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Using Sustainability as a Quantitative Approach for Analyzing Contraction Material Strength

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ABSTRACT

Sustainable reinforced concrete can be considered as more effective way to conserve the principal materials that been used in the casting of concrete parts. The study examined the procedures of decreasing the concrete mixing materials and the reinforcement with the improving of the internal strength. The impact of various moment strength was investigated on the minimum volumetric part of the concrete beam in which a reduction of the materials amounts (cement, sand, and gravel) were identified to enhance the conservation of the quantities and to figure out the contribution of using alternative materials in the aggregate on the sustainability matter for each unit length of the concrete beam. The study build the analysis by finding the effectively percent of the reinforcement and the width of the beam on the internal strength. The study assumed the ratio of beam width (b)/ effective depth (d) to derive equations that lead to these ratio and based on the ultimate strength moment to identify the minimum volume/m as well as the quantity of each material in the casting system. The study examined the using of the fiber reinforced polymer bars as a way to enhance the strength of the concrete member with less casting materials quantities. The study showed the impact of using various FRP materials like (GFRP, AFRP, and CFRP) by the knowledge of the tensile strength of these materials. The study showed the steel area required and then the reduction factor for the casting materials after using FRP reinforcement.

Keywords: Reinforced Concrete, FRP, Contraction Material Strength.

1. Introduction

Reinforced concrete beams are vital components of contemporary construction. Though , the manufacture of concrete has a significant influence on the setting due to the high amount of energy and capitals required. Sustainable design and manufacture practices are important to reducing the environmental impact of reinforced concrete beams [1] [9]. the sustainable reinforced concrete beams, counting their design, production, then environmental impacts [2] [10]. The use of sustainable materials, such as fine and coarse aggregates and extra cementations materials, is explored by way of a means of plummeting the environmental influence of concrete manufacture . Additionally, the design of reinforced concrete part including the usage of high-strength steel then innovative reinforcement methods [3] [11]. The use of high-strength steel and novel strengthening techniques, such as fiber-reinforced polymers, can reduce the amount of reinforcement required in reinforced concrete beams, lowering the carbon footprint of the building. Furthermore, the use of optimized cross-sections and pre-stressed strengthening can reduce the amount of real required, lowering the building's carbon footprint [4] [12].

1.1 Sustainable Reinforced Concrete Production

The production of long-lasting beams made of reinforced concrete necessitates the use of renewable resources, such as recycled aggregates as well as extra concretes. Aggregates are made from building and demolition waste, lowering the need for virgin granules and reducing landfill waste [5] [13]. Extra cements, such as fly ash and slag, are able to replace a portion of the concrete's cement, thereby lowering the carbon footprint of concrete production. Furthermore, using low-carbon binders, such as geopolymer then potassium hydroxide materials, can help to lower the environmental impact of concrete production [6] [14].

1.2 Fibrous Concrete

Reinforced with fibers Concrete is a mixture made up of fibrous material that adds structural integrity. It would include clinker, mortar, or concrete mixtures with discontinuous, discrete, distributed uniformly suitable fibers. Fibers are commonly used in cement to avoid cracking resulting from plastic shrinkage and drying shrinkage[15] [16]. Those who also decrease concrete's permeability, which reduces water bleeding [7] [17]. Fiber RC struts can be defined as a composite material composed of adhesive, mortar before cement, and intermittent, discrete, distributed uniformly adequate fibers[7] [18]. Grit reinforced concrete comes in a variety of forms and has numerous advantages. Discrete fibers are not constant meshes, textile materials, or long ropes as well as rods [8] [19].

3. Material and Method

3.1Design Concepts of Beam Strength

3.1.1 Strength Design Method

The service loads are increased by factors in the strength design method (formerly known as the ultimate strength method) to obtain the load at which failure is considered "imminent." This is known as the factored load or factored service load. The structure or structural element is then proportioned in such a way that the strength is achieved when the factored load acts. This strength is calculated using the nonlinear stress-strain behavior of concrete. The strength design method is expressed as follows: Provided strength [strength required to carry factored loads.

3.1.2 Quantitative Analysis

Depending on the type of structure, a concrete structure may consist of beams, slabs, columns, and foundations, among other things. The volume of concrete needed for a concrete structure can be calculated by adding the volumes of each structural member or member part. Depending on the type of structure, a concrete structure may consist of beams, slabs, columns, and foundations, among other things. The volume of concrete needed for a concrete structure can be calculated by adding the volumes of each structural member or member part. Concrete compressive strength and concrete testing are critical components of structural design. Compressive strength is initially tested by performing mix design to ensure that the grade of concrete specified in the structural design is met. Concrete cube checking or cylinder testing is used to assess the strength development of the concrete. The formula that can be used for the identifying the cement-sand-gravel for the concrete cubic meter:

$$Vc = \frac{W}{1000} + \frac{C}{1000\,S_c} + \frac{S}{1000\,S_s} + \frac{G}{1000\,S_G}$$

The total volume of concrete can be determined as:

$$Vc = L_{total} * \mathrm{b} * \mathrm{d}$$

For 1:2:4 mixing ratio of weight:

$$Vc = \frac{0.3\,x}{1000} + \frac{x}{1000 * 3.1} + \frac{2x}{1000\ 2.6} + \frac{4x}{1000\ 2.7}$$

$$Vc = 0.002783\,x$$

The volume of reinforcement (bending and shear):

$$Vs(bending) = L_{total} * As$$

$$Vs(shear) = \frac{L_{total}}{s} * L_s * As'$$

3.1.3Tensile strength of FRP

Prior to designing structures with these reinforcements, the mechanical properties and behaviors of fiber reinforced polymers (FRP), including composites with aramid (AFRP), carbon (CFRP), and glass (GFRP) fibers, should be understood. For reinforced concrete structures such as cast-in-place and pre- and post-tensioned bridges, precast concrete pipes, columns, beams, and other components, FRP systems are becoming an increasingly acceptable alternative to steel reinforcement. The benefits of FRP over steel reinforcement, including corrosion resistance, are listed on the previous page. FRP reinforcement is also beneficial to masonry structures. Structural engineers inside the public and private sectors are increasingly specifying their use as original reinforcement and also for strengthening structure.

Table 1: Typical properties of Reinforced FRP material according to ACI code

Material	Typical tensile strength (MPa)	Modulus of elasticity (GPa)
Steel	414	200
GFRP	552	41.4
AFRP	1172	82.7
CFRP	2070	152

4. Results

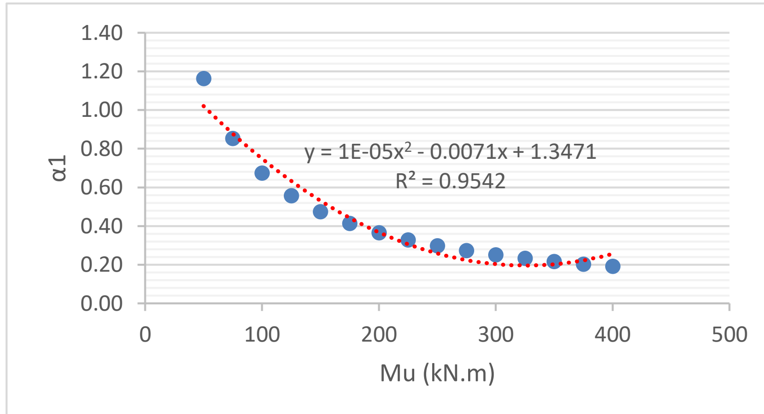
For evaluating the data related to the weights of parameters, two coefficients were considered, the first coefficient related to the ratio between the width of beam and the effective depth while the second related to the steel area and the effective depth:

$$\alpha 1 = \frac{b}{d}$$

Table 2: the determination of main coefficients (b=200 mm, As=1000 mm^2)

Mu (kN.m)	**d (mm)**	**α1**	**α2**
50	172	1.16	5.81
75	235	0.85	4.26
100	297	0.67	3.37
125	360	0.56	2.78
150	422	0.47	2.37
175	485	0.41	2.06
200	547	0.37	1.83
225	610	0.33	1.64
250	672	0.30	1.49
275	735	0.27	1.36
300	797	0.25	1.25
325	860	0.23	1.16
350	922	0.22	1.08
375	985	0.20	1.02
400	1047	0.19	0.96

From the table 2 The linear relationship between d and Mu is:

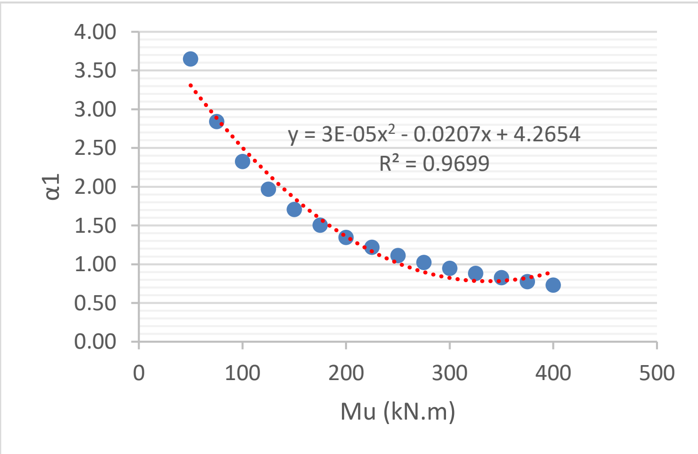


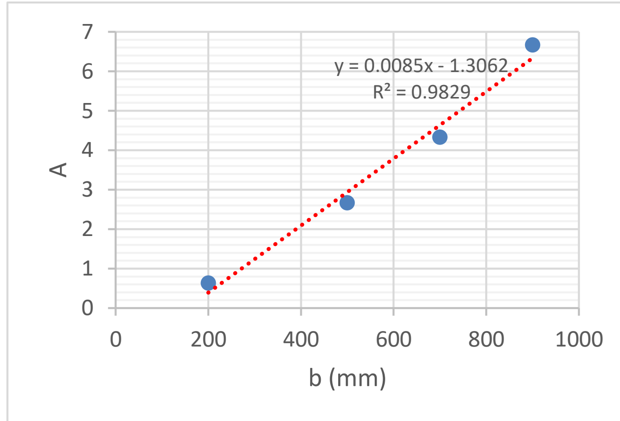
Y=47.23+2.5x

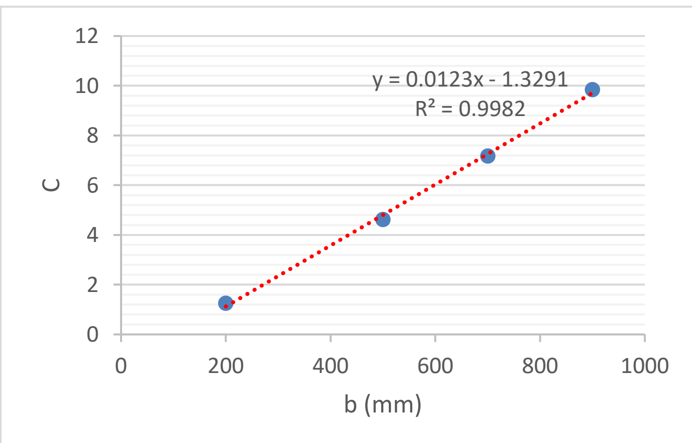
Figure 1: the quadratic fitting of Mu-α1 relationship (b=200 mm, As=1000 mm2)

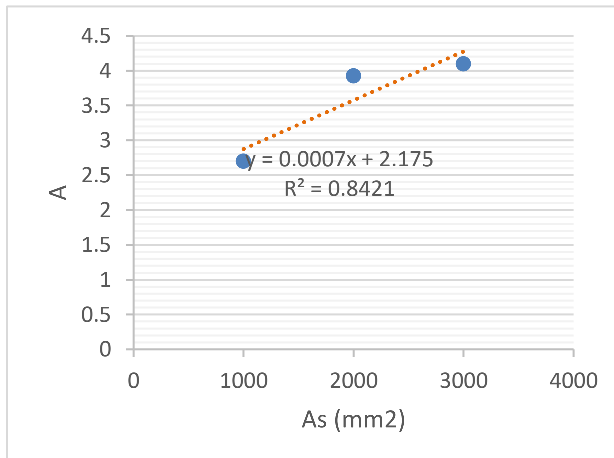
Table 3 the determination of main coefficients (b=400 mm, As=2000 mm^2)

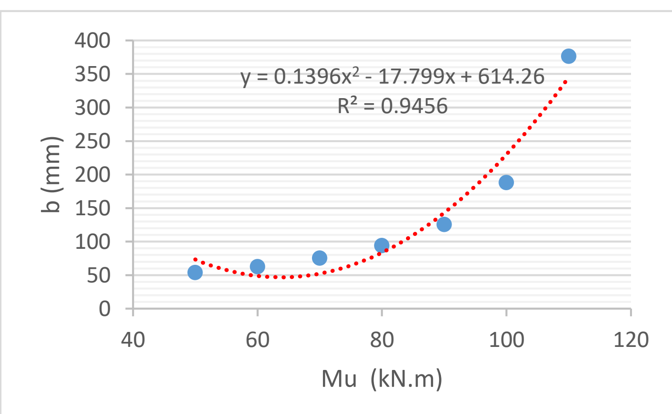
Mu (kN.m)	d (mm)	α1	α2
50	110	3.65	18.26
75	141	2.84	14.20
100	172	2.32	11.62
125	203	1.97	9.84
150	235	1.71	8.53
175	266	1.50	7.52
200	297	1.35	6.73
225	328	1.22	6.09
250	360	1.11	5.56
275	391	1.02	5.12
300	422	0.95	4.74
325	453	0.88	4.41
350	485	0.83	4.13
375	516	0.78	3.88
400	547	0.73	3.66











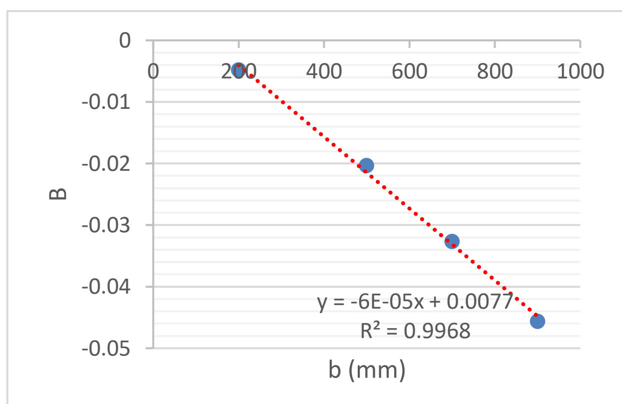


Figure 3: the slope of linear part of Mu-b relationship (d=300 mm)

$$\frac{\Delta(b)}{\Delta(Mu)} = \frac{376-94}{110-80} = 9.4$$

Figure 2: the quadratic fitting of Mu-α1 relationship (b=400 mm, As=2000 mm^2)

$$\frac{\Delta(As)}{\Delta(Mu)} = \frac{2929 - 1109}{190 - 110} = 22.75$$

Table 4: collecting the fitting equation parts for Mu- α1 equations

b	As	α1 equation		
		A (*x^2)	**B (*x)**	C
200	1000	$1.08 * 10^{-5}$	$-7.02*10^{-3}$	1.34
400	2000	$3.07 * 10^{-5}$	-0.02	4.26
800	3000	$8.5 * 10^{-5}$	-0.06	12.15

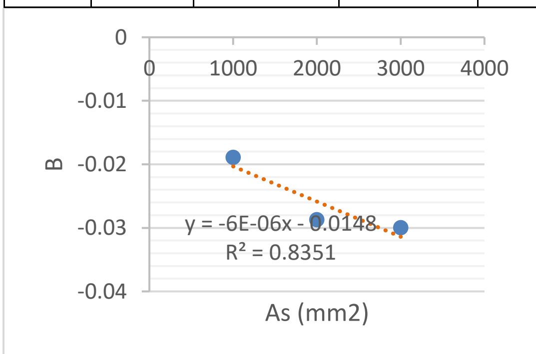


Figure 5: the linear fitting of b-A and b-B relationship

Figure 6: the linear fitting of b-C and As-A relationship

Figure 7: the linear fitting of b-B and b-C relationship

From the equations:

$$T1 = 0.705(-1.306 + 0.0085\, b) + 0.295(2.175 + 0.0007\, As)$$

$$T1 = -0.279 + 0.006\, b + 0.0002\, As$$

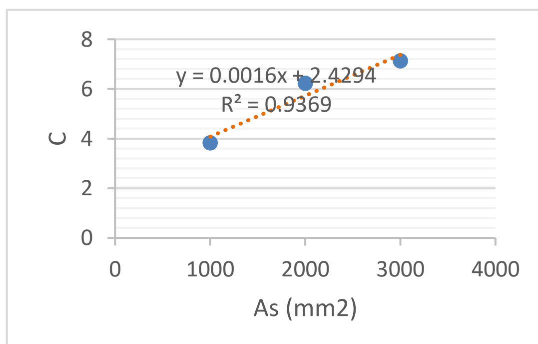
$$T2 = 0.705(0.0077 - 6 * 10^{-5}\, b) + 0.295(-0.0148\ - 6 * 10^{-6} As)$$

$$T2 = 0.00106 - 4.2 * 10^{-5}\, b - 1.77 * 10^{-6}\, As$$

$$T3 = 0.705(-1.329 + 0.0123\, b) + 0.295(2.429 + 0.0016\, As)$$

$$T3 = -0.22 + 0.00867 b + 0.00047\, As’$$

Table 5: the determination of α1 and α1 real for various Mu



Mu	b	T1	T2	T3	α1	α1 real
50	200	2.321	-0.01751	3.718	1.245	1.1624
75	250	2.621	-0.01961	4.1515	1.325	1.1104
100	300	2.921	-0.02171	4.585	1.354	1.0662
125	350	3.221	-0.02381	5.0185	1.339	1.0313
150	400	3.521	-0.02591	5.452	1.291	1.0037
175	450	3.821	-0.02801	5.8855	1.218	0.9816
200	500	4.121	-0.03011	6.319	1.129	0.9637
225	550	4.421	-0.03221	6.7525	1.034	0.9489

250	600	4.721	-0.03431	7.186	0.940	0.9365
275	650	5.021	-0.03641	7.6195	0.858	0.9260
300	700	5.321	-0.03851	8.053	0.796	0.9169
325	750	5.621	-0.04061	8.4865	0.763	0.9090
350	800	5.921	-0.04271	8.92	0.769	0.9022
375	850	6.221	-0.04481	9.3535	0.821	0.8961

3.2: Quantities Reduction By FRP Strengthen

The adding or replacing of FRP to concrete can improve the strength of the member in which reduction in the material quantities can be adopted according to the required strength moment.

Table 6: the determination of As for various Mu and Fy

Mu	α1	Fy=400 MPa	Fy=700 MPa	Fy=1000 MPa	Fy=1500 MPa
50	0.67	359	239	359	179
75	0.83	547	365	547	273
100	1.00	738	492	738	369
125	1.17	930	620	930	465
150	1.33	1124	749	1124	562
175	1.50	1318	879	1318	659
200	1.67	1513	1009	1513	756
225	1.83	1708	1139	1708	854
250	2.00	1903	1269	1903	952
275	2.17	2099	1399	2099	1050
300	2.33	2295	1530	2295	1148
325	2.50	2491	1661	2491	1246
350	2.67	2687	1792	2687	1344
375	2.83	2884	1922	2884	1442
400	3.00	3080	2053	3080	1540

Table 7: the determination of steel quantity for various Mu when Fy=750 MPa

Mu	α1	b	FRP Steel quantity (ton/m)
50	0.667	200	0.0077
75	0.833	250	0.0092
100	1.000	300	0.0107
125	1.167	350	0.0123
150	1.333	400	0.0138
175	1.500	450	0.0154
200	1.667	500	0.0169
225	1.833	550	0.0185

250	2.000	600	0.0200
275	2.167	650	0.0216
300	2.333	700	0.0231
325	2.500	750	0.0247
350	2.667	800	0.0262
375	2.833	850	0.0278
400	3.000	850	0.0284

The percent of decreasing in the materials in the concrete mixing when Fy been raised to higher values can be determined based on the reduction of the cement quantity when Fy=400 MPa.

$$RD = \frac{Qc1 - Qc2}{Qc1} * 100$$

Where:
Qc1= the quantity of cement in kg/m when Fy= 400 MPa
Qc2= the quantity of cement in kg/m when Fy> 400 MPa

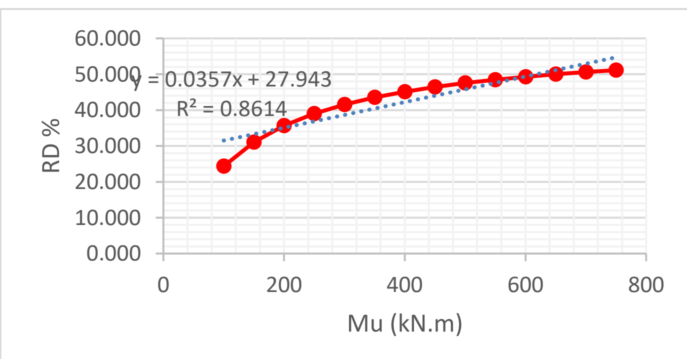


Figure 8: the increment in RD percent (Fy= 1000 MPa)

5. Conclusion

The study looked into ways to improve the strength of reinforced concrete beams by reducing the quantities of concrete casting materials (cement, sand, gravel) and reinforcement. The study assumed 1 as the division of the width of the beam by the effective depth in order to derive specific formulas based on the ultimate strength, which led to the minimum effective depth and then the minimum materials quantities used for each unit length. Three parts of the equation for calculating the b/d ratio were derived from the study. T1=f(Mu2), T2=f(Mu), and T3) were the components. The study discovered that the second part had a negative sign. Each component is also determined by the width of the beam and the area of reinforcement. The study found that increasing the sum of (T1+T3) by more than T2 can result in a higher value of 1, with the resultant effective depth being less, resulting in a reduction in concrete casting quantities. To derive the three parts of the equation, the study used a number of sketches and a fitting line. The study looked into the use of FRP bars inside the concrete beam body to achieve a higher reduction percentage. The study found that the reduction percent of the materials quantities reach to near 25% for Fy=600 MPa, while the reduction percent be about 40% for Fy=750 MPa, and 55% for Fy=1000 MPa. these reduction percent recorded for ultimate design strength been increased from 200 to 800 kN.m. The study built visual program using user form interface in which the user can input the input data for the required strength moment.

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