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COMPARATIVE ANALYSIS OF STRENGTHENING OF BUILDING STRUCTURES (MASONRY, METAL STRUCTURES, REINFORCED CONCRETE) USING FRP-MATERIALS AND TRADITIONAL METHODS DURING RECONSTRUCTION

I.N. Rudnieva,
PhD, Associate Professor

Kyiv National University of Construction and Architecture,
31, Povitroflotskiy avenu, Kyiv, Ukraine

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The aim of the research is the evaluation of the structural performance of composite fibre-reinforced elements in the wider sector of the conservation of historical, architectonic and environmental heritage, as well the more contemporary buildings of the last century, which have lost of the bearing capacity focusing reliability indexes and the appearance of the structure.

In the article was described and analyzed the existing traditional methods and the alternative methods of strengthening by FRP-materials (composite materials) such building structures as masonry, metal structures, reinforced concrete, and the computation in software ABAQUS. These procedures of strengthening building structures by FRP-materials in Ukraine are not widely used due to the lack of a regulatory framework that would regulate their use, as well because these materials are relatively expensive compared to the traditional ones.

The article analyzed the existing methods of computation and design of the strengthening using FRP-materials, and the computation in software ABAQUS was performed with conclusions and recommendations based on results of the computation.

The aim of the work was to review the technology and analyze the advantages and disadvantages of each of the strengthen methods that should be used when choosing effective solutions for strengthening building structures. In conclusion, the need for further study and researches was confirmed.

Keywords: methods of strengthening, composite materials, FRP-materials, masonry, metal structures, reinforced concrete, stress-strain state, computational methods, defects, damage, reconstruction.

1. Introduction

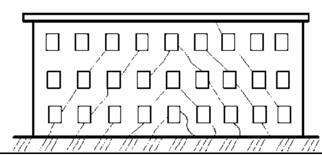
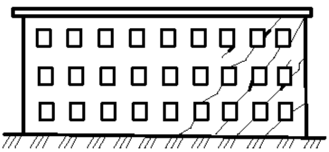
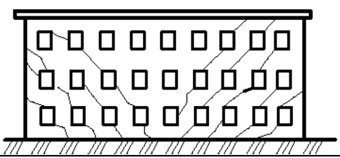
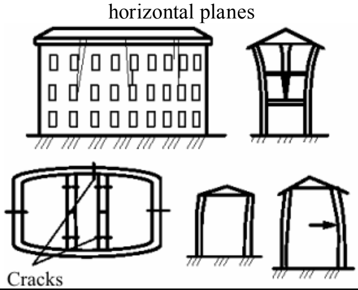
Built mostly centuries ago, heritage buildings as well the more contemporary buildings of the last century, which have lost the bearing capacityoften need restoration and strengthening, especially in seismic regions and in regions with shrinkage phenomena (subsidence region). The need of strengthening of the building constructions during exploitation appears mostly because of their premature wear as a result of technological influences and weathering, various damage and various other factors.

Traditional methods of strengthening are effective, but in some cases not appropriate or not applicable for use. An example is the increase of the load-bearing structures of historical buildings, preserving the external appearance of which is the determining factor. In this case, the use of the discussed alternative methods can be justified alternative.

Knowledge of the causes of defects and damage of structures allows to choose the best option of repairing or strengthening. Causes of the deformation of buildings are presented in Table 1 [3].

Table 1

Causes of the buildings deformation

The type and external manifestation of the strain	**Causes of the deformation**
Drawdown of the middle of the building 	1. The weak base of the middle part of the building 2. Drawdown as a result of the soaking of the subsidence soils 3. Karst under the middle of the building.
Drawdown at the right side of the building 	1. Weak base of the extreme part of the building 2. Drawdown as a result of the soaking of the subsidence soils 3. Karst in the extreme part of the base. 4. Location near the open pit 5. Location near the trenches and squeezing quicksand 6. Shift of the retaining wall that located near 7. Construction next to of a new building
Drawdown of two extreme parts of the building 	1. The same reasons as for the right of the building, acting on its two extreme parts 2. Placing under the middle of the building of a large object
Buckling and bending of the wall in the vertical and horizontal planes 	1. Tension from the truss system 2. Horizontal force from the stretching 3. Eccentric transfer of the load from the floors 4. Vibrations from machines located in the building and seismic shifts

Cracks indicate on the poor state of the structures. They may eventually will have opened and cause the development of strains that not only change the appearance of the design, but also greatly reduce its strength and carrying capacity. In a brick and masonry buildings cracks in the walls, bridges, domes and arches are caused mostly by irregular subsidence of the bases and foundations, various deformability of the loaded or unloaded walls.

In the reinforced concrete structures cracks are caused by poor reinforcement, lack of spatial rigidity, temperature and shrinkage phenomena, violations of manufacturing technology products, their ransportation, warehousing and assembly, corrosion of the main reinforcement.

For survey and inspection of buildings, the results of laboratory tests, non-destructive and quasi-non-destructive tests and researches are usually used using **some devices and instruments for such researching parameters as:**

• Strain of the building (leveling instrument, theodolite survey, photogrammetry, 3D laser scanning),

• Deflections and displacements (leveling instrument, deflectometer, 3D laser scanning),

• Concrete strength (The method of plastic deformation - the device of the shock-impulse type, Hammer Koshkarova; the ultrasonic method),

• Solution strength (The method of plastic deformation),

• Hidden defects of the material of the design (the ultrasonic and radiometric method),

• Depth of the cracks in concrete and masonry (the ultrasonic method, a calliper),

• Width of the cracks in concrete and masonry (measuring microscope, a calliper),

• The thickness of the protective layer of the concrete (magneto-metric method),

• The density of concrete, stone and granular materials (radiometric method),

• Moisture concrete and stone (Neutron method),

• Breathability (Pneumatic method),

• Heat protection quality of the wall (Electrical methods).

Scientific Researches with using of 3D laser scanner during survey and inspection of historical buildings were represented in the articles of Naif Adel Haddad [20], Terrence F. Paret [21], Golubka Necevska -Cvetanovska [51], Vincenzo Mallardoa [52], Yusuf Arayici [53].

To carry out restoration and strengthening of building structures, it is necessary to carry out the following complex of works on the project:

1. Architectural concept of building

2. Design models of structure (using 3D laser scanning, which represents today the most advanced technology available for measuring and documenting objects and structures):

• beam (farm, frame of building) model (simplified)

• surface model (detailed, if it need)

3. Composition of loads and combinations of loads under standard operation conditions

4. analysis of stress-strain state of structures:

• analytic method

• finite element method using computer's programs for simulation the stress-strain state (SSS) of buildings structures

5. Spatial stiffening of structure (if it needs)

6. Constructional drawings of main structure and structural elements

2. Traditional methods of strengthening building structures

There are the following traditional methods to strengthen masonry: partial or total replacement of elements of masonry, installation of the core, injection of special solutions, the use of the steel cages, the steel clamps, etc. Traditional strengthening methods of building structures are shown in Fig. 1, Fig. 2.

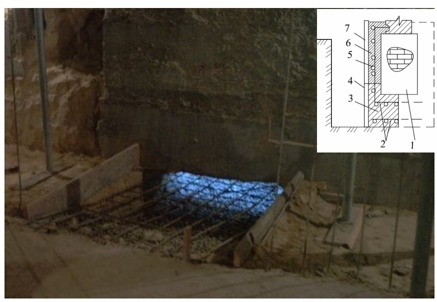

(a)


(b)


(c)


(d)


(e)



(f)

Fig. 1. Image representations traditional methods of strengthening building structures:

(a) Strengthening of reinforced concrete jumpers by metal corners;
(b) Strengthening of the floor slabs using unloading metal beams;
(c) The foundations strengthening by reinforced concrete cage;
(d) Strengthening of the supporting walls by the temporary support;
(e) Steel angles added to span across cracking in the wall;
(f) Expansion of the foundation lining of the new reinforced concrete pillow, Kiev

(a)

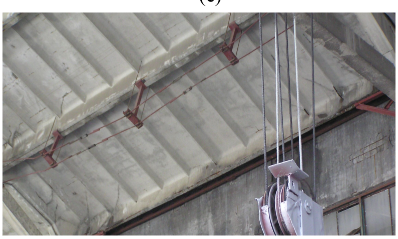
(b)

(c)

(d)

(e)

(f)



(g)

Fig. 2. Traditional methods of strengthening building structures: (a) Photo of riveted steel truss supporting roof joists and barrel vault ceiling joists; b) strengthening of brick wall by tension bars with overlays, Venice; c) installation of prestressed steel strips, Venice; d) installation of prestressed steel strips and strings with overlays, Venice; e) the strengthening of the reinforced concrete floor beam; f) strengthening of reinforced concrete beams with metal trusses; g) strengthening of the 12 meter covering slabs by consoles and by truss tightening

Using traditional methods of strengthening to increase the strength characteristics of masonry in most cases it is accompanied by a change of the external configuration of the strengthened object. When old masonry replacing to a new the strengthening is accompanied by additional time-consuming work to install the structures of unloading. Method of injection solution is useful mostly for small damages.

Strengthening as the reinforced concrete structures as well as the metal structures by the steel panels have a lot of advantages, such as relatively low cost, sufficient fatigue strength, steel panels are universal.

Disadvantages of steel panels and rods for strengthening are possible corrosion, they have considerable weight, for installation of steel elements need high labor content of the work, and consequently the high cost of labor required, to perform the work need large area, steel elements are limited in size.

Repairing or strengthening failing structures traditionally involves using bulky and heavy external steel plates that often pose their own problems. The plates are generally prone to corrosion and overall fatigue. Therefore fibre-reinforced polymer is a great alternative for strengthening reinforced concrete and metal structures.

3. The alternative methods for strengthening building structures

Used traditional methods of amplification have a relevant and effective, but they can not always be used in case of strengthening of bearing structures of historical buildings, where it is necessary to preserve not only the building as a whole, but also external architectural appearance. Because the anchors permeate the design, and they damage the surfaces of architectural structures. In such situations, it is better to use alternative methods strengthen as the metal structures as well the masonry and reinforced concrete structures using composite materials [24].

The alternative methods for strengthening building structures are methods of reinforcement by composite materials (Fig. 3).

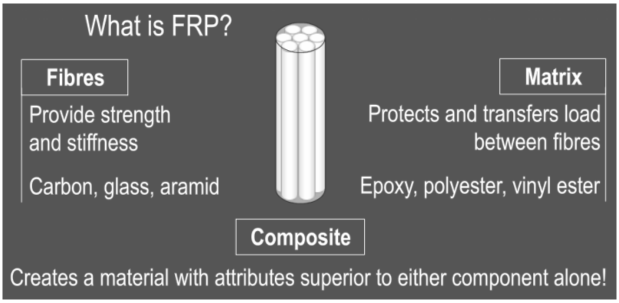


Fig. 3. Image representations composite material FRP

Composite material in the form of surface reinforcement externally bonded non-metallic strips.

FRP consists of fibers — carbon, aramid or glass — bonded together with a polymer matrix — epoxy, polyester or vinyl ester (Fig. 4).

FRP reinforcements are shaped either into composite laminates for epoxy-bonding onto the masonry surface, or into textile fabrics for laying onto the masonry surface and then impregnating the fibers with the matrix.

Fig. 4. Image representations of composite FRP materials

The main advantages of the strengthening of building constructions by composite materials are follows:

1) high durability and resistance to corrosion;

2) easy installation and low own weight;

3) high mechanical characteristics (strength and modulus of elasticity) of materials that constitute the strengthening of system;

4) a high elongation of materials strengthening;

5) possibility to joint the working element of the external reinforcement with reinforced structures at all stages of loading (such work provided by a reliable adhesive bonding).

The necessity of using FRP for strengthening building and structures is due to the internal properties of the material, such as a high strength-to-weight ratio, corrosion resistance, etc. (Tabl. 2). In addition, both the material and the geometric properties can be adapted for a specific application. Several materials are available for the fibers, e.g. glass, aramid, carbon. Therefore, a FRP with carbon fibers is abbreviated as CFRP. Properties of different fibers and typical steel are shown in Fig. 5.

Aramid fibers has good endurance and rigidity as well as low electricity and thermal conductivity. Carbon fibers are made from different starting materials. Mechanical properties of the fibers to a large extent depend on the carbonization conditions.

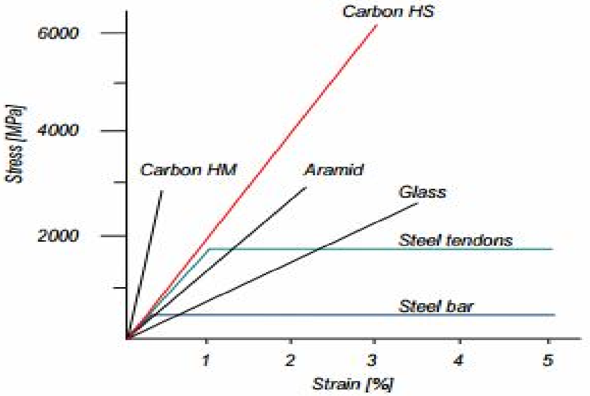


Fig. 5. Properties of different fibers and typical steel

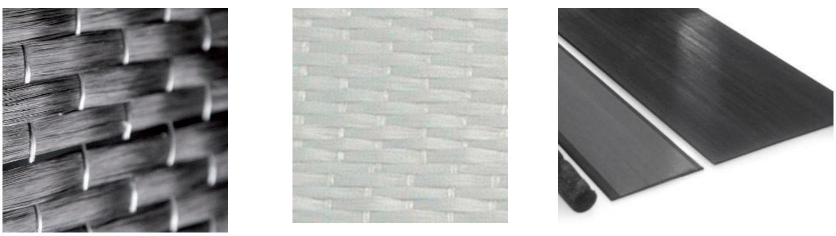
Strengthening of building structures with elements of external reinforcement made of high-strength fibers has been used for a long time, although for Ukraine, unfortunately, it is a fairly new thing. It has been in use in Switzerland or in Italy more then 45 years. Comparison of physical and mechanical characteristics of different fibers and steel represented in Table 2.

Table 2

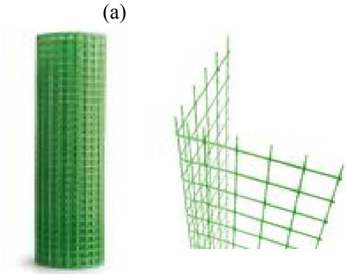
Fibres and steels properties

Fibres	E_{axial} / E_{radial} $[GPa]$	σ_{max} $[MPa]$	ε_{max} $[\%]$	ν	ρ $[g / cm^3]$	Price $[\in / kg]$
HM Carbon	380/12	2400	2.6	0.2	1.95	20-60
HS Carbon	230/12	3400	1.1	0.2	1.75	20-60
Glass	76/76	2000	2.6	0.22	2.6	1.5-3
Aramid	130/10	3000	2.3	0.35	1.45	20-35
Basalt	89/NA	4800	3.15	NA	2.75	NA
Steel	200-220	400			7.9	5-10

Samples of composite materials of the Italian company FIBERBUILT [17] are shown in Fig. 6.



(a) (b) (c)



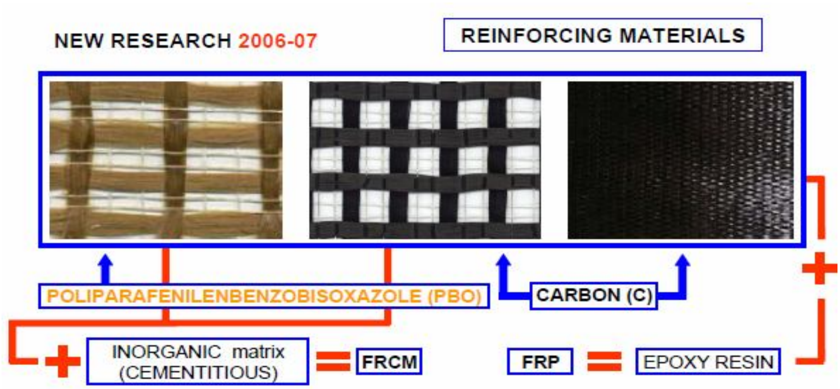
(d)

Fig. 6. Image representations composite materials of the Italian company FIBERBUILT:
(a) Carbon Fiber Reinforced Polymer CFRP;
(b) Glass Fiber Reinforced Polymer CFRP;
(c) La tecnologia FRP;
(d) Kind of composite grid in the roll of fiberglass GFRP(Glass Fiber Reinforced Polymer)

In the composite materials based on glass fiber are used quartz glass. The advantages of fiberglass are relatively low cost. Aramid fibers are used since the 70s of the last century. On chemical structure similar to nylon aramids. These fibers are anisotropic at its structure and as compared with glass have a higher strength and modulus of elasticity. They are more plastic under the influence of tensile loads, but under compression they remain elastic before failure. Important properties of a strengthening material are the stiffness, strength, and weight.

Nevertheless, drawbacks related to brittle failure, longterm durability, sensitivity to impacts, and high cost have limited their widespread use. After the diffusion of Fibre Reinforced Polymers (FRPs), mortar-based composites have been recently developed, which make use of high performance textiles (continuum dry fibres arranged in the form of open mesh or fabric) externally bonded with either cement or lime mortars. These systems are known as either TRMs (Textile Reinforced Mortars) or FRCMs (Fibre Reinforced Cementitious Matrices). Despite their adhesion strength may be lower than FRPs in certain cases, they offer important advantages in terms of fire resistance, vapour permeability, removability, and ease, time and cost of installation, thanks to the use of inorganic matrices in place of resins.

From the viewpoint of fire resistance and safety of the works the use of microcement with addition of polymer resins as an adhesive is more effective, in contrast to the epoxy adhesive. At strengthening of structures by grids for consolidate them to the surface using adhesive mortar based on cement [37]. New reinforcing material: FRCM Components Poliparafenilen Benzobis Oxazolo (PBO), Cement-based Adhesive FRCM, C-FRCM and C-FRP are represented on Fig. 7, Fig. 8.



FIBERS	Tens. strength (N/mm^2)	Failure strain (‰)	Young's modulus (GPa)	Nominal thickness (mm)
Carbon net	3500	15	240	0.047 (dir. 1 and 2)
PBO net	5800	21.5	270	0.046 (dir.1) 0.022 (dir. 2)
Carbon sheet	3500	15	240	0.17

Fig. 7. New FRCM

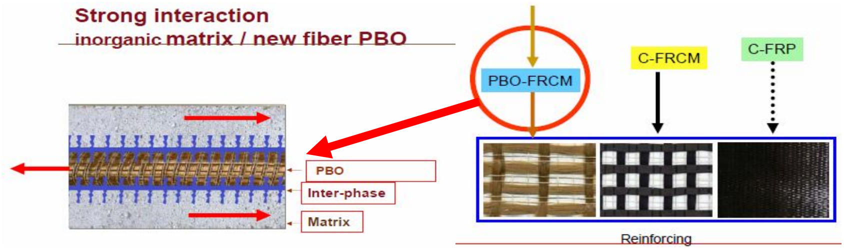
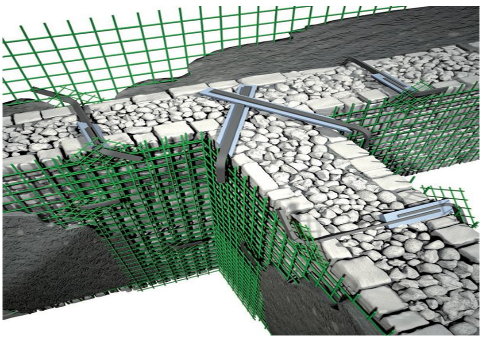


Fig. 8. Properties of new FRCM

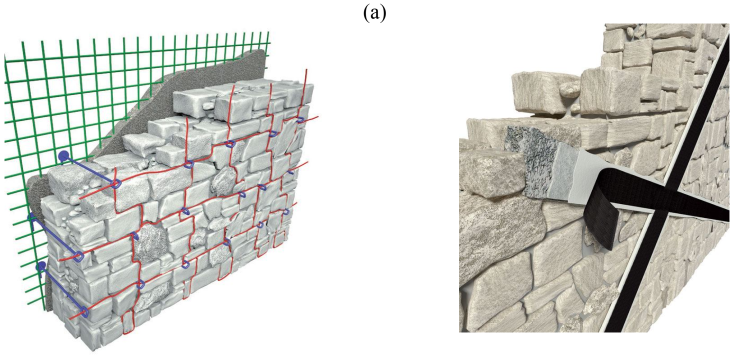
4. The main metods for strengthening building structures using FRP-materials

4.1. Masonry. The systems for strengthening of building structures vary depending on the type of consolidation required:

• FIBREBUILD FRCM (Fiber Reinforced Cementitious Matrix) [17]: "reinforced render" method, where GFRP meshes, connections and accessories are combined with lime-based mortars to obtain collaborating reinforced renders capable of improving shear, flexural and compressive strength of masonry (Fig. 9,a).



(a)



(b) (c)

Fig. 9. Image representations the systems for strengthening of masonry walls:
(a) FIBREBUILD FRCM (Fiber Reinforced Cementitious Matrix);
(b) FIBREBUILD RETICOLA; (c) FIBREBUILD FRP

• FIBREBUILD RETICOLA: "reinforced repointing" method, where stainless steel cords and connections are used to consolidate "exposed stone" masonry. The system helps reinforce masonry diffusely and successfully, while preserving the original look (Fig. 9,b).

• FIBREBUILD FRP: fibre-reinforced sheeting method, with GFRP and CFRP weaves, sheets and bars, particularly adapted to consolidate beams, pillars and columns and any other spots where masonry requires local reinforcement (hooping) (Fig. 9,c).

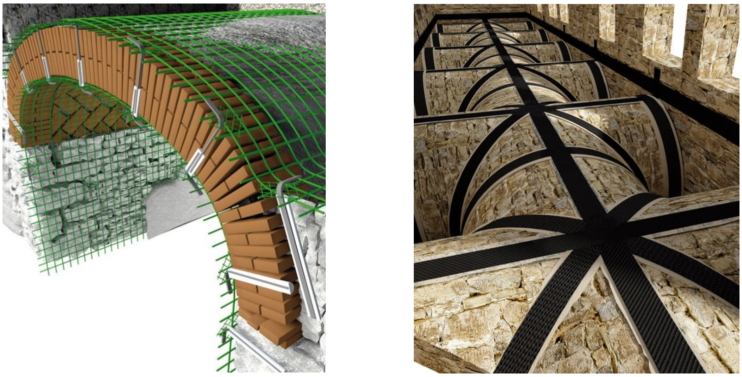
Of all architectural elements, arches and vaults made of stone or brick, be they bearing or not, are the most prone to degradation and stress caused by seismic events, changes in acting loads and foundation sinking, which cause the structure to lose its original mechanical properties. Because these elements are of great historic and architectural value, they need to be consolidated in a non-invasive, compatible and consistent way with regard to their special features.

Fibre Net developed two different methods of intervention:

• FIBREBUILD FRCM (Fiber Reinforced Cementitious Matrix): the "reinforced render" method, where GFRP meshes, connections and accessories are combined with preferably lime-based mortars to obtain a thin collaborating reinforcement capable of improving mechanical strength diffusely and homogeneously (Fig. 10,a).

• FIBREBUILD FRP: fibre-reinforced sheeting method, where GFRP and CFRP weaves are used for reinforcing individual spots, ideally recommended for oddly shaped arches and vaults (Fig. 10,b).

The esthetic superiority and the general structural characteristics of FRP-systems have been recognized by Jerzy Jasienko [12,13], Angelo Di Tommaso [11] etc, as well as following international organizations: The International Federation for Structural Concrete [4] , American Concrete Institute [5], Japan Building Disaster Prevention Association [6].



(a) (b)

Fig. 10. Image representations the systems for strengthening of arches and vaults:
(a) FIBREBUILD FRCM ; (b) FIBREBUILD FRP for arches and vaults

4.2. Reinforced concrete structures

The systems for strengthening of reinforced concrete structures by FRP-materials are represented on Fig. 11.

Fig. 11. Image representations the systems for strengthening of reinforced concrete structures by FRP-materials

4.3. Metall structures

The use of steel plates to repair and strengthen existing steel structures has been traditionally used for rehabilitation of steel girders. However, the welded detail of steel plates is sensitive to the fatigue loads.

The effectiveness of using bonded CFRP sheets or plates to improve the fatigue strength has been examined by various researchers [38, 40, 41].

Great contribution to the theory of design with using of FRP-systems was done by lot of scientists. Big contribution and good review was made by Giosuè Boscato [38].

There exists a large number of applications of the FRP-system for strengthening the metal structures for conservation of the architectural and enviromental heritage. Certainly, there are also disadvantages, such as relatively high cost and the need for protection from fire, possible delamination. This problem is studied by a number of scientists.

The study of A. Shaat and A. Fam [40] investigates the experimental behaviour of axially loaded slender steel columns composed of square Hollow Structural Section (HSS), and strengthened using high modulus-carbon fibre-reinforced polymer (HMCFRP) plates. As the slenderness ratio increases, the

HM-CFRP failure mode changes from debonding to crushing at the inner surface of the buckled column (Fig. 12, Fig. 13).

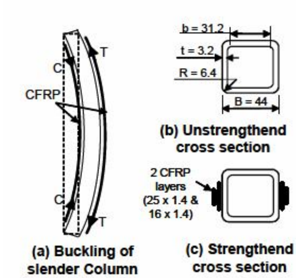


Fig. 12. Buckling and cross sectional configurations

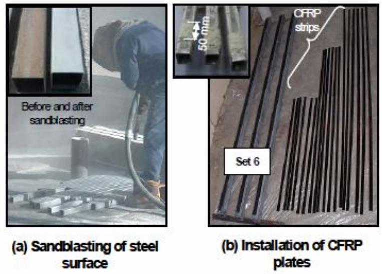


Fig. 13. Preparation of test speciments

Exploration performed during the rehabilitation of steel bridges [26] using advanced composite materials have represented many advantages of using FRP-materials for feasible and cost-effective solutions for an increasing number of deficient bridges (Fig. 14).

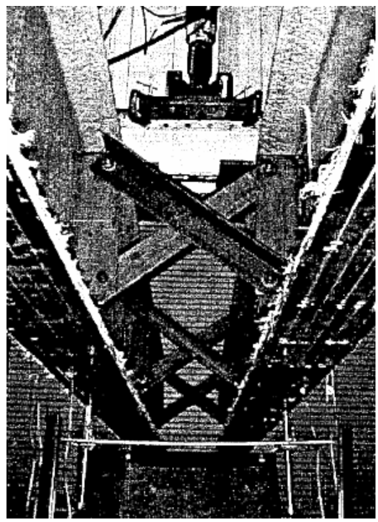


Fig. 14. Test girders are strengthened by CFRP plates

Load tests performed prior to and after the rehabilitation indicate a reduction in tension flange strains of 11%. The research demonstrated that this rehabilitation approach is a feasible and potentially cost-effective repair solution for deteriorated steel bridges.

Delamination of a strengthened element can take place in the reinforcement, in the reinforcement, in the substrate or at the interface. In a strengthened element with a metallic substrate, the possible delamination failure modes are listed below, as shown in Fig. 15:

a) Delamination at the substrate – adhesive or adhesive-FRP interface;

b) Cohesive failure of the adhesive;

c) Delamination in the strengthening material.

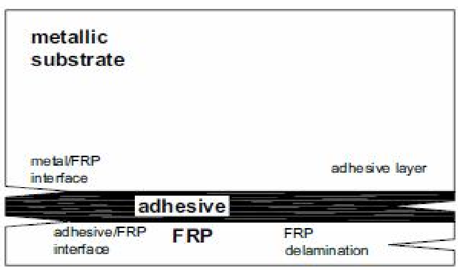


Fig. 15. Types of debonding in FRP strengthened metallic structures

5. Computation of the strengthening using FRP-system

For the calculated limit state to take the condition of achieve of the limit values of the coupling of adhesive with the reinforcing structure. Moreover, must be taken into account factors of reliability depending the used type of composite material and technology of its application.

For example, in Italy, **the main existing documents in the field of strengthening of structures by composite materials including recommendations of computation and design are:**

• Eurocode 8 - Design of structures for earthquake resistance Part 3: Assessment and retrofitting of buildings. EN 1998-3:2004. European Committee for Standardisation (November 2004) [1].

• FIB bulletin 14. Externally bonded FRP reinforcement for RC structures. July 2001 [2].

• Externally bonded FRP reinforcement for RC structures. Technical report on the Design and use of externally bonded fibre reinforced polymer reinforcement (FRP) for reinforced concrete structures. The International Federation for Structural Concrete. CEB-FIP, July, 2001 [4].

• ACI 440.2R-08. Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures. ACI Committee 440, technical committee document, 2008 [5].

• CNR-DT 200/2004 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures. Materials, RC and PC structures, masonry structures. ROME –CNR, 2004. 154 p. [7].

• CNR-DT 203/2006 «Guide for the Design and Construction of Concrete Structures Reinforced with Fiber-Reinforces Polymer Bars». ROME – CNR, 2007. 39 p. [8]

• CNR-DT 202/2005 «Guidelines for the Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures». Metallic structures. Preliminary study. ROME –CNR, 2007. 57 p. [9]

CNR-DT 201/2005 «Guidelines for the Design and Construction of Externally Bonded FRP Systems for Strengthening Existing Structures». Timber structures. Preliminary study. ROME –CNR, 2007. 58 p. [10]

5.1. Design of strengthening of reinforced concrete structures by FRP-materials (Fig. 16) according with ACI (American Concrete Institute) Committee [5]:

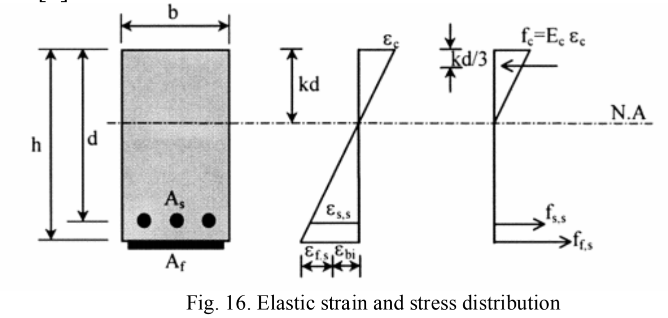


Fig. 16. Elastic strain and stress distribution

The effective stress level in the FRP reinforcement can be found from the strain level in the FRP, assuming perfectly elastic behavior $f_{fe}=E_f\cdot\varepsilon_{fe}$.

The nominal flexural strength of the section with FRP external reinforcement can be computed from

$$M_n=A_s f_s\left(d-(\beta_1 c)/2\right)+\psi_f A_f f_{fe}\left(h-(\beta_1 c)/2\right).$$

An additional reduction factor ψ_f is applied to the flexural strength contribution of the FRP reinforcement. A factor $\psi_f=0.85$ is recommended.

With the strain and stress level in the FRP and steel reinforcement determined for the assumed neutral axis depth, internal force equilibrium may be checked using

$$c=\frac{A_s f_s+A_f f_{fe}}{\gamma f_c^{'}\beta_1 b}.$$

The terms β_1 and γ - parameters defining a rectangular stress block in the concrete equivalent to the actual nonlinear distribution of stress. If concrete crushing is the controlling mode of failure (before or after steel yielding), β_1 and γ can be taken as the values associated with the Whitney stress block ($\gamma=$ 0.85 and $\beta_1=0.97-0.0025 f_c^{'}>0.67$ from Section 10.2.7.3 of ACI 318-99).

5.2. Design of strengthening of reinforced concrete structures by composite materials according with proposition from Täljsten (2006) [18]:

- the design for bending is similar for all elements the frame is performed considering the approach found in

$$A_{frp}=\frac{M/0{,}9-A_{st}f_{st}}{\varepsilon_{frp}\cdot E_{frp}},$$

where the steel area A_{st} and the yield strength of the steel, f_{st}, should not be accounted if no steel is present in the section.

- the shear contribution attributed to the strengthening material is determined as

$$t_{frp}=\frac{V_d}{0.6\cdot\varepsilon_{frp}\cdot E_{frp}\cdot b_{frp}}.$$

Guidelines for the **strengthening of tensile elements of metal structures by FRP-materials** (Fig. 17) are represented in [9].

The strengthening can be applied for the restoring of the load bearing capacity of corroded elements, as well as for the upgrading of the failure load undamaged elements.

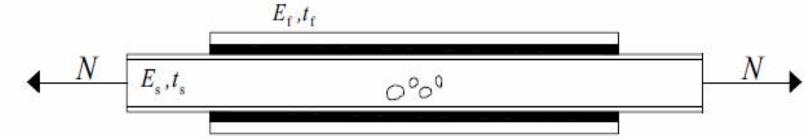


Fig. 17. Tensile element with partially corroded cross section and symmetric reinforcement.

On the conservative side, restoring of the load bearing capacity of damaged elements, not subjected to fatigue, is performed assuming that the stresses across the damaged section are bridged by the FRP materials. The Strengthening must be designed such that:

$$2A_{frp}\cdot\frac{f_{fk}}{\gamma_f}\cdot\eta\geq A_s\cdot f_{sk,\sup},$$

where: A_{frp} is the cross section area of the FRP; f_{fk} Is the lower characteristic of the composite tensile strength; γ_f is the partial factor of the reinforcement material; η Is the conversion factor; A_s Is the cross section area of the metallic substrate; $f_{sk,\sup}$ is the upper characteristic value of yielding stress (f_y) for ductile material, or failure stress (f_u) for brittle material.

Strengthening of flexural elements of metal structures by FRP-materials (Fig. 18) [9].

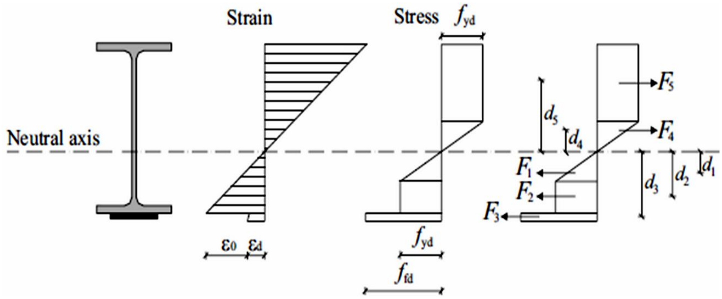


Fig. 18. Procedure for computing the flexural capacity

The ultimate limit state is checked by verifying the following Equation:

$$M_{Sd}\leq M_{Rd},$$

where M_{Sd} is the bending moment produced by the design load combination, $M_{Rd}=\sum F_i\cdot d_i$ is the design value of the flexural capacity.

The last 15 years in particular, the advent of powerful computers and the development of sophisticated nonlinear CAD software (Finite Element Analysis (FEA) Software Stand, SolidWorks, DIANA, MATLAB (finite element method FEM and discrete element method DEM), ADINA [14], ABAQUS [15], Autodesk REVIT Structure, Autodesk ROBOT Structural Analysis, ANSYS, TEKLA Structures, SCAD, LIRA and others) have enabled engineers to utilize complicated large scale structures, some of which can be classified among unique examples of engineering excellence.

6. Aanalytical modeling in ABACUS/CAE

Modeling Procedure of the steel beam. Computations of steel beam are performed in software ABAQUS.

The modeling, meshing, boundary condition and loading conditions are shown in Fig. 19.

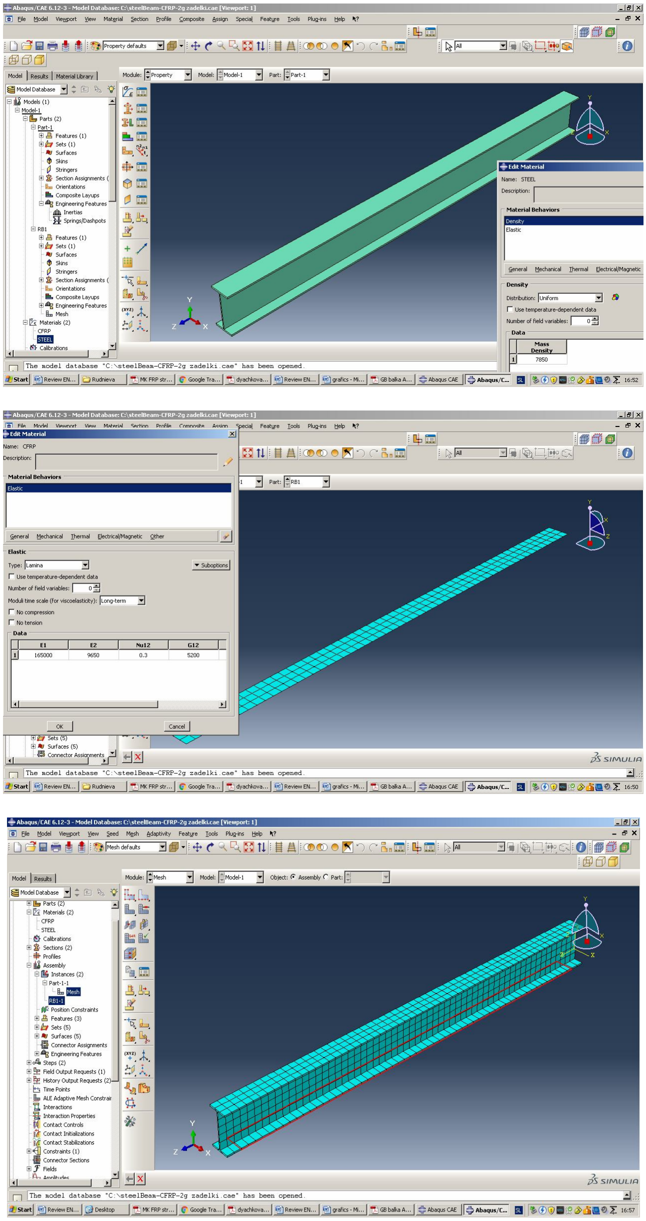


Fig. 19. Modeling, meshing, boundary condition and loading of the Steel beam in software ABAQUS (Q=15000N/m^2)

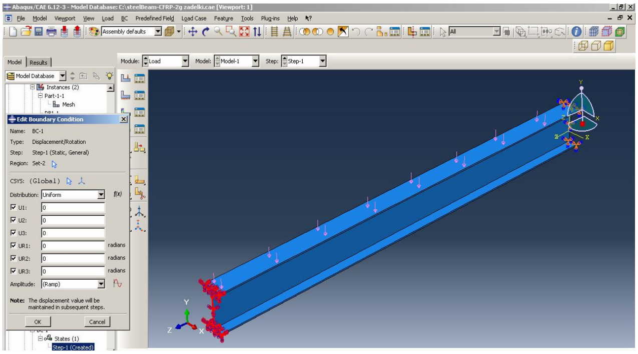
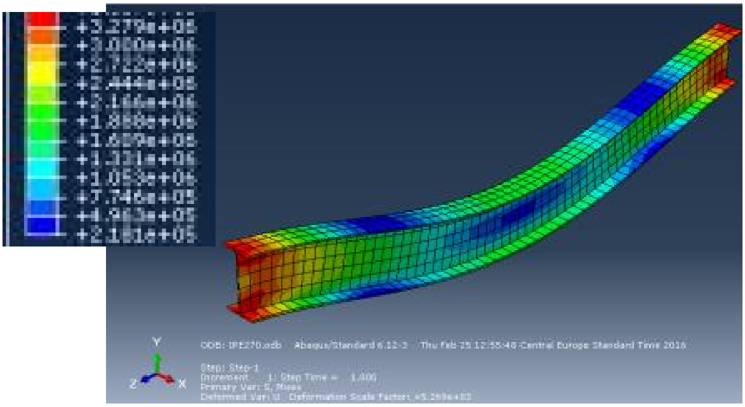
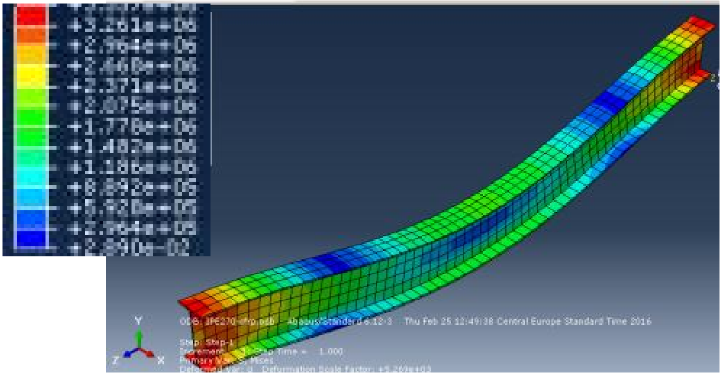


Fig. 19 (continuation). Modeling, meshing, boundary condition and loading of the Steel beam in software ABAQUS (Q=15000N/m^2)

Results of computation of the Reinforced concrete beam in software ABAQUS are represented in Fig 20.



a)

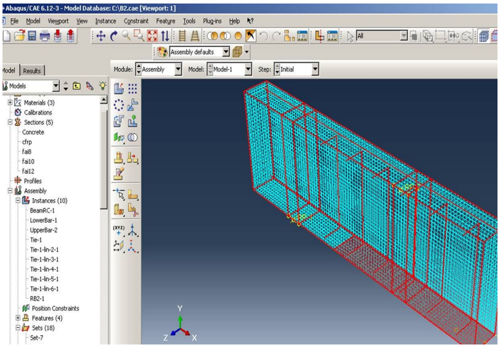


(b)

Fig. 20. Results of computation Steel beam in software ABAQUS:
(a) before strengthening by CFRP; (b) after strengthening by CFRP

Modeling of the reinforced concrete beam. Computations of reinforced concrete beam are performed in software ABAQUS.

The modeling, meshing, boundary condition and loading conditions are shown in Fig 21.



Accepted materials characteristics:

- Concrete: $f'c = 30Mpa$.
- Steel: Elastic-perfectly plastic stress-strain behavior $f_y = 507Mpa$,

$E_s = 209Gpa$ Poisson Ratio = 0.3.

- CFRP: Linear-Elastic orthotropic

$E_{11} = 165Mpa, E_{22} = 9.65Gpa,$

$\mu_{12} = 0.3, G_{12} = 5.2Gpa,$

$G_{13,} = 5.2Gpa, G_{23} = 3.4Gpa.$

Thickness of CFRP sheets 1 mm.

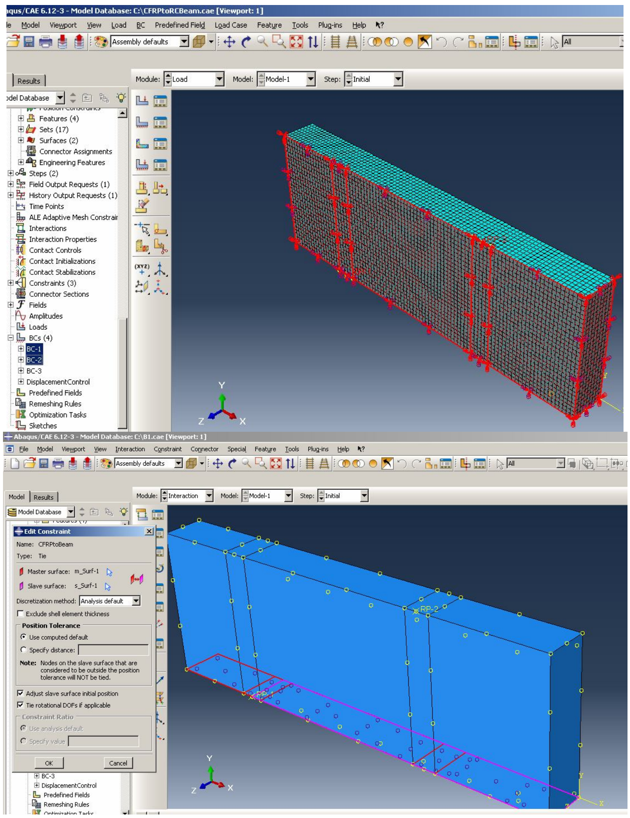


Fig. 21. Modeling, meshing, boundary condition and loading of the reinforced concrete beam in software ABAQUS (P=12MN)

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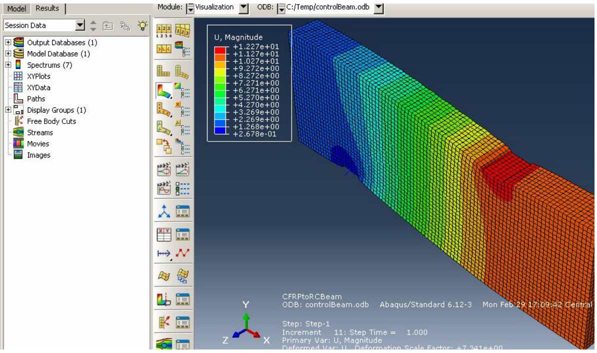
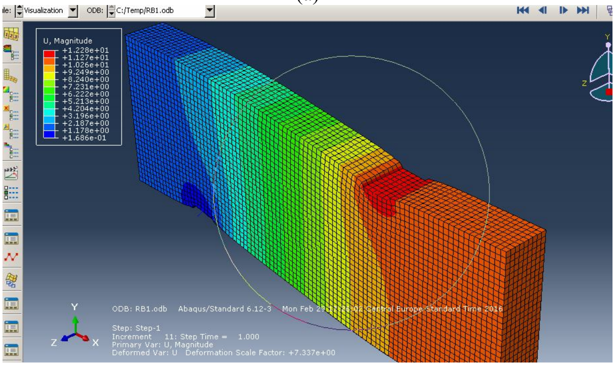
Results of computation of the Reinforced concrete beam in software ABAQUS are represented in Fig. 22.



(a)



(b)

Fig. 22. Results of computation of the Reinforced concrete beam in software ABAQUS:
(a) before strengthening by CFRP; (b) after strengthening by CFRP

7. CONCLUSIONS:

• This note has attempted a review of the latest issues and developments in the strengthening of building and structures, while also touching upon the historical perspective and including some information of general nature.

• The treatment is of necessity short in order to compress many issues into limited space. The paper has particularly addressed the latest trends and issues of concepts in strengthening of structures using composite materials.

• In the article it was considered variants of strengthening steel beam and reinforced concrete beam by composite materials. Computations are performed in software ABAQUS.

• CFRP strengthened steel and reinforced concrete beams resulted in reduce strain in the element and consequently to the possibility to insrease load carrying capacity.

• For example, in a metal beam after the inclusion CFRP in operation the percentage decrease of the vertical deflection was 5,6 %. The value of tensile stresses reduced by about 4,1 %.

• In a reinforced concrete beam the percentage decrease of the vertical deflection was 3,2 % for beams strengthened with CFRP laminates. The value of tensile stresses reduced by about 2,8 %.

• The beams strengthened with CFRP laminates show enhanced ductility.

• The main principle of placement of composite laminates, grids, rods consists in a parallel arrangement to tensile stresses.

• Despite the large amount of information about FRP-materials issues of reliability of alternative metods for strengthening building structures by FRP-materials have yet to be properly defined.

• In addition, durability requirements, adaptability to manufacture, economic efficiency, ecological and social factors should be fulfilled in total volume.

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Руднєва І.

ПОРІВНЯЛЬНИЙ АНАЛІЗ ПІДСИЛЕННЯ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ (КЛАДКИ, МЕТАЛЕВИХ КОНСТРУКЦІЙ, ЗАЛІЗОБЕТОНУ) З ВИКОРИСТАННЯМ FRP-МАТЕРІАЛІВ І ТРАДИЦІЙНИХ МЕТОДІВ ПРИ РЕКОНСТРУКЦІЇ

Побудовані в основному століття назад, історичні будівлі, а також більш сучасні будівлі минулого століття, які втратили несучу здатність, часто потребують відновлення та підсилення, особливо в сейсмічних районах і в регіонах з явищами просідання грунтів. Необхідність підсилення будівельних конструкцій в процесі експлуатації виникає головним чином через їх передчасного зносу в результаті технологічних й атмосферних впливів, різних пошкоджень та інших факторів.

Традиційні методи підсилення ефективні, але в деяких випадках не підходять або не можуть застосовуватися. Прикладом є збільшення несучих конструкцій історичних будівель, збереження зовнішнього вигляду яких є визначальним фактором. У цьому випадку використання альтернативних методів з використанням FRP-матеріалів може бути виправдане.

Знання причин дефектів і пошкоджень конструкцій дозволяє вибрати оптимальний варіант ремонту або підсилення. Метою дослідження є оцінка структурних характеристик композитних армованих елементів в більш широкому секторі збереження історичної, архітектурної та екологічної спадщини, а також в більш сучасних будівлях минулого століття, які втратили несучу здатність з фокусом на показники надійності і зовнішній вигляд конструкції.

У статті описані і проаналізовані існуючі традиційні методи і альтернативні методи підсилення FRP-матеріалами (композитними матеріалами) таких будівельних конструкцій, як кам'яна або цегляна кладка, металеві конструкції, залізобетон. Також виконано розрахунок в програмному забезпеченні ABAQUS. Ці процедури підсилення будівельних конструкцій за допомогою FRP-матеріалів в Україні широко не використовуються через відсутність нормативної бази, яка б регулювала їх використання, а також тому, що ці матеріали відносно дорогі, в порівнянні з традиційними.

У статті проаналізовані існуючі методи розрахунку і проектування підсилення конструкцій з використанням FRP-матеріалів. Розрахунок в програмному забезпеченні ABAQUS виконаний з висновками і рекомендаціями, заснованими на результатах розрахунку.

Метою роботи було розгляд технології та аналіз переваг і недоліків кожного з методів підсилення, які слід використовувати при виборі ефективних рішень для підсилення будівельних конструкцій. На завершення була підтверджена необхідність подальших досліджень на цю тему.

Ключові слова: методи підсилення, композитні матеріали, FRP-матеріали, кладка, металеві конструкції, залізобетон, напружено-деформований стан, обчислювальні методи, дефекти, пошкодження, реконструкція.

Rudnieva I.

COMPARATIVE ANALYSIS OF STRENGTHENING OF BUILDING STRUCTURES (MASONRY, METAL STRUCTURES, REINFORCED CONCRETE) USING FRP-MATERIALS AND TRADITIONAL METHODS DURING RECONSTRUCTION

Built mostly centuries ago, heritage buildings as well the more contemporary buildings of the last century, which have lost the bearing capacity often need restoration and strengthening, especially in seismic regions and in regions with shrinkage phenomena (subsidence region). The need of strengthening of the building constructions during exploitation appears mostly because of their premature wear as a result of technological influences and weathering, various damage and various other factors.

Traditional methods of strengthening are effective, but in some cases not appropriate or not applicable for use. An example is the increase of the load-bearing structures of historical buildings, preserving the external appearance of which is the determining factor. In this case, the use of the discussed alternative methods can be justified alternative.

Knowledge of the causes of defects and damage of structures allows to choose the best option of repairing or strengthening.

The aim of the research is the evaluation of the structural performance of composite fibre-reinforced elements in the wider sector of the conservation of historical, architectonic and environmental heritage, as well the more contemporary buildings of the last century, which have lost of the bearing capacity focusing reliability indexes and the appearance of the structure.

In the article was described and analyzed the existing traditional methods and the alternative methods of strengthening by FRP-materials (composite materials) such building structures as masonry, metal structures, reinforced concrete, and the computation in software ABAQUS. These procedures of strengthening building structures by FRP-materials in Ukraine are not widely used due to the lack of a regulatory framework that would regulate their use, as well because these materials are relatively expensive compared to the traditional ones.

The article analyzed the existing methods of computation and design of the strengthening using FRP-materials, and the computation in software ABAQUS was performed with conclusions and recommendations based on results of the computation.

The aim of the work was to review the technology and analyze the advantages and disadvantages of each of the strengthen methods that should be used when choosing effective solutions for strengthening building structures. In conclusion, the need for further study and researches was confirmed.

Keywords: methods of strengthening, composite materials, FRP-materials, masonry, metal structures, reinforced concrete, stress-strain state, computational methods, defects, damage, reconstruction.

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Автор (науковий ступінь, вчене звання, посада): *кандидат технічних наук, доцент кафедри опору матеріалів КНУБА РУДНЄВА Ірина Миколаївна.*
Адреса: *03680 Україна, м. Київ, Повітрофлотський проспект 31, КНУБА, кафедра опору матеріалів, Руднєва Ірина Миколаївна.*
Робочий тел.: *+38(044) 241-54-21;*
Мобільний тел.: *+38(050) 620-32-31;*
E-mail: *irene_r@ukr.net*
ORCID ID: http://orcid.org/0000-0002-9711-042X