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CRI TECHNOLOGY DIGEST

NCB MULTI-DISCIPLINARY APPROACH FOR MONITORING IN-SERVICE BEHAVIOUR OF CONCRETE STRUCTURES

National Council for Cement and Building Materials

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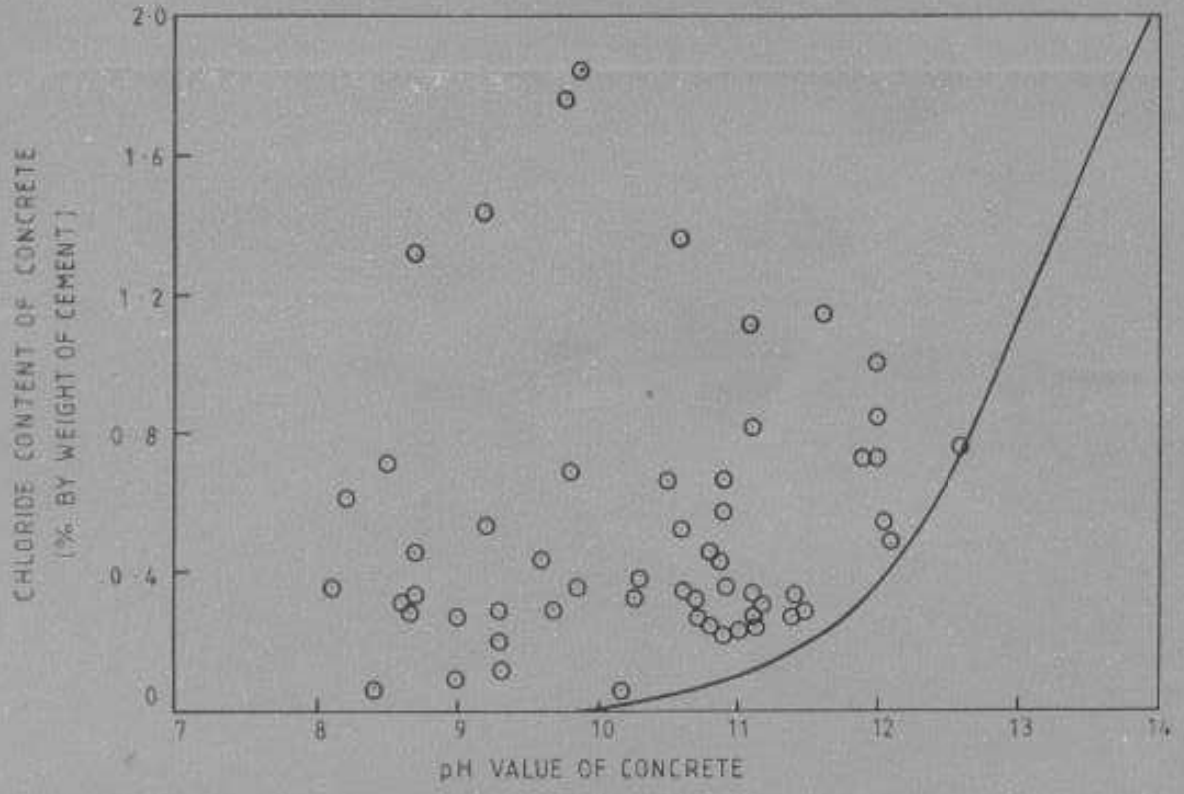
INTRODUCTION

CONCRETE structures built to appropriate specifications are expected to give trouble- and maintenance-free service for many long years. These expectations are, however, not realised when these specifications are violated and the initial constructions are not defect-free or when the service environments actually experienced are more severe than those anticipated and designed for. Remedial measures for repair, renovation or replacement then become necessary. A multi-disciplinary 'Systems' approach is recommended, wherein the performance and behaviour of a concrete structure is viewed to be dependent upon a number of causative parameters of materials, mix, environment and usage, in addition to a number of promoting and accelerating factors. Such an approach was adopted at the National Council for Cement and Building Materials for investigating distress caused to a number of concrete structures. Encompassing a number of disciplines like concrete and construction technologies, structural engineering, materials science, engineering geology, stochastics and industrial economics and employing varieties of in-situ and laboratory investigations like chemical analysis, XRD, DTA, optical microscopy and scanning electron microscopy. This Technology Digest, through selected case studies, illustrates the multi-disciplinary systems approach developed for distress investigation to concrete structures.

CORROSION OF REINFORCEMENT

Damage to concrete structures due to corrosion of rebars has been a problem not only in coastal areas but also in inland constructions. In such cases, the structural systems are first analysed to eliminate underdesign, overloading or possible settlement of foundation as the causes of distress, notwithstanding the fact that corrosion cracks are quite characteristic and distinct from those caused by the other factors in that they run along the location of reinforcements. Samples of concrete from the cracked portions are cored out and chemically analysed. From a large number of data on different concrete structures investigated so far, the importance of quality



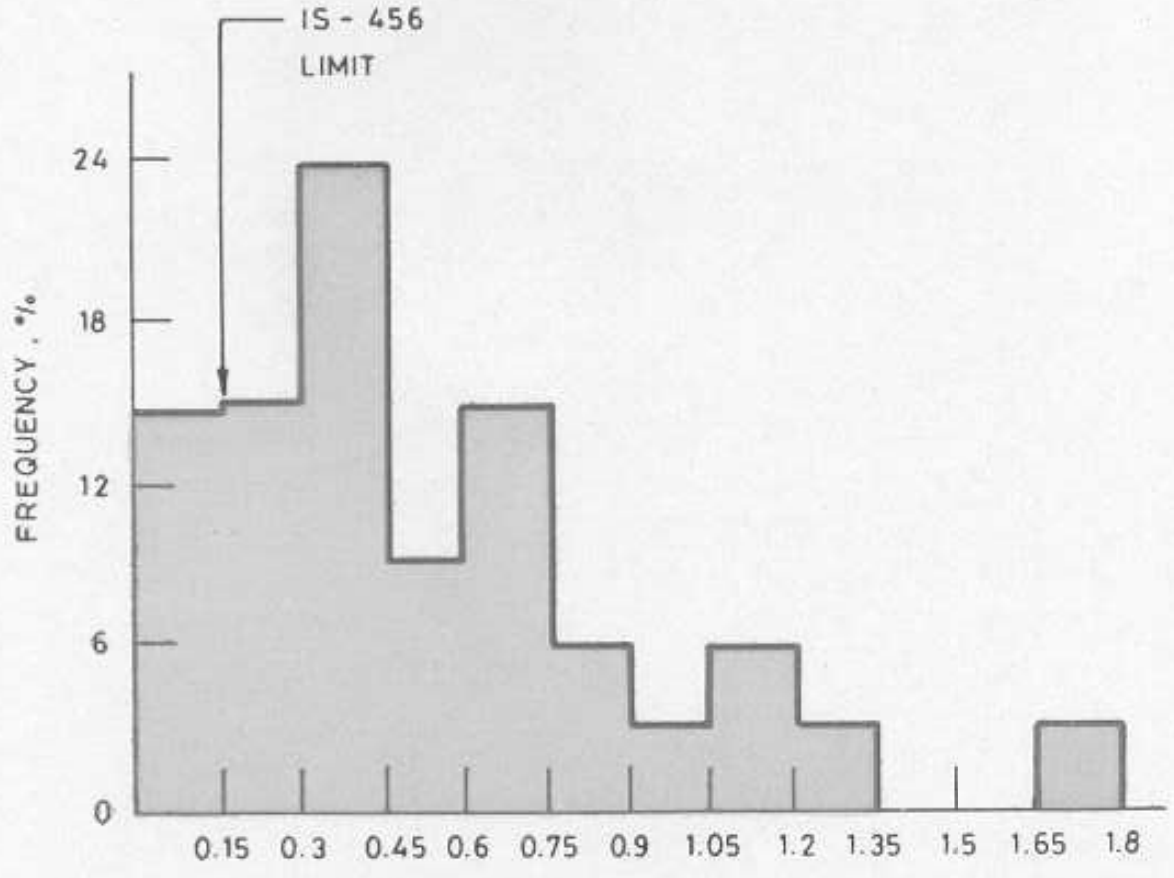
Relationship between pH Value and Chloride Content of Corrosion-Damaged Concrete

of concrete, mainly in terms of alkalinity (pH value) becomes evident. Whenever the pH value of the cover concrete was below 10, either due to carbonation or inadequate cement content, corrosion of reinforcement has invariably taken place. For concrete structures of average quality and pH value of 11 or above, a limiting chloride ion content of the order of 0·15 percent by weight of cement was found to be sufficient for the onset of corrosion. Lack of uniformity of concrete in terms of inadequate compaction, segregation or unequal cement content were also found to be factors contributory to corrosion of reinforcement.

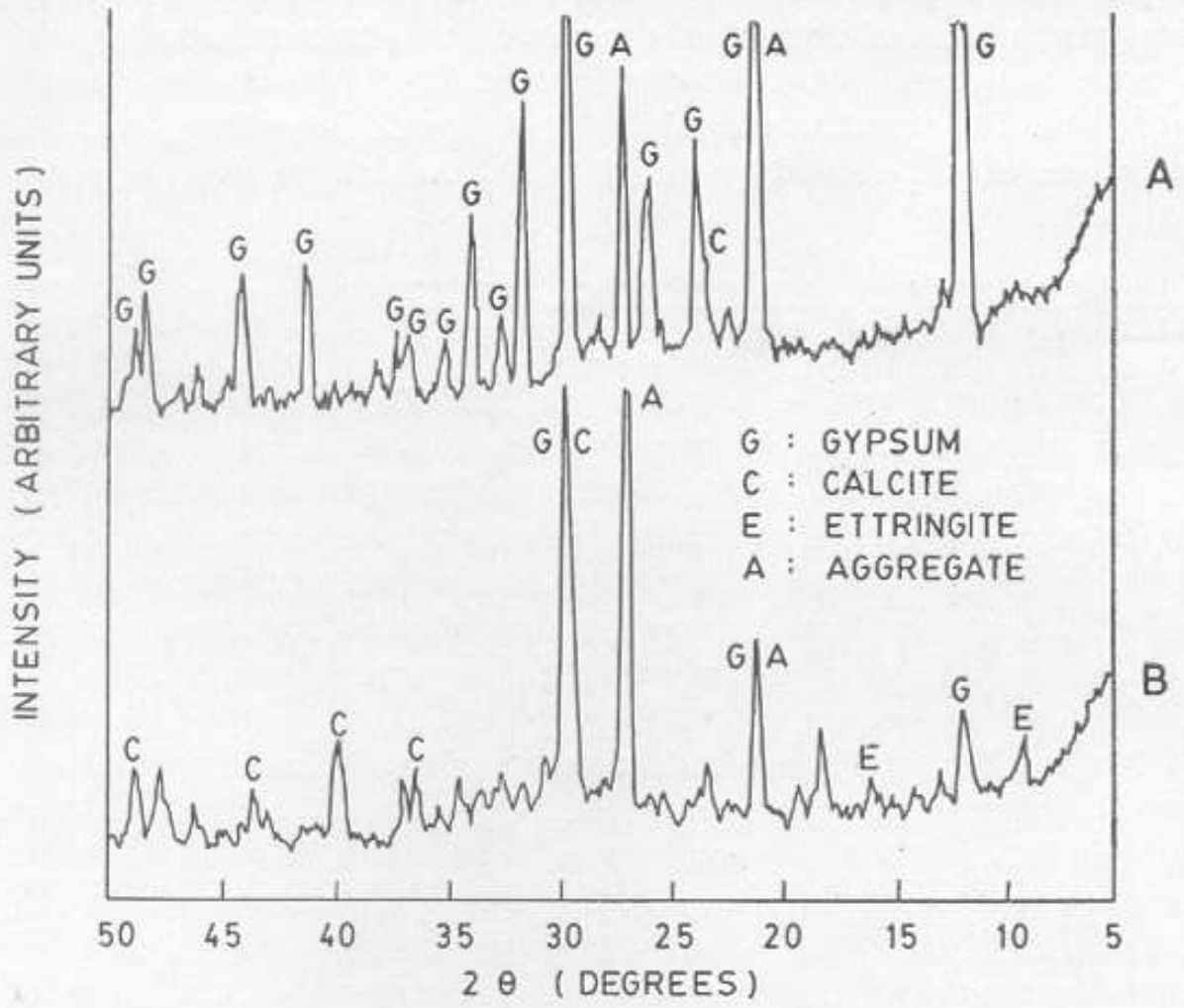
CHEMICAL ATTACK ON CONCRETE STRUCTURES

Well designed and well made concrete is highly resistant to chemical attack. However, at certain situations concrete structures have shown distress. In a sewage treatment plant, a number of sludge digester tanks which employed secondary biological treatment through either trickling filters or activated sludge process showed signs of distress, mainly in the

dome roof of the tanks, some of which had collapsed. Examination of the damaged concrete samples with chemical analysis, XRD, thermal analysis and optical microscopy related the deterioration and collapse of the domes to an initial carbonation of the concrete at the inner surface, followed by a more severe attack by sulphuric acid formed as a result of micro-biological oxidation of H_2S present in the sludge gases. Typical XRD plot showing presence of calcite and gypsum and relatively less amount of ettringite indicated that the concrete was subjected to sulphuric acid attack rather than the conventional sulphate attack. Weak construction joints accompanied by sudden decrease in the thickness at the arris and simultaneous curtailment of reinforcement at the same location were believed to have facilitated the collapse of the dome. For future constructions, recommendations were, therefore, made not only for the choice of right materials and protective paints but also of adequate care at the construction joints, detailing of reinforcement and proper ventilation of the gases.



Chloride, % by Weight of Cement in Concrete



XRD of Concrete in Digestor Tanks

FIRE DAMAGE TO CONCRETE STRUCTURES

In case of fire if the maximum temperature reached and its duration are known, the assessment of extent of damage to concrete becomes easier. Realising that exposure to high temperature brings about irreversible changes in the hydrated cement phase as well as in the aggregates, a suitable approach for assessment of fire damage to concrete structures has been evolved. It takes into account that thermal analysis (DTA, TG) of the damaged concrete samples would not show any concommitant change with increasing temperature, up to the limit to which it has been exposed during fire and thereafter it shows a steady change.

In case of fire in an RCC prilling tower in a fertiliser plant, although the external signs of damage were profound, thermo-gravimetric analysis revealed that concrete below 40 mm depth of cover was not likely to have

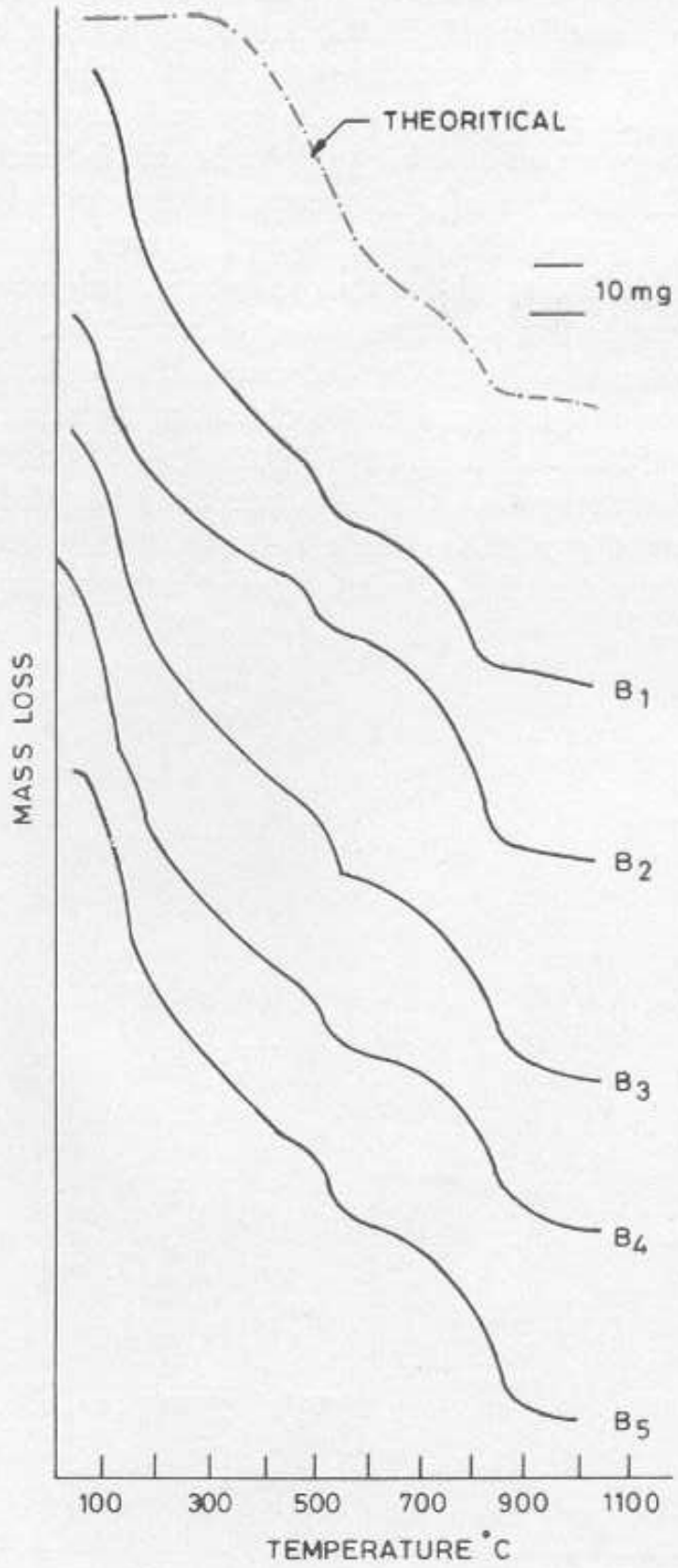
been exposed to temperature exceeding 100°C. This was also confirmed by assessment of loss of strength of concrete by non-destructive testing and tests on concrete samples at the construction site which were also exposed to the fire. The structure was rehabilitated by chipping off the damaged cover concrete and thereafter guniting to the intended profile.

DAMAGE DUE TO ALKALI SILICA REACTION

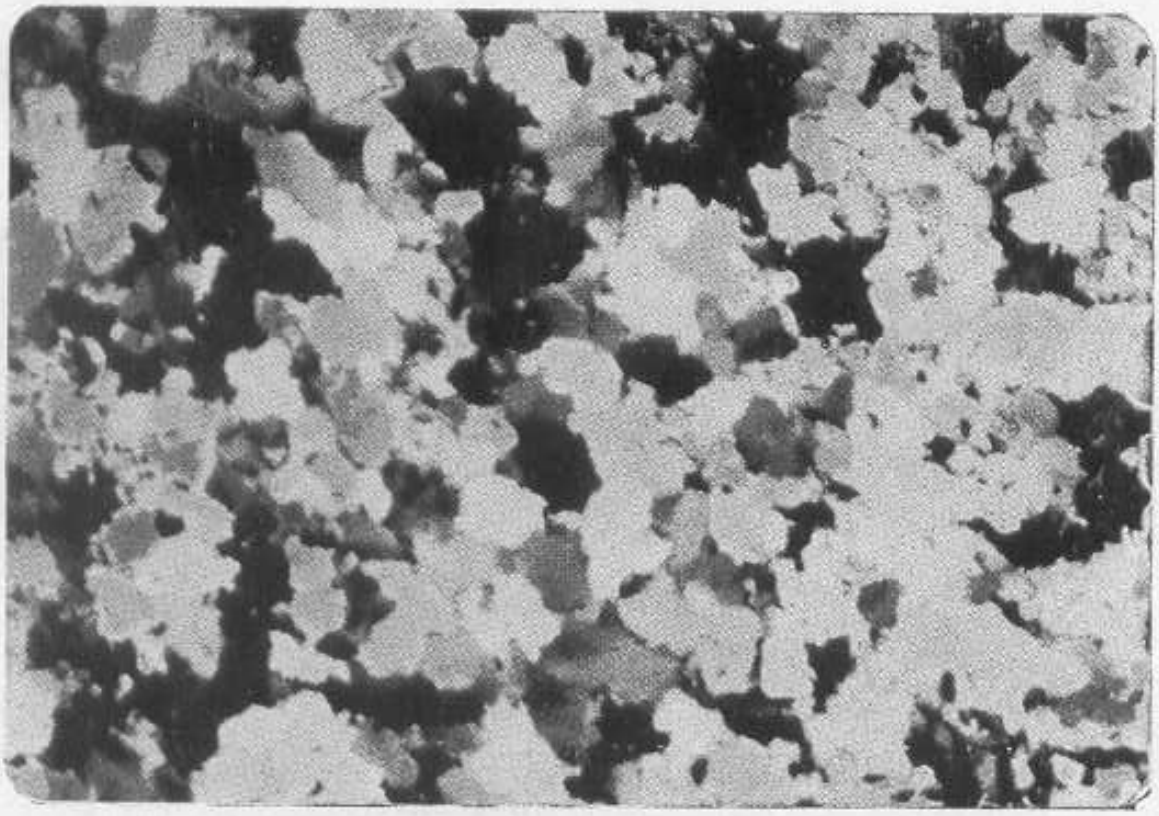
The problem of alkali-silica reaction in concrete was earlier believed to be non-existent in India. However, damages to hydraulic concrete structures eg, dams, built nearly 20 to 30 years ago have now come into notice, the distresses being manifested in the form of conspicuous "map" cracking in surface areas, longitudinal cracks in the structural members, pop-outs and bulging in concrete, shearing of metallic embedments and malfunctioning of appurtenant machineries housed in the concrete structures.

In case of one such dam, measurements of cracks and movements in concrete indicated the causes to be 'live'. A three-dimensional finite element analysis indicated that the cracks were not likely to have been caused because of presence of openings in the body of the dam or differential settlement of foundation. Vibration measurements indicated that pressure and vibration developed during different conditions of storage and gate operations were within permissible limits. On the other hand, examination of concrete samples through optical microscopy, chemical analysis and scanning electron microscope indicated alkali-silica reaction as being the most probable cause for damage. Typical white gel deposits in pockets in the concrete and formation of rims around the aggregates, which are typical of alkali-silica reaction were noticed. EDAX analysis of the reaction products confirmed alkali-silica reactions.

Further monitoring and observation of the structure was continued by monitoring the progress of cracks as well as measurement of movements in the concrete structure. Concrete core samples were stored in alkali solutions and at elevated temperatures to estimate if the deleterious reactions were over. In one case, it has been estimated that the remaining potential of expansion could be expected to be of the same order of magnitude as that has taken place so far in 25 years. The remedial measures in terms of realignment of power house machinery and creation of extra clearances are planned taking such residual expansion into account.



TG of Fire-Damaged Concrete



Optical Microscopy of Reactive Aggregates Showing 'Strained' Quartz

NCB EXPERTISE

NCB expertise and consultancy services backed by its sophisticated and most modern R&D facilities are available for investigating such complex problems requiring multi-disciplinary systems approach.

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