Adeleke University Journal of Engineering and Technology

[AUJET] Vol. 6, No 1, 240 - 252 (2023)

www.aujet.adelekeuniversity.edu.ng

ISSN: 2714 - 2450

Effect of Variation in Physical and Mechanical Properties of Reinforcing Steel on Post-Construction Parameters of Buildings in Nigeria

Ajagbe, W. O.[1], Tijani, M. A.[2]*, Ezennia, C. M.[3], Babatunde, L. A.[4] and Ganiyu, A. A.[5]

[1,3]Department of Civil Engineering, University of Ibadan, Ibadan, Nigeria
[2]Department of Civil Engineering, Osun State University, Osogbo, Nigeria
[4]Department of Quantity Surveying, Federal Polytechnic, Ede, Nigeria
[5]Civil Engineering Department, British University of Bahrain, Saar 527, Bahrain.

Corresponding Author: *murtadha.tijani@uniosun.edu.ng*

ARTICLE INFO

Received: *March / 2023*
Revised: *May / 2023*
Accepted: *June / 2023*
Published: *June / 2023*

Keywords: *Building Safety,*
Rebar Optimization,
Reinforced Concrete,
Steel Properties,
Steel Reinforcement.

ABSTRACT

The Nigerian market for construction materials has a problem of standardization as a massive range of variation in construction materials properties plagues the market. A larger number of these variations are below the accepted standards and a key material affected is reinforcing steel. This research aims to investigate the effect of variation in physical and mechanical properties of reinforcing steel on post-construction parameters (cost and safety margins) of buildings in Nigeria. Data on variation of selected properties was collected through extensive literature review and processed into tables showing the result of the input data on key building parameters. Data visualization was done using Microsoft Excel to help gain insights on trends and patterns. The trends and patterns observed informed the regression analysis carried out with Microsoft excel, aimed at establishing relationships between variable variations. A rebar optimization algorithm/software was developed to help optimize variation in standard rebar lengths and reduce waste on site, and was tested on five (5) project cases. The results show a wide range of variation for bar diameter and yield strength values, with some values falling as much as 30% below standard. The variation in young's modulus was seen to be minimal and has the least effect on safety margins. Equations were generated from regression to predict effect of these variations on safety margins. The rebar optimization algorithm proved efficient in reducing waste and saving cost. The algorithm follows a recursive approach for problem solving. The variation in these properties have a significant effect on building safety and cost. The prediction formulae generated can be used by Engineers to track safety margins and the algorithm can help with waste reduction and cost saving on projects.

1. INTRODUCTION

The built environment has input from a wide range of professionals such as, Architects, Civil Engineers, Cost Engineers, Mechanical Engineers, Electrical Engineers, Builders, Geologists, Land Surveyors, and Estate Surveyors. These professionals work within stipulated guidelines and codes of practice to create the environment we live in. Amongst various elements occupying the built environment, buildings account for a large population (Johnson and Lichtveld, 2017). Washington State Building Code Council (2020) classifies buildings based on purpose, ranging types such as residential, educational, institutional etc.

In Nigeria, the demand for these buildings is on a rise with an increasing housing deficit fuelled by an exploding population and mass urban migration (Abeku *et al.*, 2016). This has various stakeholders combining efforts and resources to bridge this observed gap. One of the major stakeholders in this industry are the Civil and Structural Engineers who have an obligation to ensure that they complete building projects within cost, time, quality and safety constraints. The effort to maintain balance between these four factors is not an easy one, as a wide range of factors affects the ability of an Engineer to maintain this balance. One of such factors is adequate information on cost of materials and their associated properties that play a role in the expected service life of the building as it tries to meet up with design and other functional requirements needed to serve the purpose of construction. Tijani and Ajagbe (2016) also mentioned cost of materials as part of the causes of project abandonment in Nigeria.

A study by Ede *et al.* (2014a) opined that amongst all building types available in Nigeria, a large number have Reinforced Concrete (RC) elements as major structural elements. RC structures have dominance in the Nigerian built environment for reasons such as, material availability, cost, construction knowledge, availability of skilled labour, acquired culture etc. As earlier stated, Engineers on building projects need to have proper information on key material properties as they greatly affect the quality of building production. The major components in RC structures are concrete and reinforcing steel usually supported by a formwork to sustain working loads until the element has attained enough strength to carry the loads experienced during the construction of the building.

Reinforcing steel plays a very important role in reinforced concrete structures. Olawale and Tijani (2018) developed steel structural member design software in order to reduce errors that might occur during traditional manual calculation which might in turn affect the safety and cost. The safety and cost margins of structural elements in a building has a high weighted contribution from the type of reinforcing steel used on the project. A number of factors come to play when building contractors procure steel reinforcement bars for their projects, and these decision-making factors thread a line between safety and cost limits. The market for reinforcing steel in Nigeria is quite vast as seen in the huge range of foreign and local product lines available in the market. This would often create a scenario where contractors have to weigh in on several material properties (physical and mechanical) to select a product that best serves the requirements of their project. The material properties of the reinforcing steel bars are a direct outcome of practices put in play by manufacturers during production, and hence, are prone to have differences as manufacturers race to stay competitive while remaining economically viable. As Engineers race to bridge the deficit of buildings in the built environment, it is important that they have a full understanding of how all construction factors ranging from materials, labour, equipment, logistics, finance, Government policies etc., affect the outcome of their projects.

The Nigerian market for construction materials has a problem of standardization (Ogunmakinde *et al.*, 2019). The Standards Organization of Nigeria (SON) is responsible for ensuring conformity to certain standards for international and local best practices. Study by Oyedele (2018) showed that SON has not fulfilled this responsibility to satisfactory levels, as a massive range of construction material plagues the market with a large variance in physical and mechanical properties. This variation implies that some materials are above quality specifications and some fall below recommended practice standards. Adegbite (2016) research showed that a larger number of these variations are below the accepted standards, and gave a recommendation for SON to pay unannounced visits to local steel rolling mills. The properties of construction materials play a key role in the outcome of a building which has direct effect on the cost, quality (durability) and safety of the produced structure. One of such construction materials facing this problem is reinforcing steel bars (Rebars) used in construction of reinforced concrete structures in Nigeria.

Hassan *et al.* (2021) investigated the mechanical and chemical properties of reinforcement bars manufactured in Nigeria. The results obtained indicate some of the rebars are suitable for use in reinforced concrete works while others are not, suggesting some tolerable and intolerable deviations from standards of BS 4449 B500B 2005. Similar results were obtained by Ede *et al.* (2014b), Adetoro and Oladapo (2017) as well as Odusote *et al.* (2019). The inability for Design Engineers to predict with high level of accuracy, the rebar properties to use in their design process, is a cause for concern, as there is a need for procured rebar properties to meet design assumed values. A significant variation between design and construction used value can lead to serious jeopardy of the safety margins for such a building which has an effect on the reputation of the Civil Engineering professionals involved in such projects, as they are likely to face disciplinary panels in cases of serious building deterioration, which in some cases leads to collapse, loss of lives and properties which also has a bearing on the owners (clients) of such projects as invested financial resources are flushed down the drains and have to reinvest huge amounts for repairs and maintenance, or in some cases, have to source funds to restart such projects from scratch in cases of a collapse, this is not without the legal issues that may come therewith.

Nigeria has recorded an increased rate of building collapse (Nicholas *et al.*, 2022; Obodoh *et al.*, 2021; Imafidon and Ogbu, 2020; Mrabure and Awhefeada, 2020; Olawale *et al.*, 2019). This has led some government agencies such as the Lagos State Building Control Agency (LASBCA) to implement stricter laws around approval and construction of buildings. Although these measures may have some effect on mitigating the occurrence of collapse, a Federal approach by SON is essential to nipping this menace in the bud, because asides the factors such as design robustness, technical expertise, and construction methodology, the quality and fair price of materials have a direct influence on the quality of produced buildings. One can say that all built environment professionals must purchase the highest quality of construction materials for their projects, but that is a utopia that may never be achieved as the state of the nation's economy accompanied with the declining value of the naira, has a direct influence on the purchase culture of individuals. Therefore, given the present state of things in the industry, time involved in bureaucracy of government policies, is not a luxury built environment stakeholders enjoy. There is a need for additional supportive measures to aid the built environment professionals keep track of the safety margins and durability of their buildings as they try to wrangle their way through realistic constraints of cost and quality. Hence, this research addresses the need for these professionals to know the extent of effect these variations could have on their projects and help them make informed decisions. The research investigated the effect of variation in physical and mechanical properties of reinforcing steel on post-construction parameters (cost and safety margins) of buildings in Nigeria.

2. METHODOLOGY

Data Collection and Analysis

This study adopted the use of secondary data sources due mainly to the wide range of data required for this study and the underlying ease of data collection through secondary sources. Hence, the study focused on the concept of "Literature Review as a Methodology". The assumptions made during the course of the collection and analysis of data include (i) Singly reinforced section is considered (ii) Section is subject to pure bending (iii) Sufficient bond stress is developed (iv) One line of reinforcement is used (v) The properties of Concrete are assumed to be constant (fixed Ecu and Fcu Values are used) (vi) Idealized Stress-Strain curve of concrete is used (vii) Concrete Strain of 0.0035 at failure is used. The gathered data had to go through cleaning to remove null and non-conforming data sets, tabulated and linked to relevant design/construction outcomes using standard formulae of practice. Table 1 shows parameters set as constants all through the process of preparation. This research adopted similar methods in Trend Analysis, which make visual analysis of line graphs and scatter plots where appropriate, as the major form of data analysis to make observations and draw conclusions. The data analysis in the research made use of Python 3.9 programming language alongside libraries to visualize data collected together with relevant relationships, these visualizations helped guide decision on regression analysis, and was then performed to establish concrete reusable relationships between parameters.

Table 1: Parameters set as Constant during Analysis

Parameter	Abbreviation	Value	Unit
	Materials		
Concrete Yield Strain	E_{cu}	0.0035	m/m
Concrete Compressive Strength	F_{cu}	25	MPa
Concrete Material Safety Factor	γ_{mc}	1.50	Nan
Steel Material Safety Factor	γ_{my}	1.05	Nan
	Analysis Section		
Width (beam case)	b_w	300	mm
Width (slab case)	B	1000	mm
Height (beam case)	H_b	600	mm
Height (slab case)	H_s	150	mm
Concrete Cover (beam case)	C_b	25	Mm
Concrete Cover (slab case)	C_s	20	Mm

Development and Testing of Rebar Optimization Software

The development and testing of the rebar optimization software was a key part of this study. This software takes advantage of the opportunity for waste reduction from rebar combination offcuts. First by utilizing computing power to find the best combination of rebar lengths in the bar bending schedule, then allowing Engineers to vary the brand of rebar purchased, based on the findings on standard length variations in the market. The algorithm deployed in this software development is similar to the modified first-fit algorithm. This research however added an extra layer of efficiency by using parallel computing to carry out a multi-directional bar combination sequence and then comparing the outcome with higher efficiency before exporting results to the Project Engineer. The development of this software made certain assumptions and limitations, which include that (i) the smallest bar length is limited to 1m for slabs, beam and column rebars (ii) the combination excludes rebars for stirrups as they fall below 1m and does not pose a schedule difficulty by human effort (iii) the combination can have a maximum of only 12 rebars in one standard length.

To broaden the justification for this software, this research conducted a survey to determine the level of need for the solution proposed. This survey is a primary source of data collection and had the participation of top tier Construction and Design Company Executives in participation. The sample population also focused on built environment professionals with experience levels well over 7 year as this has an effect on the strength of conclusions drawn from the survey. The survey also took note of the scale of projects usually engaged in by these professionals as this has a direct bearing on the scale waste reduction achievable. This solution can however be used by all built environment professionals across any scale of construction project cost. The developed algorithm was implemented using Python programming language and executed on Spyder Interactive Development Environment. This research developed the solution structure by first converting the problem to a quantitative one. Series of tests were conducted on the software, both during and post development to ensure optimal performance. The flow chart of developed rebar optimization algorithm is shown in Figure 1.

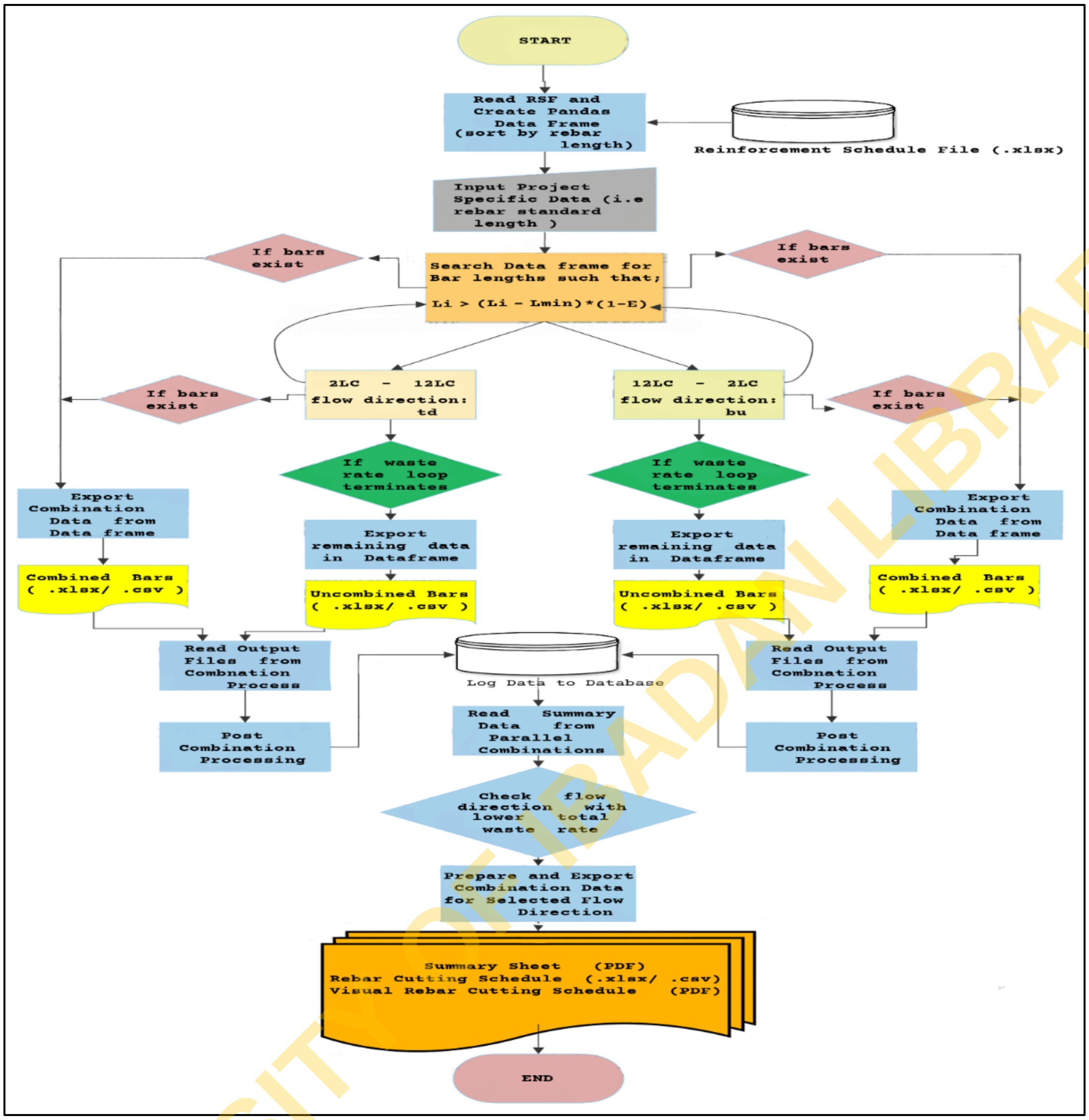


Figure 1: Flow of Implemented Rebar Optimization Algorithm

3. RESULTS AND DISCUSSION

Table 2 shows the key mechanical and physical properties of reinforcing steel. It was observed that properties of reinforcing steel that have direct bearing on safety and cost include yield strength, ultimate strength, ductility, toughness, Young's modulus and bar diameter. The research focused on properties which have direct impact on design outcomes and cost which includes yield strength, diameter, Young's modulus and standard length.

Yield Strength

Tables 3 shows the summary of variation in yield strength for 10, 12, 16, and 20mm bars as adopted from Ede *et al.* (2015). It was observed that 16 – 31% of common sizes of reinforcement bars available in the market fell below commonly adopted design strength limits, with some yield strength values falling as low as between 280 – 300 N/mm^2 for supposed "high yield" bars. It would be of note that the bars falling below the 410 mark had some really low numbers between 270 – 320 N/mm^2. The results from Ashola *et al.* (2016) in Table 4, observed over a three year period shows that 33.6% of steel bars were above code standard of 460 while the remaining 66.4% fell below, however if we take the standard below to the 410 usually designed with, we have 68.1% above and 31.9% below the mark. Figure 2 shows the variation in yield strength of steel rebars according to Joshua *et al.* (2018)· Only two out of the nine steel brands tested met the requirements of BS8110 and BS 4449. According to BS8110 (1997) a buffer has been provided in terms of partial safety factor for materials, and steel having a factor of 1.15. This means that a ± 15% variation in the measured value of yield strength should not be a cause for alarm. However, the observed variation occurrence has a high stake impact on safety thresholds of buildings as it represents a

26 – 31% decrease in design yield strength, which falls well below the safety factor provided for steel by BS8110 (1997) and also below the safe margin of 24.5% as extracted from Figure 3 when taking into account the safety factor imposed on load estimation. Equation 1 gives a relationship between percentage changes in yield strength to expected safety factor of a structural member in review. The equation can be of use to engineers in understanding and keeping track of the reliability of individual structural members, and have a knowledge of the safety margins of those members. The overall weighted design safety factor used for this research was 1.45 and therefore an approximation to Equation 1 would allow for substitution of the y-intercept with overall weighted design safety factor adopted by a design Engineer.

$$\boldsymbol{y = 0.0176x + 1.4771} \tag{1}$$

Where y = expected safety factor, x = percentage change in Yield Strength

The variation observed in values of yield strength for reinforcement bars available in the Nigerian market is sufficient to pose a risk on expected safety margins of a building. There is also a chance for a building’s structural members to become highly over-reinforced if the variation is in the positive direction, this is due to the increased value of strain required to make the steel yield. This means that the concrete in the compression zone would reach failure strain limits and fail without warning. However, because the safety margins are not affected by an upward trend, the likelihood of the loads to reach ultimate levels and result in sudden failure is low. Nonetheless, it is important to keep track using the prediction formula provided, as a downward trend has a negative impact on safety factors.

Table 2: Key Mechanical and Physical Properties

Property	**Description**	**Category**	**Governing Theory**	**Impact Safety Margins?**
Yield Strength	A material's yield strength is the stress after which its deformation becomes plastic.	Mechanical	Plasticity	Yes
Ultimate Strength	Ultimate strength is equivalent to the maximum load that can be carried per unit of cross-sectional area when the load is applied as simple tension.	Mechanical	Plasticity	Yes
Ductility	Ductility is the measure of a material's ability to undergo plastic deformation without fracturing when placed under a tensile stress that exceeds its yield strength.	Mechanical	Plasticity	Yes
Hardness	Hardness is the ability to withstand surface indentation (localized plastic deformation) and scratching.	Mechanical	Plasticity	No
Toughness	Toughness is the ability of a material to absorb energy and plastically deform without fracturing. This is an energy measure.	Mechanical	Plasticity	Yes
Young’s Modulus	Young's modulus describes tensile elasticity along a line when opposing forces are applied. It is the ratio of tensile stress to tensile strain.	Mechanical	Elasticity	Yes
Poisson’s Ratio	This is the ratio of transverse to longitudinal strain in a material under tension.	Mechanical	Elasticity	No
Diameter	This is the distance from one point on a circle through the centre to another point on the circle. It is also the longest distance across the circle.	Physical	N/A	Yes
Standard Length	This is a measure of the length of a rebar type produced by a manufacturer.	Physical	N/A	No
Cost per Length	This is the price per unit length of a rebar type produced by a manufacturer	N/A	N/A	No

Table 3: Variation in Yield Strength for 10, 12, 16, and 20mm bars

Diameter (mm)	**% Above 460 N/mm^2**	**% Between 410 – 460 N/mm^2**	**% Below 410 N/mm^2**
10	70	9	21
12	63	12	25
16	54	15	31
20	69	15	16

Source: Ede *et al.* (2015)

Table 4: Three (3) Years Yield Strength Variation in Local and Imported Steel Bars

S/N	**Nominal Size (mm)**	**Characteristic Strength (kN/mm^2) 2013**	**Characteristic Strength (kN/mm^2) 2014**	**Characteristic Strength (kN/mm^2) 2015**	**Code Requirement BS 4449-1997**	**Remarks**
1	10	356	368	373	460	All below Code
	12	440	449	412	460	All below Code
	16	464	469	382	460	All below Code
	20	422	454	422	460	All below Code
2	10	282	358	371	460	All below Code
	12	293	337	382	460	All below Code
	16	459	459	490	460	I below Code
	20	475	446	475	460	I below Code
3	10	296	447	462	460	All below Code
	12	512	504	512	460	All Above Code
	16	516	536	566	460	All Above Code
	20	543	527	543	460	All Above Code
4	10	282	359	358	460	All below Code
	12	293	372	346	460	All below Code
	16	428	422	428	460	All below Code
	20	446	446	448	460	All below Code
5	10	440	440	440	460	All below Code
	12	431	431	431	460	All below Code
	16	447	447	381	460	All below Code
	20	456	456	456	460	All below Code
6	10		361	373	460	All below Code
	12		395	386	460	All below Code
	16		413	428	460	All below Code
	20		449	456	460	All below Code
7	10		371	358	460	All below Code
	12		393	355	460	All below Code
	16		419	369	460	All below Code
	20		418	410	460	All below Code
8	10		375	388	460	All below Code
	12		389	389	460	All below Code
	16		379	429	460	All below Code
	20		396	396	460	All below Code
9	10		440	363	460	All below Code
	12		424	371	460	All below Code
	16		446	421	460	All below Code
	20		446	396	460	All below Code
10	10		499	487	460	All Above Code
	12		548	515	460	All Above Code
	16		527	600	460	All Above Code
	20		497	557	460	All Above Code
11	10		526	566	460	All Above Code
	12		520	555	460	All Above Code
	16		566	550	460	All Above Code
	20		541	596	460	All Above Code
12	10		577	526	460	All Above Code
	12		593	549	460	All Above Code
	16		578	549	460	All Above Code
	20		561	526	460	All Above Code

Source: Ashola *et al.* (2016)

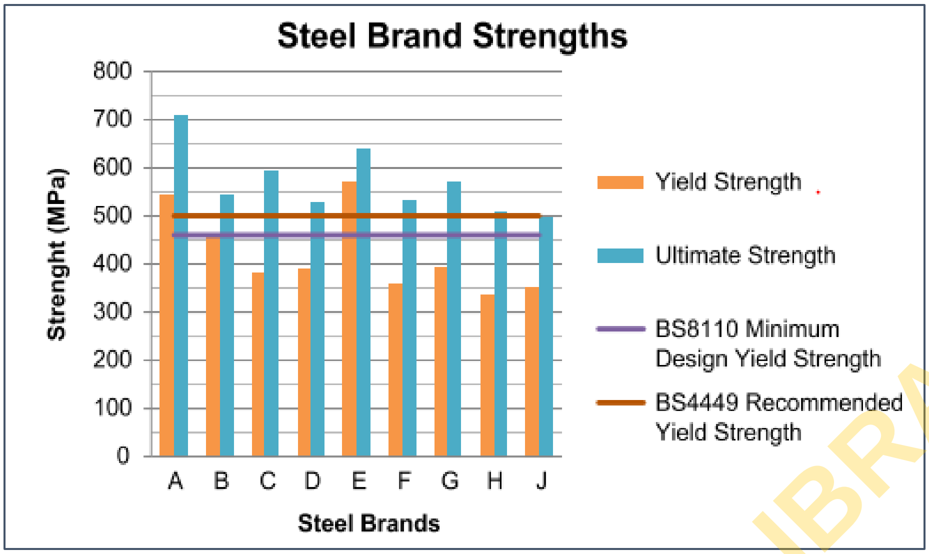


Figure 2: Variation in Yield Strength of Steel Rebars, Source: (Joshua *et al*., 2018)

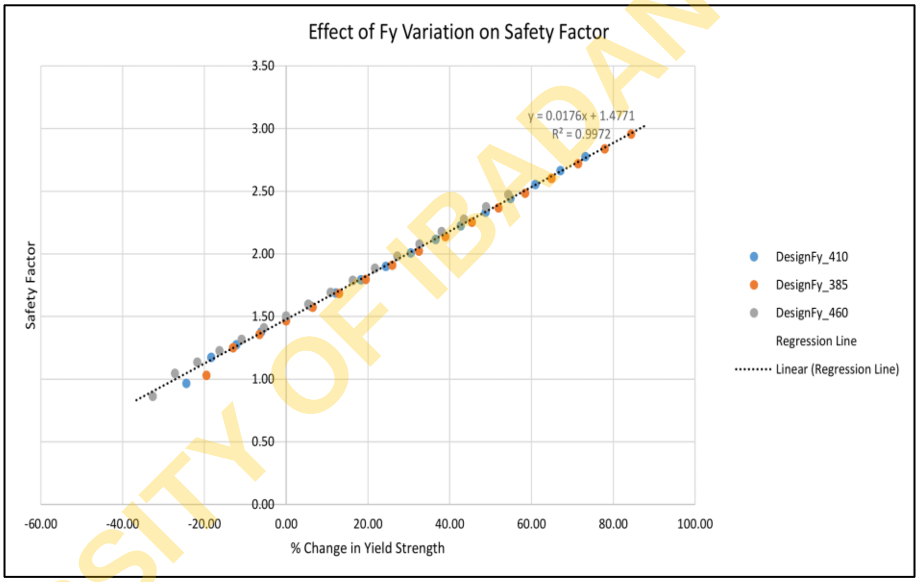


Figure 3: Change in Safety Factor with Percentage Change in Yield Strength

Bar Diameter

The data put out by Joshua *et al.* (2018) in Figure 4 shows that bar diameters fell below expected values. The results indicated that of all bars measured, none reached the value of the specified diameter. In the sample case of 12 mm bars, variation going as low as 10.55 mm was observed from the collected data, which amounts to a 9.47% decrease in diameter. This value passes in a case where the design is extremely robust and has a large buffer between area of steel required and area of steel provided of at least 22.5%. This is not often the case in many designs with a tight balance between safety and cost. The maximum allowable percentage bar diameter reduction plotted against the buffer area on steel provided is shown in Figure 5 and Equation 2 was obtained from the relationship. The equation will help engineers to keep a track on maximum allowable bar size reductions they can permit if they have a clear knowledge on the design buffers. This is extremely useful as the data shows that hardly any bar available in the market is of standard diameter specification. The variation in reinforcement diameter is sufficient to pose a risk on expected safety margins of a building. Hence, Engineers must take necessary steps to ensure they can track the effect of these variations on their project using the prediction formula provided by this research. This would mean engineers should demand access to data on buffer for area of steel required for every structural member.

$$\boldsymbol{y = 0.4079x + 0.5661} \qquad (2)$$

Where y = maximum allowable % bar diameter reduction, x = % buffer on area of steel

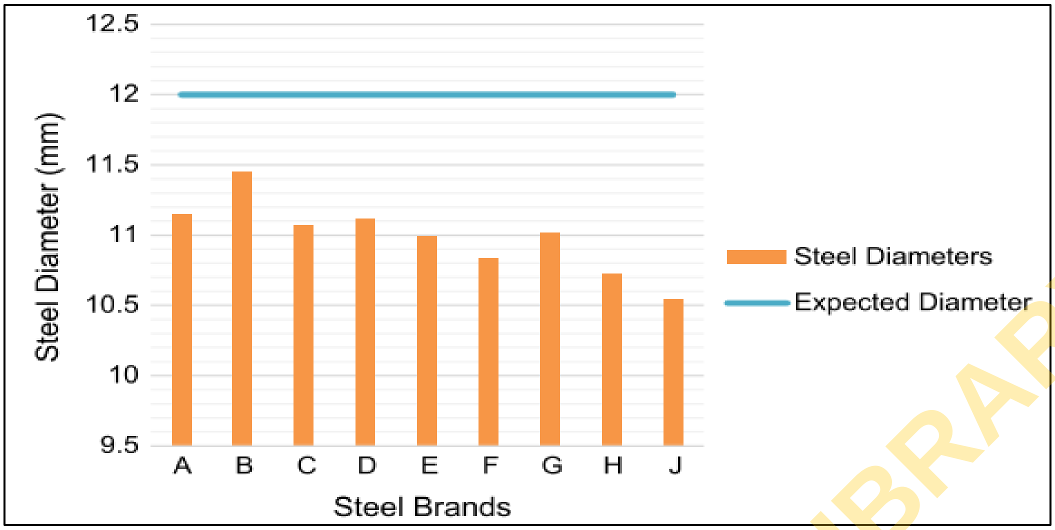


Figure 4: Variation in Rebar Measured Diameter (Joshua *et al*., 2018)

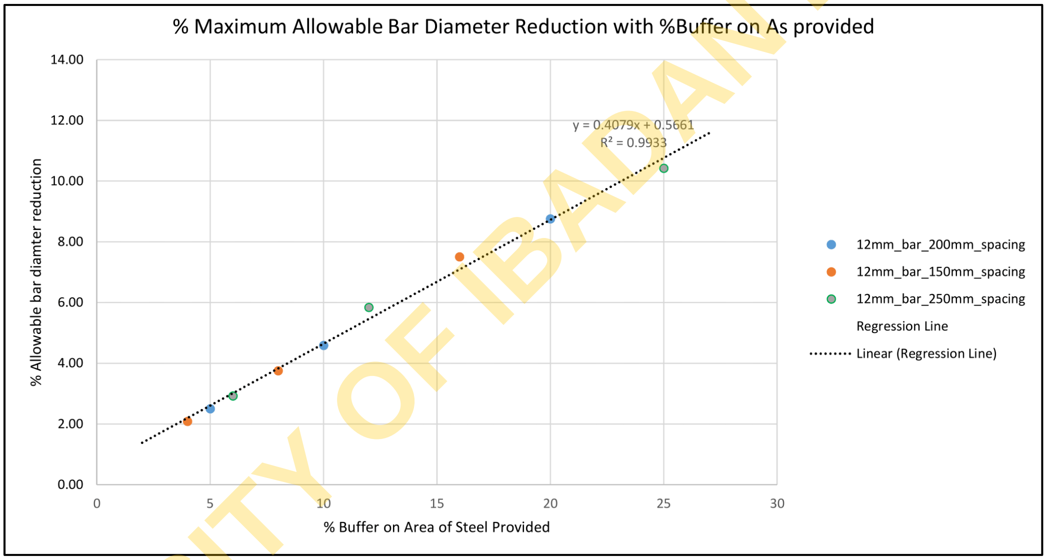


Figure 5: Maximum Allowable Percentage bar Diameter Reduction

Young's Modulus

Figure 6 shows the effect of Young's modulus variation on moment of resistance of a singly reinforced section. The Young's Modulus range as observed from literature is approximately 200 GPA ± 25. When examining the figure, comparing change in Young's Modulus values to Moment of Resistance, it was observed that for a given value of yield strength, the variation is not beyond approximately 20 kNm. This variation, when considered in design would not create a significant difference in the output specification. However, it is important to note that if there is a simultaneous variation in value of Young's Modulus as well as yield strength, the variation in moment capacity becomes large enough to be of significant concern. Equation 3 as extracted from the plots, will provide necessary guide for Engineers to monitor this variation and know when a significant moment capacity change has occurred (this is checked against reduction in safety factor caused by a downward moment change). The equation is empirical and should be used in comparing for yield strengths ± 25 N/mm^2 difference of each other, with an error margin in resulting moment prediction of ± 12 KNm

$$M2 = M1 \times \frac{Fy1}{Fy2} \qquad (3)$$

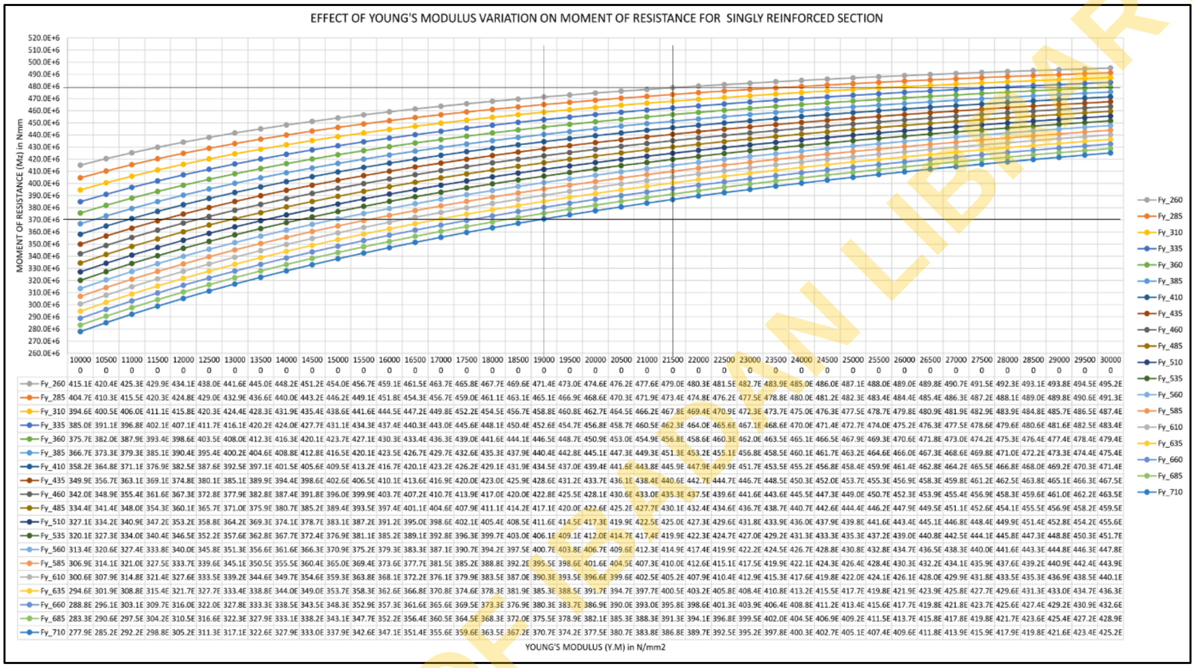
Figure 7 shows the relationship between change in young's modulus values and overall safety factor. A linear relationship was obtained as shown in Equation 4. An interesting observation of the equation was that the slope and y-intercept are factors of the overall safety factor. Weighted overall safety factor of 1.45 was calculated and hence, Equation 4 is rewritten as Equation 5. Figure 6 also shows that the change in moment capacity for case with lower yield strength values is steeper than for higher values of yield strength. The observed variation range for Young's modulus has very little effect on safety margins on its own. Figure 7 shows that for a significant change in safety factor to occur, the variation has to be from 20% and above in the downward manner; this would mean recording a Young's modulus value as low as 160 GPa. However, according to available data, the probability is extremely low, except in a case of fire which drastically reduces the value, but that is beyond the scope of this work.

$$y = 0.0145x + 1.45 \qquad (4)$$

Where y = expected safety factor, x = percentage change in Young's Modulus

$$y = \frac{\beta}{100}x + \beta \qquad (5)$$

Where β = overall weighted factor of safety for the structural member,



	100000	105000	110000	115000	120000	125000	130000	135000	140000	145000	150000	155000	160000	165000	170000	175000	180000	185000	190000	195000	200000	205000	210000	215000	220000	225000	230000	235000	240000	245000	250000	255000	260000	265000	270000	275000	280000	285000	290000	295000	300000
Fy_260	415.1E	420.4E	425.3E	429.9E	434.1E	438.0E	441.6E	445.0E	448.2E	451.2E	454.0E	456.7E	459.1E	461.5E	463.7E	465.8E	467.7E	469.6E	471.4E	473.0E	474.6E	476.2E	477.6E	479.0E	480.3E	481.5E	482.7E	483.9E	485.0E	486.0E	487.1E	488.0E	489.0E	489.8E	490.7E	491.5E	492.3E	493.1E	493.8E	494.5E	495.2E
Fy_285	404.7E	410.3E	415.5E	420.3E	424.8E	429.0E	432.9E	436.6E	440.0E	443.2E	446.2E	449.1E	451.8E	454.3E	456.7E	459.0E	461.1E	463.1E	465.1E	466.9E	468.6E	470.3E	471.9E	473.4E	474.8E	476.2E	477.5E	478.8E	480.0E	481.2E	482.3E	483.4E	484.4E	485.4E	486.3E	487.2E	488.1E	489.0E	489.8E	490.6E	491.3E
Fy_310	394.6E	400.5E	406.0E	411.1E	415.8E	420.3E	424.4E	428.3E	431.9E	435.4E	438.6E	441.6E	444.5E	447.2E	449.8E	452.2E	454.5E	456.7E	458.8E	460.8E	462.7E	464.5E	466.2E	467.8E	469.4E	470.9E	472.3E	473.7E	475.0E	476.3E	477.5E	478.7E	479.8E	480.9E	481.9E	482.9E	483.9E	484.8E	485.7E	486.5E	487.4E
Fy_335	385.0E	391.1E	396.8E	402.1E	407.1E	411.7E	416.1E	420.2E	424.0E	427.7E	431.1E	434.3E	437.4E	440.3E	443.0E	445.6E	448.1E	450.4E	452.6E	454.7E	456.8E	458.7E	460.5E	462.3E	464.0E	465.6E	467.1E	468.6E	470.0E	471.4E	472.7E	474.0E	475.2E	476.3E	477.5E	478.6E	479.6E	480.6E	481.6E	482.5E	483.4E
Fy_360	375.7E	382.0E	387.9E	393.4E	398.6E	403.5E	408.0E	412.3E	416.3E	420.1E	423.7E	427.1E	430.3E	433.4E	436.3E	439.0E	441.6E	444.1E	446.5E	448.7E	450.9E	453.0E	454.9E	456.8E	458.6E	460.3E	462.0E	463.5E	465.1E	466.5E	467.9E	469.3E	470.6E	471.8E	473.0E	474.2E	475.3E	476.4E	477.4E	478.4E	479.4E
Fy_385	366.7E	373.3E	379.3E	385.1E	390.4E	395.4E	400.2E	404.6E	408.8E	412.8E	416.5E	420.1E	423.5E	426.7E	429.7E	432.6E	435.3E	437.9E	440.4E	442.8E	445.1E	447.3E	449.3E	451.3E	453.2E	455.1E	456.8E	458.5E	460.1E	461.7E	463.2E	464.6E	466.0E	467.3E	468.6E	469.8E	471.0E	472.2E	473.3E	474.4E	475.4E
Fy_410	358.2E	364.8E	371.1E	376.9E	382.5E	387.6E	392.5E	397.1E	401.5E	405.6E	409.5E	413.2E	416.7E	420.1E	423.2E	426.2E	429.1E	431.9E	434.5E	437.0E	439.4E	441.6E	443.8E	445.9E	447.9E	449.9E	451.7E	453.5E	455.2E	456.8E	458.4E	459.9E	461.4E	462.8E	464.2E	465.5E	466.8E	468.0E	469.2E	470.3E	471.4E
Fy_435	349.9E	356.7E	363.1E	369.1E	374.8E	380.1E	385.1E	389.9E	394.4E	398.6E	402.6E	406.5E	410.1E	413.6E	416.9E	420.0E	423.0E	425.9E	428.6E	431.2E	433.7E	436.1E	438.4E	440.6E	442.7E	444.7E	446.7E	448.5E	450.3E	452.0E	453.7E	455.3E	456.9E	458.3E	459.8E	461.2E	462.5E	463.8E	465.1E	466.3E	467.5E
Fy_460	342.0E	348.9E	355.4E	361.6E	367.3E	372.8E	377.9E	382.8E	387.4E	391.8E	396.0E	399.9E	403.7E	407.2E	410.7E	413.9E	417.0E	420.0E	422.8E	425.5E	428.1E	430.6E	433.0E	435.3E	437.5E	439.6E	441.6E	443.6E	445.5E	447.3E	449.0E	450.7E	452.3E	453.9E	455.4E	456.9E	458.3E	459.6E	461.0E	462.2E	463.5E
Fy_485	334.4E	341.4E	348.0E	354.3E	360.1E	365.7E	371.0E	375.9E	380.7E	385.2E	389.4E	393.5E	397.4E	401.1E	404.6E	407.9E	411.1E	414.2E	417.1E	420.0E	422.6E	425.2E	427.7E	430.1E	432.4E	434.6E	436.7E	438.7E	440.7E	442.6E	444.4E	446.2E	447.9E	449.5E	451.1E	452.6E	454.1E	455.5E	456.9E	458.2E	459.5E
Fy_510	327.1E	334.2E	340.9E	347.2E	353.2E	358.8E	364.2E	369.3E	374.1E	378.7E	383.1E	387.2E	391.2E	395.0E	398.6E	402.1E	405.4E	408.5E	411.6E	414.5E	417.3E	419.9E	422.5E	425.0E	427.3E	429.6E	431.8E	433.9E	436.0E	437.9E	439.8E	441.6E	443.4E	445.1E	446.8E	448.4E	449.9E	451.4E	452.8E	454.2E	455.6E
Fy_535	320.1E	327.3E	334.0E	340.4E	346.5E	352.2E	357.6E	362.8E	367.7E	372.4E	376.9E	381.1E	385.2E	389.1E	392.8E	396.3E	399.7E	403.0E	406.1E	409.1E	412.0E	414.7E	417.4E	419.9E	422.3E	424.7E	427.0E	429.2E	431.3E	433.3E	435.3E	437.2E	439.0E	440.8E	442.5E	444.1E	445.8E	447.3E	448.8E	450.3E	451.7E
Fy_560	313.4E	320.6E	327.4E	333.8E	340.0E	345.8E	351.3E	356.6E	361.6E	366.3E	370.9E	375.2E	379.3E	383.3E	387.1E	390.7E	394.2E	397.5E	400.7E	403.8E	406.7E	409.6E	412.3E	414.9E	417.4E	419.9E	422.2E	424.5E	426.7E	428.8E	430.8E	432.8E	434.7E	436.5E	438.3E	440.0E	441.6E	443.3E	444.8E	446.3E	447.8E
Fy_585	306.9E	314.1E	321.0E	327.5E	333.7E	339.6E	345.1E	350.5E	355.5E	360.4E	365.0E	369.4E	373.6E	377.7E	381.5E	385.2E	388.8E	392.2E	395.5E	398.6E	401.6E	404.5E	407.3E	410.0E	412.6E	415.1E	417.5E	419.9E	422.1E	424.3E	426.4E	428.4E	430.3E	432.2E	434.1E	435.9E	437.6E	439.2E	440.9E	442.4E	443.9E
Fy_610	300.6E	307.9E	314.8E	321.4E	327.6E	333.5E	339.2E	344.6E	349.7E	354.6E	359.3E	363.8E	368.1E	372.2E	376.1E	379.9E	383.5E	387.0E	390.3E	393.5E	396.6E	399.6E	402.5E	405.2E	407.9E	410.4E	412.9E	415.3E	417.6E	419.8E	422.0E	424.1E	426.1E	428.0E	429.9E	431.8E	433.5E	435.3E	436.9E	438.5E	440.1E
Fy_635	294.6E	301.9E	308.8E	315.4E	321.7E	327.7E	333.4E	338.8E	344.0E	349.0E	353.7E	358.3E	362.6E	366.8E	370.8E	374.6E	378.3E	381.9E	385.3E	388.5E	391.7E	394.7E	397.7E	400.5E	403.2E	405.8E	408.4E	410.8E	413.2E	415.5E	417.7E	419.8E	421.9E	423.9E	425.8E	427.7E	429.6E	431.3E	433.0E	434.7E	436.3E
Fy_660	288.8E	296.1E	303.1E	309.7E	316.0E	322.0E	327.8E	333.3E	338.5E	343.5E	348.3E	352.9E	357.3E	361.6E	365.6E	369.5E	373.3E	376.9E	380.3E	383.7E	386.9E	390.0E	393.0E	395.8E	398.6E	401.3E	403.9E	406.4E	408.8E	411.2E	413.4E	415.6E	417.7E	419.8E	421.8E	423.7E	425.6E	427.4E	429.2E	430.9E	432.6E
Fy_685	283.3E	290.6E	297.5E	304.2E	310.5E	316.6E	322.3E	327.9E	333.1E	338.2E	343.1E	347.7E	352.2E	356.4E	360.5E	364.5E	368.3E	372.0E	375.5E	378.9E	382.1E	385.3E	388.3E	391.3E	394.1E	396.8E	399.5E	402.0E	404.5E	406.9E	409.2E	411.5E	413.7E	415.8E	417.8E	419.8E	421.7E	423.6E	425.4E	427.2E	428.9E
Fy_710	277.9E	285.2E	292.2E	298.8E	305.2E	311.3E	317.1E	322.6E	327.9E	333.0E	337.9E	342.6E	347.1E	351.4E	355.6E	359.6E	363.5E	367.2E	370.7E	374.2E	377.5E	380.7E	383.8E	386.8E	389.7E	392.5E	395.2E	397.8E	400.3E	402.7E	405.1E	407.4E	409.6E	411.8E	413.9E	415.9E	417.9E	419.8E	421.6E	423.4E	425.2E

Figure 6: Effect of Young's Modulus Variation on Moment of Resistance

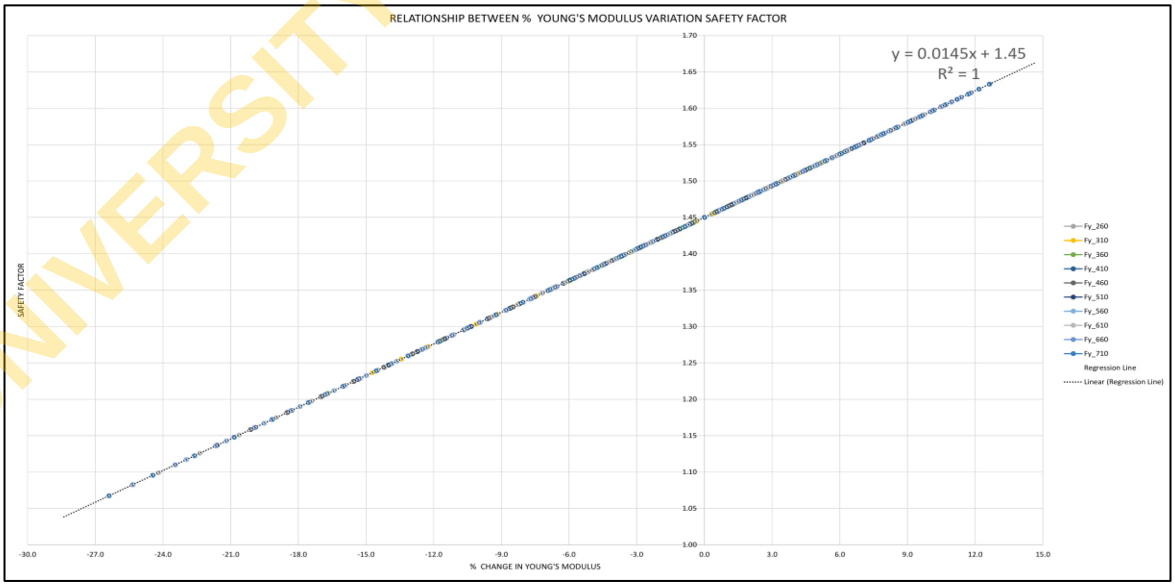


Figure 7: Relationship between Percentage Variations in Young's Modulus to Safety Factor

Standard Length

According to Chandrasekar and Nigussie (2018) who researched rebar wastage in building construction projects, it was observed that out of ten factors contributing to wastage, a strong correlation (r value between 0.89 and 0.90) existed for short cut pieces and non-optimized cutting. This further emphasizes the effect length combination plays on wastage and therefore cost margin, as wastage implies additional costs on a project. The results discussed in the section of rebar optimization algorithm points to some cutting combinations having varying total lengths. Overlaying this occurrence to the observed trend of varying standard lengths and cost per standard length, as seen in Figure 8 from various brands, a window for reducing cost margins opens up. Contractors can take advantage of these variations by making orders of different brands with varying standard lengths as they could make sufficient procurement optimization and hence, improved cost savings, which leads to an overall improvement in cost margins of their projects.

As an example, if the result of the rebar optimization software produces combinations with lengths between 10.8 m to 11.8 m, it would be smart practice to procure varying rebar brands having good mechanical properties but varying in cost per length and standard length. An Engineer on such a project can save cost by purchasing bars having standard length of 12 m, 11.5 m and 11 m respectively. These ranges of standard lengths would ensure that effectively, there is a further reduction is waste rates. The total, when aggregating the multiplication of the various costs per standard length with standard lengths used, yields in a sum with a reasonably lower amount than would have been gotten if an overall 12 m length brand were used for the project.

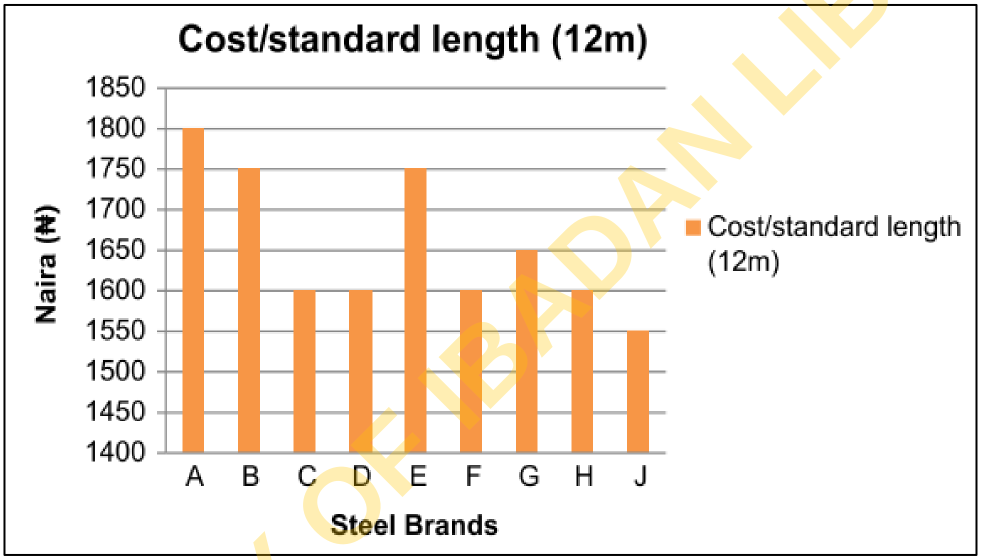


Figure 8: Variation in Cost per Standard Length (12m) of Steel Rebar (Joshua *et al*., 2018)

Survey Responses

Table 5 shows the survey responses which was conducted amongst senior management level professionals. The respondent demographic shows majority input from Quantity Surveyors, Civil/Structural Engineers and Architects. Most of the respondents have been involved in projects with an average contract sum above 1 billion naira. The contract sum gives an avenue to relate waste rates to actual cost margins. Majority of respondents attributed wastage to two major factors including excess order and inefficient cutting of reinforcement. This further emphasizes and validates the need for the rebar optimization software as a tool to help curb wastage and improve construction cost efficiency. From the interview, the best practices respondents apply to try to mitigate occurrence of excessive reinforcement wastage include preparation of schedule of rebar in accordance with the reinforcement drawings and bending schedules for procurement, as well as supervision of the cutting, bending and fixing in place; lapping of rebar no matter how plenty; scheduling of reinforcements indicating shape, cut length and sizes; efficient cutting combination of rebar to minimize off cuts; preparation of rebar procurement in accordance with reinforcement drawings and bending schedules, as well as supervision of cutting, bending and fixing to place; use of accurate bending schedule, adhering strictly to bending schedule as prescribed by the structural engineers. Although these are reasonably smart solutions, but an automated approach would save these professionals time, energy and money. The respondents show interest in the software, and are willing to part with reasonable fees for the foreseeable value.

The survey shows further that amongst available reinforcement bars in the market, the most popular are Real TMT, Tiger TMT, Ukraine and Brazil, with Real TMT being the most preferred brand. This preference for Real TMT does not necessarily mean it is the most purchased for projects, as in most cases, Engineers are trying to work a fine line between quality and cost overrun in their projects. This observed conflict of what is preferred and what is chosen is deeply rooted in financial implications of the choices. Therefore, if an alternative option of minimizing cost margins by effective combination of lengths is utilized, Engineers could have more room to explore the highest quality of construction steel reinforcement bars.

Table 5: Survey Responses

S/N	Survey Participants		Frequency	Percentages (%)
1	Profession	Civil/Structural Engineer	5	41.7
		Architect	5	41.7
		Quantity Surveyor	2	16.7
2.	Position	CEO	1	8.3
		Director	1	8.3
		Partner	1	8.3
		Principal Consultant	5	41.7
		Principal Partner	1	8.3
		Project Manager	2	16.7
		Site Engineer	1	8.3
3.	Size of Contracts Executed	₦50M – ₦500M	3	25.0
		₦500M – ₦1B	4	33.3
		₦1B and above	5	41.7
4.	Years of Professional Practice	10 – 19 years	5	41.7
		20 – 39 years	1	8.3
		40 years and above	6	50.0
5.	Major Factors Contributing to Rebar Wastage	Excess order of reinforcement	7	58.3
		Inefficient cutting of reinforcement	5	41.7
		Untraceable materials and abandonment	0	0.0
6.	Popularity of Rebar Brands Available in Nigeria	Tiger TMT	6	50.0
		Real TMT	7	58.3
		MS Square Rods	2	16.7
		Top TMT	2	16.7
		Top CTD	1	8.3
		PULKIT	2	16.7
		LCI	1	8.3
		Ukraine	9	75.0
		Brazil	6	50.0
		Federal Steel	7	58.3
		Ife Iron	0	0.0
7.	Preference of Available Rebar Brands	Real TMT	6	50.0
		Tiger TMT	2	16.7
		PULKIT	2	16.7
		MS Square Rods	1	8.3
		Ukraine	1	8.3
8.	Implementation of Elongation Factor	Yes	10	83.3
		No	2	16.7
9.	Need of an Optimization Software	Yes	12	100.0
		No	0	0.0
10.	Payment for Software Service	Yes	11	91.7
		No	1	8.3

Rebar Optimization Algorithm

Table 6 shows the summary of the result from test case of rebar optimization algorithm. The algorithm was tested against data gathered from Chinanuwatwong (2000), and comparison of waste rates wade made. It was observed that the result from the compared source achieved higher savings than the algorithm developed in this work. This is because there is a requirement of higher computing power to realize the full potential of the developed algorithm. The iterations here started from a higher allowable waste rate to reduce computational requirements. However, in one of the test cases (Project No. 2), the algorithm achieved higher cost savings. The comparison in Table 6 gives an overview of the effectiveness of the developed algorithm. A further reduction in waste rate could be achieved if bars with standard length not reaching 12 m are purchased. The combinations with sums below 11.5 m can be considered in such situations and result in a greater net saving and waste reduction. The survey for the rebar optimization software shows it would serve a great need in the construction space and professionals are willing to use such a software for the proposed value foreseeable. The results of the algorithm test case shows that there is ample cost savings achieved and hence would yield tremendous value to Engineers on project sites. There is however, a need to improve the algorithm in a manner that it utilizes computing power more effectively, so that its true potential can be unlocked.

Table 6: Summary Result from Test Case of Rebar Optimization Algorithm

Description	Project No. 1	Project No. 2	Project No. 3	Project No. 4	Project No. 5
Total bar bending length	14985.6	2634.95	12166.66	27258.5	19185.3
Number of standard length	1338	239	1125	2748	1727
Total length of standard steel	16056	2868	13500	32976	20724
Fraction from analysis (%)	6.67	8.12	9.87	17.33	7.42
Fraction from site (%)	6.80	8.60	12.60	10.80	11.40
Fraction steel saved (%)	0.13	0.48	2.73	- 6.53	3.98

4. CONCLUSION

This research focused on properties of reinforcing steel bars and how they affect cost and safety margins of buildings. The key properties observed to be of highest effect are bar diameter, yield strength, young's modulus, and standard length. The data obtained on the variation limits of these properties inform the conclusion on how much they can have an impact on safety and cost margins, and points to which properties an Engineer must constantly check to ensure projects are delivered within the best safety and cost margins. The properties of steel to be monitored in order of how their variation affect safety margins are yield strength, bar diameter and Young's modulus. The cost margins in a building are affected directly by a measure of how effectively length combinations are done, also taking advantage of variations in standard length of various brands. Generally, there is a high risk of building collapse owing to the levels and trends of variation observed in these mechanical properties of reinforcing steel available locally in the markets. The result of survey indicates there would be high acceptance for a software that aids Engineers achieve this desired level of efficiency. The rebar optimization algorithm developed has a high capacity for efficiency, and if properly utilized, achieves the goal of reduction in cost margins by efficient cutting combination of reinforcement bars.

References

Abeku, D. M., Salihu, C. and Kure, M. A. (2016). Housing Deficit, Urban Migration and Slum Development in Abuja, Nigeria. International Journal of Economic Development Research and Investment, 7(1): 39 - 50

Adegbite, A. A. (2016). Investigating the Chemical Composition of Steel Bars in the Nigerian Construction Industry. MSc. Thesis, University of Ibadan.

Adetoro A.E., Oladapo A.S. (2017). Assessment of suitability of selected reinforcement Bars Used for Construction in Nigeria. Journal of Multidisciplinary Engineering Science and Technology, 4(5): 7308-7312.

Ashola, A. M., Akinpelu, T. A., AbdulHakeem, B. and Alaboru, F. O. (2016). Open Access Assessment of the Properties of Reinforcing Steel Bars Used In the Construction Industry within Lagos State and Its Environs. American Journal of Engineering Research, (9): 39–47.

British Standards Institution (1997). BS 8110-1:1997. British Standard Institution London (1):168.

Chandrasekar, M. K. and Nigussie, T. (2018). Rebar Wastage in Building Construction Projects of Hawassa, Ethiopia. International Journal of Scientific and Engineering Research, 9(2):282–87.

Chinanuwatwong, S. (2000). Reducing Waste from Cutting Reinforcing Steel in Construction Projects. Kasetsart Journal (Nat. Sci.), 34 : 526 – 535.

Ede, A. N., Emmanuel, O. E., Gideon, O. B. and Jadesola, O. (2015). Assessment of Quality of Steel Reinforcing Bars Used in Lagos, Nigeria. International Research Journal of Innovative Engineering, 1(3):1–8.

Ede, A. N., Oluwarotimi, M. O. and Opeyemi, J. (2014b) Experimental investigation of Yield Strengths of Steel Reinforcing Bars Used in Nigerian Concrete industries. International Journal of Science and Engineering Research, 5(4): 76-82

Ede, A. N., Samuel, A., Emmanuel, U. and PraiseGod, E. (2014a). Life Cycle Assessment of Environmental Impacts of Using Concrete or Timber to Construct a Duplex Residential Building. IOSR Journal of Mechanical and Civil Engineering, 11:62–72.

Hassan, O. B., Akin, O. O., Lawan, A. and Amartey, Y. D. (2021). Mechanical and Chemical Properties of Reinforcement Bars Manufactured in Nigeria. Covenant Journal of Engineering Technology, 5(1): 56-68

Imafidon, M. O. and Ogbu, C. P. (2020). A taxonomy of building collapse causes in Lagos state Nigeria. Nigerian Journal of Technology (NIJOTECH). 39(1): 74 – 86. http://dx.doi. org/10.4314/njt.v39i1.8

Johnson, B. and Lichtveld, M. (2017). Environmental Policy and Public Health. 2nd Edition, CRC Press, https://doi.org/10.1201/9781351228473

Joshua, O., Olusola, K. O., Oyeyemi, K. D., Ogunde, A. O., Amusan, L. M., Nduka, D. O. and Abuka-Joshua, J. (2018). Data of the Properties of Rebar Steel Brands in Lagos, Nigerian Market Used in Reinforced Concrete Applications. Data in Brief, doi: 10.1016/j.dib.2018.01.083.

Mrabure, K. O. and Awhefeada, U. V. (2020). The menace of building collapse incidences in Nigeria. The need for strict enforcement of applicable planning laws. Commonwealth law bulletin Doi: https//doi.org/10.1080/03050718.2020.1804421

Nicholas, O. I., Dickson, N. M. and Okeke, F. O. (2022). Building Collapse in Nigeria and its Consequences on the Architect's Role as the Leader of The Building Team. Jordan Journal of Earth and Environmental Sciences, 13 (1): 16-25

Obodoh, D. A., Ubani, E. C. and Obodoh, C. M. (2021). Assessment of the Impact of Building Collapse Risks on Building Development in Nigeria. Environmental Review, 8(2): 10-18.

Odusote, J. K., Shittu, W., Adeleke, A. A., Ikubanni, P. P. and Adeyemo, O. (2019). Chemical and Mechanical Properties of Reinforcing Steel Bars from Local Steel Plants. Journal of Failure Analysis and Prevention. doi:10.1007/s11668-019-00695-x

Ogunmakinde, O., Sher W. and Maund, K. (2019). Challenges of the Nigerian Construction Industry: A Systematic Review. Proceedings of iiSBE Forum of Young Researchers in Sustainable Building, Praque, Pp. 195-204

Olawale S. O. A., Tijani M. A., Folayan O. I. and Bolaji E. O. (2019). Reliability Assessment of Ejigbo Campus Library Building of Osun State University, Osogbo. USEP: Journal of Research Information in Civil Engineering, 16(1): 2511 -2526.

Olawale, S. O. A. and Tijani, M. A. (2018). Development of Steel Structural Member Design Software Teaching Aid. Journal of New Trends in Civil Engineering, 1(1): 68 – 78.

Oyedele, O. A. (2018). A Study of Control Measures of Building Collapse in Lagos State, Nigeria. Proceedings of 2018 FIG Congress, Istanbul, Turkey. Pp. 1-13. Available at www.researchgate.net.

Tijani, M. A. and Ajagbe W. O. (2016). Professionals View on the Causes and Effects of Construction Projects Abandonment in Ibadan Metropolis, Nigeria. Ethiopian Journal of Environmental Studies and Management, 9(5): 593 – 603.