

Concrete Building Beams Design Calculation Using the LRFD Method

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Abstract—Development in building construction or reinforced concrete buildings continues to increase. Until now, most regions in Indonesia have a high level of vulnerability to natural disasters. It can be seen that natural disasters have struck several places in Indonesia which have caused damage and loss to various facilities and infrastructure and also damage to the soil structure layer in several affected areas. Beams are included in the main structural components which are used to distribute loads to columns. Thus, quality checks on concrete must be carried out, such as flow tests and concrete strength tests carried out by the Quality Control section.

Beam calculations are currently done manually or using Microsoft Excel so it takes quite a long time just to do the calculations. By creating a website-based Concrete Building Block Calculation Simulation using the LRFD method based on SNI 2847:2013 article 10.3.5, the block calculation only takes a short time, so the remaining time can be used to make blocks according to the planned calculation results.

Creating this website-based simulation uses the CodeIgniter framework, CodeIgniter is a form of framework that utilizes the PHP language to support the website development process quickly and efficiently. The concrete building beam calculation simulation on this website refers to the bending conditions of a single reinforced square beam. Beam calculations on this website produce nominal moment values which are a reference that the calculations have met the requirements. If the calculation results for the nominal moment value meet the requirements, the calculation has been completed and can be continued for making beams of that size.

Keywords— Beam Calculation, Simulation, Framework CodeIgniter, LRFD

I. INTRODUCTION

When constructing or drawing a building, we are often faced with the problem of calculating the size of the columns or beams that will be needed to support the building that we are designing [1]. If the building we are going to build is a multi-storey building, it will certainly affect the load that will be borne or supported by the building or its lower floors, because it has to support the building or its upper floors [2].

In essence, the dimensions of columns and foundation beams and floors are the responsibility of a building structural expert [3]. For medium to large scale buildings, it is mandatory to involve structural experts in the construction design implementation. Even though architects can carry out calculations, they do not have full responsibility for implementing the development design. Therefore, the calculation is completely for the design stage only [4].

Calculations for columns and beams have a very big influence in designing drawings of a building, both in appearance and in section [5, 6]. If we can predict in advance then we can anticipate the position or shape of columns and beams which will definitely be larger and disrupt the breadth of space. Therefore we can create and draw more accurately [7,8].

The shape of a building is the main component of the establishment of a building or buildings. The shape of the building consists of upper and lower components which are designed in such a way that they can distribute the load to the ground [9,10]. Building construction is currently an interconnected object, where buildings require fast, careful and careful calculations and analysis as well as considerations that will produce a building or structure that meets the requirements for strength, economy and aesthetics [11].

The construction of reinforced concrete buildings or buildings continues to increase [12, 13]. Until now, most regions in Indonesia have a high level of vulnerability to natural disasters [14]. We can see the earthquake disaster that has hit several places in Indonesia which has caused damage and loss to various facilities and infrastructure in several areas affected by the disaster [15].

If a natural disaster occurs such as an earthquake which results in damage to the layers of soil and building structures, therefore the author is interested in this problem, if calculations are done using Microsoft Excel it will take a lot of time. Apart from that, it also provides benefits for related fields, namely Civil Engineering, with updates which were previously carried out using Microsoft Excel, now by utilizing information technology it can make it easier for related fields in carrying out the process of calculating building blocks.

This research, the author will create a website using the CodeIgniter Framework to carry out beam calculations with the bending conditions of a single reinforced square beam using the LRFD method.

The CodeIgniter framework is a web framework that utilizes the PHP programming language, which can be used to develop a simulation, especially a website, quickly and efficiently. Regarding the CodeIgniter framework itself, we can define it as a framework, structure, classes and infrastructure that can be useful by programmers when developing a simulation or website quickly. The use of the framework itself aims to make it easy to develop websites quickly without having to lose flexibility.

The design form when carrying out the development process for a website with CI is to use MVC (Models-View-Controller). In the calculation process the author uses the LRFD method. Where it can be explained is that the LRFD method is a building planning method that takes into account load factors and foundation resistance factors. In essence, this design concept means that structural elements must be smaller than the allowable stress.

II. LITERATURE REVIEW

2.1 LRFD

LRFD (Load and Resistance Factor Design) is a method that clearly takes into account limit conditions, various load factors and resistance factors, where in this case the resistance factor is needed to maintain the possibility of a lack of structural strength while the load factor is used to anticipate the possibility of a formulated excess load $\theta R_n \geq \sum y_i Q_i$ [15]. The design concept applied is the LRFD (Load Resistance Factor Design) concept, namely the concept of structural resistance to factored loads with a review of the strength reduction factors for each structural component. The design strength of each structural component must not be less than the required strength determined based on the LRFD load combination [16].

The value of the depth factor for the β_1 stress block can be explained as follows, in the β_1 stress block there are 3 provisions, namely:

- a. For $2500 \text{ psi} < f'_c \leq 4000 \text{ psi}$

Where :

$$2500 \text{ psi} = 17,2 \text{ MPa}$$

$$4000 \text{ psi} = 27,5 \text{ MPa}$$

When translated, that is, if f'_c is more than 2500 psi and less than (\leq) 4000 psi (27.5 MPa) then $\beta = 0.85$

- b. For $4000 \text{ psi} < f'_c \leq 8000 \text{ psi}$

Where:

$$4000 \text{ psi} = 27,5 \text{ MPa}$$

$$8000 \text{ psi} = 55,1 \text{ MPa}$$

When translated, that is, if f'_c is more than 4000 psi and less than 8000 psi then $\beta = 0.85 - 0.05 ((f'_c - 4000) / 1000)$

- c. For $f'_c > 8000 \text{ psi}$

Where:

$$8000 \text{ psi} = 55,1 \text{ MPa}$$

When translated, that is, if f'_c is more than 8000 psi (27.5 MPa) then $\beta = 0.65$

2.2 Load

Dead Load, is the weight of all parts of a building/structure that are permanent during the service life of the structure, including additional elements, finishing, machines and fixed equipment that are an inseparable part of the building/structure [17]. Included in this load is the weight of the structure, pipes, electric lines, air conditioning, lights, floor coverings and ceilings. Live Load is the gravitational load that acts on the structure during its service life and arises as a result of the use of a building. This load includes the weight of people, movable furniture, vehicles and other items. Because the size and location of the load is always changing, determining the live load with certainty is quite difficult [18],

2.3 Load Planning

The structure needs to take into account the combination of loads from several loading cases that may occur during the design life. According to the Indonesian Load Planning Guidelines for Homes and Buildings 1987, there are two load combinations that need to be reviewed on structures, namely: Fixed load combinations and temporary load combinations [19]. Fixed load combinations are considered to be loads acting continuously on the structure during its design life. The combination of fixed loads is caused by the operation of dead loads and live loads. Meanwhile, temporary load combinations do not act continuously on the structure, but their influence is still taken into account in the structural analysis. This loading combination is caused by the operation of dead loads, live loads and earthquake loads. These values are multiplied by a load factor, the aim being that the structure and its components meet the strength requirements and are fit for use against various load combinations [20].

2.4 Code Igniter

One of the frameworks used in making this final assignment is Codeigniter. The author uses the codeigniter framework because to develop the program you don't need to create code from scratch so the work process feels faster. According to [21], codeIgniter is a framework created using the PHP programming language which aims to make it easier for web programmers to create or develop web-based applications. CodeIgniter has the fastest execution compared to other frameworks. CodeIgniter is open source and uses the MVC (Model View Controller) base model, which is the current modern concept model. The MVC (Model View Controller) method has three components according to [22], namely:

1. Model - managing databases (RDBMS) such as MySQL or Oracle RDMS. The model is related to the database, so usually the model will contain classes or functions to create, update, delete data, search for data and retrieve data in the database. Apart from that, the model will also relate to query commands as a follow-up to functions (create, update, delete, select).

2. View - User Interface section or the section that will later be the display for the end-user. The view can be an HTML, CSS, Javascript, JQuery and AJAX page, because the method used is MVC so the view cannot contain data processing or access related to the database, so the view only displays data resulting from the Model and Controller. The controller, the link between the view and the model, means that the model cannot be directly connected to the view or vice versa, so this controller is used as a bridge between the two. So the controller's job is to process data or Logic Program Flow, providing variables that will be displayed in the view, calling the model so that the model can access the database, error handling validation or checking input data.

III. MATERIALS AND METHODS

The research method steps can be seen in Figure 1, including literature study and problem identification, needs analysis, data collection and beam calculation.

Literature study is a series of activities related to methods of collecting data, reading and taking notes, and managing the results of the research conducted. Problem identification is part of the research process which defines the problem and makes the explanation more structured as a first step in research. The aim of research is to produce or describe a symptom or problem, a condition that occurs, and improve it so that it becomes better and so that it can explain events by looking for relationships between variables or the causes and effects of an event that occurs. The analysis process is a form of analysis of a condition or event which aims to produce information and specifications about a condition or event that occurs. Data collection is one of the strategic steps in carrying out research which is based on the main aim of carrying out research which is to produce data to meet the standards or requirements that have been set in answering a problem formulation that will be outlined in the research report.

Data collection is a form of the process of collecting research data and turning it into information that can be used by all related parties. Writing a report is a form of presenting or rearranging the activities that have been carried out in the research process, the results of observations or research must be systematic based on actual facts and events, in other words according to the facts, as seen in Figure 1.

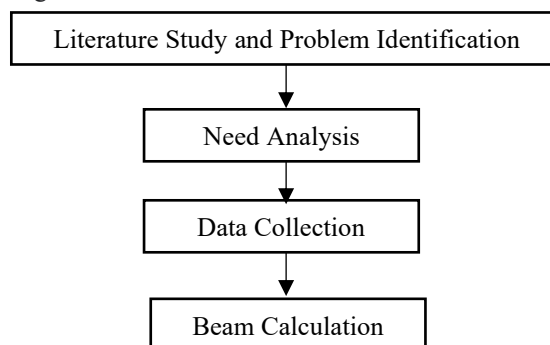


Figure 1. Research Method

The flowchart of the LRFD method in Figure 2 can be explained as follows: First, we input data on the nominal resistance moment of a single reinforced beam:

- (b) Beam width (inches)
- (d) Effective height of beam (inches)
- (As) Area of tensile reinforcement (inches)
- (fc) Strength/quality of concrete (psi)
- (fy) Steel quality (psi)

Then the simulation performs calculations and enters the formula $\rho_{min} = \frac{3\sqrt{f'_c}}{f_y}$ and $\rho = \frac{A_s}{bd}$. After that the simulation will carry out a comparison process and can be seen in the decision form with a comparison formula $\rho > \rho_{min}$. If the cross-sectional area is "No" according to the terms and conditions ($\rho > \rho_{min}$) then the calculation has to go back to the data input process again, and if "Yes" then the simulation automatically determines β which will later be used for the next calculation process. If the determination β has been determined by the simulation then it automatically performs calculations $a = \frac{A_s f_y}{0,85 f'_c b}$ and continues to $\frac{c}{d_t}$, with term condition $\frac{c}{d_t}$ is $\frac{c}{d_t} \leq 0,375$ and calculate $\epsilon_t = 0,003 \left(\frac{d_t - c}{c}\right)$ with the term of condition ϵ_t is $\epsilon_t > 0,005$. If "No" will return to the data input process and if "Yes" the simulation continues to calculate M_n , as seen in Figure 2.

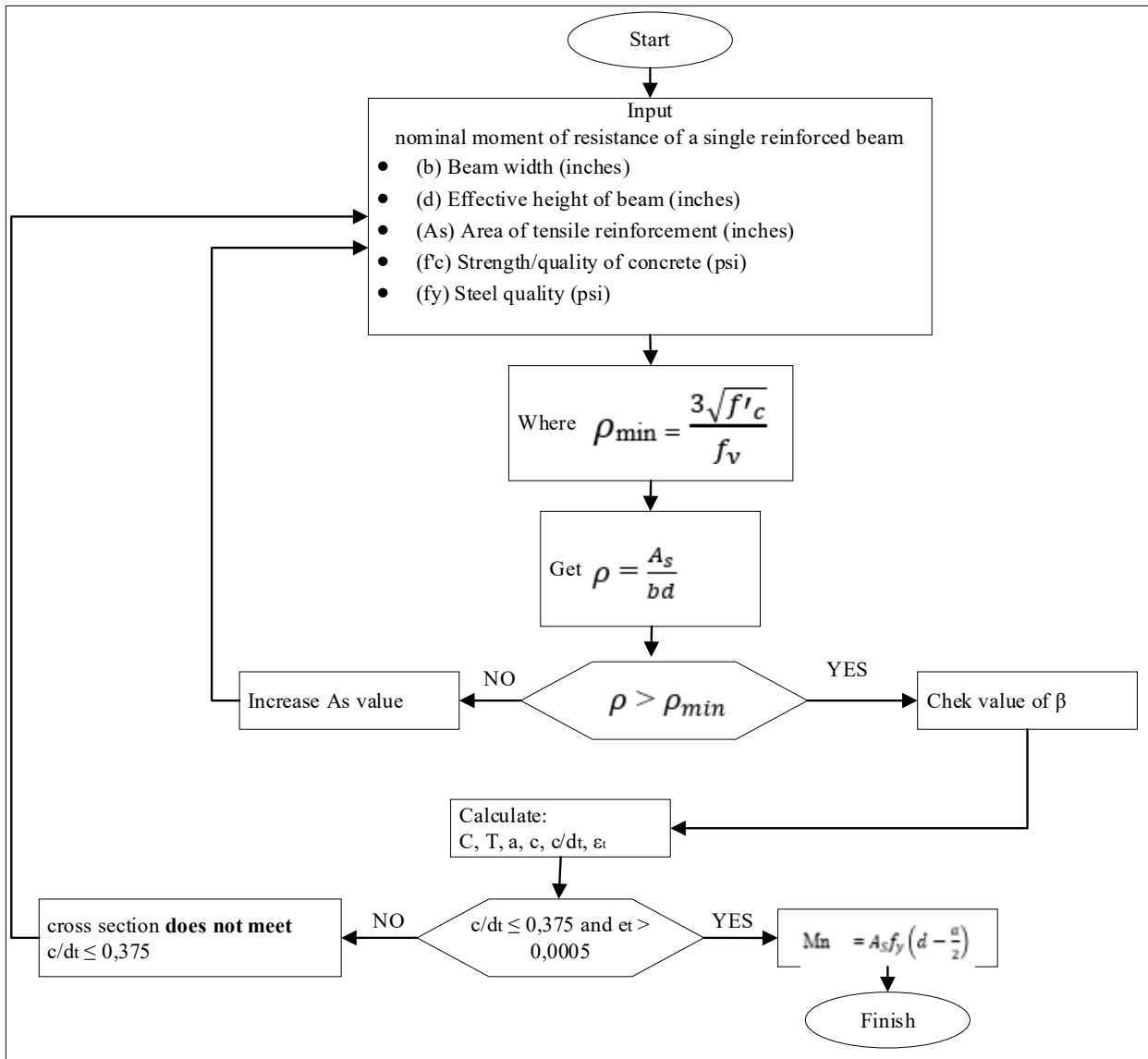


Figure 2. Flowchart of Simulation Beam Calculation

IV. RESULT AND DISCUSSION

This chapter explains the calculation of nominal moment strength if f_y is 60,000 psi (413.4 MPa) and f'_c with the condition that $f'_c = 3000$ psi (20.7 MPa), where f'_c can be seen in Figure 2.

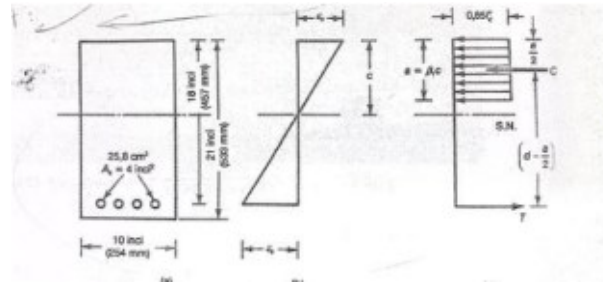


Figure 3. Strain and Stress Diagrams of Beam Cross Sections, a. Beam Cross Section Slices; b. Stretch; c. Voltage

4.1 For completion $f'c = 3000$ psi (20,7 MPa)

Completion :

$b = 10$ inci (254,0 mm)

$d = 18$ inci (457,2 mm)

$A_s = 4$ inci² (2580 mm²)

$F_y = 60.000$ psi

“Note that f_y must be in units of psi in the formulation ρ_{min} .”

$$\rho_{min} = \frac{3\sqrt{f'_c}}{f_y} \dots\dots\dots(1)$$

$$\begin{aligned} \rho_{min} &= \frac{3\sqrt{f'_c}}{f_y} \\ &= \frac{3\sqrt{3.000}}{60.000} \\ &= 0,0027 \end{aligned}$$

$$\rho = \frac{A_s}{bd} \dots\dots\dots(2)$$

$$\begin{aligned} \rho &= \frac{A_s}{bd} \\ &= \frac{4}{10 \times 18} \\ &= 0,0222 \end{aligned}$$

$$C = 0,85 f'_c ba \dots\dots\dots(3)$$

$$\begin{aligned} C &= 0,85 f'_c ba \\ &= 0,85 \times 3.000 \times 10a \\ &= 25.500a \text{ lb} \end{aligned}$$

$$T = A_s \times f_y \dots\dots\dots(4)$$

$$\begin{aligned} T &= A_s \times f_y \\ &= 4,0 \times 60.000 \\ &= 240.000 \text{ lb} \end{aligned}$$

$$a = \frac{A_s f_y}{0,85 f'_c b} \dots\dots\dots(5)$$

$$\begin{aligned}
 a &= \frac{A_s \cdot f_y}{0,85 f'_c b} \\
 &= \frac{4 \times 60.000}{0,85 \times 3000 \times 10} \\
 &= \frac{240.000}{25.500} \\
 &= 9,41 \text{ inci}
 \end{aligned}$$

$$c = \frac{a}{\beta_1} \dots\dots\dots(6)$$

$$\begin{aligned}
 c &= \frac{a}{\beta_1} \\
 &= \frac{9,41}{0,85} \\
 &= 11,1 \text{ inci}
 \end{aligned}$$

$$\frac{c}{d_t} = \frac{11,1}{18,0} \dots\dots\dots(7)$$

$$\begin{aligned}
 \frac{c}{d_t} &= \frac{11,1}{18,0} \\
 &= 0,62 > 0,60
 \end{aligned}$$

Term or condition $\frac{c}{d_t} \leq 0,375 = 0,62 \leq 0,375$ while here $0,62 > 0,60$ where 0.60 indicates controlled compression, and therefore the beam **DOES NOT MEET WITH Regulation of ACI 318**

4.2 Display of Simulation Calculation Results

The display after we have carried out the data input process on the calculation page will produce a calculation output along with the formula, apart from that, information will also appear below if the calculation results obtained do not meet the requirements with values for Beam Width of 15 inches, Effective Beam Height of 18 inches, Tensile Reinforcement Area 4 inches², the strength of the steel quality is 9000 psi and the quality of the steel is 60,000 psi, as can be seen in Figure 4.

(b) Lebar Balok (inci)

(d) Tinggi Efektif Balok (inci)

(As) Luas Tulangan Tarik (inci,²)

(f'c) Kekuatan Mutu Beton (psi)

(Fy) Mutu Baja (psi)

Figure 4. Entering Values in Beam Calculation Simulation



Figure 5. Results of Simulation of Beam Calculation

Figure 5 shows the beam calculation results obtained from the simulation. Users can create calculation results reports and save calculation results using agency headers to create reports on projects.

V. CONCLUSION

Beam calculations consist of various forms of calculations, including dead load, live load, wind load and earthquake load calculations. However, it needs to be emphasized that this research refers to one condition, namely the bending condition of a single reinforced square beam in accordance with SNI 2847:2013 article 10.3.5.

The bending condition of beam elements occurs as a result of the stretching process caused by bending stress caused by external loads. As the load is increased, the beam will resist strain which can result in the formation of flexural cracks along the beam. The improvement process, if carried out continuously without considering the capacity of the condition of the structural element, will result in failure of the structural element itself when the external load reaches the element's capacity.

If the beam material consists of homogeneous, isotropic and linearly elastic materials, then the maximum bending stress that can be obtained must use the beam bending formula $f = MC/I$. At the ultimate load, reinforced concrete beams are neither homogeneous nor elastic, thus making the formulation not applicable and instead evaluating stress. However, the basic principles of flexural theory can still be used to carry out the analysis process of the condition of the cross-sectional sections of reinforced concrete beams. In order to balance the horizontal forces, the compressive force C in concrete and the tensile force T in steel must be balanced with each other,

$$C = T$$

In calculating the bending condition of a single reinforced square beam, the first calculation is the value ρ and ρ_{min} where $\rho > \rho_{min}$ it is a term and condition for proceeding to the calculation $\frac{c}{d}$ and ϵ_t then the last one is the calculation of the Nominal Moment of Resistance (Mn).

For further research, simulations can use methods other than LRFD or change the concrete material with other materials to develop a more comprehensive simulation.

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