Source: Liashkevich A. BIM Technology Perspectives for the Computer-Aided Development of Specification Documents for Reinforced-Concrete Structures. In: Contemporary Issues of Concrete and Reinforced Concrete: Collected Research Papers. Minsk. Institute BelNIIS. Vol. 9. 2017. pp. 70–79. https://doi.org/10.23746/2017-9-5

Aleh Liashkevich, PhD in Engineering Science, Director General, Institute BelNIIS RUE, Minsk (Belarus)

Лешкевич Олег Николаевич, канд. техн. наук, генеральный директор РУП «Институт БелНИИС», г. Минск, Беларусь

BIM TECHNOLOGY PERSPECTIVES FOR THE COMPUTER-AIDED DEVELOPMENT OF SPECIFICATION DOCUMENTS FOR REINFORCED-CONCRETE STRUCTURES

ПЕРСПЕКТИВА ИСПОЛЬЗОВАНИЯ BIM-ТЕХНОЛОГИИ ДЛЯ МАШИННОЙ РАЗРАБОТКИ РАБОЧЕЙ ДОКУМЕНТАЦИИ ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ

ABSTRACT

The article considers the issue of automation of development of specification documents for reinforced-concrete structures in the furtherance of the BIM technology. The list of procedures implemented at the stage of calculations that complicate the creation of a universal algorithm for the computer-aided generation of drawings of reinforced-concrete structures is presented. The Finite Element Method provides the possibility of creating a set of variants of computational models for the same constructive model; accordingly, there are many available variants of analysis results. Thus, the solution of the issue of calculating a construction project is always not the only one available. In the course of development of computational models, the idealization of the geometric shape is used, which leads to the representation of structural elements with infinitesimally small sections. In this case, the current design standards consider the reinforced-concrete structure as a set of sections with corresponding dimensions. In most cases (especially for statically indeterminate structures), the choice of techniques and design sections can be subjective, *which complicates the possibility of developing computer-aided design algorithms. The need for this kind of simplifications and idealizations was dictated by the limited available computing resources. The urgency of this problem is currently decreasing, which makes it possible to abandon the idealization of the geometric form and, consequently, to use three-dimensional finite elements when preparing computational models. Therefrom, an approach to design models of reinforced-concrete structures in the furtherance of the BIM Technology is proposed; this approach allows overcoming the limitations of currently used analysis methods, which impede the creation and the implementation of computer development of specification documents for reinforced-concrete objects. In this case, it is necessary to take into account other requirements for the normalization of mechanical indicators of concrete.*

АННОТАЦИЯ

В статье рассматривается проблема автоматизации разработки рабочей документации для железобетонных конструкций в рамках BIM-технологии. Приводится перечень процедур, реализуемых на стадии выполнения расчетов, которые усложняют создание универсального алгоритма машинной генерации чертежей железобетонных конструкций. Метод конечных элементов предоставляет возможность создания множества вариантов расчетных моделей для одной и той же конструктивной модели, соответственно, существует и множество вариантов результатов расчета. Таким образом, решение задачи о расчете строительного объекта всегда является не единственным. При разработке расчетных моделей применяют идеализацию геометрической формы, что приводит к представлению конструктивных элементов с сечениями бесконечно малого размера. При этом действующие нормы проектирования рассматривают железобетонную конструкцию как набор сечений, имеющих соответствующие размеры. В большинстве случаев, в особенности для статически неопределимых конструкций, выбор методик и расчетных сечений может носить субъективный характер, что усложняет возможность разработки алгоритмов машинного проектирования. Необходимость подобного рода упрощений и идеализаций была *продиктована ограниченностью доступных вычислительных ресурсов. К настоящему времени актуальность данной проблемы снижается, что позволяет отказаться от идеализации геометрической формы и при подготовке расчетных моделей применять объёмные конечные элементы. На основании этого предложен подход к расчетным моделям железобетонных конструкций в рамках BIM-технологии, позволяющий преодолеть ограничения используемых в настоящее время методик расчета, препятствующих созданию и внедрению машинной разработки рабочей документации для объектов из железобетона. При этом необходимо учитывать иные требования к нормированию механических показателей бетона.*

Keywords: reinforced concrete, CAD, the BIM Technologies, the Finite Element Method, specification documents

Ключевые слова: железобетон, САПР, BIM-технологии, метод конечных элементов, рабочая документация

INTRODUCTION

Currently available computing capacities and Internet technologies provide new opportunities for implementing application software for the purposes of construction design. In the previous decade, developers of software made great strides in developing solutions that increase a designer's productivity for the needs of construction. Nevertheless, design automation remains incomplete, and its status does not allow for a fundamental reduction of the time and the cost of development of construction projects.

The development of computer-aided design (CAD) systems is currently implemented within the so-called BIM Technology, which connects the three-dimensional model of an object with a database in which additional attributes can be assigned to each element of the model. In this case, the object model in the furtherance of this technology can include all sections of the project and all the stages of its implementation (except for analysis, since they require separate simulation, which does not stay within the architectural model of the object). Thus, the problem of full automation of the computer-aided development of specification documents in the furtherance of the BIM Technology cannot be solved uniformly. For reinforced-concrete structures, it is necessary to consistently perform separate analyses with an assessment of their results at each stage and to adopt decisions on the implementation of subsequent analyses. This circumstance significantly complicates the creation of software that can independently generate specification documents for construction products and structures with all the necessary specifications on the basis of an architectural model. This article proposes an approach to the creation of algorithms for the computer development of specification documents of reinforced-concrete structures using the capabilities of the Finite Element Method and available computing capacities.

1. FEATURES OF BIM TECHNOLOGIES USED FOR THE DESIGN OF REINFORCED-CONCRETE STRUCTURES

BIM is an object-oriented technology; therefore, the basic (library) elements representing certain building elements play a key role in creating a model. These library elements contain certain information about relevant building elements, which may be needed either now or for further or complete analysis of the project (the building model) [1]. It provides for the collection of all information on technical, legal, property, operational, energy, environmental, commercial, and other characteristics of the object in a single database. Such an elementwise detailing allows using the same information to perform analyses for relevant sections of the project. Despite the fact that the technology in question is one of the most innovative design technologies, it is based on the traditional sequence of procedures.

For individual construction sectors (in particular, for industrial projects that are primarily performed in a steel frame), the introduction of BIM Technologies had obvious economic success. In case of objects made of reinforced concrete (especially, in cast-in-situ reinforced concrete), the effectiveness of BIM Technologies is not so obvious. For example, they have no tangible economic advantages when compared with traditionally applied organizational design technologies, do not lead to a significant reduction in design time and the number of personnel involved in design development. First of all, the problem is in the traditional principles of relations between performers of different sections of the project, which, in fact, implies a standard sequence of design work; therefore, there can be no question of systematically reducing the complexity of design and reducing the number of the necessary personnel.

In the furtherance of existing BIM Technologies, automation of a significant number of procedures is possible (with the only exception of development of design models of load-bearing structures with subsequent computer-aided execution of specification documents based on analysis results). If we consider the traditional process of designing a construction object as a solution to a certain mathematical function, the interval in which various analyses are performed can be viewed as a function discontinuity point. Results of the implementation of the project sections are combined in the general model; at the same time, no potentially algorithmic relationship exists between the modules which implement these sections. Given this circumstance, it can be argued that BIM Technology in its current form does not provide for the development of algorithms for the full automation of the design process nor for the solution of individual tasks thereon based (for example, the optimization of design solutions by a certain criterion).

Creation of algorithms for the computer-aided development of specification documents requires improving the design technology in terms of automating the preparation of the design diagram and performance of analyses with subsequent use of their results for the generation of structural drawings. The most important requirements for the technology is the absence of the need for direct developers of the structural section of the project: the participation of personnel must be limited to verifying and adopting the finished documentation.

2. NORMS FOR DESIGNING REINFORCED-CONCRETE STRUCTURES AND RELEVANT ANALYSIS METHODS

For the possibility of manual analysis of reinforced-concrete structures, construction standards for the design of reinforced-concrete structures have adopted a number of assumptions and simplifications.

Since methods that involve manual analysis do not allow analysing structures and elements as three-dimensional elements, the separation of structural analysis from the analysis of sections is customary in design standards. Thus, the existing practice assumes the analysis of the required reinforcement in a reinforced-concrete structure: the design of a structure with conventionally concrete sections is performed first and is followed by a number of separate analyses in different sections of structures on the basis of obtained stress values.

This technique assumes the idealization of:

1) the geometric form: conditional division into three-dimensional elements, flat elements (for example, floor structures and walls) and linear elements (for example, columns and crossbars).
2) structures: accounting for absolutely all the nuances in an element is impossible; thus, the element is simplified;
3) kinematic constraints and external force effects: element joints and boundary conditions (embedding) are difficult to describe numerically in most cases.

Real elements of the civil structure have a shape and a size; at the same time, finite elements (FEs) with an infinitesimally small size are generally used in order to simplify the modelling and to reduce the consumption of computing resources. Together with the characteristics of concrete, dimensions of the reinforced-concrete structure are considered as section rigidity indicators, which allows avoiding the use of three-dimensional elements. For example, any column is modelled by a finite element in the form of a line with a section of an infinitely small point while the floor structure is modelled in the form of a plate with an infinitesimally small thickness. This approach makes a significant simplification of mathematical models possible while keeping their dimensions at a minimum level. The disadvantage of this approach is the need to use FEs that describe the physical essence of the structure work under the influence of the load as closely as possible, which can lead to the difficulty in assessing the impact thereon by the element dimension ratio. Idealization quite simplifies the execution of analyses but leads to a decrease in their accuracy. For example, a burst of effort values appears due to the idealization of structural elements by assigning infinitesimally small cross-sectional dimensions in the analysis model to them. In real constructions, such phenomena are not observed. Various types of smoothing out such effects require considerable effort and are subjective in nature. As a result, several «transitions» are made between the three-dimensional and the flat (or linear) representation of an object and its elements during the design process from the moment of development of the process constructive model to the receipt of final specification documents.

Methods of structural mechanics are not regulated by design rules (with the exception of instructions that the methods used to calculate forces and deformations must be physically adequate). In this case, the Finite Element Method has actually become the only method of construction mechanics used to analyse buildings and structures, which is implemented using relevant software. This method provides for an almost infinite number of solution variations to the same problem. In addition to building physically and geometrically adequate models, the performer must analyse obtained results, which further reduces the overall reliability of analysis results. Thus, the quality of the use of existing methods of analysing structures and their sections critically depends on the qualification of the performer.

3. PROPOSAL ON THE ORGANIZATION OF COMPUTER-AIDED DESIGN

All known attempts to automate the development of specification documents for reinforced-concrete structures are reduced to the automated generation of formwork drawings of structures and reinforcement items as well as specifications and samples for ready terms of reference for their development. At the same time, the creation of a construction diagram and the issuance of analysis results in the form of layout of reinforcing bars and their diameters in fact is a «manual» work. Computer-aided design, on the other hand, implies the participation of a person only for the preparation of the task and the verification of results; all the analytical work must be performed in an autonomous mode. It is necessary to understand that the application of various simplifications, assumptions, and idealizations leads to the impossibility of developing a universal algorithm that is guaranteed to convert architectural models into constructive ones into design ones in a physically and geometrically adequate manner in all cases. An algorithm for converting stresses (their calculated combinations) into erection drawings for reinforcement items is also extremely complex and even impossible in some cases. For example, the so-called bursts of stresses in the joint areas of elements idealized in the design diagram will prevent decisions to reinforce structures that are adequate to their physical essence. Thus, the basic solution for the development of computer-aided design algorithms is the rejection of idealization and simplification in terms of the geometric form of objects design diagrams made of reinforced concrete. Accordingly, the calculation of any reinforced-concrete structures within scope of the BIM Technology requires the exclusive use of three-dimensional finite elements.

The increase in computing power available to designers creates the possibility of refusing to idealize the geometric shape [2]. In this case, the problem of creating a design scheme based on the constructive model of the object is quite simplified, and this procedure allows for its full algorithmization. When using such an approach in the application software, the role of the project developer will be reduced only to verification and, if necessary, adjustment of models, as well as to the subsequent evaluation of analysis results. It should be taken into account that application of characteristics of concrete obtained under uniaxial compression/stretching is incorrect when modelling reinforced-concrete structures with the use of three-dimensional finite elements. There is a relationship between stresses and deformations, as well as their increments (incrementally) for reinforced-concrete elements under three-dimensional stresses (in case of triaxial compression and various combinations of compression and stretching) [3, 4].

There is currently no standardization of concrete characteristics under triaxial compression; however, there are recommendations that can be used in the analysis of concrete and reinforced-concrete structures using the Finite Element Method [5]. The mechanistic use of three-dimensional FEs for analysis without accounting for concrete characteristics under triaxial compression (for example, for skeleton buildings) is difficult due to the normalization of relevant indicators. Concrete has an increase in volume under triaxial compression due to a violation of its structure (the so-called expansion effect), which contradicts the classical hypothesis of elastic volume variation [6].

CONCLUSION

The system of automated design of reinforced-concrete structures that significantly reduces the need for the staff of a design organization as well as the labour intensity of the development of specification documents for an object as a whole can be based on the following principles.

1. For the purposes of creating software for computer-aided design of reinforced-concrete structures, the use of the BIM Technology is possible subject to inclusion of estimated models in the general digital model of the object.
2. Transition between architectural, structural, and design models of bearing structures of a construction object must completely exclude the performer's subjective approach and be independent of the level of the performer's engineering training.
3. Idealization of a geometric form is a task that has no unique solution. Idealization greatly complicates the uniform automation of the estimated model or renders such automation impossible; therefore, the computer-aided design algorithms must exclude this procedure.
4. Instead of idealizing the geometric shape and the methods of calculating reinforced-concrete sections, it is necessary to apply models using three-dimensional finite elements and triaxial characteristics of the material. For this, it is necessary to normalize strength and deformation characteristics of concrete under triaxial compression; these characteristics must be usable when performing analyses of concrete and reinforced-concrete structures (including FEM-based analyses).

Current requirements for design standards for reinforced-concrete structures no longer correspond to the current level of information technology and computing capabilities. This delays the reduction of the labour intensity of analyses and, as a result, the design of construction projects.

REFERENCES

1. Talapov V. V. *Tekhnologiya BIM. Sut i osobennosti vnedreniya informatsionnogo modelirovaniya zdaniya* [The BIM Technology. Essence and Features of the Introduction of Information Modelling of Buildings]. Moscow, DMK Press, 2015. 410 p. (rus)
2. Agapov V. P., Vasiliev A. V. Ispolzovanie obemnih modeley kolonn ghyamougolnogo secheniya v raschetah stroitelnyh konstruktsyy metodom konechnyh elementov [Using Three-Dimensional Models of Rectangular Columns in Analyses of Construction Designs Based on the Finite Element Method]. *MSSU Bulletin*. 2012. № 9. pp. 55-59. (rus)
3. Karpenko N. I., Karpenko S. N., Ukhatsky M. L. K opredeleniyu prochnosti betona pri trehosnom rastyazhenii b smeshannyh napryazhennyh sostoyaniyah “szhatie-rastyazhenie” [On the Determination of the Strength of Concrete with Triaxial Tension and Mixed Compression-Stretching Stresses]. *The Bulletin of Volgograd State Architectural and Construction University. Series: Construction and Architecture*. 2013. № 31-2 (50). pp. 358-361. (rus)
4. Karpenko N. I., Karpenko S. N. Postroenie fizicheskih sootnosheniy dlya rascheta zhelezobetonnyh konstruktsyy pri obemnom napryazhennom sostoyanii suchetom fizicheskoy nelineynosti materialov [Construction of Physical Relationships for the Analysis of Reinforced-Concrete Structures for Three-Dimensional Stress Condition Accounted for the Physical Non-linearity of Materials]. *Housing Construction*. 2016. № 6. pp. 16-20. (rus)
5. Eberhardsteiner J., Leonovich S. N., Zaytsev Yu. V. *Prochnost i treshchinostoykost konstruktsionnyh stroitelnyh materialov ghb ckjzhnom napriazhennom sostoyanii* [Strength and Crack Resistance of Structural Construction Materials in a Complex Stress Condition]. Minsk: BNTU, 2013. 522 p.
6. Klovanich S. F., Mironenko I. N. *Metod konechnyh elementov v mehanike zhelezobetona* [The Finite Element Method in Reinforced-Concrete Mechanics]. Odessa: ONMU, 2007. 110 p. (rus)