Anchorage Length for Textile Reinforced Concrete

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Abstract- **The *anchorage length* needed for textile fabrics as reinforcement within a fine-grained concrete matrix was determined based upon *specific filament yarn pull-out tests*. The purpose of this research was to eliminate the possibility of failure due to fabric pull-out from the matrix in practical applications. Therefore, a *new test set-up* was developed, which offers the possibility for a *quick and direct determination* of the anchorage length. *Several textile fabrics* made of alkali resistant glass (AR-glass) fibres, as well as carbon fibres *were therewith tested*. Findings indicated that conventional AR-glass fabrics required large anchoring lengths, and, it's another fact to consider, that *carbon fibres* have a substantially higher strength than AR-glass fibres and *different bond behaviour*. The research further showed that an additional application of a polymer suspension *coating* to textile fabrics *greatly increased* the reinforcement's *resistance to pull-out*.**

Keywords- **textiles; anchorage; pull-out; restoration; repair**

I. INTRODUCTION

For many years applications of additional steel reinforced shotcrete have been used to improve the strength of reinforced concrete members and improve the load-carrying capacity. Textile Reinforced Concrete (TRC) represents a relatively new development in the field of strengthening and retrofitting of concrete [1]. Textile reinforcing fabrics use Alkali-Resistant Glass (AR-glass) or carbon as fiber materials for reinforcing. Slabs and beams in bending [2] as well as beams and T-beams in shear [3] can primarily be strengthened just as columns [4] or torsional beams [5] where considerable increases in the load-carrying capacity has been observed.

Knowledge of the bearable tension force in the textile reinforced strengthening layer and its related deformation behavior is crucial to develop appropriate cross-sectional models necessary to design the strengthening of reinforced concrete (RC) members. The question also arises as to whether or not the anchorage on the RC member is sufficient enough to safely transfer tensile loads from the textile reinforced strengthening layer to the concrete substrate. Various bond specimens were studied to examine the force transfer from the textile reinforced strengthening layer into the aged concrete [6].

Over the course of these experimental investigations, it was discovered that a failure of the internal bond between the filament yarns of the textile fabric and the surrounding fine-grained concrete matrix also occurred with the use of certain textile reinforcing fabrics [7]. Since this failure mode can also impact a failure in the anchorage range, it was necessary to examine this failure mechanism separately. There are lots of test set-ups existing, which were developed for testing single yarns, e.g. [8], [9], [10], [11]. But, these are not sufficient for the anchorage length, because they don't consider the influences of the textile structure. This paper discusses the experimental investigations used to easily determine the anchoring lengths of textile reinforcement in a fine-grained concrete matrix. Contrary to simple pull-out tests of individual filament yarns, these tests analysed the influence of cross-reinforcement on pull-out forces.

II. EXPERIMENTAL RESEARCH

A. Test Setup

The experimental setup for the investigation of the textile pull-out lengths (Fig. 1) was developed on the basis of the uniaxial tension tests which will be recommended by RILEM TC TDT, as well as bond tests concerning end-anchoring of textile reinforced strengthening described by Ortlepp et al. [6]. In the case of the uniaxial tension tests, the load has introduced at the upper and lower end of the specimen by clamped anchorage, which was chosen to attain the maximum bearable tensile load of the fibers while avoiding a pull-out failure from high lateral pressure. No lateral pressure exists in the case of end-anchoring of TRC strengthening to an old concrete substrate. More precisely, adhesive tensile stresses exist in the region of the end-anchorage [6]. The author designed a pull-out test setup simulating these adhesive tensile stresses that arise from within the range of the end anchoring of a TRC strengthening layer (Fig. 1). For this reason, a load introduction, by means of glued steel plates, was selected at the lower end of the specimen where pull-out was expected to occur (Fig. 2a).

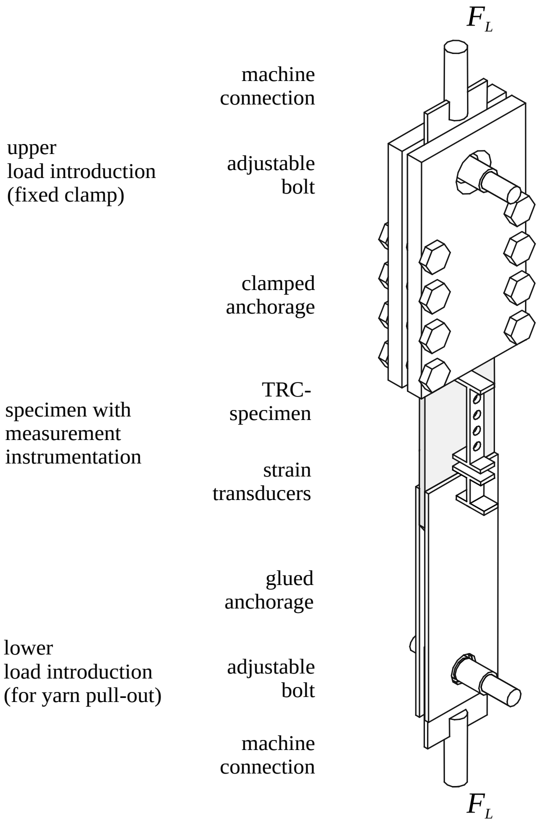
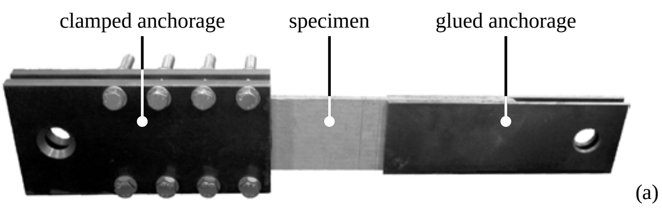


Fig. 1 *Test setup for filament yarn pull-out tests*

The clamping length at the upper end of the specimen was established as equal to or greater than that of the glued anchorage to assure pull-out failure occurred at the lower end of the specimen in additional testing. A length of 200 mm was chosen for the clamped anchorage (Fig. 2b). The adhesive bond length at the end of the specimen examined varied from 0 to 200 mm. The maximum bond length tested was, therefore, limited to 200 mm based on the clearance of the machine. One consolation to this limitation is, that TRC strengthening layers need relatively short anchoring lengths (< 150 mm for an aged concrete substrate) as determined by Ortlepp et al. [6].



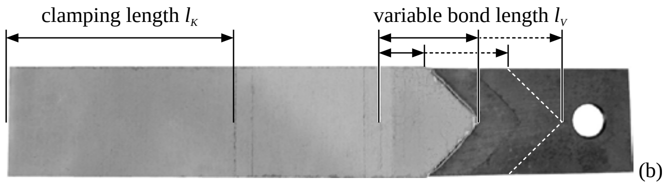


Fig. 2 *Specimen used for filament yarn pull-out tests*

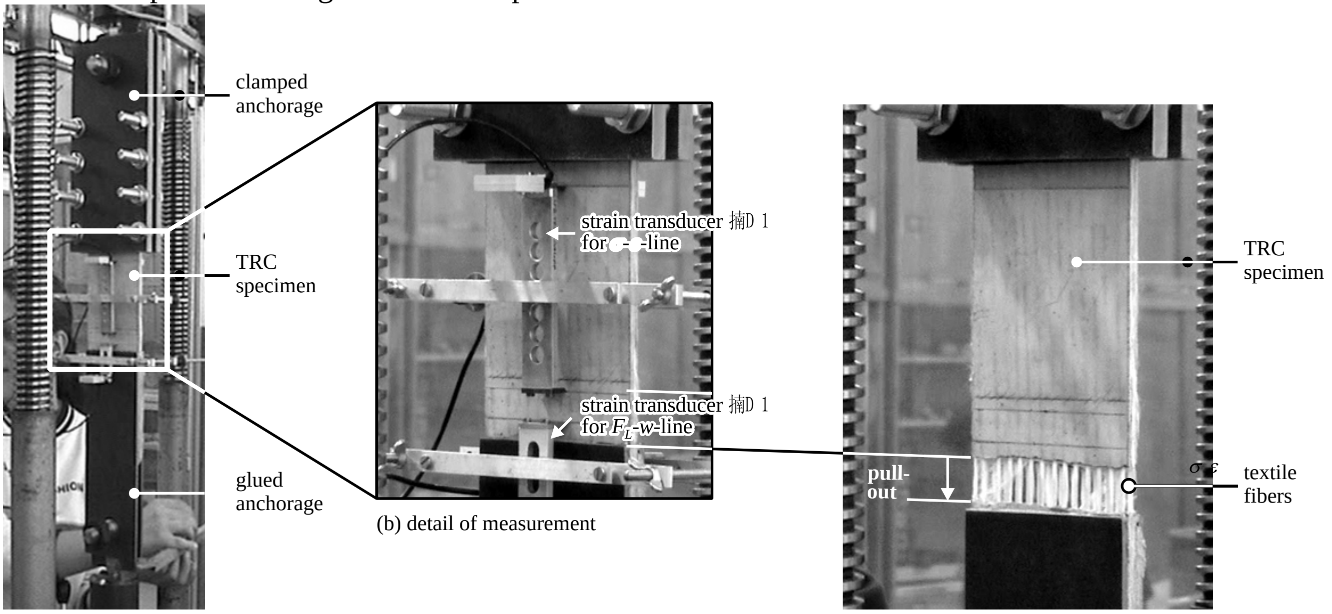
Overall, this means, that textiles of this type, in need of larger load introduction lengths than that of aged concrete and TRC, are not suitable for most types of applications, (e.g., as shear strengthening, see [3], because the pull-out length becomes crucial for the design of the anchoring range in these cases.

The bond length of the textile was varied within each series by intervals of 20 mm. The idea was to examine a bond length range by only using one, single specimen to minimize the number of specimens in one testing series. Therefore, the lower end of the specimen was cone-shaped. A 45-degree angle (Fig. 2b) was established to be the best option. In doing so, a range of bonding lengths of 50 mm (i.e., between edge bond length and middle bond length) was observed by the use of just one specimen. Each series, consisting of eight specimens with overlapping bond ranges, was intended to test one textile with a defined number of layers (bond ranges were selected accordingly – specimen 1: 0-50 mm; specimen 2: 20-70 mm; … specimen 8: 150-200 mm). By overlapping the bond ranges of specimens within each series, it was possible to verify the anchoring length obtained from each individual test.

The specimen thickness varied depending upon the number of textile layers examined, since each fine-grained concrete layer needed to be 2 mm thick both between and surrounding the textile layers. The total thickness of the strengthening increases by the same amount of thickness as that of the fine-grained concrete intermediate layers. It was possible to test specimen thicknesses of up to 25 mm under this particular testing arrangement. A variable adjustment of the centre distances of the load-introduction plates was needed to compensate for the various thicknesses of the specimens. This adjustment to the centre distance was precisely manipulated for each individual specimen by the use of an adjustable bolt (Fig. 1).

B. Specimen Production and Measurement Instrumentation

The test specimens were produced within steel formwork as plates measuring 1200 mm×700 mm, stored in a climatically controlled chamber and then trimmed with a stone saw to fit a width of 100 mm and the corresponding appropriate length. One to two days before the test, the lower load introduction plates were glued to the specimens. The tests were conducted after 28 days within a displacement-controlled, tension-pressure-testing machine. In addition to the tension force, strain



(a) test setup (b) detail of measurement (c) filament yarn pull-out

Fig. 3 *Test setup and measurement instrumentation*

within the range of the free length of the specimen as well as the crack-width opening nearest the glued anchorage were measured (Fig. 3a,b). The strain transducers were removed after reaching the ultimate load to avoid damage resulting from large deformations. A complete pull-out of all filament yarns, which had not failed by tensile breakage, was determined by applying additional deformation (Fig. 3c). The lengths of all remaining protruding fibers of each specimen tested were then measured.

C. Experimental Program

The influence of the application of an additional coating on the bond behaviour of the textile reinforcing fabrics was the primary parameter of this investigation. The portion of organic constituent in aqueous suspension, as well as the type of coating (dependent on the type of fibres), were, therefore, of essential influence. The differences in bond behaviour between warp and weft thread were also examined as well as the influence of transverse reinforcement. Textile reinforcing fabrics made of AR-glass were used in conducting the analysis of the parameter of transversal threads. A further important point to be clarified is in which way the bond behaviour changes if higher load-carrying carbon fibres are used instead of AR glass. The parameter of coating (kind and amount of polymers) is therefore analysed with AR-glass and carbon textiles. The essential parameters of the textile fabrics examined are listed in Table I.

TABLE I
PARAMETERS OF THE USED TEXTILE FABRICS

Tex-tile	Material	Yarn fine-ness [a]	Yarn dis-tance [a]	Weave, loop length [b]	Coa-ting type [c]	Coating percen-tage [d]
		[tex]	[mm]	[mm]		
A	AR-glass	1280	7.2	pt, 3.6	–	–
B	AR-glass	1280	7.2	dt, 3.6	–	–
C	AR-glass	1280	7.2	dt, 3.6	–	–
D	AR-glass	1200	7.2	dt, 3.5	s	30%
E	AR-glass	1200	7.2	dt, 2.0	s	30%
F	AR-glass	1200	7.2	dt, 2.0	s	15%
G1	Carbon	800	10.8	dt, 3.5	s	30%
G2a	Carbon	800	10.8	dt, 3.5	e	30%
G2b	Carbon	800	10.8	dt, 3.5	e	15%
H1a	Carbon	800	7.2	dt, 3.5	s	30%
H1b	Carbon	800	7.2	dt, 3.5	s	15%
H2	Carbon	800	7.2	dt, 3.5	e	15%

a. *in testing direction*
b. *pt = pillar-tricot, dt = double tricot*
c. *s = styrol butadiene, e = epoxy resin*
d. *percentage of organic constituent in suspension*

III. TEST RESULTS

The pull-out length of a textile warp knitted fabric indicates the length necessary to completely transfer the force from within the filament yarn into the surrounding fine-grained concrete matrix. The pull-out length can, thus, be regarded as anchoring length of a textile reinforcing fabric. On the basis of the specimens shown in Fig. 2b, the anchoring length of the filament yarns was determined by measuring the protruding fibers after pull-out failure of the tested specimens (Fig. 4). The filament yarns failed by tensile break beginning with the unknown filament yarn pull-out length. That is failure of specimens with very long bond lengths failed by tensile break of all filament yarns, while specimens with short bond lengths failed by complete pull-out. The limit between pull-out and tensile breaks indicated the necessary anchoring length of the textile reinforcing fabric needed in the fine-grained concrete matrix. Based on this, the unknown filament yarn pull-out length for the textiles examined resulted from specimens with a bond length range where a mixed failure occurred (Fig. 4).

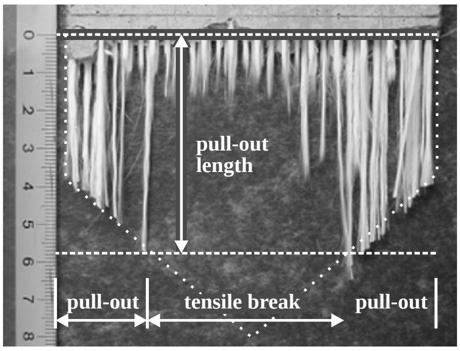


Fig. 4 *Evaluation of the filament yarn pull-out length*

Table II lists the results of these tests. The measured pull-out length for all tests in which failure occurred by filament yarn pull-out is indicated in the table. The pull-out resistance was higher than lateral tensile forces in delamination failure cases as a result of the glued anchorage. Textiles with such a failure mode can be identified as appropriate for the intended use since in many cases only short bond lengths are needed for sufficient anchoring.

The experimental investigations conducted showed that by applying a coating to textile reinforcing fabrics, a drastic increase in pull-out resistance occurred. The entire length (200 mm) of un-coated load-bearing filament yarns was pulled out of the fine-grained concrete matrix, while a remarkable reduction in the pull-out length was determined for coated tex tiles with similar load-bearing filament yarns (Fig. 5). It should be noted that the pull-out length of the uncoated textile fabric displayed in the diagram was limited by the maximum test length. The pull-out length of the uncoated fabric was larger than 200 mm. Uncoated textile fabrics were, thus, not suitable as reinforcing material for strengthening layers of structural members that require short anchoring lengths of less than 200 mm.

The application of coatings to previously stitched textile fibers creates a ribbed surface that enhances pull-out resistance [12]. This enhancement of filament yarns, however, is limited to the warp threads. Improvement to the bond from the coating was also being determined in the weft thread direction.

TABLE II
TEST RESULTS

No	Tex-tile	Load direc-tion [a]	Bond range	Appli-cation method	Failure mode [b]	Pull-out length	Ulti-mate force
			[mm]			*[mm]*	*[kN]*
1.1	A	warpd	110–160	laminated	p	160 [c]	10.03
1.2	A	warp	150–200	laminated	p	200 [c]	11.37
2.1	B	warp	110–160	laminated	p	160 [c]	10.42
2.2	B	warp	150–200	laminated	p	200 [c]	11.43
3.1	C	weft	150–200	laminated	p	200 [c]	11.50
4.1	D	warp	30–80	laminated	d	–	15.07
4.2	D	warp	70–120	laminated	d	–	14.50
4.3	D	warp	110–160	laminated	t	–	15.12
4.4	D	warp	150–200	laminated	t	–	15.16
5.1	E	weft	30–80	laminated	d	–	10.93
5.2	E	weft	30–80	laminated	d	–	12.67
5.3	E	weft	30–80	laminated	d	–	10.89
5.4	E	weft	30–80	laminated	d	–	13.95
5.5	E	warp	110–160	laminated	t	–	18.88
5.6	E	warp	130–180	laminated	t	–	19.78
5.7	E	warp	150–200	laminated	t	–	19.72
6.1	F	warp	30–80	laminated	p+t	58	13.24
6.2	F	warp	110–160	laminated	t	–	14.64
6.3	F	warp	150–200	laminated	t	–	16.74
7.1	G1	warp	50–100	laminated	p	100 [c]	13.54
7.2	G1	warp	90–140	laminated	p+t	110	22.06
7.3	G1	warp	110–160	laminated	p+t	110	21.48
7.4	G1	warp	150–200	laminated	t	–	19.81
7.5	G1	warp	70–120	sprayed	p+t	90	16.05
7.6	G1	warp	70–120	sprayed	p+t	90	15.89
8.1	G2a	warp	50–100	laminated	p	100 [c]	12.46
8.2	G2a	warp	70–120	laminated	p	120 [c]	12.85
8.3	G2a	warp	90–140	laminated	p	140 [c]	20.07
8.4	G2a	warp	110–160	laminated	p+t	140	17.85
8.5	G2a	warp	150–200	laminated	t	–	17.85
9.1	G2b	warp	50–100	laminated	p	100 [c]	7.54
9.2	G2b	warp	70–120	laminated	p	120 [c]	9.59
9.3	G2b	warp	90–140	laminated	p+t	140	13.63
9.4	G2b	warp	110–160	laminated	p+t	150	14.04
9.5	G2b	warp	130–180	laminated	p+t	150	16.85
9.6	G2b	warp	150–200	laminated	t	–	19.62
10.1	H1a	warp	50–100	laminated	p+t	90	12.39
10.2	H1a	warp	70–120	laminated	p+t	90	15.16
10.3	H1a	warp	90–140	laminated	t	–	18.85
10.4	H1a	warp	110–160	laminated	t	–	22.66
10.5	H1a	warp	150–200	laminated	t	–	22.19
11.1	H1b	warp	70–120	laminated	p	120 [c]	11.81
11.2	H1b	warp	90–140	laminated	p+t	140	14.94
11.3	H1b	warp	110–160	laminated	p+t	140	17.38
11.4	H1b	warp	130–180	laminated	p+t	140	19.36
11.5	H1b	warp	150–200	laminated	t	–	19.55
10.3	H1a	warp	90–140	laminated	t	–	18.85
10.4	H1a	warp	110–160	laminated	t	–	22.66
10.5	H1a	warp	150–200	laminated	t	–	22.19

No	Tex-tile	Load direc-tion [a]	Bond range	Appli-cation method	Failure mode [b]	Pull-out length	Ulti-mate force
			[mm]			[mm]	[kN]
11.1	H1b	warp	70–120	laminated	p	120 [c]	11.81
11.2	H1b	warp	90–140	laminated	p+t	140	14.94

a. parallel to
b. d = delamination, p = pull-out, t =tensile break
c. value was limited by the bond range

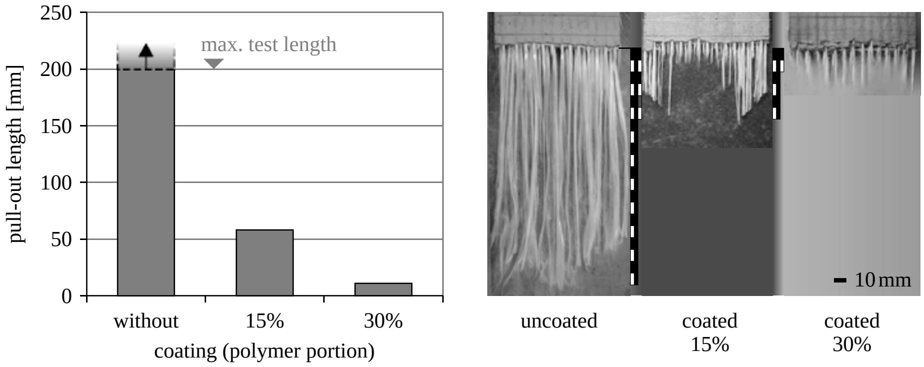


Fig. 5 *Effect of additional coating on the filament yarn pull-out length*

It must be noted that the weft threads were not encased by a stitching fiber. This suggests that, apart from the rib effect of the stitching fiber, another effect is involved in improving the bond. Krüger [13] observed that no pure filament yarn pull-out occurred with uncoated AR-glass filament yarns in contrast to carbon fibers. This means in the case of uncoated AR-glass filament yarns, the internal filaments (core fibers) were essentially pulled out, while the sleeve filaments, which were located in direct contact to the fine-grained concrete matrix, showed a tensile failure (core fiber pull-out). This was caused by a significantly diminished bond between the filaments within the filament yarn. This effect of core fiber pull-out increased as the size of the yarn’s fineness increased.

A kind of bonding occurred between the filaments from the penetration of the polymer coating into the filament yarns. This slight impregnation led to an increase in the bond of the filaments within the filament yarn. Obviously, the improved interrelationship between the sleeve and core filaments resulting from the coating affected a significant increase in the pull-out resistance of the filament yarn.

In addition to creating an improved bond, this coating also has the disadvantage of an increased flexural rigidity. This is particularly important with regard to the strengthening of structural members where the reinforcing fabric must be wound around the edges of a structural member. For this purpose, a textile fabric was coated with a smaller amount of polymer components in suspension. Under this scenario, with only half of the regular portion of polymers coated, the textile structure showed less flexural rigidity than textile fabrics coated with the standard polymer portion of 30% in suspension. This flexibility is needed for such techniques as the wrapping of columns with rectangular cross-sections. The pull-out tests on these textiles showed that a substantial reduction of the pull-out length of the textile fabric was achieved with a minimal amount of coating, (i.e., percentage of polymers of 15%) (Fig. 5).

The bond behavior of the filament yarns of a coated textile fabric was additionally affected by the layout of the transverse threads. The experimental investigations showed that a decrease in the transverse thread distance caused a small bond increase and, thus, a little reduction in the pull-out length of the coated textile fabric. From this, it is to be concluded that the anchoring length is not only dependent on the properties of the filament yarns in direction of the load; instead, the entire textile structure is to be regarded. The warp and weft threads of the same filament yarn must first be differentiated because of the rib effect of the stitching fiber. Furthermore the transverse thread distances must not be ignored due to the nodal influence. Thus, reference should be made precisely to a textile pull-out length instead of a filament yarn pull-out length.

If carbon fibers are used instead of AR-glass fibers for textile reinforcing fabrics, the bond behavior changes drastically. While it was observed that a pull-out failure could be excluded by the application of an additional coating with textiles from AR-glass fibers, textiles made of carbon fibers offer substantially larger development lengths.

IV. Summary and Conclusions

Investigations into the pull-out behavior of textile fabrics showed that a subsequently applied coating is absolutely necessary to guarantee the internal bond of AR-glass filament yarns within a fine-grained concrete matrix. In the case of predominantly uniaxial loading of textile reinforcement warp threads showed better bond properties than weft threads with coated textile structures. The warp thread direction is the preferred direction for load-bearing reinforcement functions.

Carbon fiber textiles with a normal coating have quite large anchoring lengths compared to AR-glass textile fibers. While carbon textile fiber can be used for flexural strengthening or as helical reinforcement, shorter anchoring lengths are needed for other applications such as shear strengthening of T-beams. Currently for this reason, additional developments relative to the coatings and additional anchoring details have to be researched in the future.

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