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RECON: PROGRAM IN PYTHON FOR CALCULATING REINFORCED CONCRETE BEAMS

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Abstract. The utilization of programs for making structural analysis of reinforced concrete is usual in civil engineering. Structural analysis is a fundamental step in buildings project where internal forces, dimensions and structural members design are defined, such as beams, columns and slabs. The used parameters, as well as the considerations and equations are specified at the ABNT NBR 6118/2014 – "Design of concrete structures — Procedure". The goal of this paper is to present `ReCon`[1], a Web application for calculating reinforced concrete beams. It was made to perform the design according to the specifications of the Brazilian standard. It has a friendly interface and it brings two advantages: it is free and open-source and was designed also to be used as an educational tool. The achievements obtained by `ReCon` have been compared to some examples of already solved exercises in the current literature about reinforced concrete. These comparisons have shown excellent results which prove `ReCon` as trustful program. Moreover, students of civil engineering have used `ReCon` in order to compare theirs experience solving exercises using this program to what they usually do in class. They have mentioned about the friendly interface and found a good educational tool to add in class.

Keywords: Structural analysis, Python, Reinforced concrete, Educational tool.

1 Introduction

Around the world we can see day by day a tendency to program calculations procedures, to automatize calculate and analyze industrial processes. According to Coelho [1] the advent of internet and the technology advances create a new environment of evolution in the industry. This means that new technologies will be more accessible, with low prices, and the possibility to be applied in different areas, from medicine to cosmology. MacKenzie [2] describes this new stage, named Industry 4.0, as: "smart factory", "intelligent factory" and "factory of the future".

In civil engineering, one of the stages of the project is the structural analysis to determine the stresses and the design. In this stage, the dimensions of the elements and reinforcements are defined so that they are able to withstand the requesting stresses and it requires a set of calculus based on standards.

Reinforced concrete could be classified as composite materials. It consists of a concrete matrix which contains bars of steal in specific positions to resist the forces. The procedure to determine parameters of the structural elements is well defined and in Brazil the projects may use the standard described in "NBR 6118 - Design of concrete structures - procedure", [3]. The methodology to calculate reinforced concrete beams is defined as a sequence of calculus that could be expressed as an algorithm, allowing the implementation of this process by some software. This is a great opportunity to automatize this process in civil industry and reduce the amount of work done by humans.

In this paper we propose `ReCon`[1], a Web application for calculating reinforced concrete beams according to the specifications of the Brazilian standard. In `ReCon` the user can create a new project and software calculates the design and details of the beam cross section. In addition, it presents a calculation memo that contains all the calculation done by the program step by step in the form of a report. As the user access the Web app they can

[1]https://recon.macae.ufrj.br/

create a new project and insert the information about the materials, requesting efforts, cross section, choose the way to calculate the shear and the class of environmental aggressiveness, among others specifications. The result is a detailed report with the calculation memo and a figure of the transverse reinforcement.

Although there are some softwares that are reference in analysis and design of reinforced concrete, as Eberick[2] and TQS[3], these softwares are expensive and demand some hardware requirements to run. In contrast, `ReCon` is a Web application that can run in any browser and are specified for beams design. And, as `ReCon` is more specific, it is easy for the users to use and can be used as an educational tool.

The aim of this article is to explain how `ReCon` was developed, its capabilities, presentation of results and evaluation of users, that is, how this Web application was received by others on the engineering area. `ReCon` could be useful to professional engineers but its focus is as educational tool for assisting in classes, may be worthwhile during the concrete course. With `ReCon` and a previous knowledge, students are totally able to execute any class exercise, especially to check their results. It is also possible to test all the parameters which make easier to elaborate other works, articles and final papers about beams. In conclusion, `ReCon` also allows the student to run more examples, as it is faster than solving the examples manually. All this aspects make `ReCon` a great complementary tool.

2 Methodology

The entire procedure for designing the cross section was divided into parts to facilitate the implementation of algorithm in Python and further the Web application. Each step send information to the subsequent one as could be seen on Figure 1 in the sequence of .py files.

According to NBR 6118/2014, the parameters for bending and shear design are: the stresses applied, the concrete class, the type of steel and the partial safety factors. The partial safety factors act to increase the requesting stress and reduce the strength in order to provide a certain degree of security to the structure. These factors can be found in tables 11.1 and 12.1 of the standard.

2.1 Bending design

The maximum moment that the beam can absorb using simple reinforcement is given by:

$$M_{sdlim} = \lambda \cdot \alpha_c \cdot n_{lim} \cdot d^2 \cdot b_w \cdot \frac{f_{ck}}{\gamma_c} \cdot (1 - 0,4 n_{lim}) \tag{1}$$

where, f_{ck} is the characteristic strength of concrete; γ_c is the partial safety factor for reducing the strength of the concrete; λ is the parameter for correcting the position of the neutral line, equal to 0.8 if $f_{ck} \leq 50$ MPa, otherwise given by equation eq. (2); α_c is a coefficient for considering the peak compression stress of the concrete, 0.85 if $f_{ck} \leq 50$ MPa, otherwise given by equation eq. (3); n_{lim} is the maximum ratio between the depth of the neutral axis and the useful height to have simple reinforcement, 0.45 for $f_{ck} \leq 50$ MPa and 0.35 for $f_{ck} > 50$ MPa; b_w is the width of the beam cross section. The useful height *d* is the distance between the center of gravity of the longitudinal tension reinforcement and the compressed edge, commonly considered as 0.9h.

$$\lambda = 0.8 - \frac{(f_{ck} - 50)}{400} \tag{2}$$

$$\alpha_c = 0.85 \cdot \left[1 - \frac{(f_{ck} - 50)}{200}\right] \tag{3}$$

If the requesting moment of design $M_{sd} \leq M_{sdlim}$ the design is done using simple reinforcement, otherwise the design is done considering double reinforcement. The double reinforcement is necessary because the compressed concrete is not able to fully absorb the compressive stresses, being necessary the placement of steel reinforcement to assist the concrete to absorb the compressive stresses. The position of the neutral line is given by:

[2]https://lp.altoqi.com.br/eberick-2020/
[3]https://www.tqs.com.br/

$$x = \frac{d}{\lambda}\left(1 - \sqrt{1 - \frac{2M_{sd} \cdot \gamma_c}{b_w \cdot d^2 \cdot \alpha_c \cdot f_{ck}}}\right) \tag{4}$$

For beams reinforced with simple reinforcement the steel area is given by eq. (5).

$$A_s = \frac{\gamma_s \cdot M_{sd}}{f_{yk}(d - 0,4x)} \tag{5}$$

For beams reinforced with double reinforcement the area of longitudinal tension reinforcement A_s and compressed A'_s is given by eq. (6) and eq. (7), respectively:

$$A_s = \frac{\gamma_s}{f_{yk}} \cdot \left(\frac{M_{sdlim}}{(d - 0,4x)} + \frac{M_{sd} - M_{sdlim}}{(d - d'')}\right) \tag{6}$$

$$A'_s = \frac{M_{sd} - M_{sdlim}}{\sigma'_{sd}(d - d')} \tag{7}$$

f_{yk} is the characteristic yield strength of steel; γ_s is the partial safety factor for reducing the strength of the steel; d" is the distance from the compressed edge to the center of gravity of the compressed reinforcement, commonly 0.1h and σ'_{sd} is the design compression stress on the compressed reinforcement, given by eq. (8):

$$\sigma'_{sd} = min\left[E \cdot \epsilon_u \cdot \frac{(n_{lim}d - d^{"})}{n_{lim}d}; \frac{f_{yk}}{\gamma_s}\right] \tag{8}$$

where, ϵ_u is the maximum specific deformation of concrete, equal to 3.5 for concretes with $f_{ck} \leq 50$ MPa, or given by eq. (9) for $f_{ck} > 50$ MPa.

$$\epsilon_u = 2.6 + 3.5\left(\frac{(90 - f_{ck})}{100}\right)^4 \tag{9}$$

Additionally, it should be checked whether the calculated longitudinal tension reinforcement A_s is bigger than the minimum reinforcement A_{smin}, given by eq. (10) if $f_{ck} \leq 50$ MPa, or eq. (11) for $f_{ck} > 50$ MPa.

$$A_{smin} = max\left[\gamma_s \frac{0.0784(f_{ck})^{\frac{2}{3}}}{f_{yk}} \cdot b_w h; 0.15\% \cdot b_w h\right] \tag{10}$$

$$A_{smin} = max\left[\gamma_s \frac{0.5512 \cdot ln[1 + 0.11(f_{ck})]}{f_{yk}} \cdot b_w h; 0.15\% \cdot b_w h\right] \tag{11}$$

2.2 Shear design

The theory adopted to calculate the transverse reinforcement is based on the appearance of cracks along the beam on its lateral faces. These cracks appear due to the transverse loading and have a specific angle in relation to the longitudinal axis of the beam. The NBR 6118/2014 allows the use of two models: model calculus I and model calculus II. The difference between these two calculation models consists in adopting the angle of the compressed concrete strut θ and the related equations. The design shear strength related to the collapse of the compressed concrete strut, for both models, is given by:

$$V_{rd2} = 0.6\left(1-\frac{f_{ck}}{250}\right)\frac{f_{ck}}{\gamma_c}b_w 0.9d\cdot(cotan(\theta)+cotan(\alpha))\cdot sin^2\theta \tag{12}$$

where, α is the stirrup inclination and θ is the strut inclination angle, equal to 45º if calculation model I is used and a value between 30º and 45º if model II is used. If the shear stress of design V_{sd} is bigger than V_{rd2} the dimensions of the cross section must be increased, otherwise the dimensioning can be performed by calculating the transverse reinforcement area. The transverse reinforced area per unit length, A_{sw}, is given by:

$$A_{sw} = \frac{\gamma_s\cdot(V_{sd}-V_c}{0,9\cdot d\cdot f_{ywk}\cdot(cotan(\theta)+cotan(\alpha))\cdot sin(\alpha)} \tag{13}$$

where, f_{ywk} is the characteristic strength of the stirrup, limited to 500 Mpa. The portion of the shear stress absorbed by complementary mechanisms of the truss V_c, is given by:

$$V_c = V_{c0} = 0.6\cdot\left(0.21\frac{\sqrt[3]{(f_{ck})^2}}{\gamma_c}\right)\cdot b_w d \tag{14}$$

For the model II, if $V_{sd} \leq V_{c0}$, it is considered $V_c = V_{c0}$; if $V_{sd} = V_{rd2}$, so $V_c = 0$; if $V_{c0} < V_{sd} < V_{rd2}$, linear interpolation is considered

Additionally, it should be checked whether the calculated transverse reinforced A_{sw} is greater than the minimum reinforced A_{swmin}, given by:

$$A_{swmin} = \frac{0.2\cdot 0.3\sqrt[3]{(f_{ck})^2}\cdot b_w\cdot sin(\alpha)}{f_{ywk}} \tag{15}$$

3 ReCon

`ReCon` is implemented in Python, one of the most usual programming language. Python has a simple syntax and allows developers to write clear, logical code with fewer lines than some other programming languages. It also emphasizes code readability that helps software maintenance.

Python has an extensive standard library and there are also many useful libraries developed for some specific purpose. In order to do the conversion of units, the flexural and shear design calculus, the *math* library was imported. The main functions used were square root, and trigonometry functions, such as sine, cosine, tangent and others concern with it.

In contrast with traditional desktop applications, which are installed on a local computer, `ReCon` is a Web application that uses a website as the interface and the users can easily access the application from any computer connected to the Internet using a standard browser. This approach has many advantages: there is no need to develop and test on different operating systems; there is no hardware requirement; it can be used in any device connected to the internet, this includes smart phones, tablets and laptops; there is no need to install and the updates of the software is accessible for all users.

The graphical interface of was implemented using Flask[4]. It is microframework used to render templates and static files that store the configurations and information of the interface usually known as front-end. Flask packages include templating language for Python that allow write Python syntax inside HTML templates, this way the information processed into Python could be seen on the screen. Flask uses the Jinja template engine[5] to dynamically build HTML pages using familiar Python concepts such as variables, loops and lists.

The Bootstrap[6] toolkit was used to style the application. It is a CSS framework that provides some pre-built CSS classes and helps to incorporate responsive web pages in Web applications so that it also works well on mobile browsers without writing HTML, CSS, and JavaScript codes to achieve these goals.

[4]https://palletsprojects.com/p/flask/
[5]http://jinja.palletsprojects.com/
[6]https://getbootstrap.com/

A JavaScript library called Jquery[7] was used to program some elements of the graphical interface. This library allows configuration of components animation, behavior and also event handling. Jquery facilitates to have some components, *popovers* and *tooltips* for example. The users help was programmed using Jquery.

The source code of `ReCon` is organized as shown in Figure 1. There is the home page, the web pages to create a new project or use some examples and the page to exhibits the results. The methodology of the calculus are implemented step by step in separated files beginning with the conversion of units, following by the flexural and shear analysis and then the shear and flexural design. `ReCon` is an open source and the programming code is available as a public repository in GitHub[8]. This platform is software development plataform that provides version control and enables a collaborative work.

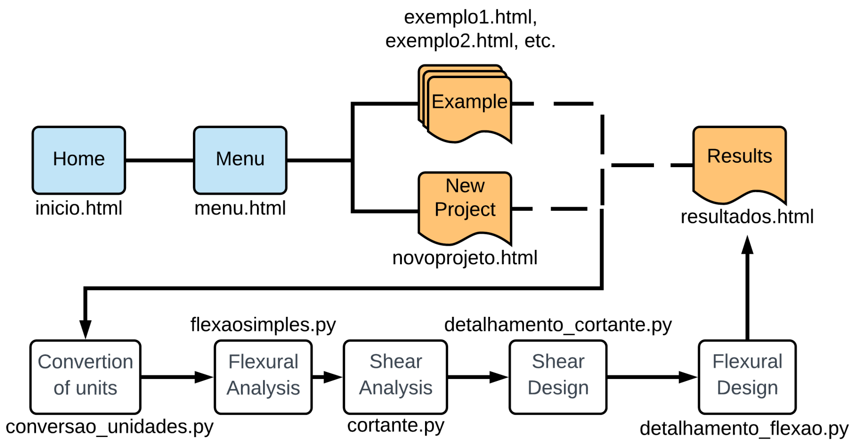
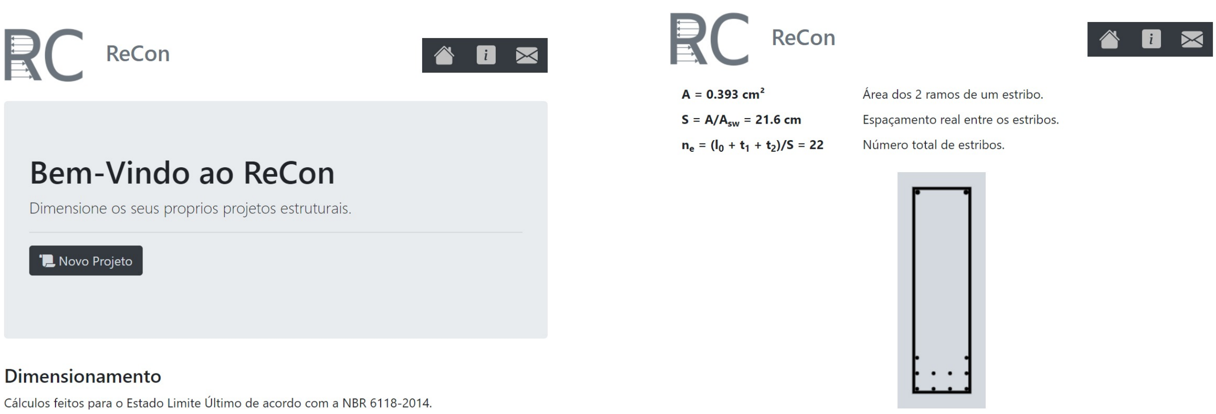


Figure 1. Website map and Python files.

Figure 2 shows the graphical interface of `ReCon`. The home page, Figure 2(a) shows some general information and there is a bottom to start a new project, this bottom will redirects the user to the menu page. In this page, there are options to start a new blank project, or to try some example. The option of run an example probably will help the user if they do not remember or do not know very well how to design reinforced concrete beams. After that, there are the page of the project with input boxes and other dynamics elements that make possible a user interaction. After complete all inputs, the user should click on the bottom at the end of the page to submit the information. Then, the results are shown, Figure 2(b), together with the calculus report. On this page, there are boxes to select where the user could choose the diameters of the steel reinforcement rebars. After that, a draw with the cross section is shown in the page.



(a) (b)

Figure 2. Graphical interface of `ReCon`. In (a) the home page where it is possible to create a new project and in (b) part of results page.

[7] https://jquery.com/

[8] https://github.com/iamvitorjesus/artigo

4 Results

In this section we present the experimental results obtained by `ReCon` and the user evaluation.

4.1 Experimental Results

In this section we describe the experiments carried out with `ReCon`, the obtained results, and a comparative study with the results from the reference literature available in [4]. We have selected different problems to test the bending and shear design. The problem, the page in the book [4] and the input variables for the bending design tests are shown in Table 1 and for the shear design tests are shown in Table 2.

Table 1. Problems to test the bending design.

Problem	Page in [4]	f_{ck}	f_{yk}	M_k	h	b	$d' = d$"
a)	143	20MPa	500 MPa	30 kN· m	40 cm	15 cm	4 cm
b)	145	20MPa	500 MPa	70 kN· m	40 cm	15 cm	4 cm
c)	145	40MPa	500 MPa	70 kN· m	40 cm	15 cm	4 cm
d)	146	70MPa	500 MPa	70 kN· m	40 cm	15 cm	4 cm

Table 2. Problems to test the sher design.

Problem	Page in [4]	f_{ck}	f_{ywk}	V_k	h	b	$d' = d$"	Model Calculus
e)	224	20MPa	600 MPa	30 kN	40 cm	12 cm	4 cm	Model I
f)	226	30MPa	600 MPa	50 kN	40 cm	12 cm	4 cm	Model I
g)	226	40MPa	600 MPa	70 kN	40 cm	12 cm	4 cm	Model I
h)	226	20MPa	600 MPa	90 kN	40 cm	12 cm	4 cm	Model I

Table 3. Comparative results between `ReCon` output and reference book.

Problem	**Reference's Result (cm^2), [4]**			**ReCon's Result (cm^2)**			**Discrepancy (%)**		
	A_s	A'_s	A_{sw}	A_s	A'_s	A_{sw}	A_s	A'_s	A_{sw}
a)	3.00	0		2.98	0		0.667		
b)	7.52	2.11		7.46	2.04		0.798	3.318	
c)	7.24	0		7.10	0		1.934		
d)	6.81	0		6.79			0.294		
e)			0.94			0.95			1.064
f)			2.30			2.30			0
g)			3.72			3.73			0.269
h)			6.90			6.91			0.145

Regarding the differences found, it was noticed that it occurred due to the rounding done in the referenced literature. In the referenced literature the problems were solved by hand, so rounding was done.

4.2 User evaluation

In order to understand the perceptions from users of `Recon`, we conducted an anonymous web-based survey. An email for professors, students and engineers from Federal University of Rio de Janeiro - Campus Macaé was sent inviting them to participate in the survey. A message was also posted in a social network group and asked for people to participate of the evaluation. A total of 13 persons answered the survey, 4 of them are civil engineers, 4 are professors and 5 undergraduate students.

First questions of the survey were about the user experience. The questions were: ”Did you run any project in ReCon?”, ”Did you have any doubt during the execution of the program?”, ”Did you like the layout of ReCon?”, ”Who is the target public of ReCon in your perception?”, ”How is the probability of you visit the site again?”. They answered that they had no doubt during the execution of the project and only 3 of them did not check if the results were right. All of them considered that the layout of the results web-page has a ”good” of ”very good” layout and 12 of them considered the same for the ”New Project” web-page. They considered that the target users for ReCon are undergraduate students and professors and that they probably would access ReCon again.

There were specific questions for the undergraduate students and professors. For the undergraduate students the questions were: ”Where do you study?”, ”Have you done some discipline related to reinforced concrete?”, ”Have you used any software similar to ReCon?”, ”Do you believe ReCon is useful to understand disciplines of reinforced concrete?”, ”Would you like to use ReCon to solve exercises in classes?” and ”Would you recommend ReCon to someone?”. About the answers, all of them are undergraduate students in Federal University of Rio de Janeiro, 4 of 5 have done some discipline related to reinforced concrete and have used some similar software. All of them would use ReCon again and believe that it is useful to be used in classes. They would also recommend ReCon.

The questions specific for the professors were: ”Would you use ReCon in your classes for complementary activity?” and ”Would you recommend ReCon to some student?”. All of them answered that they would use for complementary activity and 3 of them said that is ”very probably” to recommend Recon to the students.

At the end of the survey the users could leave suggestions and comments about the software. Some of the suggestions were to implement the function to export the results page to a pdf file and to custom the results page for the target public leaving more explanation when the public is undergraduate student and an abbreviate result when the public are professor.

5 Conclusion

This article presented `ReCon` a Web application for calculating reinforced concrete beams according to the specifications of the Brazilian standard. It is an open-source software implemented Python and the graphical interface was made in Flask and also used Bootstrap. The methodology of the calculus are presented as well as the steps of the algorithm to implement the program. The results show consistency of the experiments when comparing the calculus obtained in `ReCon` and the answer presented in the reference book [4]. `ReCon` contributes as an educational tool for assisting in undergraduate classes as shown by the user evaluation according to professors and students perspectives.

As future work, there are some improvements that could be made: implement the analysis of T-beams, calculate of prestressed concrete, export the results page to an pdf file, and an option to login and storage of the saved projects.

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