11th Canadian Masonry Symposium, Toronto, Ontario, May 31- June 3, 2009

BUILDING AND TESTING CLAY BLOCK PRESTRESSED MASONRY FAÇADE PANELS

P.R.A. Souza[1] and G.A. Parsekian[2]
[1] Former Master Student, [2] Professor ,
Department of Civil Engineering, Federal University of Sao Carlos, BRAZIL, parsekian@ufscar.br

ABSTRACT

The widespread use of precast façade panels expedites constructions and increases their quality. Using such elements enables the construction process to be conducted on industrial scale. This paper reports on a study of clay block prestressed masonry panels as an alternative for the commonly prestressed or reinforced concrete façade panels. The panel was designed to bear regular winds loads and also tested for construction and transportation loads such as self-weight. The construction process was tested in two modes. First, several small vertical panels were built, after which they were rotated to the horizontal position and joined together by prestressed cables, forming a single 5-m long horizontal panel. In the second mode, the whole panel was built and prestressed horizontally. The two complete panels were then subjected to lateral loads in order to determine the failure load and displacements. The conclusions drawn from the tests were that both panels were able to bear loads close to predicted. Also both panels are expected to resist designing load in most practical cases

KEYWORDS: prefabrication; prestressed masonry; design.

INTRODUCTION

The search for innovative systems to improve the quality and efficiency while reducing the time and cost of construction is an ongoing effort. Structural masonry and precast concrete elements usually provide a more rational mode of construction. A comparison of these modern methods of construction with traditional ones, which usually involve built-in-place masonry, reveals that the former offer several advantages, including waste reduction, better job site organization and cleanliness, elimination of formwork, reduction in the number of activities and manpower at the job site, and a consequent reduction of time and costs.

One of the fields of human endeavor that has shown the greatest advance in the last three decades when compared with other building systems is structural masonry, thanks to a variety of research programs, designer creativity, and materials with improved quality [1]. The current availability of precast masonry panels clearly illustrates this advance.

The last two decades have been marked by major developments in the prefabrication of structural masonry elements. These elements can be completely or partially prefabricated, and in the latter case they are usually combined with other traditionally built elements. The use of such elements requires modular coordination starting right from the beginning of the design process, transforming the job site into a place where construction activities are practically limited to assembling prefabricated elements.

According to ref. [2], prefabricated masonry panels are produced basically by two fabrication methods: the hand-laying method of prefabrication, which "is achieved in the same manner as conventional in-place masonry, except that it is carried out in an area away from the final location of the masonry"; and the casting method, which "involves the combining of masonry units and grout into a prefabricated element similar to precast concrete".

Ref. [3] states that prefabrication methods must keep the advantages of functionality and aesthetics of masonry constructions similar to the elements being built. Thus, they must also eliminate the disadvantages of working in uncomfortable environments, wasting time, lack of organization, and difficulties in controlling the quality of materials and of the construction process, which are common characteristics of work performed at job sites.

Several types of prefabricated masonry panels are currently being developed in the USA and Europe. Ref. [2] quotes some examples. Some cases use clay bricks while others use hollow blocks of a variety of shapes and sizes. These are employed in the construction of residential homes and apartment buildings, walls and even roofing.

In Brazil, prefabricated clay masonry panels have only recently come into use, especially for the construction of low-cost houses. Ref. [4] reports a case of such elements. Some companies are successfully selling houses built of precast masonry panels, as in the case of the company Jet Casa [5], whose production line manufactures clay block infill panels in a concrete grid, which are supplied with all the finishing and piping, leaving only the final coat of paint to be applied on the job site.

The aim of this work is to present an innovative solution using clay blocks, which combines the simplicity of masonry building with the prestressing technique. A prefabricated clay block prestressed masonry panel is presented as an alternative for the commonly prestressed or reinforced concrete façade panel.

PRESTRESSED MASONRY PANELS

This work involved the use of prestressed masonry panels as warehouse façade elements, although these elements can just as easily be used in other types of construction. Some of the advantages foreseen for the use of these elements are:

- Simplification of the construction process – basically, this involves laying blocks followed by prestressing.
- Reduction of panel weight when compared with traditional solutions, and hence, easy assembling.

- Lower costs when compared with reinforced concrete panels [6].
- Rationalization of the construction process and elimination of foundation beams when compared to built-in-place masonry.
- Aesthetically pleasing panels, which also allow for exposed masonry.

When in place, the façade panel will stand horizontally with its ends simply supported by the columns of the main structure (Figure 1). Prestressing cables are positioned inside hollow blocks perpendicular to bed joints. Thus, the panel's length is a multiple of the block height ant the panel's height is a multiple of the block length. The connection must allow for some deformation of the panel and prevent the concentration of stresses on the supports. One possibility is illustrated at Figure 2, which shows the horizontal forces transmitted from the panel to the column by single bolts at the ends, and the panel self-weight is supported by steel angles bolted to the columns. If the panel shows a small degree of deformation it will rotate slightly around the bolts.

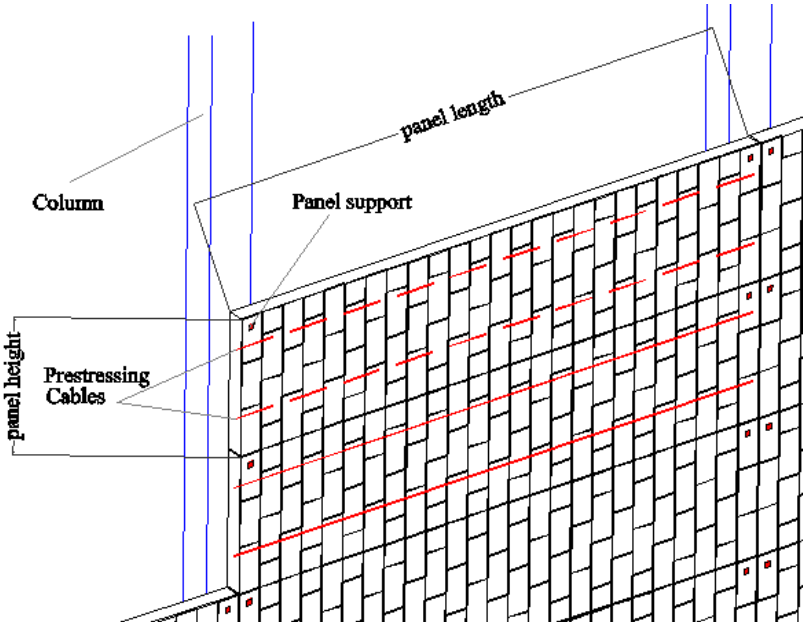


Figure 1: Detail of the facade panels in place

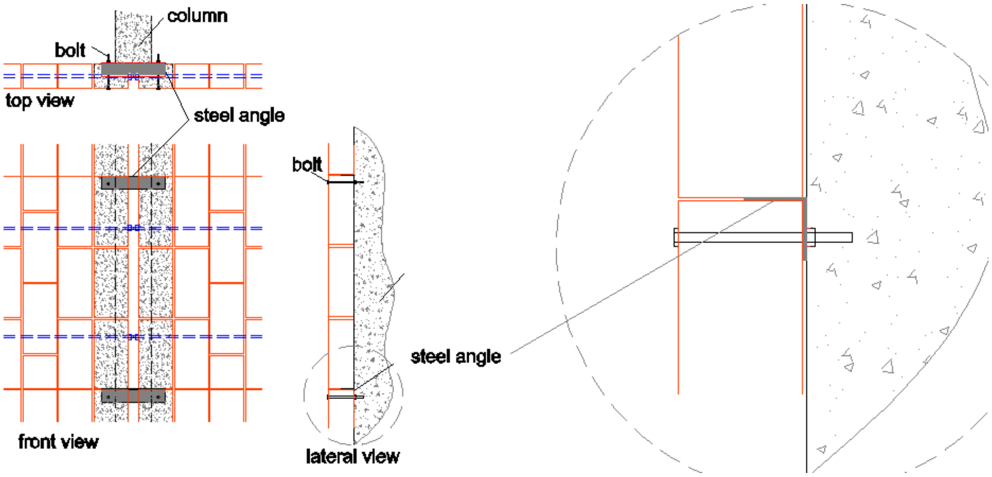


Figure 2: Masonry panel – detail of the concrete column connection

The detail in Figure 2 also indicates the distance required between the ends of two panels to avoid inference at each anchoring end. This space may later be filled with grout (not the most rational solution) or covered with a steel or plastic plate to hide the anchors from view, since they must be protected against corrosion.

Each panel is designed as a simply-supported beam with out-of-plane wind loads and in-plane self-weight loads in the final position. During transportation, the panel must be able to bear to its self-weight in an out-of-plane condition, supported at its ends. The latter condition is usually the critical one.

Prestressed masonry was designed according to the recommendations of ref. [7], since recommendations for this type of element are slated for inclusion in Brazilian codes in 2009 (and even then only in the form of an amendment and not as a code prescription). As described in the aforementioned paper, these recommendations take into account several international codes [8], [9], [10], and a research program conducted with local materials is reported in [11].

PANEL CONSTRUCTION PROCESS

Code recommendations for prefabricated masonry are scarce, although a few general specifications are given in [12] and [13]. In this work, two construction processes are proposed and described. In the first, several small vertical panels were built, rotated to the horizontal position and joined together by prestressed cables, thereby forming a single 5-m long horizontal panel. In the second process, the entire panel was built and prestressed horizontally.

The steps involved in first proposed process are described below:

1) Construction of several small walls, laying the blocks vertically like any common construction, and grouting together a set of beam blocks that will be placed at the panel ends (Figure 3).

2) Rotating each small wall and end beams and joining them together with prestressing cables (Figure 4).

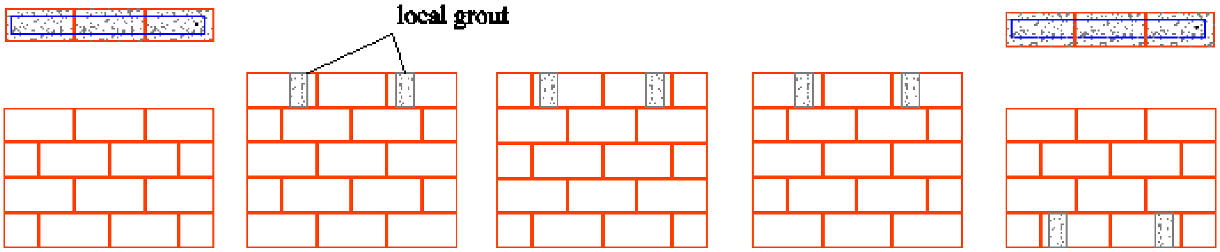


Figure 3: Construction process 1 – end beam and small walls built by laying blocks vertically

After building the small walls, they should allowed to rest for at least 24h, after which they are rotated and assembled as illustrated in Figure 4. The space between each small wall and its neighbor is filled with mortar, after which a slight prestressing force is applied. After the mortar has gained enough strength, the final prestressing is applied.

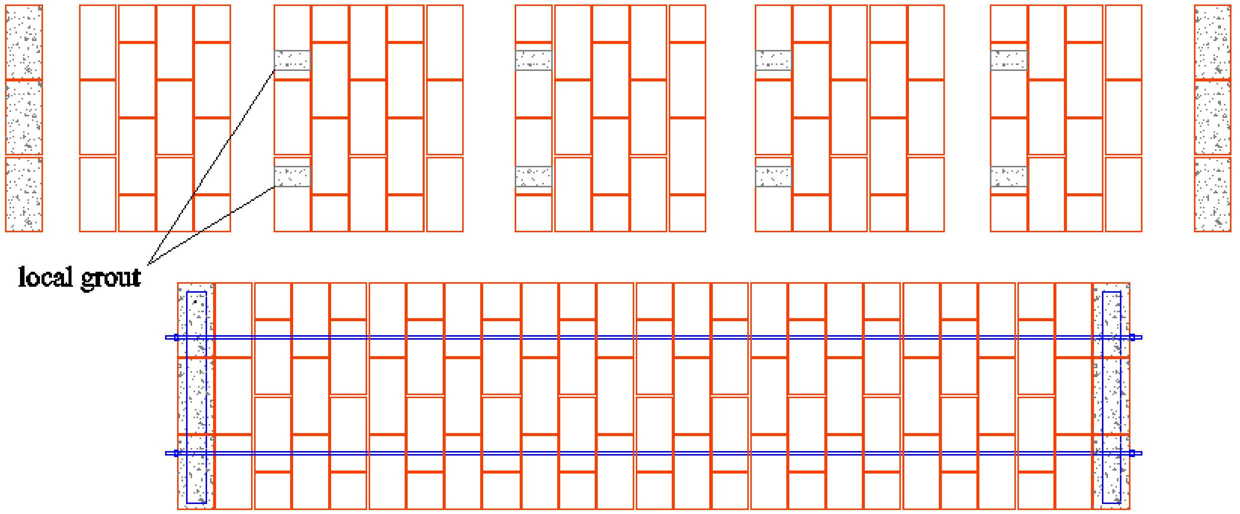


Figure 4: Joining the rotated small walls together with prestressing cables

The second suggested process consists of building the entire panel on a level floor, laying the blocks horizontally over the floor and then prestressing the panel

BUILDING OF PROTOTYPE PANELS

Two panel prototypes were built, one by each of the above described processes, and tested at the Federal University of São Carlos. Each panel was 1.2-m high and 5.0-m long (Figure 5). The materials used were:

- clay block, 140x190x390mm, f_{bk}=7,57 MPa (gross area), f_{pk}=4,76 MPa;
- 1:0.5:4.5 (cement:lime:sand) mortar;
- 15-MPa grout;
- 16-mm nominal diameter (160 mm^2 effective area after threads), 750-MPa yield strength prestressing rods.

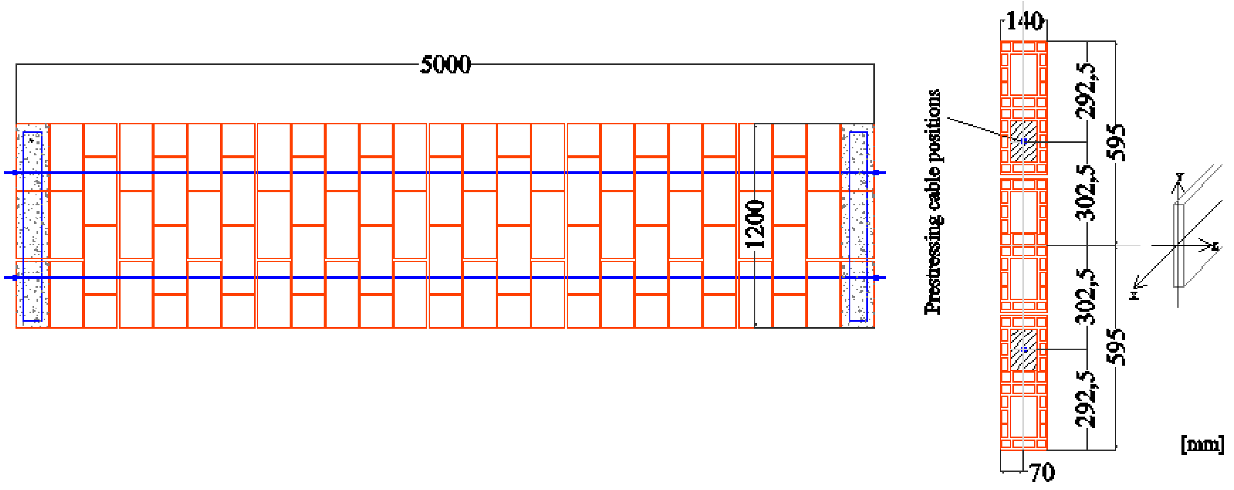


Figure 5: Dimensions of the panel prototype

Error! Bookmark not defined. This prototype was built using the first process. Four small walls, three of them 1.2-m high and one 1.0-m high, and two end beams were built by laying blocks vertically, as done for a conventional wall (Figure 6).

Figure 6: Panel building process 1 – small walls are first by built laying blocks vertically

After 24 hours, each wall was first rotated around its plane and then turned down onto the floor. Maintaining their lateral alignment, the walls were moved together, leaving a 10-mm gap between them. Each gap was then filled with mortar (Figure 7) and the assembled set prestressed the following day. A 100-kN force was applied to the panel using a manual hydraulic pump and jack and a steel beam (Figure 8). The specially designed beam allowed the two bars to be prestressed at the same time, avoiding load eccentricities.

Figure 7: Panel building process 1 – rotate walls and assemble together with prestressing cables

Figure 8: Prestressing

Panel 2 was entirely built on a level floor by laying blocks horizontally, as illustrated in Figure 9. Only the end beams were later joined to the walls by means of prestressing. Figure 10 show the element suspend by its ends during transportation.

Figure 9: Panel building process 2 – the entire panel is built by laying blocks horizontally

Figure 10: View of the completed panel – the element is suspended by its ends

TESTING

The out-of-plane loading is the critical situation of the panel, which must bear its self-weight during transportation and wind loads in its final position. A four-point load test was applied to each panel spanning its whole length with simply-supported ends (Figure 11). Two displacement transducers where placed mid-span on each side of the panel. (Figure 12). Considering the section equilibrium, as in Figure 13, the ultimate moment will be M_u = 12.7 kN.m. Subtracting the moment due to self-weight (Msw = 4.5 kN.m), the total load, P, that will produce this moment, and thus the expected failure load, is equal to 8.2 kN.

Figure 14 shows the load versus displacement plots for both tests. Note that the failure load for both cases was close to the expected one. Panel 1, built by the small walls process, failed with P = 8.2 kN and panel 2 with P = 9.3 kN, with failure moments of 12.7 kN and 13.8 kN.m, respectively.

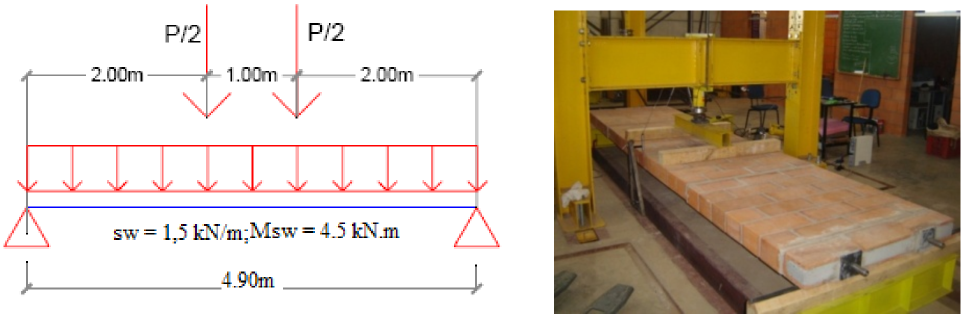
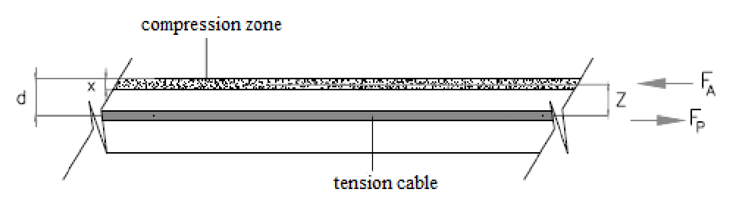


Figure 11: Overall test statics and view

Figure 12: left) Load-cell; right) LVDT at midspan



F_A = masonry force = $f_p \cdot b \cdot x$

F_P = cable force = $A_p.f_{pe}$

- $F_A = F_P$
- $(f_p.b.x) = A_p.f_{pe}$
- $M_u = A_p.f_{pe}.\ z$
- $\mathbf{M_u = f_{pe}\ .\ A_p\ (d - 0{,}5.x)}$

Figure 13: Equilibrium of prestressed section

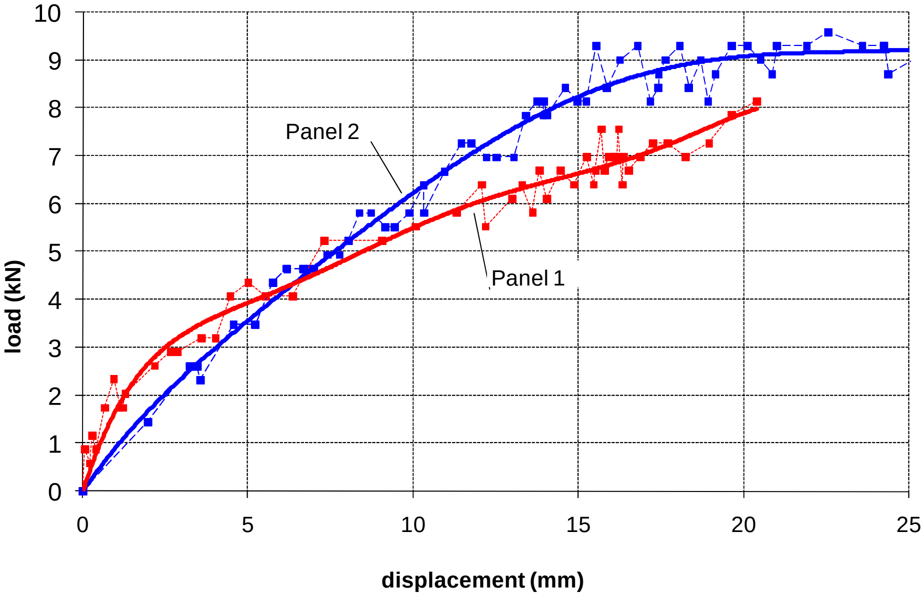


Figure 14: Experimental load versus displacement plot

An analysis of Figure 14 reveals a linear load vs. displacement plot at the beginning of the test, followed by a much more uniform curve for panel 2. Because panel 1 was built by joining together several small walls, we believe the construction process may have caused imperfections in the element that influenced its behavior. Also, the final load of this panel was slightly lower than of the other panel.

Figure 14 depicts the behavior of the central section during testing. The image on the left reveals a large crack opening without failure, which is a good characteristic behavior of prestressed masonry, showing great ductility. The image on the right shows the crushed block.

Figure 15: left) panel 1: central section during loading; right) panel 2: failure

The lateral wind force for a façade panel is in the order of 0.5 to 1.0 kN/m^2. At the highest wind force, the maximum panel midspan moment in service is in order of 3.8 kN.m, compared with the observed failure moments of 12.7 and 13.8 kN.m. Although many design considerations are necessary and will vary in each particular case, these results indicate that the element should display a good structural performance for the proposed application in many cases.

CONCLUSION

Two 1.2-m high and 5.0-m long prestressed masonry façade panels were built and tested. The first panel was built by joining together four small walls and then prestressing them together. The second panel wall was built entirely on a level floor. Both panels were tested and showed a failure load close to the expected one. Thus, the elements' structural performance proved suitable for the proposed application.

ACKNOWLEDGMENTS

The block donation from Selecta is much appreciated.

REFERENCES

1. PARIZZOTO FILHO, S. (2004). "Architectural and constructive aspects of housing types derived from pre-fabricated structured ceramic panels"; Análise arquitetônica e construtiva de tipos habitacionais edificados com painéis pré-fabricados com blocos cerâmicos. Master thesis - UNIVERSIDADE FEDERAL DE SANTA CATARINA, Florianópolis, Brasil.
2. BRICK INDUSTRY ASSOCIATION. (2001) "Prefabricated Brick Masonry – Introduction" Technical notes on brick construction n° 40, Reston,EUA,.

3. ROMAN, H.R. (2000) “Pesquisa e desenvolvimento de processos construtivos industrializados em cerâmica estrutural” Projeto FINEP. UNIVERSIDADE FEDERAL DE SANTA CATARINA, Florianópolis, Brasil.
4. CESAR, C. G. (2007). “Desenvolvimento de um processo construtivo em painéis pré-fabricados com blocos cerâmicos” PhD thesis - UNIVERSIDADE FEDERAL DE SANTA CATARINA, Santa Catarina, Brasil.
5. Sistema JetCasa © (2009). www.jetcasa.com.br. Acessed in Jan 8th, 2009.
6. SOUZA, P.R.A. (2008). “DESENVOLVIMENTO DE PAINEL PRÉ-FABRICADO EM ALVENARIA PROTENDIDA”. Master thesis - UNIVERSIDADE FEDERAL DE SÃO CARLOS , São Carlos, Brasil.
7. PARSEKIAN, G. A. ; FRANCO, L. S. ; CARVALHO, R. C. Prestressed Masonry: Recommendations to the Brazilian Code. In: 10th Canadian Masonry Conference, 2005, Banff. 10th Canadian Masonry Conference, 2005.
8. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - ABNT – Cálculo de Alvenaria Estrutural de Blocos Vazados de Concreto – NBR-10.837. Rio de Janeiro,1989
9. British Standard Institution. Code of pratice for structural use of masonry. Part 2 - Reinforced and prestressed masonry. BS5628, part 2. 1995.
10. STANDARDS ASSOCIATION OF AUSTRALIA. Masonry Structures - AS 3700. Second Edition, Sydney, 1998.
11. PARSEKIAN, G. A. (2002) “Tecnologia de produção de alvenaria estrutural protendida” Tese (Doutorado), Escola Politécnica da Universidade de São Paulo, São Paulo, Brasil.
12. MASONRY STANDARDS JOINT COMMITTEE. Code, especification and commentaries for masonry strucutures (ACI 530-05/ASCE 5-05/TMS 402-05 and ACI 530.1-05/ASCE 6-05/TMS 602-05)2005
13. American society for testing and materials. Standard Specification for Prefabricated Masonry Panels – ASTM C901. Philadelphia, 2001
14. Canadian Standards Association - CSA - Masonry Design for Buildings - S304.1-1994