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Development Length of Prestressing Strands in Post-Tensioning Slabs

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***Abstract*: One of the structural systems that are widely used nowadays is post tensioning concrete slabs with special shaped dead end (H-anchorage dead end). The special shaped dead end is formed by using a certain hydraulic jack that enables the shaping of an easy shaped and economic dead end. This paper presents an experimental work to assess the development length of 15 mm (0.6 in) diameter prestressing strand with special shaped dead in concrete slabs with 48 MPa concrete compressive strength. The experimental program included three specimens with 750 mm, 900 mm and 1050 mm length with constant specimen width and thickness 300 mm and 200 mm respectively. From the experimental test results and the analyzed data it was concluded that the development length of the prestressing strand in post-tensioning concrete slabs equal 1000 mm is sufficient to reach the strand ultimate strength.**

***Keywords*: Development length, special shaped dead end, Prestressing strands, Post-tensioning slabs.**

1. INTRODUCTION

Post-tensioning system is a structural system widely used nowadays in several structural elements, as it allows for best utilization of the concrete cross section more than the ordinary reinforced concrete. The live end where the strand is tensioned and the dead end where the strand is fixed, are two main parts in the post-tensioning system that govern the successful performance of the structural member all over the member service life. At the dead end, using an anchorage assembly (anchorage block and wedge) for fixing the strand is expensive, an economic alternative could be used by shaping the end of the straight strand by a certain hydraulic jack to allow the spreading of the wires in a special dead end shape named by onion dead end or H-anchorage dead end. This dead end is embedded inside the concrete into a certain length in order to achieve the same purpose of the anchorage assembly in fixing the strand at the dead end zone. Different bond mechanisms such as adhesion, mechanical interlocking resistance and the mechanical resistance is found in the strand with onion shaped dead end. Adhesion which is the bond between any two materials depending on the nature of each material and does not have an significant importance once one material moves relative to the other[1]–[6]. Mechanical interlocking resistance is the resistance of the concrete surrounding the straight strand against twisting during tensioning process due to the helical shape of the circumference wires. [1]–[6]. The mechanical resistance of the H-anchorage dead end (onion shaped dead end) which provides a predominant resistance against strand movement during tensioning process due to the presence of the concrete inside the 7 bent wires[1].

The development length of prestressing strand is an important defined length of the strand inside the concrete in order to ensure the member safety under the designed loads, it had been investigated previously by many researchers [6]–[12], the development length (l_d) is defined as the minimum distance required to transfer forces safely from reinforcement to concrete without concrete cracks or pull-out failure and it is measured from the point of maximum compression or tension stresses [13].

There are different factors that affect the development length assessment of prestressing strand in concrete [8], such as concrete compressive strength [6]–[10], the stress level in the stand [6], concrete cover [10] and the strand diameter [8] [10] . Kim [8] [10] studied the influence of strand size 12.7 and 15.2 mm on the transfer length, where the transfer length is the length required to reach the effective prestessing force(f_{pe}) (the force considering after losses) safely and it is part of the development length equation in many design codes[13][14].

Several researchers conducted pullout tests to estimate the development length, Jiang [11] conducted pullout tests on concentric prisms 6 in.x6 in. cross section by using 0.7in. strand diameter with ultimate strand strength equal 1860 Mpa and concrete compressive strength equal 62.7 MPa, the study investigates different embedment lengths 305, 610 and 915 mm, the research concluded that 915 mm embedment length is able to achieve the development length of the member successfully. Sorensen [12] used the same approach of Jiang [11] and performed pull-out tests on 1-1/8 in. strand and concluded that 2438 mm development length is sufficient for reaching the ultimate strength of the strand. Several researches are conducted to study the development length of prestressing strands with different variables but focusses mainly on the development length of pretension members [4], [5], [15]–[21], while few researches are conducted to study the development length concerning post-tensioning members and investigating the problems facing the anchorage dead end zones [22][23]. Due to the lack of data concerning development length of post-tensioning members with (H-anchorage dead end) onion shaped dead end, this experimental work was carried out.

2. EXPERIMENTAL WORK

2.1 Materials

The concrete constituents consists of Normal Portland Cement CEM I 42.5 N, drinking water, clean sand and coarse aggregates with 20 mm nominal maximum size. The concrete mix design used is shown in Table 1. An average concrete compressive strength of 48 MPa was achieved from testing standard concrete cubes after 28 days. Low-relaxation, 7-wire strand with 0.6 inch (15mm) diameter was used with strand mechanical properties listed in Table 2.

Ordinary reinforcement steel was used with 10 mm and 12 mm diameter, with ultimate strength and yield stress equal to 520 MPa and 360 MPa respectively.

Table 1: Concrete Mix Proportions

Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	W/C
425	660	1025	196	0.46

Table 2: Strand Properties

Diameter (mm)	Area (mm^2)	Ultimate Strength (MPa)	Breaking Force (kN)	% Minimum Ultimate Elongation	Modulus of Elasticity (GPa)
15.2	140	1860	260	3.5%	195

2.2 Test Specimens

The tested specimens represent slabs at dead end zone, all specimens having constant width 300mm with a specimen thickness equal 200 mm. Three specimens were tested with 750 mm, 900 mm and 1050 mm length respectively, specimen's details are illustrated in Table 3. The total bonded length of the strand in each specimen is equal the specimen's length subtracted by 50 mm.

The Specimen's reinforcement details are as shown in Figure 1.

Table 3: Specimen Details

Specimen ID	(L) mm	(L_b) mm	(B) mm	(ts) mm
S-750	750	700	300	200
S-900	900	850		
S-1050	1050	1000		

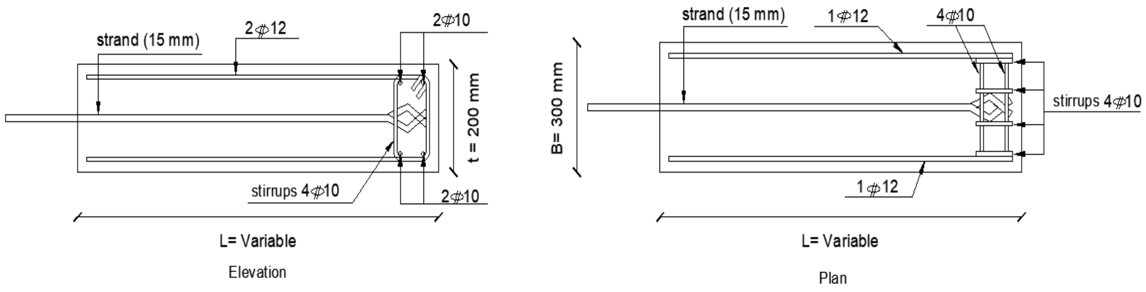

Figure 1: Specimen Reinforcement Details

2.3 Experimental Procedures and Test Setup

An indirect pullout test was used to satisfy the experimental work. The strand was fixed by an anchor and wedge on a fixed horizontal steel beam and a compression force was applied on the concrete specimen through a vertical movable steel column connected with a load cell. Four LVDTs are used for slippge mesurement. The test set up used is shown in Figure 2.

Figure 2: Test Set up

3. TEST RESULTS AND DISCUSSIONS

3.1 Crack Pattern and Failure Mode

For both specimens S-750 and S-900 longitudinal cracks were observed at both sides of the specimens, specimen S-900 was specialized by splitting of concrete cover at the dead end location, both specimens failed by concrete splitting before reaching the ultimate strand strength. S-1050 failed by strand cutting after reaching the strand ultimate strength. Failure mode for all specimens are as shown in Figure 3

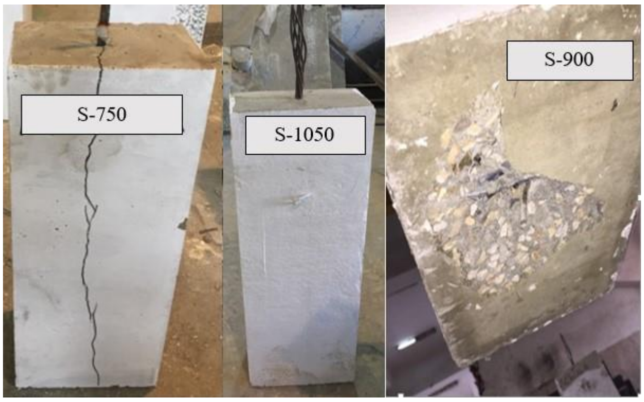

Figure 3: Failure Mode for the Tested Specimens

3.2 Maximum Load and Corresponding Slip

The maximum load and its corresponding slippage were recorded for all specimens up to failure. The maximum load (P_{max}) reached by the tested specimens was 239, 252 and 276 kN for specimens S-750, S-900 and S-1050 respectively. It was observed that the maximum load increased by increasing the bonded length as shown in Figure 4. Also slip at maximum load was increased by increasing the bonded length as shown in and Figure 5

All specimens have similar load slip relationships before reaching the maximum load, then different post peak behavior observed as shown in Figure 6. For specimen S-1050 a sudden drop after reaching the maximum load due to strand cutting. While an increasing in slip is observed for specimens S-750 and S-900 due to the initiation of cracks before failure, as they both failed by concrete splitting before reaching the strand ultimate strength.

Table 4 summarizes the experimental test result including: Maximum load (P_{max}), strand stress (f_s) reached in each specimen and evaluated by dividing the maximum load by the strand cross section area as in Equation (1). The strand stress (f_s) is compared by the ultimate strand strength 1860 MPa. It was observed that specimens with 700 mm and 850 mm bonded length exceeds 90% of the strand ultimate strength, while 1000 mm strand bonded length guarantee full bond with concrete as it reached the strand ultimate strength safely.

$$f_s = \frac{P_{max}}{\text{A}} \qquad \text{Eq.1}$$

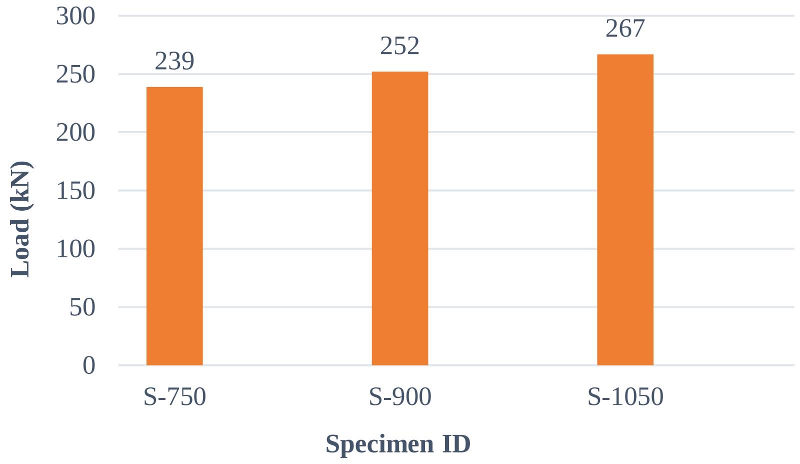

Figure 4: Maximum load for Tested Specimens

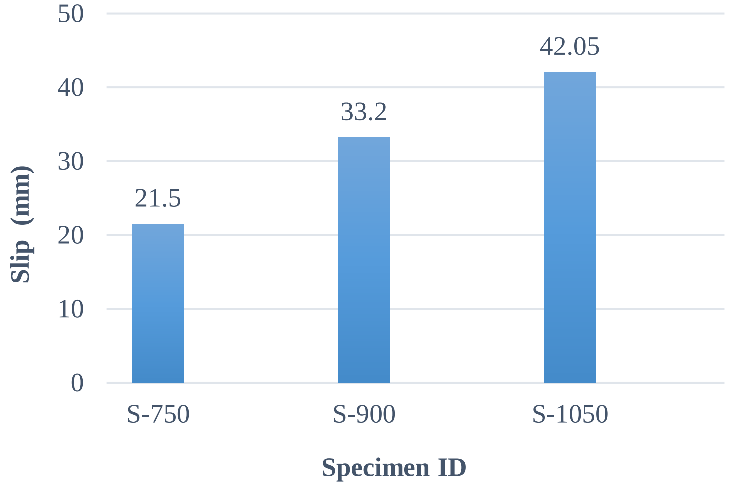

Figure 5: Slip at Maximum Load for Tested Specimens

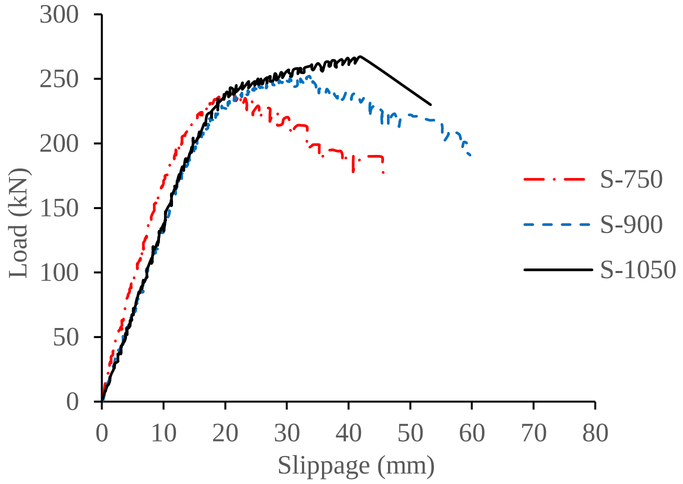

Figure 6: Load-slip Relationships for the Tested Specimens

Table 4: Maximum Load and Strand Stress for the Tested Specimens

Specimen ID	Maximum Load (Pmax) kN	Strand Stress (fs) MPa	Ultimate Strand Stress (fu) MPa	fs/ fu
S-750	239	1707	1860	0.92
S-900	252	1800		0.97
S-1050	267	1907		1.03

4. CONCLUSION

This experimental work aims to study the development length of prestressing strand with H-anchorage dead end (onion dead end) used in post-tensioning slabs. Based on the experimental work and the discussed results the following conclusions were driven:

1. 1000 mm bonded length of prestressing strand with H-anchorage dead end in post-tensioning slabs is sufficient for reaching the strand ultimate strength at 48 MPa concrete compressive strength.

2. As the bonded length of the strand in concrete increased, the maximum load achieved by the tested specimens increased.

3. Strand slip increases obviously with increasing the bonded length.

4. Almost all tested specimens shows similar load slip relationships till reaching the maximum load, then different post peak behavior is observed based on the failure mode of each specimen.

5. All specimens with total bonded length of 1000 mm reached ultimate strand strength safely, while specimens with 700 mm and 850 mm strand bonded length reached more than 90% of the ultimate strand strength .

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