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INFLUENCE OF THE CRACKING PHENOMENON ON REINFORCED CONCRETE ELEMENTS IN SERVICE

BY

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Abstract. The cracking phenomenon can be defined as accidental or intentional production due to over-stressing and cracking in a material. For reinforced concrete elements in moderate aggressive environment, the measures taken into account when designing the structure must be adapted to achieve the longest possible service life.

There are also situations where the construction or certain structural elements are prematurely exposed to the cracking phenomenon. In practice, cracks are most often caused by mechanical, physical, chemical effects resulting from plastic shrinkage, fresh concrete compaction, corrosion cracks. In this paper are presented the main types of cracks, their causes and their influence on the structural elements of reinforced concrete in exploitation.

Keywords: cracking distribution; reinforcement: plastic compression; thermal variation; plastic shrinkage.

1. Introduction

Concrete can be defined as composite and microporous material composed of matrices and aggregates of different sizes, the two components working by virtue of bonding forces that are predominantly of physical nature.

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Studies and research show that there is no possibility of making non-cracked reinforced concrete elements.

Through a correct design and the adoption of an appropriate technology of execution, it is possible to exercise a rigorous control over the state of cracking in terms of reducing the number of cracks and opening them (Răpişcă *et al., 2003*). The crack can be defined as a discontinuity in the form of a small crack at the surface or inside a post-stressed material. Such an example is illustrated in Fig. 1.

Fig. 1 – Crack in the outer wall of the water tank.

The cracks in the concrete structure represent the paths available for the transport mechanisms and the points of initiation of the progressive deterioration. This thing considerably influences the durability of the concrete (Oneț *et al.*, 2000). Under normal operating conditions, when the structure of concrete is not presenting major deficiencies, cracks caused by direct actions or imposed deformations are accepted. This thing does not determine an unfavorable adverse effect if the opening size does not exceed a predefined value, depending on the service conditions (Farrar *et al.*, 2007).

The cracks divide the continuity of the internal structure, cause the rigidity of the elements to be altered, and reduce the active section of concrete that takes part in the uptake of stresses. Under these circumstances, the cross section should be enlarged. (Cadar *et al.*, 2004)

The causes leading to concrete cracking can be grouped into three categories:

a) deformations occurring inside the concrete to the extent that the contraction on drying, temperature variations, compression or plastic contraction are hampered to develop freely, and crack-generating stretching efforts are made;

b) expansion of reinforcement in concrete, in the case in which is exposed to corrosion;

c) imposed external actions, forces or displacements.

The parameters that influence the state of cracking are the following:

a) construction and reinforcement details;

b) composition and quality of concrete;

c) type and quality of the execution process.

Depending of the type of the load and the time when the concrete is putting into operation, the Fig. 2 shows approximately the duration when different types of cracks occur.

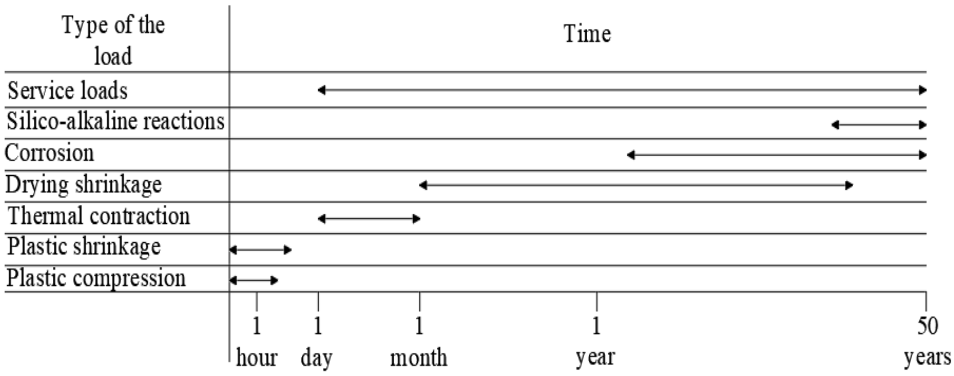

Fig. 2 – The cracking time under different load types.

The cracks occurring in reinforced concrete elements can be classified into two major categories depending on the factors that produce them:

a) cracks caused by external loads (Fig. 3);

b) cracks due to internal stresses (Fig. 4).

Under the action of external loads, the reinforced concrete elements in service present a series of cracks. These occur in large areas where the concrete elongation of the concrete is exceeded. The presence of cracks leads to the penetration of aggressive substances into the concrete mass, resulting in corrosion of the reinforcement.

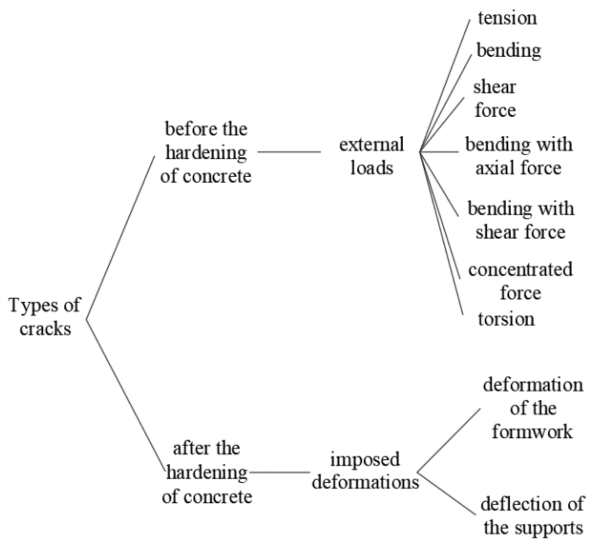

Fig. 3 – Types of cracks caused by external loads

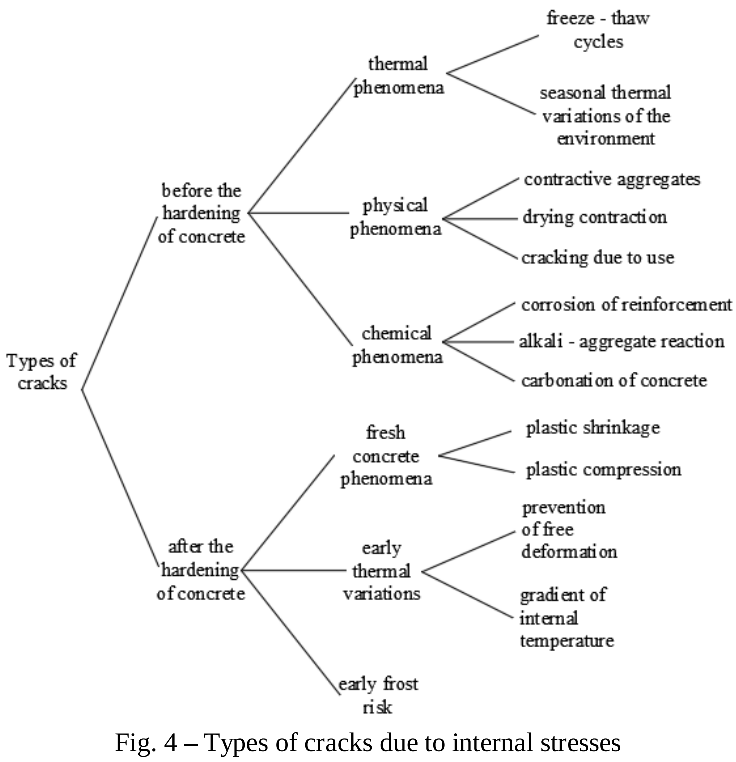

Fig. 4 – Types of cracks due to internal stresses

2. Cracks Due to Plastic Shrinkage

The plastic shrinkage represents a characteristic phenomenon of fresh concrete due to the capillary tension of pore water. This occurs in the first hours of preparation of the mixture. In the cement hydration process the phenomenon of internal water absorption by the clinker granules results in a reduction in the volume of cement plus water (Hobjilă *et al.*, 2000). Evaporation and loss of concrete water results in the contraction of the concrete, which can cause deep cracks. The process is illustrated in the Fig. 5.

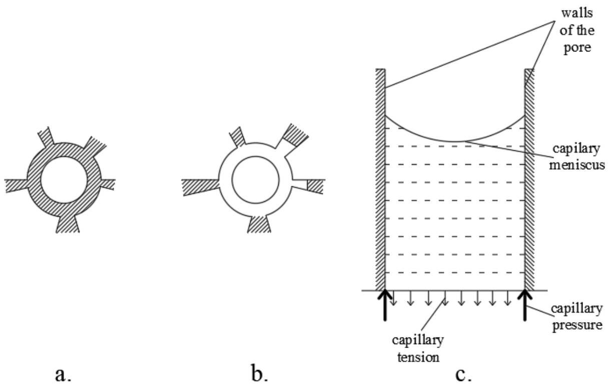

Fig. 5 – The action of water in narrow pores: (a) saturation; (b) drying; (c) capillary pressure.

The cracks resulting from the contraction of fresh concrete are fine and difficult to notice at the time of appearance. Such cracks develop, much deeper in depth than in width and along directions that intersect at angles close to 90°. (Zamfirescu *et al.*, 2003). Cracks produced by plastic shrinkage are characteristic for the slabs, an example of different types of cracks resulting from plastic shrinkage is shown in the Fig. 6.

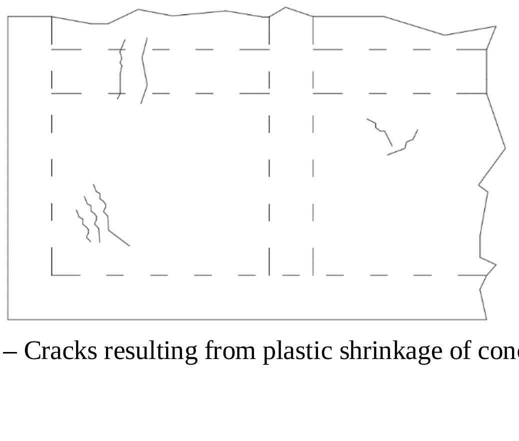

Fig. 6 – Cracks resulting from plastic shrinkage of concrete.

These cracks are parallel to the upper reinforcement when the concrete layer is low and the slab has not been properly wetted after casting. In the middle of the slabs, the cracks also appear at the top. The distance between the cracks increases with the thickness of the element, with the strength of the material and as the continuity bond between the building element and the support layer is altered.

3. Cracks Due to Plastic Compression

The cracks due to the plastic compression of fresh concrete occur in most cases in elements with higher heights (columns, beams). A reduction in concrete volume is caused by the migration of water to the surface of the fresh concrete. This phenomenon is called plastic compression (Zamfirescu *et al.*, 2003). This volume reduction is prevented by the presence of the formwork or reinforcements. In the case of reinforced concrete structural elements, longitudinal and horizontal cracks can appear in the reinforcement at the superior part or in the stirrups. An example is illustrated in the Fig. 7.

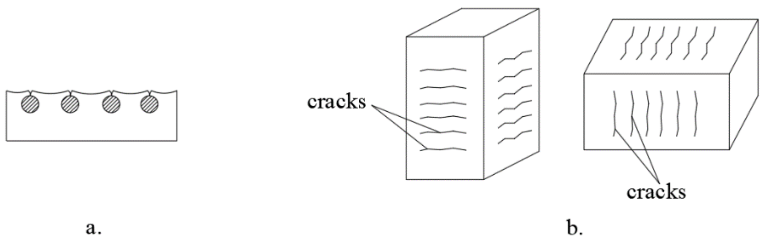

Fig. 7 – Cracks in structural elements.

In example a., between the adjacent reinforcements, horizontal cracks have been produced due to the compaction of the concrete leading to the separation of the concrete cover layer of the superior reinforcement. In example b., cracks resulting from the plastic compaction of the concrete are seen in front of the transverse reinforcement of pillars and beams. The cracks perpendicular to the direction of the reinforcements are less dangerous than those parallel to the reinforcements. In the first case, the corrosion develops at a reduced width and there is no risk of the concrete layer being detached.

4. Cracks Resulting from Thermal Variation

The main factors influencing the occurrence of cracks caused by the temperature difference are: water/cement ratio, wind intensity, external air temperature and humidity, the quality of the formwork, the dimensions of the reinforced concrete element (Oneț *et al.*, 2000). In reinforced concrete construction elements, thermal expansion generates internal compressive stresses, while thermal contraction generates internal stretching efforts. Differences in temperature are a frequent cause of cracks. The nature of the inner effort depends on the type of the structure of resistance and the position of the element within it.

The size of the expansion and thermal contraction deformers is influenced by the thermal properties of the concrete. The main thermal properties of concrete are: thermal conductivity, thermal diffusivity and thermal expansion (Ionescu *et al.*, 1997). The thermal conductivity represents the property of a material to conduct the heat. This property is influenced by many factors such as: the nature of the aggregates, the porosity and size of the aggregates, the cement dosage and the additions used, the moisture content. Thermal diffusivity represents the speed of temperature variations in the mass of the material. Thermal dilatation of concrete can be defined as the property of the concrete to expand its volume at the temperature rise. The phenomenon occurs due to the heat release which accompanies the hydration - hydrolysis processes of the cement.

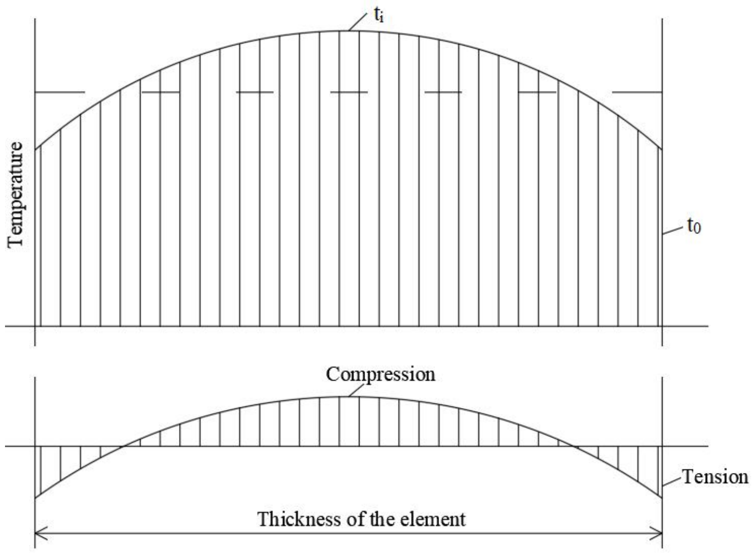

Fig. 8 – The distribution of the temperature in the thickness of a reinforced concrete element.

The temperature differences are a frequent cause of cracks. After casting the concrete, there is a risk of cracks on its surface. Tension stresses can occur in marginal areas, and compression forces can occur in the core of the element. (Zamfirescu *et al.*, 2003). The effort distribution is illustrated in the Fig. 8. These cracks are due to temperature variation between the surface and the core of the concrete element after stripping. If the tensile efforts exceed the tensile strength of the concrete, it will cause cracks.

Crack distribution will occur in an irregular manner on the surface of the element. Dimensions may vary between a few millimeters and may reach a few centimeters. In most cases, the cracks of reinforced concrete elements are not produced by the action of loads, but represent the effects of deformations caused by temperature variations. Under the effect of thermal cycles, temperature is one of the factors capable of causing severe damage. Thus, the development of cracks due to the action of temperature can produce the corrosion of the reinforcement.

5. Cracks Due to Corrosion of Reinforcement

In reinforced concrete elements, the corrosion of reinforcements represents an expansion process. Theoretically, the rust have a volume about 8 times larger than the steel or metal from which it originates. In conclusion, the expansion process causes cracking and detachment of the concrete (Ionescu *et al.*, 1997).

The influence of the opening of cracks on the corrosion rate of the reinforcement is relatively low when their opening does not exceed 0.4 mm (Budan *et al.*, 2010). Both carbon dioxide and chlorine can penetrate through cracks faster than non-dredged concrete, with the duration of over-expansion depending on the opening of cracks as in the Fig. 9.

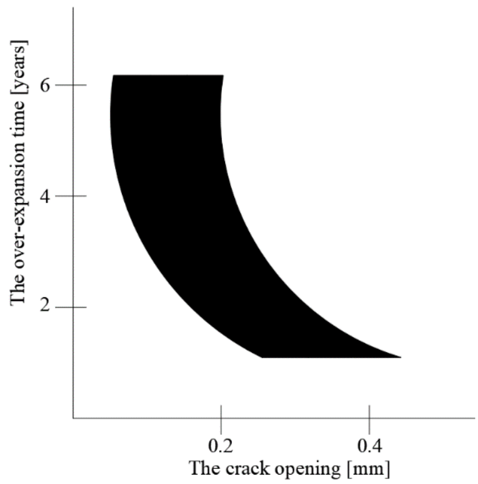

Fig. 9 – Relation between the crack opening and the over-expansion time.

The cracks oriented along the reinforcement, also called adhesion cracks, are far more dangerous than transversal cracks. In the case of transversal cracks, the corrosion is limited to a small area, and the danger of peeling of the concrete layer practically does not exist. (Rusu *et al.*, 1998). By observing corrosion cracks, the degree of corrosion allowed for normal operation can be determined.

6. Conclusions

The time of occurrence of the cracking phenomenon, seen as a destructive effect on the mechanical strength characteristics is variable. Verification at the crack boundary state will be considered as a conventional method of measuring and controlling the cracking.

Cracks appear inevitably in reinforced concrete structures. However, the crack width, orientation, magnitude and type can be controlled through the design, execution and maintenance phases. The use of a reduced number of larger diameter reinforcements and a corresponding concrete cover layer lead to more robust and more resistant structures, limiting the opening of the cracks.

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INFLUENȚA FENOMENULUI DE FISURARE ASUPRA ELEMENTELOR DIN BETON ARMAT ÎN EXPLOATARE

(Rezumat)

Fenomenul de fisurare poate fi definit ca fiind producerea accidentală sau intenționată datorată unei suprasolicitări şi a unei crapaturi înguste într-un material. Pentru elementele din beton armat situate în condiții de mediu cu agresivitate moderată, măsurile luate în considerare la proiectarea structurii trebuie adaptate pentru a obține o durată de exploatare cât mai lungă.

Există şi situații în care construcția sau anumite elemente structurale sunt expuse în mod prematur fenomenului de fisurare. În practică, fisurile sunt cauzate cel mai frecvent de acțiuni mecanice, fizice, chimice rezultate din contracția plastică, tasarea betonului proaspăt, fisuri din coroziune. În această lucrare sunt prezentate principalele tipuri de fisuri, cauzele şi influența acestora asupra elementelor structurale din beton armat aflate în exploatare.