SPLICE LENGTH OF #8 GFRP INTERNAL REINFORCEMENT BARS – YEAR 2

SUMMARY

When reinforcement is spliced together within concrete it is necessary to overlap the bars long enough for tensile stresses in one bar to be fully transferred to other bars without inducing a pullout failure in the concrete. Load transfer occurs between the bars and the concrete by bond stresses. Regarding ACI 440 requirements for Class B bars the lap splice length ought to be $1.6l_d$. In order to investigate these lap splice length requirements for different bar sizes made of glass fiber reinforced polymers (GFRP), this research program was divided in two phases. During the first and second phases #4 and #8 GFRP bars were investigated, respectively. Phase 1 research results indicate that the specified lap splice lengths for #4 GFRP bars are conservative, whereas Phase 2 results indicate that for #8 GFRP bars specifications are within those limits extrapolated from this research program.

Figure 1 Test Setup

This research program will substantiate existing design guidelines for lap splice lengths for #4 and #8 GFRP bars. In this Research Results document Phase 2 research results are presented and discussed in further detail. Phase 1 research results are presented in a separate document.

BACKGROUND

ACI 440 stipulates that the minimum length required to achieve a proper development length for the internal reinforcement is given by:

$$l_d = \frac{d_b f_{fu}}{2700} \qquad \textbf{Eq. 1}$$

Eq. 1 was developed based on a conservative estimate of the development length of FRP bars controlled by pull out failure. In Eq. 1, l_d is the bar development length, d_b is the diameter of one FRP bar, and f_{fu} is the ultimate stress value for the bar. For this experiment, the development length of a #8 GFRP bar was computed to be approximately 30 inches.

Limited data is available for the minimum lap splice length for GFRP applications. Available research has indicated that a development length of $1.6l_d$ is necessary to reach 100% of ultimate stress in these bars (Class B). ACI Committee 440 assumed that a value of $1.3l_d$ would be sufficient for a Class A splice using FRP. Since the stress level for Class A splices, is not to exceed 50% of the tensile strength of the bar, using a value of $1.3l_d$ should be conservative. The ACI Committee 440 acknowledges that more research is required in this area but recommends the values of $1.3l_d$ and $1.6l_d$ for Class A and B splices, respectively.

OBJECTIVE

To obtain data that can substantiate specifications for lap splice lengths using #8 GFRP bars.

TEST SETUP

The test setup used for Phase 2 of this research program is shown in Figure 1. Referring to Figure 2 the point loads were placed 44" apart to allow for a constant moment region over the entire splice joints. The load was applied by a hydraulic jack that transferred the load to a steel beam placed on two supports over the tested concrete beams. The applied load was transferred equally to the concrete beams through steel plates placed on wooden strips. The wooden strips were necessary to spread the load uniformly and to keep the concentrated loads from prematurely crushing the concrete.

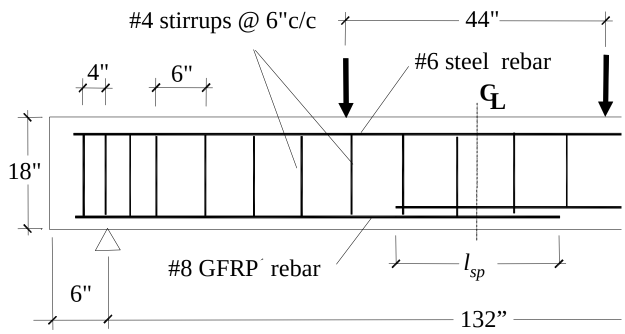

Figure 2 Test Setup and Reinf. Layout

SPECIMENS

Four beams were constructed with two #8 GFRP bars at varying splice lengths at the center of the beam in the tension region. These four beams were tested using three different lap splice lengths, namely: $0.75l_d$, $1.0l_d$, and $1.3l_d$, and a control beam with no splice (see Table 1)

Table 1 Test Matrix

Beam	Splice Length	Splice Length
B1	0	No Splice
B2	$1.3l_d$	39
B3	$1.0l_d$	30
B4	$0.75l_d$	22.5

According to this reinforcement layout the computed reinforcement ratio was 0.65%, which is below the balanced reinforcement ratio necessary to impose rupture of the GFRP bars and crushing of the concrete, which was computed at 0.74%. The reinforcement ratio was calculated using a *d* of 15.25 inches and the material properties shown in Table 2. This computed balanced reinforcement ratio does not include the compression reinforcement, which indicates that failure of the control beam was likely to be governed by FRP rupture.

Each beam was 12 feet long and spanned 11 feet between supports. The cross section of the beam is shown in Figure 3 and the overall dimensions were 18 inches tall and 16 inches wide.

Table 2 Material Properties

Concrete	4645psi
GFRP f_{fu}	80ksi
GFRP E_f	5700ksi
Steel	60ksi

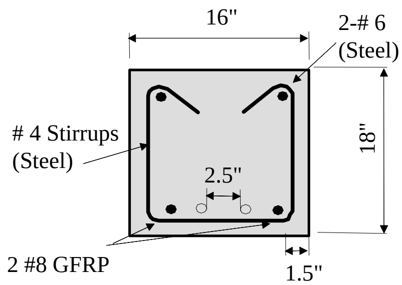

Figure 3 Beam X-Section and Reinf. Layout

INSTRUMENTATION

The applied load was recorded through a single load cell (see Figure 1). In addition, three different types of data recording instruments were used in this experiment, Strain Gages, Linear Voltage Displacement Transducers (LVDTs), and an Extensometer. The strain gages recorded strains from the GFRP bars at different locations (see Figure 4). An additional strain gage was installed on the concrete surface at midspan to measure the concrete strains and to compute the experimental curvature in the constant moment region.

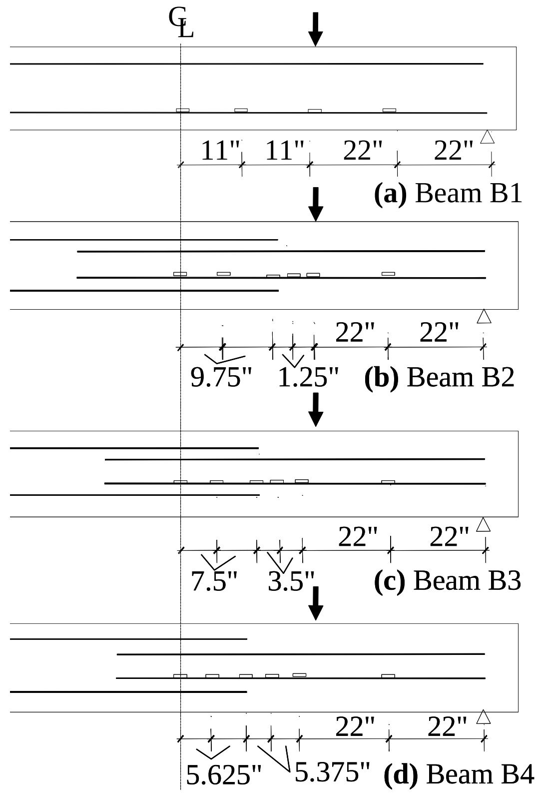

Figure 4 Strain Gages Layout

RESULTS AND DISCUSSIONS

Figure 5 shows the monotonic load deformation response for the four tested beams along with the theoretical prediction. In examining this figure and comparing results with the control beam it is clear that lap splice failure is evident for beams B2, B3 and B4. This is further corroborated by the crack pattern shown in Figure 6, which shows longitudinal cracks on all three lap splice beams. This crack pattern is indicative of large tensile stresses present in the concrete due to shear stresses transfer between the lap spliced bars.

Table 3 depicts general observations recorded during testing which shows that onset of cracking in the lap splice region occurred in beam B4 at a lower load level compared to the other beams B2 and B3. This further corroborates the lower load levels recorded for beam B4, which corresponds to the beam with a shorter lap splice length.

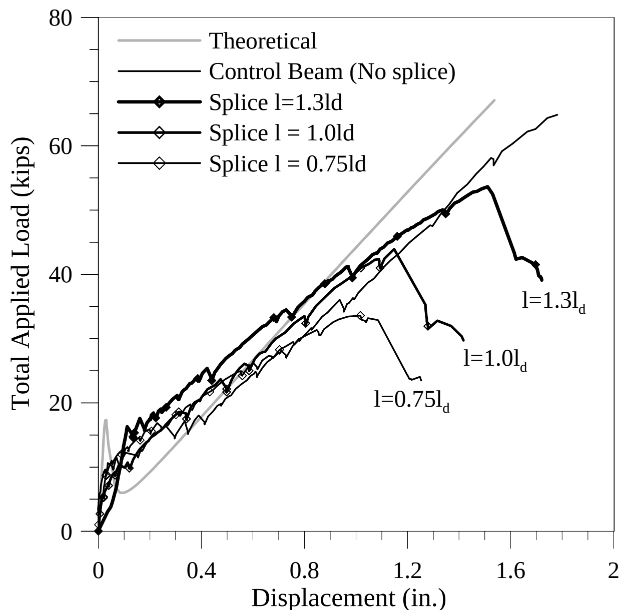

Figure 5 Load – Deformation Response

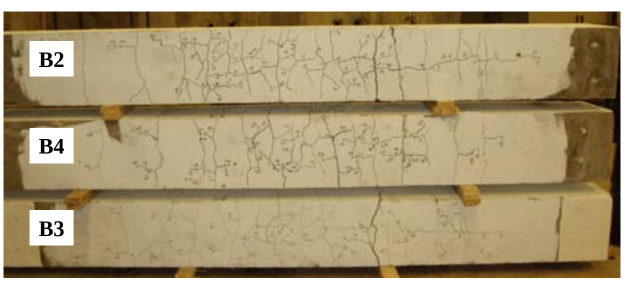

Figure 6 Lap Splice Failure - Crack Pattern

Table 3 General Observations

Beam	Lap Splice Cracking (kips) [a]	Peak Load (kips)	Normalized Peak Load (kips) [b]
B1	-	65.3	100%
B2	18.7	53.7	82%
B3	18.6	44.9	69%
B4	14.5	34.1	52%

[a] Onset of first lap splice crack.
[b] Percentage of each beam peak load versus the control beam peak load.

Referring to Figure 7 it is clear that at lap splice failure, strains in the GFRP bars, from beams B2 and B3, exceeded those values within the Class A category. This category correspond to strains that are less than or equal to 50%ε_{cu}. On the other hand, for Class B categorization none of the three lap spliced beams met the criteria for lap splice since the beams failed at a lower load level than the control beam.

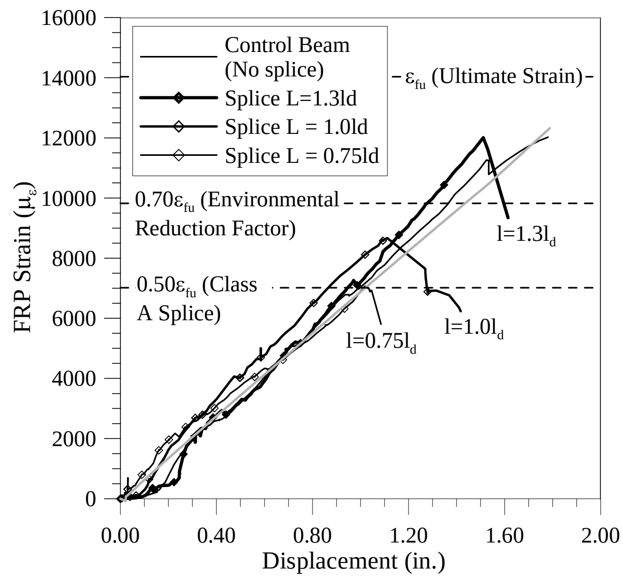

Figure 7 Strain – Deformation Response

CONCLUSIONS

The following conclusions can be drawn from the current research using #8 GFRP bars:

- None of the lap spliced beams met the Class B lap splice categorization. As such for Class B, lap splice lengths stipulated by ACI 440, which is $l_{sp}=1.6l_d$, should be used in design.
- Beams with a lap splice length greater than or equal to $1.0l_d$ met the requirements for Class

A categorization. As such for Class A, lap splice lengths stipulated by ACI 440, which are $l_{sp}=1.3l_d$, could potential be reduced to $l_{sp}=1.0l_d$ in design.

FOR FURTHER RESEARCH

Lap splices that follow within Class B should be further evaluated and two beams with a lap splice length of $1.6l_d$ and $2.0l_d$ should be investigated.

WANT MORE INFORMATION?

Details on this test program and additional data can be found in the final report.

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