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Risk analysis of the delayed ettringite formation in pile caps foundation in the metropolitan region of Recife – PE – Brasil

Análise de risco da formação de etringita tardia em blocos de fundação na região metropolitana de Recife – PE – Brasil


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Abstract

Currently, there is an awareness that is critical to assess the durability characteristics of concrete with as much attention as the mechanical properties. The durability of concrete structures can often be affected by chemical attacks, jeopardizing its performance and security. When concrete is subjected to high temperature at early ages, many physical and chemical changes in hardened concrete may occur. It iswidely accepted that concrete subjected to these conditions of temperature and exposed to moisture is prone to cracking due to Delayed Ettringite Formation (DEF). This work aims at providing a DEF risk analysis on foundation pile caps at the Metropolitan Region of Recife - PE. Temperature rise measurement was performed in situ at 5 different caps through datalogger and thermocouples equipments. Furthermore, the Duggan test was performed in order to assess the level of expansion of 3 cements studied: X (CP II E 40), Y (CP II F 32) and Z (CP V ARI RS). Simultaneously, the chemical compositions of these cements and their respective clinkers were quantified by analysis of X-ray fluorescence (XRF). The cement X (CP II E 40) showed the chemical characteristics favoring with more intensity DEF and, as a result, higher level of expansion in the test Duggan. It is noteworthy that incorporation of metakaolin (8% and 16%) and silica fume (5% and 10%) showed mitigating potential of expansions. It is important to point out that all factors related to thermal properties and chemical composition of the concrete used in the region converge to a condition of ideal susceptibility for triggering DEF. Therefore, it is essential at least minimum and basic requirements in the design specification in order to avoid high temperatures in the massive concrete elements, preventing them from delayed ettringite formation.

Keywords: delayed ettringite formation (DEF), chemical composition, temperature, prevention, risk.

Resumo

Atualmente, existe a consciência de que é fundamental avaliarem-se as características de durabilidade do concreto com tanta atenção quanto às propriedades mecânicas. A durabilidade das estruturas de concreto pode muitas vezes ser afetada por ataques químicos, colocando em risco o seu desempenho e segurança. Quando o concreto é sujeito à alta temperatura em idades precoces, muitas mudanças físicas e químicas no concreto endurecido podem ocorrer. É amplamente aceito que o concreto submetido a estas condições de temperatura e exposto à umidade é propenso a fissurar devido à Formação de Etringita Tardia (DEF). Este trabalho tem como objetivo principal realizar uma análise do risco de DEF em blocos de fundação na Região Metropolitana de Recife/PE - Brasil. Foi realizada a medição in loco da elevação de temperatura em 5 blocos distintos, com auxílio de instrumentação por meio de datalogger e termopares. Ainda, foi executado o teste de Duggan, com o intuito de avaliar o nível de expansão dos 3 cimentos estudados: X (CP II E 40), Y (CP II F 32) e Z (CP V ARI RS). Paralelamente, as composições químicas destes cimentos e de seus respectivos clínqueres, foram quantificadas por meio de análises de fluorescência de raios-X (FRX). O cimento X (CP II E 40) foi o que apresentou características químicas mais favorecedoras à DEF e, como reflexo, maior nível de expansão no teste de Duggan. Ressalta-se que, adições de metacaulim (8% e 16%) e sílica ativa (5% e 10%), apresentaram potencial mitigador das expansões. É importante salientar que todos os fatores relacionados às propriedades térmicas e composição química dos concretos utilizados na região, convergem para uma condição de susceptibilidade ideal no desencadeamento da DEF. Portanto, é fundamental a especificação em projeto de requisitos mínimos e básicos para evitarem-se altas temperaturas nestes elementos massivos de concreto, prevenindo-os da formação de etringita tardia.

Palavras-chave: formação de etringita tardia (DEF), composição química, temperatura, prevenção, risco.

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1. Introduction

Currently there is a growing concern with the durability of structures in reinforced concrete as far as the mechanical performance of these structures. In Brazil, was recently published the Performance Standard - NBR 15575:2013 – *Edificações Habitacionais - Desempenho*, which specifies a level of minimum performance regarding to service life for the systems principals that make up the residential buildings (ABNT [1]).
In turn, the durability of concrete structures can often be affected by chemical attacks, endangering its performance and safety. The two main chemicals attacks to concrete are attributed to Alkali-Aggregate Reaction (AAR) and the action of sulphates, among which stands out the Delayed Ettringite Formation (DEF - Delayed Ettringite Formation).
Due to the severity and the great number of reported cases of deterioration attributed to the RAA, currently, in Brazil, has numerous academic researches and case studies of affected structures, in order to try to eliminate or mitigate the risks of emergence the AAR (HASPARYK [2]).
Commonly, the deterioration of many concrete structures has been attributed only and exclusively to the AAR. In fact, what can be there, in many cases, is a combination of attack mechanisms, such as DEF, who also presents very similar symptoms to the AAR, which may impair diagnosis and prognosis of the problem (HASPARYK et al. [3]).
Unlike the AAR, the DEF phenomenon has few reports in Brazilian literature, like the jobs of Melo [4] and Melo et al. [5-6]. Until then there is no standardization and national guidelines of prevention related to the DEF, apart from that your formation mechanisms are complex and still poorly understood.
Before this scenario, it is justifiable to realization of this work because of the lack of concern or even ignorance on the part of the technical means about DEF. As there is no a corrective and economic measure after the triggering of DEF, becomes essential the prevention and control of the factors that trigger this pathology.
Therefore, this research explicits the various local factors that influenced and contributed positively to the development of DEF, demonstrating the short importance of your prevention and the creation of a national standartization. Among such factors, can be cited: the elevated temperatures reached by massive elements of concrete, due to the cement hydration heat Portland, as is the case of foundation pile caps, and the chemical composition of cements commonly used in the confection these concretes.
In this context, the main objective of this paper is realize a risk analysis DEF in the confection of pile caps foundation in reinforced concrete of residential buildings in the Metropolitan Region of Recife (RMR), basing in the LCPC's preventive guide combined with the Duggan's experimental method. The main hypothesis is that all factors related to thermal properties and chemical composition of the concrete used in the RMR converge for a ideal susceptibility to the triggering the DEF these foundation pile caps.

2. Delayed Ettringite Formation (DEF)

2.1 Historic of cases and influential factors

The phenomenon of the DEF, focus of this study, in the truth follows from the delayed formation of the mineral called ettringite, which generates expansions in the concrete having as consequences cracking mapped or directed in the concrete surface. The typology of cracking depends of the state of tension in which the element is subjected, as well as, the density and distribution of the reinforcement. Highlights out that the ettringite is not systematically detrimental to the concrete, since the same is product of the cement hydration.
The first case assigned to the DEF as main factor causer of damage happened in 1987, in Finland, affecting concrete precast sleepers that had been subjected to a improper heat treatment and exposed to moisture. Beyond Finland, other countries in the world also reported this phenomenon in sleepers and in various different types of precast elements after about 10 years of operation (LCPC) [7].
Apart from precast components, the DEF was also responsible for damaging several bridges in Britain, ranging between 8 to 20 years after construction. In France, initial cases were identified in the 1990s, between 5 and 10 years after construction, being that the concretes, mostly, were affected by DEF and not by alkali-silica reaction. In both cases, such concretes were more frequently casted during the summer, they had high cement content (between 420 and 550 kg/m^3) and high alkali content equivalent (> 4.0 kg/m^3). The tendency of these structural elements was to be quite thick (at least 60 cm), exposed to moisture and the maximum temperature reached inside these was estimated at approximately 80°C (LCPC) [7].
In addition to these, it was reported in southern Sri Lanka, the presence of severe cracks that affected some pile caps of the pillars of a highway bridge. After extensive investigations, it was verified that the main cause for the cracking in these pile caps was attributed to DEF (Nanayakkara [8]).
In the north-american state of Maryland, Amde et al. [9] conducted a study in a large population of bridges that had mapped cracks. Was confirmed the almost total presence of DEF in these, contrary to the limited number of cases of alkali-silica reaction, there until a few cases of coexistence between these pathologies.
In Brazil, are rare the reports of deterioration of concrete structures assigned to the DEF. Recently, an extensive investigation was performed to evaluate the probable causes that led to severe cracking in pile caps foundation of a building in the country. Based on the data of determination of the composition of the concrete and therefore, the approximate cement content, the possibility of the concrete mass has reached 80°C is immense. Most likely the concretes experiments, in association with the AAR, a characteristic attack of DEF (HASPARYK et al. [3]).
According to Mehta and Monteiro [10], there is general consensus among researchers that the DEF occurs when the source of sulphate ions is internal rather than external, arising from the use of an aggregate contaminated with gypsum or cement containing high sulfate content in the production of the concrete. Additionally, steam curing of concrete parts above 65°C can induce the delayed ettringite formation, because the same is not stable above 65°C, decomposing to form hydrated monosulfate, which is adsorbed by the CSH. Subsequently, the sulphate ions are dissolved and originate the DEF causing expansion and cracking.
According Godard and Divet [11], when the maximum temperatures in the concrete is greater than 65°C, derived from the thermal treatment or of the heat of hydration, the sulphates can be incorporated in other cement phases. The DEF is then defined as

the ettringite formation in the concrete after hardening and without any external supply of sulfate, but exposed to moisture. This problem of the DEF may occur in thick concrete elements as cross-beams, bridge pillars and foundations where the core temperature may be too high, as a result of the heat of hydration of the cement (Nanayakkara [8]).

The LCPC [7] refers to the DEF, exclusively, to the concretes that were exposed at early age to the heating which exceed 65°C. Above this temperature, the primary ettringite formed during cement hydration reactions decomposes and generates an internal source of sulphate ions. After returning to ambient temperature and in the presence of moisture, the ettringite is able of was to recrystallize in a stage in which the concrete is hardened, generating swelling pressures which cause cracking. The maximum temperature reached and the application time of high temperature considerably influence the risk of DEF.

However, Collepardi [12] proposed a holistic model for DEF and indicates that it should include two distinct types: the DEF caused by internal sources of sulfate and DEF caused by external sources of sulfate. This also comments that the thermal decomposition of the primary ettringite and the sorption-desorption of sulfate by the CSH are not sufficient conditions and essential for DEF.

There is no consensus among researchers on the DEF mechanism and the cause of the expansion, but all agree that the expansion due to DEF occurs in concretes submitted to high temperature at early age. Therefore, Nanayakkara [8] and Escadeillas et al. [13] cite that was proposed at the International Workshop RILEM TC 186 - ISA that the DEF should be correctly known as "*Heat Induced Internal Sulphate Attack*".

Therefore, in this study, the term "DEF" will only reference to the delayed ettringite formation caused by internal attack sulfates induced by the Portland cement hydration heat.

In chemical composition, Collepardi et al. [14] cites that relatively high contents of SO_3, much in the clinker (2%), as in the cement (4%), by adding gypsum, may aggravate the danger of causing high expansions related to the DEF when under heating of around 80-90°C.

The LCPC [7] mentions that the DEF can only arise if the cement used contains a high content of C_3A and sulfuric anhydride (SO_3). Regarding the alkali content, this plays a fundamental role in the progress of the DEF, being that the ettringite is much more soluble at higher rates of alkali metals.

Leklou et al. [15] comment that the development of DEF is possible even in cements with low C_3A content (<5%). However, for cements with high levels of C_3A and SO_3, the alkali of content is essential and a small variation in its content can allow or prevent the appearence of the DEF. In his work, Escadeillas et al. [13] confirm that high levels of alkalis increment the expansion risk of concrete after thermal curing.

Stark and Bollmann [16] stated that the DEF is the result of complex processes of long duration, where the concrete composition, technological factors of production and environmental effects on the concrete are important. Therefore, all these factors must be taken into consideration, since it is not enough consider only one of the factors that influence their triggering.

The cement fineness certainly also has an important role in DEF process. Generally, high early strength cements are particularly susceptible to expansion induced by DEF (CIGROVSKI [17]).

In your experience in the limitation of temperatures reached by the concretes in several projects, aiming to prevent the DEF, Cussigh [18] shows that in general, the internal cooling is not needed in face of the optimization of the proportioning and of the component materials of the concrete.

2.2 Duggan Test

Folliard et al. [19] cites which the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) does not have a test method for evaluating the susceptibility to the DEF of concretes and mortars. Consequently, various researchers have developed various methods of laboratory tests related to the DEF, however, attempts to standardize a procedure failed due to a lack of a sufficient data base and reproducible with adequate correlation to the real performance of field.

Not much different, the Associação Brasileira de Normas Técnicas (ABNT) also does not have a test method for the avaliation of DEF in cementitious materials.

There are long-term test methods, such as the method of the LCPC [7], where samples are prepared in the laboratory so that try to simulate actual field conditions. However, long-term tests become unviable because of the long duration to obtain reliable data for a proper conclusion.

Already the accelerated tests, example of the Duggan Test (GRABOWSKI et al. [20]), which in counterpart are more distant from the real field conditions, present practical results in feasible time. It has as main advantage the short duration of 30 days, can be used to assess the expansive capacity of the concrete before use or to investigate the deterioration of existing concrete structures, giving an indication of potential expansion future due to DEF.

2.3 LCPC - Technical guide of prevention to the DEF

In Brazil, there is a not preventives guide or standards of procedures of execution of structures in concrete geared explicitly to the DEF. Only the NBR 11709:2010 - *Dormentes de Concreto - Projeto, materiais e componentes* specifies various characteristics for the concrete used in the manufacture of sleepers, for example the maximum temperature reached by the concrete together with the maximum content of SO_3, however, not specifies be the DEF the main cause for this specification (ABNT [21]).

Seen the lack of normative standards to prevention of DEF in concrete structures, the LCPC [7] recently established a technical guide to prevention of the DEF. The finality of this guide is providing recommendations of preventive measures for confection of concrete elements in order to mitigate the risks associated with DEF, over the service life of the structure.

The guide is based on the realization of cross-references between the category that describes the structure (or part thereof), as well as the level of acceptable risk and environmental actions that affect the structure (or part thereof) over its service life. This cross-reference step is to establish the necessary level of prevention, which determines the set of preventive measures to be implemented. Such measures depend sorely of the maximum temperature limit reached in the core of the structural elements, during the hardening of concrete and of choice of a better conception of concrete that is satisfactory.

Table 1 – Examples of structures or structural elements classified by category (adapted from LCPC (7))

Category	Examples of structures or structural elements
Category I (small or acceptable consequences)	• Structures made of concrete rated in a strength class of less than C16/20; • Non load-bearing building components; • Easily-replaced elements; • Temporary structures; • The majority precast non-structural products.
Category II (rather severe consequences)	• The load-bearing components of most buildings and engineering structures (including standard bridges); • The majority of prefabricated structural products (including pressurized pipes).
Category III (unacceptable or nearly unacceptable consequences)	• Buildings housing nuclear power plant reactors and cooling towers; • Dams; • Tunnels; • Exceptional bridges and viaducts; • Monuments and landmark buildings; • Railroads ties.

2.3.1 Category of the given structure or structural part

The guide groups the structures, or parts thereof, in three categories that represent the acceptable level of risk related to DEF, as shown in Table 1. The choice of structural category is the responsibility of the designer and depends on the type of structure, its purpose, the consequences of changes in the desired level of security, and lastly, its future maintenance (LCPC [7]).

2.3.2 Exposure classes relative to DEF

Depending on the degree of exposure of the structural element, the guide defines three exposure classes: XH1, XH2 and XH3 (LCPC [7]). These classes take into consideration the fact of that

Table 2 – Exposure classes of the structures related to DEF (Adapted from LCPC (7))

Exposure class designation	Environmental description	Informational examples to illustrate the choice of exposure class
XH1	Dry or moderate humidity.	• Part of a concrete structure located inside buildings where the ambient air humidity rate is either low or medium; • Part of a concrete structure located outside and protected from rain.
XH2	Alternation of humidity and dryness, high rate of humidity.	• Part of a concrete structure located inside buildings where the ambient air humidity rate is high; • Part of a concrete structure unprotected by a coating and exposed to inclement weather, without any water stagnation at the surface; • Part of a concrete structure unprotected by a coating and frequently subject to condensation.
XH3	In long-lasting contact with water: state of permanent immersion, water stagnation at the surface, tidal zone.	• Part of a concrete structure permanently submerged in water; • Maritime structural elements; • A large number of foundations; • Part of a concrete structure regularly exposed to water projections.

Table 3 – Choice of level of prevention (Adapted from LCPC (7))

Structure category | Exposure class of the structural part	XH1	XH2	XH3
Categoria I	As	As	As
Categoria II	As	Bs	Cs
Categoria III	As	Cs	Ds

the presence of water or high humidity is an essential factor for the development of the delayed ettringite formation. Table 2 shows a number of examples of structural elements classified according with their exposure environments.

2.3.3 Levels of prevention

Table 3 shows the four levels of prevention that have been established by the LCPC [7]: As, Bs, Cs and Ds. The prevention level is then determined based on the category and in XH exposure class applicable to said structure.

2.3.4 Precautions adopted based on level of prevention

Each of the four levels of prevention As, Bs, Cs and Ds corresponds to a specific type of precaution to be implemented. The prevention principle is based basically on limiting the maximum temperature T_{max}, capable of being reached inside the structure and also, if hit, the maintenance time of this (LCPC) [7].

• Level of prevention As (T_{MAX} < 85°C)
For this level of prevention, the risk relative to the delayed ettringite formation must be taken into account by means of the following precaution:

- The temperature T_{max} capable of being reached within the structure must remain less than 85°C.
- In the case of heat treatment realized in precast elements is authorised to exceed temperature T_{max} = 85°C by a rise of up to 90°C, provided that the duration during which the temperature remains above 85°C is limited to 4 hours.

• Level of prevention Bs (T_{MAX} < 75°C)
For this level of prevention, the risk relative to the delayed ettringite formation must be taken into account by means of the following precaution:

- The temperature T_{max} capable of being reached within the structure must remain less than 75°C.
- However, if the maximum temperature reached within the concrete cannot be maintained below 75°C, then it must never exceed 85°C and at least one of the six conditions shown in Table 4 must be satisfied.

• Level of prevention Cs (T_{MAX} < 70°C)
For this level of prevention, the risk relative to the delayed ettringite

Table 4 – Adaptation to the Brazilian cements of six conditions of use, when the temperature limit is exceeded (Adapted from GODART and DIVET (11))

Condition I	Condition II	Condition III
1) Duration of the maintenance of the concrete above 75°C < 4 h for Bs and above 70°C < 4 h for Cs; 2) Equivalent active alkalis of the concrete < 3 kg/m³.	1) Use of cements of RS class, with: a) For precast concrete: In the case of use of cements CP I, CP I S, CP V ARI and CP II F: Equivalent active alkalis of the concrete < 3 kg/m³; b) For cast in place concrete: CP I, CP I S, CP V ARI and CP II F are not accepted.	1) Use of cements of type CP III or CP IV; 2) SO_3 of cement < 3% and C_3A of the clinker < 8%.
Condition IV	**Condition V**	**Condition VI**
1) Use of fly ashes, slags, calcinated natural pozzolans or metakaolin in combination with a cement of type CP I, CP I S or CP V ARI; 2) Additions content > 20%; 3) SO_3 of cement < 3% and C_3A of the clinker < 8%.	1) Checking of the durability of the concrete with respect to DEF, by mean of the performance test and by satisfying the criteria.	1) For precast elements, the couple concrete/foresight heating is identical or similar to a couple concrete/heating having at least 5 references of use without any problem.

formation must be taken into account by means of the following precaution:

- The temperature T_{max} capable of being reached within the structure must remain less than 70°C.
- However, if the maximum temperature reached within the concrete cannot be maintained below 70°C, then it must never exceed 80°C and at least one of the six conditions shown in Table 4 must be satisfied.

• Level of prevention Ds (T_{MAX} < 65°C)

For this level of prevention, the risk relative to the delayed ettringite formation must be taken into account by means of the following precaution:

- The temperature T_{max} capable of being reached within the structure must remain less than 65°C.
- If the maximum temperature reached within the concrete cannot be maintained below 65°C, then it must never exceed 75°C with the greeting the following conditions:
- Satisfy the condition II in Table 4;
- Validation of the concrete mix design by an independent laboratory with expert credentials in DEF.

As to the condition VI, a satisfactory reference of use corresponds to the use of a concrete/heating pair for building a structure exposed to conditions that promote DEF development (environment XH2 or XH3) over a significant period of time (at least 10 years), during which absolutely no DEF-related disorder appears. Two concrete/heating pairs are considered to be analogous whenever the concrete mix designs closely resemble one another and especially when the conditions listed below have been met:

- Heating of the project mix design does not surpass heating of the reference design;
- C_3A and SO_3 contents in the project design cement do not exceed the C_3A and SO_3 contents of the reference cement ;
- The alkali contents of the two concretes do not differ by more than 10 %;
- Aggregates used in the two concretes are derived from the same origin;
- The component mix contents do not differ by more than 10 %.

3. Materials and experimental program

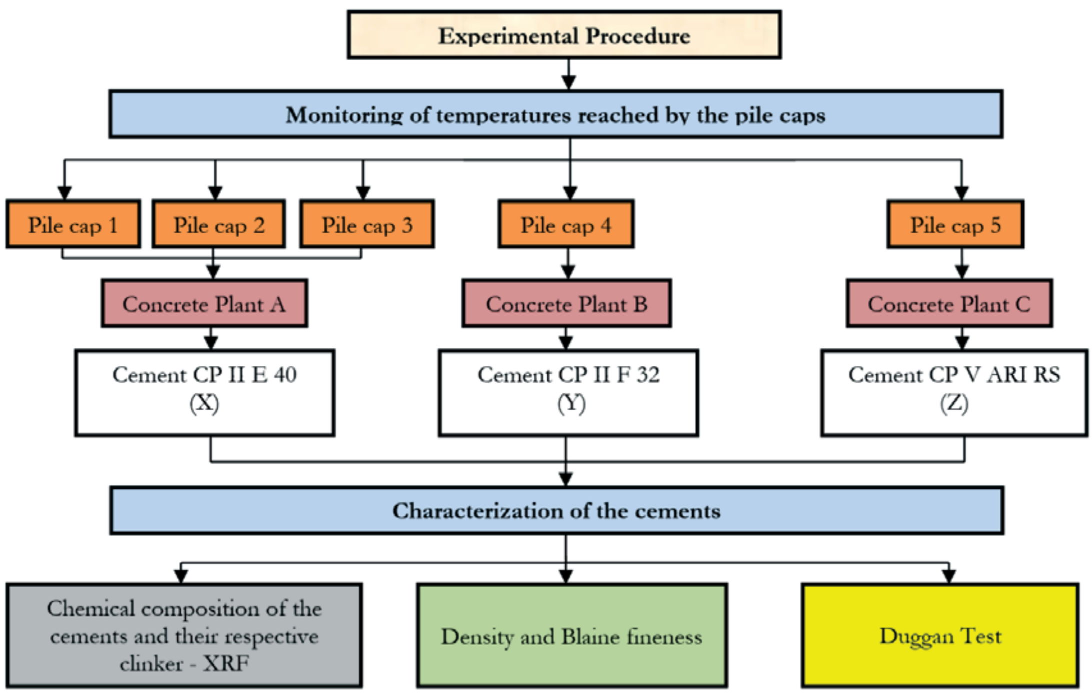
In this section is presented the experimental program this research, which describes all methods of instrumentation and monitoring the temperature of the pile caps, the characteristics of concrete and materials used in confection these and the equipments and experimental procedures used to perform the test Duggan.

Still, in order to comply to the objectives proposed in this research and feed all input data, required for risk classification and application in the LCPC preventive guide [7], is shown in Figure 1 a summary flowchart of the experimental sequence followed in this work.

3.1 Monitoring of temperatures reached by the pile caps

Was realized randomly the monitoring of the evolution of the

Figura 1 – Summary flowchart of the experimental sequence



temperature in a total of five pile caps foundation, scattered in four works attended for three ready mix concrete plants of the region.
The evolution curves of temperature x time of the concretes were obtained through instrumentation, by means of datalogger and thermocouples. A portable digital datalogger (Figure 2a) was used, model TM-947SD, manufactured by Lutron Electronic, with ability of four channels to thermocouple, resolution 0.1°C, with programmed frequency for data acquisition every 10 min over approximately 7 days.
Four thermocouples type "K" were used with exposed joint (Figure 2b), each with a total length of 5 m, three of which were allocated in specific positions of the pile caps: near the bottom, in the central core and near the surface. The remainder thermocouple was allocated outside the pile cap, with the objective of obtaining data of ambient temperature. Metal pipes were needed to aid in the correct placement and reuse of the thermocouple cables.
In all cases it was obtained the average temperature of the concrete at the time of casting, by means of a digital thermometer auxiliary TM-364 model, manufactured by the Tenmars, with capacity of two channels for thermocouple, resolution of 0.1°C (Figure 2c).
The details about the composition of the concretes used in the pile caps in study are shown in Table 5. Already the geometric details (in meters) and the allocation points of the thermocouples in each pile cap are shown in sketch and real, in Figures 3 and 4, respectively.

3.2 Characterization of the cements

To realize this step was collected in ready mix concrete plants A, B and C all materials (cement, fine aggregate, coarse aggregate, mineral additions) used as inputs to the concretes in question. In the same period they were also collected the clinker in the cement factories.

3.2.1 Chemical composition of the cements and their respective clinkers – XRF

To determine the chemical composition of oxides of the cements and the potential composition of their respective clinkers were realized chemical analysis by fluorescence X-ray (XRF) in mineralogy laboratory of the Associação Brasileira de Cimento Portland (ABCP).

3.2.2 Density and Blaine fineness

This step of the characterization was performed in the laboratory Portland cement of TECOMAT - Tecnologia da Construção e Materiais.
The density of cement were obtained according method specified in NBR NM 23 - *Cimento Portland e outros materiais em pó - Determinação da massa específica* (ABNT [22]).
To obtain the specific surfaces of the cements, we used the method specified in NBR NM 76 - *Cimento Portland - Determinação da finura pelo método de permeabilidade ao ar (Método de Blaine)* (ABNT [23]).

3.2.3 Duggan Test

Was utilized the Duggan test as testing methodology for the detection of potential deleterious expansion in the studied concretes due to DEF, because it is a fast method that lasts only 30 days and that will replace the method proposed by the LCPC, which lasts at least 1 year. It is noteworthy that the expansion in Duggan test is not due to AAR or recovery from drying shrinkage, caused by the thermal cycle through by water absorption on immersion. The main cause of expansion measured in the test is assigned to the DEF (GRABOWSKI et al. [20]). A flowchart of the sequence of activities performed in this research of the Duggan test is shown in Figure 5. The whole procedure described below was applied to the materials used distinctively for the three studied ready mix concrete plants, incorporating additions commonly found in the region, metakaolin (8% and 16%) and silica fume (5% to 10%), all substituting weight of the cement (o.w.c.), aiming their evaluation as to the potential mitigation of the expansions. As a matter of national standardization, in this work we were used molds whose dimensions are 100 x 100 x 400 mm and coarse aggregates were crushed and screened in fractions 12.5, 9.5 and 4.75 mm, unlike the original method which provides prisms of 75 x 75 x 350 mm and coarse aggregate crushed and screened in fractions of 14, 10 and 5mm. The temperature in the test room was maintained at 23±2°C. For crushing,

Figure 2 – Instrumentation used to monitoring of temperatures reached by the pile caps: a) Portable digital datalogger, b) Termocouple, c) Digital thermometer auxiliary

was used a jaw crusher, MAQBRIT brand, BM 10x6 model.
As prescribed by test method (GRABOWSKI et al. [20]), the concrete mix parameters are the following: cement = 475 kg/m³; coarse aggregate into three fractions of 292 kg/m³ each (total = 876 kg/m³); fine aggregate=656 kg/m³; w/c ratio = 0.40; and slump = 80±10 mm. All fine aggregates used in the assay were dried at 105°C. The coarse aggregates were used in the saturated surface dry (SSD) condition. The aggregates were broken up and bagged

Table 5 – Details of the concretes composition used in the manufacture of the pile caps in the study

PILE CAPS 1 and 2 (Concrete plant A)			
Cement	**Coarse aggregate**	**Fine aggregate**	
CP II E 40 (X)	Gravel 1 – Granitic rock	Quartz sand of fine cava + artificial sand from the crushing of granitic rock	
Cement content (kg/m³)	**Mineral addition**	**Rate w/c**	**f_{ck}**
400	Silica fume (5% o.w.c)	0.42	50
Admixtures			**Slump (mm)**
Additive composition: stabilizer of hydration + plasticizer of normal set + 3rd generation superplasticizer.			180 ± 30

PILE CAP 3 (Concrete plant A)			
Cement	**Coarse aggregate**	**Fine aggregate**	
CP II E 40 (X)	Gravel 1 – Granitic rock	Quartz sand of fine cava + artificial sand from the crushing of granitic rock	
Cement content (kg/m³)	**Mineral addition**	**Rate w/c**	**f_{ck}**
361	Silica fume (5% o.w.c)	0,48	40
Admixtures			**Slump (mm)**
Additive composition: stabilizer of hydration + plasticizer of normal set			100 ± 20

PILE CAP 4 (Concrete plant B)			
Cement	**Coarse aggregate**	**Fine aggregate**	
CP II F 32 (Y)	Gravel 1 + 2 – Cataclastic rock	Natural quartz sand	
Cement content (kg/m³)	**Mineral addition**	**Rate w/c**	**f_{ck}**
369	Metakaolin (≈ 12% o.w.c)	0,48	40
Admixtures			**Slump (mm)**
Uninformed			100 ± 20

PILE CAP 5 (Concrete plant C)			
Cement	**Coarse aggregate**	**Fine aggregate**	
CP V ARI RS (Z)	Gravel 0 + 1 – Granitic rock	Natural quartz sand	
Cement content (kg/m³)	**Mineral addition**	**Rate w/c**	**f_{ck}**
430	Metakaolin (% uninformed)	0,48	40
Admixtures			**Slump (mm)**
Uninformed			100 ± 20

Figure 3 – Geometric details of the pile caps and allocation of the thermocouples: a) Pile cap 1, b) Pile cap 2, c) Pile cap 3, d) Pile cap 4, e) Pile cap 5

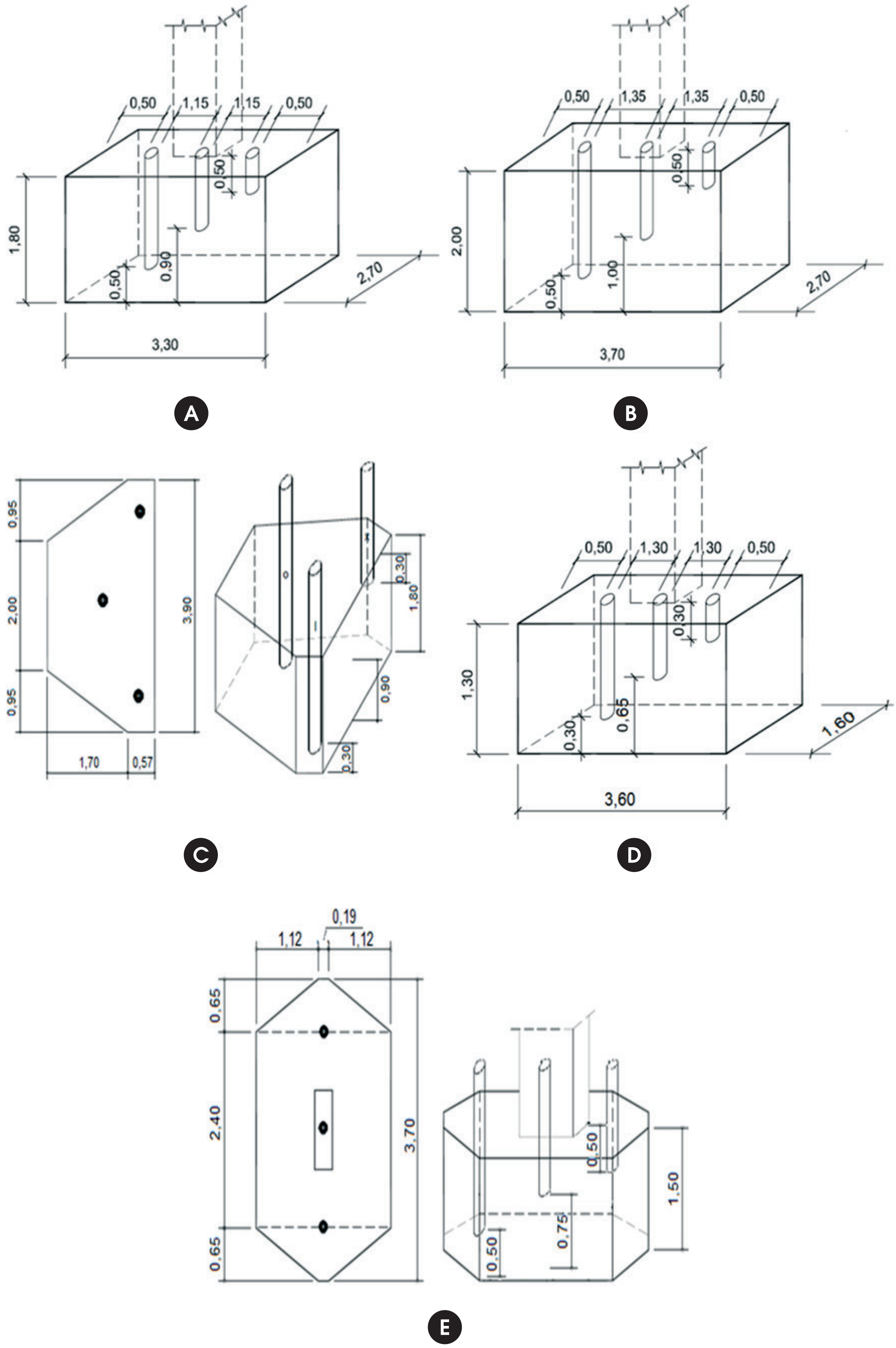


Figure 4 – Real details of the geomety of the pile caps and allocation of the thermocouples: a) Pile cap 1, b) Pile cap 2, c) Pile cap 3, d) Pile cap 4, e) Pile cap 5

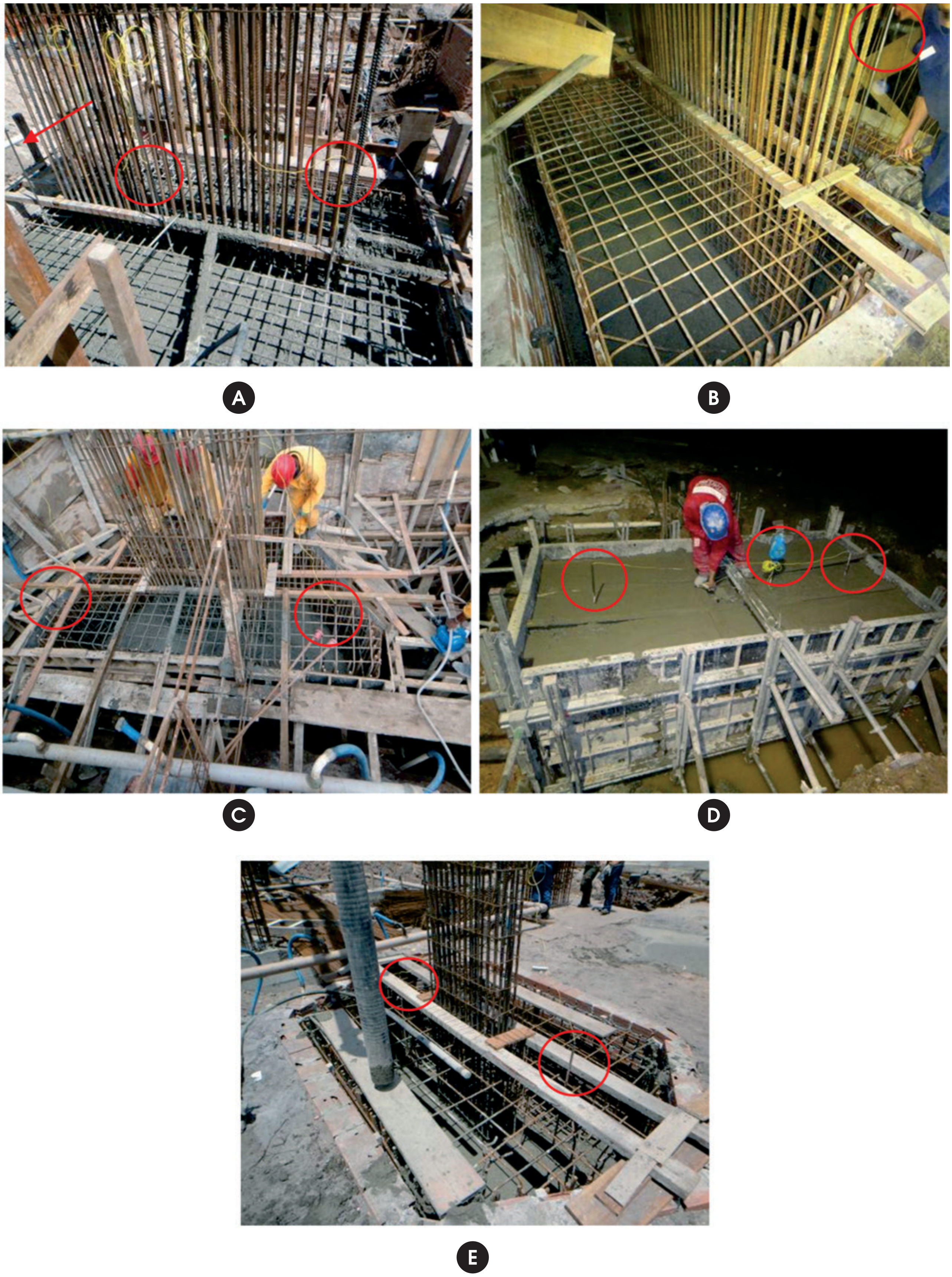
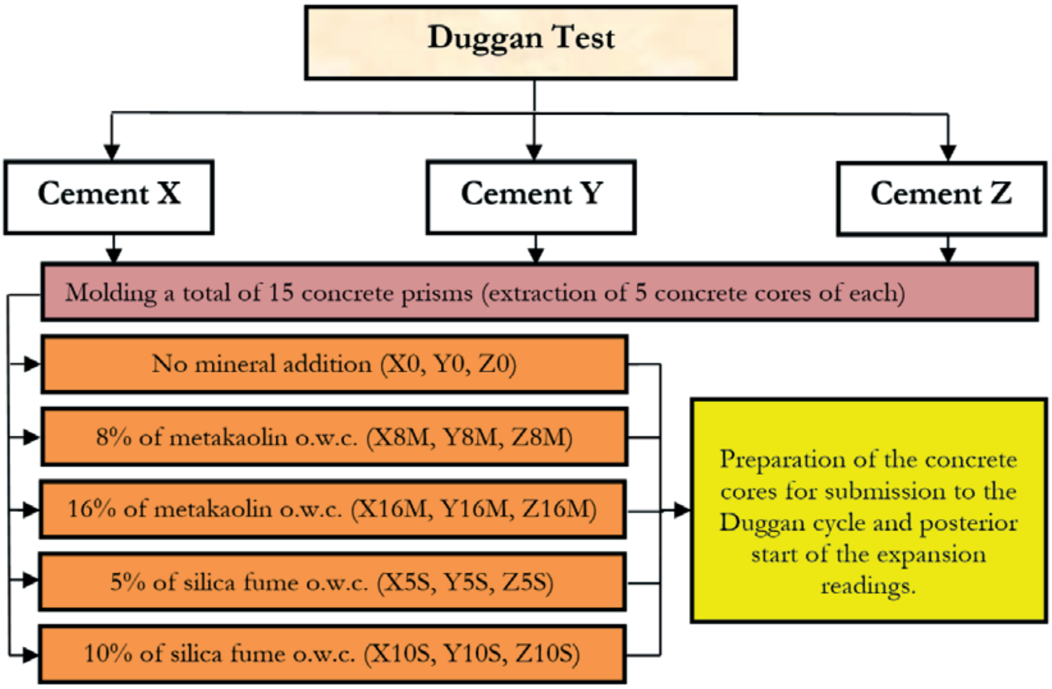


Figure 5 – Flowchart of the sequence of activities of the Duggan test



in quantities sufficient to make moldings of 15 concrete prisms and their individual slump measures.

In order to avoid loss of material, was used a planetary mixer of big volume to replace the common mixer. Cements, additions and water were weighed at the time of molding. All dried material was pre-homogenized manually with the aid of spatula and the time chosen mechanical mixing was set so as to obtain homogeneity in the mixtures: 2 min at low speed followed by 2 min at high speed.

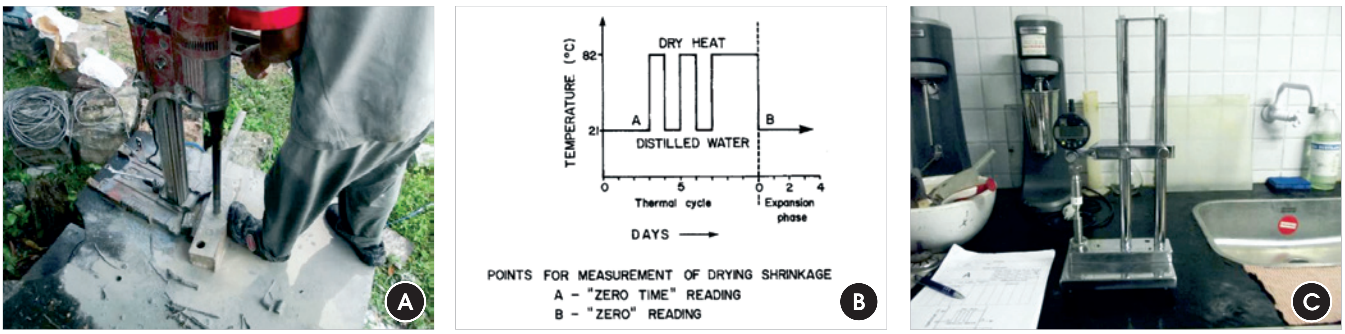
Because of the slump specified in 80±10 mm, it was used super-plasticizer 3rd generation polycarboxylate-based for possible fixes of slump. The additive dosages ranged between 0.0 and 0.6% on weight of cement.

It was used immersion vibrator in consolidation and molding of prisms. The mold was filled with only one layer of concrete and was consolidated at three equidistant points along the prism.

After molding, the prisms were subjected to accelerated thermal cure after 2-hour pre-cure at room temperature. The accelerated conditions include a ramp at 2 h the temperature reaches 85°C and then remain 4 hours at 85°C, followed by cooling to room temperature overnight in the oven. At the end of the thermal cure, all prisms followed for release and extraction of 5 cores on each prism. The extraction of the concrete cores was performed with the aid of Hilti drill machine and diamond drill, as shown in Figure 6a.

The Duggan method establishes the dimensions of the concrete core: 25 mm in diameter and 50±5 mm long. Thus, at the end of extraction, all concrete cores went for preparing. It was done the cut with help of jig and diamond saw in order to framing in the specified length. Posteriorly the holes are made in each core, with the aid of a jig, adapted in a bench drill so that they were maintained plumb and the absence of eccentricity. Made the holes, all concrete cores were dried with compressed air pistol aid.

Figure 6 – Steps of the Duggan test: a) Extraction of the concrete cores through drill Hilti, b) Thermal cycle used in the Duggan method (GRABOWSKI et al (20)), c) Equipment provided with dial indicator to realization of the expansion readings of the concrete cores



After drying, it was verified with the aid of caliper rule the depth of each hole so that it was obtained the effective gauge length, equivalent to the internal distance between the ends of the pins. The steel pins of low coefficient of thermal expansion (≤$2x10^{-6}°C^{-1}$) were fixed to the concrete cores by means of 330 Loctite adhesive, which has methacrylates as chemical base. The choice of this adhesive was made taking into account the cycles of wetting/drying and heating/cooling, proposed in Duggan test (GRABOWSKI et al. [20]), as shown in Figure 6b.

Fixed pins, the concrete cores remained immersed in distilled water for 3 days, and then being subjected to 3 cycles of heating/cooling and wetting/drying, specified in Duggan test, during for a period of 7 days. On completion of the cycle, the cores are then immersed in distilled water and measurements are performed during 20 days. Concrete cores tested by the method Duggan, which expand 0.05% or more after this time, indicate that the concrete has potential for deleterious expansion triggered by DEF (GRABOWSKI et al. [20]).

During the final period of immersion in distilled water, were realized the expansion readings. To perform these readings, is shown in Figure 6c the device used gifted of digital dial indicator, Mitutoyo brand, with a sensitivity of 0.001 mm and standard calibrator of nominal length of 80 mm, to perform the zeroing each set of 5 concrete cores. The testimonies were removed one by one of the distilled water and dried with towel. The reading was done making it a 360º spin in concrete core, in a counterclockwise direction, making the reading of the smallest value in the dial indicator.

4. Results and discussions

In this chapter are presented the results of the experimental procedure, as well as their analysis, which are geared towards the general objective of this research, confirming or not the hypothesis lifted.

4.1 Monitoring of temperatures reached by the pile caps

Follows in Table 6, a comparative summary of the thermal properties related to 5 pile caps of foundation monitored.

The Figure 7a presents the evolution graph of temperature *versus* time, referring to the pile cap of foundation 1. The average temperature of the concrete at the time of casting was 34.6°C. As expected, the highest temperature was recorded at point allocated in the core of pile cap 1. The peak temperature was 72.7°C and the maintainability time of the temperatures above 70°C was approximately 19.1 h. As the cement content was 400 kg/m³ and the thermal elevation gradient of 38.1°C, has a coefficient of thermal efficiency of approximately 0.095°C/kg/m³. Due to the low thermal conductivity of the concrete, the linear low rate of post-peak losses in the core was approximately 0.273°C/h or 6.56°C/day. The rate of pre-peak gain on the core was approximately 1.958°C/h.

The Figure 7b presents the evolution graph of temperature *versus* time, referring to the pile cap of foundation 2. In this case, the mean temperature of the concrete at the time of release was 35.1°C. As in pile cap 1, the highest temperature of pile cap 2 was recorded at point allocated in its core. The peak temperature was 75.0°C and the maintainability time of the temperatures above 70°C was

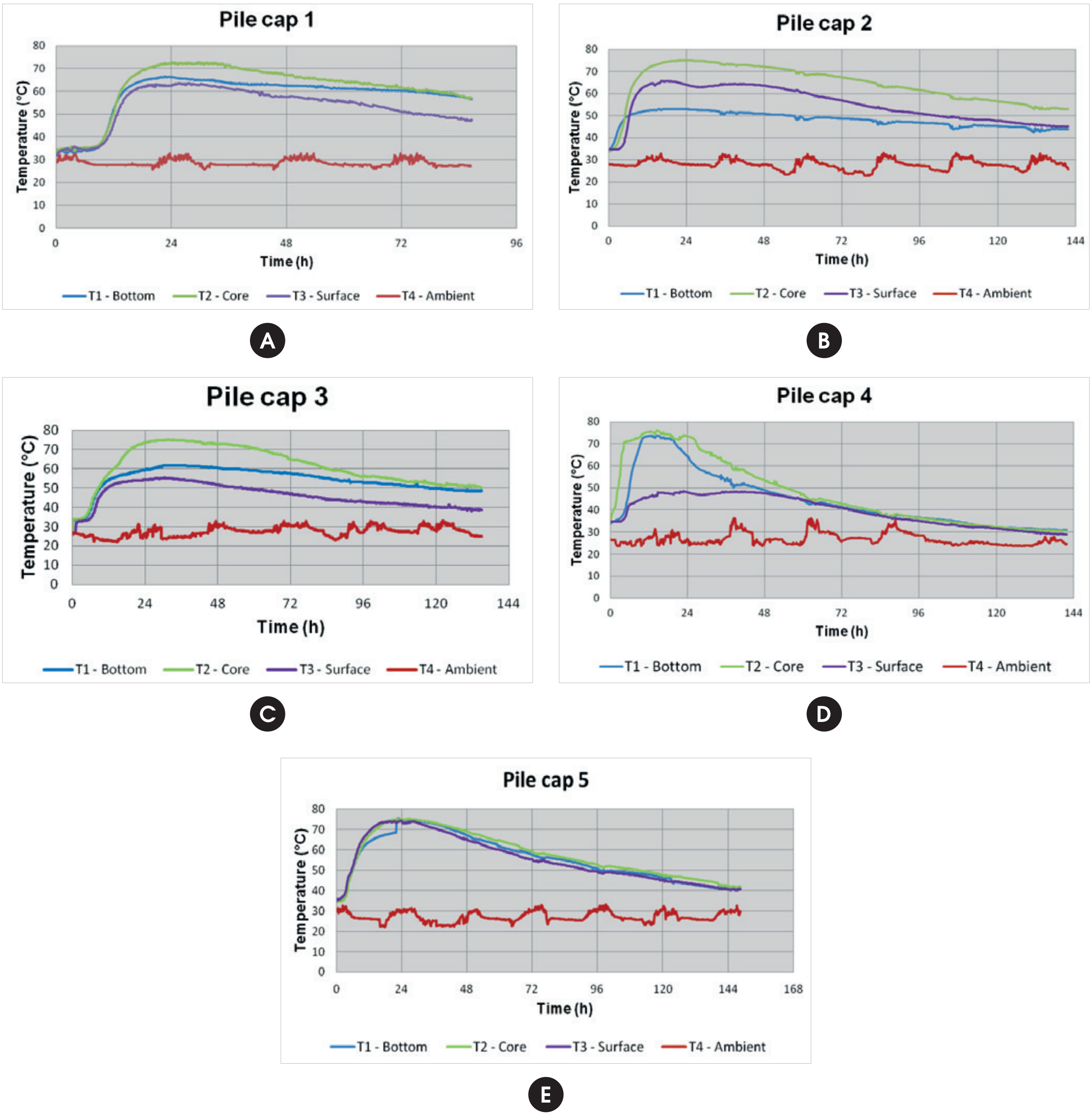
Table 6 – Comparative summary of characteristics and thermal properties of the monitored concretes

Characteristics	Pile cap 1	Pile cap 2	Pile cap 3	Pile cap 4	Pile cap 5
Cement type	X (CP II E 40)	X (CP II E 40)	X (CP II E 40)	Y (CP II F 32)	Z (CP V ARI RS)
Cement content (kg/m³)	400	400	361	369	430
f_{ck} (MPa)	50	50	40	40	40
Maximum temperature (°C)	72.7	75.0	75.0	73.7	75.3
Maintainability time - T≥70°C (h)	19.1	46.5	42.7	27.1	31.2
Average temperature of casting (°C)	34.6	35.1	33.0	35.3	35.4
Thermal gradient (°C)	38.1	39.9	42.0	38.4	39.9
Coefficient of thermal efficiency (°C/kg/m³)	0.095	0.100	0.116	0.104	0.093
Rate of pre-peak gain (°C/h)	1.958	1.836	1.447	2.798	1.654
Rate post-peak loss (°C/h)	0.273	0.204	0.270	0.322	0.271

approximately 46.5 h, value well above than the pile cap 1, possibly attributed to the greater volume of concrete of pile cap 2. As the cement content was 400 kg/m³ and the thermal elevation gradient of 39.9°C, has a coefficient of thermal efficiency of approximately 0.100°C/kg/m³. The linear rate post-peak losses in the core was approximately 0.204°C/h or 4.90°C/day, lower value than that occurring in the pile cap 1. The rate of pre-peak gain on the core was approximately 1.836°C/h.

The Figure 7c presents the evolution graph of temperature *versus* time, referring to the pile cap of foundation 3. In this case, the mean temperature of the concrete at the time of release was 33.0°C. As in previous pile caps, the highest temperature was recorded

Figure 7 – Graphs of evolution of temperature x time: a) Pile cap 1, b) Pile cap 2, c) Pile cap 3, d) Pile cap 4, e) Pile cap 5



at point allocated in its core of the pile cap. The peak temperature was 75.0°C and the maintainability time of the temperatures above 70°C was approximately 42.7 h. Despite the smaller volume of concrete, this value shows up well above of the maintainability time of pile cap 1. As the cement content was 361 kg/m³ and the thermal elevation gradient of 42.0°C, has a coefficient of thermal efficiency of approximately 0.116°C/kg/m³. The linear rate post-peak loss in the core was approximately 0.270°C/h or 6.47°C/day. The rate of pre-peak gain on the core was approximately 1.447°C/h.

The Figure 7d presents the evolution graph of temperature *versus* time, referring to the pile cap of foundation 4. The average temperature of the concrete at the time of release was 35.3°C. The highest temperature was also recorded at point allocated in its core of the pile cap. The peak temperature was 73.7°C and the maintainability time of the temperatures above 70°C was approximately 27.1 h. As the cement content was 369 kg/m³ and the thermal elevation gradient of 38.4°C, has a coefficient of thermal efficiency of approximately 0.104°C/kg/m³. The linear rate post-peak loss in the core was approximately 0.322°C/h or 7.72°C/day. The rate of pre-peak gain on the core was approximately 2.798°C/h.

The Figure 7e presents the evolution graph of temperature *versus* time, referring to the pile cap of foundation 5. The average temperature of the concrete at the time of release was 35.4°C. The highest temperature was also recorded at point allocated in its core of the pile cap. The peak temperature was 75.3°C and the maintainability time of the temperatures above 70°C was approximately 31.2 h. As the cement content was 430 kg/m³ and the thermal elevation gradient of 39.9°C, has a coefficient of thermal efficiency of approximately 0.093°C/kg/m³. The linear rate post-peak loss in the core was approximately 0.271°C/h or 6.51°C/day. The rate of pre-peak gain on the core was approximately 1.654°C/h.

It is notorious that in all cases, without exception, the pile caps reached temperatures above 70°C, able to achieve the level of 75°C, regardless of factors such as type and cement content, system type of form used, the volume of the concreted element, etc.

Still, as mentioned, the high temperatures have a fundamental role in the DEF and is widely accepted in the technical means which the concrete is susceptible to triggering this, when subjected to temperatures above 65-70°C [4, 5, 7, 8]. Therefore, of the thermal point of view, all the pile caps exceed the safe limit of temperature and therefore, are in a critical situation with respect to DEF.

Table 7 – Chemical and mineralogical composition of the clinkers X, Y and Z

Determinations	Clinker X (%)	Clinker Y (%)	Clinker Z (%)
CaO	63.11	61.00	59.54
SiO_2	19.44	18.22	17.90
Al_2O_3	5.51	4.62	3.51
Fe_2O_3	2.92	2.52	3.45
SO_3	1.98	1.92	1.94
MgO	3.14	4.73	10.32
TiO_2	0.24	0.31	0.23
SrO	0.06	0.06	0.09
P_2O_5	0.32	0.27	0.15
MnO	0.03	0.02	0.05
K_2O	1.29	0.63	0.94
Na_2O	0.06	0.11	0.12
Loss on ignition	0.76	4.48	0.59
Total	98.86	98.89	98.83
Na_2O Equivalent*	0.91	0.52	0.74
LSF* (Lime Saturation Factor)	100.27	104.81	105.24
SM* (Silica Module)	2.306	2.552	2.572
AM* (Alumina Module)	1.887	1.833	1.017
C_3S Bogue	67.91	75.15	77.77
C_2S Bogue	4.53	-4.43	-7.33
C_3A Bogue	9.66	7.98	3.46
C_4AF Bogue	8.89	7.67	10.50

(*): Na_2O Equivalent = Na_2O + 0,658.K_2O; LSF = CaO.100/(2,8.SiO_2 + 1,2.Al_2O_3 + 0,65.Fe_2O_3); SM = SiO_2/(Al_2O_3 + Fe_2O_3); AM = Al_2O_3/Fe_2O_3.

Table 8 – Chemical composition of the cements X, Y e Z

Determinations	Cement X (%)	Cement Y (%)	Cement Z (%)
CaO	56.72	62.25	63.40
SiO_2	20.13	18.65	19.04
Al_2O_3	5.47	4.41	5.01
Fe_2O_3	2.54	3.87	3.86
SO_3	3.55	3.28	3.04
MgO	3.29	0.52	0.62
TiO_2	0.28	0.25	0.25
SrO	0.06	0.24	0.01
P_2O_5	0.37	0.22	0.02
MnO	0.17	0.14	0.06
K_2O	1.02	0.49	0.22
Na_2O	0.09	0.07	0.04
Loss on ignition	5.50	4.78	3.97
Total	99.19	99.17	99.54
Na_2O Equivalent*	0.76	0.39	0.18

(*): Na_2O Equivalent = Na_2O + 0,658.K_2O .

4.2 Characterization of the cements

4.2.1 Chemical composition of the cements and their respective clinkers - XRF

The results for the clinkers respectives of the cements are shown in Table 7. Note that the SO_3 content in all the clinkers were very close and worth approximately 2%. As for the alkali content, there is a higher content in the X clinker, which possibly will reflect in the alkalis content of their respective cement.
As expected, the Z clinker, used in the manufacture of cement CP V ARI RS, presented higher C_3S content before others. However, this aspect not fundamentally reflected in the peak temperatures values reached by the monitored pile caps foundation, although the pile cap 5 made from this cement showed the highest peak temperature among them.
With respect to the negative C_2S content, it is reflex from the use of a SCF greater than 100, meaning that the CaO content in the clinker is higher than necessary, or even there no SiO_2, Al_2O_3 and sufficient Fe_2O_3 to react with CaO for the formation of basic compounds.
The X, Y and Z clinkers presented the total C_3A content of 9.66%, 7.98% and 3.48% respectively. The high values presented by clinkers X and Y may contribute to the DEF, and therefore, for the values for expansion of Duggan test. It is worth noting the low value presented by the Z clinker, which does not contribute in the ettringite formation compared to other clinkers.
The results for the cements are shown in Table 8. Note that the high content of SO_3 (> 3%) in all cements studied, being higher for the X cement (CP II E 40), which may influence the values of expansion obtained in the Duggan test. It is the X cement that also has the highest equivalent alkali content, a value well discrepant compared to others cements (0.76% for the X cement against 0.39% and 0.18% for Y and Z cements, respectively).
The amount of Fe_2O_3 is very similar in the cements Y (CP II F 32) and Z (CP V ARI RS), being well below in the X cement. This may result in greater susceptibility of the X cement to attack by sulfates due to DEF.

4.2.2 Density and Blaine fineness

The cements studied did not show great variation between their densities.
The Z cement (CP V ARI RS), showed higher fineness compared to the other cements. On the other hand, the X cement (CP II E 40) presented specific area much lower than the others, contrary to what was expected, because it is a class cement 40 and which requires a greater degree of grinding.
It is known that cement fineness is related to their reactivity, whereas, how much the thinner cement, the greater the contribution to the increase of the heat of hydration this (Mehta and Monteiro [10]).
Although the rate pre-peak gain of temperature was higher in pile cap 4, which used Y cement in its constitution, there was no significant correlation between the thermal behavior of the concretes and the fineness of its cements, since there are other influential aspects in the thermal behavior of these elements.
The results obtained of density and Blaine fineness are shown in Table 9.

4.2.3 Duggan test

The Figure 8a shows the graphic of the average expansion of 5 concrete cores *versus* time referring to the cement X (CP II E 40).

Table 9 – Densities and specific surfaces areas of the cements studied

	Cement X	Cement Y	Cement Z
Density ρ (g/cm³)	3.04	3.02	3.06
Specific surface area S (cm²/g)	3890	4670	4870

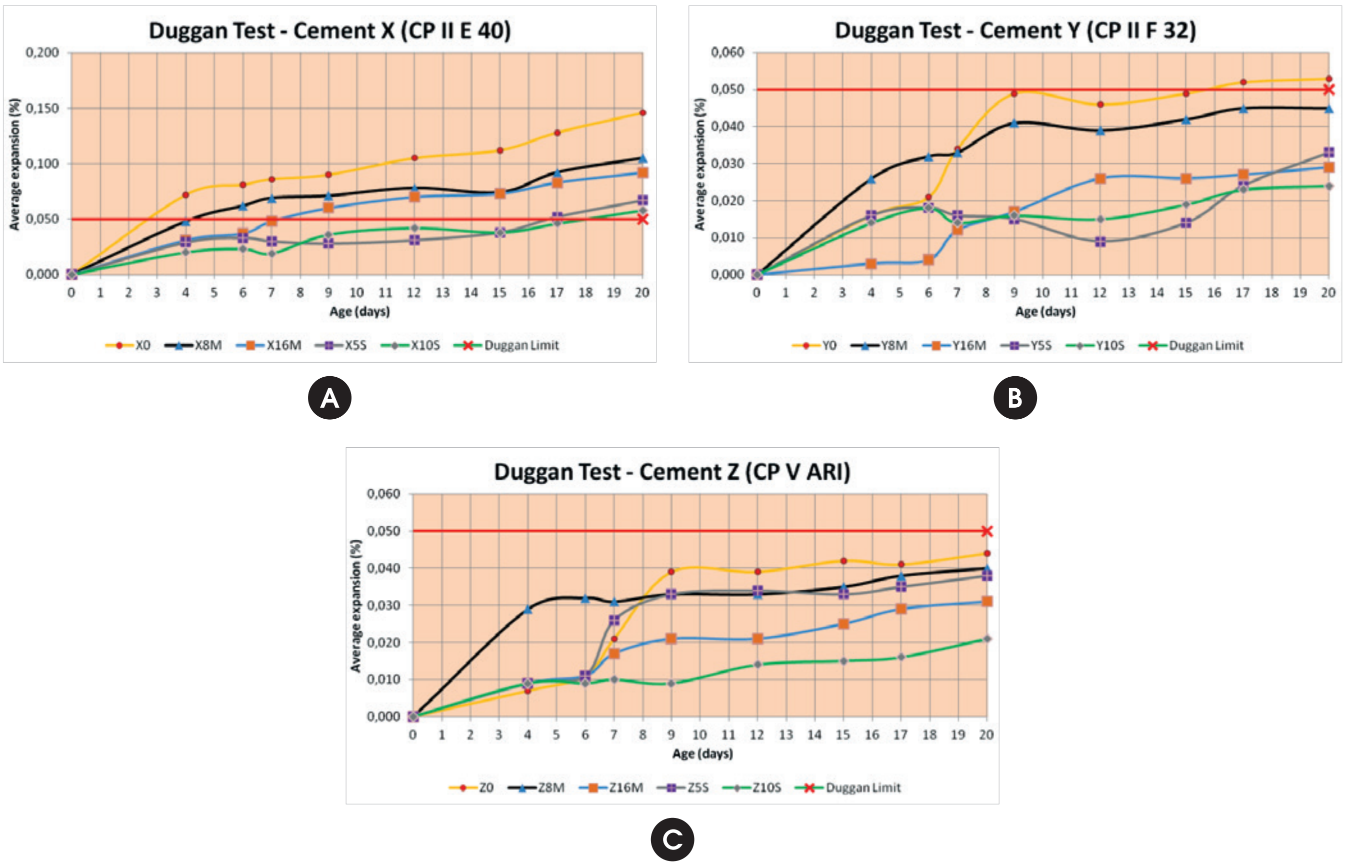
Is notorious which the high degree of expandability of the case X0, whose value at 20 days was 0.146%, well above the 0.05% limit specified by Duggan. This level of expansion was mitigated with use of mineral additions (metakaolin and silica fume), being lower in the case X10S, whose expansion was 0.058%, resulting in a 60% reduction in the average expansion of reference.

The expansion undergone by the concrete in the Duggan test confirms the analysis of chemical composition of this cement and their respective clinker. This degree of expansion can be attributed to various factors, such as: high C_3A content (9.66%) present in the X clinker and high contents of SO_3 and alkalis in the X cement (3.55% and 0.76%, respectively).

In Duggan test made with the Y cement (CP II F 32), the greatest degree of expansion occurred in the case Y0, as shown in Figure 8b, where the value at 20 days was 0.053%, also above the limit of 0.05% imposed by Duggan. The mineral additions also proved effective in the mitigation of the expansions, being lower in the case Y10S, whose expansion was 0.024%, resulting in a 55% reduction in the average expansion of reference.

The expansion undergone by the concrete in the Duggan test also confirms the analysis of chemical composition of this cement and their respective clinker. Despite the high C_3A content (7.98%) present in the Y clinker and of the SO_3 content exceeding 3% (3.28%), this has a low alkali content (0.39%), contributing to lower solubility of the ettringite and thus, to a greater impediment of the triggering of the DEF.

Figure 8 – Graphs of the average expansion of the 5 concrete cores versus time: a) Cement X (CP II E 40), b) Cement Y (CP II F 32), c) Cement Z (CP V ARI RS)



Already the Z cement (CP V ARI RS), the best was that behaved in Duggan test between sealers tested, according to the results shown in Figure 8c. Is notorious which this was the only cement, that no additions, showed lower expandability, although close to the 0.05% limit imposed by Duggan, whose value at 20 days were 0.044%. The lowest level of expansion also gave in the case Z10S whose expansion was 0.021%, resulting in a 52% reduction in the average expansion of reference.
The low level of expansion experienced by the concrete in Duggan test confirms essentially the chemical composition analysis of this cement and of their respective clinker. While treating of a cement CP V ARI, this being a tough cement to sulfates was which showed the smallest contents of compounds that enable the triggering of the DEF: low content of C_3A (3.46%) present in the Z clinker and low contents of SO_3 and alkalis in the Z cement (3.04% and 0.18%, respectively).

4.2.4 Framing of the pile caps in the LCPC guide

To better awareness of that the pile caps foundation of the Recife metropolitan region are critical regarding the DEF, these were framed in LCPC guide.
The 5 pile caps studied were classified in category II of the guide, which the consequences of a potential disorder would be quite serious. As for the exposure class, they were designated in XH3 class, which covers foundations that have lasting contact with water. Consequently, a Cs level of prevention is established in relation to the DEF, which establishes that the maximum temperature reached in the concrete is 70°C and, if not possible, this should never exceed 80°C and must satisfy at least one of the conditions of use set forth in Table 4. In Table 10, are presented the details of the framing of each pile cap.
The peak of temperature recorded in pile cap 1 was 72.7°C, while that in pile caps 2 and 3, these were equal to 75.0°C. Thus, it was not satisfied the Cs level of prevention expected. However, the value of 80°C was not exceeded and allows them to be evaluated according to the conditions of use.
The temperature maintainability time in the concrete of the pile caps 1, 2 and 3 was 19.1 h, 46.5 h and 42.7 h, respectively. All extrapolate the 4h limit allowed by the condition I, justifying the unsatisfactory condition.
It is noteworthy which the equivalent alkali content of 3.04 kg/m³ present in pile caps 1 and 2, which exceeds the limit value of 3 kg/m³. In pile cap 3, the value of alkalis is 2.74 kg/m³ and is well close to the threshold. The condition II is not satisfactory due to the fact that this cement will not be RS class and, according to manufacturer's information, has blast furnace slag content of around 16%. The contents of 3.55% of SO_3 in the cement and 9.66% of C_3A in the clinker exceeds the limits of 3% for the SO_3 in the cement and 8% for the C_3A in the clinker, does not satisfying the conditions III and IV.
Related to condition V, was taken into account the Duggan test carried out on the cement without the use of additions, so that they obtained average value was 0.146% and this exceeds the limit of 0.05% proposed by Duggan. However, it is important to note that the incorporation of mineral additions had mitigator effect in the expansions assigned to the DEF. The condition VI is not applicable because it is not precast element.
In pile cap 4, the peak of temperature was 73.7°C. Thus, it was not satisfied the Cs level of prevention expected. However, the value

Table 10 – Framing of the pile caps fundation in the LCPC guide

Characteristics	Pile cap foundation				
	1	2	3	4	5
T_{max} (°C)	72.7	75.0	75.0	73.7	75.3
$t_{maintainability}$ (h)	19.1	46.5	42.7	27.1	31.2
Alkali content equivalent (kg/m³)	3.04	3.04	2.74	1.44	0.77
Type of cement	CP II E 40	CP II E 40	CP II E 40	CP II F 32	CP V ARI RS
SO_3 of the cement (%)	3.55	3.55	3.55	3.28	3.04
C3A of the clinker (%)	9.66	9.66	9.66	7.98	3.46
Duggan test (%)	0.146	0.146	0.146	0.053	0.044
Condition of use	**Situation**				
I	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory
II	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory
III	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory
IV	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory
V	Unsatisfactory	Unsatisfactory	Unsatisfactory	Unsatisfactory	Satisfactory
VI	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

of 80°C also was not exceeded and allows them to be evaluated according to the conditions of use established in Table 4.

The temperature maintainability time in the concrete of the pile cap 4 was 27.1 h, which far exceeds the 4-hour limit allowed by the condition I, justifying the unsatisfactory condition. The condition II is not satisfactory due to the fact of this type of cement will not be accepted for concrete molded in loco. The contents of 3.28% of SO_3 in the cement exceeds the limit value of 3% and the value of 7.98% of C_3A in clinker equals to limit value of 8%, so that does not meet the conditions III and IV.

Related to the condition V, was taken into account the Duggan test carried out on the cement without the use of additions, so that they obtained average value was 0.053% and this exceeds, although very close, the limit of 0.05% proposed by Duggan. However, it is important to note that the incorporation of mineral additions also had a mitigator effect in the expansions assigned to the DEF, including being smaller than the reference value set by Duggan. The condition VI is also not applicable because it is not precast element.

In pile cap 5, the peak of temperature was 75.3°C. Thus, it was not satisfied the Cs level of prevention expected. However, the value of 80°C also was not exceeded and allows it to be evaluated according to the conditions of use established in Table 4.

The temperature maintainability time in the concrete of the pile cap 5 was 31.2 h, which greatly exceeds the limit of 4h permitted for the condition I, justifying the unsatisfactory condition. The condition II is not satisfactory due to the fact of this type of cement will not be accepted for concrete molded in loco. The condition III is not satisfied, because it is not cement CP III or CP IV and the SO_3 content in this cement was 3.04%, surpassing, even a little, the limit value of 3%. It is important to note the very low C_3A content in clinker (3.46%). Related to the condition V, the average value obtained in Duggan test was 0.044%, being the only one among the cements studied, than remained below the limit value without the use of mineral additions. Still, incorporation of additions also had a mitigator effect on expansions assigned to the DEF. The condition VI, as in all other cases, it is not applicable because it is not precast element.

5. Conclusions

The results of the present study confirm the risk of triggering of the DEF in foundation pile caps of the metropolitan region of Recife. All factors related to thermal properties and chemical composition of the concretes used in the region converge for a condition of ideal susceptibility in triggering DEF these elements.

All the pile caps, without exception, exceeded the safe limit of 70°C, and still, they remained many hours above this limit, exceeding the value of 4h defined in LCPC preventive guide. The level of peak temperatures of these showed no dependence on factors such as type, fineness and cement content, lithological type of aggregate, type of formwork system used, volume of concreted element, etc.

As for the chemical composition of X cement (CP II E 40) was which showed the higher content of C_3A in clinker and SO_3 and equivalent alkalis in the cement, so that these factors were of fundamental importance in the susceptibility to DEF of the concrete made with this cement. This fact was confirmed by the level of expansion of 0.146% presented at Duggan test.

Surprisingly, despite being a cement with a low content of additions, the Z cement (CP V ARI RS) was the only approved in Duggan test without the use of additions of metakaolin or silica fume. This is attributed to the low content of C_3A in the clinker (3.46%) and SO_3 (3.04%) and equivalent alkali (0.18%) in the cement.

Regardless of the content and type of cement, the mineral additions showed potential of mitigation of expansions assigned to the DEF. In general, the fume silica showed to be more effective than metakaolin, regarding to the reductio of the expansion due to the DEF in the concrete cores.

Due to the difficulty in the control of chemical parameters related to the cements, principally in constructions of small size of the region, is critical, in preventing DEF, the awareness of the thermal question and the establishment of the use of cements of the types CP III and CP IV, the possibility of reducing of the fck and cement content in the concrete, realization of the concreting of the elements by layers and until pre-cooling of concrete with the use of ice in partial substitution the water.

Conclusively, it is important the specification at design of minimum and basics requirements to avoid high temperatures in these concrete massive elements, preventing the delayed ettringite formation.

6. Acknowledgements

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