Letters

Scaling revisited

We enjoyed reading the article "Scaling Revisited" by David Lankard that appeared in the May 2001 issue of *CI*, pp. 43-49. The article is comprehensive, timely, and emphasizes the importance of following industry guidelines in producing scale-resistant concrete. Since we also investigate many scaling problems in all kinds of outdoor and indoor concrete flatwork throughout the U.S., we thought we might reshuffle and emphasize some ideas mentioned in the article.

The article starts by mentioning that "coarse aggregate properties, *w/cm*, and curing play major roles." We feel that it may not be appropriate to call them the major players causing scaling because there are others that we feel are equally important.

Take air entrainment and non-air entrainment for example. Figure 1 is from the U.S. Bureau of Reclamation[1] on the influence of the water-cementitious materials ratio (*w/cm)* on resistance to cyclic freezing of air-entrained and non-air-entrained concretes that were moist cured for 14 days and then stored for 76 days at 50% relative humidity. It shows that *w/cm* is important only when the concrete is air-entrained. If it is non-air-entrained, even a low *w/cm* concrete may not resist distress due to cyclic freezing. Additionally, improper finishing can result in scaling of concrete exposed in non-freezing areas.

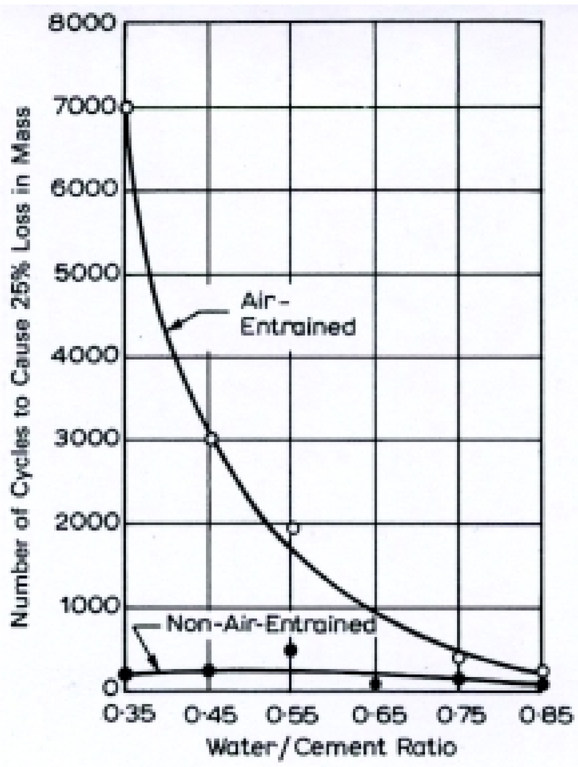

Fig. 1: Influence of *w/cm* on resistance to cyclic freezing

A $4/yd^3 increase in concrete cost for a bag increase in cement content to reduce the *w/cm*, as Dr. Lankard stated, obviously does not guarantee scale-resistant concrete if other guidelines are not followed. However, scale-resistant concrete can be produced without that cost increase, if the existing guidelines for quality concrete are followed — so why not follow them and better guarantee good performance of the concrete at a lower cost?

In numerous case studies, we have found examples similar to those reported by Dr. Lankard where the air content played a more important role than the *w/cm*. For example, concretes made using *w/cm* of 0.45 and less scaled because an air-entraining agent was not used, or there was an insufficient amount of air-entraining agent, or as Dr. Lankard reported, the air-void system developed in the plastic concrete was altered or destroyed because of prolonged mixing, or improper finishing altered the air-void system in the surface region of the concrete. Our comments are not to dispute the problems caused by his three major players, but we feel that it is inappropriate to narrow them down to only three, as we will discuss.

Dr. Lankard emphasized the importance of coarse aggregate because many coarse aggregates in Ohio, and elsewhere, have contributed to distress, such as by causing popouts due to shale and chert, and D-cracking caused by some crushed limestones and some calcareous gravels. We have seen popouts caused by sandstone, greywacke, shale, chert, argillaceous dolomite, and other porous varieties of rocks in fine aggregates. Figure 2 shows an example of ferruginous-shale-fine-aggregate particles that have caused popouts (within the boxed areas); similar potentially deleterious shale particles below the concrete surface are circled. So, in addition to coarse aggregates, fine aggregates must also be included as contributors to surface distress.

Aggregate particles commonly responsible for popouts may cause D-cracking, but not all aggregates responsible for D-cracking cause popouts. Swelling due to moisture absorption by shale and clay-rich particles can cause popouts in areas where freezing never occurs — where there is no need for air entrainment. Creating, by appropriate finishing, a relatively dense, low permeable, well-cured, low-*w/cm* surface mortar that reduces moisture uptake by porous aggregate particles may often reduce the potential deleterious effects of aggregate unsoundness and explain the better performance of some concrete made using certain unsound aggregate particles — however, we don't recommend

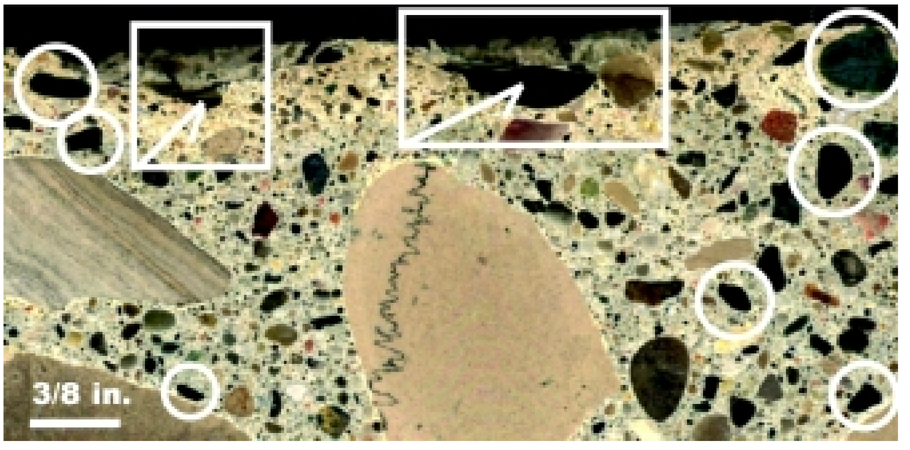

Fig. 2: Popouts caused by ferruginous-shale-fine-aggregate particles

that as a means of using "bad" aggregates.

A certain number of popouts are to be expected when aggregates conforming to Table 3 of ASTM C 33 are used because of the permissiveness of the standard.

We too have examined scales of mortar cover over the topsides of coarse aggregate particles near the surface. These scales are different from the usual lenticular-shaped scales typical of distress due to cyclic freezing of non- or poorly air-entrained concrete. They are different because while their shapes may be similar to that shown in the left boxed area of Fig. 3, more typically they have a relatively uniform thickness. We call this variety of scale mortar lift-off rather than the term popoff used by Dr. Lankard, mainly because of a confusion that can be created by use of terminology similar to popout.

The lift-offs are usually a result of improper finishing operations that develop poor bond, and sometimes micro-separations between the surface mortar and underlying coarse aggregate particle. The mortar lift-offs subsequently result due to either or combinations of: a) impact by traffic; b) expansion due to freezing of water that accumulates at the mortar cover-aggregate particle interface; and c) drying shrinkage of the mortar because the stresses created at the mortar-aggregate interface by the shrinkage is accumulative instead of being distributed along the interface if there was good bond. It does not have to occur due to freezing of critically saturated water absorptive particles (as stated by Dr. Lankard), and it usually occurs as a result of improper finishing and the mechanisms just described.

In Fig. 3, within the left boxed area is an incipient mortar lift-off, and within the right boxed area is lift-off that has exposed the topside of a sound, crushed-limestone-coarse-aggregate particle. In some instances, we have also seen mortar lift-offs due to rapid evaporation of water from the concrete surface, resulting in such poor hydration of the cement that a strong bond of mortar to the underlying aggregate particles did not result. The lift-offs can be relatively small and over the topsides of the coarse aggregate particles and coarser fine aggregate particles, or occur as a sheet-like delamination up to 1 ft. or so in size. So, improper finishing (that does not alter the air-void system) and inadequate curing also play important roles in causing the mortar lift-off type of scaling.

We appreciate that Dr. Lankard has emphasized the useful and major role that petrographic examinations play in identifying factors responsible for scaling and other types of surface distress, and for settling disputes whether it is: a) the concrete suppliers' fault for not providing adequately air-entrained concrete and sound aggregates that meet the requirements of ASTM C 33; b) a contractor's fault for not properly finishing and curing the concrete; c) due to early exposure of concrete to freezing and deicing salts before attainment of maturity; or d) combinations of the above. Air-entrained concrete will resist the adverse effects of deicing salts if it is properly finished and has attained maturity before being exposed to cyclic freezing and deicing chemicals — deicing chemicals should not initiate surface distress under other circumstances.

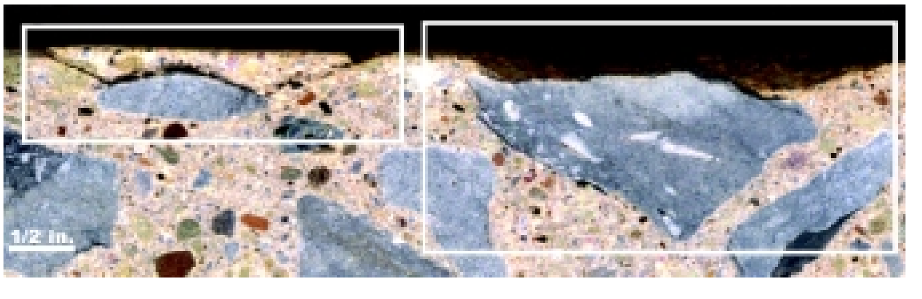

Fig. 3: Examples of mortar lift-off

We congratulate Dr. Lankard for re-emphasizing the potential pitfalls that can contribute to surface distress, and hope that we too have provided additional information that will be helpful in better understanding the nature of this decades-old problem.

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Reference

1. U.S. Bureau of Reclamation, "Investigation into the Effect of Water/Cement Ratio on the Freezing-Thawing Resistance of Non-Air and Air-Entrained Concrete," *Concrete Laboratory Report* No. C-810, Denver, Colo., 1955.

Author's response

Mr. Jana and Mr. Erlin have concluded that the factors of coarse aggregate properties, *w/cm,* and curing were singled out in my point of view article as *the* major players in the scaling of concrete flatwork. The headline to my article, which was crafted by the editors of *CI*, states that "coarse aggregate properties, *w/cm*, and curing play major roles."

When I proofed ACI's edited version of the paper, I didn't contest this headline since it was one of my intentions that the readers give more thought to how these variables affect scaling and that the variables be recognized as playing major roles. The headline does not claim, nor does my article claim, that these factors are *the* major players affecting scaling. As Mr. Jana and Mr. Erlin point out, air entrainment and finishing practices are equally important. Of course, they are, and let's include deicers and concrete strength while we're at it.

Another issue raised by Mr. Jana and Mr. Erlin involves my treatment of coarse aggregate involvement. In my article, I make the distinction between popouts and what I have called popoffs. Mr. Jana and Mr. Erlin prefer the term mortar lift-off for the latter. The distinctions between the two phenomena (popouts and popoffs) are quite clear and need no further discussion.

Mr. Jana and Mr. Erlin state that mortar lift-off "does not have to occur due to freezing of critically saturated water absorptive particles … and it usually occurs as a result of improper finishing…." To minimize or downplay the role that coarse aggregate expansion-on-freezing plays in the mortar lift-off phenomenon is to ignore the overwhelming evidence from the field studies and from laboratory studies that such expansions do occur; and that the magnitude of the expansion can vary greatly depending upon the aggregate source. Meanwhile, during a drop in temperature below freezing, the air-entrained mortar layer overlying the aggregate particles is contracting. The stage is set for something to give, even if the wearing surface layer hasn't been compromised by improper finishing and/or inadequate curing.

A point to be made here is that the variables that we agree are "major players" in the scaling phenomenon are interrelated. The *w/cm* of the wearing-surface-mortar layer overlying near-surface-coarse-aggregate particles affects (among other things) the water permeability of the mortar, which exerts a strong influence on the rate at which these aggregates become saturated. For this reason, it is expected that an "increased" *w/cm* in the wearing-surface-mortar layer will increase the potential for mortar lift-offs to occur and to be more extensive. Improper finishing is certainly involved in this dynamic, but is not involved in all instances of mortar lift-off. A *w/cm* well above 0.45 can occur in the full thickness of concrete as placed (including the wearing surface layer), even when the concrete is properly finished. This can happen with concrete that leaves the batch plant with a *w/cm* of 0.50 to 0.55 (which can still meet the strength requirement guideline), or with concrete that is retempered prior to placement.

In their concluding remarks, Mr. Jana and Mr. Erlin characterize scaling as a "decades-old problem." The fact that this is a decades-old problem is one of the reasons that led me to express my opinions in the article. Mr. Jana and Mr. Erlin suggest that scale-resistant concrete can be produced if the existing guidelines for quality concrete are followed. These guidelines have been publicized for years. Most of the concrete scaling today is air-entrained concrete. Most of the concrete scaling today leaves the batch plant with the potential for reaching the compressive strength guidelines.

Despite this, the scaling problem has reached such levels that some builders/developers won't use concrete for residential flatwork. It has been my observation that there are housing subdivisions where 20% to 30% of the driveways, aprons, or sidewalks show some form of wearing surface distress — much of it of the mortar lift-off variety. I believe that we need to go beyond the current guidelines if we want to have a meaningful impact on the scaling problem.

My thanks to Mr. Jana and Mr. Erlin for their comments and opinions.

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