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RESEARCH ARTICLE

Engineering software development for strengthening concrete structures using fiber-reinforced polymers

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Abstract

In this study, engineering software for the calculations of the strengthening applications of reinforced concrete (RC) load-bearing elements with Fiber Reinforced Polymer (FRP) composite materials is developed. This software is developed to increase the axial compression strength and ductility capacity of columns and improve the shear capacity of beams using FRP material according to provisions of the Turkısh Building Earthquake Code 2018 (TBEC-2018). In addition, this software offers designers the opportunity to perform calculations to increase the bending moment capacity of beams using FRP composite material, according to the American Concrete Institute 440-2R.17 (ACI 440-2R.17). Algorithms to be used to increase the capacities of RC load-bearing elements with FRP composite materials are formed according to the provisions of the mentioned codes. Then, computer and web-based engineering software with different coding languages are developed depending on these algorithms.

1. Introduction

The structural elements of RC structures are exposed to damage due to various reasons during their service life and their intended use may change and may be suffered from various deteriorations due to environmental effects [1]. Moreover, corrosion effects occur as a result of the exposure of the existing reinforcement in RC elements to chemical effects, and thus damages such as cracks, spills, and deterioration may occur in the load-bearing elements. These may also occur due to the effects of freeze-thaw phenomena caused by harsh climatic conditions. On the other hand, project and construction errors, changes in existing loads, and durability (durability or permanence) problems in concrete can also cause damage to RC structures.

The aforementioned situations necessitate the production of appropriate solutions to ensure the life safety of RC structures and to meet the desired performance level throughout their service life. Demolition and reconstruction of structures consume a large number of resources and energy. Therefore, the protection of existing structure stock against extreme loads and conditions such as earthquakes, winds, and environmental effects with appropriate methods is important for the efficient use of energy and resources in the construction

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and renovation process. For this purpose, the repair and strengthening of structures appear as a suitable solution [2, 3].

FRP composite materials have been preferred as an alternative to the traditional repair and strengthening techniques for existing structures. It is widely used in strengthening applications of civil engineering structures due to its advantages such as lightweight, high strength-to-weight ratio, corrosion resistance, and high construction efficiency [4, 5]. In addition, the development of strong epoxy adhesives has increased their effectiveness in repairing and strengthening structures. FRP composite materials, which have different types of applications, can be used in most civil engineering structures such as RC, steel, and masonry.

This study aimed to develop engineering software for the calculations of the strengthening applications of RC load-bearing elements with FRP composite materials. This software is developed to increase the axial compression strength and ductility capacity of columns and improve the shear capacity of beams using FRP material according to provisions of the Turkısh Building Earthquake Code 2018 (TBEC-2018) [6]. In addition, this software offers designers the opportunity to perform calculations to increase the bending moment capacity of beams using FRP composite material, according to the American Concrete Institute 440-2R.17 (ACI 440-2R.17) [7]. For these purposes, MATLAB version R2022b, GUI MATLAB program, JAVASCRIPT, PHP, HTML, and CSS coding languages are used. Also, report pages are created using the EXCEL program for the details obtained from the developed software.

2. Developed engineering software

There are many challenges in the strengthening of RC load-bearing elements with FRP composite materials such as many parameters that must be considered in calculations due to the provisions of the codes, the formulas used complicated, and the existence of processing steps that require iteration. For this reason, two engineering software, both computer and web-based, are developed for easy and fast calculation. MATLAB version R2022b coding language for the computer-based software and GUI MATLAB program for interface design is used. In web-based software, JAVASCRIPT and PHP coding languages are used. Interface design is performed by utilizing HTML and CSS coding languages. In addition, report pages are created over the EXCEL program for the details obtained from the developed software.

The developed computer and web-based software consist of four different interfaces that provide solutions for the strengthening of RC load-bearing elements using FRP composite materials. Thanks to these, the strengthening design of the relevant RC elements is made practically, depending on the input parameter values entered by the user. Finally, the process steps and the results are presented to the designer in detail, in the reporting section.

3. Computer-based software

3.1. Interface for increasing the axial compressive strength of RC columns

With this interface, the ply number of the FRP fabric required in the strengthening design to increase the axial compressive strength of the existing RC columns is calculated by considering input data such as the column cross-section details, axial load level, and the FRP composite material properties. Fig. 1 illustrates the developed interface for increasing the axial compression strength of RC columns. After the analysis, preliminary results such as the axial compressive strengths of the existing and strengthening RC column, the cross-section check results, the percentage of change in the axial compressive strength, and the strain values of the confined column can be simultaneously monitored by the user. In addition, the provisions that must be met according to TBEC-2018 can be examined by the user.

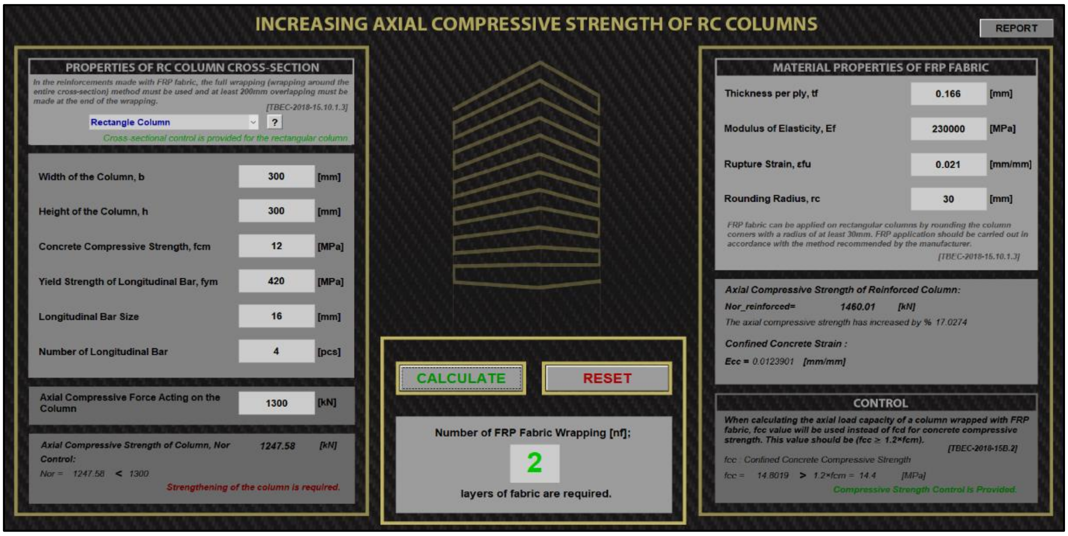

Fig. 1. Interface for increasing the axial compressive strength of RC columns

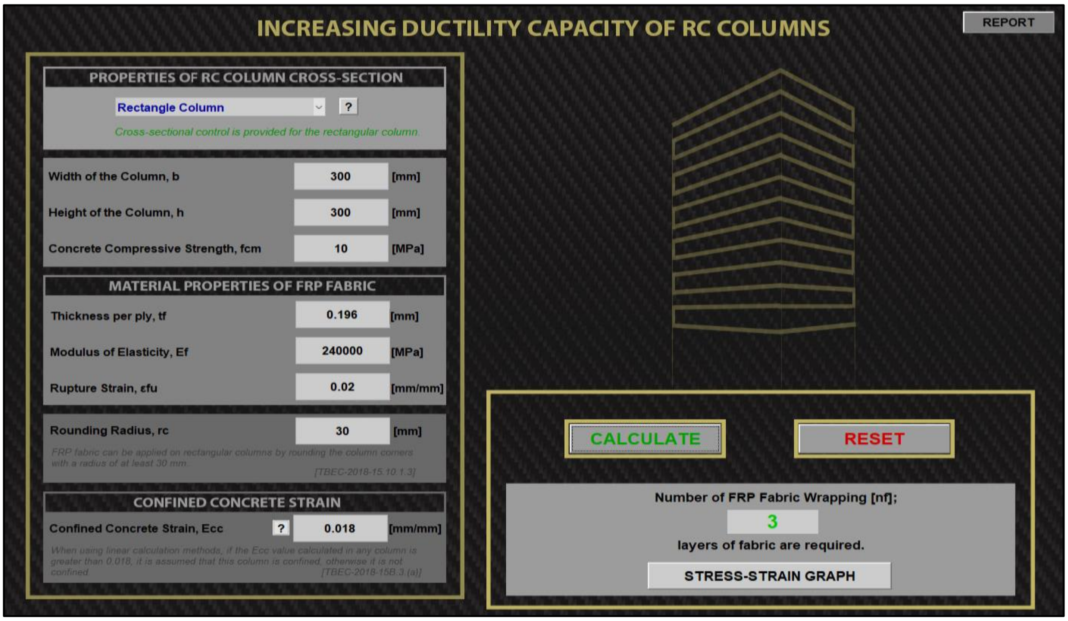

Fig. 2. Interface for increasing the ductility capacity of RC columns

3.2. Interface for increasing ductility capacity of RC columns

This interface is developed for the calculations to be carried out to increase the ductility of RC columns with FRP composite materials. To determine the ply number of the FRP fabric required in the strengthening design, cross-section details of existing columns and mechanical properties of FRP should be input data into the interface. In addition, the minimum value required for the strain of the confined concrete should be entered following the considerations of the codes. After the analysis, preliminary results such as the stress-strain graphs of the existing and strengthening RC column, the cross-section check results, and the required ply number of fabric, can be simultaneously monitored by the user. Moreover, provisions of the TBEC-2018 can be controlled. On the other hand, all processes and results are presented to the user as a report. Fig. 2 shows the developed interface for increasing the ductility capacity of RC columns.

3.3. Interface for increasing shear capacity of RC beams

By wrapping the FRP fabrics along the transverse direction of the beam, its shear capacity can be efficiently increased. According to TBEC-2018, FRP fabric can be applied as continuous or discontinuous (strip) confinement along the RC beams against shear effects. Therefore, the developed computer-based program provides the opportunity to calculate in both cases. The required FRP confinement to increase the shear capacity of the existing RC beams is calculated by considering input data such as the cross-section, reinforcement detail, design shear force, and the FRP composite material properties. If discontinuous confinement is desired, the distance between the strips and the strip width should be introduced into the program. As a result of the calculation, many results such as the contribution of concrete and transverse reinforcements to shear strength, shear capacity of existing and strengthening RC beam, and required ply number of fabric, can be obtained. Crush controls under the diagonal compressive effects are also carried out by the program. Moreover, all processes and results are presented to the user as a report. Fig. 3 presents the developed interface for increasing the shear capacity of RC beams.

3.4. Interface for increasing bending moment capacity of RC beams

With the application of FRP plates (laminated FRP) along the length of the RC beams, bending moment capacity can be improved. The design and calculation methods of ACI 440.2R-17 are taken into account in the software developed to increase the bending moment capacities of RC beams. Cross-section details of the existing beam, mechanical properties of FRP plates, environmental reduction factor given Table 9.4 of ACI 440.2R.17, and existing and expected service loads should be introduced into the program to determine the required FRP plates. In addition, the program also carries out prerequisite control for strengthening, according to ACI 440 2R.17. As a result of the calculation, the bending moment capacity of existing and strengthening RC beams and cross-section controls can be obtained. Fig. 4 shows the developed interface for increasing the bending moment capacity of RC beams.

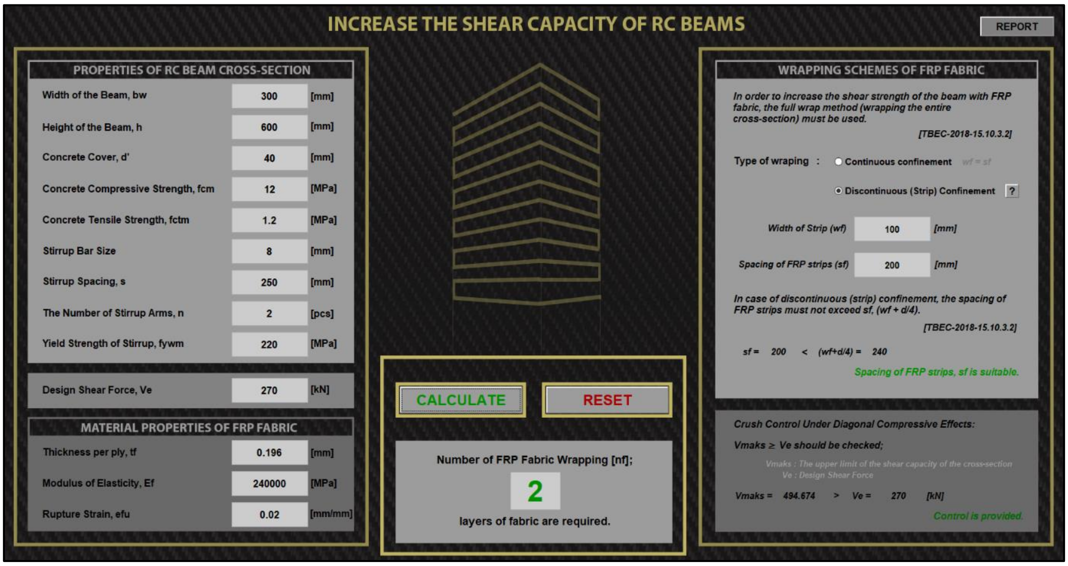

Fig. 3. Interface for increasing the shear capacity of RC beams

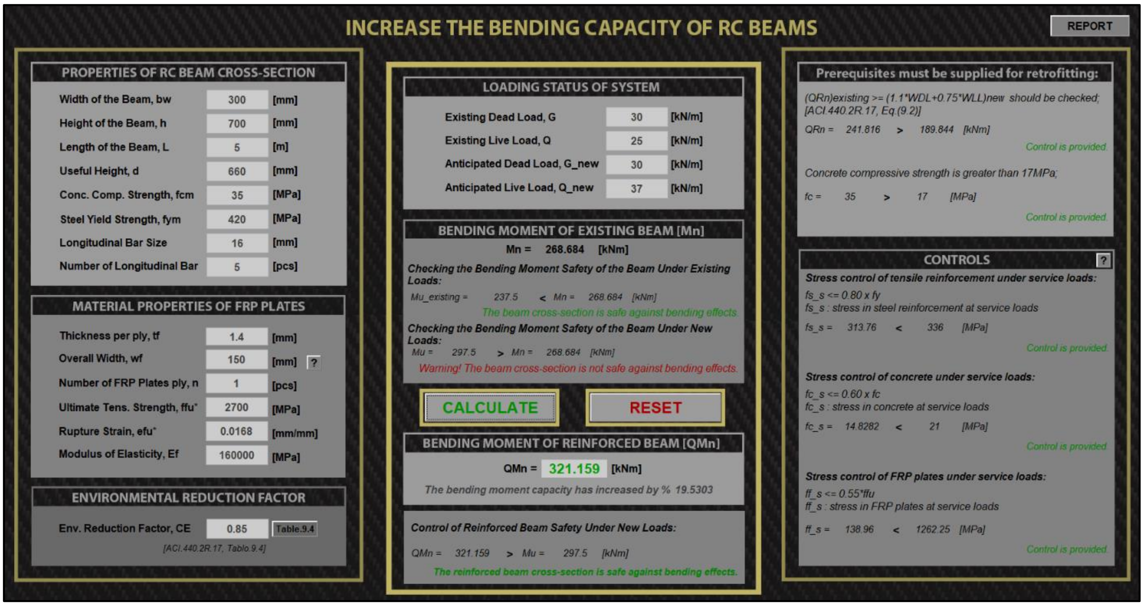

Fig. 4. Interface for increasing the bending capacity of RC beams

4. Non-linear static pushover analysis

A web-based software named "DynaFRP" for the strengthening of RC load-bearing elements using FRP composite materials is developed using JAVASCRIPT, PHP, HTML, and CSS coding languages. Since this software works with a server on the web, it offers the user the opportunity to access the program with different types of devices (computer, phone, and tablet). DynaFRP software consists of four web interfaces; (i) increasing the axial compressive strength of the RC columns, (ii) increasing the ductility capacity of the RC columns, (iii) strengthening of RC beams to shear force, and (iv) increasing bending moment capacity of RC beams. This software is used similarly to the aforementioned computer-based software and the desired strengthening design interfaces can be reached by logging into the site to which the server is connected. In addition, report pages are created over the EXCEL program for the details obtained from the developed web-based software. Figs. 5-8 illustrate the interfaces of the developed web-based software for strengthening RC load-bearing elements using FRP composite materials.

5. Conclusions

In this study, engineering software is developed for the strengthening of RC structural system elements with FRP composite materials. The provisions of TBEC-2018 given in Appendix 15B are taken into account to strengthen the RC beams against shear force, and to increase the axial compressive strength and the ductility capacity of the RC columns. In the calculations of the strengthening design against the bending effects of the RC beams, the provisions recommended in the ACI 440.2R.17 are used. Firstly, computer-based engineering software is created using the MATLAB GUI included in the MATLAB program. Then, a web-based engineering software is developed using JAVASCRIPT, PHP, HTML, and CSS coding languages. The web-based software offers the opportunity to be used on different types of devices such as phones and tablets. Thus, it is aimed to provide convenience and practicality both in field applications and in the design phase. On the other hand, report pages are created over the EXCEL program for the details obtained from the developed software. Some advantages of the developed software are listed as follows:

- It prevents the repetition of the same calculations for load-bearing elements with different cross-section properties in RC structures.
- It provides the opportunity to perform strengthening design using different types of devices such as phones and tablets via an internet server without the need for a computer.
- It provides users with the opportunity for accurate, fast, and practical solutions. In addition, the web-based program offers the opportunity to make instant designs for the elements to be strengthened at the construction site.
- Detailed reports of the processes and designs carried out by the software are presented.

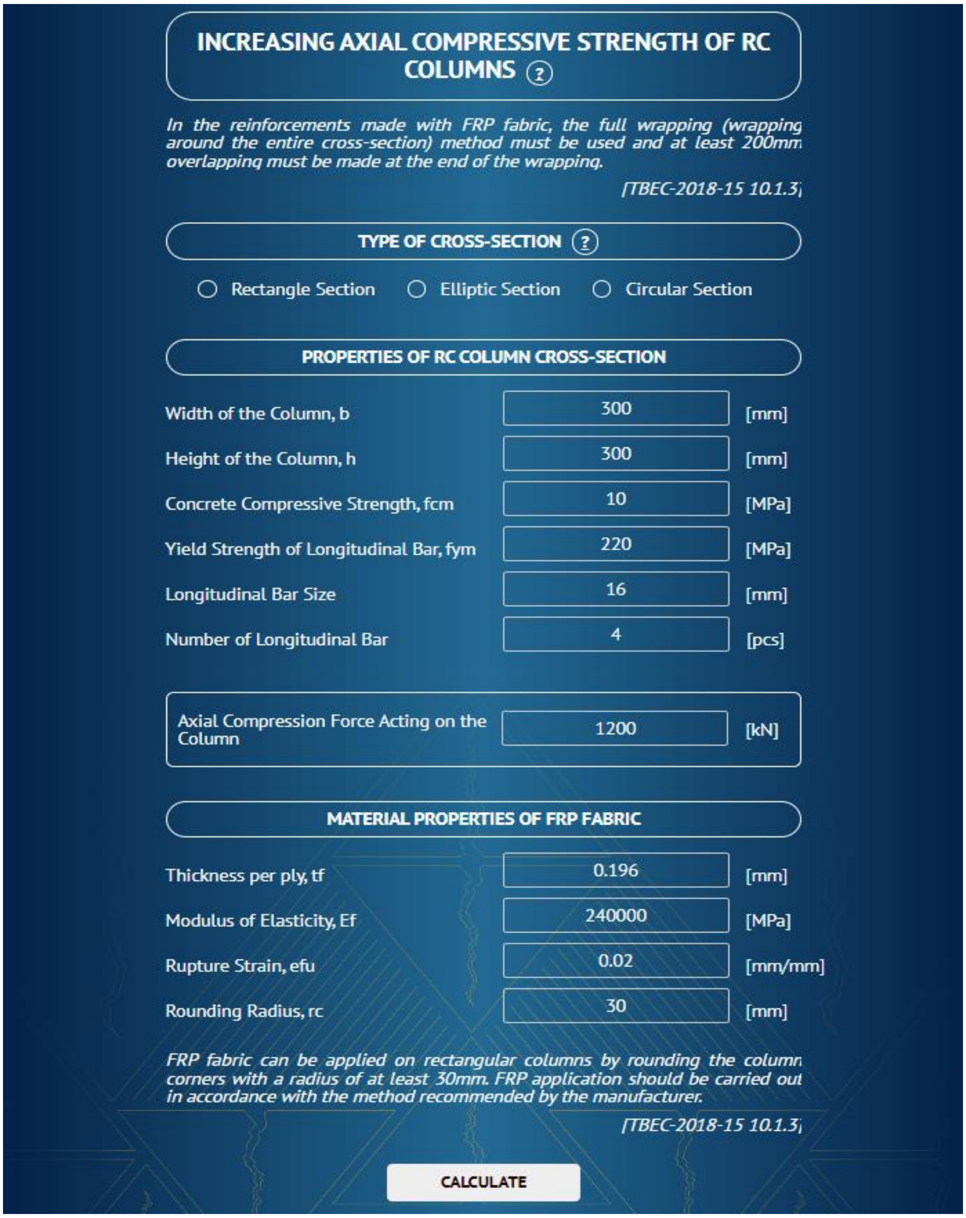

Fig. 5. Interface for increasing axial compressive strength of RC columns

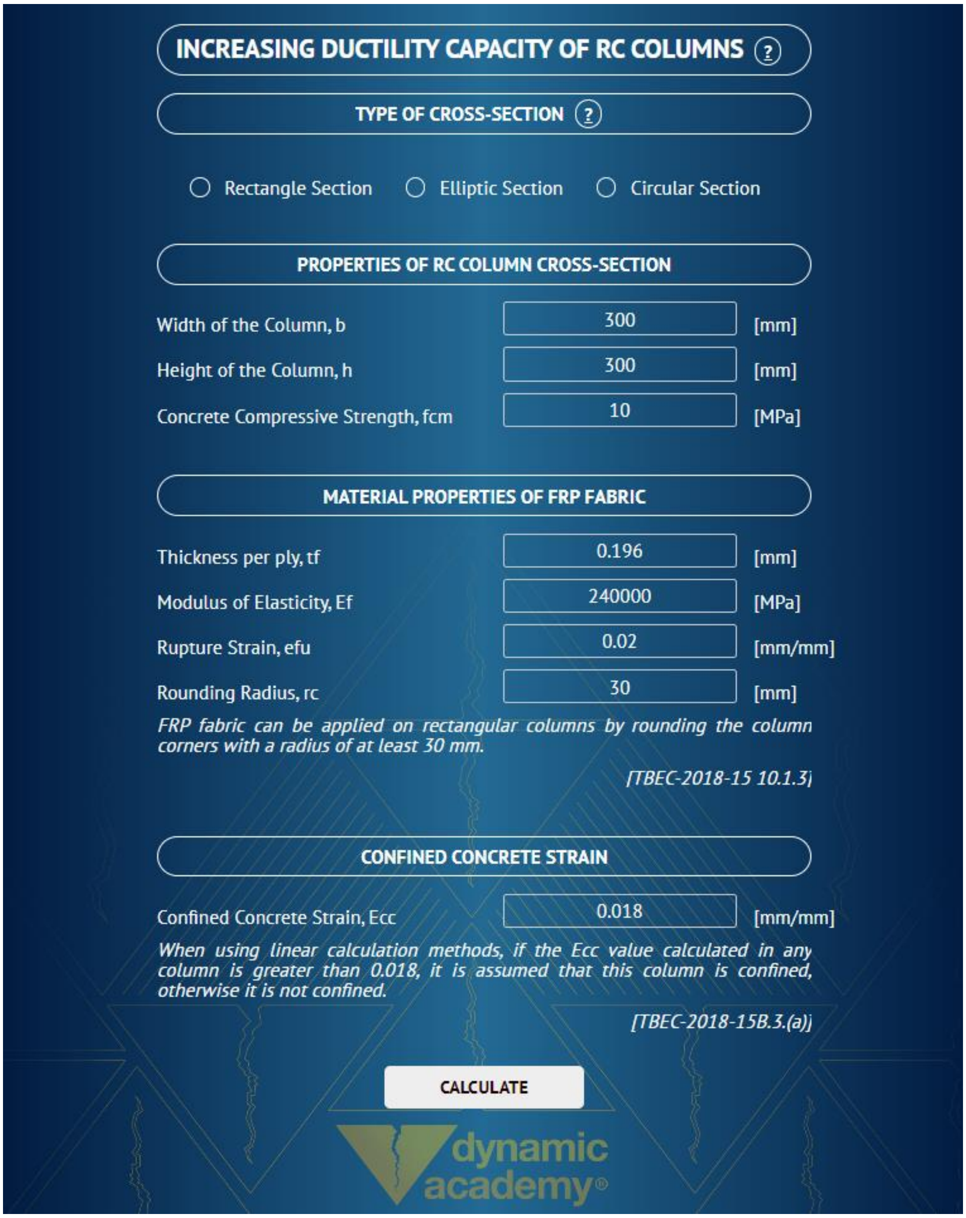

Fig. 6. Interface for increasing the ductility capacity of RC columns

Fig. 7. Interface for increasing the shear capacity of RC beams

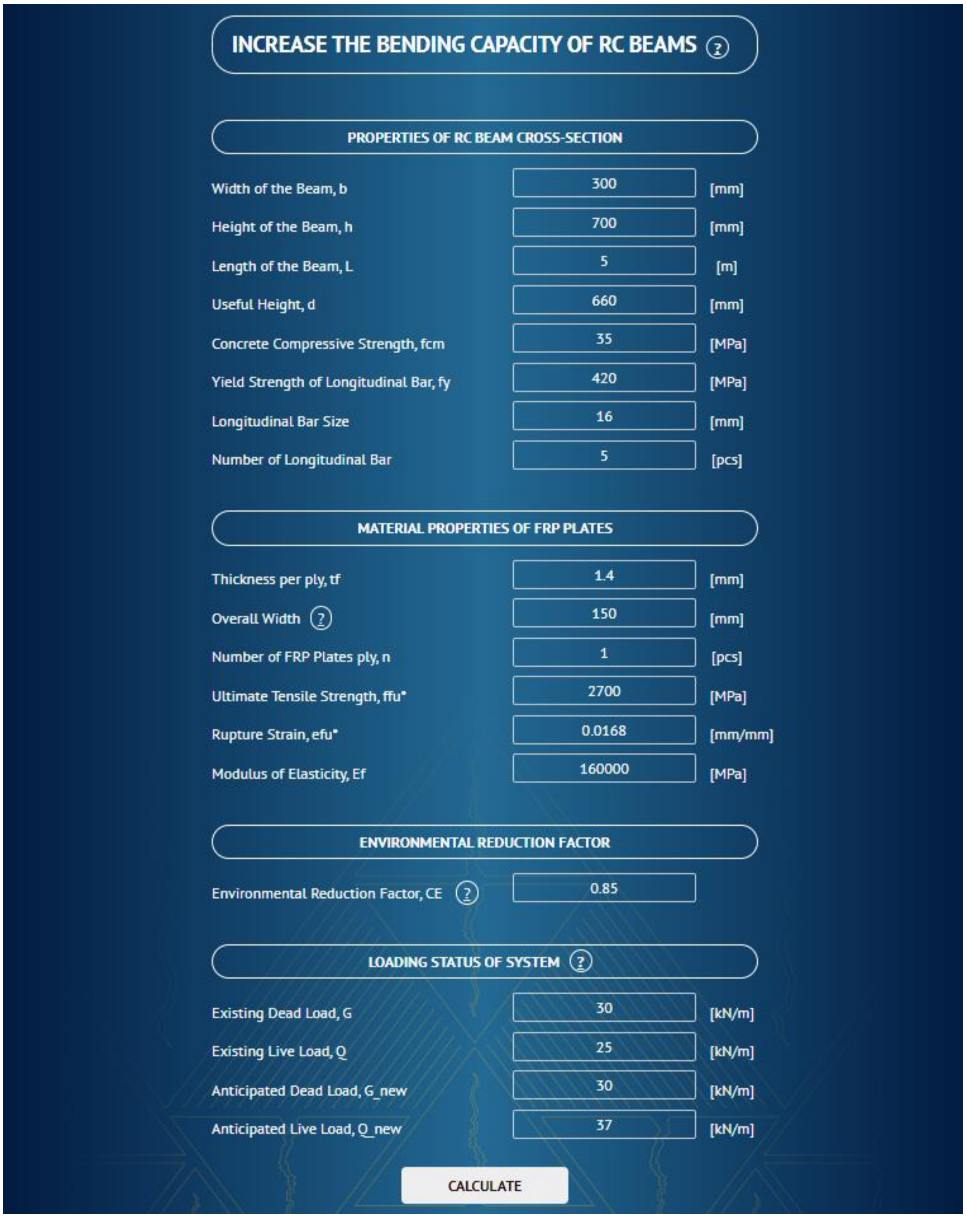

Fig. 8. Interface for increasing bending capacity of RC beams

Conflict of interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Data availability statement

No new data were created or analyzed in this study.

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