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PERFORMANCE OF MECHANICAL COUPLER FOR CONNECTION OF PRECAST CONCRETE WALL PANELS

KONG LING KAI

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
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Dedicated to my beloved wife and daughters

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ABSTRACT

In a precast wall-slab system, the wall connections played an important role in ensuring structural integrity and safety of the building. The connections are also required to cater for the provision of structural ties to enhance the building's robustness to overcome progressive collapse. In normal practice, continuity between upper precast walls and lower precast walls are carried out by lapping the reinforcement bars. This practice often caused congestion in the connection and may create honeycomb or voids in concrete if precaution is not taken during concreting. The use of mechanical couplers to replace the reinforcements lapping is a logical solution because these mechanical couplers do not occupied long lap length, easy to install and avoid bar congestion in the wall connection. However, these mechanical couplers are expansive and not many are available in the local market. In this paper, we have carried out tensile tests on ten numbers of specially designed grout filled mechanical couplers to evaluate their performances based on tensile capacity and failure patterns. These specimens were of the same make and specification but they vary in terms of type of grout material used and bolt configurations. The tests results show that higher grout strength produces better anchorage bond and subsequently higher tensile strength for the coupler. The test results also show that providing bolts on the coupler enhanced the tensile strength because these bolts act as shear keys which interlocked with the grout. The optimum arrangement of bolts shall be two bolts in a same plane. Overall all the couplers tested failed to achieve the required strength but nevertheless, the information gathered on the understandings of the causes of failure, influences of grout and bolt configurations will provide essential groundwork for future research.

ABSTRAK

Di dalam pembinaan sistem pasang siap dinding-papak, sambungan memainkan peranan yang penting untuk memastikan integriti struktur dan keselamatan bangunan adalah kukuh. Sambungan juga perlu direkabentuk untuk menambahkan kekukuhan bangunan dalam menangani keruntuhan progresif. Kebiasaannya, kesinambungan antara dinding pasang siap atas dan dinding pasang siap bawah disambungkan dengan kaedah tindihan pada tetulang besi. Tindihan pada tetulang besi lazimnya menyebabkan kesesakan dalam sambungan dan mungkin akan menyebabkan konkrit berongga. Penggunaan penyambung mekanikal pada tetulang besi adalah satu penyelesaian yang baik kerana penyambung mekanikal tidak mempunyai tindihan yang panjang, mudah dipasang serta tidak membawa kesesakan pada sambungan. Akan tetapi, harga penyambung mekanikal dalam pasaran adalah mahal dan tidak mudah diperolehi. Di dalam kertas kerja ini, ujian tegangan akan dijalankan keatas sepuluh spesimen yang direkabentuk khas untuk menilai kekuatan tegangan dan corak kegagalannya. Penyambung mekanikal ini adalah dibuat daripada bahan dan spesifikasi yang sama tetapi berbeza dari segi penggunaan grout simen dan susunan bolt. Keputusan ujian mendapati bahawa kekuatan grout simen mempengaruhi kapasiti tegangan penyambung. Keputusan ujian juga menunjukkan bahawa dengan menggunakan bolt pada penyambung dapat menambahkan kapasiti keupayaan penyambung kerana bolt berfungsi sebagai kekunci ricih yang mengunc kegelnciran grout. Penyusunan bolt yang optima adalah dua bolt pada satah yang sama. Secara keseluruhan kesemua penyambung gagal mencapai kekuatan yang diperlukan tetapi maklumat mengenai corak kegagalan, kesan kekuatan simen grout pada coupler dan susunan bolt yang optima dapat memberikan informasi yang penting untuk kajian seterusnya.

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A_b	-	area of bar being developed or spliced
	-	area of largest bar being developed or spliced (CEB-FIP 1990)
A_{tr}	-	area of each stirrup or tie crossing the potential plane of splitting adjacent to the reinforcement being developed, spliced or anchored.
c	-	spacing or cover dimension (c_{min} + $d_b/2$)
c_b	-	bottom concrete cover for reinforcing bars being developed or spliced
c_{max}	-	maximum (c_b , c_s)
c_{med}	-	median (c_{so},c_b,c_{si}+d_b/2) that is, middle value (Esfahani and Rangan)
c_{min}	-	minimum cover used in expressions for the bond strength of bars not not confined by transverse reinforcement.
	-	minimum (c_{so},c_b,c_{si}+d_b/2) ((Esfahani and Rangan)
	-	smaller of minimum concrete cover or ½ of the clear spacing between bars
c_s	-	minimum of (side concrete cover, ½ fo the bar clear spacing 0.25in
c_{si}	-	1/2 of the bar clear spacing
c_{so}	-	side concrete cover for reinforcing bar
d_b	-	diameter of bar
E_c	-	modulus of elasticity for concrete
f_c	-	stress in concrete
f_c'	-	concrete compressive strength based on 6x12in. (150x300mm) cylinders
	-	specified concrete strength of concrete
f_{ct}	-	average splitting tensile strength of concrete

f_s	-	stress in reinforcing bar
f_y	-	yield strength of steel bar being developed or spliced
f_{yt}	-	yield strength of transverse reinforcement
l_d	-	development or splice length
$l_{d, min}$	-	minimum development length
$l_{s , min}$	-	minimum splice length
n	-	number of bars being developed or spliced
N	-	the number of transverse stirrups, or ties, within the development or splice length.
r	-	constant used in expressions for bond strength of bars not confined by transverse reinforcement; a function of Rr
	-	3 for conventional reinforcement 9Rr = 0.07) (Esfahani and Rangan)
Rr	-	relative rib area of the reinforcement
s	-	spacing of transverse reinforcement
s_r	-	average spacing of deformations on reinforcing bar
t_d	-	term representing the effect of bar size on Ts
	-	$0.72d_b + 0.28$, $(0.028d_b + 0.28)$* (Darwin et al. 1996a,b)
	-	$0.78d_b + 0.22$, $(0.03d_b + 0.22)$* (Zuo and Darwin 1998,2000)
t_r	-	term representing the effect of relative rib area T_s
	-	$9.6\ R_r + 0.28$ (DFarwin et al. 1996a,b; Zuo and Darwin 1998,2000)
T_b	-	total bond force of a developed or spliced bar ; $T_c + T_s$
T_c	-	concrete contribution to total bond force, the bond force that would be developed without transverse reinforcement
T_s	-	steel contribution to total bond force, the additional bond strength provided by the transverse reinforcement
u	-	bond stress
u_b	-	bond strength of a bar confined by transverse reinforcement; $u_c + u_s$
u_c	-	average bond strength at failure of a bar not confined by transverse reinforcement
u_s	-	bond strength of a bar attributed to the confinement provided by the transverse reinforcement

CHAPTER 1

INTRODUCTION

1.1 Introduction

The overwhelming demand to reduce the country's dependency of unskilled foreign labor is one of the contributing factors of the government's drive to use Integrated Building System (IBS) for all government projects. Precast concrete system is one type of IBS system that is able to reduce manpower and increase construction speed. The use of precast concrete elements in building structures has increased gradually over the years. The latest generation of precast concrete structures had evolved into buildings of high specification. These types of buildings are able to meet high standard of architectural requirements in term of aesthetic values and good quality finishes, as well as fulfilling the building's structural needs.

In a precast concrete structure, the structural elements are fabricated off-site and delivered on site during erection. In this way, the construction process is expedited, less manpower on site required, less construction debris on site (e.g. formwork) and also cleaner environment. The precast elements which are fabricated off-site are produced in a controlled factory environment resulting in high quality finish. It is also possible to use higher concrete grade or prestressed concrete to minimize the element sizes and maximizing the span. This will reduce the dead weight of the structure and therefore saving in the foundation.

1.2. Scope & Objectives

The objectives of this research paper are

(i) To review various types of mechanical rebars couplers.
(ii) To study the behavior of mechanical couplers as an alternative method for traditional reinforcing bars lapping in connection for precast concrete wall panels.
(iii) To propose new mechanical couplers suitable for local market needs.

The scope of work will focus on studying the behavior of mechanical rebar couplers for precast wall panel connections and literature reviews on the introduction of structural ties in enhancing the robustness and stability of precast concrete building. Laboratory tests will also be carried out to evaluate new proposed mechanical couplers.

1.3 Problem statement

In normal practice, continuity between upper precast walls and lower precast walls are carried out by lapping the reinforcement bars. The lap length is normally between 30 and 40 the diameter of main bar depending on the concrete grade as recommended by BS code. The lapping length of bars often caused congestion in the connection and may create honeycomb or voids in concrete if precaution is not taken during concreting. In addition the extra lapping length also increases the reinforcing bars cost.

In theory, the use of mechanical couplers to replace the rebar lappings might be a logical solution because mechanical couplers do not occupied long lap length, easy to install and avoid bar congestion in the wall connection. In this research, we will study in depth the practical aspect as well as the engineering point of view on the role of mechanical couplers in providing continuity for structural reinforcing bars in precast wall panels. The cost of mechanical couplers available in the market is quite expansive, as such; experimental research will also be carried out on new proposed mechanical couplers that maybe able to fulfill market needs.

1.4 Expected finding

Toward the end of this research, we would be able to evaluate the viability of using mechanical couplers in precast wall panels and advise accordingly on its benefits and limitations. We would also be able to assess the performance of new proposed mechanical couplers based on results obtained from experiments carried out. Expected results from the experiments carried out will be relationships between Force – Deformation graphs and Stress – Strain curves.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In Malaysia, there are basically five common types of fully developed Industrialised Building Systems (IBS) which are the Precast Concrete System, Steel Formwork System, Steel Framing Systems, Prefabricated Timber Framing System and Block Work Systems. From the five types of IBS systems, Precast Concrete System and Steel Framing System are the two systems that can reduce construction time considerably because of their off site fabrication and on site installation. However, if we were to consider the two, it is clearly Precast Concrete System have an edge over the latter because of the raising cost of structural steel.

2.2 Structural Concept for Precast Concrete Systems

The structural concept for precast concrete systems is similar to cast-in-situ conventional reinforced concrete building system. The main difference between a precast building and a cast-in-situ concrete building is the structural continuity. In cast-in-situ building the structural continuity is intact as the building is being constructed because the joints between beams, slabs, columns and walls are cast in a monolithic manner. This is not so for precast concrete system where the structure components are prefabricated elsewhere and jointed together to form a structural system. The connections between these precast elements need to be rigid to form a bridging link to provide structural stability and safety to the precast system. A stable structural system will only be formed when the precast structural elements are jointed together, thus, it is important to consider in the design stage its stability and safety throughout all stages from construction to completion stage. The overall behavior of a precast building is very much dependent on its connections which should be able to transmit the vertical and horizontal loads to the structural elements, ductility to deformation, volume changes, durability, fire resistance, production.

In order to fully realize the full advantages of precast concrete, the structure should be conceived according to its specific design philosophy: long spans, appropriate stability concept, simple details and etc. It is also crucial to consider the possibilities, restrictions and advantages of precast concrete it’s detailing, manufacture, transport, and erection and serviceability stages before completing a design in precast concrete.

2.3 Wall – Slab Frame Structural Systems

One of most common type of precast structural system is the wall – slab framing system. In the wall-slab frame system, the walls not only function as load bearing vertical elements but also act as lateral load resisting members. Vertical loads comes from the dead weight of the floor slabs, brick walls sitting on the slabs, floor finishes such as cement rendering, floor tiles, and imposed loads specified in the relevant code of practice. Wind loadings or notional loads formed the lateral loads acting on the building. An effective or efficient structural wall-slab system should have both cross walls and longitudinal walls to absorb horizontal forces. The walls are usually made up of concrete precast wall panels and the slabs are precast hollow-core slabs.

This type of structure is suitable for multi-storey hotels, retail units, hospitals, and offices. The structural vertical walls not only function as load bearing elements but are also used for partitioning.

Figure 2.1 – Wall – Slab Frame Precast System

2.4 Progressive Collapse

Progressive collapse can be defined as all or a large part of building that collapse is caused by a failure or small damage of a primary structural element in the building. This kind of catastrophic failure comes in the form of "domino effect" whereby a failure starting in a particular component rapidly propagates to other components precipitating a major or even a total collapse. The most famous landmark case of progressive collapse failure is the Ronan Point apartment collapse on 16 May 1968.

2.4.1 Ronan Point Apartment Collapse

On the morning of 16 May 1968, Mrs. Ivy Hodge, a tenant on the 18th floor of the 22-story Ronan Point apartment tower in Newham, east London, struck a match in her kitchen. The match set off a gas explosion that knocked out load-bearing precast concrete panels near the corner of the building. The loss of support at the 18th floor caused the floors above to collapse. The impact of these collapsing floors set off a chain reaction of collapses all the way to the ground. The ultimate result can be seen in Figure 1: the corner bay of the building has collapsed from top to bottom. Mrs. Hodge survived but four others died. While the failure of the Ronan Point structure was not one of the larger building disasters of recent years, it was particularly shocking in that the magnitude of the collapse was completely out of proportion to the triggering event. This type of sequential, one-thing-leading-to-another failure was labeled “progressive collapse” and the engineering community and public regulatory agencies resolved to change the practice of building design to prevent the recurrence of such tragedies. [2]

Figure 2.2 – Ronan Point Building after 16 May 1968 collapse [2]

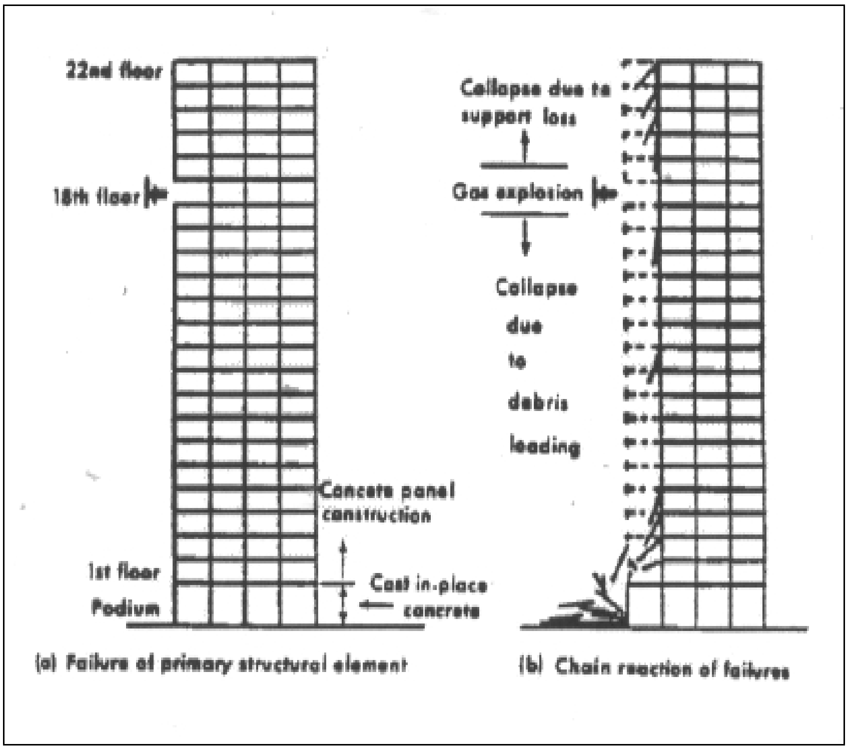

Figure 2.3 – Schematic of Ronan Point Building collapse [4]

2.4.2 Provision in BS8110 on progressive collapse

Clause 2.2.2.2 of BS8110:Part1:1997 stipulates that the structure should be "Robust" and capable to resist accidental loads. In no circumstances a localized failure of a small part or single element of the structure would lead to the collapse of a bigger portion of the structure. .

2.2.2.2 ***Robustness***
Structures should be planned and designed so that they are not unreasonably susceptible to the effects of accidents. In particular, situations should be avoided where damage to small areas of a structure or failure of single elements may lead to collapse of major parts of the structure.
Unreasonable susceptibility to the effects of accidents may generally be prevented if the following precautions are taken.
a) All buildings are capable of safely resisting the notional horizontal design ultimate load as given in **3.1.4.2** applied at each floor or roof level simultaneously.
b) All buildings are provided with effective horizontal ties (see **3.12.3**):
1) around the periphery;
2) internally;
3) to columns and walls.
c) The layout of building is checked to identify any key elements the failure of which would cause the collapse of more than a limited portion close to the element in question. Where such elements are identified and the layout cannot be revised to avoid them, the design should take their importance into account. Recommendations for the design of key elements are given in **2.6** of BS 8110-2:1985.
d) Buildings are detailed so that any vertical load-bearing element other than a key element can be removed without causing the collapse of more than a limited portion close to the element in question. This is generally achieved by the provision of vertical ties in accordance with **3.12.3** in addition to satisfying a), b) and c) above. There may, however, be cases where it is inappropriate or impossible to provide effective vertical ties in all or some of the vertical load-bearing elements. Where this occurs, each such element should be considered to be removed in turn and elements normally supported by the element in question designed to "bridge" the gap in accordance with the provisions of **2.6** of BS 8110-2:1985.

Figure 2.4 – Extracts from BS8110: Part 1: 1997 [1]

To minimize the effects of progressive collapse of a building, BS codes recommended three mitigation measures as follows:

(i) The structure should be designed to resist the notional horizontal design ultimate load which acts at the same instant applied at each floor and roof level. Notional load equals 1.5% of the characteristic dead weight of the structure between mid height of the storey below and either mid height of the storey above or roof surface. (Clause 3.1.4.2: BS8110)

(ii) The building should be provided with horizontal and vertical ties around the fringe or outer boundary, internally and to columns and walls. In cast-in-situ concrete buildings, the structural beams which are connected monolithic to the columns act as horizontal and vertical ties for the building. This is not the case for precast concrete building where all the precast elements are jointed together to form a structural system, therefore, to ensure structural continuity the provision of vertical and horizontal ties is important.

(iii) The structure framing should avoid any key elements in the building. Key elements refer to the important of a particular structural member which when removed will lead to a large portion of the building to collapse. However, if this cannot be avoided, these elements should be designed with a higher factor of safety.

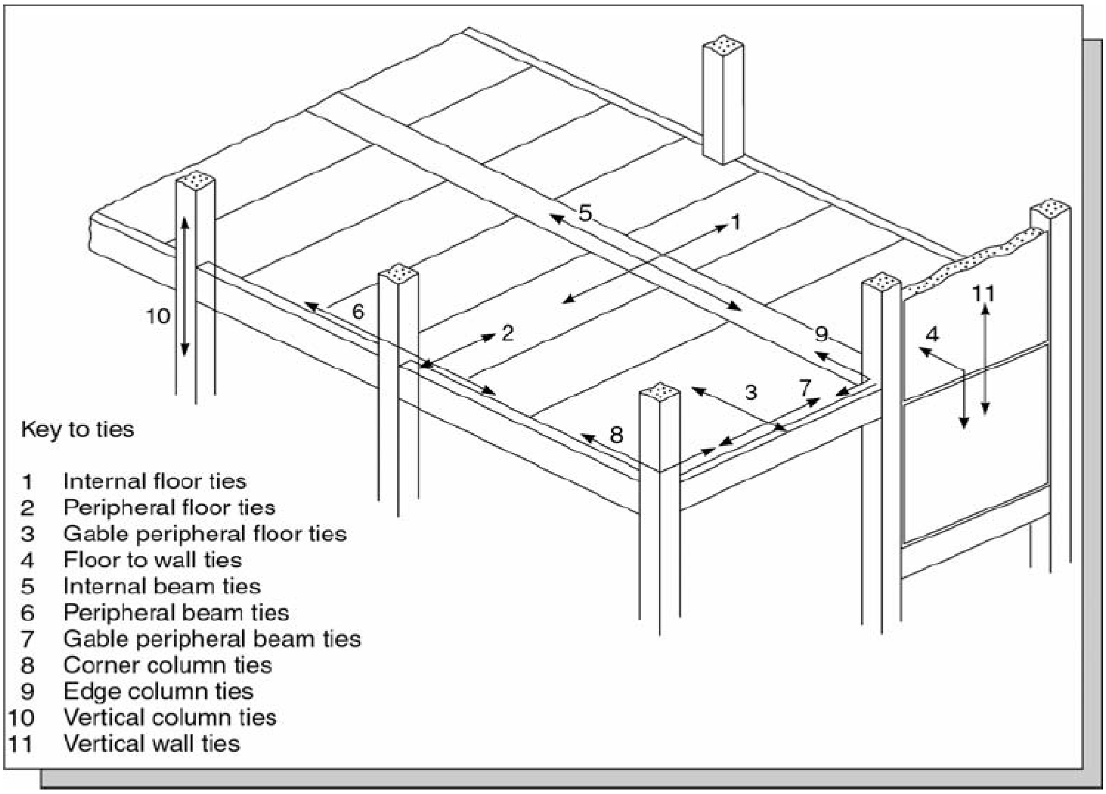

Figure 2.5 – Location of ties in precast skeletal structure [2]