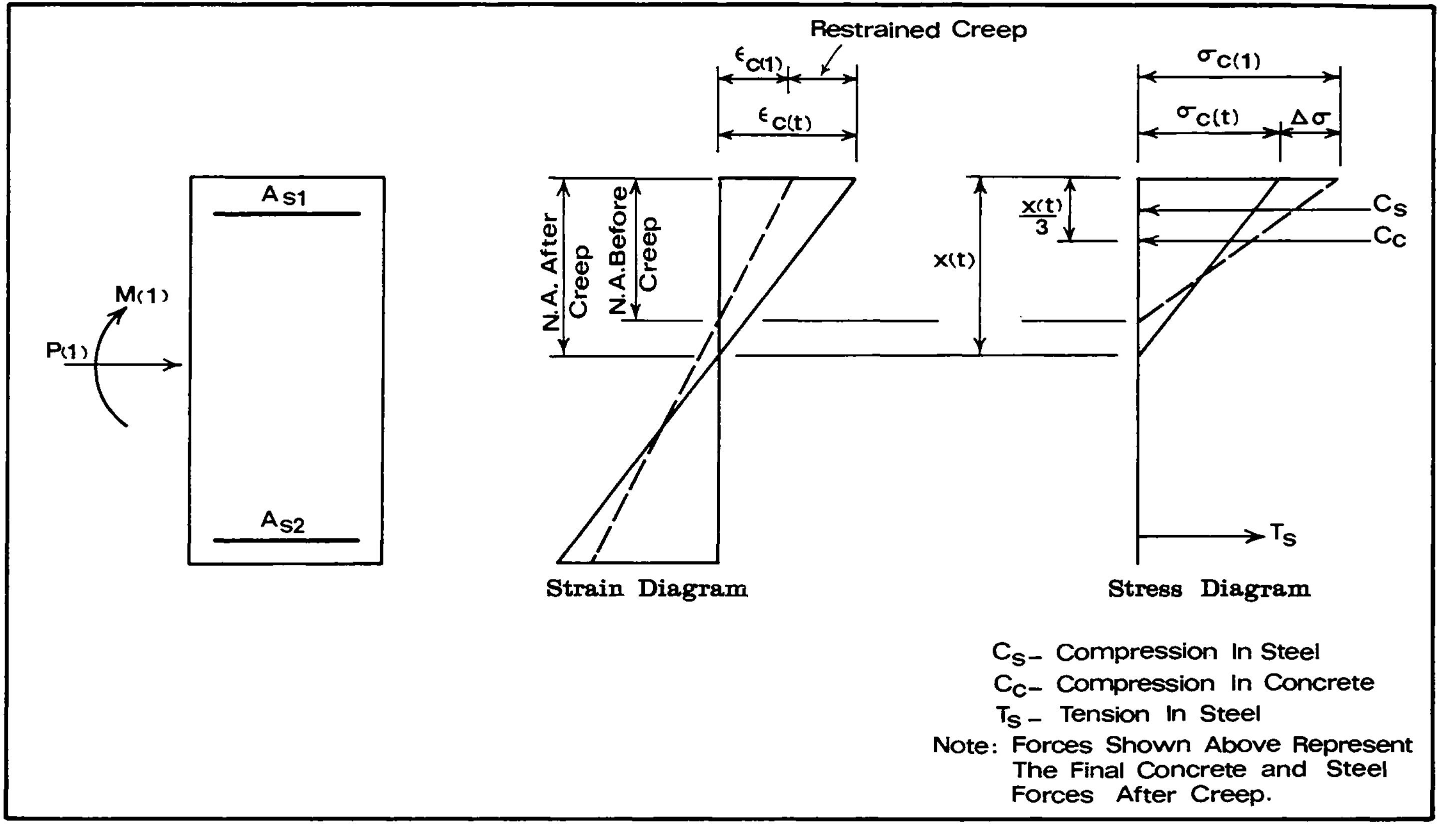

Fig. 6--Strain and stress diagrams before and after creep (creep analysis of cracked section)

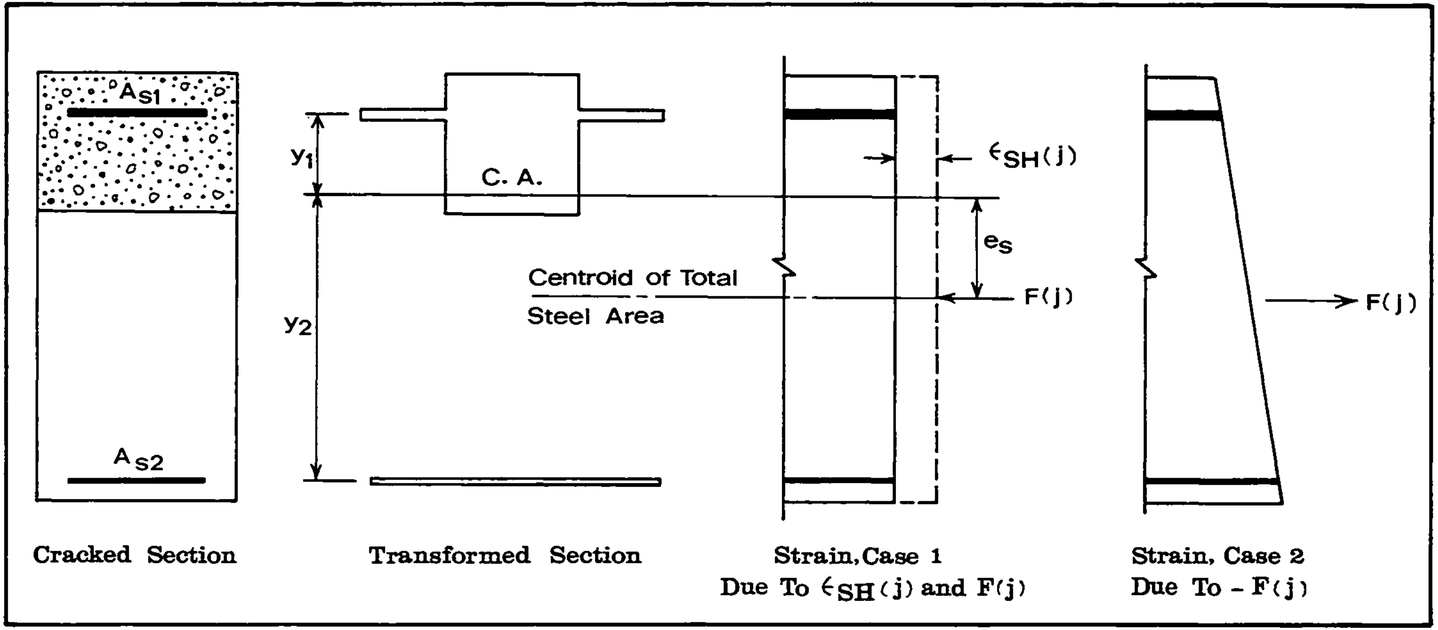

Fig. 7--Shrinkage analysis of cracked section

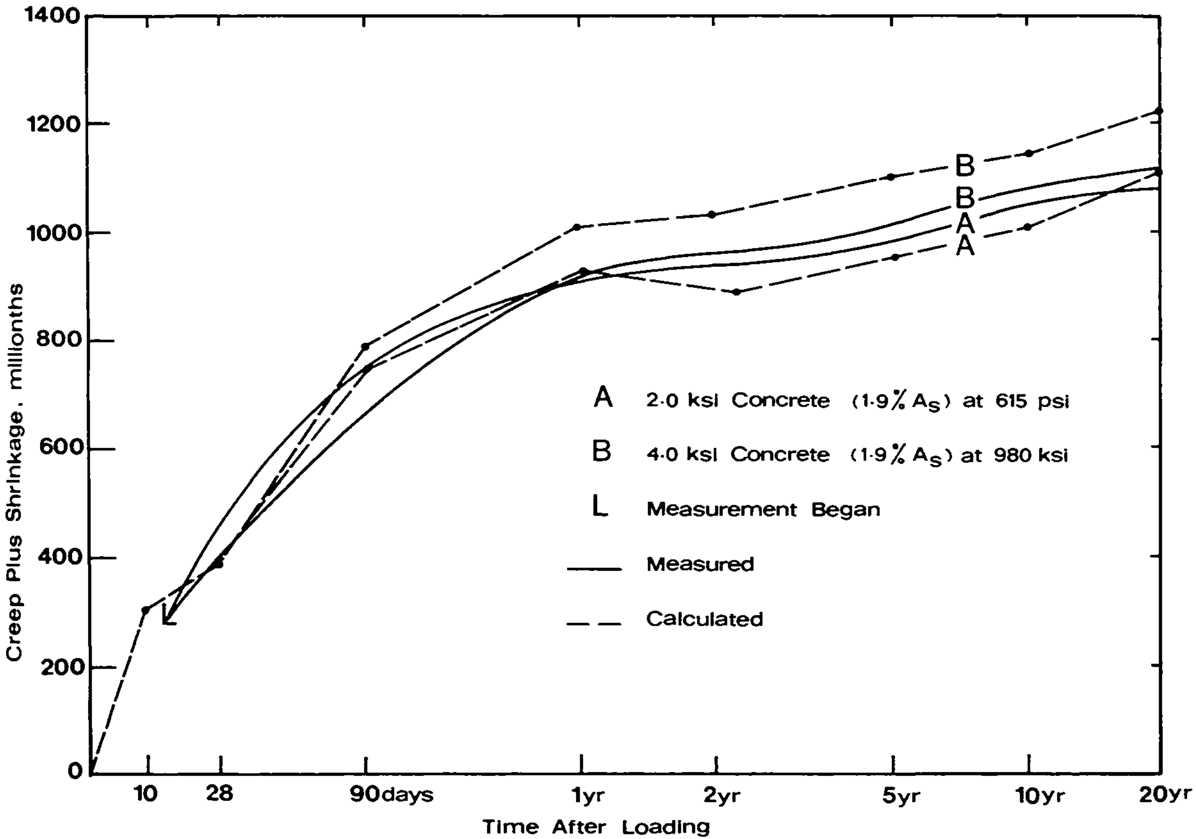

Fig. 8a--Analysis of column tests
of Reference 18, inelastic strain

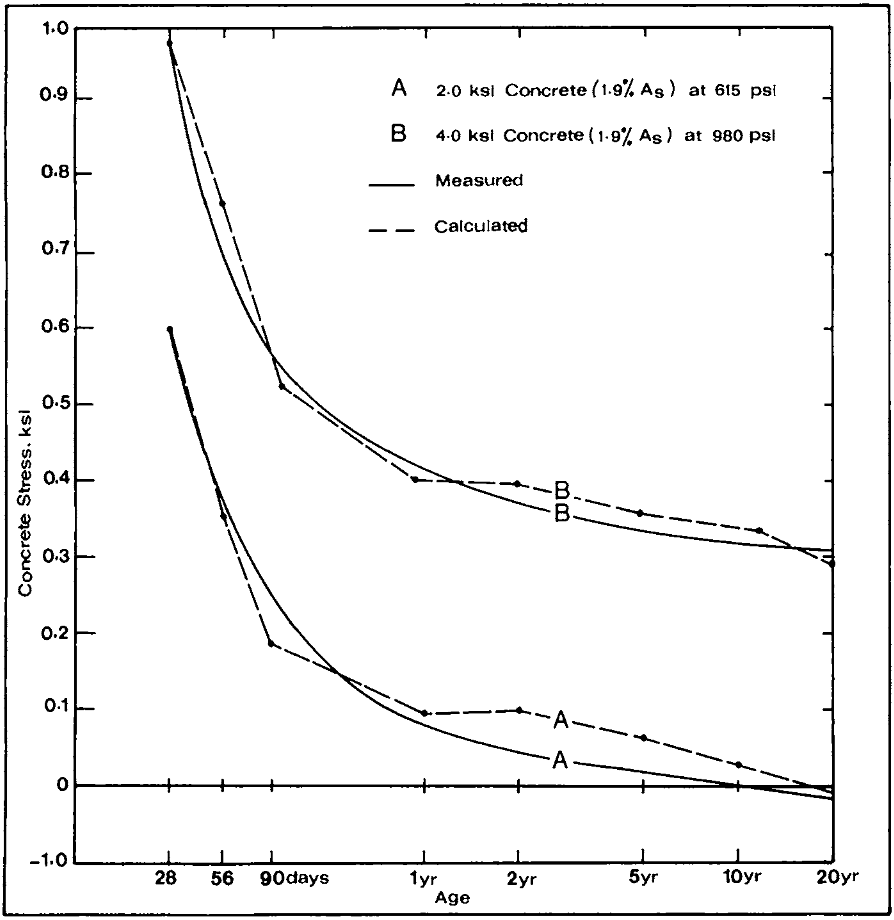

Fig. 8b--Analysis of column tests of Reference 18, concrete stress

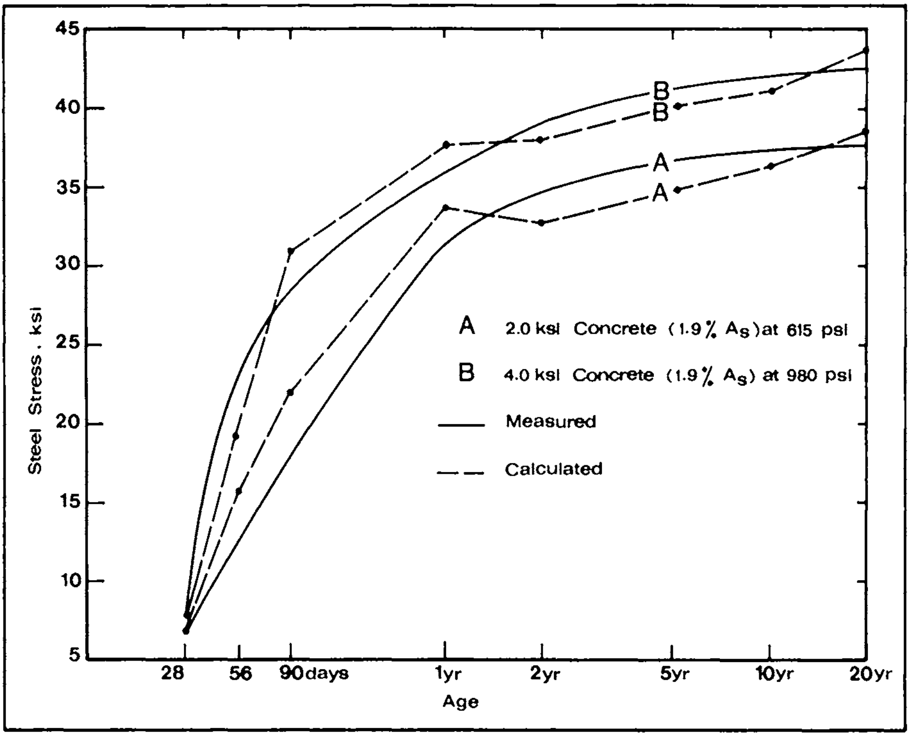

Fig. 8c--Analysis of column tests of Reference 18, steel stress

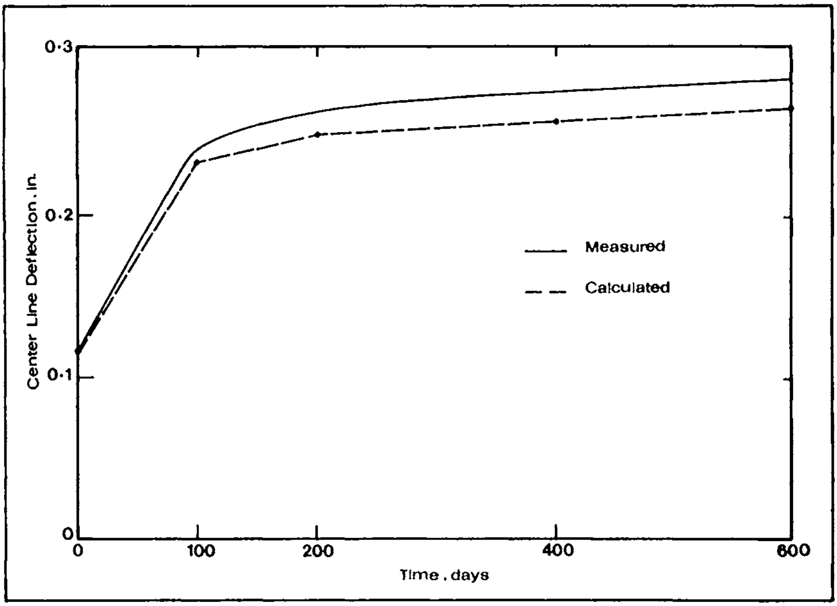

Fig. 9a--Deflection of beam C1, Reference 19

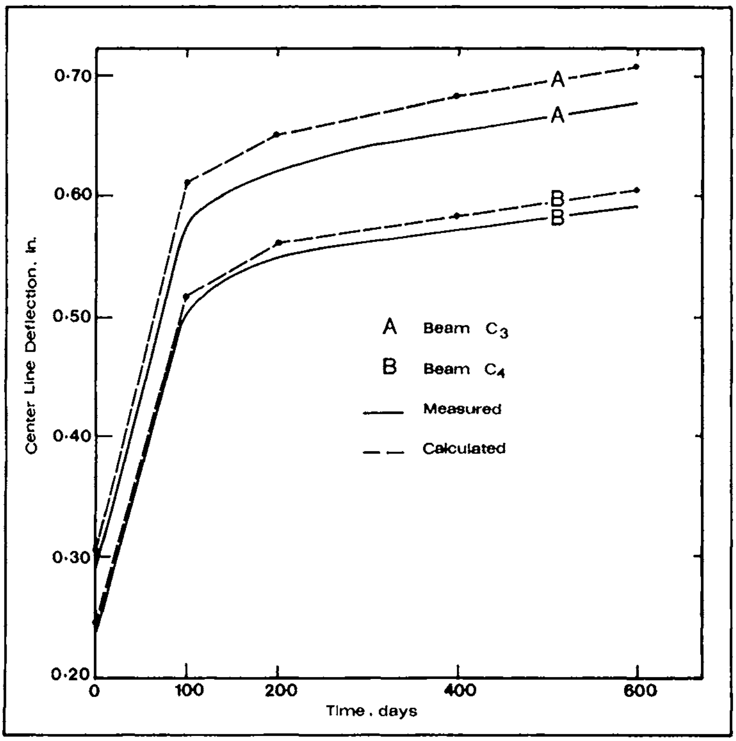

Fig. 9b--Deflection of beams C3 and C4, Reference 19

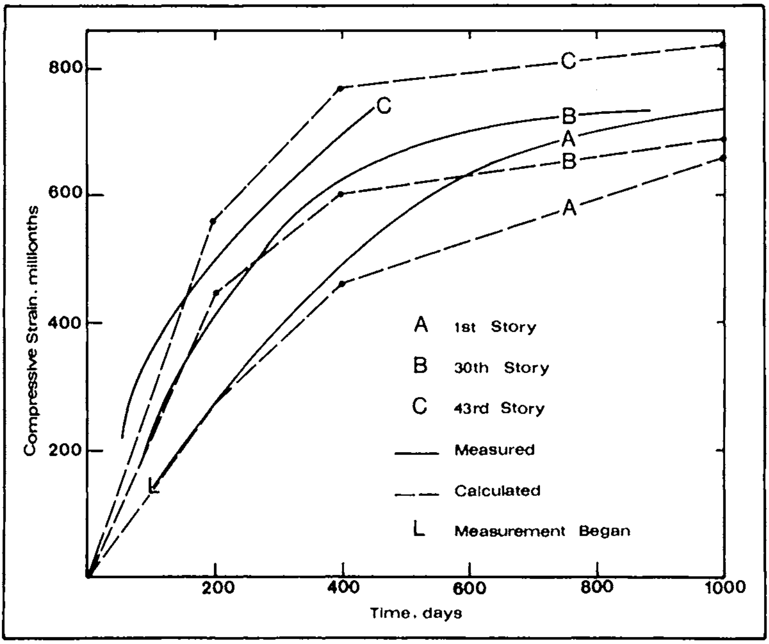

Fig. 10--Strains in Lake Point Tower Columns, Reference 20

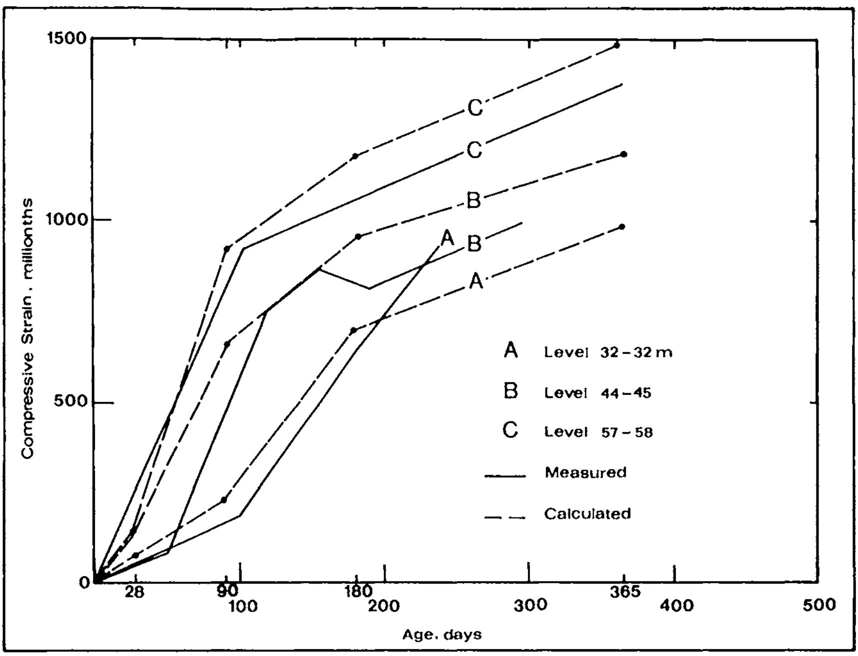

Fig. 11--Strains in Water Tower Place columns, Reference 21

SP 117-7

The Rehabilitation of Eisenhower Lock

by V. Novokshchenov

Synopsis: This paper describes deterioration of concrete in the chambers and the culverts of Eisenhower Lock that were observed soon after the lock was completed in 1958. Investigators from the U.S. Army Engineer Waterways Experiment Station (WES) postulated that the most probable cause of deterioration was pressure created by freezing water in critically saturated concrete that was not mature enough to withstand the pressure. Slow strength gain of the concrete was believed due to the use of natural cement.

The investigation conducted by the author prior to repairs performed at Eisenhower Lock in the winter of 1985-1986 suggested that poor durability of the in-place concrete may have been caused to a large extent by inadequate control over concrete operations during construction works. Therefore all precautions have been taken to assure that the newly placed concrete will perform adequately under severe service conditions. The only operation that caused concern was adding hot water at the project site to the dry concrete mix containing portland cement.

Keywords: concrete durability; concretes; culverts; deterioration; freeze-thaw durability; inspection; locks (waterways); natural cement; quality control; renovation; repairs

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INTRODUCTION

Background Information

Dwight D. Eisenhower Lock is located in the Wiley-Dondero Canal north of Massena, NY. The lock is a part of the 2250 mile (3620 km) St. Lawrence Seaway connecting the Gulf of St. Lawrence with the Great Lakes. The lock, a mass concrete gravity structure, is 860 ft (282 m) long, 80 ft (26 m) wide and 30 ft (9.8m) deep over the sills (Fig. 1a and b). The maximum design lift of the Eisenhower Lock is 45 ft (14.8 m). In addition to the mitering type gates the lock has an emergency lift gate to prevent loss of water from the Lake St. Lawrence. The highway tunnel was built through the lift gate sill of the lock to provide an access to Long Sault Dam and Barnhart Island Powerhouse.

Two types of concrete mixes were used for construction of the lock walls: interior and exterior having cement contents of 260 and 360 lb/cu yd (154 and 214 kg/m^3), respectively (Table 1). The cement was a blend of Type II portland cement and natural cement. Coarse and fine aggregates were manufactured from dolomite quarried near the construction site. On some occasions river sand was also used to adjust gradation of the manufactured sand. Maximum size of coarse aggregate was 6 in. (152 mm). Water for concrete mixing and curing was pumped from the St. Lawrence River. Both concrete mixes were designed to contain about 6.0 to 6.5% entrained air.

Concrete Failures

Problems with concrete at Eisenhower Lock started in 1960 when the top 5 ft. (1.64 m) lift of the upper sill was accidentally dislodged by a freighter (1). During repairs it was noticed that the top surface of the adjacent lower lift was float finished.

In April 1962 the top lift of the lower sill debonded. The cause of the problem was basically the same as in the upper sill, i.e. lack of bond between the lifts. The problem also was aggravated by freezing of water entering joints between the lifts and by the presence of uplift.

While evaluating the failure of the lower sill WES personnel noticed that concrete in the lower gate recesses deteriorated to the depth of several inches. Later more damaged concrete was found in various areas of the lock that was excavated and replaced during routine winter shutdowns (Fig. 2).

The first significant deterioration of concrete was noticed in 1964 in the filling and emptying culverts of the lock where the concrete was eroded by moving water to the depth of 10 in. (254 mm). In some areas the concrete was observed to be cracked and covered with heavy deposits of carbonated products of cement hydration leached out of the concrete. In several instances delamination type cracks were detected beneath the sound concrete. These cracks ran parallel to the wall surface and separated the top 2 to 8 in. (51 to 203 mm) thick layer from the main monolith. One of the common types of concrete deficiency in the lock walls was rubble pockets up to 2 ft. (0.66 m) deep (Fig. 3).

In 1967 continuous cracks were observed in the north and south culverts of the lock. These cracks occurred along the landward ceiling corner of the culverts and penetrated through the wall to the backfill. In some areas adjacent to the crack, water was leaking through the cracks causing concrete to spall. Concern had arisen that these cracks could have jeopardized stability of the entire lock.

As a result of these and other failures the conclusion was made that concrete in Eisenhower Lock was generally deficient in quality and that fundamental rehabilitation works would be required to restore structural integrity and to maintain serviceability of the lock.

CAUSE OF CONCRETE DETERIORATION

Studies Conducted by WES

During 1962-1966, the WES carried out a thorough investigation in an attempt to determine the cause and the extent of the damage. Despite vast test data