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Load Factor Design for Steel Buildings

REVIEW OF CZECHOSLOVAK AND FRENCH SPECIFICATIONS

by

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ABSTRACT

This report reviews Czechoslovak and French specifications for steel building structures based upon the load factor (limit states) design concept.

The Czechoslovak specifications were selected as a representative example of the design procedure being used in COMECON countries. The French specifications present the approach developed by a member of the European Convention for Constructional Steelwork Associations.

The difference between the load factor design philosophy and the present allowable stress or plastic design concepts is briefly discussed.

The study is a supplementary investigation to AISI S&P Engineering Subcommittee Project 163 at Washington University, St. Louis. The purpose of this report is to review and summarize useful information and data which may be taken into consideration in developing AISI specifications for load factor design in steel building structures.

1. INTRODUCTION

During the past decade, a significant development has taken place in the area of structural safety. The traditional design concepts (e.g., the allowable stress design of steel structures) are subject to criticism with repsect to the more rational criteria of reliability and economic design.

In the area of steel highway bridges, tentative design criteria were recently developed(1) based upon the load factor concept. At present the load factor design criteria are being prepared for steel building structures.(2) Similar concepts already have been introduced in several countries as a replacement for the allowable stress design philosophy.

At present attention may be turned especially to two groups of specifications:

(1) Those developed in COMECON countries and based upon the concept specified in COMECON recommendations.(3)

(2) Those which have been under preparation by the European Convention for Constructional Steelwork Associations.(4)

The specifications in both groups were prepared considering statistics and probability as essential tools for the better understanding of the actual behavior of structures. In Appendix 1, the use of probability or reliability concepts in actual structural design is briefly discussed.

For the review of actual design procedure and criteria, the Czechoslovak specifications (CSN) were selected as a representative example in the first group, while French specifications were chosen from the second group. Both sets of specifications have been used in actual design.

The purpose of this study is to review Czechoslovak and French interpretations of the new design concept in specifications and to summarize useful data in order to assist in the preparation of AISI design criteria.

2. CZECHOSLOVAK SPECIFICATIONS

The Czechoslovak specifications recently introduced in civil engineering may be considered a representative example of the load factor design concept used in East European countries and based on COMECON recommendations.(3)

The concept is called "limit state design" and is applied in the entire area of civil engineering as simplified schematically in Fig. 1. Some documents are common for all or several materials and/or types of structures. Documents related to the design of steel building structures are indicated by heavier boxes.

2.1 General Review

Steel building structures are designed according to three main documents:

(1) CSN 730031 - Design of Structures and Foundations.(5) This document specifies the design philosophy, and defines limit states and main terms for the entire area of civil engineering.

(2) CSN 730035 - Loading of Building Structures.(6)
Working loads, load factors and the simultaneous effect of several loadings are specified in this document, which is valid for steel, concrete, timber and plastic building structures and their structural components.

(3) CSN 731401 - Design of Steel Structures.(7)
This document is valid for the limit state design of steel structures of a minimum thickness of 4mm. for each component (or for rolled shapes and tubes of a minimum thickness of 2.5 mm., and steel with a minimum of 18% elongation).

The document contains the requirements common for all steel structures and details the requirements for the design of steel industrial and building structures.

An additional set of secondary specifications is available to assist the designer. These documents are related to particular problems such as anchor bolts, crane rails, tolerances, friction bolts, etc.

The explanations and discussion of the main coduments with respect to the design of steel building structures are presented in the commentary.(8)

In 1968 the limit state design specifications listed replaced the specifications CSN 05 0110 (1949)(9) based on the allowable stress design concept.

2.2 The Limit State Design Concept

This philosophy is specified in document CSN 730031(5) common for all types of structures and structural materials, as well as for foundations and soil mechanics problems.

Limit States are defined as states at which the structure ceases to satisfy performance requirements. The structure must be proportioned according to three limit states: strength, deformation, and crack initiation in concrete.

(1) Limit State of Strength - proportioning of structures according to the relevance of the following:

1. the strength limit (elastic or plastic analysis may be used)

$$\Sigma\ n\ L_w < \text{"minimum" carrying capacity}$$

(where n is the load factor and L_w the working load)

2. the stability limit (buckling, overturning, etc.)

3. fatigue limit

4. fracture limit

(2) Limit State of Deformation - the designer must prove:

- either that the flexibility, deflection, vibration, etc. are within permissible range
- or he must keep to the limitations suggested in specifications.(7)

(3) Limit State Crack Initiation - for concrete or composite structures only.

2.3 Loading of Building Structures(6)

The loading function is generally considered independent of the resistance function.

The document consists of the following main chapters:

(1) General Information

The document recognizes:

working loads L_w

LOADS

"factored" working loads = $L_w \cdot n$

where n is the load factor.

LOADING → dead load (D)

LOADING → live load
- long-term (L1)
- short-term (L2)
- extraordinary (L3)

Simultaneous Effect of Loading

Three main combinations of loads are to be considered in the design

Basic ...(Σ n D + Σ n L1 + [the most significant n L2])

Broader ...(Σ n D + Σ n L1 + 0.9 [all possible n L2])

Extraordinary...(Σ n D + Σ n L1 + 0.8 [possible n L2] + one L3)

where 0.9 and 0.8 are factors of simultaneous loading effects.

The classification of loads and the evaluation of load factors are discussed in Appendix 2.

(2) Permanent (dead) Loads

Permanent loads (weight of structures) are defined and corresponding load factors n are listed. Examples of load factors are shown in Table 1.

(3) Live Loads

Working loads and load factors are listed for floor loads, concentrated loads, equipment, machinery and vehicles. For examples, see Table 1.

(4) Temporary Structures

(5) Crane Loads

The evaluation of working loads, lateral forces and braking forces is described for five main types of cranes (overhead, bracket, suspended, cats and portal cranes). The dynamic and load factors n are listed in the document. For examples of n, see Table 1.

(6) Snow Load

The "working" snowload p_s^n* is determined by the equation

$$p_s^n = p_s \cdot C_s$$

where p_s is the basic snow load per $1/m^2$ area as specified in a "snow map" of Czechoslovakia (the map is enclosed in CSN 730035), and C_s is the roof shape factor, which is

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*Symbols as used in CSN 73 0035

defined for different roof slopes and several roof configurations.

The "adjusted" snow load is equal to

$$p_s^r = p_s^n \cdot n_s$$

where $n_s = 1.4$ is the load factor.

(7) Wind Load

The "working" wind load is equal to $w^n = w \cdot C_w$ where w is the basic wind pressure specified in the document for different heights of the building, and C_w is the aerodynamic coefficient specified for different shapes of the structure.

The "adjusted" wind load is equal to

$$w^r = w^n \cdot n_w$$

where n_w is the load factor 1.2 or 1.3 (depends on the ratio of height to width of the building) - see Table. 1.

(8) Load Factors for Other Loadings

The load factors for temperature effect, creep, settlement of foundations, mining subsidence, and some others are specified.

The dynamic coefficients are defined.

(9) Temporary Requirements and Instructions

- Earthquake
- Supplementary comments and information
- List of related specifications

Appendix 1

Weights and Specific quantities and weights of different materials.

Appendix 2

Map of snow areas in Czechoslovakia.

2.4 Design of Steel Structures

The document CSN 73 1401(7) contains the following chapters:

(1) Symbols

(2) General Instructions

- The designer must consider the service requirements of the structure, economy (material and labor), unification of elements and details, and resistance to corrosion.

- Two limit states are considered in the design of steel structures: the limit state of carrying capacity, and the limit state of deformation. Chapters 5 - 9 of the document are related to the first limit state, while conditions related to the second limit state are described in chapter 10.

(3) Materials

This chapter summarizes the steel grades recommended for structural members, welds, rivets and bolts.

Significant mechanical properties are listed. The yield stress of recommended steel grades is in the range of 31 ksi - 53 ksi.

To assist in the selection of steel grade, structures are classified into groups 1 thru 5 with respect to service conditions and type of joints (welded, riveted, bolted).

(4) Design Stress and Other Properties of Structural Materials.

The resistance function in CSN specifications usually is related to the so called "design stresses" designated R. This value corresponds to the probability 0.001 of the statistical distribution curve if variations of the actual yield stress and the variation of the cross sectional area are considered in the statistical analysis. Examples are discussed in Appendix 3.

The following table shows three examples of "design stresses".

Steel Identification	"min σ_y"*	"design stress" R
CSN 11 373	36 - 30	30 - 38.5 ksi
CSN 11 423	37 - 34	31.5 - 30 ksi
CSN 11 523	52 - 49	41.5 - 40 ksi

(* depends on the thickness - see CSN 73 1401(7))

The document contains similar tables of "design stresses" for castings, forgings, weldments, bolts, rivets and locally concentrated loads.

This chapter also includes so called "factor of the function conditions". This factor is related to some special conditions not part of the loading analysis or resistance function. For example, a particular column is supposed to be pin-ended, but the end detail does not guarantee the centric application of the load ($m = 0.9$).

(5) Strength of Structural Elements

Axial and Shear Stresses:

According to CSN 731401, the axial and shear stresses are to be checked in design using the following formulas:

$$\sigma = \frac{N}{A_e} + \frac{M_x\, y}{I_x} + \frac{M_y\, x}{I_y} + \frac{B_\omega\, \omega}{I_\omega} \leq R$$

Axial Force	Biaxial Bending	Warping Torsion
Shear Force	St Venant Torsion	

$$\tau = \frac{T\, S}{I\, b} + \frac{M_t\, d}{I_t} + \frac{M_\omega\, S_\omega}{I_\omega\, d} \leq R_s$$

where: σ, τ are axial and shear stresses, R - "design axial stress", and the moments (M_x, M_y, B_ω, M_τ, M_ω), axial force (N) and shear force (T) correspond to the product of working loads and load factors considering simultaneous effect as already discussed in Article 2.3.

Plastic Design:

The application of plastic analysis is, in this document, rather limited*.

The proportioning of a structural member may be demonstrated in the following example.

In the case of uniaxial bending, dimensions of a beam are checked using the equation

$$\frac{M}{W_o^{pl}} \leqq R$$

where M is the bending moment corresponding to the factored load, W_o^{pl} is the plastic section modulus of the section and R is the "design" stress.

(6) Compression Members

This part of the document contains the following

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*Special CSN code for the plastic design is under preparation.

subchapters:

- centrically loaded columns (warping considered)
- stability of compression flanges in beams
- combination of compression and bending
- latticed and battered columns - centrically loaded
- latticed and battered columns - centrically loaded (combination of axial force and bending)
- tempered compression members
- compression members and variable compression force
- arches (compression only)
- arches (compression and bending)
- limitation of the slenderness ratio

The various stability considerations are demonstrated next in one simple example - the stability of pinned-end columns.

The designer must prove that

$$C \frac{N}{A} < R$$

where C is the "buckling coefficient", N the magnitude of axial force (all factored loads and loading combinations considered), A is the cross sectional area, and R is the "design" stress.

The buckling coefficient C was derived for each slenderness ratio $\frac{L}{r}$ (L is the buckling length; r the radius of inertia) considering initial out-of-straightness m_o

$$m_o = 0.3 \left(\frac{L}{100r}\right)^2$$

representing all imperfections, residual stresses, etc., and considering specified yield stress F_y (not the "design" yield stress R).$^{(8)}$

The design procedure for pinned-end columns is demonstrated in Fig. 2. The designer must prove that, for the particular slenderness ratio $\frac{L}{r}$, the maximum possible axial stress $\Sigma\, n\, \sigma_w$ corresponding to the maximum possible loading combination (all three combinations of loads must be considered) is less than the defined minimum carrying capacity $\frac{R}{C}$.

$$n\, L_w < \frac{R}{C}$$

In Fig. 2, the scatter of carrying capacity f_c and the scatter of loading are schematically shown.

The distribution f_{co} represents the scatter of yield stress and cross-sectional area only.

(7) Buckling of Webs

Critical and postcritical criteria are considered for the buckling of webs.

This chapter also includes the stability criteria for some types of shells.

(8) Strength of Connections

Design criteria for welded, bolted, and riveted connections are included. For the design of friction joints, a special document, ON 73 1495, is available.

(9) Fatigue

If a structure is subjected to cyclic or impact loading the design stresses R have to be further reduced by the coefficient σ

$$\sigma = \frac{1}{(a\beta \pm 0.3) - (a\beta \mp 0.3)\ S}$$

where coefficient a depends on the grade of steel and service conditions, β is the stress concentration factor and $S = \frac{S_{min}}{S_{max}}$ = the ratio of the minimum and maximum forces (moments, stresses, etc.).

(10) Deformations of Structures

This chapter contains the limitations related to the second limit state. General criteria for vertical deflections are specified as well as limitations for particular structures and structural members, namely crane girders, floor beams and girders, roof girders, site runners, etc.

Lateral deflections of tall buildings are restricted to 1/1000 of the height in the case when brick walls are used, and 1/500 in other cases.

Lateral deflections are also limited in the case of crane girders and columns in industrial buildings.

(11) Design Recommendations for Steel Building Structures

In this part of the document several useful instructions concerning temperature effects are summarized.

These include expansion gaps, riveting, welding, beamings, and protection against corrosion.

Appendix 1

Determination of the buckling length for frames and trusses.

Appendix 2

Design of welds (examples).

Appendix 3

Stress concentration factors (fatigue).
Fatigue coefficients δ (nomograph).

A list of relevant Czechoslovak and foreign specifications is enclosed.

3. FRENCH SPECIFICATIONS

The French interpretation of the load factor design concept for steel buildings is presented in "Regulations for the Design of Steel Structures" (Specifications)(10) which has been available since December 1966. However, the designer may use the allowable stress design concept as well.

The "Regulations" are presented in a single volume containing three documents: Specifications, Commentary, and Appendices.

For Specifications and Appendices only odd pages were used, while the even pages contain corresponding commentary. The Appendices are printed on green paper.

3.1 Specifications

The document consists of a preface and six chapters.

(0) Preface: General information about nomenclature, units, subject of the specifications, scope, validity, and references to related specifications.

(1) Justification of Structural Safety

According to Specifications, the safety of a construction (structure) is admitted to be insured when it is ascertained by computations based on theories of strength of materials in the elastic range, that the structure will remain stable even if subjected to the combination of the most unfavorable dead and live loads considered for the project, multiplied by load factors.

On one hand, the "load factors" have been chosen as functions of the type of dead and live loads, and of the possibility of their simultaneous presence, in such a way that the different possible combinations of the increased loads give the same risk of failure to the structure. On the other hand, the Regulations lead to the computation of "characteristic stresses" determined in such a way as to have the same risk of failure of one element, whatever the loading or the combination of loadings, when the characteristic stress reaches the value σ_e taken as the basic criteria of failure. In this way, a nearly homogeneous degree of safety is obtained."(10)

The design of a steel structure subsequently consists of the following steps$^{(11)}$:

- each load to be multiplied by an appropriate load factor
- compute stress, based on elastic theory, due to the factored loads
- deduce a factored stress σ
- insure that $\sigma < \sigma_e/K$ for complex cases involving stability (bending, buckling, etc.). The stress σ_e is the yield stress and K is a factor larger than 1.0. Formulas for K for all situations are given in the regulations.

The chance of accidental overloading is expressed by "load factors".

1. For structures under normal service conditions in the computation for the strength and stability check (stability of the whole structure as well as its elements), the loads (effects) must be considered in such a way as to give the unfavorable combination, their values being multiplied by the "load factors" as listed in Table 2.

2. Erection - The builder must provide the necessary apparatus to insure the stability of the structure

during the different phases of erection.

Overall stability is concerned with strength against translation and overturning. The means chosen (bracing, etc.) must insure stability with a factor of safety of at least 1.2. For the strength of the elements, the "load factors" used for the structure under service loads must be applied. Deviation from this principle is eventually accepted in the following cases:

The "Load Factors" can be taken as 1 in the case of operations of very short duration, but the characteristic stresses must be less than $0.9\sigma_e$. When it is intended to introduce favorable internal stresses in the structure (prestressing, predeforming ...), the "load factors" applied to certain elements can be decreased if it can be justified that the failure or an excessive deformation of these elements does not endanger the safety of the remaining structure.

3. Exceptional Circumstances - When failure in construction can have more disastrous consequences

than in ordinary construction, the owner can prescribe an increase in the "load factors" used for his computation.

On the other hand, in certain exceptional cases, when some limited disorder and even a small risk of failure can be admitted, the "load factors" can be reduced in agreement with the owner.

When the damage caused by a catastrophe is only limited, even a stability check can be performed by reducing to unity all load factors applicable to live, dead and exceptional loads occurring during the catastrophe.

It is in this way that, in the check of structures under extreme climatic loads (snow and wind), as in the check of resistance against earthquake, which can be eventually prescribed, all possible effects influenced by "load factors" including dead loads, are reduced to unity.

Resistance Function

The "minimum" carrying capacity of a structure or structural element is related to the σ_e value of the specified yield stress.

In the case of simple tension or compression, the stress corresponding to the factored load shall be less than or equal to σ_e. In the case of simple shear, the safety is given by

$$1.54\tau < \sigma_e$$

where τ is the shear stress corresponding to the factored loads.

(2) Variation of Mechanical Properties

The yield stress for a particular steel grade is either specified or guaranteed by the producer, or may be obtained by statistical analysis of a large population of samples as a value corresponding to the mean value minus two standard deviations.

(3) Strength and Deformation - General Rules

This chapter includes information related to the proportioning of structures and structural elements. Following are the contents of individual subchapters.

- values of E, G, etc.
- simple tension
- simple bending
- biaxial bending
- shear stresses
- compression, buckling

In stability cases, the relevant criteria are specified and the check is given generally by

$$K\sigma < \sigma_e$$

where σ is the stress corresponding to the factored loads and K is related to the particular stability (etc.) considerations. (In Appendix 5 the design of pinned-end columns is discussed).

- deformations
  (influence of deformations, assumptions for computations, deformations due to axial force, bending, shear).

(4) Connections

The design procedure of welded, riveted and bolted connections is specified in detail.

(5) Special Requirements for Some Structural Components

This chapter contains useful instructions on the design of columns and floor beams in buildings, foundations, base plates and anchor bolts, detailing work of bolted or riveted splices, etc.

(6) Load Test

Testing procedure, conditions required for inspection, and interpretation of results are described. are described.

3.2 Appendix

About 130 pages contain symbols, supplementary information, tables and nomographs.

3.3 Commentary

The commentary includes explanations, evaluation of some formulas, sketches and tables directly related to the provisions described in the specifications.

3.4 Comment

No fatigue considerations have been included in the document.

4. Discussion

Chapters 2 - 3 of this study contain just a brief review of two foreign specifications without background information about the design philosophy, analysis of loading and resistance functions, statistics and probability considerations, etc.

The purpose of the following discussion is to show some of the basic considerations of the load factor design concept and to point out the differences with respect to the traditional approaches.

4.1 Justification

The new design concept is gradually being introduced mainly to improve the safety and reliability of structures. Several reasons further justifying the load factor design concept are summarized in Appendix 6.

4.2 General Description

The load factor design concept for steel structures generally recognizes two basic limit states:

(1) Limit state of carrying capacity, related to the confrontation of external loading with the carrying capacity of the structure or structural components.

(2) Limit state of performance, which includes limitations for deformations, vibrations, cracks, fatigue, fracture, corrosion, etc.

Both limit states may be considered equally signigicant and must be considered in the design.

While probability and reliability concepts may be used as a strong tool to define the limit state in the analysis of the first limit state statistics, a more general definition is not available in the case of the second limit state due to the very different factors involved. Each possible case requires special attention. Further discussion is focused on the first limit state.

As indicated in Fig. 3, loading and resistance functions may be considered statistical variables and represented by frequency distribution curves f_L and f_C. For example, some of the current design concepts proportion structural members by comparing the working load L_W with the "allowable" carrying capacity equal to the "defined" carrying capacity divided by factor of safety FS, as shown in Fig. 3. In the load factor design, the "maximum possible load" is compared with the "minimum" carrying capacity. In Fig. 3b frequency distribution curves f_L for the loading function and f_C for the resistance function are shown again. "Maximum" load is product of working load L_W (service conditions) and load factor n (overloading). Similarly, the "minimum" carrying capacity may be defined using the frequency distribution curve f_C. Subsequently, the design strength criterion is

$$L_W \times n < \text{"minimum" carrying capacity.}$$

In order to stress the difference between the current allowable stress and load factor design concepts, loading and resistance functions versus the ratio of the live load to the total load are schematically plotted in Fig. 4.

In Fig. 4a, the allowable stress design (ASD) was considered. The magnitude of the carrying capacity and its scatter, indicated by the frequency curve f_C, are constant and obviously not dependent upon the ratio of the live load to the total load. Similarly, the magnitude of the defined working load L_W is constant; however, the scatter f_L exists and must be considered a variable. For a very low live load, the scatter band is usually very narrow. For a ratio close to 1.0 the band is wide. In the ASD, the factor of safety FS is defined

$$FS = \frac{\text{"defined" carrying capacity}}{\text{working load}}$$

and includes part of the scatter band f_C, part of scatter band f_L, and additional "safety" indicated by the distance d in Fig. 4a.

Assuming the magnitude and the scatter of loading are the same as before, the idea of proportioning structural members using load factor design is schematically indicated in Fig. 4b. For a particular ratio of live load to total load, the "maximum" load must be lower than the "minimum" carrying capacity.

A comparison of Fig. 4a and 4b shows not only the difference, but also the potential chance of significant material savings, especially in the case of low live loads.

In <u>Allowable Stress Design</u> (ASD), the strength S is usually defined with respect to the first yielding. The designer must prove that the working load is lower than or equal to the defined strength reduced by the factor of safety. The variation of strength and loading is considered only by single factor of safety.

In Plastic Design (PD), the strength S_u is defined considering the ultimate magnitude of carrying capacity; however, the defined ultimate strength S_u is related to specified yield stress, specified sectional properties, etc. and does not include the variation in ultimate strength. The designer must prove the working load multiplied by so called "load factor" LF, is less than the defined ultimate carrying capacity. Apparently, the "load factor", LF, in this case is not only related to the variation of load, but includes the variation of carrying capacity as well.

In Load Factor Design (LFD), the maximum possible load must be smaller than the defined minimum carrying capacity. The load factor n is related to the loading function only.

Subsequently, the differences between the design concepts show that the allowable stress and load factor designs are contradicting methods, and, as is already the case in several countries, allowable stress design is being replaced by load factor design. The plastic and load factor designs are not in conflict. However, to use the same basic considerations, the load factors, LF, in plastic design must be divided into two parts-load factor, LF_1, identical to n (related to the load function only), and LF_2, representing the possible diviation of "minimum" ultimate strength from the defined ultimate strength.

4.3 Significance of individual variables

The main design concepts differ not only in the interpretation of "safety" (safety factor, load factors, etc.), but also regarding how the individual components of loading and resistant functions are included and considered in the design concept.

Table 3 presents a simplified comparison of the allowable stress design, plastic design, and load factor design concepts. Individual components of the loading and resistance functions and special conditions are specified. For each design concept, the components considered in the design procedure and design factors used to represent their effects are shown. In the case of ASD, a single factor of safety (FS) is used to represent certain specific components. Similarly, the PD concept uses the so-called "load factor" to represent the same scope of components. It is to be stressed the the "load factor" in the plastic design concept represents not only the ratio of maximum possible loading to the working load, but also a variation of the resistance function.

The load factor design concept attempts to distinguish particular groups of components using factor s for the simultaneous effect of loading, n for the load factor for different types of loads, R for the resistance function related to the statistically defined "minimum" carrying capacity, and factor m in considering special conditions.

The purpose of Table 4 is to give a simple comparison of the main properties of the three main design concepts, and to show the significant qualitative differences in each philosophy.

It should be mentioned that the difference between allowable stress design and plastic design concerning the definition of "maximum" carrying capacity, is not the subject of Table 3. Similarly, it should be noted that the load factor design may be based on both elastic and plastic analyses.

5. Summary and Conclusions.

This study reviews two foreign design specifications for steel building structures. The Czechoslovak specifications were selected as an example of the design approach used in COMECON countries, while the French specifications are the first interpretation of the load factor design concept introduced by a member of the European Convention for Constructional Steelwork Associations.

The review is focused mainly on the system of interpretation of the load factor concept and on the main provisions, scope, and arrangement of these two specifications. However, some background information and the comparison of main design concepts is discussed in Chapter 4 and Appendices.

5.1 Czechoslovak Specifications (CSN)

The "limit state design" is being introduced in the entire area of civil engineering. The specifications for steel buildings are just part of a system of specifications based on some philosophy.

The load function is separated from the resistance function for steel structures. Two limit states are considered: (1) limit state of carrying capacity (the "maximum" possible load is compared with "minimum" carrying capacity). (2) limit state of deformation.

The extremes of the loading function are expressed by the load factors and the resistance function is related mainly to the adjusted "design" yield stresses. The evaluation of these values, statictics and probabilities was extensively applied. However, the information contained in the specifications was completed using the deterministic approach as well in some cases.

5.2 French Specifications

The document is oriented to steel building structures only.

The load function is separated from the resistance function.

Very few load factors are used in the document for single loads and combinations of loads.

The specifications lead to the computation of "characteristic stresses" determined in such a way to be close to the same risk of failure of one element, whatever the loading or the combination of loadings, when the characteristic stress reaches the value taken as a basic criteria of failure.

5.3 Concluding Comments and Recommendations

(1) Revision of the definitions and terminology may be advised to avoid the use of some expressions with more than one meaning (e.g. "load factor").

(2) In both reviewed sets of specifications, loading and carrying capacity are considered independent variables. The loading is not a "property" of the structural system or component.

(3) More attention should be given the loading analysis. Variation of loads and their simultaneous effects should be studied considering probability.

(4) Statistics and probability are significant tools for rationalizing the structural design; both were used extensively in the preparation of the reviewed specifications. However, the load factor design specifications also may be developed solely on a deterministic basis. In such a case, the chance of the future replacement of

deterministic values (load factors, design stresses, column curves, etc.) by the results of statistical analysis should be considered.

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7. NOMENCLATURE

7.1 Symbols

7.2 Definitions

7.1 SYMBOLS

A	Specified Area
A_a	Actual Area
A_e	Effective Area
C	Buckling Coefficient
CC	Carrying Capacity
D	Dead Load
d	"Additional" Safety
$d_{\bar{R}}$	Standard Deviation of $\bar{R}$
F_c	Allowable Stress (AISC)
FS	Factor of Safety
f_c, f_{co}	Frequency Distribution of Carrying Capacity
f_L	Frequency Distribution of Loading
f'_w, f''_w	Frequency of Working Load
H	Horizontal Force
h	Distance
H_w	Lateral Working Load
K	Coefficient
$\frac{KL}{r}$	Slenderness Ratio
L	Buckling Length
L_a	Allowable Load
L_1	Live Load Long Term

L_2	Live Load Short Term
L_3	Live Load Exceptional
LF	Load Factor in Plastic Design
LF	Load Factor in French Specifications
LF_1	Components of Load Factor in Plastic Design
LF_2	Components of Load Factor in Plastic Design
L_w	Working Load
$L_{\bar{w}}$	Mean of Working Load
L_w	Median of Working Load
$\bar{L}$	Mean of the Loading
L	Defined Magnitude of Loading
L_y	Load Corresponding to First Yielding
m	Factor of Function Conditions
m_o	Initial Out-of-Straightness
$m_{\bar{R}}$	Mean of $\bar{R}$
m_{max}	Load Factor, Maximum Value
m_{min}	Load Factor, Minimum Value
N^a, M^a_x, M^a_y, B^a_ω, T^a, M^a_t, M^a_ω	"Adjusted" Forces and Moments
P	Load
P	Prestressing Force
P^a	"Adjusted" Load

p	Probability
R	"Adjusted" Yield Stress
$\bar{R}$	Variable
R_s	"Adjusted" Shear Stress
r	Radius of Inertia
$R_c(x,t)$	Critical Resistance of a Structure as a Function of Location and Time
S	Strength.
s	Factor of Simultaneous Effect of Loading
S_L	Force Generated by Applied Load
S_p	Force Generated by Prestressing
S_u	Ultimate Strength
V	Vertical Force
v	Distance
V_w	Vertical Working Load
$x, \Delta x$	Distance
$y, \Delta y$	Distance
$Z_c(x,t)$	Critical Loading as a Function of Location and Time
Δt	Time Interval
σ_a	Allowable Axial Stress
σ_e	Specified Yield Stress (French specifications)
σ_w	Working Stress
$\sigma_{y,min}$	Minimum Yield Stress (Probability 0.001)

7.2 DEFINITIONS

LOAD FACTOR (Plastic Design): [LF]

A factor of a working load is multiplied by to determine an ultimate design load. (The factor includes the possible loading variation and variation of the carrying capacity).

LOAD FACTOR (Limit State Design): [n]

A factor of a working load is multiplied by to determine the "maximum possible" load related to a particular level of probability. (The factor depends only on the loading function).

ALLOWABLE STRESS DESIGN: [ASD]

A method of proportioning structures based on working loads, such that computed stresses do not exceed prescribed values.

PLASTIC DESIGN: [PD]

A design method for continuous steel beams and frames which defines the limit of structural usefulness as the "maximum load".

LIMIT STATE DESIGN: [LSD]

A design method of proportioning the structure based on three limit states: strength, performance, and initiation of cracks (in concrete). Loading and resistance are considered two independent functions, and statistics and probability are used to define "maximum load" and "minimum" carrying capacity.

LOAD FACTOR DESIGN: [LFD]

A term selected by the AISI to express the limit state design concept (see LSD).

8. APPENDICES

Appendix 1.

Statistics and Probabilistic Considerations.

The probabilistic applications in structural engineering recognize that both loading and resistance functions have statistical frequency distributions that must be considered in evaluating safety. In the early studies of design concepts in structures, all load variability and variability of resistance usually were expressed by one factor - i.e., "factor of safety". Initial studies on probabilistic concepts lumped load variability into a single random variable, and similarly, variability of resistance was expressed by one variable. These studies were focused on factors of safety, coeffiecients of variations and frequency distributions.(12,13,14,15) Current development, furthermore, is oriented to the reliability analysis of complex multi-member and multi-load structures, different levels of failure, and various applications of decision theory, as presented in Ref.(16,17,18,19,20,21).

While the theoretical development of probability (or reliability) based design philosophy may already be considered very advanced, its practical interpretation for structural steel design practice is not. However, in several countries, attempts have already been made to replace design specifications based on deterministic concepts with design criteria considering statistics and probability. The concept of "limit state design" was introduced in the USSR in the 1960's,(22) and later in some East European countries,(3) and in certain West European states as well.(10,4)

One of the significant problems in the formulation of design specifications is the lack of statistical data. According to the level of the application of actual statistical data probabilistic analysis, four main approaches may generally be mentioned.

(1) "Deterministic" Approach.

In this case the design concept uses several factors corresponding to different variables (load factors, reduction of the resistance function, etc.); these are determined according to past experience or estimated, and statistics and probability are not used at all. However, this approach allows the gradual replacement of "deterministic" factors with results of statistical analysis whenever such data are available.

("Deterministic" approach was used in Ref. 1.)

(2) "Simple Maximum" approach

Statistics are used to define the extreme magnitudes of each individual variable for a particular probability. It is assumed that all these extreme magnitudes may be considered simultaneously. This simple approach, however, is very conservative. It was applied in the preparation of ČSN specifications.

(3) Functions of Statistical Arguments

The simultaneity of unfavorable values of individual variables must be analyzed. This means a resulting distribution curve, and corresponding parameters must be found from the statistical parameters of each argument.

In this case the statistical character of different formulas used in structural analysis can be expressed, as discussed in Ref. 23. A very simple application of this approach is demonstrated in Fig. 6. The strength of a pinned-end column depends on several factors. Consider just yield stress and the out-of-straightness variables, expressed in Fig. 6 by the distribution curves $f_{\sigma y}$, and $fe_{/L}$. For a particular probability (e.g. 0.0005 in this case) in interaction curve g can be obtained. The curve h expresses the variation of ultimate strength computed for a particular column and corresponding to combinations of σ_y and $e/_L$. The value P_{MIN} = 859 kips is the minimum carrying capacity corresponding to a given probability and the distribution of σ_y and the excentricity obtained from the theoretical approach, using a computer program as described in Ref. 29.

(4) General Method

Generally all components of loading and strength are time- and location- dependent variables. The variation may be represented by periodic and nonperiodic surfaces in a coordinate system (location versus time versus magnitude of the function). The probability of a structural failure may be expressed by the probability of the contract of a surface Z_c (x,t) representing the "critical" loading, with the surface R_c (x,t) representing the "critical" resistance of the structure.(24)

Appendix 2.

Loading Functions and Load Factors.

In the load factor (limit state) design concept the loading function should be considered an independent variable.

So far, little attention has been given the systematic investigation of individual loads and their statistical characteristics, or the simultaneous effect of several loads.(25) While an extensive research program is being focused on the different aspects of the resistance functions of steel structures and structural components in order to rationalize design criteria, loading analysis research of structures may be considered inadequate. However, both the loading and resistance functions are comparably significant for economic design.

Present load factor design specifications are based on different considerations concerning loading analysis. However, two main common terms are being used:

-working (or service) load (L_w)
(related to normal service conditions)

and -load factor (n)
(related to the possibility of
extreme loading conditions*)

The product of the working load and the load factor defines the "maximum" of the loading function.

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*Load Factor is not identical to dynamic factor. Dynamic factors represent the results of dynamic analysis. The working load in the case of dynamic effects must be multiplied by n and the dynamic factor.

Load Factor

The magnitudes of L_w and the load factor essentially may be obtained in three different ways:

1. Deterministic Method

The magnitudes of the working load (L_w) and the extreme exceptional load, $n \times L_w$, or load combinations, $\sum n \times L_w$, are estimated and represent the value of the loading function.

2. Probabilistic Analysis

obviously, a purely statistical method may be applied very seldom due to lack of statistical data. Figure 7 schematically demonstrates the probabilistic estimate of the load factor assuming a large collection of data is represented by a frequency distribution curve f_L. The statistical distribution can be described by the mean $\overline{L}$, standard deviation, and other statistical characteristics.

The magnitude of the working load L_w can be equated to the mean $\overline{L}$, or another magnitude of the load L, as in the case of the weight of a concrete shape, when the mean is usually higher than the weight corresponding to specified dimensions and specific gravities.(25) For the designers convenience in such a case, the working load L_w is equated to the load $\tilde{L}$ corresponding to the design dimensions and specific gravity given in specifications.

The maximum load L_{max} for a particular selected probability p is defined on the frequency curve f_L, and the load factor is

$$n_{max} = \frac{L_{max}}{L_w}$$

This approach was used to select some of the load factors in the Czechoslovak specifications.(6)

Figure 7 further defines the "minimum" load corresponding to probability p

$$L_{min} = n_{min} \times L_w$$

This magnitude of the load may also be used in the design, as demonstrated in Fig. 8. To prove the stability of a structure against overturning, the maximum possible lateral load and, simultaneously, the minimum gravity load must be considered in proving

$$v\ n_{min}\ V_w > n_{max}\ H_w h$$

where H_w is the lateral working load, V_w the vertical working load, v and h distances and n_{min}, n_{max} load factors.

3. Semiprobabilistic Approach

A combination of statistical analysis and deterministic considerations can be used to obtain the load factors.

An example is shown in Fig. 9. Assuming long-term wind-velocity measurements w are available as shown in Fig. 9a, the statistical evaluation can be conducted in different ways, e.g.:

(a) All local maximums of w can be represented by a frequency curve f_w as shown in Fig. 9b. The mean $\overline{w}$ and the maximum value corresponding to a particular selected probability can also be obtained.

(b) The analysis of local maximums over a period of

50 years, for example, may be very difficult. Therefore, as in Fig. 9a, a particular time interval Δt may be determined, and the frequency curve f''_w obtained considering only one maximum in each interval (Fig. 9b).

The difference between the distributions f'_w and f''_w depends on the magnitude of the interval Δt selected for the semi-deterministic approach.

As a "working" wind velocity, the mean $\overline{w}$, or as often the case, the magnitude $\tilde{w}$, corresponding to the median of the distribution, may be selected.

Eventually, the evaluated wind velocities $\tilde{w}$ (or $\overline{w}$) and max w are to be converted to wind "loads" and the load factor is again defined as

$$n = \frac{L_{\max w}}{L_{\tilde{w}}}$$

A similar semi-deterministic approach may be used for the analysis of other cases, such as live loads on bridges, snow, etc.

SIMULTANEOUS EFFECT

The simultaneous effect of loads is to be considered in the load factor design concept. The load is generally a time dependent variable, as in Fig. 10. Only the dead load has a constant magnitude during the life span of a structure; all live loads vary with time. As further specified schematically in Fig. 10, live loads may be divided into three main categories: long-term, short-term, and exceptional loads.

Long-term loading may be considered that load which has only short intermissions and permanently affects the structure (for example, technological equipment disassembled for checking once in two years, some temperature effects, or irregular settlement of foundation due to soil conditions, mining,(26) etc.).

All other loadings expected to affect the structure (wind, snow, cranes, floorloads, etc.) belong in the short-term category.

The last category includes all exceptional loads which may or may not occur during the lifetime of a structure. If they should occur, the effect will be very short (for example, explosion, defects in production lines, earthquake, etc.). In some areas (California), earthquakes are considered short-term loads.

It is obvious that the maximum total of all time-dependent loads (considering particular level of probability) may be much smaller than the simple sum of maximum individual loads. A reasonable analysis of the simultaneous effect of loads is not yet available for practical purposes. Present load factor design specifications use one or two simple reduction factors.

APPENDIX 3

Resistance Function

It has already been schematically shown in Chapter 4 that the load factor design concept compares the "maximum" possible load with the "minimum" carrying capacity equal to the defined minimum of the resistance function.

While, in the past, the investigation of the resistance function was related mainly to the mean value, and the scatter of the carrying capacity was included in the factor of safety, the load factor design concept attempts to define the minimum carrying capacity corresponding to a selected level of probability. The problem is demonstrated in three examples:

(1) Yield Stress is considered one of the most significant factors in the strength of a steel structure actually a statistical variable. Figure 11 shows a result of a statistical investigation of 2131 specimens of CSN 11 373 steel grade (equivalent to A36) undertaken to evaluate the magnitude of "minimum" yield stress corresponding to the probability 0.001.(26) The analysis has shown the

mean was 38.2 ksi, the standard deviation 2.03 ksi and the "minimum" yield stress (corresponding to p=0.001)

$$\sigma_{y,min} = 38.2 - 3.09 \times 2.03 = 32 \text{ ksi.}$$

(2) "Adjusted" (design) tress

In the Czechoslovak specifications the minimum magnitude of the resistance function is related to an "adjusted" (design) level of yield stress designated R. This magnitude was obtained for each steel grade from a statistical analysis of a large population of test results as well as possible variation of the cross sectional area, considering probability 0.001.(24)

The variation of yield stress is shown in Fig. 11. The magnitude of the "adjusted" (or "design") stress R was obtained from a statistical analysis of a function

$$\overline{R} = \sigma_y \frac{A_a}{A}$$

where σ_y is the variable yield stress, A_a, the actual (variable) cross sectional area, and A, the specified cross sectional area.(24) Using mathematical statistics, the frequency distribution of $\overline{R}$, which is the function of two random variables, can be obtained, as well as the mean and the standard deviations. The magnitude of the "adjusted" yield stress R is then defined as

$$R = m_{\overline{R}} - 3.09\ d_{\overline{R}}\ .$$

where $m_{\overline{R}}$ is the mean of variable $\overline{R}$, and $d_{\overline{R}}$, the standard deviation. The coefficient 3.09 corresponds to the level of 0.001 probability for normal symmetrical distribution.

(3) Column Strength

As shown in Fig. 12, the CRC column curve, in the present allowable stress design,(27) should represent the mean carrying capacity, while the variation of strength is included in the factor of safety.

In Fig. 13, the approach used by the European Convention(28) is demonstrated. For a particular column shape, the scatter in carrying capacity is represented by the frequency distribution curve f_c obtained by tests or theoretical investigation. As indicated in Fig. 13a, the minimum strength is derived from the mean by deducting two standard deviations. The column curve obtained using such an approach defines the minimum carrying capacity for each slenderness ratio with the same magnitude of probability.

- values of E, G, etc.
- simple tension
- simple bending
- biaxial bending
- shear stresses
- compression, buckling

In stability cases, the relevant criteria are specified and the check is given generally by

$$K\sigma < \sigma_e$$

where σ is the stress corresponding to the factored loads and K is related to the particular stability (etc.) considerations. (In Appendix 5 is discussed the design of pinned-end columns.)

- deformations
  (influence of deformations, assumptions for the computations, deformations due to axial force, bending, shear).

(4) Connections

The design procedure of welded, riveted and bolted connections is specified in detail.

In order to rationalize the design for different column shapes, the attempt is being made to introduce more than one column curve. As indicated in Fig. 13b, all available column shapes should be grouped into several categories so the initial frequency distribution curve f_c will be substituted for by f'_c, f''_c, f''_c, etc., and curves 1, 2, and 3 will be defined for each group, considering a particular level of probability.

APPENDIX 4

Economic Considerations

It was mentioned earlier that the introduction of load factor design may contribute certain material savings. The following examples show the difference between results from the CSN allowable stress design concept and CSN load factor design concept concerning required weight of steel or dimensions of shapes.

Example 1 - Tension Member

A tension member carrying total working load

$$D + L2 = 100 \text{ kips}$$

is designated accoring to allowable stress and load factor designs for different ratios of dead and live loads D/L2. Steel grade CSN 11373 (about equivalent to A36) is to be used. Considering load factors 1.1, for dead load D, 1.4, for live load L2, and a 1.5 factor of safety, the following are the magnitudes of P_1 (maximum load in load factor design) and P_2 (allowable stress design).

Limit State Design - CSN (Present) R=30 ksi	Allowable Stress Design - CSN (Former) $\sigma_{all.} = \frac{\sigma_y}{FS} = \frac{36}{1.5} = 24$ ksi.
$P_1 = D \times 1.1 + L_2 \times 1.4$	$P_2 = D + L_2$

The required cross area A_R versus the ratio of and (D + is plotted in Fig. 14. Considering allowable stress design, the required area is $A_R = 41.6$ in^2, which is constant for any magnitude of $\frac{L_2}{D+L_2}$. The required area obtained from load factor design depends on the ratio, and varies from 36.7 in^2 if only dead load D has been applied, to 46.8 in^2 if only live load L2 is considered.

The comparison of results demonstrates significant material savings for the low ratio $\frac{L2}{D+L2}$, while even more material is required for a high live load than what allowable stress design would necessitate.

Example 2 - Column Strength

Figure 15 presents a comparison of column strength according to the AISC and CSN. Steel grade A36 was assumed. For a particular magnitude of the slenderness ratio, the maximum allowed working stress according to the AISC is shown dotted and designated F_a. Considering different load factors n (= 1.0, 1.1, 1.2, 1.3), the maximum allowed working stress (according to the CSN) for each particular slenderness ratio is shown by a set of curves.

For low magnitudes of $\frac{KL}{r}$, the load factor design allows much higher stresses and therefore smaller shapes are required. Some results of both design approaches are designated (1) if n=1.1, (2), if n=1.2, and (3) if n=1.3.

For high slenderness ratios, the LFD requires larger sections than the AISC allowable stress concept.

APPENDIX 5

Comparison of Column Design According to French Specifications and AISC

To demonstrate the design procedure using the French load factor concept, an example of pinned-end column design is shown in Fig. 16. The CRC column curve, the F_a (AISC)(27) curve, and French(10) column curves are plotted assuming and A36 steel grade. According to the French regulations, the designer must prove that for a particular slenderness ratio, the factored working stress $\sigma = LF_y x \sigma_w$ multiplied by the buckling coefficient C is lower than the yield stress ($=F_y$)

$$C\,\sigma < \sigma_e$$

For three main loading conditions (permanent load, combination of loads, and live load), additional curves are plotted in Fig. 16 representing the maximum permissible levels of the working stress σ_w. Comparison with the AISC curve shows that, for low slenderness ratio, $\frac{KL}{r}$ about 100 , the AISC design is very conservative. For a higher $\frac{KL}{r}$, the French load factor design, requires larger shapes.

APPENDIX 6

Justification of the Load Factor (Limit State) Design Concepts

The following is a brief summary of several reasons which may be considered significant for the justification of load factor (limit state) design concepts.

1. Same or very similar level of reliability for each structural component. It may easily be shown that the current deterministic concepts, allowable stress design for steel structures, for example, generate different levels of actual safety by neglecting the variation of scatter of loading and resistance functions.

2. Economical Considerations. As mentioned in Appendix 4, the load factor design may bring significant material savings, especially in structures subjected primarily to a dead load.

3. Plastic Design. In plastic analysis and design, The load factors had to be introduced instead

of safety factors.$^{(30)}$ Developments in this area were recently investigated and the load factors used in plastic design reviewed and summarized in Ref. 31 (Table 4).

4. Prestressed Structures. It was shown$^{(32)}$ that the allowable stress concept is not suitable for prestressed steel structures and the load factor design may be considered the best approach.

The following example is used to demonstrate the difference between the actual and required safeties of a prestressed steel truss if allowable stress design is used. A truss prestressed by a high strength tendon is shown in Fig. 17. Due to prestressing force P in the member 1-2, compressive force S_p is generated. Assuming for example:

$$\frac{KL}{r} = 100$$

and steel A36 is used, the maximum allowable stress$^{(27)}$ in member 1-2 is

$$\sigma_a = 12.98 \text{ ksi (compression)}$$

After the external loads L are applied, the total axial force generated in member 1-2 will be $S_p + S_L$,

(Fig. 17) while the corresponding maximum allowable stress is

$$\sigma_a = 21.6 \text{ ksi (tension)}$$

According to the definition of the factor of safety

$$FS = \frac{L_y}{L_a} = \frac{12.98 + 36}{12.98 + 21.6} = 1.41 \ll 1.67$$

where L_y is the magnitude of the load corresponding to the first yielding, L_a the allowable load, and 1.67 the required magnitude of FS.(27)

5. <u>Second Order Considerations</u>. If the redistribution of second order moments and forces is not negligible, the allowable stress design is not suitable as a reliable method for proportioning the structure and proving safety. A hinge arch road bridge over the Vltava River, which was designed in the 1950's, may be used as an example. The pilot analysis of a slender arch (Fig. 18) of a span L = 1000 feet has shown that the second order effect is very significant and

$$H.y - V.x + H(y + \Delta y) - (x - \Delta x)v$$

In such a case, the factor of safety used in allowable stress design does not express the actual safety of a structure. To prove the safety in the design, the required factor of safety was partially expressed as a load factor and partially as a reduction of the specified yield stress of the material used.(33)

6. Column Design. One more comment may help justify the attempt to divide the load and resistance functions. In Fig. 12, the CRC column curve, which should represent a mean of column strength for a particular slenderness ratio and the AISC allowable stress curve, are shown. The scatter of the carrying capacity due to difference in shape, residual stresses and some other factors, is represented by frequency distribution curve f_c. The loading function, considered to be independent, is represented by the distribution f_L. Subsequently, the "safety" as defined by present specifications(27) includes the variation of both independent statistical variables.

8. TABLES AND FIGURES

TABLE ①

Examples of Load Factors (CSN 73 -035)

Type of Loading	Number of Load Factors Specified by CSN**	Example	n
Self-Weight of Structures	6	Steel Structures Concrete Structures	1.1(0.9)* 1.2(0.9)*
Floor Loads	17	Office Library	1.4 1.2
Vehicles and Technical Equipment	5	Machinery Loaded Trucks	1.2 1.3
Cranes	5	Overhead Cranes up to 5t capacity Brachet Cranes	1.3 1.25
Snow	1		1.4
Wind	2	Height-Width Ratio < 5 Height-Width Ratio > 5	1.2 1.3
Temperature	3	Usual Conditions	1.1
Creep, Relaxation	1		1.1
Mining Subsidence, Settlement	2	Permanent Control of Settlement No Control	1.0 1.2

* Whatever is less favorable.

** For each type of loading, the magnitudes of working loads are specified in CSN 73 0035 as well, however, they are not included in this table.

TABLE ②

Permanent Load	Dead Load, Influence of the Mode of Construction	Either 4/3 or 1, whichever is more unfavorable.
Variable Load	test loads or live loads, normal loads of snow, normal loads of wind	3/2 This value is reduced to: 17/12 in the computations which take into account simultaneously the effects of loads belonging to two of the three categories: a) Test loads or live loads b) Snow c) Effects of wind 4/3 in the computations which take into account simultaneously the loads belonging to all three categories.
Effects of temperature changes		4/3

		ASD	PD	LFD
LOADING FUNCTION	SIMULTANEOUS EFFECT OF LONG-TERM, SHORT TERM AND EXCEPTIONAL LIVE LOADS			s
	APPROXIMATIONS IN THE LOADING ANALYSIS	F.S.	L.F.	s,n
	MULTIPLE LOAD FACTORS			n
	SINGLE LOAD FACTOR	F.S.	L.F.	
RESISTANCE FUNCTION	MATERIAL PROPERTIES DIMENSIONS OF MEMBERS RESIDUAL STRESSES QUALITY OF WORKMANSHIP APPROXIMATIONS AND UNCERTAINTIES IN THE METHOD OF STRENGTH ANA. STRESS CONCENTRATIONS LOCATION OF STRUCTURES, ETC.			R
	SECONDARY CONDITIONS RELATED TO THE RESISTANCE FUNCTION			m
SPECIAL CONDITIONS	INTERACTION OF LOADING AND RESISTANCE FUNCTION			

TAB ~~4~~ 3.

~~TABLE 6~~.—LOAD FACTORS FOR PLASTIC DESIGN IN VARIOUS COUNTRIES

Country (1)	Assumed shape factor (2)	Dead load + live load (3)	Dead load + live load + wind or earthquake forces (4)	Number of load factors (5)
		(a) Single-Load Factors		
U.S.A.	1.12	1.70	1.30	2
Australia	1.15	1.75	1.40	2
Belgium	1.12	1.68	1.49 (1.12) (for extreme wind)	3
Canada	1.12	1.70	1.30	2
Germany	—	1.71f	1.50f	2
India	1.15	1.85	1.40	2
South Africa	1.15	1.75 (Portal Frames) 1.50 (Multistory Braced Frames)	1.40	3
Sweden	—	1.57	1.34	2
United Kingdom	1.15	1.75 (Portal Frames) 1.50 (Multistory Braced Frames)	1.40	3
		(b) Multiple-Load Factors		
Czechoslovakia	1.20 (max.)	$[F_1D + F_2(L_1 + L_2)]\frac{1}{k}$	$[F_1D + F_2L_1 + 0.9(F_2L_2 + F_3W + 1.4S)]\frac{1}{k}$[b] or $[F_1D + F_2L_1 + 0.8(F_2L_2 + F_3W + 1.4S + E)]\frac{1}{k}$	
Hungary[a]	1.05	Proposal 1: (single-load factor) 1.2 - 1.5 depending on combinations of D, L_1, and L_2. Proposal 2: (multiple-load factor) Many possible combinations.		3 4
Japan[a,c]	—	$1.2D + 2.1(L + S)$ or $1.4(D + L + S)$ (normal condition) $(D + L) + 1.5E$ or $(D + L + nS) + 1.5E$ (under earthquake) $(D + L) + 1.5W$ or $(D + L + nS) + 1.5W$ (under typhoon)		6
Yugoslavia	1.12	$D = 1.49$, $L = 1.68$ + Additional Combinations		several

[a] Under study

[b] $F_1 = 1.1 - 1.3$; $F_2 = 1.2 - 1.4$; $F_3 = 1.2 - 1.3$; $k = 0.87$ for $\sigma_y = 34{,}3$ ksi; and $= 0.80$ for $\sigma_y = 51.4$ ksi; D = dead load; L = live load; L_1 = regular (long-time) live load; L_2 = irregular (short-time) live load; E = earthquake force; f = shape factor; S = maximum snow load; and W = wind force.

[c] Period of snowdrifts: $n = 0$ for less than one month; $n = 0.5$ for one month; $n = 1.0$ for three months.

Tab 4.

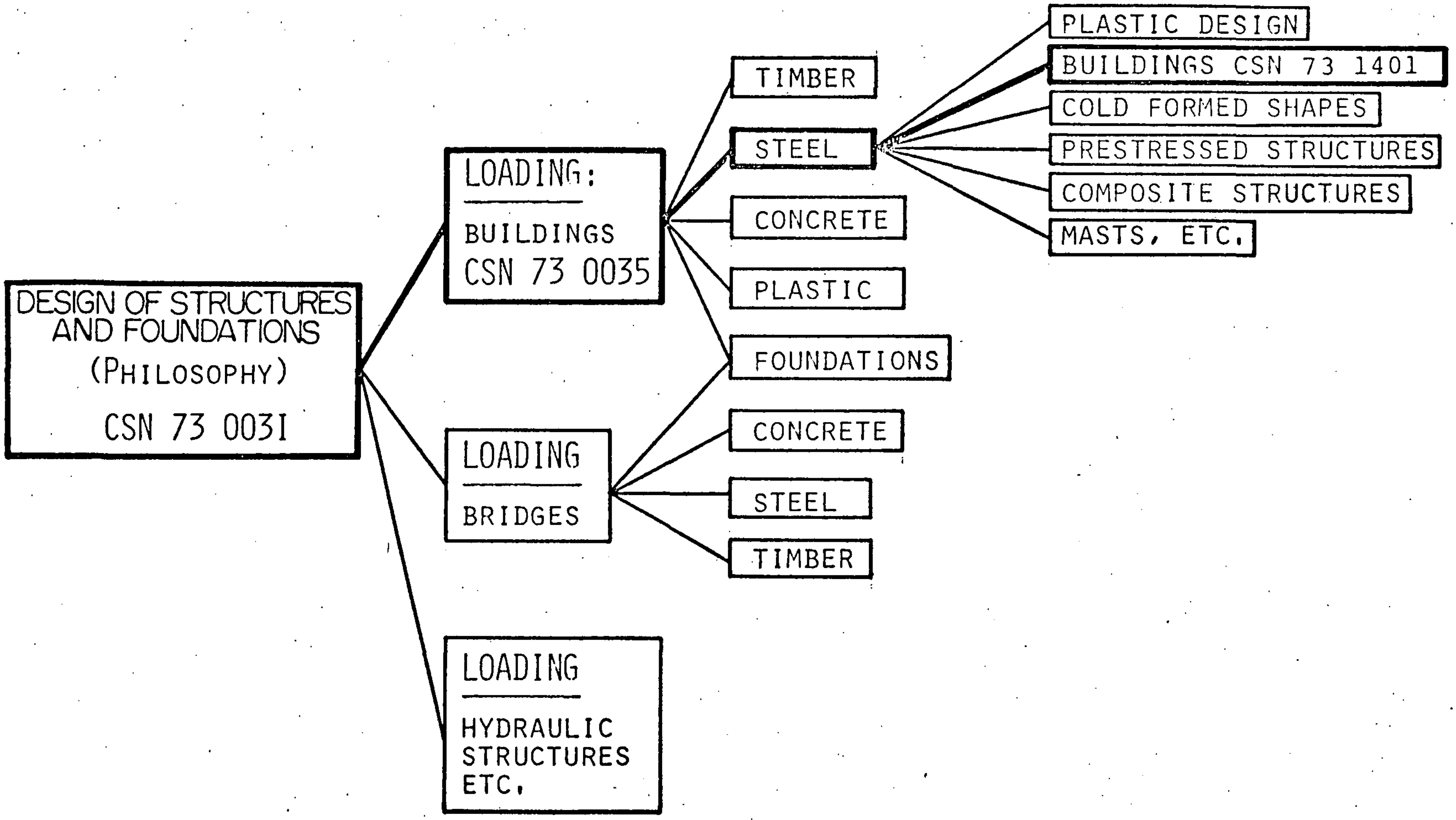
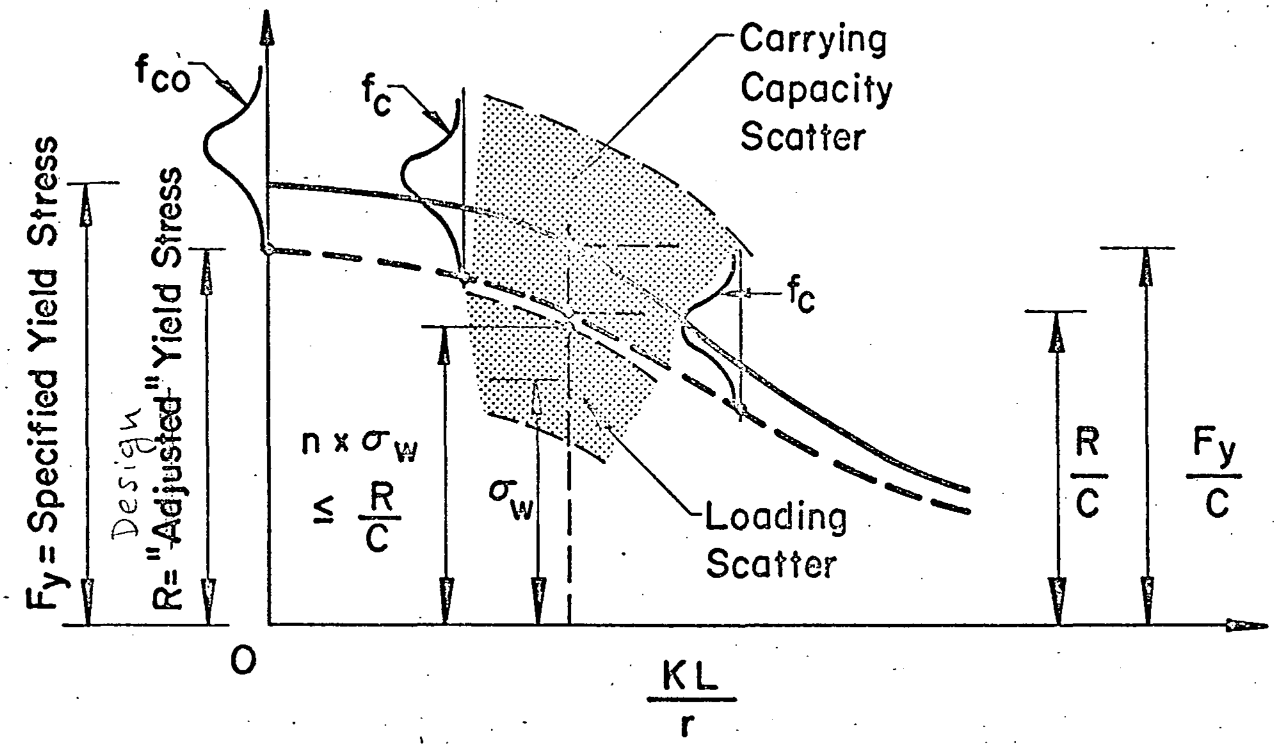

DESIGN OF STRUCTURES AND FOUNDATIONS
(PHILOSOPHY)
CSN 73 0031
LOADING:
BUILDINGS
CSN 73 0035
LOADING
BRIDGES
LOADING
HYDRAULIC STRUCTURES ETC.
TIMBER
STEEL
CONCRETE
PLASTIC
FOUNDATIONS
CONCRETE
STEEL
TIMBER
PLASTIC DESIGN
BUILDINGS CSN 73 1401
COLD FORMED SHAPES
PRESTRESSED STRUCTURES
COMPOSITE STRUCTURES
MASTS, ETC.

Fig. 1.

LIMIT STATE DESIGN (CSN)



n - Load Factor

σ_w - Working Stress

C - Buckling Coefficient

Fig 2

~~Fig 14~~

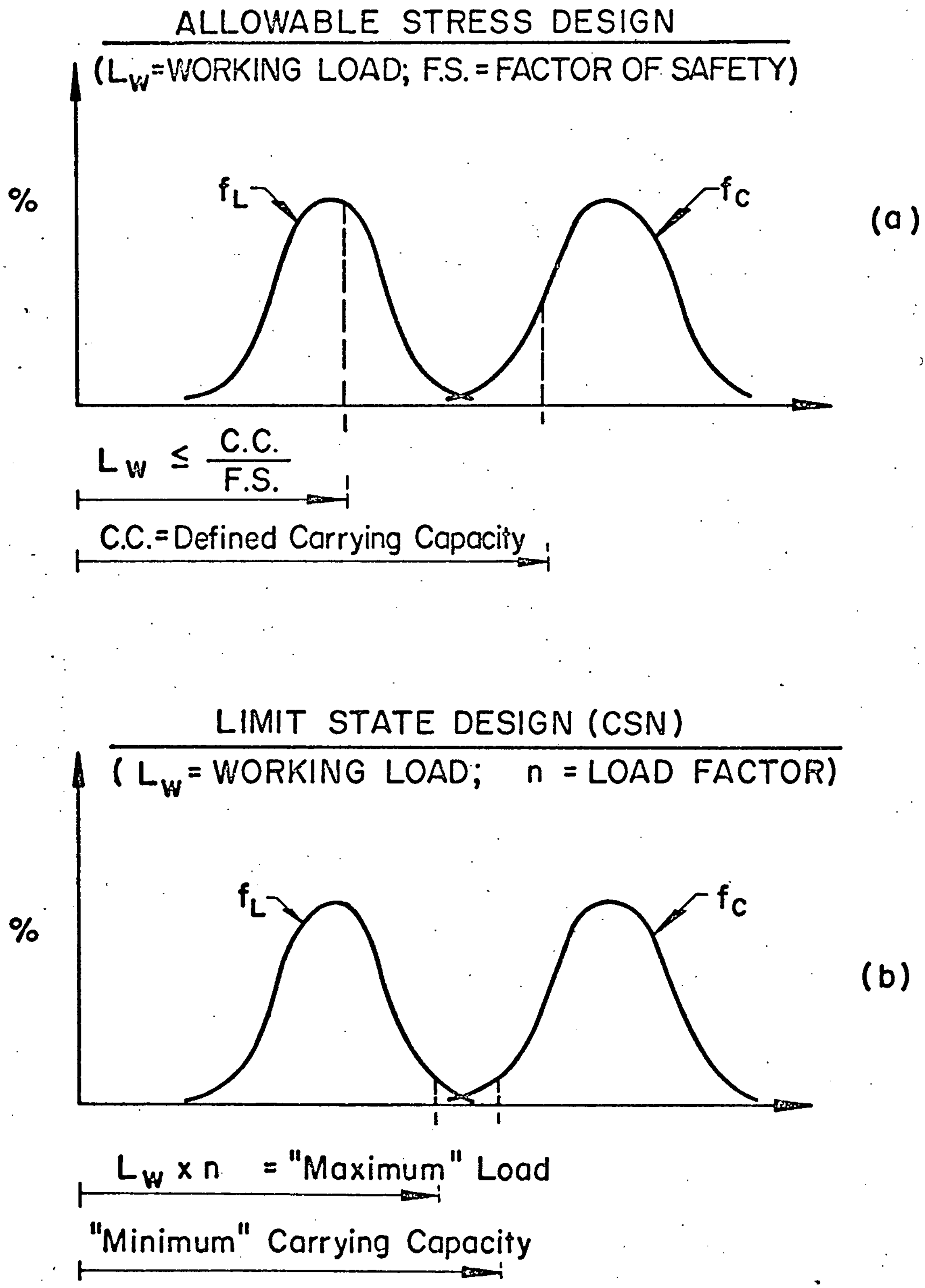

ALLOWABLE STRESS DESIGN
(L_W=WORKING LOAD; F.S.=FACTOR OF SAFETY)
%
f_L
f_C
(a)
$L_W \leq \frac{C.C.}{F.S.}$
C.C.=Defined Carrying Capacity
LIMIT STATE DESIGN (CSN)
(L_W= WORKING LOAD; n = LOAD FACTOR)
%
f_L
f_C
(b)
L_W x n = "Maximum" Load
"Minimum" Carrying Capacity

Fig 3

~~Fig 4~~

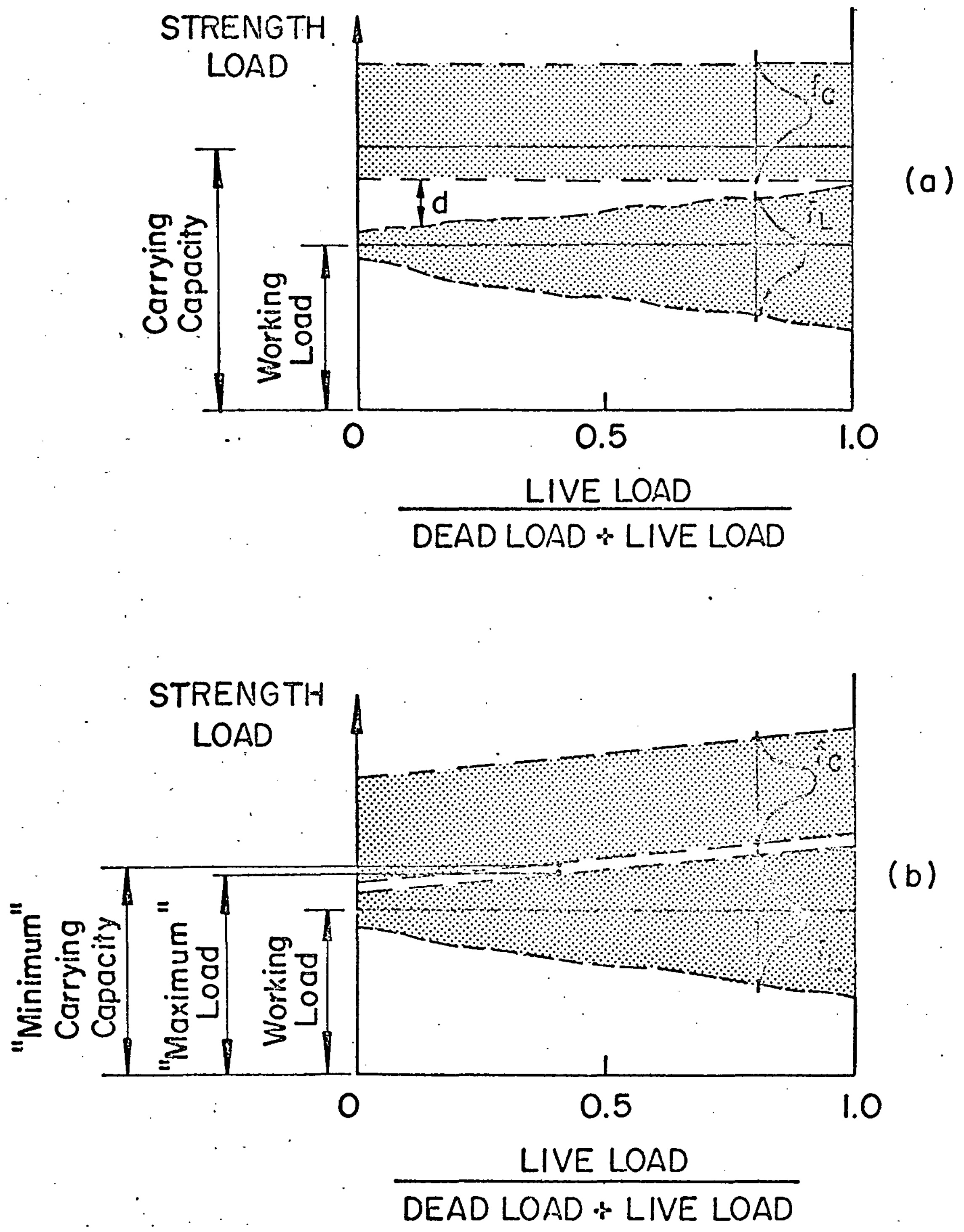

STRENGTH
LOAD
Carrying Capacity
Working Load
d
f_C
f_L
0
0.5
1.0
LIVE LOAD
DEAD LOAD + LIVE LOAD
(a)
STRENGTH
LOAD
"Minimum" Carrying Capacity
"Maximum" Load
Working Load
f_C
0
0.5
1.0
LIVE LOAD
DEAD LOAD + LIVE LOAD
(b)

Fig 4
[illegible]

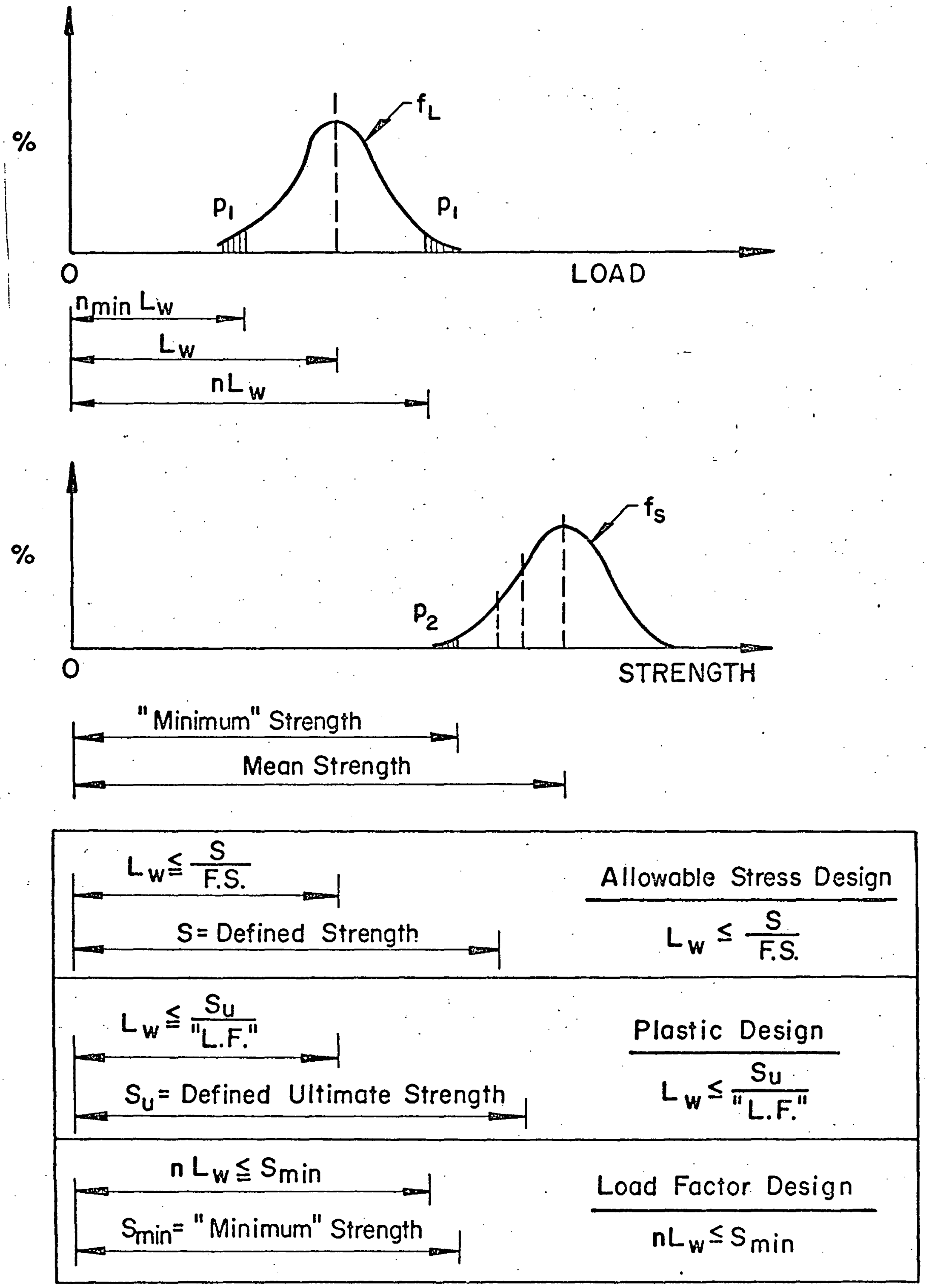

%
f_L
p_1
p_1
0
LOAD
$n_{min} L_W$
L_W
nL_W
%
f_S
p_2
0
STRENGTH
"Minimum" Strength
Mean Strength
$L_W \leq \frac{S}{F.S.}$
S = Defined Strength
Allowable Stress Design
$L_W \leq \frac{S}{F.S.}$
$L_W \leq \frac{S_u}{\text{"L.F."}}$
S_u = Defined Ultimate Strength
Plastic Design
$L_W \leq \frac{S_u}{\text{"L.F."}}$
$nL_W \leq S_{min}$
S_{min} = "Minimum" Strength
Load Factor Design
$nL_W \leq S_{min}$

Fig ~~#2~~ 5

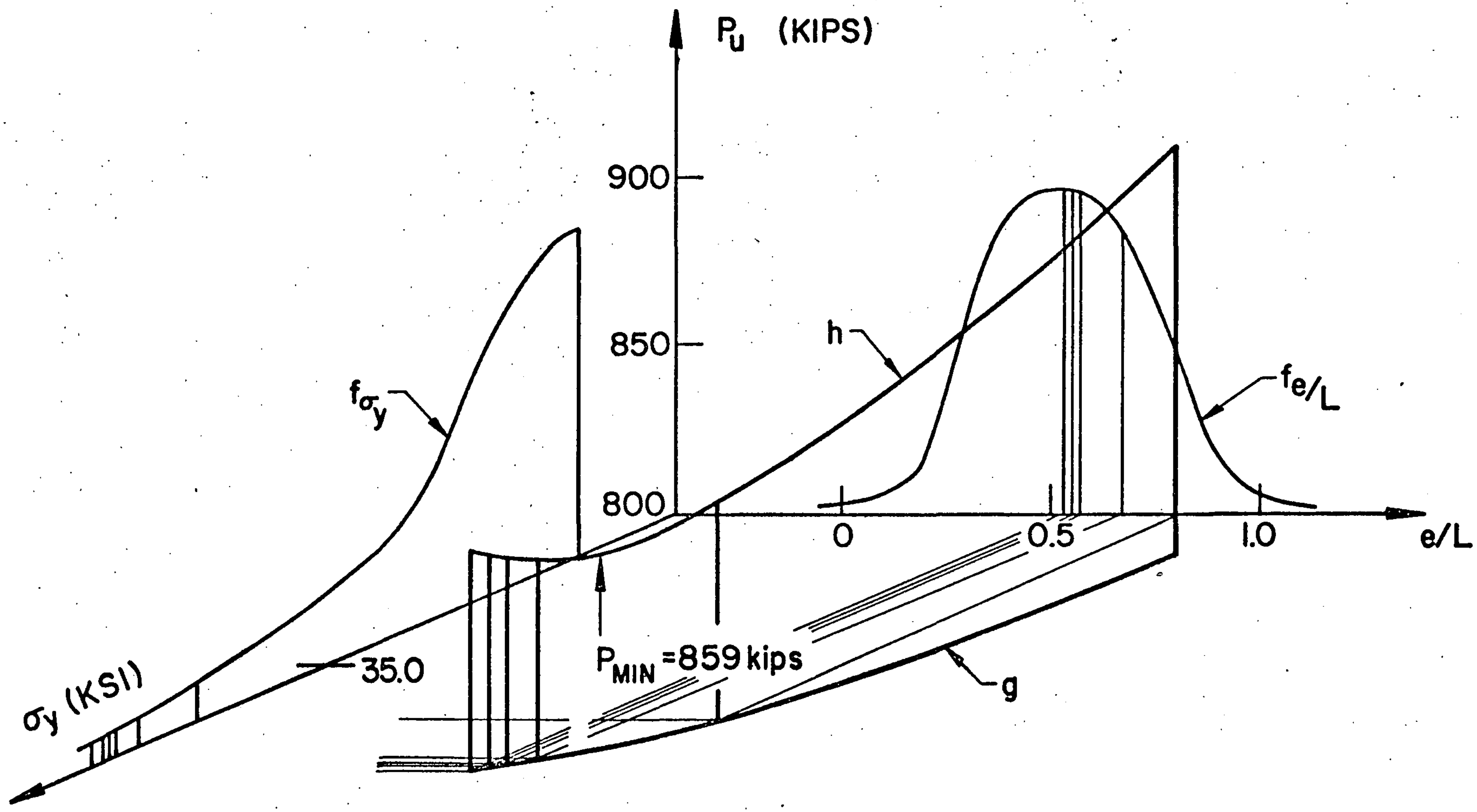

P_u (KIPS)
900
850
800
h
f_{σ_y}
$f_{e/L}$
0
0.5
1.0
e/L
σ_y (KSI)
35.0
P_{MIN} = 859 kips
g

Fig. 6.

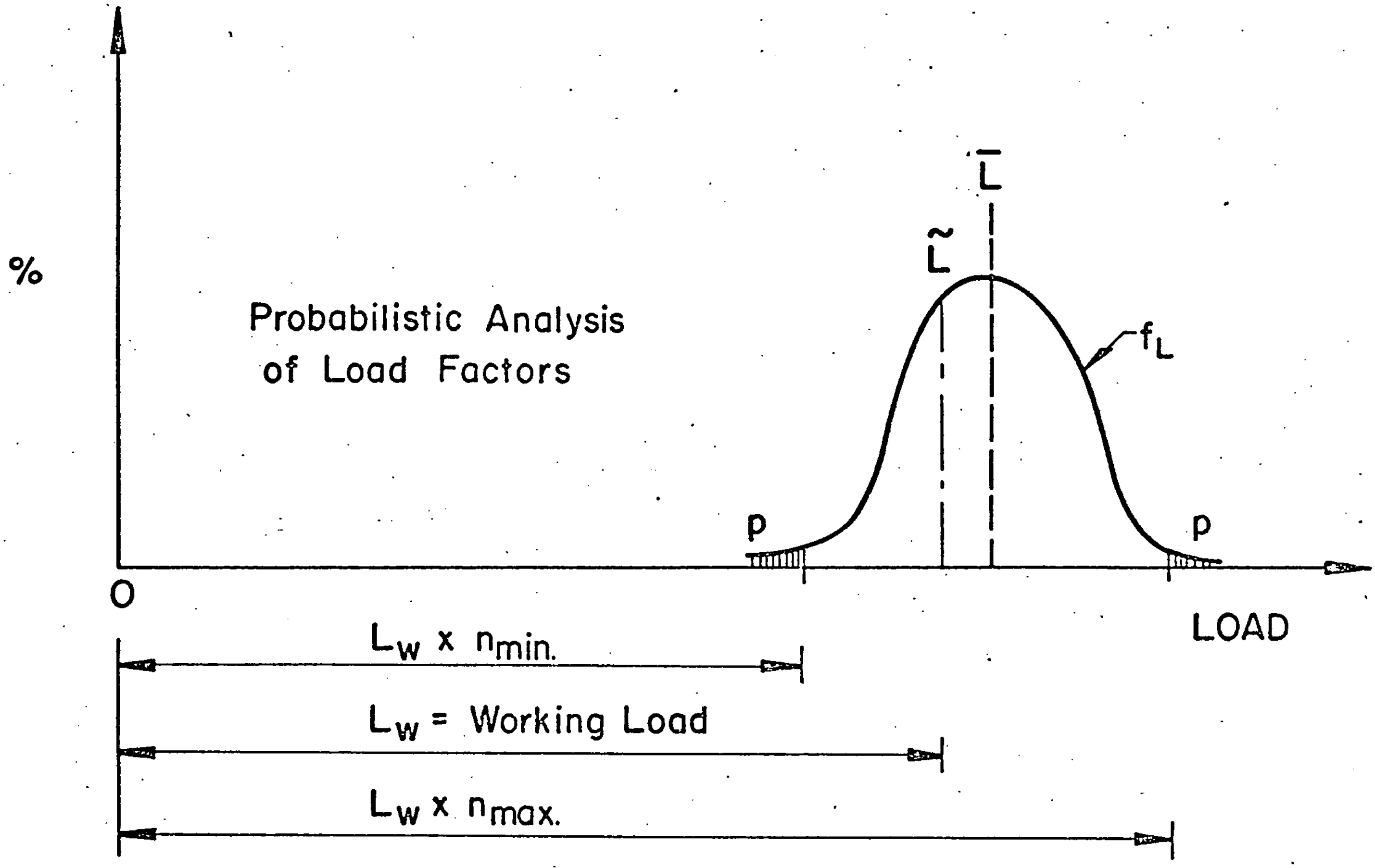
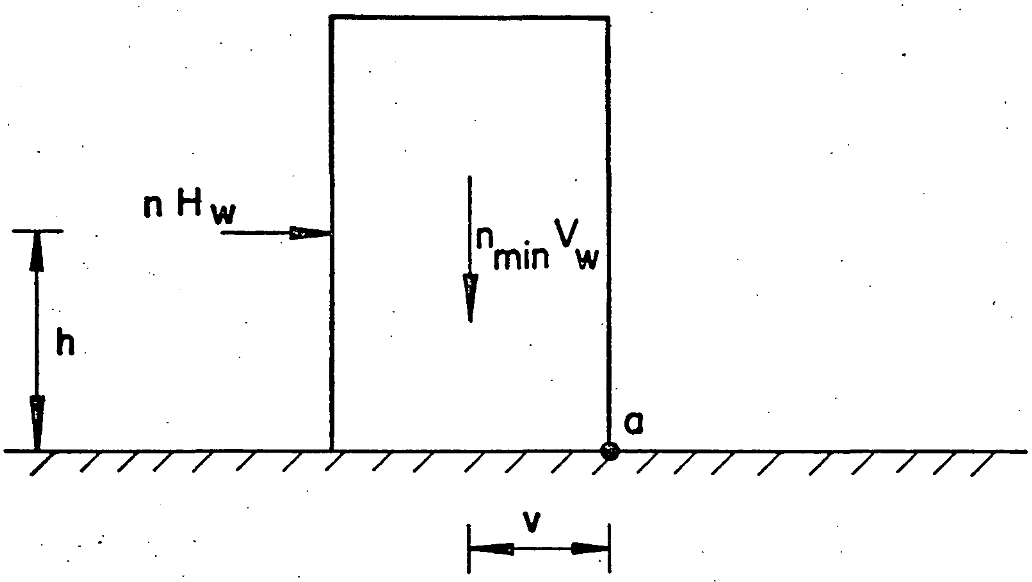
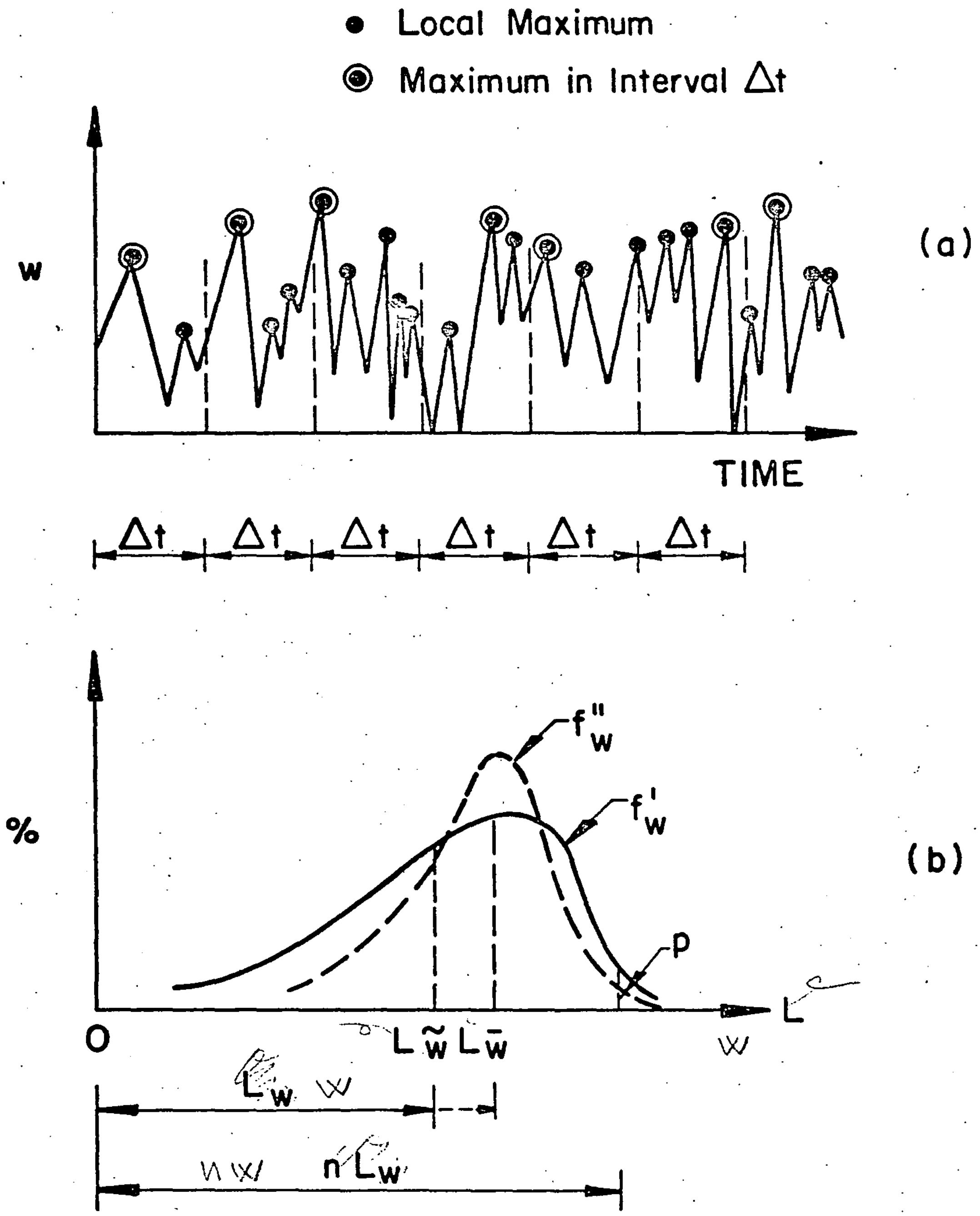

%
Probabilistic Analysis of Load Factors
$\bar{L}$
$\tilde{L}$
f_L
p
p
O
LOAD
$L_W \times n_{min.}$
L_W = Working Load
$L_W \times n_{max.}$

Fig 7
~~Fig 6~~



$$v \quad n_{min} V_w > n\, H_w \quad h$$

Fig 8.


● Local Maximum
◉ Maximum in Interval Δt
w
TIME
Δt
Δt
Δt
Δt
Δt
Δt
(a)
%
f''_w
f'_w
p
O
$L_{\tilde{w}}$
$L_{\bar{w}}$
L
w
L_w
w
n w
nL_w
(b)

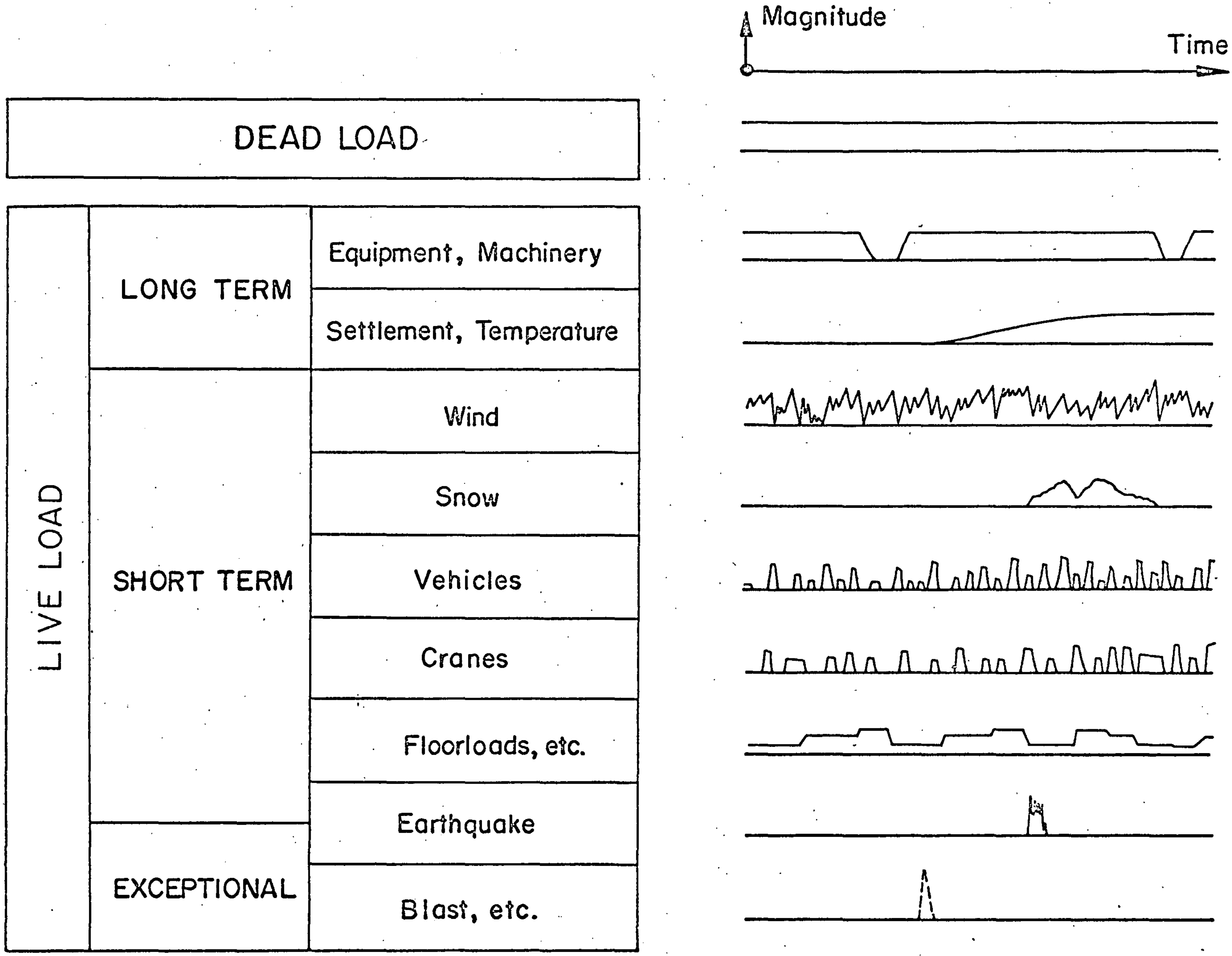
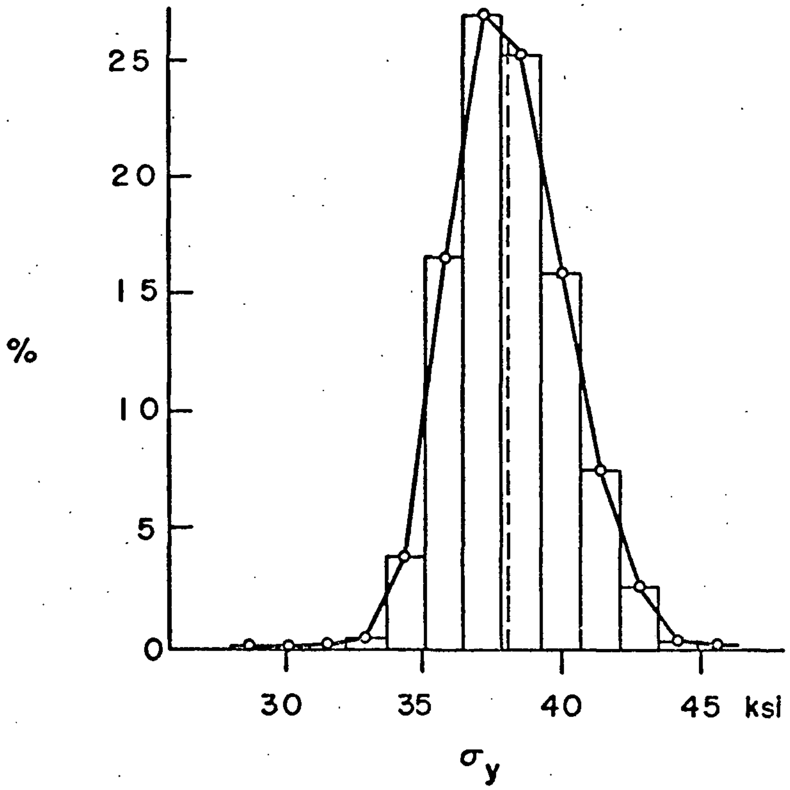
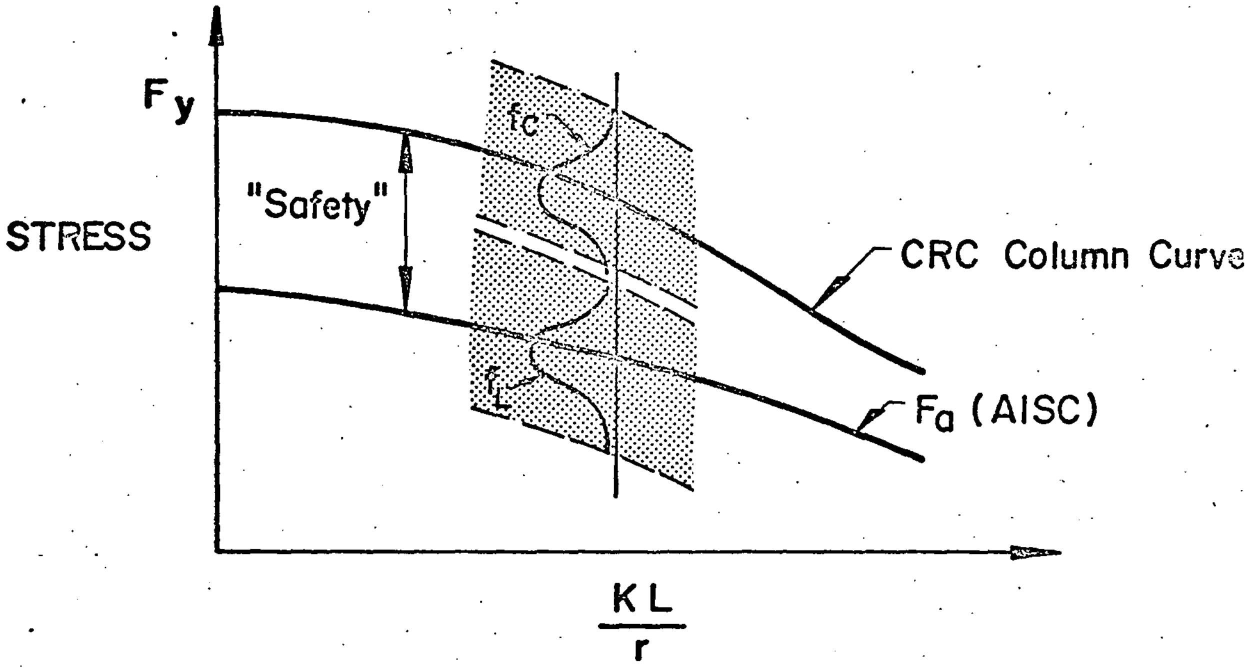

Magnitude
Time
DEAD LOAD
LIVE LOAD
LONG TERM
Equipment, Machinery
Settlement, Temperature
SHORT TERM
Wind
Snow
Vehicles
Cranes
Floorloads, etc.
EXCEPTIONAL
Earthquake
Blast, etc.

Fig. 2
10



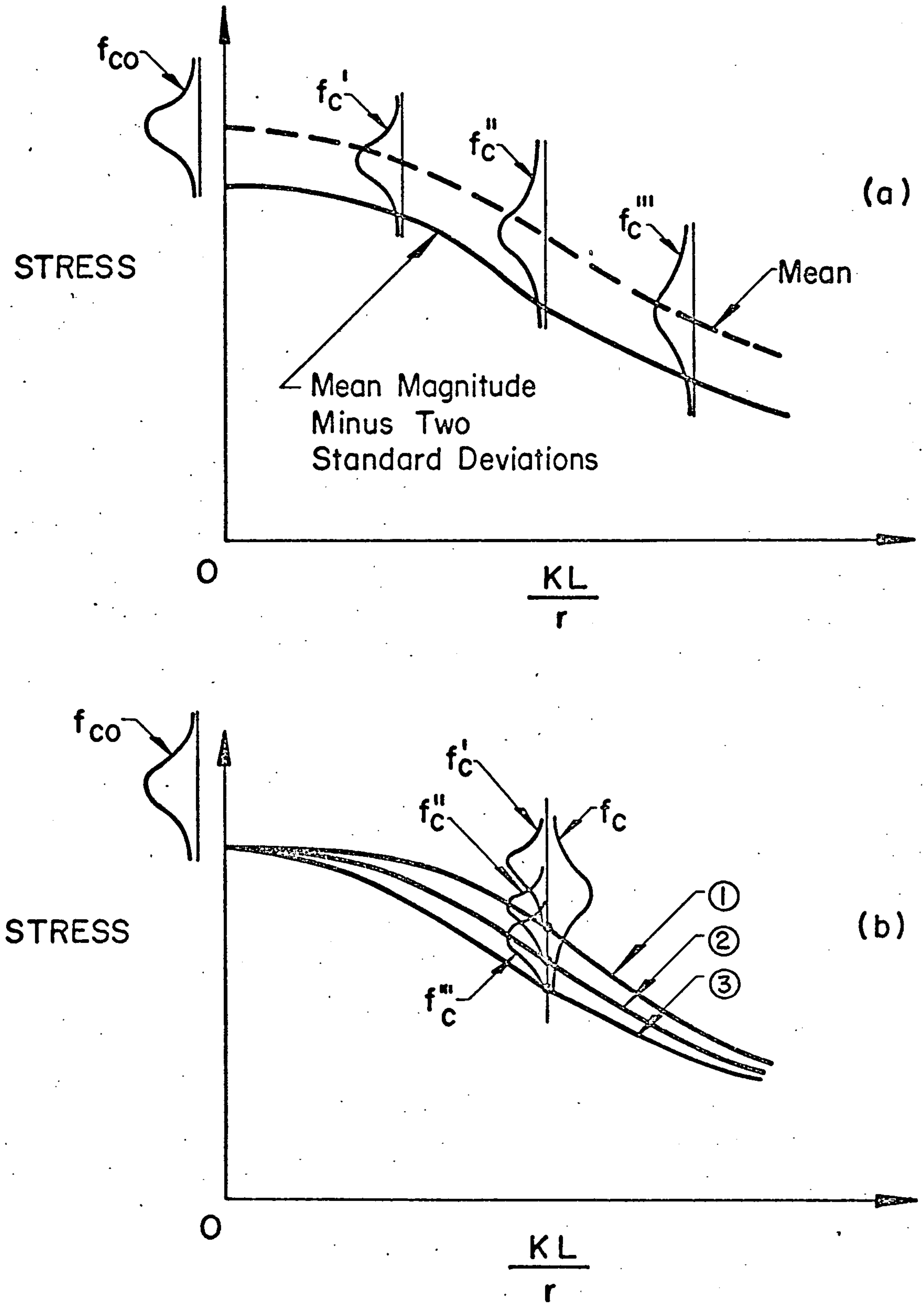
11

Fig ~~10~~.

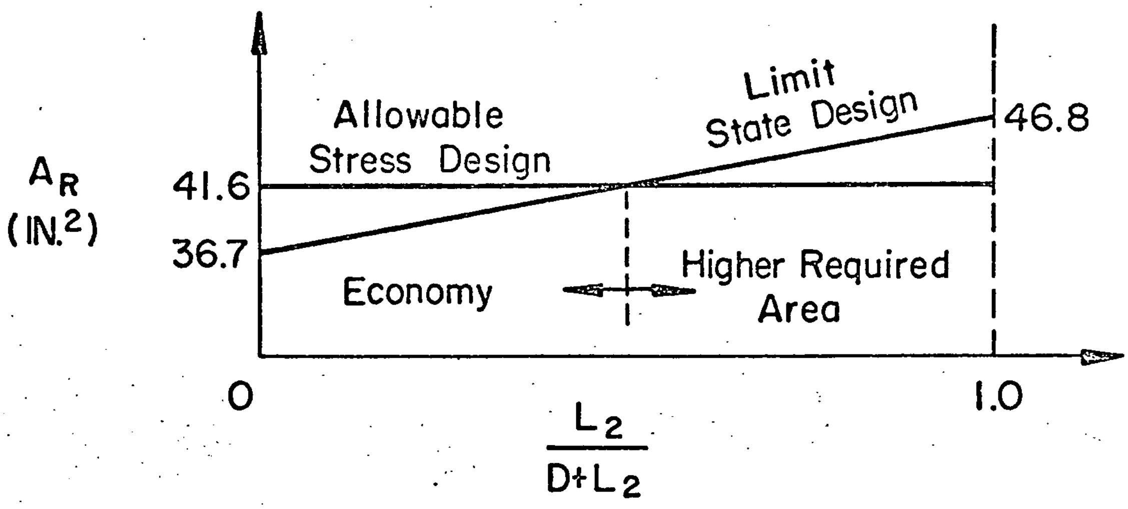


12

Fig 3.

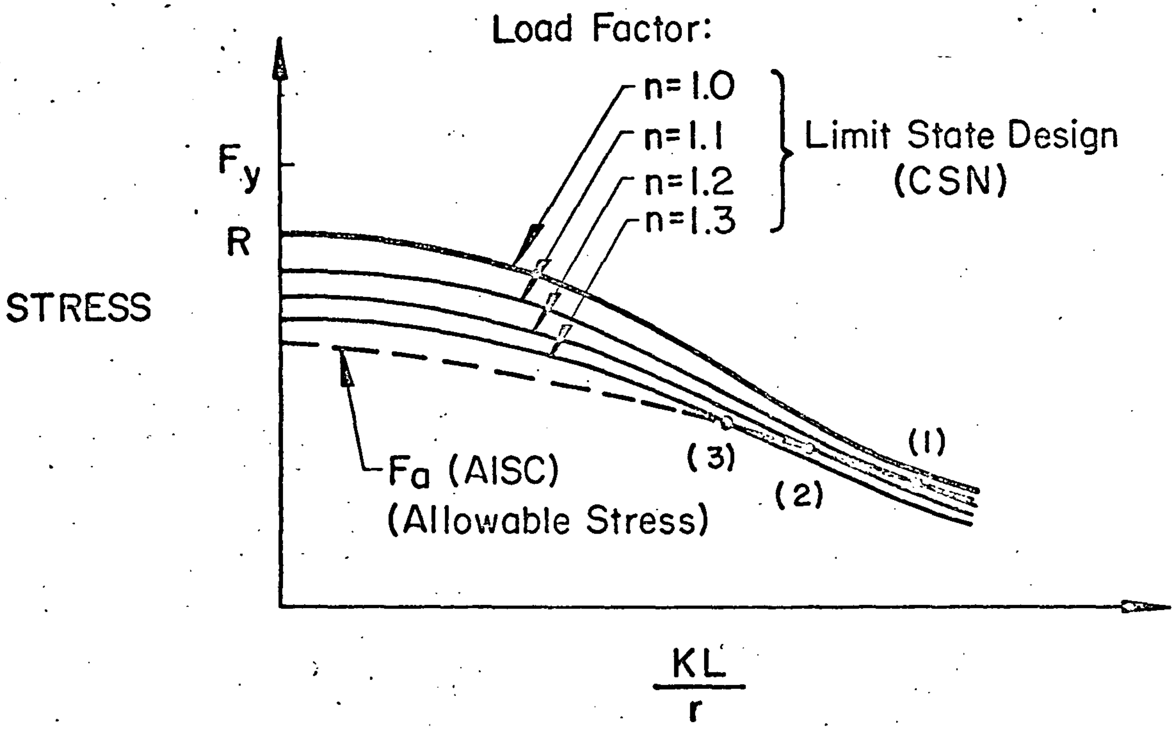


13a,b
Fig ~~12a,b~~


Allowable
Stress Design
Limit
State Design
A_R
(IN.^{2})
41.6
36.7
46.8
Economy
Higher Required
Area
0
1.0
$\frac{L_2}{D+L_2}$

14

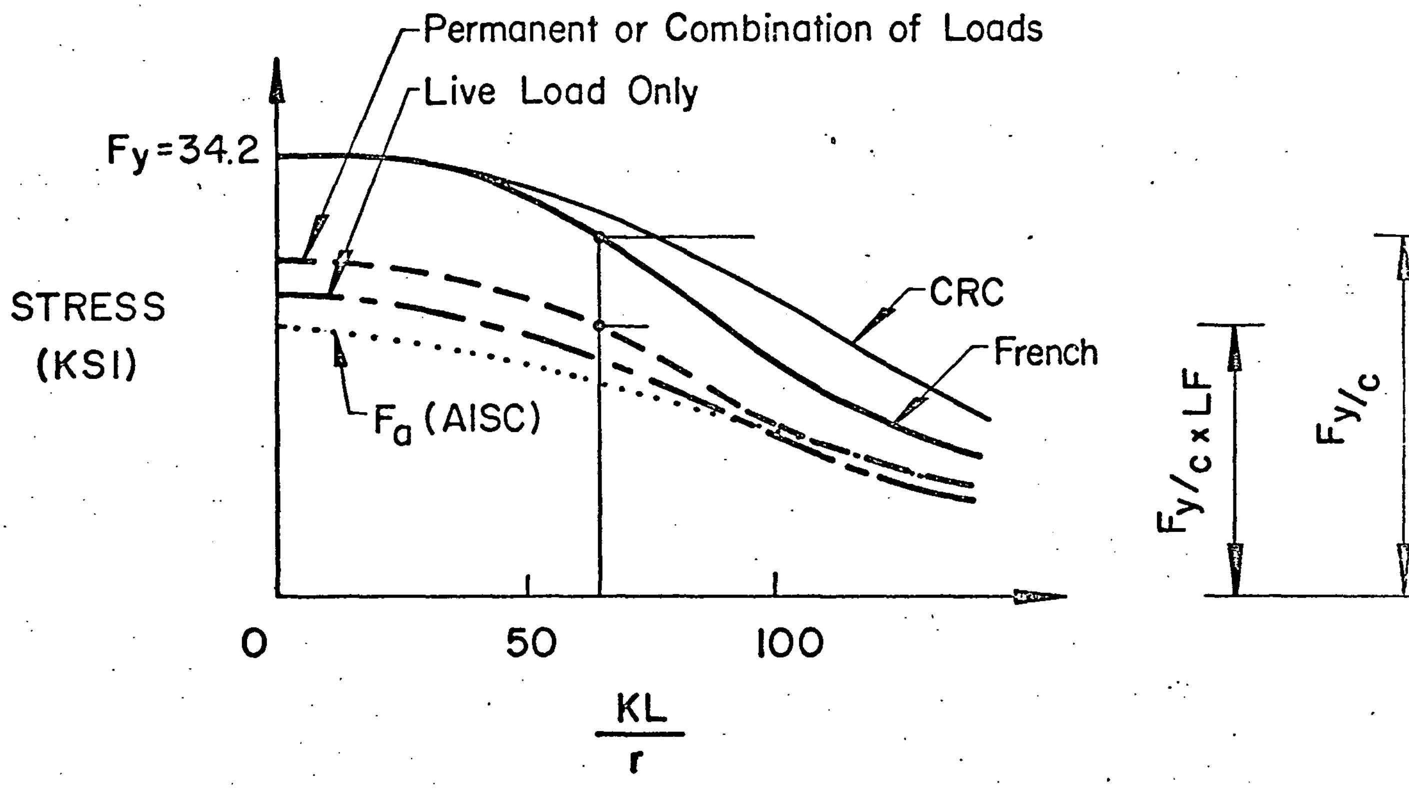
Fig ~~18~~


Load Factor:
n=1.0
n=1.1
n=1.2
n=1.3
Limit State Design
(CSN)
F_y
R
STRESS
(1)
(2)
(3)
F_a (AISC)
(Allowable Stress)
$\frac{KL}{r}$

15

Fig ~~16~~

LOAD FACTOR DESIGN
(French Specification)

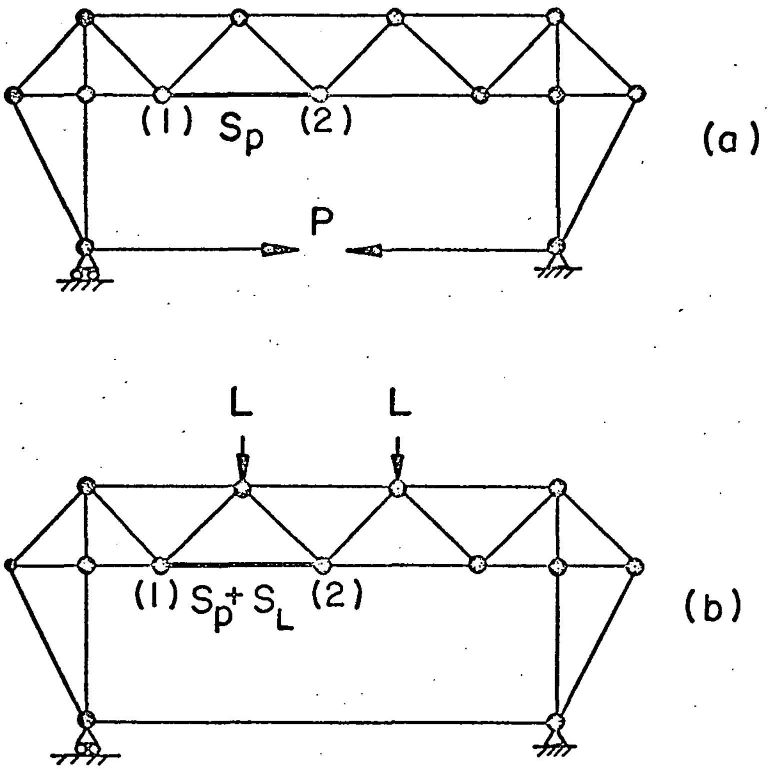


LF - Load Factor
σ_w - Working Stress
C - Buckling Coefficient

$$\boxed{\sigma_w \leq \frac{F_y}{C \times LF}}$$

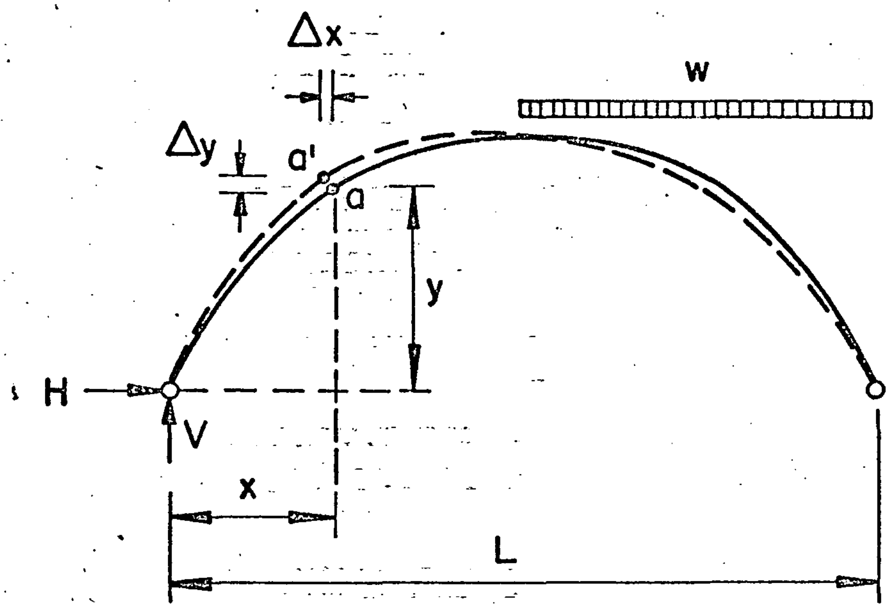
16

Fig 2a



17

Fig 4.



18

Fig. ~~2~~.

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