the consequences of errors become more and more apparent. One reason for this development is that most of the unfavourable influences are gradually eliminated as technology evolves. A second reason is that in view of the increased potential damage (e.g. nuclear plants, high-rise buildings, chemical facilities), the possible effects of errors are more and more complex. More over in several cases they cannot be fully considered. The increasing number of cases of damage (e.g. the insurance premiums of civil engineering firms alone have increased about 120% since 1953) confirms this trend, and provides unmistakable evidence that a comprehensive safety strategy must include a systematic procedure against errors [8,28,45,55,56,57,92,93,94].

It is of course true that errors have always been countered in the past, and more so nowadays, by means of suitable measures such as checks at various steps in the building process, or problem-oriented staff education and training programs. However, in most cases this is still being done without the benefit of a proper strategy.

The present report is an attempt to fill the obvious gaps in a systematic way. It describes the various errors that lead to structural failures, and proposes measures applicable in practice. It should thus provide the building specialist with a document that will help him identify possible errors in his field, as well as establish and apply suitable measures for their prevention and detection. In order not to exceed its scope, this report, will only incidentally deal with the quantitative assessment of such measures and the evaluation of their efficiency in different problem areas, the applicability of these measures to problem-oriented management strategies, or the use of electronic data processing techniques. For the same reason, it was necessary to limit the investigations to the more essential aspects in a number of related fields. The report as a whole is based on the results of structural failures that were investigated [58]. In order to make our systematic strategy against errors as complete as possible, it was necessary to incorporate briefly also measures which are already being used in the building industry on a more or less systematic basis.

A 2. Errors in the building process

A 2.1 The building process

Buildings are constructed for a purpose. They are used for a wide variety of activities, i.e. residential, production, transport, etc. The construction of buildings involves a number of procedures that follow each other, from the declared intention to build them to their demolition. The term building process is used to describe such a series of procedures, thereby extending the usual meaning of that term to encompass the various phases of use (including maintenance and alteration). A distinction is then made between the planning, design, construction and utilization phases.

During the planning phase, the intended use of the structure is defined, the initial situation (building site, environment, etc.) is determined, the building concept is selected, the hazards are investigated, as well as the measures that will be used to eliminate them. During the design phase, the various structural components are dimensioned in a suitable way, usually by computation, and the required drawings and lists are made available. During the construction phase, work is initiated and carried out. In the utilization phase, finally, the building is used, supervised, and maintained, as a rule, according to the provisions of the planning phase.

In contrast to other production processes which are often repetitive and uniform, building processes must adapt themselves to varying initial situations (e.g. building site, environment), constantly changing utilization requirements and participants, and so on. At each step in the building process, and for each activity of those involved, there is a possibility of error, especially because of the above mentioned characteristics of the building process.

A 2.2 Definition of error

There is a need to define "error" in this context, since this word covers a variety of linguistic meanings. Error can mean the difference between a measured value and the true value (which may or may not be known) or the required value. Technically speaking, however, not every deviation from a required value is called an error. Some deviations are often tolerated, and are incorporated into plans as so-called tolerances. In such cases, there is an error only if the deviation exceeds the tolerance between the nominal value and the real value. Instead of values we may have actual situations, in which case an error is deemed to have been made if the deviations between nominal and real situations exceed given tolerances.

Errors defined this way refer primarily to the situations under consideration. Investigation of the reasons for such errors shows that, some human element is inevitably involved. In the final analysis, errors are a human phenomenon. It is a matter of human choice whether the influences that lead to deviations are ignored or knowingly accepted as a risk. In the latter case, we no longer speak of errors, but must face the possibility of not achieving our goal, and having to answer the question as to whether the risk was justified. Consequently, real errors are those caused by people as a result of influences that were not or not sufficiently taken into consideration.

That meaning of error which is often called "human error" is our starting point. Accordingly, an error is a deviation between a nominal and a real situation exceeding established tolerances, caused by people.

This report is limited to errors which lead to structural failures. Other errors, e.g. completion delays, supply shortages, or exchange rate losses, will not be dealt with.

A 2.3 Causes of errors

The systematic use of measures against errors requires a knowledge of the causes of such errors. These causes can at times form a fairly long sequence. The collapse of a structure, for example, may be due to the following chain of causality that leads to human error, and perhaps even further: failure of the reinforcing bars - error in the drawing - wrong information from the engineer - error in computation of the engineer - tiredness of the engineer - personal problems, and so on. The sequence of causes is usually interrupted at the level of human behaviour, since information about further causes is difficult to obtain, or falls outside the scope of the building process. Accordingly, errors in the building process are sought basically within the building phases, among the participants and their patterns of organization, and finally traced back to human behaviour. Figure A-2 outlines some results of damage analysis [58] attributed to causes of error defined in this way.

The percentages shown in the figure might suggest that errors are due to the engineer much more often than to the architect. This is not so. It is simply that the architect usually precedes the engineer in the building process, so that the engineer who shows average vigilance will detect some of the architect's errors, and take corrective measures. The same holds true for the engineer, whose errors are often corrected by the contractor. Moreover, the architect, as a rule, is directly involved only in high-rise projects, whereas the engineer and contractor cover the whole spectrum. The present report is based on the above mentioned error categories.

Errors in the phases of the building process	%
Planning	11
Planning & Design	34
Construction	49
Utilization	6

Errors by participants	%
Contractor	39
Engineer	33
Architect	8
User	5
Other participants	15

Error in human behaviour	%
Ignorance, negligence, carelessness	35
Insufficient knowledge	25
Underestimation of influences	13
Forgetfulness, mistake	9
Reliance on others	6
Unknown situations	4
Others	8

Figure A-2. Percentage distribution of cases of damage according to sources of error [58].

A 3. Measures against errors

Measures are actions that are taken deliberately to achieve a certain goal [58]. With respect to errors, measures are characterized by the goal to be achieved, and the steps taken, i.e. the means used.

A 3.1 Goal of measures

Basically, errors can either be prevented through suitable measures, or - also through suitable measures - detected in time and corrected.

Measures to prevent errors are first applied to the assumed initial situation. These measures eliminate the differences between the assumed and the actual situation. Hence the term situation-oriented measures. However, even if the assumed initial situation is correct, errors will occur in the actual process, and process-oriented measures will help prevent them.

Nevertheless, in spite of the abovementioned measures, errors will still occur. It is therefore necessary to supplement such measures with others designed to ensure the timely detection and correction of errors. These are called control and correction measures. Figure A-3 provides an outline of these various types of measures [55].

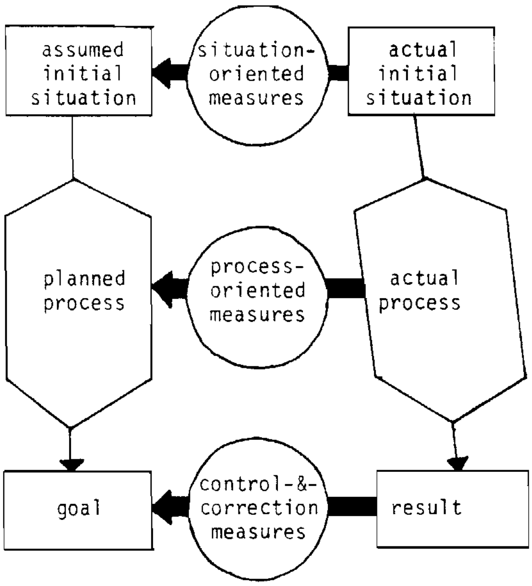


Figure A-3. Types of measures against errors.

When a goal-oriented process is being planned and defined, initial conditions are assumed. These include all elements which are present in the initial situation, which are required by the process, or which have some influence on the process. Consequently, the initial conditions encompass the materials, the working tools, the techniques, the participants, as well as the environment. Some of the elements in the initial situation, however, may remain unknown or unrecognized by the participants, or they may be ignored by them. The extent to which the assumed and the actual situation fail to coincide, i.e. the extent to which the assumed situation is actually fulfilled, depends on the knowledge and diligence of the assessor.

Errors at the level of the initial situation are eliminated by situation-oriented measures, which are aimed at ensuring maximum similarity between the assumed and actual situation encountered.

If the actual process differs from the planned one, the result could fall outside the specified tolerance limits. Possible sources of deviation are errors in task formulation, in design, or in actual execution. Process-oriented measures are therefore aimed at ensuring that the process unfolds according to plan.

Finally, there are controls aimed at assessing the actual situation, i.e. the results of a process, comparing it with the assumed situation, i.e. the specified tolerance limits, and identifying any deviations. If the deviations exceed the tolerance limits, they must be corrected. Timely controls and corrections in connection with individual phases of the building process often make it possible to avoid significant errors or accidents. In short, control and correction measures are aimed at detecting errors and then correcting them.

A 3.2 Means used

Depending on the means used, it is possible to identify three types of measures against errors: behavioural, organizational, and technical measures. In this respect, control measures, for example, would consist of a competent supervisor (behaviour-oriented measure), the use of control instructions and checklists (organizational measure), and the use of measuring devices (technical measure).

Behaviour-oriented measures obviously include the selection and mobilization of competent people (e.g. for supervision), but they also encompass all efforts aimed at improving the behaviour of people in their activities (introduction of principles, rules, education, training, penalties, etc.). Behaviour-oriented measures are especially suited to small building processes that can be monitored, where error prevention lies mainly at the level of the people involved. They are not sufficient for more complex building processes, which require the application of suitable organizational measures.

Organizational measures consist chiefly of written documents such as regulations, lists, instructions, checklists, plans, models, examples, etc. These measures are aimed at ensuring that the activities of people unfold without ambiguity. This report deals with such measures in great detail. If the use of organizational measures is not sufficient, e.g. because an error could result in an accident of grave consequence, technical measures are also used.

Technical measures may replace, complement, limit or hinder the activities of people. They include the use of machines, devices, instruments, electronic data processing (EDP), etc., as well as construction and structural measures. Even simple, limited measures such as the symmetrical arrangements of reinforcing bars, the use of standardized components, or the application of different colours in multi-layer coatings may prevent errors or facilitate their detection.

The use of electronic data processing (EDP) occupies a special place among technical measures. Rapid developments in this area, especially with respect to so-called microcomputers, point to much more extensive use of EDP in the future, not only for specific calculations, but also in such areas as organization, data transmission and storage, staffing, assessment of expertise, etc. This report does not deal with such possibilities in any detail, though it does point out the obvious potential of EDP.

A 3.3 Application of measures

As a rule, the above measures are applied in combination. For reasons of cost-effectiveness, it is important to find for each individual case the best combination of suitable measures that will lead to the prevention and/or detection of errors.

In the case of errors that are easily detected and corrected, it is advisable to place more emphasis on control and correction procedures. Whenever errors can lead directly to failure, they must be eliminated by means of situation-oriented and process-oriented measures.

The cost of measures against errors depends on the measures that are applied and the means that are used. Costs increase when, for example, principles are replaced by instructions, or instructions are replaced by structural changes. Accordingly, behaviour-oriented measures are preferred for simple processes, whereas large, complex building processes require more intensive use of organizational and technical measures.

A 4. Organization of the report

A 4.1 Classification of measures against errors

The systematic classification of measures against errors in the building process is based on the hierarchy of errors outlined in section A 2. As a result, the report is divided into parts B, C and D, which deal with the sources of errors and their elimination, and section E, which describes measures used to detect and correct errors (figure A-4).

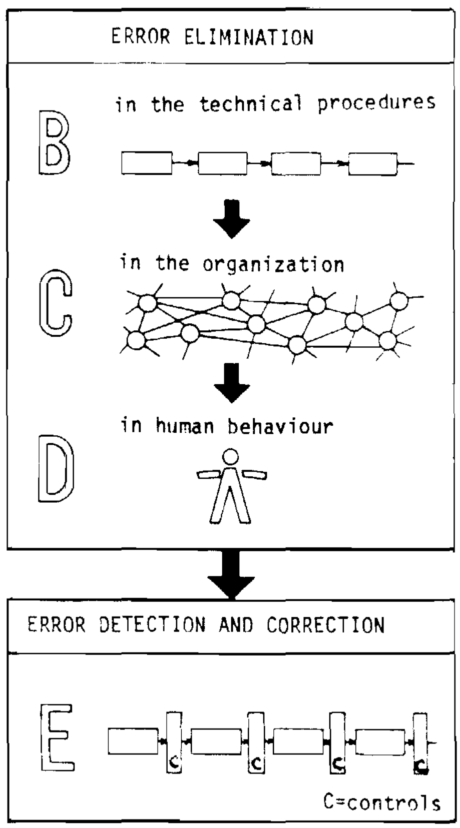


Figure A-4. Systematic strategy against errors in the building process (parts B,C,D,E of the report).

Part B is concerned with sources of errors in technical procedures of the building process, and their elimination. These include inadequate documentation, incomplete calculations, insufficient lists and drawings, gaps in processes, poor monitoring of risks, etc. Only the individual processes and their relationships are considered, both the organization and the behaviour of the participants being deemed "error-free". The measures described in this section of the report seek to ensure that the various stages in the building process remain integrated, and unfold as planned. The main emphasis is on sources of error in the planning and design phases, since error elimination during these phases is particularly effective. Errors in the construction and utilization phases, on the other hand, are better avoided through measures which deal with sources of organizational and human error.

Part C is concerned with sources of errors in the organization and management and their elimination. These include ambiguous duties, faulty transmission of information, poor cooperation, etc. While organizational errors are considered, both the technical aspects and the behaviour of the participants are deemed "error-free". The measures described in this section seek to ensure that the duties and functions of the participants are clearly defined and administered, that responsibilities and duties are spelled out without ambiguity, that information is transmitted intact, and that there is an effective cooperation among the participants.

Part D is concerned with sources of personal errors and their elimination. These include insufficient knowledge, negligence, carelessness, oversights, confusion, etc. While the behaviour of participants is considered, both the technical aspects and the organization are deemed "error-free". The measures described in this section seek to ensure proper performance and willingness to work in the participants.

Part E is concerned with measures aimed at detecting and correcting errors, since it is not always possible or sensible to eliminate all sources of errors. In such cases, it is advisable to provide timely detection of errors through proper controls, followed by the necessary corrective procedures.

A 4.2 Hints for the reader

The present report is concerned with errors, and does not deal with questions of responsibility for using and carrying out the measures described. Such questions depend on the complexity of the objectives, the forms of organization adopted and the participants themselves, and are therefore beyond the scope of this report.

Being concerned with errors, this report is nevertheless interested in any and all participants, and hopes to point out the sources of error in each and every area, as well as means of preventing them.

There are three basic steps:

- to identify sources of errors in the technical procedures, in the organization and management and in the participants,
- to define measures and apply them to prevent errors or to detect and correct them in time,
- to supervise the success of the measures used.

Our report can serve as a guide in this process. It describes potential errors, indicates possible measures or means to be used, and points to various feedback techniques.

The various parts of this report will not be of equal interest to all readers. Some will lean towards sources of errors in the technical procedure, and others towards sources of personal errors. In such cases, it is recommended that readers thoroughly consult part A and the "Overview" sections in each of parts B, C, D, and E before concentrating on those sections of particular interest. The table of contents will provide further guidance. Figure A-5 can also be of use.

Errors in the building process	Category	Type of error	Errors deal with...	Error prevention	Error detection & correction
Errors in the building process	Errors in the Technical procedures	Errors in planning	Goal formulation	B2.1,B2.2	E2,E3.2
			Situation assessment	B2.1,B2.3	E2,E3.2
			Building concept	B2.1,B2.4	E2,E3.2
			Hazard identification	B2.1,B2.5	E2,E3.2
			Planning of measures	B2.1,B2.6	E2,E3.2
		Errors in design	Design Calculations	B3.1,B3.2	E2,E3.3.1
			Structural detailing	B3.1,B3.3	E2,E3.3.2
			Drawings and lists	B3.1,B3.4	E2,E3.3.2
		Errors in construction	Preparation of the construction	B4.1,B4.2	E2,E3.4
			Preparation of the work procedures	B4.1,B4.3	E2,E3.4
			Execution of the work procedures	B4.1,B4.3	E2,E3.4
		Errors in utilization	Utilization documents	B5.1,B5.2	E2,E3.5
			Utilization	B5.3,B5.4	E2,E3.5
			Alteration	B6	E2
	Errors in the organization/management	Errors in defining responsibilities	Documentation	C2,C3	E2
		Errors in the flow of information	Transmission, reception Storage, retrieval	C2,C4	E2
		Errors in cooperation	Coordinating, delimiting	C2,C5	E2
	Personal errors	Inappropriate personal performance	Ability to work Willingness to work	D2	E2
		Poor behaviour	Disturbing influences	D3.1,D3.2	E2
			Impaired performance	D3.1,D3.3	E2
			Intentional behaviour	D3.1,D3.4	E2
			Unintentional behaviour	D3.1,D4	E2

Figure A-5. Types of errors and corresponding sections.

A 5. Feedback and research

A 5.1 Feedback

The proposed measures against errors and the concept governing their application must always adapt themselves to the evolution and new requirements of increasingly complex building processes. Feedback, especially from failures and near failures, is needed to develop more appropriate measures, or to improve existing ones (figure A-6).

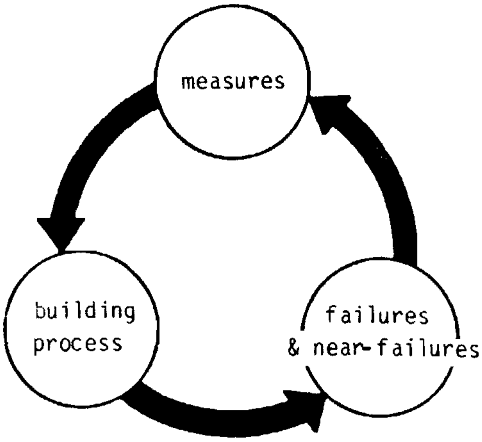


Figure A-6. Feedback pattern between measures, the building process and failures or near-failures.

In this respect, it is interesting to consider not only actual cases of failure, but also near-failures which, fortunately, have not resulted in failure. Near-failures have essentially the same causes as failures, but they lend themselves much better to an evaluation, for obvious reasons. In the process, feedback procedures operate at three different levels:

- the specific building process itself,
- the choice of measures used within the building process,
- the comprehensive safety concept applied, for example, to all the building processes of a country through standardization.

During the course of any building process, the detection of errors and the observation of failures and near-failures draw attention to inappropriate measures. It is therefore necessary, in any building process, to set up a feedback mechanism so that the measures used may be made more appropriate, especially for repetitive processes.

Failures and near-failures within a given building process also provide information about the suitability of the concept and the influence of individual measures against errors. Such information provides feedback for the improvement of the concept used. Since, in the final analysis, measures against errors are an important element in the overall safety concept, we will now deal with the systematic analysis of experience.

A 5.2 Analysis of experience

The systematic analysis of failures and near-failures provides information not only about the effectiveness of measures used against errors, but also about the admissibility of accepted risks. Furthermore, it provides information about unknown phenomena. A systematic analysis of this type is based on investigations of individual cases [54,58].

a) Investigations of individual failures

Information about each case of failure or each near-failure is studied (i.e. within the firm) according to a standard procedure in terms of facts, causes, and consequences.

The facts of a given failure or near-failure refer to objective information such as the time, the type of damage, the description of the damaged or endangered component, and the unfavourable influences.

If the failure is attributed to a consciously accepted risk, the investigation determines whether the risk was justified. If it is due to an error, the investigation determines the building phase, the participants, and the type of human failure involved. Finally, it is important to determine which measures have failed, and which measures could have been used to prevent the error or detect it in time.

In terms of conclusions, the investigation determines how similar failures or near-failures may be reduced or eliminated in the future. The conclusions refer to measures that may reduce accepted risks, the application or improvement of measures against errors, and information about required steps in the case of unknown phenomena.

b) Comprehensive analysis of investigations of individual failures.

Insurance companies, administrative services, architectural and engineering firms, businesses, etc. have a great deal of information about failures and near-failures, but it is largely disorganized. Such information must be analyzed systematically and uniformly, preferably in a computerized form, by centralized and largely impartial organizations (e.g. universities, professional associations, insurance companies). In this way, both the access to information and its analysis are improved. The gathered information is then suitably formatted, and stored in a computer, so that it may be retrieved selectively in answer to various queries.

c) Feedback

The results of such comprehensive analyses of failure and near-failures are used to:

- improve measures against errors,
- develop more extensive safety concepts, and
- initiate research projects on unknown phenomena.

A further possibility would be the establishment of a national or international "warning system", which would respond to increases in occurrences involving certain areas of the building industry, or certain materials or processes, etc., and warn the building community accordingly.

One essential feedback technique is to prepare reports of failures and near-failures for journals, conferences, etc. In addition to published accounts of informative failures and near-failures, summary of results are also of interest.

Finally, an appeal must be made to everyone involved to play a more active role against failures. We all learn from experience. Withholding information gained from experience interferes with progress. It should be a matter of pride and duty to allow others to benefit from personal experiences of failures. Unfortunately, much remains to be done in this area.

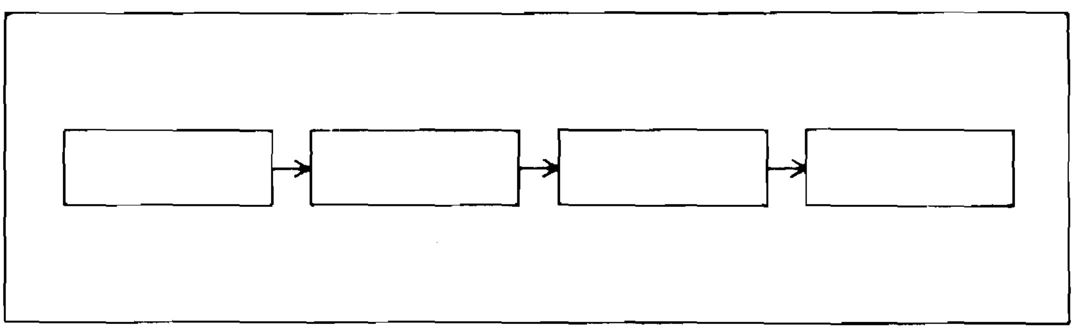
A 5.3 Influence and task of research

A first function of research is to elucidate unknown phenomena to which attention is usually drawn through failures or near-failures. However, research is also needed when, for example, large structures or new processes extend beyond the usual realm of experience. Past cases of structural failure have shown that when our knowledge is extrapolated beyond the limits of experience, the results often lead to failures [109]. Structural components or factors which play no essential role within familiar bounds can take on special significance beyond these bounds. Such components or factors can be recognized in time through research. Accordingly, research and the publication of basic results always constitute a major instrument against errors.

However, there is a need for still more research in the area of interest to us here, and that is the development of suitable strategies against errors. A first task would be to investigate the effectiveness of the measures proposed herein under various circumstances. Only with such additional knowledge will it be possible to design, for the various problem areas in the building industry, sets of measures that can meet the objectives as inexpensively as possible. Such problem-oriented measures are obviously an important element in the management of building processes.

PART B

SOURCES OF ERRORS IN THE TECHNICAL PROCEDURES OF THE BUILDING PROCESS AND THEIR ELIMINATION



B 1. Overview

The measures outlined in this section for the elimination of errors refer exclusively to the technical procedures of individual phases in the building process and their relationships. Sources of errors in the organization/management and in the participants and the corresponding measures against such errors are dealt with in parts C and D.

Errors in the technical procedures of the building process include missing, false or insufficient documents, ambiguous rules of construction or workmanship, inappropriate instructions, etc. This type of errors can be eliminated by specific measures aimed at the source of the error. These measures are represented symbolically by arrows pointing to the left in figure B-1 and all similar figures.

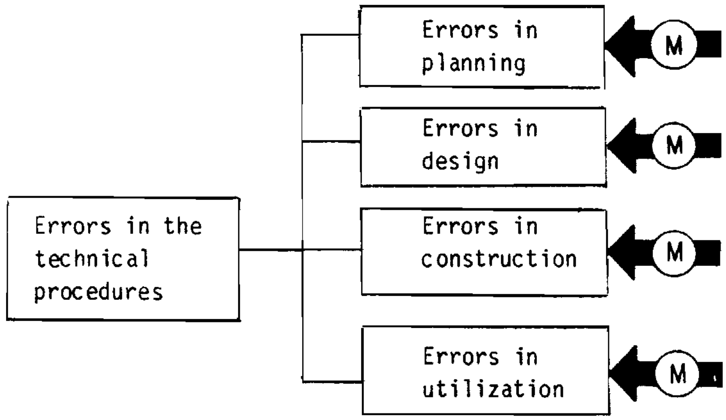


Figure B-1. Errors in the technical procedures during building process and their prevention.

Effective measures against errors in the technical procedures ensure a clear, unambiguous evolution of the technical processes involved in the planning, design, construction and utilization phases. The following sections will first examine the errors discovered through failure analyses, and then describe suitable preventive measures. As can be seen, the following is essentially a systematic study of the documents needed for the construction and utilization of buildings.

B 2. Sources of errors in the technical procedures during the planning phase and their elimination

B 2.1 General outline

The importance of the planning phase is often underestimated in relation to other phases of the building process, although decisive choices are made during this stage.

The planning phase is unavoidably fraught with various pitfalls, and this situation is not likely to change substantially in the future. A special effort will therefore have to be made to ensure an earnest and critical approach to this phase. Tasks should be defined clearly and unequivocally. It is essential that decisions about the purpose of structures, about matters of serviceability and safety, and about the risk of personal injury or property damage are made by those who have the required knowledge. This is especially true in view of the complexity of modern buildings.

The increased demands made on buildings, the use of new materials, methods, and so on, make it necessary to adopt a systematic strategy against errors. It is possible to distinguish five types of errors in this respect (figure B-2).

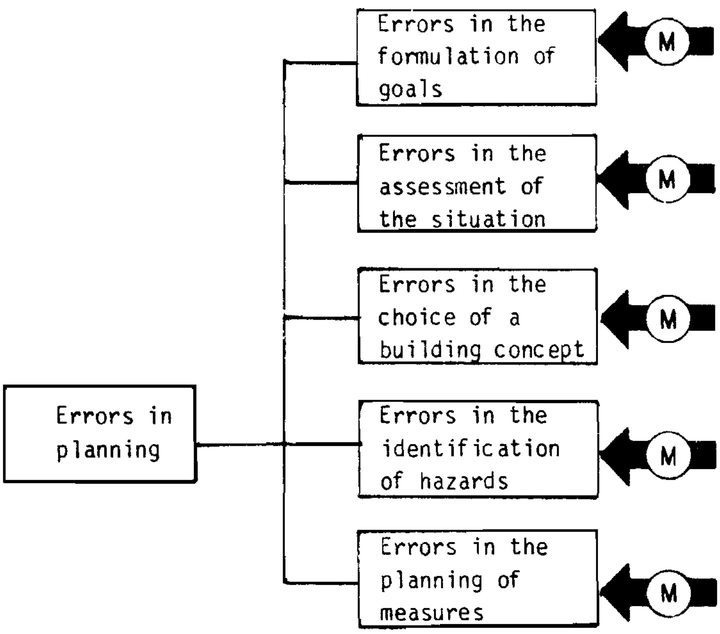


Figure B-2. Errors in planning and their prevention.

A substantial proportion of errors in the technical procedures of the building process as a whole can be prevented during the planning phase by systematically laying the basis (figure B-3) for the subsequent phases. This should be done according to suitable principles and methods, as described below.

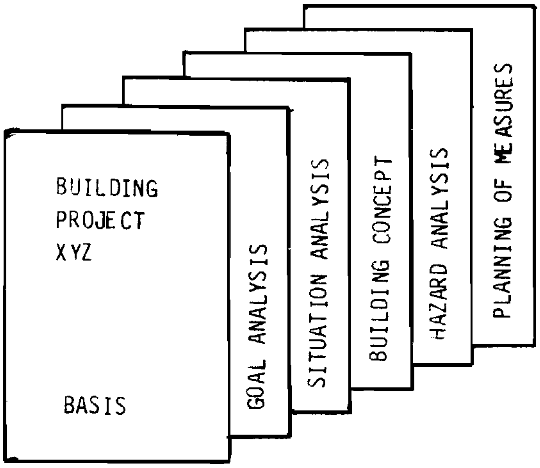


Figure B-3. Laying the basis for the planning, design, construction and utilization.

Goal analysis is aimed at identifying all the expected activities in the building, as well as its utilization, and establishing the corresponding requirements.

Analysis of the initial situation includes all the parameters of the initial situation, i.e. the building site, superstructures, conduits, etc., as well as the resulting interface conditions.

The building concept must be carefully defined and adjusted to the established goals and interface conditions laid down in the analysis of the initial situation.

Hazard analysis is aimed at identifying and evaluating the hazards that are linked with the planned building concept. The hazards represent unfavourable influences in the natural environment, in human activities, and in the various building components (bearing structure, finishes, utilities, equipment, etc.).

In the planning of measures it is intended to determine which hazards will be eliminated by what means, and which hazards will be accepted as a risk. If, in the process, it is found that a building concept suited to the intended use involves major hazards whose elimination would be too costly, or whose acceptance as a risk does not appear justified, a more suitable building concept will have to be found.

B 2.2 Goal analysis

Human activities in a variety of sectors (residential, production, transportation, etc.) create a need for buildings. A systematic approach to goal analysis provides clear, unequivocal definitions of goals, which in turn help reduce errors in goal selection (figure B-4).

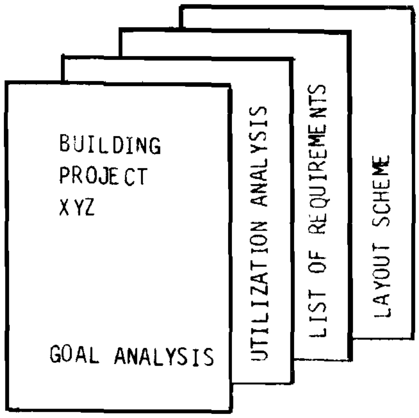


Figure B-4. Subdivisions of goal analysis.

The systematic analysis of goals entails a utilization analysis, with a corresponding list of requirements and a layout schemes based on the utilization analysis.

B 2.2.1 Utilization analysis

As a rule, when the intention to build is first formulated, only the main features of intended use are known. These are further studied through utilization analysis, along with related construction and operational requirements. Utilization analysis is carried out in the form of a so-called work tree [29], which involve three steps:

a) Determine the overall purpose

The overall purpose refers to the main intended use, i.e. residential, production, supply, etc.

b) Determine the accompanying activities

The overall purpose "Residential use", for example, would cover the following activities: cooking, washing, sleeping, bathing, etc. If production is the overall intended use, it involves: handling, storing, drilling, welding, assembly, controls, etc. A systematic study makes it possible to assign various activities to the overall intended use.

c) Establish requirements

It is necessary to study and define:

- Requirements for the technical operations, such as size of rooms, necessary utilities such as water, gas, power, telephone, etc.

- Working conditions such as climate, lighting, ventilation, working area, etc.

The utilization requirements that are identified in this way are translated into practical requirements of the building during the next step; the result is a list of requirements.

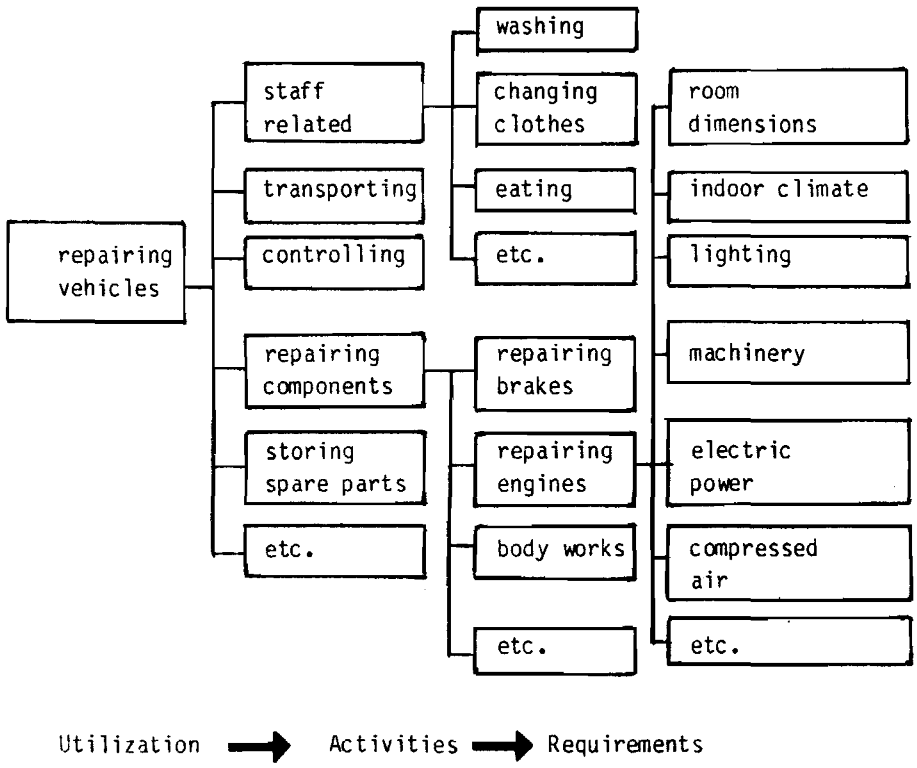


Figure B-5. Example of utilization analysis (with only some of the branches).

B 2.2.2 List of requirements

The purpose of this list is a realistic arrangement, expressed in numerical terms, of individual building requirements, e.g. in the form of a plan of the size and use of the rooms [46]. Although so-called functional performance descriptions are developed as a method for an overall approach to building objectives and criteria [32], mainly to ask for prices according to the requirements, they can nevertheless be helpful in the present context.

Requirements may be divided into:

- general requirements,
- requirements for building components (figure B-6).

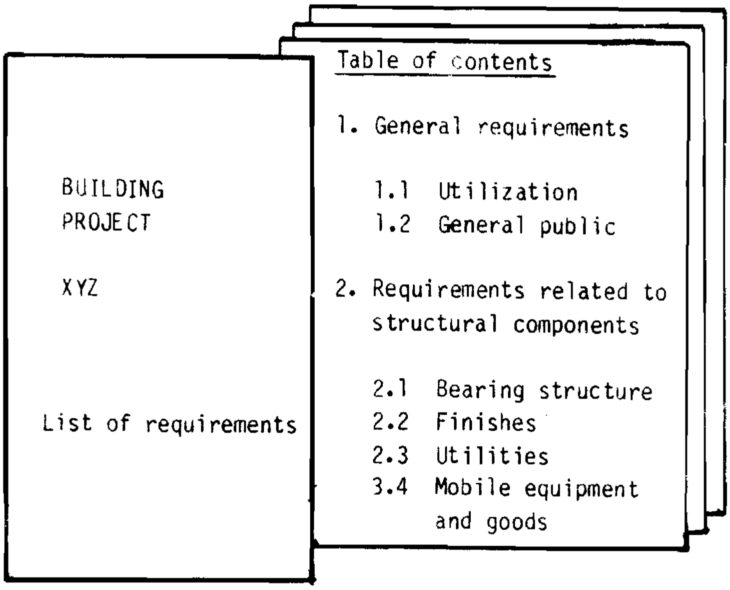


Figure B-6. Subdivisions of the list of requirements.

General requirements include the utilization requirements identified by the owner and the intended users, as well as public demands. Utilization requirements are defined through the utilization analysis, and refer to real data such as the number of rooms, the water and power demand, etc. Public demands, in the form of laws, rules and regulations, cover such matters as safety, groundwater protection, environmental management, etc.

On the basis of the general requirements, the necessary building components are determined and their requirements are formulated accordingly. Building components include the structure, finishes (finishing, floor covering, windows, etc.), utilities (supply and disposal conduits, elevators, heating, etc.), mobile equipment and goods (furniture, machinery, bulk goods, etc.). Requirements for building components can be further divided, as is done in figure B-7 for the load-bearing structure.

It is often possible to formulate requirements in the form of real, numerical data, i.e. load 5 (kPa), temperature 80°C, maximum deflection of span/400, maximum settlement of 30 mm, etc. For current structures, many of these requirements are provided in existing standards, guidelines, and so on. A suitable reference to the corresponding documents is sufficient in such cases.

2.1 Requirements related to the structure.
Architectural requirements - spatial design - esthetic effect - flexibility - extension and alteration capability Economic requirements - costs - construction time - maintenance - period of use - demolition Serviceability requirements - effects of occupancy - additional effects - durability - dimensional discrepancies and tolerances - sound insulation - heat insulation - impermeability - other properties Safety requirements - static safety - fatigue safety - fire safety - additional safety requirements

Figure B-7. Requirements related to the structure.

As a rule, requirements are of varying significance. In this respect, it is often important to distinguish between so-called mandatory and desirable requirements [43]. Mandatory requirements are those which must be fulfilled if the intended utilization is to be guaranteed, or if there is to be no public objections. They include structural safety requirements, serviceability, cost-effectiveness, etc. Desirable requirements are those which, though desirable, are not absolutely required for utilization, i.e. in the eyes of the owner, the users, and the public. Depending on the intended utilization, they include esthetic considerations, ease of alteration, spatial configuration, and so on. Desirable requirements are also of varying importance, and may at times be weighed or assessed.

B 2.2.3 Layout scheme

Requirements in terms of the spatial configuration of individual areas of use or functional units (storage, production, etc.) can be represented as layout schemes (layout [46] [78]) (figure B-8).

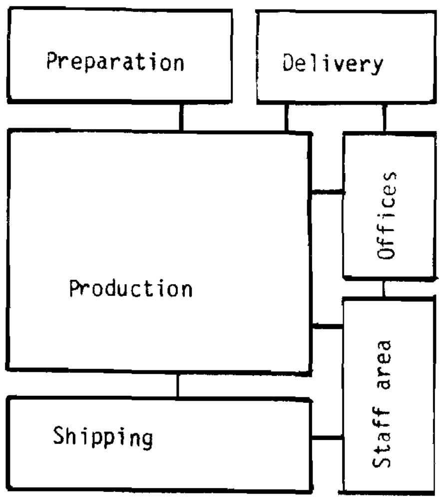


Figure B-8. Example of a layout scheme.

The layout scheme is based on the necessary or desirable functional relations between the individual areas of use. The storage of materials in a plant, for example, should be placed in the direct vicinity of the processing area, and, similarly, the workrooms for teaching staff and students in a university should be placed as close as possible to the classrooms. By analyzing the movements of people, the flow of materials, the energy supply, etc. [78], it is possible to identify and assess the relations between the various areas. Such analyses form the basis for a functional layout of individual areas. The final layout, however, also depends to a large extent on analysis of the initial situation (see B-2.3), and sometimes on hazard analysis (see B-2.5).

B 2.3 Analysis of the initial situation

The particular circumstances of the initial situation, as well as the relevant influences, must be determined and recorded. A systematic analysis of the initial situation and a careful study of the accompanying documents makes it possible to reduce errors due to insufficient understanding of the elements of an existing situation (figure B-9).

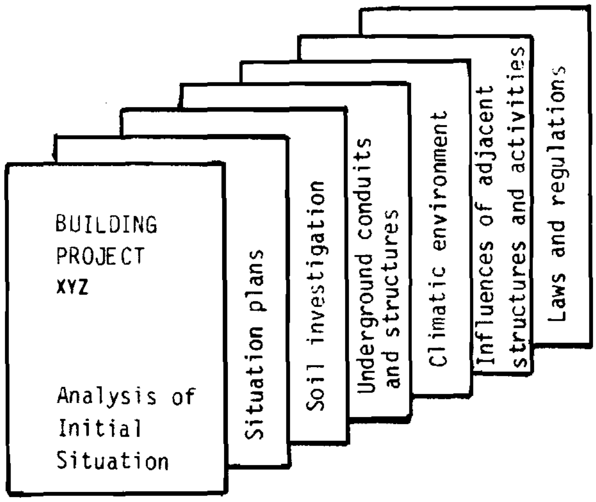


Figure B-9. Subdivisions of the analysis of the initial situation.

Analysis of the initial situation is basically concerned with the facts and elements which describe the location and the environment of the proposed building. Priority is given to those facts which affect the technical aspects. Such factors as financing, recruitment of manpower, etc. will not be dealt with here. The various factors are classified according to their origin (in the natural environment, in human activities) and relationship with the site (over, on, below), and are then identified, described, and checked for completeness on the basis of that classification (figure B-10).

B 2.3.1 Plans of the initial conditions

The situation plans provide a graphic representation of the relevant characteristics of the building site (topography, existing and planned structures, etc.). According to the type and scope of such characteristics, various plans of initial situation can be identified [46]:

Overall regional plan

Coordination of the local planning of a region, that functionally belongs together. This plan is drawn usually in the sense of a standard plan.

Influcences of the initial situation	
due to natural environment	due to human activities
Over the site: - wind - rain - heat - frost - lightning - hail - fog - snowfall - other	Over the site: - aircraft - noise - air pollution - power lines - cableways - other
On the site: - rainwater - floods - snowcover - avalanches - streams - lakes - slides - other	On the site: - structures - vehicles - human activities - power lines - fill - other

Below the site:
- soil materials
- stratification
- water table
- settlement
- springs
- landslides
- weathering
- earthquakes
- other
	Below the site:
	- conduits for:
	  - gas
	  - electric power
	  - water
	  - telephone
	  - wastewater
	  - other
	- tunnels
	- mining tunnel
	- backfill
	- other

Figure B-10. Influences of the initial situation.

Zone plan

Legally binding planning instrument used to establish zones having the same building requirements.

Traffic plan

Layout of vehicle and pedestrian traffic, also called street plan or development plan.

District plan

Legally binding regulation for streets, building lines and boundaries within a particular town district.

Development plan

Establishment of privately contracted overall development as the basis for real estate registration or gradual further development.

Site plan

Stipulation of the building project in terms of the site, dimensions and relations to the environment (terrain, boundaries, access, building lines, easements, grade levels, and so on). In most cases, this is done with the help of an official land register, which then forms part of the building application.

Environmental plan

Description of the immediate area with detailed data on grades, surface features, drainage, roads and grounds, planted areas, and so on.

B 2.3.2 Soil investigation

The purpose of the soil investigation is to determine the structure and features of the soil, the sequence of layers, the water table, and other information relevant for the building. The nature and scope of this investigation depends on the type of building and the complexity of the soil itself. The "soil investigation" should, first of all, describe the type of investigation (visual assessment, soundings, measurements, comparisons with other buildings, etc.); it should then contain an evaluation of the results of the investigation; finally, it should make recommendations (construction procedure, type of foundation, and so on) and indicate relevant control measures. For the sake of hazard analysis (see B-2.5), complete details about possible hazards (i.e. slip planes, evidence of creep, etc.) should also be provided.

B 2.3.3 Underground conduits and structures

Cases of damages are often due to underground conduits, or involve conduits or other structures in the soil [58]. Conduits for power lines (high, medium and low voltage), telephone wires and, water, sewer, gas, heating and oil pipes, etc., are mainly affected. Conduits may be damaged by the building (additional load, settlement), or they may have some influence on the construction work or on the building itself. A leaky water pipe, for example, may cause a change in soil properties that can undermine the excavation or result in settlement of the structure.

B 2.3.4 Climatic environment

Documents dealing with the climatic environment should contain all the essential information for the building project, and, especially, data on wind, snow, rain, temperature (daily, annual), insolation, fog formation, etc. Such information can be gathered on the basis of local measurements and statistics, interviews with local residents, enquiries to the authorities, etc. In making plans for a highway, for example, it is important to consider, in addition to other factors, fog formation and icy conditions.

B 2.3.5 Influence of adjacent structures and activities

The documents prepared under this heading should encompass all possible effects of adjacent structures (streets, buildings, industrial plants, etc.) and activities (transportation, production, storage, etc.) on the planned structure. Transportation routes, for example, could constitute a collision hazard (vehicle crashing into parts of the building); similarly, the storage of explosives would represent a hazard, and so on.

B 2.3.6 Laws and regulations

This heading covers all the laws and regulations that have some bearing on the construction work, the building itself, and the intended use, including such matters as the allowed building height, building lines, distances between buildings, utilization factors, etc. Some important data may be provided by the relevant of the initial situation.

B 2.4 Selecting a building concept

The basic document entitled "Building Concept" is used to describe the building components (structure, finishes, conduits, etc.), the selected materials, the planned method of construction, as well as the chosen procedures and techniques, and to provide precise reasons for such choices. By building concept is meant the systematic arrangement of the various building components (structure, heating system, etc.), the rational use of materials and methods of construction, as well as the systematic sequencing of individual processes with the corresponding methods of construction (figure B-11). In this respect, it is important to keep in mind the circumstances of the initial situation as given conditions, as well as the requirements for utilization.

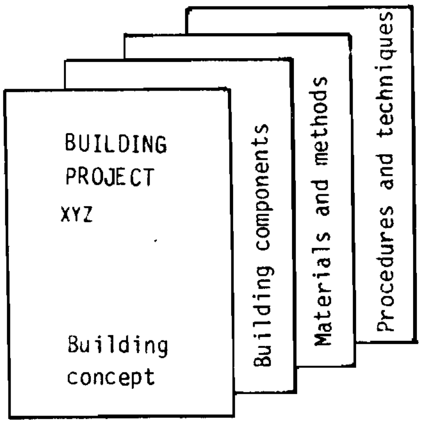


Figure B-11. Subdivisions of the document "Building concept".

The section on "Building components" describes and substantiates the choice of components in terms of the requirements (see B-2.2), together with the relevant initial situation (see B-2.3).

The section on "Materials and methods" describes and explains the building materials, with their characteristics and range of application, as well as how they are to be used.

The section on "Procedures and techniques" explains various aspects of the building procedures and techniques used in relation to the selected components, including relevant regulations and boundary conditions to be taken into consideration, and provides reasons for choosing them.

As a result of hazard analysis (see B-2.5), or once the measures have been planned (see B-2.6), it often becomes obvious that the initial building concept needs revision, because it would be impossible or very expensive to eliminate the hazards linked with it.

B 2.5 Hazard analysis

The various hazards related to the construction and use of a building are identified through hazard analysis, and spelled out in writing. Errors in the sense that individual hazards are subjectively unknown, or are not taken into consideration, may be prevented or reduced by means of suitable methods of hazard identification and appraisal [3,4,29,30,31,66,67, 72]. With the hazard identification, hazards in the "building" system and in the environment are determined qualitatively. This requires a careful definition of the system. A functional distinction can be made within the "building" system between structure, finishes, utilities, mobile equipment, and so on. This type of qualitative hazard identification is often sufficient as far as the planning of measures is concerned [44]. However, an appraisal of hazards is also needed at times as a decisional aid for the selection of measures and the evaluation of risks. Hazard appraisal is essentially concerned with the potential extent of failure and the probability of its occurrence, but it also deals with consciously accepted risks, risk aversion, etc. [31,60,95] (see B-2.6.3). In most cases, however, the first two items mentioned are sufficient [26].

There are various procedures and techniques of hazard identification and appraisal. In simple cases, it is sufficient to use existing legislation, regulations, standards, etc., as well as personal knowledge and experience, for hazard identification. For complex buildings, however, this is not enough, and a systematic procedure is required. There are two basically different types of procedure.

One type goes from the causes to the consequences ("inductive" procedure). The failure of individual components (cause) is studied in terms of its effects (consequence). According to the type of component under study, the following analyses may be appropriate: energy analysis, analysis of unfavourable influences, failure-effect analysis, or interface analysis.

The other type goes from the consequences back to their causes ("deductive" procedure). Starting from an unwanted occurrence, the possible components or hazards that caused it are systematically investigated. This is called fault tree analysis (figure B-12).

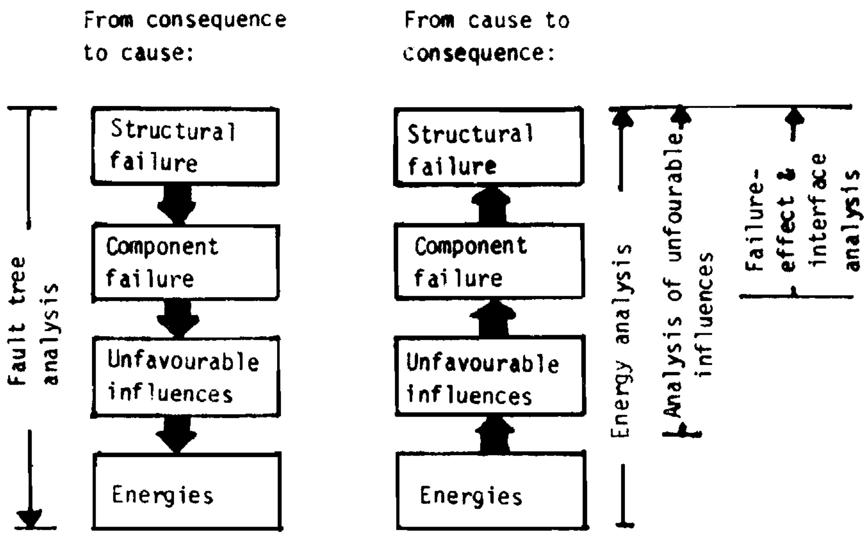


Figure B-12. Methods of hazard identification in terms of structural failure and its causes.

In the case of buildings, hazard analysis also begins with hazard identification of a qualitative nature (following the principle that a known hazard is only half a hazard). Once a decision has been made concerning acceptable risks, an appraisal of the hazards may be appropriate or even necessary.

Some of the techniques of hazard analysis and appraisal will now be described in more detail.

B 2.5.1 Hazard analysis based on laws and regulations

Frequent hazards, especially those which the public wishes to avert, are described in laws, regulations, standards, and so on, and are therefore readily available. As a result, such laws, regulations and standards are a source not only of obligation but also of information. In some cases, hazard recognition may therefore simply consist in compiling the hazards mentioned in laws, regulations, standards, and so on. In the case of complex buildings, this type of compilation often forms the basis for further hazard analyses.

B 2.5.2 Hazard analysis through personal experience

Hazards may be identified on the basis of the knowledge and experience of the participants in the building process. This can often be done in the course of a discussion involving specialists (so-called intuitive analysis [13,31,66]), who assess a specific system (building, structural component, etc.) from their respective points of view. What to one may appear unimportant might be very significant to another, and deemed hazardous. Although this procedure, in principle, is not systematic, and is difficult to control, it is effective in many cases.

B 2.5.3 Energy analysis

All changes in an existing situation and all processes are the result of released energy. This forms the basis for energy analysis [4,30,67,72], which studies the energies present in a system and the accompanying consequences.

ENERGY LIST	
Gravity - mass - height difference Pressure forces - in the structure - on the structure Kinetic energy - means of transportation - tools and machinery - environment Electricity - sources - supply - distribution - consumers	Chemistry/Biology - corrosion - explosion - fuel - toxic sources - biological sources Thermal energy - planned - unintentional Radiant energy - thermal - acoustic - electromagnetic

Figure B-13. Example of an energy list (excluding nuclear). ([30] short version)

For a well-defined system such as a building or a structural unit, all the energies within its range of influence are evaluated. This process is facilitated by checklists and energy lists [30,67,72], as is illustrated by the example in figure B-13 [30].

The energies listed there are further investigated in terms of their unwanted release and potential effects, and the result is described qualitatively or quantitatively.

B 2.5.4 Analysis of unfavourable influences

All buildings and all structural components are subject to unfavourable influences. Analysis proceeds from such influences, and studies their potential effects on the building or the structural components.

A distinction is made between unfavourable influences in the natural environment, in human activities (building utilization, traffic, adjacent objects, the building process, war and sabotage), and in the internal structure of the components [58,94]. The individual influences are determined essentially on the basis of influences identified through analysis of the initial situation, but the process can be facilitated by the use of lists of unfavourable influences (so-called hazard lists [67]). For buildings and their components, for example, it is possible to use the list in figure B-14, in which relevant influences can be checked off.

That list (or any list for that matter) is not complete, but it can be of use in identifying unfavourable influences.

B 2.5.5 Failure-effect analysis

This type of analysis [4,31,68,72] (FMEA=Failure Modes and Effects Analysis; HMFA=Hazard Modes and Effects Analysis) is concerned with the failure of individual system components (structural components) and its effects on the corresponding system (building). The purpose of such analysis is to identify those components in the system whose failure would have dangerous consequences. It only deals with effects, not with the causes of failure. The simultaneous failure of several components or combinations of failures are not recorded, at least not directly.

DETERMINING THE UNFAVOURABLE INFLUENCES

1) From the natural environment (see Figure B-10)

2) From human activities

INFLUENCES \ ACTIVITIES	Building utilization	Traffic	Adjacent structures	Construction procedures	War and sabotage
Loading					
Oscillations					
Vibrations					
Impacting objects					
Fire					
Explosions					
Radiation					
Temperature					
Water					
Humidity					
Changing water table					
Conduits					
Excavation influences					
Chemical influences					
Biological influences					
Other					

3) From structural components

INFLUENCES \ BUILDING COMPONENTS	Structure	Finishes	Utilities	Mobile equipment
Loading				
Dimensional discrepancy				
Failure				
Low strength				
Too elastic				
Too brittle				
Corrosion sensitivity				
Fatigue sensitivity				
Permeability				
Not durable				
Shrinkage				
Creep				
Swelling				
Other				

Figure B-14. Determining the unfavourable influences.

Failure-effect analysis consists of the following steps:

- identifying the components of the system, and numbering them;
- defining the type of failure of each component;
- describing the effects on other components and on the system;
- assessing the effects (e.g. the extent of possible damage);
- assessing the possibility of occurrence (e.g. probability, classes, etc.).

The above information can be supplemented by answers to such questions as: How can a failure be discovered in time? How can a failure be averted? The advantage of this kind of analysis lies mainly in its qualitative search for effects. In particular, failure-effect analysis makes it possible to recognize critical items or elements. The failure of a single column, for example, can lead to the collapse of the entire structure. The dreaded "domino effect" or progressive collapse is prominent in this type of analysis.

The application of failure-effect analysis to buildings will now be illustrated by a simple example (figure B-15), which uses the following classification schemes:

Classification of personal injury (PI):

0 - no persons involved,
1 - one to five persons involved,
2 - six to ten persons involved,
3 - more than ten persons involved.

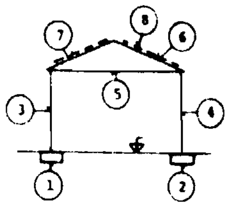
Classification of property damage (PD):

0 - less than 5,000 Swiss Francs,
1 - 5,000 to 50,000 Swiss Francs,
2 - 50,000 to 250,000 Swiss Francs,
3 - more than 250,000 Swiss Francs,

Classification of the probability of occurrence (W):

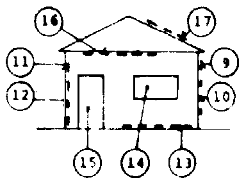
0 - less than 0.001
1 - 0.001 to 0.01
2 - 0.01 to 0.1
3 - 0.1 to 0.5
4 - 0.5 to 1.0

STRUCTURE



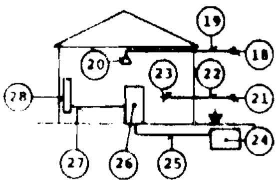
No.	Components	Failure	Effects	Classific. PI	PD	W
1	Foundation	Settlement	Cracks	0	0	3
2	Foundation	Settlement	Cracks	0	0	3
3	Wall	Failure	Collapse	3	3	0
4	Wall	Failure	Collapse	3	3	0
5	Reinforced concrete ceiling	Failure	Collapse	3	3	0
6	Wooden beam	Failure	Partial collapse	2	2	1
7	Wooden beam	Failure	Partial collapse	2	2	1
8	Roof beams	Failure	Partial collapse	0	1	2

FINISHES
(only a few components)



No.	Components	Failure	Effects	Classific. PI	PD	W
9	Stucco	Flaking	Blemish	0	1	2
10	Exterior paint	Peeling	Blemish	0	1	2
11	Interior plaster	Flaking	Use impaired	0	1	1
12	Interior paint	Peeling	Use impaired	0	1	1
13	Flooring	Loosened	Accident hazard	1	1	1
14	Windows	Not tight	Heat losses	0	1	1
15	Doors	Catch	Heat losses	0	1	1
16	Ceiling facing	Breaking off	Danger of injury	1	1	1
17	Roofing skin	Not tight	Property damage	0	1	3

UTILITIES
(only a few components)



No.	Components	Failure	Effects	Classific. PI	PD	W
18	Electric power	Interruption	Use impaired	0	0	4
19	Electric wiring	Breakdown	Fire	1	3	1
20	Light fixture	Breaking off	Danger of injury	1	0	1
21	Water supply	Interruption	Use impaired	0	0	4
22	Water pipes	Breakdown	Water damage	0	1	3
23	Water faucet	Broken	Water damage	0	1	2
24	Oil tank	Not tight	Oil damage	0	2	2
25	Oil pipe	Not tight	Oil damage	0	1	2
26	Burner	Interruption	Frost damage	0	1	2
27	Heater circuit	Not tight	Water damage	0	1	1
28	Radiator	Not tight	Water damage	0	0	2

Figure B-15. Example of a failure-effect analysis of a simple building.

For the sake of simplicity, only one type of failure is indicated, but several failures or types of failure are often possible.

B 2.5.6 Interface analysis

From a technical point of view, interface analysis is concerned with the study of hazards which might occur at the interface between individual components of the system. Examples in a building would be the "interface" between bearing structure and finishes, or between finishes and utilities. The same is true for the interface between the structural components themselves (in the bearing structure, for example: expansion joints, connections, bearings, etc.). Furthermore, interface analysis plays an important role in organizational matters (see C-5.2.2).

Interface analysis is essentially a form of failure-effect analysis, in which the collapse at the interface constitutes the failure.

B 2.5.7 Fault-tree analysis

Fault-tree analysis makes it possible to systematically assess the possible causes of an unwanted occurrence [3,26,29,31,32,70,72]. This type of analysis begins with a definition of an unwanted occurrence, and investigates the possible causes of that occurrence. In the next step, each causal factor is itself considered an unwanted occurrence, and its possible causes are studied. Successive causes are identified until no further cause is known, or until further investigation would be pointless. The chain of causality takes on the form of the branches of a tree (hence the name "fault tree analysis"). Because of their logical structure, fault trees are also called logical diagrams.

The process is especially appropriate for the appraisal of hazards. Such appraisal can limit itself to a calculation of the probability of occurrence of the unwanted event, since the possible damage has already been defined, and can easily be estimated.

Calculating the probability of individual events must be based on the probability of the accompanying components and their relationships. There are two basic types of relationships, identified as "and" and "or" connectors. In the case of "and" connectors, several components must be present for an event to occur, and the probabilities of the individual components are multiplied. In the case of "or" connectors, the presence of only one of the components is sufficient for the event to occur (i.e. one component or another), and so the probabilities of the components are added.

Fault tree analysis can thus be described in terms of the following steps:

- defining the unwanted situation or the unwanted occurrence in the system;
- determining the causal components and the relations between them;
- assessing the probability of occurrence of the ultimate components;
- calculating the probabilities of occurrences successively up to the unwanted event.

This procedure is outlined in simplified form in figure B-16.

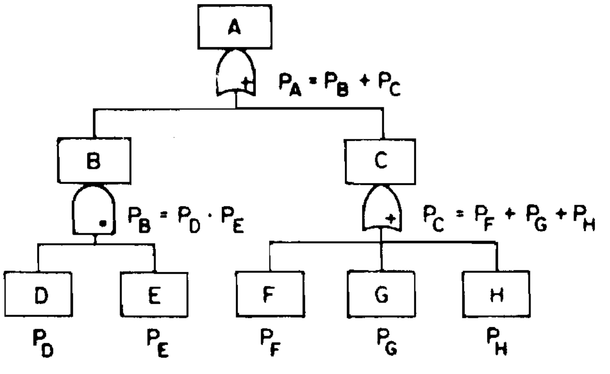


Figure B-16. Example of a fault tree.

Nomenclature:

A - unwanted event
B, C, D ... - components of the unwanted event
 - "and" connector: all relevant components are required for the event to occur
 - "or" connector: only one of the possible components is sufficient for the event to occur
P_i - probability of occurence of component "i"

The procedure outlined in figure B-16 is illustrated by means of an example in figure B-17. For the sake of simplicity, only some of the branches are depicted, and arbitrary probabilities are used.

In the ideal case, all probabilities would be known, and calculations would yield the "actual" probability of the unwanted event, as well as the most hazardous path (critical path) in the system under consideration. In practice, and particularly for buildings, the probabilities are rarely known. They must be replaced by estimates which more or less correspond to weighted values of hazards. Nevertheless, the dominance of certain hazards does become evident, and there is thus clear evidence of those factors which merit more detailed study and of those measures which might be used effectively to avoid hazards.

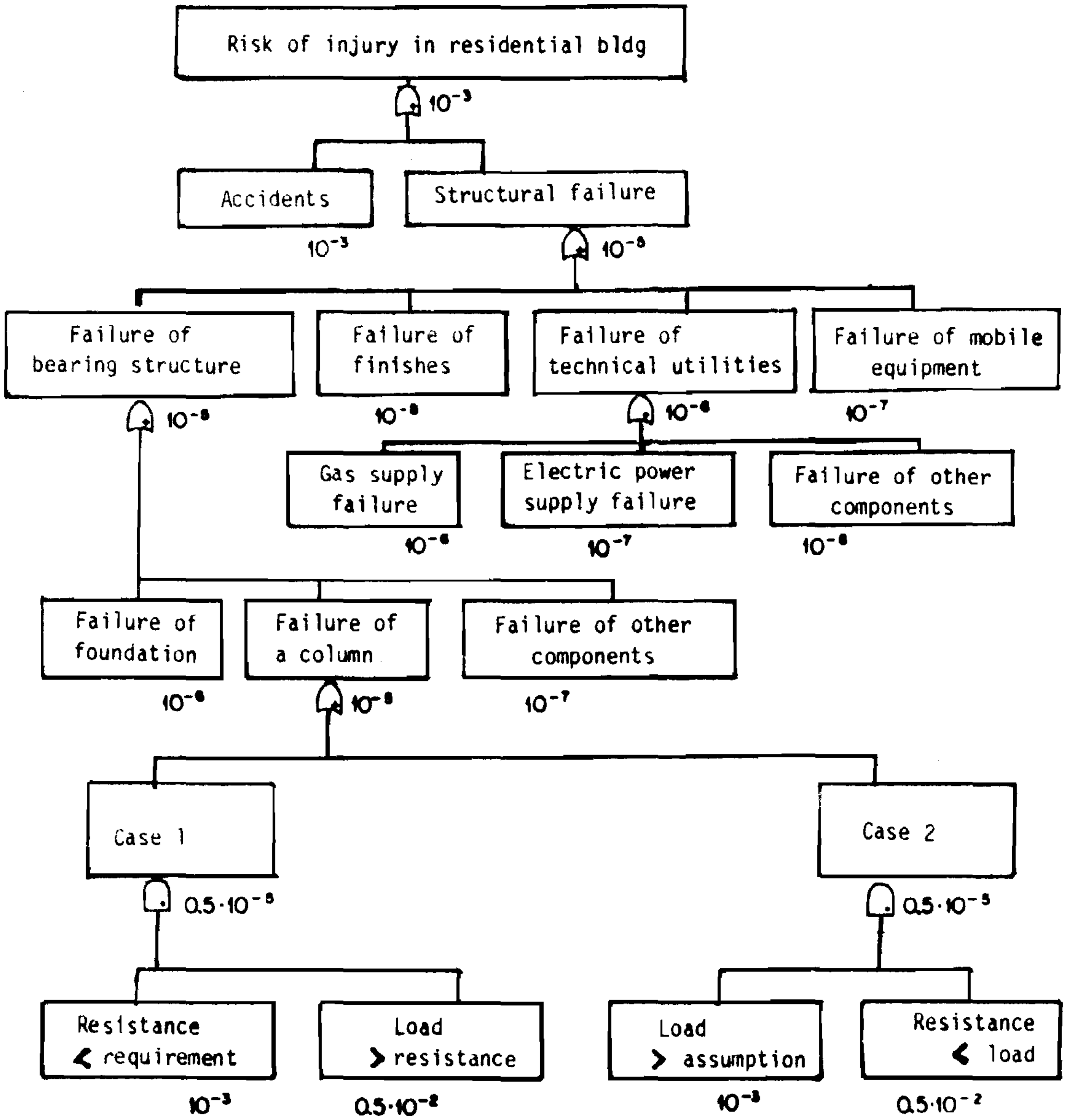


Figure B-17. Example of a fault tree applied to the risk of injury in a residential building.

B 2.6 Planning of measures

Errors may occur during the preparation of decisions about suitable measures for the quality of the structure. For example, planning of measures in general, or design plans in particular, may be incorrect or incomplete. The inadequate clarification of accepted risks and the use of erroneous or wrongly applied measures can lead to accidents. Such errors can be avoided by carefully laying the basis for the planning and design, execution, and utilization phases (figure B-18).

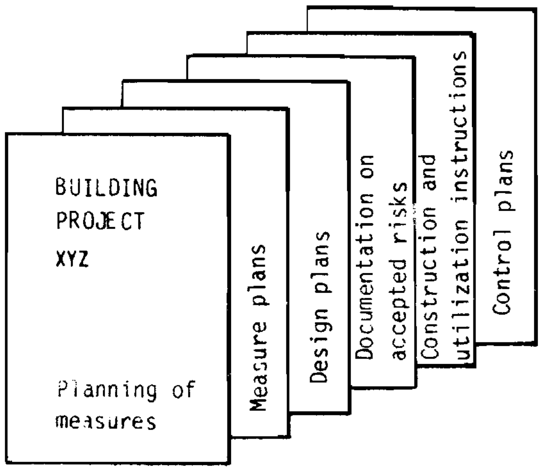


Figure B-18. Documents used to plan measures.

B 2.6.1 Documentation of measures

In the measure plan, relevant hazardous situations or "hazard scenarios" [107] for the various structural components (structure, finishes, conduits, etc.) are described, and suitable counter measures are established [69]. The hazardous situations are described through the hazards identified with the hazard analysis, and suitable measures are found to counteract them. The term "measure" is taken here in the broader sense, and is not restricted to the design of the bearing structure. The hazards of a given situation may be avoided through the following measures:

- getting around the hazards by modifying the building project or the building concept;
- eliminating the hazards at their source;
- reducing the effects of any hazards (e.g. exhaust valve);
- compensating for the effects of any hazards (e.g. bearing resistance);
- containing any hazards through controls and monitoring;
- accepting the hazards as a risk.

As a rule, the above preventive measures are used in combination. Snow loads, for example, may be dealt with to a certain extent by a suitably designed bearing structure, but snow removal would be an added measure in cases where design values might be exceeded. Most hazards can be averted through a proper combination of the above measures. In cases where the magnitude of a hazard cannot be fully ascertained, or where its complete elimination is either impossible or unjustified for economic reasons, only parts of its effects are averted, and the rest is accepted as a risk. The extent to which hazards are eliminated or accepted as risks depends on the goal requirements. In this respect, documentation of measures might represent so-called utilization plans on the one hand, or so-called safety plans on the other [107]. The utilization plan is based on the intended use; it indicates which hazards are to be eliminated in terms of the intended use (e.g. earthquakes), and formulates corresponding measures. Incurred risks are linked primarily with property damage, and are usually discussed with the owner. The safety plan is concerned basically with personal safety in and around buildings, and establishes the appropriate measures. Risks accepted in the safety plan are usually restricted to the minimum admitted by society.

Documentation of measures can often take on a very simple form [69], e.g. a list that is set up directly opposite the hazards of a given situation. This may be sufficient in simple cases. In more complex cases, however, the documentation of measures serve as an overview, and are outlined in design plans, in the documentation on accepted risks, as well as in working and utilization instructions, control and supervision plans that provide necessary details.

B 2.6.2 Documentation for design

Documentation for design provides detailed information about the type and magnitude of influences and hazards that are to be taken into consideration in the design of structural components. In addition to influences and hazards, documentation for design also deals with construction and other materials, including their properties, conditions and requirements to ensure their properties, guarantees, etc. Such information is especially important in the case of materials for which little experience has been accumulated (e.g. new types of insulation or fasteners), or for which there exist no standards, regulations or guidelines. In the case of materials such as concrete and steel, whose properties and applications are laid down in standards and regulations, a reference to the corresponding document is usually sufficient.

B 2.6.3 Documentation of accepted risks

Risks are often incurred without proper knowledge and investigation. The result can be unexpected failure. To minimize this type of error and find measures which reduce its effects, it is important to provide a systematic study of the incurred risks in the "Documentation of accepted risks". The term "accepted risks" indicates that these are not simply incurred risks (i.e. the result of carelessness or negligence), but risks which have been examined carefully, whose possible consequences have been discussed with the people involved, and which were found acceptable and documented in writing. This type of risk documentation should include the following:

a) Possible damage

Damage is defined generally as a loss of property [58], and property is taken in its widest sense. When assessing any possible damage, it is essential to distinguish between personal injury and property damage. The latter can be overcome more or less completely through financial means, but in the case of personal injury, the financial consequences can at best be mitigated. In addition to direct damage, there is usually some consequential loss, including damage to adjacent objects and loss that only becomes apparent at a later date (e.g. production breakdowns, delays). Consequential loss often exceeds direct damage many times over.

b) Probability of failure

Probabilities assign a numerical value to the possibility of damage. This value is often only an approximation, however, since more accurate information is not available. Probabilities can sometimes be estimated by comparing the possible damage with similar events.

c) Basis for decision

The basis for decision are the various aspects which are taken into consideration when a decision is made. Each aspect consists of a number of criteria which are used to measure risks [90]. Some objective basis for decision should first be established, such as the so-called expected damage, which is the product of the possible damage and the corresponding probability of failure. The expected damage is then compared with the benefits of the incurred risk, and the results of the comparison indicate whether the risk can or cannot be incurred. An objective decision of this type is not always possible because:

- not all the essential aspects can be included in the decision;
- the benefits cannot always be expressed numerically, so that formal optimization is not possible;

- the absolute extent of damage must be taken into consideration, since it is important to know whether a given expected damage results from a very large failure with low probability, or from a relatively small failure with a high probability (so-called risk aversion [60] and criticality [31]);
- it is difficult to appraise personal injuries and to compare them with property damage and benefits;
- there are financial, political, military or social constraints;
- subjective desires and conceptions are involved.

In view of the multiplicity of aspects and criteria on which a decision can or must be based, the basis for decision must be indicated in the risk documentation.

d) Risk bearer

Risks are often incurred with no clear indication of those who actually bear the risk. As a rule, those who enjoy the benefits of an incurred risk should also be the risk bearers. When the risk bearer is clearly identified, ambiguities are avoided, and the risk bearer is forced to decide whether he is able or willing to bear the risk, or whether others are to bear it. Insurance plays and important role in this respect. A distinction between insignificant, small, large, and catastrophic risks can be made [38]. The individual can:

- bear insignificant and small risks himself;
- cover average risks as much as possible through insurance;
- always insure himself against large and catastrophic risks.

Of course, the appropriate arrangement depends on the financial resources of the individual involved.

e) Risk supervision

A failure occurs when a number of specific circumstances occur together. Since some of these circumstances are already present in a given situation, the actual occurrence only depends on a few additional influences [58]. By monitoring these additional influences as well as suitable risk indicators, it is usually possible to detect a potential occurrence in time. Risk indicators are any conspicuous and readily observed or measured changes in the situation under consideration; they include deformations, ground movement, smoke generation, water outlets, etc. [107].

Risk supervision is planned along the following lines:

- identifying existing circumstances and additional influences that could trigger an occurrence;
- making a detailed study of the additional influences;
- determining the threshold limit values;
- defining the risk indicators;
- specifying the supervision measures.

The scheduled risk supervision procedure is laid down in supervision plans, control instructions and checklists. Individual aids are described under error detection and correction in Part E.

Within the framework of risk monitoring, it is always important to consider objectively or subjectively unidentified hazards in any situation. These can be detected and corrected in time through risk supervision, provided that any signs and indications of danger are reported using appropriate, prearranged means by those responsible for risk supervision.

f) Preventing personal injuries

It is not always possible to directly prevent personal injuries. The timely identification of a threat, however, makes it possible to warn the people concerned, and evacuate them from the area.

Plans to prevent personal injuries are based on the following steps:

- identifying and defining the risk indicators and the corresponding action;
- determining the evacuation procedure (transportation, exits, etc.);
- defining and preparing suitable escape objectives.

Depending on the type of risk, such measures are recorded in alarm and evacuation plans.

g) Reducing property damage

As in the case of personal injuries, it is possible to reduce property damage. It is important to establish which warning signs will lead to the removal of which material assets from the danger area.

h) What to do in the case of a failure

If a failure occurs, it is important to minimize any direct or consequential loss. The first priority is to care for any injured persons. It is important to establish who will provide first aid where, how, and when, and to indicate where a doctor can be reached (telephone number), the location of a hospital, and how injured persons are to be transported. The second priority is to prevent spread of property damage, e.g. through fire fighting, makeshift shoring, etc. For larger accidents, emergency or disaster plans are required.

i) Repair of damage

Finally, plans must be made to overcome any damage that does occur. Plans to repair the damage, within the framework of identifying accepted risks, lead to swift restoration of desirable conditions and a reduction of consequential damages.

B 2.6.4 Construction and utilization instructions

Dealing with hazards is not simply a matter of technical measures, but also of proper actions of the people involved [91]. As a result, the people involved must be regarded as components of the system and "designed" as such. In this respect, proper action is ensured by asking people to follow instructions. Such instructions contain a description of the hazards and detailed information about appropriate actions. If necessary, they are supplemented by checklists. Due consideration for instructions and the use of checklists make it easier to manage the people involved, while preventing or reducing potential errors.

B 2.6.5 Control plans

The controls outlined in the documentation of measures or in the documentation of accepted risks are combined to form control plans. A control plan indicates which items are to be controlled when and how. Controls are either scheduled or required at certain times called control stops [107]. After a given control stop, the building process may continue only if controls indicate agreement between nominal and actual conditions, or if any required corrections have been made. If controls are used for supervision purposes (e.g. of accepted risks), the corresponding plans are called supervision plans. Part E of the report deals with control plans and controls themselves in greater detail.

B 3. Sources of errors in the technical procedures during the design and their elimination

B 3.1 General outline

The conditions for which the various structural components must be designed are established during the planning phase and recorded on design drawings. The decisions made during the planning phase are carried out during the design phase, i.e. structural components are calculated, detailed and drawn. Accordingly, the design phase is divided into three units: design calculation, structural detailing, drawings and lists.

Errors in this design phase are avoided by appropriate measures aimed at the source of the problem (figure B-19).

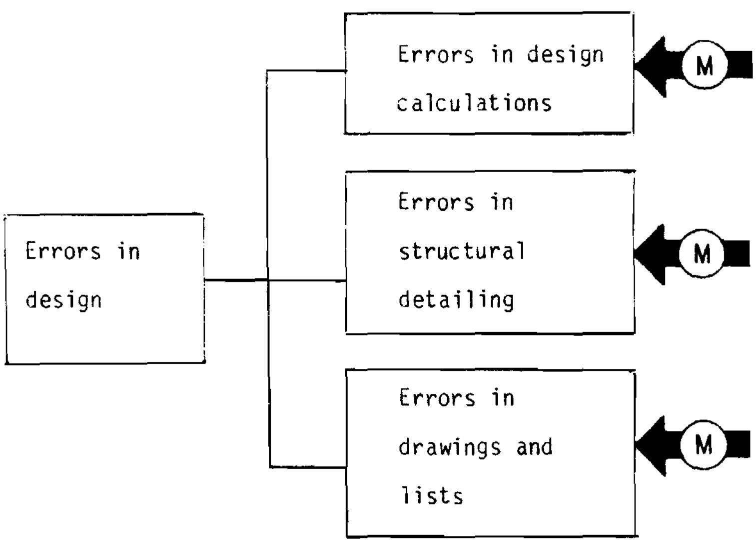


Figure B-19. Errors in the design phase and their elimination.

Suitable measures include, essentially, a clear description of facts, the use of examples, organizational technics, principles and methods, as well as carefully prepared building documents.

B 3.2 Design calculations

Usually, errors in design calculations are simple, elementary errors [58]. For example, the wrong stability systems may be chosen, loads may be overlooked, numbers interchanged, and results represented incompletely or erroneously. Generally speaking, three basic types of errors can be distinguished: missing, incomplete or incorrect calculations (figure B-20).

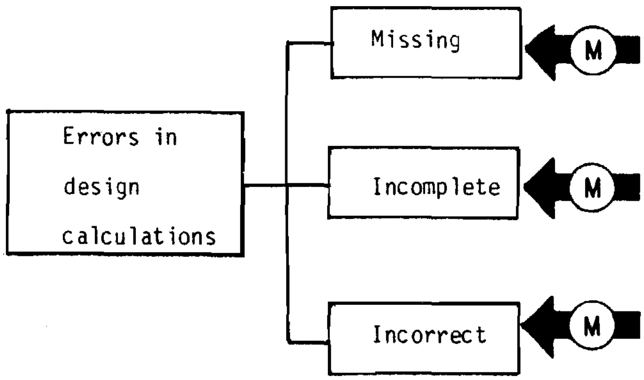


Figure B-20. Errors in design calculations and their elimination.

The search for the causes of errors and the corresponding preventive measures, as outlined in the following sections, deals primarily with structures. However, the information provided is generally valid for the design of other structural components, including finishing operations, utilities, mobile equipment, construction equipment, and temporary structures for the construction of the building.

B 3.2.1 Necessity for design calculations

Structural elements are basically dealt with under the heading "Design Calculations" (or "Structural Analysis"). This also applies to simple structures for which rules of construction or workmanship are sufficient. In these cases, the document entitled "Design Calculations" need only contain the more important information concerning structural and utilization conditions, materials and methods used, and notes on the need for calculations. Such a document might be limited to a few pages, or even a single page with the proper remarks.

"Design Calculations" documents ensure that the required calculations are available, while avoiding ambiguities at the interface between the need for a calculation and the limits of validity of the rules of construction and workmanship.

B 3.2.2 Systematic arrangement of design calculations

The investigation of failure cases [58] has provided evidence of the following types of error: design calculations were incomplete; data concerning loads and assumptions were deficient; some structural elements were simply not calculated; the calculation consisted of separate, disconnected sheets; etc.

The author of the "Design Calculations" document often does not himself know, later on, what in fact he has calculated. This and other errors are avoided or reduced by arranging the calculation in a systematic way. All design calculations of the structure, scaffolding, excavation, etc. should be divided as follows (figure B-21).

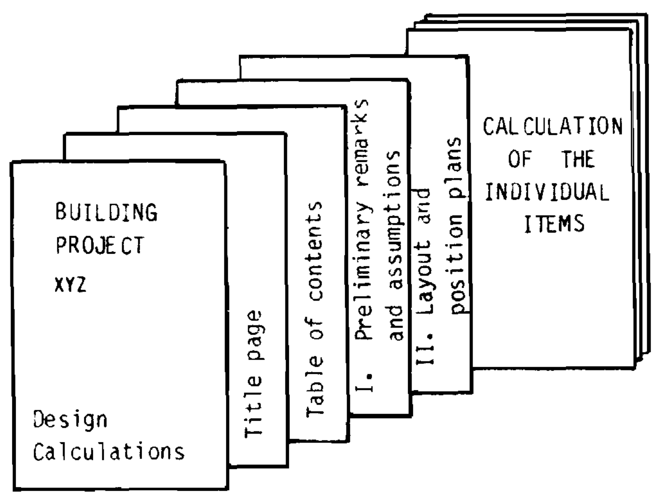


Figure B-21. Systematic arrangement of "Design Calculations".

a) Title page (figure B-24)

The title page carries the words "Design Calculations of the structure" (or "of the scaffolding", "of the excavation", etc.), as well as the following information:

- Name of the owner,
- Designation of the structure,
- Engineering firm and project number,
- Date and signature of the person preparing the calculations,
- Notes about checks as the case may be.

b) Table of contents (figure B-24)

The table of contents provides quick access to the proper section, as well as an outline of the calculated structural elements. A look at the table of contents is often sufficient to immediately determine whether certain structural elements have in fact been calculated, and whether specific information is in fact included.

c) Preliminary remarks and assumptions (figure B-24)

This section contains all the information that is needed to prepare, define, and clarify the design calculations. The information is based on the planning phase, and in particular on the documents for safety measures and design. (figure B-22).

I. Preliminary remarks and assumptions

1. Documents
   - 1.1 Plans
   - 1.2 Building site survey and situation
   - 1.3 Standards and regulations
   - 1.4 Design plan
   - 1.5 Bibliography
   - 1.6 Other documents

2. Description of the structure
   - 2.1 General description
   - 2.2 Structure in the utilization phase
   - 2.3 Structure in the construction phase
   - 2.4 Foundation

3. Building materials

4. Conditions in the utilization phase
   - 4.1 Serviceability and safety requirements
   - 4.2 Influences to be considered for serviceability and safety

5. Conditions in the construction phase
   - 5.1 Serviceability and safety requirements
   - 5.2 Influences to be considered for serviceability and safety

6. Assumptions and their verification
   - 6.1 Building site
   - 6.2 Construction process
   - 6.3 Utilization

7. Notes regarding page and item numbering

Figure B-22. Subdivisions for "Preliminary remarks and assumptions".

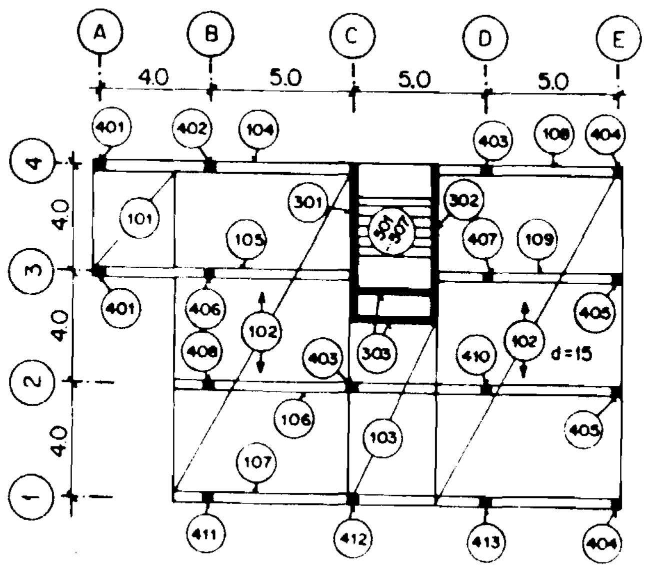
This section also helps to ensure that no conditions, assumptions or circumstances are left out or neglected.

d) Layout and location plans (figure B-24)

This section begins with a table of contents, followed by the individual plans. The layout plans help visualize the structure and locate the structural components. The location plans show the division of the structure into the various components to be calculated [33]. Each component has a location number (figure B-23).

POSITION PLAN: CEILING OVER 4th FLOOR

(scale 1:200)



Ceiling slab	- thickness:	15 cm	* Bn 250 St III	
Joists	- width/thickness:	30/40	Concrete cover:	
Supports	-	30/30	Slab	1.0 cm
			Joist	2.0 cm
			Column	2.5 cm

* Specifications for concrete and reinforcement quality.

Figure B-23. Example of a position plan.

Position plans help prevent or reduce basic errors:

- The individual components and their significance in the overall structure are easily recognized (the "overview" or "scale" is not lost sight of).
- The division of the structure into distinct components ensures that the design calculations proceed clearly and systematically.
- No structural parts are overlooked.
- The preparation of the construction drawings is made easier. The draftsman follows the location plan and takes the information he needs from the corresponding component.

e) Calculation of the various components (figure B-24)

The components laid down in the location plans are calculated in the proper sequence, and the required checks are carried out. Possible errors in this area are dealt with in sections B-3.2.3 to B-3.2.8.

B 3.2.3 Systematic pagination

The pages and items of the design calculations can rarely be numbered in one final sequence, since some documents are often still missing, and certain data are changed or supplemented, and so on. Furthermore, the design calculations may be carried out by more than one person. Accordingly, it is preferable to divide the design calculations into distinct sections, which are then designated independently. As a result, page numbers consist of section numbers followed by running numbers within each section. Revised pages are indexed a,b,... to indicate a first, second,... revision. Pages which are added subsequently are numbered with a preceding diagonal stroke, and placed after the last page number.

To clearly identify every page of the design calculations, it is important to indicate on each page the project number and the office code. To help find any item quickly, it is a good idea to add the location number at the top of the page. The example in figure B-24 can be used as a model.

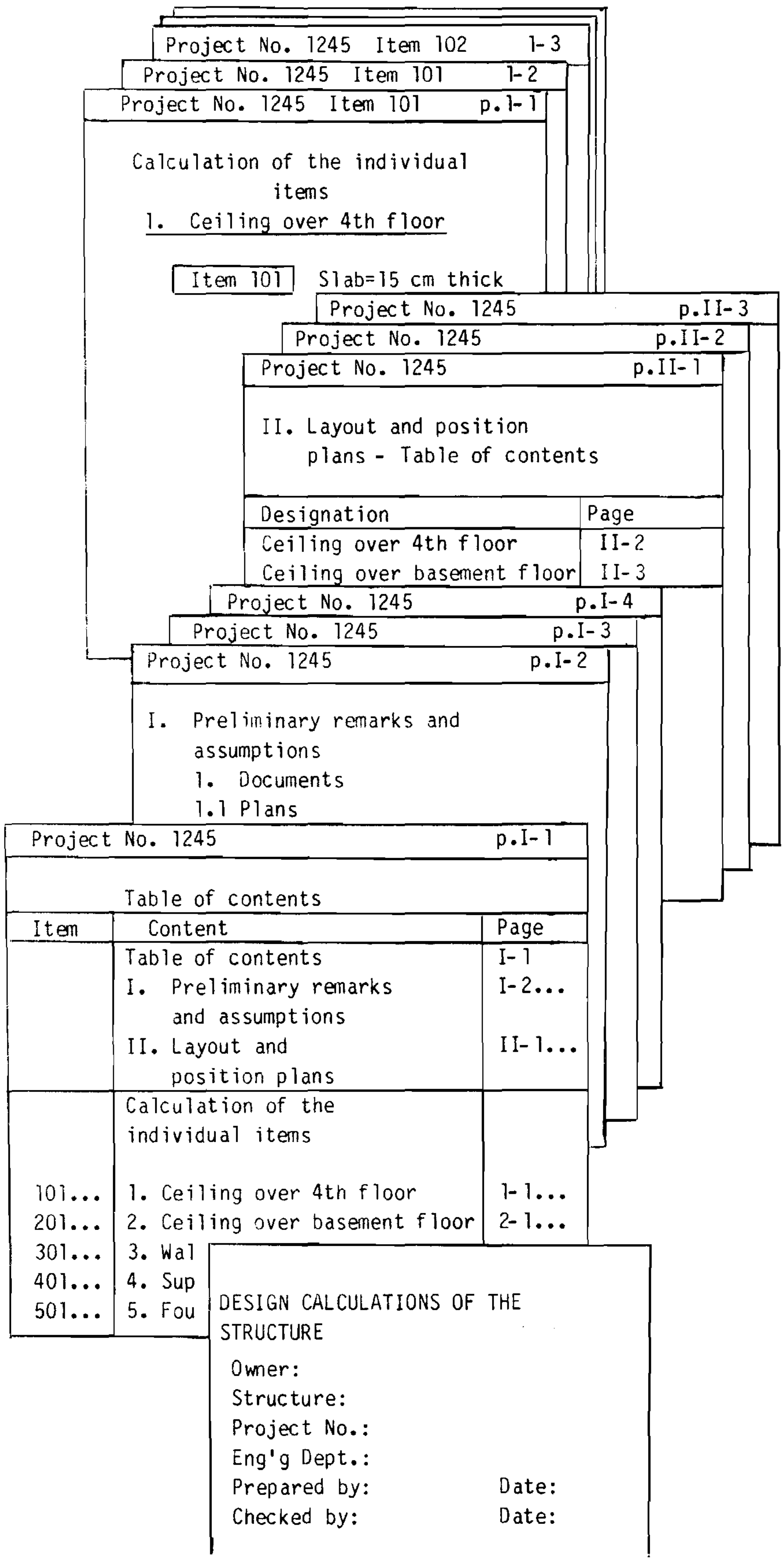


Figure B-24. Example of the arrangement and numbering of design calculations.

B 3.2.4 Principles for calculation

When individual structural components are being calculated, errors may occur in the description of the components, the choice of system, the determination of internal forces, the design, the checking, or the representation of the results. As in the overall calculation, errors may be due to deficient, erroneous or incomplete data. Such errors may be avoided by integrating calculating principles within a model, and by proceeding systematically. The principles for calculation are as follows:

First principle: Every calculation should be prepared as if it were meant for another person. This principle ensures that the calculation is accompanied by comments and references to the relevant documents (e.g. bibliography).

Second principle: The calculation should be self-explanatory. Any little-used or largely unknown formula should first be written out before actual numbers are introduced (commonly used formulas are exempt). The equations with actual numbers should always be written according to the general formula.

Third principle: The results of a calculation must be presented in such a way that they may be used directly by another person (e.g. the draftsman), without the need to repeat the whole calculation. This ensures that partial and final results are included and summarized (underlined, marked off, sketched), so that even draftsmen with no special training may be able to use them.

Fourth principle: Every revision, if need be, must be followed up and annotated. Small changes may be added, with comments (e.g. in the margin), directly on the appropriate page. Major revisions are added on additional pages.

B 3.2.5 Calculation scheme

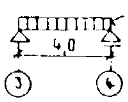
Every calculation of a structural component should be prepared according to a standard model (figure B-25).

Eng'g Dept. XY Neustrasse 13 8049 ZURICH Tel. 01/3775 Telex Z

Project No. 1245	Item 102	1-3

Item 102 Slab 15 cm thick, axes 3-4/A-B

System: $g+p = 5{,}0 + 5{,}0 = 10\ KN/m^2$



Loading:

Covering		= 1.25 KN/m^2
Dead weight 0.15.25		= 3.75 KN/m^2
	g	= 5.0 KN/m^2
	p	= 5.0 KN/m^2
	q	= 10.0 KN/m^2

Reactions and internal forces:

$A_3 = A_4 = \frac{1}{2} \cdot 10{,}0 \cdot 4{,}0 = 20{,}0\ KN/m$

$M = \frac{1}{8} \cdot 10{,}0 \cdot 4{,}0^2 = 20{,}0\ KNm/m$

Dimensioning:

Bn 250, St III, $d/h = 15/13\ cm$

$k_h = 9{,}2 \quad k_e = 4{,}6 \quad F_{e\,erf} = \frac{20}{13} \cdot 4{,}6 = 7{,}1\ cm^2/m$

selected:

Steel type: St III ø 12 e = 15 cm ($F_{e_v} = 7{,}5\ cm^2/m$)

Reinforcement sketch:

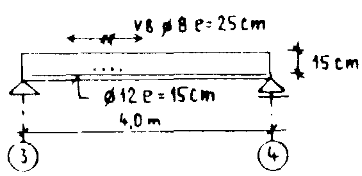


Figure B-25. Calculation scheme.

The calculation scheme consists of the following elements:

a) Description of the component

Information such as the location number, the designation of the structural component, the location (axes), the materials and the dimensions.

b) Static System

Information about the static system, including dimensions, spans, stiffness and loading arrangement (see also section B-3.2.6).

c) Loading

Determination of the loads and other influences (e.g. temperature changes, support settlement) on the basis of the "Preliminary remarks and assumptions", as well as the results of the calculation of loads on the structural component under consideration. The number of these items must always be indicated (e.g. from item No. 302, Force F=10.0 KN).

d) Reactions and internal forces

Information about any reactions and internal forces (transverse forces, moments, etc.) needed to calculate and check the component and adjacent components (see also section B-3.2.7).

e) Dimensioning for allowable or required values

The internal forces are used to determine the dimensions of the structural component keeping in mind the allowable values or required safety factors.

f) Verification of conditions and requirements

A dimensioned structural element must often be verified to ensure that certain conditions or special requirements have been met, e.g. shear stresses, secondary stresses, deflections, assumed rigidity, etc.

g) Presentation of the results (sketch)

Results should be presented in such a way that the draftsman can make direct use of them. A sketch containing the key data allows the results to be used both correctly and quickly.

B 3.2.6 Choice of a static system

Errors can occur in the choice of a static system; for example, the chosen system may not be in good agreement with reality, load transfer to other units may not be assured, spans may be incorrect, etc. Such errors may be avoided by choosing the static system in a systematic way, i.e. by using the following steps:

a) Determining the constraints

The constraints such as spans, overall height, support conditions, recesses, etc. are determined on the basis of available documents, especially the plans. If the constraints are unfavourable, improvements must be made (e.g. better column layout, recesses).

b) Formulating simple static systems

As a rule, the more complex the static system, the more complex the calculation, and therefore the greater the probability of error. Simple static systems are easily consulted, and easily controlled.

c) Drawing static systems, cross-sections, etc. according to scale

All required sketches should be drawn to scale to allow a visual understanding of the proportions of various units, as well as easy checking. Oten, this makes errors immediately identifiable.

d) Boundaries and support of the structural elements

The greater the dependence of internal and other forces on the conditions of support, the greater the care that must be used for the evaluation of the supports. Forces must be transferred through to the ground (they do not "disappear").

B 3.2.7 Determining loads and forces

Errors in load determination may be avoided or reduced by proceeding systematically, and using a number of aids:

a) Compile the loads and loading conditions

Initially, all loads and significant combinations are to be grouped together.

b) Define the location and direction of support and internal forces

It is important to clearly designate and represent both the location and direction of forces. Once they are adopted, designations should be maintained so as to avoid misinterpretation and confusion.

c) Use patterns and examples, etc.

Good examples are helpful in preparing a structural analysis. Patterns and examples etc. make it easier to set up a structural analysis by indicating what to do and how to do it.

d) Applying formulas and methods

The hasty acceptance of inappropriate formulas and methods may lead to erroneous calculations. It is therefore important to check the range of validity of formulas and methods. Each formula and method should be checked in terms of extreme values and dimensional validity and, whenever possible, should be derived independently. The same holds true, in principle, for the use of tables.

e) Graphic representation of internal forces

Representing the internal forces graphically according to scale makes it easier to locate the important sections and detect possible errors.

B 3.2.8 Problems with the use of EDP

Two types of error may occur when electronic data processing is used. There may be an error in the electronic calculation itself, or at the interface between the EDP-calculation and subsequent works.

To avoid errors at the interface between the electronic calculation and subsequent work , it is important to prepare the data carefully and to make rational use of the results in continuing the design calculations.

EDP itself can lead to errors in terms of the input, output or interpretation of the data [61,74]. Preventive measures are aimed at these specific sources of error, as is shown in the following examples.

a) Input

Data input should be organized as clearly and simply as possible. The data should always be printed out in full, and presented graphically as much as possible (e.g. frame geometry, network distribution, etc.). Calculations should proceed only if the input data has been checked.

b) Computer program

Computer programs should be as easily understandable as possible, e.g. composed of distinct subprograms. Program descriptions should be supplemented by appropriate sketches, text and comments [27]. Furthermore, computer programs should be rigorously tested before they are used. When the results of computer calculations are introduced in the "Design Calculations" document, the corresponding program should be described briefly (e.g. origin and designation of the program, assumptions and simplifications, scope, etc.) [116].

c) Output

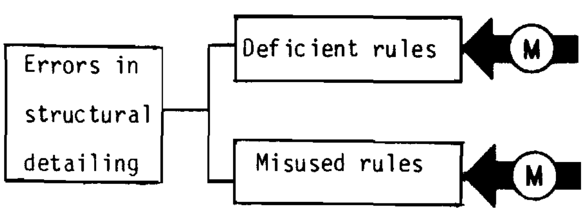
The output should allow a clear and reliable interpretation of the data. It should therefore be well structured and easily understood, with explanations, graphics, etc.

d) Independent check

The results should always be checked independently, especially in terms of the order of magnitude of the numerical data, to allow detection of errors concerning decimal points, plus or minus signs, internal force distribution, etc. Simple models are usually sufficient for this type of checking. Part E of the report provides a more detailed description of the corresponding controls.

B 3.3 Structural detailing

During the design calculations of structures, etc., not all influences are taken into account, and not all sections and structural components are calculated. Structural detailing must take this into account. Errors in this area are usually due to deficient or misused detailing rules (figure B-26). Occasionally, however, such rules are not formulated explicitly. In such cases it is up to the structural engineer to provide additional measures beyond the results of design calculations.



Figures B-26. Errors in structural detailing and their prevention.

Errors are avoided in this area through careful preparation of detailing rules and the use of suitable principles of structural detailing, with accompanying patterns and examples.

B 3.3.1 Detailing rules

Preparing detailing rules for frequently occurring problems, e.g. standard hooks, spacing limits, minimal dimensions etc., makes structural detailing both easier and simpler. Detailing rules are prepared by various construction and engineering firms, specialized organizations, etc., and are made known through internal publications, as well as through books, journals, recommendations, guidelines, standards, etc. Detailing rules should contain the following information:

a) Addressee

It is important to indicate for whom the detailing rules are intended, and where they should or must be used.

b) Validity and scope

The limits of validity and scope of application must be clearly defined.

c) Content

The "blind" application of detailing rules can lead to misunderstanding and errors. Detailing rules should therefore not limit themselves simply to the required information, but also include explanations of their background, relationships and effects. It is also important to indicate which influences are covered by the rules, and how the rules originated (e.g. tests, calculations, experience).

d) Presentation

Correct interpretation should be ensured through simple but informative formulas, sketches, detailed drawings, etc., and proper use should be facilitated through examples of applications and various aids (e.g. tables, diagrams, preprinted labels).

B 3.3.2 Principles of structural detailing

The following principles help avoid or reduce errors in structural detailing and the application of detailing rules.

First principle: Structural components that have not been calculated must always be considered for structural detailing.

Calculations limit themselves to important sections and components. Remaining sections and components must then be designed according to detailing rules.

Second principle: It is especially important to follow the detailing rules for those influences which have not been analysed by calculation.

Calculations are concerned with very specific static systems and influences. Influences not specified in such models must then be analyzed through careful structural detailing. In such cases, clear detailing rules are often more useful than more or less obscure calculations (e.g. with fictitious "equivalent" influences).

Third principle: Structural detailing must meet requirements for implementation and utilization.

For example, it must allow for minimum dimensions conditioned by manufacturing or utilization, minimum wall thicknesses, adequate spacing (e.g. for placing concrete), unambiguous data correlations concerning geometry and position to avoid confusion (see also section B-4.4.3).

B 3.4 Drawings and lists

Errors may occur in the preparation of tender drawings, architectural drawings, formwork drawings, reinforcing schedules, and so on. Drawings may be deficient or ambiguous, or entire sections or components of the structure are missing, some details are incorrect, etc. (figure B-27).

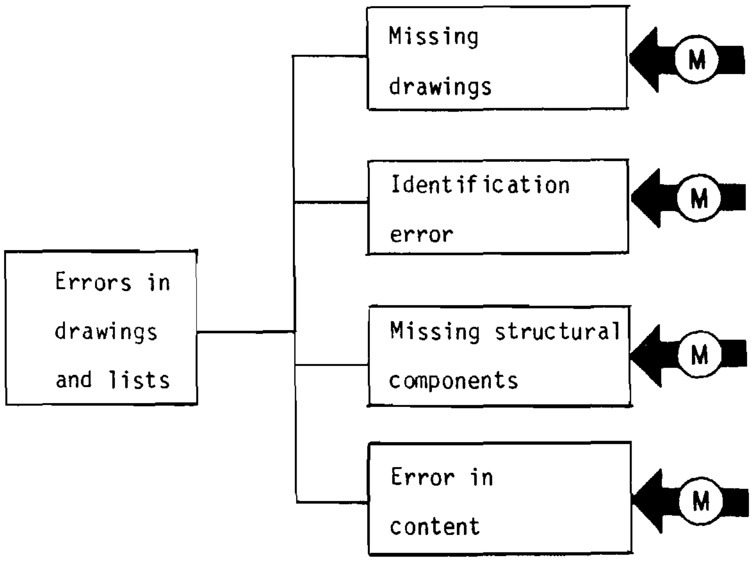


Figure B-27. Errors in drawings and lists and their elimination.

These and other errors may be avoided through: lists of drawings, clear identification of documents, uniform labelling, complete documentation, careful definition of drawing contents in relation to other drawings (e.g. by means of adequate principles of representation). The following sub-sections are mainly concerned with problems affecting construction drawings, but they are also valid for drawings and lists in general.

B 3.4.1 Lists of drawings

The drawings needed for the construction of a building should be arranged into various groups (e.g. architectural, formwork, reinforcements, list of reinforcement), and listed for easy consultation (figure B-28).

This makes it easy to determine which drawings or lists have been prepared, and if and when they have been revised.

CH Tel. 01/3775 Telex Z

Project No. 1245 Office building ZASW			page 3							
List of formwork drawings										
Plan No.	Date	Designation	Revision - index/Date							
			a	b	c	d	e	f	g	h
1245-S211	25.1.81	Foundations axis C-D/8-9	6.2	10.2						
1245-S212	5.2.81	Foundations axis A-C/8-9	10.2	15.2						
1245-S212	11.2.81	Foundations axis D-E/7-8	1.3							

Figure B-28. Example of a list of formwork drawings.

B 3.4.2 Title block

It is important that drawings are clearly identified if confusion and ambiguities are to be avoided. For this reason, the use of a uniform title block is recommended [33]. The amount of information provided depends on the type or structure, the method of construction, the size of the structure, the proposed controls, etc. Figure B-29 provides a model of a title block.

Any title block should contain the following information.

a) Identification

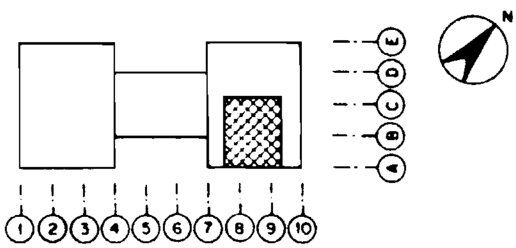
As a rule, the drawings needed to build a structure are prepared by different departments or firms, which establish an order number or project number. This order number and the department code help avoid a mix-up of drawings for different buildings. The drawings themselves may be classified according to type by means of a letter (e.g. F for formwork plan, R for reinforcement schedule), followed by successive numbers. Other information includes the owner, the structure (abbreviations are common), the scale, the date, and names (draftsman, checkers, etc.).

b	*single foundation axis B/B expanded*	*15.2*	*F2*	*Fu*	*Ma*
a	*opening for conduits*	*10.2*	*F1*	*Fu*	*Ma*
Index	Revision	Date	Drawing	Check	Seen

Additional controls

Issued by	Name	Date
Proof engineer	*W. Maier, Ing. Büro Kontroll AG, Zurich*	*20.2.81*
Sanitation	*K. Müller, Fa. Sanit AG, Zurich*	*22.2.81*
Coordinator	*B. Küttel, Stadtwerke, Zurich*	*23.2.81*

Plan sketch:



ENG'G FIRM XY, Neustrasse 13, 8049 ZURICH, Tel. 3775

Owner: STADTWERKE ZURICH

Structure: Office Building ZASW

Object:

Formwork plan - Foundations - axis A-C/8-9

Related plans: List of installations Plan No. 21-3

Scale:	Date: *5.2.81*	Drawing No.	Type:
1:50	Drawn by: *H. Fischer*	1245-S212b	F
1:20	Checked by: *K. Furer*		
	Seen by: *F. Magel*		

Figure B-29. Example of a title block.

b) Plan sketch

A schematic plan sketch provides a quick survey of what is dealt with in the drawing (using shaded areas for example).

c) Revisions

When a drawing is revised (a common occurrence), the drawing or plan number is indexed accordingly (e.g. the letter "a" for the first revision, "b" for the second, and so on). It is also important to indicate where and by whom a revision was made, and who checked it.

d) Further checks

When drawings are further checked by other people (e.g. proof engineer, architect), it is important to indicate check notes and the issuance of the drawings in the title block.

B 3.4.3 Preparatory work for the draftsman

Preparing the work for the draftsman requires a systematic procedure if incomplete, insufficiently delimited or obscure drawings are to be avoided. Such a procedure should include the following steps.

a) Preparation of documents

All the required documents should be made available, including location plans, calculations, sketches as well as rules and regulations, etc.

b) Content and presentation

The content of the drawing (which structural components or sections) and its presentation (plan sketch, views, sections, details, scale, format, lead or ink, computer graphics, etc.) are established before work begins (sketch of the drawings) [33].

c) Delimitation

The component or section dealt with must be clearly indicated. Any references to drawings of neighbouring components or related drawings (e.g. installations in the formwork) should be indicated on the drawing.

B 3.4.4 Making the drawings

With drawings and lists some very specific information should be imparted. To avoid misinterpretations it is therefore important to adhere to the following principles.

First principle: The data should be presented in such a way that even less qualified personnel are able to make use of the drawing. Realistic ideas of the simplest procedure on the construction site should lead to logically arranged drawings (e.g. numbering the reinforcement lots according to the order of placing).

Second principle: Misinterpretations during execution can be avoided if additional information is provided on the drawings (additional notes, sections, details, etc.).

Third principle: Information that can be depicted should not be replaced by text. When a drawing contains several similar components, attempts are often made to simplify the work, for example by indicating: "Component XY is symmetrical to axis K", or "component XZ resembles component XX, but...". This could lead to errors when other documents are prepared (e.g. lists of reinforcement). In any case, it is a source of misunderstanding, further checkback, and errors on the building site. Graphic representation is always preferable to text.

Fourth principle: Dimensions should be outlined by dimension lines located outside the drawn structural element. Complete dimension lines are an incentive to thorough dimensioning, and they make it easier to check dimensions.

Fifth principle: Important dimensional tolerances must always be indicated. When component parts are combined or built in, tolerances must be taken into consideration, and should always be indicated in the drawing. Complete dimensioning should indicate precisely the limits permitted by the tolerances.

Sixth principle: Information that is important for the construction phase should always be included in the drawings. Any information that is conditioned by calculations, detailing or other requirements, but that cannot be depicted in the drawing itself, should be included in appropriate texts (e.g. "construction joints should be roughened", or "joints should be cleaned before the concrete is poured"). Such information should always be marked off and, whenever possible, placed near the title block.

Seventh principle: Information for the construction phase should be indicated on the appropriate plans. Information contained in drawings will only reach those people who actually work with them. Data about the required quality of concrete would be useless on lists of reinforcement, for example, and would be very perplexing for the user of the lists of reinforcement. Clear instructions are needed in such cases (see also section B-4.3.4).

B 4. Sources of errors in technical procedures during construction and their elimination

B 4.1 General outline

In spite of careful planning, errors do occur in the construction phase. Work preparation may be insufficient or deficient, documents may be incomplete, assumed conditions may not materialize, work sequences may not proceed as planned, etc.

Errors in the technical procedures during construction can be avoided through careful preparation of the construction phase, systematic planning of the work sequences, application of principles of execution and work instructions, as well as technical measures. (figure B-30).

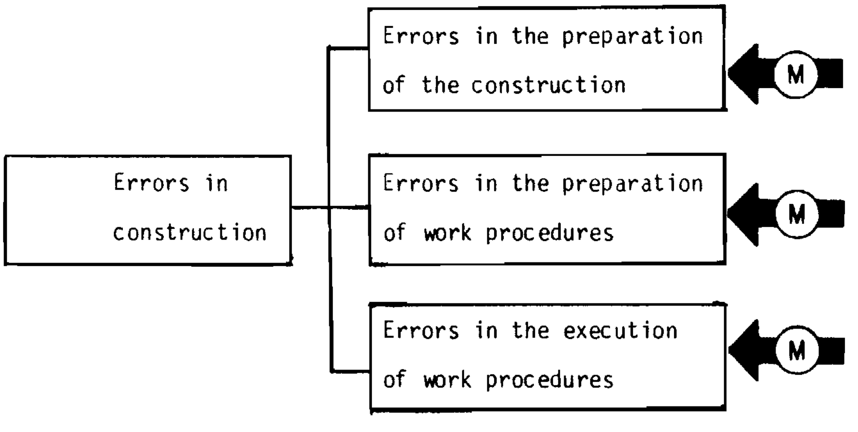


Figure B-30. Errors in the construction phase and their prevention.

Execution of the various components (site facilities, excavation, bearing structure, finishes, etc.) and parts of the building requires careful planning. This involves two steps.

Construction planning (see section B-4.2) covers the construction phase in general terms, without treating special work operations in greater detail. The required documents are brought together, the building process is planned, and the equipment and materials are selected.

The second step (see section B-4.3) is concerned with the detailed work procedures. In many cases it may be sufficient to use rules of workmanship, while in other cases it will be necessary to study work procedures systematically and integrate the most important points in work instructions and checklists (see also section B-4.3.4 and part E).

When the construction has been planned technically, there is little probability of error. The probability of error may be reduced even more, or eliminated, through the use of suitable principles of execution, additional information on the building site, and finally preventive technical measures (see section B-4.4).

B 4.2 Construction planning

B 4.2.1 Documentation

Construction planning is based on available documents. Care must be taken to ensure that no documents are overlooked or missing. The following checklist may help to ensure that all the required documents are available.

- Review the proposed construction sequences (see section B-2.4);
- Verify the completeness of calculated or checked building conditions (see section B-3.2.2);
- Consider the list of accepted risks during the construction (see section B-2.6.3);
- Verify the completeness of construction instructions (see section B-2.6.4);
- Study the control and supervision plans (see section B-2.6.5);
- Look for special features in the plan sketch and layout plans (see section B-2.3);
- Look for special features in the construction drawings (i.e. formwork drawings, reinforcement schedules, etc.);
- Summarize and evaluate the laws, regulations, standards, recommendations, etc., which are relevant to the proposed structure.

At the time the documents are made available, it is important to provide clear indication of any deviations that are tolerated (e.g. already allowed for in the design), or that must be avoided as errors.

B 4.2.2 Detailed schedule of the construction procedures

Poorly prepared construction procedures often lead to an inappropriate or wrong sequence of operations, as well as delays, bottlenecks, etc. Important building or environmental conditions often remain ignored. Such errors can be avoided by means of a detailed work preparation, including:

a) Detailed subdivision of the construction procedures
The construction procedures are subdivided into its distinct components, and their proper time sequence is established. This subdivision is based on the project itself and the building conditions ascertained during the design phase. Changes are often made to allow for factors not foreseen in the design phase and to provide a more appropriate construction sequence. Such changes have an impact on the construction procedures and on the various building components (structure, finishes, conduits, etc.). If the impact is not assessed, errors may result.

b) Building materials and storage
The required materials are assessed in qualitative terms (strength, tolerance, durability - see also section B-4.2.3), as well as in quantitative terms. It must then be decided which materials should be stored on the site, where, and in what quantities. If such storage represents a significant load on the structure, its admissibility must always be determined (e.g. loading of floors).

c) Equipment and workforce
On the basis of the proposed work procedures, decisions must be made about which machinery, equipment and supplies (power, fuel, etc.) will be used where and when, and how many workers will be needed. Additional site installations (i.e. shop for repair and maintenance, canteen, etc.) must also be selected. For more detailed information, see section B-4.2.4.

d) Building and environmental conditions
The environmental conditions laid down for the execution of the construction work must be stipulated, along with rules to cover possible deviations.

The most important events in the planned construction procedure are recorded in appropriate documents. These include bar charts, network plans, work schedules, as well as installation plans, etc.

B 4.2.3 Determining quality of materials

The delivery and/or use of improper or faulty materials and components can be avoided or reduced through the following measures.

a) Quality assurance

It is advantageous to ask the manufacturer or supplier for data about his quality assurance program [82,85]. Such data provide important information about manufacturing methods and the product uniformity that can be expected. References, documents and results from similar previous projects may also be useful.

b) Quality requirements

A clear indication of quality requirements provides a sound basis for the manufacturer or supplier. If such requirements are not standardized, they should be submitted in writing, and the consequences of non-compliance should be spelled out.

c) Acceptance conditions

Conditions must be established for the acceptance of building materials and components. Acceptance or entry controls make it possible to exclude inadequate materials (part E), and also have some impact on the manufacturing and supply processes themselves. The possibility that inadequate shipments will be rejected makes it necessary for manufacturers and suppliers to exercise controls and operate in an orderly manner.

B 4.2.4 Determining equipment

The term equipment covers machinery, tools and supplies (power, fuel, etc.). Careful planning will filter out any unsuitable or faulty equipment. Such planning involves the following steps.

a) Requirements

Provision must be made for the machinery and tools that will be needed, as well as for working conditions (dust, moisture, etc.) and supplies (power, fuel, etc.).

b) Machinery and tools

New purchases of machinery and tools should be based on similar previous acquisitions, as well as other experience, with due consideration for warranties and service.

If machinery is chosen from existing stock, it should be appraised on the basis of maintenance and repair records, and reconditioned if need be.

c) Supplies

Based on the actual situation, the provision of supplies on the construction site is analyzed, and suitable measures are established.

d) Maintenance

It is important to determine which machines and tools are to be maintained at what time intervals, and by whom (see also section E-3.4.3).

e) Shortages

Equipment shortages can lead to improvisation and frequently to errors. It is therefore necessary to analyse the effects of any shortages and plan measures to prevent or neutralize them. It is important, for example, to determine whether machines will be repaired and reused, or whether backup machinery will be made available.

In the case of supply shortages (e.g. power failure), it is important to determine whether work stoppage and resulting delays can be tolerated, or whether countermeasures such as an emergency power supply must be planned.

B 4.3 Preparation of the work procedures

B 4.3.1 Necessity for work preparation

A detailed and written work preparation is not needed for every type of work. Rules of workmanship are often sufficient. For each structure, each structural component, and each work process, however, there should be some provision for determining whether workers and foremen have sufficient basic knowledge, or whether detailed work preparations are needed. The extent to which skills and training are sufficient can often be determined on the basis of experience, but it is not always directly recognizable.

Decisive factors for the work sequence, however, should always be laid down in work instructions. These reduce complex processes into simpler elements that can be handled by the people involved.

B 4.3.2 Use of approved work sequences

The use of approved work procedures helps to prevent those errors which are particularly related to novel, untried work procedures. Nevertheless, approved work procedures are often based on specific conditions which, if they are not realized, may lead to errors and damage. This can be readily observed in particular cases of damage, for example, which occur in repetitive patterns (e.g. the so-called repetition method). Thus, a work procedure which has been carried out many times successfully may break down as a result of some inconspicuous change in conditions (staff, temperature, diligence, etc.). In the building industry, conditions change during a project and from one project to another. For this reason, preparation of work procedures should give special consideration to possible changes in the use of approved work sequences, and include measures or instructions to neutralize such changes.

B 4.3.3 Work analysis

The introduction of novel or insufficiently tested work procedures should be preceded by a thorough work analysis to identify any requirements and dangers. Work analysis is usually based on the five key components of any work process, i.e. people, technique, equipment, materials and environment. The demands made on these components are identified, as are the hazards and the appropriate preventive measures. The steps involved in this type of analysis can be described in terms of the following questions:

1) What is the goal?
2) What do the work procedures look like?
3) What could obstruct the work procedures?
4) What measures should be planned?
5) What are the risks that must be taken?

In simple cases, a direct answer to these questions is sufficient. In difficult cases, detailed work analyses must be worked out. A brief outline of the five steps is therefore provided below, using a simplified example to show the detailed procedure.

<u>First step: Defining the problem</u> The target situation is formulated, and the initial situation is described. The action needed to bring about the required change in the initial situation is defined.

Second step: Determining the appropriate work procedures The required action and its components are analysed. The detailed analysis may be represented clearly outlined in a so-called action tree [29]. Such a tree begins with the formulation of the intended action. The latter may take place, generally speaking, once the five main components, i.e. people, technique, equipment (machines, tools, etc.), materials and environment, have reached suitable quantity and quality. These main components may be further explained by other components, and the resulting sequence of components and interconnections yields a "tree structure" (figure B-31).

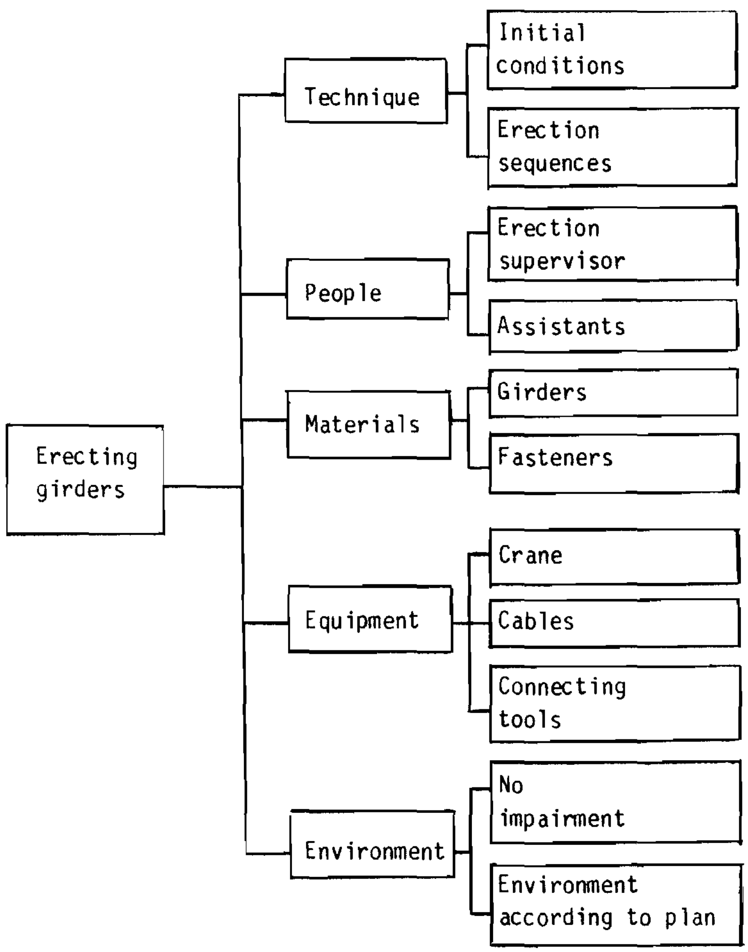


Figure B-31. Simplified example of an "Action tree" (a few branches only).

For the sake of simplicity, the various interconnections are not depicted in full detail.

Third step: Determining the hazards The hazards linked with the work procedures are analysed. Hazard analysis is based on the methods described in the planning phase (see section B-2.5). In the present case, methods are specifically related to the work procedures (see figure B-32).

Here as in figure B-31, for the sake of simplicity, interconnections are not shown in detail.

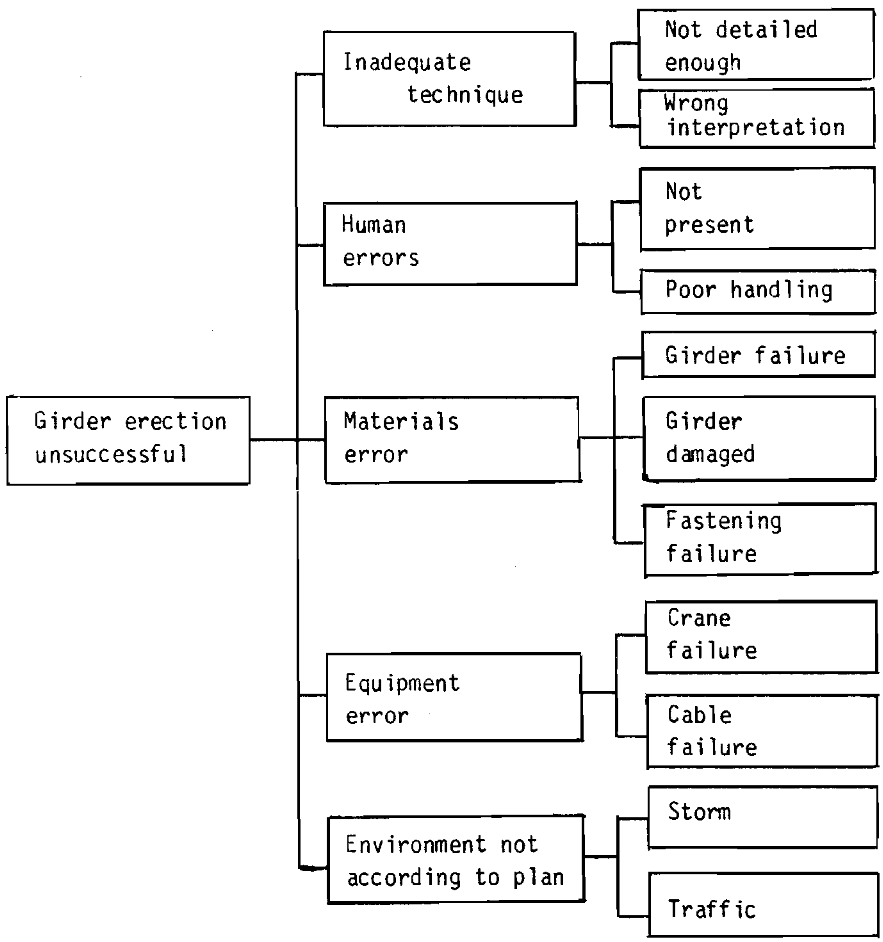


Figure B-32. Simplified example of hazard analysis (a few aspects only).

Fourth step: Planning of various measures The identified hazards are either eliminated through appropriate measures or accepted as a risk (see also section B-2.6). On the one hand, there are material measures; on the other, the adequate behaviour of the people involved is often a possibility to reduce the risk.

Fifth step: Accepting risks It is important to define the elements of risk, and in particular the probability of damage (see section B-2.6.3). Only on the basis of the elements of risk can a sound decision be made about accepting a risk or taking other, more appropriate measures.

The results of work analysis are usually integrated directly into the work instructions established for a given work procedures.

B 4.3.4 Work instructions and checklists

Work instructions reduce complex work procedures to smaller units which can be handled on the basis of the knowledge of the people involved. Work instructions contain a detailed account of the prerequisites (supplies, people, materials, environment) and the methods for the various operations (figure B-33). In the aircraft industry, for example, practically all operations are carried out in accordance with work instructions (work manuals).

Work instructions should only be described in as much detail as is absolutely required, given the qualifications of the people involved. Excessively detailed regulations are counterproductive, for psychological reasons. It is therefore recommended that general instructions be used, and that they be supplemented by checklists that provide a detailed, step-by-step description of the intended operation. Instructions and checklists are further dealt with in part E, sections E-2.2.2 and E-2.2.3.

B 4.3.5 Providing materials, equipment and work force

Finally, the equipment, work force and materials required for the work must be made available. If this is not done properly, there will be delays and improvisations, and these in turn can have damaging consequences. This type of error actually belongs to part C (organization and management) and part D (human behaviour). We mention it here, in relation to the technical aspects of the building process, for the sake of completeness.

Construction firm XX Altgasse 13 8049 ZURICH Tel. 01 / 3775 Telex Z

Office building ZASW	p.1
Work instruction for the erection supervisors	
Object: Erection of a reinforced concrete girder (10 Mp)	
Time and date: 9:00, 11.5.81	

Prerequisites and procedure:

Environment
Check the spacing and position of supports, divert traffic on the site, block off access points, start erecting under normal conditions.

People
The crane operator and the two assistants work directly under the erection supervisor, who gives detailed instructions and first runs a simulated operation.

Materials
Check the dimensions, the support surfaces, and the quality of the girder.

Equipment
Ensure proper support for the mobile crane (120 Mpm).
Make a visual check of the cables.

Technique
(1) Secure the cables to the girder. (2) Lift the girder 5 cm. (3) Ensure vertical and horizontal position. (4) Raise the girder 1 m. (5) Move the girder to its support. (6) Position. (7) Set down. (8) Check proper location. (9) Remove the cables.

Comments concerning risks and measures:
- Bad weather: listen to the weather forecasts, and delay erection if need be.
- Crane breakdown: postpone erection, solve the problem or request a substitute crane.
- Damaged girder: tell Mr. Meier and request an alternate procedure from him.

Completion of work:
Once the erection has been completed, report to both the project representative and Mr. Meier.
Prepared in Zurich, April 30, 1981
by: K. Meier

Figure B-33. Example of work instruction

B 4.4 Execution of work procedures

B 4.4.1 Principles of execution

Errors related to the execution of work procedures can be avoided through the use of the following principles:

First principle: The relevant documents should be complete and up to date. Incomplete documents are sources of ambiguity and undesirable improvisation. Documents that are out of date make it necessary to carry out additional corrections.

Second principle: Work should only begin once the assumed conditions have been met. If the assumed conditions do not materialize, and cannot be realized, the possible consequences should be investigated before work begins.

Third principle: Work should only be carried out in accordance with existing documents. Often, an apparently better procedure is suggested and used, without due consideration for decisive factors and possible consequences. Such rash changes usually lead to some form of damage. Whenever there is some departure from an intended procedure, it should always be treated as a change according to the procedure laid down in part C.

Fourth principle: Both intentional and unintentional deviations from a planned procedure should always be reported to senior staff. Deviations are usually due to unfavourable influences or some type of error. Sometimes, however, the experience gained from a process used repeatedly (learning effect) might suggest some quite sensible deviation from planned procedures. The fact remains that there must be a timely notification of any deviations and proposed corrective measures, as well as a careful explanation of consequences, if damage is to be avoided.

B 4.4.2 Information at the building site

Special information is needed at the building site, where working documents may not be sufficient, or may not be readily available to the people involved. They include data about safe loads for lifting equipment, elevators, cables, chains, presses, etc., data about machinery controls, about the safe piling up of materials, restrictions on the movement of heavy equipment, no-smoking areas, etc.

B 4.4.3 Technical measures

In spite of error-free documents and sufficient information, there will be cases of improper girder assemblies, non-embedded reinforcing bars, incorrect welds, etc. Such errors are related to human behaviour (see part D), not to the technical process. Nevertheless, it is wise to anticipate such errors through technical measures. Suitable decisions should be made as early as the design phase, especially during structural detailing (section B-3.3.2) and work analysis (section B-4.3.3). The following preventive measures should be considered:

a) Preventing errors by limiting the number of possible procedures

It is often more economical to spend a little extra money on technical measures than to have to repair subsequent damage. Specially designed components, for example, as well as limiting or locking devices, often impose the correct handling procedure. Such measures are especially recommended when the workforce is little qualified, when high turnover is expected (e.g. foreign projects), or when mishandling could lead to major damage.

b) Rendering errors harmless through standardization

Possible confusion is eliminated when similar elements are standardized (e.g. through symmetrical reinforcing of supports, ensuring uniform dimensions of welded joints, identical prefabricated units, etc.). The extra cost of standardization is often more than compensated by shorter construction periods, fewer opportunities for error, and reduced control costs.

c) Making errors improbable through clear distinctions

In cases where it is not possible or sensible to limit the number of possible procedures or provide standardization, existing distinctions can be reinforced, e.g. through more pronounced size differences (reinforcing bars, screws, welded joints, etc.), the use of different colours (cables, supply conduits, protective coatings, etc.), and so on. Such means for preventing errors should be put to good use.

B 5. Sources of errors in the technical procedures during utilization and their elimination

B 5.1 General outline

The structure must not be used in ways that go against the assumptions of the planning or design phase. Non-compliance with the intended use, incorrect or inadequate maintenance, uncontrolled changes in utilization, and insufficient supervision of incurred risk indications, etc. can result in errors and damage [58] (figure B-34).

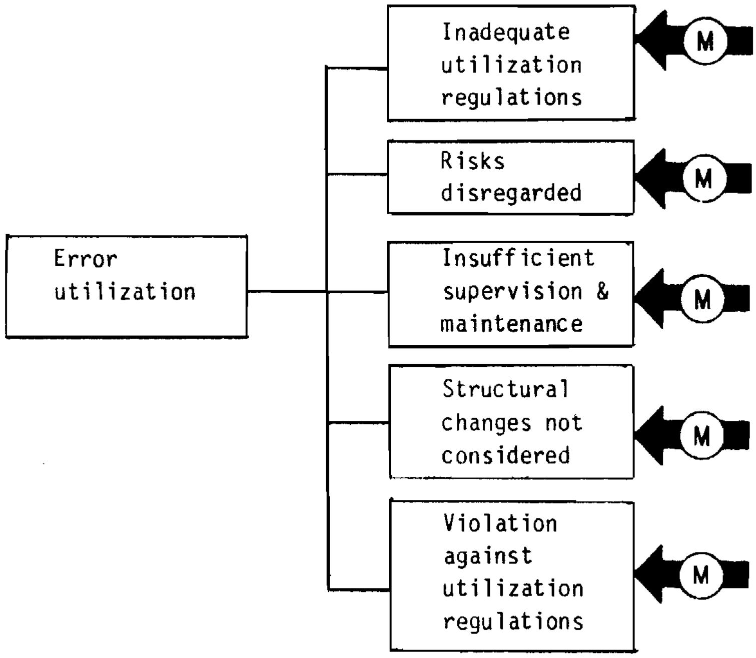


Figure B-34. Errors in the utilization phase and their prevention.

Errors in the technical procedures during utilization can be avoided by preparing and carefully maintaining a utilization manual, through on-site data, and by using various design measures.

B 5.2 Utilization manual

B 5.2.1 Setting up a utilization manual

The utilization manual is a tool which provides clear and complete utilization records and rules, with supervision and maintenance instructions, for the owner and occupants, as well as for people responsible for supervision and maintenance (figure B-35). For every piece of equipment, nowadays, there is usually a document of this type, and it is difficult to understand why the same has not been done for such complex systems as buildings.

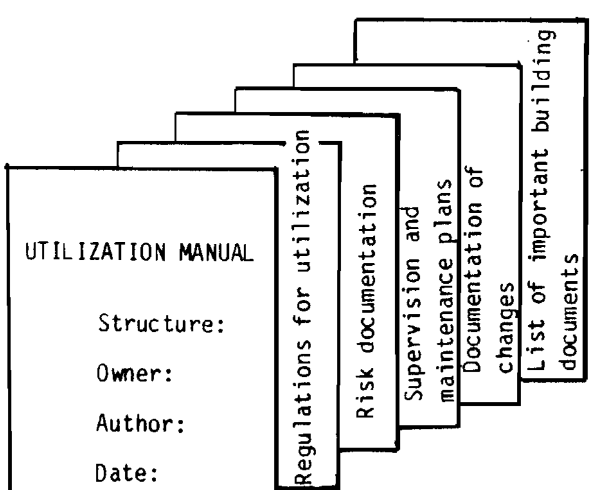


Figure B-35. Arrangement of the utilization manual.

The utilization manual for the building consists of various parts, the contents of which are described below.

B 5.2.2 Regulations concerning utilization

Such regulations govern the following points:

a) Responsibilities and duties

The responsibilities and duties of the owner (or his representative) and the user are stipulated, as are any demands made on them. Certain details may also be settled through an agreement (e.g. tenancy agreement). More information is provided in part C.

b) Regulations regarding utilization

Such regulations cover all matters related to the serviceability, durability, and safety of a building, including:

- Occupancy load schedules

  On the basis of the utilization plan used in the design process, it is important to prepare occupancy load schedules that can be understood even by the layman. These describe any restrictions (distributed loads, vehicles, single loads, stack height, etc.), as well as the conditions under which a particular use is approved.

- Safety of the intended utilization

  All measures regarding the supervision and safety of the intended utilization are established, including instructions for users, utilization information on the premises, technical measures, etc. The conditions under which the building or the components should not be used are also described, as are the circumstances under which it should be evacuated or cordoned off. A sports stadium, for example, should not be used as long as snow loads on the roof exceed design load values [73,97]. If need be, a snow removal regulation could of course be included.

c) Proposed or observed changes

It is important to establish corrective steps before any deviation is made from the regulations concerning utilization, or before a structure or its parts are changed. Warning procedures should also be established for cases where changes are detected in a structure (e.g. cracks, major deformation, etc.).

B 5.2.3 Risk documentation

Such documentation contains all the data concerning risks incurred in the utilization phase, as well as information about measures aimed at minimizing damage. Detailed data on incurred and accepted risks and their supervision are contained in "Documentation on accepted risk" (section B-2.6.3). This documentation can usually be integrated into the building's utilization manual.

In addition to consciously incurred risks, however, there are always some residual risks [58], which are due to unforeseen influences. Such risks can often be detected through careful supervision of the structure and by normal vigilance on the part of users. The duty to report changes which represent danger signals should be spelled out in regulations regarding utilization (e.g. as an item in tenancy agreements), as well as in supervision and maintenance plans, and the reporting procedure should be indicated.

B 5.2.4 Supervision and maintenance plans

The building components (bearing structure, finishes, services, mobile facilities) must be monitored and maintained during the utilization phase. Careful selection of a suitable procedure within the supervision and maintenance plans will help prevent damage. Several fires and explosions, for example, are due to inadequate supervision or maintenance (repairs).

A record should be kept of the control and maintenance work that is carried out, and the records should be kept with the supervision and maintenance plans. More detailed information about supervision and maintenance is provided in section E-3.5.2.

B 5.2.5 Documentation of changes

Such documentation describes all the structural and utilization changes that have been carried out or detected. Now and then, for example, permissible occupancy loads may be changed, heavier machinery may be used, additional openings may be made in floors, and strengthening may be added. In addition to such changes, it is important to record all detected alterations, e.g. cracks, settlement, warping, etc. If need be, a special investigation should be carried out.

B 5.2.6 List of important building documents

All the important documents needed for a subsequent appraisal of the structure must be kept in a safe place, usually by the owner. Such documents include safety measures, utilization and safety schedules, static calculations, working drawings, etc. [103,107]. The utilization manual contains a list of these important documents, and indicates where they can be found.

B 5.3 Utilization restrictions on the premises

Whenever there may be doubts concerning regulations, or user education would be impossible or insufficient, or ignorance on the part of users could lead to errors and possible damage, it is essential that admissible uses and directions for use be clearly displayed in the building itself.

B 5.4 Technical measures

Regulations concerning use, user education, and information displayed within the building are not always sufficient to guarantee proper utilization. In such cases, special measures are required (see also section B-4.4.3). These include various types of barriers, limited stack height, fencing to mark off roadways, as well as locking devices on elevators.

B 6. Alterations and restoration

Alterations and restoration work often results in considerable damage. In one reported analysis [58], for example, 1% of all cases of damage occurred during alterations, but they accounted for 5% of the total property damage, which means they had relatively grave consequences. Causes of damage include inadequate appraisals of structural conditions, poor design and construction of alterations, and improper utilization of buildings after alterations.

The causes of damage show that building alterations and reconstruction are not simply a technical activity in the life of a structure, but form a part of the "building process" as defined in this study. As such, alterations give rise to planning, design, construction and utilization phases just as much as new projects, with the corresponding measures to prevent errors.

A careful analysis of the initial situation is of particular importance (section B-2.3). This consists essentially of a factual description of the building in all its important features. According to one author [118], the following steps are required for the proper appraisal of a building that is to be altered or restored.

a) Inspection

The condition of the building is described using all available information:

- Visual inspection, physical tests, chemical analyses, etc.;
- Existing documents (utilization manual) describing the life of the building;
- Determination and evaluation of actual loads and influences.

b) Diagnosis

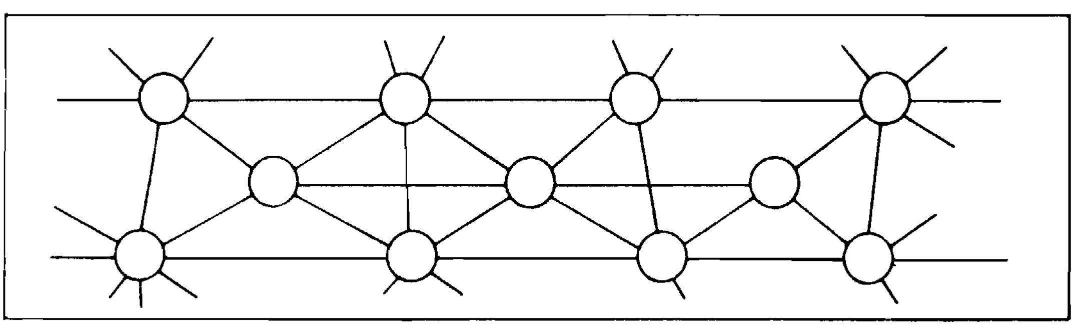
The causes of any damage or deficiencies in the building must be determined and checked.

c) Prognosis

The state of the building, especially in terms of safety, serviceability and durability, is assessed on the basis of available information. This can occasionally be checked by means of test loading. On the basis of such a thorough appraisal of the initial situation, appropriate measures can be planned and carried out (e.g. reinforcing, replacing, etc.).

PART C

SOURCES OF ERRORS IN THE ORGANIZATION AND MANAGEMENT AND THEIR ELIMINATION



C 1. Overview

The errors dealt with in part C of this study, as well as the corresponding preventive measures, are concerned specifically with the organization and management of the participants. The participants themselves, or more precisely their incorrect behaviour patterns, are the subject of part D.

The technical aspects of the building process, dealt with in part B, are implemented and carried out through activities of the participants. If these activities are not clearly defined, if responsibilities and duties are ambiguous, or if there is poor cooperation, inadequate flow of information, etc., errors may result in spite of good technical planning [58,62,119]. Organization/management errors may be prevented or reduced through measures aimed at three major sources of error (figure C-1).

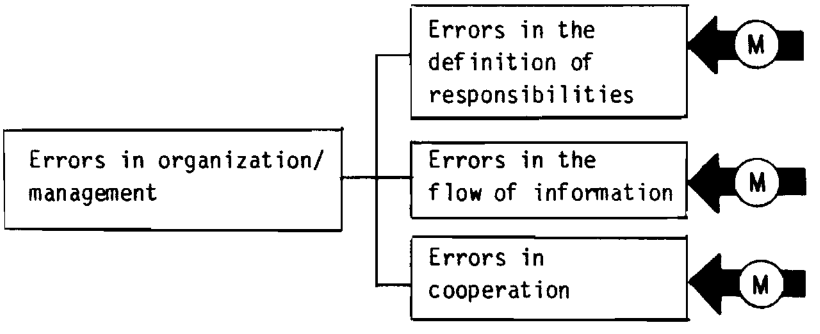


Figure C-1. Errors in organization/management and their elimination.

A number of basic measures in organization/management can be found in laws, regulations, standards, guidelines, etc. [99,101,102,107]. As a rule, such general sources are insufficient, and additional explanations are needed, to meet the special requirements of a specific case. Suitable measures for the prevention of errors can be found in simple management principles, but it is also important to carefully compile building documents using organizational aids.

The elimination of errors, whatever the source, is intrinsically a matter of management. The quality of management of a firm, company or contractor depends of course on the quality of the production oriented measures, but also on the use of error-preventing measures within an overall strategy which is organization - and management-oriented.

The present study is concerned with errors, and describes various measures against errors. It does not deal in any detail with overall strategies (see also section A-4.2). Part C, will therefore be concerned with preventive measures against errors in the organization/management of the building process, and not with topics dealing with management itself.

C 2. Organization/Management principles

Errors related to ambiguous responsibilities and duties, inadequate flow of information and poor cooperation can be reduced or prevented through the following, simple organization/management principles.

First principle: There should always be one person to assume responsibility over several others and for their actions (leader principle).

This simple principle helps prevent errors frequently observed in situations of anonymity, where none of the participants feels any responsibility. The duties of the person responsible are partly derived from the power to decide how assigned processes or tasks are to be subdivided and entrusted to subordinates or fellow workers. In the process, the person responsible relies on the following principles.

Second principle: Each participant must know the exact activities for which he or she is personally responsible (activity principle).

It is important to clearly indicate:

a) From whom participants may receive information or assignments.
Information and assignments are not issued by just anyone, nor should participants accept information and assignments from just anyone. Ignoring this principle could lead to accidents, e.g. if a crane operator is given instructions by several people.

b) Which task the participant must carry out.
If clear instructions are provided, it is less likely that the participant will relinquish his responsibility to other participants (e.g. during inspection), or that the task will exceed his or her knowledge and experience.

c) To whom the participant must deliver information and report results.
This ensures, for example, proper notification that one job is done and another can begin.

Third principle: Each participant is bound to cooperate (teamwork principle). Teamwork involves active participation in the assignment and careful interfacing where one job ends and another begins. Teamwork depends on the following conditions.

a) Initial conditions (green light)

It is important to clearly define not only the time element, but also the initial situation. A given activity should only begin once the previous one has been properly completed. The use of clearly defined initial conditions and procedures to check them before the start of an activity helps detect many errors from previous activities without any additional organizational controls [58].

b) Operating conditions

We are dealing here with the environment of a given activity, especially in relation to other activities occurring at the same time. Any change in the operating conditions, or any undesirable incident, should be investigated or reported to the person responsible before proceeding any further.

c) Termination conditions

These refer to the time element, the tolerance limits, the type of delivery, etc., while indicating when a task is considered terminated.

Fourth principle: Each participant must act to prevent errors and failures. It is a fact that errors can be discovered in time, and corrected, through normal vigilance and proper handling by the participants [58]. It is therefore the duty of each participant:

- to report any error or ambiguity to the person responsible;
- to investigate any error or ambiguity that he or she may come across.

This principle helps prevent people from intentionally or unintentionally failing to report incidents on such dubious grounds as: "That doesn't concern me, I'm only responsible for my work", "Don't get involved in someone else's business", etc. Furthermore, anyone who is made aware of an error or ambiguity is required to look into it, determine its causes, and take corrective steps. This principle is reflected in a number of laws, regulations and standards [101,102,103].

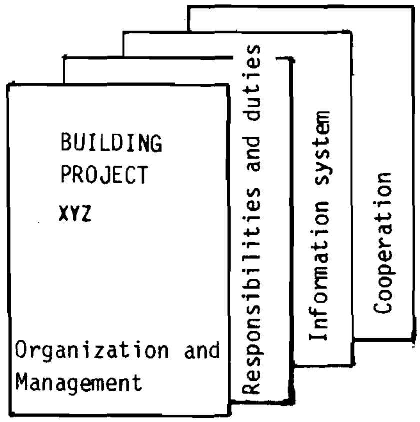


Figure C-2. Documents related to the organization and management.

Whenever the number of participants is small, as in erection operations carried out by small teams, or in specific planning and execution tasks, the above principles may be used directly. In more complex situations, the responsibilities and duties, flow of information, and any necessary rules of cooperation must be laid down in writing, keeping in mind the principles described above (figure C-2).

The following sections deal with specific building documents related to organization and management, as well as any useful aids.

C 3. Sources of errors in the definition of responsibilities and duties and their elimination

C 3.1 General outline

The responsibilities and duties of people involved in the building process are usually laid down in writing. The scope of the relevant documents depends on the type of project, its size and complexity, and the number of participants.

In simple cases, it may be sufficient to refer to laws, standards, guidelines, etc., and, if need be, to provide suitable instructions in agreements. In such cases, the documentation may be limited to the required data concerning the participants (designation, address, telephone number, etc.), with references to contractual provisions.

In complex cases, there is a need for thorough documentation using organizational aids (figure C-3).

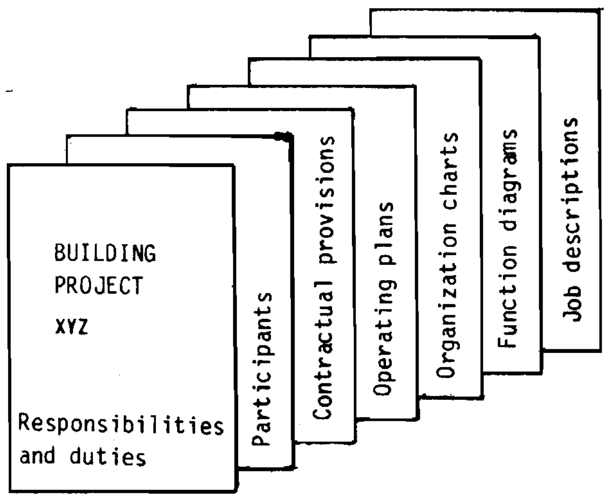


Figure C-3. Documents concerning responsibilities and duties.

The use of such aids helps eliminate any errors related to responsibilities and duties. Organizational aids make it possible to subdivide the operations of technical procedures and provide an outline of each subprocedure or task, indicating who will be involved, when, where, and according to what functions, and how the work is to unfold.

Of the many possible organizational aids (e.g. [11,22,46,77,99]), we will only consider operating plans, organization charts, function diagrams, and job descriptions.

C 3.2 Organizational aids

C 3.2.1 Operating plans

The definition of responsibilities and duties of the people involved in the building process is based on organizationally structured processes. This takes into account the required technical procedures, as well as the people involved. The organizational sequences as a whole can be described along the following lines.

- Establishing intermediate goals

  The building process or project is subdivided into intermediate goals that can be studied individually (some authors speak of a project structure plan [10]).

- Defining elementary procedures
  The established intermediate goals are reached through elementary procedures that can be compiled into a list of procedures [10].
- Planning a time schedule
  On the basis of the technically defined procedures, including deadlines, available materials, participants, equipment, etc., a time schedule for the elementary procedures is prepared, e.g. in bar charts, network plans and line charts [10].
- Participants
  Decisions are made about which persons will be involved in what elementary procedures.

The time schedule, the relationships between activities and their assignment to the people involved are represented clearly in a so-called flow chart [77] (figure C-4).

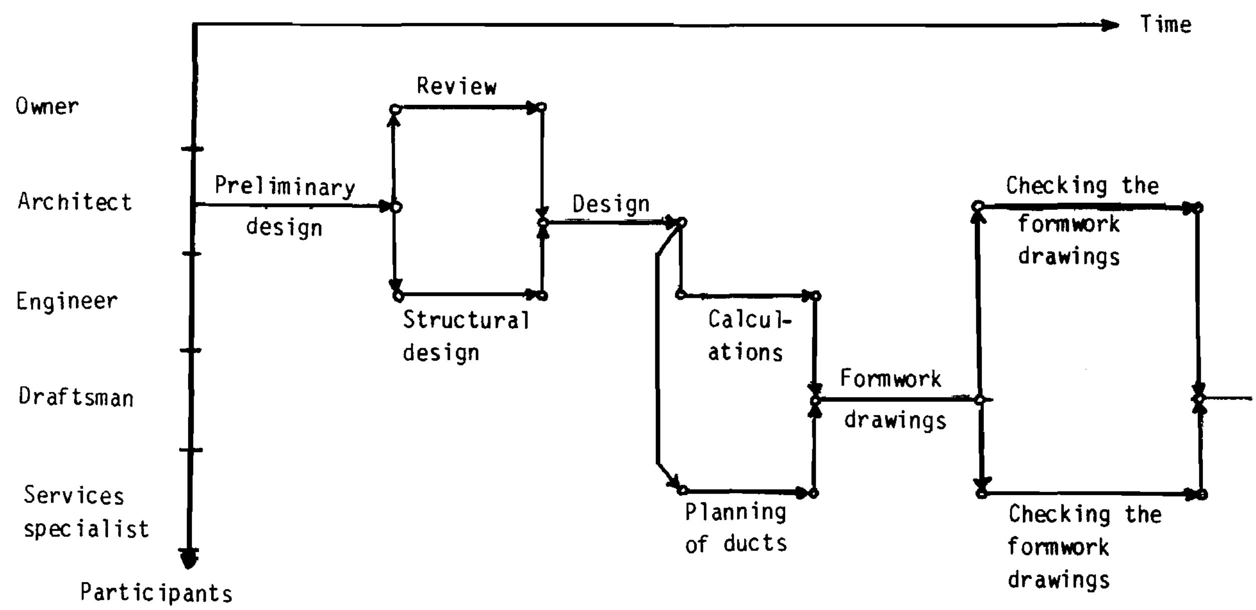


Figure C-4. Example of a flow chart.

Flow charts readily indicate who carries out which tasks at what time, and what information is needed from whom at what time.

The following methods or aids may be used to provide a detailed account of individual processes and their interrelationships:

- bar charts;
- line charts;
- cycle programs;
- network planning technique.

Individual methods and aids will not be dealt with here. Additional information may be found in the literature [10,12,22,57,77].

C 3.2.2 Organization charts

Organization charts explain the relationships between the people involved in the building process and the corresponding job areas. They are useful whenever it is important for several people to work as a team, i.e. in planning offices, enterprises, agencies, as well as in erection crews, project organizations, etc. [9,11,22,46,77,99,107]. They help prevent errors due to vaguely regulated and ambiguously differentiated responsibilities and duties within an organization.

It is important, within organization charts, to distinguish between staff positions and line positions. Staff executives provide information, advice and assistance to line executives, who make decisions and issue orders within a distinct hierarchy (figure C-5).

The preparation of an organization chart can be described along the following lines:

- establish the hierarchy of line positions;
- specify staff positions;
- indicate job designations and possibly the names of incumbents and substitutes;
- indicate the relationships between positions by means of connecting lines; the type of relationship (contractor, employee, etc.) can be shown directly on the organization chart using solid lines, broken lines, dotted lines, etc.

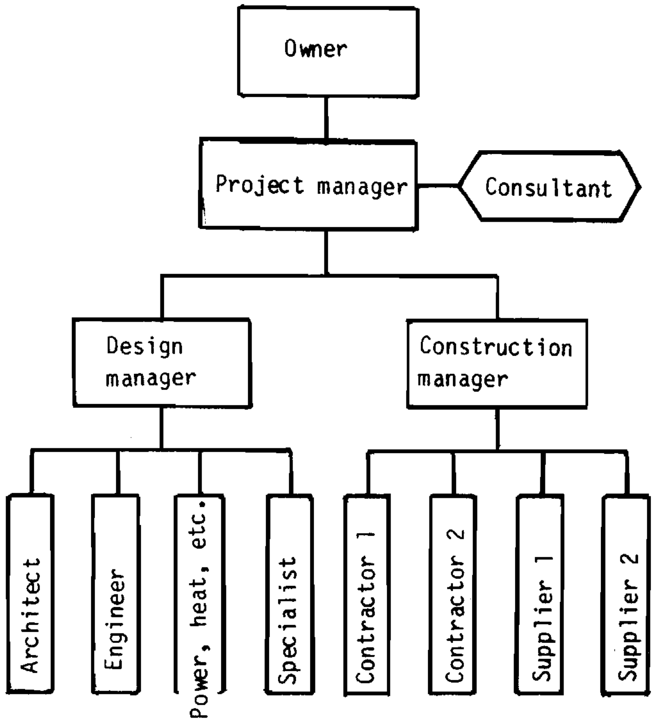


Figure C-5. Example of an organization chart.

For the sake of simplicity, charts usually limit themselves to job designations, and other data (names, incumbents, substitutes, firms, addresses and telephone numbers) are compiled in separate lists or job descriptions.

C 3.2.3 Function diagrams

Function diagrams provide an outline of the activities and functions of the participants. They are useful whenever several people are involved in particular tasks, and provide response to the activity principle described in section C-2. They also help prevent ambiguities in the definition of responsibilities and duties as they relate to the various activities of the participants (figure C-6).

Function diagram for Office Building ZASW										
Participants / Assignments	Owner	Project manager	Design manager	Construction manager	Architect	Engineer	Power specialist	Heating specialist	Testing engineer	...
⋮										
Drawings - structure		C,R	R	R	R	E,F	R	R	R,V	...
⋮										

Abbreviations:

C- coordinating
E - executing
F - forwarding information
R - receiving information
V - verification and checking

Figure C-6. Example of a function diagram.

Function diagrams list various tasks for the individual people involved. They show the powers and duties of the participants for each task listed, as well as their areas of responsibility. For each item, the functions or activities can be described in more or less detail (execute, check, coordinate, decide, provide information, receive information, etc.) [9,11,46,77,99].

C 3.2.4 Job descriptions

A job description provides a complete account of the duties and attributes of a position, and its place within the organization [77]. It is used basically for processes which specifically require proper handling by the person involved. A job description contains the following items [10,11]:

a) Job

   Designation and possibly rank.

b) Level

   Immediate superiors and immediate subordinates.

c) Replacement

   The person replaced by the incumbent, and the person who substitutes for the incumbent.

d) Purpose

   Objective of the job within the overall operation.

e) Duties

   All the essential duties which the incumbent must perform, including conditions.

f) Special duties

   All the duties which are not normally part of the incumbent's job, but which are performed for practical reasons. Special duties include those which are not related to the job, but to the personal knowledge of the incumbent.

g) Information

   The person(s) from whom the incumbent receives information, how the information is processed, and to whom it is forwarded.

h) Powers

   Powers of decision, of action, of disposal; signing authority; special powers.

i) Additions

   Changes in items a to h which may occur subsequently.

j) Supplementary information

   References to rules, service instructions, etc.

Figure C-7 provides a simple example of a job description.

A description may be limited to a compilation of the duties of a job, in which case it is simply a list of duties. If organizational errors are to be avoided, however, lists of duties should always be replaced by job descriptions.

Job description

a) Job designation

Structural engineer B in the "K5 Industrial Plant" project

b) Level

The immediate supervisor is Section Head K

Immediate subordinates are draftsmen X, Y, Z

c) Replacement

The incumbent B substitutes for Structural Engineer A, and is replaced by Structural Engineer C

d) Purpose

Design the structure for the agreed use according to stated hazards

e) Duties

The industrial plant consists of two production and one storage facility, two silos, and connecting conduits. The duties include:

- proposing a concept for the structure (reinforced concrete)
- preparing a utilization plan
- preparing, with project manager L, hazard scenarios and a safety plan
- carrying out design calculations of the structure
- control and supervision of the drawings
- making changes only with the supervisor's permission

f) Special duties

Checking reinforcement and welded joints of prefabricated units following the control plan. Recording the results in a record.

g) Information

Receiving information only from immediate supervisor K and project manager L. Processing and transmitting information following instructions from K and L

h) Powers

Power of decision for the selection of structural models and methods and the assignment of draftsmen, signing authority for letters

i) Additions

j) Supplementary information

Figure C-7. Example of a job description.

C 4. Sources of error in the flow of information and their elimination

C 4.1 General outline

In order to carry out their duties, the people involved in the building industry need information. Information is transmitted, received, stored, and retrieved. These activities give rise to various sources or error (figure C-8).

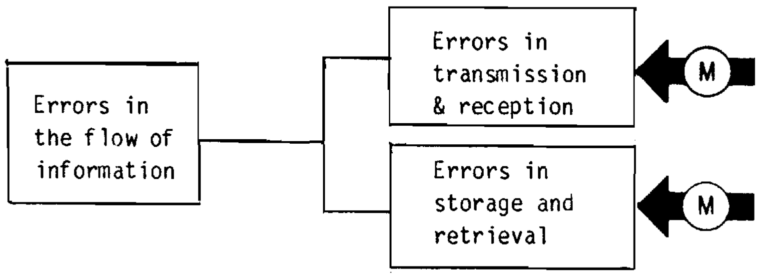


Figure C-8. Sources of error in the flow of information and their elimination.

It is important to design an information system that will ensure an error-free flow of information. This involves decisions about how the information is to be transmitted, received, stored and retrieved, in terms of format and transfer modes. An information system consists in principle of a communications system (transmitting and receiving) and a documentation system (storage and retrieval)(figure C-9).

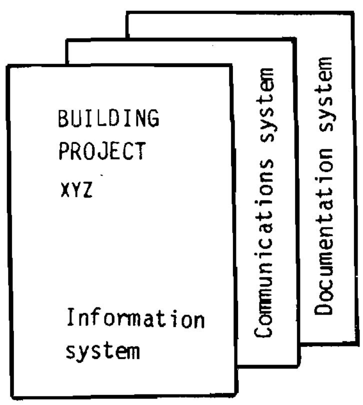


Figure C-9. Components of an information system.

Measures against errors in the flow of information include careful documentation of the information system, as well as the use of suitable principles and information tools. The following sections provide an outline of the basic possibilities. Information theory, communications technology and data processing cannot be dealt with in greater detail here; there is abundant literature on those subjects [76,87,88,112,114].

C 4.2 Communications

C 4.2.1 Communications principles

The errors involved in transmitting and receiving information can be prevented or reduced through proper communications principles.

First principle: All information must be identifiable.

This means that all information should include the following characteristics:

- Designation (title, code number)
- Content
- From whom
- To whom
- Date

Second principle: Information must be transmitted in a "common language", with explanations if need be.

There are various forms of information transfer, i.e. pictures, language, written text, and sound [98,112,114]. In the absence of a "common language", particularly for essential expressions, there is a risk of misinterpretation. This is particularly true for communications between different professional categories, occupational groups, and countries. The compressive strength of concrete, for example, is defined normally in Switzerland as the 16th percentile of the cube strength, in the Federal Republic of Germany as the 5th percentile, in the CEB Model Code also as the 5th percentile, but measured on a cylinder.

Third principle: Information transfer must be insensitive to disturbing influences.

Every mode or medium of information transfer must be designed in terms of such influences as noise, fire, breakdown, theft, courier and equipment reliability. If disturbing influences are overlooked, accidents and damage are often the direct result.

Fourth principle: The information transfer modes must be suitable.

The direct transmission of information with no additional modes is only feasible for short items in a disturbance-free environment, such as hand signals between an erection supervisor and a crane operator, or the limited use of colloquial, technical or symbolic language. As the information becomes more complex, and is transmitted over greater distances amidst interference, there is a need for information modes. Information modes that provide no storage facility include telephones, walkie-talkies, radios, television, warning systems, etc. Information modes offering storage facilities include plans, written instructions, reports, films, magnetic tapes and discs. They help prevent incomplete reception, they make information available at will, and they provide easier storage, assuming of course that there is no interference or technical defect in the corresponding equipment (third principle).

Fifth principle: There should be confirmation that the information has been received.

In direct exchanges, the recipient of a message can indicate he has duly received the information by repeating it. In other cases, reception is confirmed through a letter, a messenger, a receipt, etc. In this respect, confirmation can take the form of a verbal or written reply, but it also includes "no reply", i.e. in cases where the recipient is expecting the information (e.g. the plan).

C 4.2.2 Aids for communication

The reliability of communications can be improved by means of proper aids or information transfer modes. There are detailed reports of such aids in the literature [11,76,87,88,114]. For this reason, the following sections only deal with written communications and the corresponding aids.

Many transmission errors can be prevented through simple, informal written communications, especially in cases with extensive information amidst disturbing influences. Written communications are handled differently in various offices, firms, etc. in accordance with their size number of employees etc. Some companies may rely more heavily on letters, while others will use standard forms to ease communications. Although numerous specific or general-purpose forms are often available, only a few will in fact be used. This is due to the form itself. A specific form may simply not be found in a particular case, or a multi-purpose form may be considered too involved and complicated. Studies have shown that a form should contain only the most important and frequent elements; other information can be entered "by hand".

A functional written communication system is based on two basic principles:

- a system for written communication must be defined;
- the established communication system must be used consistently.

It appears that a simple - and for this very reason functional - information system can exist with only three communications vehicles:

- letters;
- note pads;
- communication slips.

Letters are used mainly for formal written communications involving information of major importance. The note pads are used for informal written communications, as are communication slips. Both types of pads should be available on every work desk. In this way, important information can be recorded immediately and with ease. The use of two formats is based on the reasoning that the single all-purpose form is not feasible, and that three or more forms cannot be used consistently in practice. Let us consider the three communications vehicles in more detail.

a) Letters

Letters can be used for all types of information. They contain such preprinted items as the name, address, telephone and telex numbers of the firm, etc.

b) Note pads

These forms are used to record a variety of information items (written, typed, drawn, etc.), including reports, sketches, notices, work instructions and calculations. Basically, a squared writing pad would be quite sufficient, but a minimum of preprinted items makes it easier to record the information and deal with it effectively. It is recommended that only the items included in figure C-10 be printed in advance.

It is preferable to enter any missing or additional information on an ad hoc basis, rather than making a form cumbersome through rarely needed data. The adequacy of this type of form for all essential written information is illustrated by figures B-24, B-25, B-28, C-14, E-7 and E-8.

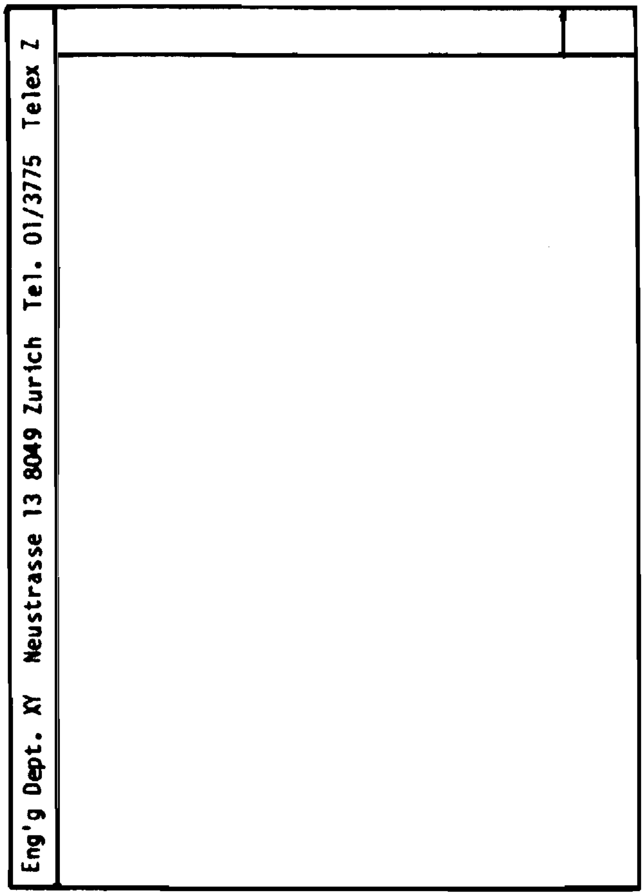


Figure C-10. Form for note used to record written information.

c) Communication slips

Communication slips can serve innumerable purposes, provided they are not too small. They are used for written communications, as covering notes, and as delivery slips for plans, etc. They can replace other frequently used forms such as telephone messages and internal memos (figure C-11).

The recommended format is 210/110 mm. This size of paper can still be called a slip, and is less likely to produce the "fear of the blank page". It also takes up less storage space. It might be useful to provide coloured slips, i.e. a yellow slip is easier to find among a pile of other papers. Slips contain preprinted information covering frequent situations, and the appropriate item can simply be checked off, so that there is a minimum of writing. The recommended format is illustrated in figure C-11.

Eng'g Dept. XY Neustrasse 13 8049 Zurich Tel. 01/3775 Telex Z

☐ message	☐ at your request	☐ for clarification
☐ delivery slip	☐ as discussed	☐ for checking
☐ covering note	☐ returned with thanks	☐ for signature
	☐ for your information	☐ for approval
________	☐ for finishing	☐ for your files
________	☐ for comment	☐ note and return
________	☐ please call .... Tel.	
________	☐ please forward to	

Date Signature

☐ cont'd on reverse

Figure C-11. Communication slip.

In the upper lefthand corner, the precise nature of the slip is checked off. On the right, above the address field, a number of possible situations are printed in advance. These should be limited to basic requirements, in order that the slip be simple and easy to read and check off. Any other important information or comment is simply entered by hand on the left side. The address field is located in such a way that it will fit properly in a window envelope.

C 4.2.3 Organization of communication

The communication system determines:

- what information will be transmitted (building dimensions, results of discussions, controls, etc.);
- its form (written, verbal);
- its means of transfer;
- the modes of transfer (drawings, telephone, etc.).

This is done as follows:

a) Description of the communications system

The communications system is described on the basis of existing documents such as flow charts, operating plans, organization charts and function diagrams.

b) Schematic representation of the communications system

Essentially, the communications system can be represented directly in a flow chart (figure C-4) or operating plan. In such diagrams, the modes of communications through which the information is transmitted are shown as connecting lines. The most important components of the communication system are represented directly by the form of information, modes of transfer, number of copies, etc. (figure C-12).

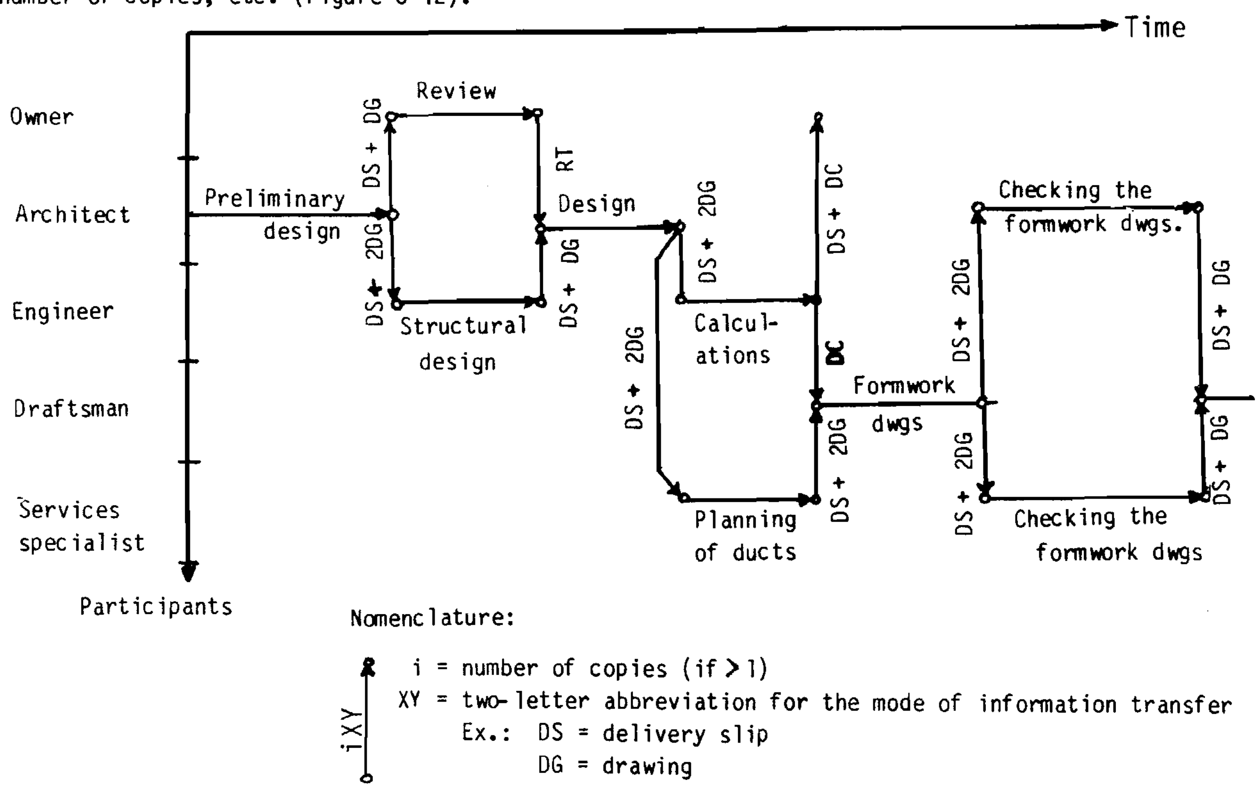


Figure C-12. Flow chart with communications data.

Data about the form of information the means and modes of transfer, can be provided through abbreviations [87], e.g. design calculations (DC), report (RT), letter (LR), delivery slip (DS), drawing (DG), etc.

In simple cases, the communications system can be outlined directly in an organization chart [10,75,77]. In more complex cases, however, it is necessary to include diagrams of transmission for each type of information (formwork drawings, reinforcement schedules, design calculations).

C 4.3 Documentation

C 4.3.1 Documentation principles

Any information that will be needed at a later date must be stored for future retrieval. Information that is not too complicated is usually stored in people's memories. This is not very reliable, since information may become very extensive, and people may become forgetful. Moreover, it is often important to make information available to other people. In practice, then, all information should be handled in such a way that it can be stored and readily retrieved. In this process, a number of principles should be kept in mind:

First principle: The information to be stored should be identified through a variety of tags or labels.

Information must in fact be described by such identifiers as dates, names and subject headings. The more identifiers, the better the description.

Second principle: The type of storage that is selected depends on the extent of the information as well as on the proposed means of retrieval.

Information may or may not be stored using such technical aids as drawings, lists and data processing [112]. In addition to the type and extent of information involved, it is important to consider retrieval requirements (e.g. how often, by whom, what format).

Third principle: It must be possible to find whatever information is stored.

Information storage would be meaningless if the information could not be called up again [112]. Information should therefore be gathered, indexed and catalogued in such a way that it is easily handled, e.g. using special containers, files, time schedules, transparent folders, punched cards, card catalogues, tapes and discs with table of contents.

Fourth principle: Measures must be taken to protect stored information from loss.

Stored information may be lost or destroyed through such hazards as fire, mishandling, theft, and sabotage. Such hazards must be systematically identified, and suitable preventive steps must be taken (see also sections B-2.5 and B-2.6).

Fifth principle: Stored information must be kept available.

There must be clear instructions concerning the retrieval of stored information. If plans, books, etc. are borrowed, steps should be taken to ensure that they remain available.

Sixth principle: Stored information must be kept up-to-date.

As soon as new information is received, it should find its proper place with the stored information. Steps should also be taken to scan any stored information at regular intervals, and remove items that are no longer needed.

C 4.3.2 Aids for documentation

Various aids are available to simplify the application of the above principles. Such aids are beyond the scope of this study, but have been described in the literature [11,22,46,76,88,112]. In the following, we will simply deal with the access of each participant to information, through the so-called information book.

An information book is used to store important information for the personal use of participants. Practically all information that is not available to participants in the form of letters, memos, and the like, either directly or through photocopies, will likely be lost. Even written information may become lost or misplaced. Such errors can be avoided if every participant (draftsman, designer, foreman, project manager, etc.) files the information that has been received in his or her personal information book. On every project, each participant should have an information book, properly divided into sections, e.g. daybook, memos, discussion minutes, letters, other information (see figure C-13). A personal information book might find wider use, as when a person's work, for one reason or another, must be taken over by someone else.

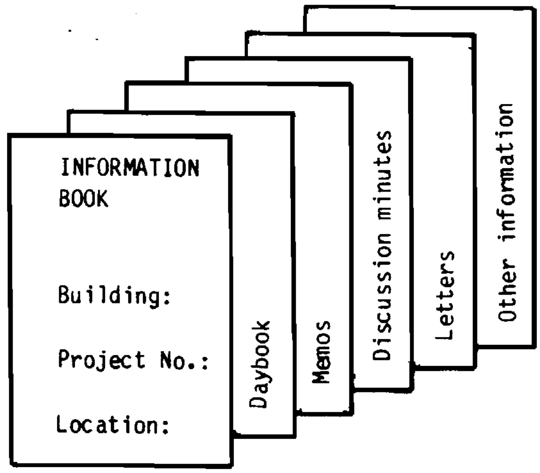


Figure C-13. Information book.

In this respect, a daybook plays a special role. For each incoming or outgoing item of information, it shows the time, the information content, the necessary reaction, and the name of the person responsible for taking such action. Once the action has been properly executed, this is noted in the daybook (figure C-14).

The daybook, then, is used:

- to record verbal communications;
- as a table of contents of written information that is transmitted and received;
- as a means not only of storing information, but of providing a way to control reactions.

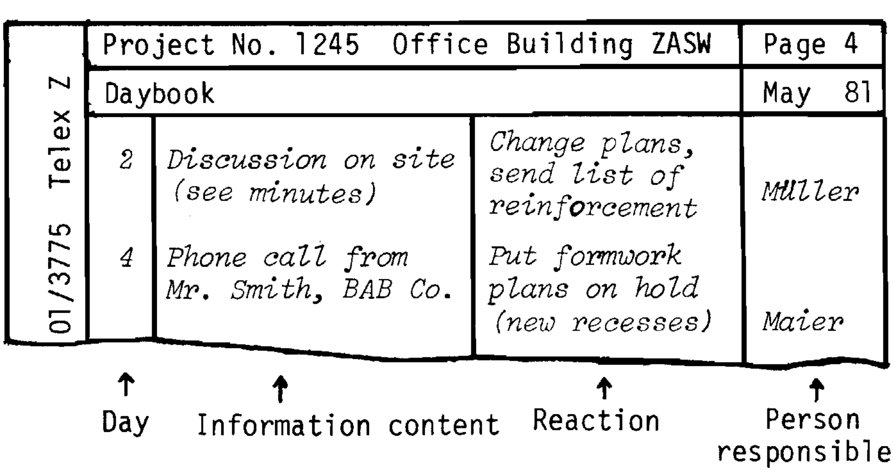


Figure C-14. Sample page from a daybook.

Daybooks are used or recommended under a variety of names for different purposes, e.g. building diary [46,106], project diary [11], project history [22].

The purpose and function of the other items in the information book, i.e. memos, discussion minutes, letters, etc. are well known, and need not be described in greater detail here.

C 4.3.3 Organization of the documentation

Reliable storage and retrieval of information requires a good documentation system [76]. The following subdivisions may be made:

- Documentation intended for each individual participant;
- Centralized documentation covering important records in each design department or firm, etc.;
- Documentation covering important records for the completed structure.

Documentation intended for each participant is handled through the information book (see section C-4.3.2).

Important information concerning the project or the building process is kept in a comprehensive file in a central location. This includes plans, drawings, instructions, calculations, etc. The basic documents were described in part B (sections B-2.6.3, B-3.2, B-5.2). Documents are kept in a central file in each engineering department or firm, etc., and in each case, it is important to determine which documents are to be filed where and how, who will be responsible for them, how they can be located, to whom they may be transmitted, and how their movements are to be recorded (e.g. in-coming and out-going lists).

Finally, once the project has been completed, the most important documents should be brought together to form a component of the utilization manual (see section B-5.2) kept by the owner. Such documents or the utilization manual itself may then be used at a later date to plan and carry out alterations and maintenance work.

C 5. Sources of error related to cooperation and their elimination

C 5.1 General outline

The various operations in the building process require the close cooperation of all the people involved in the construction work (see the "organization/management principles" in section C-2). This type of cooperation is especially important between:

- people who are working simultaneously on a given operation;
- people who come together at a given interface.

Poor teamwork can have serious repercussions (figure C-15).

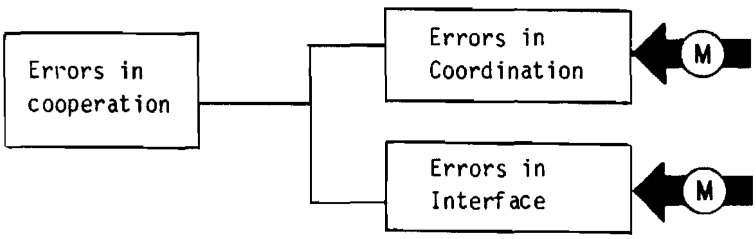


Figure C-15. Errors in cooperation and their prevention.

Such repercussions can be avoided or reduced if careful plans are made to ensure proper cooperation. Such plans are supported by contractual rules, meetings, careful interfacing, as well as reliable methods of making changes and improvements (figure C-16).

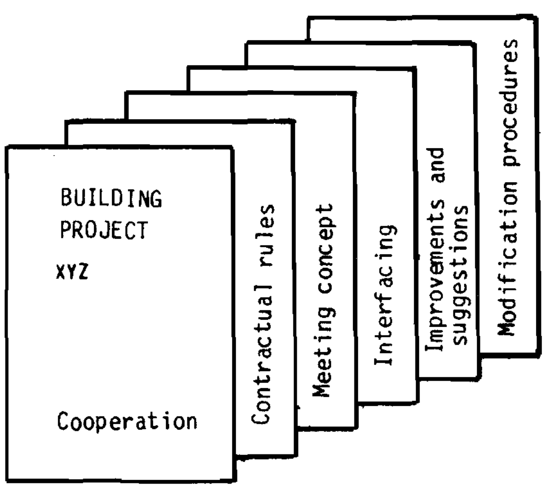


Figure C-16. Documents related to cooperation.

C 5.2 Assurance of cooperation

C 5.2.1 Meeting concept

Meetings are held to actively promote cooperation, and to ensure a rapid exchange of information among the participants. Continued cooperation is more likely to be maintained during the entire project if various groups can come together in an organized fashion [2]. This requires a clear identification of:

- the purpose of each meeting (e.g. site coordination meeting, construction commission meeting);
- the date of each meeting (e.g. weekly, monthly, specific weekdays);
- the participants who are to attend each meeting;
- the documents that will be required, and who will distribute them.

In addition to regular meetings, it is important to make provisions for special meetings, e.g. in cases of accidents or poor weather conditions, and to determine how such meetings are to be convened.

C 5.2.2 Interfacing

In promoting systematic cooperation, it is important to determine the major areas where groups of participants interface, and to ensure teamwork in these specific areas. One example would be the interface between the completion of one operation and the beginning of the next operation (e.g. inspection, testing). Personal contacts between participants at an interface are recommended.

C 5.2.3 Improvements and suggestions

Timely improvements of the methods and processes used, as well as the early detection and correction of errors, are positive steps towards reducing or eliminating accidents.

The official report of the Commission appointed by President Carter [17] clearly indicates that the accident at the Harrisburg nuclear power plant could have been avoided if information supplied by someone not directly involved had been taken into consideration. Such accidents, which should not occur, call for improved cooperation.

The teamwork required of the participants can be promoted by means of a suitable procedure. In this respect, it is important to establish:

a) How suggestions for improvements are to be formulated, and how shortcomings or errors can be detected. There are various possibilities, including:
- active assistance and cooperation from each participant;
- controls over the initial and operating conditions by each participant, with the obligation to report any deviations or ambiguity to the person responsible;
- regular inspections of the workplace, and in particular of the building site;
- on-site discussions of important observations and possible errors or improvements;
- additional controls (see Part E).

b) Who should (or must) report a possible improvement or an error to whom, and in what form. There are various forms of report, including:
- verbal communication, in which a possible improvement or error is transmitted orally;
- written communication, whenever a possible improvement may produce a basic change, or whenever an error may have repercussions, e.g. delayed consequences (see [102]);
- notes dropped in a suitably located suggestion box.

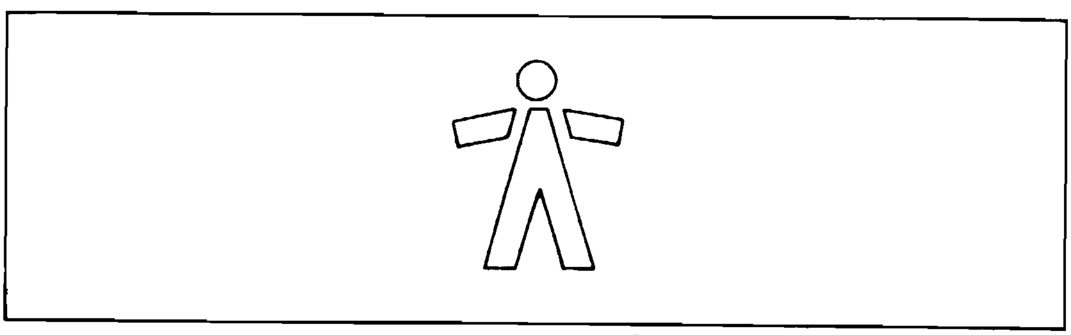
c) How such reports are to be handled, and by whom. The motivation of the participants plays a decisive role in any improvement or suggestion scheme. Motivating factors are based on the desires of the participants for such things as personal recognition, willingness to help, loyalty ("we are all in the same boat" [2]), as well as individual benefits (bonuses). All types of reproach or persecution against someone who has made an error are counterproductive, since subsequent errors, especially individual ones, may go unreported. Motivating factors are dealt with in greater detail in Part D.

C 5.2.4 Modification procedures

Unforeseen events and better work procedures often lead to a need for change. Such modifications usually have repercussions on the building process and on the building components (structure, finishes, ventilation, etc.). If such repercussions are not followed up in time, there will be a risk of error. A well organized modification procedure is needed if such errors are to be avoided. Any major change is first described in writing (e.g. on a form [42]) or graphically (e.g. directly on a plan), and brought to the attention of all the people involved. These people study the repercussions of the change in their area, and express an opinion. If agreement is reached, instructions are given to "go ahead", or to incorporate any proposed changes. If some opposition remains, it must first be cleared up. If this cannot be done, the anticipated change must be abandoned.

PART D

SOURCES OF PERSONAL ERROR AND THEIR ELIMINATION



D 1. Overview

Part D of this report deals with the skills and modes of behaviour of the people involved in the building process. Personal error will be investigated as a last cause of error [58,111]. Personal error can of course be traced to still other causes, e.g. social environment, inadequate education, family difficulties, and so on. Such further causes, however, fall outside our present framework, i.e. the building process. We will therefore limit our discussion of measures against personal error to its immediate causes within the building process.

The measures discussed in the following sections are based on failure investigations, supplemented with suitable aids described in the literature. The following should not be considered as a manual of industrial psychology or occupational physiology, but rather as a collection of suggestions aimed at the systematic prevention of errors due to the "human element".

Measures against personal errors, like the measures against errors in technical procedures and in the organization and management, are selected on the basis of each particular problem within the framework of overall management strategies. In this respect, the assignments and the performance of various groups of people are of prime importance. In Part D, however, as in the whole study, we will be dealing with errors which, in the final analysis, are always due to individuals. For this reason, the measures discussed here as a means to prevent errors are aimed at the behaviour of individual people. Group behaviour is dealt with only when it appears necessary in the present context.

Everyone involved in the building process is assigned very specific tasks. Carrying out these tasks requires the analysis of circumstances and the development of solutions, as well as decisions and finally the execution. These four basic activities are outlined in figure D-1.

If these basic activities are not carried out, or are performed incorrectly or insufficiently, errors will occur. There will be personal error. The various forms of personal error are described in the results of damage analysis [58] (see figure D-2).

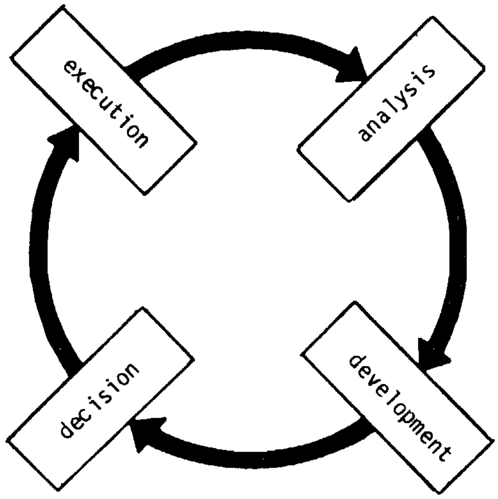


Figure D-1. Basic activities involved in carrying out tasks.

Type of personal error	as a percentage... ...of 76 failure cases caused by architects	...of 212 failure cases caused by engineers	...of 261 failure cases caused by contractors	...of 30 failure cases caused by users
Insufficient knowledge	30	36	14	28
Forgetfulness, misunderstanding	16	13	4	7
Ignorance, negligence, carelessness	24	14	54	45
Underestimation, poor judgment, others	30	37	28	20
Total %	100	100	100	100

Figure D-2. Breakdown of failure cases according to type of error caused by people involved [58].

Only the most important types of personal error are outlined in figure D-2. Other forms, such as "ambiguous responsibilities", "reliance on others", or "unknown phenomena", are included under "other". They are largely covered by measures in technical procedures and in organization/management. Given the different forms of personal error, it is useful to establish a distinction between situation-oriented and process-oriented measures (figure D-3; see also section A-3.1).

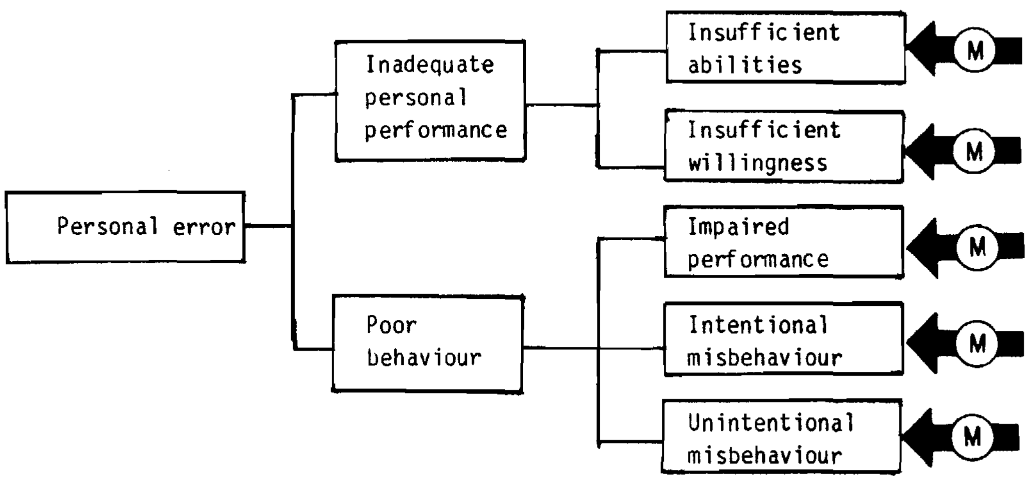


Figure D-3. Personal errors and their elimination.

Situation-oriented measures are aimed at ensuring the necessary ability and willingness to work. Process-oriented measures are applied against disturbing influences and against intentional and unintentional behaviour. The following sections deal with these topics in greater detail.

D 2. Ensuring adequate personal performance

D 2.1 General outline

The level of personal performance required for a given task or activity can only be ensured if both the necessary ability and willingness to work are present [41,89]. If one or the other requirement is not met, or is met only partially, error and failure may occur. Failure analyses (e.g. [58]) have shown that inadequate personal performance caused about half the cases of damage (see figure D-2).

Basically, personal performance is satisfactory if the requirements laid down by the employer for a given job are in good agreement with the skills and expectations of the worker who executes the assignment (see figure D-4).

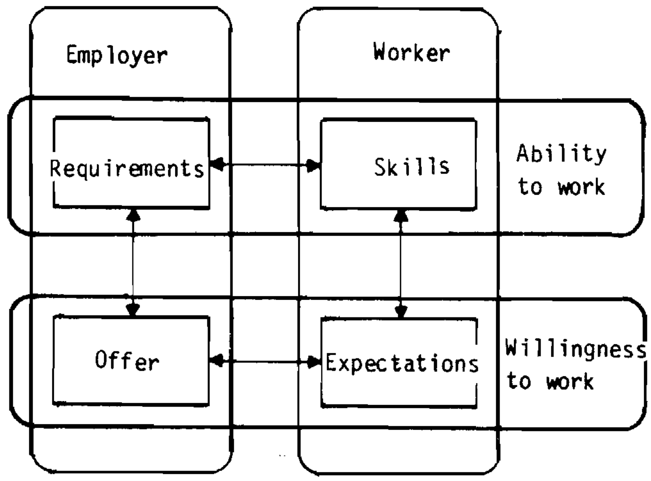


Figure D-4. Ensuring adequate personal performance.

The use of so-called profiles may be helpful in checking personal performance. Such profiles are based on a systematic listing of characteristics, and include qualitative as well as quantitative assessments. In this respect, it is useful to distinguish between requirement profiles, skill profiles, expectation profiles and offer profiles (see figures D-5 and D-7). The main characteristics included in each profile are as follows:

- Requirement profile: the specific requirements of an assignment, as laid down by the employer;
- Skill profile: the skills possessed by the worker;
- Expectation profile: the expectations entertained by a worker in return for the use of his skills;
- Offer profile: the benefits offered by the employer.

The ability to do a job is present when the skill profile corresponds to the requirement profile. The willingness to do a job is present when the expectation profile corresponds to the offer profile. If there are gaps, it is important to determine whether it would be possible and desirable to eliminate them by reconciling the profiles. The general procedure for ensuring adequate personal performance therefore consists of the following steps:

- preparing requirement profiles and offer profiles;
- finding people and determining their skill and expectation profiles;
- comparing profiles and selecting suitable people;
- if need be, improving the ability and willingness to do the work by reconciling the profiles.

The following sections deal with individual steps or profiles in greater detail.

D 2.2. Determining the ability to work

D 2.2.1 Requirement profile

A requirement profile is used to determine the requirements of a given assignment or job as they relate to the people who carry it out. Such a profile consists of various skills, and includes an assessment of the requirements that are listed [14,41]. The skills may be divided into various categories, such as knowledge, aptitude and will. The second category may be further subdivided into physical aptitude (strength, endurance, etc.), mental aptitude (ability to think, creativity, etc.) and social aptitude (leadership, adaptability, etc.). In preparing a requirement profile, it is important to analyze the anticipated job in terms of:

- location: where the work will be done (area, social environment);
- time: initial date and duration (winter season, nighttime);
- type of work: manual, mental;
- environmental factors: climate, noise, dust.

The specific requirements are first assessed qualitatively by means of key words and categories; they are then assessed quantitatively, as much as possible, using codes from 1 to 5 for example (figure D-5).

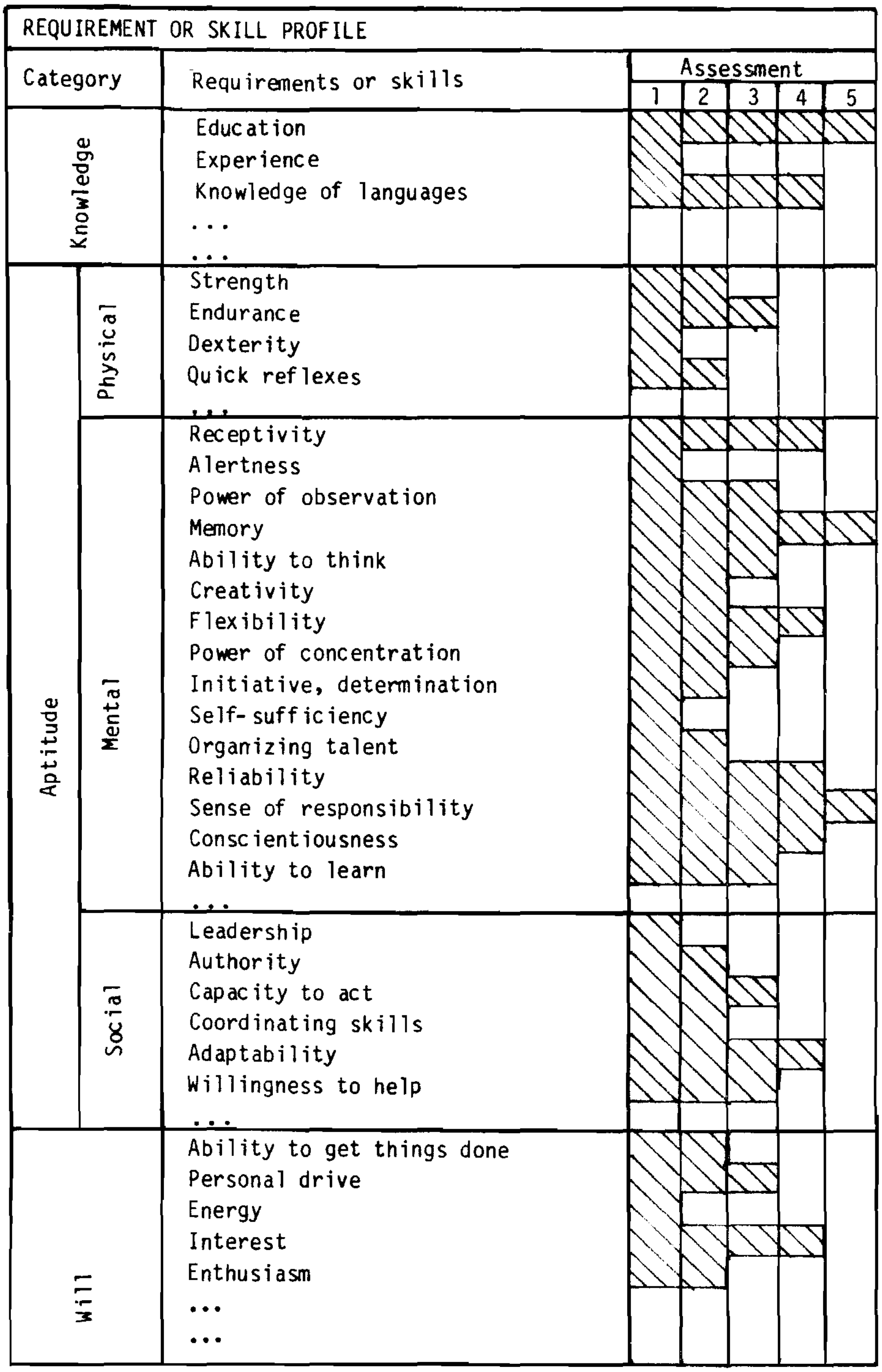


Figure D-5. Example of a requirement or skill profile.

Figure D-5 provides a helpful model for the preparation of requirement profiles, and can be used as:

- a checklist of required skills;
- a form on which to enter notes and remarks;
- a quantitative assessment of individual skills.

The requirement profile is used as a basic tool to help find and appoint or assign suitable people, following the principle of "the right person in the right job". In this respect, however, a detailed profile is not always necessary. A rough outline of skill categories and a rough system of assessment (e.g. fair, good, very good, excellent) are sufficient to provide a good understanding of requirements. This type of profile is meant to describe requirements in a more systematic way than is often the case nowadays.

D 2.2.2 Skill profile

A skill profile is used to assess a person's skills. It corresponds in principle to the requirement profile, although it is specifically skill-oriented [14] (figure D-5).

The assessment may be carried out through self-evaluation or through an evaluation by others. Self-evaluation, which is not synonymous with self-criticism, is meant to help describe actual skills in a systematic way. It is based on such questions as "what do I know", "what can I do", "what am I interested in".

An evaluation by others, on the other hand, is based on the following information:

a) Documents
School transcripts, confirmations of work done, course certificates, etc. are useful tools in the evaluation process. Such documents are often insufficient, however, and must be supplemented by other information.

b) Additional information
Additional information is obtained through tests and examinations [41] and by means of interviews. These should concentrate above all on people's knowledge, since the dominant cause of human failure is insufficient knowledge (figure D-2). Tests and examinations often meet with resistance from the candidate, so that the necessary information is preferably obtained through

interviews. Even a visual assessment a person's tools (e.g. a measuring tape [59], a measuring instrument, a saw, an axe, etc.) is often sufficient to judge a person's aptitudes (e.g. in terms of conscientiousness). An evaluation of personal tools has been used traditionally by master carpenters who recruit journeymen.

Interviews must be prepared carefully, i.e. using the requirement profile, if they are to produce sound results. It is particularly important to decide which questions will be asked, and in what form [121].

Documentary evidence supplemented by additional information provides a fairly good picture of a person's aptitudes. This is not to say that inaccurate assessments can always be avoided. These can be overcome, however, to some extent, by establishing mutually agreeable trial periods.

c) Assessment during a trial period

The trial period is used to assess people and their performance and the results are then compared with existing information. This is a widespread practice, and it has been proven useful.

d) Influence of time

Depending on the type of work, skills may change with time. People acquire experience through the years, while forgetting little used technical knowledge.

D 2.3 Determining the willingness to work

D 2.3.1 Expectation profile

A skilled person who lacks the willingness to work is not going to perform at expected or potential levels. The willingness to work is based on a participant's motivation.

Everyone, including the people involved in the building industry, has a variety of needs and aspirations. The posssibility of fulfilling those needs is what motivates people. As a result, people live in the hope of success and the fear of failure. Their hopes and fears are very much influenced by economic, political, social and other influences. During a time of widespread unemployment, for example, the need to maintain a job will dominate other needs. In times of prosperity, however, wages and vacation will be given more importance. Recognition of a person's performance, in this respect, is very often a motivating influence. When a need is fulfilled, new ones are formulated. It is possible to establish a basic hierarchy of needs and aspirations [53] (see also figure D-6).

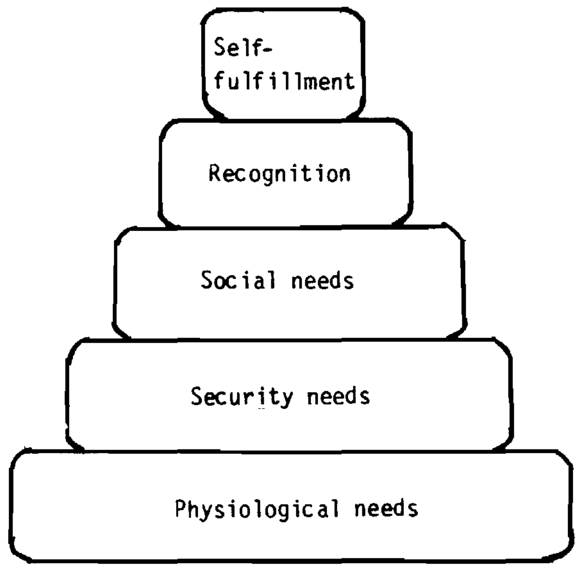


Figure D-6. Basic needs arranged hierarchically [53].

Physiological needs are those which help maintain life. They include food, clothing, sleep, movement, and so on.

Once physiological needs have been satisfied, life is nevertheless threatened by a multitude of influences. People need to protect themselves from hazards. This need for security makes people look for protection from catastrophes, strive for personal health and seek proper provisions for their old age, as well as adequate resources, law and order, stability and national safety.

Once physiological and security needs have been met, according to individual demands, social needs become a motivating factor. These include a sense of belonging, affection, friendship, love, etc.

The need for recognition encompasses the need for self-respect and the need for respect from others. The need for self-respect finds expression in the desire for a good personal image in terms of strength, ability, responsibility, competence, talent, knowledge, self-sufficiency. The need for respect from others is expressed in the desire for a good reputation, appreciation, status, worthiness, respect, fame, etc.

Finally, people need to do what they feel able to do; in a word, they seek self-fulfillment. This includes personal development, self-advancement, self-realization, etc.

Once people have satisfied their needs and aspirations at one level, they seek to fulfill those at the next levels. The higher those needs are located in the hierarchy, the more difficult it is to satisfy them, and therefore the less people reach their goals and aspirations. One study [53], for example, has produced the following percentages of satisfied respondents:

Physiological needs	85%
Security needs	70%
Social needs	50%
Need for recognition	40%
Need for self-fulfillment	10%

People involved in the building industry expect some of their needs to be met by their participation in the building process. If such expectations, which vary with each individual, are described by means of key words, and assessed, the result is an expectation profile (figure D-7).

Expectations begin with basic needs, and can be subdivided as follows [40,122]:

a) Payment for work

Payment for work includes salary, bonuses, goods, official car and/or residence, etc. It makes it possible for people to meet, first and foremost, their physiological needs. These needs are satisfied indirectly, since people use their salary to buy food, clothing, etc., and to fulfill other needs which can be met through money or status.

b) Industrial safety and job protection

A sufficient degree of industrial safety and job protection is part of the need for security. People seek protection against the dangers associated with their work. This need for security includes such items as:

- Rules and regulations governing the jobs of workers (e.g. hours of work, sufficient notice, etc.);

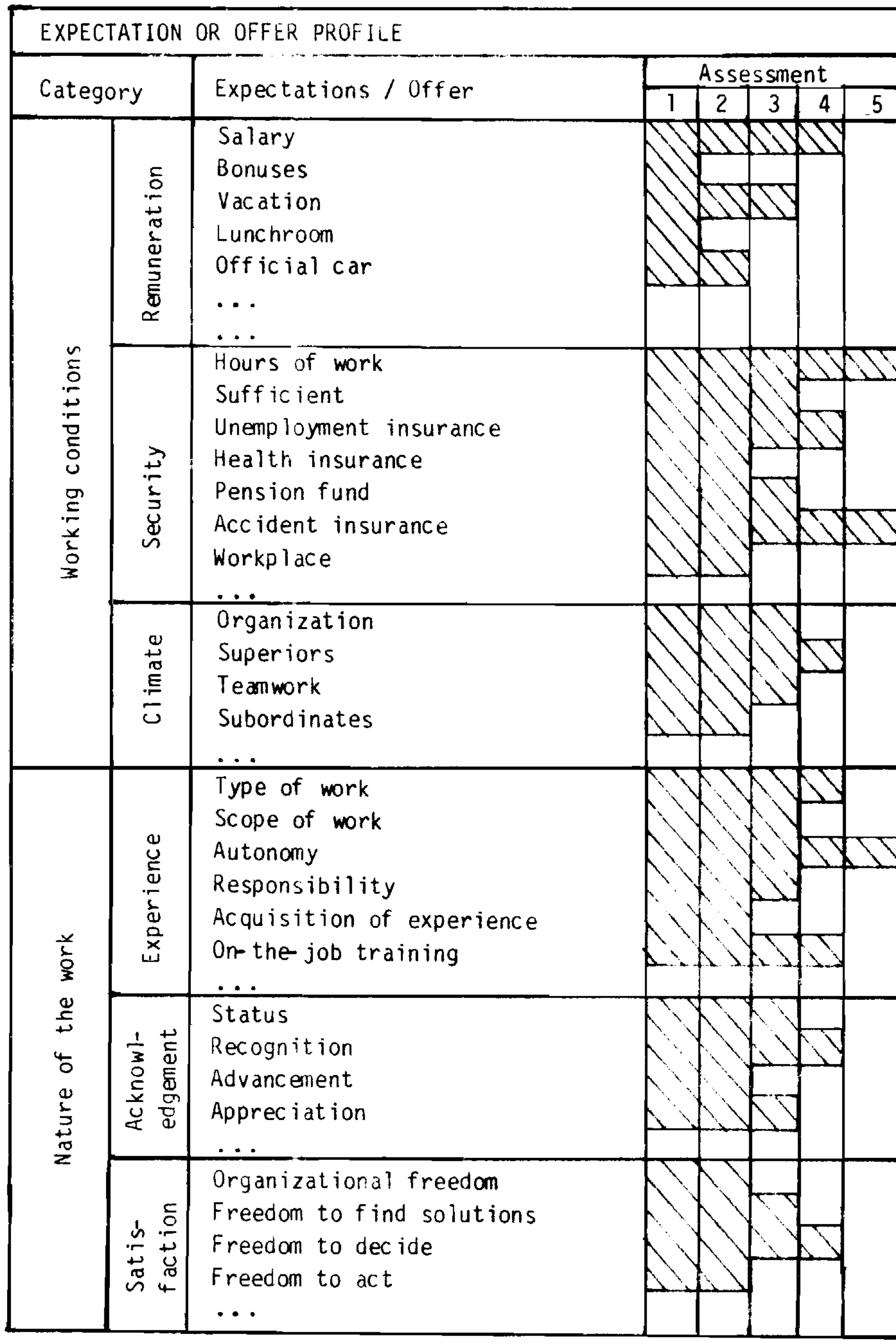


Figure D-7. Example of an expectation or offer profile.

- Insurance against unemployment, accidents, sickness, as well as a pension fund or plan, etc.;
- Working environment in relation to hazards, fatigue, health, and so on.

c) Atmosphere at the workplace

The desire for good working conditions is in fact a social need. People look for support and a sense of community, and therefore make certain demands or expectations on their employer and colleagues.

d) Work experience

The desire for a rich work experience is related to the need for self-respect. People want to experience personally the success of their work. Their expectations are related to the type of work and its scope, as well as self-sufficiency, responsibility, etc.

e) Acknowledgement

People's desire that their work be acknowledged is part of their need to gain respect from others, and includes such factors as respect, recognition, appreciation, advancement, position in the hierarchy, and so on.

f) Job satisfaction

Job satisfaction is related to the need for self-fulfillment. People expect a suitable amount of freedom in their work (organizational freedom, freedom to decide, etc.).

The model outlined in figure D-7 may be used to prepare the expectation profile. It helps people to better understand and express their expectations. As a result, the expectation profile reflects the actual conditions under which people are willing to offer their skills (skill profile).

D 2.3.2 Offer profile

The expectation profile is compared with the offer profile, just as the skill profile is compared with the requirement profile. People involved in the building industry hope that their job will enable them to fulfill their expectations. The extent to which these hopes are realized depends on the benefits that are provided by the employer. The analysis and assessment of these benefits results in a so-called offer profile (figure D-7). Such profiles are usually based on minimum benefits which are laid down as working conditions in laws, standards, or agreements (e.g. wage agreements). Minimum benefits are determined in accordance with the type of assignment and the complexity of the requirement profile, and are then assessed. While it is clearly not possible to provide a definite assessment of all the benefits, many of them do have a quantitative value (e.g. 4 weeks of vacation, $25,000 salary, etc.). It is often useful to give specific benefits a relative value, i.e. in terms of a typical or average situation. Thus benefits which are difficult to quantify can be assessed.

D 2.4 Selecting appropriate professionals

A person's ability to work is assessed by comparing the requirement profile with the skill profile. The first step consists in choosing those people whose skill profile is in good agreement with the requirement profile. Major differences between the profiles point to overextension or underextension. In the case of overextension, a person subjected to excessive stress may perform poorly [41,120]. In the case of underextension, the resulting boredom may also lead to poor performance levels [41,120].

A person's willingness to work, on the other hand, is evaluated by comparing the expectation profile with the offer profile. If there is extensive agreement between the profiles, the candidate will in all probability find fulfillment in that job. If both the ability and the willingness to work appear adequate, a suitable candidate has been found for the job. If profile comparisons reveal discrepancies, however, it is important to determine whether these could be overcome by improvements, i.e. by adjusting the profiles (see also sections D-2.5 and D-2.6). If the answer is no, the candidate should be considered unsuitable. The decision process is outlined in figure D-8.

The final selection or assignment can be based on a wide variety of criteria: minimum difference, minimum training costs, minimum labour costs, maximum profit, etc. [14].

Since the people registered on the short list often do not meet all the requirements, or feel that the benefits offered do not meet all their expectations, it is important to find a mutually agreeable basis for comparing the differences. Such comparisons can be simplified if minimum and maximum values are assigned to the requirements and expectations. The resulting tolerance limits [14] provide a relative basis for the consideration of differences.

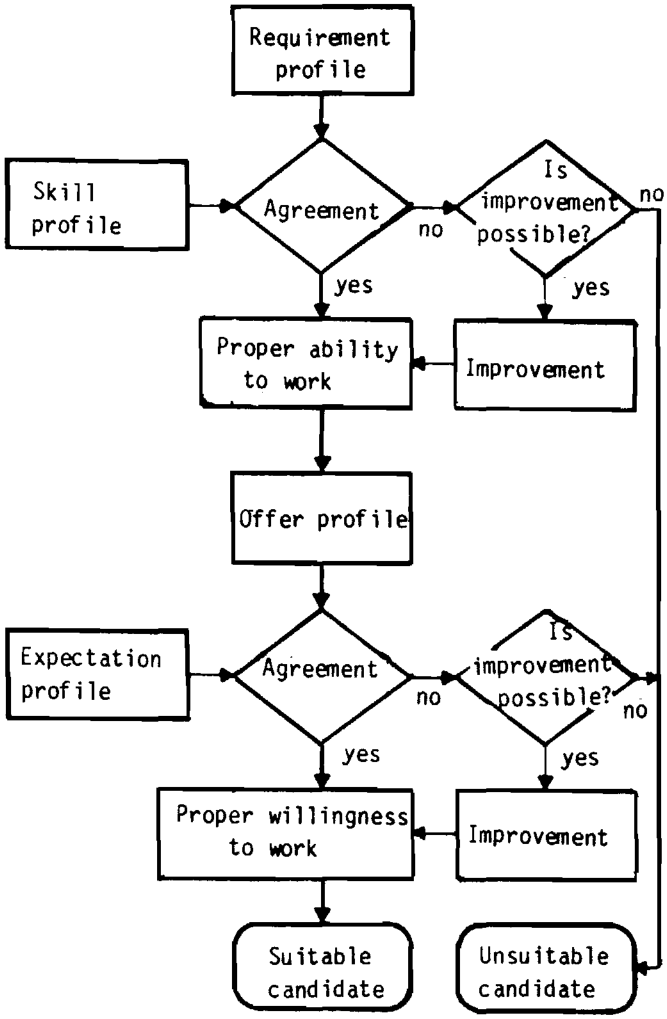


Figure D-8. Staff assessment and selection.

D 2.5 Improving the ability to work

Gaps between a requirement profile and a skill profile can be overcome through adjustments in the requirement profile or through improvements in the skill profile. While the requirement profile is usually prescribed by the job under consideration, the skill profile often leaves room for improvements.

A person's innate skills cannot be influenced inasmuch as they constitute his natural ability [50,89]. On the other hand, skills acquired through education and experience can be influenced and improved [14]. Basically, a skill profile can be improved through:

- appropriate education;
- systematic training;
- becoming aware of experience;
- continuing education.

The detailed analysis of education, training, etc. falls outside the scope of this report, but the following sections will describe how, and under what conditions, a person's ability to work can be improved.

D 2.5.1 Appropriate education

The problem of education has been dealt with extensively in the literature [23,47,52]. With respect to improving a person's ability to work, two aspects should be mentioned, namely the so called threshold of activity and the preparation of educational programs.

It is impossible for education (school education, vocational training) to cover all future requirements. As a result, emphasis is usually placed on providing a broad foundation. Nevertheless, the knowledge and skills that are provided should reach a level which, at least in some areas, extends beyond the so-called threshold of activity. The latter defines the minimum knowledge or skills needed for specific activities [37].

The suitability of a course of education is determined partly on the basis of the education program, which must include the following items:

- goals and objectives;
- type of material and scope;
- person in charge;
- timetable (e.g. number of hours);
- form of education (lectures, exercises, demonstrations, etc.), in accordance with the three stages of learning, whereby "facts must be conveyed, acquired, and strengthened" in order to be used;
- monitoring the knowledge learnt (examinations, tests, etc.).

The skills thus acquired are further developed in terms of specific tasks by means of training, experience, and continuing education.

D 2.5.2 Systematic training

Each person who begins a new job or assignment must be given ample opportunity for systematic training [100]. This involves both an exchange of information and proper practice of the relevant procedure [52]. Practice is especially important in the case of special tasks which require correct handling (complex assemblies, work done under difficult conditions, etc.).

To ensure proper training, it is often necessary to follow a specific program. The following checklist may help set up such a program.

- Objectives

It is important to determine what the employee should know and be able to do after the training period.

- Attendant

The name of the person responsible for the supervision and implementation of the program;

- Duration

It is important to indicate when the training is to take place, in what area, in which form, and under whose supervision. The duration and the method used are determined individually. Special precautions should be taken if there is any risk of property damage or personal injury. In some cases, systematic training may even be carried out with the help of simulators.

- Documents

The documents that may be needed should be identified.

- Evaluation of training

It is important to determine how the success of a training program will be evaluated. This may be based on information from the attendant, or on tests, interviews, etc. The goal is to decide whether the employee is able to perform his duties satisfactorily.

D 2.5.3 Activation of experience

By experience is meant the knowledge that is acquired through completion of a task. A person's ability to work in the building industry is indeed improved through experience. Although it is not possible to directly measure a person's experience, a great deal of importance is given to it, particularly in the building industry. In some cases, for example, specific tasks are only assigned to people with a few years of "experience", however questionable this requirement may be. Experience is only helpful if it is available in the first place. It must therefore be acquired, analyzed and stored, and that depends on each individual. Experience is stored in a person's memory, but people tend to forget, so various strategies must be used to help save interesting solutions, procedures with certain advantages and disadvantages, details of workmanship, models, references to the literature, etc. Furthermore, such strategies make it possible for people to profit from each other's experience. Two simple strategies will be described here.

a) File system

The easiest method of gathering experience is to simply accumulate notes freely in a file. This system nevertheless requires a fairly good memory, and is suited only for a limited amount of information. This system is particularly well suited for a training period, for example, since much new material is acquired which is difficult at first to put in order. As the amount of information grows, however, it is useful to establish subject areas. If an item deals with more than one subject area, cross-references may be helpful. At first, only major subject areas should be used, with a subdivision entitled "other" for all remaining items. As the "other" items become too numerous, new sections are introduced for recurrent subject areas. The file system allows direct handling of copies of plans, examples, and so on.

b) Card system

This system makes it possible to index information according to several subject areas for easy retrieval using a single set of codes. People who have chosen this type of documentation system usually carry a few cards with them in order to have direct access to information, whether it be on the job, at a conference, or elsewhere. Index cards are an excellent way of storing references to documents that are kept in another location.

D 2.5.4 <u>Continuing education</u>

Acquired knowledge must constantly adapt itself to new developments in science and technology. For people in the building industry, this can be done through continuing education. Many people in the building industry, as their career progresses, come to work in areas for which their basic education did not provide the required knowledge (e.g. project management, investment and financial planning, cost accounting, etc.). This is a major problem in the building industry, and a large source of potential errors, which can only be overcome through continuing education.

Continuing education is, above all, a matter of personal initiative, and cannot be dealt with in great detail here. However, whenever efforts are made to improve people's ability to work through plans for continuing education, it is important to ensure careful preparation and rational implementation. If such plans are made within a firm, for example, a person should be made responsible for the program, and the following considerations should be kept in mind:

- Participants

It is important to determine which participants (draftsmen, bricklayers, structural engineers, etc.), working in certain areas (technology, organization, accident prevention, etc.), encounter different types of problems, and the extent to which continuing education might be needed and/or desirable.

- Objectives

The objectives of continuing education are identified on the basis of requirements in the workplace, of the aptitudes of the participants, and of existing problems.

- External program

Existing possibilities, such as courses, conferences, journals, etc. already provided by universities, colleges, professional associations or companies, should be identified, and assessed in terms of specified objectives.

- In-house program

If there are no external possibilities, or if these are inadequate, an in-house program should be considered (courses, conferences, reports, internal communications, etc.).

- Costs and feasibility

The time requirements, the financial costs, the feasibility of granting workers educational leave, and similar aspects should be given due consideration.

- Continuing education program

Any such program should include a periodic assessment (e.g. each year) of the type of education to be provided, and who should benefit from it.

- Implementation

The required funds, facilities, etc. must be provided, and suitable people must be selected to implement the continuing education program.

A variety of strategies are possible within a continuing education program, and these are discussed in the following paragraphs.

a) Written information

A significant contribution to continuing education can be made by circulating a selection of journal articles, books, etc. This type of information can be passed on from one person to another, or it can be made available to everyone in a particular location.

b) Information exchange

One way to actively promote the transfer of information or experience is to organize a system of information exchange, along the following lines for example:

- identifying subject areas;
- assigning particular areas to certain people;
- distributing technical documents of interest under the proviso that the people responsible for certain subject areas be made aware of any relevant information;
- ensuring that information in the various subject areas is analyzed by the appropriate people;
- organizing an exchange of information at specified times.

This type of exchange provides a stimulus for discussion, and helps promote teamwork among the participants.

c) Courses, lectures, seminars, etc.

It is important to decide who will attend what courses, lectures, etc. If only a few people are allowed to attend, they should prepare a written report or an in-house seminar so that important information can be shared with others. Such a requirement offers two advantages: the participant must make a special effort to follow the proceedings, and his colleagues and co-workers are informed of major items. The reports and lectures should have the following structure:

- Purpose
- Topics discussed
- Interesting aspects
- Possible applications in the field of work
- Examples
- Name of the author (in case there are requests for further information).

A program should not offer only courses and lectures which deal exclusively with new developments, but should also include refresher courses at certain time intervals, as well as regular exercises and tests. A review of already acquired skills is especially important for people who are assigned to tasks which only occur infrequently (e.g. company fire brigades, safety in the workplace, emergency aid). Since the corresponding skills may be used only rarely, if at all, they might be lost for lack of practice, and must therefore be renewed at regular intervals through specific exercises. Such exercises should of course incorporate any new scientific and technical developments.

d) Evaluation of experience

People gain experience from their work and other activities, and they receive information about failures and non-failures, unfavourable influences, and so on. This type of information might be of interest to others at some future time. It is therefore important to evaluate such information, to analyze it in a systematic way, and to store it for easy retrieval. This can be done through short reports, for example, and published in a company newsletter.

Should such information be of interest to a wider circle of people, it can be disseminated through journals, lectures, etc. This type of information dissemination, which is a form of feedback on the state of the art, should get special support from professional associations, universities, etc.

An example of such systematic evaluations is provided by the German Federal Railways, which have used standardized sketches, checklists and check items to help improve their designs [110].

D 2.6 Improving the willingness to work

Gaps between expectation and offer profiles (see section D-2.4) can be reduced or eliminated if expectations are lowered and/or benefits increased. Lowered expectations usually lead to dissatisfaction, however, with a drop in the willingness to work. Nevertheless, lowered expectations in one area can often be compensated by extra benefits in another area (e.g. less pay but a very pleasant workplace and interesting work, or above-average pay but dull work). The willingness to work can of course be increased by improving the offer profile, i.e. through better working conditions (see figure D-7) [24,40,120,122]. Motivation is often viewed only in terms of the type of work [40,122]. However, working conditions, and salary in particular, play a very important role. In fact, a survey of 4,000 employees in all lines of work, carried out in 1975 [6], produced the results outlined in figure D-9.

Job satisfaction criteria	%
Proper payment	73
Good boss	56
Pleasant relations with colleagues	56
Congenial workplace	53
Working conditions and health protection	43
Interesting work	39
Good social facilities	30
Suitable schedule of working hours	29
Good career opportunities	20

Figure D-9. Results of a survey on job satisfaction [6].

Accordingly, the willingness to work can be improved in the following ways.

Remuneration:

This includes higher pay, bonuses, longer vacation, privileges, etc. Remuneration is particularly important when it is difficult to meet some of the "higher" basic needs (e.g. auxiliary jobs or heavy work).

Working conditions:

This includes additional insurance, making work easier, a better workplace, allowing people to add a personal touch to their office, etc.

Working atmosphere:

This includes participation in making decisions, fair and impartial superiors who take sufficient time [6], working in groups, mutual assistance (even outside the workplace), etc.

Work experience:

This includes interesting work and the possibility of acquiring knowledge and expertise, on-the-job training, shared responsibilities, etc.

Recognition:

This includes recognition for work well done, opportunities for development and advancement, assignment of more demanding work, etc.

Job satisfaction:

This includes the possibility of planning one's own work, organizational freedom, the freedom to make decisions, etc.

D 3. Measures used against disturbing influences

3.1 General outline

People involved in the building industry are exposed to a host of disturbing influences during the performance of their duties. Efforts are made to eliminate such factors, but since complete success cannot reasonably be expected, some disturbing influences will inevitably lead to downtime, reduced performance, and mistakes (intentional or unintentional).

The measures used against such errors are therefore aimed at reducing the disturbing influences, assessing possible sources of impaired performance, and preventing mistakes (both intentional and unintentional). Section D-4 deals specifically with the latter.

D 3.2 Reducing disturbing influences

D 3.2.1 Disturbing influences, fatigue and stress

Disturbing influences may be subdivided into:

- external disturbing influences,
- internal disturbing influences.

External disturbing influences are a product of the human environment. They include poor lighting, noise, cold and heat, poor ventilation, and so on [35,50,111]. If such factors exceed an individual's personal threshold, they are regarded as disturbing, and lead to various forms of poor performance.

Internal disturbing influences are often the result of external influences, and they take such forms as fatigue, stress and sickness.

People who work and are exposed to external disturbing influences experience a loss of energy, eventually followed by fatigue [35]. One author [50] has established a distinction between biological fatigue, work tiredness, and weariness (figure D-10).

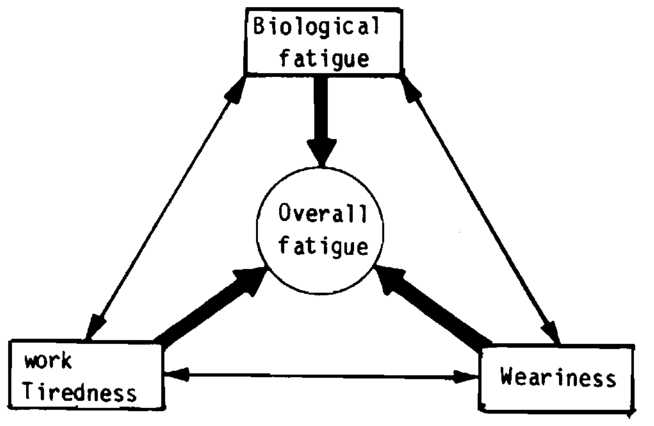


Figure D-10. Forms of fatigue [50].

Biological fatigue is directly influenced by the time of day and people's living habits. Each individual's physiological disposition to work follows a daily rhythm. The higher this is, the lower the rate of poor performance, as has been confirmed both by productivity studies [34,50] and by accident statistics [111] (see figure D-11).

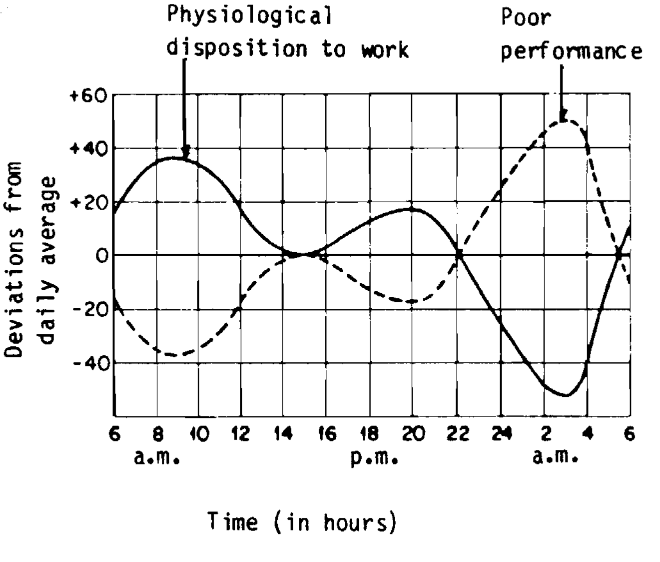


Figure D-11. Daily rhythm of physiological disposition to work and poor performance [34,50,111].

An individual's daily rhythm can be deliberately modified, but this usually requires a period of adaptation. Furthermore, the pattern outlined in figure D-11 simply reflects an average value in Western industrialized countries. In hot climates, the average physiological disposition to work is shifted towards cooler periods of the day.

On the other hand, a person's physiological disposition to work is not entirely transformed into productive work; some of it is required for involuntary functions such as breathing and metabolic processes. Deliberate control of fluctuations in the physiological disposition to work can only operate to a limited extent. There are, of course, some autonomic reserves, but these can only be released during threatening situations, under hypnosis or through drugs (figure D-12).

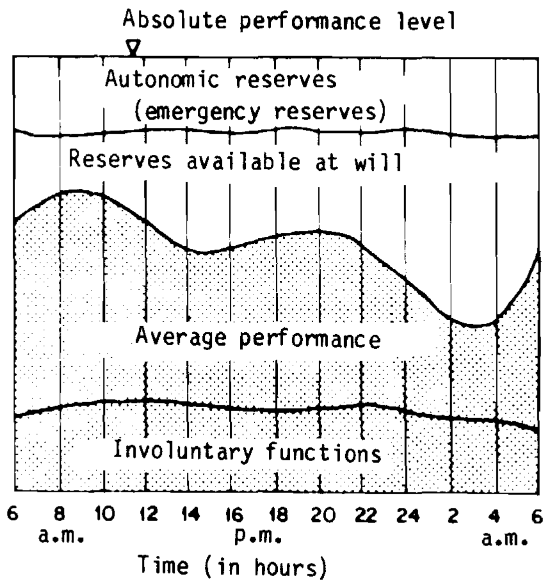


Figure D-12. Human performance levels [34,50].

Work tiredness is the result of previous physical and mental stress. The symptoms are diminishing strength, reduced ability to concentrate, etc., and can be overcome through well-timed rest periods (breaks, days off, vacations) [35].

Weariness is the result of reduced motivation. The symptoms are loss of interest, reluctance, feelings of boredom, etc., and can be overcome by renewed motivation.

Another cause of error is harmful stress [111]. People can be regarded as under stress when they feel overworked. Stress can be caused by time pressures, social pressures, noise, family problems, etc. It can often be overcome through organizational measures and through mental training.

There are measures to overcome both internal and external disturbing influences. They are based on the findings of ergonomics, industrial psychology and behavioural science [35,41,50,89,111], and consist basically of the following:

- organization of workplace;
- organization of work schedule;
- organization of work operations;
- organization of teams.

D 3.2.2 Organization of workplace

Many of the factors which have a disturbing influence on people's work and environment, as well as their performance levels, can be reduced or eliminated if the workplace is organized rationally. The three following principles should be taken into consideration.

First principle: The workplace is adapted to the worker.

This adaptation, which applies both to physical characteristics and to bodily movements, can be achieved through the following steps:

- providing enough space for the work at hand (tunnel construction, scaffolding, excavations, etc.);
- providing equipment and tools that are properly designed in terms of weight, shape, ease of handling, etc.;
- selecting processes that are suited to the people involved.

Second principle: The workplace is arranged in terms of the group members.

The cooperation between several people working in a group is usually intense. A suitable arrangement of work stations is conducive not only to productivity, but also to teamwork, and even team spirit.

Third principle: Disturbing influences are eliminated.

Disturbing influences in the work environment should be eliminated as much as possible. This concerns such areas as lighting, colours, noise, mechanical vibrations, bad odours, etc.

D 3.2.3 Organization of work schedule

Properly scheduled hours of work help minimize both biological fatigue and work tiredness, as well as the resulting lower performance levels. Work scheduling involves the following steps.

a) Working time

Productivity is influenced by the number of hours of work (figure D-13) [35,41]. Fatigue increases with working time, leading to a drop in productivity and a higher frequency of errors. This is confirmed by accident statistics [111].

b) Rest periods

Properly planned rest periods help reduce or overcome fatigue (figure D-13) [35,41].

The following principles should be taken into consideration when planning rest periods [35,41].

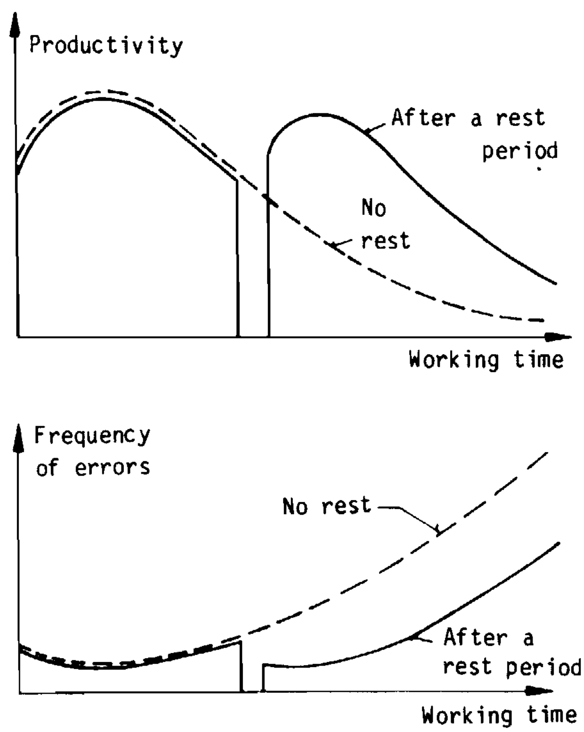


Figure D-13. The dependence of productivity on hours of work and rest periods.

First principle: Several short rest periods are more effective than a few long ones. A relatively high degree of relaxation is reached in the very first part of a rest period (exponential curve). Minibreaks (< 1 minute) and short breaks (1-8 minutes) are therefore especially useful as compared to long rest periods.

Second principle: The frequency of short breaks should increase as the working time grows longer.

If there is only one rest period, it should occur roughly after two thirds of the working period. If there are two scheduled breaks, the second should be longer than the first [111].

Third principle: Heavy physical and mental work requires more frequent breaks.

Fourth principle: Rest periods should be spent in areas not exposed to any disturbance.

Fifth principle: Rest periods should not be spent doing some other job work.

c) Hours of work

Working hours should coincide as much as possible with the highest levels of personal disposition to work (see figure D-11). Whenever people are able to work independently of one another, it should be possible to establish individual working hours. The use of core times helps ensure that people who are allowed to set their hours of work will be available at specific times of the day.

D 3.2.4 Organization of work operations

A number of largely work-oriented disturbing influences such as boredom, lack of work, dissatisfaction, etc. can be overcome by a proper work operations [14,48,120]. The following principles may be helpful.

First principle: Complex tasks are to be subdivided, as much as possible, into simple subtasks that can be done quickly (division of work).

As a result, there should be fewer internal and external disturbing influences, and progress should be more apparent. Tasks should not, however, be subdivided to such an extent that people are forced to work like robots, since their willingness to work might then be sharply reduced.

Second principle: The scope of assignments should be broadened (work extension).

If a number of working operations are combined in one job, people experience more variety. This is especially useful when workers are not able to make use of all their skills in one working operation. One particular application of this principle is the provision of job rotation.

Third principle: Decision and control functions should be broad (work enrichment).

The applications of this principle are aimed at people's "higher" basic needs (see also section D-2.3.1), and help promote willingness to work.

D 3.2.5 Organization of teams

By promoting teamwork in small groups, in accordance with the findings of group dynamics [51], it is possible to improve the willingness to work in addition to reducing or overcoming undesirable stresses [48,120]. The awareness of belonging to a group and the recognition and social support provided by the group are decisive factors in this respect.

People involved in the building industry have a natural tendency to form their own groups, depending on the organization of the building site, office or workshop, etc. The positive aspects of this type of association can be promoted if the group leader is familiar with group dynamics. This may be done through continuing education. Accordingly, the group leader's function is to stress the common objective ("all in the same boat"), to assign work properly within the group, to encourage teamwork through personal efforts, to provide common feelings of accomplishment, and to foster a constant team spirit within the group (even using activities outside normal working hours, e.g. ski days or excursions).

D 3.3 Impaired performance

It is not possible to eliminate all disturbing influences. Weather problems (snow, floods), as well as strikes, sickness and accidents, cause various forms of impaired performance that are more or less unavoidable and severe. Countermeasures are based on questions like the following:

- Where might impaired performance be expected?
- How long could it last?
- How would it make itself felt?
- Which work procedures would be affected?
- How could the problem be minimized or overcome?

There are two possible ways to consider the consequences of unavoidable performance impairment.

a) Subsequent performance

One solution is to accept the problem, and overcome it through subsequent effort. Work delays and disturbances can be prevented through properly planned "buffer periods" and extra shifts.

b) Substitute performance

The use of substitute manpower may compensate for the loss of certain workers. Substitutes may be found among existing workers [14], or help may be sought from other firms, temporary manpower, etc. This is not an adequate solution, however, if substitutes do not have the required skills and information (drawings, work instructions, etc.).

D 3.4 Measures against intentional misbehaviour

D 3.4.1 Modification mechanisms of human behaviour

Intentional misbehaviour takes the form of ignorance, negligence, carelessness (figure D-2), as well as sabotage [58].

Mechanisms related to the modification and strengthening of human behaviour can form the basis for rational efforts to overcome intentional misbehaviour [1,39] (figure D-14).

a) Proper behaviour strengthened

Proper behaviour can be strengthened if the result is experienced as a success by the participant, who is then motivated to maintain proper behaviour, and even improve it. Proper behaviour thus becomes a habit.

b) Proper behaviour weakened

Proper behaviour can be weakened if the result is not experienced as a success, e.g. because of insufficient information or personal disadvantage. This type of behaviour modification is often observed in repetitive work (e.g. in bridge construction using the so-called cyclic work method). Initially, tasks are carried out properly, according to work instructions for example. However, since success is not perceived as a direct result of proper work, behaviour is modified. Important steps are handled with less care, and this soon leads to errors and damage, as is shown by damage analyses [58].

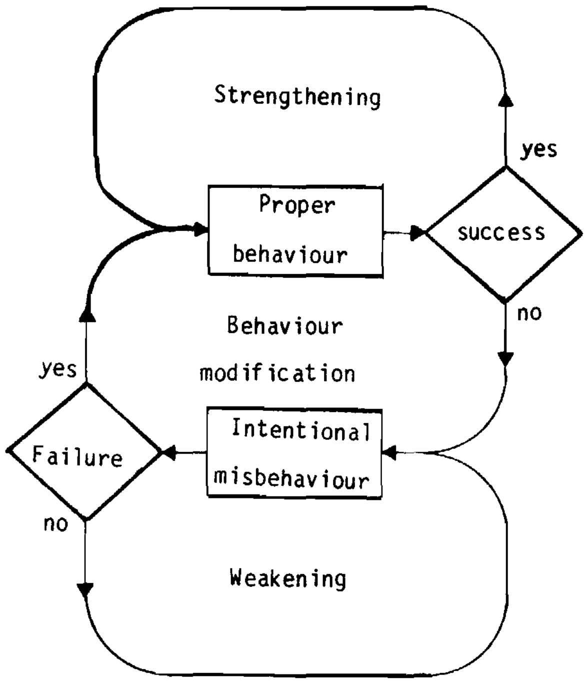


Figure D-14. Modifying human behaviour.

c) Misbehaviour strengthened

Intentional misbehaviour can be strengthened if it does not result in failure (damage), or if it leads to some personal reward (e.g. time saved, work easier). Intentional misbehaviour that provides personal advantages will be preferred to proper behaviour. The participant hopes to perform his or her tasks in spite of improper behaviour, and is confirmed in that attitude by such dubious arguments as "it turned out all right; nothing happened". As a result of this negative confirmation, improper behaviour becomes a habit. A construction worker, for example, might remove safety devices in order to be able to work faster. As long as there is no accident, his behaviour will be confirmed, in spite of the risks, by the advantages of the extra output.

d) Misbehaviour weakened

Intentional misbehaviour can be weakened if it results in failure, i.e. damage, an accident, injury, personal loss, etc. Failure, however, does not always lead to modified behaviour, since the person responsible may blame someone else instead of himself. Before improper behaviour can be modified in a positive way, there must be a feeling of personal responsibility for any failure or risk of failure.

Given these mechanisms for the strengthening or weakening of human behaviour, it is possible to define a number of principles, and design a series of countermeasures based on rewards, penalties, or compulsory steps. If even compulsory steps are insufficient to prevent misbehaviour or its consequences, in cases of sabotage for example, suitable measures must be used to minimize any repercussions. Such measures usually have no impact on people's actions, and are therefore regarded as technical measures applied against disturbing influences (see section B-2.6).

D 3.4.2 Principles against intentional misbehaviour

There is no need to wait for accidents or damage to act as modifiers of intentional misbehaviour before making use of the following principles.

First principle: Proper behaviour should become an acquired habit.

All noticeable disadvantages of proper behaviour, even if they relate only to personal feelings, should be eliminated and replaced by personal rewards. This leads to strengthening of proper behaviour, which in turn becomes an acquired habit.

Second principle: Improper behaviour should be modified each time it is observed.

Whenever improper behaviour is detected, efforts should be made to modify it, through explanations and persuasion, through deliberate provision of personal rewards (e.g. bonuses), and, if need be, by pointing out the consequences. As a last resort, compulsory steps should be established.

D 3.4.3 Measures based on rewards

People and the groups in which they work want to experience success and avoid failure. This need forms the basis for measures in which rewards are used to strengthen proper behaviour. Intentional misbehaviour can be modified by the following reward-oriented steps.

A first step is to focus attention and interest on proper behaviour using all available means, thereby showing that the hope for success is justified [111].

Such interest is not sufficient, however, and individuals must be personally convinced that only the proper behaviour provides lasting success. This can be achieved through such information modes as slide projections and written communications, through the example set by supervisors, as well as through discussions, instructive tests, etc.

Proper behaviour must then be strengthened by rewards, such as direct news about the successful completion of a job or the effectiveness of a safety measure, a bonus [5] or other recognition. Finally, all forms of weakening of proper behaviour must be avoided through constant vigilance.

Reward-oriented measures are not only effective against improper behaviour, but also make a substantial contribution to job satisfaction, since they are related to people's "higher" basic needs (e.g. recognition) (figure D-6).

D 3.4.4 Measures based on penalties

Penalty-oriented measures are based on the fact that people, as well as the groups in which they work, are afraid of unpleasant penalties. Such measures, basically, are aimed at arousing this type of fear, rather than producing the penalties themselves. Intentional misbehaviour can be modified by the following penalty-oriented steps.

A consistent pattern of penalties should be established, including, for example, fines, personal responsibility for costs, loss of privileges, transfer, dismissal, etc.

The threatened penalties must be clearly spelled out. It is often sufficient to advise a person verbally of the penalties of some form of improper behaviour. If there is no change, it may be advisable to lay out the penalties in writing.

If there is still no change in spite of clear, repeated warnings, the penalties must follow directly. This is important not only to ensure that violations are punished, but also to maintain credibility and confirm the warning for other people.

Penalty-oriented measures are often used with success in practice. However, they contribute little to job satisfaction, since they are aimed at people's "lower" basic needs (e.g. security and social needs) (figure D-6).

D 3.4.5 Compulsory measures

Whenever countermeasures based on rewards and penalties are insufficient, or greater risks are involved, intentional misbehaviour must be prevented through compulsory steps. These are basically technical operations which allow only the proper function to be carried out, or else trigger some locking mechanism as soon as improper handling occurs.

Such technical mechanisms include barriers, shields, screens, etc., which only allow the proper function to be carried out, as well as switches, safeguards, emergency devices, locks and brakes, which block the function and prevent further risk, e.g. by jamming a lifting device when design loads are exceeded.

D 4. Measures against unintentional misbehaviour

D 4.1 General outline

Even when suitable people are working in a suitable place, and disturbing influences have been overcome, there remains the possibility of improper behaviour that is not deliberately willed. People can avoid such behaviour by performing their tasks in a systematic way, and by making an intentional effort to improve their basic activities (figure D-1).

D 4.2 Assuring the basic activities

D 4.2.1 Principles of a systematic approach

The following principles help provide a systematic approach to the performance of various tasks.

First principle: The circumstances should be known.

A task, considered here as an assignment, a goal to be reached, involves an objective as well as an initial situation. A person facing an assignment must be aware of all the relevant circumstances and sift out the key facts before the search for solutions can begin.

Second principle: Adequate solutions must be found.

The most important facts must be further examined, and new relationships ascertained. The result is a synthesis [16]. This synthesis is aimed at finding solutions to the problem at hand. The search for solutions is based on experience, thinking, and intuition.

Third principle: Decisions are prepared and made carefully.

There are usually a number of solutions for any given problem. The decision process is aimed at adopting one final solution.

Fourth principle: The selected solution is implemented.

There are various ways of implementing the adopted solution. It is therefore important to keep in mind the planned procedure and the anticipated conditions, so as to correct any deviations that may occur.

There are various techniques and aids which promote a systematic approach. The following sections describe further principles and techniques which help find adequate solutions (second principle) and reach sound decisions (third principle).

D 4.2.2 Using available solutions

There are reliable solutions for many of the problems in the building industry. And yet, new solutions are often sought for problems which are more or less familiar, and for which a solution has already been found [21]. For each assignment, therefore, it is important to determine whether reliable solutions already exist. With the exception of solutions to routine tasks, many existing solutions are readily available in such documents as books, journals, guidelines, standards, etc. Companies often have their own documents in the form of reports, samples, examples and completed projects. One particular problem in this respect is the availability of documents, which must be ensured internally through suitable measures (see also section D-2.5.4). Another source that is often very useful is the material personally acquired by people during their studies or training, or through continuing education, as well as through their own experience (see section D-2.5.3).

The search for existing solutions can be made a lot easier if standard solutions are worked out, with special reference to problems that are encountered frequently. Tables, standard plans and standard calculations are some examples.

D 4.2.3 Principles related to thought processes

The search for solutions can be made easier by following certain principles [13]:

First principle: A problem is considered from several points of view.

If a problem is tackled from a single viewpoint, it will be difficult to avoid an incomplete or inadequate solution. A multidimensional solution is one that is reached through an open-minded, unbiased exchange of ideas, in group discussions for example (see section D-4.2.4 on brainstorming).

Second principle: It is important not to be sidetracked by self-invented conditions.

Improper solutions are often reached because of the sudden introduction of arguments which are really not required. In essence, thought processes should be based only on clearly identifiable and well-defined conditions.

Third principle: The alienation effect should be put to good use.

The so-called alienation effect prevents people from getting into a "rut".

It can be used in various way:

- standing back to look at the situation from a detached vantage point;
- establishing analogies;
- alternating more frequently between abstraction and concrete facts;
- visualizing ideas;
- reversing relationships.

Fourth principle: Postponing of judgment.

Hasty judgment often prevents the proper development of a good concept. Derogatory remarks, such as "That is too complicated, that is not our problem", can also block the progress of good ideas ("idea killers" [36]). It is therefore a good idea to:

- avoid hasty judgments ("sleep on it");
- avoid derogatory remarks;
- look at ideas from as many perspectives as possible.

D 4.2.4 Creative techniques

The search for solutions can make good use of so-called creative techniques. According to one author [16], creative techniques make use of special principles and rules to foster creativity and the development of ideas. They are applied in particular to situations in which a problem has no known solution. Such techniques can be divided into two groups [13,16]:

- techniques based on intuition (brainstorming, synectics, etc.);
- techniques in which systematic thought patterns are given priority (analogy, morphology, etc.).

A few of these techniques [13,16,36,42,123] are described in the following paragraphs.

a) Brainstorming

Brainstorming is a group activity which is carried out according to definite principles in an effort to elicit ideas, insights, and possible solutions to a given problem. People who might help solve a problem, in view of their knowledge or experience, are invited to attend a meeting at which the problem is clearly formulated. The meeting is headed by a leader, and the proceedings are carefully recorded. Unlike many other discussion formats, brainstorming encourages an exchange of ideas that is spontaneous and largely free of constraints. In order to avoid personal or psychological inhibitions, the participants are asked to adhere to a number of principles. The major principles, which correspond to findings of group dynamics, are as follows:

- as many ideas as possible should be expressed, but not evaluated;
- statements should be kept short;
- only positive statements are permitted, so as not to inhibit anyone's imagination (word "but" is forbidden);
- the participants are encouraged to pursue exotic ideas;
- the meetings last at least 20 minutes, but not more than one hour.

b) Modified forms of brainstorming

Different authors have modified brainstorming in a variety of ways. As a result, such methods as the Little Technique, Phillips 66, the Trigger technique, Method 635, and Delphi have been introduced. A review of these and other techniques will be found in the literature [13].

c) Synectics

This is a method which uses certain analogies to foster creativity among the participants within the framework of a new idea. The method is based on the principle that creativity is more a matter of emotions, and less of rational thought. As in brainstorming, the problem is outlined to a group of people, who then seek analogies which are analyzed. The analogies are then applied to the original problem in a effort to find a practical solution [13,36,42].

d) Morphological box

This method is aimed at the systematic study of the relations between individual parameters [36,42,123]. Depending on the number of axes for the arrangement of parameters, various multidimensional relationships are produced. In practice, the relations between parameters are usually studied in a two-dimensional matrix. The matrix representation makes it necessary to consider all the combinations systematically. Premature interruption of the process is of course possible, but it is hindered by a systematic strategy.

The method involves the following steps:

- the problem is described;
- independent parameters related to the problem are identified, and arranged according to axes in two or more dimensions;
- the relations between the various parameters are investigated;
- the associations suggested by the method are analyzed.

D 4.2.5 Preparation for decision-making

Possible solutions are assessed on the basis of such factors as personal conviction, financial and political considerations, etc., and the decision process is prepared. There are countless factors, some of which are inevitably overlooked. The final decision is based only on those factors which were taken into account, and which form the so-called basis for decision [90]. A decision is only as good as the corresponding basis for that decision. In this sense, a decision may be logically consistent in terms of the actual objective, but nevertheless wrong. It is therefore important that the widest possible basis for a decision be established, using decisive factors and the criteria which help measure those factors [90], as well as suitable means of assessing the criteria.

Depending on the problem under consideration, there are a number of techniques for decision-making, including decision trees, investment planning, economic analysis, cost-benefit analysis, linear optimization, game theories, etc. Further information about these methods can be found in the literature [13,15,16,43,71,96].

D 4.2.6 <u>Principles for decision-making</u>

After a decision is made the details of a given solution are worked out and, the solution is implemented. In the building industry, the decision to adopt a solution and the decision to implement it are often made simultaneously; we will therefore not lay more emphasis on this basic distinction.

As a rule, assignments are in fact subassignments of overall tasks within a hierarchy. For this reason, a decision should only be made once higher items in the hierarchy have themselves been decided. This is not always the case, however, and there are examples of assignments that were decided and implemented although the overall task had not yet been decided. Errors which may result from such occurrences can be avoided with the help of the following principles.

<u>First principle</u>: Decisions should always be made according to a hierarchical pattern.

A decision should only be made once the decision on the "level above" has been established.

<u>Second principle</u>: It is important to adhere to higher level decisions.

Decisions reached at a lower level should not produce any change in decisions reached at a higher level.

<u>Third principle</u>: Decisions should be clearly stated.

Ambiguous decisions can lead to misunderstandings, especially among the participants at the lower levels of the hierarchy. It is therefore essential that decisions be formulated in such a way that they are correctly understood by the people concerned.

D 4.3 Improving basic activities

In spite of a systematic approach in carrying out assignments (see section D-4.2.1), the risk of unintentional misbehaviour remains. This is due to errors committed by people themselves, as a result of distraction, misinterpretation, forgetfulness, oversight, uncoordinated movements, and so on. Such errors can be overcome if certain principles and aids are put to good use. These help improve behaviour, including basic activities (figure D-1). In cases where unintentional misbehaviour may have grave consequences, it is necessary, just as for intentional misbehaviour, to use compulsory and technical countermeasures (see sections D-3.4.1 and D-3.4.5).

D 4.3.1 Improving vigilance

People have limited perceptual ability [50,89]. Perception is a biological function, and human sense organs (receptors) are able to perceive only specific stimulations within a limited range. Furthermore, perception depends on the degree of vigilance, and the latter can be sharply reduced by certain factors.

The selection of suitable people is one way of meeting the biological requirement for good perception, so we will focus on vigilance. One study has shown that one third of traffic accidents are due to lack of vigilance [18]. In the building industry, lack of vigilance is also responsible for many design errors, construction errors, failures, accidents, etc. The use of the following principles and aids may improve vigilance.

First principle: External stimulation should be strengthened.

Relatively simple aids may be used to render key factors so conspicuous that they will be less easily overlooked. Examples of this are underlined or framed results of calculations, colour-coded switches, standard signals for crane operations and flashing lights to indicate hazardous or unusual shipments. etc.

Second principle: Several sense organs should be activated.

The activation of several sense organs such as sight, hearing and feeling leads to a correspondingly higher perceptual redundance [98]. Verbal information might be supplemented by pictures or sketches, for example, and optical signals might be coupled with acoustic signals.

Third principle: Perceptual distortion should be avoided.

Actual circumstances can be perceived in a distorted way because of some distracting interest, experience, need, attitude, feeling or emotion ("things are often perceived as we would prefer or desire them to be"). This type of distortion can be overcome through increased concentration for facts, repeated perception, suppression of feelings and emotions, etc.

Fourth principle: Distraction should be avoided.

Disturbances and too much information can lead to distraction in terms of basic operations. Distraction may be overcome through partitioning and design of the workplace, and by making sure that information is structured and relevant.

D 4.3.2 Avoiding misinterpretations

Information that is properly transmitted and received (see part C) can nevertheless be misinterpreted. Two principles can help overcome this problem.

First principle: All information that is received should be considered in terms of its actual content (the "what for and why" principle).

Errors in interpretation can only be detected if relationships are scrutinized. Asking "what for and why?" and looking for meaningful answers is also helpful. If relationships are not directly evident, further questions, and even systematic analyses, may be needed [13,16,71].

Second principle: It is important to ask questions in order to eliminate ambiguities, confusion, etc. (the "question" principle).

Questions and enquiries are used to overcome uncertainties. Important information, major gaps and key factors are often identified only as a result of some "silly" question. Questions and answers help describe situations with greater precision, and thus prevent misinterpretations.

D 4.3.3 Activation of memory

The ability to store perceived facts and recall them at will is called memory. A distinction can be made between three types of human memory [7,115].

a) Very-short-term memory (immediate memory)

In this type of memory, information is stored up to 20 seconds. The transition from immediate to short-term memory resembles a filter which provides protection against excessive information loads.

b) Short-term memory

In this case, information is stored up to 20 minutes. If the information is not further processed (coded), it will be lost.

c) Long-term memory

Here, only coded information is stored and maintained.

When using the word "forget", we should always consider the type of memory involved. In both very-short-term and short-term memory, the information is lost irretrievably. In the case of long-term memory, the information is retained, although under certain circumstances a person might not be able to recall it. The major causes of forgetting are the following:

Disuse

The more rarely information is used, the more likely it is to be forgotten. This is especially true for immediate and short-term memory.

Interference

New information is added to already stored information. Remembering new information may be hampered by already stored information, and vice versa.

Repression

People seek a certain equilibrium. Unpleasant information interferes with that equilibrium, and tends to be repressed. A typical example is provided by the behaviour of people who drive past an automobile accident. At first, as they become aware of what has happened, they slow down. The experience is soon repressed from their short-term memory, however, and they resume normal speed.

Blockage

At certain times, it may not be possible to recall stored information (e.g. during an exam). Access to the information may be blocked by a variety of factors (stress, a fixed idea, tiredness, etc.).

Given the three types of memory, and the causes of forgetting, a number of memory-activating principles can be formulated.

First principle: The capacity of immediate memory has to be taken into account.

Given the limited capacity of immediate memory, information should be well structured, and transmitted in small amounts (e.g. short sentences, proper intervals, etc.). This helps shift information into short-term memory.

Second principle: Information has to be repeated.

Items (e.g. messages, discussion points, questions, etc.) that are repeated are less likely to fade away.

Third principle: Possible interference of information has to be taken into account.

New information should be communicated in such a way that it is found interesting, and is not confused with already stored information.

Fourth principle: Multiple combinations of information modes are used.

Multiple combinations of information modes (pictures, sounds, logic, rewriting, etc.) promote transfer to long-term memory, and improve recollection.

Fifth principle: Blockage can be overcome.

A relaxed atmosphere helps reduce the stress that causes memory blocks. These can also be overcome after a rest period or a shift to a different type of work. Making a fresh start is often the answer. A typical example is provided by a long, frustrating attempt to find a bug in a computer program. After a "mental break" (overnight, or different work), the error can often be detected in no time.

The application of the above principles can be made easier by memory training [117] and by memory aids such as lists, drawings, books and checklists. Many of these aids have been described in parts B and C. The use of checklists is particularly useful, and for certain tasks they provide direct memory support. This is especially true of procedures which involve a very specific sequence. It is difficult to dissociate aeronautics, for example, from the use of checklists.

"Memory errors" occur while assignments are being carried out, but they might also cause an entire task to be overlooked. This can be avoided if all assignments are entered in appointment books, schedules, office charts, lists, etc. Charts and lists are especially helpful, since assignments can be entered even if the person involved is absent. Furthermore, completed assignments can be readily checked off.

D 4.3.4 Avoiding mistakes

Bits of information that have been memorized are recalled and associations are established between them. This mental process can lead to mistakes and mix-ups, as a result of some physiological obstruction or distraction of the thought activity. Such involuntary breaks in the thought process may crop up suddenly as a result of the demands made on people. Prolonged strenuous demands lead to correspondingly long and frequent mental breaks, which in turn lead to more frequent errors [35,85].

Distraction or lack of concentration are another causes of mistakes. The following principles help reduce or eliminate mistakes.

First principle: It is important to concentrate.

Reduced concentration leads to errors for which no explanation can later be found. In a calculation, for example, a number may be left out, or the wrong figures may be entered. If many such errors are detected, the job should be interrupted, and a change made to less demanding work (see figure D-13).

Second principle: Stress should be avoided.

Stressful situations cause impaired thinking, mental jumps, etc. This is usually due to time constraints and overwork. Autosuggestion (e.g. "we have enough time to do a proper job") may often reduce this type of stress.

Third principle: Periods of mental rest should be provided.

Careful planning of timely rest periods will help reduce the number and frequency of mental blocks.

Fourth principle: Thought processes should be repeated.

Repeating a thought process will often help detect an error in logic. In addition to mistakes in thinking, mistakes in execution may also be discovered. Such mistakes or oversights are the result of poorly controlled operations (writing 24 instead of 42 for example).

Fifth principle: Self-control is an important factor.

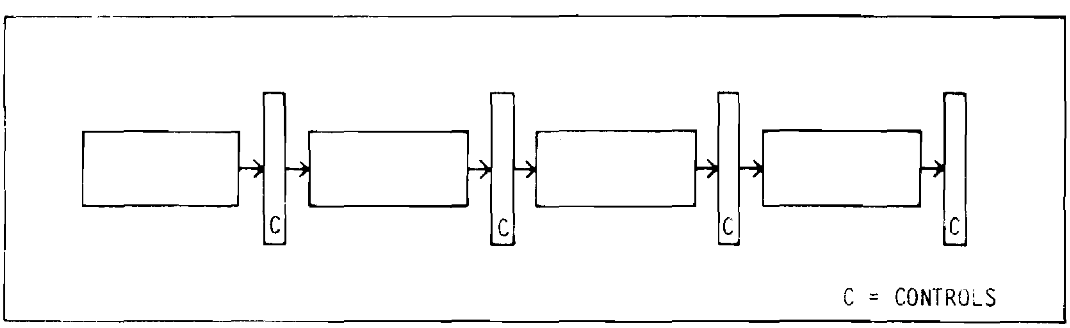
Although controls are dealt with separately in part E, it is useful here to point out that self-control is one of the most important elements of human behaviour. Self-control not only plays a passive role as a means of detecting errors, but also plays an active role as a means of direct control over thought processes.

D 4.3.5 Coordination of movements

In the final analysis, the execution of a task depends on purely manual operations. According to the type of work, more or less dexterity is needed. Between the control function of the brain and the exercise of muscular power, there is room for interference and mishandling. In fact, even such well-known exercises as writing are often performed poorly. In many cases, this can be overcome by training and proper coordination. Whenever lack of coordination may lead directly to personal injury or property damage, as in the operation of elevators, machines or other equipment, training is particularly important.

PART E

DETECTION OF ERRORS THROUGH CONTROLS, AND CORRECTION OF ERRORS



E 1. Overview

Parts B, C and D of the present study were concerned with measures aimed at the prevention or reduction of errors. Since, however, the complete elimination of errors is not always possible, or feasible - on the basis of cost for example (see section A-3.3), it is essential to ensure the timely detection of any errors that may occur, and to overcome them through correction. That is precisely the subject of this final part of the study. Like the rest of this study, Part E is basically error-oriented; it investigates possibilities for checking against possible errors without raising the question of responsibility for checking and correction, nor the problem of the effectiveness of various measures. Nor can we indicate here which combination of error-preventing measures and checking procedures will represent the best management strategy in a given situation.

Control and correction are indeed essential procedures in any management function. In this respect, control functions are much less a matter of verifying that individuals carry out their duties, than of ensuring that the various task groups and their relations are stable and functional. The verb "control" implies in fact the power to direct or regulate and the ability to use effectively. Our purpose here is not to elaborate on this basic concept, but to describe the timely detection of errors within the overall building process.

In terms of the definition indicated above, controls are usually effective as well as economical. Errors that are detected in documents, materials, components, etc. can usually be overcome with minimum effort. Much more serious consequences or damages can thereby be avoided, as is confirmed by damage analyses. According to one study [58], for example, roughly 85% of the cases of property damage and 90% of the cases of personal injury could have been avoided through timely checks followed by corrective procedures (fig. E-1).

Controls are now used extensively in the building process. However, they only reach some of the truly critical points, and, in part for historical reasons, they are largely unsystematic and limited to individual phases (e.g. concrete testing, design calculations). What is needed is a much more systematic application of suitable controls, aimed at the critical points in the building process, and consisting of two steps:

- planning controls with a control plan that includes instructions and checklists;
- implementing controls or corrections on the basis of suitable principles and methods.

		as a percentage...			
		...of the 493 failures	...of the total damage for those 493 failures	...of the 35 failures involving injury	...of the 38 failures involving death
Additional controls in	Planning and design	33	32	23	21
	Construction	17	9	10	17
	Utilization	5	18	7	6
Timely detection of errors impossible		13	15	9	11
Detection of errors possible without additional controls		32	26	51	45
	Total %	100	100	100	100

Figure E-1. Breakdown of 493 failures according to effectiveness of additional error control [58].

Section E-2 deals with specific control criteria and principles, as well as the overall procedure for planning and implementing control and correction, including such methods as control plans, instructions, checklists, control and correction records and reports. Section E-3 deals with control and correction, including specific methods used in the planning, design, construction and utilization phases.

E 2. General procedure of control and corrections

E 2.1 Preliminary remarks

E 2.1.1 The term "control"*

Controls involve three activities:

- identifying actual conditions;
- comparing actual conditions with assumed conditions;
- assessing any discrepancies.

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* Translator's note. The term "checking" would often be used in English but "control" was generally retained in the translation. See E 1.

The identification of actual conditions is carried out at a specific time, and is limited to a few main characteristics that can usually be measured. The actual conditions so identified are compared with previously defined assumed conditions. This type of comparison usually reveals certain discrepancies, which are assessed on the basis of permissible or allowable deviations within fixed tolerance limits. When the discrepancies exceed the stated tolerance limits, the term error is used. Errors are overcome through corrective measures. As a rule, the reasons for such errors are also eliminated, so as to avoid recurrences.

The effectiveness of even highly efficient controls is not without limitations. In fact,

- the identification of actual conditions can only be carried out at certain times, and does not cover all characteristics;
- not all characteristics can be compared with assumed conditions;
- controls reveal errors which often can only be overcome at great expense;
- controls themselves are a procedure which is subject to error.

As a result, controls are practical only if an error can be readily identified using a few characteristics at the right time, and if it can be overcome at a low cost [63,64,65].

E 2.1.2 Time factor and characteristics checked

On the basis of the time factor, it is possible to distinguish three types of controls (fig. E-2):

- initial controls,
- intermediate controls,
- final controls.

Initial controls are used to detect errors which may be present in the initial situation. It is important, for example, to check materials, equipment, environmental conditions, etc.

Intermediate controls are used to detect errors which may occur during individual activities. It is important, for example, to check intermediate results of calculations, environmental factors, or the consistency of concrete.

Final controls are normally used to provide confirmation that planned conditions or objectives have been achieved. Accordingly, they deal with the end results of procedures or completed assignments.

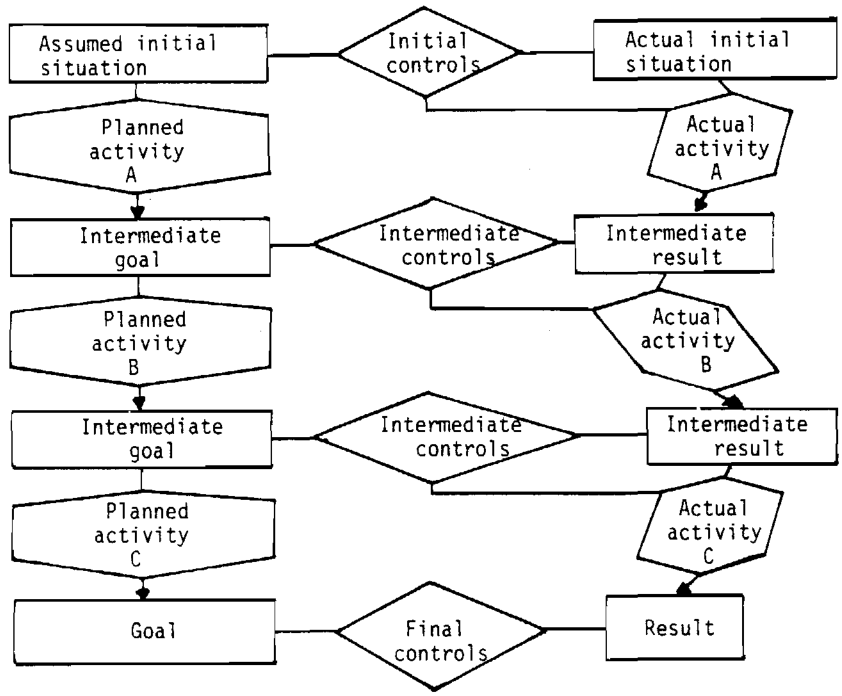

Figure E-2. Initial, intermediate and final controls.

Final controls are usually sufficient. Initial and intermediate controls must be provided, however, whenever errors might lead directly to failure, or might no longer be readily detected or overcome at a later time. These controls are aimed at such factors as people, materials, tools, methods and environmental conditions and their various components. In this respect, it is important to determine which controls are most effective for a given set of components and characteristics. This varies with each process and building phase.

E 2.1.3 Responsible people and authorities

Once the time factor and the characteristics have been established, it is necessary to appoint individuals or responsible bodies to carry out the controls. It is possible to distinguish the following categories of controls:

- self controls,
- in-house controls,
- controls by the people involved in the building process,
- controls by other authorities.

a) Self controls

Self controls form the basis for all quality assurance. They help discover errors at the personal level, and involve each and every participant. Experience shows that self controls provide the earliest possible detection of most errors, usually requiring the least costly corrective steps. It is a fact that the self controls now used in many areas are inadequate and not very effective, because they are not applied consistently. The general approach which states that "everyone bears the responsibility of error-free work and therefore of personal vigilance" is not enough. It also takes knowledge and expertise to use self controls effectively. Deliberate procedures must be integrated within the work itself [83].

In addition to the detection of errors, self controls affect the behaviour of participants. Their work is enhanced, and the awareness of quality is heightened [120].

b) In-house controls

Self controls do not cover all errors. Individuals are often caught up in their work or its results, and often fall into incorrect thought patterns and improper procedures. Furthermore, the individual himself is not aware of all relevant factors. In addition, a job often involves several people. There is then a need for in-house controls. These can be carried out by colleagues, supervisors, or at some other level internally. The provision of several levels of control, however, will only improve the probability of error detection if they are truly independent of one another [63,65,86]. In practice, controls are often interdependent, and the people involved often have the same training and experience as those whose work they are checking, and use the same basic documents. Besides, people who know that their work will be checked might be tempted to rely on that fact [86], and neglect self controls.

On the other hand, in-house controls also have a beneficial effect on the behaviour of individuals, since people who know that their work will be checked by others might be prompted to do a good job (see section D-3.4.4 which deals with countermeasures based on consequences).

c) Controls by the people involved in the building process

Experience has shown [58] that self and in-house controls cannot eliminate errors entirely. However, many of the errors which slip through can be detected, even without adding another level of controls, if the people involved in the building process remain alert and follow proper procedures according to their position in the hierarchy, from architects to engineers to contractors, etc. [58] (fig. E-3). However, this requires a psychologically favourable climate for the reporting of errors, based not on a spirit of incrimination, but of joint efforts towards a common goal, i.e. building a sound structure while avoiding personal injury and property damage. Special emphasis must be placed on this important aspect.

Possibility of timely error detection		as a percentage... ...of the 493 failures	...of the total damage for those 493 failures	...of the 35 failures involving injury	...of the 38 failures involving death
	Engineer - Contractor - Project representative	11	10	14	16
	Contractor - Project representative or Engineer - Project representative	15	13	38	28
	Architect - Contractor - Project representative	6	1	0	0
	Other combinations	6	5	2	0
	Next person absent	13	18	9	11
	Error detection improbable	49	53	37	45
	Total %	100	100	100	100

Figure E-3. Breakdown of 493 failures according to damage characteristics and the possibility of effective error detection by the people involved in the building process. The error of the first named participant could have been detected by the next person in the sequences of the building process [58].

Among the participants, those people who hold leading positions play a particularly influential role in the detection of errors. They support teamwork especially at the interface between participants, and strive to promote a spirit of positive cooperation. They also assume responsibility for quality control and work supervision. In particular, they check the instructions laid down in relevant quality standards, and they supervise the acceptance control of parts or all of the completed building.

d) Controls by other authorities

Depending on the complexity of the building process, other controls are carried out by one or more independent authorities. Depending on the country, these may be required by law, standards, guidelines, building permit procedures, insurance companies, etc., or they may be necessary because of the nature of the project [25]. In the case of particularly difficult projects, or of structures whose failure would have particularly negative repercussions, the intervention of independent levels of control is a must.

E 2.1.4 Control principles

The planning and execution of control procedures is based on four principles. The first three principles deal with the three basic types of errors, while the fourth is concerned with other factors. Processes and their outcome are subject to error if:

- they are missing,
- they are wrong,
- they are insufficient.

Figure E-4 indicates the percentage distribution of these types of error, based on a particular study [58].

		as a percentage... ...of the 493 failures	...of the total damage for those 493 failures	...of the 35 failures involving injury	...of the 38 failures involving death
Unfavourable influence	not taken into consideration	35	46	41	42
	wrong consideration	41	43	57	50
	insufficient consideration	24	11	2	8
	Total %	100	100	100	100

Figure E-4. Breakdown of 493 failures according to whether the unfavourable influence (type of error) was considered [58].

It is possible to distinguish four control procedures on the basis of the four principles outlined below.

First principle: Available information should be checked for completeness ("completeness principle").

Information such as plans, drawings, influences, building components, etc. should be checked for completeness before their correctness and reliability is ascertained. The purpose of this procedure is to identify any missing items. Without it, controls would only deal with facts available, and could get bogged down in details.

Second principle: Available information should be checked for correctness ("correctness principle").

The application of this principle should lead to the discovery of incorrect or unreliable circumstances. The controls in this case are detailed, and they determine whether the circumstances to be checked are reliable and correct, or incorrect, on the basis of available control documentation.

Third principle: Actual circumstances should be entirely verified independently of any previous controls ("principle of independent overall control").

Once the circumstances have been checked basically in terms of completeness and correctness, and are known in detail, a final, independent, overall check allows possible "gaps", "weak points" or "critical points" to be detected. This principle has also been described in terms of "taking a step back [90] to look at relevant circumstances". This type of detached look at actual circumstances, without reference to the available control documentation, makes it possible to get an overall picture, and to zero in on critical points or circumstances that may not otherwise be considered. This principle involves such questions as "is that actually the case?", "is that really all of it?", "has every factor really been taken into account?", etc.

Fourth principle: The feedback from actual circumstances should be assessed in terms of the building process ("feedback principle").

Although actual circumstances might be declared error-free on the basis of previous control procedures, their integration within the building process at various interfaces might result in error. For this reason, it is important to check relationships and interface situations, and to assess any impact the circumstances under consideration may have on the technical procedures of the building process, areas of responsibilities and duties, the flow of information, cooperation, and the participants. This principle has also been described in terms of "taking a step back [90] in the building process". A detached look at interconnecting areas can indeed result in improvements at individual points in the building process (see also sections A-6.1 and E-2.3.3).

E 2.1.5 Methods of control

Control and correction procedures, as they are planned and carried out, are themselves subject to error. For this reason, it is important not only to carry out the control and correction procedures, but also to use appropriate methods for the procedures themselves, so as to ensure:

- error-free control procedures,
- clear areas of responsibilities and duties,
- proper reporting of discrepancies and errors, as well as the assignment of qualified people.

Suitable methods include control plans, control instructions and checklists, as well as control and correction procedures, reports, and instructions for corrective steps. The following sections provide a more detailed description of the methods used to plan and carry out control and correction procedures.

E 2.2. Planning of control and correction procedures

E 2.2.1 Control plan

A control plan (proof plan [20]) provides full details about proposed controls. It indicates what controls will be carried out by whom, how, and when. There are control plans for the building process as a whole, as well as for individual phases and activities. The following steps are required:

- analyzing work operations and procedures;
- establishing suitable control times or so-called control stops [107];
- determining the components to be checked (results, materials, machines, documents, environmental influences, people) as well as the relevant characteristics;
- assigning a person to be responsible for controls;
- setting tolerance limits and establishing a procedure for cases of discrepancy.

The degree of detail of a control plan depends on the procedures that are to be checked, as well as the available manpower. In the case of simple structures, the control plan for the building process as a whole can be very simple, indicating only the most important control times (fig. E-5).

Control schedule	Control program	Responsibility
Before planning and design begin	Qualifications of experts called in; their awareness of the owner's intentions; their knowledge of the boundary conditions of their work.	Project manager
Before the project is authorized	Completeness and technical correctness of the project in accordance with the relevant standards, guidelines, regulations, etc.; compliance with boundary conditions.	Engineering dept. Project manager Building authorities Other control bodies
Before the construction work is assigned	Qualifications of contractors and suppliers; knowledge of major details of the project; awareness of the conditions of their work.	Project manager
Before construction begins	Construction programs and schedules; proposed building processes.	Project manager Contractor
Before the foundations are laid	Characteristics of the construction site.	Engineer Specialist
Before materials are used	Properties of materials.	Supplier Contractor Site supervisor
Special operations	Excavation, erection procedures, etc.	Contractor Site supervisor
Before takeover of parts or all of the project	Dimensional data, materials quality (e.g. inspection of reinforcements).	Owner Site supervisor Engineer Contractor
Before delivery	Regulations regarding utilization and maintenance (utilization manual)	Owner Project manager
During utilization	Periodical inspection and maintenance	Occupants Specialists

Figure E-5. Basic control schedule in a building process [107].

For complex building processes, figure E-5 can be used as a basic program and checklist for the preparation of detailed control plans which cover individual phases of the building process.

In any case, control plans normally contain only the most important information. Details are often laid down in existing standards, guidelines, etc. If such is not the case, control procedures must be described in detailed instructions.

E 2.2.2 Control instructions

Control instructions provide a detailed description of the relevant procedure. Depending on the type of controls and their importance, the instructions can be given verbally or in writing. In the case of major controls, however, written instructions are invariably used. Written instructions should follow the model outlined below.

a) Identifying the actual conditions

The following information is needed to identify the actual conditions:

- the person responsible for controls (who);
- the location or site (where);
- the object of the controls (what);
- the time of the controls (when), as well as the time intervals and the conditions (environment, work progress) under which the controls can or must be carried out;
- the procedure to be followed (how), including:
  * visual controls and comparisons with plans, models, experience, etc.;
  * controls using measurements of individual parameters and comparisons with theoretical values;
  * controls using special testing procedures;
  * scope of the controls (how much), e.g. all components, selected samples, etc.;
  * the various steps in the control procedure should, as much as possible, be spelled out in the form of a checklist.
- the equipment and the documentation (what with), including devices, instruments, etc.

b) Assumed situation and assessment

The following information is needed to compare the actual situation with the assumed situations, and assess any discrepancies:

- the assumed values of parameters and permissible or acceptable variations;
- the rules according to which the actual, observed data (mean values, standard deviations) are to be used in order to assess the situation under consideration.

c) Conclusions

It is important to indicate the consequences of any discrepancies, and to specify what should be done with control results. The following information is needed for this purpose:

- the consequences for further operations, e.g.:
  * stop operations;
  * continue operations under certain restrictions;
- the scope of corrective measures that may be required;
- the impact on:
  * technical operations;
  * areas of responsibilities and duties;
  * information flow;
  * teamwork;
  * participants;
- the method of reporting control results, e.g. verbally, records, reports, recipients.

E 2.2.3 Checklists

Checklists describe individual control procedures, step by step, using keywords, short phrases and questions. They make it easier to implement controls, and also help ensure accuracy and completeness. For this reason, anyone involved in controls should use checklists as much as possible, and, if need be, should take part personally in the preparation of suitable checklists. That is the only way to ensure that all criteria and relationships are taken into consideration. In the case of procedures that are used frequently, it is a good idea to have checklists printed in advance, so that they can be simply checked off. There are two types of checklists in terms of content:

- closed checklists,
- open checklists.

Closed checklists are used for controls having a distinct, clearly defined content, e.g. checking the dimensions of building components or the individual steps of a process. When closed checklists are used, controls usually deal only with the strict content of the checklist.

Whenever the influences and circumstances to be checked cannot be brought completely together in a checklist, additional influences and personal judgment must be brought into play. For this reason, the corresponding checklists are called open checklists. To maintain the overall function of such checklists, questions are kept as short as possible. Keywords, sometimes with question marks, are often sufficient to trigger the proper check.

CHECKLIST
REINFORCEMENT IN FORMWORK

1. PREPARATION
   - Documents available?
   - Up-to-date?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS
   - Reinforcement in place?
   - All areas reinforced?

   FOR CORRECTNESS
   With respect to the structure
   - Steel grades
   - Diameters
   - Number, spacing
   - Vertical position
   - Horizontal position
   - Length of bars
   - Bending of bars
   - Anchor lengths
   - Joints
   - Connecting bars
   - Spacers
   - Erection reinforcement
   - Concrete covering
   - Handling reinforcement (prefab)
   - Suspended components

   With respect to structural detailing
   - Adequate supports
   - Brackets and corbels
   - Column capitals (flat slab floor)
   - Surfaces of construction joints
   - Recesses, openings
   - Fixtures, installations
   - Splicing
   - Special reinforcement in corners of two-way slabs
   - Crossing of reinforcement
   - Top reinforcement in position
   - Joint detailing
   - Gaps for vibrator
   - Conduits
   - Possibilities of confusion in placing

   FOR INDEPEDENT OVERALL CHECKING FOR
   - Critical points?
   - Influences?
   - Additional circumstances?

3. FEEDBACK TO:
   - Technical procedures
     . Concrete work?
     . Subsequent operations?
     . Other operations?
   - Areas of responsibilities and duties
   - Information flow?
   - Teamwork?
   - Participants?

Figure E-6. Example of a checklist for the control of reinforcement in the formwork.

In addition to the most important points to be checked, open checklists also contain instructions and questions concerning an independent inspection (see section E-2.1.4), e.g. "where could an error have gone undetected?", "what remains to be checked?", "other sources of errors", "additional influences". In addition to actual control instructions, checklists should also make provision for the inspection of relationships and areas of interface, while gathering feedback for both technical and organizational activities, as well as the participants themselves (see section E-2.1.4)(figure E-6).

The less easy it is to clearly describe the various items that must be checked, the more personal judgment is required, and therefore the more descriptive questions will be used in the checklist, indicating possible sources of errors, all of which will lead to greater expectations in terms of technically qualified inspectors (see section D-2.2.1).

E 2.3 Implementation of control and correction procedures

E 2.3.1 Control and correction notes

The various control steps (see section E-2.1.4) require that all errors be properly noted, along with any planned corrective measures, so that nothing will be forgotten later on. Proper notes can often be kept right on the relevant documents (plans, lists, etc.), preferably with a coloured pencil. If this is not possible, notes must be kept on a control sheet (figure E-7).

Telex 304 — Tel. 01/3775

Project No. 1245 Office Building ZASW	Page 1
Control sheet for "Design Calculations"	1981.09.26
Errors / Corrective measures	Done
Item 105 Horizontal force should be carried by item 205	✓
Item 207 Support sensitive conditions to be clarified	✓
Item 210 Missing: 4 ∅ 20	✓
Item 212 Measurement error: 4.2 m instead of 5.2 m	✓
Item 305 Buckling length too small	✓

Figure E-7. Example of a control sheet.

In addition to their passive function of identifying errors and establishing corrective measures, control sheets also play an important active role since they themselves represent a "checklist" on the basis of which various corrective steps will be carried out and then checked for completeness. Once corrective measures have been duly carried out, they are checked off as "done". Accordingly, control sheets are used:

- to describe errors,
- to establish corrective measures,
- as a checklist to carry out corrective measures,
- as a basis for the preparation of records and reports,
- as a document in cases of dispute or conflict.

E 2.3.2 Records and reports

The results of control operations which affect further operations and have some impact on the quality of a structure are written down in a set of records or in a report. If several people are involved in control operations, as is the case for acceptance of work, the records are prepared jointly (figure E-8).

In other cases, the results are included in a report (see section C-4.3). The preparation of records or reports is made easier through the use of preprinted forms (e.g. following standards SIA 160/3, DIN 1076, DIN 1084, DIN 4159).

Essentially, records and reports should contain the following information:

- general information, such as the name of the building, the owner, the location, the date, the time, the person in charge of controls, the people present, etc.;
- the objective;
- any errors and deviations;
- corrective measures, possibly with remarks concerning their execution;
- further action;
- distribution list.

Such records or reports should be distributed to everyone involved, to be used as a guide and/or checked off.

Keller Eng'g Dept. Neustrasse 13 8049 Zurich Tel. 01/3775 Telex 304

Office Building ZASW Inspection records	No. 3
Reinforcement -(Ceiling over first floor) Zurich	1981.06.30
Time 10:00	Müller
<u>Present:</u> K. Meier Foreman Neubau Ltd. P. Egli Site supervisor, Architektenbüro Iten K. Müller Keller Eng'g Dept.	
<u>Findings and needed corrections:</u>	Responsible:
- The top reinforcement (axis B-D/5-6) has too few spacers. The number of spacers should be doubled.	Meier
- For the recess (axis E-F/8-9) additional reinforcements are needed (see plan) for each 3 ø 16.	Meier
- In the area of axes B-D/10-12, ø 14 e = 20 cm were laid instead of ø 16 e = 20 cm. To correct this: lay ø 14 with e = 15 cm.	Meier
- At the expansion joint (axis E) detailing reinforcement 4ø20 was further designed on site. This should be taken into consideration in the reinforcement plans for other floors.	Müller
- Fixtures of Kunz Ltd. not properly anchored. Improper load transfer. Further anchors were discussed with Kunz Ltd. and should be installed by 1981.07.04.	Bucher
<u>Further action:</u> Individual corrective measures to be carried out by the people responsible and checked by the site supervisor. Afterwards, concreting can proceed.	Egli
<u>Copies to:</u> K. Meier, P. Egli, K. Müller; P. Bucher (Kunz Ltd.); K. Weber (Project Manager).	

Figure E-8. Example of inspection records.

E 2.3.3 Corrective measures

It is possible to distinguish two types of corrective measures:

a) Correction of actual errors

In a number of cases, especially when something is actually missing, the required corrective measures can be applied directly during the course of control operations. If such is not the case, i.e. if errors and/or their causes require a detailed investigation, corrective measures will have to be established at a later time, and made known to the people involved [43].

In this respect, the following procedure should be used:

- determine the corrective measures,
- study the effects of corrective measures on related operations and/or the participants,
- provide instructions for carrying out corrective measures, including the person responsible, the proper procedure, aids, etc.,
- document any changes brought about by corrective measures with respect to previously planned procedures (see section C-5.2.4).

b) Corrections to eliminate the causes of errors

To prevent the reccurrence of a given error, it is important to determine which factors within the building process have caused the error, and which measures are likely to eliminate it. This is essentially a feedback mechanism (see section A-5.1) aimed at improving the error-prevention process (see also "feedback principle" under section E-2.1.4). Measures aimed at the causes of errors are especially important in the case of repetitious processes, to avoid the same error from occurring over and over again [20].

E 3. Control and correction in the various phases of the building process

E 3.1 Preliminary remarks

Within the individual phases of the building process, documents are prepared, materials are ordered and put to use, components are built, etc. To prevent any errors in one phase from being carried over to the next phase, it is very important to carefully plan and carry out key controls at major areas of "interface" in the building process (the so-called control stops [107]). In this respect, the procedure described in section E-2 can be useful. The following sections deal with basic control and correction procedures for the various phases of the building process, using suitable checklists and examples.

E 3.2 Control and correction in the planning phase

The basic data or documents which are compiled during the planning phase, to be used in the design, construction and utilization phases, should be checked for possible errors before they are put to further use. The actual control procedure can make good use of checklists which conform to the various types of errors (figure E-9).

CHECKLIST
DOCUMENTS OF THE PLANNING PHASE

1. PREPARATION
   - Documents available?
   - Up-to-date?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS AND CORRECTNESS
   Utilization analysis
   - Planned utilization?
   - Requirements linked with utilization?

   Requirements made on the structure
   - Structure?
   - Finishes?
   - Utilities?
   - Mobile equipment?
   - Stored goods?

   Analysis of the initial situation
   - Situation (situation plans)?
   - Building site?
   - Conduits and structures on the site?
   - Influence of adjacent structures and activities?
   - Laws and regulations?

   Building concept
   - Materials?
   - Methods?
   - Building process?

   Hazard analysis
   - Laws and regulations adhered to?
   - Methods appropriate?

   Planning of measures
   - Safety measures?
   - Design plan?
   - Accepted risks?
   - Construction and utilization instructions?
   - Control plans?

   FOR INDEPENDENT OVERALL CONTROL
   - Comparisons with similar projects?
   - Experience?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-9. Example of a checklist for the control of documents compiled during the planning phase.

The procedure is based on the following steps:

a) Check for completeness

Available documents are gathered on the basis of the checklist, and checked for completeness.

b) Check for correctness

Available documents are checked in terms of correctness or reliability. Wrong figures, improper assumptions, etc. can thus be detected.

c) Carry out independent controls

Available documents are assessed independently. This is meant to uncover errors in insufficient or inadequate documents. It may be done on the basis of comparisons with completed projects, determination of proportionality factors, comparison with values taken from experience, etc.

d) Assess possible feedback

Relationships and areas of interface are assessed, as well as possible repercussions on technical procedures, on organization/management, and on the participants.

e) Corrective measures

Errors discovered during various control operations, as well as the planned corrective measures, can often be indicated directly on the relevant documents. Otherwise, they are recorded on control sheets (see section E-2.3.1). These control sheets are also used as checklists when the corrective measures are carried out. Missing documents are requested or made available, and deficient documents are corrected or replaced by accurate ones. In this respect, it is important that any documents which have undergone corrections are identified accordingly, to avoid any mixup with superseded or incorrect documents.

E 3.3 Control and correction in the design phase

E 3.3.1 Design calculations

The transmission of errors occurring when building components or units are being designed can be avoided by timely control procedures. Since such errors often have grave consequences, considerable importance is given to controls during design calculations [79]. In fact, many countries have made provision for independent controls in this context.

The following steps constitute a sensible control procedure:

a) Preliminary examination

This step is aimed at ensuring that all the necessary documents are available, that preliminary notes and assumptions contain all the necessary data and information, that the location plans are complete, and that all structural components have been identified, etc. (figure E-10).

CHECKLIST
PRELIMINARY EXAMINATION - DESIGN CALCULATIONS

1. PREPARATION
   - Documents available?
   - Up-to-date?

2. CHECK
   FOR COMPLETENESS AND CORRECTNESS
   Title page
   - Name of the owner?
   - Designation of the building?
   - Engineering department and project number?
   - Date and signature?

   Table of contents
   - All sections?
   - All required information?

   Preliminary notes and assumptions
   - Description of documents?
   - Description of the building?
   - Materials?
   - Conditions in the utilization phase?
   - Conditions in the construction phase?
   - Verification of the assumptions?
   - Page numbers (changes)?

   Location and layout plans
   - Table of contents?
   - All components properly designated with locations?

   Calculation of the various items
   - All items calculated?
   - All calculation sheets accounted for?

   FOR INDEPENDENT OVERALL CHECK
   - Additional documents?
   - Additional calculation sections?

3. FEEDBACK TO:
   - Design Calculations of:
     . Site facilities?
     . Excavation?
     . Auxiliary structures?
     . Bearing structure?
     . Finishes?
     . Building services?
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-10. Checklist for the preliminary examination of Design Calculations.

b) Checking of preliminary remarks and assumptions, layout and location plans

Following the preliminary examination, checks are directed towards preliminary notes and assumptions, as well as layout and location plans, with special reference to information about interface conditions, influences, assumed quality of materials, etc. (figure E-11).

CHECKLIST PRELIMINARY REMARKS AND ASSUMPTIONS/LAYOUT & LOCATION PLANS
1. PREPARATION - Documents available? - Up-to-date? 2. CHECK FOR COMPLETENESS AND CORRECTNESS Description of the building - Structure? - Important components? - Type of foundation? - Bracing? Materials - Quality of materials? - Additional test required? - Authorization required? - Design values identified? Conditions during the utilization phase - Strength requirements? - Serviceability requirements? - Influences . According to standards? . According to agreements? - All conditions to be designed adequate? Conditions during the construction phase - Strength requirements? - Serviceability requirements? - Influences . According to standards? . According to agreements? - All construction conditions adequate? Assessment of the assumptions - Soil? - Construction procedures? - Utilization? - Risks? Position and layout plans - Agreement with other plans? - Unambiguous designation of the items? FOR INDEPENDENT OVERALL CHECK - Comparisons with similar calculations? - Critical points? - Other criteria? 3. FEEDBACK TO: - Technical procedures? - Areas of responsibilities and duties? - Information flow? - Cooperation? - Participants?

Figure E-11. Checklist to verify preliminary remarks and assumptions, as well as location and layout plans.

c) Checking individual items

Finally, the various items subject to design calculations are checked. In this respect, a distinction can be made between dependent and independent checks.

In the case of dependent checks, the calculation is examined step by step; each figure and each operation is checked. This type of operation should be carried out largely during the calculation itself. In this way, spelling mistakes and calculation errors are discovered at once.

Such a procedure, however, is not very efficient in the context of additional subsequent checks, where independent checks are more effective, since they also uncover errors due to incorrect assumptions, improper procedures, or inadequate calculation models. Independent checks start from the assumptions, and check the results through independent calculations (e.g. by using a different method, by determining characteristic values, or by checking the order of magnitude, etc.), without using the previously applied algorithm.

In the case of computer calculations, the major items to be checked are the assumptions and the data that are used. The results themselves must always be checked by approximate calculations for order of magnitude, signs, etc.

When checking the calculations of individual items, it is easier to use a checklist (figure E-12).

d) Overall assessment of critical points and feedback

This procedure is essentially an attempt to uncover errors due to factors that are either not recognized or underestimated. After performing the previous operations, the person responsible is able to identify details of the overall building, as well as its "weak points". An overall assessment to uncover possible weak points makes it possible to pinpoint missing or insufficient investigations. The overall assessment is aimed at the building as a whole (overall loadbearing function, soil/structure interaction, etc.), as well as at various sensitive components (figure E-13).

Finally, possible areas of interface and feedback on the building process are checked. This procedure is based on such questions as "are the calculations sufficient for the preparation of drawings?", "are the draftsmen properly qualified to work directly from the calculations?", "is there an established procedure for transferring the calculations to the proper people?", "has the building contractor been informed of the verified conditions in the construction phase?", etc.

CHECKLIST
CALCULATION OF VARIOUS ITEMS

1. PREPARATION
   - Documents available?
   - Up-to-date?

2. CHECK
   FOR COMPLETENESS AND CORRECTNESS
   Description of the items
   - Location number?
   - Location in the building (axes)?
   - Material and dimensions?

   System
   - Dimensions and span widths?
   - Assumptions?
   - Transmission of reaction forces?

   Loading
   - Reactions from other structural elements
   - Impact of "Preliminary notes and assumptions"?
   - Utilization conditions?
   - Construction conditions?
   - Computer data input (plot, output)?

   Reactions and internal forces
   - Calculating operation understandable?
   - Applied formulas?
   - Important values?
   - Internal force distribution?
   - Secondary influences?

   Calculation and verification
   - Governing forces (bending, shear, compression, etc.)?
   - Permissible values adhered to?
   - Strength and serviceability substantiated?
   - Material and dimensions in agreement with the description of items and the system?

   Results
   - Results, sections?
   - Floor plans, sketches?
   - Dimensions and material?

   FOR INDEPENDENT OVERALL CHECK
   - Critical points?
   - Order of magnitude?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-12. Checklist to verify the calculation of various items.

CHECKLIST OVERALL ASSESSMENT OF THE DESIGN CALCULATIONS IN TERMS OF CRITICAL POINTS AND FEEDBACK
INDEPENDENT OVERALL CHECK CONCERNING SUCH CRITICAL POINTS AS: - Structural system - Connections between components - Compatibility of the materials - Interface between building components - Interface between the structure and the soil - Effects of adjacent structures - Settlement - Inclination - Additional construction conditions - Additional utilization conditions - Assumptions for the building process - Assumptions for the utilization phase - Other criteria? FEEDBACK TO: - Technical procedures? - Areas of responsibilities and duties? - Information flow? - Cooperation? - Participants?

Figure E-13. Checklist to verify the design calculations in terms of critical points and possible feedback.

Every structure is different. As a result, checklists used for independent overall inspections can never hope to be complete. They merely serve as tools.

e) Corrections

Errors detected during various checking operations, as well as proposed corrections, can often be noted directly in the calculation (e.g. using a coloured pencil). Sometimes, errors and/or corrections are noted on a control sheet (figure E-7). It is on the basis of such entries that corrections are carried out, and that missing documents are requested or made available. As a rule, small corrections which deal with wrong numbers or a small transgression can be corrected directly on the calculation sheet. Corrected or modified pages must be properly identified (see section B-3.2.3). If additional verification is needed, supplementary pages, properly coded, can often be inserted within the calculation (see section B-3.2.3). Extensive corrections are dealt with in a separate section of the calculation.

f) Checking notes

Once a calculation has been checked and corrected, a note to that effect must be recorded on the title page (see section B-3.2.2), e.g. using a stamp, date and signature. Items of importance:

- calculations checked personally by the person who prepares them should show a date and signature ("prepared by");
- calculations checked internally (e.g. by a colleague) should show a date and signature ("checked by");
- additional controls by independent bodies should be identified.

The results of controls conducted by independent bodies must always be recorded in a report.

E 3.3.2 Drawings and lists

Drawings and lists are the most important documents for the construction phase. Control and correction procedures related to such documents are particularly crucial. Experience and failure investigations [58], however, have shown that there is often no systematic control procedure. The following steps are advisable:

a) Checking for completeness

The goal is to make the necessary floor plans, views, sections, details, etc. available, with the required dimensions, reference data, and so on. Correctness is not an immediate concern. It is essential to determine whether the drawings and lists are adequate for the construction of the building.

b) Checking for correctness

The information contained in the drawings and lists is checked in terms of correctness. It is important to determine:

- whether cross sections, dimensions, materials, etc. have been applied according to the results of the design calculations;
- whether sections, components, etc. not verified by calculations are detailed according to proper rules;
- whether lengths, dimensions, etc. are recorded correctly, and whether descriptions and textual information are accurate and sufficient;
- whether construction procedures and erection stages have been given due consideration, and are adequately described in the plans.

c) Independent overall check

On the basis of the previous control procedures, the gathered information is checked in overall terms without reference to available control documents. "Weak points" are identified, and, if necessary, additional data are entered in the drawings and lists. Obvious calculation errors are often uncovered at this stage, e.g. by comparing dimensions and reinforcement percentages.

d) Assessing feedback

As was the case for Design Calculations (section E-3.3.1), it is also important to assess drawings and lists in terms of feedback for the construction phase. This is done on the basis of such questions as "are the examined plans sufficient for the construction phase?", "are the people in charge of construction properly qualified?", "is there a clear procedure for the flow of information concerning drawings?", etc.

e) Checklists

Checklists make it easier to monitor the various control steps. Figures E-14 to E-18 may be used as examples.

f) Corrective measures

Errors detected during the different checking operations, as well as any proposed corrective measures, are normally recorded directly on a copy of the drawing (using a coloured pencil for example). Additional checking and correction information can be entered in the margin or on a control sheet (figure E-7). It is on the basis of such information that actual corrections are carried out. Should corrections produce a change in drawings that have already been made available to other people, the latter must be provided with an adequate descriptive index (see section B-3.4.2).

g) Checking notes

Completed checks are recorded in the title block of the drawing (see figure B-29), as well as on individual lists. Items of importance:

- Drawings checked personally by the draftsman should show the date and signature ("drawn by");
- drawings checked internally by a structural engineer or another person should show the date and the signature of that person ("checked by");
- drawings and lists checked internally as part of an overall inspection (e.g. by the project's technical director) should show a date and signature ("seen by");
- additional controls by independent authorities, architects, the owner, contractors, etc. should show the date of issuance and a signature ("additional controls").

CHECKLIST
FORMWORK PLANS

1. PREPARATION
   - Documents available?
   - Up-to-date?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS
   - Scope of the drawing?
   - Floor plans, sections, details, etc.?
   - Adequate representation?

   FOR CORRECTNESS
   In terms of design calculations
   - Material data
   - Dimensions
   - Supports (bearings)
   - Camber

   In terms of structural detailing
   - Connections
   - Fixtures, installations
   - Recesses (power, water, heating, etc.)
   - Minimum dimensions
   - Expansion joints
   - Possibilities of confusion

   In terms of information on drawing
   - Specifications
   - Overall dimensions, dimensions, axes
   - Elevations
   - Reference dimensions (recesses)
   - Title block (changes, check)
   - Additional plans and lists

   In terms of the construction procedures
   - Work periods
   - Construction conditions
   - Crane anchorage
   - Building equipment and machinery
   - Building materials - storage
   - Schedule for removal of forms
   - Schedule for back filling

   FOR INDEPENDENT OVERALL CHECK
   - Critical points?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-14. Checklist to verify formwork drawings.

CHECKLIST
REINFORCEMENT PLANS

1. PREPARATION
   - Documents available?
   - Complete?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS
   - Scope of the drawing?
   - Floor plans, sections, details, etc.?
   - All components and zones reinforced?
   - Adequate representation?
   - Title block?

   FOR CORRECTNESS
   In terms of design calculations
   - Steel grades
   - Types of concrete
   - Dimensions
   - Diameter and spacing
   - Position
   - Concrete cover
   - Check the moment envelope
   - Web reinforcement

   In terms of structural detailing
   - Anchor lengths
   - Connections
   - Joints
   - Two-way reinforcement
   - Spacers
   - Special reinforcement in corners of two-way slab
   - Reinforcement against cracking
   - Erection reinforcement
   - Distribution reinforcement
   - Forces resulting from a change in direction
   - Construction joints
   - Expansion joints
   - Installations
   - Recesses
   - Gaps for vibrator access
   - Supports
   - Brackets
   - Column capitals
   - Possibilities of confusion

   In terms of information on plan
   - Designations
   - Overall dimensions
   - Elevations
   - Reference dimensions
   - Title block (changes, check)
   - List of reinforcement
   - Additional plans and lists

   In terms of the construction procedure
   - Construction sequences
   - Construction conditions (scaffolding, equipment)
   - Anchorage (crane, scaffolding)

   FOR INDEPENDENT OVERALL CHECK
   - Critical points?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-15. Checklist to verify reinforcement drawings.

SUPPLEMENTARY CHECKLIST
"PRESTRESSING" - FORMWORK AND REINFORCEMENT PLANS

1. PREPARATION
   - Documents available?
   - Up-to-date?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS AND CORRECTNESS
   Tendons
   - Type of tendons
   - Number of wires
   - Prestressing force
   - Position - ground plan
   - Gaps for vibrator access
   - Location - front view
   - Tendon clamps
   - Radius of curvature
   - Straight pieces (anchors and couplings)
   - Slope (anchors)
   - Concrete cover

   Anchorage
   - Type of anchor
   - Arrangement of anchors
   - Anchor plates (type, spacing, recess depth)
   - Space requirements (reinforcement, other components)
   - Couplers
   - Grouting inlets

   Additional reinforcement
   - Splitting tensile forces
   - "Stressless" corners
   - Coupler joints
   - Tie down cables
   - Structural detailing

   Prestressing schedule
   - Partial prestressing
   - Sequence of operations
   - Prestressing operations
   - Prestressing records
   - Lowering the scaffold
   - Pumping grout

   FOR INDEPENDENT OVERALL CHECK
   - Critical points?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-16. Supplementary checklist to verify formwork and reinforcement drawings for prestressed concrete.

SUPPLEMENTARY CHECKLIST "PRECAST ELEMENTS" - FORMWORK AND REINFORCEMENT PLANS
1. PREPARATION - Documents available? - Up-to-date? - Control procedure identified? 2. CHECK FOR COMPLETENESS AND CORRECTNESS - Weight - Suspension - Transportation reinforcement - Connections - Dimension tolerances (manufacturing) - Erection tolerances - Plan of location in structure - Auxiliary scaffolding - Bracing and support during erection (wind, crane impact) - Transport - influences - Erection operations FOR INDEPENDENT OVERALL CHECK - Critical points? - Other criteria? 3. FEEDBACK TO: - Technical procedures? - Areas of responsibilities and duties? - Information flow? - Cooperation? - Participants?

Figure E-17. Supplementary checklists to verify formwork and reinforcement drawings for precast elements.

CHECKLIST
STEEL CONSTRUCTION DRAWINGS

1. PREPARATION
   - Documents available?
   - Up-to-date?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS
   - Scope of the drawings?
   - Floor plans, sections, details, etc.?
   - Drawings of all units?
   - Adequate representation?
   - Title block?

   FOR CORRECTNESS
   In terms of design calculations
   - Profiles, cross sections
   - Material quality
   - Bolt and rivet sizes
   - Dimensions of welded joints

   In terms of structural detailing
   - Tolerances
   - Supports
   - Bearings
   - Connections
   - Fatigue-stressed connections and details
   - Camber
   - Force transfer
   - Connecting bars
   - Stiffening against
     . Buckling of columns
     . Overturning
     . Buckling of plates, shells
   - Accessibility of all connections and connectors
   - Accessibility for painting
   - Ventilation of enclosed space
   - Continuous welds (hot galvanizing)
   - Possibilities of confusion
   - Fire protection
   - Maintenance (corrosion)

   In terms of information on drawings
   - Location of major axes
   - Elevations
   - Reference dimensions
   - Specification and notes
   - Lists of pieces and finished parts (material, profile)
   - Title block (changes, check)
   - Related plans and lists

   In terms of safety of construction procedures
   - Accident prevention
   - Erection phases
   - Erection scaffolding
   - Stability
   - Connections for erection equipment
   - Removal of forms
   - Principal items on the erection layout

   FOR INDEPENDENT OVERALL CHECK
   - Critical points?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-18. Checklist to verify steel construction drawings [113].

E 3.4 Control and correction in the construction phase

E 3.4.1 Control procedure

During the construction phase, errors are usually detected through the results of individual operations, i.e. through final controls. However, if errors are difficult to detect, or if costly corrective measures can be anticipated, plans should also include initial and intermediate controls. These are aimed at individual components (materials, machines, equipment, people, methods) or the results of particular operations.

Planning of controls in the construction phase is similar to that outlined in section E-2.2:

- the necessary controls are laid down in control plans; the supervision and maintenance of machines and equipment are usually outlined in separate plans;
- the necessary checking operations are regulated through instructions and checklists;
- relevant items are checked for completeness and correctness, as well as for critical aspects and possible feedback, with the help of instructions and checklists, in accordance with the four principles described in section E-2.1.4;
- any errors and planned corrective measures are recorded on control sheets, which in turn form the basis for carrying out corrections or preparing test and verification reports.

The following sections provide a description of the essential aspects of various control procedures, as well as information about the preparation of instructions and checklists, including some examples.

E 3.4.2 Quality control

Quality control [20,81,84,107] is related to the quality of the materials, components and parts of the building. The essential features of quality control are defined in standards and guidelines (e.g. [105,106]).

a) Nominal values, target values and tolerance limits

In terms of cost-effective building practice, certain deviations in structural properties from a specified target value must be tolerated. As a result, design calculations take into account certain deviations (T) from specified nominal values (N). Those values which indicate the tolerance limits from the nominal value are called limit values (G); they draw the line between tolerated and non-tolerated values (figure E-19).

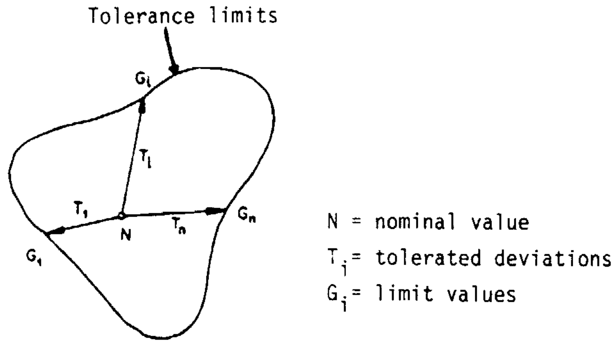

Figure E-19. Determining nominal values and tolerance limits.

If, for example, the nominal value for the height of a fixture is defined as H_n = 100 cm, and the tolerated deviations are specified as T_i = -2 cm and Tj = + 3 cm, the limit values are H_{min} = 98 cm and H_{max} = 103 cm.

Accordingly, the producer will have to ensure that items fall within the established tolerance limits. He will define a target value (Z) on the basis of his expected deviations (A) and the established limit values (G) (figure E-20). This target value is often different from the established nominal value.

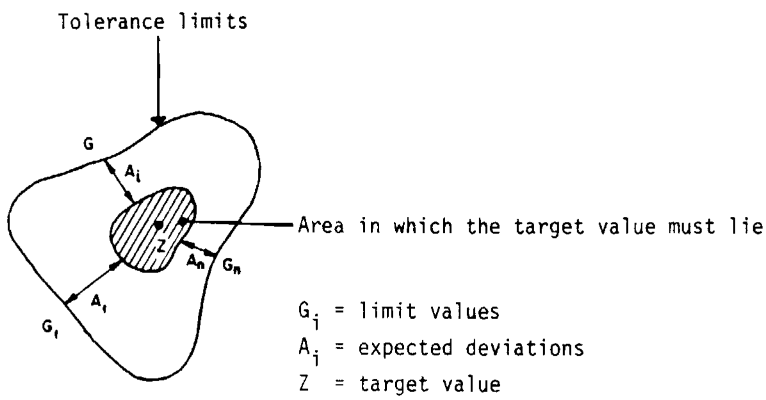

Figure E-20. Determining target values.

In the above example, the producer might expect deviations of A_i = -2 cm and A_j = +2 cm. He will therefore set a target value of Hz = 100.5 cm, and proceed accordingly.

b) Types of quality control

Final controls or product controls are used to determine whether the intended properties have in fact been achieved. This is done by pressure tests for pipes, compressive cube strength tests for concrete, tensile strength tests for steel, etc. In many cases, such final controls are sufficient. However, whenever corrective measures would be impossible or too costly, initial and intermediate controls must be carried out (figure E-21).

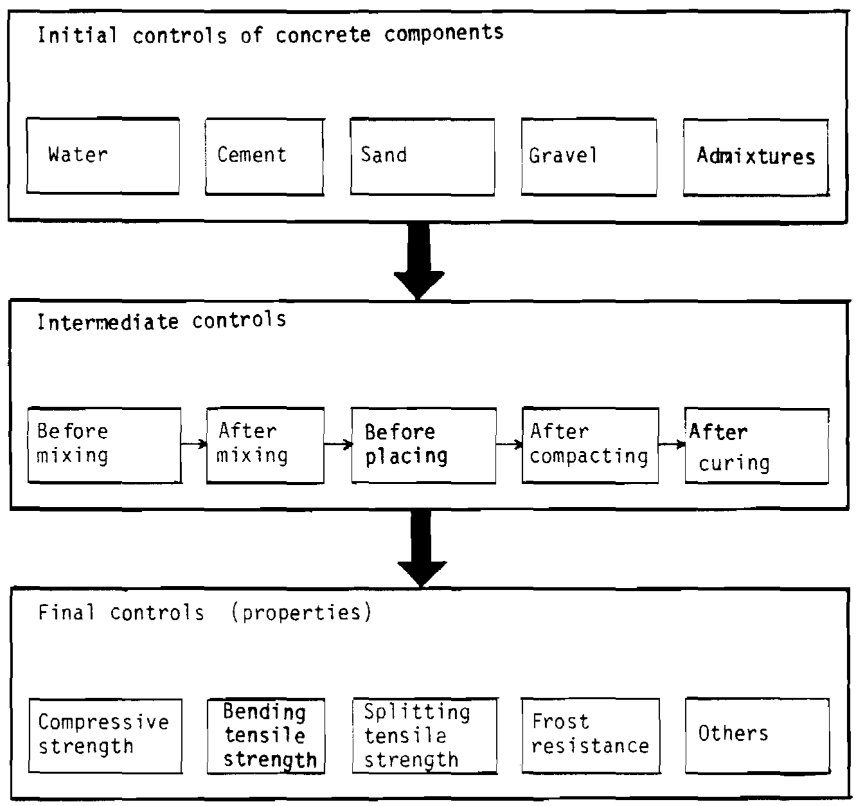

Figure E-21. Examples of initial, intermediate and final controls in the production of concrete.

Initial controls (suitability or delivery controls) help detect errors in materials and components that are delivered or used, as well as in prefabricated elements. They are subject to established, pre-arranged rules (e.g. for cement, sand, gravel, bricks, timber, etc.).

Intermediate controls help detect errors in the work procedures of a given process. Timely, and usually simple corrective steps are then used to bring the process within the specified tolerance limits. The production of concrete, for example, is monitored in terms of consistency.

Acceptance tests, finally, are a special form of combined initial and final controls. They occur when responsibility or property rights are transferred upon completion of well-defined work phases (e.g. acceptance of masonry by plasterers). To avoid subsequent disputes, it is important to prepare test records and submit them to participants for confirmation. Acceptance tests are frequently governed by standards (e.g. [103,105]).

E 3.4.3 Supervision and maintenance of building machinery and equipment

The breakdown of machines and equipment (e.g. lifting apparatus, vibrators, concrete mixers) produces delays in the building process, and also causes damage to particular structural components. According to one study [58], site facilities (mostly machines and equipment) account for 7% of all cases of damage, 10% of all cases of injury, and 13% of all cases involving death. Such occurrences can be avoided, or at least reduced, through proper supervision, i.e. by checking and maintaining machines and equipment at specified time intervals. A systematic approach can be provided through supervision and maintenance plans, or so-called SPM programs (systematic preventive maintenance [49]), which contain detailed descriptions of the necessary measures.

Supervision and maintenance procedures can be properly planned and carried out using the following guidelines:

- set up a catalogue of the available building machinery and equipment;
- establish a supervision and maintenance plan;
- establish control and maintenance intervals (periods), and place people in charge;
- prepare instructions, and, if need be, checklists;
- carry out the supervision and maintenance operations;
- record the results (control book);
- if necessary, check whether controls are carried out properly and at the right time (using the control book).

E 3.4.4 Supervision of work procedures

Errors in work procedures (e.g. wrong sequence, failure to adhere to planned methods) can be uncovered in time through rational supervision. It is especially important to supervise work procedures in which errors could lead directly to damage.

The supervision of work procedures must be planned and set out in control plans. The procedure outlined below provides a sound model:

- list important and/or hazardous work procedures;
- select the type of supervision, and place people in charge;
- prepare control instructions and checklists;
- carry out the supervision;
- enter the control procedure and any findings in records or reports.

E 3.4.5 Checklists for the construction phase

People who carry out controls on the job site are exposed to a variety of disturbing influences (noise, traffic, too many activities occurring at the same time, etc.), and are often under considerable psychological pressure. Such influences can lead to loss of concentration and to interruptions in the control procedure. Preestablished checklists are therefore particularly useful. The following steps provide a sound basis for the preparation of checklists:

- gather the required documents (plans, lists, instructions, programs, etc.), and make sure they are up-to-date;
- select a control procedure, e.g. in terms of areas or components;
- check for completeness;
- check for correctness;
- provide an independent overall control;
- assess the possible feedback of findings on the building process.

A few examples of such checklists will be found in figures E-6, E-22, and E-23.

CHECKLIST
INSTALLED TENDONS

1. PREPARATION
   - Documents available?
   - Up-to-date?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS
   - All tendons installed?
   - Additional reinforcements available?

   FOR CORRECTNESS
   Tendons
   - Type of tendons
   - Number of wires
   - Prestressing force
   - Position
   - Gaps for vibrator access
   - Bar crossings
   - Tendon clamps
   - Radius of curvature
   - Straight pieces (anchoring and couplings)
   - Slope (anchoring)
   - Concrete cover
   - Hollow ducts (intact and impervious)

   Anchorage
   - Type of anchor
   - Arrangement of anchors
   - Anchor plates (type, spacing, recess depth)
   - Space requirements (reinforcement in tendon anchorage zone, other components)
   - Couplings
   - Grouting inlets

   Additional reinforcement
   - Splitting tensile forces
   - "Stressless" corners
   - Coupler joints
   - Tie down cables
   - Structural detailing
   - Supports
   - Installations
   - Recesses

   Prestressing schedule
   - Partial prestressing
   - Sequence of operations
   - Prestressing operations
   - Prestressing records
   - Lowering the scaffold
   - Pumping grout

   Construction procedures - influences
   - Construction sequences
   - Scaffolding and formwork
   - Schedule for form removal
   - Construction machinery and equipment
   - Construction materials-storage

   FOR INDEPENDENT OVERALL CHECK
   - Critical points?
   - Possibilities of confusion?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-22. Checklist used to check installed tendons.

CHECKLIST
FORMWORK AND SCAFFOLDING

1. PREPARATION
   - Calculation available?
   - Other documents?
   - Up-to-date?
   - Control procedure identified?

2. CHECK
   FOR COMPLETENESS
   - Formwork?
   - Sturctural elements?
   - Bracing of structural components, connections?
   - Foundation, support?

   FOR CORRECTNESS
   Formwork
   - Dimensions
   - Cross sections
   - Slope
   - Camber
   - Support

   Scaffolding elements
   - Material quality
   - Dimensions
   - Position
   - Defects
   - Stiffening of
     . Columns
     . Upper flange
     . Bearings
   - Force transfer
   - Impact forces
   - Support of columns (wedges, pillars)
   - Beam support
   - Bracing

   Scaffold connections
   - Centering the members (joints)?
   - Number of screws?
   - Welded joints?
   - Couplings tightened?
   - Anchorage?

   Scaffold foundation
   - Foundation dimensions?
   - Settlement?
   - Scouring?
   - Piles (position, slope)?
   - Substructure capable of supporting load?

   Construction procedures - influences
   - Erection procedure?
   - Erection equipment, elevators?
   - Construction materials?
   - Construction operations - sequence?
   - Influence of concreting operations?
   - Sequence for removal of forms?
   - Timetable for removal of forms?

   FOR INDEPENDENT OVERALL CHECK
   Critical points?
   - Formwork - Scaffolding?
   - Scaffolding - Foundation?
   - Scaffolding - existing structure?
   - Inclined construction?
   - Braces?
   - Possibilities of confusion?
   - Other criteria?

3. FEEDBACK TO:
   - Technical procedures?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-23. Checklist used to check formwork,scaffolding.

E 3.5 Control and correction in the utilization phase

E 3.5.1 The purpose of controls in the utilization phase

According to one study [58] (figure A-2), errors which occur in the utilization phase account for 6% of the cases of damage due to errors, and 14% of the total damage. Included in these figures are actual utilization errors, as well as inspection errors, maintenance errors, and changes in the utilization process. Such errors can be discovered in time, and corrected, through careful inspection and proper maintenance of the building and its components, as well as through periodic inspection of actual utilization patterns [80]. Planned controls and/or maintenance procedures are entered in the utilization manual (section B-5.2), and their implementation is also documented in the utilization manual.

A utilization manual should be used from the beginning in the case of new buildings. Such a document is often lacking in the case of existing structures, so that inspection and maintenance operations may be inadequate. When alterations are called for, the occupant should be informed of the need for inspection and maintenance; he should then appoint a specialist to provide an inspection and maintenance program for his structure, and subsequently set up a utilization manual.

E 3.5.2 Inspection and maintenance of buildings

The various components of a buidling (e.g. structure, finishes, utilities) are exposed, during the utilization phase, to a wide variety of influences and to inevitable wear and tear. It is therefore necessary to inspect and maintain these components. There are two types of controls:

- assessment of conditions;
- inspection of failure symptoms.

Assessments of condition are aimed at specific components (e.g. elevators, conduits, warning equipment); actual values are recorded, as a rule, and then compared with theoretical values; deviations are assessed, and, if need be, corrective steps are initiated.

The inspection of failure symptoms is advisable for those components (e.g. structure, finishes) which are less exposed to actual wear and tear than to unfavourable influences of an environmental nature. It is usually sufficient, for such components, simply to consider any changes as symptoms of potential failure (figure E-24), the state of the building having been inspected when the latter was taken over or put into service. Potential failure is thus identified, and the required corrections can be initiated.

CHECKLIST
BUILDING COMPONENTS FOR POSSIBLE FAILURE SYMPTOMS

1. PREPARATION
   - Utilization manual?
   - Other documents?
   - Control procedure identified?

2. CHECK FOR POSSIBLE FAILURE SYMPTOMS

   In terms of component geometry
   - Deformations
   - Settlement
   - Angular deviations

   In terms of building materials and components

   Reinforced concrete
   - Cracks
   - Spalling
   - Gravel pockets
   - Rusty reinforcement
   - Corrosion of tensioning cables
   - Damp spots, water flow
   - Leaching
   - Expansion
   - Physical damage (impact, additional reinforcement, etc.)

   Steel
   - Corrosion
   - Faulty screws
   - Faulty rivets
   - Unsound welded joints
   - Cracks
   - Physical damage (perforations, deformation, etc.)

   Masonry
   - Efflorescence
   - Leaching
   - Expansion
   - Cracks
   - Spalling
   - Loosened blocks
   - Missing blocks
   - Damp spots, water flow
   - Physical damage (openings, recesses, cracks, etc.)

   Wood
   - Rot
   - Parasites
   - Cracks
   - Faulty joints
   - Damp spots, water drainage
   - Physical damage (holes, clamps, etc.)

   INDEPENDENT OVERALL CHECK

   Critical points?
   - Connections?
   - Supports?
   - Bearings?
   - Hinges?
   - Brackets?
   - Expansion joints?
   - Seals?
   - Protective coats?
   - Other criteria?

3. FEEDBACK TO:
   - Further utilization?
   - Areas of responsibilities and duties?
   - Information flow?
   - Cooperation?
   - Participants?

Figure E-24. Checklist used to check building components for possible failure symptoms [79, 104].

The following steps provide a sound basis for planning and carrying out inspection and maintenance operations:

- list the major components of the structure, the finishes, and utilities (elevators, conduits);
- identify those components which are particularly affected by utilization and other influences;
- describe the inspection and maintenance of major components in a inspection and maintenance plan (see section B-5.2.4);
- establish a schedule or timetable for control and maintenance operations, and place people in charge;
- prepare control instructions and any checklists that may be needed [104] (figure E-24);
- carry out the control and maintenance operations;
- ensure that the results of controls and of maintenance and repair work are entered in records or reports, and documented in the utilization manual (see section B-5.2.4).

Careful inspection and timely maintenance are especially important for structures such as bridges and dams, as well as for certain components such as elevators and oil reservoirs. Relevant standards, guidelines, regulations, etc. are usually available (e.g. [19,104] for bridges, [108] for elevators).

E 3.5.3 Supervision of utilization

The occupants of a structure should be properly informed of the provisions or stipulations of the utilization plan. Improper use remains a possibility, however, and utilization activities must therefore be supervised. Individual controls and internal controls (see section E-2.1.3) are one aspect of this. It is often sufficient to appoint one of the persons involved to supervise utilization. This person is to be informed of the proposed utilization, as well as of possible errors, changes, and failure symptoms. This type of information is best recorded in a checklist (figure E-25).

Whenever such controls are insufficient, or appear unreliable, additional controls are required; these might include automatic supervision, e.g. to avoid overloading of elevators. The proposed supervision measures should be properly described in the utilization manual (see section B-5.2.4).

CHECKLIST SUPERVISION OF UTILIZATION IN INDUSTRIAL BUILDINGS
1. PREPARATION - Utilization manual? - Other documents? - Proposed utilization? - Control procedure identified? 2. CHECK FOR COMPLETENESS AND CORRECTNESS - Stored materials and goods? - Available material? - Available machinery? - Available facilities? - Loads (magnitude and location) . Uniform loads? . Single loads? . Edge loads (recesses)? - Oscillations, vibrations? - Impact, shock? - Moisture? - Chemical influences? - Fire hazard? - Other factors? FOR INDEPENDENT OVERALL CHECK - Critical points? - Other criteria? 3. FEEDBACK TO: - Further utilization? - Areas of responsibilities and duties? - Information flow? - Cooperation? - Participants?

Figure E-25. Example of a checklist used to supervise utilization in industrial buildings.

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