Chapter 1

Introduction

1.1. Historical background

During his evolution, man has continuously improved his ability to use resistance and rigidity properties of materials in order to build the constructions he required. The efficiency of the use of materials, their qualities and the technologies used in building the constructions reflect the level of knowledge of the materials' properties.

The idea of using materials having complementary resistance and rigidity properties was necessary at a time when the only available materials were soil (which is compression resistant), ligneous fibers obtained by primitive work with plants (elongation resistant) and wood (having similar resistance and rigidity properties for both elongation and compression), which was accessible only in wooded areas.

This statement is supported by the existence, until today, of some very ancient buildings, made of materials having complementary properties of resistance and rigidity. An example of this, for instance, is the ziggurat of Agargouf (Iraq), built by the Babylonians during the 15^{th} century BC, which is made of unfired (sun dried) clay bricks, laid with bitumen mortar reinforced with a network of reed stems every five layers.

Later, the Romans used metallic tie rods to take over the pushing stress in constructions with brick or stone vaults. Some other, more recent, achievements are the use of iron and stone beams (end of the 18^{th} century), wood (compressed bars) and steel (stretched bars) lattice girders and cast iron-steel lattice girders (end of the

19th century and beginning of the 20th century), as well as wood-aluminum lattice girders (middle of the 20th century).

Before listing the achievements of modern times, we have to remind ourselves of a technique whose origin is extremely ancient but which is still widely used, namely the use of mudbricks (unfired, sun dried, bricks made of clay reinforced with straw).

Due to its wide diffusion and applications, the most spectacular achievement in using materials having different physico-mechanical properties to manufacture resistance structures for constructions is reinforced concrete, a creation of the 20th century. Reinforced concrete elements include steel bars laid out in the tensioned areas to compensate for the low tension resistance of the concrete.

Further achievements in this field (prestressed concrete and composite structures) may be considered, both from a theoretical point of view and for practical applications, such as improvements to reinforced concrete in order to increase its strength and, implicitly, in order to enlarge its application field.

Further achievements of the 20th century are reinforced soil constructions, the use of geogrids that take over the tension stress of soil constructions and, lastly, the manufacture of reinforced concrete with dispersed reinforcements.

This brief chronological list of achievements in the field of use of materials having different and complementary resistance and rigidity properties shows that progress is only evident in the technological field, in the creation of strong building materials and in their effective use. This implies a thorough knowledge of the resistance and rigidity properties of materials and an appropriate use of this knowledge in designing and building constructions.

Until the end of the 18th century, constructions were built using empirical rules, so that the maximum stresses in their constitutive elements had very reduced values compared to the strength capacity of the materials from which they were made.

Innovative solutions, resulting from the architect’s intuition, were rare and they were integrated into current practice only if the on-going behavior of the construction was satisfactory. The resulting constructions were massive, very rigid and required large quantities of materials and labor. The small values of the stresses reduced the vulnerability of constructions in their interaction with the foundation ground. High rigidity of the constructions leads to uniform pressures exerted by the foundations on the foundation ground and, implicitly, to quasi-uniform ground settlements, that do not modify the initial stresses and strains state of the constructions.

The adoption, during the 17th and 18th centuries, of the linear elastic behavior model of building materials, based on investigations carried out on their properties, allowed the development of mathematical models for calculating resistance structures for constructions. The first to be adopted were the simple structures: straight beams, arches, vaults, frameworks having specific configurations. Towards the middle of 20th century general methods of calculating the stresses and strains of any form and configuration of resistance structures were elaborated by generalization and systematization, the general method of stresses and the general method of strains.

1.2. Considering the plastic and rheological properties of materials in calculating and designing resistance structures for constructions

Research aiming to evaluate the safety of resistance structures imposed the adoption of behavior models for building materials that are as close as possible to reality, such as the perfect elastoplastic body model (Prandtl) or the hardening elastoplastic body models.

The adoption of these behavior models for building materials within the analysis of resistance structures is difficult and involves a huge amount of calculations. This is why, at the beginning, these models served only for the analysis of the strength capacity of the section of the structural components and for the safety analysis of some simple resistance structures.

The development, during the second half of the 20th century, of computers able to perform a large amount of operations in a short period of time, allowed the use of these models for the calculation of resistance structures of constructions. This was achieved by the adaptation, in view of the use of models corresponding to the elastoplastic body or the hardening elastoplastic body, of the general methods given by the constructions' mechanics for the linear elastic body.

In this context, we should mention that the results of the calculations obtained by using the elastoplastic behavior models for building materials serve only to evaluate their safety. The stresses generated in the elements of the resistance structures by the actions and loads of normal operation have, for well-dimensioned structures, values well within linear elastic behavior of the materials from which the structures are made.

Although the fundamental notions of rheology were developed during the 19th century, the rheological properties of building materials drew the attention of civil engineers after the failure recorded at the beginning of the 20th century in the manufacturing of prestressed concrete.

Based on the progress recorded in the knowledge of the rheological properties of materials, whose behavior is always being researched, some calculation models were worked out for specific types of resistance structures, such as prestressed concrete structures and steel-concrete composite structures.

Particular effort has been made to develop calculation models for resistance structures having particular configurations that take into account the rheological properties of the foundation ground.

However, it should be mentioned that none of the calculation models developed until today have been based on the description of the phenomenon of continuous redistribution of the stresses and strains among the components of the structures, due to the rheological properties of the materials from which they are made.

The successes obtained in building resistance structures made from materials having rheological properties are due to satisfactory but simplified assumptions used for the development of the calculation models as well as for the constructive provisions and devices adopted in order to fit the concrete structure to the calculation model.

This work includes a general mathematical model describing the behavior of the resistance structures taking into account the rheological properties of the materials from which the constitutive elements are made, including those corresponding to the foundation grounds.

The mathematical model we present is based on the principles and equations of viscoelasticity, on the knowledge we currently have about the viscoelastic rheological properties of the building materials, synthesized in their constitutive laws.

As for the resistance structures, where we consider the elastoplastic behavior model of the materials, we must also notice the fact that using the proposed model for calculating the resistance structures by taking into account the rheological properties of the materials can be successful only providing the existence of computers and adequate computing software.

1.3. The basis of the mathematical model for calculating resistance structures by taking into account the rheological properties of the materials

The mathematical model this work presents describes evolution in time and, taking into account the rheological properties of materials, of the state of stresses and strains of the resistance structures subject to the actions and loads corresponding to normal operation. This model is based on the constitutive laws of the imperfectly viscoelastic bodies.

The constitutive laws of building materials are presented in the form of general parametric equations, so that the attribution of particular values to the parameters allows the simulation of the behavior of a broad range of materials having viscoelastic rheological properties.

We have to mention that the scope of the mathematical model developed thereafter is imposed by the definition domain of the constitutive laws and that this generally includes the definition domain due to the field of stresses generated in resistance structures by the actions and the loads of the normal operation of a construction.

We also have to mention that the stresses and strains state generated in the resistance structures by the actions and loads of normal operation, as well as by the phenomenon of redistribution due to the rheological properties, can strongly influence the strength capacity of the structures, and make them vulnerable to accidental actions and loads.

Additionally, we have to mention that the parameters defining the constitutive laws of building materials are influenced by many factors, so that, until now, no quantitative correlation between the size values of the factors of influence and the value of the parameters could be established. The values presented in the design standards and/or specialized literature result from the processing of observed values through statistical methods.

The values of the parameters of the constitutive laws used in numerical experiments, which are presented in Chapter 5, were taken from Romanian standards for bridge design or from the specialized literature.

Equations describing the evolution of the stresses or strains state for a bar (element) which is homogenous from the point of view of its rheological properties are presented using the analogy principle (Volterra), exposed in Chapter 2, and formulated according to the stress relaxation as well as the creep. The assemblage of the structure from its elements (which are homogenous from the point of view of their rheological properties), as well as the construction of the equations expressing this operation, were carried out by applying the conditions of instantaneous elastic equilibrium. At whatever moment, during the existence of the entire structure, its status of elastic equilibrium implies the simultaneous fulfillment of the following conditions:

– the static equilibrium condition – the external forces are balanced by the internal forces;

– the compatibility condition – the deformed position of the structure is compatible with the existing connections and with the material continuity of its elements.

The calculation model this work presents was developed assuming that the offset between the deformed position of the structure and its original position falls in the range of small offsets, so that when we apply the static equilibrium conditions, the balanced system of forces refers to the original position of the structure.

Analysis of the types of constitutive laws of building materials having rheological properties highlights the fact that these properties do not meet the condition, presented in Chapter 2, that allows the superposition of the effects (Boltzmann) – see the creep and stress relaxation functions of concrete and high resistance prestressed reinforcements.

Equations reflecting the instantaneous elastic equilibrium conditions and describing the evolution in time of the stresses and strains state of the structures according to the rheological properties of the materials take into account the restriction imposed by the fact that applying the Boltzmann principle of superposition is fulfilled neither when it is formulated according to the creep, nor when it is formulated according to the stress relaxation (Chapter 3).

The validation of the mathematical model developed in this work was ensured by the development of adequate mathematical and numerical methods able to determine the solutions of the integro-differential equation systems describing the evolution in time of the stresses and strains state of the resistance structures and taking into account the rheological properties of the materials from which the structures are made (Chapter 3).

This book contains the development of the generalized mathematical model that includes all the types of resistance structures made of materials having rheological properties (Chapter 3), as well as the specific form – corresponding to the different assembly possibilities of the structures – of the integro-differential equation terms describing their evolution (Chapter 4).

Lastly, we should also mention that this book includes two appendices whose purpose is to ease the use of the presented mathematical model.

In Appendix 2, we describe the methods and solutions for the three types of integro-differential equations corresponding to the different types of resistance structures from the point of view of the mathematical model, also considering the rheological properties of the materials.

In this context, we have to emphasize that the method corresponding to the discrete combined action (cooperation) structures (equations containing discrete unknown quantities, depending only on the "time" variable) was employed within the framework of the RALUCA computer applications system, which was used to carry out the numerical experiments described in Chapter 5.

The appendix includes the solutions of the equations corresponding to the initial phase of the stresses and strains state of some simple structural elements – falling in the category “with continuous collaboration” – that are submitted to actions with frequently used distribution.

The purpose of these solutions in the context of this book is obvious if the reader intends to develop software application; the results presented in the appendix can be used in order to validate the software module operating with the elements of the presented type.