ANALYSIS OF BRAZILIAN LOW-RISE STRUCTURAL MASONRY BUILDINGS

A. S. FREIRE

Professor
Centro Federal de Educação Tecnológica do Piaui
Parnaíba, PI, Brazil

G. A. PARSEKIAN

Professor
Department of Civil Engineering
Federal University of Sao Carlos
São Carlos, SP, Brazil

SUMMARY

This paper describes and analyzes details commonly adopted in the design of Brazilian residential structural masonry buildings. Some of these details are block and mortar material and dimensions, wall-to-wall intersections and reinforcement ratios. The research methodology consisted of assessing 120 designs by different engineer firms. Material consumption data were quantified and project pointers were calculated from each design. These pointers include details of the foundation, such as the number of piles and total load per building area, amount of steel reinforcement in concrete and masonry elements, average concrete and grout volume, and number of each type of block usually required for the construction of the building. The project pointers presented herein can be used as benchmark values to estimate the cost of new projects and to help check new building designs.

INTRODUCTION

Structural masonry buildings are found in every part of the world. In fact, this type of building is known to be one of the earliest forms of human construction, and low-rise buildings of up to twelve floors are common worldwide. The choice for this type of structure appears to be on the decline in many parts of the world, including Europe and North America. However, low-rise structural masonry buildings have become increasingly popular in Brazil since the 1990s pursuant to a research program conducted by several Brazilian institutes, which led to the development of a national technique and technology. This technology soon transformed the local building industry to a point where structural masonry frequently replaces the once common reinforced concrete structures in low-rise middle class buildings. Relatively lower labor costs, the absence of earthquake loads and the presence of only moderate wind loads contribute to the effectiveness of the masonry solution in local construction.

a) Twelve-floor residential condominium on a reinforced concrete transition floor at ground level typically used as a garage

b) Four-floor residential condominium with apartments at ground level

c) Single-family two-floor townhouses (ABCP, 2002)

Figure 1 – Examples of local structural masonry buildings

Today, masonry is a common solution for single-family or multiple-floor residential buildings (Figure 1). The single family building is usually a two-storied detached house or townhouse made of hollow concrete or clay blocks. The foundation, usually made of concrete floor beams supported by foundation piles or concrete footing or sometimes slab-on-grade foundation, is built at ground level (basements are rare in local construction) and the masonry structure starts from there. Multiple-floor buildings usually have four apartments per floor. The very common four-floor building has apartments at ground level, where the masonry structure starts upon a concrete pile and beam grid foundation. Taller buildings are usually made of concrete blocks, with the ground level sometimes consisting of a reinforced concrete (RC) structure which serves as a garage. In this case, the RC structure must be able to support all the structural masonry floors above it, often involving seven to twelve floors and sometimes even twenty or more floors. This RC structure is called a transition floor.

The masonry is typically a 140-mm thick single-width wall with plaster rendering. This rendering usually 25-mm thick cement-lime stucco for the exterior façade and 5 to 15-mm thick cement-lime or gypsum plaster rendering for the interior walls. Reinforced concrete slabs and unreinforced masonry are the norm. Constructive horizontal reinforcement and grouting using beam blocks at mid-height and below the RC slab for external walls and below the RC slab only for internal walls are common (Figure 2). Vertical reinforcement and grouting are the norm at masonry corners and ends. Vertical reinforcement is usually increased at wall ends in taller buildings because the masonry is designed as shear walls to resist lateral wind loads.

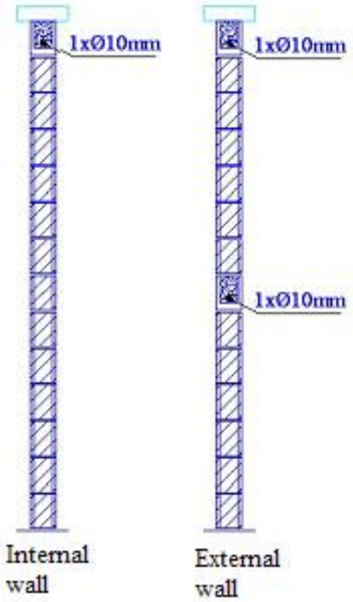

Figure 2 – Typical horizontal reinforcement

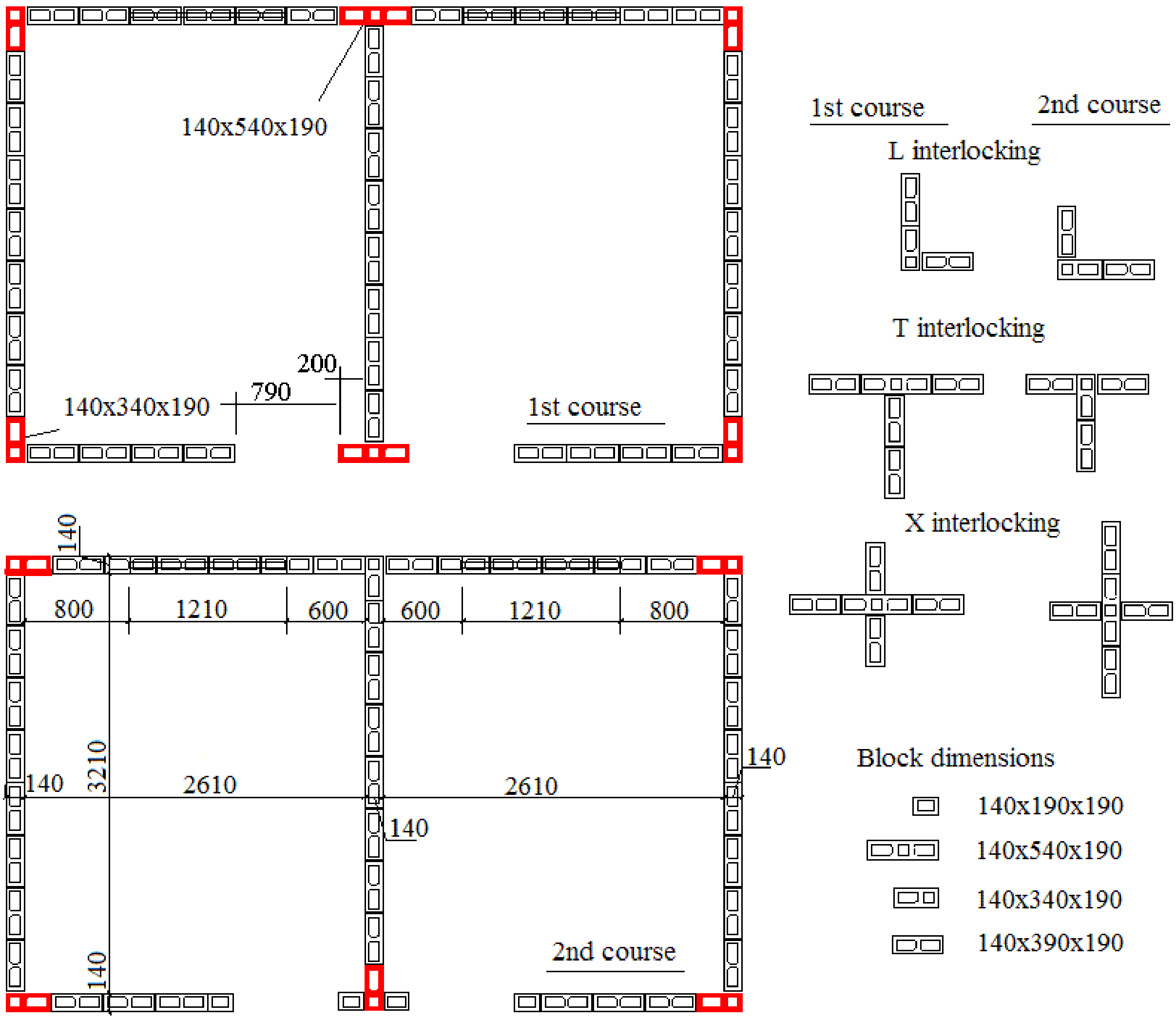

Figure 3 – The 40-family (types of dimensional blocks)

Because of their dimensions, two-family blocks are common. The 40-family block consists of standard 140x390 mm (width by length) blocks, 140x140 mm half-blocks and 140x340 mm special blocks applied in corners or L-interlocking, and 140x540 mm blocks used for T or X interlocking, as illustrated in Figure 3. The name of the family regards the standard block length in the centimeter unit as used in the local construction. This family was developed because local designers strongly recommend that each wall intersection be interlocked by blocks overlaid in alternating courses. This constructive design increases the building's lateral stiffness and provides better distribution of vertical loads. Because the first machines for producing blocks were imported, the 390-mm long block was the first standard unit since that is the standard in other countries where the 190-mm wide block is more common. Subsequently, it was found that a 140x290 mm standard block would facilitate the construction process, because the nominal length of the block is twice its width, allowing for direct corner interlocking using only the standard block. The 140x140 mm half-block and the 140x440 mm block for T and X interlocking complete the so-called 30-family. In both "families", beam blocks are available and the standard block height is 190 mm. Figure 3 and Figure 4 give dimensional details of each family of blocks.

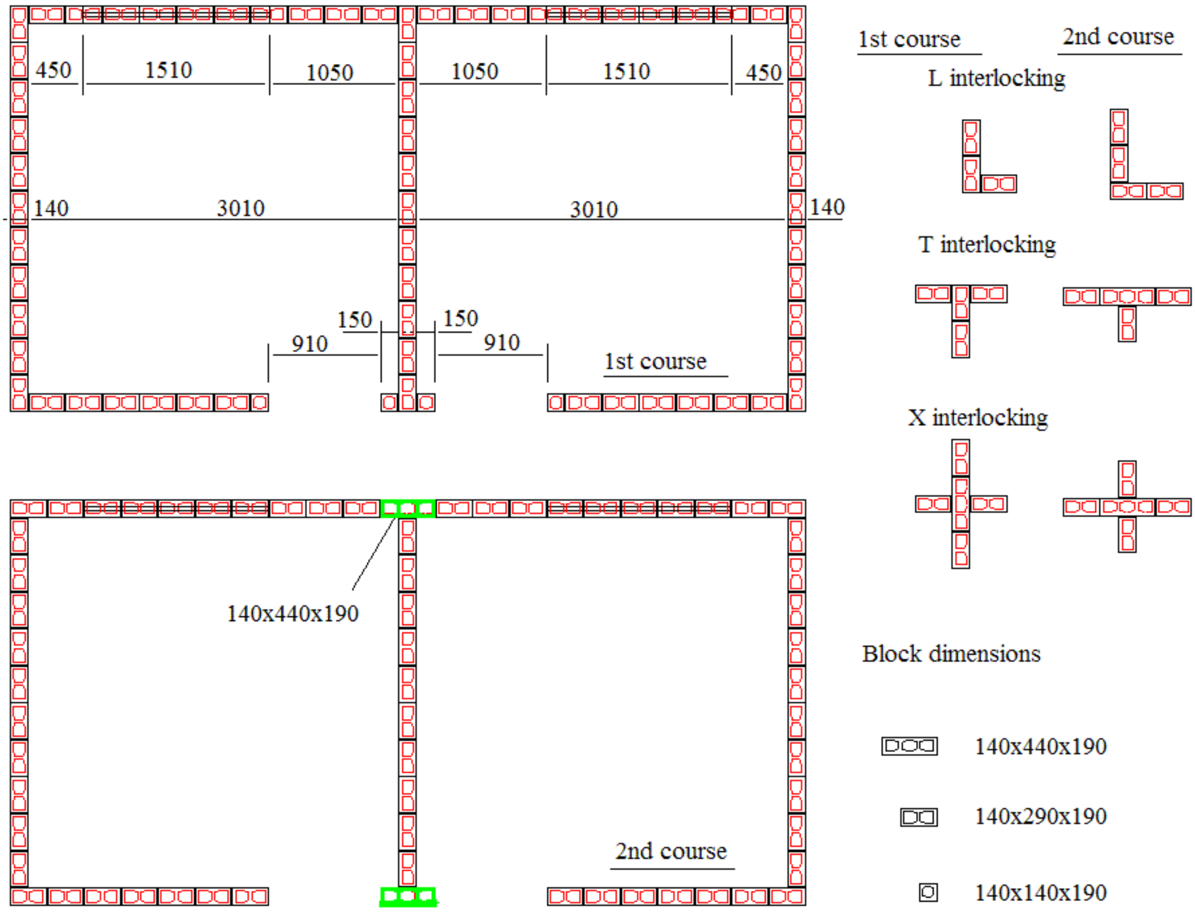

Figure 4 – The 30-family (types of dimensional blocks)

The purpose of the work reported here was to check several structural masonry designs to assess material consumption and specification data. Project pointers were calculated and specifications analyzed. Average values were identified and are reported based on these data. These benchmark values are very useful for estimating the cost of new projects and for

checking design results.

RESEARCH METHODOLOGY

Three structural design firms were invited to participate in the research. The firms, hereinafter referred to as A, B and C, supplied full sets of the structural designs of masonry buildings. Each design project was grouped according to the following classification:

· Two-floor buildings – "30-family" and "40-family" blocks
· 3, 4 and 5 floors – ground level with structural masonry apartments – "30-family" and "40-family" blocks
· 7, 8 and 9 floors – ground level with structural masonry apartments – "30-family" and "40-family" blocks
· 10, 11 and 12 floors – ground level with structural masonry apartments – "30-family" and "40-family" blocks
· More than 12 floors – ground level with structural masonry apartments – "30-family" and "40-family" blocks.
· 7, 8 and 9 floors with a RC transition floor at the ground level – "30-family" and "40-family" blocks.
· 10, 11 and 12 floors with a RC transition floor at ground level – "30-family" and "40-family" block.
· More than 12 floors with a RC transition floor at ground level – "30-family" block only.

Nine buildings of each of these eight groups were analyzed, three by each firm, except for the "30-family" cases, where six buildings were assessed because only two firms provided examples. Firm B did not specify this block family. A total of 120 sets of designs were analyzed. All the designs specified the use of hollow concrete blocks.

The following project pointers were calculated for each example:

· **Total load per pile** (kN/un) – the total unfactored vertical load divided by the number of foundation piles;
· **Load rate per building area** (kN/m^2) – the total unfactored vertical load divided by the building total area (area of all floors);
· **Pile range area** (m^2/un) – building footprint area divided by the number of foundation piles;
· **Ratio of steel reinforcement to volume of concrete in the columns, beams and slabs of the transition floor** (kg/m^3) – total weight of steel reinforcement divided by total volume of concrete;
· **Ratio of formwork to slab area for the columns, beams and slabs of the transition floor** (m^2/m^2) – formwork area divided by slab area;
· **Average thickness of the columns, beams and slabs of the transition floor** (m^3/m^2) – volume of concrete divided by the slab area;
· **Ratio of steel reinforcement to slab area for the masonry** (kg/ m^2) – total weight of steel reinforcement in the structural masonry divided by the slab area;
· **Ratio of structural masonry to slab area** (m^2/ m^2) – ratio of masonry area to slab area;
· **Ratio of horizontal and vertical grout volume to slab area** (m^3/m^2) – ratio of grout volume to slab area;
· **Ratio of standard block to slab area** (un/m^2) – number of standard blocks per floor divided by the slab area;

· **Percent ratio of half-block, beam-block and special-block to standard-block** (%) – number of each type of block divided by the number of standard blocks.

The specified compression strength of the mortar, block and prism for each slab was also analyzed.

RESULTS AND DISCUSSION

Table 1 indicates the calculated project pointers divided into different groups: all the designs, only the 30- or 40-families, firm A, B or C, and each of the building groups described earlier.

Foundation

An analysis of the **load rate per building area** reveals an average of 11.7 kN/m^2, considering the 120 designs, with a small coefficient of variation of 9%. The results of the individual firms also show very similar averages, indicating that they are representative. The **total load per pile** varies from a minimum of 36 to 840 kN, but when this value is divided by the number of floors, as indicated in Table 1, one can see a linear tendency for 55 kN/pile/floor. The **pile range area** pointer indicates that one pile is specified at approximately 3.9 m^2.

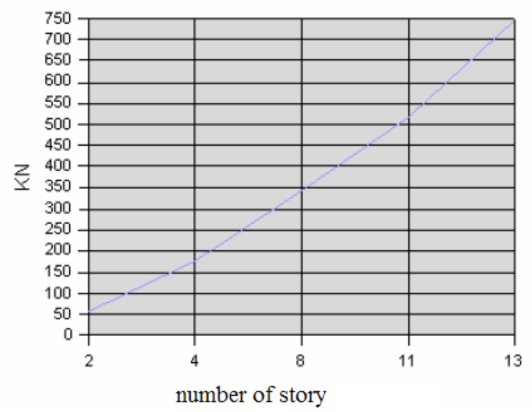

Figure 5 – Average load per pile versus number of floors

Transition floor

With regard to the **ratio of steel reinforcement to volume of concrete** of the transition floor, the columns, beams and slabs show average values of 360, 140 and 75 kg/m^3, respectively, while the floor shows an overall value of 154 kg/m^3. The coefficient of variation (COV) of the 45 designs with transition floors is lower than 10%. The **ratio of formwork to slab area** for columns ranged from 0.3 to 0.8 m^2/m^2, with an average value of 0.5 m^2/m^2. In the case of beams, this ratio ranged from 0.7 to 1.7, with an average of 1.1 m^2/m^2. In both cases, the COV was close to 22%. The **average thickness of the columns, beams and slabs** was 40, 110 and 80 mm (m^3/m^2 x 1000), respectively. An overall value of 230 mm thickness was found for the whole floor considering all the designs, but a slightly higher value of 250 mm was calculated for buildings with more than 13 floors. The COV in this case was lower than 10%.

Table 1 – Calculated project pointer for each group

		All projects					Designer A					Designer B					Designer C					30-Family Block					40-Family Block				
	Project Pointer	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n
1	Total load per pile	402	839	36	60%	91	335	836	36	71%	31	472	839	52	52%	22	417	745	39	57%	38	379	774	36	62%	34	416	839	45	60%	57
2	Load rate per building area (area of all floors)	11.7	15.0	10.0	9%	116	11.5	14.4	10.0	8%	47	11.7	13.8	10.1	9%	23	11.8	15.0	10.0	9%	46	11.6	14.5	10.0	9%	47	11.7	15.0	10.0	8%	69
3	Pile range area (building footprint area)	3.9	5.6	1.6	24%	91	3.6	5.3	1.6	28%	31	4.2	5.6	2.3	18%	22	4.1	5.5	2.0	22%	38	4.0	5.4	1.6	25%	34	3.9	5.6	1.9	23%	57
4	Steel reinforcement by concrete volume - columns of transition floor	360	629	218	30%	42	391	629	218	33%	17	336	442	264	16%	8	340	531	220	30%	17	390	629	236	30%	18	338	541	218	28%	24
5	Steel reinforcement by concrete volume - beams of transition floor	140	350	59	47%	42	145	350	59	50%	17	133	173	105	19%	8	139	345	61	52%	17	159	350	59	58%	18	127	214	83	23%	24
6	Steel reinforcement by concrete volume - slabs of transition floor	75	131	36	35%	42	78	123	36	36%	17	68	104	36	33%	8	75	131	41	36%	17	81	121	36	30%	18	70	131	36	39%	24
7	Steel reinforcement by concrete volume - transition floor	154	232	105	23%	42	160	232	106	26%	17	140	163	123	12%	8	155	227	105	22%	17	175	232	123	19%	18	138	232	105	20%	24
8	Formwork by floor area ratio - columns of transition floor	0.5	0.8	0.3	23%	45	0.5	0.7	0.3	24%	18	0.5	0.7	0.4	20%	9	0.6	0.8	0.4	19%	18	0.6	0.8	0.4	22%	18	0.5	0.7	0.3	22%	27
9	Formwork by floor area ratio - beans of transition floor	1.1	1.7	0.7	22%	45	1.1	1.6	0.7	25%	18	1.2	1.7	0.8	23%	9	1.1	1.4	0.7	20%	18	1.1	1.6	0.7	25%	18	1.1	1.7	0.7	21%	27
10	Formwork by floor area ratio - slabs of transition floor	1.0	1.1	0.4	12%	45	0.9	1.1	0.4	16%	18	1.0	1.1	0.9	8%	9	1.0	1.1	0.8	8%	18	1.0	1.1	0.8	10%	18	1.0	1.1	0.4	13%	27
11	Average thickness - columns of transition floor	0.04	0.09	0.02	35%	45	0.04	0.05	0.02	28%	18	0.04	0.05	0.02	30%	9	0.04	0.09	0.02	40%	18	0.04	0.09	0.03	33%	18	0.04	0.08	0.02	36%	27
12	Average thickness - beams of transition floor	0.11	0.17	0.06	24%	45	0.11	0.17	0.06	29%	18	0.12	0.16	0.09	22%	9	0.10	0.14	0.06	18%	18	0.11	0.17	0.06	30%	18	0.11	0.16	0.06	20%	27
13	Average thickness - slabs of transition floor	0.08	0.11	0.03	18%	45	0.08	0.10	0.03	19%	18	0.09	0.10	0.05	20%	9	0.08	0.11	0.05	18%	18	0.08	0.10	0.07	12%	18	0.08	0.11	0.03	22%	27
14	Average thickness - transition floor	0.23	0.32	0.12	19%	45	0.23	0.32	0.12	22%	18	0.24	0.30	0.16	19%	9	0.23	0.31	0.17	16%	18	0.23	0.32	0.16	18%	18	0.23	0.31	0.12	19%	27
15	Steel reinforcement by floor area ratio for the masonry	1.4	3.0	0.2	36%	120	1.4	3.0	0.4	40%	48	1.4	2.1	0.2	38%	24	1.5	3.0	0.6	31%	48	1.5	3.0	0.4	41%	48	1.4	2.1	0.2	32%	72
16	Structural masonry area by floor area ratio	1.9	3.7	1.0	21%	120	1.9	3.3	1.0	20%	48	2.0	3.7	1.5	26%	24	1.9	3.1	1.0	20%	48	1.9	3.3	1.0	22%	48	1.9	3.7	1.0	21%	72
17	Horizontal grout volume by floor area ratio	0.019	0.058	0.009	42%	120	0.020	0.058	0.009	45%	48	0.019	0.035	0.010	30%	24	0.019	0.050	0.009	43%	48	0.020	0.058	0.009	51%	48	0.019	0.048	0.009	34%	72
18	Vertical grout volume by floor area ratio	0.013	0.059	0.003	66%	120	0.014	0.059	0.003	78%	48	0.011	0.024	0.006	41%	24	0.012	0.039	0.005	57%	48	0.012	0.049	0.003	80%	48	0.013	0.059	0.005	58%	72
19	Standard block by floor area ratio	20.3	44.4	11.0	27%	120	20.6	31.1	11.0	26%	48	18.3	27.1	11.2	21%	24	21.1	44.4	11.2	30%	48	24.4	44.4	17.2	21%	48	17.6	27.1	11.0	23%	72
20	Percent ratio of half-block by standard-block	9	21	2	42%	120	10	21	3	40%	48	9	20	2	50%	24	8	20	2	36%	48	8	13	3	30%	48	10	21	2	47%	72
21	Percent ratio of special-block by standard-block	16	47	1	82%	120	14	46	1	97%	48	22	43	11	41%	24	14	47	1	90%	48	3	9	1	52%	48	25	47	7	39%	72
22	Percent ratio of beam-block by standard-block	14	26	5	34%	120	14	25	6	36%	48	15	26	8	28%	24	13	24	5	33%	48	13	24	6	36%	48	15	26	5	32%	72

	Two-story					3,4,5 story					7,8,9 story - no transition					7,8,9 story - with transition					10,11,12 story - no transition					10,11,12 story - with transition					> 13 story - no transition					> 13 story - with transition				
	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n	Avg.	Max	Min	COV (%)	n
1	60	142	36	45%	15	178	242	122	19%	15	344	488	239	19%	14	521	712	349	18%	12	518	658	370	17%	9	597	745	288	23%	10	745	839	582	12%	10	649	709	515	11%	6
2	11.6	13.6	10.0	9%	15	11.7	15.0	10.4	10%	15	12.5	14.5	10.3	11%	14	11.9	12.8	11.3	5%	12	11.2	12.9	10.0	7%	15	11.7	12.9	10.1	8%	15	11.7	12.6	10.5	4%	15	11.2	12.8	10.1	8%	15
3	2.9	5.6	1.6	36%	15	3.8	5.1	1.9	24%	15	3.4	4.2	2.6	12%	14	4.6	5.4	3.8	11%	12	3.9	4.6	3.0	13%	9	4.6	5.5	3.5	15%	10	4.7	5.3	3.7	10%	10	4.3	5.0	3.7	12%	6
4	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	299	541	220	33%	15	N/A	N/A	N/A	N/A	0	454	629	303	22%	12	N/A	N/A	N/A	N/A	0	346	442	218	19%	15
5	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	195	350	121	39%	15	N/A	N/A	N/A	N/A	0	115	184	59	33%	12	N/A	N/A	N/A	N/A	0	105	171	63	22%	15
6	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	68	123	42	30%	15	N/A	N/A	N/A	N/A	0	101	131	72	16%	12	N/A	N/A	N/A	N/A	0	61	99	36	38%	15
7	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	160	232	105	28%	15	N/A	N/A	N/A	N/A	0	171	232	111	19%	12	N/A	N/A	N/A	N/A	0	135	169	122	10%	15
8	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	0.5	0.7	0.4	19%	15	N/A	N/A	N/A	N/A	0	0.5	0.7	0.3	24%	15	N/A	N/A	N/A	N/A	0	0.6	0.8	0.4	23%	15
9	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	1.2	1.5	0.7	18%	15	N/A	N/A	N/A	N/A	0	1.0	1.6	0.7	24%	15	N/A	N/A	N/A	N/A	0	1.2	1.7	0.7	22%	15
10	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	1.0	1.1	1.0	3%	15	N/A	N/A	N/A	N/A	0	0.9	1.0	0.4	16%	15	N/A	N/A	N/A	N/A	0	0.9	1.0	0.8	9%	15
11	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	0.04	0.04	0.02	21%	15	N/A	N/A	N/A	N/A	0	0.03	0.05	0.02	32%	15	N/A	N/A	N/A	N/A	0	0.05	0.09	0.03	38%	15
12	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	0.11	0.13	0.08	13%	15	N/A	N/A	N/A	N/A	0	0.10	0.14	0.06	20%	15	N/A	N/A	N/A	N/A	0	0.12	0.17	0.06	29%	15
13	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	0.09	0.11	0.07	12%	15	N/A	N/A	N/A	N/A	0	0.07	0.09	0.03	21%	15	N/A	N/A	N/A	N/A	0	0.08	0.10	0.07	16%	15
14	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	0	0.23	0.26	0.19	10%	15	N/A	N/A	N/A	N/A	0	0.20	0.25	0.12	18%	15	N/A	N/A	N/A	N/A	0	0.25	0.32	0.16	20%	15
15	1.0	3.0	0.2	88%	15	1.4	2.1	0.7	32%	15	1.9	2.7	1.0	26%	15	1.1	1.4	0.7	17%	15	1.7	2.2	1.4	14%	15	1.6	3.0	1.1	29%	15	1.4	1.7	1.1	14%	15	1.5	2.1	1.1	15%	15
16	2.3	3.7	1.5	28%	15	2.1	3.3	1.4	23%	15	2.0	3.1	1.4	23%	15	1.9	2.3	1.3	13%	15	1.8	2.5	1.5	16%	15	1.8	2.1	1.5	10%	15	1.7	2.2	1.0	21%	15	1.8	2.2	1.2	13%	15
17	0.036	0.058	0.022	31%	15	0.020	0.025	0.014	17%	15	0.017	0.026	0.011	26%	15	0.017	0.022	0.013	13%	15	0.016	0.022	0.010	20%	15	0.017	0.020	0.015	10%	15	0.016	0.021	0.009	23%	15	0.017	0.020	0.010	14%	15
18	0.028	0.059	0.012	49%	15	0.013	0.017	0.010	16%	15	0.013	0.024	0.003	48%	15	0.009	0.013	0.006	24%	15	0.008	0.017	0.005	37%	15	0.009	0.015	0.003	36%	15	0.009	0.012	0.005	21%	15	0.010	0.017	0.007	29%	15
19	19.6	44.4	11.2	49%	15	17.9	31.1	11.0	29%	15	18.3	27.2	12.9	30%	15	25.9	30.6	14.1	19%	15	21.0	25.4	13.5	19%	15	20.6	25.1	14.1	17%	15	19.9	24.1	13.8	13%	15	19.2	24.1	11.2	16%	15
20	9	16	3	43%	15	10	21	6	39%	15	13	20	6	45%	15	8	15	6	29%	15	8	12	4	33%	15	10	15	5	26%	15	9	15	6	28%	15	6	13	2	58%	15
21	14	24	1	74%	15	15	31	1	71%	15	24	46	2	79%	15	17	36	1	80%	15	15	38	1	89%	15	18	47	2	79%	15	14	38	4	68%	15	11	34	2	78%	15
22	14	20	13	18%	15	18	24	9	25%	15	15	25	5	38%	15	9	18	6	41%	15	12	26	8	45%	15	13	17	9	17%	15	14	20	7	28%	15	15	17	9	16%	15

Quantity of masonry, grout and reinforcement

The average **ratio of structural masonry to slab area** was calculated as 1.9 m^2/m^2 (COV = 21%), with an average **ratio of steel reinforcement weight to slab area** of 1.4 kg/m^2 (COV = 36%). With regard to **grout volume**, the average consumption was found to be 35 litres per m^2 of slab area, with a slightly higher consumption of horizontal than vertical grout. An analysis of the different values calculated for each group indicates that the use of grout in two-floor buildings is higher than the overall average, i.e., approximately 64 litres/m^2.

Number of blocks

In the 30-family case, the average number of blocks per square meter of slab was found to be 24 units/m^2 while the 40-family case showed 18 un/m^2. The number of half-blocks and beam-blocks is usually close to 10% and 15% of the number of standard blocks.

Compressive strength

Table 2 summarizes the specifications according to the specified block strength. It should be noted that the prism and block strength in this text correspond to the gross area, which is the standard practice in Brazil. Since the net area of the block is approximately 50% of the gross area, the net area compressive strength is approximately double that of the values reported here. With regard to the grout's compressive strength, designers specify this value as double that of the block strength (the gross/net area ratio). The minimum mortar strength is specified as 5.0 MPa and the ratio of prism to block compressive strength is commonly assumed to be 0.8 for concrete blocks.

Table 2 – Compressive strength

		block (fb)				
		4.5	**6.0**	**8.0**	**10.0**	**12.0**
mortar	**mean (MPa)**	5.0	5.0	5.0	5.0	5.0
	average (MPa)	4.9	4.9	5.1	5.2	5.0
	SD (MPa)	0.4	0.3	0.4	0.5	0.0
	n	317	215	104	61	56
	max	5.0	6.0	6.0	8.0	5.0
	min	3.0	3.5	4.0	5.0	5.0
	average/fb	1.1	0.8	0.6	0.5	0.4
grout	**mean (MPa)**	9.0	12.0	16.0	20.0	24.0
	average (MPa)	9.5	12.4	15.8	19.6	24.3
	SD (MPa)	1.5	1.0	0.4	1.7	1.5
	n	317	215	104	61	56
	max	15.0	15.0	16.0	20.0	30.0
	min	9.0	12.0	15.0	12.0	20.0
	average/fb	2.1	2.1	2.0	2.0	2.0
prism	**mean (MPa)**	3.6	4.8	6.4	8.0	9.6
	average (MPa)	3.6	4.5	6.4	7.9	9.6
	SD (MPa)	0.1	0.6	0.0	0.5	0.1
	n	124	91	64	48	15
	max	3.6	4.8	6.4	8.0	10.0
	min	3.0	3.0	6.4	6.0	9.6
	average/fb	0.8	0.8	0.8	0.8	0.8

Table 3 and Figure 6 indicate the specified block compressive strength according to the number of floors supported by the masonry. There is a clearly visible linear ratio of 1.0 MPa per floor, limited to a minimum value of 4.5 MPa (minimum value specified by the Brazilian ABNT NBR 10837 standard) and to a maximum value of 12.0 MPa. Although blocks of greater strength are available in the local market, this maximum value is probably imposed by the contractor, who does not want to limit the number of supplies since higher strength blocks may not always be in stock. This option certainly leads to the need for vertical wall grouting.

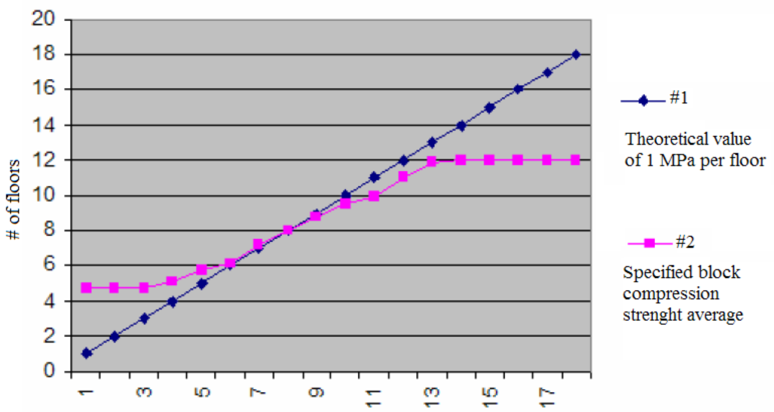

Figure 6 – Block compressive strength (gross area) vs. number of floors

Table 3 – Block compressive strength

		number of floor above and including the same level																	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
block	**mean (MPa)**	4.5	4.5	4.5	4.5	6.0	6.0	6.0	8.0	8.0	10.0	10.0	12.0	12.0	12.0	12.0	n/a	n/a	n/a
	average (MPa)	4.7	4.7	4.7	5.1	5.7	6.1	7.2	8.0	8.8	9.5	9.9	11.0	11.9	12.0	12.0	12.0	12.0	12.0
	SD (MPa)	0.6	0.6	0.6	0.8	0.7	0.8	1.2	1.1	1.2	1.2	1.2	1.2	0.5	0.0	0.0	n/a	n/a	n/a
	n	99	99	84	80	74	69	69	65	52	45	37	26	15	8	3	1	1	1
	max	8.0	8.0	8.0	8.0	8.0	10.0	10.0	10.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	min	4.0	4.0	4.0	4.0	4.5	4.5	6.0	6.0	6.0	8.0	8.0	9.0	10.0	12.0	12.0	12.0	12.0	12.0
	average/#pav.	4.7	2.3	1.6	1.3	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.7	0.7

CONCLUSIONS

Based on the analysis of 120 construction designs, several project pointers are presented which can be used as benchmark values to estimate the cost of new designs and as an aid in checking the designs of new buildings.

ACKNOWLEDGMENTS

The MSc fellowship from the CAPES (Coordination for the Improvement of Higher Education Personnel Agency, Ministry of Education of Brazil) is much appreciated.

REFERENCES

ABCP – Associação Brasileira de Cimento Portland (Brazilian Association of Portland Cement). Structural Masonry Course Notes. 2002, CD-ROM.

ABNT – Associação Brasileira de Normas Técnicas (Brazilian Association of Technical Standards). Cálculo de alvenaria estrutural de blocos vazados de concreto: NBR 10837. Rio de Janeiro: ABNT, 1989.