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Experimental Investigation on the Impact of Longitudinal Rebar Ratio on the Cracking Characteristics of R/C Components

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Abstract **-** Cracking phenomenon in reinforced concrete members has troubled researchers and engineers worldwide due to the many mechanical parameters affecting this phenomenon. One such mechanical parameter is the longitudinal reinforcement ratio used for the detailing of structural components in reinforced concrete structures. Although, the percentage of rebar content has been studied, it is the first time that cracking behaviour is studied using varying ratios of rebars strained under a uniaxial tensile loading till a high degree of elongation found only at buildings sustained severe earthquake actions. This research is experimental. Four test specimens in the form of R/C ties are used and strained using a monotonic uniaxial tensile loading simulating the tensile type of loading during the first cycle of dynamic seismic action. All specimens are strained till an elongation degree equal to 30‰. The ratios used for the reinforcement of column specimens take values equal to 1.79%, 4.02%, 5.47% and 7.15%. Significant conclusions are reached concerning cracking behaviour for different longitudinal ratios, e.g., number of cracks, crack width, etc.

Keywords**:** Longitudinal Ratio, Cracking, Components, Width

1. Introduction

Several international researchers have explored the phenomenon of cracking in reinforced concrete structures [1–5]. Although most of the given structures are typically reinforced in two directions, most studies carried out worldwide to investigate the behaviour of cracking have involved uniaxially strained reinforced concrete members with reinforcement in only one direction. To date there is not yet a widely established and accepted methodology for predicting cracking characteristics, e.g. crack widths and spacings between cracks [6–9]. In addition, most of the existing research conducted has been strictly limited to the state of the stabilized crack pattern only and does not involve cracking behaviour and crack characteristics deep in the yield region [10], [11]. It has to be noted the fact that cracking can occur in several situations, e.g., transverse buckling of R/C structural walls or retaining walls under cyclic seismic loading [12–15], phenomena appearing due to soil-structure interaction [16], [17], etc. The cost of repairing the cracking and the possible resulting corrosion to the reinforcement bars is something which needs to be taken into account by consulting engineers, too [18–21]. Furthermore, cracking can reduce the load-bearing capacity of R/C members [9], [22], [23].

In the framework of the current study, an experimental program has been conducted involving reinforced concrete members detailed in two directions using longitudinal rebars and transverse reinforcement in the form of ties. This is a common construction practice used, in at least, the vast majority of concrete structures. As per the results outlined within this work, cracking behaviour and the crack characteristics are discussed. Afterwards, the aforementioned experimental results are analysed and the results of the analysis given in the form of diagrams are discussed. Useful conclusions concerning cracking for different longitudinal reinforcement ratios are derived.

2. Experimental Program

The current experimental program consists of four test specimens. The thickness of each specimen is 7.5 cm and the length of the cross-section is 15 cm. The ratio between the length and the thickness of the cross-sectional area is equal to 2, which is a typical ratio for constructing reinforced concrete columns. The total height of the test specimen is equal to 90 cm. Each of the four specimens is subjected to a uniaxial central tensile loading. The main test element is between the metal plates and its height is 64 cm (Figure 1). A universal testing machine was used to apply the load. The nominal degree of elongation for all specimens is 30.00‰. Figure 2 displays the experimental configuration for imposing the central tensile load. The rate of loading was slow, of the order of 4 mm/min, so no result was affected by the influence of the strain rate [24–28].

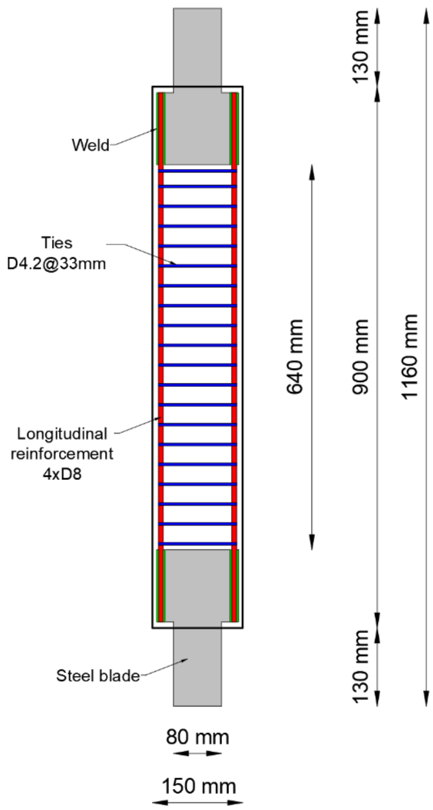


Figure 1: Vertical reinforcement layout for specimen reinforced with 4xD8.

Figure 2: Loading test configuration.

Table 1 shows the geometrical and detailing characteristics of all four specimens. All four segments tested here have been worked on in two directions through deformed bars in terms of reinforcement. The reinforcement for the first two prisms simulates a typical reinforcement found in the reinforced concrete columns of typical construction buildings or in the confined boundaries of reinforced concrete seismic walls but for the last two prisms, the reinforcement is higher than the biggest rebar ratio allowed by codes due to research reasons. The construction scale used to simulate typical columns or typical confined boundaries was equal to 1:3, commonly used for research purposes worldwide [29], [30].

The degree of elongation is equal to 30.00‰ for all specimens. The transverse reinforcement consists of transverse ties placed along the height of the prism. The centre-to-centre distance between two ties is about 3.3 cm and the diameter of each tie is 4.2 mm. The only variable differentiating specimens from each other is the longitudinal reinforcement ratio. The rebar percentage takes values equal to 1.79%, 4.02%, 5.47% and 7.15%. It is well known that in real constructions, longitudinal ratios up to 4.00% are allowed [31–35]. However, there is also, of course, the research interest itself, in examining what happens to cracking characteristics and their behaviour when such rebar percentages are used.

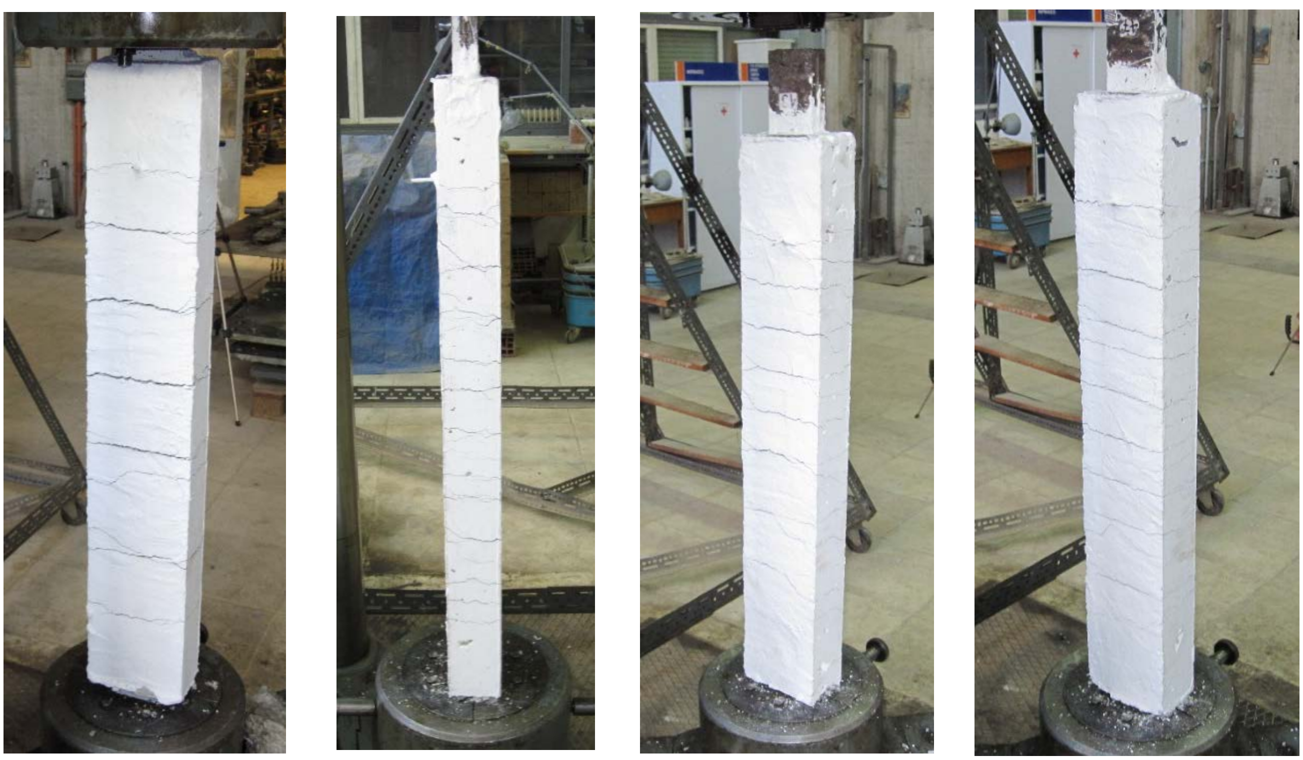
Table 1: Properties of prism specimens

N/A	Specimen name	Length (cm)	Thickness (cm)	Effective height (cm)	Longitudinal reinforcement	Longitudinal reinforcement ratio [ρ_l] (%)	Transverse reinforcement	Nominal tensile strain (‰)
1	C-1.79-4Ø8	15	7.5	64	4xD8	1.79	D4.2@33 mm	30.00
2	C-4.02-4Ø12	15	7.5	64	4xD12	4.02	D4.2@33 mm	30.00
3	C-5.47-4Ø14	15	7.5	64	4xD14	5.47	D4.2@33 mm	30.00
4	C-7.15-4Ø16	15	7.5	64	4xD16	7.15	D4.2@33 mm	30.00

3. Results and Discussion

3.1. Experimental Findings

After conducting the tensile experiments, different cracking formations and eventually cracking characteristics were noticed for each specimen. Figure 3 shows the state of each specimen after the end of the uniaxial tensile test. Cracks of various widths are obvious for the four specimens detailed with variable longitudinal reinforcement ratios. It is apparent that the final cracking formation differs between the specimens, depending on the longitudinal rebar percentage they are reinforced with.



(a) **(b)** **(c)** **(d)**

Figure 3: Specimens after the uniaxial tensile test: (a) C-1.79-4Ø8, (b) C-4.02-4Ø12, (c) C-5.47-4Ø14, (d) C-7.15-4Ø16.

3.2. Analysis of Experimental Findings

The results of the analysis of the test findings for all segments are brought together in the following table and Table 2 presents the width characteristics of the cracks. Figure 4 displays the variation of the crack width characteristics. Figure 5 – Figure 8 use column charts to display the results for the same type of cracking characteristics, e.g., maximum width, average width, etc.

Table 2: Crack width characteristics.

N/A	Specimen	Number of cracks [N]	Minimum crack width [W_{min}] (mm)	Maximum crack width [W_{max}] (mm)	Average crack width [W_{ave}] (mm)	W_{min}/W_{ave}	W_{max}/W_{ave}	W_{max}/W_{min}
1	C-1.79-4Ø8	8	1.3	4.3	2.813	0.46	1.53	3.31
2	C-4.02-4Ø12	10	0.7	3.0	1.830	0.38	1.64	4.29
3	C-5.47-4Ø14	12	0.6	2.3	1.485	0.40	1.55	3.83
5	C-7.15-4Ø16	13	0.5	1.5	1.125	0.44	1.33	3.00

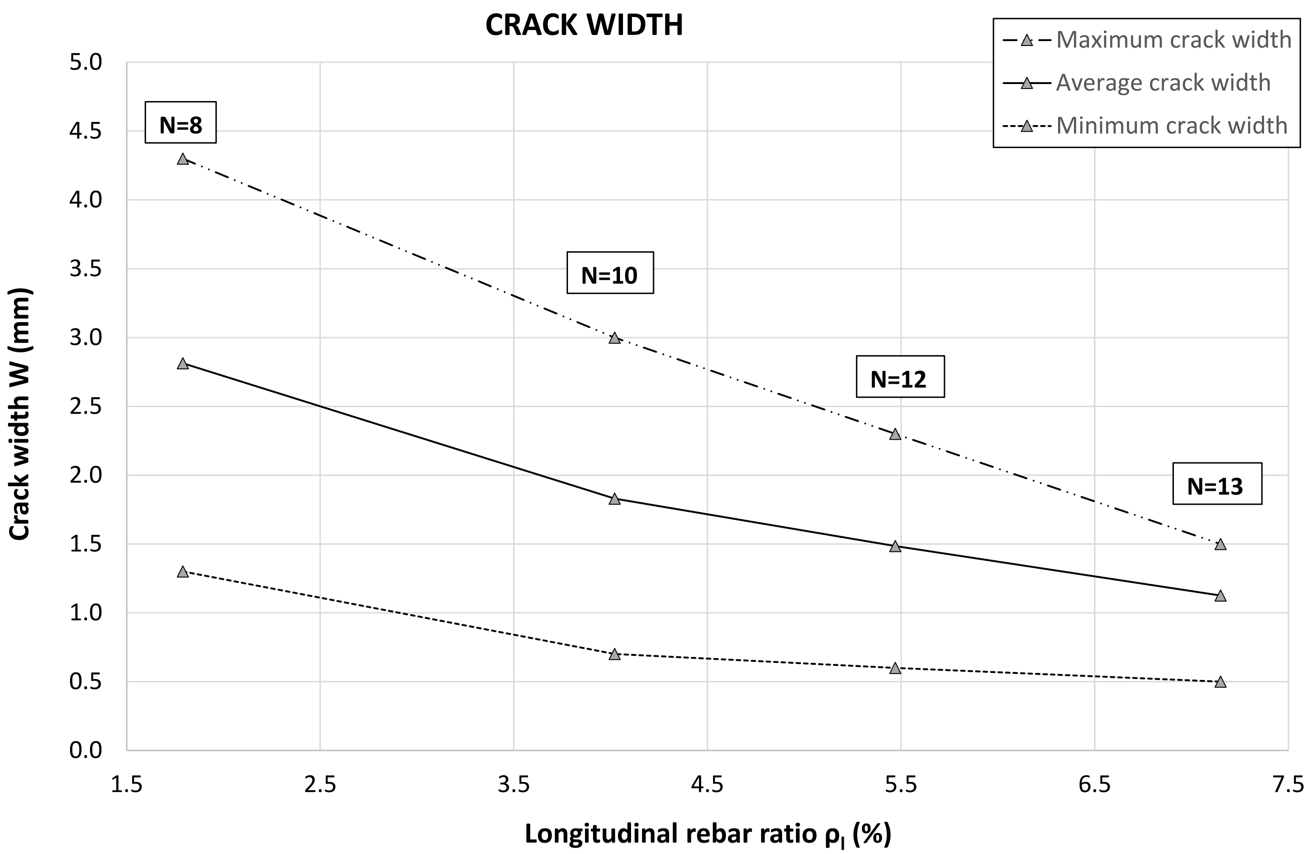


Figure 4: Variation of crack width relative to the longitudinal reinforcement ratio.

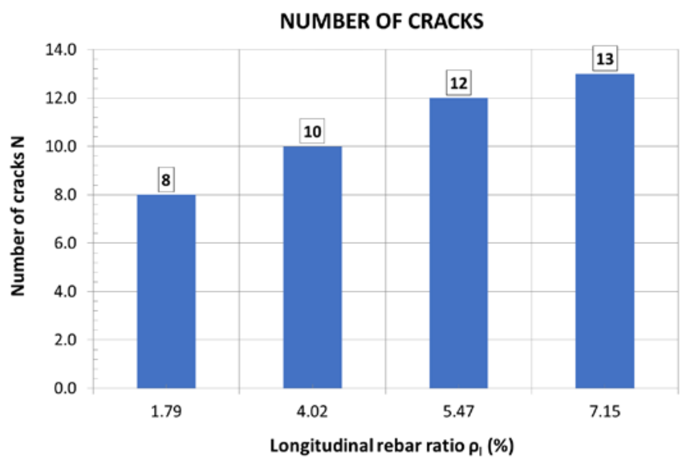


Figure 5: Column chart of number of cracks regarding the longitudinal rebar ratio.

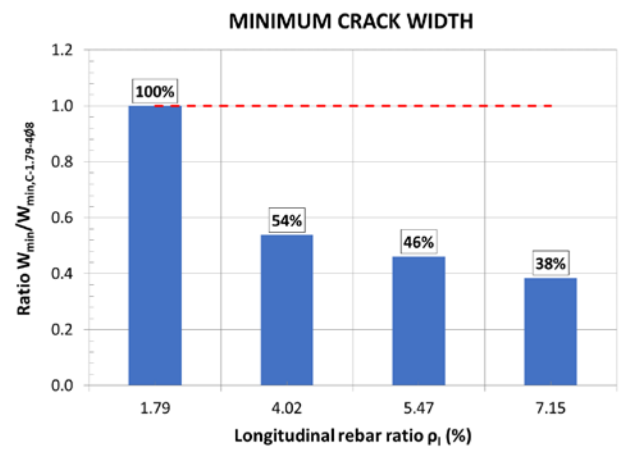


Figure 6: Column chart of minimum crack width as a percentage of the minimum crack width of the reference specimen.

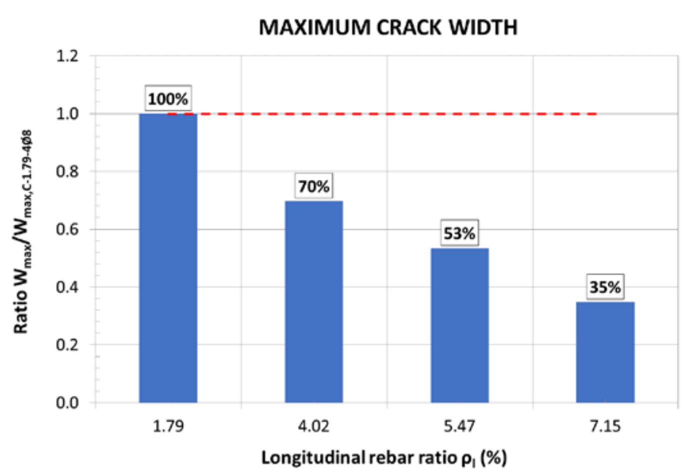


Figure 7: Column chart of maximum crack width as a percentage of the maximum crack width of the reference specimen.

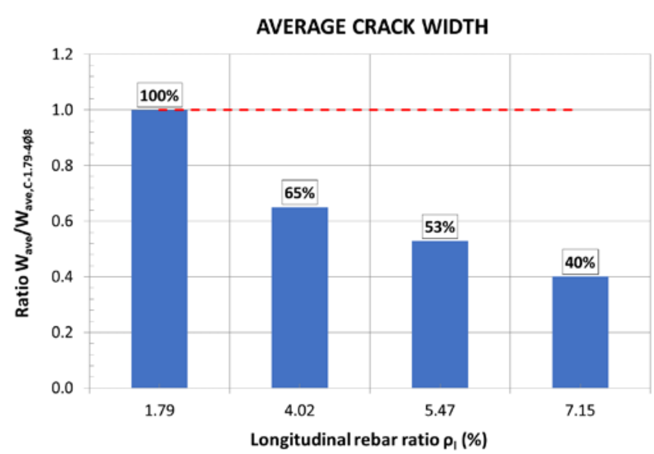


Figure 8: Column chart of average crack width as a percentage of the average crack width of the reference specimen.

The experimental findings of the test specimens were then analysed and evaluated:

1. Comparing the number of cracks formed according to the longitudinal rebar ratio each specimen is detailed with, it is obvious that the number of cracks formed increases with the increase of the longitudinal reinforcement ratio used (Table 2, Figure 5). For a better understanding of this phenomenon, more experiments concerning different longitudinal reinforcement ratios and arrangements of rebars need to be performed.
2. Comparing the crack width with the rebar ratio used, it can be seen that the width becomes smaller as the rebar ratio used increases (Table 2, Figure 4). It is noteworthy that all types of crack width decrease with the increment of the rebar ratio – meaning the minimum, maximum and average crack width.

3. Specimen C-1.79-4Ø8 is characterized as the reference specimen. It is noticeable that although the rebar ratio (7.15%) is about four times greater for specimen C-7.15-4Ø16 compared to the rebar ratio of the reference specimen (1.79%), the decrease for the minimum crack width is three times less compared to the crack width of the reference specimen.
4. The decrease of the minimum widths, the maximum widths and the average widths is about of the same order for all three specimens compared to the reference specimen.
5. The damage state of specimens indicates that cracks appear at or near to the tie positions (Figure 3). Thus, the presence of steel ties helps and promotes the disorganization of concrete around them.

4. Conclusions

This paper looks at four specimens to investigate cracking formation and behaviour in terms of crack characteristics for variable longitudinal reinforcement ratios. The following conclusions are drawn:

1. The degree of rebar ratio holds a significant part in terms of the formation of cracks and their characteristics, e.g., the number of cracks formed and the width of cracks.
2. Higher percentages of reinforcement result in cracks with smaller widths. Thus, the design of reinforced concrete structural components should take into account the ratio of longitudinal reinforcement because, as it is well known, large crack widths can lead to oxidization and deterioration of rebars and eventually affect structural safety.
3. The question arises whether, apart from the longitudinal ratio, the arrangement of rebars plays an essential role, too. Further research is needed on the subject using test specimens with different longitudinal reinforcement ratios and arrangements. This will help to check the impact that the mechanical factor of rebar arrangement has.

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