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METHODS OF MODELING OF COMPOSITE MATERIALS AND COMPOSITE STRUCTURES ON «LIRA-SAPR»

This paper provides detailed suggestions for the process of structural reinforcement modeling by composite materials on the software package «LIRA-SAPR». It also provides the implementation of bearing capacity checks for reinforced elements on the program called «ESPRI». The article offers an algorithm for calculation of the construction objects in case of design situation changing, considering the modeling of the composite structure reinforcement. It considered the modeling process of reinforcement of structures using classical methods, such as using of metal casing. It also investigated a numerical modeling example of the frame structure reinforcement, with the selection and verification of the composite material.

***Keywords**: stress-strain state, composite material, strains, deformations, material nonlinearity, software «LIRA-SAPR».*

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МЕТОДИ МОДЕЛЮВАННЯ КОМПОЗИТНИХ МАТЕРІАЛІВ І КОМПОЗИТНИХ КОНСТРУКЦІЙ В ПК «ЛІРА-САПР»

У статті розглянуто процес моделювання підсилення конструкцій композитними матеріалами в програмному комплексі «ЛІРА-САПР» зі здійсненням перевірки несучої здатності підсилених елементів в програмі «ЕСПРІ». Запропоновано алгоритм розрахунку об'єктів будівництва при зміні проектної ситуації з урахуванням моделювання підсилення конструкції. Досліджено процес моделювання підсилення конструкцій металевою обоймою. Наведено приклад чисельного моделювання підсилення рами, з підбором та перевіркою композитного матеріалу.

***Ключові слова**: напружено-деформований стан, композитні матеріали, деформація, фізична нелінійність, програмний комплекс «ЛІРА-САПР».*

Introduction. While in operation of buildings and structures, if change of loads takes place, during reconstruction or when a building structural scheme changes, it becomes necessary to increase load bearing capacity of some structural elements. Therefore, the question about the bearing capacity increasing of constructions is very relevant. One of the most effective innovative methods to strengthen the reinforced concrete structures is the application of composite materials (fiber reinforced polymers (FRP)).

Analysis of the latest research sources and publications. The first composite material of modern type is deemed to be unidirectional glass-fibre reinforced plastic created by A. Burov in the 30s. In the 60s in the UK the carbon fibers were created, which provided impetus for the development of new generation of composite materials, which are highly used in the design and reconstruction of buildings nowadays. In consequence of steady increase of the interest in composite materials (fiber reinforced polymers) and composite reinforced structures a lot of works have recently been devoted to the development of this issue: many works created by Storozhenko L. [6, 7], Lapenko O. [7, 9, 13], Ermolenko D. [4], Hvozdeva A., Klyueva S., Kurlapova D. [12], Khayutina Yu. [15], Chernyavskii V. [15, 16] and others. A lot of works of Kuznetsov V., Vatin N., Hrigorieva Ya. were dedicated to the development of calculation methods of reinforced concrete structures strengthened by fiber reinforced polymers. Many works devoted to the topic were created abroad, for example, some works written by Belarbia A. [18], Acunb B., David D. [19], Grace N. [21] and others.

Identification of previously unresolved areas of a common problem. The analysis of the latest works on the considering subject showed that up to date there are a lot of works devoted to experimental researches and analysis of experimental data on the reinforced concrete structures strengthening. But, the question about the computational modelling of reinforced structures and the analysis of its stress-strain state is still quite undecided.

Problem formulation. The goal of the article is mathematical modeling of construction by the finite element method (FEM), taking into account the work of the strengthening system from composite materials. And also the creation of computer modeling of construction work before and after strengthening. The implementation of the goal was carried out on the basis of the software package «LIRA-SAPR» and using the engineer electronic reference book «ESPRI».

Main material and results. Materials that consist of two or more components or phases are called composite materials. A continuous phase is called matrix, and components are called filler or a reinforcing phase. The role of fillers is that they change the properties of the continuous phase in the desired direction. Such materials may have a polymeric, metallic or ceramic continuous phase. The mechanical properties of composite material depend on the used continuous phase (matrix). Polymer phases are characterized by relatively low strength and modulus of elasticity. Ceramic phases have high strength and rigidity, but their disadvantage is high brittleness. Metal phases are characterized by intermediate values of strength, modulus of elasticity and they are more plastic than ceramic phases.

Composite materials based on fiber, which used in reconstruction and strengthening of buildings or structures, are made of microfibers. They combined within polymer and thus are pieced. The most common types of fibers: aramid, carbon and fiberglass. The physical and mechanical properties of composite materials are determined by the type and number of fibers which are used.

Supporting of the load-bearing ability and stability of any construction is laid on the basis of computer and numerical analysis of their stress-strain state.

So let's consider a procedure of structure analysis in SP «LIRA-SAPR», taking into account the increasing of carrying capacity of its elements.

In the event of changing of the design situation (it may be the load increasing at the object, defect identification within any structural elements, changing the object's purpose or reconfiguration of the building object), first of all, the static analysis of the construction is made, taking into account the impact of the new loads and some changes within the elements. Based on the results of the static analysis the necessary reinforcement for reinforced concrete elements can be matched.

Taking into account the selected reinforcement, the analysis of the structure take into consideration the physical nonlinearity is performed. As a result of the analysis one determines damaged structural elements, in which cracks appear. Consequently elements that are in need of strengthening are determined.

At the following step of the design the parameters of the fiber reinforced polymer material are to be selected which will be used to strengthen the construction. The bearing capacity of the strengthened element could be checked in «ESPRI». As a result of the check in «ESPRI» new reduced rigidity of the strengthened element is got.

After selection of the composite material and testing the load-bearing capacity of the strengthened element, on the SP «LIRA-SAPR» the new stiffness to the finite elements of the analytic model is set. To do this, the type of the finite elements, which are in need of being strengthened, is to be changed. The new type of these finite elements must be the physically nonlinear universal three axes bar finite element №210. After setting the new stiffness (taking into account the strengthening of the construction by fiber reinforced polymers materials) a new calculation has to be made. After the evaluation of the obtained stress-strain state of the analytic model decision about the additional strengthening of the other structural elements has to be sold.

After the strengthening, in the analytic model the redistribution of the forces takes place. So if desired, in «ESPRI» it is possible to re-test the load-bearing capacity of the strengthened structural elements, with the new forces obtained on the SP «LIRA-SAPR» in these elements.

Consequently, the calculation procedure of the analytical model in the SP «LIRA-SAPR» and «ESPRI», taking into account the strengthening, can be displayed in the form of the following algorithm, which is shown in Fig. 1.

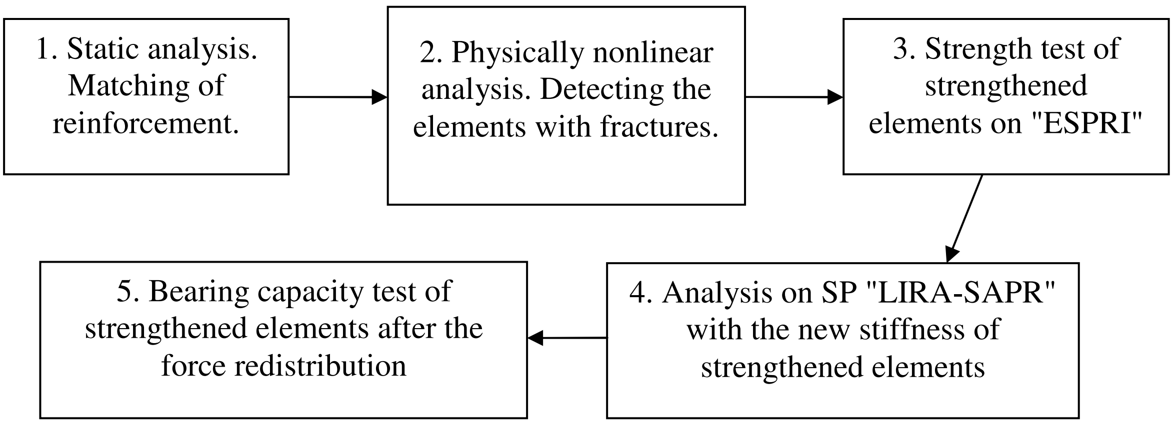

Figure 1 – The analysis algorithm of strengthened structures on SP «LIRA-SAPR».

Letus consider the procedure for obtaining the parameters to model the strengthen of a structure on SP «LIRA-SAPR» by the example of the frame analytic model (Fig. 2).

After the static analysis, for the considered analytic model the appropriate reinforcement is selected.

Then the physically nonlinear analysis was carried out, in which the corresponding parameters of the concrete deformation (Fig. 3) and reinforcement were specified.

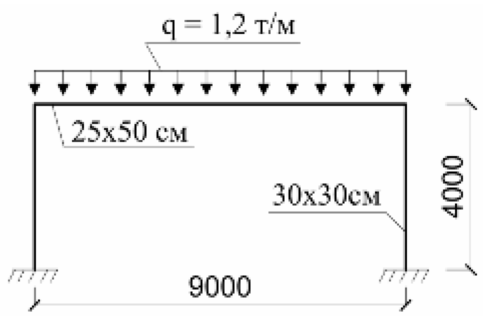

Figure 2 – Frame analytic model

Parameters	Values
Ecm(-)	3.25E+010
Ectm(+)	2.9E+010
fcm(-)	-38000000
fctm(+)	2600000
Epscu(-)	-0.0035
Epsc(-)	-0.0022
Epsctu(+)	0.00012

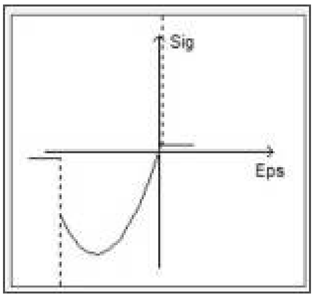

Figure 3 – Characteristics of nonlinear concrete deformation, Pa

During the physically nonlinear analysis the parameters to calculate the deformation of the structure, taking into account creep of concrete are specified. The change of the creep coefficient in time was determined with the 44th piecewise creep law.

The creep coefficient $\varphi(\tau)$ was calculated with formulas:

$$\varphi(\tau) = \varphi(t')\,f(t - t'), \tag{1}$$

$$\varphi(t') = C_0 + \sum_{k=1}^{m} \frac{A_k}{(t')^k}, \tag{2}$$

$$f(t - t') = \sum_{k=0}^{m} B_k e^{-\gamma_k (t - t')}, \tag{3}$$

where t is a point of time for which deformation is determined;

t' is a point of applying the stress elementary increment;

B_k and γ_k are constants which depend on the concrete, and also $B_0 = 1$, $\gamma_0 = 0$ and $\gamma_k > 0$.

The value C_0 is the extreme value of the creep coefficient; A_k is characteristic, which depends on the properties and ageing conditions of the using concrete.

After the physically nonlinear analysis the schemes of the stress-strain state of the frame is received (Fig. 4).

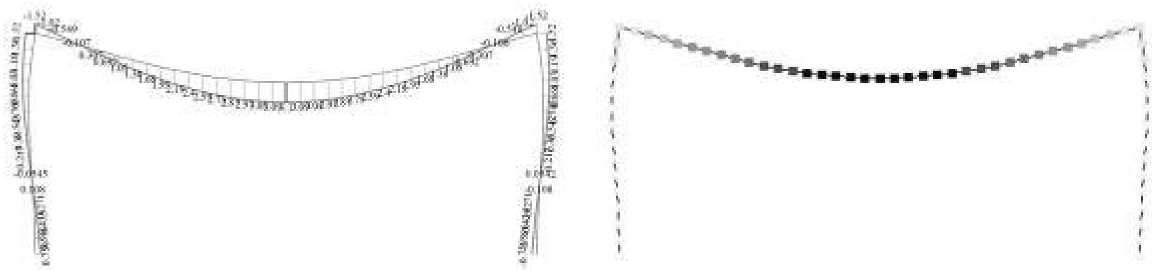

Figure 4 – Stress-strain state schemes

As a result of the analysis, it was determined that on the third stage of creep deformation manifestation the cracks appear in some elements of the analytic model. Figure 5 shows the diagrams of stresses and strains within the cross-sections of the beam and columns, before and after appearance of the cracks.

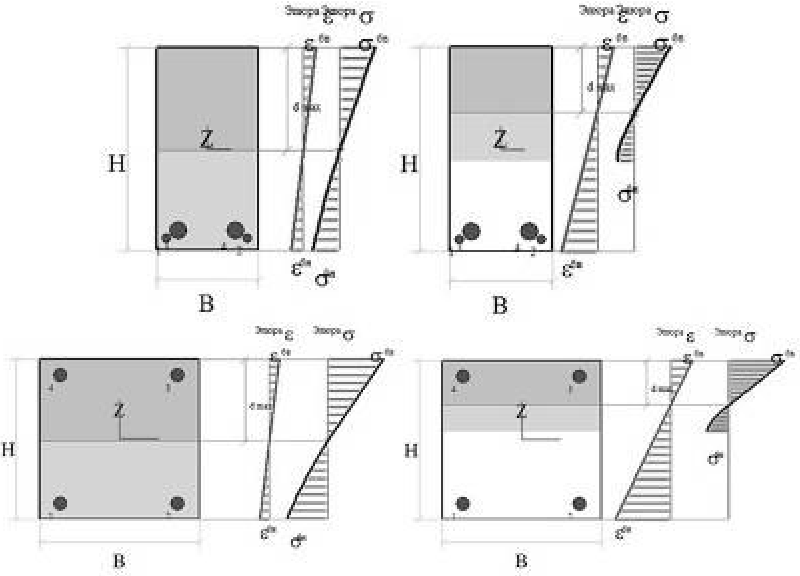

Figure 5 – Stress-strain diagrams within the crosss-sections of the analytic model

To strengthen the frame elements in which cracks appeared, we selected the fiber reinforced polymers Aslan 400 CFRP Laminate with the following stiffness characteristics is selected:

– monolayer thickness: 1,4 mm;
– modulus of elasticity, E: 131000 MPa;
– strength of a material: 2400 MPa;
– deformation at rupture: 0.0187 %.

The work condition coefficient was assumed equal to unity.

After selection the composite material for strengthening, on «ESPRI» the load-bearing capacity of the strengthened frame element was tested.

For strengthened elements which work on compression, the load-carrying capacity check is performed using the following formulas:

– when strengthening by external reinforcement longitudinally:

$$Ne \le f_{cd}bx(d-0{,}5x)+f_{scd}A_s'(d-a')+f_{fd}A_f a\,, \tag{4}$$

– when strengthening by external reinforcement edgeways:

$$Ne \le f_{cd3}bx(d-0{,}5x)+f_{scd}A_s'(d-a')\,. \tag{5}$$

For elements that work on bending, the check is performed on a bending moment:

– for rectangular cross-sections:

$$M \le f_{cd}bx(d-0{,}5x)+f_{scd}A_s'(d-a')+f_{fd}A_f a\,, \tag{6}$$

– for T-section, if the compressive zone bound is through the girder web:

$$M \le f_{cd}bx(d-0{,}5x)+f_{cd}(b_f'-b)h_f'(d-0{,}5h_f')+f_{scd}A_s'(d-a')+f_{fd}A_f a\,. \tag{7}$$

In the formulas (4), (5), (6) and (7) the following symbols are used:

f_{cd} – design value of the cylinder compressive strength of concrete,

f_{cd3} – axial design value of the cylinder compressive strength of concrete,

f_{scd} – design value of the compressive strength of reinforcing steel,
f_{fd} – design value of the cylinder strain strength of fiber reinforced polymer,
d – cross-section effective depth,
A_f – cross-section area of fiber reinforced polymer reinforcement,
$h_{f'}$ – depth of the flange of a T-bar (I-bar) cross-section in the compressive zone,
$b_{f'}$ – width of the flange of a T-bar (I-bar) cross-section in the compressive zone,
b – cross-section effective depth.

After the strengthening material matching and the strength test of the reinforced structural elements, the reduced rigidity of the strengthened elements is obtained. To calculate the analytic model, taking into account the new stiffness, the FE №10 with the FE №210 is replaced, which was given the new reduced stiffness characteristics.

One of the most common classic variants to increase the bearing capacity of the structure is the increasing of its rigidity, by installing metal casing. Let us consider a calculation example of the strengthening of a column of the considered frame, using the metal casing. To do this, instead of selecting composite materials, choose the dimensions of the metal angle bar (or plates) with which should be to strengthen the elements of the structure. The verification of the strengthened elements whish also are implemented on the «ESPRI» program. For this purpose, in the subroutine «Check of the steel concrete column cross-sections» (section Reinforced Concrete Structures) it is necessary to choose a check of the steel concrete cross-sections with metal angle bars and set the parameters of the angle bars in such way that they model the metal casing around the column.

The check of the composite cross sections could be carried out by limit states and also by deformation model, as well as by the two-line and three-linear deformation diagrams which are represented in figure 6.

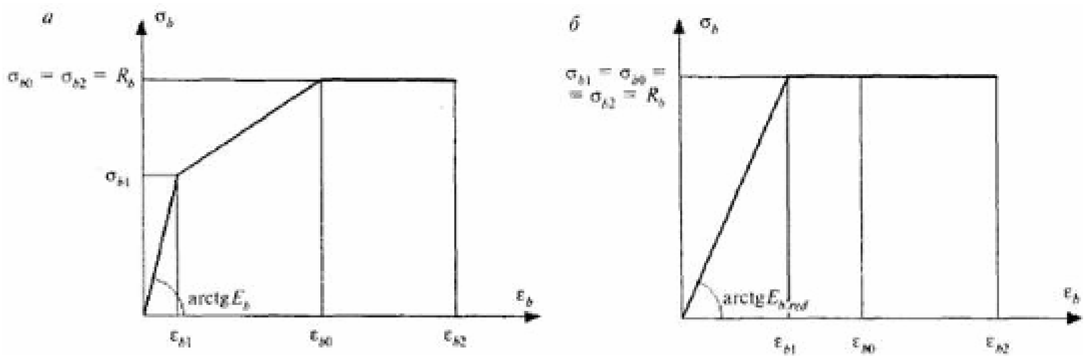

Figure 6 – Deformation diagrams of steel concrete elements.

Comparison of the frame stress-strain state at different design stages, taking into account the strengthening, is shown in Table 1.

Table 1 – Comparison of efforts and displacements of the frame at various formulation of the problem

	Lineal elastic calculation		Physical nonlinearity		Together with the strengthening	
	Disp-lacements Z, mm	Efforts M_y, t*m	Disp-lacements Z, mm	Efforts M_y, t*m	Disp-lacements Z, mm	Efforts M_y, t*m
Column	0	±1,65	-0,1	±1,89	0	±2,06
Beam	-2,8	2,96	-7,6	2,7	-7,3	2,26

Also, on the program «ESPRI» it is possible to calculate other cross sections of the steel concrete structures, which examples are shown in Fig. 7.

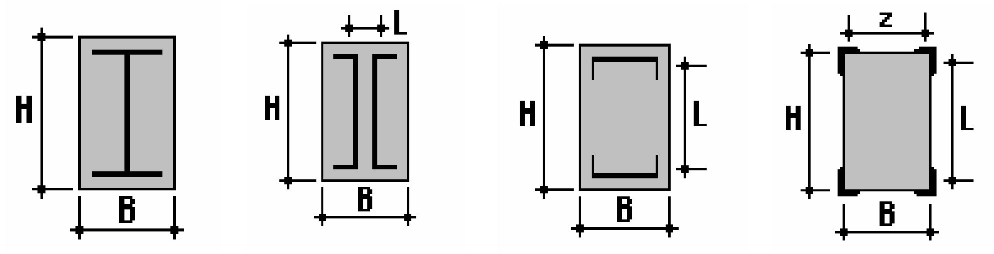

Figure 7 – Cross-section types of steel concrete structures which could be calculated on the "ESPRI" program

Conclusion. Usage of fiber reinforced polymers to strengthen structures allows significantly to increase the load-bearing capacity of the elements of buildings and structures. It also allows to extend their service life, prevent or eliminate the emergency situation, correct construction or design mistakes, and the most important that it allows to ensure reliable operation and durability of the structures.

In this paper, the model technique for strengthen structures by fiber reinforced polymer materials is proposed. The variant of modeling the strengthening of a construction by metal casing is considered. The values of the element stress-strain state within the analytic model are obtained.

The result of the research is the evaluation of the stress-strain state of the structure while simulation its strengthening by fiber reinforced polymer with the physically nonlinear formulation of the problem.

The results of this work can be used for wider application to increase the bearing capacity of buildings and structures.

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