DEVELOPMENT OF DURABLE FIBER REINFORCED POLYMER GROUTED SPLICE CONNECTION

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This thesis is dedicated to my beloved father, Abbas Koushfar who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my beloved mother, Fatemeh Razavi who taught me that even the largest task can be accomplished if it is done one step at a time. This thesis is dedicated to my dearest brothers.

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ABSTRACT

Presently, the ease of field assembly offered by precast concrete systems is weighted against the larger numbers of connections that are required in precast concrete systems, which pose a problem. In this regard, grouted splice sleeve connections are gaining popularity. However, the existing splice sleeve connectors in the market are proprietary and patented by foreign companies resulting in the high cost of adaption, particularly in Malaysia. Over the last few years, the use of composite materials has become an increasingly popular method of repairing and strengthening ageing civil engineering structures. The primary cause of corrosion in steel joint connectors is exposure to sodium chloride that is present in marine environments or de-icing salts that are applied to bridge decks and parking structures. This research aims to use durable and non-corrosive FRP connections as alternatives to current steel precast connection methods. The development of an FRP connection component will benefit the precast industry, FRP manufacturers, contractors and owners. This research follows the method of grouted splice sleeve connectors. This new type of connector is an alternative method for connecting precast concrete structural members with non-metallic FRP components to provide the continuity between two separate steel bars in precast structures. Durable and non-corrosive FRP connection is efficient and economical alternatives to current steel precast connection methods. Since there is no need to modify the internal surface of the sleeve and to use threaded connection between reinforcement bar and sleeve, the newly developed FRP connector can be easily produced as a single unit compared to the conventional grouted pipe connectors. All it requires is a tapered FRP sleeve to connect reinforcement bars. This project summarizes the experimental program and also the performance of the newly developed FRP splice connector under axial tension. The influence of several parameters of the proposed connector is identified. These parameters include the incorporation of the tapered FRP sleeve, internal diameter of the mid-length of the FRP connector, and number of wrapping FRP layers. The experiments examined the tensile strength as well as the failure mode of the connectors. The results of this research prove successfully that the invention of a non-metallic FRP connector used for precast concrete construction is possible by using FRP material as the conventional steel pipes. By using the newly developed FRP connectors in the precast construction industry, the service life of the connections increase due to the FRP material properties and elimination of the steel components in structures which reduce the life cost of the structures.

ABSTRAK

Saat ini, kemudahan pemasangan lapangan yang ditawarkan oleh sistem konkritpracetak adalah tertimbang terhadap sejumlah besar Sambungan yang diperlukandalam sistem konkrit pracetak, yang menimbulkan masalah. Dalam hal ini, grouting sambungan lengan sambatan yang mendapatkan populariti. Namun, penyambung lengan yang ada sambatan di pasaran adalah proprietary dandipatenkan oleh syarikat asing yang menyebabkan tingginya biaya adaptasi, terutamadi Malaysia. Selama beberapa tahun terakhir, penggunaan material komposit telah menjadi kaedahsemakin popular memperbaiki dan menguatkan struktur awam penuaan. Punca utama dari korosi pada baja penyambung bersama adalah paparan natrium klorida yang ada dalam persekitaran laut atau de-icing garam yang diterapkan ke deck jambatan dan struktur parkir. Penyelidikan ini bertujuan untuk digunakan tahan lama dan non-mengkakis SambunganFRP sebagai alternatif untuk kaedah sambungan baja pracetak saat ini.pembangunan komponen Sambungan FRP akan menguntungkan industri pracetak, FRP pengilang, kontraktor dan pemilik. Penyelidikan ini mengikuti kaedah grouting penyambung lengan sambatan. Jenis baruini penyambung adalah sebuah kaedah alternatif untuk menyambung anggota strukturkonkrit pracetak dengan komponen FRP non-logam untuk memberikan kesinambunganantara dua batang baja berasingan dalam struktur pracetak. Durable dan bukan-mengkakis Sambungan FRP adalah alternatif yang cekap dan ekonomi untuk kaedah sambungan baja pracetak saat ini. Kerana tidak ada perlu mengubah permukaan dalaman lengan dan menggunakan sambungan threaded antara bar penguatan dan lengan, yang baru dibangunkanpenyambung FRP dihasilkan lebih mudah sebagai unit tunggal berbanding denganpenyambung konvensional paip grout.Yang diperlukan adalah lengan FRP meruncing berhubung Bar penguatan. Projek ini meringkaskan program percubaan dan juga prestasi penyambung FRP barudibangunkan sambatan bawah voltan paksi. Pengaruh beberapa parameter dari penyambung yang dicadangkan dikenalpasti. Parameter ini meliputi penggabungan dari lengan FRP runcing, diameterpanjang-tengah penyambung FRP, dan jumlah lapisan pembungkus FRP. Percubaan menguji kekuatan tarik serta mod kegagalan penyambung. Keputusan kajian ini berjaya membuktikan bahawa penemuan penyambung FRPnon-logam digunakan untuk pembinaan konkrit pracetak ini dimungkinkan dengan menggunakan bahan FRP sebagai paip baja konvensional. Dengan menggunakan penyambung FRP baru dikembangkan dalam industripembinaan pracetak, kehidupan perkhidmatan sambungan meningkat akibat sifatmaterial FRP dan penghapusan komponen baja dalam struktur yang mengurangkankos hidup dari struktur.

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d	-	Nominal bar diameter
D_i	-	Internal diameter at the mid-length of the connector
D_o	-	Sleeve diameter at both ends
f_b	-	Bond Stress
f_{bu}	-	Design ultimate anchorage value
f'_c	-	Concrete compressive strength
f_{cu}	-	Grout compressive strength
f_n	-	Lateral confining pressure
L_d	-	Bar embedment length
L_e	-	Bar embedment length
L_s	-	Sleeve length
P	-	Failure load
P_{safe}	-	Safe load
t	-	Sleeve thickness
U	-	Bond strength of the concrete
β	-	Coefficient dependent on bar type
φ	-	Nominal bar diameter (for calculation of the bond stress at bar)

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CHAPTER 1

INTRODUCTION

1.1 Introduction

A System which has been prepared, cast, and cured in a location which is not its final destination is called precast systems. The most important difference between precast systems and conventional methods (cast in situ) is its response to the external and internal loads, because in precast systems a member has a finite size and should be jointed to the other elements to complete the structure.

FRP materials have been used in building construction for some 40 years. Initially introduced in the form of translucent corrugated sheeting intended primarily as roof lighting, FRP has since achieved a wider use as an opaque cladding for building. The number of designs in which FRP fulfils a structural or semi-structural role is increasing, but the rate of increase will be constrained unless the material can be used efficiently. This will only come about with the availability of accurate design data relating to strength properties (short-term and long-term) and durability.

In this experimental research, tapered GFRP sleeves are used instead of conventional steel sleeves. Compared to the conventional steel sleeves, FRP materials are more advantageous. It is stronger than the steel, it weighs 3.5-4 times less than the conventional steel sleeves, and it has the high modulus of elasticity when the relative extension coefficient is low. Besides it has strong durability as respects to stress loads. FRP component doesn't corrode, changes its mechanical properties rather weakly under the influence of acids, salts and alkalis.

Glass Fiber Reinforced Polymer (GFRP) is a composite material, which consists of polyester thermosetting resin as matrix and glass fibers as reinforcement. GFRP is mainly used a structural section and as structural rehabilitation and repair material. This study is conducted experimentally to investigate the engineering properties of GFRP material and its performance under axial tension load. Two different fiber orientations of GFRP fabrics selected for the test specimens. They were fabricated by a local manufacturer according to the commercial quality requirements. A total of twelve specimens including 3 control specimens were tested. The specimens were tested for mechanical performance. The results of this experimental study prove that the newly developed FRP splice sleeve is feasible.

Precast constructions can be completed much faster than conventional methods such as cast-in-place concrete construction. Prefabricated pieces of precast system can be installed rapidly and reduces the construction time by speed of assembly. Because of these reasons it is cost effective which can save days on a project compared to the cast-in-place concrete. Precast concrete components are cast into structural members under factory conditions and they are controlled by off-site manufacturers which leads to a high quality. This fact enables precast concrete to have a high resistance to heat, water, and moisture.

When volumetric changes caused by load shrinkage or thermal, precast elements try to move apart. Precast elements movement is resisted by friction between internal surfaces of precast elements. This fact emphasizes the importance of the connections in precast concrete structures. Connections alone can dictate the type of precast frame, the limitations of that frame, and the erection progress (Elliot, 2002). The purpose of designing connections is to transfer the forces between structural members and provide the stability of the structure by their strength and ductility. There are different ways to have a satisfactory connection, e.g. welding, bolting, or grouting. The used method should be simple and applicable on the site.

As mentioned above, members in precast systems should be jointed to the other elements to complete the structure, so one of the possible problems in these systems is the structural continuity. There are two different types of connectors: conventional method or lapping reinforcement bar and mechanical connectors.

Grout filled splices connection is a form of mechanical connector which have been used to connect precast members. During the fabrication, sleeves are inserted on one side of the connected member. Reinforcing bars received from the other side. In the next step, projecting bars are inserted into the sleeves to fit two sides of the members. Then, the space between the bars and sleeves is filled with non-shrink grout. Figures 1.1 and 1.2 give examples of common grout splice sleeve connections. By having a good installation of the connection, the sleeves can withstand applied forces and they can develp the full strength of the bars to have a monolithic behavior as cast in situ concrete.

Figure 1.1: Lenton Interlok

Figure 1.2: NMB U-X Splice Sleeve

1.2 Problem Statement

The structural behavior of precast elements may differ substantially from that of similar members that are monolithically cast in place. The major difference is the nature of connections. Connections are designed to transmit forces due to creep, temperature change, shrinkage, and elastic deformation. Details of precast concrete connections are especially important to ensure equivalent behavior of a conventionally designed, cast-in-place, monolithic concrete structure (ACI Committee 550R-96). This continuity in cast-in-place systems can be achieved by providing lapped bars to have a monolithic system. Components in precast concrete systems are prefabricated, so lapping length may not be appropriate for precast concrete systems, because it needs to extend for significant length. Therefore several new methods have been invented to prevent this.

The sleeve connectors available on the market are proprietary products and little information has been published about the mechanism of the connection system. Also, they could only be purchased from certain companies which belong to foreign countries, therefore designing a new type of sleeve connector which could be cost effective and simple to produce is necessary.

In order to design a new type of sleeve connector, it is necessary to understand the bond mechanism and factors that might affect the bond strength of grouted sleeve connector. The effectiveness of the splice sleeve connector largely depends on the bond strength between the grout and reinforcing bar.

1.3 Objectives

The objectives of the current research presented are:

1. To study the feasibility of the new grouted splice connector
2. To study the effect of inclination angle (internal diameter at the mid-length) of tapered FRP sleeve
3. To investigate the bond mechanism of the new connector
4. To study the behavior and failure mode of grouted splice connector subjected to axial tension

1.4 Scope of Research

The scope of the current research program includes testing a new type of FRP grouted splice connector that was developed as parts of this research. Several specimens of the new connector were prepared and tested under axial tension load only to carry out the objectives of this study.

References

ACI Committee 116 (1962), Glossary of terms on Cement and Concrete Technology Increment No. 1. ACI Journal, Proceedings V.59, No.12, pp.1761-1770.

ACI Committee 440 (2006). "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars," ACI 440.1R-06, Farmington Hills, MI.

ACI Committee 439 (1991) Mechanical Connections of Reinforced Bars. ACI Structural Journal, March - April, pp.222-237.

ACI Committee 550, ACI 550.1R-01 report – Emulation Cast-in-Place Detailing in Precast Concrete Structures.

Adajar, J.,Yamaguchi, T., and Imai, H., "An Experimental Study on the Tensile Capacity of Vertical Bar Joints in a Precast Shearwall," Proceedings, Japan Concrete Institute, V.15, No.2, 1993, pp. 1255-1261

Andrew J. Tibbetts, Michael G. Oliva, Lawrence C. Bank, "Durable Fiber Reinforced Polymer Bar Splice Connections for Precast Concrete Structures" COMPOSITES & PLOYCON 2009 American Composites Manufacturers Association January 15-17, 2009 Tampa, FL USA

Azizinamini, A., Stark, M., Roller, J.J and Ghosh, S.K. (1993) Bond Performance of Reinforcing Bars Embedded in High-Strength Concrete. ACI Structural Journal, September – October, pp. 554.561.

British Standard Institution (1997) BS 8110. London, British Standard Institution.

British Standard Institution (1997) BS 8110. Structural use of concrete-part 1 code of practice for design and construction BS8110-1:1997, British Standard, clause 3.4.5 and clause 3.12.7.1.

Clarke, J. L. The need for durable reinforcement. In Alternate Materials for the Reinforcement and Prestressing of Concrete, ed. J. L. Clarke, Blackie, 1993, ch. 1, pp. l-33

Cox, J.V & Herrmann, L.R. (1998) "Development of a Plasticity Bond Model for Steel Reinforcement". Mechanics of Cohesive-Frictional Materials, John Wiley & Sons, Ltd., pp.155-180

Dahl, K.L. (2001) High Strength Grouted Pipe Coupler. U.S Patent No. 6,192,647

David Darwin, Shahin S. Zavaregh, "Bond Strength of Grouted Reinforcing Bars", ACI Structural Journal, V. 93, No. 4, July – August 1996

Einea, A., Yamane, T., Tadros, M.K. (1995) “Grout-filled Pipe Splices for Precast Concrete Construction”, PCI Journal, January-February, pp.82-93.

ERICO, LENTON INTERLOCK – Product Brochure.

Hayashi, Y., Shimizu, R., Nakatsuka, T., and Suzuki, K., “Bond Stress-Slip Characteristic of Reinforcing Bar in the Grout-Filled Coupling Steel Sleeve,” Proceedings, Japan Concrete Institute, V.15, No.2, 1993, pp. 265-270.

Hungspreug, S., (1981) “Local Bond Between a Steel Bar and Concrete Under High Intensity Cyclic Load”. Phd Thesis, Cornell University, 449 pp.

J. M. Lees, B. Gruffydd-Jones and C. J. Burgoyne, “Expansive cement couplers A means of pre-tensioning fibre-reinforced plastic tendons” Construction and Building Materials, Vol. 9, No. 6, pp. 413423, 1995

J. M. Lees, B., C. J. Burgoyne, “Transfer bond stresses generated between FRP tendons and concrete” Magazine of Concrete Research, 1999, 51, No. 4, Aug., 229-239 229

Keith L. Coogler, Kent A. Harries, and Marcella Gallick “Experiment Study of Offset Mechanical Lap Splices Behavior,” ACI Structural Journal, V. 105, No. 4, July- August 2008, pp.478-487.

Losberg, A., and Olssen, P., “Bond Failure of Deformed Main Bars Based on the Longitudinal Splitting Effect of the Bars,” ACI Journal, V.76, No.1, January 1979, pp. 5-18.

Malvar, L.J. (1992) Bond of Reinforcement under Controlled Confinement. ACI Materials Journal, November – December, pp.593-601.

Nilson, A. H., “Internal Measurement of Bond Slip,” ACI Journal, V.69, No.7, July 1972, pp. 439-441.

Nomura, K., Hara, N., Mutsuyoshi, H., and Machida, A., “Experimental Study on Joints of Main Bars in Prestressed Concrete Formworks,” Proceedings, Japan Concrete Institute, V.15, No.2, 1993, pp. 259-264.

PCI Committee, Design and Typical Details of Connections for Precast and Prestressed Concrete.

Prestressed Concrete Institute (1988). “Design and Typical Details of Connections for Precast and Prestressed Concrete,” PCI, Chicago, IL.

Rostasy, F. S. and Budelmann, H. Principles of design of FRP tendons and anchorages for post-tensioned concrete. In Fibre- Reinforced-Plastic

Reinforcement for Concrete Structures -Internutional Symposium, SP-138 (eds. A.

Nanni and C. Dolan) ACI, 1993, pp. 633-650

Soroushian, P., and Choi, K., Park, G., and Aslani, F., “Bond of Deformed Bars to Concrete: Effects of Confinement and Strength of Concrete” ACI Materials Journal, V.88, No.3, May-June 1991, pp. 227-232.

Soroushian et al. (1991) reported the results of a bar pull-out testing program.

Soroushian, P., and Choi, K., “Local Bond of Deformed Bars with Different Diameters in Confined Concrete,” ACI Structural Journal, V.86, No.2, March-April 1989, pp. 217-222.

SSNA, General Brochure of NMB Splice Sleeve Systems.

Untrauer, R. E., and Henry, R. L., “Influence of Normal Pressure on Bond Strength” ACI Journal, V.62, No.5, May 1965, pp. 577-585.

Yankelevsky, D. Z., “Bond Action Between Concrete and a Deformed Bar- A New Model,” ACI Journal, V.82, No.2, March-April 1985, pp. 154-162.