Monte Carlo simulation of the load carrying capacity of members in space trusses

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Monte Carlo Simulation of the Load Carrying Capacity of Members in Space Trusses

Simulation de la force portante d'éléments en treillis à trois dimensions moyennant la méthode Monte Carlo

Simulation der Tragfähigkeit von Elementen in Raumfachwerken mit Hilfe der Monte Carlo-Methode

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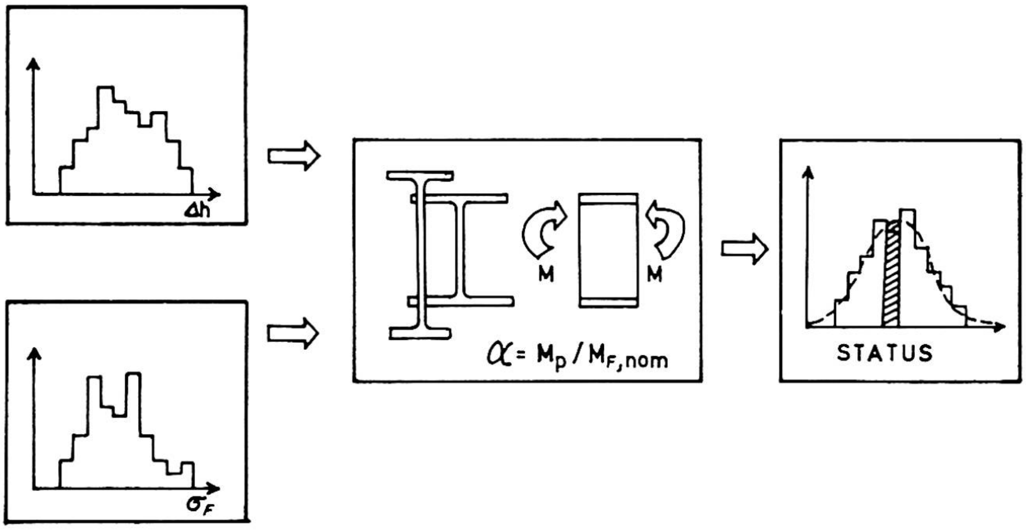
In their paper on the Influence of Member Quality on the Safety of Space Trusses Messrs. Tolman and de Witte use a Monte Carlo Simulation Method to determine the theoretical probability distribution of the collapse load of a truss. The number of bars, the bar arrangement and the number of inferior members with equal degree of inferiority $f < 1$ are given. The authors seem to use the term "analogous simulation" in the sense of "representing some aspects of the real world by a mathematical model which may be easily manipulated to facilitate their study", i.e. what often is simply called simulation, [1], p. 1.

As single random variable Tolman and de Witte introduce the location of the inferior members. Their paper is an interesting study of the load carrying capacity of multiple-member structures with random defects. By use of the finite element method the same Monte Carlo procedure may be applied to problems of nonhomogeneous plates, membranes and shells.

In the following the main principles of a computer program system for Monte Carlo simulation of structural strength will be given. The interest will be focused on the determination of the scatter in the load carrying capacity of single members. As a consequence of this study it is suggested that a simulation of a space truss should be performed where f is treated as a random variable, and where $f \geq 1$ is allowed.

Monte Carlo simulation program

A Monte Carlo method, i.e. a numerical procedure where random numbers are used, is suited for the investigation of different phenomena governed by stochastic variables [1]. Here we are especially interested in how the scatter in material properties and cross sectional dimensions affect the mean values and the scatter of the load carrying capacity of structural members [1] [2].



This block diagram shows the three main steps of our simulation method :

1. Input of known distribution functions (histograms) for the geometrical and strength variables.

2. A mathematical model for the load carrying capacity. The governing variables are randomly chosen for each play.

3. Output of the statistical distribution (i. e. histograms) of the load carrying capacity of the member. Statistical analysis of the results.

Example. Steel compression member [3]

The relative buckling load $\beta = P_k/P_{F,nom}$ of a centrally loaded initially straight steel column of I-section is computed using the tangent modulus theory and the following mathematical model, which considers elastoplastic behaviour and residual stresses. Here $P_{F,nom} = \sigma_{F,nom} A_{nom}$ is the yield load of a nominal cross section, and $P_k = \sigma_k \cdot A$ is the buckling load of the actual column with cross section area A and buckling stress σ_k.

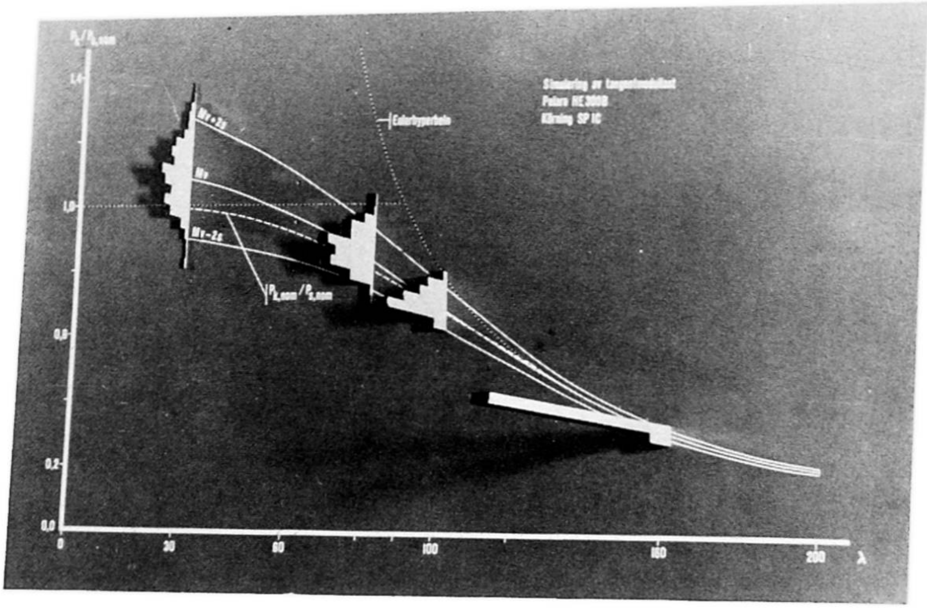
$$\sigma_k = (\pi^2 E/(L/i)^2)\, \sigma_r^{-q} \cdot (\sigma_F - \sigma_k)^q \ , \quad \sigma_k \geq \sigma_p = \sigma_F - \sigma_r \, , \quad 0 \leq q \leq 1$$

$$\sigma_k = \pi^2 E/(L/i)^2 \ , \quad \sigma_k \leq \sigma_p$$

The column has length L and radius of gyration i. E is Youngs modulus, σ_F the yield stress, and $\sigma_r = k_r \cdot \sigma_F$ the maximum compressive residual stress.

The input data consist of seven stochastic variables (yield stress and cross sectional dimensions) and three deterministic variables (k_r, q and E). For the exponent q, which determines the form of the stress-strain-diagram, the values q = 1/2 and 2/3 were chosen [3].

The results are printed as histograms of the relative buckling loads β for every nominal slenderness ratio. The different histograms may be gathered in a 3-dimensional diagram.



The figure given here refers to a column HE 300 B and a mathematical model with q = 1/2 and $\sigma_r = 0.5\ \sigma_F$. The assumed yield stress has a rather large scatter (coefficient of variation = 9.25 %).

In [3] the results of a series of simulations with different input data are statistically analysed and compared with each other and with experimental results. The large scatter in the simulated buckling load for short and medium length columns is mainly due to the variation in yield strength.

References

[1] Edlund, B. - Leopoldson, U.: Monte Carlo Simulation of the Strength of Steel Structures. Part I. Method and Basic Data. Publ. S 71:3. Chalmers Univ. of Technology, Division of Steel and Timber Structures, Göteborg 1971.

[2] Edlund, B. - Leopoldson, U.: Monte Carlo Simulation of the Load Carrying Capacity of Steel Beams. To be published in Acta Polytechnica Scandinavica.

[3] Edlund, B. - Leopoldson, U.: Simulering av bärförmåga hos stålpelare. Delrapport 1. Statistisk variation hos tangentmodullasten för valsade pelare med I- och H-tvärsnitt. Chalmers Tekniska Högskola, Inst. för Konstruktionsteknik, Stål- och träbyggnad, Int. skr. S 70:8, Göteborg 1970.

SUMMARY

With knowledge of the statistical distribution of member properties, such as geometry, modulus of elasticity and yield strength, the distribution of the load carrying capacity of a member can be determined by a three step simulation procedure. As an example the scatter of the tangent modulus load of a compression member is computed.

RESUME

En connaissant la distribution statistique des propriétés des éléments, tel que la géométrie, le module d'élasticité et la tension de fluage, la répartition de la force portante d'un élement peut être déterminée par un procédé de simulation en trois étapes. Le calcul du dispersement de la charge (calculée à l'aide du module tangent) d'un élément comprimé, est présenté ici comme exemple.

ZUSAMMENFASSUNG

Aufgrund der Kenntnisse über die Verteilungsfunktion von Elementeigenschaften wie Geometrie, Elastizitätsmodul und Streckgrenze kann die Verteilungsfunktion der Elementtragfähigkeit mit Hilfe einer dreistufigen Simulationsmethode bestimmt werden. Als Beispiel wird die Streuung der Tangenten-Modul-Last eines gedrückten Stabes berechnet.