THE IMPORTANCE OF CALCULATION OF STEEL STRUCTURES

Dženana Gačo[1], Edvin Bolić[1], Amel Porić[2]
[1] Faculty of Technical Engineering Bihać, dr. I. Ljubijankića bb, 77 000 Bihać, BiH, dzgaco@bih.net.ba
[1]Faculty of Technical Engineering Bihać, dr. I. Ljubijankića bb, 77 000 Bihać, BiH, edvinbolic@hotmail.com
[2]Ul. Hodzinac 34,77 240 Bosanska Krupa, BiH, aamelxx@hotmail.

Abstract: *Structures made of metal, mainly steel, have extensive application in engineering structures. As for all load-bearing structures, the basic requirement for metal structures is their sufficient safety against capacity failure mechanisms, which is determined by the technical regulations on the design and execution of construction, and the conditions of maintenance and use. For metal, or steel supporting structure, the international regulations Eurocode 3 are applied. Eurocodes require that every building during its construction and during its use satisfy the essential requirements. These requirements are capacity, usability, fire resistance, strength, durability and reliability. It was demonstrated for most structural damages that the problem was in bad static calculation, and that it is necessary to conduct static analysis and process of elements dimensioning prior to construction, in order for cross-sections to have optimal dimensions, to avoid over-sizing, and unnecessary expenses.*

Keywords: *steel structures, Eurocode 3, static calculation.*

1. INTRODUCTION

Calculating proof of bearing capacity and safety of structures has begun to be applied in the last decade of the last century, and until that time, it was established that the proportions and dimensions of objects remain in the framework of dimensions similar to already built structures.

The development of mathematics and applied mechanics lead to the gradual application of mathematical operations and experiential mathematical and mechanical models in structural design. Since then and until today, the imperative in the design of any building construction became the development of the project that should represent the optimal solution, which is the most cost-effective, technically feasible and acceptable, and at the same time meets the aesthetic criteria. The structure is considered reliable if it meets all the requirements regarding safety, functionality and durability.

The main goal of design is to meet the functional tasks of construction and to satisfy a number of conditions such as feasibility, strength, stability, lifetime, cost, and others. For each of these conditions it is necessary to determine in advance the rational limits within which it is considered that the condition is satisfied. When designing the structure it is important to aim at maximum fulfilling the required conditions.

The most important criteria that the design needs to meet is the safety criterion. The design must be calculated (dimensioned) so that with the appropriate level of security it can accept all expected loads that will occur during installation and during the scheduled exploitation period [2]. If the criteria of safety, for whatever reason, is not satisfied, there can occur a fracture of the structure or its part thereof, or the loss of stability of the structure as a whole or as a rigid body (overturning, sliding), which results in significant material damage, and seldom human victims.

Functionality criterion should ensure special requirements important for the successful functioning of the facility in accordance with its purpose. The most common are related to deformations which may adversely affect the comfort of the user, operation of the equipment or have an adverse aesthetic effect. Vibrations can also adversely affect the functionality of the facility. The process of design of steel structures should not disregard the verification of these functionality criteria.

The durability of the object, first of all, can be affected by the choice and quality of construction materials, as well as performing quality work, but also structural design details. Proper design can significantly increase the durability of the structure with respect to corrosion resistance, especially in engineering structures (e.g. bridges, power lines poles, antenna poles, chimneys, silos, etc.), which are directly exposed to the atmospheric elements. In addition, the application of appropriate corrosion and fire protection also favorably affects the durability of metal structures, with appropriate regular and periodic maintenance.

Construction of steel structures requires basic technical knowledge of construction materials, loads affecting the structure, calculation and dimensioning of elements, technology of assembly and welding, as well as quality assurance for all activities in the production process.

2. CALCULATION METHODS

Depending on the approach to determining the safety and ways of introducing the coefficient of safety, calculation methods are divided into deterministic and probabilistic. In the past, most engineering calculations were based on a deterministic approach. Loads and material properties were considered determined (certain) values and are usually prescribed.

Safety coefficient (ν), as the third basic element of the calculation, is also determined value. Based on the coefficient of safety, allowable stresses are prescribed, which must not be exceeded in the structural elements at any stage of its life cycle. Bearing in mind that this deterministic calculation method is based on the allowable stress, it is usually referred to as a method or theory of allowable stress. With the development of the theory of probability (probabilistic theory) a new way of calculation has been developed which is probabilistic in its approach.

The calculation introduces parameters affecting the safety of the structure as a random variable size and takes into account the probability of their occurrence, whereas safety factors are attached to the load and the material properties. According to this concept, there is no absolute safety of the structure, rather possible random combination at which the demolition occurs, with prescribed, sufficiently small possibility of occurrence. The method of calculation which was created as a result of this concept is the boundary condition method and is based on semi-probabilistics because it contains a series of simplifications [3].

The development of the linear theory of elasticity enabled the mathematical tools to analyze the behavior of steel structures in the field of elastic - linear behavior. The calculation, besides the assumption that the steel is ideally elastic material until reaching the yield strength, which behaves in accordance with Hooke's Law, also adopted the attitude that the yield stress is determined by the beginning of structure's fracture. A direct consequence of such adopted assumptions is the method of allowable stress, one of the oldest methods of calculation which is still a widely accepted concept of evidence of safety of steel structures.

The method of allowable stress is based on the condition that due to external loads, in any section of the structure, the maximum normal (σ_{max}) and transverse (τ_{max}) load cannot be higher than permitted (σ_{dop} and τ_{dop}), respectively:

$$\sigma_{\max} \leq \sigma_{dop} = f_y / \nu \quad (1)$$

$$\tau_{\max} \leq \tau_{dop} = (f_y / \sqrt{3}) / \nu \quad (2)$$

where:

f_y - Load at yield stress,

ν – Safety coefficient, whose value must be larger than 1,0.

All irregularities in the assessment of the load, material characteristics, the assumed and actual geometries of the structural elements, as well as the deviation of actual influence in the construction of calculation due to inadequate static models or methods of analysis are included in the safety coefficient [3]. In this way, the elastic behavior of structural elements is provided for all the time of its duration, which means that the structure is secured from the fracture.

As the structure consists of various elements, there are also different load combinations that are mostly independent and variable over time (snow, wind, seismic, thermal effects...), and can operate at the same time, as well. The method of allowable stress does not allow the reduction of the load in the simultaneous action, which would in some consider the reduced probability of simultaneous action of a number of different variable loads.

In the case of different effects on the structure, all impacts are taken into full amount whereby the different combinations and prescribed with different safety coefficient. Legal technical regulation defines three cases of loads and their corresponding safety coefficients (Table 1).

Table 1: Safety coefficients for different cases of loading

	Load case	Safety coefficient
1	I load case (basic)	υ^{I} =1,50
2	II load case (basic + additional)	υ^{II} = 1,33
3	III load case (basic + additional + extraordinary)	υ^{III} = 1,20

Calculation method according to the allowable stress is not only characterized by certain value of loads, load combinations and safety coefficient, which are determined based on historical heritage. Its features also include the following assumptions: the elements are calculated with secondary loads in sections; the calculation does not include residual stress states due to rolling, cutting, welding and other processing operations; the calculation does not introduce effects of stress concentration during the deviation of force flow and geometrical imperfections of elements.

Test method of dimensioning steel structures according to allowable stress, correctly applied in the calculation with proper construction and execution, was never a cause of damage and demolition of steel bearing structures, as evidenced by worldwide experience from many years in the past, when the method of allowable stress was the only known method of calculation.

Given that almost all materials for construction have extremely elastic-plastic behavior, especially steel, and the assumption that an ideal elastic material is not valid for loads above the yield point, the designers introduced as realistic parameters in the calculation itself as possible. They are introduced in the calculation by their characteristic values.

The characteristic value is determined by the size that with a certain degree of probability will not be exceeded in an unfavorable sense. Other factors of uncertainty include the transformation of the characteristic values in calculation, using partial safety coefficients.

Instead of a single coefficient of safety that was prescribed in the method of the allowable stress, the method of boundary condition uses more partial safety coefficients related to the load and resistance [3].

The difference between the calculation by the method of allowable stress and the method of boundary condition is that there is no dimensioning of the structure that has an absolute certainty in relation to the effect of a certain load, resulting in a structure, which with a certain probability, will experience a certain boundary condition, or more possible boundary conditions.

The basic requirement to be placed in front of the designer is to design and construct a structure that will be suitable for the use for which it was designed, with special care of its durability.

The degree of probability that guarantees safety of the structure in each case shall be adopted according to the severity of the consequences of potential accidents. In order for structure to endure the effects and impacts that will occur during construction (assembly), possible load test and exploitation, and in order to adequately meet the demands of functionality during use and adequate durability, it is necessary to calculate the structure.

Boundary condition may occur at any time of use and life of the structure and represents the state in which the structure or any of its parts is losing the function for which it was designed.

Depending on the way the structure ceases to fulfil a specific function, there are different types of boundary conditions: boundary bearing capacity condition and boundary application condition.

Boundary bearing capacity condition refers to the destruction or other forms of loss of capacity of the structure, which endangers the safety of people. The most common causes of bearing capacity condition are: loss of static balance or large displacement of the structure as a rigid body, fracture of the structure or its part as a result of exceeding the resistance of the cross section, the loss of stability of the element or structure as a whole

due to the effects of second order, transfers of the system in full or partial mechanism by forming plastic joints, excessive stress and fatigue [1].

Boundary application condition is defined by the criteria of functionality. In the case of exceeding the boundary application condition, calculation requirements, relating to the special exploitation criteria, are not satisfied. Most often these specific requirements are connected to deformations (deflections) and vibrations.

Deformation adversely affects the appearance and efficient exploitation of the building structure while the vibrations cause discomfort in humans, damage secondary elements and limit the functionality of the equipment.

In calculating steel structures with method of boundary conditions it is necessary to conduct analysis of structural behavior in relation to all of the critical boundary conditions.

It is common that the structure is dimensioned in relation to the boundary bearing capacity condition, and checked by boundary application condition.

Boundary conditions are expressed by a numerical model that includes various parameters and variable sizes, such as impact (load, forced deformation, temperature...), material properties and geometrical data.

In general, the condition for the detection of the boundary condition, whether it is a boundary bearing capacity condition or application condition, can be expressed with the following equation:

$$S_d \leq R_d \tag{3}$$

Where S_d is calculated value of action (internal forces, loads, deformations, etc.) due to external influences, whereas R_d is corresponding calculated bearing capacity value (material properties, resistance).

Safety of the structure is defined by two basic values, the load or impact acting on the structure S, and resistance of the structure R.

However the value of a resistance (R) and the value of action on the structure (S) are themselves the functions of other so-called basic variables:

$$\begin{aligned} &R=R(f_c,f_y, E, I, W, A...) \\ &S=S(g, q, w, s...) \end{aligned} \tag{4}$$

In deterministic procedure all of these values are treated as certain (determined) values, which are given to us by regulations, and in probabilistic approach all values of basic variables are treated as random values [4].

The basics of the new structure calculation procedure are contained in the European standard EN 1990, the main Eurocode within coherent set of European standards for structural design -Structural Eurocodes.

3. CONCLUSION

The complexity of today's structures requires great creativity from the standpoint of engineering design, so that the bearing capacity and usability of structures are insured under the effect of loads applied to the structure. The main goal of the design is to meet the functional tasks of construction and to satisfy a number of conditions such as feasibility, strength, stability, lifetime, cost, and others.

For each this condition it is necessary to determine in advance the rational limits within which it is considered that the condition is satisfied. When designing the structure the tendency is to meet the maximum given conditions. The calculation of the structure is proof of usability and bearing capacity of the structure under the influence of prescribed load throughout the duration of construction. Since the process of engineering design, i.e. structural engineering, stresses the importance of pre-design construction, it also emphasizes the importance of the type of analysis that is used in order to calculate the stress and strain in structural elements.

The advancement of computer technology made it possible that today the design process is increasingly using non-linear structural analysis since the calculation is much easier.

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