INNOVATIVE METHOD USED TO EVALUATE THE EFFECT OF POWER WASHING ON MARINE CONCRETE

A UK SITE STUDY

BY PETER HUGHES

Power washing is becoming more commonly used by maintenance teams throughout the world but the inappropriate use of high-pressure washing may have a devastating effect on the long-term durability of many material surfaces.[1] This article reports early findings from an ongoing study into the effects of power washing concrete. The study was conducted at a site on the northwest coast of England (Fig. 1), where concrete revetment armor with a design life of 100 years has been monitored for surface changes over a period of 3 years (Fig. 2).

Fig. 1: Equipment used to manage biofouling at the study site

Fig. 2: Revetment armor steps colonized with algae

HISTORY OF POWER WASHING

Early industrial cleaning using water-jet technology reaches back to the 1920s in the steel industry. In the late 1950s, as reliable high-pressure pumps were developed, the water jet revolutionized sewer and pipe cleaning. Reviews about early cases of water-jet use for material removal—namely, for soil removal and hydraulic mining—are provided elsewhere.[2] Today, commercialized water jetting covers many cleaning applications: concrete, stone and masonry, cement kiln and autoclave vessels, chemical pipes, sewers, and ship hulls.

CHARACTERISTICS OF POWER WASHING

Water-jet applications can be distinguished according to the level of the applied operational pressure. Power washing can be defined as the use of pressurized water applied below 5000 psi (34.5 MPa),[3] with or without the addition of other liquids or solid particles, to remove unwanted matter from various surfaces. Dated UK published guidance tackles the removal of algae from concrete recommending power washing at velocities between 725 to 2175 psi (5 to 15 MPa).[4] This type of pressure is applied to clean marine structures, jetties, and steps to combat biofouling and reduce slip hazard. A modest 1200 psi (8.2 MPa) was used at the UK study site.

Further advances in high-pressure water-jet cleaning and maintenance management incorporate hot water and a 15-degree fan nozzle at an appropriate distance (at least 6 in. [150 mm]) from the surface, and with appropriate pressure.[5] In general, the higher the water pressure, the more effective the cleaning and the greater the potential damage to the concrete surface.

DAMAGE FROM POWER WASHING

Research has quantified the erosion of concrete, focusing on a range of pressures and flow rates used in the routine cleaning and maintenance of drains and sewers.[6] Damage from jetting tests was measured, and volumetric erosion rates reported at 4000 psi (27.6 MPa) on concrete were 240 ft^3/s (6.90 mm^3/s).

Power washing can start a devastating vicious cycle.[7] The frequency of cleaning and the cleaning method used (especially high-pressure cleaning) could have an influence on concrete deterioration.[8] While good-quality concrete shows excellent resistance to the steady flow of clear water, nonlinear flow at velocities exceeding 39.4 ft/s (12 m/s) (23 ft/s [7 m/s] in closed conduits) may cause severe damage to concrete.[9] The water exits the nozzle at both a high pressure and a high velocity. The resulting momentum is great enough to dislodge not only dirt and debris but also creates flakes, popouts, and even concrete spalls.[7]

METHODS OF MEASURING DETERIORATION

Deterioration of concrete structures usually starts at the surface and progresses into the structure. To study the effect of aggressive cleaning practices and its implications, a number of testing methods were used.

The surface roughness of the revetment armor was measured over time (Fig. 3). While no standard method for measuring surface roughness of concrete has currently been adopted, a range of nondestructive testing (NDT) methods are available. These methods are in use for measuring the surface texture of concrete floors, but no method is accepted as a standard and different organizations use different methods.

Holt and Musgrove[10] carried out a review of the main methods of surface texture classifications that are summarized in an ASTM International special technical publication. The interest in measuring the surface texture of floors stems from its effect on skid resistance. Wambold et al.[11] used the mean texture depth as a measure of surface roughness. Silfwerbrand[12] suggested a different method of quantifying the surface roughness in his study on the effect of roughness on bond of repair materials.

Surface roughness measurements were taken with an interferometer on 28-day; 56-day; and 1-, 2-, and 3-year concrete samples. Semi-direct paths for interferometric readings were chosen using an angle of 45 degrees and a modest path. Readings were taken on 10 surface-dry units with ambient temperatures at 70°F (21°C). At 3 years, the poor condition of the surface at the nose of the units being monitored made further use of the instrument inappropriate because of liberating aggregate from the revetments.

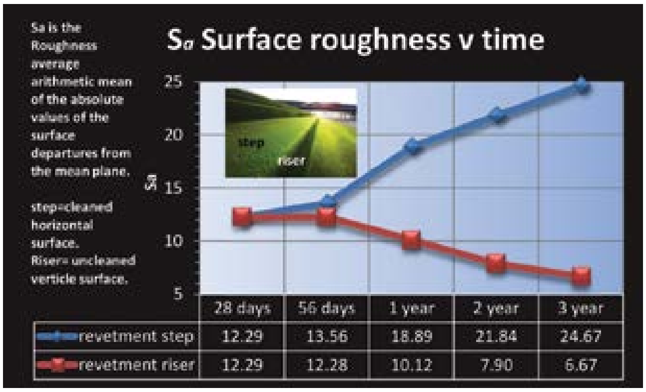

Fig. 3: Revetment armor surface roughness measurements

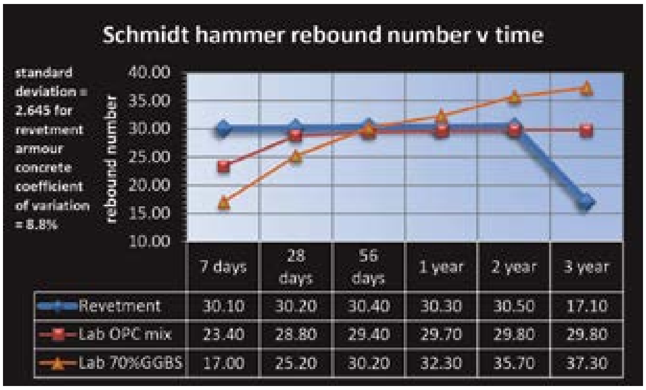

Fig. 4: Revetment armor surface hardness measurements

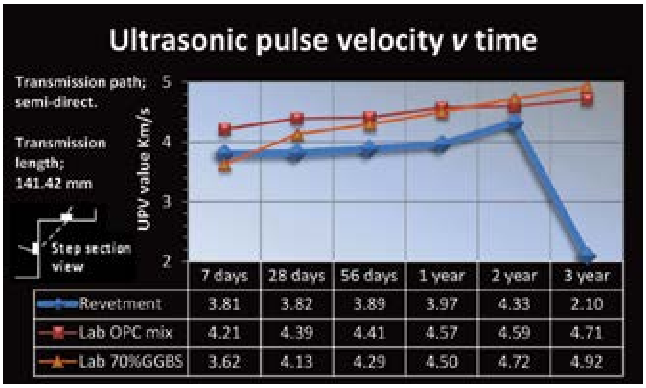

Fig. 5: UPV readings taken from revetment armor

Schmidt/rebound hammer tests were used to evaluate the surface hardness of the concrete (Fig. 4). Tests were performed on site on 1-, 2-, and 3-year placed revetment armor units. For hardness comparisons, replicas were cast and tested in the laboratory. Two laboratory control mixtures were used: an ordinary portland cement (OPC) mixture and a 70% ground-granulated blast-furnace slag (GGBS) mixture—neither of which containing synthetic fibers.

Ultrasonic pulse velocity (UPV) testing was used to appraise the quality of the concrete (Fig. 5). UPV information allows the variations in concrete quality to be assessed and areas of poorer quality

Fig. 6: Newly placed concrete tested in this research

Fig. 7: Nose of the step of the unit shown in Fig. 6 after 5 years' exposure

concrete to be identified. High UPV readings are generally indicative of good-quality concrete. A general relation between concrete quality and pulse velocity is well-accepted.[13] Because the pulse cannot travel through air, the presence of a crack or void on the path increases the path length. As the pulse goes around the flaw, an increase in the transit time will be recorded. Consideration was given for seawater within the units, as moisture normally present in concrete may encourage a higher reading.[14]

Weekly site surveys yielded a comprehensive photographic archive so visual evidence could also be observed. Figure 6 shows a photo of the new unit at the test site and Fig. 7 shows the condition after 5 years of exposure.

Replication was used as a means of performing a comparative surface analysis. This technique uses silicone-based replicating polymers and produces an exact copy of the surface (Fig. 8). After curing, the sample is removed and examined microscopically in the laboratory.

DISCUSSION OF RESULTS

Surface roughness measurements were taken on the step (horizontal) and the riser (vertical). Areas of testing were focused away from the nose of the step. The surface roughness increase on the step, rather than the riser, indicates that power washing the step has altered the surface. The marine environment in which this surface exists should have partly been responsible; however, over time, the riser that was not power washed became smoother. Results showed that in 3 years the surface roughness on the steps doubled from S_a12.29 to S_a24.67. The steps were power washed approximately 150 times at 1200 psi (8.2 MPa) over the course of the 3 years. The risers of the steps were not power washed and were subject to the same tidal impacts, but they showed a smooth erosion pattern—from S_a12.29 to S_a6.67.

Schmidt/rebound hammer readings from the surface of the armor units remained consistent at around 30*r*. After 2 years, a common pattern of degradation appeared on the units. An area or band of liberated aggregate approximately 3.9 in. (100 mm) wide occurred on the leading edge of the step and the impact hammer could no longer be used because the hammer would have further damaged the surface.

Abrasion resistance was also evaluated and is generally affected by the same influences as surface hardness. Research on this subject[15] has suggested that the rebound number may be used to classify this property.

UPV readings from the surface of the armor remained steady for 2 years at 2.4 to 2.7 miles/s (3.81 to 4.33 km/s) and then reduced substantially in the third year to 1.3 miles/s (2.1 km/s). These results initially indicated good-quality concrete; however, the decline in UPV values showed the deterioration of the concrete. The substantial reduction in the third year of the study indicates a correlated reduction in compressive strength of more than 50%. The reduction in UPV is particularly significant, suggesting the core of the concrete may be affected by the weakening process.

Replication techniques proved to be extremely useful and adaptable. The ability of the polymers used for replication to provide a visual microscopic picture of three-dimensional surfaces while, at the same time, yielding accurate dimensional data, was useful as a permanent record for subsequent reference or monitoring purposes and could lay the foundation for the development of a new NDT method for concrete surface analysis.[16]

The replicating compounds used had a resolution better than 0.1 microns[17] and were able to accurately recreate the surfaces being studied. Confirmation of this accuracy can be found in a comprehensive study of three different materials used for surface roughness replication on five different types of machined surfaces. The results were reported in Reference 18.

POSSIBLE EFFECTS ON LONG-TERM LIFE OF CONCRETE

Various techniques were used to investigate how the surface of the units performed to build a more complete picture of their performance over 3 years. The surface of the precast elements were investigated, examined, and monitored. The results revealed that the steps became rougher with power washer use and the risers became smoother, even though they were exposed to the same tidal conditions. Early degradation of these units from power washing was observed and the expected design life of 100 years for the concrete could be compromised by the power-washing activities.

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Fig. 8: Surface that was copied using silicone-based replicating polymers

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