Valuation of the Durability of the Concrete Used in the Precast Great Soviet Panel System

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Abstract

The durability of the concrete of the precast Great Soviet Panel system is valued through the resistance to compression, ultrasonic pulse velocity, surface methods, humidity and potential of corrosion. The evaluation is approached, essentially, through experimental and statistical methods, nevertheless, historical-logical and technical methods, such as surveys and interviews, are used in order to gather a bigger amount of information on the resistance to compression of the elements in the original project. While analyzing the results, we can conclude that, in elements in a good technical-constructive state that conform the constructions in exploitation, concrete has an average resistance. However, in elements with the presence of pathological damages, the resistance is low due to the fact that elements show chemical deterioration processes caused by water exposure, which generates the formation of soluble paste compounds, loss of mass, and decrease in mechanical resistance, among other alterations. At the same time, carbonation of concrete is

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triggered, which, in turn, causes the corrosion of the reinforcing steel. This corrosion leads to the cracking of concrete, delamination of steel, decrease of the concrete-steel adhesion, and other manifestations that affect the durability of concrete. Therefore, the incidence of the durability of concrete should be valued in the structural seismic behavior of constructions.

Keywords: compression resistance; concrete system; humidity percentage; potential of corrosion; surface methods; ultrasonic pulse velocity.

Valoración de la durabilidad del hormigón prefabricado utilizado en el sistema gran panel soviético

Resumen

Se valora la durabilidad del hormigón del sistema prefabricado Gran Panel Soviético, a través de la precisión de la resistencia a compresión, la velocidad del pulso ultrasónico y el índice esclerométrico. Igualmente, se determinan otros parámetros como la humedad y el potencial de corrosión, que también inciden en la durabilidad del hormigón. Se recurre esencialmente a métodos experimentales y estadísticos, no obstante, se emplean métodos como el histórico-lógico y técnicas como las encuestas y entrevistas, para recopilar mayor cantidad de información sobre la resistencia a compresión de los elementos prefabricados en el proyecto original. Al analizar los resultados se concluye que, en los elementos en buen estado técnico-constructivo, que conforman las edificaciones en explotación, el hormigón es de resistencia media al igual que lo prescribe el proyecto original de este sistema prefabricado. Sin embargo, en los elementos con presencia de daños patológicos la resistencia es baja. Debido a que en estos elementos se evidencian procesos de deterioro químico, causado por el ataque del agua, que generan formación de compuestos solubles de la pasta, la pérdida de masa y la disminución de resistencia mecánica entre otras alteraciones. A la par se desencadena la carbonatación del hormigón, que provoca a su vez la corrosión del acero de refuerzo. Esta corrosión conduce al agrietamiento del hormigón, delaminación del acero, disminución de la adherencia hormigón-acero y demás manifestaciones, que afectan la durabilidad

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del hormigón. Por lo tanto, se debe valorar la incidencia de la durabilidad del hormigón, en el comportamiento sismorresistente de estas edificaciones.

Palabras clave: índice esclerométrico; porcentaje de humedad; potencial de corrosión; resistencia a compresión; sistema prefabricado; velocidad del pulso ultrasónico.

Valoração da durabilidade do concreto pré-fabricado utilizado no sistema grande painel soviético

Resumo

Valora-se a durabilidade do concreto do sistema pré-fabricado Grande Painel Soviético, através da precisão da resistência à compressão, à velocidade do pulso ultrassônico e ao índice esclerométrico. Igualmente, determinam-se outros parâmetros como a humidade e o potencial de corrosão, que também incidem na durabilidade do concreto. Recorre-se essencialmente a métodos experimentais e estatísticos, mesmo assim, empregam-se métodos como o histórico-lógico e técnicas como as enquetes e entrevistas, para recopilar maior quantidade de informação sobre a resistência à compressão dos elementos pré-fabricados no projeto original. Ao analisar os resultados conclui-se que, nos elementos em bom estado técnico-construtivo, que conformam as edificações em exploração, o concreto é de resistência média ao igual que o prescreve o projeto original deste sistema pré-fabricado. Porém, nos elementos com presença de danos patológicos, a resistência é baixa. Devido a que nestes elementos evidenciam-se processos de deterioro químico, causado pelo ataque de água, que geram formação de compostos solúveis da pasta, a perda de massa e a diminuição de resistência mecânica, entre outras alterações. Juntamente, desencadeia-se a carbonatação do concreto, que provoca por sua vez, a corrosão do aço de reforço. Esta corrosão conduz à fissuração do concreto, delaminação do aço, diminuição da aderência concreto-aço e demais manifestações, que afetam a durabilidade do concreto. Portanto, deve-se valorar a incidência da durabilidade do concreto, no comportamento sismorresistente destas edificações.

Palavras chave: índice esclerométrico; porcentagem de humidade; potencial de corrosão; resistência a compressão; sistema pré-fabricado; velocidade do pulso ultrassônico.

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I. INTRODUCTION

The Giprostroy Institute in the former Soviet Union created the I-464 series of buildings in the late 1950s. In reality, this was the Soviet adaptation of the French Camus system, patented in 1949 to industrially precast large-format concrete panels. Its use became massive, not only in many former Soviet republics, but in other countries in Europe, as well as in Chile and Cuba.

In Cuba, the implementation of this prefabricated system, under the name of the Great Soviet Panel (GPS), was exclusive in the Santiago de Cuba province; also, some buildings were experimentally constructed in Pilón, Granma province. In the Santiago de Cuba province, between 1964 and 1991, 769 GPS buildings were built, 665 of them were concentrated in the municipality of the same name. These buildings are developed vertically, with four to five levels, and they are characterized by being symmetrical in length and elevation. The architectural plan shows a structure with one to six staircases, but contemplates expansion joints at almost every two staircases; that is, every 32 meters long. Also, there are buildings with and without a balcony, as shown in Figure 1.

Fig. 1. Buildings built with GPS, with balcony (left), without balcony (right).

All the structural elements of the GPS system are industrially precast. In the catalog, the exterior panels are designated by the letter E and the interiors by letters I, S, and T. The letter P is used to designate the precast slabs.

The precast GPS system, due to its structural conception and joint types between its structural elements, has shown adequate behavior in the face of earthquakes of

great intensity, which have occurred in Chile (1985, 2010 and 2012), as well as in Armenia (former Soviet Republic) in 1988. However, the community of specialists in the province of Santiago de Cuba has shown concern for these buildings for some time now, due to the pathological damage present in structural elements and joints, as well as to the changes suffered in weight and stiffness.

Díaz [1] carried out one of the first related investigations, where he identified the presence of chloride, sulfate and carbonation ions in the panels of a kitchen, bathroom and living room, as well as in the mezzanine and in covering slabs. The conclusion is that these buildings show a high deterioration. Other researchers such as Morejón et al. [2] focused their objective on evaluating the seismic vulnerability of buildings, stating that they resist a high-intensity earthquake. However, in their analysis, they did not consider the increases in weight and the changes in stiffness present in these buildings, both due to the placement of water tanks, the addition of masonry walls, filling of the lattices, opening or removal of panels and slabs, among others.

With the intention of carrying out more in-depth studies, the present research focuses on evaluating the durability of the concrete used in the prefabricated Great Soviet Panel system, to later on see its possible impact on the seismic-resistant behavior of buildings made with said system. Compressive strength, ultrasonic pulse rate and sclerometric index will be specified, as well as other parameters such as humidity and corrosion potential, which affect the durability of the concrete. Essentially, experimental and statistical methods are used, however, historical-logical methods and techniques, such as surveys and interviews, are used to collect more information on the compressive strength of structural elements in the original project.

II. MATERIALS AND METHODS

An experimental program was carried out to determine the quality and properties of the concrete of the precast GPS system, under the current exploitation conditions and the ones in the original project. Destructive and non-destructive tests are carried out on precast elements located in the warehouse area of the "Gran Panel Santiago"

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Precast Plant. Non-destructive tests are also applied on precast elements that conform buildings in use. The number of elements to be tested and the necessary controls were defined in correspondence with regulations [3-5]. The equipment, standards and evaluation criteria that were considered in each of the tests carried out are detailed below.

A. Destructive Test to Determine the Compressive Strength According to the Conditions of the Original Project

For the determination of the compressive strength of the concrete, cores were extracted from 7 precast elements of the Great Soviet Panel system, which still exists in the warehouse area of the "Gran Panel Santiago" Precast Plant. All elements have production date July 18, 1991 and were classified as compliant at the time of production. To extract the cores (3 cores per element, for a total of 21), the HILTI 00-130 equipment was used with a 4.5 cm diameter cutting auger; the requirements of the regulations were considered [6].

The compressive strength test was performed according to the standard [7]. The specimens were not submerged in water, since the concrete has been in production for more than 30 years.

B. Non-destructive Tests with Ultrasound and Sclerometer

These tests were carried out to confirm:

- Compressive strength according to the conditions of the original project
- Compressive strength under current operating conditions with elements in good condition
- Compressive strength under current operating conditions with elements with presence of pathological damage

The same elements from which control samples were taken, elements found in the precast plant, as well as elements that conform buildings in operation (Building E-16; E-18 and Building U-142; U-143) were tested. In total, the test included 22 elements with the presence of pathological damage with severe involvement levels, as well as 11 in good technical-constructive condition.

To measure the speed of the ultrasonic pulse, the steel bars were located first, since the wave propagation speed is twice as high in these as in concrete. Then measurements were made close to the bars, parallel to the propagation direction. A total of four measurements of the ultrasonic pulse were made in each element analyzed with the Pundit Lab equipment. The quality of concrete was classified according to the specifications established in Table 1.

Table 1. Qualitative evaluation of concrete according to the speed of the ultrasonic pulse [8].

Pulse Speed (m/s)	Concrete Condition
Over 3660	Good
From 2135 to 3660	Regular
Less than 2135	Poor

For sclerometer, the N-type Schmidt hammer was used, and the test was carried out according to standards [9-10]. A total of 15 impacts were made on each element tested and the qualitative evaluation of concrete was made according to the specifications established in Table 2.

Table 2. Qualitative evaluation of concrete according to the Sclerometric Index [10].

Sclerometric Index (IE)	Concrete quality
Values> 40	Good
30 to 40	Average
20 to 29	Poor
Values < 20	Cracks and delamination

C. Non-destructive Tests with Humidimeter and Corrosimeter

These tests were used to determine the percentage of humidity and the corrosion potential in elements with pathological damage. To evaluate the humidity percentage, 10 elements with the presence of humidity were chosen after a visual inspection, these elements are part of buildings in operation. The measurements on the panels were made at 50 cm from the floor level (in the center) and at 50 cm below the slab, in order to also define whether the humidity is rising or falling. In the case of the slabs, a 15 x 15 cm grid was made, measurements were done in areas where there were moisture stains. The HMT600 Humidimeter was used.

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The ranges of the percentage of humidity in relation to its incidence on corrosion have been established based on the percentage of relative humidity in Cuba. According to Tejera and Álvarez [11], in order to accelerate corrosion, it is necessary, together with a sufficient supply of oxygen, for the humidity of the element to be at least 50% of the relative humidity. Considering that the average annual relative humidity in Cuba is 78%, Table 3 establishes the ranges of the percentage of humidity in relation to its incidence on corrosion.

Table 3. Incidence of the percentage of humidity in the corrosion.

Moisture percentage	Incidence on corrosion
Up to 39%	Minimum
Greater than 39%	Maximum

The measurement of the corrosion potential was carried out in elements in which exposed steels were observed; the Canin corrosimeter was used. 15 x 15 cm grids were made in the area prepared for carrying out the test, in an aim to cover most of it. At the beginning of the measurements, a ground cable connected to the exposed steel reinforcement was placed, and factors that influence the results such as humidity, temperature, thickness of the concrete cover and the oxygen content in the reinforcement, were considered. Typical orders of magnitudes for evaluating the state of corrosion of the steel surface within concrete are shown as intervals in Table 4.

Table 4. Classification of concrete according to the corrosion potential- Typical magnitudes of the measurements [12].

Water-saturated concrete without 0_2	from -1 000 to -900 mV
Chloride-contaminated wet concrete	from -600 to -400 mV
Chloride-free wet concrete	from -200 to +100 mV
Carbonated wet concrete	from -400 to +100 mV
Carbonated dry concrete	from 0 to +200 mV
Non-carbonate dry concrete	from 0 to +200 mV

III. RESULTS

Table 5 shows the results of the destructive and non-destructive tests on the elements of the "Gran Panel Santiago" Precast Plant. On the other hand, tables 6 to

8 show the results of non-destructive tests on the elements that conform buildings in operation. Some of the elements tested were from buildings in operation that are in good condition (11), while others (22) present pathological damage such as humidity, corrosion and/or concrete disintegration mechanisms.

A. Destructive and Non-destructive Tests on Elements of the Precast Plant

The values of the compressive strength of the series of specimens extracted from the elements are presented below, as well as the measured values of the sclerometric index (IE) and the speed of the ultrasonic pulse (V) in these elements.

Table 5. Results of the tests on the elements of the precast plant.

Elements	f´cs (MPa)	Sclerometry		Ultrasonic pulse speed	
		IEs	Concrete quality	Vs (m/s)	Concrete quality
E-1	19.00	33	Average	2300	Regular
I-10	16.83	32	Average	2500	Regular
E-9	18.33	34	Average	2800	Regular
E-12	7.66	20	Poor	500	Poor
E-2	17.00	33	Average	2500	Regular
P-7	19.43	35	Average	2900	Regular
P-4	21.00	38	Average	3000	Regular

B. Non-destructive Tests on Elements in Good Condition from Buildings in Operation

The results detailed in Table 6 correspond to the values obtained from the IE and V, when testing elements in good condition that are part of buildings in operation.

Table 6. Results of sclerometry and the speed of the ultrasonic pulse in elements in good condition.

Elements	Sclerometry		Ultrasonic pulse speed	
	IEs	Concrete quality	Vs (m/s)	Concrete quality
I-4	34	Average	3000	Regular
I-3	34	Average	3000	Regular
E-12	43	Good	3200	Regular
I-8	34	Average	3000	Regular
I-7	34	Average	3000	Regular
E-1	37	Average	3000	Regular
I-7	34	Average	3000	Regular
T-1	30	Average	3000	Regular
P-4	39	Average	2800	Regular
P-7	39	Average	2900	Regular
P-4	39	Average	2900	Regular

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C. Non-destructive Tests on Elements with Pathological Damage in Buildings in Operation

Tables 7 to 9 show the values obtained for IE, V, percentage of humidity, and corrosion potential, when 22 elements from buildings in operation with the presence of pathological damage were tested.

Table 7. Results of sclerometry and ultrasonic pulse speed in elements damaged.

Elements	Sclerometry		Ultrasonic Pulse Rate	
	IEs	Concrete quality	Vs (m/s)	Concrete quality
I-7	27.40	Poor	1089	Poor
I-2	25.70	Poor	784	Poor
I-5	20.00	Poor	305	Poor
I-4	28.26	Poor	2117	Poor
T-2	30.93	Average	3116	Regular
S-2	30.66	Average	3121	Regular
E-11	24.13	Poor	539	Poor
T-1	20.80	Poor	309	Poor
E-4	26.73	Poor	623	Poor
E-10	26.26	Poor	845	Poor
E-2	25.60	Poor	737	Poor
I-7	28.40	Poor	921	Poor
I-5	23.86	Poor	306	Poor
P-4	32.80	Average	3070	Regular
P-7	33.60	Average	3233	Regular
E-6	29.00	Poor	2130	Poor
T-3	27.00	Poor	2130	Poor
S-2	22.00	Poor	2000	Poor
E-5	28.00	Poor	2200	Poor
E-9	28.00	Poor	2100	Poor

Table 8. Percentage of humidity in damaged elements.

Elements	% humidity at a height of:			Incidence on corrosion
	0.50 m	1.35 m	2.20 m	
S-2	32.4	44.6	52.4	Maximum
I-2	39.4	52.1	54.7	Maximum
I-4	37.5	39.2	47.9	Maximum
T-2	50.1	51.5	52.4	Maximum
T-1	32.4	39.9	53.4	Maximum
I-7	37.6	41.9	50.5	Maximum
E-11	33.4	34.2	45.0	Maximum
	% humidity			
P-7	45.2			Maximum
P-15	57.8			Maximum
P-7	33.2			Minimum

Table 9. Corrosion potential in damaged elements.

Elements	Results intervals (mV)	Observations
E-4	(-341 y -184)	Carbonated wet concrete
I-7	(-324 y -160)	Carbonated wet concrete
E-11	(-362 y -197)	Carbonated wet concrete
P-4	(-380 y -185)	Carbonated wet concrete
S-2	(-325 y -169)	Carbonated wet concrete
T-1	(-379 y -19)	Carbonated wet concrete
E-5	(-154 y 46)	Wet concrete without chloride
I-4	(-301 y -167)	Carbonated wet concrete
P-7	(-167 y 90)	Wet concrete without chloride

IV. DISCUSSION

The results of the destructive and non-destructive tests are analyzed below, and the compressive strength of the precast concrete used in the precast Soviet Grand Panel system is obtained, both under the conditions of the original project and under current operating conditions.

A. Destructive testing on elements of the Precast Plant

From the calculation of the average compressive strength of each series of test piece f´cs, the mean compressive strength of the batch (f'_{cm} = 17.03 MPa) and the standard deviation of the batch (S_L = 4.05 MPa) were obtained. These are evaluated as acceptable in terms of the uniformity of the concrete batch for the plant control according to the standard [13]. Since there is a doubtful value of 7.66 MPa corresponding to the series taken from element E-12, the statistical value t_n is determined, which is compared with h = 1.94 (for a significance level of 5%). Since t_n = 2.31> h, the series is debugged and the mean compressive strength and batch standard deviation are recalculated. The results are f'_{cm} = 18.59 MPa and S_L = 1.43 MPa, which are evaluated as excellent. Considering the Student T percentile with a t value = 1,104, the characteristic resistance is f'_{ck} = 17.01MPa. Therefore, it is a medium strength concrete.

This result is confirmed through documentary analysis and interviews. In documents and plans consulted in the file of Project Company No. 15, on February 1, 2019, it is specified that the precast concrete of the Soviet Great Panel System has a characteristic compressive strength value f'_{ck} = 20 MPa for a 10 x 10 cm cube. The equivalent strength for a cylindrical specimen is 16 MPa. These values were also

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provided by two founding civil engineers of the Great Soviet Panel Precast Plant in Santiago de Cuba [14].

The compressive strength of the precast concrete of the GPS system obtained is adjusted to the manufacturing requirements of the stages of emergence of the precast system (1940s) and implementation in Cuba (1964-1991). In turn, these results are in correspondence with the international trend of those periods. The report [3] shows that in the period of 1920-1949, concrete strengths were achieved in walls of 14.07 MPa and, between 1950-1969, of 17.5 MPa.

B. Sclerometry and Ultrasonic Pulse Speed Tests on Elements of the Precast Plant

It is appreciated that in the 7 types of elements there are coincidences with the qualitative evaluation of both trials. The quality of the concrete is medium to regular in 6 types of elements, and in the series concrete taken from element E-12, poor quality was obtained. But, since this series was rejected in the determination of the compressive strength, it will not be considered in the determination of the characteristic IE (IE_k) either. In other words, the value of 20.00 is rejected because $t_n = 2.30 > h = 1.94$ (for a significance level of 5%). When the values are recalculated, we have: $IE_m = 34.16$ and $SL = 1.95$, so: $IE_k = 32$.

The correlation analysis of the results of the destructive test and sclerometry was performed. Figure 2 shows the regression line and the correlation equation (1) obtained.

$$y = 0.6645\ x - 4.1038 \quad (1)$$

Where "y" is f'_{ck} in MPa and "x" is IE. The trend, since the correlation coefficient is positive ($R = 0.9025$), is to increase the compressive strength of the concrete when the IE increases. Since the coefficient of determination (defined as the square of the linear correlation coefficient) $R^2 = 0.8146$, is in the range between 0 and 1, the estimated line is representative for the data. It can be concluded that the f'_{ck} can be obtained from the IE results. Therefore, equation (1) allows us to determine the compressive strength of the elements that conform the buildings in operation, where the extraction of cores is not possible.
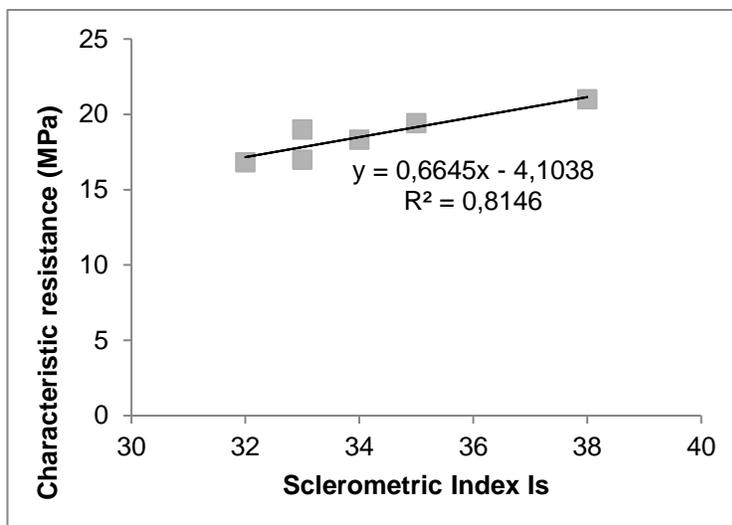
Fig. 2. Regression line for GPS precast concrete.

When IEk is substituted with the elements of the precast plant in equation (1), we obtain f´ck = 17.16 MPa, 7.20% greater than the characteristic value according to the project.

C. Sclerometry and Ultrasonic Pulse Speed Tests on Elements in Good Conditions that Conform the Buildings

There are coincidences in the qualitative evaluation of both trials for 10 elements, where an average to regular quality was obtained. A good quality by IE and regular by V was observed in only in one element.

As it was impossible to carry out destructive tests on the elements that are part of buildings to obtain their compressive strength, it was necessary to correlate the results of the destructive tests, and the sclerometry and ultrasound pulse speed tests of the precast plant, with the results of these same non-destructive tests for elements that conform buildings. For this, the correlation equation (1) is used, with "x" being the IE of the elements tested in the buildings, also, the Sonreb template was used [15]. For the application of the template, coefficients "a", "b", and "c" of the Sonreb curve are determined in the first sheet, introducing the values of the compressive strength according to the destructive test and the V with the IE of the elements found in the warehouse area of the precast plant. Then, in the second sheet, the V and IE

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of the elements that conform buildings are introduced; thus, the compressive strength of these is obtained.

Table 10 shows the values of the compressive strength obtained by equation (1) and applying the Sonreb template. The results are appreciated as approximate. Then, an average value of these results is determined.

Table 10. Compressive strength of the elements in good condition.

Elements	f´$_c$ according to equation (1) in MPa	f´$_c$ according to in MPa
I-4	18.49	17.72
I-3	18.49	17.72
E-12	24.46	25.77
I-8	18.49	17.72
I-7	18.49	17.72
E-1	20.48	20.43
I-7	18.48	17.72
T-1	15.83	14.35
P-4	21.81	22.83
P-7	21.81	22.57
P-4	21.81	22.57
f´$_{cm}$ in MPa	19.87	19.73
S$_L$ in MPa	2.30	3.18
f´$_{ck}$ in MPa	17.46	16.4
f´$_{ck}$ average en MPa	16.93	

D. Sclerometry Tests, Ultrasonic Pulse Speed, Determination of the Percentage of Humidity, and the Corrosion Potential in Elements with Pathological Damage that Conform Buildings

High humidity percentages were obtained in 9 elements out of 10, with a maximum incidence on corrosion. In the panel elements, it can be seen that the humidity distribution is not uniform and the highest percentages were found at 2.20 m high. It can be concluded that the humidity in the panels is descending by infiltration and that the markedly non-linear gradients that exist, due to the non-uniform distribution of humidity, are one of the causes of the fissures that these have. Helene and Pereira [16] argue that the presence of markedly non-linear gradients generate stresses that can exceed the deformation capacity and tensile strength of the material.

In 16 elements out of 20, there is agreement in the qualitative evaluation of the sclerometry test and the determination of the ultrasonic pulse. The quality of the concrete in these cases is poor for both tests. However, in elements S-2, T-2, P-4

and P-7, which have high percentages of humidity, the qualitative evaluation of concrete according to the speed of the ultrasonic pulse is regular (with values above 3000 m / s); according to sclerometry, it is average. These results are in correspondence with the values obtained for the corrosion potential. Since we have elements with high percentages of humidity, according to the result of the measurement of the corrosion potential, a carbonated wet concrete was obtained in these cases. Therefore, the carbonation of the concrete has caused a hardening of the surface and that is why superior qualities are obtained. According to Contreras [17], the only favorable factor of carbonation in concrete is the decrease in porosity when the pores are filled by the $CaCO_3$ deposit, producing an increase in mechanical resistance.

Since carbonation causes a reduction in the pH of the concrete, it triggers the corrosion of steel. So, despite the positive consequences in relation to concrete, they are not relevant when compared with the negative effects generated by the corrosion of reinforcements.

Analyzing the results of the measurement of the corrosion potential in particular, it can be seen that in 7 elements out of 9 tested, the values of the interval of the corrosion potential are negative, in a range that indicates that in these elements the concrete is wet carbonated. The incidence of the average annual relative humidity in Cuba of 78% is clear, and the humidity of the elements is between 32.4% - 57.8% in these results. Chávez et al. [18] point out the influence of relative humidity on the value of the corrosion potential, reaching more negative values when the relative humidity increases.

Table 11 shows the compressive strength obtained by equation (1) and by the Sonreb template [15]. After the statistical analysis of these results, it is obtained that the compressive strength of the concrete in the damaged elements is: 11.20 MPa and 13.59 MPa, respectively, in both ways.

Table 11. Compressive strength in damaged elements.

Elements	f´c according to equation (1) in MPa	f´c according to Sonreb in MPa
I-7	14.10	17.11
I-2	12.97	17.08
I-3	9.18	15.20

Elements	f´c according to equation (1) in MPa	f´c according to Sonreb in MPa
I-4	14.67	13.77
T-2	16.44	14.90
S-2	16.26	14.73
E-11	11.93	17.31
T-1	9.71	16.17
E-4	13.65	19.62
E-10	13.34	17.33
E-2	12.90	17.31
I-7	14.76	19.18
I-6	11.75	20.44
P-4	17.69	16.56
P-7	18.22	16.96
E-6	15.16	15.15
T-3	13.83	13.43
S-2	10.51	9.71
E-5	14.50	14.13
E-9	14.50	14.34
f´$_{cm}$in MPa	13.80	16.02
S$_L$ in MPa	2.35	2.38
f´$_{ck}$ in MPa	11.20	13.59

On the other hand, Lewicki [19] considers that the humidity in the concrete reduces its resistance to compression by 10 to 15%, when the humidity in the element goes from 5 to 20%. Since all the elements to which the humidity percentage was measured exceed these values, this reduction, applied at 16 MPa and 13.6 MPa, is obtained. It is observed that the results are approximate and an average value of these is determined, being f´ck = 12.79 MPa.

V. CONCLUSIONS

From the results of the destructive and non-destructive tests carried out in the framework of this research, it is specified that: i) The compressive strength of the concrete of the precast GPS system according to the project is 16.00 MPa, and ii) It can be assumed that the resistance to compression of concrete in precast elements in good technical-constructive conditions, which conform buildings in operation, is 16.93 MPa, as well as 12.79 MPa in elements with pathological damage.

That is, in the precast elements in good technical-constructive condition, which conform the buildings in operation, the compressive strength is 5.80% higher than that required by the project, remaining within the range of medium strength. However, in the elements with the presence of pathological damage it decreases by

25.78%, classifying it as low resistance. In these elements, chemical deterioration processes are evident, caused by the water exposure, which generates the formation of soluble paste compounds, loss of mass, mechanical resistance, among other alterations. The carbonation of the concrete is also triggered, which in turn causes the corrosion of the reinforcing steel. This corrosion leads to the cracking of concrete, delamination of steel, decrease of the concrete-steel adhesion and other manifestations, which affect the durability of the concrete. Therefore, the impact of the durability of concrete on the seismic resistance of buildings built with this precast system must be evaluated.

AUTHOR´S CONTRIBUTION

Socarrás-Cordoví report writing, information research and testing; González-Díaz review of the report and information research; Álvarez-Deulofeu review of the report and information research; González-Fernández carrying out of the tests; Roca-Fernández: Carrying out of the tests; and, Torres-Shoembert carrying out of the tests.

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