

Investigation on Flexural Performance of Concrete Beams Reinforced with Steel Bars available in Rwanda

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ABSTRACT: Present infiltration of substandard steel reinforcing bars on local market have had a serious concern and impacts on strength and stability of buildings and other engineering structures that are being built with them. Some buildings have collapsed in both Rwanda and in neighboring countries where most of rebars are imported from and investigations have pinpointed substandard steel reinforcing bars. Primary objective of this study was to investigate the flexural performance behavior of concrete beams reinforced with steel bars available in Rwanda, where 24 samples of concrete beams reinforced with steel bars of 12mm and 10 mm θ separately were investigated for flexural performance behavior. The steel bars from four different sources available in Rwanda were randomly picked from warehouses, examined for their mechanical properties compliance to standard codes in a separate study and results were used to investigate RC beam flexural performance. Results obtained showed that the ultimate load of RC beams made of Y12 mm were in range of 114.6 KN to 142.6 KN while their respective flexural strength ranged from 25.7 N/mm² to 33.4 N/mm² as compared to design load of 111.8 KN and design flexural strength of 25.1 N/mm² respectively. The flexural load of RC beam made of Y10 mm was found to be in range of 93 KN to 131.5 KN while their respective flexural strength ranged from 20.89N/mm² to 32 N/mm² as compared to design load of 78.2 KN and design flexural strength of 17.6 N/mm² respectively. Incidentally both experimental ultimate load and flexural strength of RC beams met their respective design requirements despite poor performance of steel bars that failed at 45.8%.

Keywords: RC beam¹, ultimate load², flexural strength³, flexural performance behavior⁴.

1. INTRODUCTION

In the light of the fast growing construction industry in Rwanda to meet sustainable development envisaged in vision 2020, the structural stability status of buildings and other civil engineering structures are uncertain. Construction companies and individuals purchase the steel bars from open local markets and take them directly into use without being subjected into any technical examination. It is suspected that most times manufacturers supply well tested quality reinforcing steel bars to big companies and contractors who make capital orders and who are known for being conscious with quality and who may possibly re-test the supplied reinforcing steel bars. While reinforcing steel bars supplied to local open market are intentionally made of poor quality because it known that they are never examined to confirm the quality. Strength and stability of structures depend to large extent on the strength of reinforcing bars that reinforces their structural elements which should be appreciated first through laboratory tests before being subjected into any use. Some building have collapse in Rwanda, while others have threatened to collapse, there has been also quite a number of collapsed buildings in our neighboring countries where steel reinforcing bars are imported from, which gives extra reason of suspicion.

Mwasame, G et al (2012) reported series of collapsed buildings between 2006 and 2012 within Nairobi city. While Figueroa, P.H F. (2014) surveyed 24 construction sites in Nairobi and 51 existing buildings in the metropolitan area of Nairobi, it was revealed that construction materials' results were often of less quality than the laboratory test results which eventually lead to structural instability of buildings. The survey further reported incidences of collapsed buildings in different countries and in relatively few years between 2006 and 2014. 17 in Kenya killing 82 people and causing 291 injuries, 1 Accra, Ghana, killing 12 people factory in Bangladesh that claimed over 1,100 people, a church in Nigeria that killed 44 persons, in addition to the death, the incidences witness quite a huge number of fetal injuries. Nassaka, F (2016) in the independent magazine reported a number of collapsed buildings in different parts of Kampala: 2015 in Kansaga and Lungujja claiming 5 lives, in 2013 down town Kampala killing 15 instantly with uncountable fetal injuries. Spencer, C. (2016) indicated number of buildings that collapsed due to use of counterfeit materials, one in 2016 a six storey building at Kyaseka in Makerere in Uganda collapsed and 8 people lost their lives. In the same year a six storey residential building collapsed in Kenya and more than 33 people were reported dead. Again in 2013 a building collapsed in Nyagatare - Rwanda killing six people instantly. While more than 100 people most of whom were visitors from South Africa died when a church guesthouse collapsed in Nigeria in 2014.

Flexural strength test being a measure of a structural member's ability to withstand the bending forces, it becomes the main effective way of assessing how much flexural forces can be applied to a member before it fails. Investigation

conducted by Kumar, G N. and Karthik, S. (2017) proved that any increase in percentage of steel reinforcement results in an equal increase in flexural load value. Kulkarni S. K. et la (2012) in the analysis of the behavior of simply supported reinforced concrete beam subjected to gradual increasing loading, observed two phases of initial uncracked and ultimate condition at collapse. The two stages relates to the beam ductility and subsequent ample time before total failure.

Kwan A.K.H et la (2015) investigated the effects of concrete grade and steel yield strength on flexural ductility of reinforced concrete beams. The study revealed that flexural ductility decreases slightly with the tension steel yield strength as well as the concrete strength but increases slightly with the compression steel yield strength. It was also observed that the use of a higher concrete strength could increase either the flexural strength or the flexural ductility or both hence achieving flexural strength and flexural ductility simultaneously.

Abdelhamid, C. et la (2016) in the assessment of flexural behavior of beams reinforced with steel bars exceeding the nominal yield strength observed that steel mechanical properties have more often exceeded the minimum nominal strength values for a specific grade of steel. Consequences are unexpectedly high values of steel yield stress that reduce the beam ductility.

Kumar, D. S and Rajkumar, R. (2016) carried out an experimental investigation on the flexural behavior of concrete beams, which revealed that the 1st cracking load is directly related to concrete tensile strength which is in turn a function of compressive strength, hence increasing the concrete compressive strength is expected to yield higher cracking loads. This further leads to the fact that before cracks of the beam, the entire section is effective in resisting the resulting moments hence both steel and concrete are effective. Until applied moments (M) are equal to cracking moments (Cr) from where the steel takes over. Many factors have been found to have influence on the flexural tensile strength of concrete in different researches. According to Mohd, A. et la (2014) stress level, size, age and confinement to concrete flexure member have a larger influence to flexural tensile strength as increase in compressive strength and age of the concrete equally increases flexural tensile strength.

Balamoorthi, K et la (2017) investigated flexural behavior of reinforced concrete beam by varying the concrete grade in tension zone. (below the neutral axis) since concrete serves minimal purpose in tension only to transfer strain from steel to concrete which is sacrificial. Aim of the study was to find ways of reducing material cost of the structure without interfering with its strength. Results revealed that flexural behaviour was almost similar for beams with lower grade beam performing slightly better for 1st crack loads while solid beam also performed slightly better for ultimate loads.

2. MATERIALS and METHODS

Twenty four (24) concrete beams of 150mm x 250mm x 1800mm were prepared each with four (4) steel bars of 12 mm \emptyset and 10mm \emptyset were separately used in different beam specimens held together by a 8 mm \emptyset shear bar (stirrups). Rebars from four different sources available in Rwanda namely Kenya, Tanzania, Turkey and Rwanda were used in this research, each source were represented by six (6) samples, three (3) of which were made of 12mm \emptyset and three (3) of 10mm \emptyset .

Timber formworks were fabricated to appropriate pre- determined sizes and linseed with oil internally to ensure that concrete does not stick on formwork sides. Steel cage beams were equally prepared and arranged in four sets based on four sources. After which steel cages were put into formworks in the order of their labels and source of steel reinforcing bars. This was followed by casting of concrete in predetermined mix ratios and consistency.

Beam formworks were then rebelled for easy identification and casted for 2 days in way that at least each source had 3 beams of different bar sizes casted on the same day as shown in table below.

RC beams labeling and casting schedule

RC Beams were labelled based on rebars source (S1 to S4), rebars size and beams from B1 to B6 as elaborated below.

Key: sample identification vs bar size

Y 12Beams	Y 10 Beams
B1	B2
B3	B4
B5	B6

Casted on 1st day

No	Specimens	Bar size
1	S ₁ B ₁	12mmØ
2	S ₁ B ₂	10mmØ
3	S ₁ B ₃	12mmØ
4	S ₂ B ₁	12mmØ
5	S ₂ B ₂	10mmØ
6	S ₂ B ₃	12mmØ
7	S ₃ B ₁	12mmØ
8	S ₃ B ₂	10mmØ
9	S ₃ B ₃	12mmØ
10	S ₄ B ₁	12mmØ
11	S ₄ B ₂	10mmØ
12	S ₄ B ₃	12mmØ

Casted on 2nd day

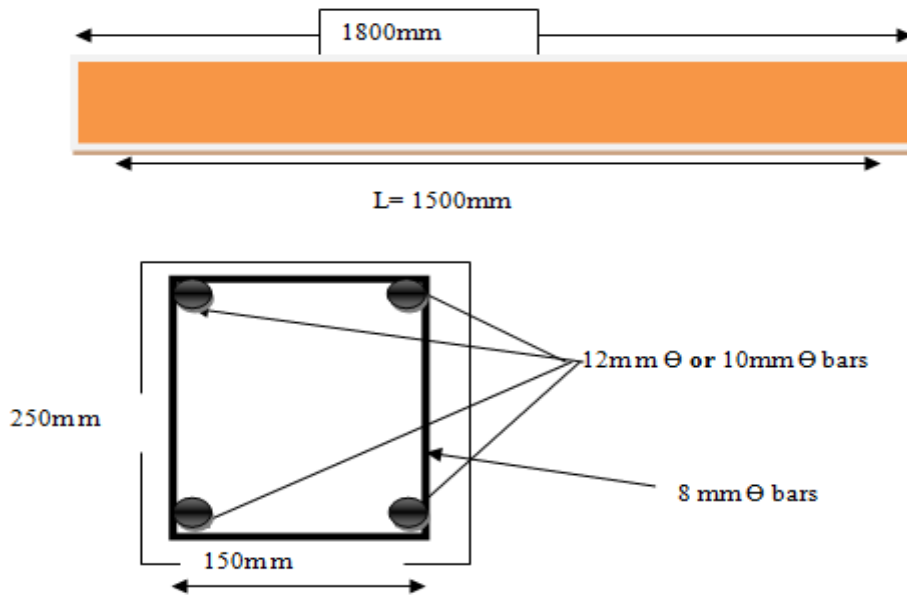
No	specimens size	Bar
1	S ₁ B ₄	10mmØ
2	S ₁ B ₅	12mmØ
3	S ₁ B ₆	10mmØ
4	S ₂ B ₄	10mmØ
5	S ₂ B ₅	12mmØ
6	S ₂ B ₆	10mmØ
7	S ₃ B ₄	10mmØ
8	S ₃ B ₅	12mmØ
9	S ₃ B ₆	10mmØ
10	S ₄ B ₄	10mmØ
11	S ₄ B ₅	12mmØ
12	S ₄ B ₆	10mmØ

After fixing steel cages in molds, concrete were placed and then vibrated using vibrator after 2 days they were removed out of formwork and beams rebelled as formworks were removed.

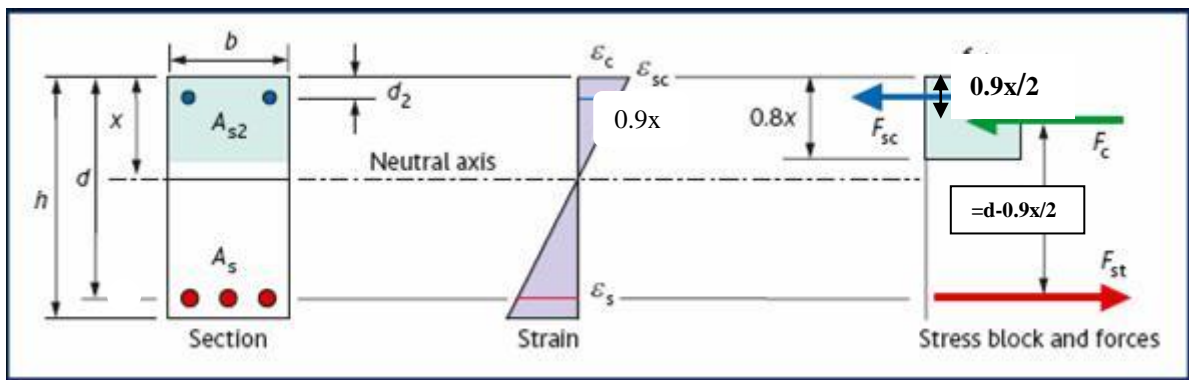
Before preparation of the RC beam specimens for testing, they were first designed based on BS 8110: 1997 to suit certain structural requirements for which reinforced concrete beams should be examined for and satisfy. Both flexural load and flexural strength were designed and compared with experimental results based on pre-determined beam size, shape, rebars' size and number hence the area. Beams were designed for ultimate limit state (ULS) and checked for serviceability limit state (SLS) and the general theory for ultimate flexural strength design took assumptions as stipulated in section 3.44 of BS 8110: 1997.

Primary information available for the RC beam design

	Design data	value
1	F_y	460 N/mm ²
2	F_{cu}	30 N/mm ²
3	Effective length (L) = overall length (1800mm) - over hangs (150mm x 2)	1500 mm
4	W	150 mm
5	h	250 mm
6	$d = h - \text{conc cover} - \frac{1}{2} \text{ bar} - \text{stirrup} = 2500 - 25 - 6 - 8 = 211$	211 mm
7	$A_s (12 \text{ mm } \emptyset) = (3.14 \times 6^2) 2 =$	223.9 m ²
8	$A's (12 \text{ mm } \emptyset) = (3.14 \times 6^2) 2 =$	223.9 m ²
9	$A_s (10 \text{ mm } \emptyset) = (3.14 \times 5^2) 2 =$	157 m ²
10	$A's (10 \text{ mm } \emptyset) = (3.14 \times 5^2) 2 =$	157 m ²
11	Steel rebars design strength = $F_y / \gamma_m = 460 / 1.15$	400 N/mm ²
12	Concrete design strength = $F_{cu} / \gamma_{mc} = 30 / 1.5$	20 N/mm ²



Design stress- strain block



Y12 Beams

$$M = WL^2/8 = 56.9 \text{ KNm}$$

$$\text{Design load (F)} = \omega \times \text{effective span} = 111.8 \text{ KN}$$

$$\text{Flexural strength } (\sigma) = Fl/bd^2 = 25.1 \text{ N/mm}^2$$

Y10 Beams

$$M = WL^2/8 = 40.2 \text{ KNm}$$

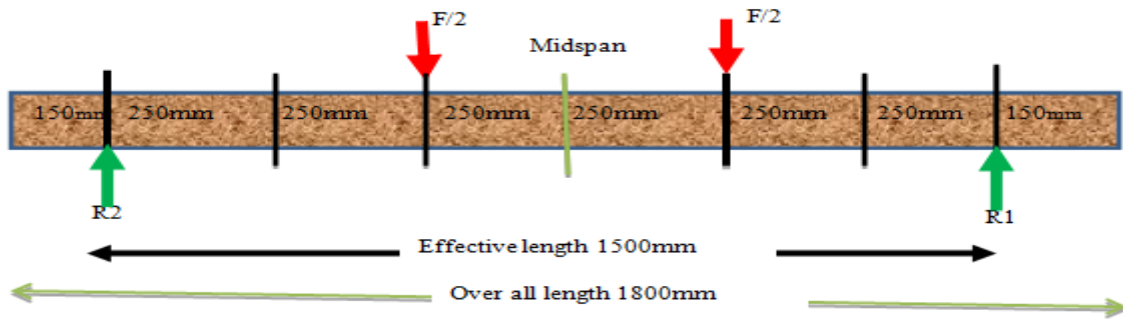
$$\text{Design load (F)} = \omega \times \text{effective span} = 78.2 \text{ KN}$$

$$\text{Flexural strength } (\sigma) = Fl/bd^2 = 17.6 \text{ N/mm}^2$$

Concrete mix design was also performed according to DOE (British) Mix Design Method, that is commonly used in Rwanda. The concrete mix ratio was obtained as 1: 1.5: 3, with water -cementation of 0.5 and plastic concrete slump of 50mm.

After 28 days of complete curing, reinforced concrete beam specimens were taken off curing materials and wiped off water and any loose substances on surface, then calibrated for the whole length of the beam.

RC Beam specimen calibrated for loading and testing



The scope of investigation of reinforced concrete beams were restricted to few parameters in order reduce number of variables low enough so as to achieve detailed and definitive conclusions. Simple rectangular beams of the same size with one method of loading, concrete of same mix ratio, same slump and same age of 28 days.

RC Beams after 28 days of complete curing



(a) Specimens ready for testing



(b) specimen under testing machine

The flexural test on the concrete beams was carried out on Universal Testing Machine (UTM), each of the specimens had a clear span of 1500 mm and over hangs of 150 mm. The load was applied vertically at the center of RC beam by a hydraulic jack which transmitted the load on to specimens through a steel spreader laid on two bearings on spaced at 500 mm top of the beam. Other instruments connected to the beam include: loadcell to measure applied load, strain gauge to measure surface strains, displacement transducer (LVDT) at mid span to monitor deflection of the beams at different incremental loadings, all of which were then connected to data logger which records the measured data.

Load was applied to beam until the first crack was noticed and corresponding load and deflections were recorded, and then regular intervals until the final collapse of the beam was reached. At the end of each load increment, the load was held constant, crack patterns were marked as shown in the figure below.

RC beam under flexural test connected to all instruments and developed flexural cracks



(c) Beam specimen (d) developed flexural cracks (e) Transducer (f) Hydraulic Jack (g) Load cell (h) Steel plate that distributes load evenly (i) Two bearing that transmits load into specimen

3. RESULTS AND DISCUSSION

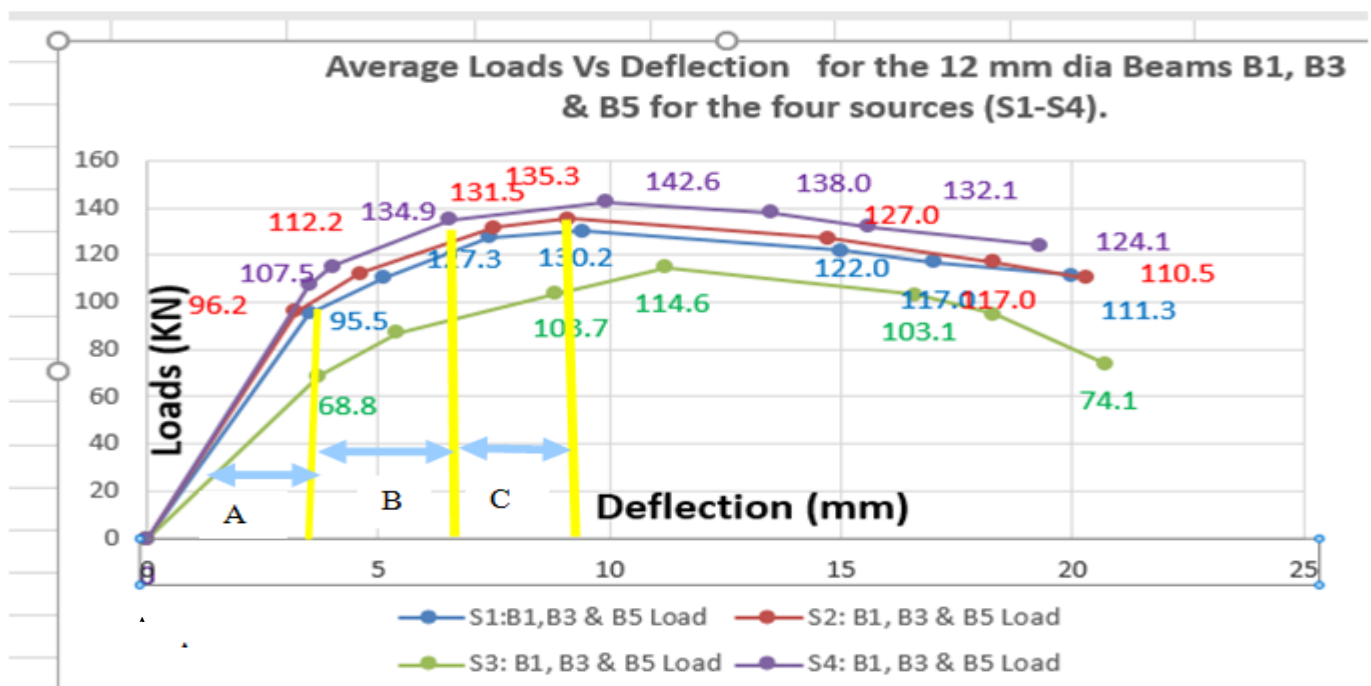
3.1 Ultimate Load results

(a) RC beam (12mm bars) average ultimate load - deflection results

S1: B1, B3 & B5		S2: B1, B3 & B5		S3: B1, B3 & B5		S4: B1, B3 & B5		Failure status
Deflection (mm)	Load	Deflection mm	Load KN	Deflection mm	Load KN	Deflection mm	Load KN	
0	0	0	0	0	0	0	0	
3.5	95.5	3.2	96.2	3.7	68.8	3.5	107.5	Cracking load (Pcr)
5.1	110.4	4.6	112.2	5.4	87.0	4.0	115.2	load at 2nd crack
7.4	127.3	7.5	131.5	8.8	103.7	6.6	134.9	Yield load (Py)
9.4	130.2	9.1	135.3	11.2	114.6	9.9	142.6	Ultimate load (Pu)
15.0	122.0	14.7	127.0	16.6	103.1	13.5	138.0	Descending loads 1st
17.0	117.0	18.3	117.0	18.3	95.1	15.6	132.1	2nd
20.0	111.3	20.3	110.5	20.7	74.1	19.3	124.1	3rd

Comparing above results with obtained design ultimate load of 111.8 KN, it is noticed that all experimental load superseded design ultimate load with sound safety margins apart from S3 beams which is very close to design load of 114.6 KN.

RC beam -12mm bars: load-deflection curve

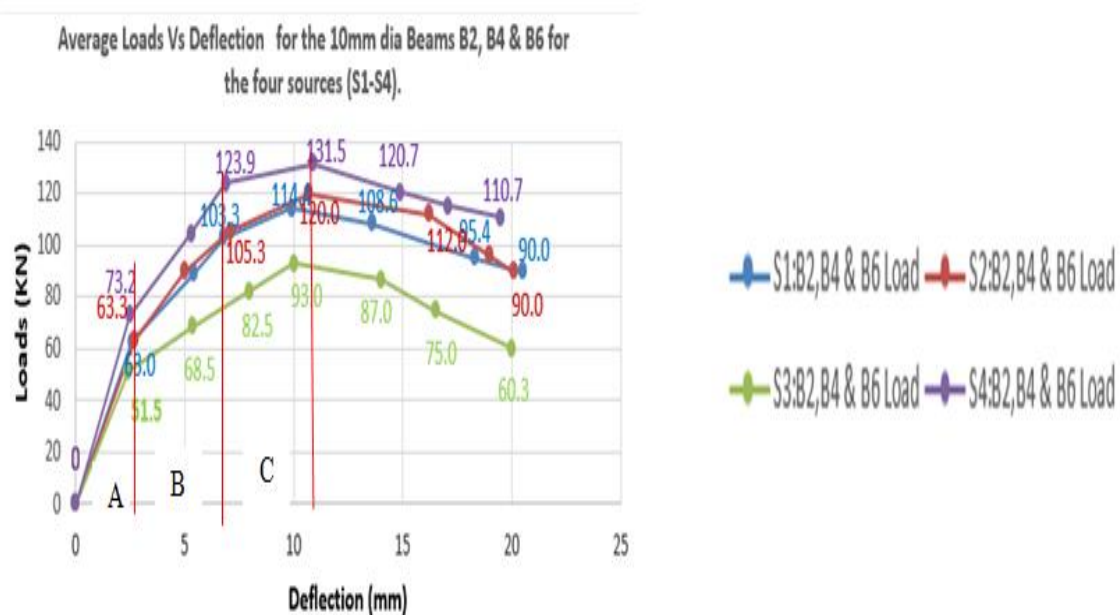


Regions A, B and C indicate three stages of loaded RC beam before total failure.

(b) RC beam (10mm bars) average load - deflection results

S1:B2,B4 & B6		S2:B2,B4 & B6		S3:B2,B4 & B6		S4:B2,B4 & B6		Failure status
Deflection	Load	Deflection	Load	Deflection	Load	Deflection	Load	
0	0	0	0	0	0	0	0	
2.6	63.8	2.7	55.8	2.4	51.5	2.5	73.2	Cracking load (Pcr)
5.4	89.0	5.0	79.0	5.4	68.5	5.3	104.6	load at 2nd crack
6.8	103.3	7.1	99.0	8.0	82.5	6.9	123.9	Yield load (Py)
9.9	114.4	10.7	107.7	10.0	93.0	10.9	131.5	Ultimate load (Pu)
13.6	108.6	16.2	99.9	14.0	87.0	14.9	120.7	Descending loads 1st
18.3	95.4	19.0	94.5	16.5	75.0	17.1	115.2	2nd
20.5	90.0	20.1	90.0	20.0	60.3	19.5	110.7	3rd

RC beam -10mm bars: load-deflection curve



In general experimental loads were found exceeding the design loads of (78.2 KN) with good safety margins, as may be seen from above table the least flexural experimental load is 93.0 KN for S3 and the difference with beams is not quite big as is the case of 12mm bars, . From the two load- deflections of beams Y12 and Y10 shown above it is noticed that:

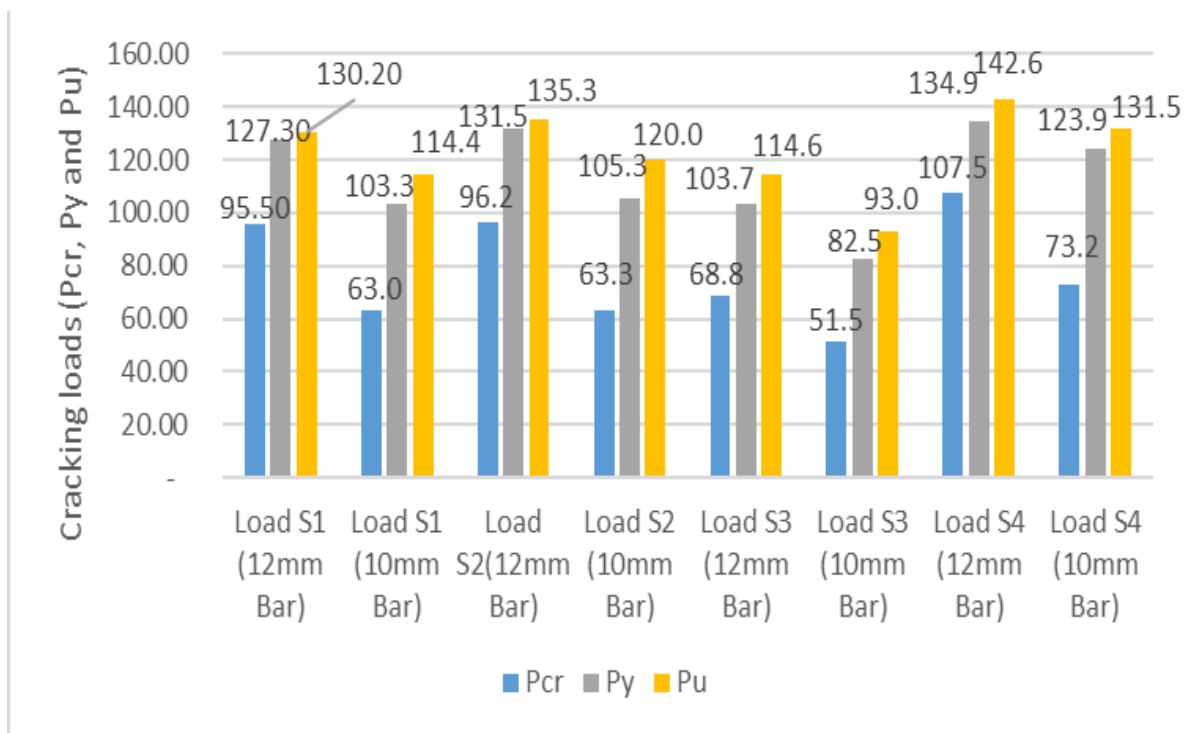
In this region A, before any crack or pre-cracking state, beams are still elastic in nature where loads are directly proportional to deflection. In this region both steel and concrete serve the purpose of carrying the applied loads.

In region B, after 1st crack, beams become semi- elastic, a situation where proportionality is lost. Deflection is a little bit higher at an equal loading increment as compared to pre-cracking state. At this point steel is said to have started yielding with yield load (Py). Concrete starts losing the strength to support the applied which goes to steel.

In this region C, this is situation where beams are said to be in a plastic state, cracking intensity becomes rampant leading to total failure. The neutral axis in this zone translates to the compressive edge of cross section, until the full cracking of the concrete in the critical cross section compression zone appears. Consequently the beams fails

Applied loads Vs progressive cracks on different RC beam bar sizes

	Load S1 (12mm Bar)	Load S1 (10mm Bar)	Load S2(12mm Bar)	Load S2 (10mm Bar)	Load S3 (12mm Bar)	Load S3 (10mm Bar)	Load S4 (12mm Bar)	Load S4 (10mm Bar)
Pcr	95.50	63.0	96.2	63.3	68.8	51.5	107.5	73.2
2nd crack	110.40	89.0	112.2	90.1	87	68.5	115.2	104.6
Py	127.30	103.3	131.5	105.3	103.7	82.5	134.9	123.9
Pu	130.20	114.4	135.3	120.0	114.6	93.0	142.6	131.5



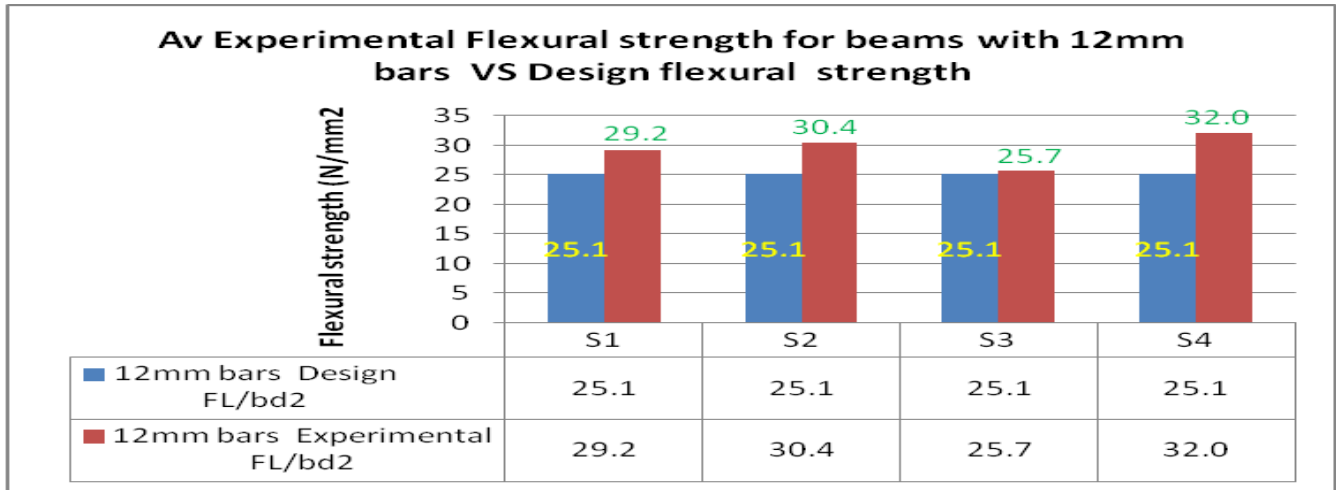
Comparing loads applied to beams with their subsequent cracking to failure effect (1st crack (Pcr), yield load (Py) and finally ultimate load (Pu), it is clear that same loads would cause different effect on different beams. For instance loads that would result into 1st on S4 beams would cause a more dangerous structural effect of yield on S3 beams. **Pcr (S4₁₂) > Py (S3₁₂)**. It is also important to note that some Y10 beams would serve purpose better than Y12 beams.



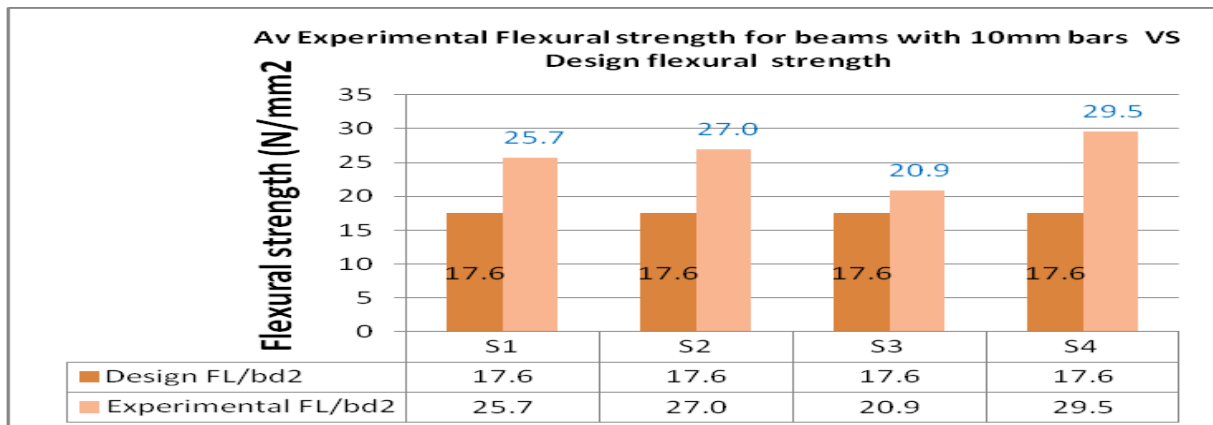
3.2 RC beam Flexural strength results

(a) Y 12 beams

Experimental flexural strength VS flexural design strength Y 12 beams



(b) Y 10 beams



Again like flexural loads, experimental flexural strength of Y12 beams supersedes the design flexural strength with some good safety margin apart from S3 beams whose values are very close 25.7 VS 25.1 N/mm². However, this is different from Y10 beams where experimental flexural strength supersedes the design flexural strength with good safety margin. The least being 20.9 N/mm² as opposed to 17.6N/mm². Further analysis is on Y12 beams VS Y10 beams flexural strength results, as may be observed from two graphs Y10 beam experimental flexural strength, some Y10 beam exhibits more strength than Y12 beams while some Y10 beams exhibits if larger strength.

$$S1\text{-Y10 beam } (\sigma) = S3\text{-Y12 beam } (\sigma)$$

$$\begin{array}{l}
 \text{And} \\
 S2\text{-Y10 beam } (\sigma) \\
 S4\text{-Y10 beam } (\sigma)
 \end{array}
 \left. \vphantom{\begin{array}{l} S2\text{-Y10 beam } (\sigma) \\ S4\text{-Y10 beam } (\sigma) \end{array}} \right\} > S3\text{-Y12 beam } (\sigma)$$

Further assessment of the RC beam flexural performance results in comparison with other results from previous studies in literature review of the same 12mm bar sizes and number, it is observed that the ultimate loads were in the same range of between 85 KN to 124 KN for one of the experiments, the other experiments had 112.2 KN, the 3rd one had 117.6 KN which is comparable the current research results that ranged between 114.6 KN to 142.6 KN. The 4th experimental results which

was for 10 mm bars gave 95 KN which in range of our research experiment results for the same bars size that ranged from 93KN to 131 KN. The flexural strength obviously depends on beam cross section area and the length.

Conclusion and Recommendation

- a) The flexural load of RC beam made of Y12 mm was determined to be in range of 114.6 KN to 142.6 KN while their respective flexural strength ranged from 25.7 N/mm² to 33.4 N/mm² as compared to design load of 111.8 KN and design flexural strength of 25.1 N/mm² respectively.
- b) The flexural load of RC beam made of Y10 mm was found to be in range of 93 KN to 131.5 KN while their respective flexural strength ranged from 20.89N/mm² to 32 N/mm² as compared to design load of 78.2 KN and design flexural strength of 17.6 N/mm² respectively.
- c) Despite poor performance of steel reinforcing bars as observed in previous study, their concrete beams reinforced with them rebars have performed well meeting the expectations, this may resulting from concrete strength general contribution to the overall beam flexural performance.

Recommendations

Further research is recommended on the concrete strength contribution to RC beam flexural strength, further research is also recommended on other different bigger sizes of steel bars such as 16 and 20 mm Θ available in Rwanda, which are frequently used as well.

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