

# Reinforced Concrete (RC) beam design application for android based on SNI 2847:2013 (CEMA)

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**Abstract.** In Indonesia RC structures are widely used for high rise, low rise, shop offices, as well as residential buildings. In February 2018, the first author introduced an RC beam design application for Android [12] for two options. Option one is for calculating nominal moment ( $M_n$ ) and nominal shear force ( $V_n$ ) of the section when the beam dimensions ( $b, h$ ) and reinforcements are known; option two is to calculate the number of reinforcements for  $M_n$  and  $V_n$  when the dimensions ( $b, h$ ) are known. In this paper, the first author added option three, namely the optimization for the design of RC beams when the internal forces are known and the application calculates the most optimal dimensions ( $b, h$ ) and reinforcements. The application developed is named Civil Engineering Mobile Application for Concrete Beams (CEMA) and is called C<sup>2</sup>. In CEMA the user can follow the step by step calculation and the results of the calculation are stored in a database. For option three of CEMA (optimization of RC beam sections), the application was validated by another method called Teaching-Learning-based Optimization (TLBO) method [10]. It is believed that CEMA which is based on SNI 2847:2013 can be useful for Indonesian structural engineers designing and supervising actual construction RC buildings.

## 1 Introduction

The widespread use of RC structures in Indonesia as well as in other countries, necessitate engineers to make attempts to optimize the structural design of RC sections such as RC beams. Due to the advancement of technology, the authors attempt to develop an application for Android to design RC beam sections as well as to optimize a particular RC beam section.

So far, many publications already created similar attempts. However, it must be stressed that CEMA only optimizes a particular RC beam section for known loading and not necessarily optimizing the entire RC structure.

Some "RC beam optimization" publications that are already available dealing with minimization of cost and weight of RC beams using Genetic Algorithms (GA) [1, 4, 6] and Discretized Continuum-type Optimality Criteria (DCOC) [2, 3], using Artificial Neural Network (ANN) [5], Teaching-Learning-based Optimization (TLBO) [10], Random Search Technique (RST) [8], and analytical approach [11], to cite a few.

## 2 Problem formulation

CEMA is based on SNI 2847:2013 and the design of RC beam sections is based on ultimate limit states (ULS) method. While the design criteria for RC beams are well established, the optimal design problem requires to be clearly defined by its objective, design parameters enforced by codes or prompted by practical restrictions [9].

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## 2.1. Optimization objective

The objective of the optimization is to get saving from the concrete as well as the steel reinforcement costs of one particular beam. The cost of concrete of one particular RC beam is calculated as follow:

$$C_c = u_{pc} [bhL - L(nA_{s1} + n'A'_{s1})] \quad (1)$$

The cost of steel reinforcement for one particular RC beam is calculated as follow:

$$C_s = u_{ps} L(nA_{s1} + n'A'_{s1}) \quad (2)$$

$$C_t = C_c + C_s \quad (3)$$

where

- $C_t$  is the total cost per beam,
- $C_c$  is the cost of concrete in net condition,
- $C_s$  is the cost of steel reinforcement,
- $u_{pc}$  is the unit price of concrete per  $m^3$ ,
- $u_{ps}$  is the unit price of steel reinforcement per kg,
- $L$  is the length of beam span,
- $n$  is the number of tension reinforcement,
- $n'$  is the number of compression reinforcement,
- $A_{s1}$  is the unit area of tension reinforcement,
- $A'_{s1}$  is the unit area of compression reinforcement.

## 2.2. Design parameters

For this application the following design parameters must be defined by the user as input:

1. specified compressive strength of concrete ( $f'_c$ )
2. concrete cover
3. minimum yield stress of flexural-reinforcement ( $f_y$ )
4. tension diameter ( $d_s$ )
5. compression diameter ( $d'_s$ )
6. clear space inter-reinforcement
7. maximum reinforcement ratio ( $\rho_{max}$ )
8. minimum yield stress of shear-reinforcement ( $f_{yv}$ )
9. shear diameter ( $d_v$ )
10. beam span ( $L$ )
11. unit price of concrete
12. unit price of reinforcement
13. forces ( $M_u, N_u, V_u, T_u$ )

The following results of design are generated from flexural, shear, and torsion design calculation:

1. height of beam ( $h$ )
2. width of beam ( $b$ )
3. area of tension reinforcement ( $A_s$ )
4. area of compression reinforcement ( $A'_s$ )
5. total cost of concrete
6. total cost of reinforcement
7. number of tension reinforcement ( $n$ )
8. number of compression reinforcement ( $n'$ )
9. main shear-reinforcement
10. minimum shear-reinforcement
11. overall cost (concrete and reinforcement)

## 2.3. Requirements of the calculation

In CEMA the following requirements based on SNI 2847:2013 are used [7].

### 2.3.1 Factored moment capacity

As specified in SNI 2847:2013 [7],  $M_r$  is a factored moment capacity (by factor  $\phi$ ) and based on the outer tensile strain ( $\epsilon_t$ ).

$$M_r > M_u \quad (4)$$

### 2.3.2 Minimum tension reinforcement

To make sure that tension reinforcement in an RC beam compensates the loss of tensile strength caused by cracking in the concrete, it is a must to give minimum area of reinforcement as expressed in the following equation:

$$A_s \geq \max\{0.25bd\sqrt{f'_c}/f_y ; 1.4bd/f_y\} \quad (5)$$

where  $A_{s,min} = \max\{0.25bd\sqrt{f'_c}/f_y ; 1.4bd/f_y\}$  is the minimum reinforcement.

### 2.3.3 Maximum tension reinforcement

The maximum area of reinforcement is given to avoid brittle concrete-controlled failure.

$$A_s/A_g \leq 0,025 \quad (6)$$

where  $\rho_{max} = A_s/A_g$  is the maximum ratio for earthquake resistant structure and  $A_g$  is the area of concrete in gross condition.

### 2.3.4 Shear capacity

In ductile fracture, shear capacity ( $V_s$ ) should be less than  $V_{s2} = 0.66bd\sqrt{f'_c}$ .

$$V_s = (V_u - \phi V_c)/0.75 \quad (7)$$

$$V_s \leq V_{s2} \quad (8)$$

where  $V_u$  is the ultimate shear force and  $V_c$  is the shear capacity of concrete area.

### 2.3.5 Axial capacity

As a bending element, a beam must be checked by ultimate axial force. The force is not allowed to overreach maximum axial force,  $N_{u,max} = 0.1 f'_c A_g$ .

$$N_u \leq N_{u,max} \quad (9)$$

Apart from the SNI specifications, the following common practices are also applied.

### 2.3.6 Maximum beam width to depth ratio

As a general beam (not a deep beam), most of the commonly used ratio between height of beam and width of beam should less than three.

$$h/b \leq 3 \quad (10)$$

### 2.3.7 Maximum beam depth to span ratio

In general, the height of beam is estimated as follow:

$$h \leq L/16 \quad (11)$$

## 3 Methods

### 3.1. Calculation in CEMA

Optimization of RC beam section design was done with “loop all with constraints” technique as shown in Fig. 1. The first step is trying both width of beam ( $b$ ) and height of beam ( $h$ ) from 50 mm. When all the combinations of  $h$  are fail, the width of beam is extended 50 mm per loop.

In this application configuration of reinforcement is configured first. The configuration follows some rules as explained below:

1. Clear space inter-reinforcement must be specified by user.
2. If number of reinforcements are not enough to configured in one layer, the remaining reinforcements will be placed in the next layer.
3. Distance of layer to layer is same as clear space inter-reinforcement.
4. The first remaining reinforcement will be placed in far-left and the second remaining reinforcement will be placed in far-right.
5. Other remaining reinforcements will be placed between the first and second remaining reinforcement, however, if the space between them is not enough for the remaining reinforcements, the layer will be added, and thus, the rules are same as point 3 and 4.

After acquiring a suitable dimension, volume of both concrete and reinforcement are calculated. From the volume, cost of the material can be calculated. The loop is to be continue until all combinations of  $h$  and  $b$  are used up. Therefore, there are some solutions of suitable dimension that can be used. From those solutions, the most economical dimension with lowest cost of both concrete and reinforcement is chosen.

### 3.2 Development of CEMA

CEMA was developed using Android Studio version 2.3.3. Programming languages used are Java and XML. Java is used to create the software and XML is used to create user interface (UI) components.

The current CEMA is an improvement of previous one [12]. The improved application has an additional menu to calculate the cost of the optimized RC beam section. As mentioned in the abstract, CEMA consists of three menus as follow:

1. Menu for calculating nominal moment ( $M_n$ ) and nominal shear force ( $V_n$ ) of the section when the beam dimension and reinforcement are known
2. Menu to calculate the number of reinforcements for  $M_n$  and  $V_n$  when the dimension ( $b, h$ ) are known.
3. Menu to calculate the most optimal dimension ( $b, h$ ) and reinforcement for RC beam section design when the internal forces are known.

The first and second menu are available for rectangular and T-beam, while the third menu is only used for rectangular beam.

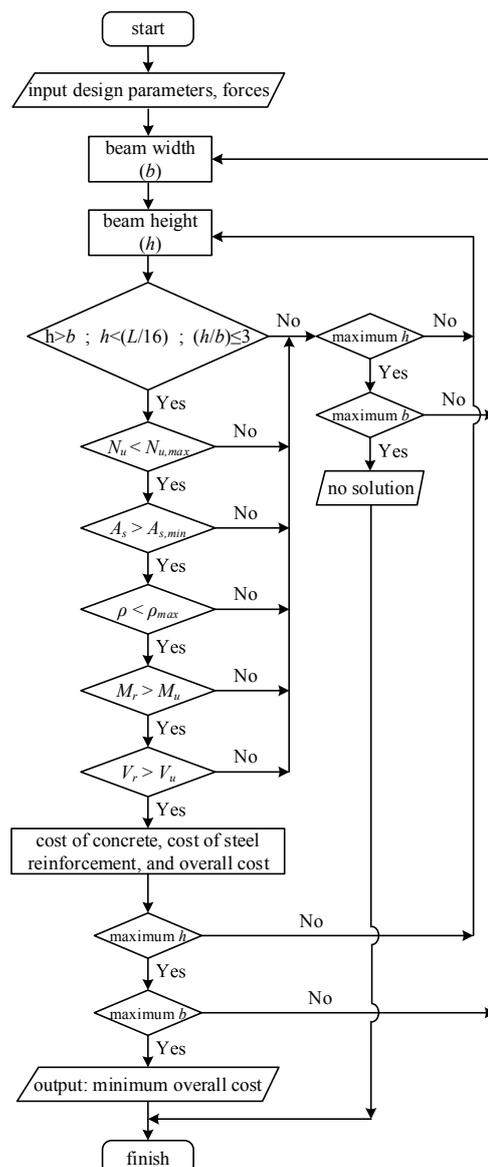


Fig. 1. Calculation flowchart in CEMA.

## 4 Results and discussions

### 4.1. Validation

To check the accuracy of the application, validation was performed for dimensions, reinforcement, as well as overall cost of both concrete and reinforcement and compared with the results of TLBO method [10].

Optimization of RC beam section was done for 10 different ultimate moments between 50 kNm and 500 kNm for rectangular beam with possibility of doubly RC beam (see Fig. 2). The design parameters such as the clear cover of the reinforcement, the specified compressive strength of concrete, the specified yield strength of reinforcement, the cost of concrete and reinforcement are 35 mm, 20 MPa, 420 MPa, 40 \$/m<sup>3</sup> and 0.4 \$/kg, respectively.

Comparison results between CEMA and TLBO method are given in Table 1, Table 2, Table 3, Table 4, and Table 5. Relationship between ultimate moment and overall cost, ultimate moment and net area of concrete, also ultimate moment and area of reinforcement can be seen in Fig. 3, Fig. 4, and Fig. 5, respectively.

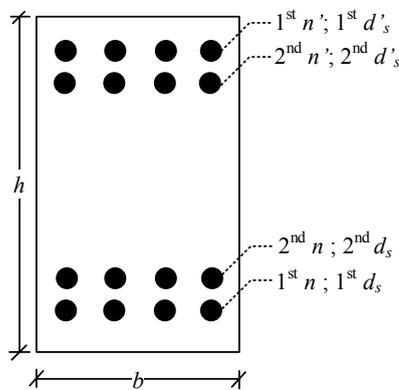


Fig. 2. Doubly RC beam section.

Table 1. Ultimate moment 50 kNm and 100 kNm.

Variables	Ultimate Moment (kNm)			
	50		100	
	TLBO	CEMA	TLBO	CEMA
$h$ (mm)	350	350	400	400
$b$ (mm)	250	150	250	250
1 <sup>st</sup> $d_s$ (mm)	14	14	16	12
2 <sup>nd</sup> $d_s$ (mm)	12	14	10	12
1 <sup>st</sup> $d'_s$ (mm)	12	12	16	12
2 <sup>nd</sup> $d'_s$ (mm)	14	12	24	12
1 <sup>st</sup> $n$	2	2	3	6
2 <sup>nd</sup> $n$	2	2	4	2
1 <sup>st</sup> $n'$	0	0	0	0
2 <sup>nd</sup> $n'$	0	0	0	0
$A_s$ (mm <sup>2</sup> )	534.071	615.752	917.345	904.779
$M_r$ (kNm)	57.31	53.668	111.22	102.275
safety factor	0.872	0.932	0.899	0.978
cost of concrete (\$/m)	3.479	2.075	3.963	3.964
cost of steel (\$/m)	1.677	1.933	2.880	2.841
overall cost (\$/m)	5.156	4.009	6.844	6.805
difference (%)	22.243		0.569	

Table 2. Ultimate moment 150 kNm and 200 kNm.

Variables	Ultimate Moment (kNm)			
	150		200	
	TLBO	CEMA	TLBO	CEMA
$h$ (mm)	500	500	500	550
$b$ (mm)	250	200	250	250
1 <sup>st</sup> $d_s$ (mm)	16	16	28	18
2 <sup>nd</sup> $d_s$ (mm)	12	16	10	18
1 <sup>st</sup> $d'_s$ (mm)	10	12	10	18
2 <sup>nd</sup> $d'_s$ (mm)	10	12	10	18
1 <sup>st</sup> $n$	4	3	2	5
2 <sup>nd</sup> $n$	2	3	3	0
1 <sup>st</sup> $n'$	0	0	0	0
2 <sup>nd</sup> $n'$	0	0	0	0
$A_s$ (mm <sup>2</sup> )	1030.442	1206.372	1467.124	1272.345
$M_r$ (kNm)	167.71	162.698	222.42	205.523
safety factor	0.894	0.922	0.899	0.973
cost of concrete (\$/m)	4.959	3.952	4.941	5.449
cost of steel (\$/m)	3.236	3.788	4.607	3.995
overall cost (\$/m)	8.194	7.740	9.548	9.444
difference (%)	5.548		1.087	

Table 3. Ultimate moment 250 kNm and 300 kNm.

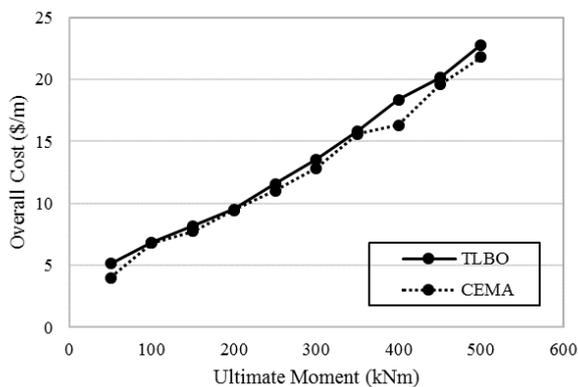
Variables	Ultimate Moment (kNm)			
	250		300	
	TLBO	CEMA	TLBO	CEMA
$h$ (mm)	500	550	500	550
$b$ (mm)	250	250	300	300
1 <sup>st</sup> $d_s$ (mm)	26	18	22	16
2 <sup>nd</sup> $d_s$ (mm)	12	18	14	16
1 <sup>st</sup> $d'_s$ (mm)	14	18	12	16
2 <sup>nd</sup> $d'_s$ (mm)	14	18	12	16
1 <sup>st</sup> $n$	3	4	5	6
2 <sup>nd</sup> $n$	2	3	2	4
1 <sup>st</sup> $n'$	2	0	2	0
2 <sup>nd</sup> $n'$	0	0	0	0
$A_s$ (mm <sup>2</sup> )	2126.858	1781.283	2434.734	2010.619
$M_r$ (kNm)	279.29	250.791	333.48	304.036
safety factor	0.895	0.997	0.900	0.987
cost of concrete (\$/m)	4.915	5.429	5.903	6.520
cost of steel (\$/m)	6.678	5.593	7.645	6.313
overall cost (\$/m)	11.593	11.022	13.548	12.833
difference (%)	4.928		5.276	

Table 4. Ultimate moment 350 kNm and 400 kNm.

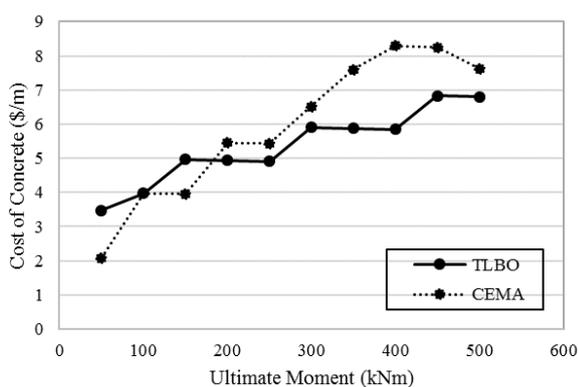
Variables	Ultimate Moment (kNm)			
	350		400	
	TLBO	CEMA	TLBO	CEMA
$h$ (mm)	500	550	500	600
$b$ (mm)	300	350	300	350
1 <sup>st</sup> $d_s$ (mm)	26	19	30	19
2 <sup>nd</sup> $d_s$ (mm)	12	19	10	19
1 <sup>st</sup> $d'_s$ (mm)	16	19	16	19
2 <sup>nd</sup> $d'_s$ (mm)	14	19	10	19
1 <sup>st</sup> $n$	4	7	4	7
2 <sup>nd</sup> $n$	4	2	2	2
1 <sup>st</sup> $n'$	3	0	5	0
2 <sup>nd</sup> $n'$	0	0	0	0
$A_s$ (mm <sup>2</sup> )	3179.292	2551.759	3989.823	2551.759
$M_r$ (kNm)	388.94	352.584	458.12	429.753
safety factor	0.900	0.993	0.873	0.931
cost of concrete (\$/m)	5.873	7.598	5.840	8.298
cost of steel (\$/m)	9.983	8.013	12.528	8.013
overall cost (\$/m)	15.856	15.610	18.368	16.310
difference (%)	1.547		11.204	

**Table 5.** Ultimate moment 450 kNm and 500 kNm.

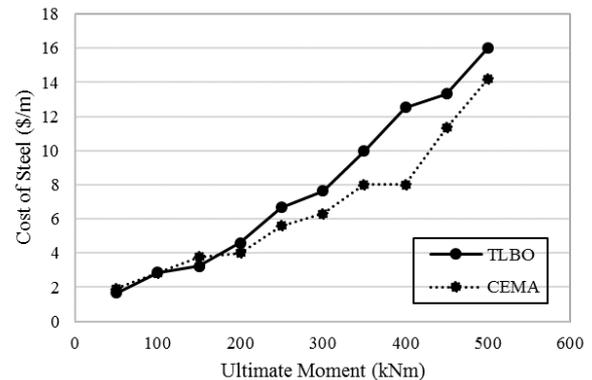
Variables	Ultimate Moment (kNm)			
	450		500	
	TLBO	CEMA	TLBO	CEMA
$h$ (mm)	500	600	500	650
$b$ (mm)	350	350	350	300
1 <sup>st</sup> $d_s$ (mm)	28	22	28	30
2 <sup>nd</sup> $d_s$ (mm)	10	22	16	30
1 <sup>st</sup> $d'_s$ (mm)	16	19	20	25
2 <sup>nd</sup> $d'_s$ (mm)	10	19	10	25
1 <sup>st</sup> $n$	5	6	5	3
2 <sup>nd</sup> $n$	2	2	3	2
1 <sup>st</sup> $n'$	5	2	4	2
2 <sup>nd</sup> $n'$	0	0	2	0
$A_s$ (mm <sup>2</sup> )	4241.150	3608.119	5095.663	4516.039
$M_r$ (kNm)	500.11	523.092	556.69	597.603
safety factor	0.900	0.860	0.898	0.837
cost of concrete (\$/m)	6.830	8.256	6.796	7.619
cost of steel (\$/m)	13.317	11.329	16.000	14.180
overall cost (\$/m)	20.148	19.585	22.797	21.800
difference (%)		2.791		4.373



**Fig. 3.** Relationship between ultimate moment and overall cost.



**Fig. 4.** Relationship between ultimate moment and cost of concrete.



**Fig. 5.** Relationship between ultimate moment and cost of reinforcement.

In **Table 1** above, the minimum width of beam designed by CEMA is 150 mm and TLBO method is 250 mm, while, the maximum width of beam is 350 mm for both CEMA and TLBO method (see **Table 5**).

From **Fig. 3** it can be seen that the results of both CEMA and TLBO methods with regards to the overall cost from ten ultimate moments are similar.

The reinforcing bars diameters used in TLBO method varies in diameter, while in CEMA all reinforcing bars diameters are the same. For an example, in **Table 3**, TLBO optimization result used various reinforcing bars diameter in the different layers, whereas, CEMA used the same reinforcing bars diameter for each layer. CEMA used same reinforcing bars diameter to make the construction works more practical and simple.

From **Fig. 4** and **Fig. 5**, it can be seen that the high cost obtained from the TLBO method most probably was caused by the tendency to use more reinforcing bars while the concrete dimension is constant. Unit price of steel reinforcement is more expensive than concrete. Therefore CEMA prefers to reduce the use of steel reinforcement in RC beam and increase the use of concrete.

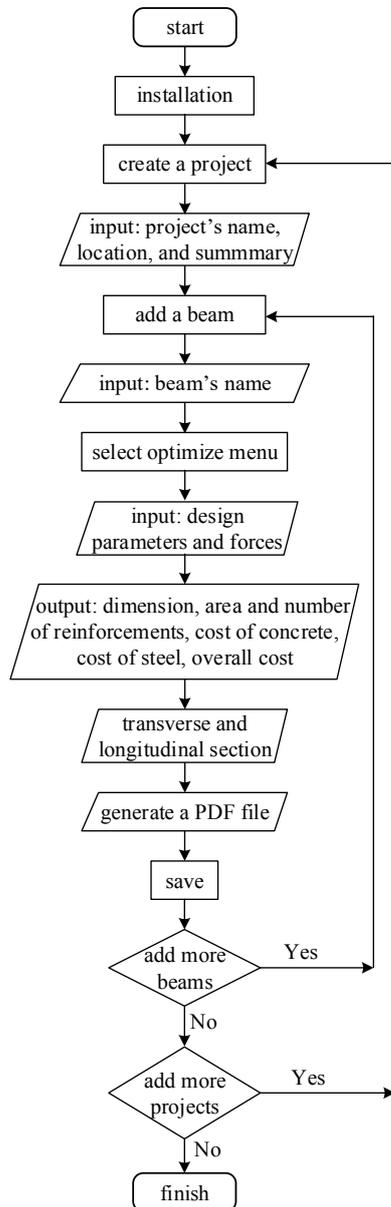
#### 4.2. CEMA Operation and Results

As described previously, this paper developed an Android-based mobile application that can be used to optimize RC beam section. To use CEMA, the first step is to install C<sup>2</sup> in an Android-based mobile device with Android version of 5.0.0 or later. As soon as the application is activated, user can easily follow the steps as shown in **Fig. 6** to do calculation.

Usually, each type of beam has its own name code and the design results should be properly saved. As mentioned above, CEMA use SQLite database to save many projects and retrieve them when needed.

As output samples, transverse and longitudinal sections are shown in **Fig. 7** and **Fig. 9**. For transverse sections, there are three parts, namely support sections and middle section. In each part, dimension of the cross section is shown. Number and diameter of reinforcements are also shown for practicality.

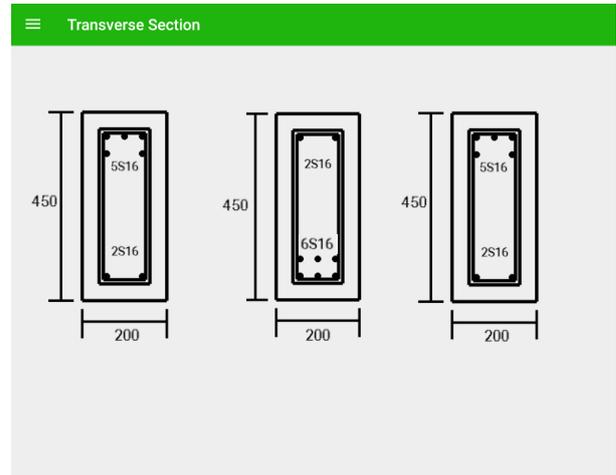
In the longitudinal section, user can pinch-to-zoom the picture. As outlined below, there are informations such as the position of the main-shear as well as minimum-shear reinforcements, diameter of shear reinforcements, also clear space inter-shear reinforcements. All values for transverse and longitudinal sections are in metric unit.



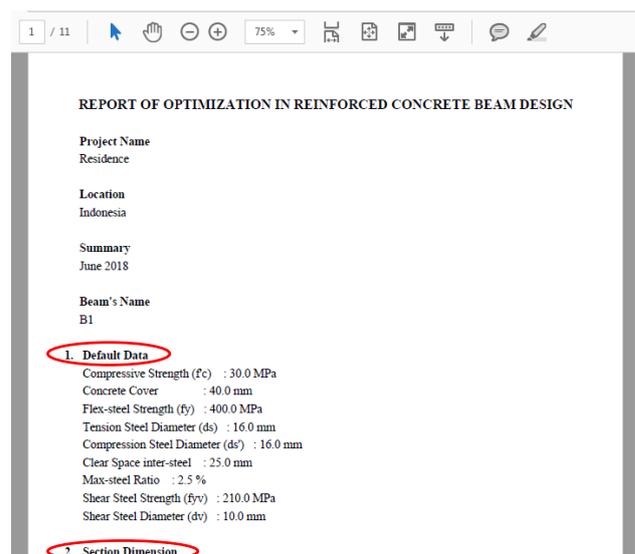
**Fig. 6.** Application flowchart of CEMA

Part of a screenshot of report generated from the application is shown in **Fig. 8**. The report is for a particular beam span which consists of three beam's sections (at supports and in the middle of span). The report also contains some subsections such as:

1. Default Data
2. Section Dimension
3. External Forces
4. Flexural Design
5. Shear Design
6. Torsional Design



**Fig. 7.** Transverse Section from CEMA



**Fig. 8.** Part of a screenshot of report from CEMA.

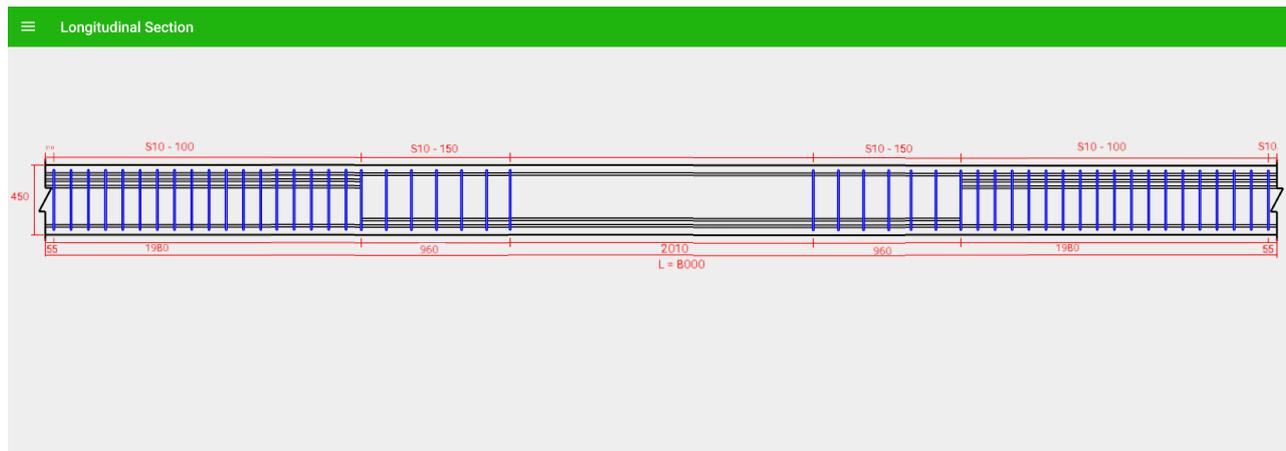


Fig. 9. Longitudinal Section from CEMA.

## 5 Conclusion

With the widespread use of mobile devices, engineers in Indonesia can utilize CEMA when performing a quick check of RC beams design when encountering a problem on site.

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