Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete

Reported by ACI Committee 212

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The use of high-range water-reducing admixtures is increasing substantially in the concrete industry. They are used to increase strength of concrete and provide greatly increased workability without the addition of excessive amounts of water. This guide contains information on application, uses, and effects on freshly mixed and hardened concretes; and quality control of concretes containing high-range water-reducing admixtures. The guide is designed for use by concrete suppliers, contractors, designers, specifiers, and all others engaged in concrete construction.

Keywords: admixtures; batching; consolidation; mixing; mix proportioning; portland cements; plasticizers; quality control; water reducing agents; workability.

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* Members who produced the report.
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CHAPTER 1 — GENERAL INFORMATION

1.1-Introduction
From the late 1970s, use of a new class of chemical admixture has increased substantially in various segments of the concrete industry. The admixture can be used to significantly increase slump without adding more water, or to greatly reduce water content without a loss in slump. Properly categorized as a high-range water-reducing admixture (HRWRA), meeting requirements of ASTM C 494 Type F or G or ASTM C 1017 Type 1 or 2, this material is sometimes referred to as a “super water-reducer” or “superplasticizer.” As originally marketed in Germany and Japan in the late 1960s, these materials consisted primarily of sulfonated condensation products of naphthalene or melamine.

Information on the properties and uses of HRWRAs was published during the period of their introduction into the U.S. market, roughly from 1974 to 1981. The literature included two ACI special publications based on proceedings of international symposia [SP-62 (1979), SP-68 (1981)], a Transportation Research Record (1979), and publications by the Portland Cement Association (1979), CANMET (1979), and the Cement and Concrete Association (1976). Recently published textbooks on concrete admixtures (Ramachandran and Malhotra, 1984; Rixom and Mailvaganam, 1986), also contain considerable information on HRWRAs.

In the early years, the use of HRWRAs was limited because of problems such as a higher than normal rate of slump loss. Lowered resistance to freezing and thawing and deicer scaling following application of deicing agents in the laboratory was also reported. Experience eventually demonstrated that concretes containing HRWRAs were at least as durable as conventional mixtures in field exposure. However, slump loss continued to be an issue, leading to development of new products aimed at increasing efficiency, improving cohesiveness, and maintaining workability for longer periods of time.

An “extended life” HRWRA was developed, which imparted an even longer working life to concrete, This allowed adding HRWRAs at the batch plant rather than at the job site, thereby reducing wear on truck mixers and lessening the need for ancillary equipment, such as truck-mounted admixture tanks and dispensers, The result was an increase in the use of HRWRAs in almost all areas of the concrete industry.

1.2-Specifications
Two ASTM specifications cover high-range water-reducing admixtures. The first of these, ASTM C 494, “Standard Specification for Chemical Admixtures for Concrete” describes two types: Type F, used when high-range water reduction is desired within normal setting times; and Type G, used when high-range water reduction is required with a retarded setting time. When the admixtures are used to produce conventional slump concrete at reduced water content, ASTM C 494 is normally cited.

When high-slump “flowing” concrete is desired, HRWRAs are generally specified to conform to the second document, ASTM C 1017, “Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete.” Flowing concrete is defined by ASTM as “concrete that is characterized by a slump greater than 7½ in. (190 mm) while maintaining a cohesive nature . . . .” Two types of admixtures are included in ASTM C 1017. Type 1 is appropriate for flowing concrete having a normal setting time. Type 2 is appropriate for flowing concrete having a retarded setting time.

This Committee recommends that manufacturers’ material safety data sheets (MSDS) be reviewed prior to the use of all HRWRAs.

CHAPTER 2 — USES FOR HIGH-RANGE WATER-REDUCING ADMIXTURES

2.1-General uses
HRWRAs can be used in concrete to: increase slump; increase strength by decreasing water content and water-cementitious materials ratio (w/cm); or decrease water and cement content, thus reducing temperature rise and volume change. These results are attainable in a wide variety of concrete mixtures, from conventional types to specially concretes, and in a number of grouts and pre-packaged concretes used for repair and rehabilitation.

2.2-Increased slump
Concrete slump is increased when HRWRAs are added to concrete mixtures and no other changes are made in mixture proportions. The slump may be in-
creased by either a moderate or large increment, depend-
ing on the performance requirements of the concrete. For example, flowing concrete can be proportioned with an even higher slump to be self-leveling; that is, capable of attaining a level surface with little additional effort from the placer. However, for a properly consolidated concrete, some compaction will always be required.

When the slump is very high, as in flowing concrete, the mixture tends to segregate or bleed, although the presence of HRWRA lessens this tendency. In such cases, it is especially important that the fines are carefully proportioned, making sure that they are added in ade-
quate amounts and at a grading suitable for the available coarse aggregate.

High-slump or flowing concrete can be used to advan-
tage in the ready-mixed, precast, and prestressed con-
crete industries. The concrete’s ability to flow easily makes it especially beneficial in applications involving areas of congested reinforcing steel, or special form linings or treatments where the embedments obstruct concrete placement. The flowing characteristic is also advantageous for filling deep forms, where the flowing concrete can achieve intimate contact with the rein-
forcing or prestressing steel. Ready-mixed flowing con-
crete is used in flatwork and foundations where it can improve the rate of placement. In general, flowing con-
crete can greatly reduce costs of placing, consolidation, and finishing operations.

In the precast prestressed concrete industry, precast units often have architectural details that require the use of high-slump concrete. But the concrete must also gain strength quickly to permit early form stripping and turn-
around. Increasing the slump of conventional concrete by adding water will retard early strength gain and delay form stripping. Flowing concrete provides high slump plus the strength-gain rate needed for early form remov-
al. Use of a HRWRA to produce flowing concrete with the same or a lower w/cm than normal concrete may also reduce heat curing requirements for precast concrete.

The rate of strength development in flowing concrete is similar to that of low-slump concrete, assuming a con-
stant w/cm in each mixture. Flowing concrete mixtures are proportioned to meet both conventional strength — 3,000 to 4,000 psi (20 to 28 MPa) — and high strength — 6,000 psi (41 Mpa) and greater — requirements. Normal strength concretes are used for slabs, foundation mats, grade beams, slurry trench walls, and similar on-grade placements. Applications requiring workable high-
strength concrete with low water content include struc-
tural elements that are either thin or congested with steel, and certain types of bridge repairs.

2.3-Decreased water-cementitious materials ratio

As may be used to reduce the water content of con-
crete, thus decreasing the w/cm and increasing the strength. High-strength concrete is used in ever-
increasing applications, among them high-rise commercial buildings, high-strength prestressed beams and slabs, impact-resistant structures, and offshore structures. A low w/cm is also beneficial in specialty concretes, including the following: (a) dense (low-permeability) concrete mix-
tures having high cement content and low w/cm, used for bridge deck overlays; (b) silica-fume concretes, used to obtain very low permeability and very high strength con-
cretes in structures such as parking garages, where they protect reinforcing steel from corrosive deicing agents; and (c) various grouts and prepackaged concretes used for repair and rehabilitation.

In addition to reaching high ultimate strength, con-
crete with a HRWRA and reduced w/cm exhibits strength increases above normal concrete at all ages. This characteristic is desirable in precasting operations where early form stripping may permit an increase in plant output.

2.4-Decreased water and cement contents

High-range water-reducing admixtures may be used to reduce both water and cement contents, thus permitting the use of less cement without reducing strength. Any cost savings from the reduced cement content are depen-
dent on the relative prices of cement and HRWRA. In most cases, the direct economic benefits are minor, al-
though the indirect benefits may be significant. For example, an application may demand lower concrete heat rise or drying shrinkage without changing the slump or w/cm (and hence strength). Such concrete is desirable for use in massive sections because of its reduced tendency to crack when it cools and dries.

CHAPTER 3 - EFFECTS ON FRESHLY MIXED CONCRETE

3.1-General

Concrete containing a HRWRA may require the use of procedures not normally required for conventional concrete. For instance, a flowing concrete, when placed rapidly, may increase the pressure on formwork. Other job site problem areas may involve slump loss, slow setting, or segregation and bleeding. Early identification of these problems is aided by using field trial batches, which will reflect job site conditions more accurately than laboratory testing.

3.2-Slump

The rate of slump loss in concrete containing a HRWRA can be affected by the type of HRWRA, the dosage used, the simultaneous use of a C 494 Type A, B, or D admixture, the type and brand of cement, the class of concrete, and the concrete temperature. These factors are by no means the only ones affecting slump loss, but they are those that can typically be controlled by the user. Ambient temperature is not as controllable but it can also have a dramatic effect on the performance of a HRWRA. It is commonly believed that all HRWRA con-
Concrete rapidly loses workability. As stated in Chapter 1, this is not necessarily true (Collepardi and Corradi, 1979).

Both specifications for HRWRAs (ASTM C 494 and C 1017) mention slump loss, but neither requires tests for slump-loss characteristics. As a result of advances in HRWRA technology and the numerous products available, it has become advantageous to describe these products not only by the requirements of ASTM standards, but also by the method of addition. A high-range water-reducing admixture may be added at the job site or at the batch plant.

When normal HRWRAs are added at the job site, the concrete exhibits moderate to rapid slump loss and normal or retarded initial setting characteristics. Special products added at the batch plant can extend slump retention in the concrete (Collepardi and Corradi, 1979), along with either retarded or normal initial setting characteristics. The difference in performance does not indicate that one product is better than another, but that certain products may be more appropriate in some construction situations than in others.

Generally, the higher the dosage rate of HRWRA in concrete, the lower the rate of slump loss (Ravina and Mor, 1986). However, each product has an operating range beyond which other properties of the concrete may be affected. If the dosage rate is increased beyond this range as a means of further lowering the rate of slump loss, the results may include changes in initial setting characteristics, segregation, or bleeding. HRWRAs should be used in accordance with the manufacturer’s recommended dosage range.

The chemical composition of cement can also affect the performance characteristics of concrete containing a HRWRA. This is not to say that a HRWRA will not work with a certain type of cement, but that slump loss and other characteristics may be different. For example, Type I and Type III cements typically contain more tricalcium aluminate (C₃A) than Type II and Type V cements. Because of this, concrete made with Type I and Type III cements exhibit more slump loss at a normal HRWRA dosage rate. Dosage rates may also vary from brand to brand for different types of cement.

Concrete temperature is another important factor that should be considered when using a HRWRA. As with all concrete, the higher the concrete temperature the more rapid the slump loss. This reaction can be minimized in different ways. One way is to choose a product that conforms to ASTM C 494, Type G, or to add a retarder (ASTM C 494 Type B or D) to the concrete in addition to the HRWRA. The retarding effect can be beneficial in reducing rapid slump loss. Also, a product specifically formulated to minimize slump loss may be added at the batch-plant. Following hot-weatherconcreting procedures outlined in ACI 305 will also reduce slump loss caused by high concrete temperature.

3.3-Time of setting

ASTM C 494 specifies the minimum performance criteria required for chemical admixtures. One criterion is the initial time of setting. ASTM C 494 requires that concrete containing Type F HRWRA reach the initial time of setting no more than 1 hour before or 1½ hours after that of a reference concrete of similar slump, air content, and temperature. Concrete with retarding Type G HRWRA must reach its initial time of setting at least 1 hour after, but not more than 3 1/2 hours after, the initial setting time of a reference concrete. The specification requires that these criteria need only be met at one dosage rate.

Most manufacturers of HRWRAs recommend a particular dosage range for their product. However, adhering to the recommended range does not necessarily mean the product will meet the requirements of ASTM C 494, Type F or Type G, throughout this range. This is especially true for the initial time of setting. In most cases, the higher the dosage rate of HRWRA, the greater the retardation in setting. It is necessary for manufacturers to provide an acceptable range of dosages, because these products are used in a variety of situations and climatic conditions.

3.4-Air entrainment

Numerous tests have been conducted to study the influence of HRWRAs on air-entrained concrete, which is typically used to resist deicer scaling as well as freezing and thawing. Most tests have shown that the air-void system of air-entrained concrete is altered by the addition of a HRWRA. Typically, the air-void spacing is greater than the recommended value set by ACI 201.2R. This spacing is caused by an increase in the average bubble size and a decrease in the specific surface compared to an air-entrained concrete without a HRWRA (see Section 4.6).

3.5-Segregation

Segregation in concrete is the separation of mixture components resulting from differences in their particle size or density. Segregation does not normally occur in concrete containing a HRWRA used as a water reducer. However, when the admixtures are used to create flowing concrete, segregation could occur if precautions are not taken. Improper proportioning and inadequate mixing can both result in localized excess fluidity and segregation.

Proportioning deficiencies might not be apparent in relatively low-slump concrete. However, the higher slump of flowing concrete accentuates these deficiencies and may cause segregation during handling. One way to assure proper proportioning is to increase the quantity of the smaller sizes of coarse aggregate and of fine aggregate. Under ideal conditions, the coarse aggregate is suspended in a cohesive mortar that does not segregate, although adding more admixture or water may dramatically reduce this cohesiveness.

The self-leveling characteristics of flowing concrete
have given rise to a false belief that such concrete does not require vibration. In fact, flowing concrete must be adequately consolidated, with or without vibration. Unfortunately, most concrete slabs, including those constructed using flowing concrete, receive little or no vibration.

3.6-Bleeding

Bleeding is the process by which solids settle in fresh concrete, allowing some mixing water to rise to the surface.

In concrete where a HRWRA is used as a water-reducer, the bleeding generally is decreased because of the lower water content. This effect has been verified for concrete containing Types I, II, and V cements (Rama-chandran and Malhotra, 1984).

Bleeding may be further reduced by incorporating the same measures as are used to reduce segregation. In addition, bleeding may be reduced by limiting the types of admixtures used in concrete made with a HRWRA. The hydroxylated carboxylic acids, for example, tend to increase to varying degrees the bleeding tendencies of concrete containing HRWRAs (ACI 212.3R). Field trial batches should be made to determine the most suitable materials and proportions that will provide a mixture having the least amount of segregation and bleeding, and at the same time provide the necessary workability to meet placing requirements.

3.7-Pumpability

Pumping is a common method of placing concrete at the construction site. A small amount of slump loss through the pump line is common in any concrete. When excessive slump loss occurs, the causes may stem from a variety of factors including proportioning, aggregate porosity, loss of air-entrainment, degradation of aggregates, climatic conditions, and inadequate pumping equipment. When pumpability becomes a problem, adding water to the concrete should not be considered an acceptable solution. Besides lowering the quality of concrete, the addition of water dilutes the mortar. Pumping pressures then may push mortar ahead of the coarse aggregate, causing a pumpline blockage.

In the past, the following options for solving pumpability problems have been used successfully:

1. Modify mixture proportions, giving particular attention to the cement content, the fine aggregate content, and use of mineral admixtures such as fly ash.
2. Use larger and more powerful pumps.
3. Pump from one pump to another (staging) before arriving at the final point of placement.

Adding a HRWRA can provide an economical alternative to the above options by significantly lowering the pumping pressure requirement and increasing pump efficiency. Investigations have shown that the addition of a HRWRA can reduce the pumping pressure by 25 to 35 percent for normal weight concrete, and by 10 to 20 percent for lightweight concrete (Kasami, Ikeda, and Yamane, 1979).

4.1-Compressive strength

The primary effects of HRWRAs on concrete compressive strength are derived from their effect on the water-cementitious materials ratio (w/cm). When a HRWRA is used to lower water requirements at the same slump and cementitious materials content, the resulting decrease in w/cm will significantly increase concrete strength at all ages. If mixes with the same w/cm are compared, those containing HRWRA exhibit a slight increase in strength because of the cement dispersing effect. At early ages, this strength increase represents a significant percentage of total strength.

Users of HRWRAs should first calculate the w/cm and then estimate concrete strength using tables in ACI 211.1. This estimate will be conservative because of the cement dispersing effect mentioned above. It is advisable to develop data on w/cm versus strength for materials used on each job. The same data can also be used to determine the influence of the admixture on the rate of concrete strength development at early ages. The changes in early strength resulting from the use of HRWRAs should not be great in flowing concrete unless a specifically designated retarding or accelerating formulation is used. Where a HRWRA is used to increase strength by a reduction in w/cm, the effect on early strength will be positive.

Because of their effectiveness in reducing the w/cm, HRWRAs are beneficial in producing concretes with compressive strengths greater than 6000 psi (41 MPa) at 28 days, and are essential in achieving 28-day strengths that exceed 10,000 psi (69 MPa) under field conditions.

4.2-Tensile strength and modulus of elasticity

High-range water-reducing admixtures in concrete will affect the tensile strength in the same way they affect the compressive strength. Methods for estimating the tensile strength and modulus of elasticity based on compressive strength are the same as those used for concrete without a HRWRA.

4.3-Bond to reinforcement

No data have been found to indicate that the use of flowing concrete has an effect on its bond to reinforcing steel. The bond strength of flowing concrete to reinforcing steel depends on concrete strength, degree of consolidation, bleeding and settlement, and the time of setting. Flowing concrete may show no change in bond strength compared to lower slump concrete with an equal water-cement ratio, provided the following conditions are met: the concrete is vibrated; the concrete sets rapidly
after consolidation; and it exhibits a higher compressive strength than conventional concrete. If these conditions are not satisfied, however, a reduction in bond strength may occur (Brettman, Darwin, and Donahey, 1986). Flowing concretes that aren’t vibrated may have significantly reduced bond strengths as compared with lower slump or flowing concretes that are properly vibrated. Proper consolidation around reinforcement is more easily achieved with flowing concrete.

4.4-Temperature rise

The temperature rise in flowing concrete due to heat of hydration is not significantly affected by the addition of a Type F HRWRA unless the amount or composition of the binder is changed. There may be a small change in the time at which the peak concrete temperature from hydration is attained, but this difference can generally be disregarded. When HRWRAs are used to achieve water reduction, some increase in temperature rise may result because of the lower water content.

4.5-Drying shrinkage and creep

Laboratory studies indicate that adding a HRWRA to a cement paste increases the drying shrinkage of the paste. Some laboratory data confirm that HRWRAs can increase concrete drying shrinkage at a given water-cement ratio and cement content (given paste content), but this effect has not been definitively established. Therefore, the drying shrinkage of flowing concrete should be similar to, or slightly greater than, that of the same concrete mixture without any HRWRA. If there is a simultaneous reduction in cement content and w/cm when the HRWRA is added, drying shrinkage can be reduced.

If drying shrinkage is a critical factor for the structure being built, the shrinkage (ASTM C 157) should be measured before the mix proportions are finalized to ensure that the desired value is not exceeded. Shrinkage values of concrete with and without HRWRA should be compared at equal strength of the concrete, not equal time (age), so that concretes are compared at a similar porosity.

Although few studies have been made on creep characteristics, it is expected that adding HRWRAs to concrete should affect creep to the same extent that they affect shrinkage.

4.6-Frost resistance

Concretes containing HRWRAs exhibit the same degree of resistance to freezing and thawing and deicer salt scaling, as do well consolidated concretes without HRWRA, if the w/cm and air-void system are the same. Resistance of the concrete is further improved if the w/cm is decreased. The proper sequence should be established for adding the air-entraining admixture relative to other mixture constituents (see Section 3.4) in order to avoid excessive loss of entrained air during mixing or placement. The increase in spacing factor L from 0.008 in. to 0.01 in., or higher, may not adversely affect resistance to freezing and thawing under field conditions.

4.7-Durability

When HRWRAs are used to produce high strength, the lowered w/cm also lowers concrete permeability. The lower permeability and higher strength should improve such concrete properties as sulfate resistance and abrasion resistance.

CHAPTER 5- TYPICAL APPLICATIONS OF HIGH-RANGE WATER-REDUCING ADMIXTURES

5.1-General

Concrete containing HRWRAs can be used effectively to satisfy a variety of project needs. The ready-mixed concrete producer uses HRWRAs to increase slump without adding water, to improve the efficiency of the cement used, and to help assure the required concrete strength levels at different ages. The concrete contractor uses flowing concrete to ease placing and consolidating, and to speed placement. In addition, the contractor may also be able to reduce crew size and speed up the construction cycle, thus increasing profits.

5.2-High-strength concrete

High-strength concrete is defined as one that achieves compressive strengths higher than 6,000 psi (41 MPa) at 28 or 56 days. The water-cementitious materials ratio may range from 0.25 for 56-day strengths of 12,000 and 14,000 psi (82 and 96 MPa) to 0.40 for some 6,000 psi (41 MPa) mixtures at 28 days. Important factors for producing high-strength concrete include good strength-producing properties of the cement; low w/cm; and a strong, clean, properly sized and graded aggregate. The size and grading of aggregates are dictated by the type of placing method used and the size of the structural member being constructed.

When the w/cm is below 0.35, HRWRAs are often added at the plant to assure control of the water, and then again in the field for placing purposes. For example, if a mixture has a w/cm of 0.33 and a maximum water content of 250 yd$^3$ (150 kg/m$^3$), a moderate dose of HRWRA can be added at the plant to produce a 4 to 6 in. (100 to 150 mm) slump. When the concrete is transported to the job site, a second dose of HRWRA can be added to achieve the slump required for pumping or other type of placement. This two-step method of adding HRWRA results in less set retardation and is particularly useful when the concrete is placed in slabs that must be finished by troweling. Other types of applications may not require the same method of addition. For column concrete the dosage of HRWRA added at the central mix plant may be high enough to eliminate the need for a second dosage at the job site. For instance, the con-
crete may have a 9 in. (235 mm) slump at the central mix plant and may not require additional admixture unless construction delays occur.

5.3-Prestressed concrete
In a 1990 survey of prestressed concrete producers, 100 percent of the respondents indicated they used HRWRAs in all prestressed products, including bridge girders, beams, slabs, piles and poles. This rate of use reflected a dramatic increase from 1983, when approximately 65 percent of the producers used HRWRAs. The benefits of low w/cm, early strength gain, ease of placement, and rapid form cycling are clearly recognized by the prestressed concrete industry.

5.4-Architectural concrete
Architectural concrete is exposed concrete designed to present a pleasing and consistent appearance, with minimal defects. The concrete must reflect the formed surface as much as possible. The concrete mixture must be uniform and workable, without sticky characteristics that tend to cause bug holes and other defects either on the exposed surface or slightly below it. A high-range water-reducing admixture may be added to architectural concrete to increase its workability. The optimum proportions and vibration methods with given materials should be determined by constructing sample panels. Vibration needs will vary with the materials used in making the concrete. Some flowing concrete mixtures can be adequately compacted with very little vibration. With different materials the flowing concrete may require a considerable amount of vibration to achieve the same blemish-free surface.

The formwork for architectural concrete containing HRWRAs may be subjected to greater pressures than from conventional concrete mixtures. These pressures can be countered by using forms that are stronger than normal, and by sealing form joints and tie holes with stable materials that will hold fast under high form pressures. Failure to take precautions against the high pressures will result in form-leakage lines and sand streaks.

5.5-Parking structures
Parking structures require dense, low w/cm, low-permeability, air-entrained concrete that is properly placed, consolidated, finished and cured. With HRWRAs, easily pumpable or placeable concrete can be proportioned with a w/cm of 0.40 or lower. It is extremely important to minimize voids by properly consolidating the concrete, but maintaining an adequate air content throughout the concrete, especially the top surface. The mixture should not exhibit excess bleeding or segregation.

Over-finishing the concrete surface in parking structures should be avoided because the procedure may reduce the air content at the surface. Evaporation retardants are commonly sprayed on the surface of the freshly placed concrete one or more times during fin-ishing to prevent plastic-shrinkage cracking. Cracks caused by plastic shrinkage or drying shrinkage must be minimized because they allow deicers to more easily penetrate the concrete. Properly proportioned concrete with a HRWRA can better resist the ingress of chloride ions than conventional concrete of equal water-cement ratio (Lukas, 1981). Since watertightness of any concrete is also a function of w/cm and curing, the concrete placed in parking structures must be properly cured.

5.6-Rapid-cycle high-rise projects
Rapid-cycle high-rise projects are typically structures with many repetitive floor placements where the speed of construction is essential to the success of the project. The choice of a concrete frame over a steel frame building is always made with the expectation that the speed of concrete construction will be a major economic benefit. Most rapid-cycle high-rise projects require a strength of 3,000 psi (21 MPa) at 1, 2, or 3 days, with an appropriate safety factor.

Flowing concrete is often used on rapid-cycle projects because it can be pumped or otherwise placed rapidly so that the finishing operation can take place during regular working hours. The flowing concrete must have a w/cm that is low enough to ensure early strength development with an adequate safety factor. Concrete containing a HRWRA uses cement more efficiently and satisfies the requirements of rapid-cycle projects extremely well. The lower w/cm achieved with HRWRA produces the highest percentage increase in strength at early ages. In cold weather a non-corrosive, non-chloride accelerator, or Type III cement can be added to offset the effect of low temperatures on initial setting and early strength gain.

5.7-Industrial slabs
Industrial slabs are subjected to varying degrees of vehicular traffic that place special demands on the concrete. Desirable slab characteristics include flatness and levelness values within specified tolerances, high compressive strength and abrasion resistance of the top surface, and a minimum of cracking and curling. A high-range water-reducing admixture is very helpful in producing concrete that can be proportioned and easily adjusted to accommodate placing and finishing operations without compromising quality of the hardened concrete.

Changes in mix proportions may be needed to permit easier placing and finishing. To reduce slab shrinkage, the changes should minimize water content while allowing optimum slump for the method of placement to be used. For strips 25 ft (7.6 m) wide or less that are placed directly from the truck mixer and finished with a vibratory screed, an initial slump of 2 to 3 in. (50 to 75 mm) may only need to be increased to 6 in. (150 mm) by adding a HRWRA. For wider strips, more difficult access, or when the placement method involves pumping, HRWRA dosage can be increased to produce a higher slump without altering other mixture proportions. The
appropriate mixture and the desired setting times should be discussed and resolved at a meeting before the beginning of slab placement. After the concrete proportions have been determined, the placing, consolidating, and leveling procedures can also be finalized.

The slump at which the concrete is placed also affects the ‘window of finishability’ necessary for applications of shake-on hardeners and for restraightening of the slab to achieve the specified flatness and levelness. For example, a common specification for an industrial floor slab would include a shake-on metallic hardener at 1.5 lb/ft² (7.3 kg/m²) and a flatness and levelness tolerance of $F_{25}/F_{L 20}$ (ACI 302, Section 7.15). This flatness specification demands two or more restraightening operations with a highway straightedge to achieve the degree of smoothness required by the specification. Concrete must remain plastic long enough for completion of these cutting and filling operations, even when shake-on hardener applications are required. Concrete having an initial slump of about 3 in. (75 mm) cannot be restraightened; therefore, the concrete surface cannot achieve any flatness requirement above about $F_{L 20}$. Concrete requiring restraightening should have a target slump between 5 and 9 in. (125 and 235 mm). In most cases, concrete with a higher slump must contain a HRWRA because the alternative — adding water to produce the slump increase — will increase shrinkage and bleeding, and have other undesirable consequences.

Cracking and curling are related to water content and homogeneity of the concrete mixture. A slab normally experiences water loss due to evaporation only from the top surface. It therefore develops differential shrinkage between the top and the bottom surfaces, which leads to curling. Minimal bleeding is desirable since the top and bottom slab surfaces should preferably have the same $w/cm$. Adding a HRWRA permits the use of lower water-content concrete that bleeds less.

5.8-Massive concrete

Concrete sections that are 2 ft (0.6 m) thick or greater present problems in placement, consolidation, setting times, heat generation, shrinkage and cracking. Cementsitious material and water content should be minimized to reduce heat generation and shrinkage. At the same time, enough workability is needed to permit proper concrete placement and consolidation in large sections where reinforcement may be closely spaced. Flowing concrete containing a HRWRA is well suited for this use. Even though water reductions in lean mass concrete may not be as high as those for richer concrete, use of a HRWRA is beneficial. Flowing concrete with properly modified setting characteristics can be placed faster and with fewer problems related to cracking, inadequate consolidation, or cold joints. For example, an 8000 yd³ (6120 m³) mat, 5% to 7 ft (1.7 to 2.1 m) thick, was successfully placed in 13% hours using 100 trucks on the International Crossroads project in Mahwah, New Jersey. Some 10-yd³ (7.7 m³) trucks were discharged in less than a minute. This speed of discharge and ease of placement improves the probability of successful massive concrete placements.

CHAPTER 6 — QUALITY CONTROL

6.1-Introduction

Quality control procedures for concrete containing high-range water-reducing admixtures should be an extension of procedures established for conventional concrete. For both types of concrete, established procedures should ensure that the following areas are adequately addressed:

Personnel training
Selection of materials
Mixture proportions
Storage of materials
Plant equipment
Batching, measuring, and mixing of materials
Delivery equipment
Delivery coordination
Placement and consolidation
Finishing
Curing

Several areas need additional attention when using HRWRA:

Slump control
Measuring and dispensing of HRWRA
Mixing
Redosing with HRWRA

6.2-Slump control

Slump control is the primary method for controlling the water content, and hence the $w/cm$, of concrete. Once concrete has a HRWRA added, the resulting slump is affected by the starting slump (associated with the initial water content) and the HRWRA. When a HRWRA is used, slump control prior to the addition of the HRWRA is critical for quality control, whether the admixture is added at the plant or job site.

Accurate measurement and compensation of aggregate moisture is crucial to slump control. Although an error of 1 percent in moisture compensation for both fine and coarse aggregates would have a minor impact on the amounts of aggregate batched, the batch water could be off by 3 to 4 gal/yard³ (8.7 to 11.6 l/m³).

Central-mixed operations should use watt meters, amp meters, or other means of indicating slumps prior to adding a HRWRA. The HRWRA can then be measured and added to the central mixer using conventional dispensing equipment.

Any water left in a truck mixer or from washing down hoppers and blades must be carefully accounted for, and the amount of water batched should be reduced accordingly.

6.2.1 Plant-added HRWRA — One potential advantage
to plant-added HRWRAs is that control of initial slumps is centralized under the supervision of one person.

Transit-mixed operations should have suitable procedures for measuring and controlling slump prior to the addition of a HRWRA. These procedures might include a visual check of the slump or the use of slump meters for estimating the slump.

6.2.2 Job site-added HRWRA — Where a HRWRA is added from a bulk dispensing system at the job site, the basic procedures discussed previously should be followed. The investment in storage and dispensing equipment normally limits this approach to large projects.

When truck-mounted tanks are used to dispense a HRWRA, several additional procedures need to be addressed. Since these procedures are not routine, drivers should be adequately trained in their use.

At the plant, a HRWRA is normally measured by the batcher and introduced into the truck tank by the driver. This process requires careful coordination. Procedures should ensure that the driver: (a) is made aware that he is to receive the HRWRA in addition to his load, (b) is familiar with valving on the truck dispensing equipment; and (c) makes sure that the HRWRA is discharged into the truck tank.

Once at the job site, the driver should make sure that the slump is within the target range — typically 2 to 3 in (50 to 75 mm). Slump meters or visual checks are often used, supplemented by slump tests as needed.

The HRWRA is then introduced and mixed into the load. Best results are obtained when the HRWRA is discharged directly onto the concrete. This may require reversing the drum to move partial loads to the rear of the drum before discharging the admixture. Care must be taken during discharge to prevent the stream of admixture from striking the mixer blades and being deflected down the chute. This could result in loss or concentration of the HRWRA in a small pump hopper or crane bucket, if the truck is already in position on the job. The load should be mixed at mixing speed for a sufficient time to ensure a consistent slump throughout the load, typically 70 to 100 revolutions.

When the HRWRA in a truck tank is not used for any reason, the tank should be emptied, or the HRWRA accounted for, in order to eliminate “double dosing” subsequent loads.

6.3-Redosing to recover lost slump
Additional dosages of HRWRA may be used when delays occur and the required slump has not been maintained. Up to two additional dosages have been used with success. Typically the compressive strength is maintained, but air contents are decreased. In order to redose, a supply of material and some satisfactory method of measuring and dispensing it must be provided.

6.4-Placement of flowing concrete
Flowing concrete can be placed quickly and easily since it tends to be self-leveling. Proper consolidation can be accomplished with much less effort than with conventional concrete, but the need for vibration is not eliminated. Observations should be made to assure that the mixture is cohesive and nonsegregating. If segregation occurs, mixture proportions must be adjusted. This problem can usually be solved by increasing the fine-to-coarse-aggregate ratio. Increasing the entrained air content within specification limits, or including or increasing the amount of an appropriate mineral admixture, may also be beneficial.

CHAPTER 7 — REFERENCES

7.1.Selected and recommended references
Documents from the various standards-producing organizations referred to in this report are listed below with their serial designations. Some of these documents are revised frequently, and therefore should be checked for the latest versions with the sponsoring group.

American Concrete Institute
201.2R Guide to Durable Concrete
211.1 Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
212.3R Chemical Admixtures for Concrete

ASTM
C 157 Standard Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete
C 494 Standard Specification for Chemical Admixtures for Concrete
C 1017 Standard Specification for Chemical Admixtures for Use in Producing Plowing Concrete

The preceding list of publications may be obtained from the following organizations:
American Concrete Institute
P.O. Box 19150
Detroit, MI 48219-0150

ASTM
1916 Race Street
Philadelphia, PA 19103

7.2-Cited references


Collepardi, Mario; and Corradi, Marco, 1979, “Influence of Naphthalene-Sulfonated Polymer Based Superplasticizers on the Strength of Ordinary and Lightweight
Concrete,” *Superplasticizers in Concrete*, SP-62, American Concrete Institute, Detroit, pp. 315-336.

“Developments in the Use of Superplasticizers,” 1981, SP-68, American Concrete Institute, Detroit, 561 pp.


Kasami, H.T.; Ikeda; and Yamane, S., 1979, “On Workability and Pumpability of Superplasticized Concrete — Especially in Japan,” *Superplasticizers in Concrete*, SP-62, American Concrete Institute, Detroit, pp. 67-85.

Lukas, Walter, 1981, “Chloride Penetration in Standard Concrete, Water-Reduced Concrete, and Superplasticized Concrete,” *Developments in the Use of Superplasticizers*, SP-68, American Concrete Institute, Detroit, pp. 253-269.


Ravina, Dan; and Mor, Avi, 1986, “Effects of Superplasticizers,” *Concrete International: Design & Construction*, V. 8, No. 7, July, pp. 53-55.


“Superplasticizers in Concrete,” 1979, SP-62, American Concrete Institute, Detroit, 427 pp.


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This report was submitted to letter ballot of the committee and was approved in accordance with ACI balloting procedures.