Case study involving the use of mechanical couplers for construction of precast elements: Parque da Cidade São Paulo - Brazil

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Abstract

In recent years it has become common practice to see the construction of tall buildings in large metropolitan cities, many of which have structural designs with immense complexity. Due to this complexity these tall buildings require engineering solutions that are practical, economical, versatile and of high quality. Aligned to these concepts, the use of precast elements in buildings plays an essential role and has been gaining its fair share of the market; however, the connection of precast elements in the structure is still debated amongst professionals. Parallel to this discussion, is the application of mechanical couplers to connect reinforcing bars. Mechanical couplers are often specified by structural engineers and used as an alternative to the traditional lap splice method for making connections in precast structures. This paper presents a case study about a bolted and threaded coupler application with the main purpose to connect precast beams and columns at a shopping mall called Parque da Cidade, located in São Paulo, Brazil. Promoting overall structural integrity in accordance with the design was extremely important when evaluating if the use of mechanical couplers would be a viable option. Through the use of previous studies, developing the proper connection specifications for ductility and strength, developing proper technical and installation procedures, and a high effort in quality control, mechanical couplers were proven to be an economical alternative for making connections in large precast structures and were ultimately used on this project.

Keywords: mechanical splice; coupler; precast; connection; building.

1 Introduction

Inspired by the concept of compact cities, urban sustainability, enhancement of the environment and integration between private and public spaces, in 2010 the City Park project was developed. It is one of 18 projects around the world that integrates the Climate Positive Development Program from C40 Cities group and the Clinton Climate Initiative Cities from Clinton Foundation. The complex has an unprecedented set of sustainable solutions that makes it capable of seeking different green certifications, achieving LEED-ND (Leadership in Energy and Environmental Design for Neighbourhood Development) Silver level from USGBC (U.S. Green Building Council) pre-certification still unheard of in South America and, unlike the other seals, considers the surroundings of the buildings and the neighbourhood. In addition to validating the enterprise as a whole, they also emphasize

aspects of sustainable development combined with practices of green buildings.

Located in the heart of the city of São Paulo on an area of approximately 82.000 m², the multipurpose complex Parque da Cidade (Figure 1) was divided into four stages (A, B, C and D) and will consist of two residential buildings, five corporate towers (one already delivered), a commercial tower (already delivered), a hotel, a shopping mall and restaurants integrated by a linear park of 62.000 m². The park consists of cycle paths, a leisure area, jogging tracks and several sitting squares.

This paper explores the good engineering practices and procedures employed in the construction of the Parque da Cidade building complex, addressing in detail the application of couplers for the mechanical splices of the precast concrete elements.

Figure 1. Perspective of the Parque da Cidade complex, kindly provided by Odebrecht Realizações Imobiliárias.

2 Concept on precast connection

From the point of view of structural behaviour, the presence of connections is what basically differentiates a precast concrete structure from a conventional. Thus, when it is desired to know the behaviour of a precast concrete structure, initially, it is important to know the behaviour of its connections, which are responsible for the redistribution of loads throughout its structure.

In addition, the demand for cleaner and more rational construction with less waste and better use of resources requires the use of standardized components and processes and it is precisely in this context that precast fulfils its essential role. According to Jeremias Junior (2007), particularly in precast concrete crosslinked structures, the overall stability is greatly influenced by the strength and flexural stiffness of the beam-pillar connections and, assuming that most of this type of connection has a partial set-up, design idealizations for perfect articulation or crimping may be inadequate for the determination of second order effects on the structure.

According to Ferreira (1999), connections of prefabricated elements have a semi-rigid behaviour, a term initially used in the 1930's and that corresponds to an intermediate behaviour between the rigid nodes and the joints, which can be approximated to one of these situations. Consideration of the deformability of the connections at the ends of the beam members in the structure causes a modification in the stiffness of this member, promoting a redistribution of forces and displacement along the structure.

There are several sorting systems that establish separation limits between these rigidity classes for semi-rigid connections. Bjorhovde et al. (1990) proposed a system based on linear M-θ bi diagram

for the moments and the normalized rotations, as shown in Figure 2.

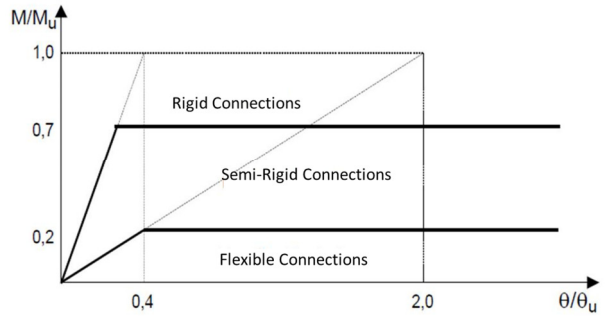

Figure 2. Classification system for semi-rigid connections, according to Bjohvode et al. (1990).

FERREIRA *et al.* (2002), presents in Table 1 a classification system for links in which they are subdivided into five distinct zones. This system is based on the rotation restraint factor (α_R) which takes into account the deformability of the links and is a dimensionless number that relates the rigidity of the connection to the stiffness of the beam that competes with it. For bonds considered semi-rigid this restriction factor varies from 0.15 to 0.85. The coefficient of partial packing (M_E/M_R) represents the ratio of the bending moment at the beam end (M_E) to the perfect bending moment (M_R).

Table 1. Semi-rigid connections classification on precast concrete structures [Ferreira et al. (2002)].

Zones	**Restriction Factor** α_R	**Partial Embedment** M_E/M_R	**Connection Classification**
Zone I	$0 \leq \alpha_R < 0{,}14$	$0 \leq M_E/M_R < 0{,}20$	Articulated (or Flexible)
Zone II	$0{,}14 \leq \alpha_R < 0{,}40$	$0{,}20 \leq M_E/M_R < 0{,}50$	Semi-Rigid with Low Restriction
Zone III	$0{,}40 \leq \alpha_R < 0{,}67$	$0{,}50 \leq M_E/M_R < 0{,}75$	Semi-Rigid with Medium Restriction
Zone IV	$0{,}67 \leq \alpha_R < 0{,}85$	$0{,}75 \leq M_E/M_R < 0{,}90$	Semi-Rigid with High Restriction
Zone V	$0{,}85 \leq \alpha_R < 1{,}00$	$0{,}90 \leq M_E/M_R < 1{,}00$	Perfectly Rigid

3 Mechanical splices for precast concrete structures

Although they have been used in Brazil since the 1970s, mechanical splices are still underutilized in big projects. The preference for the use of traditional lap splice methods over mechanical couplers is large in part cultural. A shortage of academic research makes the use of mechanical couplers less appealing on a professional level and in turn these products are not heavily considered in the design phase of a project.

There are many advantages in using mechanical couplers as listed below:

- Help ease congestion in heavily reinforced sections;
- Improvement structural integrity at the connections;
- Labor and material reduction and the consequent overall cost of the structure;
- Simple and fast installation;
- Reduction of the cracks in concrete;
- It allows the use of the full strength of the reinforcing steel.

Despite being a material that lacks a "culture acceptance" in Brazilian civil engineering, there are currently several types of couplers for mechanical splices available in the market. These solutions have applications used in a variety of infrastructure projects, but mainly the greater technical-economic feasibility is related to large complex projects. Some typical examples of these types of projects are hydroelectric plants, buildings, subways, dams and precast structures.

For the specific case of the Parque da Cidade complex, two types of couplers were used to connect the precast concrete elements: bolted and taper threaded ranging in reinforcing steel sizes from 20mm-40mm. These couplers were tested for tensile strength, ductility, and were compared to control reinforcing steel from the same lot. Once the tests were concluded they were reviewed for acceptance to the most current standards.

ABNT NBR 8548 (1984) establishes that the results obtained in the tensile strength tests with and without the application of couplers as an element for a rebar connection, must meet the minimum requirements defined by the ABNT NBR 7480 (2007), it means, for the yield strength (f_y), the minimum value for CA50 steel must be 500 MPa, while the minimum ultimate strength (f_u) must be 540 MPa (108% f_y).

3.1 Bolted coupler

This type of mechanical splice is composed of shear screws that use the integral force of the rebar to improve the structural integrity in both tension and compression. This system is being used much more frequently in Brazil, especially in emergency or repair situations where conventional couplers can't be used due to the required bar end preparation.

Bolted couplers (**Erro! Fonte de referência não encontrada.**) are available for rebar of any diameter and perform well in compliance with the requirements of current Brazilian and international standards. Its installation is quite simple and is made with an impact wrench, the shear of the screw head will occur when the specified torque is reached (Figure 4).

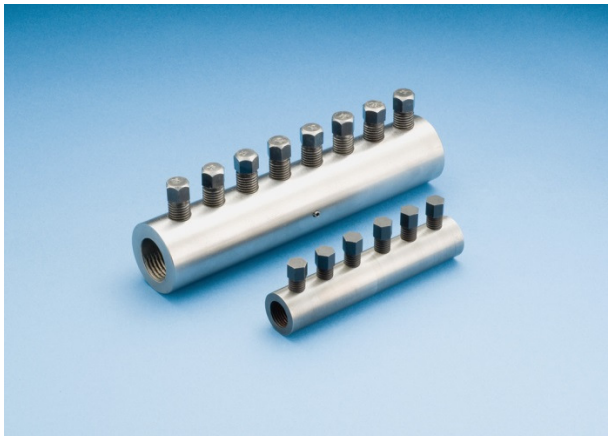

Figure 3. Bolted coupler (ERICO, 2011).

Figure 4. Bolted coupler with torquimetric heads sheared.

3.2 Taper threaded coupler

Used in Brazil since the 1990's, the taper threaded coupler (Figure 5) has been frequently featured in buildings, power plants and precast concrete structures, mainly due to its competitive costs when compared to lap splices. This is the most common rebar connection used in Brazil. The coupler is manufactured with an internal taper thread at both ends, creating a mechanical joint for two rebar sections. The ease of installation during alignment gives this coupler a great advantage especially at high altitudes and can be used on any diameter of reinforcing steel.

Figure 5. Taper threaded coupler (ERICO, 2011).

This thread is typically produced in situ using equipment specially developed for this purpose. The quality control is made using a pipe wrench or torque wrench.

4 Basic data on the structural design

The entire design of the precast concrete structures was based on the concept of structural skeleton structures that consist of a set of pillars, beams, and slabs that are interconnected to form a structural system that is capable of supporting and transferring the vertical and horizontal forces of the floors and facades into the foundation. This type of solution is commonly used in buildings and parking lots. In addition, the lack of space for the construction staging at the project site also influenced the decision to this option for the projects. It was even necessary to carry out a provisional containment in the subsoil region by soil nailing around the perimeter of the shopping mall.

General design considerations in precast concrete structures include structural system selection, component optimization, service provision (fabrication, transportation and assembly); and special features and other items requiring specifications, as well as aesthetic aspects, all of which imposed on the architectural design. Parque da Cidade shopping mall is consists of 6 floors and 6 basements.

Modulation and standardization were key factors in the project in question, especially in relation to economic considerations relative to production and execution in addition to the reduced time to design the project itself. This option arose mainly due to the low cost of the forms and the industrialization of the precast process with substantial gains in productivity.

Regarding the roofing, alveolar and isoporical slabs were used, whose floor systems are the most appropriate for buildings of this type due to their great capacity to reach large spans (maximum specified in the project was 9.30 m) and decrease thicknesses. Alveolar slab elements with 200 (with layer) and 400 mm (with a super layer) of thickness were used, while the isoporical slab has 450 mm, and used 3 kN/m² as the load.

As mentioned above, the connections between precast concrete structures are one of the most important topics that should be studied by designers. The importance of each connection is to make a positive connection in the precast elements to form a structural system capable of resisting all the acting forces as well as, creep, thermal movements, fire, etc. In order to properly develop the structural design, the forces along the structure when subjected to vertical and horizontal loads must be calculated. Also, how the connections are to interact with the elements within the entire structural system must be reviewed.

The connections between precast structures must meet different design and performance criteria, being their primary function is to transfer stress between the interfaces of the precast elements, so that they interact with each other as a single structural system. Due to the complexity of this architectural project, mechanical couplers were considered from the beginning of the design phase. Figure 6 illustrates an application of taper threaded couplers at one of the first basement columns.

Figure 6. Detail of the taper threaded coupler applied on the basement column.

According to ABNT NBR 6118 (2014), rebar splices can only be made by lap splice not exceeding a 32 mm bar. At Parque da Cidade job, there is also the application of a 40 mm taper thread coupler, so it was decided to standardize the splice solution, aligning practicality to economy.

5 Results and analysis

The results of the tests carried out in a suitable laboratory will be presented below. Tests were made on 20, 25, 32 and 40 mm bars with couplers and control bars.

Table 2 gives a summary of the results of the yield strength (f_y) and ultimate strength (f_u). As a reference, **Erro! Fonte de referência não encontrada.** shows the stress versus strain graph of the taper threaded coupler for the 25 mm bar. All the results for the yield strength (f_y) and ultimate strength (f_u) were higher than 500 MPa and 540 MPa, respectively, both specified on ABNT NBR 7480 (2007) for all bar tested. This way, all couplers were able to be used as a connection of precast columns and beams.

Table 2. Summary of the tensile strength test results on the control bar and mechanical splices

Rebar / Mechanical Splice		Yield Strength f_y			Ultimate Strength f_u		
Diameter (mm)	**Type**	**Minimum (MPa)**	**Test (MPa)**	**Variation (%)**	**Minimum (MPa)**	**Test (MPa)**	**Variation (%)**
20	Control bar	500	527	+5.4	540	628	+16.3
	Bolted		525	+5.0		629	+16.5
	Taper threaded		529	+5.8		632	+17.0
25	Control bar	500	556	+11.2	540	657	+21.6
	Bolted		525	+5.0		649	+20.2
	Taper threaded		529	+5.8		652	+20.7
32	Control bar	500	555	+11.0	540	667	+23.5
	Bolted		559	+11.8		670	+24.1
	Taper threaded		572	+14.4		672	+24.4
40	Control bar	500	539	+7.8	540	658	+21.9
	Taper threaded		556	+11.2		668	+23.7

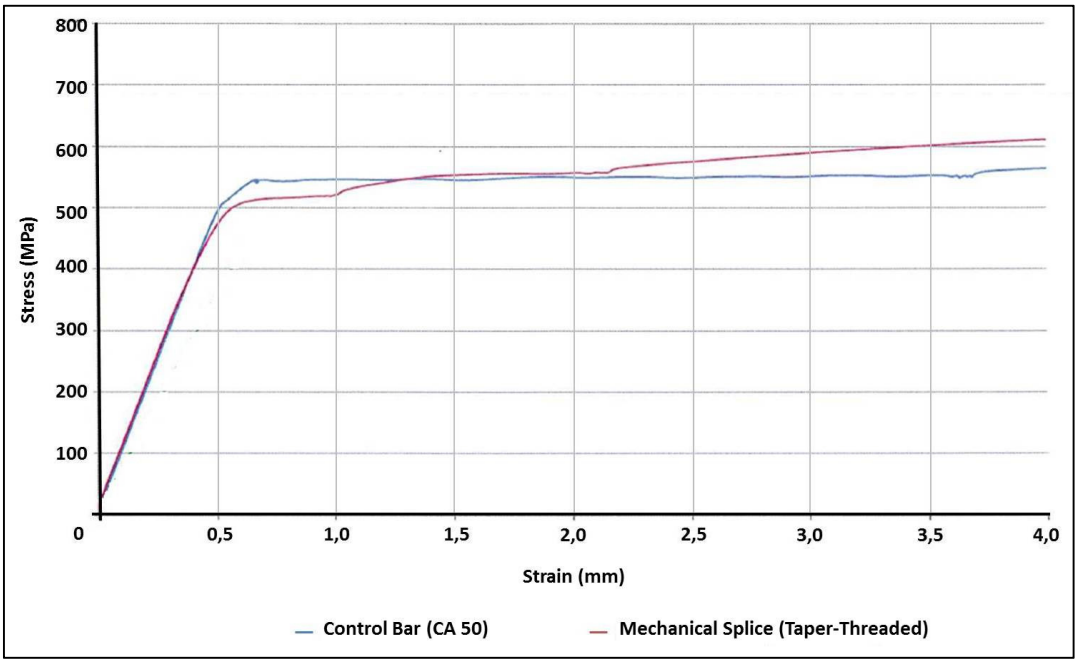

Figure 7. Stress versus strain graph for tensile strength test of the 25 mm taper threaded coupler.

After being tested on the laboratory, couplers had been economic verified and then installed into the job. A panoramic view can be seen on Figure 8, Figure 9 and Figure 10 which shows the evolution of the execution of the precast concrete structure of the mall of Parque da Cidade complex.

Figure 8. Panoramic view of Parque da Cidade mall.

Figure 9. First phase of the precast columns installation.

Figure 10. Lateral view of the mall during concrete phase of the fifth basement.

6 Conclusions

This paper, based on the prescriptions of the structural design and the laboratory tests carried out, revealed mechanical splices are a good alternative for connections in a precast concrete structure. Furthermore, they minimize congestion of the armature. It was also observed that the assumptions established during the design of the structural project were determining factors to promote a structural element intact after execution, enabling a very satisfactory final result. In addition, all tensile strength tests performed for this project, were in accordance with ABNT NBR 7480 (2007), both for the yield strength f_y and ultimate strengthf_u.

Although mechanical couplers have been used for more than 30 years on the international market, the specification of mechanical couplers in Brazilian projects of any size is still going slow, and much work still needs to be done to diffuse it as a solution for most projects, since it is currently used only on special occasions where lap splice cannot be applied.

Therefore, as a final mention, the authors strictly recommend the development of more accurate and academic research focused exclusively on the behaviour of couplers, in addition to promoting a complete revision of the ABNT NBR 8548 (1984) standard, which is lagged in terms of instrumentation and parameters of interest to be obtained in the tests, so that the designers have more confidence in specifying this important solution in infrastructure projects in Brazil.

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