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Inspection of Buildings in Rio de Janeiro-Brazil: Proving the greater tendency of corrosion at the base of reinforced concrete columns using potential corrosion technique

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Abstract: Monitoring the corrosion of steel embedded in concrete is a way to assess the degradation of civil structures. A technique used for this is the measurement of corrosion potential, which includes the use of a reference electrode, connected to a high input impedance voltmeter. There are many factors influencing the measurement of corrosion potential, such as: degree of concrete moisture content, the oxygen access, existence of micro fissures, chloride penetration, carbonation and concrete cover thickness. This study aims to analyze the measurement of corrosion potential for the copper/copper sulfate (Cu/CuSO4) electrode obtained in the inspection work of four residential buildings located in Barra da Tijuca, Rio de Janeiro, Brazil. The evaluation aims to investigate the difference in measurements of corrosion potential in the middle and bottom of each inspected column. The reason for the research is to explain a practical realization: the reinforcement corrosion can be seen more often at the columns base than in the remaining of this type of structural element. General data for all the 4 buildings inspected indicates that 77% of all 109 inspected columns have more negative corrosion potential values at the base. The reasons for this discovery are discussed throughout this paper.

Keyword: *inspection; corrosion potential; reinforced concrete; reference electrode*

I. INTRODUCTION

Having started in the United States of America around the 70's, the use of the method for evaluating the corrosion potential in inspecting reinforced concrete structures, became widely used in U.S.A and also in Europe in recent years. One good use for this method is mapping the values of corrosion potential as these mappings enable the identification of compromised areas and areas with steel depassivation [1].

The corrosion potential can be identified in places with thermodynamic conditions which enable the beginning of electrochemical corrosion in the steel reinforcements of the concrete even though the corrosion has not yet manifested visibly in the surface of the reinforcement steel.

Actually, there are also other methods based on electrochemistry which not only enable identification of these areas but also provide quantitative data on the kinetics of the corrosion process, for example, the methods for evaluating corrosion speed by electrochemical impedance or by the resistance of linear polarization. These procedures which combine the interpretation of corrosion potential values with corrosion speed are currently most recommended for monitoring the durability of reinforcements of reinforced concrete structures.

This study aims to analyze the measurement of corrosion potential for the copper/copper sulfate (Cu/CuSO4) electrode obtained in the inspection work of four residential buildings located in Barra da Tijuca, Rio de Janeiro, Brazil. The evaluation aims to investigate the difference in measurements of corrosion potential in the middle and bottom of each inspected column. The motive for the research is to explain a practical realization: that the reinforcement corrosion can be seen more often at the columns base than at the remaining of this type of structural element.

Real cases are still in a learning phase and models are being developed and adjusted to make service life predictions more accurately. This work is inserted in this context, disseminating data obtained from on-site inspection of reinforced concrete structures that were weather-exposed to a marine environment for years, helping to understand the work in service of real reinforced concrete structures.

II. DETAILS OF THE METHOD

The tendency of any metal to react with an environment is indicated by the potential it develops in contact with the environment. In reinforced concrete structures, concrete acts as an electrolyte and the reinforcement will develop a potential depending on the concrete environment, which may vary from place to place [2]. The method for evaluating corrosion potential includes the use of a reference electrode connected to a high input impedance voltmeter as shown in Figure 1.

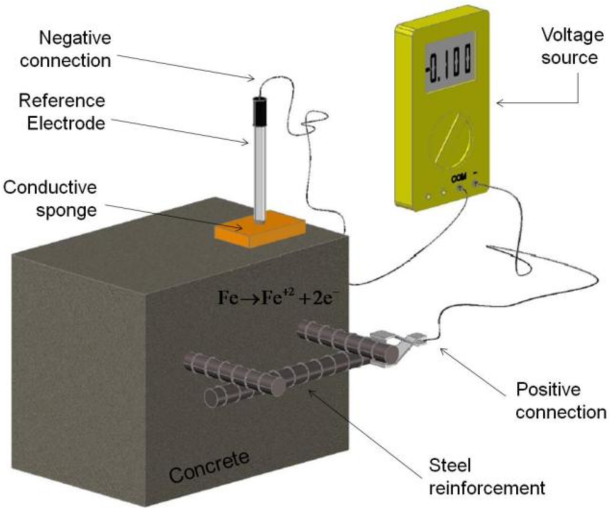

Figure 1 – Schematic of the technique being applied to study corrosion potential [3].

The test is generally performed in sample pieces or in reinforced concrete structures for monitoring or punctual evaluation, in case of an inspection where there is no time to monitor the readings over a long time. Thus, it is necessary to have a reference electrode (usually a copper/copper sulfate - Cu/CuSO4) where the potentials are referred to.

The readings of corrosion potential provide evidence of corrosion risks as indicated in Table 1.

Table 1 – Criteria for evaluating measurements of corrosion potential [4].

The corrosion potential related to the reference electrode (Cu/CuSO4) - (Ecorr)	Probability of Corrosion (%)
< - 350 mV	90
Between – 350 and – 200 mV	Uncertain
> - 200 mV	10

Using the method, a measurement of electrochemical potential difference is made at certain points of the structure, between an unstable electrolyte system (steel/concrete) and another stable one which is the reference electrode. When the device is applied they create an electrochemical cell formed by the two systems previously mentioned.

Generally, what is observed in electrode potential measurements made in reinforced concrete is a current flow going from the reinforcement to the reference electrode, closing the circuit between the two parts occurring in an ionic way through a highly conductive interface.

Normally, the obtained values are negative regardless the state of the reinforcement because the potential of the reference copper/copper sulfate electrode is nobler (more positive values) than the steel/concrete system potential.

The reference electrode can be moved over the concrete surface to create a potential map that shows the possible locations of active corrosion in the structure.This tool has been widely used in the field because it provides a fast and low cost way to identify areas of steel depassivation that require analysis or repair. However, test results may be affected by the following factors:

Concrete moisture content**:** The corrosion in reinforced concrete is an electrochemical process and therefore depends on the existence of an electrolyte, or in other words, a sufficient level of humidity in the capillary pores of concrete. Hence corrosion will occur only when there is a minimal level of humidity and the highest the level is, the higher the mobility of ions participating in the electrochemical process. Therefore, strong additional moistening or preferably saturation of concrete is recommended before starting the potential reading. The ideal situation would be concrete saturation, at least one hour before the start of readings to ensure the correct measurement [5]. According to Poursaee and Hansson [6], potential measurements begin no sooner than 15 minutes after the first measurement area is wet.

Depending on the concrete moisture content (or on its resistivity) at the moment when the inspection is performed, the steel embedded in a reinforced concrete structure, carbonated or contaminated by chlorides, may be classified according the criteria of ASTM C876 [4] as being either in a active or in a passive state of corrosion [7].

Aeration (access to oxygen)**:** In order to have electrochemical corrosion with formation of ferruginous and expansive products (rust), it is necessary to have an access to oxygen. Oxygen is required for the reaction forming oxides/hydroxides of iron, porous and expansive. These products from corrosion may have variable colors such as black, green, reddish and rusty brown denoting different levels of oxygen availability, the black color on the beginning of the process (and unstable) and brown being the end of the process and a stable environment with normal access to oxygen. Thus the existence of more negative potentials in cases with low access to oxygen is possible (before fissures and in saturated concrete), compared to fissured regions or with detached concrete (highly deteriorated regions) [5]. This means that not always the corrosion potential values are directly proportional to the rate or level of corrosion. Saturated concrete, for example, has high conductivity, high tendency to more negative potentials, but limited access to oxygen which results in low corrosion rate.

Micro fissures**:** Local electrochemical corrosion can be accelerated or facilitated by micro fissures which also reduce the ionic resistivity of the concrete, affecting the measurement of corrosion potential [8].

Chloride penetration**:** According to Browne et al. [9], chlorides on the surface layer of concrete may result in different values of potential for more negative rates, since the chlorides improve the ionic movement in the concrete porous solution, an essential part of the electrochemical corrosion process.

Carbonation**:** increases the electrical resistivity of carbonated concrete and makes the corrosion potential less negative.

Thickness of concrete cover**:** the greater the thickness is, the less negative the values of corrosion potential are. Figure 2 shows an image illustrating the effect of concrete cover thickness in the readings of corrosion potential.

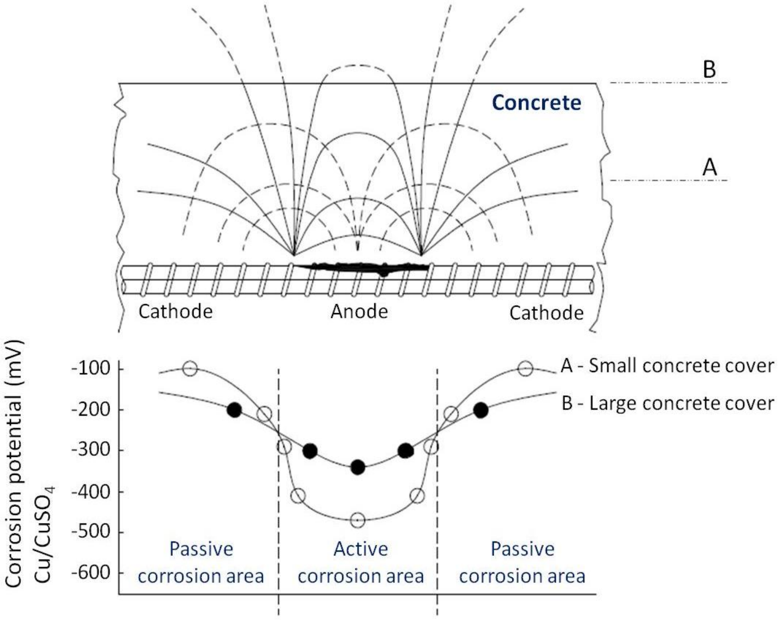

Figure 2 – Influence of concrete cover on readings of corrosion potential [5].

For the reasons specified by ASTM C 876 [4] the criteria from Table 1 must be taken carefully, with restrictions in special situations such as: very dry concrete, deeply carbonated, having a painted or film coated surface or when the reinforcement has a galvanized metal coating or epoxy paint. Although this method of half-cell potential is widely applied, it must be noted that it is not quantitative, since the corrosion rate is not determined.

When there is a protective layer on the concrete, such as epoxies, polyurethane, acrylic, among others, the electrical contact between the reference electrode and the concrete surface is impaired and the technique should not be used unless the protection is removed, even locally, for measurements [10]. Figure 3 shows a general scheme of activities sequence forming the method for evaluating corrosion potential.

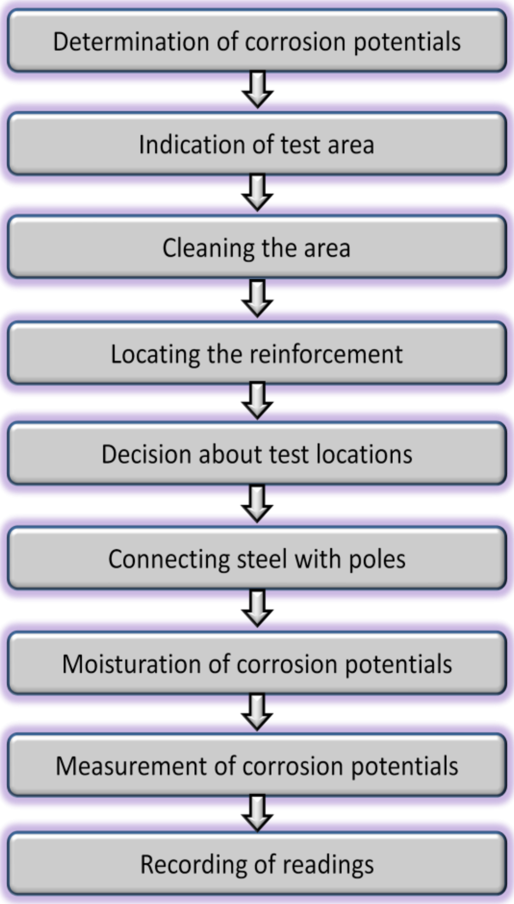

Figure 3 – Flow diagram of process [11].

III. METHODOLOGY

An inspection work is much more than just reading corrosion potentials. However this study focused on evaluating this method in four residential buildings where the inspection work was completely carried out. Table 2 shows details of buildings that were part of this work.

Table 2 – Identification of buildings of this study.

	Details
Building 1	A building with 14 residential floors + 2 (2-floors apartment) + ground floor + 2 basement floors = total 21 floors
Building 2	A building with 35 residential floors + 1 (2-floors apartment) + floor with home machines + ground floor + 2 basement floors = total 40 floors
Building 3	A building with 14 residential floors + 2 (2-floors apartment) + ground floor + 2 basement floors = total 21 floors
Building 4	A building with 14 residential floors + 2 (2-floors apartment) + ground floor + 2 basement floors = total 21 floors

All of the buildings are located in Barra da Tijuca, Rio de Janeiro, Brazil about 700m from the seashore. The environment where all four buildings are located is considered as a strongly aggressive environment according to NBR 6118 [12]; EN 1992-1-1 [13]; EN 206-1 [14], ACI 201.2R [15].

The measurements of corrosion potential were conducted on the columns of the inspected buildings and the site of every reading was saturated beforehand. The saturation procedure was done with a constant supply of water to the surface of the columns. Water was allowed to penetrate into the concrete by the absorption mechanism by capillary suction. In every analyzed column the readings were taken both at the column base and at the height of 1.5m from the floor slab as illustrated in Figure 4.

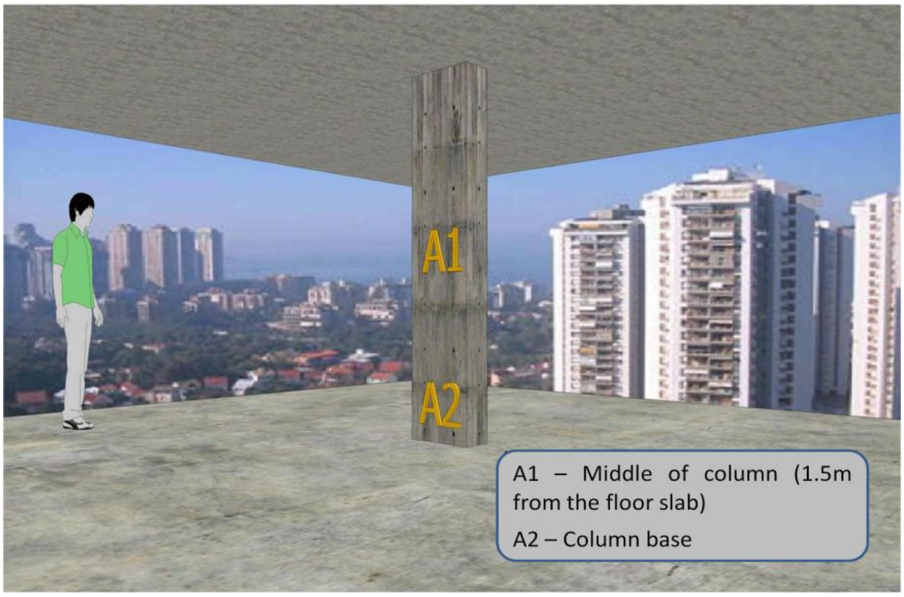

Figure 4 – Positioning schematic for readings taken.

Sampling was done from the inspection work in four buildings and the sample space in each building is shown in Figure 5. The number of sampled columns was limited due to the time available for inspection work as indicated on the work contract. However, it can be considered a great opportunity to use practical experience in order to learn about the functioning of reinforced concrete structures. Figure 5 shows a total of 109 columns that were inspected in the four buildings.

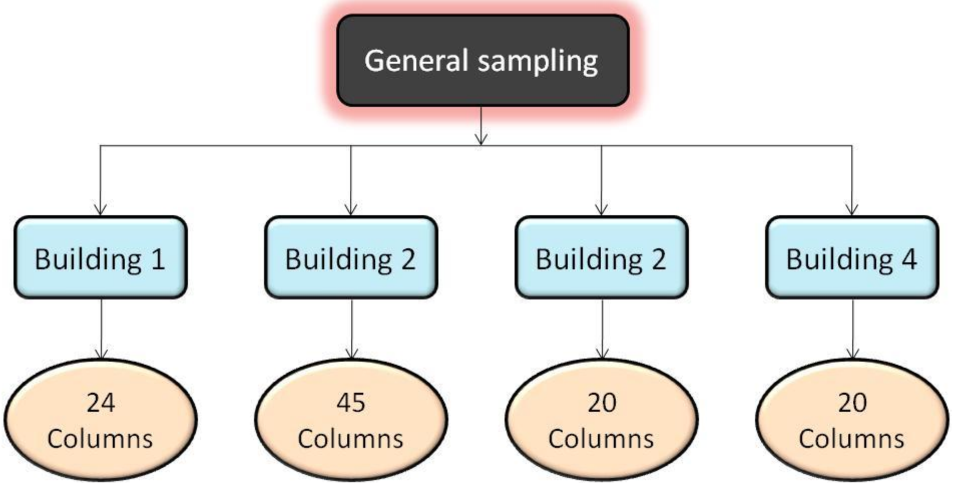

Figure 5 - General overview of sampling.

IV. RESULTS AND DISCUSSION

4.1 Building 1

Figure 6 has the obtained results from every column and floor where the values of corrosion potential were registered in Building 1. It is easy to notice that in this building there is a tendency for the existence of more negative corrosion potential values at the columns bases.

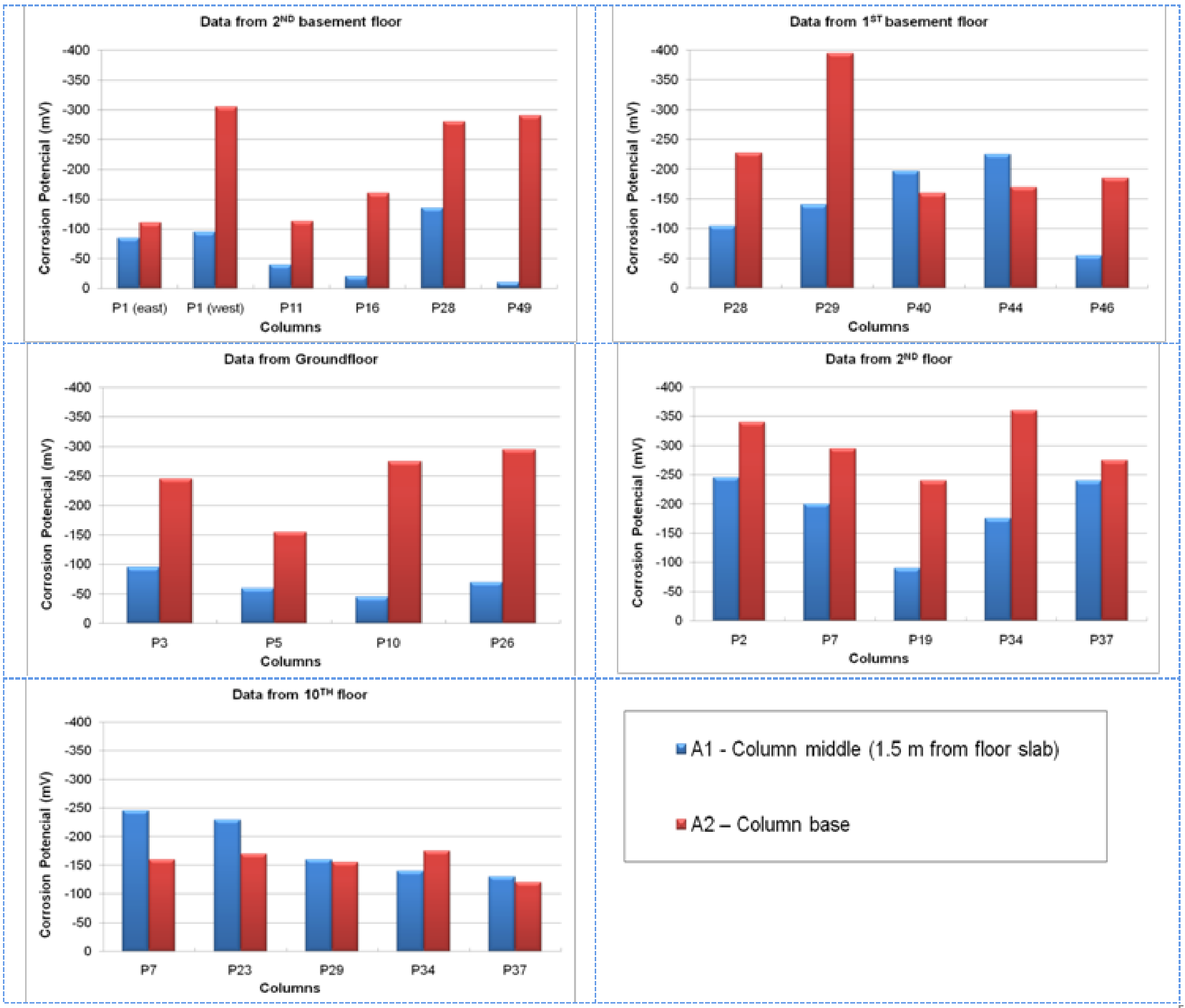

Figure 6 – The corrosion potential (Ecorr) data for building 1.

This is more evident in Figure 7 showing the percentages for the more negative corrosion potential values in the columns bases (A2) and at the columns central region (A1). In this case, it was shown that 75% of the more negative corrosion potential values were in the columns bases.

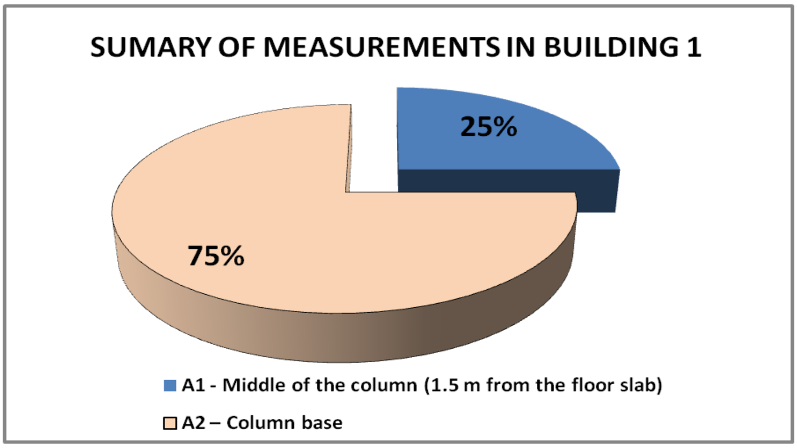

Figure 7 – Percentage of columns with more potential values of negative corrosion in base and central region of inspected columns in Building 1.

4.2 Building 2

Figure 8 presents the results obtained for each one of 45 columns sampled along the floors where the readings of corrosion potential were recorded in Building 2. It is clear that the results trend is contrary to the results from Building 1. Figure 9 shows an overview of these results indicating that in this building the values of more negative corrosion potential are concentrated in the columns middle (at height of 1.5m).

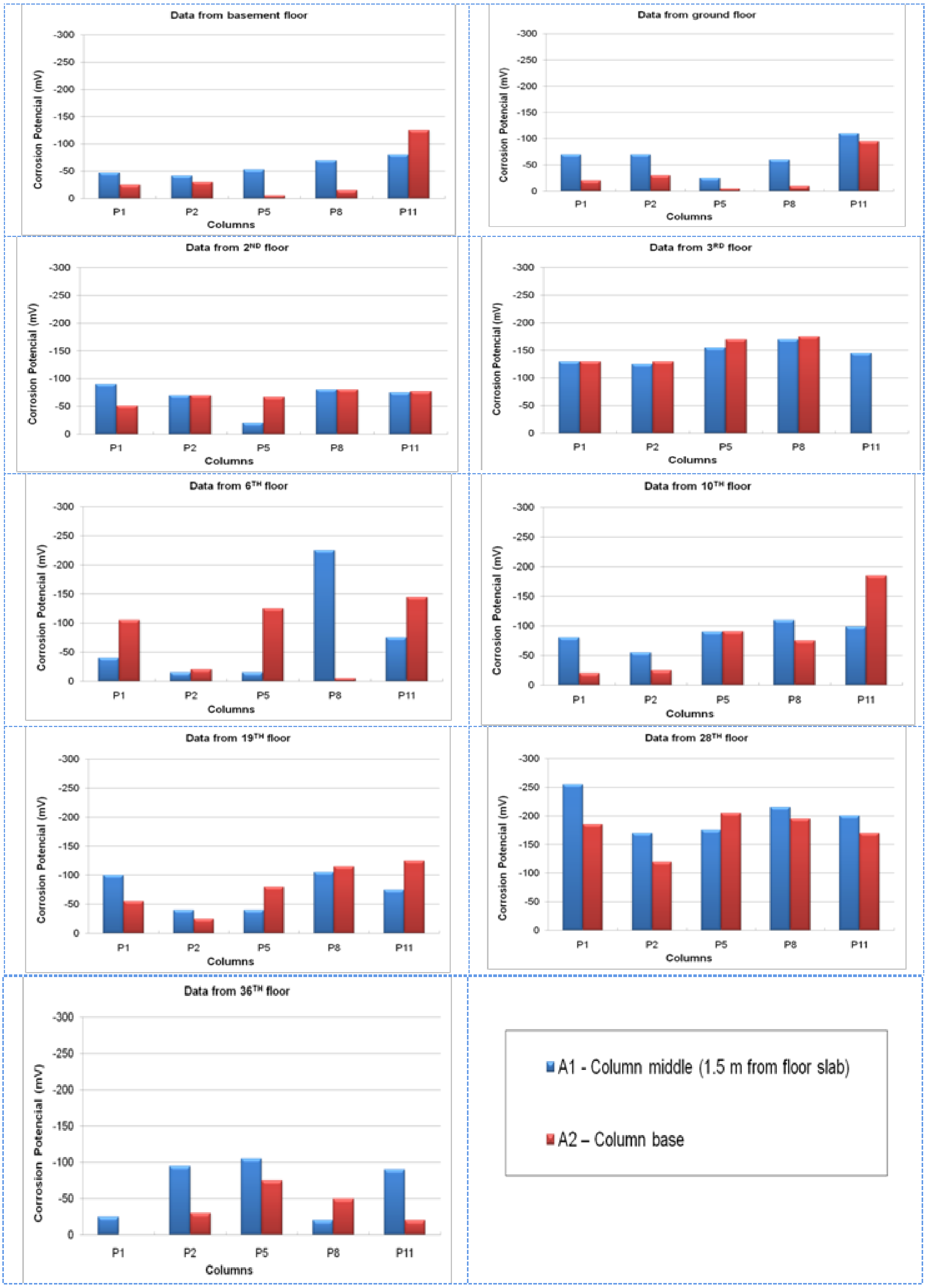

Figure 8 – Corrosion potential (E_{corr}) data for building 2.

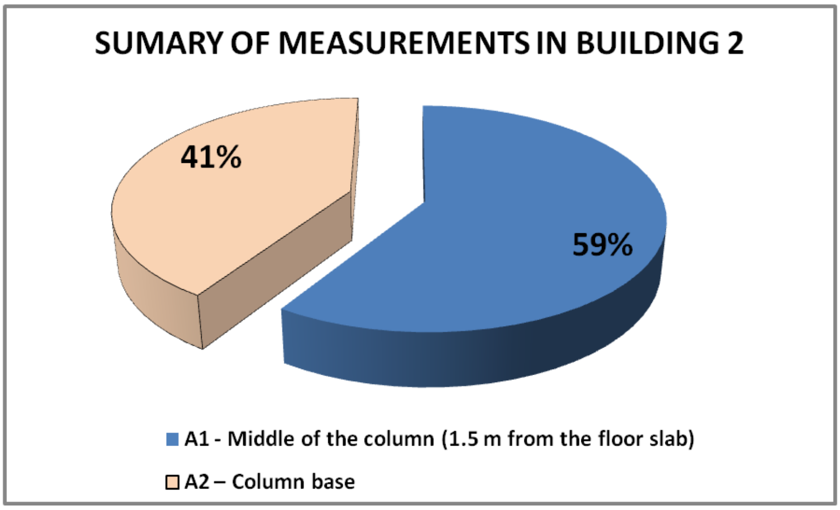

Figure 9 – Percentage of columns with more potential values of negative corrosion in base and central region of inspected columns in Building 2.

4.3 Building 3

Figures 10 and 11 indicate the same trend as results from Building 1. It is important to notice that in this case the value of corrosion potential at the base is more negative than in the middle in 100% of the inspected columns. This result is in accordance with the obtained in Building 1.

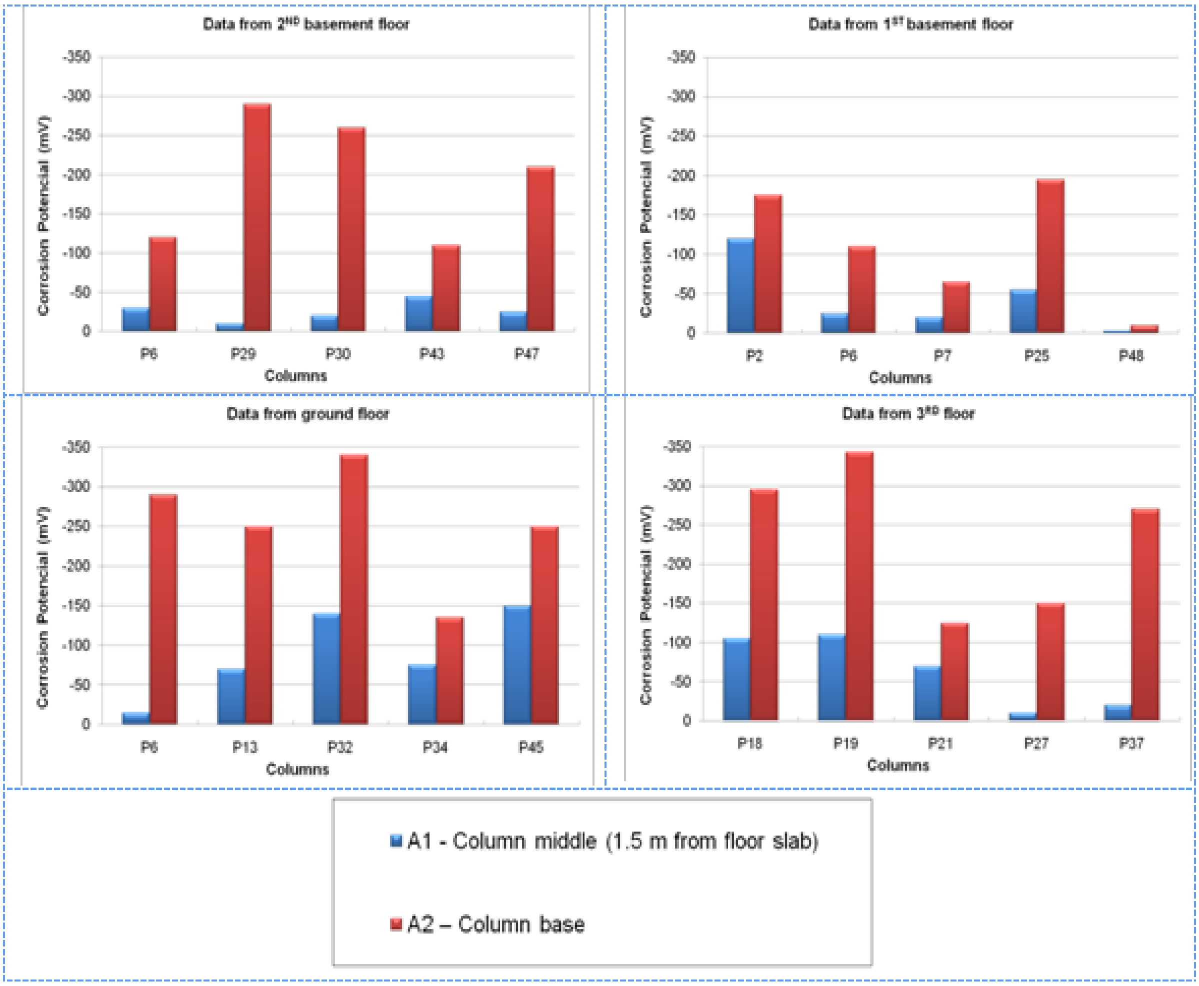

Figure 10 – Corrosion potential (E_{corr}) data for building 3.

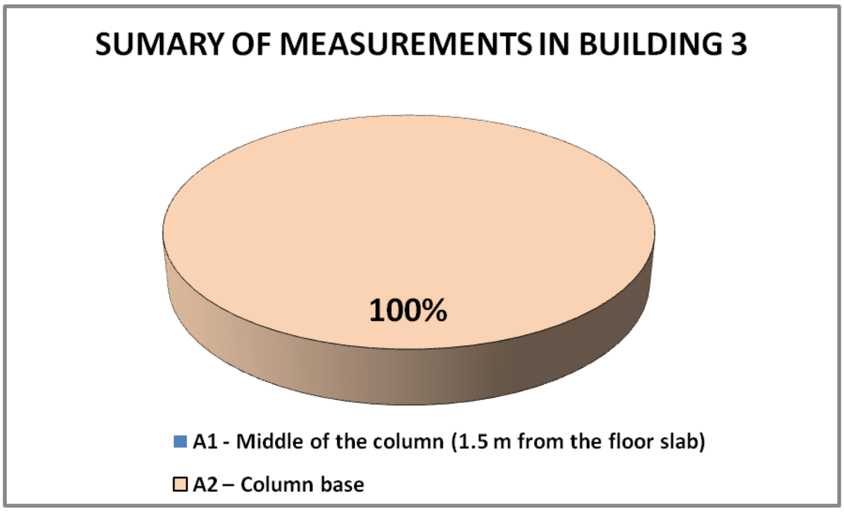

Figure 11 – Percentage of columns with more negative corrosion potential values in the base and the central region of inspected columns in Building 3.

4.4 Building 4

Finally, Building 4 indicates the same trend as buildings one and three. As Figures 12 and 13 show, the individual results for each column inspected and an overall outcome of this study is presented respectively. It is noteworthy that in 75% of the cases the most negative values of corrosion potential are located at the columns base in Building 4 as showed in Figure 13.

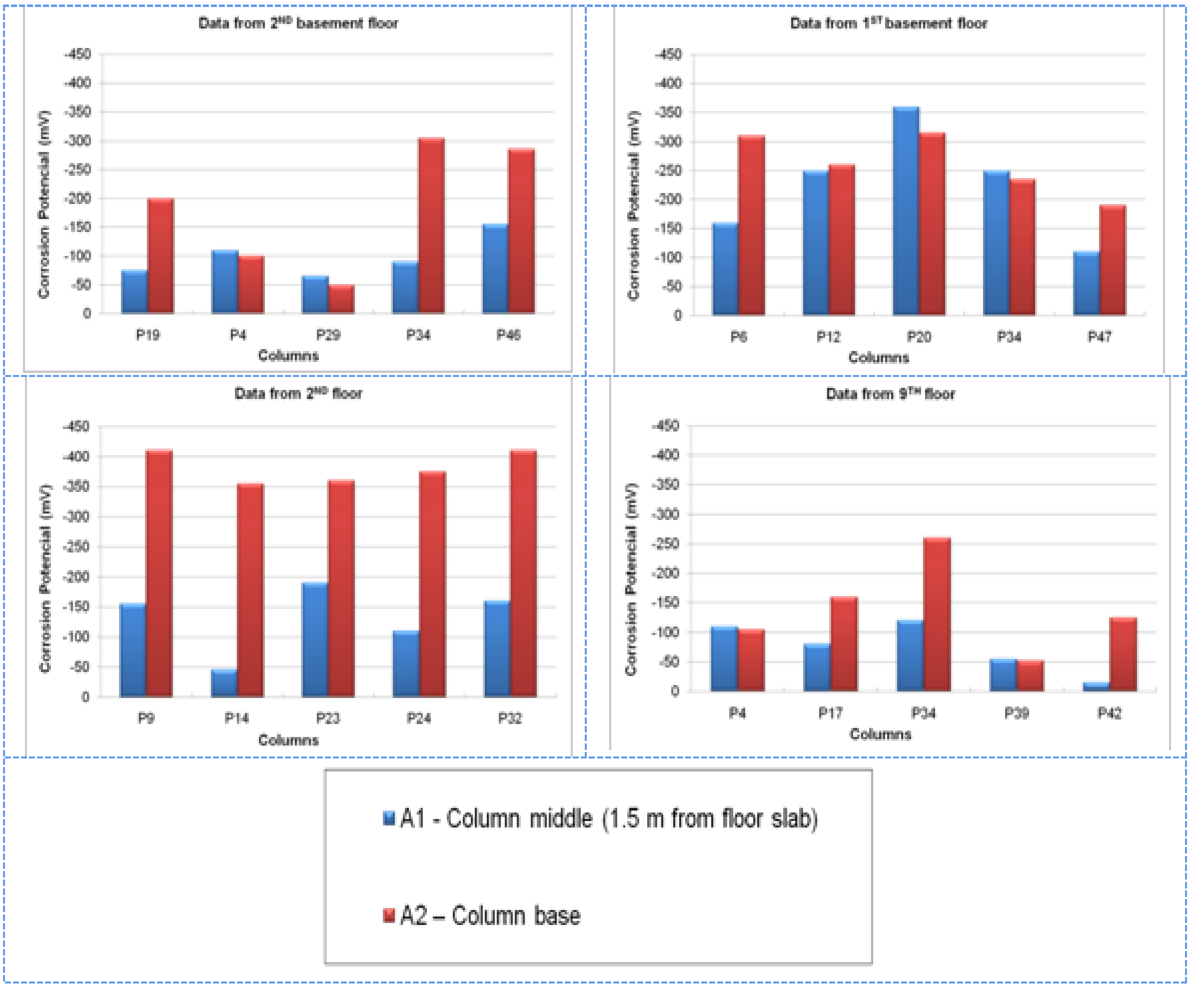

Figure 12 – Corrosion potential (E_{corr}) data for Building 4.

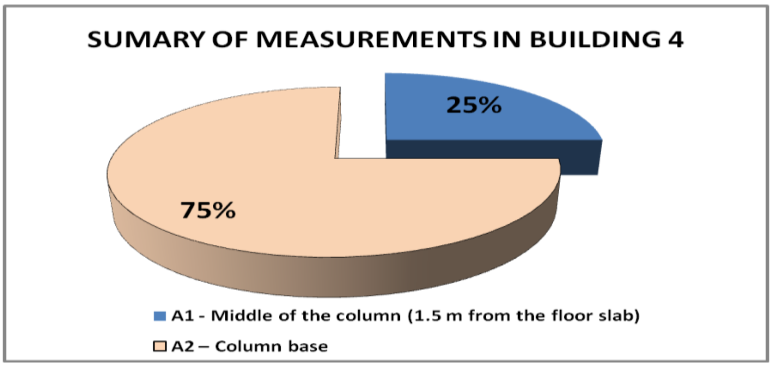

Figure 13 – Percentage of columns with more negative corrosion potential values in the base and the central region of the inspected columns in Building 4.

4.5 Discussion of results

Figure 14 shows general data for all 4 buildings inspected indicating that 77% of all 109 inspected columns have more negative corrosion potential values at the columns bases. This result is a very relevant amount, indicating high prevalence of this presented occurrence.

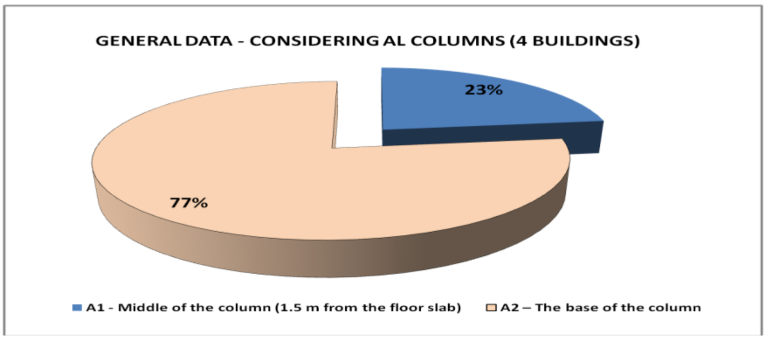

Figure 14 – General percentage of columns with more negative corrosion potential values in the base and the central region of the inspected columns.

In addition, Figure 15 shows that, in 75% of the inspected buildings, the trend to have a tendency to negative values of corrosion potential in the columns bases was validated.

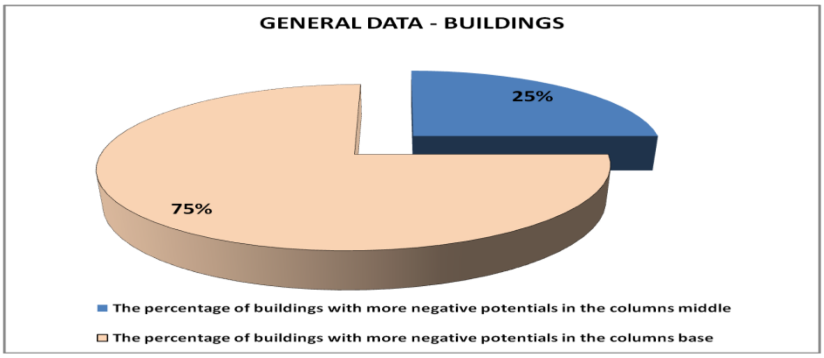

Figure 15 – Percentage of the buildings that follow the tendency of columns with more negative corrosion potential in the base.

As shown in most cases, the corrosion potential is more electronegative in the column base than in the central region. Some theories to explain this trend follow:

1) *Placement of concrete*: There is a consensus that placement of concrete from a height without extra care may lead to segragation, which tends to happen mainly in the columns base. As a result, there is a larger concentration of agregates in the base region of many columns. This creates a region with richer cement and a region with poor cement. The poorer region is precisely located in the columns base where a tendency exists for more negative values of corrosion potential.

2) *High concentration of steel reinforcements*: The column base consists of a region with a higher quantity of steel bars because it is the connection area of the reinforcement. This fact can complicate the densification of concrete in the columns bases and is also an influencing factor in the values of corrosion potential.
3) *Humidity*: When exposed to the environment during longer periods of time, the water inside the columns has a tendency to accumulate in their bases because of gravity. Thereby, it is known that a humid column dries faster near the roof slab than in the base, near the floor. This also explains the negative values of corrosion potential at the columns bases.
4) *Synergy between 1, 2 and 3*: The effects of nature and the synergy between the factors mentioned earlier also explain the trend of results. If the concrete in the column base has a tendency to be more porous because of segregation and difficulties in densification because of the high quantity of steel reinforcement, it is easy to conclude that this is a region with a tendency to suffer more contamination of chloride ions and carbon dioxide. Consequently, these regions also suffer from faster corrosion of steel. As already argued, it is a region with a tendency to have a higher level of humidity which, for its part, also advances the development of corrosion in the reinforcement in this area.

V. CONCLUSIONS

The data presented here is a result from an inspection of reinforced concrete structures directly exposed for weathering during more than five years. It is possible to conclude, according to presented facts, that there is a strong trend to have more negative values of corrosion potential in the columns base. This was verified in 77% of the 109 concrete columns inspected. This also explains the fact that the reinforcement corrosion occurs more often at the columns base.

The method of evaluating corrosion potential proved to be an important tool to detect changes in the state of the steel, helping to realize when the state of the reinforcement changes from passive to active corrosion and vice versa, confirming that the method is an useful tool in inspection services and evaluation of the durability of reinforced concrete structures.

It is important to highlight that the considerations made here need validation supported by a more detailed experimental study. This is due to the fact that in a real structure there are several variables that are not controlled, such as: uniformity in concrete mixture and proportioning, changes along the building, changes in cement, humidity rate in the measurements, thickness of concrete cover, temperature and others. Thus, this work results should be seen as a reference of a practical experience that triggers laboratory studies.

VI. ACKNOWLEDGEMENTS

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