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EVOLUTION OF ENGINEERING STANDARDS AND ESTIMATION METHODS

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ABSTRACT

The article discusses the evolution of engineering standards and estimation methods. The development of the philosophy of ensuring the safety of buildings and *structures being engineer, took place in separate stages and in its main course always developed under the slogan of more and more detailed forecasting of structures, studying the nature of the strains affecting on these structures, more clearly describing the requirements for a constructive form and conditions for meeting such requirements.*

Key words: allowable stresses, Claude Louis Marie Henri Navier, estimation methods, factor of safety, Hammurabi Codex, stress, Vitruvius.

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1. INTRODUCTION

Standardization of the requirements for the stability and safety of buildings under construction has a long history.

The earliest known written building regulations are included in the Hammurabi Code, which dates from around 1772 BC.

It says:

- If a builder constructs a house for someone not properly, and the house he built collapses and kills his owner, then this builder must be executed.
- If the house kills the owner's son, the builder's son must be executed.
- If the house kills the slave of the owner, then he must pay for the slave of the owner of the house.
- If the house destroys the goods, the builder must compensate for everything that was destroyed, and since he did not properly build the house, he would have to re-construct the house at his own expense.
- If a person was negligent in relation to the stability of the dam, which is on his land, then in punishment he must pay damages up to the sale of himself into slavery [1].

Successful engineering solutions tested by practice were repeated in subsequent constructions.

A generalization and description of such reliable solutions is presented in the only remaining ancient work on architecture - the treatise of Vitruvius "Ten books on architecture" (13 BC).

The author summarized in the treatise the experience of Greek and Roman architecture, considered a set of related town-planning, engineering and technical issues, practical rules of the construction art and principles of artistic perception. As a result, the treatise is an encyclopedia of technical knowledge of its time.

The first Russian code of requirements "Construction Charter" appeared in the XI century under Yaroslav the Wise. He determined the terrain and materials suitable for construction, the height of the buildings, gave recommendations on the location of the premises in the buildings [2-4].

2. METHODOLOGY

The purpose of all the requirements of the standards for the construction of buildings is to prevent collapse or to make them such that the inevitable wear and tear can be compensated by repairs.

There are two types of destruction in which restoration or restoration rarely makes sense:

- Destruction from fire in case of fire;
- Collapse of structures.

That is why both of these forms of destruction of buildings have been objects of certain precautions for long times.

3. EVOLUTION OF CALCULATION METHODS

Special regulatory measures relating to Fire protection of buildings existed in ancient Rome, in London they appeared in the 17th century, when after a major fire in 1666 a law drafted by Sir Matthew Hale regulated the restoration and new construction of the city [5].

The issues of rationing for ensuring strength are much more complicated than fire prevention measures.

Rationing strength can be implemented within two principles:

- Copying time-tested structures (Vitruvius);
- Theoretical substantiation of the reliability of the structure.

Galileo published in 1638 “Dialogues Concerning Two New Sciences” One of these industries was the study of strength.

Galileo is the first in the history of mankind, who raised the question of the strength of bodies as a question of scientific knowledge and first tried to solve it.

Galileo examined the strength of bodies at the time of their destruction (in modern terms - in the limit state).

He was not interested at all in what way and through what stages the body reached this state. The approach of Galileo was accepted without objections and all the experiments, that were few in that era (and then it was the only way of research) were put with the sole purpose – to find the amount of destructive load and the form of destruction.

Knowledge of the limits of change or even the exact value of the breaking load has not give an answer to the question - how to practice this knowledge in practice.

The builders had to solve this riddle according to their own understanding. This question was solved intuitively, by numerous trials and errors, learning by accidents and collapses of structures.

The theoretical bases for the construction of structures are formulated in the methods of Structural mechanics.

The approach to the problem belongs to Claude Louis Marie Henri Navier (1785–1836), who chose the way of studying the actual work of the structure under load and its calculation on the working condition.

With this approach, it was necessary to study the stresses of the operational state and find their relationship to destructive stresses.

Claude Louis Marie Henri Navier (1785 –1836)

If a steel beam collapses at a stress of 4000 kgf / cm2, then Navier suggests taking the allowable stress during bending equal to 1300 kgf / cm2 [6].

The development of mechanics allowed the calculation to determine the predicted value of stresses in the structure and its elements from the action of the loading factor, which formed the idea of using stress criterion in the structure behavior forecast.

Such approach (for "allowable stresses") in general form can be represented as a relation: $S \leq R$

S – stresses in the structure and its elements from the action of the loading factor;

R – the resistance of the structure, expressed in the same units as the value of S.

Thus, it became necessary to determine the value of the second criterion in the ratio of performance prediction - R (structural resistance).

Obviously, the value of R depends on the material of the construction, which allows us to obtain characteristic constants on the basis of studies of structural materials, that determine their strength properties (tensile strength), which can be expressed in units corresponding to the units of stress measurement.

The idea of calculating the "allowable stresses" can be described as the dimensions of the elements of particular structure assigned from such condition, in which stresses acting in them would not exceed the allowable stresses.

On other hand, the level of allowable stresses is taken as a fraction of the strength of the material.

The ratio of the ultimate strength of the material to the allowable stresses has been called the "factor of safety (FoS) ", the value of which was to consider all the various factors and features of the work not only of the material in the structure, but also of the structure itself under the effects of various types.

For example, the ultimate tensile strength for the same structures of the same material has significant differences with single and multiple loading, which leads to different values of the "factor of safety" for the same material.

It must be emphasized, that the magnitude of allowable stresses makes sense only with proportionality between the actual load and stresses up to destruction, which occurs only in rare cases. The method of calculation for allowable stresses assumes a hypothetical elastic body, ignores the ductile properties of building materials and does not fully consider the actual condition of the structures under load.

So, the whole calculation is reduced to a comparison of the actual operating stresses to the allowable stresses.

Requirement: for any fiber construction the following inequality was fulfilled: $k\sigma \leq \sigma_d$

σ_d - Allowable stress,

σ - Stress in the fiber, determined by the methods of structural mechanics,

k - Factor of safety.

Because of that, the calculation of the working condition is often called as the estimation of allowable stresses.

What is the magnitude of the allowable stresses, i.e. value of the factor of safety?

W.J. Renkin, a Scottish engineer, physicist and mechanic, considered acceptable the value of the safety factor k=4,0.

The Chamber of Commerce of Great Britain established the value of the safety factor k = 4.0 for ductile iron (the main structural material at the time in railway bridge constructions) in 1840.

Then, as additional researches were done, the safety factor gradually decreased, but the principle itself generally remained until the middle of the XX century.

Russian naval engineer A.N. Krylov (author of the theory of shipbuilding) in 1907 [7]:

"During battleships building, it is supposed to use 3 types of steel:

- Ordinary steel with a temporary resistance of 42 kg / mm^2;
- High-strength steel with a temporary resistance of 63 kg / mm^2;
- High resistance steel with a temporary resistance of 72 kg / mm^2;

Design calculations should be performed with the following operating stresses:

- For ordinary steel - 11 kg / mm^2;
- For high-strength steel - 16 kg / mm^2;
- For high resistance steel - 23 kg / mm^2;

The safety factors k are:

- For ordinary steel - 3.82;
- For high-strength steel - 3.93;
- For high resistance steel - 3.13;"

3. ANALYSIS OF ALLOWABLE STRESSES CALCULATION

Allowable stresses make up some of the hazardous (limit) stresses.

For ductile materials, such a dangerous stress is the yield point σ_y at which deformations quickly grow, which impedes the normal operation of the structure.

For construction steel, the allowable stress equals the yield strength divided by the factor of safety k_1: $[\sigma] \leq \sigma_y / k_1$

For brittle materials, such a dangerous stress is the ultimate strength σ_u at which the destruction of the material occurs.

Therefore, the allowable stress is defined as $[\sigma] \leq \sigma_u/k_2$

As a general rule, $1{,}2 \leq k_1 \leq 2{,}5$; $3{,}5 \leq k_2$

For natural and ceramic stones $10 \leq k_2 \leq 30$

For steel structures, its value established in the technical specifications for the supply of metal was taken as the yield point.

In the 50s of the XX century, for Russian steel St.3, the yield strength $\sigma_y = 2100$ kgf / cm ^{2}. The safety factor was taken as $k_1 = 1{,}36$.

Thus, the allowable stress was equal to: $[\sigma] = 2100/1{,}36 = 1600$ kg / cm ^{2}.

This is the most common value of allowable stresses was taken in the estimation only for the main load.

Under the action of primary and secondary loads, the safety factor was taken lower, and the allowable stress increased to 1800 kg / cm ^{2}.

4. DISCUSSION

The factor of safety (FoS) $\boldsymbol{k}$ should take into account all adverse factors that affect the structural behavior.

For example:

- conditions for the construction and operation of the structure;
- lifetime of the structure;
- type of effort in the construction;
- the nature of the loads;
- fluctuation in the quality of the material;
- approximation of the estimation.

Therefore, the factor of safety is a summary measurement that ensures the safety of structures.

The safety summary function is excessive. It should be noted at the same time that the safety factor is basic and takes into account only the general factors of the structural behavior.

Considering additional (particular) factors (stress concentration, variability of the action of loads, longitudinal and eccentric bending, etc.) is carried out by introducing additional safety factors that complement the basic coefficient.

5. CONCLUSIONS

The method of estimation the allowable stress is quite simple, which is its main advantage. Its disadvantage is the choice of permissible stress or the establishment of a safety factor, which is made without sufficiently considering all the working conditions of the structures associated with the peculiarities of the actions of various loads with the presence of possible changes in the properties of individual materials used.

The works of scientists from different countries and epochs formed basis for the development of modern standards and methods of estimation, by setting requirements for the construction of buildings, in accordance to building materials, as well as to existing technologies.

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