THE IMPLEMENTATION OF HYBRID BEAM TO COLUMN CONNECTION IN PRECAST CONCRETE FRAME

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DEDICATION

I dedicate this work to my father, YAHAY YAHYA ALMARRANI and to my entire family members.
ACKNOWLEDGMENT

I thank ALLAH for giving me the opportunity to accomplish my Master project report writings and completing my program at University Tun Hussein Onn Malaysia. I would like to express my greatest appreciation to my supervisor, Assoc. Prof. Dr. Goh Kai Chen, for his generous guidance, advice and motivation throughout this research. A special thank dedicated to my beloved parents and family, for their continuing financial and morale supports throughout my studies. On the other hand, my sincere appreciation also extends to all my friends, especially Mr Mustafa Mogalli and others, those who were directly or indirectly involved in the process of producing this research report, for their generous assistance, useful views and tips. Finally, I would also like to show my appreciation to all academic and non-academic staff of the Faculty of Technology Management and Business.

Thank you all.
ABSTRACT

The connections between precast concrete components play an important role in determining the successful of precast concrete framed structures. In particular, the connection between beam-to-column that affected the load distribution, strength, stability and constructability of the global structure. The understanding on the behavior of the connection is important for the housing project. The main objective of this research is to investigate the stress behavior and the displacement of the hybrid beam-to-column connections in precast concrete frames. The experimental test was conducted comprised of one model, which was limited to hybrid beam-to-column connections in precast concrete frames. MSC NASTRAN PATRAN software version 2016 was used to model and analysis. The behavior of load displacement relationships, stress relationships and types of failure in connections are also investigated. Moreover, the development of safe, economical, simple and hybrid precast beam-to-column connections conforming to building code requirements. The overall outcome was the stress behavior remains at the acceptable rate, and the displacement did not exceed the allowable value.
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CHAPTER 1

INTRODUCTION

1.1. Research Background

The new innovation that has been actualized in the advanced development industry, which is Industrialized Building System (IBS). This technology in the construction industry for Malaysia has demonstrated the significance of prefabricated concrete segments in the late improvement of construction development. As a result of the disservices of structural steel sections in term of expense, prefabricated concrete application has gotten widely known among specialists and designers. The achievement of prefabricated concrete constructions relies on the connections of the segments in specifically the connection between beam and column. Typical connection between precast beam and precast column details that are suggested by the Pre-stressed Concrete Institute (PCI), they have demonstrated more than one disservices, for example, slow erection on site, no dependable moment capacity, development resistance issue and high cost of connection hardware, (CIDB, 2004).

As indicated by Elliot et al. (1998), approximately 24 tests had been directed utilizing welded plate and bolted connectors, however, experimental study on the concrete connection corbel with hardened cleat types have not generally completed. Although the Pre-stressed Concrete Institute (PCI) manual contains details of typical
beam-to-column connections satisfying numerous capacities, the distributed test outcomes are accessible for just a couple of them. Accordingly there is as yet missing of exploratory information for the ductile connection points of interest for beam-to-column connection in precast concrete structure. What's more, precast connection conduct must be legitimately surveyed by research facility testing or demonstrated execution.

There has been expanded with the utilization of precast concrete for basic parts in structures on the world in the course of recent years. This is principally because of precast components having high quality control, site ownership time and a stamped increment in rate of development. Significant expansions in the use of precast concrete in moment resisting frames and structural walls started in the mid to late 1980s. Today, precast seismic frames, walls, and ground surface framework have turned into the standard for use in structures all through the world (Hajjar, 2002).

Industrialized Building System (IBS) is the term formulated by the business and government which is CIDB in Malaysia to speak to the reception of development industrialization and the utilization of construction of parts in building development. IBS is characterized as a development system in which segments are fabricated in a controlled domain (on or off site), transported, situated and gathered into a structure without extra equipment on site. It comprises of precast part frameworks, manufactured steel structures, creative mold frameworks, modular block systems and pre-assembled timber structures as development segments. Parts of the building that are repetitive but difficult – and too time consuming and labor intensive to be casted onsite – are outlined and detailed as standardized segments at the factory and are then manufacturing plant and are then conveyed to the site to be gathered. The on location throwing exercises in IBS use inventive and clean shape advances (Ahmed, 2006).

"The term ‘hybrid’ is used to describe mixed construction where precast concrete is utilized in part of mix with other building media, such as cast in-situ concrete, steelwork, masonry and timber". "It must not be mistaken for the term ‘composite’, which also additionally utilizes both precast and other material, however where the structural performance depends on the interaction between two". "Accordingly, a precast concrete connection can be called as ‘hybrid connection’ if it involves bolting, dowels, cleats, cast-in sockets, sleeves and so forth". "Numerous sorts of beam-to-column
connections have been created to join precast beam elements to column elements" (Ahmed, 2011).

The current issue is the visible part of the connection, which is not improving the appearance standard for the architects, because they want the connection to be hidden to fulfill their demands in term of spacing.

1.2. Problem statements

One of the current issues in the construction industry is cost overrun due to delay when the traditional method is applied.

According to Ahmad Baharuddin, (2006), after the IBS has been introduced to the construction industry, there are some issues occur when the IB system is applied, such as technical issues which it can be classified into two categories:

1. Lack of learning capacity in planning the details of ties and connections of the precast segments especially in precast concrete development.

2. Poor connection framework may make issue to site work such that the connections cannot be legitimately because of poor development of construction details. (Refer Figure 1.1).

Figure 1.1: Poor connection system leads to the issue of comfort and safety (Ahmad, 2006)
Other related architect issues is one type of beam-to-column connection which architectures are not satisfied about that type of connection known as ‘conventional corbel’, because of the visible part of the connection as shown in Figure 1.2.

Figure 1.2: Beam-to-Column conventional corbel connection (Ahmad 2006)

Thus, in this study there will be explained about the suitable connection which is precast concrete corbel, which has many advantages such as, it can be modeled for both steel flange and concrete flange beams, saves space for pre-stressed reinforcement and got several sizes covering most building applications, the most important part to satisfy the architectures is precast concrete corbels are totally hidden, esthetic connection and no visible part.

Corbels are widely used in precast concrete structures in view of the advantages in improving of the production speed, because the Corbel’s position can be adjusted on both vertical and horizontal direction after casting, also easy and fast beam installation-there is no separate installation parts-. More advantages of using this type of connection such as; no need for additional fire protection, besides that when the corbel is installed after casting, therefore the column’s formwork can be re-used, which can provide lower construction costs. Furthermore the precast concrete corbel is much easier to cast than conventional corbels because the steel corbel is bolted to the column after the form has been stripped. The precast concrete corbel also allows final adjustments at the site.
So this study is focused on replacing the conventional connection with hybrid connection in small projects such as housing project, because the space has a high level of importance, which the hybrid beam to column can provide it by replacing the visible part with hidden connection with high quality in term of structural behavior. The hybrid beam to column connection has an acceptable resistance of displacement, because it provides a high capacity of steel plate that adds strength to the structure.

1.3. Research questions

Q1: What is the stress of the hybrid beam to column connections?
Q2: What is the displacement behavior of hybrid beam to column connection in precast concrete frame?
Q3: How to improve the hybrid connection between the column and beam in hybrid structure?

1.4. Objectives

The main objectives of this study are as follows:

i. To determine the stress behavior of hybrid beam-to-column connections in precast concrete frames, by using finite element software.

ii. To study the displacement behavior of beam-to-column connection.

iii. To recommend the appropriate beam to column connection in the IBS.

1.5. Scope of study

The extent of this research is constrained to improve the traditional corbel by replace it with hidden corbel, and improve its structural behavior by adding steel application into the connection system. The precast beams, hybrid corbels and columns for this experiment were designed according to EUROCODE, because the standard provides all
the requirements for designing this type of structure. As per EUROCODE the suggested techniques for configuration of design and detailing for reinforced concrete and pre-stressed concrete also applied to precast concrete. Aside from that, the connectors such as plates and bolts were designed based on EUROCODE. The size of a beam is 250x300 x 1000 mm, jointed in a 250x250 x 1000 mm column, because these sizes are used in small projects such as housing projects. The testing was done to study the structural behavior and performance of hybrid beam-to-column connections in precast concrete frames.

The precast concrete corbel connection gives a basically supported joint that offers very little moment transfer between beam and column. This connection is simple to design, prefabricated and erect. There are many advantages such as low construction cost, simple formwork, and small size: fits into low beams and slabs, appropriate for requesting architectonical developments and most effortless approach to cast more than two corbels at the same height. This hidden corbel has a capacity of up to 1500 KN; also it provides direct stability against transverse load.

1.6 Research significance

The purpose of this research is to expand the body of knowledge on the term of hybrid connectors in Industrialized Building System (IBS) frames to provide a basis for possible modifications to the building code. This research focused on frame connection particularly on the improvement in conventional corbel appearance by replace it with hidden connection with improving its physical properties, and to reduce the time while constructing any structure project. Also increase the design capacity of steel plate and providing extra shear reinforcement.

1.7 Thesis structure

The research will be divided into five chapters which is summarised in the organisation of chapter in (Figure 1.3). Chapter one will be explaining about the history of hybrid
connections in the past also will discuss about the problems facing this type of connection. Chapter two will discuss about what people had done in the past by testing several types of connections and their results. Chapter four will identify the design concept and procedure of the specimens, also the materials that will be used. Chapter four will be the final steps in carry over the test and obtain the results to analyse them. Chapter five is the final part which will be the summery of the research and give some recommendations to be done in further studies.

Figure 1.3 Thesis structure
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter generally describes the variation and several definitions and history of Hybrid Concrete Construction system (HCC). In particular, this chapter concentrates on the researches have been yet done about the necessities and goals to remove the concrete corbels and replace them with appropriate options.

IBS system have been getting well known and being generally connected in development division today. The fast development of the construction industry along with expanding interest for quality buildings requires the construction industry to continuously seek for development, leading to industrialization in this industry. Cost reduction is achieved through lesser construction time and amount of labor (Farah, 2004).

"The historical backdrop of precast concrete goes back to couple of decades prior in which several factors such as rising steel costs, material deficiencies, the expanded highway construction program, and the development of mass production methods to minimize labor costs have all been factors leading to the use of precast concrete in United States" (Sheppard & Philips, 1999).

As indicated by review by Kamal et al. (2009), IBS is accepted as negative methodology due to past failures in Malaysian construction. For instance, the project of
Pekeliling Flats in Kuala Lumpur and Taman Tun Sardon, Gelugor, Penang (refer Figure 2.1 & 2.2). These two flats were using pre-fabricated construction in mass to produce low cost accommodation. However, the design was very basic and not considering the aspect of serviceability such as the need for wet toilets and bathrooms. The lack of design concern results in leakage problem that become hot issues with precast buildings. Based on this scenario, it implies that low cost housings are not maintained properly. At last, it just gives bad image of IBS building.

Figure 2.1 Pekeliling Flat, Kuala Lumpur Kamal et al. (2009)

Figure 2.2 Taman Tun Sardon Gelugor, Penang Kamal et al. (2009)
The poor image of IBS building has also additionally influenced the client recognitions. Client impression of an IBS product is seen regarding absence of adaptability, risky settlement, such as leaks and faults, low quality finish and use of unfamiliar materials (Nawi et al., 2007). This bad perception leads them to avoid project by using IBS system.

As far as Architectural configuration, some designers are not inspired by receiving IBS because of lack of ecstatic value and limited creativity in design (Hamid et al., 2008). Designers in Malaysia believe that it is easier to stick to conventional construction methods rather than adopting IBS (Kamar et al., 2009; and Nawi et al., 2007).

2.2 Types of design

In codes of practice and specifications, connections are included in requirements and recommendations, which should be met in the design procedure. Three different methods of design can be considered as follows:-

2.2.1 Simple design

As load factors are reduced and higher strength concretes and steels are introduced, column design becomes more critical especially with the advent of very high buildings or in very high bridge piers. This theme Report reviews the practical methods available for the design of short and long columns. Frame stability is discussed briefly and column design recommendations are given. The connection between members is assumed to carry shear only, and not to develop moments adversely affecting either the members or the structure as a whole. Beams are generally designed as pin ended and columns are designed for the moments which result from nominal beam connections (Fuang, 2007).
2.2.2 Rigid design

The connections are thought to be moment carrying and to be capable of improving the strength and stiffness required by an analysis assuming full continuity. Rigidly connected members on which bending moment, axial force, and shear force work at the same time.

2.2.3 Semi-rigid design

Few degree of connection stiffness is assumed but insufficient to develop full continuity, and also insufficiently strong to develop the full moment capacity of the connected members.

It follows that whichever of the design methods is used for the frame analysis, the primary connections must be of a type which will perform as assumed in the design.

The major function of beam-to-column hybrid connections is only to transfer the loads applied on the beams and floor system to the columns.

Generally, beam-to-column connections are classified as simple, rigid or semi-rigid connections. They are also classified as pinned, flexible, stiff and rigid. In design terms this means that the size of the beam section depends on the type of connection, i.e. support, provided at its ends. When a flexible connection is provided, a heavy beam section is expected to be used in comparison to that when a rigid connection is provided. Further, semi-rigid and rigid connections introduce some degree of rotational stiffness at the ends of the beams in each floor at multi-floor building (Crisp et al., 2008)

2.3 Types of connections

The literature review shows that the benefits of using different connectors in precast concrete frame include:

1. Conventional Corbel Connector.
2. Hybrid Moment-Resisting Precast Beam-Column Concrete Connection.
3. Pre-Tensioned Frame.
4. Elastic Nonlinear Connections UN-deformed.
5. Friction Connection.
6. Hidden Corbel Connection.

This all will be described briefly in this chapter for further information about their appearance and their physical properties.

2.3.1. Conventional Corbel Connector

This connection has a visible part which is carrying the beam and the transfer the load from the beam into the column. In this type of connection it needs extra formwork to shape the required design of the corbel, which it means extra cost and visible part that the architect are not satisfied about it.

![Corbel connection](image)

Figure 2.3 conventional connection "Corbel connection" (Ahmed, 2006)

In that Figure there is a conventional corbel beam-to-column connection which the architectures are not satisfy about it because of its visible part and some physical properties such as slow erection and low moment capacity, besides the low of cost. Some experiments and laboratory had been done to this type of beam-to-column connection in Malaysia at University Technology Malaysia (Ahmed, 2006).

Producing precast concrete structures that meet strict code requirements for seismic conditions has long challenged designers and precasters because of its visible part. Some of experimental investigation on conventional corbel connection 'hybrid
connection' were found that cracking in some cases occurred on the corbel with no effect on the column and beam as shown in Figure 2.3 and Figure 2.4.

![Figure 2.4 Pinned precast concrete beam-to-column connection (Ahmed, 2006).](image)

The cost of this connection was high because of its formwork, thus it cannot be used for another type of column as shown in Figure 2.5 (a), (b).
This ‘conventional corbel’ got many dis-advantages, for examples slow erection, no reliable moment capacity, construction tolerance problem and expansive connection hardware, also the visible part of the connection. The Corbel’s position cannot be adjusted on both vertical and horizontal direction after casting, which was conventional corbel connection (Ahmad, 2006).

2.3.2. Moment-Resisting in Precast Beam-Column Connection

Another type of beam-to-column connection was tested, refer Figure 2.6. The test specimens represented at one-third scale a beam-to-column connection from the bottom story of a prototype office structure. The basic structural system for this building was a perimeter moment-resisting frame. The prototype building was rectangular, 12 stories high, had plan dimensions of 30.48 x 60.96 m (100 x 200 ft., 6 bays x 12 bays), a 5.49-m (18-ft) column spacing, and a 3.96-m (13-ft) story height. The column dimensions were 914 x 914 mm (36 x 36 in). The forces for the prototype were UBC (ICBO, 1988) Zone 4 loads, assuming $R_w = 12$. The beams in the prototype were 457 x 1219 mm (18 x 48 in.) and carried a factored moment $M_r$ of 2440 kN-m (1800 kips-ft.) at the column face. In a conventionally reinforced system, four No. 11 and three No. 10 bars top and bottom $(p = 1.27\%$) would suffice. The column size was based on the UBC requirements
for a strong column-weak beam design and on joint shear. A 914x 914-mm (36x 36-in.) column with 28 No. 14 bars (p=4.86 percent) fulfilled this need. The properties of these prototype members were close to those used in Phases I through III that comparisons were possible (Geraldin et al., 1994).

![Figure 2.6 Hybrid Moment-Resisting Precast Beam-Column Concrete Connection (Geraldin et al., 1994)](image)

2.3.3. Pre-tensioned frame

Pre-Tensioned frame connection (Figure 2.7) – Continuous partially bonded pre-tensioned beams are connected to column segments extending from the top beam at one floor level to the bottom of the beam at the level above. The moment connection is established between the beam and column by extending the column mild steel reinforcement below the beam through sleeves located in the joint. The extended reinforcement is spliced to the column longitudinal reinforcement at the following level adjoining the joint (Elias et al., 1995).
2.3.4. Elastic Nonlinear Connections Un-deformed

For this connection type, nonlinear behavior is achieved through crack opening and closing at the interface between each beam and column. This nonlinearity is related to geometric nonlinearity rather than material nonlinearity. Beams used in this connection type were pre-stressed, with tendons unbounded through the joint and for some length on each side of the column. Cracks or joints at the column face open when bending moments produce flexural stresses large enough to exceed the pre-compression stresses at the face of the column. Pre-stressing steel does not yield if it is unbounded over an adequate length. The behavior of this connection type is completely different from the first two types. In this connection type, energy dissipation is minimal. However, because of the pre-stressed beam, only small residual drifts are expected following strong ground movement. As a result, this connection also is described as “self-righting”. Examples of this connection type are shown in Figure 2.8 (Elias et al., 1995).
2.3.5. Friction connection

In this connection type, energy is dissipated through friction when slip occurs between connecting elements. Special material can be used to enhance the slip behavior. The advantage of this connection type is reinforcing steel does not yield, resulting in cracking in the precast members that is relatively small even at large displacement levels. The same concept can be used as in the tension/compression connections where slip occurs on one side of the beam while the other side permits only rotation. A gap also must be provided to allow the slip to occur in both directions. An example of this connection type is shown in Figure 2.9 (Elias et al., 1995).
The visible parts and the material used in this type of connection noticed as disadvantages such as slow erection, not economical and low capacity.

2.4. Hidden corbel connection

2.4.1. Description of hidden corbel connection

This type of connection can be defined as connections using column insert or cast-in steel insert. The structural mechanism for this type of connection is based on static strength, stiffness, load transfer into the connecting component, temporary stability and structural integrity (Ling, 2004).
Usually, hidden corbel connections are designed for the least favorable position between contact surfaces, while taking into account the accumulation of frame and component tolerance, refer Figure 2.10 & 2.11.

The gap between the precast component is concreted using sand/cement (or concrete) grout containing propriety expanding agent, refer Figure 2.12.

In some instances, particularly where the cover to the surface of the nearest steel insert exceeds about 50 mm, small diameter links are spot welded or otherwise will be attached to the inserts to form a small cage.

Figure 2.10: Hidden corbel connection (Ling, 2004)
Figure 2.11: 3-Dimensional solid view of hidden corbel connection (Ling, 2004)
2.4.2. Ductile Connections in Precast Concrete Moment Resisting Frames

2.4.2.1. Test Specimen and Connection Details

Phase I test specimens were modeled as exterior joints of a multistory building. They were designed according to the strong column and weak beam design philosophy and scaled down approximately to half the size of a prototype structure in geometry. It should be noted that the minimum scaling factor for test specimens is given as one-third in ACI's T1.1-01 Acceptance Criteria for Moment Frames Based on Structural Testing. The cross section of the beams was 11.8 in. × 19.7 in. (300 mm × 500 mm), and the beam clear span was 5.25 ft. (1600 mm). Hence, the shear span-to-beam depth ratio (a/h) was about 3.2. The reason for such a low a/h was to make the precast concrete connection govern the design at higher shear forces. The height of the column was 6.3 ft.
(1920 mm), and it had a square cross section with 15.75 in. (400 mm) dimensions. The
cover thickness in the precast concrete beam and column was 0.8 in. (20 mm). Figure
2.13 shows the dimensional detail of the subassembly (Onur et al., 2006).

Figure 2.13: Dimensional detail (Onur et al., 2006)

2.4.2.2. Testing Procedure

The test setup was designed to apply the procedure and scheme specified in ACI’s T1.1-
01: Acceptance Criteria for Moment Frames Based on Structural Testing. Figure 2.14
presents the test setup and the locations of the deformation measurements. The precast
concrete column was supported on a pinned connection at its base, and the top of the
column was free to move and rotate. A roller-supported “free end” was designed for the
beam; hence, the points of contra flexure for both the beam and the column were
achieved within the test setup (Onur et al., 2006).
2.5. **Moment-Resisting**

The following conclusions can be drawn from the study:

1. The use of both un-bended PT and bonded mild steel for connecting precast concrete beams and columns is feasible. The PT steel clamps the beam against the column to provide shear resistance, while the mild steel dissipates energy through cyclic yielding.

2. The best PT arrangement is to use strands, placed at mid-depth of the beam, running over the full length of the building. They should be stressed less highly than in conventional consumption.

3. The mild steel experiences high local strains at the beam-column interface. These could lead to premature fracture if they are not alleviated. Deboning a short length on either side of the interface is a potential solution.
4. The amount of energy dissipated by the specimens containing bonded mild steel was equal to or greater than that in the conventionally reinforced system up to approximately 1.5 percent drift. 5. A more detailed study, which uses the details that were identified here as being the best, was necessary to find the most suitable values of parameters such as pre-stressing stress. Such a study is reported in Cheek & Stone (1994).

However, due to structural and architectural demands, concrete corbels are not desirable anymore, and another era of joining structural elements and construction development is due.

2.6. Hybrid Connection

The most important connection in a skeletal structure is between the beam and column, where architectural demands have led to the design of the so-called invisible or hidden connection, i.e., the entire connection is contained within the beam. The stress fields in these regions are known to be complex and designers have used bewildering arrangements of reinforcing bar cages, steel inserts, couplers, and sliding plates in order to safely transfer high shear forces from the beam to the face of the column. While researchers have ignored the flexural behavior of these connections, designers have continued to specify connections as pin jointed the knowledge that fictitious flexural stresses are also present (Razzak et al., 2010).

The hybrid connection has been shown to be a viable candidate for a moment resisting precast frame. It provides a way of connecting the precast members for transferring the large forces needed in severe seismic ones and takes advantage of the best features of pre-stressed construction and combines them with the energy dissipation of conventional reinforced concrete structure (Glass et al., 2004).
REFERENCES


