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Structural Engineering Report 154

DEVELOPMENT OF STRUCTURAL STEEL DESIGN STANDARDS

by

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DEVELOPMENT OF STRUCTURAL STEEL DESIGN STANDARDS

PART A

Are Qualitative Changes in Design Standards Needed?

PART B

On a Basic Standard for Structural Steel Design

by

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PART A

ARE QUALITATIVE CHANGES IN DESIGN STANDARDS NEEDED?

ARE QUALITATIVE CHANGES IN DESIGN STANDARDS NEEDED?

Abstract

A review of the increasing complexity of existing standards for structural steel design shows that a discrepancy exists between them and the increasingly sophisticated assessment process that utilizes computer technology and cybernetics to the full. A qualitative change in the arrangements of standards is proposed. The basic standard should define the "rules of the game", defining all reliability conditions for both groups of limit states (carrying capacity and serviceability), based on the application of the theory of reliability. Secondary standards should then deal with situations that commonly occur. Supporting the standards are extensive computerised data bases. Essential to the intelligent use of the proposed layout is the development of expert systems. With the introduction of basic standards, data bases and expert systems, the present standards could be slimmed down to essential truths and no longer would be unmanageably complex.

1. Introduction

Standards for the design of steel structures such as CSA Standard S16.1 (Canadian Standards Association, 1924-1984) and Czechoslovak Standard CSN 73 1401 (Institute for Standards Measurements 1929-1986), have undergone, like similar standards in other countries, a significant development during their existence. Since the first versions issued in the 1920's containing simplified rules with few equations and stipulations, the standards have been gradually expanded and give methods for assessing various selected elements, components and systems as related to material characteristics. Advances in reliability theory led to a qualiltative translation from Allowable or Working Stress Design (ASD) to Limit States Design (LSD). In addition to this, the design process has been increasingly and dramatically affected by the development of computer technology.

Fig. 1 illustrates schematically the expansion of standards for structural steel design in Canada (CSA, 1924-1984) and in Czechoslovakia (Institute for Standards and Measurements, 1929-1986) expressed by the number of equations in these standards from the time the first standards were published until now. A prognosis of further development up to the year 2000, assuming that the present trend will proceed, is shown dotted.

In Table 1, information on the number of pages, figures, tables and appendices, in the Canadian standard for steel buildings also illustrates this trend. As for the structural steel design standards, associated standards such as those dealing with special types of steel structures, materials,

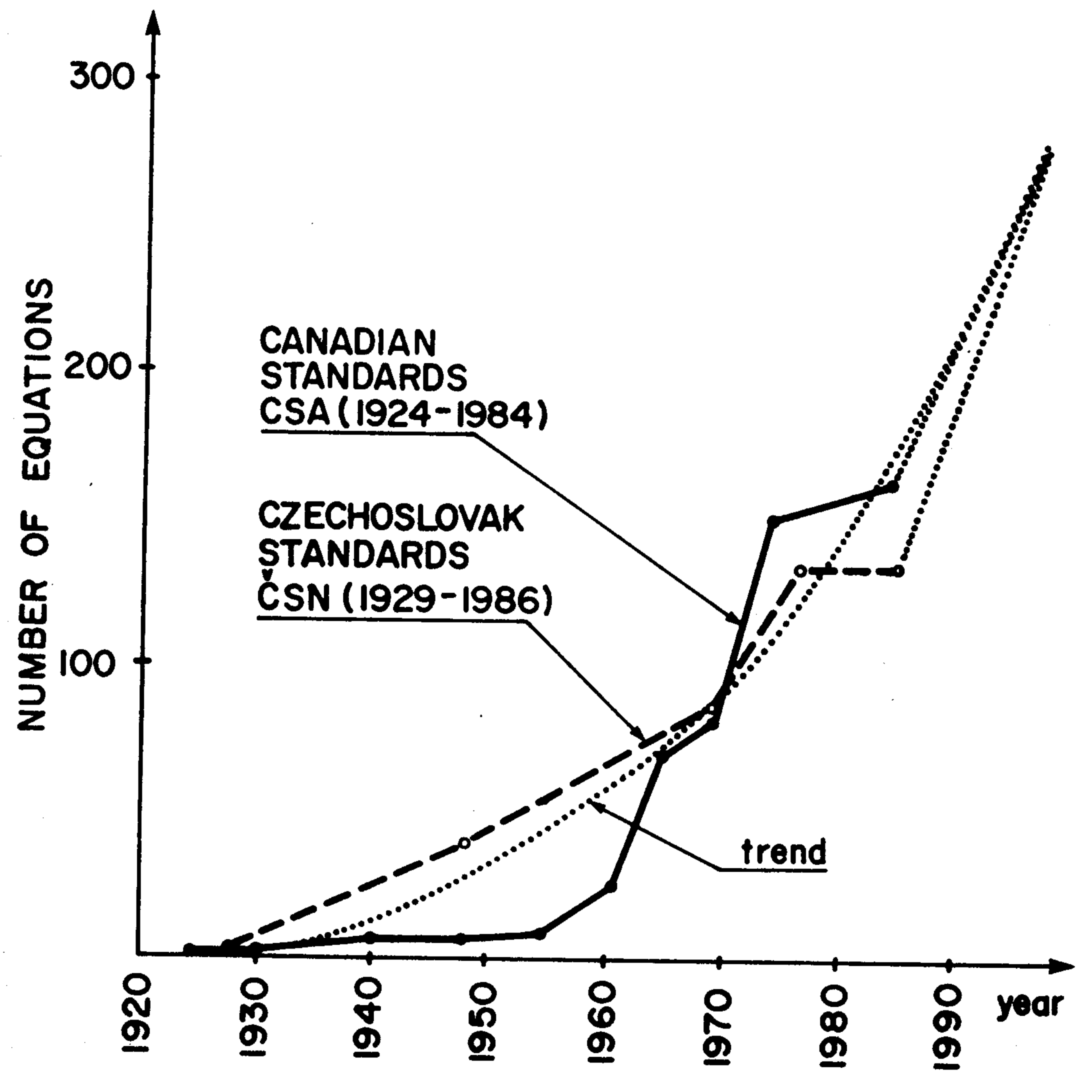


Fig. 1. Expansion of Standards

Table 1. Expansion of the Canadian Standard "Steel Structures for Buildings"

Edition	Number of Equations	Figures	Tables	Chapters	Appendices	Publications	Pages	Pages Related to Assessment of Reliability	Designation
1924	2	3	5	9	2	17	23	5	A.16
1930	2	3	5	10	3	29	25	6	A.16
1940	6	0	3	11	2	0	20	11	S.16
1954	8	1	7	33	3	10	31	21	S.16
1961	25	3	10	34	4	19	43	36	S.16
1965	69	4	13	34	4	34	70	55	S.16
1969	80	4	5	34	5	54	90	67	S.16
ASD → LSD									
1974	150	13	13	29	11	54	100	94	S.16.1
1984	162	13	13	29	12	51	172	162	CAN3-S.16.1-M84

quality control, welding, and the like get more numerous. Table 1 also shows the number of publications referred to in the S16 series.

The increase in the number of equations, tables, figures, and such like, as given in Fig. 1 and Table 1, implies that a growing number of problems can be solved with improved accuracy or at least sophistication in design practice.

Fig. 2 illustrates the qualitative change in the design method with a distinct jump around 1970 when allowable stress design was replaced in structural steel design standards by the more advanced limit states design.

Fig. 3 is a representation of developments in the use of computer technology with a qualitative change in the fifties due to the beginning of application of mass-produced computers in design practice. The width of the bands represents the relative use of the various tools. The prognosis up to the year 2000, shown in Fig. 1, draws attention to questions of the further development of standards in the near future and to problems associated with this development:

(a) Will the development of standards proceed according to the accelerating trend indicated in Fig. 1 to meet the demand of design practice, or should essential qualitative changes in the arrangement and content of the standards be made?

(b) How will the development of reliability theory, taking into account economic considerations, affect further development of the standards?

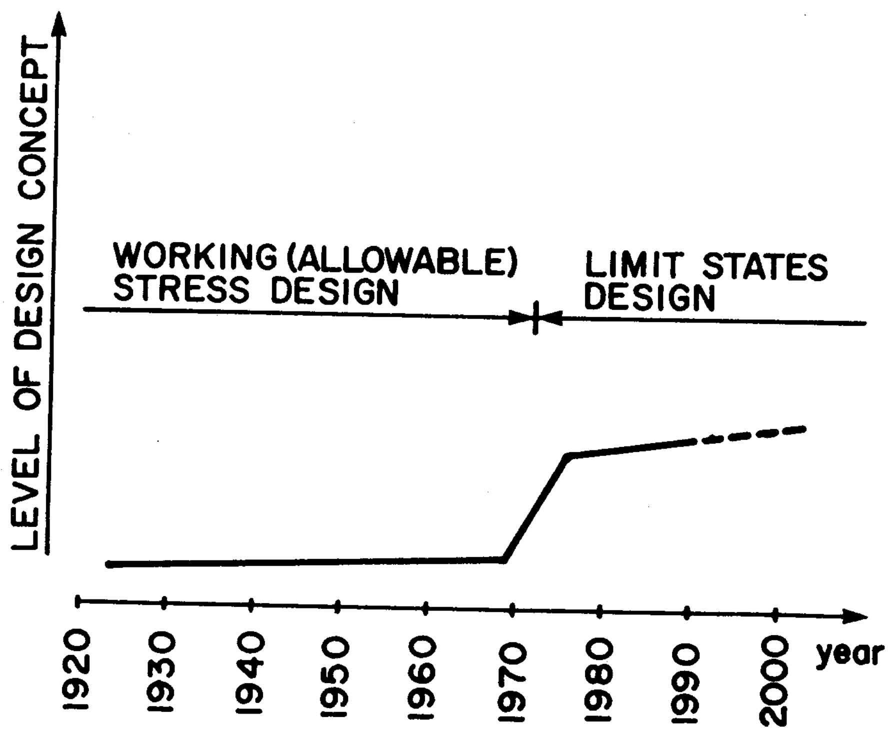


Fig. 2. Qualitative Change in Design Methods

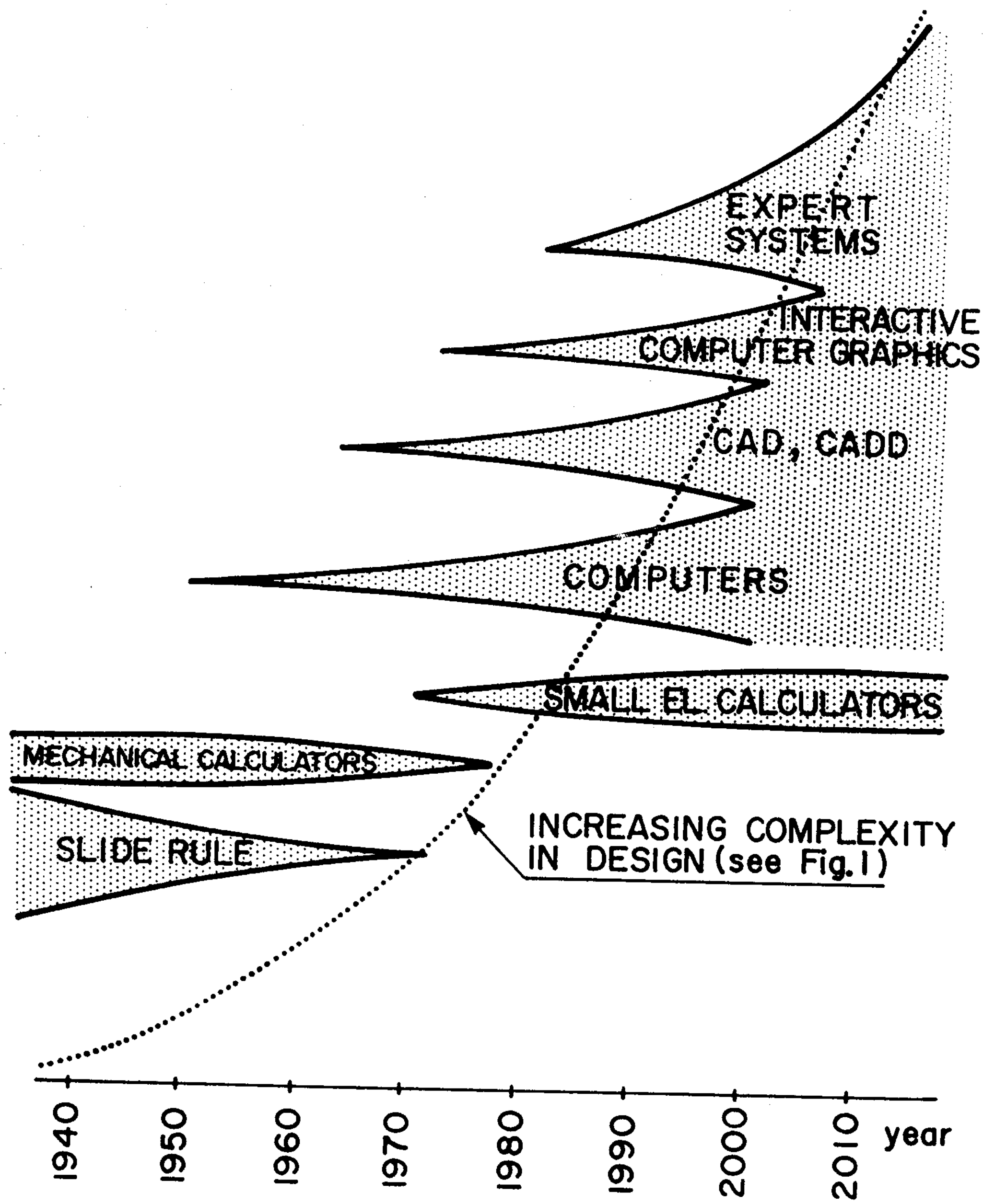


Fig. 3. Developments in Calculation and Computer Techniques

(c) Is the existing concept of standards and the design process in agreement with the possibilities offered by rapidly advancing computer technology and cybernetics?

Preparation of new standards, associated commentaries, design guides and aids as well as the training of designers and the introduction of the new standards into design practice, requires a considerable amount of time. This is particularly true if significant qualitative changes are introduced, as was the case in the 1970's with the transition from ASD to LSD (Kennedy, 1984). For this reason it appears useful to consider even now what the situation in structural steel design is likely to be by the end of this century. Then, according to the results of the prognosis, we should begin without delay to prepare a structure and scheme of standards corresponding to the expected level of application of computer technology, cybernetics, theories of reliability and structural analysis.

This paper summarizes reasons for the need for qualitative changes in standards for structural steel design (especially for the assessment of reliability), and presents suggestions for resolving the problems indicated above.

2. Comments on Existing Standards

Standards are in essence a summary of the current "know-how" expressed by an incomplete set of equations and instructions for assessing the reliability of selected elements, components and systems. Many shortcomings exist in standards and none cover all eventualities specifying lucidly and explicitly the general rules for reliability assessment in a way that would allow the designer to proceed according to the "rules of the game" in all instances which can arise in the design of steel structures in practice.

The development of standards has hitherto resulted in a rapid increase in their size while the number of problems whose solution is neither stipulated nor indicated has decreased relatively slowly. This state of affairs, which is not in agreement with the advances of computer technology and the theory of structures, can be illustrated by several examples.

(i) Standards specify the procedure for assessing the carrying capacity of members subject to axial forces, bending moments or a combination of the two. However, they do not stipulate how to assess generally a member subject to the general force system of 6 quantities acting at both ends. Advanced theories of structures, with the use of computers, allows the response to loading of a space frame to be determined very precisely in the elastic range and even into the elasto-plastic range. Standards have not yet provided information for the general loading case on how to prove compliance in the elasto-plastic range or even in the elastic range.

(ii) The Finite Element Method (FEM) permits elasto-plastic response of a structural element to loading to be determined, yet existing standards do not specify how to assess the structural element carrying capacity of such element under conditions of mono-, bi- and triaxial elasto-plastic deformation. Rather than hindering the effective utilization of sophisticated FEM in practice, standards should be extended to utilize FEM.

(iii) Trusses have generally been designed assuming that the members are joined by pins. Long-term experience has shown that this assumption is usually satisfactory. If the designer considers the joints to be rigid, which they undoubtedly are, the resulting frame analysis - a more precise transformation model, could lead to a 20-25% increase in weight as a result of taking into account the secondary moments due to joint rotation. This paradox arises because simplified pin-connected models based on the designer's experience, implicitly recognize the elasto-plastic shake-down of the members near the joints. The assumption of pin-connection therefore corresponds to the actual behaviour of the structure better than the assumption of elastic frame system behaviour.

(iv) present standards are focused, for the most part, on reliability conditions related to strength and stability. Some information on fatigue is presented but other conditions such as low cycle fatigue, shake-down, brittle fracture and rheological problems may receive rather scant attention.

It appears impossible to include in standards all possible options for the mechanical properties of structural grade steels, all equations for assessment of all types of structural elements, components and systems exposed to different types of loading, and all the possible ways of expressing the carrying capacity and serviceability limits. It thus becomes the designer's responsibility to decide on the process of assessing those cases not specified in the standards. Such decisions should be based on elementary rules defining the assessment process and the individual reliability conditions with adequate precision and clarity. However, the development of standards up to the present tends to proceed towards increasing the number of equations (see Fig. 1), instructions and regulations for a limited number of cases, without providing rules of general validity.

The development of standards may thus have entered a blind alley, as the historic form of standards corresponding to the slide rule period does not provide conditions for efficient utilization of all the facilities offered by cybernetics, by continuously advancing computer technology, by advances in theory, and by achievements in the experimental investigation of steel structures.

3. The Process of Designing Load-carrying Structures

In discerning the way towards a qualitatively new arrangement of future standards for the design of steel structures, one can begin by considering the entire process of activities starting from the instigation of a project and ending with the disposal of the structure at the end of its service life as shown in the schematic diagram in Fig. 4. The series of activities are:

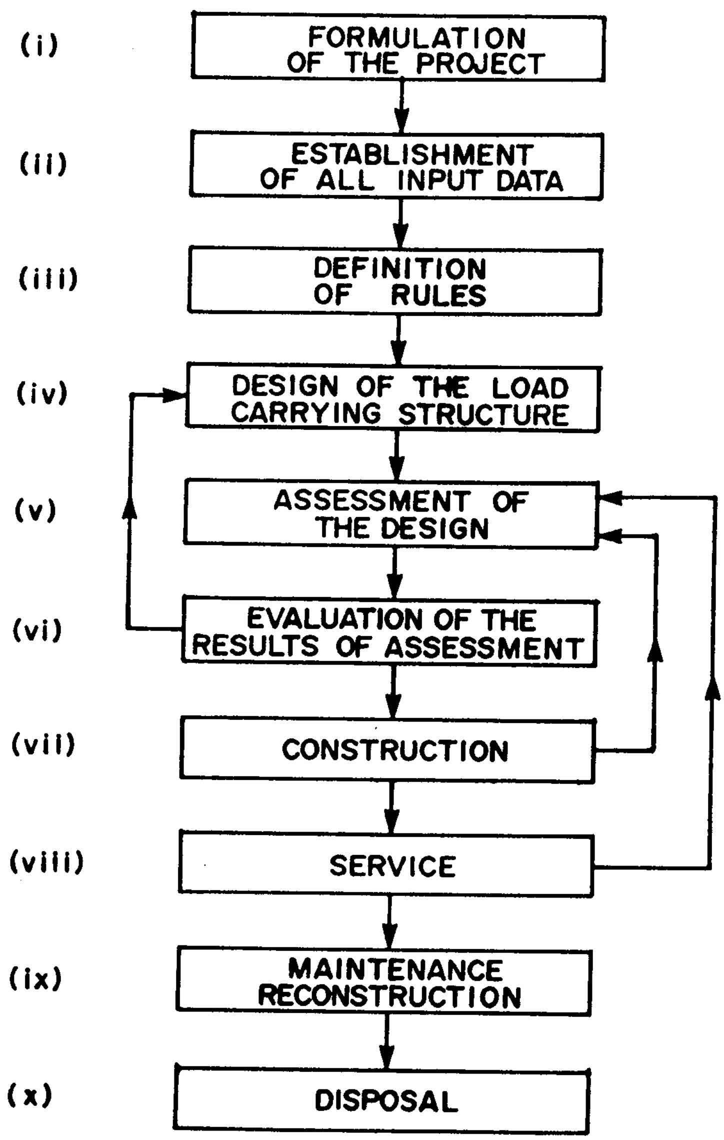


Fig. 4. Sequence of an Engineering Project

(i) formulation of the project,

(ii) establishment of all input data, spatial requirements, environmental conditions, loading and economic considerations,

(iii) definition of the rules, that is the codes or standards or particular specifications that are to be followed in assessing the adequacy and reliability of the structure,

(iv) conceptual design of the load carrying structure and its components including selection of form, materials and proposed dimensions,

(v) assessment of the design according to the rules given in (iii),

(vi) evaluation of the results of the assessment which may require changes and therefore a return to (iv),

(vii) construction, including fabrication, transportation to the site, erection and putting into service,

(viii) the structure is in service for its useful life during which,

(ix) maintenance, overhauling or reconstruction may be required,

(x) disposal, that is dismantling and removal of the structure at the end of its useful life.

The following feedback loops are of particular significance:

(vi) to (iv). To change the design (iv), using the provisions (iii), the designer adjusts the concepts and dimensions by estimating or by using optimization procedures.

(viii) to (v). When difficulties arise in the determination of loading in (ii) or when the response characteristics cannot be calculated with adequate precision in (v) the structure may be designed and assessed on the basis of estimates of the input data. The designer designs in the face of uncertainty. Following construction the actual response of the structure in service as exemplified by strains, deformations, accelerations, may be recorded and reintroduced into the assessment of the particular structure i.e. determination of its actual reliability in accordance with rules (iii). There is also an increase in the body of knowledge that may be applied to other structures.

(vii) to (v). Loading tests on a finished structure (vii) allow assumptions introduced in assessment (v) to be verified.

Various standards and codes of practice exist for most of steps (ii) through (x) for steel structures. We examine, particularly, those related to steps (iii), (v) and (vi) associated directly with reliability of the structure and the assessment and evaluation of its adequacy.

4. Assessment of Adequacy and Reliability of the Structure

4.1 Definitions of Reliability Conditions in Design Standards

Step (iii) in Fig. 4 should include definitions of the overall rules for assessment of reliability. In earlier standards the allowable stress design methods were used whereas nowadays the limit states design method (Canada and Czechoslovakia) or LRFD (AISC, 1986) is applied. In the future the design method may be more advanced to place greater emphasis on the economy of the structure over its service life.

In Fig. 5 is shown the procedure for the assessment of the design of structures, step (vi) of Fig. 4. On the left side are the most unfavourable loading characteristics for the various reliability conditions. These loads are transformed into load response by suitable transformation models that represent, insofar as practicable, the actual structure. The response characteristics constitute one of the 2 inputs needed to apply the reliability conditions with the other being the limit values shown on the right side. For each reliability condition there is a load response and the corresponding limit value. There are two sets of reliability conditions: those related to carrying capacity, designated "U", and those related to serviceability designated "S".

Step (iii) of Fig. 4 defines the rules for assessment of the reliability of the structure. In using the limit states design method for this assessment, the structure and its components are considered to have adequate reliability if the defined most unfavourable responses, the extreme characteristics, do not exceed the limit values. These values, defined for all the reliability conditions during the life of the structure, can be grouped into carrying capacity limit states (sometimes called ultimate limit states) and serviceability limit states as proposed by Marek (1986).

Carrying capacity reliability conditions include:

U1 strength, including second-order effects

U2 shake-down

U3 low-cycle fatigue, (alternating plasticity)

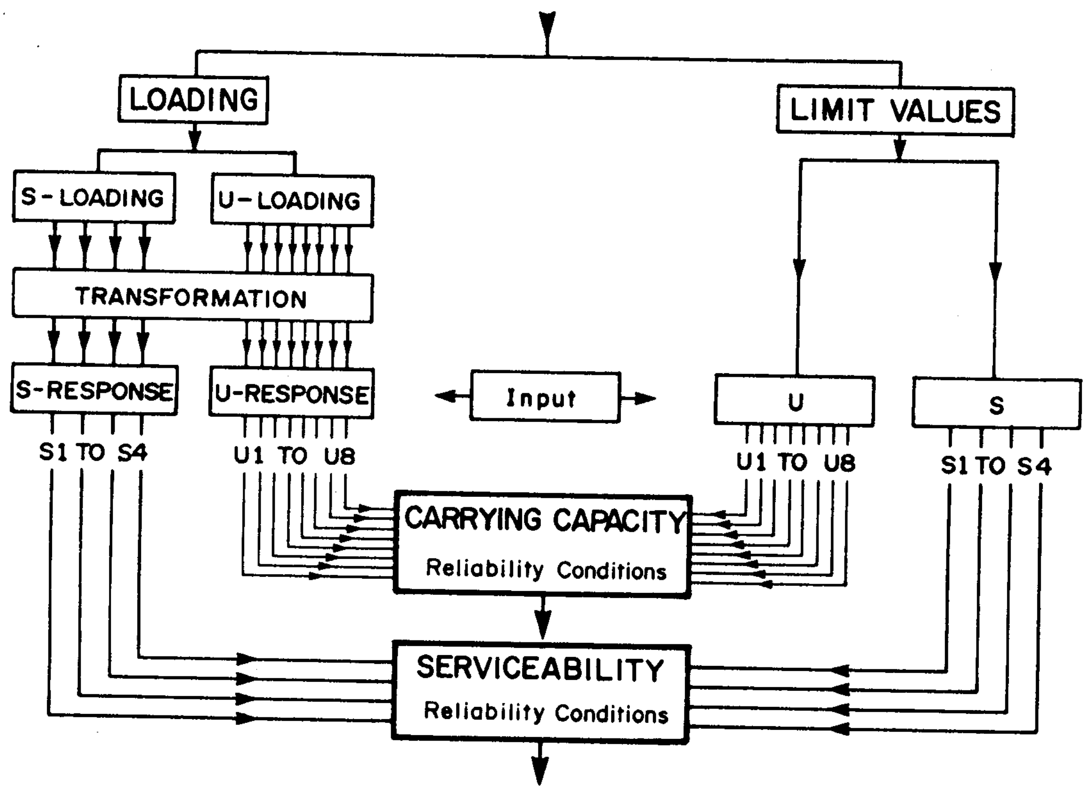


Fig. 5. The Assessment of Design

U4 high-cycle fatigue

U5 brittle fracture

U6 overall stability (sliding, overturning, lifting, rotation)

U7 rheological effects on strength

U8 combinations of the above.

Serviceability reliability conditions include:

S1 human comfort

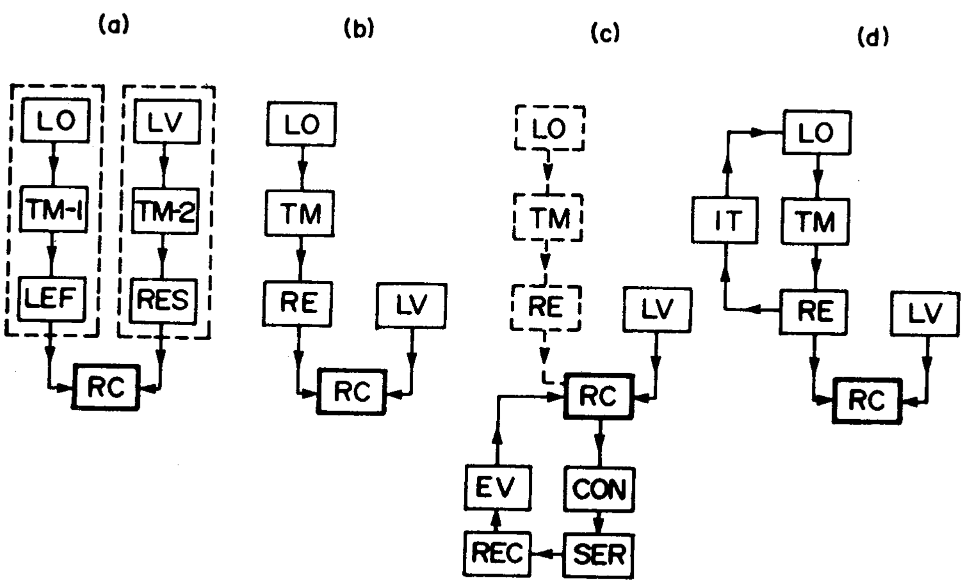
S2 adequate performance of mechanical, chemical, electrical and electronic equipment

S3 minimization of damage to building finishes, such as glazing partitions and curtain walls

S4 gas and water tightness as required; suppression of noise generated by service of the structure, special requirements.

4.2 Formal Expression of Reliability Conditions

Reliability conditions can be expressed formally in standards in several ways. Fig. 6a illustrates the arrangement most frequently found in standards to express strength conditions. By use of the transformation model (TM-1), the loads are converted into load effects (LEF), that is the structure is analyzed under the action of the loads to determine the axial forces, shears and moments acting on the ends of members and at all cross sections to be investigated. The designer performs this function. Transformation model (TM-2), serves to establish the resistances (RES), that is the carrying capacity of the cross



LEGEND:

CON	CONSTRUCTION	RE	RESPONSE
EV	EVALUATION	REC	RECORDING
IT	ITERATION	RES	RESISTANCE
LEF	LOADING EFFECT	RC	RELIABILITY CONDITIONS
LO	LOADING	SER	SERVICE
LV	LIMIT VALUES	TM	TRANSFORMATION MODEL

Fig. 6. Formal Expression of Reliability Conditions

section, component or member working from some defined limit value (LV) that is established using theory, assumptions, such as the amount of initial imperfections, and experimental evidence. Generally TM-2 is given in standards. The load effect is then compared to the resistance to see if the reliability condition (RC) is satisfied.

Reliability conditions for which TM-2 models are not given in standards cannot be assessed by the method of Fig. 6a and a more general format is therefore needed. Fig. 6b shows this more general approach. The general transformation model converts the loads not into load effects but into the response of the structure and its components as may be expressed in terms of stresses, strains, deformations, load-deflection curves, accelerations, stress-range spectra, stress intensity factors, etc. The designer performs this function and satisfies the reliability conditions by comparing the response to defined limit values obtained from standards or other sources based on LSD rules. This approach is used in some contemporary standards in assessing high-cycle fatigue. The most unfavourable characteristics of the response history, as expressed by the stress range spectrum are compared, using some cumulative fatigue damage criterion, to a limit value expressed by an S-N curve. The approach is completely general and can be applied to assess any reliability condition both for carrying capacity and serviceability. It is currently frequently used for serviceability conditions as is the case when we compare a deflection response to limit values. It is also the approach we use, in assessing the carrying capacity of member, when we compare the sum of the axial force and moment ratios to the limit value of 1.

Fig. 6c illustrates the third approach which may be used when there are substantial uncertainties in the loading and/or the transformation model to establish the response to the loads as discussed in the feedback loop (viii) to (v) of Fig. 4. The structure is built and assessed subsequently based on observations in service. The response history is then evaluated and used as feedback to assess the reliability conditions. This approach is used quite frequently in the assessment of the reliability condition for fatigue. It may lead to modification of the existing structure or to an increase in the general body of knowledge. A subset of this procedure is the case when load tests are used to assess the load carrying capacity of a structure.

Another approach suggests itself as shown in Fig. 6d which deals with the case when the loads depend on the response of the structure. Consider the case of a roof that deflects due to weight of rain water or the case of soil-structure interaction. The transformation model determines the response for an initial set of loads but an iterative procedure is then required to find the response due to the changed loads. When the response stabilizes it is compared to the limit values to prove the reliabilty condition.

4.3 Reliability and Standards

A structure is deemed to be reliable when it meets reliability conditions such as safety, durability, serviceability, maintainability or even economic limits. The term reliability reflects such aspects and is used in that sense. The random variables that must be evaluated in assessing reliability are the loading, the transformation models and the limit values as shown in Fig. 6. These three groups of random variables may be dealt with at three different levels in standards.

In the level 1 method each of the groups of random variables is analyzed separately. The most unfavourable characteristics are determined for each group. Many current standards are based on this approach and in assessing the reliability condition take the most unfavourable loads, conservative transformation models and the least favourable limit values.

In the level 2 method two groups of the random variables are combined. For example in CSA Standard S16-1 (CSA, 1924-1984) and in the AISC Load and Resistance Factor Design specification (AISC, 1986) resistances (strength reliability condition U1 in Fig. 4) combine the random variables of the transformation models and of the limit values. The resistance formulations include the variability of mechanical and geometrical properties (limit values), and imperfections and fit of the transformation model (transformation variability).

In the level 3 model, not yet generally used, the joint occurrence of the 3 groups of random variables are considered.

The Level 1 method does not consider the joint probabilities of occurrence; the Level 2 method, in the example cited, considers the joint probabilities of occurrence in determining the strength reliability condition but does not consider the loading; the Level 3 method encompasses all.

Within this framework there is an increasing use in standards of statistical data and probabilistic evaluations but where information related to any of the three random variables is lacking the designer is still called upon to exercise his professional judgement. Also in quantifying new standards it is common practice to calibrate or verify them against existing experience. The application of statistics and probabilistic methods is helping to refine our reliability assessment but will never replace completely the exercise of judgement by the designer.

5. Suggested Rearrangement of Standards

5.1 Comments on the Present Situation

The accelerating advances in computer technology have brought significant changes to the design and construction processes ranging all the way from computer drafting to computer scheduling of the job. Computer aided design is becoming commonplace and includes sophisticated analyses programs and interactive computer graphics. With computers, the static and dynamic response of structures can be determined. Structures can be analyzed and redesigned to arrive at optimum proportions. Computers are used to draw plans and to investigate erection schemes and establish construction sequences. It seems logical therefore that computer technology be used to change qualitatively the scheme or arrangement of standards. Apart from the qualitative change in standards from deterministic working stress design standards to probability-based limit states design standards the form of standards is the same today as it was in the days of the slide-rule and hand computation. Standards still give equations, albeit more numerous and more complex, to define selected design cases. Computer technology is so far limited to the development of algorithms to represent these cases. The arrangement of standards should be re-evaluated to take full advantage of the developments in cybernetics and the rapidly expanding computer technology.

5.2 Qualitative Changes

The upper line in Fig. 7, taken from Fig. 1, shows the trend of increasing complexity in standards. How can the format of standards be changed to utilize computer technology effectively? Fig. 7 suggests such a qualitative rearrangement. Up to 1990, say, in the present scheme of things, as shown, standards give the basic rules and are supplemented with numerous secondary standards dealing with materials and particular components. A significant body of information exists in data bases. Such data bases currently include tables of geometric properties of cross-sections, mechanical properties of steels, resistances of welds, bolts, compression, tension and flexural members. See Appendix I. These data are consistent with the

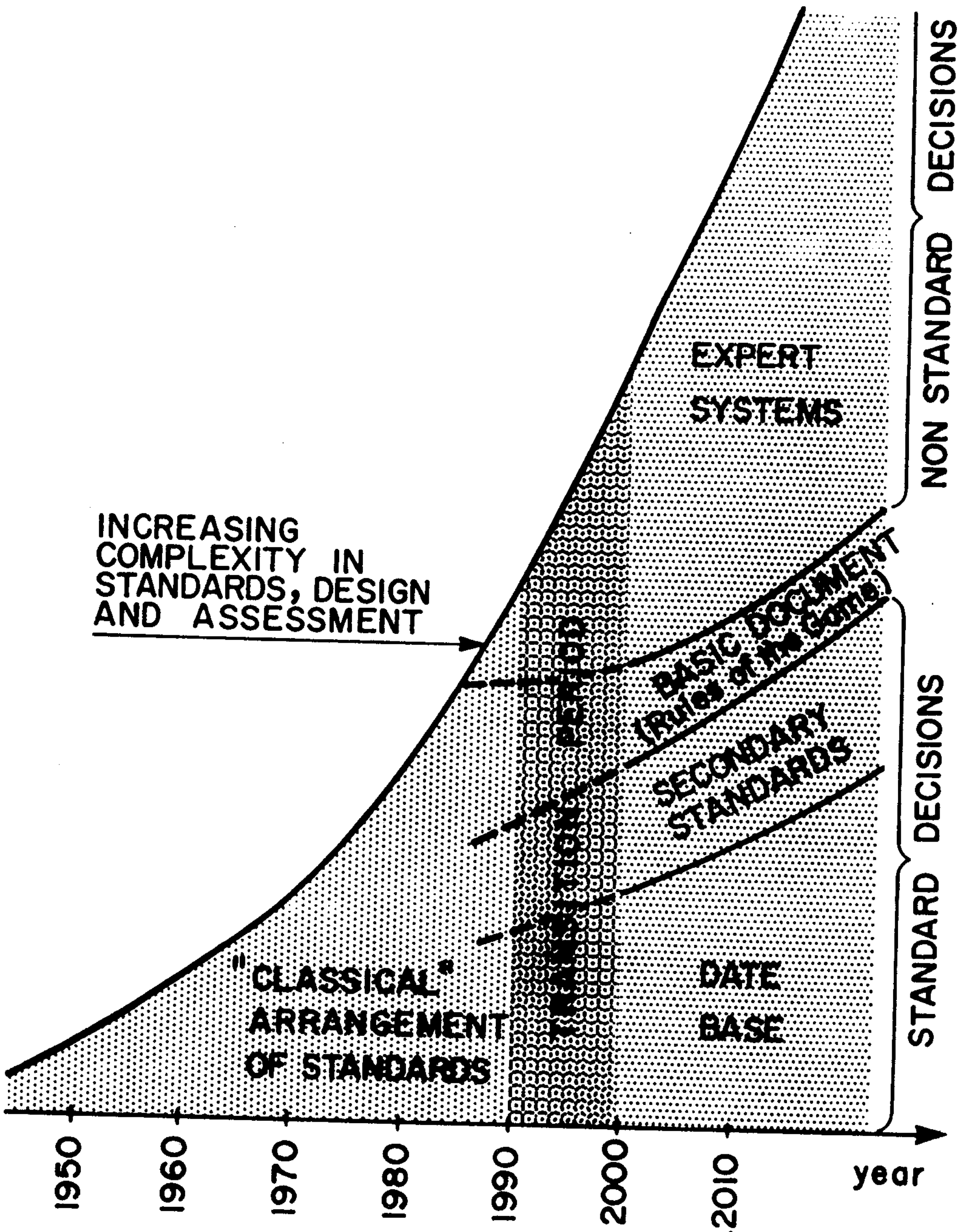


Fig. 7. Proposed Qualitative Changes in Standards

rules of the game and are accepted verbatim by the designer. While generally available in tabular form more and more of these data are being made accessible through computers.

In the transition period, say 1990 to 2000, the standards could be reorganized to present the basic rules of the game and not just mathematical expressions which interpret those rules. With this approach the standards can cover the full spectrum for the design of structures as proposed in Part B of this report. Currently in CSA Standard S16.1, to take a single example, the designer is restricted to using 2 column curves for all steel cross-sections from angles to jumbo wide flange shapes. These curves attempt to reflect the statistical variations in mechanical and geometric properties and to take into account out-of-straightness and residual stresses. Should not the standards give the basic rules, that is, what quantities are to be considered in arriving at the strength of a compression member? Then the designer has the freedom, following the basic rules, with access to computerized data bases to assess the column strength. There are few prescriptions to follow but the basic rules must be met.

The standard of course then presents basic rules related to all reliability conditions that are not yet fully covered and at the same time gets rid of narrow prescriptions. Basic rules would be given for assessment of all conditions related to carrying capacity and serviceability as shown in Fig. 5. The data bases can be developed and updated independently of the standard. Secondary standards, also accessible through the computer, can be developed to cover many of the commonly occurring cases, but of course must follow the basic rules. Secondary standards could, for example, give S-N curves for common details. The basic rules by which these S-N curves are derived are given in the standard and the designer would apply these basic rules (perhaps a crack propagation approach) to more complicated situations.

The key to this qualitative change in the formulation of standards is the development of expert systems.

In Fig. 7, moving through the transition period, the growth in complexity is taken care of by some growth of the computerized data bases and by the major growth of the expert systems. Expert systems help the designer to make non-standard decisions, and represent the body of computerized knowledge. Expert systems are a storehouse of knowledge containing the findings, recommendations, experience and examples of those experts who have contributed to the development of the particular facet. In consulting the expert system the designer is given advice on how to proceed. For example, the designer presents information about a proposed building (number of storeys, area, height, lateral extent, location and earthquake zone and potential wind loading) and receives information on possible lateral load carrying systems. The expert system will advise him on the characteristics of the possible systems, their advantages and disadvantages, the factors to be assessed such as ductility, low-cycle fatigue, and the strategy for assessment. The computer revolution has automated calculations; computer expert systems should automate reasoning. See Appendix II. Of course the expert systems are continuously updated and do not wait on a change in standards.

5.3 On the Question of Responsibility

Responsibility for the correctness and use of information in the three general areas of standards, data bases and expert systems lies with different people.

The responsibility for the correctness of the basic documents giving the rules of the game lie ultimately with the authority issuing the standards. Similarly, secondary standards and data bases must conform to the rules of the game and the issuer of these is responsible again for their correctness. Of course the designer is responsible for interpreting the basic standard, secondary standards and data bases correctly.

A different situation exists with the use of expert systems. Here the designer must take responsibility for his use of the information made available to him. He has latitude in using the information, and in interpreting the information, but finally the decision on how to use it and therefore the responsibility rests with him. Expert systems are continuously evolving and contributors will only continue to contribute when the user (the designer) accepts responsibility for his use of the systems.

6. Summary and Conclusions

A review of the increasing complexity of existing standards shows that a discrepancy exists between them and the increasingly sophisticated design process that utilizes computer technology and cybernetics to the full. Standards, for the most part, give a set of prescriptions of restricted validity and do not contain, even with their increased complexity, the general rules to assess the various reliability conditions.

A qualitative change in the arrangement of standards is proposed. The basic standard should define the rules of the game, defining reliability conditions for both groups of limit states (carrying capacity and serviceability) taking into consideration loading, analyses, selection of adequate transformation models to obtain the response, and definition of limit values. An outline of a proposed basic standard is given in part B of this report.

Secondary standards, derived from the basic standard, deal with commonly occuring situations that are easily documentable. Supporting the basic standard and secondary standards are extensive computerized data bases, consistent with the basic rules of the game, and containing all numeric data on mechanical and geometric properties, and such like.

Essential to the intelligent use of this layout is the development of expert systems containing a broad base of knowledge related to the many facets of structural engineering.

With the introduction of the basic standard, data bases and expert systems, the present standards can be slimmed down to essential truths and no longer would be unmanageably complex.

The qualitative change proposed in design standards requires thorough long-term preparations with a start now if we wish to be operating effectively by the turn of the century. Our present standards are outmoded.

Acknowledgements

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Appendix I

Role of Data Bases in Structural Steel Design[1]

In structural steel design, data management is becoming more and more essential. The volume of data related to the design (including the assessment of reliability) has been growing and cannot be accommodated within standards. When data bases are compiled and evaluated, data can be shared by users in the field of structural design.

Data base management systems are necessary to manage and maintain the large volumes of data that are required in the design and assessment of steel structures. They are an essential element in the development of the design process, standards and

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1. General comment based on Gero (1985).

integrated environments for computer aided design.

Data bases should be as flexible as possible and at the same time the data contained therein should be precisely defined. In developing data bases areas to be considered include:

(a) the form in which the data is presented, that is, as real members, vectors, matrices or mathematical models for example. The storage of the data requires the corresponding processing capability,

(b) the integrity of data, and

(c) limits on the validity of the data (constraints) must be given.

Appendix II

Expert Systems in Structural Steel Design[4]

Most current applications of computers in structural steel design are based on two fundamental concepts: calculus of real numbers and computer programs. This application is unable to represent and manipulate knowledge in an explicit and coherent form.

The design and assessment of the reliability of steel structures are bound up with the concepts, ideas, judgement, and experience of the designer. With this knowledge the designer satisfies the reliability conditions specified in the standard.

4. These comments are based on Gero, (1985) and on Kosem and Maher (1986)

The knowledge and its use appears to be outside the realm of traditional computing. The designer makes use of his knowledge but only a part of his work is the strict application of rules or requirements contained in standards. His design decisions are limited by the extent of his knowledge or by the knowledge he can readily acquire.

Expert systems capture the knowledge of experts in a computer program that can advise non-experts. Expert systems can distill the expertise of one or many experts. Large amounts of experimental data and physical measurements can be assimilated. Advanced expert systems are capable of surpassing any one experts' ability to deal with today's accelerating complexity and change.

Design standards contain a large amount of knowledge compiled over a long period of time, by people dealing with different aspects of the same discipline. This knowledge is usually widespread and may be ill structured. Consequently, to find and interpret the necessary information, is often difficult and time consuming. Expert systems can provide the means of representing and manipulating the knowledge presently contained in standards, commentaries, design aids, textbooks and other sources.

PART B

ON A BASIC STANDARD FOR STRUCTURAL STEEL DESIGN

ON A BASIC STANDARD FOR STRUCTURAL STEEL DESIGN

Abstract

The discrepancy between existing standards for structural steel design and the increasingly sophisticated assessment process that utilizes computer technology is discussed in Part A of this report. A suggested qualitative change in the arrangement of standards contemplates first of all a basic document that defines the "rules of the game". Such a proposed basic document is outlined here and the fundamental characteristics explained. The key to the assessment of reliability is the application of two equally significant groups of reliability conditions, related to carrying capacity and serviceability. Definitions of the reliability conditions are proposed. Although probability and statistics are significant tools used in the analysis of variables, nevertheless, the application of estimates and knowledge of the designer remain a significant part of the assessment process. His creative work should be based on a complete understanding of the design scheme and rules. The basic document is a general and complete set of instructions for the designer. It should be accompanied by secondary standards, data bases and expert systems as discussed in Part A of this report.

1. Introduction

In Part A of this report it was shown that, with the increasing complexity of existing standards for structural steel design, discrepancies exist between them and the increasingly sophisticated assessment process that utilizes computer technology. A qualitative change in the arrangements of the standards was proposed. The suggested arrangement consists of the basic document defining the "rules of the game", computerized data bases containing data on mechanical properties of materials, etc., and secondary standards (corresponding to the basic document) dealing with commonly occurring situations. Essential to the intelligent use of the proposed layout is the development of expert systems (Kostem and Maher, 1986).

The detailed outline of a basic standard is given in Section 2. The key to the assessment of reliability is expressed by two sets of conditions corresponding to the commonly used definitions of the limit states of carrying capacity and serviceability. Applications of reliability theory are considered. The lack of information may, however, even in the future, require some of the data to be based on qualified estimates, recommendations obtained from expert systems or on experience. The complex character of the assessment process is considered and the regulations related to individual phases of the process are outlined.

With the introduction of a basic standard, data bases, secondary standards and expert systems, the present standards can be slimmed down to essential truths, while the proposed arrangement would allow further up-dating, and improvements without revisions of unmanageably complex standards.

In chapter 3 the various sections of the proposed standard are discussed while in chapter 4 a summary and conclusions are presented.

2. Proposed Outline of a Basic Standard

2.1 Scope

This proposed standard contains the basic rules and regulations for the assessment of the reliability of steel structures according to the Limit States Design Method.

The term, "steel structures" relates to:

(a) all types of load carrying systems, members, components and elements including their joints and connections;

(b) all types of structural steel sections and other steel products, including bolts, welds, and other fasteners as well as supplementary components;

(c) steel structures defined by (a) and (b) may be found in buildings, bridges, silos, towers, masts, off-shore structures and other projects in all phases of existence such as construction, service, reconstruction and disposal and, as well, under all environmental conditions (temperature, corrosion, etc.), and gravity conditions.

2.2 General Definitions

2.2.1 Limit States and Reliability Conditions

Limit States are limiting states of a structure at which it ceases to fulfill its intended function.

Carrying capacity limit states are those associated with safety and durability of the structure.

Serviceability limit states are those associated with restrictions on intended use of the structure.

Assessment of the reliability of the structure is performed by applying two sets of reliability conditions:

(a) Carrying capacity reliability conditions refer to all types of failure of a structure; the response of the structure corresponding to the expected loading history during the construction and the life shall be considered. (see 2.5).

(b) Serviceability reliability conditions refer to service requirements and are based on defined limiting values (see 2.6).

All data and their interrelationships applied in the reliability conditions should preferably be based on probabilistic analyses to establish an acceptable level of the probability of exceedance of the limit states. In cases where the statistical information is inadequate for a complete probabilistic analysis the evaluation may be carried out using conservative estimates of data, judgement and knowledge.

All reliability conditions contained in both sets have equal significance.

The input data for the reliability conditions are:

(a) response characteristics, of the structure to the expected loading events (see Sec. 2.3),

(b) limit values (see Sec. 2.4).

Safety is established for the carrying capacity reliability conditions, when the response characteristics are less than the corresponding limit values (see Sec. 2.5). Both the responses and limit values shall be determined in accordance with the rules specified in this basic document.

Serviceability conditions are met when the response characteristics, do not exceed the limit values during a defined portion of the service life (see Sec. 2.6).

The defined response characteristics, the limit values and the portion of the service life shall express the essence of the individual reliability conditions.

2.2.2 Scheme for Assessment of Reliability

The schemes for the assessment of reliability include:

(a) Basic scheme:

The expected loading events are transformed, using an adequate transformation model, into the response. The response characteristics so obtained are compared with the limit values.

(b) Load effect and resistance scheme:

The expected loading events are transformed, using a first transformation model into loading effects (expressed by moments and forces on a member or component). Using a second transformation model, the resistance of the member component is defined. The loading effect is then compared with the resistance.

(c) Loading-response interaction scheme:

In some instances the response affects the loading (e.g. ponding), and is best determined iteratively. The response characteristics are compared with the limit values.

(d) Feedback scheme:

When information on the loading or transformation models is lacking the actual response of the structure is used to provide these data. The response is then compared with limit values and the structure is modified if necessary.

(e) Other schemes:

In case of reconstruction and in some other instances, the scheme of assessment has to be adjusted in order to include the effects of the past loading history into the response and limit values.

2.2.3 Application of Reliability Theory

The three groups of variables affecting the assessment process, generally considered as random variables, are:

(a) loading events,

(b) fit of the transformation model including imperfections of the structure,

(c) limit values.

Depending on the data available and the character of the structure being assessed, reliability theory may be applied according to:

Level I Method:	Each set of variables (a), (b) and (c) is evaluated separately, or
Level II Method:	Two sets of variables are evaluated together [(a+b) or (b+c)] while the remaining set is evaluated separately, or
Level III Method:	All three sets of variables [(a) + (b) + (c)] are evaluated jointly.

The reliability index approach (first order second moment) used in AISC, (1986) and CSA (1984) corresponds to the Level II Method.

The Level III Method is the ideal probabilistic approach, which is considered not to be realistic for design in the near future.

To define the response events and the limiting values, the probabilistic analysis shall be based on probabilities of exceedance as shown in Table 1, for example, where p* is a basic probability of exceedance established by the regulatory authority.

When adequate statistical data are not available, response events and limiting values shall be based on simplified probabilistic approaches and/or qualified estimates, experience, calibration with existing practice and knowledge.

Table 1

	Sets of Variables and Sets of Combinations		Importance of Structure		
			Low	Medium	High
I	Loading (LO)		10 p*	p*	10^{-1} p*
I	Transformation Model (TM)		10 p*	p*	10^{-1} p*
I	Limit Values (LV)		10 p*	p*	10^{-1} p*
II	LO + TM	TM + LV	p*	10^{-1} p*	10^{-2} p*
II	LV	LO	10 p*	p*	10^{-1} p*
III	LO + TM + LV		10^{-2} p*	10^{-3} p*	10^{-4} p*

2.2.4 Importance of the Structure

The evaluation of safety considering response and limit values in carrying capacity reliability conditions shall take into account the consequences of collapse as related to the use and the occupancy of the structure and as suggested in Table 1. In the absence of adequate statistical data conservative estimates shall be used (see 2.2.3).

2.3 Loading - Transformation Models - Response

2.3.1 Loading

Loading is a time dependent phenomenon which causes changes in stresses, strains and position of the structure.

Loading may be expressed in terms of forces, pressures, accelerations, velocities, energy, imposed deformations, temperature changes and combinations of these quantities. The simultaneous occurrence of two or more loadings events shall be evaluated.

2.3.2 Transformation Models

The transformation model shall be appropriate for the response of the structure to the loading and shall represent the behaviour of the structure as closely as possible. Simplifications may be introduced to make the problem tractable.

To simulate the actual structure the transformation model selected may be:

(i) theoretical

(ii) semi-empirical

(iii) empirical

To simulate the response of the structure the model selected may be:

(i) elastic or elastoplastic

(ii) static or dynamic

(iii) first order or second order theory with correlations as applicable.

Combinations of (i) to (iii) shall be considered.

2.3.4 Evaluation of the Response

The response is one of the two inputs into the assessment of the reliability condition. Response may be expressed (generally considering time-dependency) in terms of stress, strain, stress intensity factors, stress-range spectra, acceleration, deflections, moments and forces and the like as appropriate for the particular reliability condition being assessed. The response considered shall take into account possible changes in the use of the structure that can be anticipated by the owner.

2.4 Limit Values

2.4.1 Limit Values for Carrying Capacity

The probability of exceedance of limit values for the carrying capacity reliability conditions during the life of the structure shall be as given in Table 1.

The main groups of limit values are:

(a) Mechanical properties of materials (Sec. 3.5).

(b) Limit values defining failure (collapse) of systems or members or elements (strength reliability condition). These values depend on the mechanical properties of the material, on the initial imperfections and on the configuration of the structure and its components and on the loading process.

(c) Limit values for the case of accumulation of damage (fatigue damage or incremental collapse). These values depend on the mechanical properties of the material and on the configuration of notches or on the structural system.

(d) Limit values for overall stability.

The limit values are established by the designer to meet the safety requirements implicit in this document.

2.4.2 Limit values for serviceability reliability conditions may be exceeded during a portion of the life if approved by the owner.

(a) The limit value for permanent deformation shall be determined and approved by the owner with regard to the nature and intended use of the structure.

(b) The limit value of acceleration of the structure shall be determined with regard to the human comfort.

(c) The limit values for accelerations and deformations shall be determined so that equipment functions properly according to the requirements formulated by the equipment supplier and owner.

(d) The limit values for deformation and acceleration shall be determined to minimize the damage of building finishes.

(e) The limit value for other quantities (noise, opening of gaps and other) shall be as agreed upon by the owner.

2.5 Carrying Capacity Reliability Conditions

The following conditions (Marek, 1986) shall be met:

2.5.1 Strength

This condition refers to the extreme response. The strength carrying capacity may be exhausted by reaching the collapse level of the member or structural system, by local buckling, by failure of the fasteners, by reaching strain limitations and limits of energy absorption; (see commentary).

2.5.2 Shake-down Condition

When the response is elastoplastic, the shake-down reliability condition as shown in Fig. 1 shall be met as follows:

(a) If negligible plastic reversals and negligible accumulation of plastic damage (increments of permanent deformation) occur, the shake-down condition is met.

(b) If non-negligible plastic reversals occur, the low-cycle condition (see Sec. 2.5.3) shall be met.

(c) If non-negligible accumulation of plastic damage occurs, total accumulation shall be such that the strength limits (see Sec. 2.5.1) over the life of the structure are not exceeded.

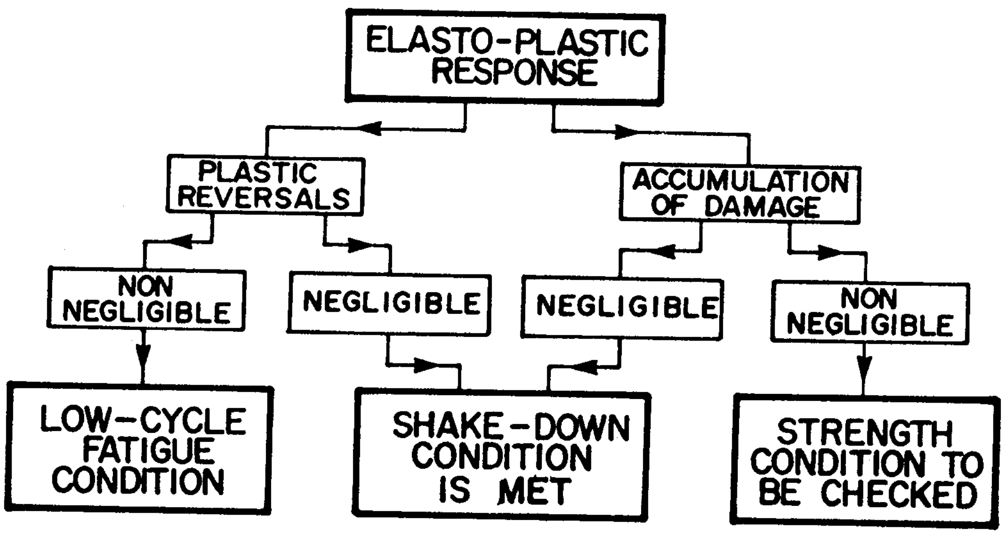

Fig. 1. Shake-down Reliability Condition

2.5.3 Low-Cycle Fatigue

If the response consists of non-negligible plastic reversals, the low-cycle reliability condition shall be met, that is the total accumulation of damage shall not exceed the limit values.

2.5.4 High-Cycle Fatigue

The accumulation of fatigue damage (expressed, for example, by the extension of fatigue cracks over the life of the structure) shall be less than the limit value (expressed, for example, by the crack length corresponding to the failure by fracture of the remaining section).

2.5.5 Brittle Fracture

The response of the structure as may be expressed by local stresses, strains, stress intensity factors and similar quantities and, taking into consideration initial imperfections, initial cracks, other defects, residual stresses, strain rate and environmental conditions (temperature and corrosive environment), shall be less than the corresponding values again corresponding to the temperature, environment and strain rate.

2.5.6 Positional Stability

The positional stability of the structure or its components (sliding, overturning, lifting from bearings) evaluated using extreme maximum of active actions and extreme minimum of passive actions shall be satisfied.

2.5.7 Rheological Aspects

Where materials, members or the structure exhibit time dependent properties, the response over the total life of the structure shall not exceed the appropriate limit values.

2.5.8 Combinations of Conditions

The interaction of reliability conditions given in 2.5.1 to 2.5.7 shall be considered.

2.6 Serviceability Reliability Conditions

Serviceability reliability conditions are characterized both by limit values and the portion of the service life during which the limit values may be exceeded. These limitations shall be approved by the owner.

2.6.1 Permanent Deformations

The limit values are expressed by permanent deformation or by total elastoplastic deformation. The response considered is that corresponding to a probability of exceedance p^{**}, generally greater than or equal to p^{*} the probability of exceedance considered for the strength reliability condition (Table 1). See Sec. 3.7.3.

2.6.2 Human Comfort

The response of the structure, as expressed by acceleration for example, shall not exceed the limit values during the specified period.

2.6.3 Proper Functioning of Equipment

The response of the structure, as expressed by acceleration and deformation, shall not exceed the limit values during the time of operation of the equipment.

2.6.4 Minimization of Damage to Building Finishes

The response expressed by deformation and acceleration shall be less than the limit values approved by the owner with regard to the extent of damage to building finishes.

2.6.5 Other Conditions

Noise caused by the structure in service, opening of gaps and other conditions, shall not exceed the limit values during the portion of the service life as required by the owner.

2.7 Interaction with Data Bases

Quantities, data and information derived according to the rules given in Sections 2.2 to 2.6 and approved by the authority having jurisdiction, may be stored in data bases.

Stored quantities shall be clearly defined and the basis of their establishment shall be given.

2.8 Application of Expert Systems

Recommendations, strategy for solving individual problems, references, examples and further information related to the assessment process, as stored in the expert systems, shall correspond to the basic rules specified in Sec. 2.2 to 2.6.

2.9 Responsibility

2.9.1 Basic Standard

The responsibility for the correctness of this basic standard giving the rules of assessment lies with the authority issuing this standard.

The designer is responsible for interpreting the basic standard correctly.

2.9.2 Secondary Standards, Data Bases and Expert Systems

The responsibility for the correctness of data stored in data bases and for secondary standards related to the basic document lies with the issuing authority. The designer is responsible for correct use of data and other information from data bases and secondary standards.

The designer is responsible for his use of information made available to him in expert systems.

3. Commentary

3.1 Scheme of Design Documents

Compared to existing standards as discussed in Part A of this report the proposed basic document defines first of all the complex rules of assessment of reliability. Details such as the evaluation of loading, the selection of transformation models and the determination of limit values consistent with the probabilities of exceedance are left to the designer.

For common cases the designer may apply secondary standards and data bases developed in accordance with the basic document.

The creative work of the designer should be based on a complete understanding of the design scheme. The secondary standards, data bases and software for analyses are tools to achieve this creative end. Only a part of a designer's work is related to so called standard decisions corresponding to a unique interpretation of data contained in standards. The most significant part of a designer's activities relates to non-standard decisions. Expert systems should provide a significant assistance to the designer in making non-standard decisions.

3.2 Application of Reliability Theory

It is considered that a complete third level safety analysis is unlikely to be performed in the actual assessment process of steel structures for some time. It may not be possible to evaluate the safety of structures by analyzing the complete interrelationship of all random variables involved. Therefore a second, or even first level analysis, is likely to be performed with reliability expressed by comparison of two quantities, each of them corresponding to the evaluation of a set of variables.

The key to the assessment of reliability proposed here is the application of two groups of reliability conditions reflecting all types of limitations of carrying capacity and of serviceability.

Probability and statistics are significant tools used in the analysis of random variables and for evaluation of input data for reliability conditions. They allow improvements of the reliability assessment format, however the application of estimates, experience and judgements of the designer are considered to remain a significant part of the assessment process.

The assessment process requires the active involvement of the designer using his knowledge and experience innovatively and imaginatively, not just passively interpreting standards.

3.3 Loading

In present standards load factors are commonly used when considering strength reliability conditions. This may be considered as a heritage in the transition from the allowable stress method to the limit states method and arose so that extreme loads (the specified loads multiplied by the load factors) could be considered. It is suggested that load factors need not be used in the future but that the evaluation of the reliability conditions be carried out corresponding to the expected extreme load events.

3.4 Transformation Models

The selection and application of the transformation models are the responsibility of the designer. In order to assist in assuring fit and adequacy of models, the models referred to in the secondary standards may be used or expert systems may be consulted.

3.5 Response of the Structure to the Loading

The loading to be considered in the design of any structure is the total of loading events that are expected to occur during the life of the structure. From these loading events the response events are determined and serve as input for the evaluation of the reliability conditions.

3.6 Limit Values

Limit values that should be considered, related first of all to mechanical properties, for example, are shown in the schematic diagram of Fig. 2. The extent of this figure shows that it is becoming increasingly difficult to contain all of these values in traditional standard format. The vertical axis gives material properties related to various reliability conditions. The other axes show that the variation with temperature must be considered and that the material properties must be given for various products. Consider example 'A' where a steel structure is required to perform at an elevated temperature. A limit value of concern is the yield strength of the parent steel at that temperature. Example B presents the case where the designer is concerned with the brittle fracture of a weldment at low temperatures. Point 'B' represents the K_{IC} value of the weld involved at that temperature. In the assessment of high cycle fatigue at normal temperatures shown by example C, the designer may need information on the rate of crack growth.

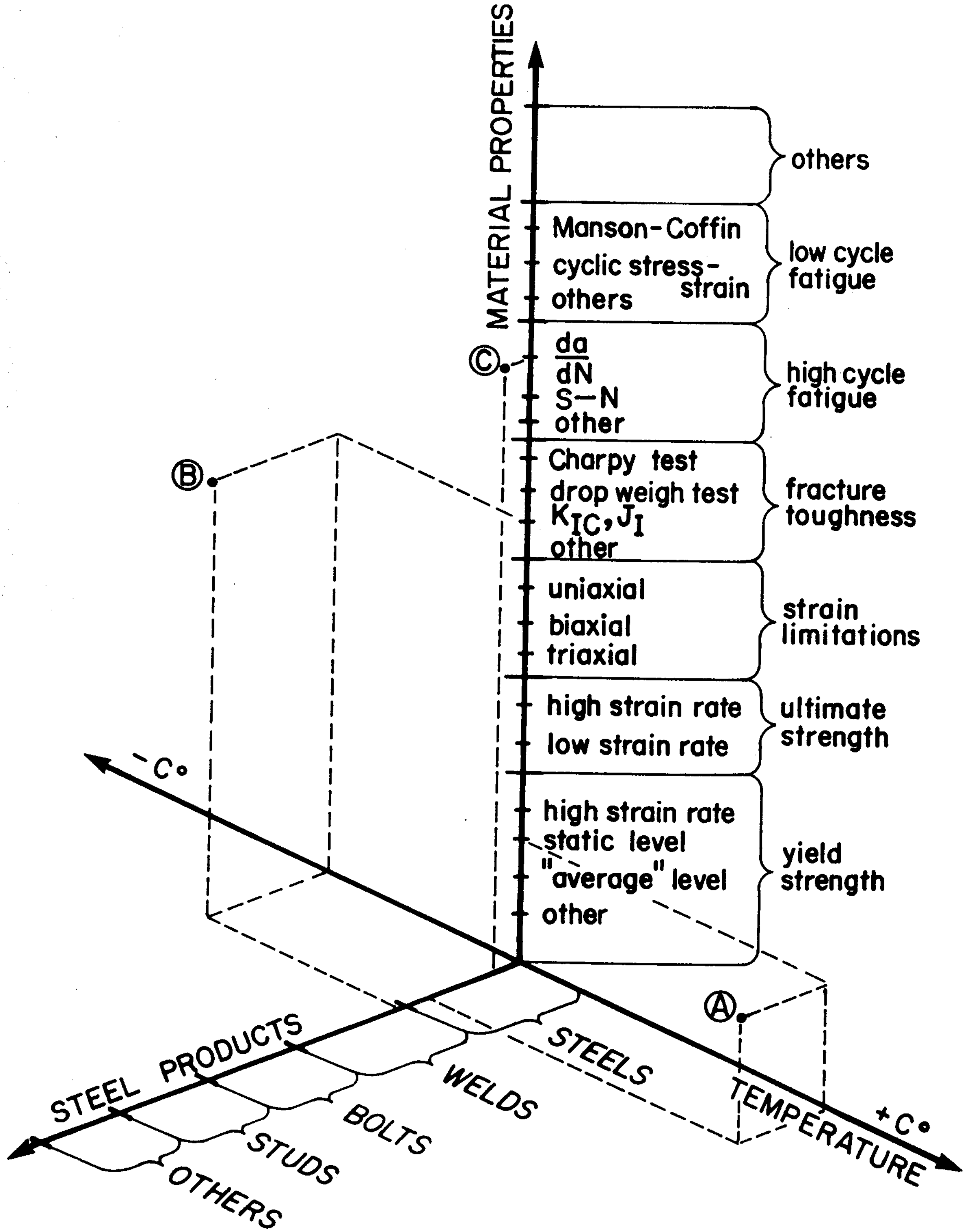

Fig. 2. Data Base for Mechanical Properties of Steel Products

Other sets of limit values for the assessment of other reliability conditions, for example, permanent deformations, accelerations, frequency, and amplitude as related to human comfort must also be developed. These could be constructed with the rules of the basic standard and contained for common cases either in secondary standards or data bases.

3.7 Reliability Conditions

3.7.1 General

Carrying capacity reliability conditions, as related to safety, must be met over the entire life of the structure. Serviceability reliability conditions may be exceeded over a portion of the life of the structure as agreed upon by the owner.

The strategic approach to the assessment starts by considering the complex and complete set of reliability conditions in both groups of limit states. The non-significant conditions are gradually neglected in the set of conditions which must be checked.

3.7.2 Carrying Capacity Reliability Conditions

Ideally reliability conditions are expressed in terms of probability of exceedance. In Fig. 3(a) this corresponds to establishing the overlap of the probability density functions for the limit (LV) value and the response (RE) to give the probability of exceedance. When statistical data are lacking the maximum value of the response and the least value of the limit value are compared as given in Fig. 3(b).

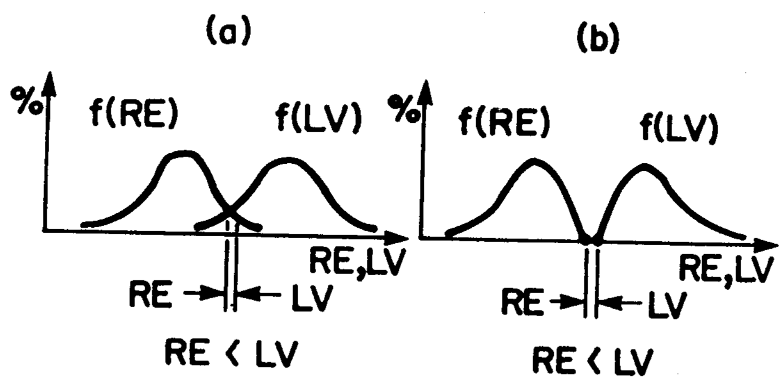

Fig. 3. Reliability Format (a) Probability of Exceedance (b) Maximum and Minimum Values

Fig. 4 shows four cases when the strength carrying capacity is reached for both static and dynamic response. In Figures a1, b1, c1 and d1, where the loading (LO) is expressed by forces, the cases depicted are, respectively, collapse of the structure (COL), local failure of some element (LOC), maximum strain limitation (STR) and local buckling (LB). In each case the response (RE) is just equal to the limit value (LV). Figures a2, b2, c2 and d2 show similar conditions of dynamic response where the energy for the limit value (LV_{EN}) is just equal to the energy for the loading (RE_{EN}).

For the case when the shake-down condition is not met (see Fig. 1), the strength is to be checked considering limit values shown in Fig. 4, or the low-cycle fatigue condition must be applied.

For the carrying capacity reliability condition related to low-cycle fatigue the damage of macro-elements due to plastic reversals must not exceed limit values as may be expressed by the Manson-Coffin law (Manson, 1966) for example.

For the many types of steel structures that exist, ranging from hot rolled sections that may have welded connections with significant residual stresses and geometric discontinuities, through light gauge cold-formed construction to cables comprised of many wires, the fatigue damage has different characteristics. For welded connections the phenomenon is related to crack initiation and propagation. For light gauge construction fatigue damage may be related to bearing capacity problems adjacent to fasteners as discussed by Strand, 1981. The

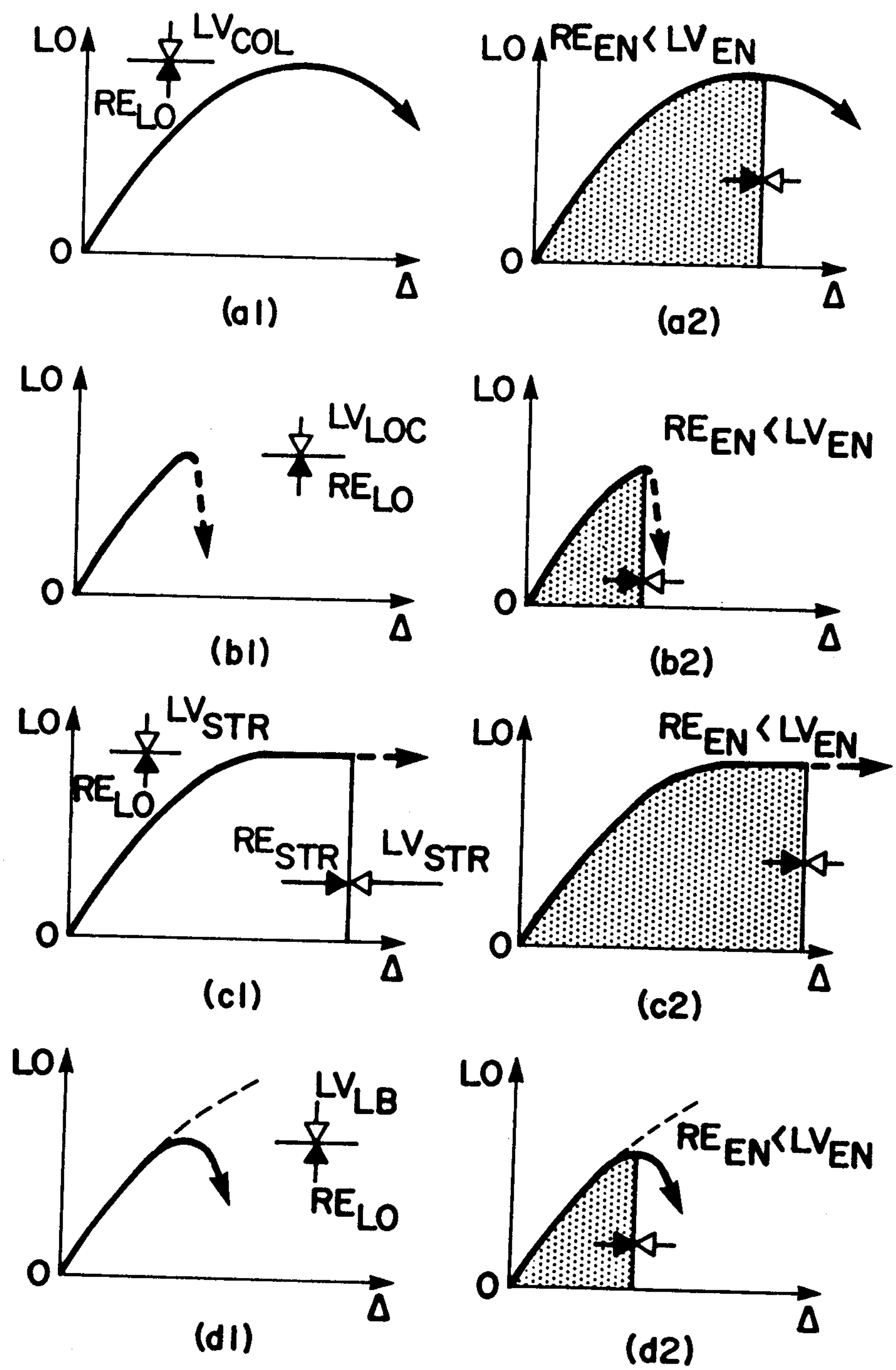

Fig. 4. Definition of Strength Reliability Condition (1) Static and (2) Dynamic Response

fatigue failure of cables is discontinuous as the wires fail one after another. Different approaches are therefore necessary for the evaluation of the response and the setting of limit values for high-cycle fatigue.

In assessing the positional stability (the kinematic mechanism) the interaction of the structure and its foundation with the supporting medium may alter the boundary conditions.

In certain circumstances, such as the use of steel exposed to elevated temperatures, composite steel-concrete structures or cables under long term loading the rheological aspects, (time-dependent phenomena), must be considered.

In some situations, the interaction of two or more reliability conditions must be considered as for example, in the case of significant accumulation of high-cycle as well as low-cycle fatigue damage.

3.7.3 Serviceability Reliability Conditions

As approved by the owner, the serviceability reliability conditions have to be met either during the total service life, or may be exceeded during specified portions of the life. In the latter case the portions of the life are established, for example, as a fraction of the service life, or correspond to a required probability of response exceedance.

Fig. 5 presents the load-deformation (LO-Δ) response for a structure (considered here to be deterministic) and three different load distribution functions, f(LO), represented by cases (a), (b) and (c). The limit of elastic response is EL

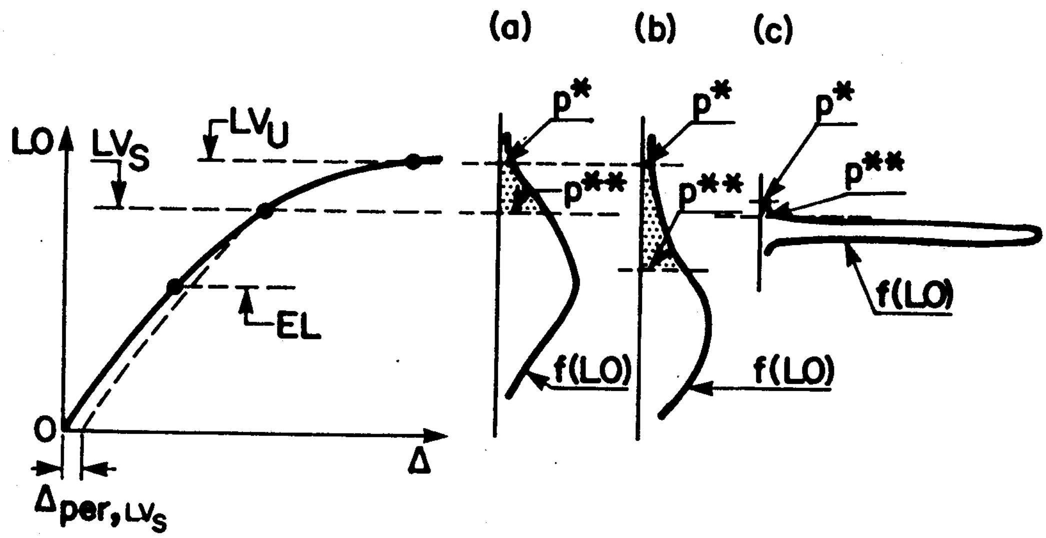

Fig. 5. Relationship between Load Distributions and Limit Values of Strength and Serviceability

while LV_S and LV_U are the limit values for serviceability and strength (ultimate limit state or maximum load carrying capacity). The limiting value defining the serviceability limit state is the permanent deformation Δ_{per,LV_S}. Either the permanent deformation reliability condition or the strength reliability condition may control the design depending on the load distribution.

For all of the load distributions the desired probability of exceedance, p*, (see Table 1) for the strength reliability condition is smaller than that, p**, for the permanent deformation reliability condition. Exceedance of the limit value Δ_{per,LV_S} for permanent deformation of the structure would require replacement, reconstruction or repair of the deformed structure. For the load distribution represented by case (a), the limit value corresponding to strength (carrying capacity) condition expressed by probability of exceedance, p*, and the limit value of permanent deformation (serviceability) expressed by probability of exceedance, p**, are met at the same time. For the load distribution represented by case (b) the strength condition (p*) controls the reliability of the structure as the permanent deformation corresponding to p** is less than Δ_{per,LV_S} In case (c) the probabilities p* and p** are close together and the permanent deformation limit value controls the reliability. The limit value for the carrying capacity condition LV_U exceeds p* considerably.

Fig. 6 carries this comparison of the strength reliability condition and the permanent deformation reliability condition

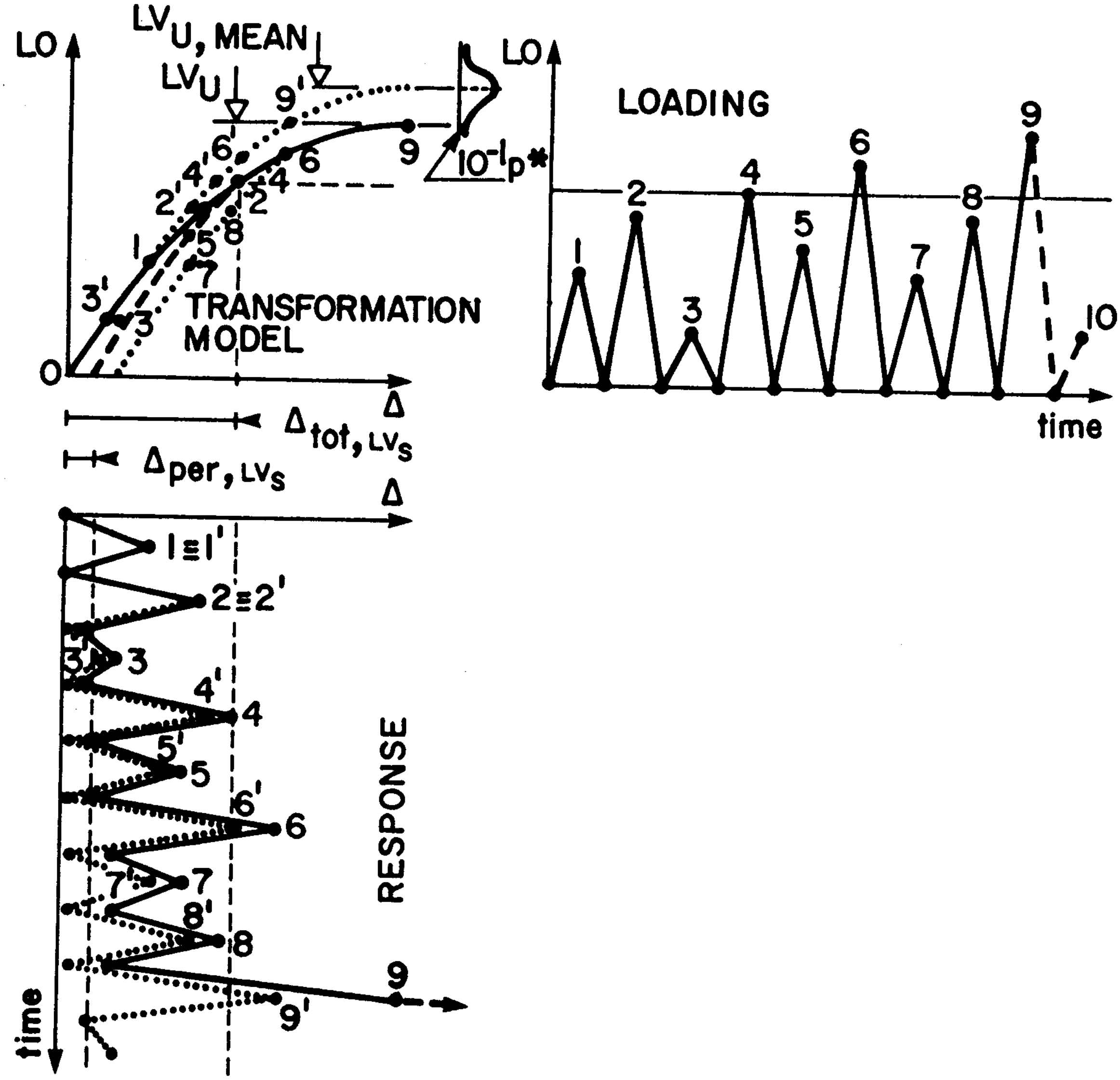

Fig. 6. Load Events-Transformation Model and Response Events

further. The figure shows the sequence of loading, the transformation model and the response. Ten loading events are depicted. The transformation model, shown as a solid line, is derived to reflect some specified response probability of exceedance, in this case 10^{-1} p* (see Table 1). Also shown on the load-deformation (LO-Δ) diagram is the mean value of the transformation model. At the upper end of the load deformation curve the probability density function for the transformation model is depicted. The response diagram gives the response both for the transformation model with a high probability of exceedance and for the mean transformation model.

Consider the transformation model shown by the solid line. The corresponding response curve, also solid, shows that at load event 4, the limit value for permanent deformation is reached. Load event 6 exceeds this limit value, corresponding to total elasto plastic deformation, $\Delta_{tot,LV}$, and results in a permanent deformation exceeding the limit value Δ_{per,LV_S}. The structure however, does not collapse. With load event 9 (having the required small probability of occurrence) the limit value for strength LV_u is reached and the structure deforms without limit and its carrying capacity is lost. Note that beyond load event 4 the structure has a permanent deformation equal to or greater than Δ_{per,LV_S} the limit value and that this permanent deformation increases for loads greater than load event 4.

The response diagram corresponding to the mean transformation model shown dotted is, as would be expected, more favourable with less permanent deformation occurring for the same loading and as a matter of fact at load step 9 the structure with the mean transformation model does not collapse. This serves to point out that the joint probabilities of the loading and transformation models are to be considered when dealing with the response and with collapse.

Other transformation models would yield similar results although they may differ quantitatively.

3.8 Balanced Design Process

The individual phases of the complete design process including assessment of the reliability conditions (loading, transformation model response and limit values) deserve equal care from the designer. Each phase must be considered carefully to ensure that on the one hand errors do not accumulate and on the other hand that sophisticated tools are not used where they are not warranted. The exercise of such care should minimize the possibility that the assessment of some reliability conditions are omitted.

4. Summary and Conclusions

The discrepancy between existing standards and the increasingly sophisticated assessment processes that utilize computer technology was discussed in Part A of this report. A suggested qualitative change in the arrangement of standards consists first of all in the basic document that defines the "rules of the game".

A proposed basic document is outlined in Section 2 and the fundamentals are explained in the commentary of Section 3. It is considered that:

(a) as compared to the complex character of the assessment process, existing standards are in essence an incomplete set of equations and instructions for assessing the reliability of selected elements, components and systems,

(b) the key to the assessment of reliability is the application of two groups of reliability conditions reflecting all expected types of limitations of carrying capacity and of serviceability,

(c) probability and statistics are significant tools used in the analysis of random variables and for the evaluation of input data for reliability conditions. The designer's use of estimates and his knowledge will remain a significant part of the assessment process,

(d) the creative work of the designer should be based on a complete understanding of the design scheme and rules outlined in the basic document. His activities cannot be restricted just to the interpretation of standards.

(e) the basic document is a general and complete instruction for the designer, who, following the basic rules, may solve the whole spectrum of problems. For common cases, secondary standards developed according to the basic rules, can be used by the designer.

(f) all reliability conditions should be considered to be of equal significance,

(g) the difference between carrying capacity reliability conditions and serviceability reliability conditions should be related to different levels of exceedance of limit values, and to the portion of the life of the structure during which the limit values may be exceeded.

(h) in future developments of standards load factors related to the strength reliability conditions should be phased out.

(i) the basic document should be accompanied by secondary standards, data bases and expert systems as discussed in Part A of this report.

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