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# STRUCTURAL EFFECTS OF CHEMICAL EXPANSIVE REACTIONS IN CONCRETE

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## Extended Abstract

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# 1. ABSTRACT

Chemical reactions, either intrinsic or extrinsic, are one of the main causes for concrete's deterioration. The present dissertation consists on an analisys of the chemical expansive reactions in concrete, the alkalis – aggregate reaction, and the internal sulfatic reaction.

Unknown for a long time, recent studies have shown that these reactions can be a major cause for the reduction of the service life of the structures. Its effects can interfere irreversibly with the structural performance, leading sometimes to the demolition of the structure itself, in order to avoid major disasters.



**Key-words:**

Structural concrete; durability; structural safety; alkalis –aggregate reaction; internal sulfatic reaction


# 2. INTRODUCTION

In Portugal, the discovery of structures affected by internal expansive reactions is recent, but the type and number affected are already important enough to cause great interest in understanding its evolution in short to medium term, and hence their effect on the safety of concrete structures. This form of degradation, specifically the alkali-silica reaction (ASR) and internal sulfatic reaction (ISR), has affected mainly structures exposed to a severe environment, such as dams and bridges.

Therefore, the usual sections of columns bridges were modeled using the finite element method, in order to analyse what the effects on the structure are. Afterwards, the results of the models are compared to see which section was most affected by these reactions.

# 3. INTERNAL CHEMICAL EXPANSIVE REACTIONS IN CONCRETE

The internal chemical mechanisms of deterioration are intrinsic mechanisms that come from substances inside the concrete, which includes the reactions between alkali aggregates and internal sulfatic reactions. Here, the substances are present inside the concrete, and they migrate to the direction of the reactive substances, developing the reaction. One of the prime conditions to the existence of an internal chemical reaction in concrete is the presence of water, either in liquid form or gaseous form.

Reactions alkali - aggregate (RAA) are chemical reactions that develop among certain types of mineral aggregates, the alkali ions and hydroxyl (OH-) present in the interstitial solution of the cement paste in concrete. Such reactions occur as a consequence of the high solubility that certain amorphous, disordered or poorly crystallized silica forms presents in highly alkaline solutions. This reaction leads to the creation of a hygroscopic alkaline gel.

Generally, those reactions are highly expansive, leading to the development of internal stresses and consequent cracking of the concrete, and are often accompanied by the emergence of efflorescence and exudations on the concrete surface (Silva, 2005).

Consensually, three distinct types of alkali-aggregate reactions are named: alkali-silica reaction (ASR), with silicon atoms coming from silica aggregates (quartz, opal, caledonia, etc); alkali-silicate reactions, where the silicon atoms come from aggregate, where they are mixed with other elements under the silicate form (feldspats, pyroxenes, amphiboles, etc.) and alkali-carbonate reaction, involving certain dolomite's calcareous rocks. The last reaction, however, is very uncommon (Castro, et al.).

According to what was previously said about ASR, factors that promote its development in concrete are the following (Silva, 2005):

- Highly alkaline concrete's interstitial solution;
- Existence of reactive aggregates at concentrations within a critical range;
- High humidity.

It appears that ASR will only occur when all three conditions are met. Consequently, if one of these factors is missing, degradation of the concrete will not happen. In these situations, additional measures to prevent ASR are not required. The actual specifications attempt to exclude at least one of these factors in order to prevent ASR (Reis, et al., 1997).

In addition to the alkali-aggregate reactions, one can also mention the sulfatic reactions as another important cause of chemical deterioration of concrete.

The deterioration of concrete by sulfatic activity is known about a century ago, its origin being sometimes attributed to the constituents used in the manufacture of concrete. This pathology is named as internal sulfatic reaction (Soares, et al., 2008).

This reaction causes the expansion of the material, which can cause structural degradation problems, including cracking. This expansive phenomenon results from the formation of ettringite that under certain thermodynamic conditions features expansive characteristics.

The origin of the sulfates can be linked to several sources, namely late release of sulfate from the clinker, dissolution followed by reprecipitation of primary ettringite resulting from normal hydration of cement, or secondary or delayed ettringite formation (DEF) due to the effect of temperature, even though the latter type of ettringite is the only one that causes expansion of concrete.

The degradation caused by DEF has been found in particularly sensitive concrete composition when exposed to environments with frequent humidity and a relatively high heat treatment (> 70 º C), or exposed to equivalent temperatures for other reasons, such as massive pieces of concrete and concreting in the summer period. However, it appears that this type of degradation is detected essentially in prefabricated elements, and massive pieces of bridges/dams concreted in situ.

The formation of ettringite is considered the cause of most of expansions and the deterioration of concrete structures that are involved in sulfates attacks, not implying, however, that all attacks by sulfates necessarily cause the formation of ettringite. Indeed, there are many factors that influence the formation of this compound, for example, the constituents of concrete, specially the type of aggregates, the type of cement, the water / cement ratio and the mineral additions, as well as the humidity and temperature to which concrete is exposed (Soares, et al., 2008).

Thus, the internal sulfatic reaction (ISR) can manifest itself if:

- Concrete presents on its constituents anything that can work as a supplier of sulfates;
- Concrete has been submitted to a heat treatment (or too much heat developed during curing).

Moreover, the presence of the following factors is required (Soares, et al., 2008):

- Hairline cracks;
- Late release of sulfates;
- Presence of water.

According to various literature sources, the factors required for the expansion of concrete to occur are (Soares, et al., 2008):

- High concrete temperature;
- Presence of a certain amount of alkali in concrete, and aluminates and sulfates in the binder;
- Concrete being exposed to humidity;
- Presence of a certain amount of calcium hydroxide in concrete.

As mentioned earlier about the ASR, here it is imperative that all the above conditions meet in order to the internal expansive sulfatic reaction to manifest, otherwise it won’t occur.

# 4. STRUCTURAL ANOMALIES AS A RESULT OF INTERNAL EXPANSIVE REACTIONS

Typically, the detection of internal expansive reactions is firstly associated to a structural phenomenon visible on the surface of concrete, immediately identifiable by visual inspection, named cracking, which can affect, sometimes severely, the functionality of the structures.

Cracking associated with these reactions is often irregular (type "craquelet"), but it can also show a defined orientation when the compressive stress on the existing structure restrains cracking in random orientations. (Appleton, et al., 2010).

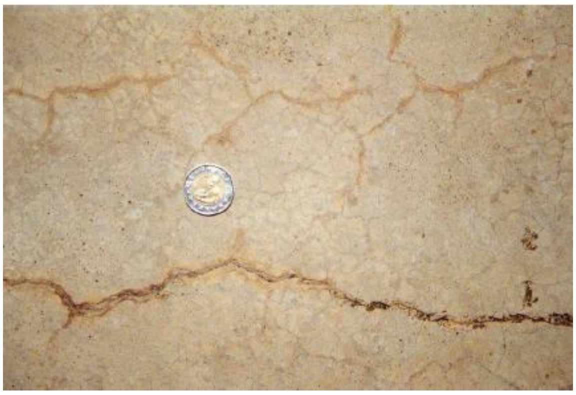

**Figure 0.1 - Cracking type "craquelet "on the pavement of a dam crest (Silva, 2010)**

Apart from the crack, some other structural degradation processes with extreme importance in structural safety can be identified, particularly, (Appleton, et al., 2010):

- Important deformations that reach more than 5 ‰ (500 x $10^{-5}$), which is equivalent to a temperature variation of 500 º C, which explains the severe damage observed in some constructions caused by these reactions;
- Corrosion of reinforcement with consequent loss of section, delamination and loss of section of the concrete, loss of steel-concrete adhesion and reduction of steel ductility;
- Introduction of tensile stresses on the reinforcement, to which the observed expansion deformation is imposed, crossing the cracks;
- Reduction of deformability characteristics (elastic modulus of concrete) and strength of concrete;
- Global expansion of the construction. On winter, the contraction due to temperature reduction is exceeded by far by the expansive reactions, favored by the high humidity during this period. This situation can cause crushing of the structure if the expansion is restrained, with huge resulting damage;

# 5. STRUCTURAL MODELING OF INTERNAL EXPANSIVE REACTIONS

As mentioned earlier, both internal expansive reactions lead to the expansion of concrete parts, as a result of the products formed during these reactions, leading to its cracking, subsequently influencing the structural performance.

In order to understand the structural effects resulting from internal expansive reactions on columns, numerical simulations applying the finite element models are presented and analyzed. In order to figure out which cross section is the most susceptible to these effects, the most common sections of the columns of bridges were analyzed before and after cracking of concrete, namely, the circular, diamond (hollow) and rectangular sections (Figure 2).

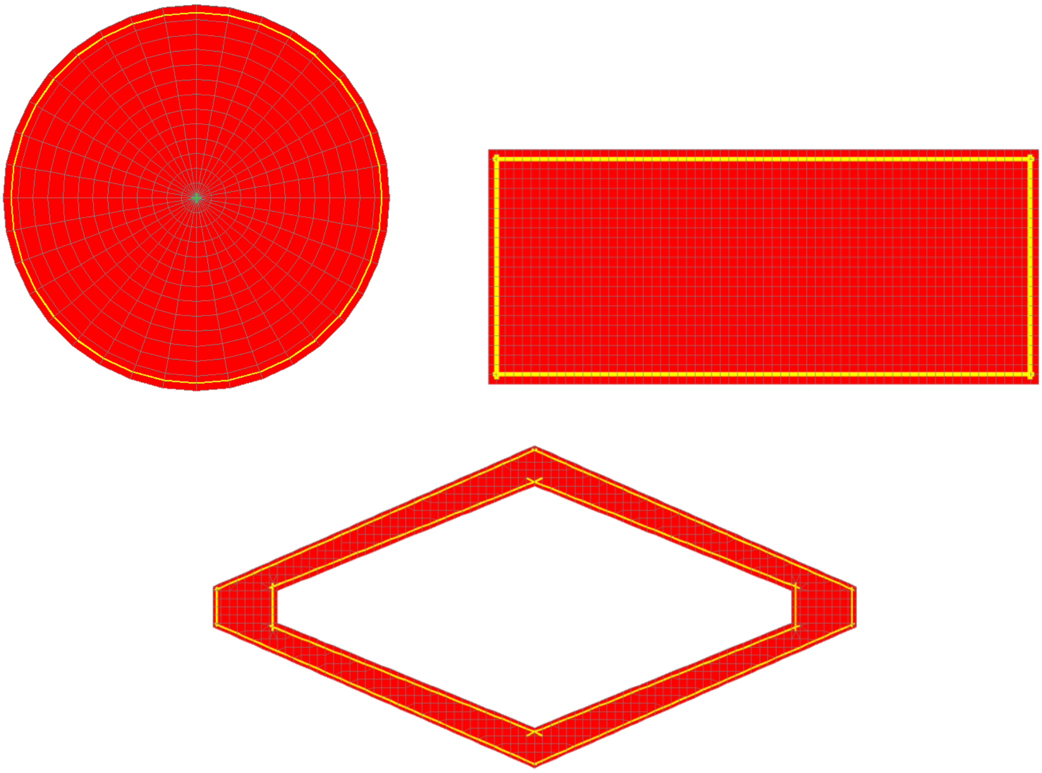

**Figure 2 - Analyzed models of the cross sections columns**

The expansive chemical reactions were modeled assuming that the expansion in concrete can be simulated as an imposed deformation on the concrete, such as a temperature variation. So, to each analyzed section's elements chosen randomly, is assigned a unit temperature variation which represents the expansion.

## 6.1. Presentation of results

Considering all the information collected from the modeling of the three sections, the values obtained were compared, in order to conceive what type of section would be the most affected by the occurrence of internal expansive reactions.

Starting by analyzing the tensile stresses obtained for the concrete, the results obtained show that the circular cross section is more influenced if IER occurs, as expected, followed by the diamond section, and finally the rectangular section as the least affected. These results show that, in the case of stress in concrete, and considering the change in temperature required to initiate the crack, the geometry of the section has an important role.

Indeed, for the circular section, where the effect of the geometry of the section is more effective, it appears that the early cracking occurs for lower values of temperature, and consequently for lower $\varepsilon_{IER,}$ compared to the other two sections, even though the values are very close to those observed for the diamond section. For the rectangular section, temperatures and $\varepsilon_{IER}$ values required for cracking of the concrete to occur are almost twice the ones mentioned previously (Figure 3).

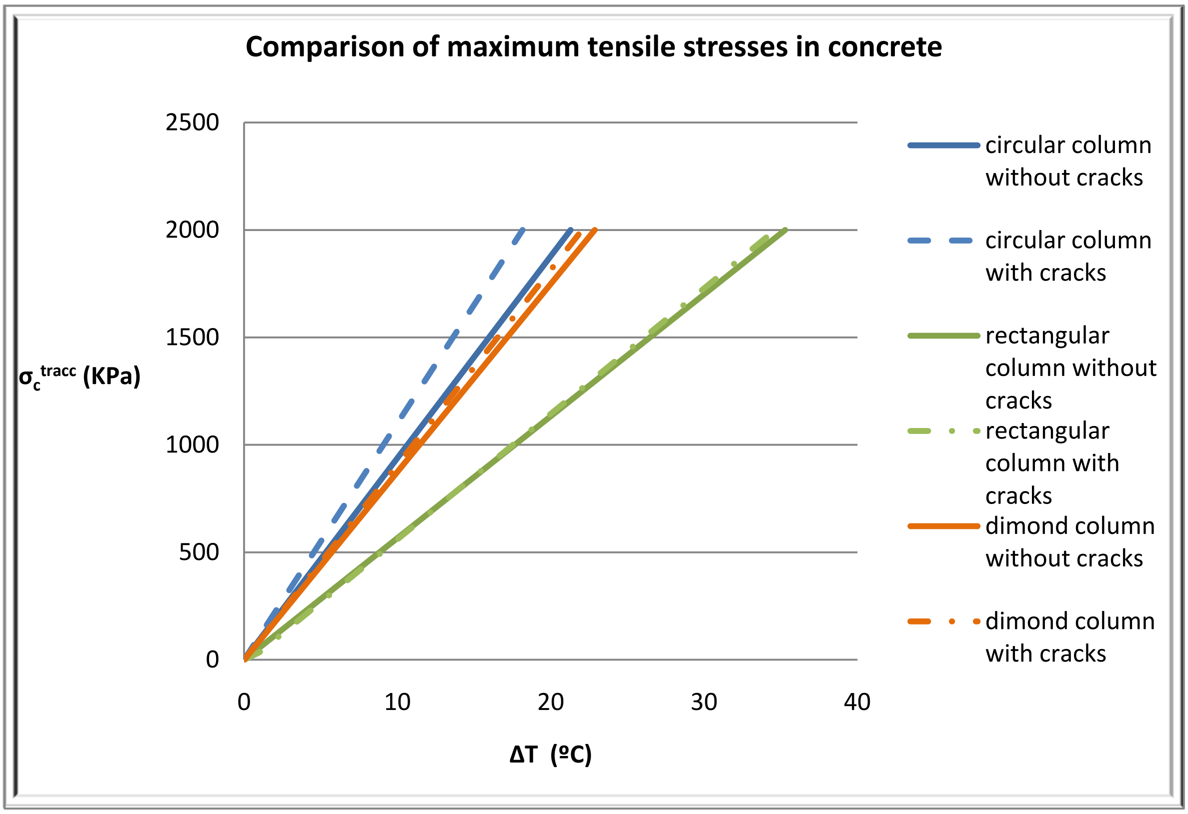


**Figure 3 - Comparison of maximum tensile stresses in concrete, in circular, rectangular and diamond sections before and after cracking**

In what concerns values of deformations obtained for the reinforcement, two situations were compared, for each section: averages tensions and peak stresses in the area of the cracks. The results are presented in figures 4 and 5.

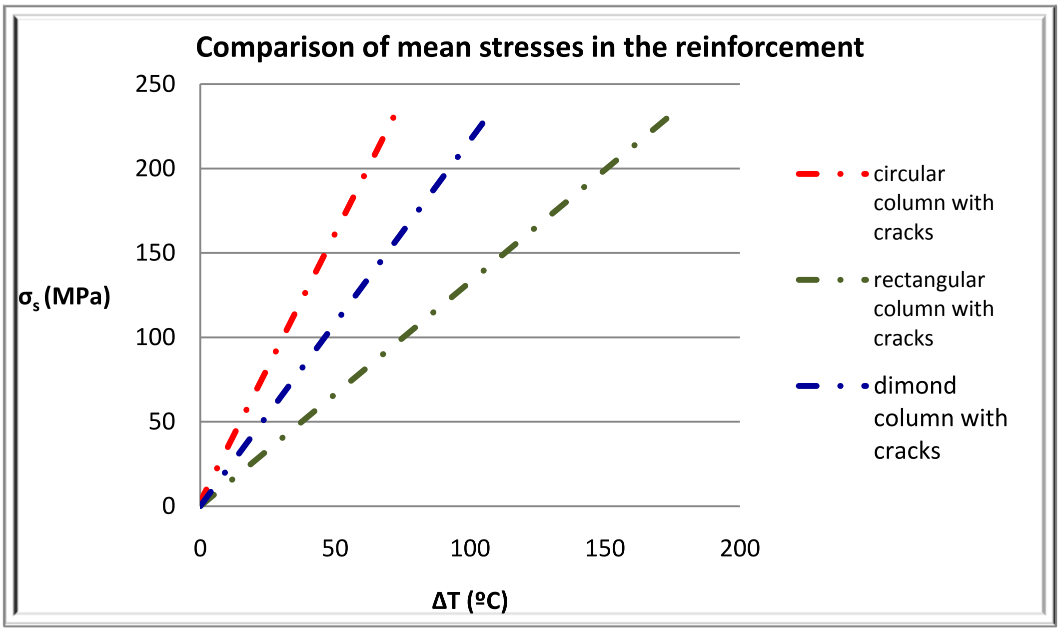


**Figure 4 - Comparison of mean stresses in the reinforcement of circular, rectangular and diamond sections after cracking**

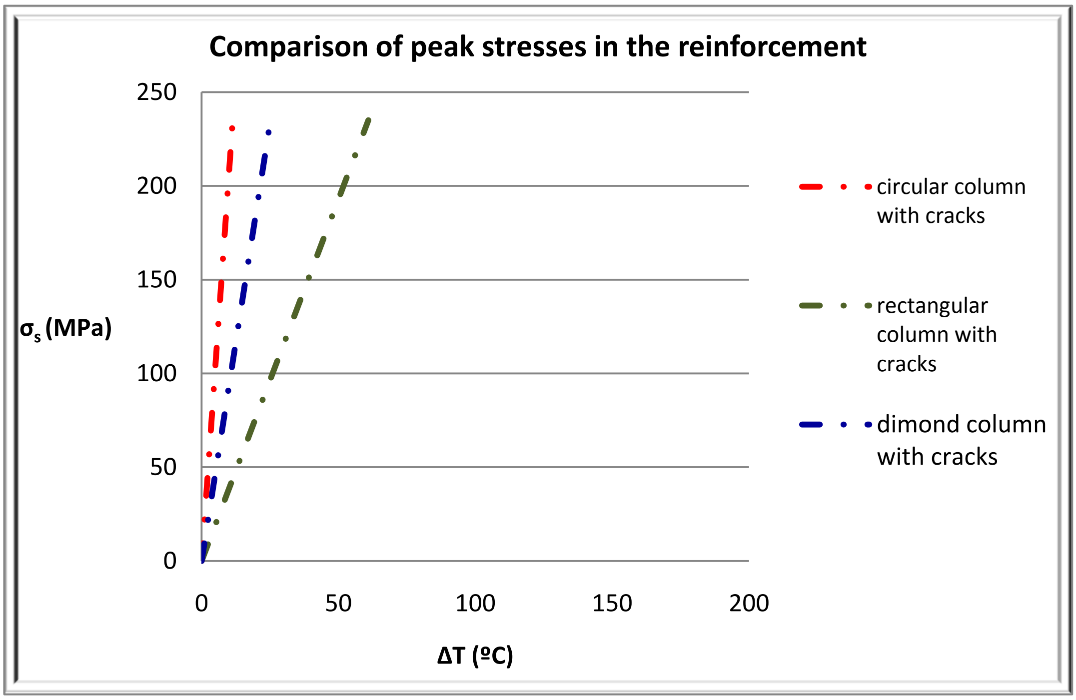


**Figure 5 - Comparison of peak stresses in the reinforcement of circular, rectangular and diamond sections after cracking**

Analysing the graphics above, the circular section turned out to be affected by a smaller change of temperature and, consequently a smaller extent $\varepsilon_{IER}$, in order to occur the yield of reinforcement. Actually, yielding occurs for values of only 41 ° C, ie a $\varepsilon_{IER}$ = 4.1 E-04, considering the average stress in transverse reinforcement, and a worrying value of about 12 ° C, corresponding to a $\varepsilon_{IER}$ = 1.2 E-04 in the case of peak stresses. Measurements in structures show that values of $\varepsilon_{IER}$= 0,035 occur frequently.

Finally, relevant extensions necessary for the yield of transverse reinforcement were compared. The results are exhibited in the table 1.

**Table 1 - Extensions necessary to the yield stirrups of each of the sections analyzed**

| Sections / Measures | IRE extensions |
|---|---|
| **Circular** | $1,14 \times 10^{-4}$ |
| **Rectangular** | $6,10 \times 10\text{-}^{4}$ |
| **Diamond** | $2,52 \times 10^{-4}$ |

Indeed, the lowest value is acknowledged in the circular column, followed by diamond hollow column, and finally the rectangular column, where the value is a little distant from the other two values, as a result of the effects of temperature and consequent IRE extensions.

Yielding of stirrups eliminates the effect of confinement of the concrete column and the constraints of the longitudinal bar, also removing the restriction of reinforcement to the opening of cracks in concrete. Consequently, the crack propagation due to the extent IER also leads to propagation of the cracks, eventually occurring the sectioning of the column, and inevitably a reduction of the resistance both for bending and shear.

## 6. CONCLUSION

The effects of internal expansive reactions in concrete have structural repercussions whose severity depends on the specific problem, in the worst cases leading to long-term collapse of further the structures strongly affected by it. In this abstract the results of the evaluation of structural effects of these reactions were presented in several sections of bridge columms.

During the first analysis of cross sections, we acknowledged, as expected, that tensile stresses are not supported by concrete, thus creating cracks. In what concerns sections analyzed, it was concluded that the circular section is the most affected, being the first in which it reaches the tensile stress of concrete, rectangular section appearing last. After this cracking occurs, tensile forces generated accumulate in the reinforcement. The modeling of the same sections, using cracked sections, in order to understand the behavior of the reinforcement when subjected to such stresses, was presented.

Effectively, the tensions in reinforcement actually increase, which means that these reactions can quickly lead to rupture of the transverse reinforcement of the columns. Similar to what happened in the analysis of the sections not cracked, the circular column is where the yielding of the reinforcement happens first, appearing the diamond's column coming in second and, finally, the rectangular column as the one where the yield stress of the reinforcement occurs last.

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