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A case history of concrete degradation induced by an absorbing well

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Abstract. This case history concerns the severe degradation of concrete foundation plinths and piers of an about 35-year old building, imputable to sulphate attack promoted by sulphate-rich groundwaters. The presence of ettringite and thaumasite, near a significant amount of gypsum, was shown by X-ray diffraction analyses performed on ground concrete samples. Large gypsum crystals were mostly located at the interface between the cement paste and aggregates, as observed by scanning electron microscopy coupled to EDS microanalysis. An absorbing well located in the proximity of the building was recognized as the sulphate source. Consequences of this attack were a very poor bond-strength between cement paste and aggregates and a severe cracking of the concrete cover of the steel reinforcement.

Introduction

In this study the causes of a severe degradation of concrete foundation plinths and piers of an about 35-year old building located in the suburbs of Torino (Italy) have been investigated. The concrete appeared very severely deteriorated from the plinth level up to 2m. The bond-strength between the cement paste and aggregates was poor. The concrete cover of the steel reinforcement was, in many cases, cracked or even spalled off. The metallic reinforcement was corroded. From the geological maps, the soil on which this building insists does not contain gypsum and it was never crossed by industrial waste waters. However, once the building was located outside the limits of the urban sewerage system and for 15 years an absorbing well, located at about 9m from building foundations and 8m-deep, was used for collecting sewage. After then, it was disused but not eliminated. Stagnant water was still present on its bottom.

Because of the extensive concrete degradation, some preliminary sclerometric measurements were performed on the foundation plinths and piers. Two clear trends were put in evidence. Concrete strength increased from the plinth to the higher part of the piers and the lower values were observed on the plinths located in the proximity of the absorbing well (10-12 MPa), whereas at about 2.5 m from the plinth values of 15-18 MPa were measured. Part of the building not affected by this degradation presented strength of 35-40 MPa.

Experimental

For investigating the causes of the above degradation, representative concrete samples were collected from plinths and at different heights of the piers, namely at 1m and 3.5m from the plinth. X-ray diffraction analyses were performed on powdered materials, obtained by milling the entire concrete sample, whereas scanning electron microscopy (SEM) observations and microanalyses by energy-dispersive spectroscopy (EDS) were carried on as-collected samples.

In this paper the results obtained on the samples collected on the plinth and pier, showing the lower mechanical performances and more closely located by the absorbing well, are mainly presented.

Results and discussion

The plinth concrete samples were extremely wet. A mass loss of 15% after drying at 105°C was observed on the plinth nearer located by the well. Moving from it, the mass loss decreased to 12% and 5%, respectively at 2.5m and 5m far from it.

X-ray diffraction patterns of the samples collected from the above plinth and pier are reported in Fig. 1. Gypsum was clearly detected only in the sample at a height of 1m from the plinth. Small amounts of ettringite/thaumasite were present in the three samples collected from the plinth, and at a height of 1m and 3.5m respectively from the plinth.

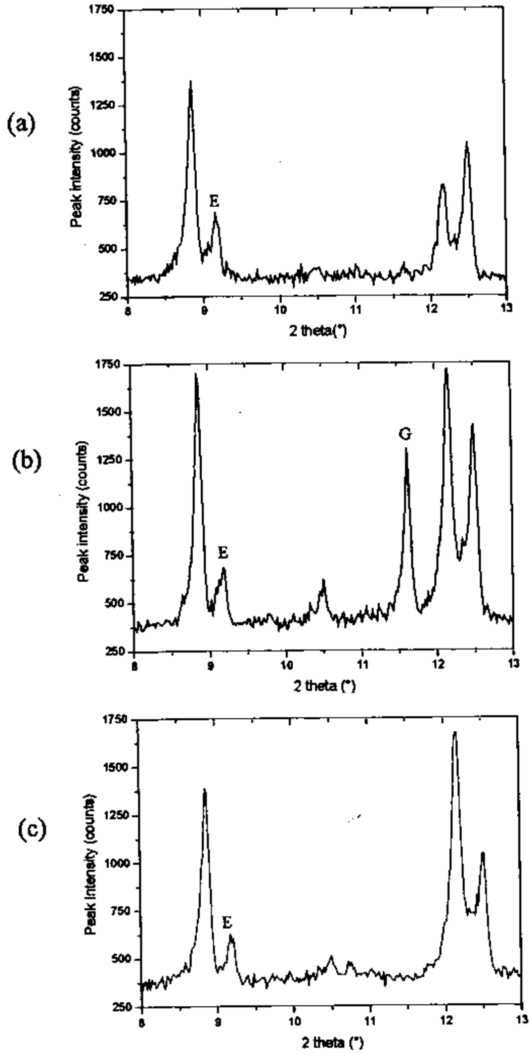

Fig. 1. XRD patterns of degraded concrete samples: a) plinth sample; b) sample collected at a height of 1m from the plinth; c) sample collected at a height of 3.5m from the plinth (the peaks not indexed in the patterns are due to the aggregates; E = ettringite/thaumasite; G = gypsum)

SEM observations confirmed the XRD data. The plinth sample presented only very few regions affected by gypsum and/or ettringite, even if it appeared highly porous and cracked. Frequently large voids were observed all along the interface between cement paste and aggregates. In the 3.5m-samples neither gypsum nor ettringite were identified, whereas the 1m-samples were significantly affected by gypsum, as shown in the following figures.

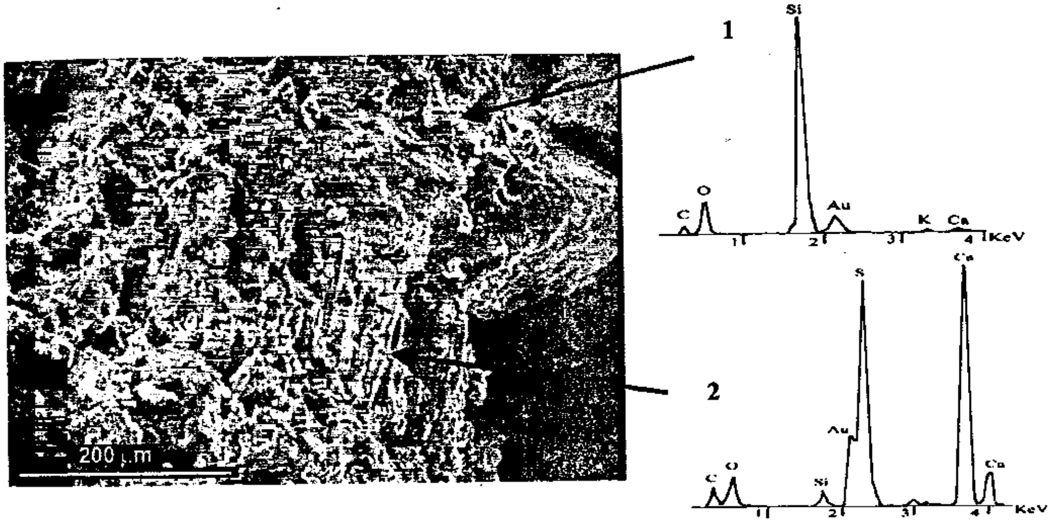

Fig.2. SEM micrograph of a degraded concrete sample collected at height of 1.0m from the plinth: point 1) quartz grain; point 2) gypsum crystals

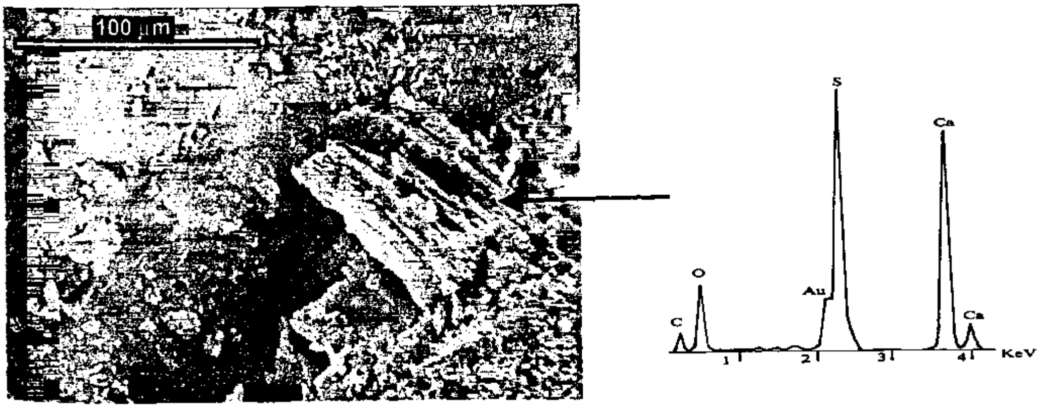

Fig.3. Detail of the contact zone between cement paste and quartz aggregate: gypsum crystals growing at this interface

A low-magnification image of the contact region between quartz aggregate and columnar gypsum crystals is shown in Fig.2: the phase compositions were identified by EDS analyses performed in the indicated regions. In many cases the growth of gypsum crystals at the interface between cement paste and aggregates (Fig.3) led to an almost complete detaching, which should be responsible of the significant strength decrease. Gypsum was only sometimes detected in the cement paste.

From the above results, it clearly appears that the concrete underwent a significant sulphate attack, which led to the formation primarily of gypsum and minor amounts of ettringite and/or thaumasite. However the strength loss recorded through the sclerometric measurements can be imputed to the decalcification [1] of C-S-H to form either gypsum ($C\hat{S}H_2$) or thaumasite ($C\hat{S}.CS.C\hat{C}.H_{15}$) according to the following reactions:

$$\begin{matrix} CH \\ C\text{-}S\text{-}H \end{matrix} \xrightarrow[H_2O]{SO_4^{=}} C\bar{S}H_2 \qquad \begin{matrix} C\text{-}S\text{-}H \\ CH \end{matrix} \xrightarrow[H_2O]{SO_4^{=},\ CO_3^{=}} CS \cdot C\bar{S} \cdot C\bar{C}H_{15}$$

The explanation that gypsum was mainly located at the interface between the cement paste and aggregate lies in microcracks originally present in the transition zone between the aggregate and the cement paste. These cracks are larger in width than most capillary cavities present in the cement paste matrix and therefore they can act in establishing interconnections, which increase the permeability of the system [2].

Sulphates were neither originally present in the soil nor brought from industrial waste waters. Their origin can be imputed to the presence of the absorbing well; in fact, it is well known [3] that sulphur compounds present in the sewage are reduced by micro-organisms to sulphides where anaerobic conditions prevail. Some of the sulphides can escape as hydrogen sulphide gas, which dissolves in the atmosphere moisture and condenses on the walls of the well. Here it is converted by sulphur-oxidising bacteria to sulphuric acid. This phenomenon is increased by slime stagnation, which provides an excellent breeding ground for sulphide-producing organisms. The most severe attack was, consequently, observed on the walls of the well and, after that, on the nearest plinth and pier of the building. In fact, the waste water collected in the well and progressively acidified by sulphuric acid yielding moved to the building foundations, due to a favourable ground structure.

The evolution of gypsum amount in the above plinth and pier (a low gypsum content detected in the plinth and higher values at a height of about 1.5m from it) can be reasonably imputed to the work stoppage of the well after about 15 years from the building construction. The well was neither drained nor filled up by ground. Therefore, it was still active in keeping wet the building foundations. The previous severe sulphate attack made the plinth concrete more permeable, allowing the water rise higher and higher in the pier. Multiple dissolution-precipitation steps of gypsum due to water evaporation at increasing height in the pier can explain the present distribution of gypsum amount, which shows a typical "knee" trend already observed, for instance, in the case of the content of water-soluble salts in masonry as a function of height [4].

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