*- Technical Paper -*

# ANCHORAGE LENGTH IN TEXTILE REINFORCED CONCRETE BEAMS SUBJECTED TO BENDING MOMENT

Bui Si MUOI[*1] and Minoru KUNIEDA[*2]

ABSTRACT
Textile Reinforced Concrete (TRC) has emerged in recent years as a promising material used to repair and/or strengthen structural elements of existing construction works. A practical application of TRC is, however, hindered by the lack of standardized specifications regarding the anchorage length of textile reinforcement. This study aims to investigate the flexural failure behavior of TRC beams with an anchorage zone, and therefore providing knowledge for further research on determining development length. The result showed that the development length should be more than or equal to 300 mm.
Keywords: Textile reinforced concrete, TRC, anchorage length, development length

## 1. INTRODUCTION

Reinforced concrete is considered as one of the most important construction materials. However, in addition to the advantage of mechanical behavior and low-cost fabrication, this material has historically shown disadvantages in terms of durability due to corrosion of re-bars. For this reason, new materials providing higher mechanical performance, long-term durability as well as sustainability are becoming a major driving force for innovation in the construction industry. At present, Textile Reinforced Concrete (TRC) has emerged as an alternative to traditional construction material [1]. TRC is a concrete or mortar matrix reinforced by multi-axial noncorrosive textile fabrics. The innovative attributes offered by TRC spans over a wide range, including favorable mechanical performance, high corrosion resistance, and longer life service [2]. Therefore, TRC is very suitable for the production of structural and nonstructural elements, such as road and pedestrian bridges, and silos as well as façades and/or sandwich panels. Furthermore, a thin layer of TRC with very high tensile strength is possible for repairing or strengthening of existing structures [3].

In terms of the promising application of TRC, the practical use of this new material needs structural detailing provisions including anchorage length of textile reinforcement. The fundamental requirements of strength and robustness of a TRC structure cannot be met unless the tensile reinforcing bars at each critical section are sufficiently anchored on both sides of the critical section. The anchorage on each side of a critical section must ensure that the bar force is fully transferred to surrounding concrete through bond. The minimum required length of anchorage to develop such a condition is known as the development length (required for the anchorage of a reinforcement, also referred to as "anchorage length").

In the literature, some researches were conducted on investigating structural behavior and determining the anchorage length of TRC members. However, most investigations were carried out with specimens subjected to uniaxial tensile load. Lorenz and Ortlepp (2009) conducted tensile tests by using specimens with varying numbers of textile fabric. The experiments aimed to verify the possibilities of shortening the required anchorage length of textile structures to avoid extract failure within the textile layer. A test setup was proposed. At the upper end of the test configuration, the specimen was clamped between two sufficiently stiff steel plates using a bolt connection. At the lower end of the specimen, there have been glued steel sheets onto both sides of the examination area. The results of the research showed that the development length of the original textile fabric was 80 mm. The verification of the effectiveness of an epoxy resin coating revealed a decrease of the required anchorage lengths by 50 % to 40 mm. Two failure modes were observed: yarn fracture could be seen at sufficiently bound filament yarns and too short anchorage lengths resulted in yarn extractions [4].

In 2018, Ortlepp proposed an adaptive test method to determine development length of TRC members under tensile force. The idea was to minimize the number of specimens per testing series for economic reasons. At the lower end of the specimen, a cone-shaped was using to give the opportunity for such an optimization. With this configuration, different anchorage lengths were examined by the use of just one specimen. Based on the results of the test, three failure modes were observed including yarn fracture, pull-out, and delamination failure. Specimens with delamination failure can be identified as safe against a pullout failure [5].

As mentioned above, most researches on anchorage length of TRC members were carried out under uniaxial tensile loading. However, the conditions favorable for the development of bond stress in the tensile tests are very rarely present in practical TRC members, where the situation is more complex due to the presence of one or more cracks crossing the anchorage length. In addition, factors such as splitting, diagonal tension, shear force, and the change of moment along the anchorage length may lead to more

*1 Graduate School of Engineering, Gifu University, JCI Student Member
*2 Prof., Dept. of Civil Engineering, Gifu University, JCI Member

complicate flexural behavior within the anchorage zone of flexural members. As a result, the determination or estimation of flexural development length based on the result of the tensile test is not reasonable and reliable. Therefore, this research aimed to interpret the flexural failure behavior of the anchorage zone and determine the development length of TRC beams through a four-point bending test.

## 2. TEST PROGRAMS

### 2.1 Materials description

(1) Mortar

The mortar used for TRC must meet special demands regarding production processes, mechanical properties of binders, and durability of the textile reinforcements. Typically, to ensure the sufficient penetration of mortar into the textile, the mortar must have highly flowable fresh property. This special property is achieved by using a small aggregate, high binder contents, adding pozzolanic additives, and superplasticizer. This leads to a more homogeneous and finer structure compared to ordinary concrete. The examined specimens were fabricated of mortar according to the mix proportions described in Table 1. The physical and mechanical properties of mortar are compiled in Table 2.

Table 1 Composition of used mortar

| Composition | Mass rate (-) | Quantity (kg/m$^3$) |
|---|---|---|
| High early strength cement | 3.00 | 518 |
| Fly ash | 1.00 | 173 |
| Sand | 8.00 | 1380 |
| Water | 1.00 | 173 |
| Super plasticizer | 0.04 | 7 |

Table 2 Mechanical properties of the mortar

| Characteristics | Unit | Value |
|---|---|---|
| Density | kg/m$^3$ | 2335 |
| Compressive strength | N/mm$^2$ | 75.3 |
| Tensile strength | N/mm$^2$ | 7.8 |
| Elastic modulus | kN/mm$^2$ | 36.5 |

(2) Textile reinforcement

The textile reinforcement mesh in this study was stitch-bonded biaxial fabric with an equal quantity of fiber rovings in two orthogonal directions [0°/90°] (Fig. 1). The textile fabrics consisted of two types of carbon filament yarns, the longitudinal yarn (warp yarn) and the transverse yarn (weft yarn). The mesh size was 10 mm and 8.5 mm in warp and weft directions, respectively. At the joint points, knitting threads were used to hold the rovings together in a stable manner. Each roving contained thousands of small filaments. Hence, bundling the filaments with their small diameters causes microscopic hollow spaces between the fibers, so that small or even the finest concrete particles cannot penetrate them. For improving adhesion at the interphase layer of roving and mortar as well as enhancing the uniform stress distribution between individual filaments, a secondary coating layer – Styrene butadiene – was utilized to coat textile reinforcement. The impregnation mix is far finer than the concrete, can penetrate deep into the core of the roving and can activate the inner filaments for load dissipation as well. Besides, impregnating the carbon reinforcement, therefore, makes it possible to systematically achieve the required characteristics, such as tensile stress at break and permanency [5]. Properties of roving including the cross-sectional area of individual roving, the distance between two adjacent rovings and mechanical properties are shown in Table 3.

Table 3 Properties of roving

| Type of yarn | Cross-sectional area (mm$^2$) | Roving distance (mm) | Tensile strength (MPa) | Elastic modulus (GPa) |
|---|---|---|---|---|
| Warp/weft | 1.91 | 12.5 | 1700 | 140-200 |

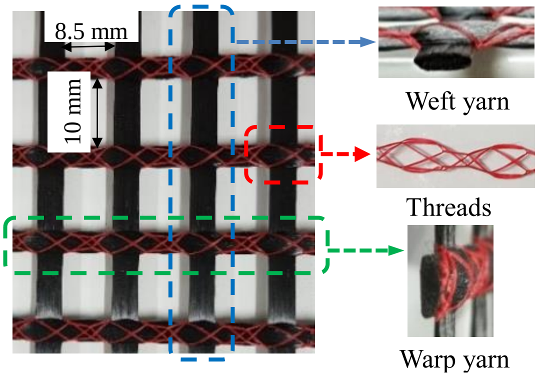



Fig.1 Textile fabric used

### 2.2 Specimens

The TRC specimens with a dimension of 200 mm x 1200 mm x 100 mm were cast into metal formworks. The textile fabric, rebars, and mortar layers were placed into the formwork alternately with a mortar layer in its bottom and top. At first, a thin layer of mortar of 20 mm was poured into the formwork. Then, the textile fabric was placed on the top of the mortar layer. Special attention was the longitudinal yarns were set along the length of formworks and the anchorage zone was arranged in the middle of specimens. Afterward, three rebars with a diameter of 10 mm were used to reinforce the beams. Plastic spacers were used to keep the accuracy of a concrete cover thickness of 30 mm. Finally, the remaining mortar layer with a thickness of 80 mm was poured into the formwork. All specimens were cured in a constant temperature room (20ºC) for 28 days. Five series of specimens were fabricated. The test specimen properties including geometrical details, the number of specimens and the value of anchorage length have been listed in Table 4. In particular, series L0 was made from continuous textile fabric without any rebars.

Before the test, textile fabrics were stuck to specimens by glue. These textile layers partly covered specimens to isolate the anchorage zone and prevent the failure that might form outside the constant moment zone. The dimension and location of these covered textile layers were described in Fig.2. Besides, a notch was sawn by means of a diamond saw with a depth of 5 mm at the soffit of each specimen. The position of the notch coincided with the discontinued point of the rebars. This means that the distance between the notch and discontinued point of textile fabric was the anchorage length of the considered specimen. Pre-determined cracks initiated at the position of the notch. If the notches were not created, the primary cracks would form randomly in the pure moment area resulting in the variation of anchorage length. For control specimens (series L0), the notch located at one of two bottom edges of the constant moment zone.

Table 4 Test series

| Series | Anchorage length $L_a$ (mm) | Dimension (mm) | Quantity |
|---|---|---|---|
| L0 | - | 200 x 1200 x 100 | 2 |
| L50 | 50 | 200 x 1200 x 100 | 2 |
| L100 | 100 | 200 x 1200 x 100 | 2 |
| L200 | 200 | 200 x 1200 x 100 | 2 |
| L300 | 300 | 200 x 1200 x 100 | 2 |

## 2.3 Test setup

As illustrated in Fig.3, four-point bending tests were conducted on test specimens where the middle part of the beams was subjected to pure bending. The anchorage zone was located in the middle zone to eliminate the effects of shear actions on the results. The test setup was designed to provide simple supports at both ends of the beams. Two-point loads were applied to the top face of the specimens through a spreader beam using an actuator. The distance between two point loads was 300 mm. On the top of the spreader beam, a load cell with a capacity of 100 kN was utilized to measure applied loads. Two LVDTs were employed at the bottom surface to record the deflection at the sections that load applied. Two other LVDTs were placed on the top surface to measure the displacements at the section of supports

## 3. RESULT AND DISCUSSION

The results of the four-point bending test on TRC members in terms of failure mode, failure load, and corresponding displacement were reported in Table 5. Furthermore, the load-deflection relationship of five series was described in Fig.4. It is obvious, the load-bearing capacity of flexural specimens increased steadily with the increase of anchorage length. Series L300 has an average bearing capacity of 17.2 kN which is much greater than the average failure loads of series L200, L100, and L500. Also, the results show that the failure loads of both series L300 and L0 are approximately equal and their flexural behavior is almost the same. These indicate that the development

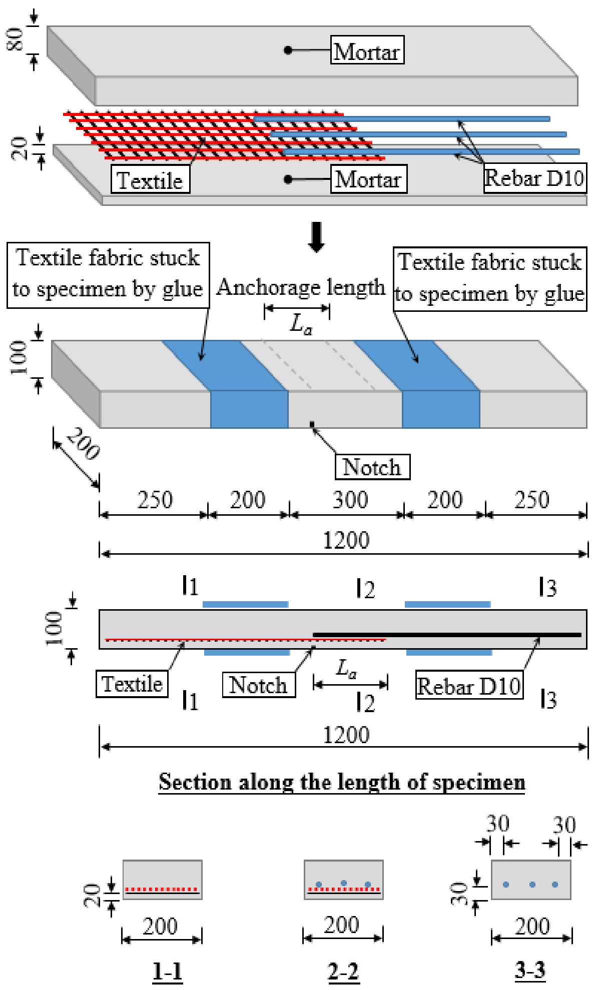



Fig.2 Sketch of specimen used for flexural test

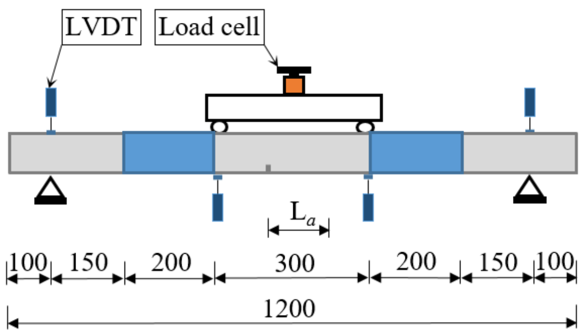


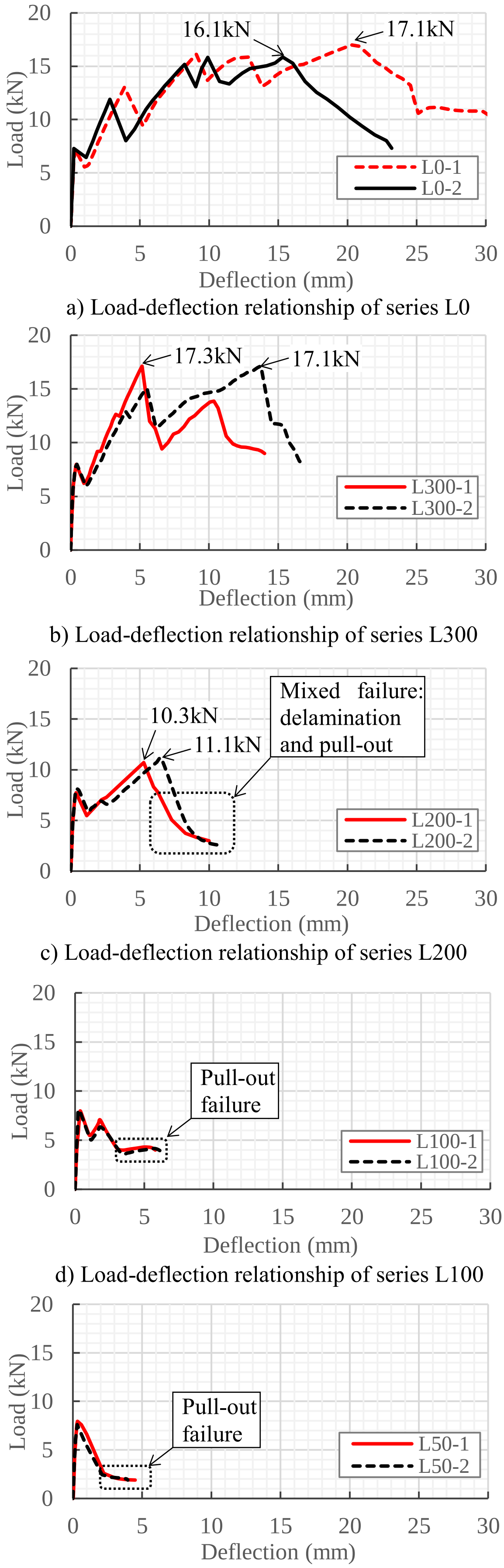

Fig.3 Sketch of test setup

length of 300 mm could effectively transmit the tensile force from textile reinforcement to surrounding concrete. Besides, different failure modes were observed including pull-out, delamination, and mixed failures, but the fracture of the textile itself did not occur.

For control series L0, the flexural behavior of specimens with continuous textile reinforcement was described in Fig.4a. The deflection increased linearly together with the increase of applied load in the elastic stage of the uncracked specimens. The first crack initiated at the position of the notch when the ultimate tensile strain of the concrete at the edge of the tension zone had achieved. The load-displacement curve fluctuated during the formation of secondary flexural cracks within a constant moment zone. The dominant failure of this series was delamination/longitudinal concrete splitting between textile and concrete. Furthermore, this delamination failure occurred outside the pure flexural zone as shown in Fig.7b.

The results showed the anchorage length of 50 and 100 mm (Series L50 and L100) was not enough to guarantee the complete transfer of tensile stresses from the textile fabric to surrounding concrete and the dominant failure mode was pull-out. All specimens of these two series had unique crack formed at the position of the notch, and the extraction of the yarns was accompanied by the widening of this crack (see Fig.5). The load-deflection relationship of series L100 in Fig.4d presents the typical characteristics of pull-out failure. Firstly, the deflection increased almost linearly with the increase of the applied load. When the concrete reached tensile strength, a crack initiated at the position of the notch and the applied load suddenly dropped. As the concrete lost the load-bearing capacity, the mechanical bond between the concrete and reinforcement was activated that was depicted by an ascending branch of the load-deflection curve. After reaching the bond strength, the destruction of the mechanical bond occurred due to debonding of the yarn from the matrix. As a result, the failure due to yarn extraction happened. Simultaneously, there is a significant increase in the relative displacement between textile reinforcement and mortar. Lastly, the friction mechanism between textile reinforcement and surrounding concrete was contributed to the bond strength resistance, which was identified by a considerable plateau. These pull-out characteristics are similar to those of members under a uniaxial force that was addressed in several pieces of research [6-8]. Decreasing the anchorage length to 50 mm resulted in a slight change in the flexural behavior of series L50. Shorter anchorage length led to smaller bond strength. Therefore, series L50 was vulnerable to the damage under the impact of crack propagation. As shown in Fig.5, the extraction of textile yarns from concrete occurred immediately after the cracking of concrete and the second peak was almost not observed. Besides, the results of the two series showed that the average applied load during the pull-out phase was proportional to the anchorage length of the textile reinforcement. The applied load of series L50 was 2 kN which is half that of series L100.

For series L200, increasing the anchorage length to 200 mm led to the significant increase of load-bearing capacity compared to those of series L100 and L50. Series L200 failed in flexure at an average load of 10.7 kN, greater than the failure loads of series L100 and L50. Besides, as illustrated in Fig.4c, the load-deflection curve of the series L200 is relatively similar to that of the L100 series with a dual-peak response. However, series L200 displayed a markedly different failure mode than series L100 and L50. A mixed failure, including delamination and pull-out failure, was




a) Load-deflection relationship of series L0

b) Load-deflection relationship of series L300

c) Load-deflection relationship of series L200

d) Load-deflection relationship of series L100

e) Load-deflection relationship of series L50

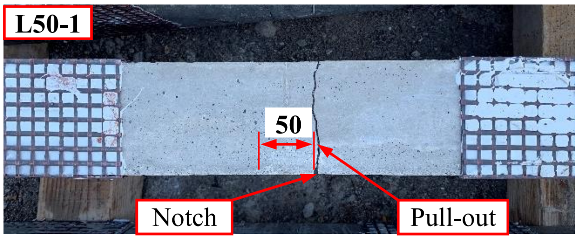
Fig.4 Load-deflection relationship of all series observed (see Fig.6). The failure mechanism was carried out in the following order. The delamination at the interface between textile fabric and concrete originated at the position of the crack towards the discontinued endpoint of the textile fabric. It means that the expansion of the splitting area results in a shortening of the anchorage length. When the anchorage length was small enough, a mixed failure including splitting and slipping occurs, which resulted in a sudden decrease in load-bearing capacity.

In the series under consideration, the series L300 displays a flexural behavior broadly similar to the control series L0. This is evidenced by several characteristics: (i) It can be seen that the load-deflection curves of both series L300 and L0 are insignificantly different; (ii) These two series have the average failure load, respectively, 17.2 kN and 16.6 kN, which are approximately equal; (iii) Series L300 shows a crack pattern quite similar to control series with the formation of secondary cracks within pure moment zone (see Fig.7a); (iv) Both series failed by the delamination between textile fabric and concrete although the distribution of splitting zones among two series is slightly different. These indicate that the anchorage length of 300 mm can provide sufficient composite performance between textile and concrete, hence the series L300 is fully mechanically guaranteed compared to control beams with continuous textile fabrics. In previous tests on determining lap splice length of textile reinforcement, a minimum lap splice length of 300 mm was also required to provide for TRC members [9, 10]. Thus, it was possible to prove that the anchorage length of the textile reinforcement in the TRC member is 1.0 times the value of the lap splice lengths.

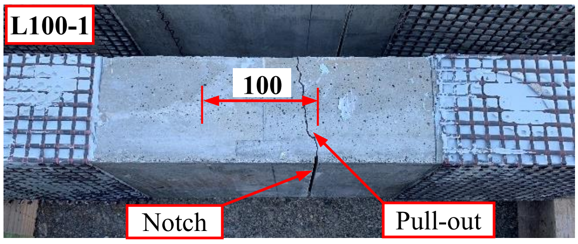
Table 5 Test result

| Series | Specimen | Failure load (kN) | Disp.* (mm) | Failure mode |
|---|---|---|---|---|
| L0 | L0-1 | 17.1 | 20.5 | D |
| | L0-2 | 16.1 | 15.4 | D |
| L50 | L50-1 | N/A | N/A | P |
| | L50-2 | N/A | N/A | P |
| L100 | L100-1 | 7.1 | 1.8 | P |
| | L100-2 | 6.3 | 1.9 | P |
| L200 | L200-1 | 10.3 | 4 | D + P |
| | L200-2 | 11.1 | 6.6 | D + P |
| L300 | L300-1 | 17.3 | 5.0 | D |
| | L300-2 | 17.1 | 13.8 | D |

Disp. *– Displacement corresponding to failure load.
D – Delamination failure (the separation between the textile layer and mortar together with the occurrence of horizontal cracks on both sides of specimens).
P – Pull-out failure.
N/A – Not Available due to pull-out failure occurred as soon as the first crack had formed.




a) Side view of specimen L50-1




b) Side view of specimen L100-1

Fig.5 Pull-out failure of series L50 and L100

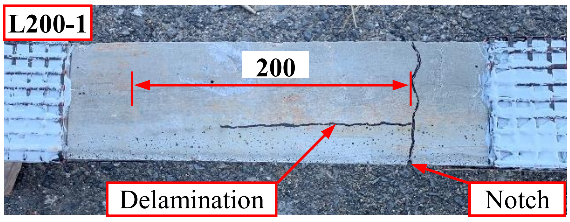
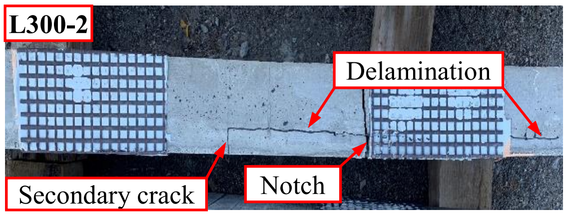
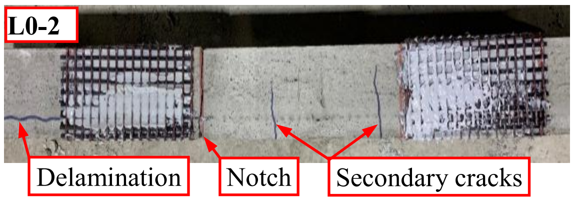



Fig.6 Delamination failure of series L200




a) Side view of specimen L300-2




b) Side view of specimen L0-2

Fig.7 Failure mode of series L300 and L0

## 4. CONCLUSIONS

An experimental program on 5 series of TRC beams with different anchorage lengths was carried out to investigate flexural failure behavior. The following conclusions are given:

(1) For the short anchorage length of 50 and 100 mm, pull-out failure was dominant.
(2) A mix failure consisted of delamination and pull-out failure occurred in specimens of series L200.
(3) To ensure the mechanical performance of TRC beams, the anchorage length of textile reinforcement should be more than or equal to 300 mm.
(4) The fracture of yarn did not occur in all specimens. The reason may be due to the splitting between textile and concrete. Hence, delamination was the most critical failure mode hindering the exploitation of the capacity of textile reinforcement to its full extent. Further experiments and discussions are needed to improve composite performance between textile fabric and concrete.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] Brameshuber, W.,"Textile Reinforced Concrete: State of the Art Report," RILEM TC 201-TRC, RILEM Publications, Paris, France, 2006.
[2] Hegger, J., and Voss, S.,"Investigations on the bearing behavior and application potential of textile reinforced concrete," Engineering Structures, Vol. 30, 2008, pp. 2050-2056.
[3] Vogel, F.,"Production and use of the Textile Reinforced Concrete," Advanced Materials Research, Vol. 982, 2014, pp. 59-62.
[4] Lorenz, E. and Ortlepp, R.,"Basic research on the anchorage of textile reinforcement in cementitious matrix," Proceedings of the 9th International Symposium on Fiber Reinforced Polymer Reinforcement for Concrete Structure, Sydney, 2009.
[5] Ortlepp, R.,"Efficient Adaptive Test Method for Textile Development length in TRC," Advances in Civil Engineering, Vol.2018, 2018, pp. 1-14.
[6] Lorenz, E. and Ortlepp, R.,"Bond Behavior of Textile Reinforcements-Development of a Pull-out Test and Modeling of the Respective Bond versus Slip Relation," High Performance Fiber Reinforced Cement Composites, 2012, pp. 479-486.
[7] Lorenz, E. and Ortlepp, R.,"Anchoring failure mechanisms of textile reinforced concrete strengthening of RC structures," Proceedings of the ACI 2010 Fall Convention, Pittsburgh, 2010.
[8] Muoi, B.S. and Kunieda, M.,"Evaluation of Pull-out Behavior of Textile Reinforced Concrete," Annual Proceedings of JCI, Vol.41, Sapporo, 2018, pp. 401-406.
[9] Muoi, B.S., Ando, H. and Kunieda, M.," Flexural Failure Behavior of Textile Reinforced Concrete Beams with Lap Splice," Proceedings of the Concrete Structure Scenarios, JSMS, Vol. 19, Kyoto, 2019, pp. 331-336.
[10] Muoi, B.S. and Kunieda, M.,"Experimental Approach to Determine Lap Splice Length of Textile Reinforced Concrete Members Subjected to Tensile Force," Session on Materials, Analysis, Structural Design, and Applications of Textile-Reinforced Concrete/ Fabric Reinforced Cementitious Matrix, ACI 2019 Fall Convention, Cincinnati, 2019.