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EFFECT OF LAP LENGTH ON SHEAR FAILURE IN STEEL-CONCRETE COMPOSITE CONNECTIONS USING EPOXY ADHESIVES

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ABSTRACT

This study investigates whether structural adhesives can provide reliable shear transfer in steel-concrete composite connections, focusing on how lap length affects interface capacity. A push-out test program evaluated three bonded specimens with lap lengths of 100 mm, 150 mm, and 200 mm using a two-part epoxy. Each specimen combined an IPE steel section with a plain concrete block and a 5 mm adhesive layer. Results showed sudden, brittle failure governed by the concrete close to the bonded interface for all cases. The 150 mm lap length achieved the highest measured shear stress, suggesting that bond geometry influences capacity beyond bonded area alone. The findings support prior evidence that capacity tends to saturate beyond an effective bond length and that width to length proportion can shift stress concentrations. Practical implications include selecting lap lengths that balance constructability with reduced stress peaks, improved reliability, and minimized surface preparation demands. Limitations include single tests per configuration and potential setup variability, so future work should include replication and parametric studies of width to length ratio, surface treatment, and adhesive type.

KEYWORDS: epoxy adhesive, lap length, push-out test, steel-concrete composite, shear failure, bond geometry.

1. INTRODUCTION

Structural adhesives are increasingly used to join similar or dissimilar materials in civil engineering due to their uniform stress transfer, corrosion resistance, and potential for accelerated construction compared with mechanical connectors (Kumar, Patnaik, & Chaudhary, 2017). In steel-concrete composites, interfacial shear is typically resisted by mechanical connectors or by adhesion, interlocking, and friction, but mechanical connectors can concentrate stresses and exhibit limited fatigue performance. Adhesive joints offer smoother stress gradients and can be attractive when thin sections or dense reinforcement preclude mechanical devices. However, bond performance depends on joint geometry and materials, including the bonded length, width, and adhesive properties (Custódio, Broughton, & Cruz, 2009; Kang & Howell, 2012). A critical practical question is how lap length affects shear capacity in epoxy-bonded steel-concrete connections. While prior studies suggest that capacity saturates beyond an effective bond length and that edge effects can trigger peeling stresses (Branco, Tadeu, & Nogueira, 2003; Bizindavyi & Neale, 1999; Yao, Teng, & Chen, 2005), design guidance for epoxy-bonded steel-concrete interfaces remains limited. This study examines the effect of lap length on shear failure using a controlled push-out test program and interprets the results in light of bond geometry mechanisms reported in the literature.

2. Literature Review

Bond geometry governs stress distributions along the adhesive layer and at concrete edges, which in turn affects capacity and failure mode. Reviews emphasize that joint configuration, bonded width, and lap length alter peak shear and peeling stresses, fracture energy, and dominant failure mechanisms (Custódio et al., 2009; Kang & Howell, 2012). For a fixed area, capacity has been shown to increase with bond width due to reduced edge stress intensity, especially for higher strength concretes (Branco et al., 2003). Edge effects can be mitigated by setting the bond line back from the loaded edge or by rounding corners to avoid three dimensional cracking (Bizindavyi & Neale, 1999). Several studies indicate a diminishing return in ultimate strength beyond an effective lap length, consistent with exponential decay of shear transfer over distance and redistribution after first cracking toward the unloaded end (Yao et al., 2005; Volnyy & Pantelides, 1999). Experimental and numerical investigations on epoxy bonded steel-concrete beams confirm that geometry, surface preparation, and temperature influence joint response (Bouazaoui, Jurkiewiez, Delmas, & Li, 2008; Bouazaoui, Perrenot, Delmas, & Li, 2007; Jurkiewiez, Meaud, & Michel, 2011). Push-out testing is widely used to study shear transfer and to relate interface behavior to full scale composite action (Ernst, Bridge, & Wheeler, 2010).

3. MATERIALS AND METHODS

3.1. Materials

Concrete was produced with ordinary Portland cement, natural sand, and crushed granite. A nominal 1:2:4 mix and a water to cement ratio of 0.50 were used with a superplasticizer. An IPE steel section, 150 mm by 75 mm with 5 mm plate thickness, served as the steel adherend. The adhesive is a two part epoxy, epoxy used in this study was a readymade epoxy bought at a chemical company and the name of this particular epoxy was Master Brace ADH 2200. Master Brace ADH 2200 is a non- slumping epoxy bedding compound and adhesive. It is a two pack, fine aggregate filled, fast curing material, ideal for a variety of bedding, gap filling and concrete repair applications. Master Brace® ADH 2200 is a stiff but easily workable compound that can be applied by either trowel, spatula or knife. It cures to give high mechanical properties typical of epoxy compounds. It is resistant to oils, greases, petroleum, salts, many acids and alkalis and most commonly met corrosive media. It does not shrink on curing, and is designed to be used when cured from below freezing point to 60°C. Its impact resistance, and mechanical strength is greater than that of concrete. For surface repairs of fine cracks and spalls. For gap filling, grouting, bedding fixtures etc.

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Figure 1.0: Epoxy.

3.2. Steel Section

The steel used was cut from IPE 140 rolled beam of dimension 150mmX75mm with plate thickness of 5mm. IPE is the short form for bar shaped building elements or beams with parallel internal surface of the flanges and dimensions according to EN 10365. A stainless-steel beam can be either built up by welding together its single components or it is hot rolled or extruded. Upper and lower horizontal part of the beam is called flange, the connecting vertical middle part is called web. IPE stainless-steel beams are used in commerce and industry but also in machinery and equipment building. The use of stainless-steel profiles is characterized by a high flexibility of composition and a fast and cost reduced construction (through the possibility of prefabrication in the steel production). Stainless-steel profiles are produced mainly from scrap and can be recycled again after utilization so new resources can be conserved.

I-beams are commonly made of structural steel but may also be formed from aluminum or other materials. A common type of I-beam is the rolled steel joist (RSJ). I-beams are widely used in the construction industry and are available in a variety of standard sizes. Tables are available to allow easy selection of a suitable steel I-beam size for a given applied load. I-beams may be used both as beams and as columns. I-beams may be used both on their own, or acting compositely with another material, typically concrete. internal surface of the flanges and dimensions according to EN 10365. A stainless-steel beam can be either built up by welding together its single components or it is hot rolled or extruded. Upper and lower horizontal part of the beam is called flange, the connecting vertical middle part is called web. IPE stainless-steel beams are used in commerce and industry but also in machinery and equipment building. The use of stainless-steel profiles is characterized by a high flexibility of composition and a fast and cost reduced construction (through the possibility of prefabrication in the steel production). Stainless-steel profiles are produced mainly from scrap and can be recycled again after utilization so new resources can be conserved.

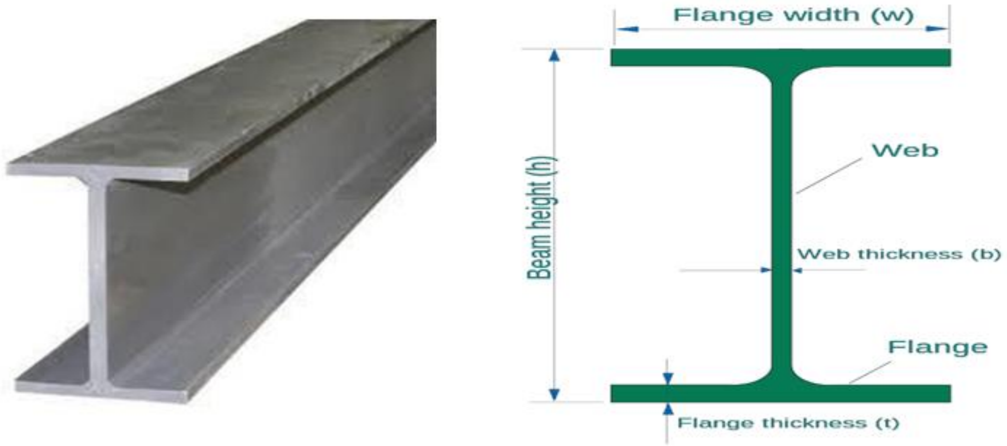


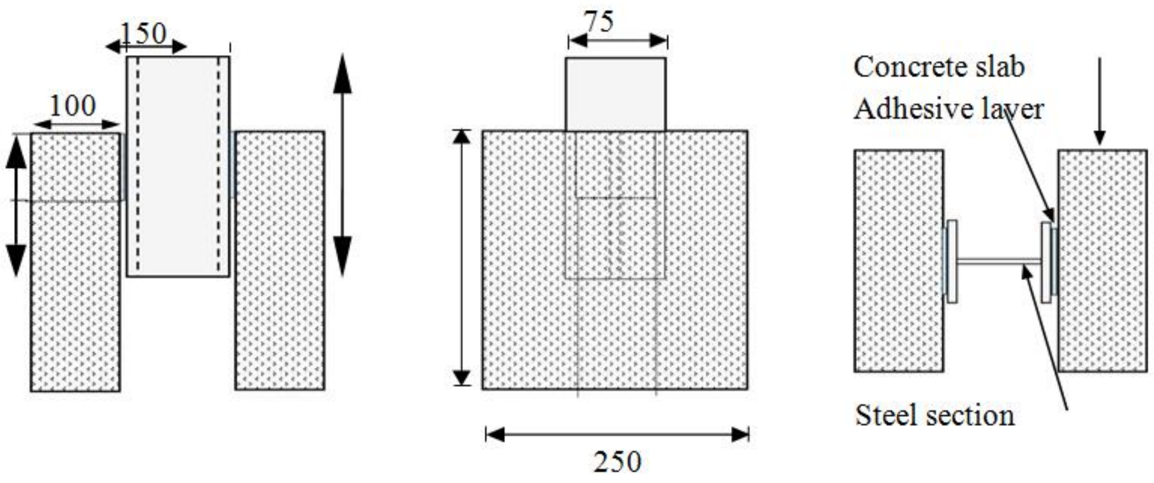
Figure 2.0: Steel section.

3.2 Specimen Geometry and Variables

Three push out specimens were prepared, each consisting of two plain concrete blocks and one steel section bonded on both flanges with a 5 mm adhesive layer. The concrete blocks measured 250 mm by 250 mm by 100 mm. The variable was lap length, 100 mm, 150 mm, and 200 mm. Surface preparation for the concrete included roughening by chopping, cleaning, and applying a primer before epoxy placement. After assembly, specimens cured prior to testing.

3.2 Experimental Setup

Each specimen was positioned on a universal testing machine equipped with a force transducer and computer based data acquisition. A rigid loading plate distributed load uniformly on the top of the steel section, and axial compression was applied. The applied load and the shear response at the steel concrete interface were recorded simultaneously with a data logger. Where applicable, measurements in the loading direction were taken at the midpoint of the bonded length for the bonded connection. A constant stress based loading protocol was used at a crosshead speed of approximately 10.0 mm per minute.



(a) Font View **(b) Side View** **(c) Plan View**

Figure 3.0: Experimental Setup.

Table 1: Details of the experimental set-up.

SPECIMEN	LL(mm)	SL(mm)	TA(mm)
C	100	200	5
D	150	250	5
E	200	300	5

LL = Lap Length

SL = Steel Section Length

TA = Thickness of Adhesive Layer

3.3 Mechanical Testing

Compressive strengths of cubes were measured at 14 and 28 days, cylinders at 28 days, and splitting tensile strength of cylinders at 28 days. Push out tests were conducted on a universal testing machine at a constant crosshead rate, approximately 10.0 mm per minute. Load and interface response were recorded electronically. Failure modes were documented visually. For reference, the maximum permissible bond length in single shear is

$$I. = \frac{Ft_yt}{\tau}$$

And for a double shear test:

$$I. = \frac{\frac{Ft_yt}{2}}{\tau}$$

Where F_{ty} is the yield strength of the adherend; t is the thickness of the adherend; τ is the average shear stress (Yao et al., 2005).

3.4 Data Reduction and Analysis

Peak stress was calculated from the measured peak load and bonded area, and results were compared across lap lengths. Interpretation focused on the influence of lap length and the role of width to length proportion in shifting stress concentrations.

4. RESULTS AND DISCUSSION

4.1 Material Properties

Compressive and tensile test results showed expected variability across nominally identical specimens at 14 and 28 days. Variations in peak and yield stress were observed, which underscores the need for replicate testing when drawing statistical conclusions.

Table 2: Compressive Strength Result on Cube Test (Day 14).

Test no	Stress@Peak(N/mm2)	Stress@Yield(N/mm2)
1	16.461	16.461
2	19.413	19.413
3	19.921	19.921

From the 14days compressive cube test result, stress at peak and yield was 16.461N/mm2, 19.413N/mm2, 19.921N/mm2 for cube 1, 2 and 3 respectively.

Table 3: Compressive Strength Result on Cube Test (Day 28).

Test no	Stress@Peak(N/mm2)	Stress@Yield(N/mm2)
1	18.103	16.378
2	21.925	21.925
3	24.841	24.841

Table 4: Compressive Strength Result On Cylinder Test (Day 28).

Test no	Stress@Peak(N/mm2)	Stress@Yield(N/mm2)
1	13.499	13.499
2	16.082	16.082
3	18.886	18.886

***Table 5: Tensile Strength Result On Cylinder Test (Day* 28).**

Test no	Stress@Peak(N/mm2)	Stress@Yield(N/mm2)
1	9.581	9.581
2	8.918	8.918
3	7.604	7.604

Table 6: Compressive Strength Result On Cylinder Test (Day 28).

Test no	Stress@Peak(N/mm2)	Stress@Yield(N/mm2)
1	13.499	13.499
2	16.082	16.082
3	18.886	18.886

Table 7: Tensile Strength Result On Cylinder Test (Day 28).

Test no	Stress@Peak(N/mm2)	Stress@Yield(N/mm2)
1	9.581	9.581
2	8.918	8.918
3	7.604	7.604

4.2 Push-Out Behavior and Failure Modes

Push out testing is widely used to estimate shear strength, load transfer mechanisms, failure modes of connections, and effective bond length in composite interfaces (Ernst et al., 2010, Yao et al., 2005). In comparative studies, the load–slip behavior of push out specimens has closely matched that of full scale composite beams, allowing reliable prediction of shear connector performance from push out results (Ernst et al., 2010).

In this study, each specimen was positioned on a universal testing machine equipped with a force transducer in the load path and a computer based data acquisition system. A rigid loading plate distributed the load uniformly on the top of the steel section, then a compressive load was applied. During the test, the applied load and the shear response at the steel–concrete interface were recorded simultaneously with a data logger. Measurements in the loading direction were taken at the midpoint of the bonded length for the bonded connection. A constant stress based loading protocol was used at a test speed of 10.000 mm per minute.

Figure 4.0: Push-out test.

Figure 5.0: Failure mode.

The three specimens recorded the same value for stress both at peak and at yield which showed the failure occurred suddenly as the peak was reached. Specimen C recorded a yield stress of 50.453N/mm2 while specimen D recorded 188.933N/mm2 and specimen E recorded 51.085N/mm2.

Table 8: Specimen Result.

Specimen	Stress@Peak(N/mm2)	Stress@Yield(N/mm2)
C	50.453	50.453
D	188.933	188.933
E	51.085	51.085

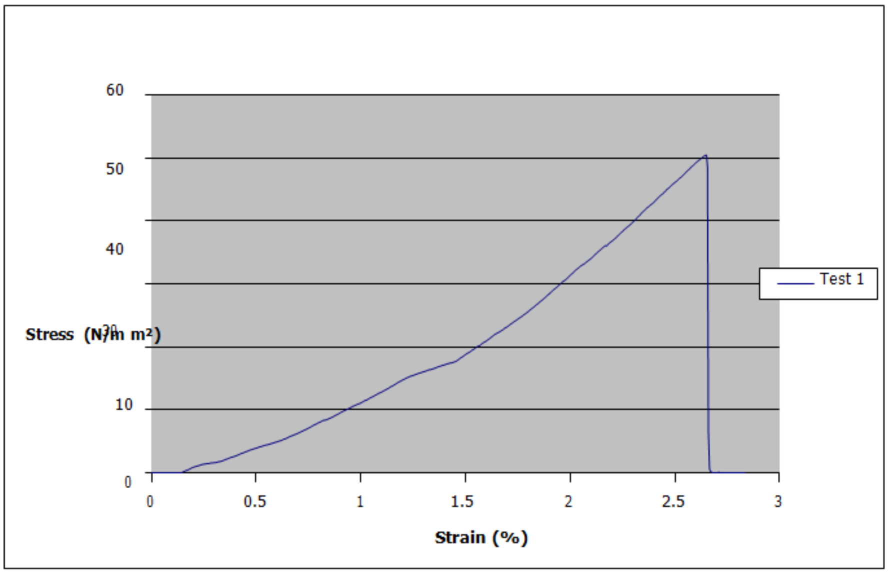


Figure 6.0: Specimen C.

The graph above showed that there was a sudden failure on the specimen which means that there was no initial failure on the specimen before the peak was reached and it failed immediately the peak was reached.

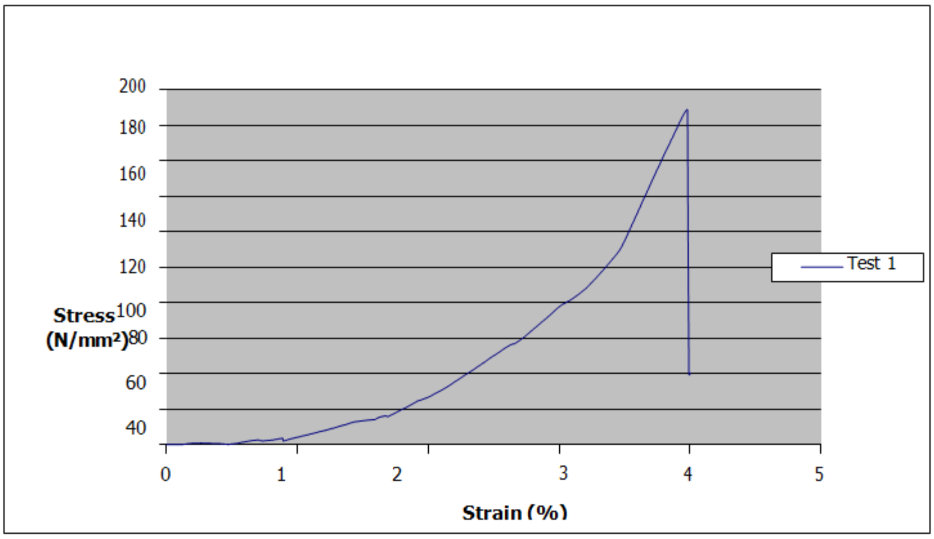


Figure 7.0: Specimen D.

The graph above showed that there was a sudden failure on the specimen which means that there was no initial failure on the specimen before the peak was reached and it failed immediately the peak was reached.

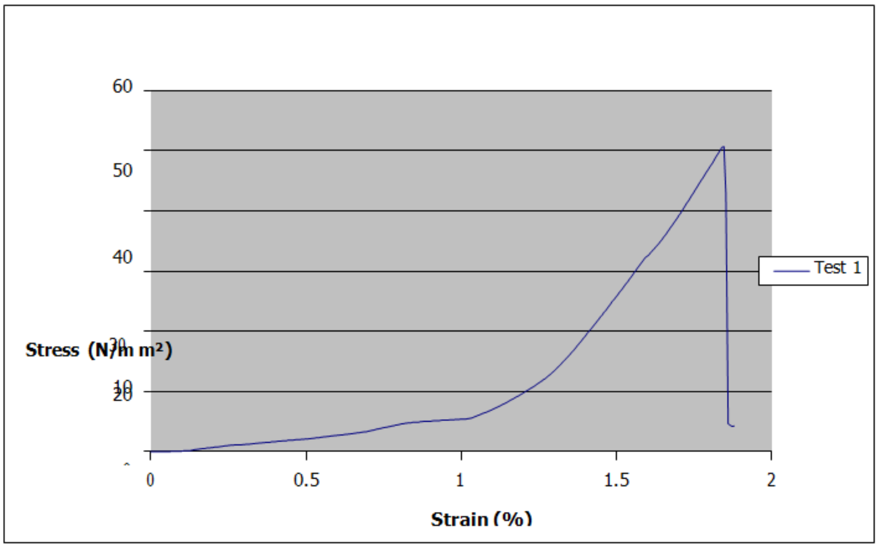


Figure 8.0: Specimen E.

The graph above showed that there was a brittle failure on the specimen which means that there was no initial failure on the specimen before the peak was reached and it failed immediately the peak was reached.

4.2.1 Specimen Similarities

The similarities in the specimens required of this study are as follows;

- All the specimens have same concrete dimensions.
- The three specimens were under same temperature.
- The three specimens have same adhesive bonding thickness.
- The experimental study was carried on the specimens on same day.
- Epoxy adhesive was used for bonding the three specimens.
- In the three specimens, failure occurred in the concrete near the interface of concrete and adhesive.

4.2.2 Specimen Differences

The difference between the two specimens required for this study are as follows;

- The three specimens were of different lap lengths.
- The three specimens steel sections were of different length.
- The three specimens were of different bonding strength to the difference in lap lengths.

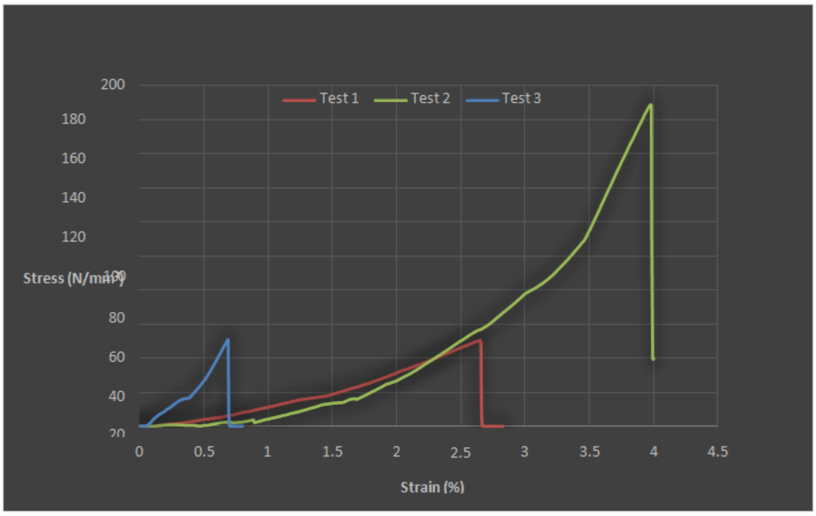


Figure 9.0: Specimen Result Comparison.

4.3 Effect of Lap Length on Capacity

Measured peak stresses were approximately 50.45 N/mm² for the 100 mm lap, 188.93 N/mm² for the 150 mm lap, and 51.09 N/mm² for the 200 mm lap. The 150 mm configuration achieved the highest capacity in this series. Given that the 200 mm lap did not exceed the 150 mm result, an effective length effect is plausible, where additional length beyond a certain range adds little strength. The pronounced advantage at 150 mm may also reflect a favorable width to length proportion that reduced edge peeling stresses, in line with findings that capacity is sensitive to this ratio (Branco et al., 2003). Because only one specimen per configuration was tested, replication is recommended to quantify dispersion.

4.4 Practical Implications

Results suggest that selecting a lap length near an effective range can maximize capacity without unnecessary adhesive use or preparation effort. Attention to corner detailing, setback from edges, and surface preparation can further reduce stress concentrations and enhance reliability. Where mechanical connectors are undesirable, epoxy bonding with tuned geometry is a viable option, provided quality control of surfaces and adhesive thickness is maintained.

4.5 Limitations

Single tests per configuration limit statistical power. Potential setup variability, differences in curing conditions, and sensitivity to surface preparation may influence results. Future work should examine the role of bonded width, corner radius, surface preparation methods, and temperature, along with replication to establish confidence intervals.

5. CONCLUSION

This research examined whether structural adhesives can replace mechanical connectors for steel to concrete bonding, with a focused study on lap length. Bond strength at the interface is influenced by many factors, including the physical, mechanical, and chemical properties of the adhesive and adherends, the geometry of the bonded area, adhesive layer thickness, adherend shape and surface preparation, the presence and type of fillers, and curing and service conditions such as moisture, temperature, and humidity. To isolate one key variable, the tests compared three lap lengths, 100 mm, 150 mm, and 200 mm, at a constant width of 75 mm.

During push out testing, all specimens exhibited sudden failure localized near the concrete to epoxy interface, consistent across the series. The separated slab and fracture pattern indicated shear failure that was brittle and cohesive in the concrete close to the bond line. The smallest lap length, 100 mm, achieved the lowest bond strength. Increasing the lap length to 200 mm improved capacity, however the highest bond strength occurred at 150 mm. This suggests the presence of an effective bond length, where capacity increases with length up to a threshold, after which gains diminish. The superior performance at 150 mm likely reflects a favorable width to length proportion of 1 to 2, and alignment of the adhesive length with the I section web, which can reduce edge induced stress concentrations. Given that only one specimen was tested for each configuration, laboratory variability cannot be ruled out. To confirm these trends and quantify dispersion, three or more replicate tests per lap length are recommended. Overall, bond strength increased with lap length up to the effective range near 150 mm, and capacity also depends on the bonded width, which should be considered together with lap length in design.

The effect of lap length on shear failure of steel-concrete composite connections has been investigated. From the investigation, the following recommendation has been made.

- In order to ascertain the factors affecting the bonding capacity and to increase the reliability of such push-out tests an increase in the number of identical specimens to three or more is recommended.
- Failure occurred in the concrete. Therefore, high strength concrete is recommended.

REFERENCES

1. BASF. (2020). MasterBrace ADH 2200 technical data sheet. https://technocretetrading.com/wp-content/uploads/2020/10/6basf-masterbrace-adh-2200-tds.pdf
2. Bizindavyi, L., & Neale, K. W. (1999). Transfer lengths and bond strengths for composites bonded to concrete. Journal of Composites for Construction, 3(4): 153–160.
3. Bouazaoui, L., Jurkiewiez, B., Delmas, Y., & Li, A. (2008). Static behaviour of a full scale steel concrete beam with epoxy bonding connection. Conference paper.
4. Bouazaoui, L., Perrenot, G., Delmas, Y., & Li, A. (2007). Experimental study of bonded steel concrete composite structures. Journal of Constructional Steel Research, 63: 1268–1278.
5. Branco, F. J., Tadeu, A. J., & Nogueira, J. A. (2003). Bond geometry and shear strength of steel plates bonded to concrete on heating. Journal of Materials in Civil Engineering, 15(6): 586–593. https://doi.org/10.1061/(ASCE)0899-1561(2003)15:6(586)
6. Custódio, J., Broughton, J., & Cruz, H. (2009). A review of factors influencing the durability of structural bonded timber joints. International Journal of Adhesion and Adhesives, 29(2): 173–185. https://doi.org/10.1016/j.ijadhadh.2008.03.001

7. Ernst, S., Bridge, R. Q., & Wheeler, A. (2010). Correlation of beam tests with push out tests in steel concrete composite beams. Journal of Structural Engineering, 136(2): 183–192. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000107.
8. InterDominion. (2022). MasterBrace ADH 2200 product data sheet. https://interdominion.in/wp-content/uploads/2022/12/MasterBrace-ADH-2200.pdf
9. Jurkiewiez, B. (2021). Push out and bending tests of steel concrete adhesively bonded composite elements. Engineering Structures, 234: 112094.
10. Jurkiewiez, B., Meaud, C., & Michel, L. (2011). Nonlinear behavior of steel concrete epoxy bonded composite beams. Journal of Constructional Steel Research, 67: 389–397. https://doi.org/10.1016/j.jcsr.2010.10.007
11. Kang, T. H. K., & Howell, J. (2012). A review on debonding failures of FRP laminates externally adhered to concrete. International Journal of Concrete Structures and Materials, 6(2): 123–134. https://doi.org/10.1007/s40069-012-0013-0
12. Kumar, P., Patnaik, A., & Chaudhary, S. (2017). Structural adhesives in concrete and steel concrete composites, performance factors and applications. International Journal of Adhesion and Adhesives, 77: 1–14. https://doi.org/10.1016/j.ijadhadh.2017.04.007
13. Mostofinejad, D., & Esfahani, M. (2021). Generic assessment of effective bond length of FRP to concrete bonded joints. Composites Part B: Engineering, 216: 108836.
14. Shao, J., Zhang, Z., Li, A., & Delmas, Y. (2025). Experimental study on flexural behavior of bonded steel concrete composite structures. Engineering Structures, 305: 118625.
15. Yao, J., Teng, J. G., & Chen, J. F. (2005). Experimental study on FRP to concrete bonded joints. Composites Part B: Engineering, 36(2): 99–113. https://doi.org/10.1016/j.compositesb.2004.04.002
16. Yazdani, A. (2023). Evaluation of existing FRP to concrete bond strength models. Journal of Composites for Construction, 27(5): 04023031.