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Modified mortar pad behavior in the transfer of compressive stresses

Comportamento de almofadas de argamassa modificada na transferência de tensões de compressão



J. D. DITZ [a]
jackson.ditz@gmail.com

M. K. EL DEBS [b]
mkdebs@sc.usp.br

G. H. SIQUEIRA [c]
siqueira@fec.unicamp.br

Abstract

This research aims to analyze the compressive stress transfer between precast concrete elements using cement mortar pads modified with polypropylene fibers, styrene-butadiene latex and heat-expanded vermiculite. The stress transfer analyses are performed interleaving a cement-bearing pad between two concrete blocks, subjecting the entire specimen to different compressive load tests. The parameters analyzed in the tests are: surface roughness (using bosses on the bonded phase of different thicknesses), compressive strength with monotonic and cyclic loadings. The main results obtained in this study are: a) the presence of pad increased the strength in 24% for thicknesses of imperfections of 0.5 mm and approximately 12% for smooth faces blocks; b) gain of effectiveness of the bearing pad when the concrete strength was reduced; c) for cyclic loading, the bearing pad increased in 48% the connections strength.

Keywords: bearing pad, mortar pad, stress transfer.

Resumo

O objetivo deste trabalho é analisar a transferência de tensões de compressão entre elementos de concreto pré-moldado através de almofadas de argamassa modificadas com fibras de polipropileno, látex estireno-butadieno e vermiculita termo-expandida. As análises de transferência de tensões foram realizadas intercalando uma almofada entre dois blocos de concreto e submetendo o corpo de prova a ensaios de compressão. Os parâmetros variados foram: rugosidade superficial (saliências na face ligada de diferentes espessuras), resistência à compressão do concreto dos blocos e carregamento monotônico e cíclico. Os principais resultados dos ensaios de ligação foram: a) a presença da almofada aumentou a resistência em 24% para espessuras de saliências de 0,5 mm e cerca de 12% para blocos com faces ligadas lisas; b) a efetividade da almofada aumentou à medida que se reduziu a resistência à compressão do concreto; c) para carregamento cíclico, a almofada de apoio aumentou em 48% a resistência da ligação.

Palavras-chave: almofada de apoio, almofada de argamassa modificada, transferência de tensões.

[a] *Faculdade Meridional - IMED, Escola de Engenharia Civil, Passo Fundo, RS, Brasil;*
[b] *Universidade de São Paulo, Departamento de Estruturas, Escola de Engenharia de São Carlos, São Carlos, SP, Brasil;*
[c] *Universidade Estadual de Campinas, Departamento de Estruturas, Campinas, SP, Brasil.*

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1. Introduction

The connections between precast concrete elements are very important in the design of this type of structural solution [1-2]. Depending on the existent superficial irregularities in precast elements, a stress concentration with early rupture can occur in the region of connections with direct contact. A possibility to avoid these stress concentrations are the use of a bearing pad between the connected parts. The use of these pads tend to distribute uniformly the compressive stresses, allowing some relative movement between the precast elements.

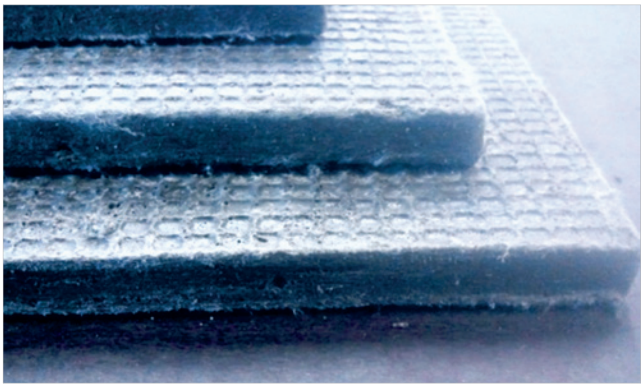
The most commonly used materials in the pad is the polychloroprene. The other alternatives used to transfer the compressive stress in the contact surfaces are the fulfillment of the space between elements with grout or the use of a steel plate in the connection.

Instead of the use of these classical materials, this work analyzes the compressive stress transfer in precast concrete connections using an alternative cement-based material, simply called here as a modified mortar pad (MMP). The MMP is produced introducing in the Portland cement-based mortar a styrene-butadiene latex, polypropylene fibers and heat-expanded vermiculite. The use of these additions results in a material with greater deformability and higher toughness, compared to an ordinary cement mortar, being able to transfer the compressive stresses in an appropriate manner. More details about these types of alternative materials and their applications can be found in EL DEBS [3].

Compression tests were conducted in concrete samples, simulating column-to-column connections, composed of two prismatic blocks interleaved with a MMP and the results were compared to a monolithic specimen [4-5]. The pads had 10 mm thick and smooth surface, with average compressive strength of 34.9 MPa, average tensile strength of 2.66 MPa and average elastic modulus of 13.1 GPa. The concrete blocks had compressive strength ranging from 52 to 61 MPa. Some of the upper concrete blocks had a rough surface, with different thicknesses ranging from 0.75 mm to 1.5 mm, which aimed to simulate the imperfections found in real structures. The experimental results revealed that presence of the MMP increased the connection strength in samples with the thickness of rough surface between 0.75 mm and 1.0 mm. For specimens with smooth surface and rough surface of 1.5 mm thickness, there were no significant increase in the connection strengths.

SIQUEIRA & EL DEBS [5] also evaluated the stiffness of MMP with smooth surface under cyclic loads. After some tests varying the number of cycles and the level of compressive load applied, the experimental results demonstrated that the stiffness for the MMP did not suffered significant change when compared to samples loaded monotonically. These results confirmed the resilient capacity of the pad. Additionally, it was observed that with an increase in the amount of vermiculite in the mixture, there was a significant reduction in the mechanical properties of the composite material. They concluded that the optimal amount of vermiculite in the composite was around 10%.

Figure 1 – Modified mortar pad with roughness surface



EL DEBS e & BELLUCIO [6] introduced a small surface roughness in the MMP observing that the presence of this surface roughness tends to reduce the stiffness of the pad in the hardened state. In this study, two different diameters for the polypropylene fibers (12 μm and 180 μm) were tested in the mixtures. After some experimental tests, it was concluded that the use of polypropylene fiber with a diameter of 12 μm provided smaller stiffness and greater toughness values to the material.

This current research aims to continue to the study that has been done in the School of Enginnering of São Carlos since the late nineties. Compressive tests are performed in connections between concrete specimens with and without MMP, varying the thickness of the rough surface of prismatic blocks, the concrete compressive strength and the type of load (monotonic and cyclic) applied on the blocks. The experimental test program conducted in this study aims to verify the behavior and the applicability limits for the MMP, simulating different situations for column-to-column connections of precast concrete that can be found in real structures. More detailed information about the tests performed and the results obtained are available in DITZ [7].

2. Materials and experimental program

The MMP production is carried out using the products described as follow: a) Portland cement CP-V-ARI; b) Sand with specific mass of 2630 kg/m³ and a maximum diameter of 0.6 mm; c) Heat-expanded vermiculite with specific mass of 113 kg/m³;

Table 1 – Reference mixture for the MMP (in mass)

Cement	Sand	Vermiculite	Latex	Fiber	Superplasticizer	Water	Cement consumption (kg/m³)
1	0.285	0.015	0.1	0.02	0.025	0.25	1220

d) Styrene-butadiene latex with solid contents of 50%; e) Polypropylene fibers with length of 10 mm and diameter of 12 μm; and f) Superplasticizer Glenium 51.
The base mixture of the MMP used in this work is presented in Table [1]. The cure process adopted in this study was based on the recommendations of RAY & GUPTA [8] for cementitious composites modified with polymers. The first 48 hours with 100% of humidity (moist chamber). After this period, the samples were cured in dry conditions, at ambient temperature with at least 50% humidity. All tests were performed with the age of pads between 14 to 21 days.
To determine the mechanical properties of the cement mortar composition used in this study, cylindrical samples with 50 mm diameter and 100 mm height were tested. The results of the experimental tests demonstrates that the mixture has an average compressive strength of 27.65 MPa, an average tensile strength of 3.62 MPa and an average static elastic modulus of 11.53 MPa.
To evaluate the capacity to transfer the compressive stresses of

Figure 2 – Detail of concrete block containing nine protuberances (dimensions in mm) (Adapted from EL DEBS et. al. (2008)): a) Side view; b) Roughness surface view; c) Detail of block protuberance

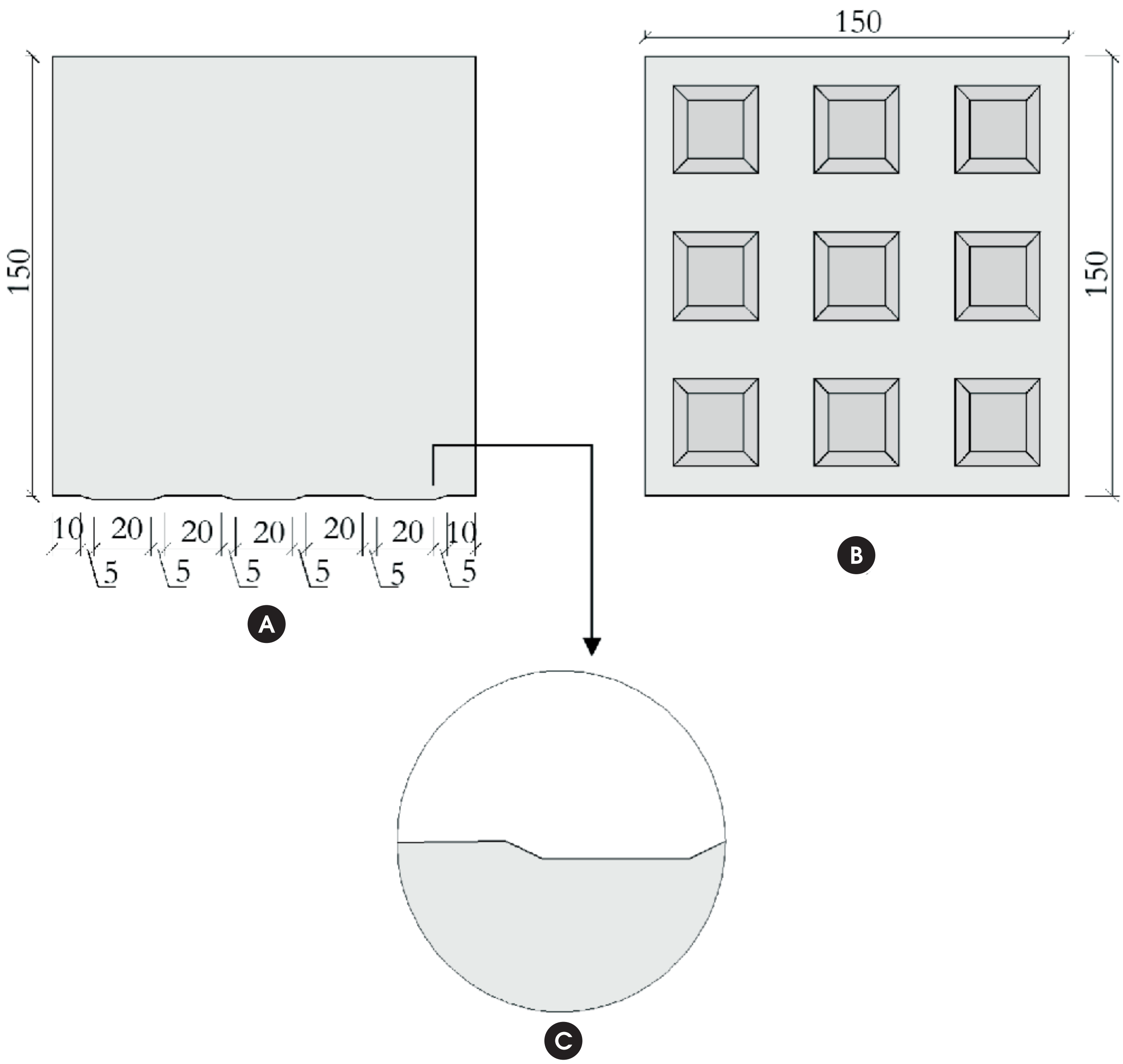


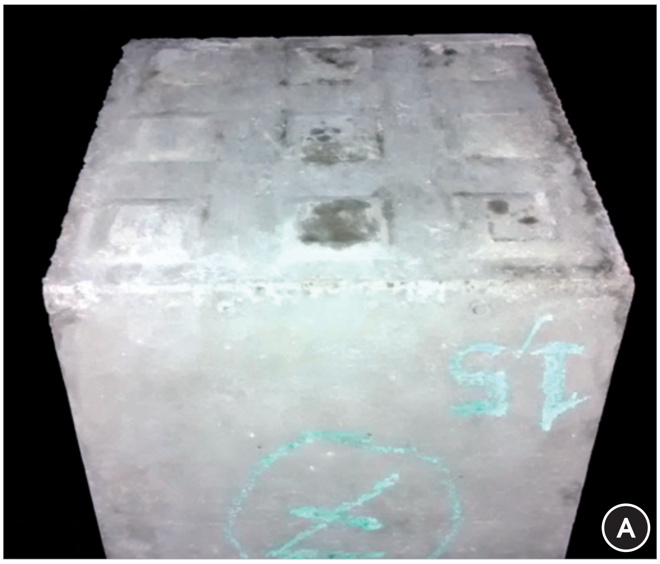
Table 2 – Series analyzed in the connection tests

Serie	Protuberance thickness (mm)	Blocks concrete compressive strength class (MPa)	Presence of bearing pad	Monotonic or cyclic regime
S065SM	0	65	Yes	Monotonic
S0.565SM	0.5	65	Yes	Monotonic
S1.065SM	1.0	65	Yes	Monotonic
S1.565SM	1.5	65	Yes	Monotonic
S065NM	0	65	Not	Monotonic
S0.565NM	0.5	65	Not	Monotonic
S1.065NM	1.0	65	Not	Monotonic
S1.565NM	1.5	65	Not	Monotonic
S1.040SM	1.0	40	Yes	Monotonic
S1.090SM	1.0	90	Yes	Monotonic
S1.065SC	1.0	65	Yes	Cyclic
S1.065NC	1.0	65	Not	Cyclic
Monolithic	–	65	–	Monotonic

the cement-based bearing pad for precast concrete connections, samples of 150 mm x 150 mm x 10 mm (MMP) with rough surface, as can be seen in Figure [1], were introduced between cubic concrete blocks with 150 mm of lateral edges. The upper concrete block had nine protuberances in the connection surface with variable thickness of 0.50 mm, 1.0 mm and 1.50 mm, as indicated in Figure [2]. In addition to these intentional roughnesses, a connection with smooth surface is also considered in this research. All the results are compared to a prismatic monolithic concrete block with 150 mm x 150 mm of base and 300 mm height. In addition to the surface roughnesses, another variable also evaluated is the effective contribution of the MMP for connections using concrete with different average compressive strengths. In this case, the MMP is placed between concrete blocks with compressive strengths of 40, 65 and 90 MPa, with a fixed value of 1.0 mm for the protuberances in the upper concrete block.

For each casting, six cylindrical samples with 10 cm x 20 cm were molded as a control of compressive strength. For the tests that

Figure 3 – a) Block containing protuberances in one surface after desmolding; b) Block with protuberances in featured



aimed to verify the effective capacity of MMP to transfer the compressive stresses varying the thickness of protuberances in upper concrete blocks, a concrete with a constant value of 65 MPa for the compressive strength is used.

The results are presented directly in function of the compressive strength of the connection, with or without MMP, being compared to the strength of a monolithic concrete block. To be able to evaluate the effective capacity of the MMP to transfer compressive stresses of connections using concrete blocks with different compressive strenghts, a coefficient called L/C relationship is stipulated. This coefficient comes from the ratio between the connection strength and the average compressive strength of the cylindrical concrete samples (10 cm x 20 cm), considered as a reference of concrete compressive strength. Therefore, the connection strength for concrete with different classes of compressive resistance is determined as a percentage of the compressive strength of reference concrete.

The different names, assigned to each connection specimen, are based on each variable of interest studied, as presented in table [2]. A total of six samples are tested for each series analyzed. After a statistical work, uncertain values were discarded based on the criterion of Chauvenet.

The curing process for the prismatic concrete blocks and cylindrical samples were done with a 100% humidity; during the first 24 hours, the samples were kept in molds under a saturated foam, and after unmolding, the rest of the curing process was done in moist chamber. All the tests with concrete samples are executed with age of seven days. In Figure [3], examples of concrete blocks are presented, highlighting the protuberances after unmolding. Due to the cubic geometry of the blocks, it was not possible to perform a surface rectification. However, to correct the irregularities in the surface in contact with the plates of test machine, a treating with a plastic mass was done to obtain a flat surface.

A scheme of stress transfer test for precast concrete connections is presented in Figure [4]. It can be observed from this figure, the protuberances with variable thicknesses and the MMP position during the tests. Figure [4b] presents the scheme of stress transfer test without the presence of MMP.

The results for this stress transfer test are compared to the results of monolithic prismatic samples with transversal section of 150 mm x 150 mm and 300 mm height. The loading rate for discontinuous specimens was 0.3 kN/s. Due to limitations in the test machine, for the monolithic specimens, the loading rate was increased to 0.9 kN/s. Accordingly to ANDRADE & TUTIKIAN [9], this level of change in the loading rate will be responsible for changes around only ±5% in the experimental results.

Figure [5] presents the entire specimen placed into the test machine, where it can be observed the presence of MMP and the upper concrete block with surface irregularities. Also in the figure, an extended view of block-pad-block contact can be seen with more details (Figure [5b]).

In the connection subjected to the cyclic loadings, the objective is to simulate real conditions of cycles for loading and unloading using the MMP, to verify the performance of the pad to transfer compressive stress between connections in which loadings may vary during time. This test is divided in three stages. The configuration of each stage, adapted accordingly to the capacity and limitations of the test machine (INSTRON 8506), is presented as follow: a) Stage 1: 50 cycles at a load rate of 10 kN/s varying from 0.2 to 45.0 kN. This last value, representing a compressive stress of 2.0 MPa, is considered as a load that promotes an accommodation of the initial imperfections in the connection region; b) Stage 2: 200 cycles at a rate of 20 kN/s varying from 2.0 to 6.0 MPa. This increase for the loading rate was necessary due to limitations of the test machine, as discussed in previous sections.; c) Stage 3: Monotonic rupture test. In this test, the specimen is charged monotonically

Figure 4 – Scheme of centered compressive stress transfer test: a) With bearing pad; b) Without bearing pad

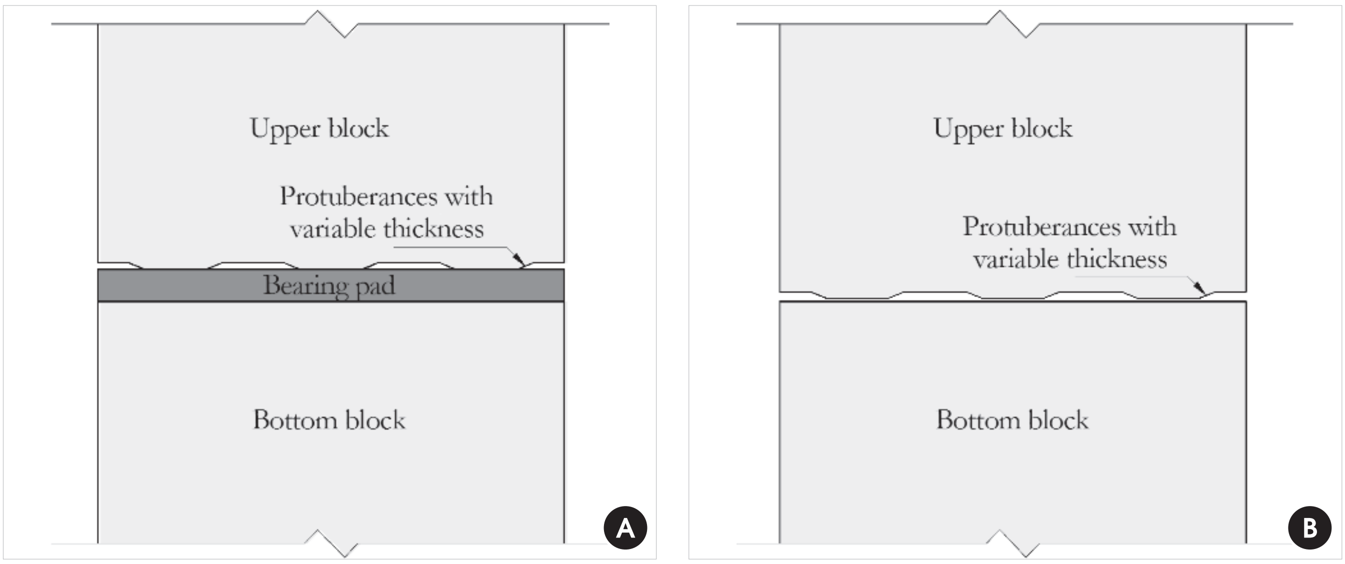
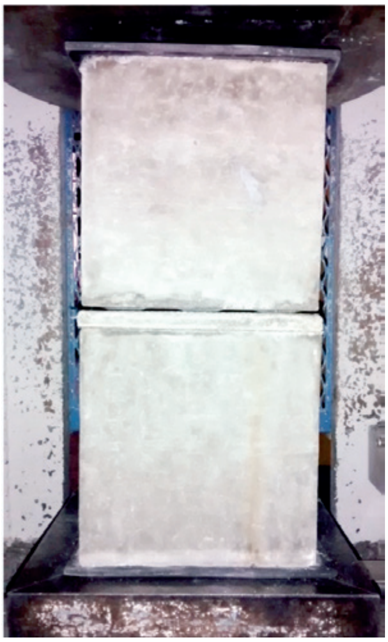


**Figure 5 – Entire specimen placed into the test machine:
a) General view; b) Detail of block-pad-block contact**



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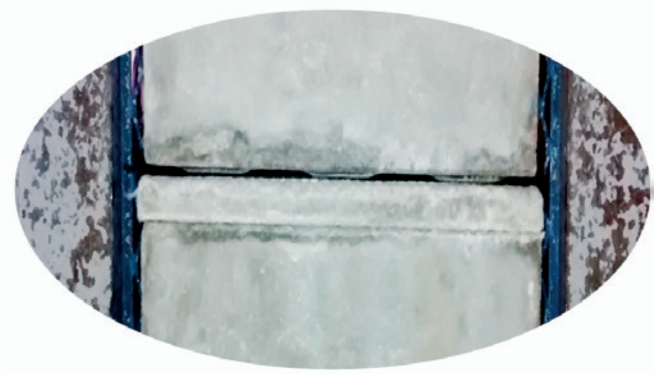


B

until the complete rupture of the connected elements. As a matter of security related to the test machine operation, in this test the specimen is loaded using displacement control at a rate of 0.005 mm/s. The thickness of protuberances considered during the cyclic load experiments are 1.0 mm and different tests were conducted with and without the MMP.

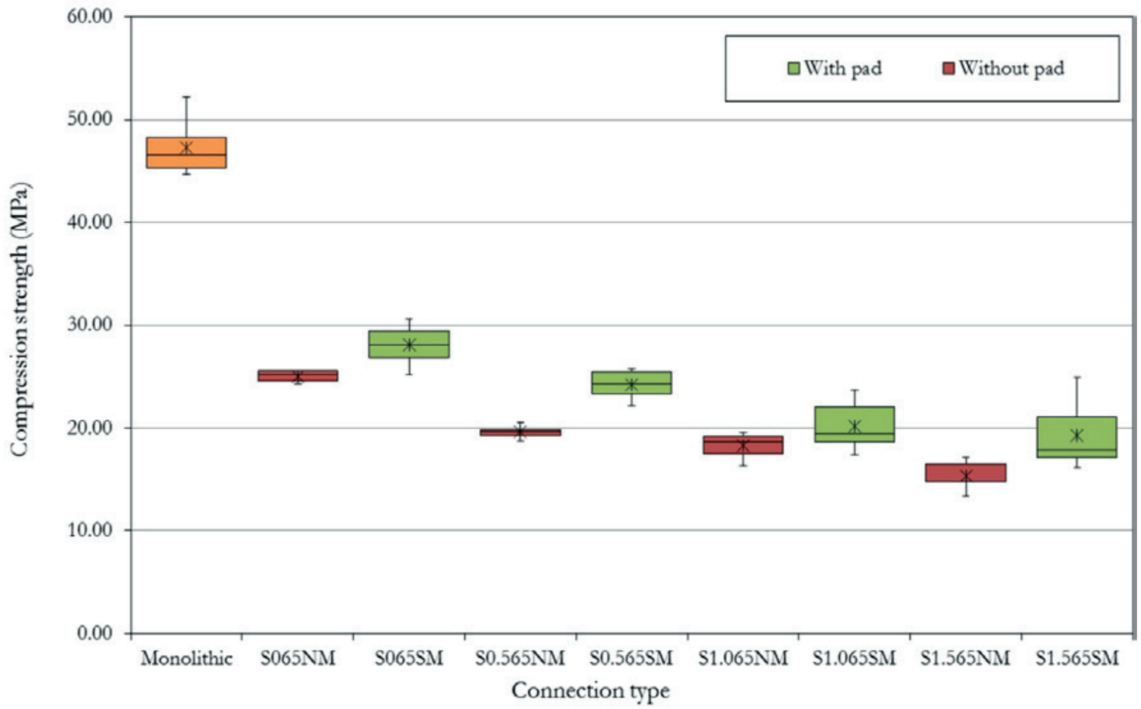
3. Results and discussions

To the analysis of experimental results, graphics box-and-whisker-plots type are used. This type of graphic representation has the advantage to present the variation of experimental results, with their respective concentration around the median value of the distribution, as well as the variation and differences between median and mean values of the set of data. Box plot graphics are very useful to exhibit simple and clear informations about comparative experiments (HODD & LEDOLTER [10]) and useful to compare two or more sets of data allowing easy evaluation of the results graphically (HINES et al. [11]). This representation type has been used in statistical studies for evaluation of seismic vulnerability of reinforced concrete structures (SIQUEIRA et al. [12]).
In the graphics, the asterisk represents the arithmetic average value of the results, while the central horizontal black line represents the median value of peak responses (50th percentile); the upper and the bottom of the boxes indicate the limits of 25th and 75th percentiles while the whisker plots represent the minimum and maximum values of all data.

3.1 Influence of the surface roughness in the concrete blocks

The experimental results of compressive strength for column-to-column connections according to the level of surface roughness is presented in Figure [6]. These results are obtained to concrete blocks with compressive strength of 65 MPa and different values of surface roughness, as presented above. A monotonic loading is used in this kind of test.
Comparing the results presented in Figure [6], one can see that the monolithic model had significantly higher average compressive strength compared to discontinuous specimens. From the comparison of compressive strength for monolithic and discontinuous block with smooth surface (without surface roughness), it can be seen that the average compressive strength of the monolithic block is approximately 90% higher than the respective value of blocks with smooth surface without the MMP. In the case of connections with the MMP, the difference observed is around 70%, demonstrating clearly an improvement of connection strength in the presence of MMP.
Comparing only the results for smooth surface discontinuous blocks, it can be observed that the average compressive strength and the median (50th percentile) values are very close, and presence of MMP assures a gain of approximately 12% in the compressive strength for the connection. However, one can observe that there are some differences between the results presented by SIQUEIRA & EL DEBS [4], where the presence of MMP did not result in significant differences for the compressive strength, and the results presented in this study where a gain of compres-

Figure 6 – Connections compressive strength with and without bearing pad for all levels of protuberances in the surface of connected block



sive strength is observed. These differences are mainly due to the adoption of a new composition for the cement mortar and the intentional surface roughness adopted in the MMP used in this work (Figure [1]).

As one can observe, the use of the cement cushions provides higher benefits to intermediary thickness values of the protuberances on the upper concrete block in the connected elements. For protuberances with 0.5 mm thickness, the presence of the MMP increased in approximately 24% the compressive strength of the specimen when compared to specimens without the MMP. It is also possible to observe that there is a good distribution for the ranges of the upper and lower limits of the distribution (25th to 75th percentile) as well as a good agreement between the median and mean values of the distributions for specimens with and without the MMP.

For higher thickness values of surface roughness, as in the case of thickness above 1.0 mm, there is a great variability and important differences between mean and median values, the whisker limit values (maximum and minimum) and, the upper and bottom box values (25th and 75th percentile) for the obtained experimental results. These variabilities results in additional difficulties to obtain accurate and clear conclusions about the improving of the behavior for the blocks in the presence of MMP with roughness surface in these conditions. As it can be observed in Figure [6] for the cases of surface roughness with 1.0 mm and 1.5 mm, there is a trend to the improvement in the experimental results with presence of the MMP, but these results present less efficiency than in case of protuberances with 0.5 mm.

Overall, it can be observed that the presence of MMP increases the variability in the results for all cases studied in this research. However, the range of values between the 25th to 75th percentiles are higher than the results of the specimens without the MMP. It is important to notice that higher variability in the results for samples with MMP demonstrates the need for a larger amount of experimental tests that would establish reliable range values for the mean and the median values of compressive strengths of these elements. Nevertheless, it can be seen that the presence of MMP ensures median and mean values of compressive strength higher than the values for the strength of specimens without the MMP, demonstrating a trend of improvement for the experimental results of connections in the presence of the MMP.

Figure 7 – Cracks formation in compressive stresses transfer test in blocks containing protuberances in the connected surface

In Figure [7], a crack pattern for concrete blocks with different surface roughnesses is demonstrated. For all specimens with surface roughness, the crack pattern that determine the rupture of the upper concrete block, initiates in the discontinuous central region, independent of the presence of MMP and the type of load applied. This is not the case for the connections with smooth surfaces, where the crack initiates on the extremities of the specimen and propagates in the vertical axis direction, until the failure of the concrete block occurs.

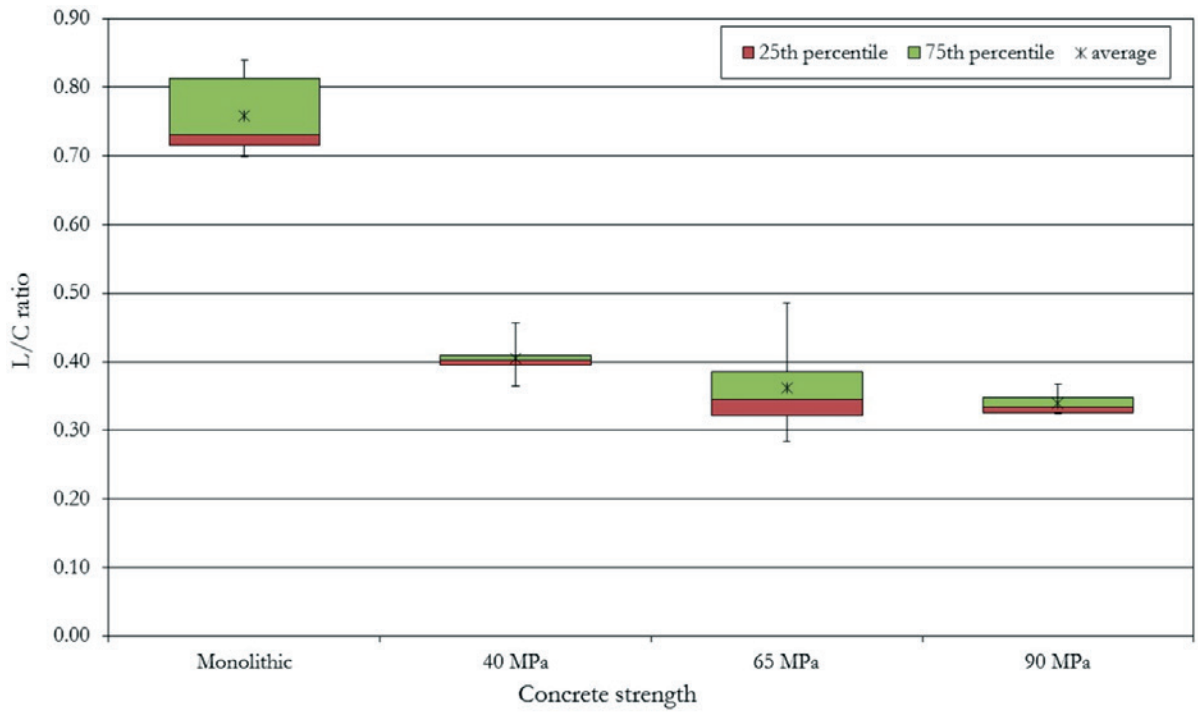
3.2 Influence of the compressive strength variation from the concrete blocks

In tests of connection between concrete blocks with different compressive strengths, as presented in Figure [8], it is possible to observe a trend of increase in the performance of connections with MMP for concrete blocks with lower values of compressive strength. In this figure, the values of the upper and the lower boxes and, the whisker plots for the L/C relationship of monolithic concrete blocks with 65 MPa of compressive strength are presented. Also in the figure, a comparison between these values of L/C of monolithic blocks are compared to the values of L/C for discontinous connections with different classes of compressive strength for the concrete blocks (40, 65 and 90 MPa).
From the results presented in the figure, it is possible to observe that reducing the compressive strength of the concrete blocks from 90 MPa to 65 MPa, there is an increase of approximately 6% for the L/C relationship, varying from 0.34 to 0.36. With a reduction of the compressive strength for the concrete blocks from 65MPa to 40 MPa, the L/C relationship increases about 14%, varying from 0.36 to 0.41. This behavior can be explained by the fact that increasing the compressive strength of the concrete blocks, the entire specimen used for the connection test becomes more fragile, inducing a reduction for the contribution of the MMP in the connection performance. It is important to notice that the concrete blocks are not reinforced, which would possible affect the behavior of the connection performance.

3.3 Influence of cyclic loads

Tests with cyclic loads are performed in two series, with and without the MMP, for connections with surface roughness of 1.0 mm thick on the upper concrete block.
In Figure [9], it is possible to observe graphically the different load patterns applied during the tests, as explained in previous sections. The first load stage is indicated as the point 1 in Figure [9], corresponding to a 50 cycles of load ranging from 0 to 2.0 MPa. The point 2 indicates the second load level, corresponding to 200 cycles ranging from 2.0 MPa to 6.0 MPa. Finally, points 3 and 4 indicates the monolithic loading ramp and the rupture of the connection, respectively.
Figure [10] presents the L/C ratio for connections submitted to cyclic and monotonic loading, with and without the MMP. Also in the figure, as a matter of comparison, the results of L/C ratio for monolithic samples tested with monotonic loading are presented. In Figure [10], the horizontal axis indicates the presence or absence of

Figure 8 – L/C ratio for connections containing bearing pad and concrete with different strength classes



the MMP as well as the monolithic sample. The average value of the experimental results and the loading type (monotonic or cyclic) are indicated in the legend.

As it can be observed, the connections containing the MMP presented a better performance also in cyclical regime. Comparing the results of connections submitted to cyclical loads, with and without the MMP, there is an increase of 48% in the connection strength in the presence of MMP. Regarding the results of connection strength for monotonic and cyclic loading, comparing just the specimens without the MMP, the cyclic regime is responsible for a reduction of approximately 33% in the connection strength. In the case of connection strength for specimens with the MMP, comparing the experimental results for monotonic and cyclic loads, this reduction is about 16%. These differences between the reduction of the connection strength for specimens with and without the MMP confirms that use of MMP improves the general connection behavior, not only for monotonic loadings, but also for cyclic loadings.

4. Conclusions

From experimental and statistical analysis of connections between concrete blocks, some inferences about their overall behavior with and without the use of MMP are presented below:

a) In tests to evaluate the effectiveness of the MMP on connections submitted to monotonic compressive loadings, it is observed that the efficiency of MMP is optimal to intermediate levels of surface roughness. For protuberances with 0.5 mm thick, the improvement on the connection strength is approximately 24%. In the case of connections with smooth contact surface, it is observed an improvement on the connection strength about 12%. The results for connections with smooth surface are contrary to the findings of SIQUEIRA & El DEBS [5], in which the presence of MMP did not present a significant increase on the connection strength when compared to specimens without the MMP. The increase in the current connection strength is mainly due to the new mixture of the cement-based material and the intentional surface roughness of the MMP, as introduced in EL DEBS & BELLUCIO [6];
b) For surface roughness values above 1.0 mm thick, the results obtained present great variability and reliable conclusions could not be established, demonstrating the need to carry out a greater number of tests. However, there is a trend of improvement for the connection strength in the presence of MMP;
c) In specimens containing surface roughness in the upper concrete block, first cracks occurred in the central region of the discontinuity, expanding vertically until the complete rupture of the specimen. For blocks with smooth contact surface, the cracking pattern originates at the edges of the specimens;
d) A trend of better performance for the connection could be observed for concrete with usual compressive strengths, which means values below 50 MPa;
e) The use of MMP improved the connection strength even when cyclic loads are applied. In this case, the improvement of connection strength, with surface roughness of 1.0 mm thick, is approximately 48% when compared to specimens without the MMP. Comparing the results of connections for monotonic and cyclic load regimes, the connection strength is reduced about 33% for specimens without MMP. In the presence of the MMP,

Figure 9 – Cyclic load in stress transfer test sample

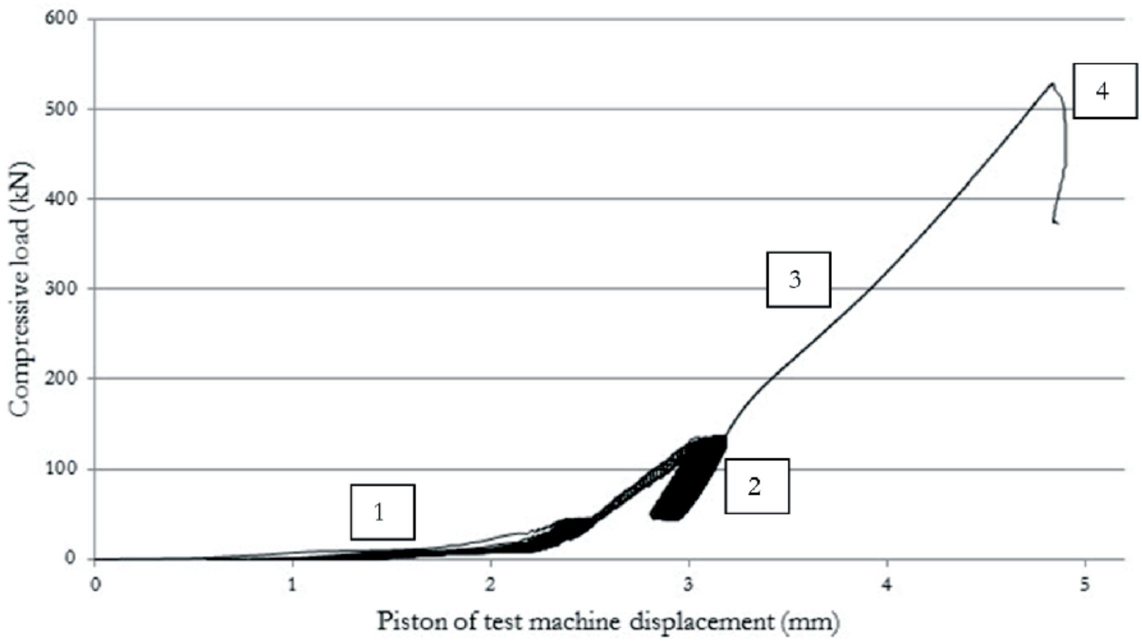
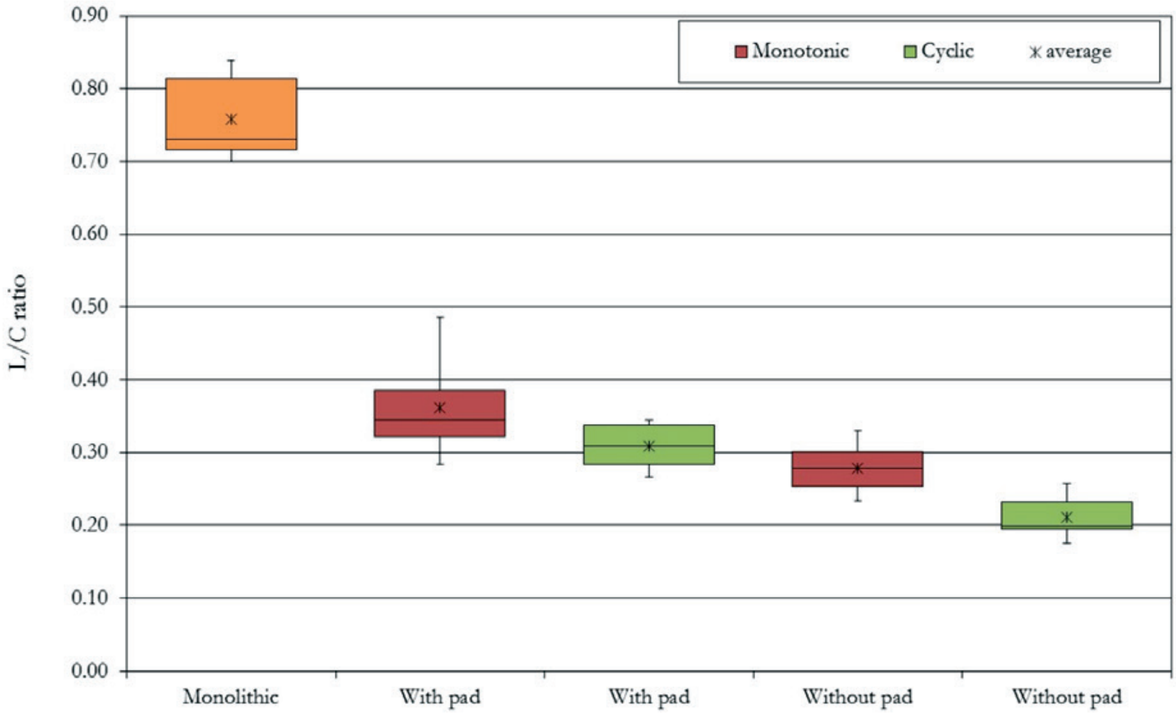


Figure 10 – L/C ratio for connections with monotonic and cyclic loading



this reduction is around only 16%, demonstrating the efficiency of the MMP for different types of load regimes.

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