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Final Report

Controlling Air Content in Concrete That is Being Pumped, A Synthesis Study

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16. Abstract

Changes in the air content of fresh concrete that is being pumped can occur at a number of places. These locations include the initial loading of the concrete into the pump hopper, as it passes through the pump line, and when it exits the line. This synthesis reviews the findings of recent research studies which deal with air content change in pumped concrete and summarizes methods of reducing air loss caused by handling.

Three main mechanisms by which air content is lost in fresh concrete that is being pumped have been noted. These factors include the high-pressure dissolution of air voids, the bursting of air voids by vacuum, and the loss of air content due to impact force. Entrained air content can be retained by proper attention to the pump operation and set-up. Keeping steeply descending sections of pump line to a minimum, using kinks, elbows, or reducers at the end of the line to slow the rate of concrete flow, and pumping the concrete at the lowest pressure possible will keep air content losses to a minimum. Further beneficial actions include not allowing rain water to enter the pump's hopper, and minimizing the distance that the concrete must fall from the end of the pump line to the placement surface. Testing the air content of concrete at the point of placement will yield the most indicative results of the concrete in the finished structure.

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Contents

1 Introduction

Changes in the intentionally entrained air content of fresh concrete can occur at a number of places in the pumping process. These locations include as the concrete is initially being loaded into the pump hopper, as it passes through the pump line, and when it exits the line. This synthesis reviews the findings of recent research studies which deal with air content change in pumped concrete and summarizes methods of reducing entrained air loss caused by handling.

2 Changes in Air Content at Delivery

Some change of air content in concrete being delivered to the site and loaded into the pump has been noted. Yazdani (1996) reports that, "a small amount of air appears to mix with the concrete when the concrete first enters the pump due to the pressure present in the pump line." He further notes that:

> The concrete and the pump should be protected from adverse weather. If pumping has to occur during rain, a method should be implemented to keep excess water from building up in the pump's hopper. This water can increase the concrete air content because the excess water which does not hydrate eventually evaporates and causes air voids.

These air voids are not intentionally entrained, are not in a bubble form, and therefore do not contribute to freeze/thaw durability. Other changes in the air content may take place if the delivering trucks must wait a long time to unload. Continuous mixing of concrete containing micro-silica or fly ash may shift the void size finer, which an air meter might interpret as a loss of air content (Hover 1989).

3 Air Losses in the Pump Line

Air void losses in the pump line have been attributed to three main causes. These causes are: dissolution by high pressure, bursting due to vacuum, and mechanical rupture by impact (Yingling et al. 1992, Boulet et al. 1997).

3.1 High Pressure Dissolution of Air Voids

Boulet et al. (1997) report at length on the factors influencing the dissolution (loss in volume and number) of air voids by high pressure in the pumping process. High pressure forces the air voids in concrete to become smaller or disappear, from which they don't entirely recover when the pressure returns to lower levels. Dissolution affects the smaller air voids much more so than larger ones. These are normally the entrained bubbles needed for freeze/thaw durability. Therefore, the loss of air through this effect is potentially more detrimental to concrete durability than air lost through the vacuum or impact effect.

In the research performed by Boulet et al., when concrete was exposed to a 5.5 MPa (800 psi) pressure the number of voids decreased by a factor of 100, and all of the voids less than 100μm disappeared. This led to a decrease of the specific surface of the air voids as obtained from the ASTM C457 microscopical examination of the concrete. Furthermore, the ASTM spacing factor of the air voids was shown to increase linearly with pressure as the flow length increased exponentially. Normal pumping pressures rarely exceed 3.5 MPa (500 psi).

The influence of pressure was found to affect all types of concrete in the same manner. Changes in the water/cement ratio, or in the types of admixtures used did not affect the basic relationship of pressure to air loss.

Dissolution of the air bubbles was noted in the very first seconds after the concrete was subjected to pressure. The calculated spacing factor and flow length (distance excess water must travel to escape a freezing capillary pore) increased significantly in this time and then remained stable. Since this process occurs very quickly, increasing the pumping rate to reduce the time that the concrete is under pressure is not thought to be an effective means of lowering the amount of damage to the concrete's air void structure.

3.2 Bursting of Voids by Vacuum

When concrete is pumped down a descending section it may overcome the effects of friction, slide, and create a vacuum. This condition can lead the larger air voids to burst due to their internal pressure. The bursting of voids through this process can lead to significant detected air loss (Hover 1989, Yingling et al. 1992, Yazdani 1996). However, the loss of the larger air voids is reported by Boulet et al. (1997) as having little effect on the air void spacing factor.

Hover (1989) found in his study that:

> The angle of the concrete pipeline had a significant and consistent effect on the loss in air content. Placing concrete close to a truck-mounted boom pump such that the concrete was first pumped up at a steep angle, and then down the far side at a steep angle, consistently resulted in a loss of 4% air

> . . . When the placement had progressed so that the pump angle was nearly horizontal, air loss in pumping for the same concrete was consistently 2%.

His analysis of this phenomena was that, "pumping 'downhill' may result in a pressure drop in the fluid concrete in the pipeline which may favor the escape of entrained and entrapped air."

3.3 Impact Force

Yingling et al. (1992) report that the air loss mechanism in pumped concrete may largely be the impact of rapidly moving concrete contacting stationary objects and thus breaking the internal air voids through mechanical action. It was found that a significant portion of the initial air content—20 to 40%—could be lost by the effect of impact. Other researchers have found similar results.

Hover and Phares (1996) noted from their research that:

> A long vertically descending pump line is in reality a long tremie, or elephant trunk , and . . . the impact of fresh concrete on the walls, joints, and finally the deck knocks air out of the system.

From the same study they report that, "Pumping with unimpeded free-fall generally reduced air content by 0.5 to 2 percentage points."

3.4 Controlling Air Loss

To reduce the amount of air loss in the pump line due to the three mechanisms mentioned above, a number of suggestions have been proposed. The first is to avoid pumping down long descending sections. This will reduce the likelihood of a vacuum forming as well as limiting the impact force acting on the concrete both in the pipeline and when it exits. When pumping downward 50 feet or more, the American Concrete Institute (1996) recommends placing an air release valve in the middle of the top bend of the pump line to prevent either vacuum or air buildup.

Where descending sections are used, measures to build up resistance in the line and slow the descent of the concrete have also proven effective in controlling air loss, mainly by limiting excessive impact forces. These measures include adding 90 degree turns at the end of the line, laying the last ten to twenty feet of line horizontal, and moving the pump or boom to reduce vertical sections (Yingling et al. 1992, Hover and Phares 1996, Yazdani 1996). The Indiana Department of Transportation's Standard Specifications (1995) also limit the distance concrete being placed can be allowed to fall in open air to two feet and require a flexible end section at least ten feet long.

To avoid dissolution of air voids, the pumping pressure should be kept to a minimum. Yingling et al. (1992) reported no loss of air content in their study when concrete was being pumped horizontally at a low pressure. Boulet et al. (1997) found the highest pressures, and therefore the most damaging ones, occurred in cases where concrete was being pumped vertically through a narrow nozzle.

4 Testing for Air Content

In most situations air meters are relatively accurate in determining the air content of fresh concrete, however some discrepancies have been noted. Ozyildirim (1991) reports that:

> The air content of fresh concrete measured by pressure meters and that determined by the microscopic method for essentially the same concrete after hardening are, for practical purposes, the same. The air content obtained by a volumetric meter as normally run in the field is generally lower than that obtained for the same hardened concretes by the microscopical method. . . . a higher air content in hardened concretes . . . is likely to be present if water is added during placement.

In contrast, Hover (1989) found in his case studies that, "the air pressure meter was found to significantly underestimate the air content." He further stated that:

> It has been suggested that the discrepancy between fresh and hardened air contents may be due to the inaccuracy of the pressure meter in measuring the total air content of concrete mixes with very small entrained air bubbles. It has been qualitatively proposed that the air meter becomes increasingly less accurate as the bubbles become smaller.

Testing for air content at the point of placement will obviously provide the most accurate results for determining the amount of entrained air in the final structure. As the American Concrete Institute (1996) states, "The quality of the concrete being placed in the structure can only be measured at the placement end of the line." Some difficulties in testing at the placement point have been seen however. On this subject Hover and Phares (1996) noted the following:

> To temporarily halt a bridge-deck-placing operation to deposit point-of-placement samples directly from the pump into the tester's bucket or wheelbarrow will probably require that the pump boom, line configuration, and pumping rate be changed. For better or worse, such samples may not be representative of the concrete in the structure.

The most feasible procedure for taking fresh concrete samples should be agreed upon during the pre-construction meeting.

5 Conclusion

The change in air content of concrete that is being pumped can be attributed to three main actions. The dissolution of air voids by high pressure, the bursting of voids by vacuum, and the mechanical rupture of voids by impact forces. These detrimental actions can be controlled by keeping steeply descending sections of pump line to a minimum, using kinks and elbows at the end of the line to slow the rate of concrete flow, and to use the lowest pressure possible in the pumping operation.

The air content of concrete may also rise during the placing operation when it is remixed in the hopper prior to pumping. Rain water being allowed to enter the hopper and thereby getting mixed in with the concrete may also raise the ultimate air content.

Testing of the concrete for air content is best done at the point of placement rather than as it is loaded into the pump's hopper. The results of a test at this point will be the most indicative of the concrete in the structure, but may not be an exact match due to changes in the pumping configuration needed to acquire the sample.

6 Implementation

The implementation of best construction practices should be discussed in detail at the pre-construction conferences in which the three main mechanisms of air void loss are explained. The constructor should have the opportunity at these meetings to describe how they will minimize these effects, and agreement reached on the practice which will be followed in the field. Proper freeze/thaw durability is essential in nearly all highway applications and should not be sacrificed for a construction expediency such as using higher slumps for easier placement.

The procedure for air content testing should also be discussed and agreed upon at the pre-construction conferences. Special emphasis should be given to where the sample will be taken, and what standard procedures will be followed during the testing (e.g. method of consolidation).

7 Recommended Further Activity

It is recommended that a short instructional video be prepared to cover the primary points of this synthesis and the accepted practices for concrete placement. It is further suggested that a number of pre-construction or pre-bid conferences be attended to gather information on what types of questions are of the most concern to constructors in relation to the proper placement of fresh concrete.

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