U.S. Department of Transportation

Federal Highway Administration

Publication No. FHWA HI-95-024
March 1995

NHI Course No. 13119

Portland Cement Concrete Materials

Participant Notebook

National Highway Institute

Office of Engineering
Construction and Maintenance
Division
Materials Branch

PORTLAND CEMENT CONCRETE MATERIALS

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May 1995

Previously released as FHWA-ED-89-006

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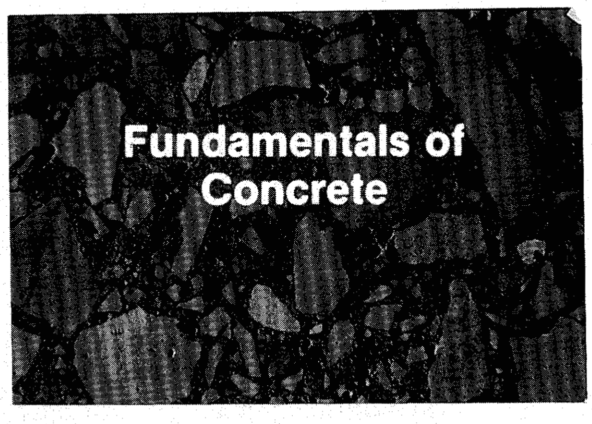
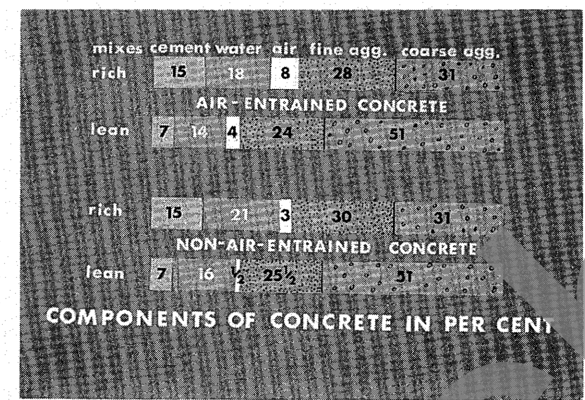
Chapter 1

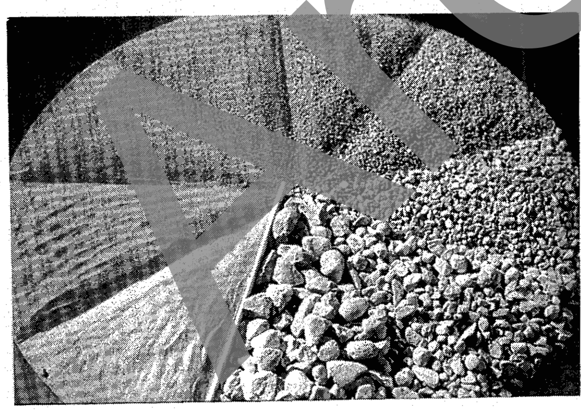
FUNDAMENTALS OF CONCRETE



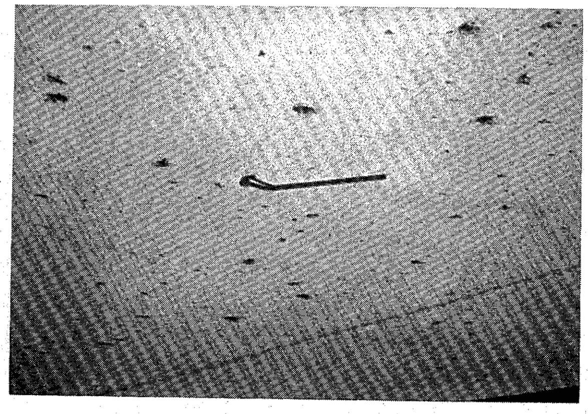
1. This introduction provides an overview of the fundamentals of concrete and is a frame of reference for this course. To begin, concrete is a mixture of two primary ingredients: aggregates and portland cement paste. The paste, through a chemical reaction called hydration, binds the aggregate into a rock-like mass.



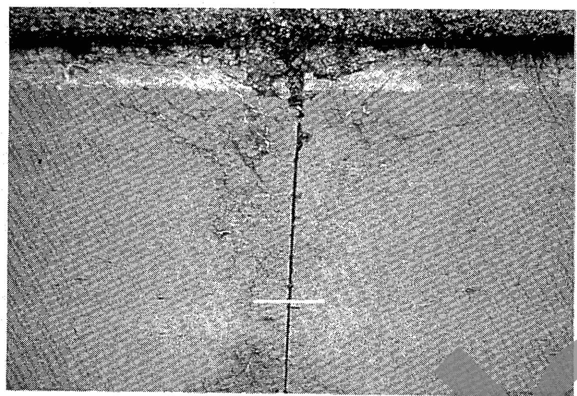
2. The paste portion of the concrete, water, cement and air, constitutes from 25 to 40 percent of the volume. The aggregates, both coarse and fine, make up the remaining 60 to 75 percent. The 1st and 3rd mixes shown here are rich, while the 2nd and 4th mixes are lean. Rich mixes are mixes with a high percentage of paste. Note that the air content ranges from 8 percent in air entrained concrete to 1/2 percent in the non-air entrained.



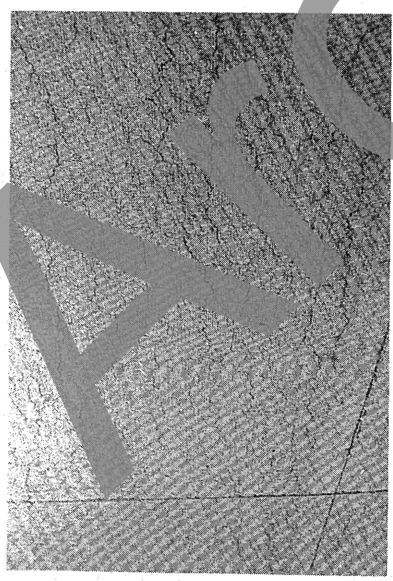
3. Since aggregates make up most of the mix volume, they should consist of particles with adequate strength and resistance to exposure conditions, and should not cause deterioration of the concrete. Aggregates can be divided into two groups: fine and coarse. Fine aggregates are sands composed of particles which pass the 4.75 mm sieve. Coarse aggregates are particles retained on 4.75 mm sieve and range upward in increasing size. Aggregate gradations of well-graded sizes provide for efficient use of the cement and water paste.



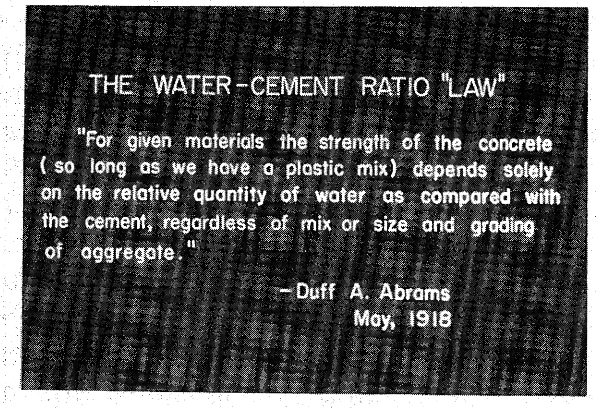
4. Many concrete problems are caused by poor quality aggregates. Here, soft aggregates have caused pop outs in the concrete surface.



5. Another aggregate induced concrete problem is D-cracking. When aggregates with porous structures are subject to moisture along with freeze-thaw cycles, the aggregates deterioate and generate this characteristic D-cracking pattern.



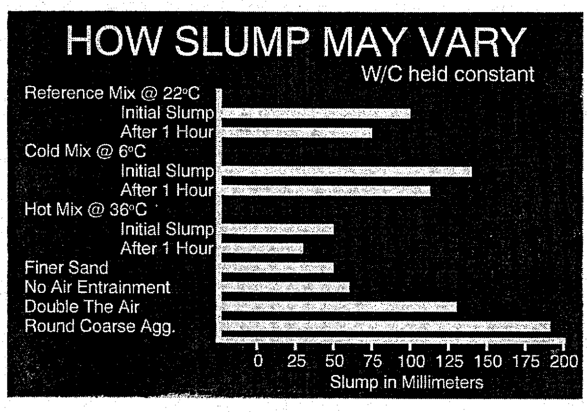
6. Some siliceous aggregates will react with the alkali in the cement. This is called alkali-silica reactivity. When this reaction occurs the concrete may expand resulting in this map cracking pattern.



7. The quality of concrete also depends upon the quality of the cement paste. This paste contains Portland Cement, water, and entrapped or purposely entrained air. The strength of the concrete is determined by the water-cement ratio. This principle was understood as early as 1918 by Duff Abrams, who pioneered the current mix design procedures. The indiscriminate addition of water will increase the water-cement ratio and adversely affect the concrete strength and durability. Some of the advantages of decreasing the water content are:

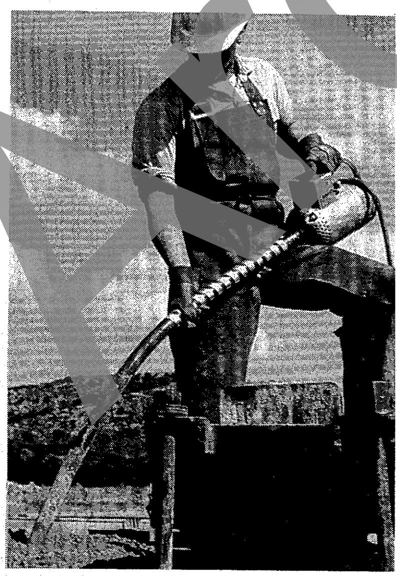
- Increased compressive and flexural strength
- Increased watertightness
- Lower absorption
- Increased resistance to weathering
- Better bond between successive layers
- Better concrete and reinforcement bond
- Less volume change from wetting and drying

8. Factors of concern with fresh concrete include uniformity, workability, consolidation and hydration. Fresh concrete should be plastic or semi-fluid, capable of being molded by hand. Each particle of aggregate should be coated with paste and all spaces between aggregate particles should be completely filled. A plastic mix keeps the components in place and does not allow segregation during transport. Plastic concrete should not crumble, but should flow sluggishly.



9. Plastic concrete should be uniform from batch to batch. To have a finished product that is of consistent quality throughout, each batch of plastic concrete that goes into a structure should be uniform. A commonly used measure of uniformity or consistency is slump. A number of factors can influence the slump of concrete as can be seen from this chart. A thorough understanding of the factors that can influence the slump is important, and a change in slump should not be simply compensated for by varying the water content.

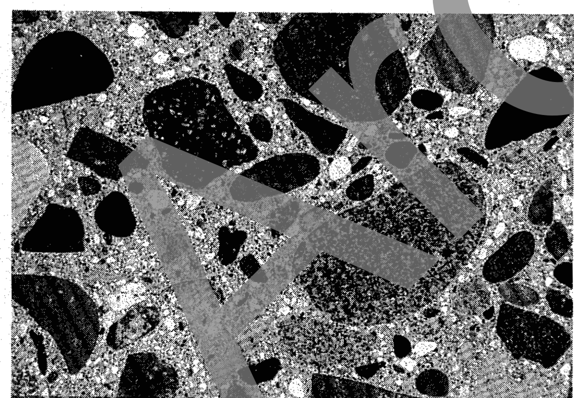
10. Workability refers to the ease of placing and consolidating concrete. The concrete should not segregate or bleed while being worked. It is important to transport and deposit each load of fresh concrete as close as possible to its final position.



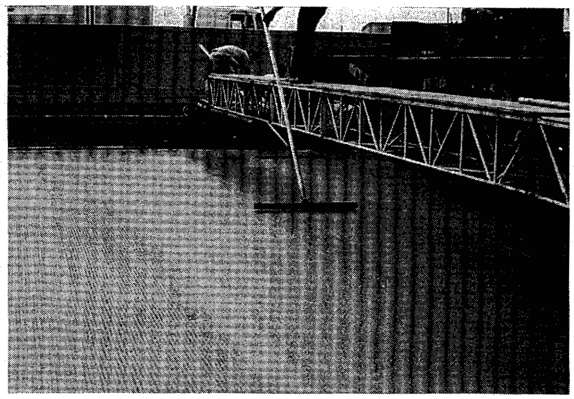
11. Consolidation is another important consideration of fresh concrete. Vibration sets the particles in concrete into motion, allowing the mix to become mobile. This allows the concrete to mold to forms and around reinforcing. Vibration permits the use of stiff mixtures with a larger proportion of fine aggregate. It also aids in placing concrete of high coarse aggregate content. The greater the amount of large aggregate, the less volume needs to be filled with paste (since there is less surface area to be covered). The less paste that is needed, the more economical the mix.

12. Over vibration or vibrating normally workable mixes can cause segregation. Conversely, under consolidation can result in honeycombing. Here, all of the entrapped air has not been driven off through vibration.

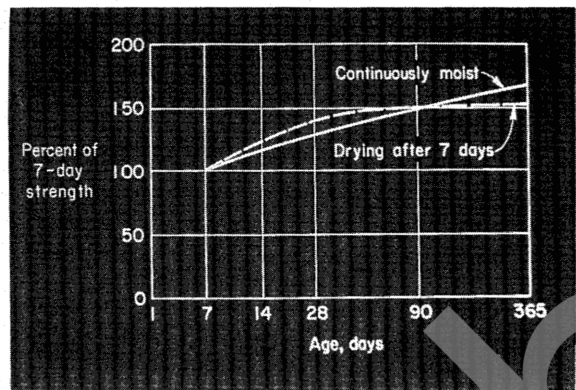
13. Concrete should never be moved by use of a vibrator.



14. Hydration is the chemical reaction between cement and water and results in the cementitious properties of Portland Cement. Portland Cement is an inorganic substance made up of many compounds. The initial chemical composition of cement is transformed during hydration to form calcium hydroxide (lime) and calcium silicate hydrate. The concrete properties of set time and strength depend upon the formation of this latter compound. Knowledge of the heat released during hydration and the rate of the reaction are important to proper construction planning.

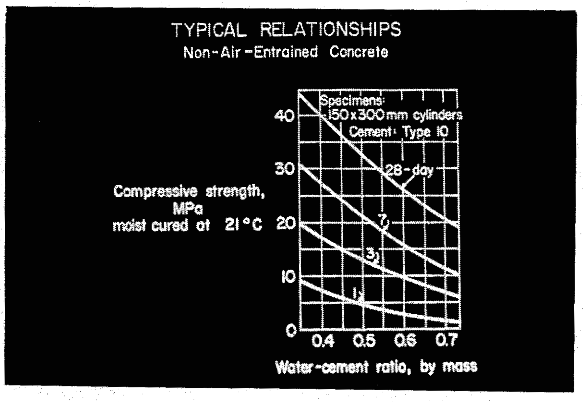


15. Hardened concrete should be durable, that is, it should have the properties of strength, abrasion resistance and resistance to freezing and thawing.



16. Concrete will continue to hydrate and gain strength as long as there is moisture available for the reaction. For this reason it is very important to keep concrete continuously moist during curing. This figure shows that after 7 days, concrete kept continuously moist will ultimately reach a strength greater than concrete allowed to dry. It is important to remember that concrete does not harden by drying. When concrete dries, it ceases to gain strength, and even though it is dry, there is no indication that it has sufficiently hydrated.

17. Strength is normally considered the primary property of concrete quality. Compressive strength is needed for bridges and structures, flexural strength is needed for pavements and slabs. As a general rule of thumb, flexural strength of normal weight concrete is about 7.5 to 10 times the square root of the compressive strength.

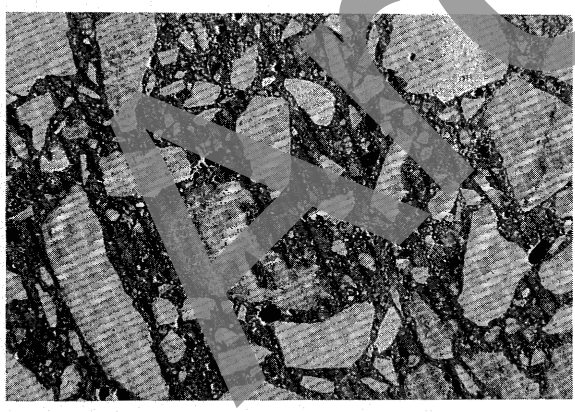


18. The principle factors affecting concrete strength are water-cement ratio and age. This figure shows compressive strengths for a range of water-cement ratios and ages. Note how strength increases with a decrease in water-cement ratio and an increase in age. Air entrained concrete tends to have slightly lower strength. This loss in strength, however, is offset by the fact that a lower water-cement ratio can be used for air entrained concrete.

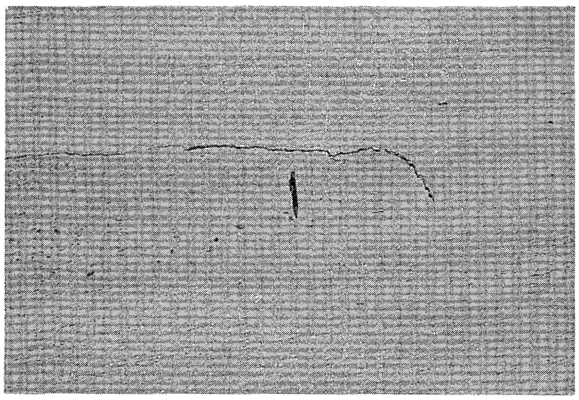
WEIGHT OF CONCRETE, kg/m^3
(Air Entrained)

[illegible]	[illegible]	Concrete Weight, kg/m^3		
		Aggregate specific gravity		
		2.55	2.65	2.75
19	6.0	2194	2259	2323
38	4.5	2259	2339	2403
76	3.5	2307	2387	2467
152	3.0	2355	2435	2515

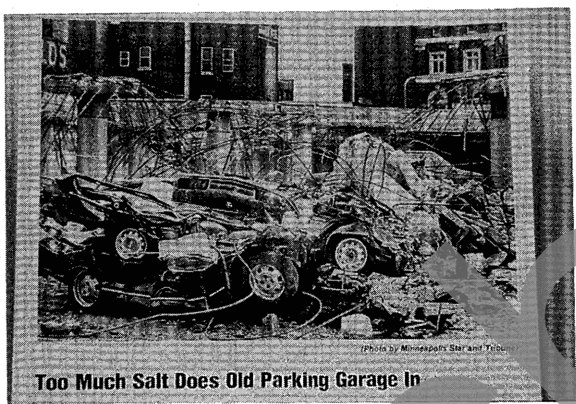
19. Concrete that is normally used in highway work has a unit weight (or density) of 2240 to 2400 kg/m^3. The unit weight test can be used to determine the uniformity of concrete from batch to batch. Factors affecting the unit weight are aggregate density, air content, and the water and cement content as influenced by the maximum aggregate size. Specialty concretes can provide a large diversity of unit weights. Lightweight concrete used for insulation can be as low as 240 kg/m^3 and heavy weight concrete can run as high as 6010 kg/m^3.



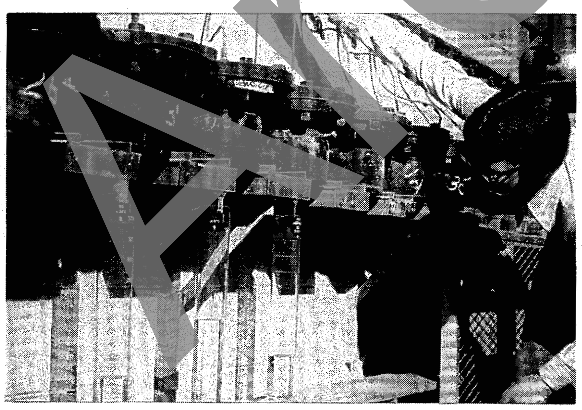
20. For concrete to have a long life and low maintenance requirements, it must be durable. Durable concrete must have high strength, be resistant to freeze-thaw, be watertight, be abrasion resistant, and crack free. Nondurable concrete suffers from deterioration often caused by the freezing of the water in the paste. With air entrained concrete, however, resistance to freeze thaw is greatly improved. During freezing, the air bubbles provide chambers for the particles to expand into.



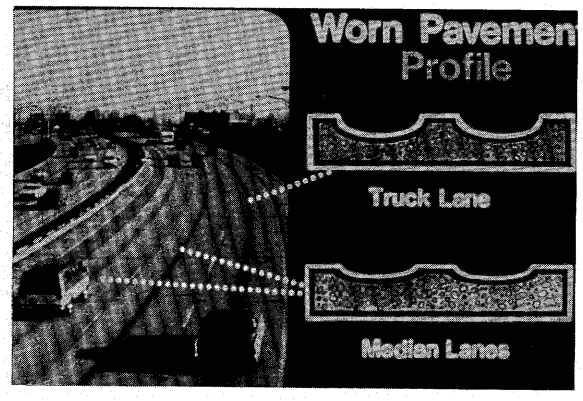
21. Concrete made without air entrainment is subject to scaling. Under severe conditions, however, even air entrained concrete can exhibit scaling.



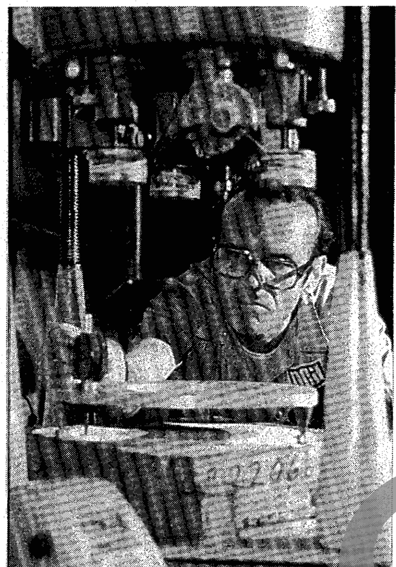
22. Concrete exposed to weather or severe conditions should be watertight. Water can penetrate permeable concretes. If the intruding water contains a high chloride content then the reinforcing steel can deteriorate and result in failure of the concrete element.



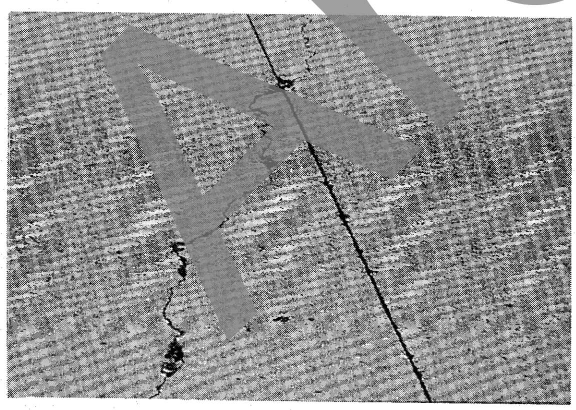
23. The permeability of concrete depends on the water-cement ratio and the length of moist curing. This apparatus determines the permeability of cement mortar disks. The results indicate that the lower the water-cement ratio, the less water leakage occurs through the sample. Also, the longer the specimens are moist cured, the more watertight the concrete.



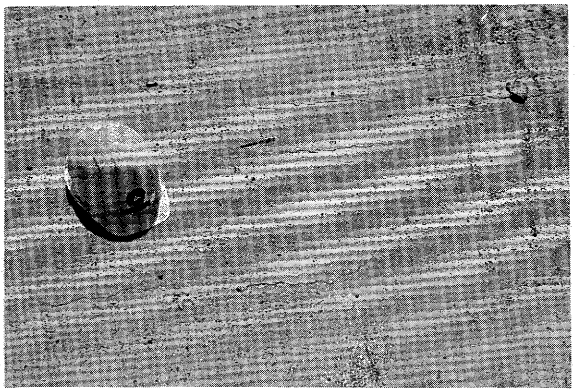
24. Depending on the use of the concrete, abrasion resistance becomes an important consideration. Concrete pavements can become worn with age, particularly where studded tires have been used. Worn pavements can be slippery if the aggregates are easily abraded.



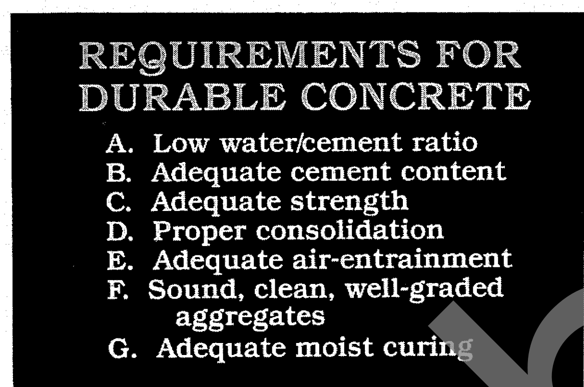
25. This picture shows the test apparatus for measuring abrasion of concrete used in pavements. Abrasion is influenced by concrete strength and aggregate type.



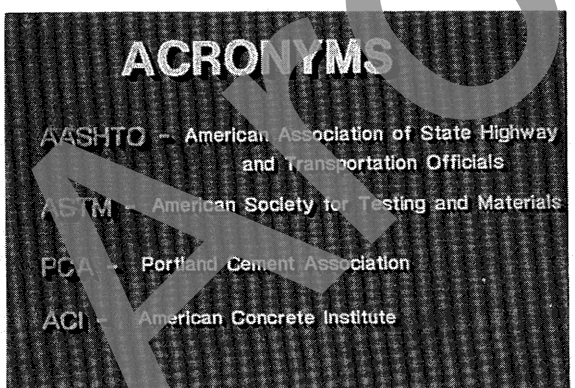
26. One final consideration for obtaining durable concrete is the control of cracking. Cracking can be caused by applied loads, expansion and contraction, or drying shrinkage. Proper placement of joints in concrete work can reduce the amount of cracking. In concrete pavements, timely sawing of joints will prevent this type of cracking.



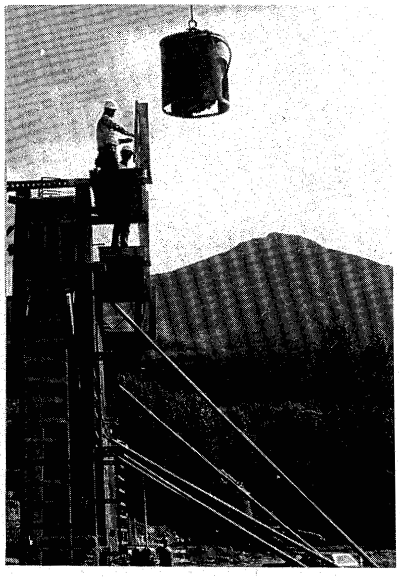
27. Plastic shrinkage cracks result when the water in the concrete evaporates from the surface too rapidly. This problem is most common when concrete is placed in hot, windy, and/or low humidity weather.



28. This chart summarizes items necessary for durable concrete.



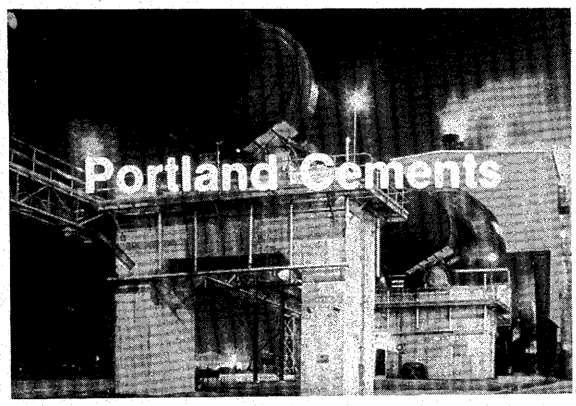
29. Material for this presentation on concrete was taken from sources that included AASHTO, ASTM, PCA, ACI, and FHWA.



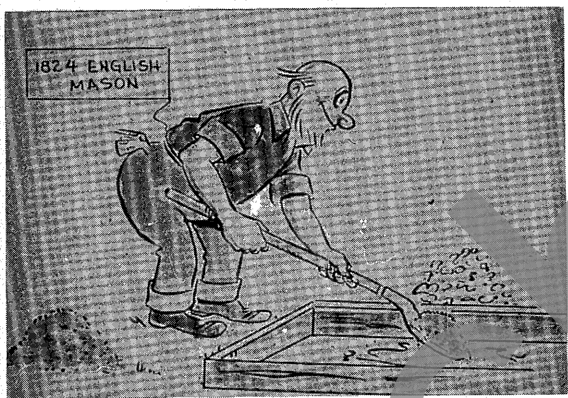
30. In conclusion, this course will emphasize high standards rather than common practice. In most cases, concrete of poor quality will cost the same to produce as concrete of high quality. Many of the high standards presented will improve the concrete uniformity and quality so that the effort invested will be rewarded by a smoother operation, a higher production rate, and a better concrete product.

Chapter 2

PORTLAND CEMENT



1. Portland Cements, by definition, are hydraulic cements; that is, they set and harden by reacting with water. The process is called hydration. The invention of Portland Cement is credited to an Englishman named Joseph Aspdin.



2. Aspdin, a mason, obtained a patent for his product in 1824. He named it Portland Cement because it produced a concrete that resembled a natural limestone which was quarried on the Isle of Portland in the English Channel. David Saylor started the United State's concrete production in the early 1870's, in Coplay, Pennsylvania.

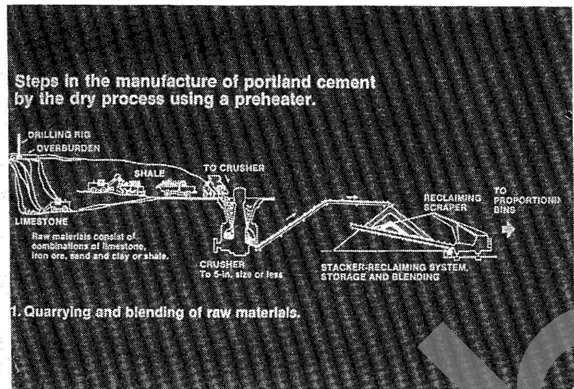
3. Portland Cement is produced in a plant where raw materials are heated in a rotary kiln. The high heat in the kiln causes a chemical reaction that converts the raw materials to clinker. The clinker is then pulverized to form the cement.

SOURCE OF MAJOR COMPONENTS IN PORTLAND CEMENT

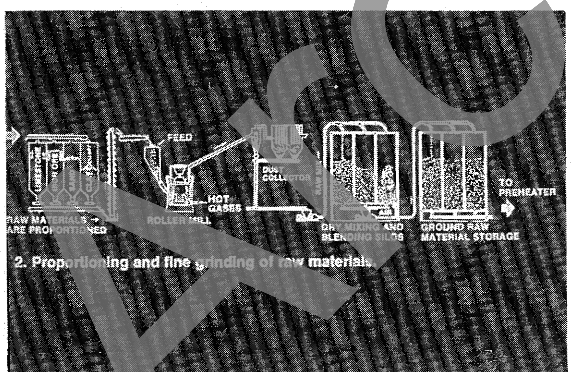
Lime CaO	Iron Fe_2O_3	Silica SiO_2	Alumina Al_2O_3
Calcite Limestone Marl Shale Aragonite	Clay Iron ore Mill scale	Clay Marl Sand Shale	Aluminum ore refuse Clay Fly ash Shale

Also used: Anhydrite or Gypsum, $CaSO_4 \cdot 2H_2O$

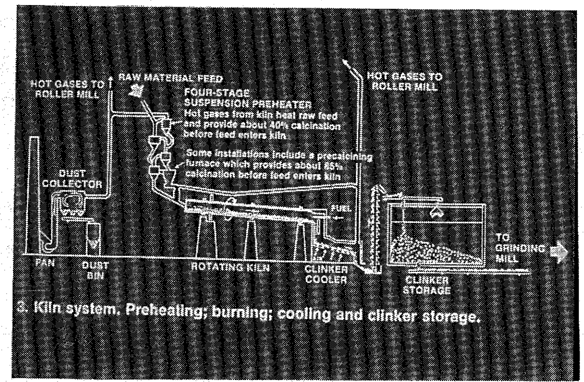
4. The four major chemical components that must be present in the raw materials in order to produce Portland Cement are Calcium, Iron, Silica, and Alumina. Sources for these raw materials are illustrated here. Note that some raw materials are available from the same source.



5. The raw materials can be combined in either a dry or a wet process. This illustration and the next three depict the steps involved in manufacturing Portland Cement by the dry process. The raw material is first put through a crusher to break it down to 125 mm or smaller.

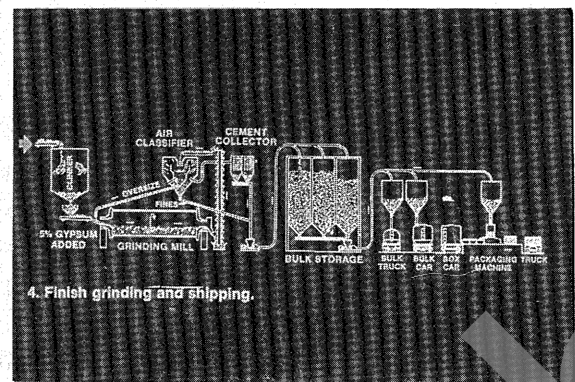


6. Following primary crushing, the raw materials are proportioned, put through another grinding, and then dry mixed. This provides the proper chemical composition for making the clinker.



3. Kiln system. Preheating; burning; cooling and clinker storage.

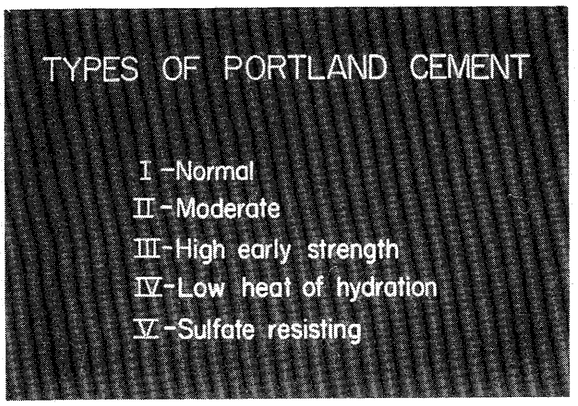
7. The raw materials are preheated, and then enter a kiln with temperatures from 1425°C to 1650°C where they are chemically changed into cement clinker. As the clinker exits the kiln, it is air-cooled. The rate of cooling must be controlled as it can affect the properties of the cement. The cement clinker consists essentially of hydraulic calcium silicates.



4. Finish grinding and shipping.

8. The clinker is cooled, pulverized, and then stored or shipped.
Note that at the pulverizing stage, gypsum is added to the clinker to control concrete setting time and aids in its obtaining optimum strength.

9. After the final grinding, the cement is a fine powder with particles so small that they could pass through a sieve with 62 openings per square millimeter.



10. Different types of cement are manufactured to meet different physical requirements and for specific purposes. The five basic types of cement are as follows:

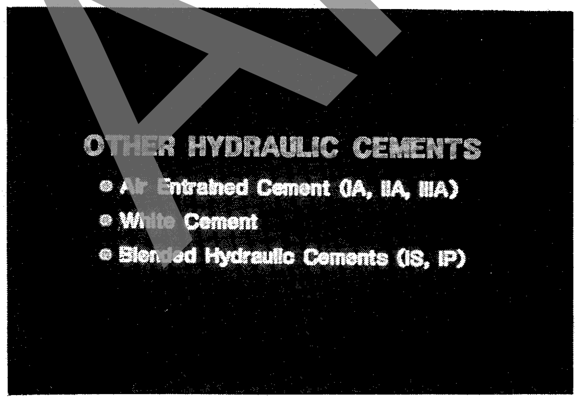
- **Type I** is a **general purpose cement** that is used when there are no extenuating circumstances.

- **Type II** is used where there is a need to protect against moderate **sulfate attack**. Naturally occurring sulfates such as sodium and magnesium are sometimes found in soils or dissolved in groundwater where concrete is to be placed.

- **Type III** is a **high-early-strength cement** used where high strength concrete is needed in a short period, usually one week or less. Uses would include situations where forms must be removed early, where a structure has to be put into service quickly, or in cold weather.

- **Type IV** is a **low heat of hydration cement** that is used in large structures such as dams where a heat rise is a critical factor. Excessive heat rise could cause cracking due to volume change.

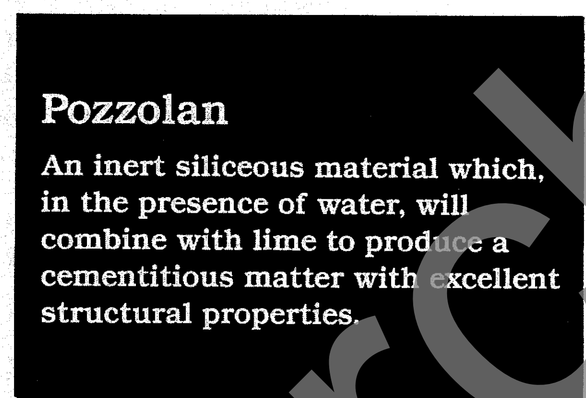
- **Type V** is a **high sulfate-resistant cement.**



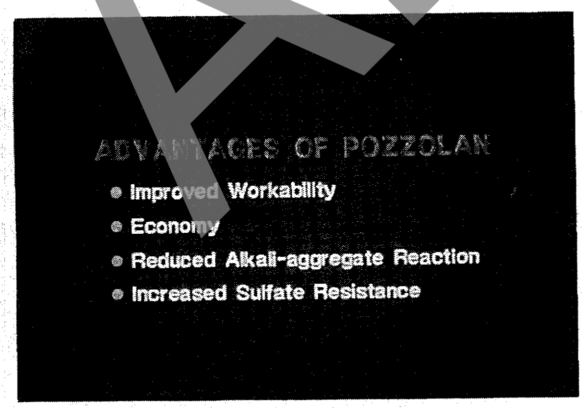
11. There are also other less common types of hydraulic cements. For example, there are **Type IA, IIA and IIIA** cements that are Type I, II or III cements with a small amount of **air-entraining agent** interground with the clinker.

It is also possible to specify a **White Portland Cement**, however, this is used mostly for architectural purposes or for color contrast, such as in curbs and median barriers. **Blended hydraulic cements** (ASTM C 595) consist of Portland Cement combined with some other ingredient.

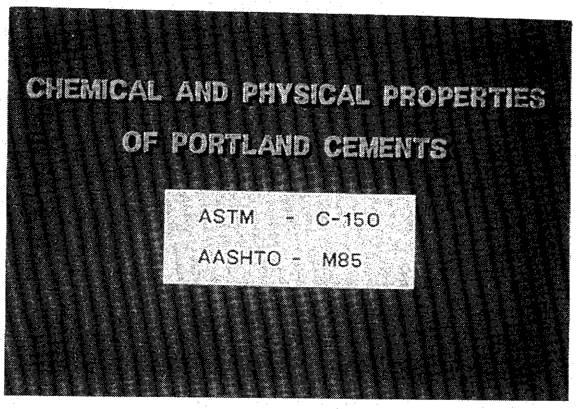
There are several types of blended cements and they are classified by the material interground with the clinker. Type IS cements have had blast-furnace slag added. As much as 65 percent to 75 percent slag may be substituted for the cement. Type IP cements have had a pozzolan added in place of a portion of the cement clinker.



12. A **Pozzolan** is a siliceous or siliceous and aluminous material, which, alone, possesses little or no cementitious value but will react with water and calcium hydroxide to form compounds possessing cementitious properties. The most common Pozzolan is Fly-Ash. Here again, intergrinding is the common manufacturing process and the **Pozzolan may account for 15 to 40 percent of the weight of the cement.**



13. Some advantages of using a Pozzolan are improved workability, economy, and sulfate resistance. Otheradvantages are reduced alkali-aggregate reaction, heat generation, volume change and bleeding.



14. ASTM C 150 and AASHTO M 85 both provide the chemical and physical properties for each type of cement.

COMPOSITION OF CEMENTS

Type	Compounds, %				Wagner fineness, m^2/kg
	C_3S	C_2S	C_3A	C_4AF	
I	55	19	10	7	180
II	51	24	6	11	180
III	56	19	10	7	260
IV	28	49	4	12	190
V	38	43	4	9	190
White	33	46	15	2	

15. Cement types can be identified by the percentages of their four compounds. When the clinker is formed during the manufacturing process, four principal compounds are created. The figures shown in the chart represent typical compositions.

- Tricalcium silicate (C_3S) hydrates rapidly and is responsible for initial set and early strength. Note that Type III (High Early) is made up of 56 percent tricalcium silicate. C150 limits C_3S to a maximum of 35 percent for Type IV cement only.

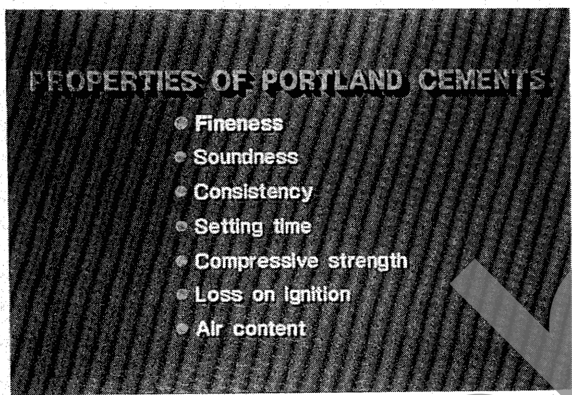
- Dicalcium silicate (C_2S) hydrates slowly, thus it generates a low heat of hydration and is responsible for long term strength. Type IV (Low heat of hydration) cement has the highest percentage of C_2S. C150 limits C_2S to a minimum of 40 percent for Type IV cement.

- Tricalcium aluminate (C_3A) liberates large amounts of heat during early hydration and contributes to early strength development. High amounts of this material, however, contribute adversely to the resistance to sulfate attack. Consequently, Type III cement (High Early Strength) has a higher percentage of C_3A than Type V (Low Sulfate).

C150 limits C_3A to a maximum as follows:

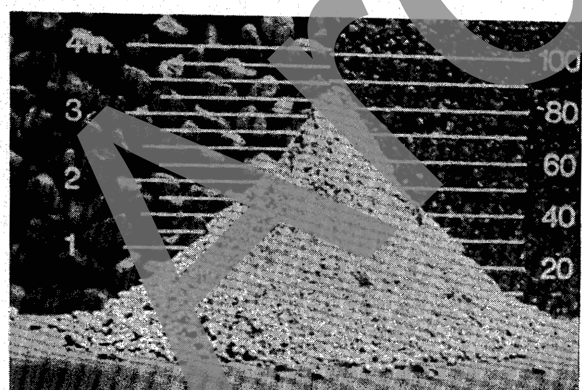
8 percent for Type II
15 percent for Type III
7 percent for Type IV
5 percent for Type V

Tetracalcium Aluminoferrite (C_4AF) reduces the clinkering temperature, and thus assists in the manufacturing process. It acts like a flux in burning the clinker. C150 limits C_4AF to a minimum of 20 percent for Type V cement only.

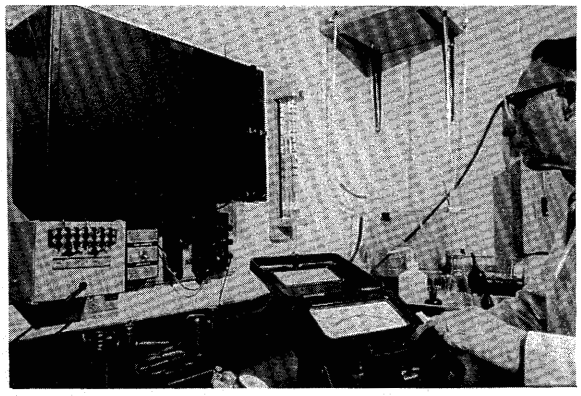


16. There are a number of properties of the Portland Cement that are important.

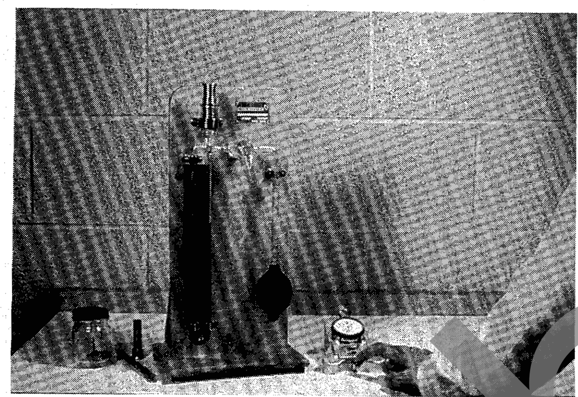
-- Fineness
-- Compressive Strength
-- Soundness
-- Heat of Hydration
-- Consistency
-- Loss on Ignition
-- Setting time
-- Specific Gravity
-- False Set
-- Weight



17. **Fineness of the cement affects the rate of hydration.** Greater fineness increases the surface available for hydration which causes higher early strength and more rapid generation of heat. Type III cement has a high fineness and therefore exhibits these properties. Because of the extremely small size of the particles, they do not lend themselves to analysis by means of sieving. Special methods have been developed to make approximations of the size distribution.

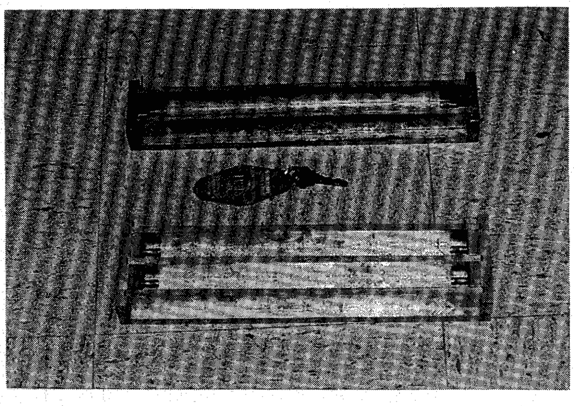


18. This is the **Wagner Turbidimeter**. It is an older method for determining size of cement particles. It operates by shining a light through a suspension of the cement. The light passing through is measured by a photoelectric cell. Through calibration, the fineness can be determined from the light passing through the suspension. This test is AASHTO T 98 or ASTM C 115. The measure of fineness is the specific surface and is the summation of particle surface area in square meters for one kilogram of cement.



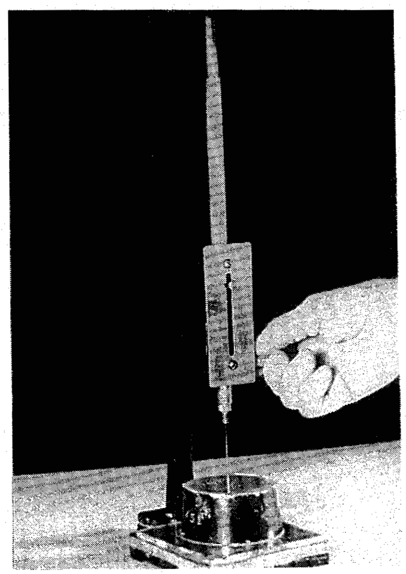
19. Another test for fineness is the **Blaine air permeability test**, ASTM C 204 or AASHTO T 153. This test is performed by drawing a known quantity of air through a bed of cement. The fineness can be correlated to the flow rate. Most cements have a Blaine fineness from 260 to 500 m^2/kg. ASTM requires a minimum of 280 m^2/kg for Type I cement. Cements with a fineness below 280 m^2/kg may produce concrete with poor workability and excessive bleeding. The U.S. Department of the Interior Concrete Manual indicates that the Blaine method correlates to about 1.8 times the Wagner method.

20. **Soundness** refers to the ability of hardened cement paste to retain its volume after setting. Expansion of the cement is caused by excessive amounts of lime or magnesia in the cement. The test for cement soundness is the **Autoclave expansion test**. This is ASTM C 151 or AASHTO T 107.

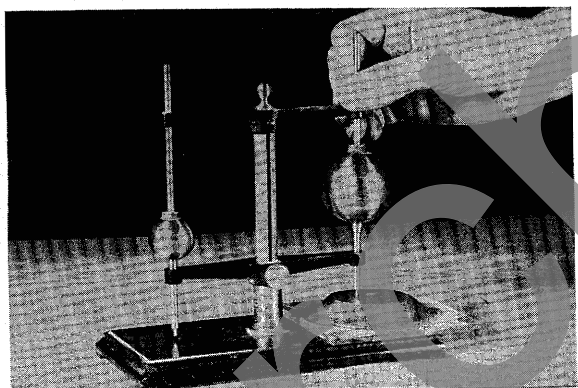


21. 25 by 25 by 285 mm molds are used to form cement paste specimens. After curing for 24 hours, the specimens dimensions are verified, and then placed into the autoclave.

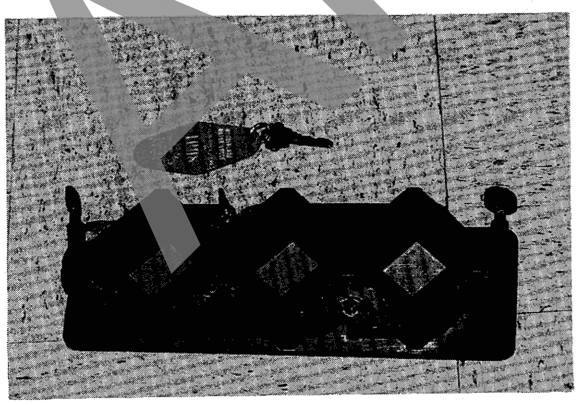
22. The specimens are subjected to saturated steam at 2.0 Mpa for 3 hours. They are then removed, cooled and remeasured. The difference in length of the specimen before and after testing is reported as the autoclave expansion and is measured to the nearest 0.01 percent.



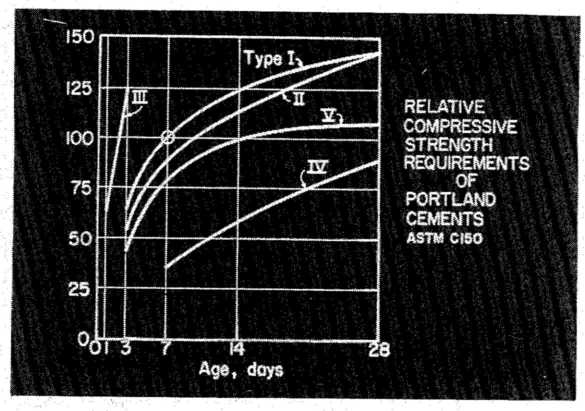
23. The cement should not set up too soon nor should it set up too late. Setting time tests are performed to determine if normal hydration is taking place in the first few hours. Demonstrated here is the **Vicat apparatus** in which a needle is allowed to settle into cement paste. Time is recorded until the needle penetrates 25 mm. This is the initial setting time. Final set is when the needle stops sinking. This test is ASTM C 191 or AASHTO T 131. The Vicat apparatus is also used to determine the consistency of cement. Consistency means the cement's ability to flow. In this test, the needle is replaced with a 10 mm diameter plunger. Normal consistency is defined as a 10 mm drop of the plunger in 30 seconds. The moisture content used to obtained this consistency is then used for mixing the paste in the setting time test. (ASTM C 187)



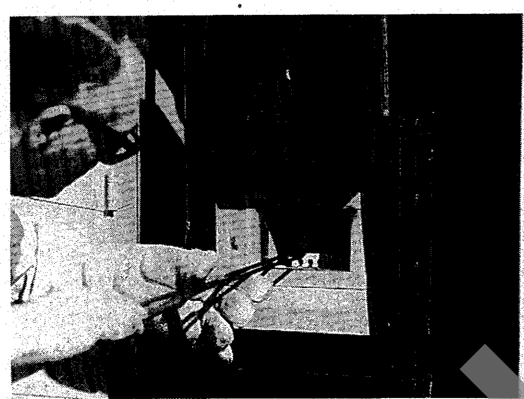
24. Another test for setting time is the **Gilmore test**. The apparatus is shown here. In this test, two needles of different weights are used. When the needles no longer make an indentation into the paste, it is defined as initial set for the small weight and final set for the large weight. There is no correlation between these tests and the setting time of concrete. This test is ASTM C 266, or AASHTO T 154.



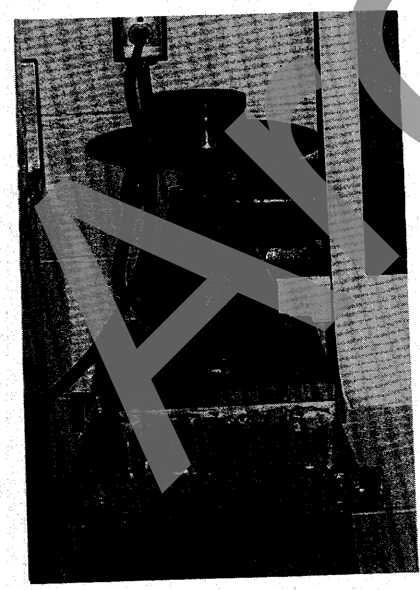
25. ASTM C 150 and AASHTO M 85 specify certain minimum cement **compressive strength** requirements. The test is performed on 50 mm mortar cubes produced in these molds.



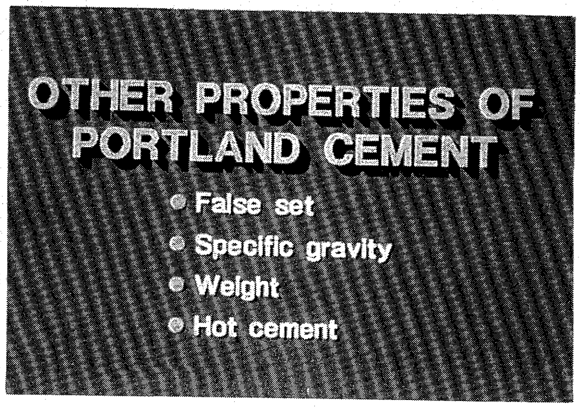
26. For a Type I cement, 7-day strength of 50 mm mortar cubes should not be less than 19.3 MPa. Using that as a reference, this chart shows the relative percent compressive strength requirements for the various cements at various ages, compared to that of the 7-day strength for the Type I cement. Compressive strength testing is described in AASHTO T 106 or ASTM C 109.



27. This picture shows a technician performing a **loss on ignition test**. The cement sample is heated to 1000°C until it reaches a constant mass. The mass loss can then be calculated. This is test ASTM C 114. A high loss of 3 percent or more is an indication of prehydration and carbonation. This may be caused by improper or prolonged storage.



28. AASHTO M 85 and ASTM C 150 also specify the **air content** of mortar. The purpose of the test is to determine whether or not the hydraulic cement meets air-entrained requirements. To perform the test, a cement mortar is placed in a flow mold, on a **flow table**. The mold is removed and the table dropped 10 mm, 10 times in 6 seconds. The flow is the increase in diameter of the specimen. Various water contents are tried until a flow of 80 to 95 percent is achieved. Through weighing a predetermined volume and knowing the percentage of moisture, the air content can be determined.



29. There are several other physical properties of cement which we should mention.

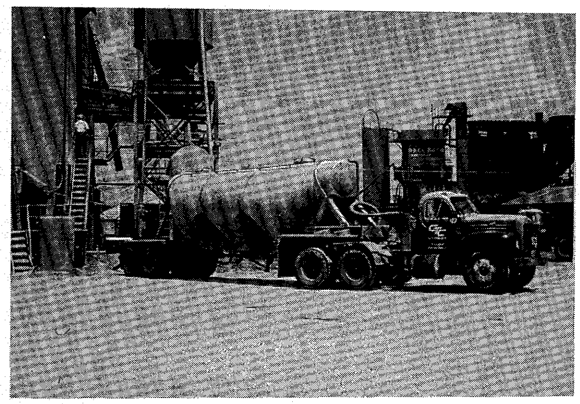
False set is a significant loss of plasticity shortly after mixing. This presents no problem if the concrete is remixed before it is placed. False set is an erratic condition that can be blamed on the character of the gypsum used.

Specific gravity of cement is about 3.15 and is used in the mix design calculations.

Weight of cement can be measured by the bag at 50.0 kg. **Density of cement** is not usually considered since it can be fluffed up quite easily. For this reason, cement is weighed for each batch of concrete.

Hot or green cement is sometimes encountered. Sometimes during peak periods cement plants will have difficulty keeping up with demand. Consequently, cement may be coming directly from production to the concrete plant. Also, cement may become hot due to silos being located in direct sunlight. When this happens, cement at elevated temperatures could be used in concrete. This could cause stiffening of the concrete mix. An upper limit of 65°C to 80°C is recommended for cement.

30. One final item to cover is **cement storage.** Cement is a moisture sensitive material that will retain its quality indefinitely if it is kept dry. When storing bagged cement, a shed or warehouse is preferred. Cracks and openings in store houses should be closed, humidity should be as low as possible, and bags should be stacked on pallets away from outside walls. Bagged cement stored outdoors should be stacked on pallets and covered with a waterproof covering. Bags should not be stored near ponded or runoff rain water.

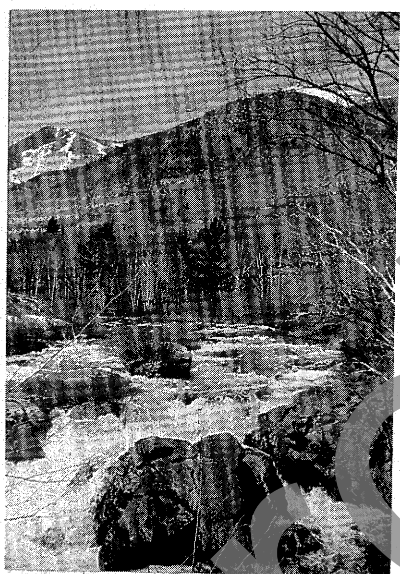


31. Most cements that arrive on a construction project will be by bulk. Storage of bulk cement should be in a watertight bin or silo. Separate compartments or bins should be provided for each type of cement. Transportation should be in vehicles with watertight and properly sealed lids. Cement conveyance systems, such as screw conveyors or air slides, should provide for constant flow and precise cutoff. Compressed air systems for moving cement should have water traps. Lumpy cement results from improper storage and handling. Loss on ignition or strength tests should be performed on cements that have been stored for long periods of time.

Chapter 3

MIXING WATER

1. **Water** is the next concrete ingredient to consider.

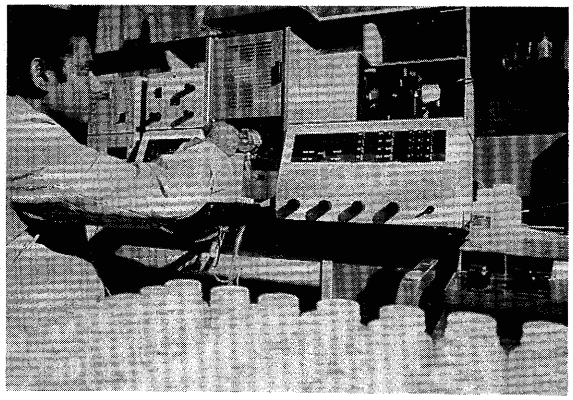


2. Water has two main functions; it reacts with the cement during hydration and lubricates the materials, contributing to the workability of the concrete. Because of this, it is important that the water be relatively pure.

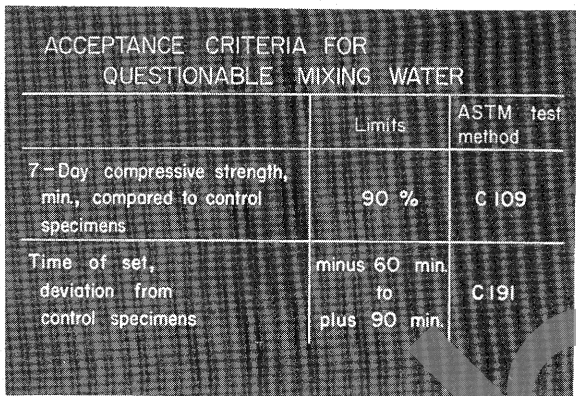
3. Pure, or potable water is suitable for use as mixing water for concrete. Some water suitable for making concrete, however, may not be suitable for drinking. Two questions should be considered when evaluating water for concrete.

   - Will the impurities affect the concrete quality?

   - What level of impurity can be tolerated?



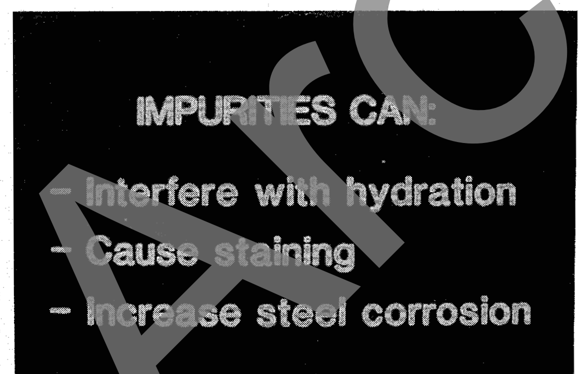
4. When the water is of questionable quality, it should be tested to determine if there are impurities in the water. Here an atomic absorption spectrophotometer is used to detect metallic or chloride ions.



ACCEPTANCE CRITERIA FOR QUESTIONABLE MIXING WATER

	Limits	ASTM test method
7-Day compressive strength, min., compared to control specimens	90 %	C 109
Time of set, deviation from control specimens	minus 60 min. to plus 90 min.	C 191

5. The water's affect on the physical properties of the concrete should be performed to determine if the levels of impurities will be harmful. Strength and time of set tests should be performed. Mortar cubes made with the proposed water should have 7 and 28 day strength at least equal to 90 percent of the strength of mortar cubes made with known good water (distilled).



6. Impure water can shorten or extend the set time of concrete, cause efflorescence, and stain the concrete, as well as corrode the concrete reinforcing steel.

HARMFUL IMPURITIES

Sugar	Paint
Tannic acid	Sewage
Fertilizer	Leaves
Wood	Rags
Salts	Oil

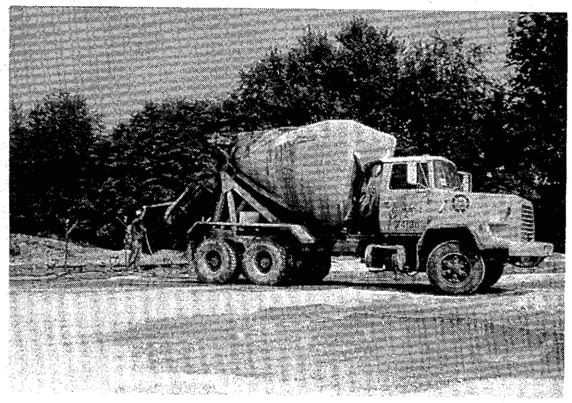
7. Water that is considered to be harmful may contain excessive amounts of any item indicated here. The source of the water (municipal, well, stream) would dictate which of the impurities would be suspected of contaminating the supply. In general, concrete plants are well established and have been using the same resources for a number of years. Nevertheless, it is possible for a water supply, particularly shallow well water, to become contaminated.

CHEMICAL LIMITS FOR MIXING WATER

Chemical		Concentration, Max. ppm	Test method
Total Solids		50,000	AASHTO T26
Chloride as Cl	Bridge decks or prestressed concrete	500	ASTM D512
	Other concrete containing rebars, aluminum, galvanized metals or dissimilar metals	1,000	
Sulfate as SO_4		3,000	ASTM D516
Alkalies as $(Na_2O + 0.67K_2O)$		600	

8. The AASHTO and ASTM limits for certain chemicals in mixing water are shown here. Mixing water should not contain an excessive amount of silt or suspended solids. This chart shows a maximum concentration of solids of 50,000 PPM. PCA and the Bureau of Reclamation recommend that if the turbidity exceeds 2000 PPM, the water should be tested for its effect on strength and time of set. The chloride ion content of mixing water is also of the major concerns due to its effect on reinforcing steel. Chlorides can be introduced to the concrete mix through admixtures, aggregates, or cement in addition to the mixing water. Placing a level on the chloride content of water becomes difficult because of these various sources. Generally, water containing less than 500 PPM of chloride ion will produce acceptable concrete.

9. The requirements for **concrete curing and washing water** are not as strict as those for mixing water because this water is in contact with the concrete for only a relatively short time. The permissible amounts of some impurities, however, are still restricted. If there is any doubt, the water should be tested prior to use.



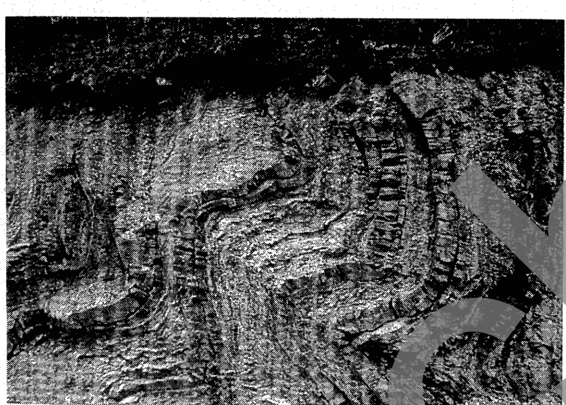
10. The **disposal of washing water** may be a problem in a concrete operation. This water may contain large amounts of fines and, therefore, has the potential of polluting lakes or streams.

11. One solution to the washing water problem would be the use of settling basins. Also the wash water may be recycled for use as mixing water as long as it meets minimum standards. If used for mixing, the intake end of the supply line should be covered with a wire mesh to prevent foreign matter from entering the system.

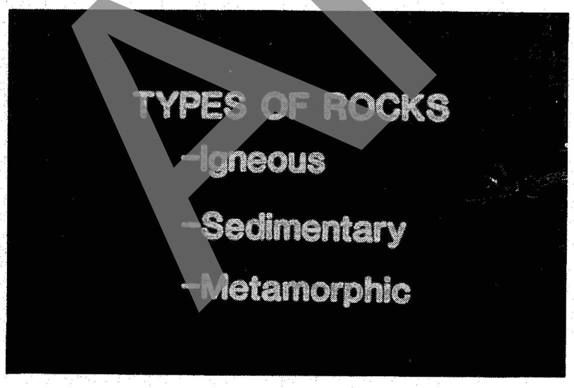
12. In conclusion, if the water is drinkable, it is usable for all aspects of a concrete operation. If there is any question about the concrete-making quality of the water, a sample should be submitted for evaluation. If the water does not have any particular taste, odor, or color, and does not fizz or foam when shaken, there is no reason to assume that such a water will hurt the concrete.

Chapter 4
AGGREGATES

1. Aggregates constitute about 60 percent to 80 percent of the volume of concrete and have a strong influence on the concrete's properties. For this reason, aggregates must conform to certain standards. For best results, they should be clean, hard, strong, durable particles free of absorbed chemicals, clay or other materials that could affect hydration or bond. Aggregates that should not be used are those that are friable (readily crumbled), those that contain shale, or those that contain other soft and porous materials. Aggregate with these characteristics can cause surface defects such as popouts.



2. Naturally occurring aggregates used in concrete are a mixture of minerals and rock. **Minerals** are defined as naturally occurring inorganic substances of a definite chemical composition and a specific crystalline structure. **Rocks** are generally composed of one or more minerals. Rocks compose most of the coarse aggregates and minerals compose most of the fine aggregates.



3. Rocks are classified in accordance with their origin; that is igneous, sedimentary and metamorphic.

IGNEOUS ROCKS		
INTRUSIVE	EXTRUSIVE	
COARSE GRAINED	FINE GRAINED	VOLCANIC
Granite	Rhyolite	Ash
Diorite	Andesite	Tuff
Gabbro	Basalt	Agglomerate

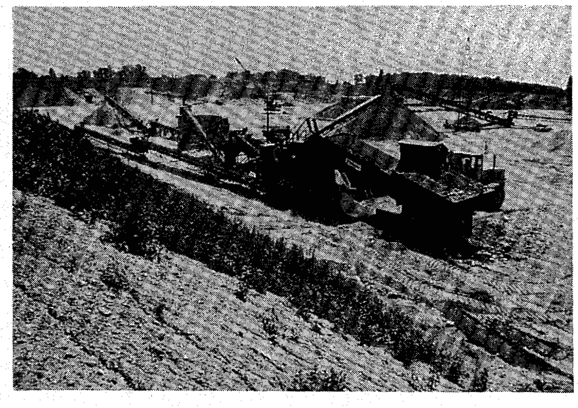
4. **Igneous rocks** are those that have cooled from a molten rock mass. Igneous rocks can be subdivided into intrusive or coarse grained and extrusive or fine grained. Intrusive rocks are formed during slow cooling of the molten mass and are exemplified by granites. Extrusive rocks are cooled more quickly, such as during a volcanic eruption, and include basalts. In general, igneous rocks are hard, tough and dense and make excellent concrete aggregates.

SEDIMENTARY ROCKS	
[illegible]	[illegible]
CONSOLIDATED:	CALCAREOUS:
Shale	Limestone
Siltstone	Dolomite
	SILICEOUS:
Sandstone	Chert
Conglomerate	Opal

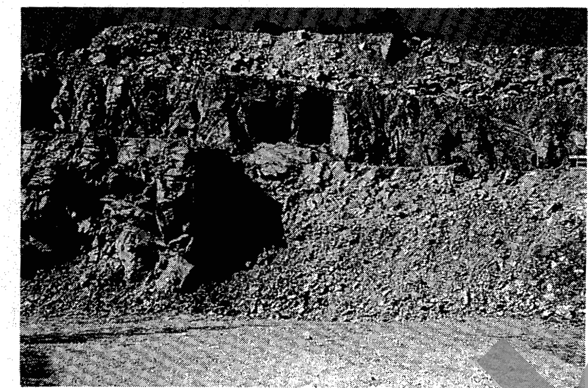
5. **Sedimentary rocks** are stratified rocks laid down under water and pressure. The sediments are usually composed of particles of pre-existing rocks, organic materials, or the hardened skeletons or shells of ancient organisms. Sedimentary rocks are divided into two groups based on their principle mineral component. Calcareous rocks contain compounds of lime or magnesium. These are the carbonates (limestone and dolomite). The other groups are made up chiefly of silica. Sedimentary rocks range from hard to soft. The softer ones should be avoided.

METAMORPHIC ROCKS
Igneous or sedimentary rocks changed by heat or pressure
GNEISS (metamorphosed granite)
SLATE (metamorphosed shale)
MARBLE (metamorphosed limestone)
QUARTZITE (metamorphosed sandstone)

6. **Metamorphic rocks** start out as either igneous or sedimentary rocks. Through the application of heat, pressure, water or any combination of these, the rock is physically altered or metamorphosed into a new type of rock. Sedimentary rocks, which undergo metamorphosis are generally harder, tougher and more durable than the parent material, while igneous rocks remain relatively unchanged. Marble is metamorphosed limestone, and is an excellent concrete aggregate. Quartzite is metamorphosed sandstone and is also a good aggregate.

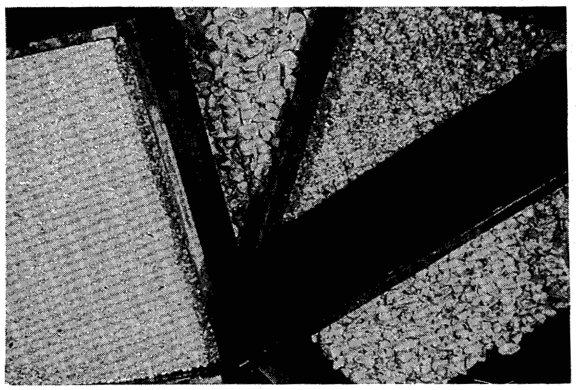


7. Concrete aggregates are generally gravels and crushed stone. Naturally occurring aggregates are called gravels. Sometimes gravels are put through a crushing operation to reduce their size or to improve their shape. Some artificial aggregates are used for special purpose concretes such as light weight concrete made from expanded clay.

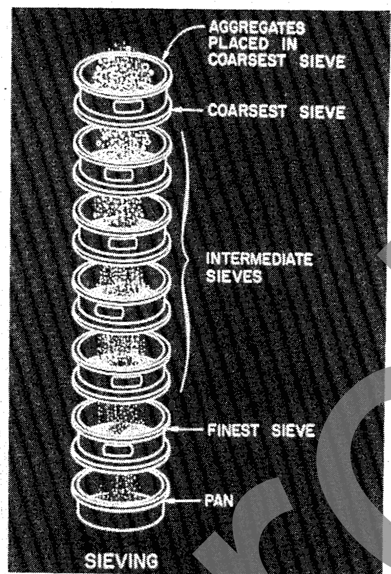


8. About half of the concrete aggregates used in the United States come from gravels, the other half come from a rock source such as a quarry where the rock has been put through a crusher. A very small amount come from recycled concretes.

9. **Natural fine aggregate** is simply the smaller fragments that result when the edges of rocks are worn away. Due to the way it is formed, natural sand is generally quite round. If there is a shortage of natural sand, a **manufactured sand** may be used. These are generally much more angular, however, and may cause different working characteristics in the concrete.



10. The most important property of concrete aggregate is its **gradation**. The gradation measures the maximum particle size, the range of particle sizes, and the amount of a particular particle size. The gradation is important because of its effect on mix workability, economy, and strength. Concrete mixes which contain too much coarse material become difficult to finish. For a given water-cement ratio, the amount of cement required will decrease as the maximum size aggregate increases. On the other hand, concrete mixes which contain too much fine material will require more cement and water in order to coat each particle and make the mix flowable.



11. Grading of aggregates is the distribution of particles among various sizes. The gradation is determined by performing an analysis with a set of sieves. Sieves are stacked with larger sizes on top. **Gradation is usually expressed in terms of a percentage passing or a percentage retained on the various sieves.**

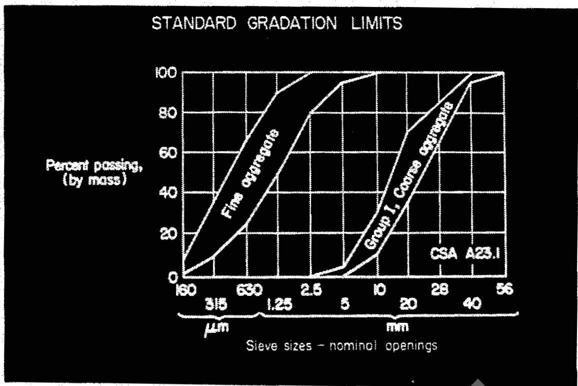
COARSE AGGREGATE SIEVES

SI UNITS	US UNITS
37.5 mm.	1 1/2 inch
25.0 mm.	1 inch
19.0 mm.	3/4 inch
12.5 mm.	1/2 inch
9.50 mm.	3/8 inch
4.75 mm.	No. 4 (0.187 inch)

12. To make testing of aggregates more manageable, the aggregates are classified as either **coarse aggregate** or **fine aggregate**. The dividing line between these two classes is the 4.75 mm sieve. This sieve has openings which are just slightly smaller than a lead pencil. Any aggregates not passing this sieve are classified as coarse aggregates. Any aggregates passing this sieve are classified as fine. This table depicts typical sieves used in a coarse aggregate analysis.

FINE AGGREGATE SIEVES	
SI UNITS	US UNITS
4.75 mm.	No. 4 (0.187 in.)
2.36 mm.	No. 8 (0.0937 in.)
1.18 mm.	No. 16 (0.0469 in.)
0.600 mm.	No. 30 (0.0234 in.)
0.300 mm.	No. 50 (0.0117 in.)
0.150 mm.	No. 100 (0.0059 in.)
0.075 mm.	No. 200 (0.0029 in.)

13. There are many sieve sizes that could be used for analysis of fine aggregates. This is a listing of some of the most commonly used sieves for fine aggregates associated with highway work. Notice that each sieve is about one half the size of the sieve above it. This ensures that there will be no gaps in the gradation analysis.



14. The results of the sieve analysis are sometimes plotted on a **gradation chart.** An experienced inspector can tell a great deal about the character of a concrete mix by examining the gradation chart. Limits or ranges are usually specified for the percentage of material passing each sieve. This is done since the gradation and the maximum size of aggregates will affect the cement and water requirements, workability, economy and durability of the concrete. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results.

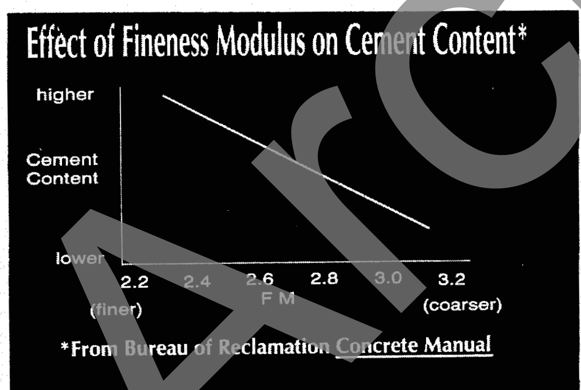
Sieve Analysis and Fineness Modulus of Sand

Sieve size	Percentage retained between sieves*	Cumulative percentage passing, by mass	Cumulative percentage retained, by mass
5 mm	2	98	2
2.5 mm	13	85	15
1.25 mm	20	65	35
630 mm	20	45	55
315 mm	24	21	79
160 mm	18	3	97
Fineness Modulus = 283 / 100 = 2.83			283

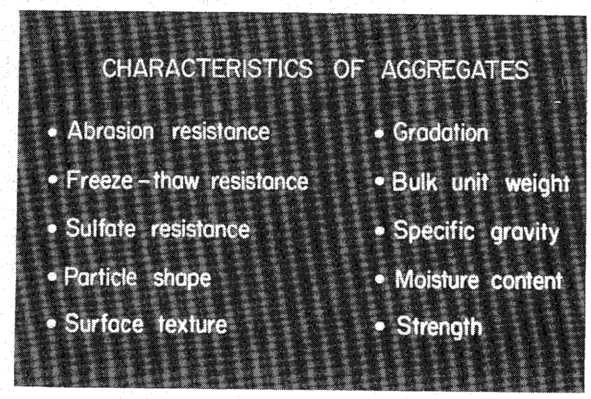
*45% maximum, ASTM C33.

15. One important characteristic that can be determined from the fine aggregate gradation is the **fineness modulus (FM).** Developed in 1919 by Duff Abrams, the **FM is the sum of the total percentages retained on each of a specified series of sieves divided by 100.** This value represents an average particle size. Aggregate gradations having the same FM should require approximately the same amount of water and cement to produce concrete of approximately equal strength and consistency. Note that only certain sieves are used for calculating the FM of the aggregate. The FM should not be less than 2.3 nor more than 3.1. Also it should

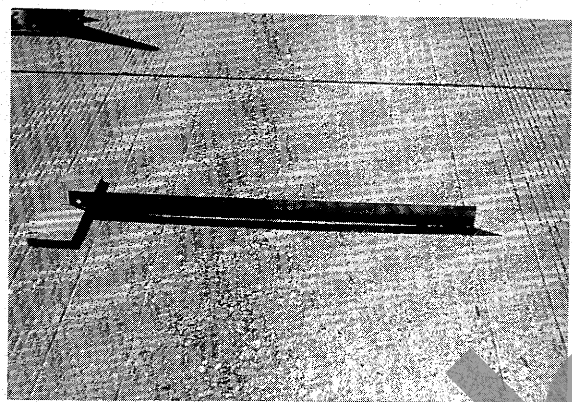
not vary more than 0.2 from the value assumed in selecting proportions of the concrete mix design. If this value is exceeded, the fine aggregate should be rejected unless suitable adjustments are made in proportions of fine and coarse aggregates. The desirable fine aggregate gradation depends upon the work involved, the richness of the mix, and the maximum size of coarse aggregate. In general the coarser the fine aggregate the harsher the mix. The higher the FM the coarser the aggregate. A very large amount of very fine material, that is material passing the 75 μm sieve, will cause the FM to go down. In addition, a low FM will reduce the air content and more air entraining admixture will be required. ASTM C 33 or AASHTO M 6 specifies the sieve sizes to be used and recommends the 0.2 tolerance.



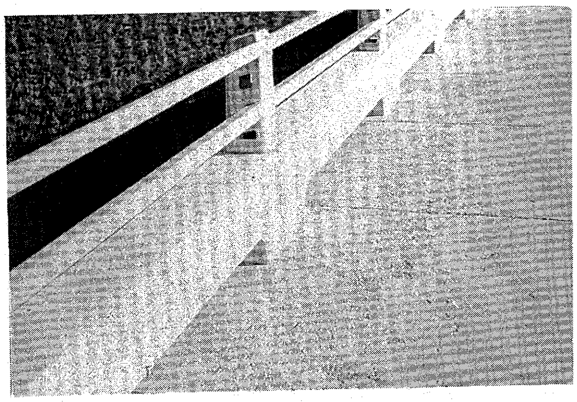
16. The FM of the sand will also affect the required cement content of the concrete mix. As the FM gets lower, the sand gets finer. This increases the surface area of the sand, and will increase the required amount of cement to insure that all aggregate particles are completely coated with paste.



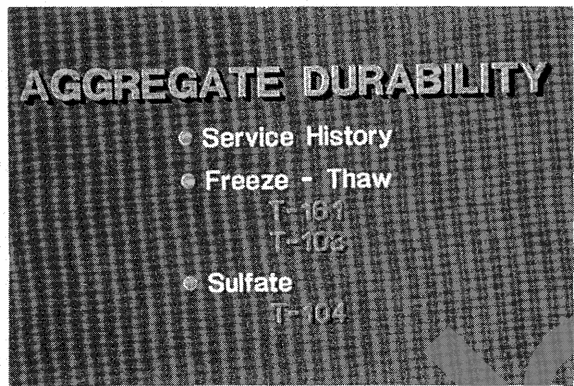
17. There are a number of other aggregate characteristics that should be considered, and are listed here.



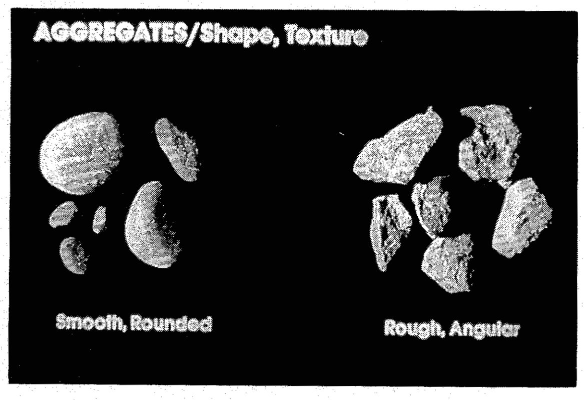
18. **Abrasion resistance** is often used as a general index of an aggregates quality. Abrasion resistance plays an important role in pavement surface life. As the concrete's mortar surface is worn off, the pavement will rely upon the abrasion resistance of the aggregate to provide good skid resistance. Aggregates that tend to polish under these circumstances will result in unsafe or "slippery when wet" conditions. Skid resistance is also dependent upon the fine aggregate. To provide good skid resistance, the PCA recommends that the siliceous particle content of the fine aggregate should be at least 25 percent. Consideration should be given, however, to the possibility of alkali-silica reactions when this is done. In addition, some manufactured sands can produce slippery surfaces and should be investigated thoroughly before being used.



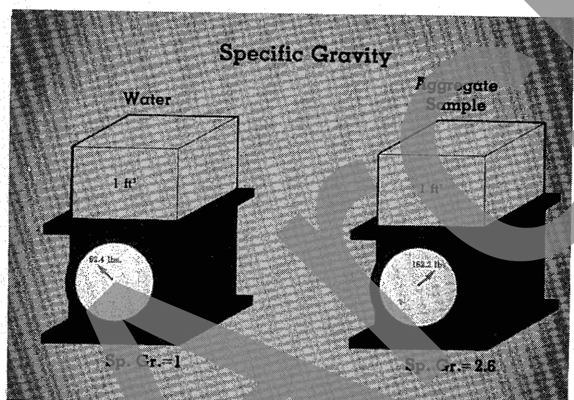
24. Another problem related to concrete durability is the occurrence of **popouts or spalling.** Popouts occur from freezing and thawing of saturated porous aggregate particles near the surface of the concrete. When the concrete becomes critically saturated, there will be insufficient unfilled pore space to accommodate the expansion of water during freezing. These situations are usually isolated within the concrete matrix. As will be discussed later, popouts can result from other aggregate properties.



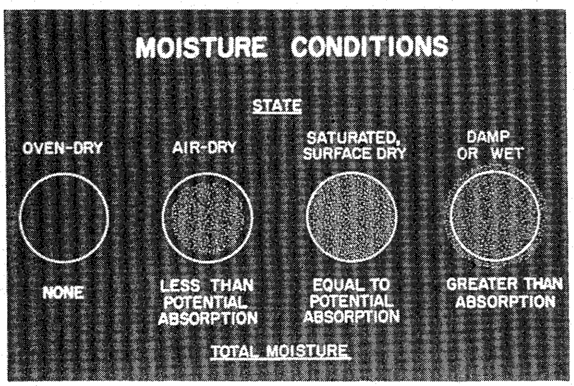
25. There are several ways to evaluate the performance of aggregates under freeze-thaw conditions; first and perhaps most useful is the past performance history of the aggregate. Second, if an aggregate has an unknown history, it can be subjected to a freeze-thaw test in accordance with ASTM C 666 or AASHTO T 161. In this test, concrete samples made with the aggregates are subjected to alternating freezing and thawing while submerged in water. This is the preferred method for determining D-crack susceptibility. AASHTO T 103 provides a similar procedure for subjecting just the aggregates to freezing and thawing cycle. A third method of determining aggregate durability is through a **sodium sulfate or magnesium sulfate** test (ASTM C 88 or AASHTO T 104). In this method, salt crystals grow in the pores when the aggregate is immersed in a sulfate solution thus simulating the pressures produced by freezing water. Unfortunately, while they are quicker to perform, sulfate tests are not always repeatable.



26. **Particle shape** influences the properties of fresh concrete more than the properties of hardened concrete. Rough angular aggregates require more water to produce workable concrete then smooth, rounded aggregates. If more water is required, then more cement will be required to maintain the same water cement ratio. **Elongated or flat particles** tend to produce concrete which is difficult to finish. In a like manner, **surface texture** will impact the workability of fresh concrete. Surface texture, however, has a more significant bearing on the concrete's strength. The bond between the cement paste and the aggregate increases as the aggregate surface texture becomes rougher. The rougher surface provides greater surface area for the development of this bond, thus higher strengths. Bond is also influenced by the cleanliness of the aggregate. Coatings on the aggregate will reduce the bond.



27. Another important property of aggregates is the aggregate **specific gravity**. Specific gravity is the ratio of the weight of the aggregates to the weight of an equal volume of water. Most aggregates have a specific gravity of between 2.4 and 2.9. In general a low specific gravity indicates a porus, weak and absorptive aggregate while a high specific gravity represents good quality. The specific gravity is used in certain mix and control calculations.



28. There are four possible moisture conditions for an aggregate:

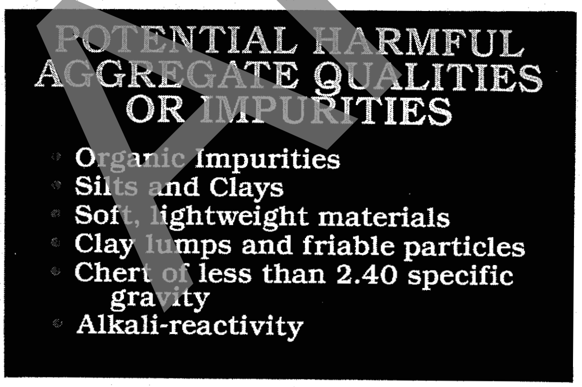
a. Aggregates with no water in the pores or on the surface are called **oven-dry** and represent a laboratory condition.

b. Aggregates with a dry surface and variable amounts of water in the pores are **air-dried** and will absorb water from a concrete mix.

c. In the **saturated, surface dry** (SSD) condition, the pores are filled but the surface is dry. Since the weight of water given in a mix design is based on SSD aggregates, the amount of water added during job mixing must be adjusted for the aggregate's moisture condition.

d. In the **damp or wet** condition, the aggregate pores are filled and free water is present on the surface. Aggregates in this condition contribute water to a concrete mix.

Since the aggregate weight will vary depending on the moisture condition, specific gravities are determined at a fixed moisture content, either oven dry or SSD.



29. There are several aggregate qualities or impurities that are **potentially harmful** to concrete.

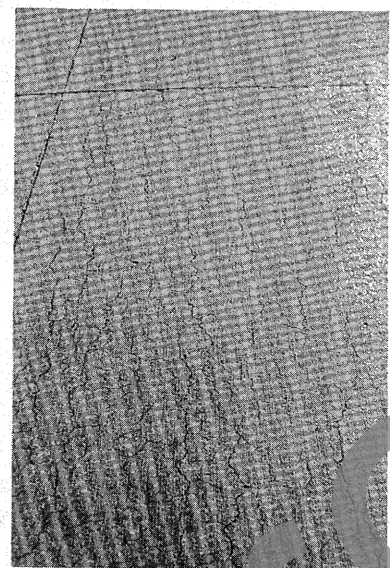
- **Organic impurities** may delay setting and hardening of concrete and may also reduce strength gain.

- **Material finer than the 75 μm sieve,** such as silts and clays, can cause a thin dust-like coating on the aggregate, thus weakening the bond between the aggregate and paste and resulting in low strength.

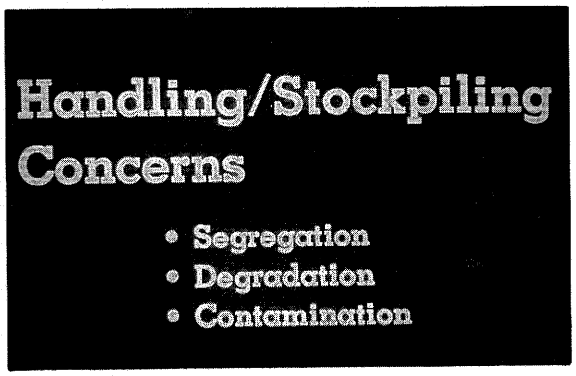
- **Coal, lignite, and other soft particles** will cause popouts and a loss in durability and wear resistance.

- **Clay lumps** in concrete may absorb mix water and may break down from freezing and thawing or wetting and drying. They can cause popouts and reduce the concrete's durability and wear resistance.

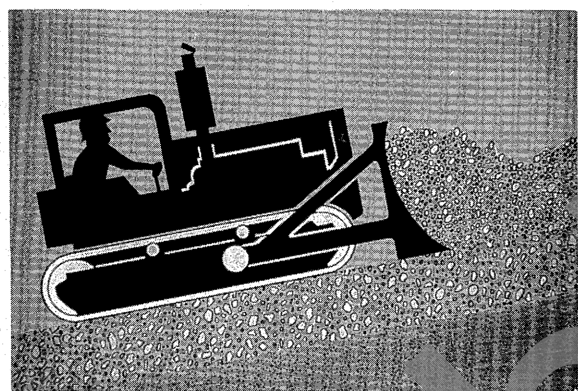
- **Chert** also affects the durability of concrete and, due to its high absorption, can cause popouts.



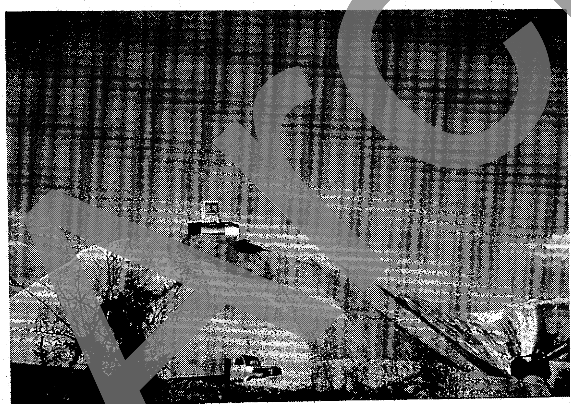
30. **Alkali-Aggregate reactions** known as Alkali-Silica Reactivity (ASR), and Alkali-Carbonate Reactivity (ACR) can cause abnormal expansion or map cracking in concrete. It is caused by a reaction between some siliceous and carbonaceous aggregates and alkali from the cement. During this reaction, a highly absorptive material is formed on the surface of the aggregate. When this material absorbs water, it will expand and cause cracking. The reactions only occur when **alkali, silica or carbon, and moisture** are combined in the concrete. Limiting any of the three reduces the reaction. Deterioration can be minimized by limiting the alkali content of the cement to 0.6 percent when reactive aggregates are suspected or known. The addition of an adequate amount of a suitable pozzolan can also limit this reaction. Reactive aggregates can be found anywhere, but are most prevalent in the western and southern states. The best indicator of an aggregate's suitability is its service record. If the aggregate has been producing quality concrete, it generally will continue to do so. Should there be any doubt or problem with an aggregate, testing, such as petrographic examination or mortar bar tests should be performed to ensure suitability for making concrete.



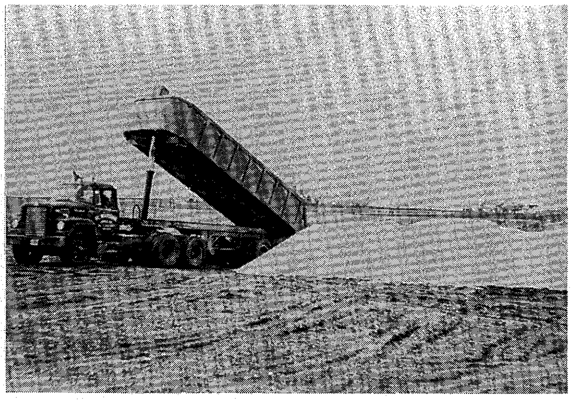
31. The objectives of a well designed aggregate storage and handling system are to provide an adequate supply of aggregates and to prevent segregation, breakage and contamination.



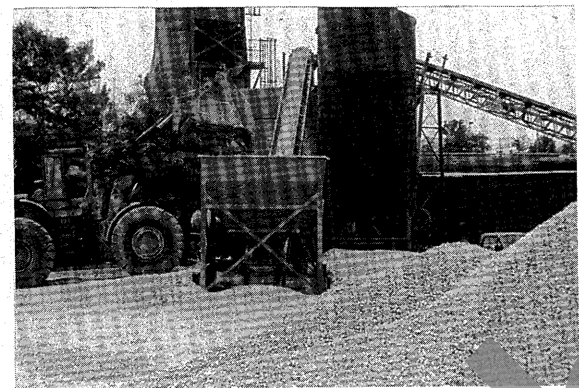
32. The preferred method of building stockpiles is to build them in layers of uniform thickness by depositing material in tightly placed loads. This applies to stockpiles built by clamshell or truck delivery. Stockpiles that are spread by a dozer are acceptable, however, the aggregate should be watched for degradation. Rubber tired equipment is preferred to metal tracked equipment.



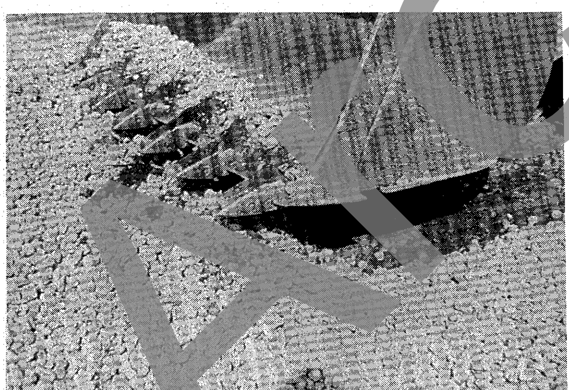
33. Segregation can result if the material is bulldozed over the edge of the stockpile, even though the rest of the stockpile has been properly constructed.



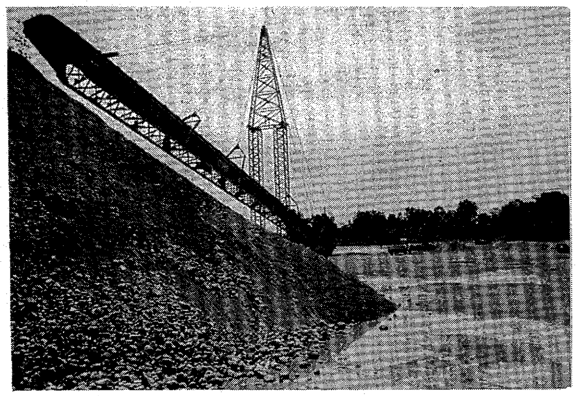
34. Aggregate stockpiles should also be constructed on smooth, hard surfaces in order to prevent contamination from underlying soils.



35. Removing aggregates from stockpiles and feeding hoppers can be accomplished through underground feeds from stockpiles, by clam shell buckets, or by charging hoppers with front-end loaders.

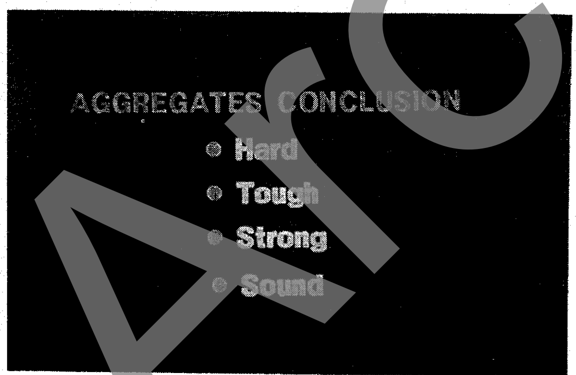


36. Slices from a stockpile made with a front-end loader should be from bottom to top so that each slice contains a portion of each horizontal layer. Care should also be taken to avoid taking material from the very bottom of the stockpile where existing soils could contaminate the aggregates.



37. Conical stockpiles promote aggregate segregation and should be avoided, unless the materials can be satisfactorily remixed before it is used. Concrete made from the lower portion of a segregated stockpile will be harsh and soupy while the concrete made from the upper part, with excess fines, will be dry and stiff.

38. Bulkheads and dividers should be used to avoid contamination of stockpiles.

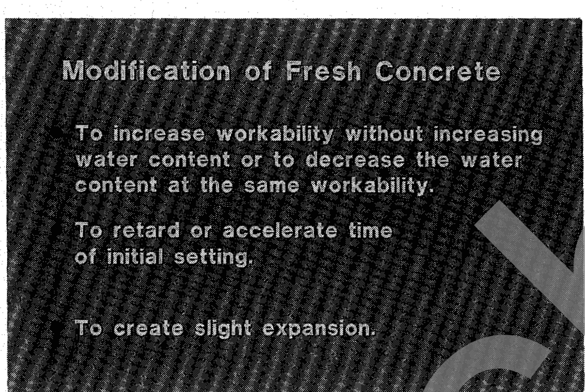


39. In conclusion, aggregates should be clean and well graded, properly stockpiled, hard to resist grinding, tough to withstand impact, strong to stand up under heavy loads, and sound to remain whole during freezing and thawing.

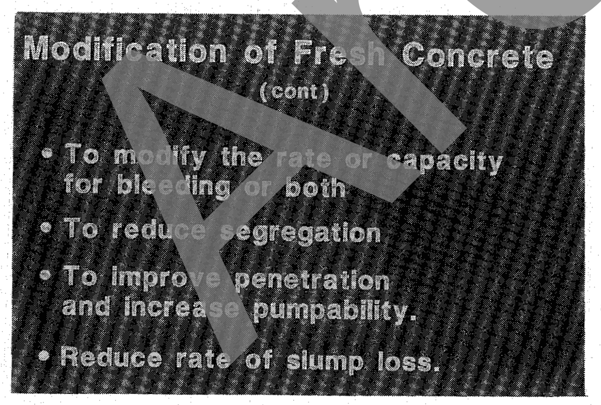
Chapter 5

ADMIXTURES

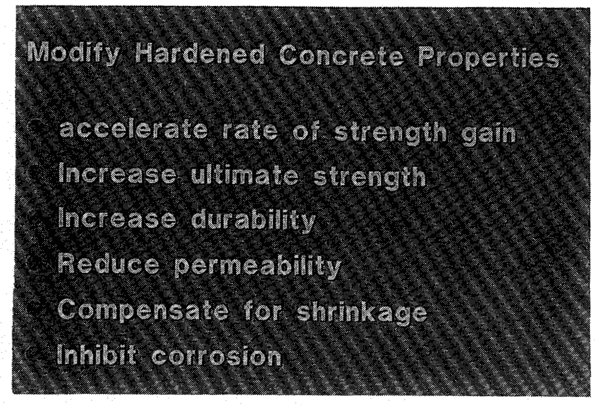
1. **An admixture is** defined by ASTM as: **"A material other than water, aggregates, hydraulic cement, and fiber reinforcement used as an ingredient of concrete or mortar, and added to the batch immediately before or during its mixing."** Admixtures are used to improve both the plastic and hardened properties of portland cement concrete. It should be noted that admixtures are not a substitute for good concrete mix design but can be used to enhance the properties of a concrete mix.



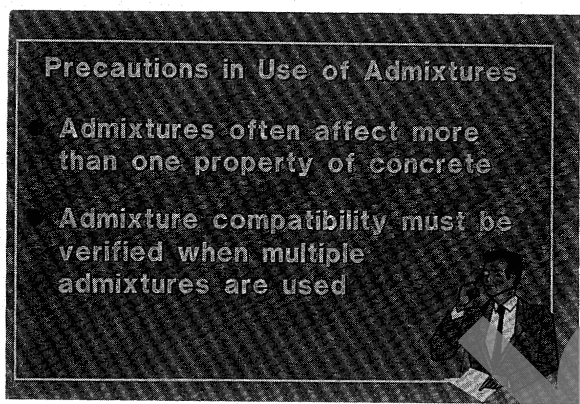
2. Admixtures can be used to enhance the following properties of **plastic concrete:** increase workability at the same water content, change the rate of set, compensate for shrinkage,...



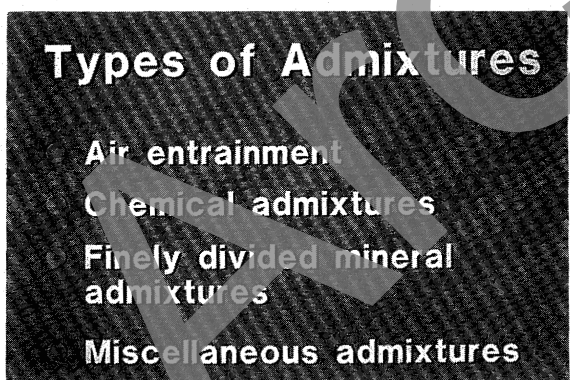
3. reduce bleeding, reduce segregation, improve pumpability, and reduce the rate of slump loss.



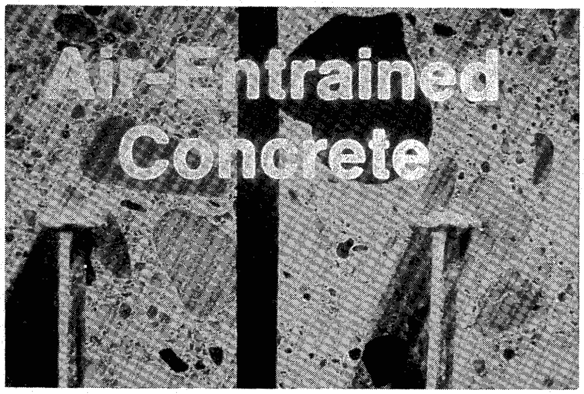
4. Admixtures are also used to enhance the following properties of **hardened concrete:** accelerate the rate of strength gain, increase ultimate strength, increase resistance to freeze-thaw damage, increase the resistance to alkali aggregate reactions, increase the resistance to sulfate attack, reduce permeability, compensate for shrinkage, and inhibit corrosion of reinforcing steel.



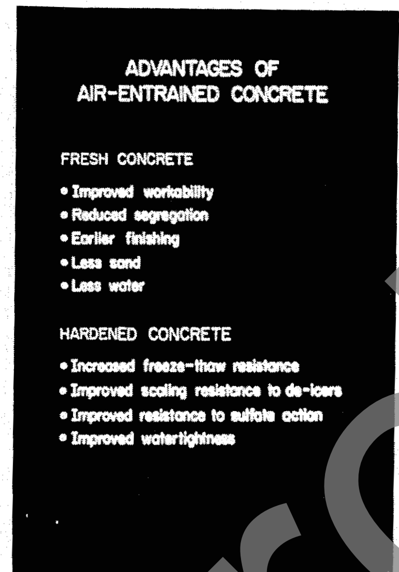
5. Many admixtures affect more than one property of concrete and in some cases they may affect a desirable property in an unfavorable manner. For instance, multiple admixtures used in combination can cancel out the effectiveness of any one or all of the admixtures. This is another reason for performing trial batches with all of the proposed ingredients.



6. There are four types of admixtures used in Portland Cement concrete. They are **air entraining, chemical, finely divided mineral, and miscellaneous admixtures.**

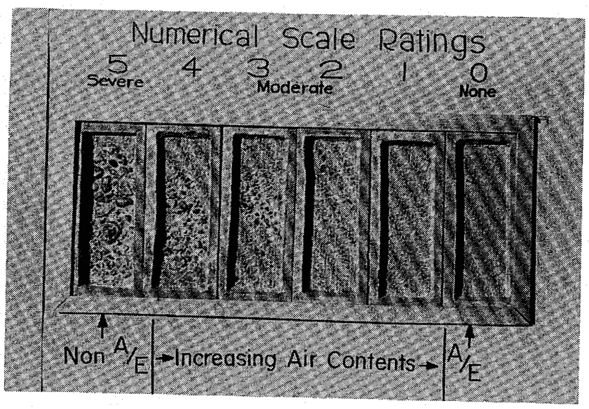


7. **Air entraining admixtures** are the most commonly used admixtures in the industry today and are used in almost all concrete. These admixtures act by stabilizing microscopic air bubbles created during mixing. These bubbles result in increased freeze-thaw durability of the concrete. The specification requirements for air entraining admixtures are contained in AASHTO M 154 and ASTM C 260. While particular mixes may vary, typically 0.05 percent by weight of air entraining agent is added per weight of cement. Some agents are fluid and can be measured by volume.

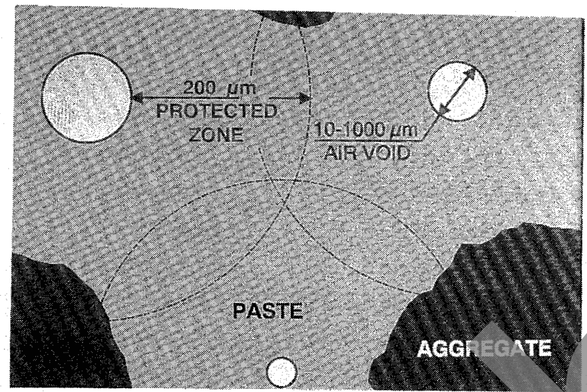


8. In hardened concrete, air-entrainment, in addition to providing resistance to freeze-thaw cycles, can also increase the water tightness, improve resistance to scaling caused by de-icing salts, and increase resistance to sulfate attack. In plastic concrete the use of air-entraining admixtures can improve workability, help reduce segregation, and cut down on bleeding when compared to non-air-entrained mixes. Air entrained mixes typically require less sand and water because of the increase in workability of the mixes.

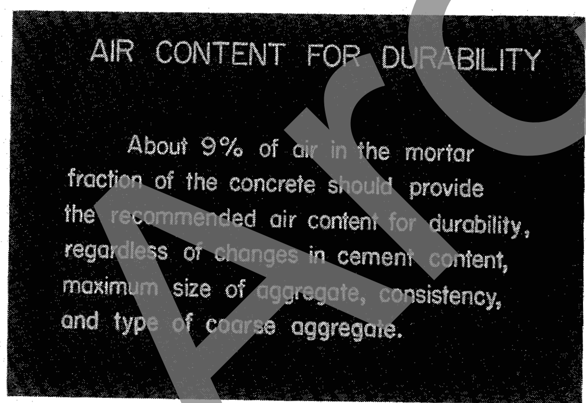
9. For each 1 percent increase in air content, the compressive strength will be reduced by 2 to 6 percent.



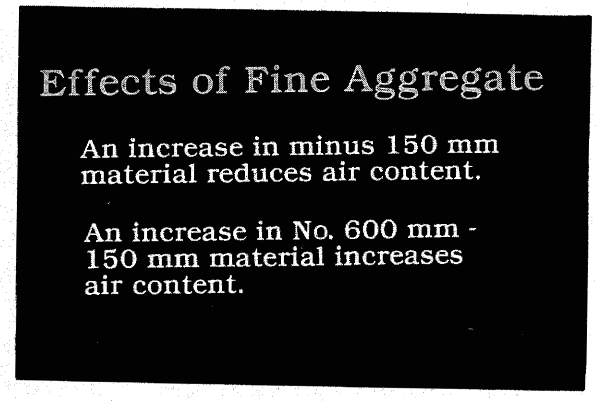
10. Freeze-thaw damage is due to water which expands up to 9% on freezing. Entrained air creates pockets in the hardened concrete to allow room for the expansion of the freezing water so the expansive pressures do not damage the concrete.



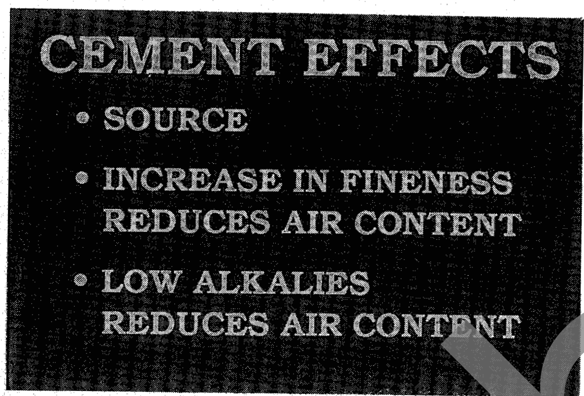
11. The measured air content in concrete records both **entrapped air** and **entrained air.** Entrapped air does not help in freeze-thaw durability due to its coarse distribution. Entrained air provides the freeze-thaw durability by its proper size air bubbles and fine spacing. There can be 500 to 800 billion air bubbles in a cubic meter of concrete.



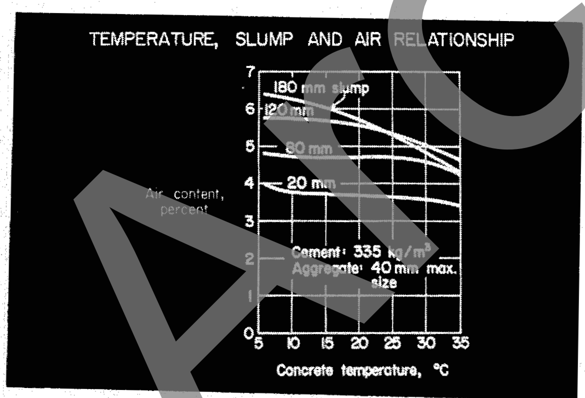
12. As a rule of thumb, there should be approximately 9 percent total air in the mortar fraction of the mix. The measured air content and recommendations for air content include 2 to 3 percent entrapped air which does not provide any benefit to the concrete.



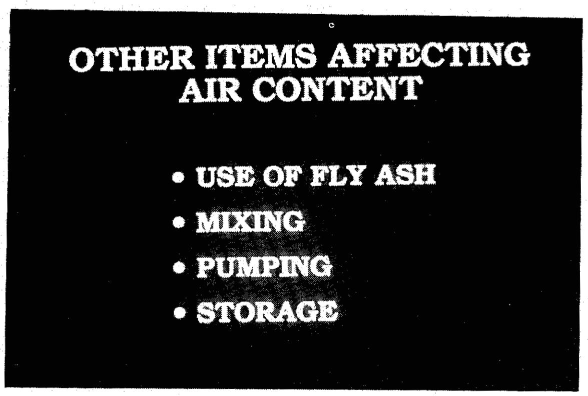
13. The gradation of the fine aggregate will affect the ability of the concrete to entrain air. An increase in the amount of material passing the 150 μm sieve will result in a reduction of air content. An increase in the amount of material between the 600 μm and the 150 μm sieves will result in an increase in air content. The fineness modulus can be used to indicate that a change has occurred in the gradation of the fine aggregate.



14. The properties of the portland cement can also affect the ability of the mix to entrain air. An increase in fineness or low alkalies will result in a reduction of air content. A change in source of cement may also affect the air entraining capability of the concrete.



15. As the temperature increases the air content will decrease. As a result it may be necessary to adjust the amount of air entraining admixture during the course of a placement. An increase in slump may result in an increase in air content.



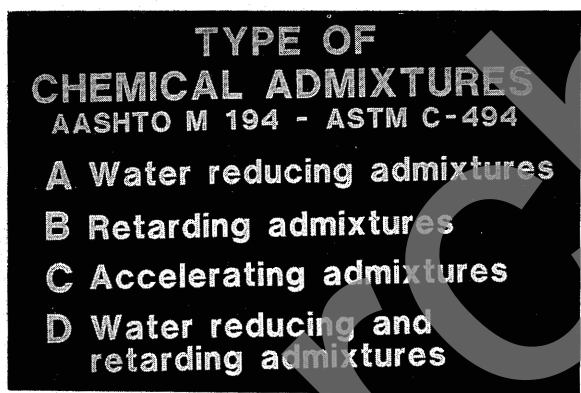
16. Other items may also affect the ability of the concrete to entrain air.

- The use of a non uniform fly ash may result in a large variability in the air content, and is discussed later in this chapter.

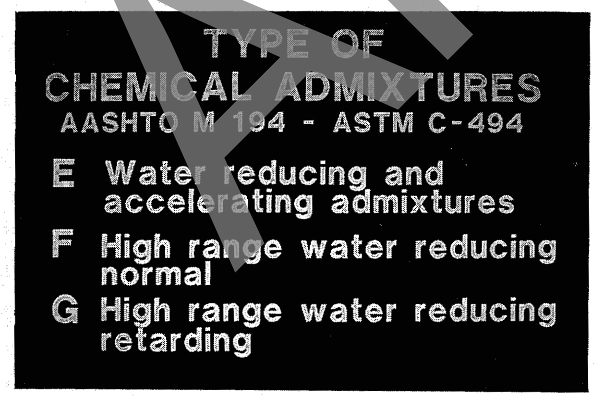
- While adequate mixing is necessary for the formation of air bubbles, excessive amounts of mixing can reduce the amount of air in the concrete.

- Pumping concrete will reduce the air content in the concrete. This will be discussed further in the chapter on conveying, placing and finishing.

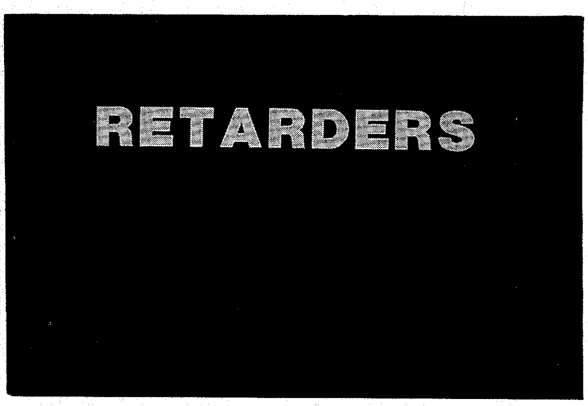
- Admixtures stored for longer than 6 months should be tested.



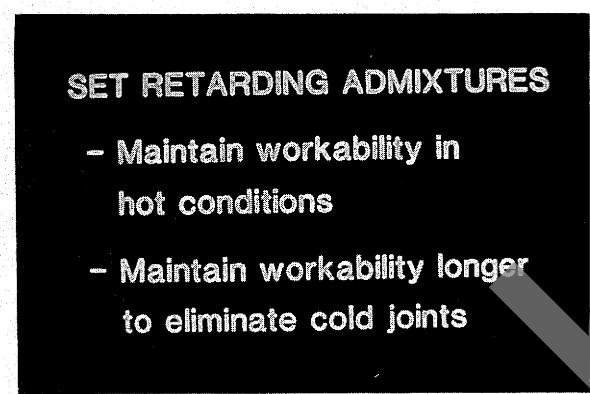
17. The specification requirements for **chemical admixtures** are contained in AASHTO M 194 and ASTM C 494. All admixtures have specific set requirements. In addition, the Type A,D,E,F,and G admixtures have water reducing requirements. The specifications also allow lower durability than mixtures without these admixtures.



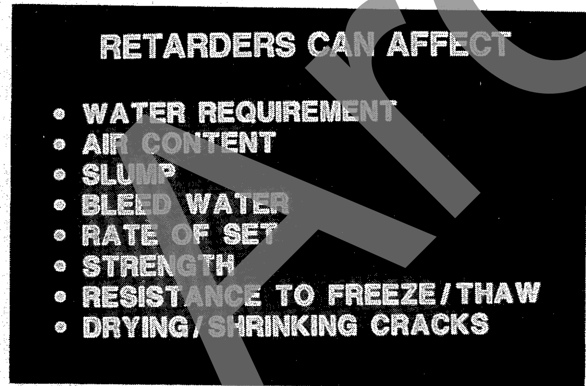
18. Properties will be discussed of the following categories of admixtures: retarders, water reducers, accelerators, and high range water reducers (superplasticizers).



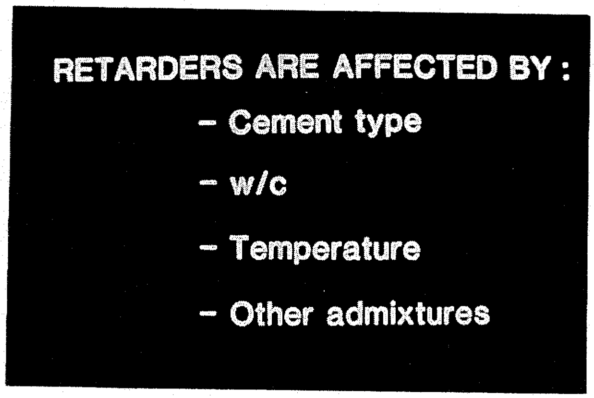
19. **Retarders** are the second most commonly used admixture in the highway industry. Most retarders are also water reducers. The most common use is in the construction of bridge decks.



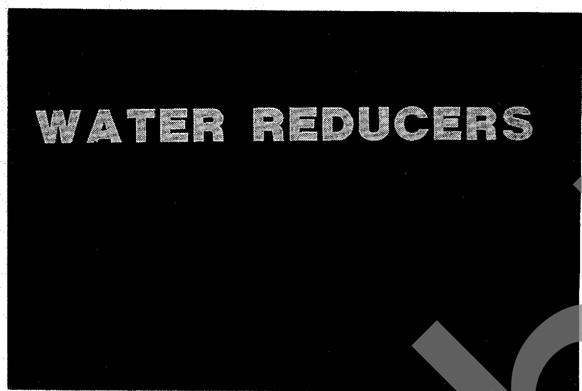
20. Set retarding admixtures function by temporarily encapsulating the cement particles and preventing hydration from taking place. They are used primarily to offset the accelerating and damaging effect of high temperature and to keep concrete workable during the entire placing operation. This will help avoid the formation of cold joints. In addition, it will prevent damage due to dead load deflection of the bridge deck, since the concrete remains plastic during the placing operation.



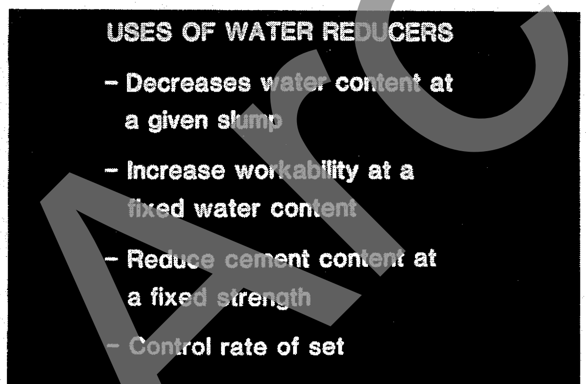
21. The retarder can affect, 1) water demand, 2) air content, 3) slump, 4) bleed water, 5) rate of set, 6) strength, 7) resistance to freezing and thawing, and 8) drying shrinkage. Bleeding may increase with some admixtures. If retarders are used, an increase in shrinkage is allowed. Different chemicals which can qualify as retarders will affect these properties differently. This is another reason for making trial batches with the materials which will be used in the mix.



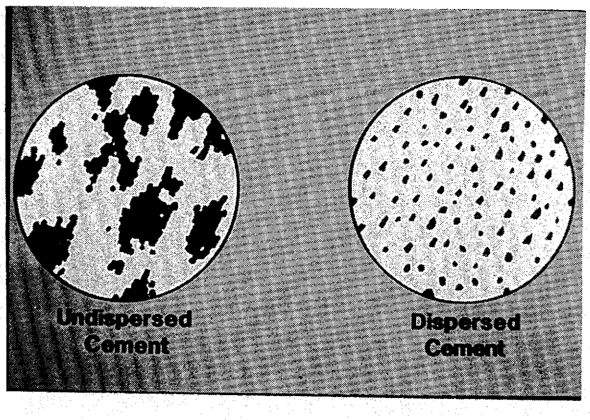
22. The specific effects of set retarding admixtures vary with cement, water content of the mix, concrete temperatures, ambient temperatures, and the presence of other admixtures.



23. The use of **water reducers** by the highway agencies has been increasing over the last few years. They have been used primarily in bridge decks, low slump concrete overlays, and concrete patching.



24. Initially, water reducing admixtures were used just for what their name implies - to reduce the amount of water needed to achieve a given slump. Now, water reducing admixtures provide many additional benefits which included controlling the rate of set and providing flowable concrete. Reduction in cement contents must be made with caution to insure that durability will not be decreased. The majority of the water reducers are set retarders. Water content can be reduced by as much as 12 percent when water reducers are used.



25. Water reducers are dispersion agents. Cement particles tend to clump together, and reduce the efficiency of the hydration process. Water reducing admixtures give electrical charges to cement particles. This causes the particles to repel one another and reduces the size and number of clumps. Hydration then proceeds more efficiently since the water can react much more fully with each of the cement particles. This ensures that the concrete reaches its full potential strength.

BENEFITS OF WATER REDUCERS

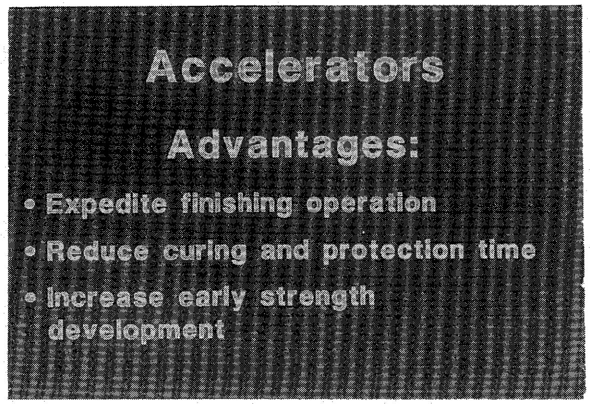
- Improved finishability
- Improved durability
- Increased strengths (early and ultimate)
- Increased water tightness

26. Water reducers have several other benefits. In addition to being a workability agent, water reducers improve finishability and enhance many hardened concrete properties, such as water tightness, durability, permeability,and both early and ultimate strengths.

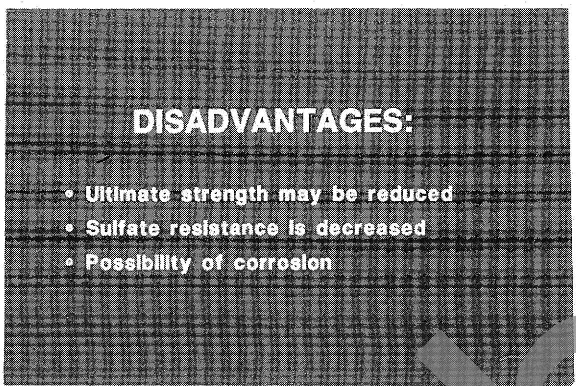
WATER REDUCERS CAN AFFECT

- WATER REQUIREMENT
- AIR CONTENT
- SLUMP
- BLEED WATER
- RATE OF SET
- STRENGTH
- RESISTANCE TO FREEZE/THAW
- DRYING/SHRINKING CRACKS

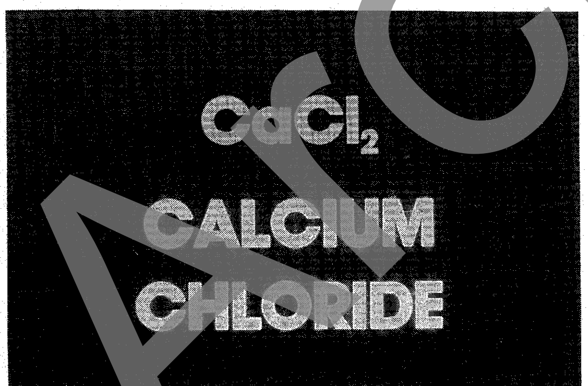
27. The water reducer can affect, 1) water demand, 2) air content, 3) slump, 4) bleed water, 5) rate of set, 6) strength, 7) resistance to freezing and thawing, and 8) drying shrinkage. Bleeding may increase with some admixtures. If water reducers are used, an increase in shrinkage is allowed. Different chemicals which can qualify as water reducers will affect these properties differently. This is another reason for making trial batches with the materials which will be used in the mix.



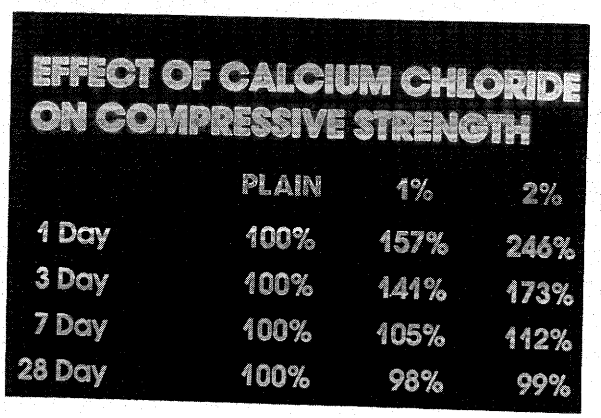
34. Accelerators offer a number of advantages for concrete construction. In concrete's plastic state they can allow earlier finishing. In hardened concrete, accelerators will reduce curing and protection time and increase early strength development.



35. Accelerators also have some disadvantages. The ultimate strength of the concrete may be reduced, the sulfate resistance of the concrete will be reduced, and since most accelerators are salts the potential for corrosion is increased.



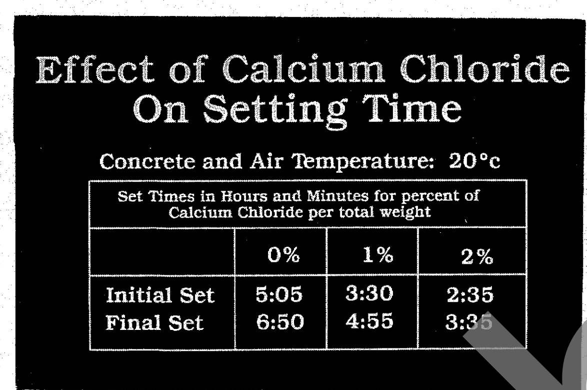
36. **Calcium chloride** is the most commonly used accelerator. Other soluble salts such as chlorides, bromides, fluorides, carbonates, nitrates, and silicates have been used along with some organic compounds such as triethanolamine. The amount of calcium chloride should be limited to 2 percent maximum by weight of cement to prevent corrosion of reinforcing steel.



EFFECT OF CALCIUM CHLORIDE ON COMPRESSIVE STRENGTH

	PLAIN	1%	2%
1 Day	100%	157%	246%
3 Day	100%	141%	173%
7 Day	100%	105%	112%
28 Day	100%	98%	99%

37. This table shows the effect of calcium chloride on compressive strength. Note the dramatic increase in compressive strength at the early ages of the concrete.

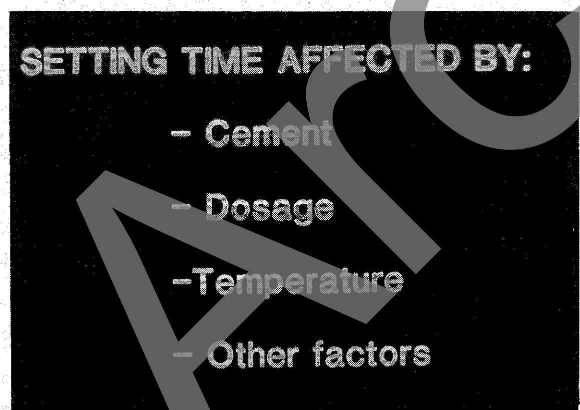


Effect of Calcium Chloride On Setting Time

Concrete and Air Temperature: 20°c

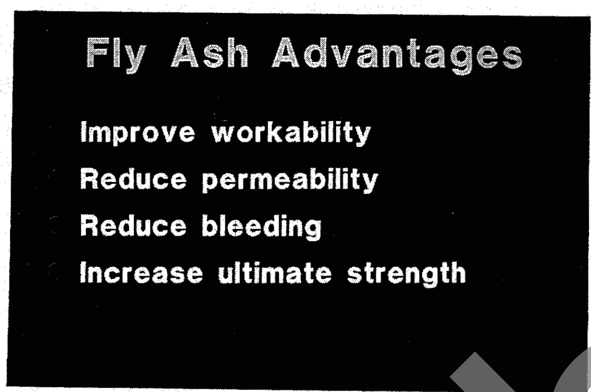
Set Times in Hours and Minutes for percent of Calcium Chloride per total weight			
	0%	1%	2%
Initial Set	5:05	3:30	2:35
Final Set	6:50	4:55	3:35

38. Accelerators will also reduce the setting time of concrete. The accompanying table shows the test results on 20°C concrete that is placed at 20°C. The initial set of this plain concrete was 5 hours and 5 minutes. With 1 percent calcium chloride initial set was reduced to 3-1/2 hours. By increasing the calcium chloride content to 2 percent, the time to initial set was 2-1/2 hours. Similar percentage reductions occurred in the final set of the concrete.

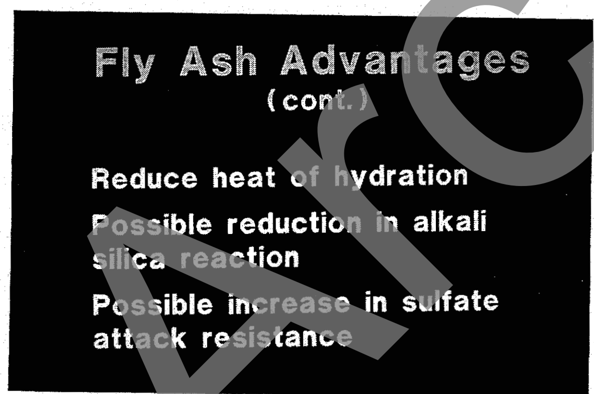


39. When using calcium chloride, the setting time will also be affected by other conditions such as type or brand of cement, concrete temperature, admixture dosage, water, and other admixtures.

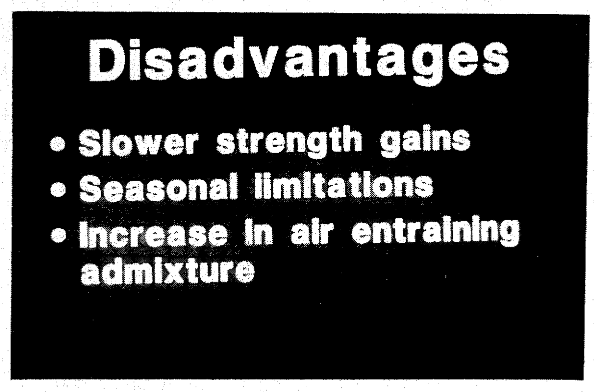
46. Fly ash is used as a partial replacement for Portland Cement. State highway agency specifications will allow between 15 and 25 percent of the cement to be replaced with fly ash on a 1 - 1.2 to 1 ratio based on the weight on the material. Since fly ash weighs less than cement (fly ash S.G. = 2.65 compared to cement S.G. = 3.15) the mix proportions need to be changed accordingly. Typically the amount of fine aggregate is reduced.



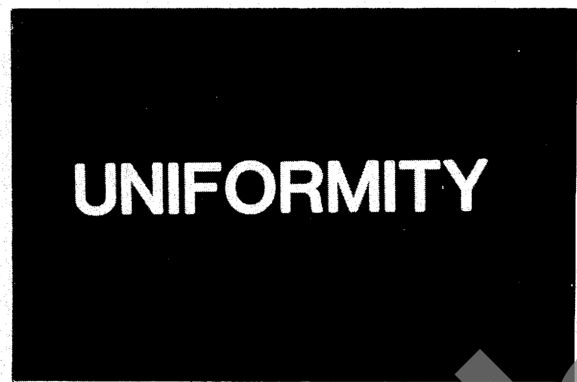
47. Fly ash has several positive affects on the properties of the concrete. The fineness and spherical shape of the material improve the workability of the mix. The fineness also reduces bleeding and permeability, and the ultimate strength is increased due to the formation of the products of the pozzolanic reaction.



48. The heat of hydration is reduced due to less cement. Alkali reactivity can also be reduced due to a lower cement content and the consumption of alkalies in the pozzolonic reaction, and sulfate resistance can be improved. Some fly ashes however, class C for instance, may adversely affect the sulfate resistance of the concrete.

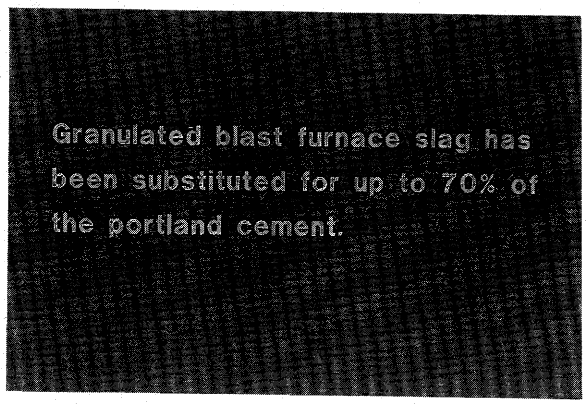


49. Fly ash also has several disadvantages: The rate of strength gain will be reduced, the pozzolanic reaction will cease at 4°C, so temperature restrictions should be used, and the use of fly ash will require additional amounts of air-entraining admixtures.

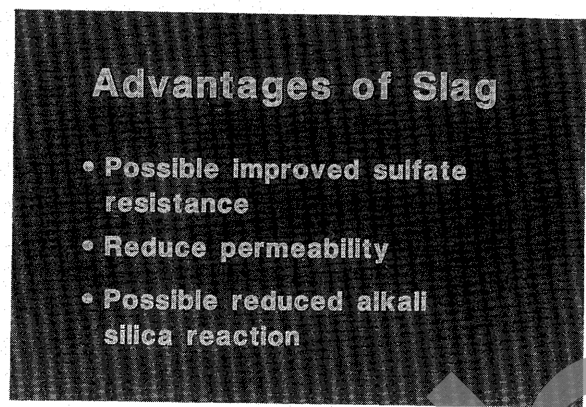


50. The fineness and the carbon content of the fly ash affect the air content of the mix. However, the uniformity of these properties is more important than the actual values. The operation of the power plant burning the coal affects the variability of the fly ash. Therefore, source approvals and certifications should be based on individual power plant production. When air entrained concrete is specified, the fly ash specification should include the optional uniformity specifications. An easy way of determining if the fly ash is uniform is to test the air content of each load of concrete until it is determined that the source of fly ash is uniform.

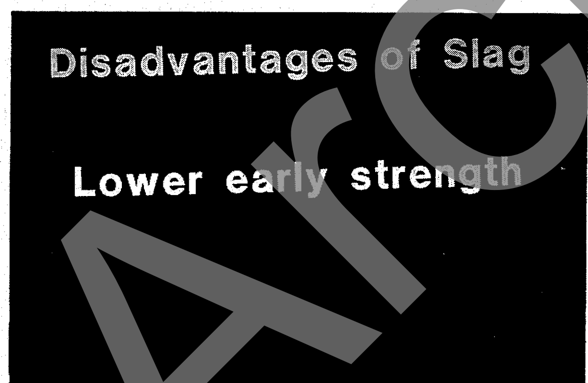
51. **Granulated blast furnace slag** is the glassy granular material formed when molten blast furnace slag is rapidly chilled. Granulated blast furnace slag is specified in AASHTO M 302.



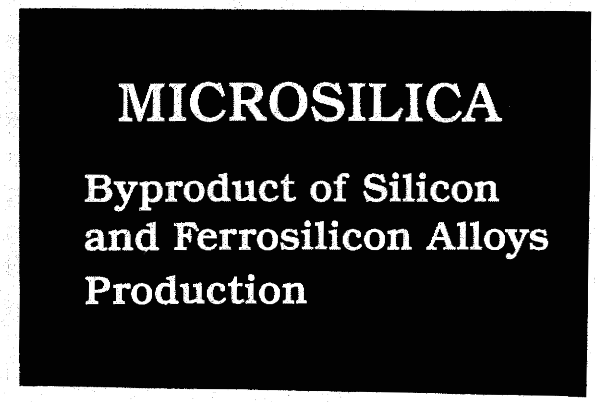
52. Granulated blast furnace slag has been substituted for up to 70 percent of the portland cement. The typical replacement rate is in the range of 50 percent.



53. Granulated blast furnace slag can benefit a concrete mix by reducing permeability, possibly improving the sulfate resistance, and possibly reducing the alkali aggregate reactions.

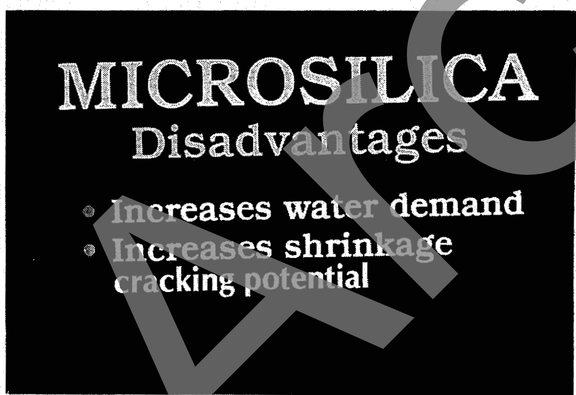


54. The primary disadvantage to using granulated blast furnace slag is lower early strength.



55. **Microsilica** is a relatively new admixture, and is specified in AASHTO M 307. Microsilica is the by-product of the production of silicon and specialty steels. It is almost a pure siliceous material. As with fly ash, microsilica relies on the pozzolanic reaction and fine particle effect for strength gain. Microsilica has been used by some States as an additive in bridge deck concrete. Addition rates are in the range of 5 to 15 percent by weight of cement.

56. Microsilica has several **advantages**. As with most pozzolans the concrete which contains microsilica has a reduced permeability due to the products of the pozzolanic reaction. Early strength is obtained due to the lower water cementitious ratios. Higher ultimate strengths are reached due to the pozzolanic reactions, and alkali-silica reactions are reduced.

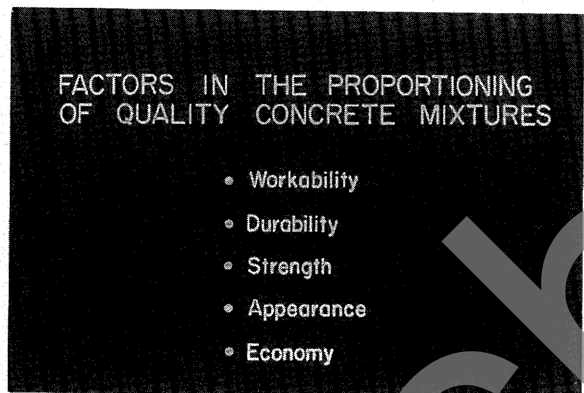


57. Microsilica also has some **disadvantages**. The higher water demand requires water reducers with 5 percent additions, and high range water reducers with higher addition rates. There is also an increased potential for shrinkage cracking with the use of microsilica.

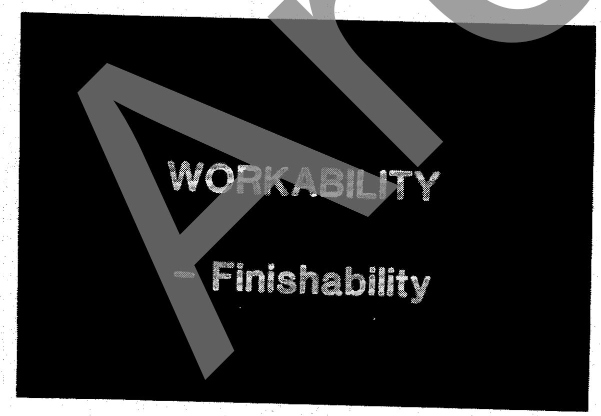
Chapter 6

PROPORTIONING NORMAL CONCRETE MIXES

1. This section will discuss the factors that are considered in proportioning concrete mixes, and an example of the procedures used will be provided.

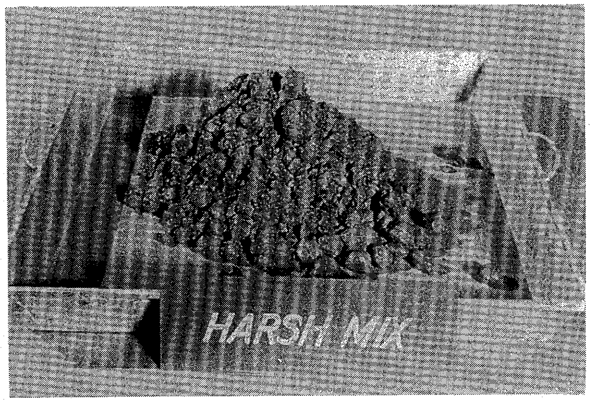


2. The following factors and associated criteria will be discussed: workability, durability, strength, appearance, and economy.

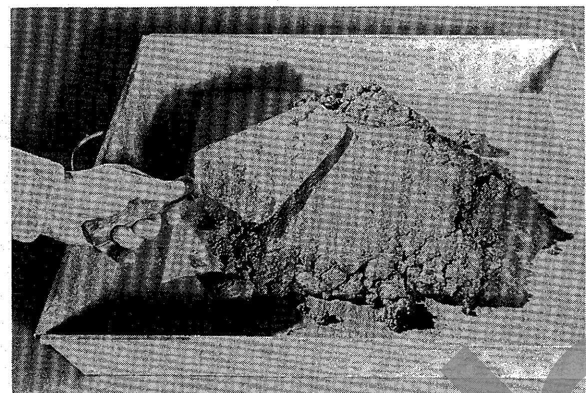


3. The term **workability** in concrete construction is used to indicate how well the concrete finishes or how easily the concrete closes up when a hand trowel is used on it. It is also necessary for the mix to be tight enough so that excessive bleeding will not occur. Evaluation of workability in a concrete mix is somewhat subjective and depends upon the person doing the evaluating. **Slump** is a measure of consistency and can indicate a change in workability of mixes with the same proportions but can not be used to compare the workability of mixes with different proportions.

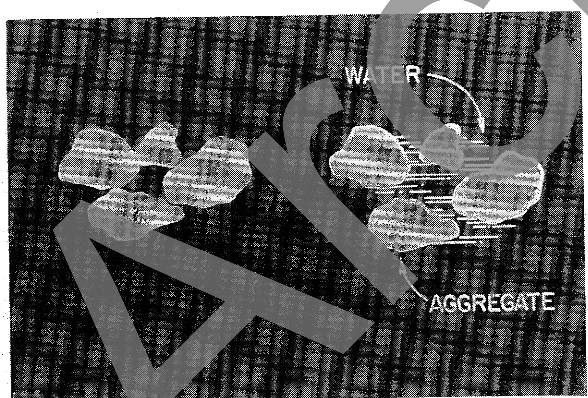
4. A **workable** mix is one in which the paste, that portion of the concrete which is made of the cement, water and fine aggregate, can be worked up to the surface very easily. The surface of a workable mix closes quite readily without excessive bleeding or segregation.

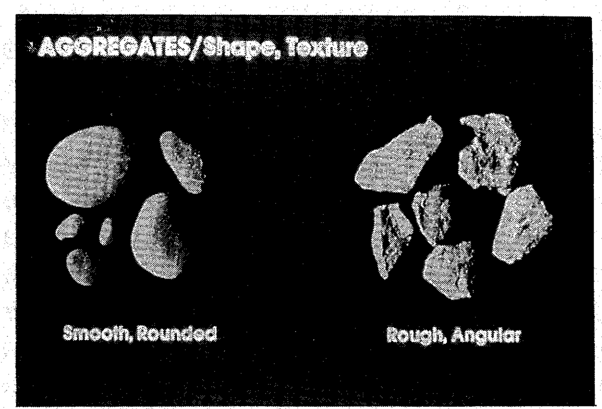


5. A **harsh** mix is one that does not close up well under a trowel. The trowel may tear the surface when it is used on the concrete.

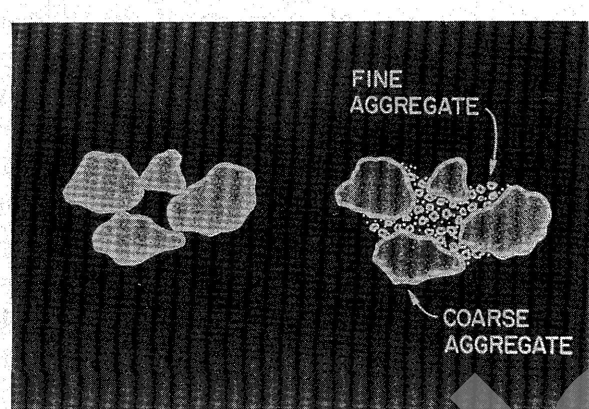


6. There are several factors that affect the workability of concrete. The one having the most effect and the easiest to understand is the water content. Water in a concrete mix acts as a dispersing agent that puts more space between aggregate particles and acts as a lubricant.

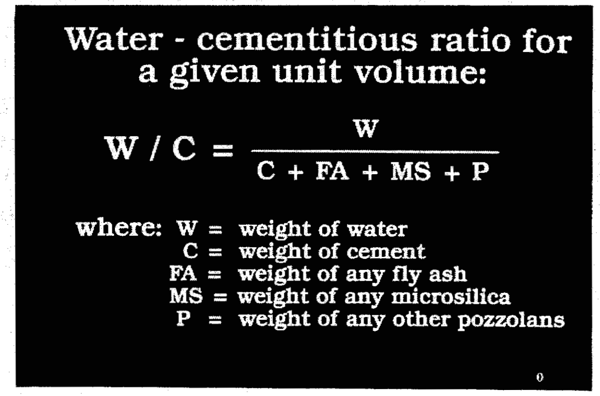




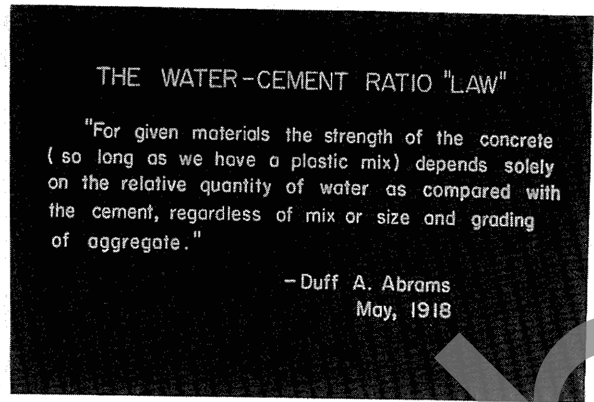
7. The **shape** and **angularity** of aggregate particles will also affect the amount of water required to produce a given slump. Round stone and smooth gravel require less water than angular crushed stones, all other factors being equal. However, concrete made with rounded aggregate will have lower strength than concrete made with angular aggregates.



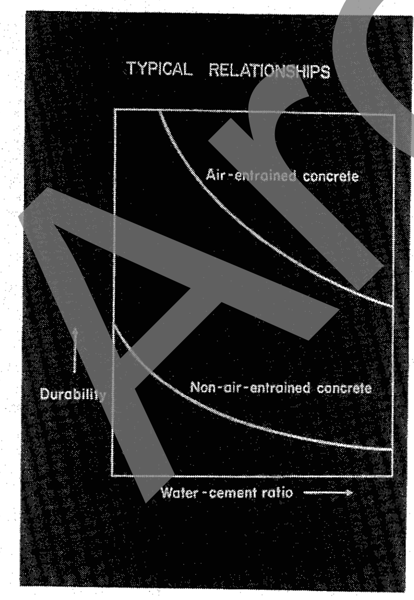
8. **Gradation** particularly of the fine aggregates, can have a significant influence on slump. Aggregates that are relatively fine have more surface area to be coated by the cement paste. This results in less space between particles and an increase in the particle friction and interaction, resulting in a lower slump. The ratio of the amount of the fine aggregate to coarse aggregate in a concrete mix also has an affect on slump. However, if this ratio is changed, the results are not quite as obvious as some of the other factors. If the percentage of fine aggregate in a mix is increased, the slump will be less but the workability may actually be improved. This better workability develops because the fine aggregates reduces the coarse aggregate interlock. If the percentage of fine aggregate is increased too much, a point will be reached where more cement is needed in the mix to maintain the concrete strength. If workability problems occur, the total gradation should be examined, as it may be due to a gap gradation.



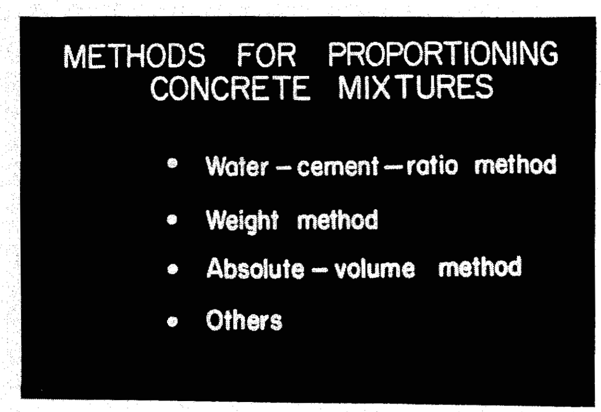
14. The water-cementitious ratio is the ratio, by weight, of water to cementitious material. This term is the equivalent to the term water-cement ratio except the cementitious material includes cement and any pozzolanic material.



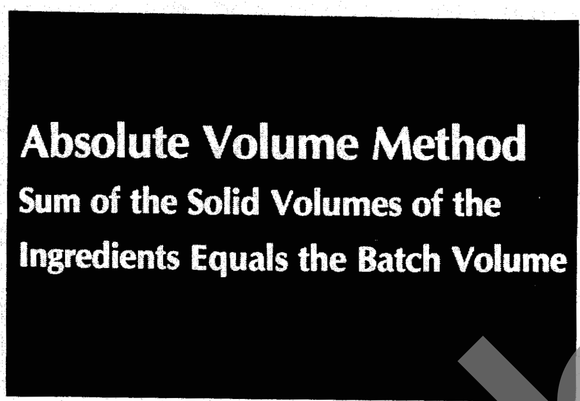
15. As the water-cementitious ratio is lowered the strength increases provided that the other materials remain the same.



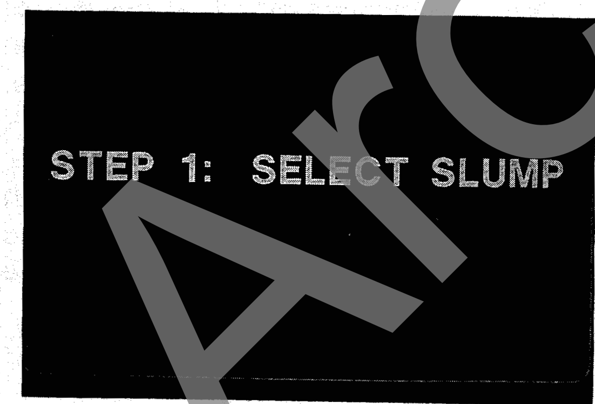
16. Durability improves with air-entrainment and lower water-cementitious ratios.



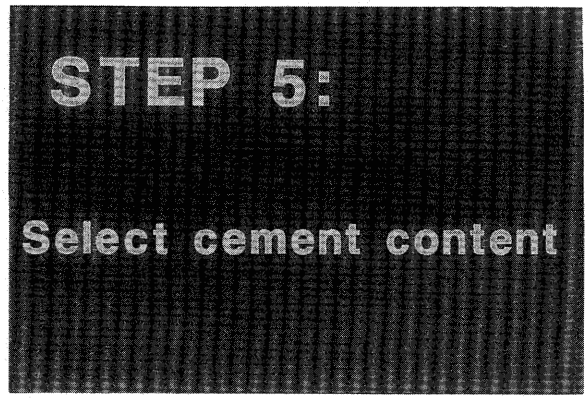
17. There are several ways to proportion concrete. Since concrete is batched by weights, all methods eventually require making adjustments to the proportions based on the materials weight volume relationships .



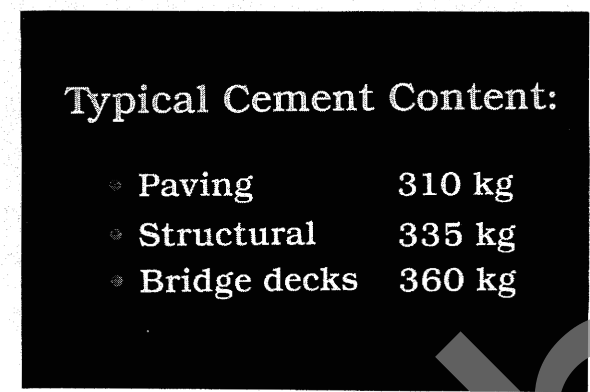
18. The following 8-step discussion and example will center on the **absolute volume method** since a majority of State Highway Departments proportion their mixes based on this method, or a modification of it.



19. The first step is to select a **maximum slump**. The choice of a slump depends on the type of construction which will be performed and the desired workability.

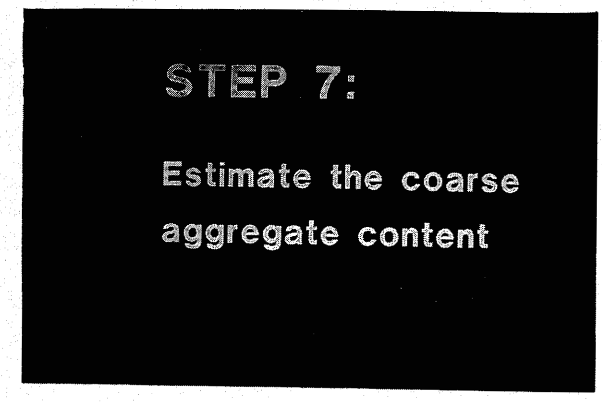


26. Fifth, the **cement content** is selected based on the desired strength, exposure, and expected construction variability.

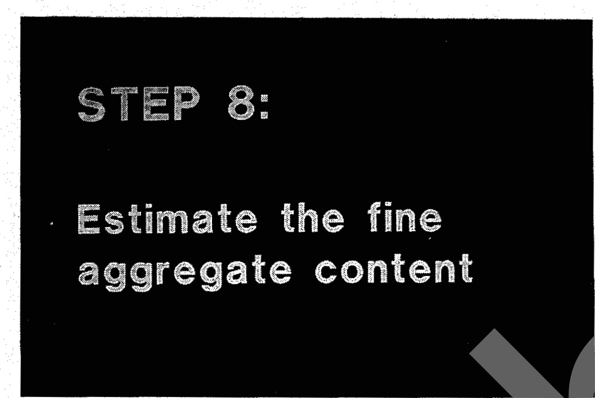


27. These are typical cement contents used by highway agencies to obtain the above desired properties. They fall in line with the recommendations in ACI for severe exposure.

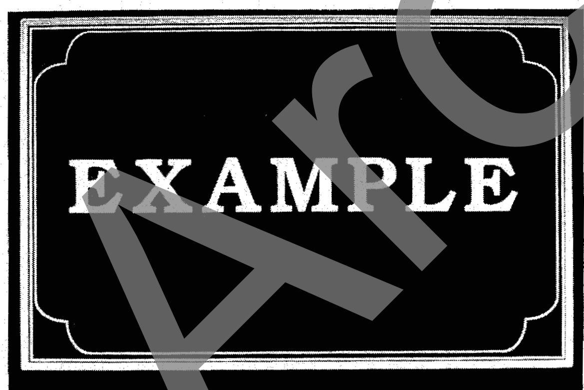
28. Sixth, at this point the **maximum allowable water** is calculated by multiplying the maximum water-cementitious ratio and the minimum cement content. The maximum water should not have to be used for paving and structural concrete.



29. Seventh, the **estimate of the volume of coarse aggregate** in the mix is made based on the maximum aggregate size and the fineness modulus of the fine aggregate.



30. Finally, the estimate of the fine aggregate is the volume that is left over after the volumes of cement, water, air, and coarse aggregate are accounted for.



31. At this point an example of proportioning will be presented.

32. The following is specified criteria for the mix.

Concrete Mixture Criteria

310 kg cement (min)
0.50 w/c ratio (max)
37.5 mm coarse aggregate size (max)
40 mm slump (max)
5.5 percent air content (target)

33. The physical properties of the aggregate is provided in this slide.

Coarse Aggregate

S.G. (SSD) 2.60 — absorption 0.5%
Dry rodded unit wt 1600 kg / m³ — total moisture 2%

Fine Aggregate

S.G. (SSD) 2.65 — absorption 0.7%
FM 2.80 — total moisture 6%

34. At this time the volume of coarse aggregate is determined from this chart. A coarse aggregate volume of 0.71 is found by entering the chart with a maximum size aggregate of a 37.5 mm and a fineness modulus of 2.80.

VOLUME OF COARSE AGGREGATE PER UNIT VOLUME OF CONCRETE

Maximum size of aggregate, mm	Fineness Modulus of sand			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19.0	0.66	0.64	0.62	0.60
25.0	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

CONCRETE MATERIAL MASS CALCULATIONS

Cement -	=	310 kg
Water - 310 x 0.50	=	155 kg
Coarse aggregate (dry) - 1600 x 0.71	=	1136 kg
Coarse aggregate (SSD) - 1136 x 1.005	=	1142 kg

35. The weight of the cement, water and coarse aggregate is determined for a cubic meter. The **weight of the cement** is given as 310 kg. The maximum **water content** is found by multiplying the weight of cement and the maximum water cement ratio. The **weight of the coarse aggregate** is determined by multiplying the dry rodded unit weight of the coarse aggregate of 1600 kg, and the previously determined percent volume of coarse aggregate to be included in the concrete mix. A weight of 1136 kg is obtained.

CONCRETE PROPORTIONS

Cement - 310/(3.15 x 1000)	= 0.098 m^3
Water - 155/(1.00 x 1000)	= 0.155 m^3
Coarse Aggregate - 1142/(2.60 x 1000)	= 0.439 m^3
Air Content - .055 x 1.000	= 0.055 m^3
Subtotal	0.747 m^3
Fine Aggregate Volume - 1.000 - 0.747	= 0.253 m^3
Fine Aggregate Mass (SSD) - (0.253) x (1000) x (2.65)	= 670 kg

36. At this point the absolute volumes of the mix components are determined and the weight of the fine aggregate is determined. The **volumes of the cement, water and coarse aggregate** are determined directly from the previously determined weights and their specific gravities. The **air volume** is found directly by percent air content of the mix. The **volume of the fine aggregate** is the volume remaining after the volumes of the other materials are calculated. The weight of the fine aggregate is then determined from the volume and its specific gravity.

MOISTURE CORRECTIONS

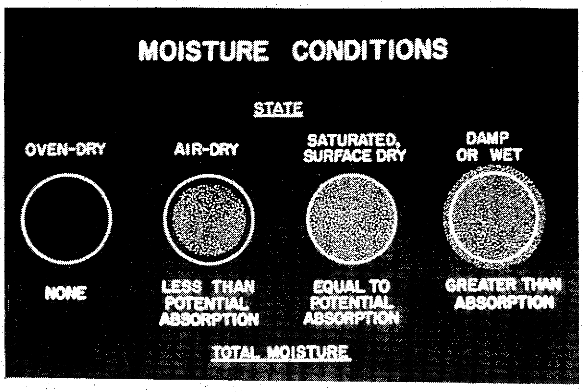
Adjust aggregate mass

Coarse aggregate (2% moisture)
1136 x 1.02 = 1159 kg

Fine Aggregate, Dry (0.7% absorption)
670/1.007 = 665 kg

Fine Aggregate, (6% moisture)
665 x 1.06 = 705 kg

37. The aggregate batch weights need to be adjusted to account for the weight of water due to their moisture contents. The resulting weights are used in the batching the concrete.



38. At this point, the mix water needs to be adjusted to account for the moisture content of the aggregates. The maximum w/c ratio is based on the total free water not the total water in the mix. The free water is the water content above that required to obtain a saturated surface dry condition in the aggregate.

Moisture Corrections

Adjust Water

Maximum Theoretical Water	= 155 kg
Less Coarse Aggregate Moisture 1136 (0.020 - 0.005)	= (-) 17 kg
Less Fine Aggregate Moisture 665 (0.060 - 0.007)	= (-) 35 kg
Maximum allowable mix water	= 103 kg

39. The amount of free moisture in the aggregate is determined by multiplying the dry aggregate weight by the difference in the moisture content and the absorption of the aggregate. The free moisture from both aggregates is then subtracted from the theoretical maximum water content to obtain the batch weight for the water

Batch Proportions

Cement	310 kg
Water	103 kg
Fine aggregate (6% moisture)	705 kg
Coarse aggregate (2% moisture)	1159 kg

40. This table shows the final batch weights.

TRIAL BATCH

- Check yield and workability
- Make strength specimens

41. At this point, a trial batch would be performed in the laboratory with the ingredients to be used in the mix. The yield, workability, air content, and strength should be checked. In addition, durability tests such as freeze-thaw testing may be required if an adverse aggregate reaction is suspected. A trial batch should also be performed at the plant to insure that the desired properties are achieved.

TYPICAL CORRECTIONS

- Water content
- Fine aggregate content
- Air content

42. In our example, the maximum water content was used. It would not be expected that the entire amount of water would be required to maintain the desired workability. If water is withheld from the mix, the aggregate proportions must be adjusted to compensate for the volume of water withheld. The ratio of fine to coarse aggregate may need to be changed in order to obtain the desired workability. It may also be necessary to adjust the air content.

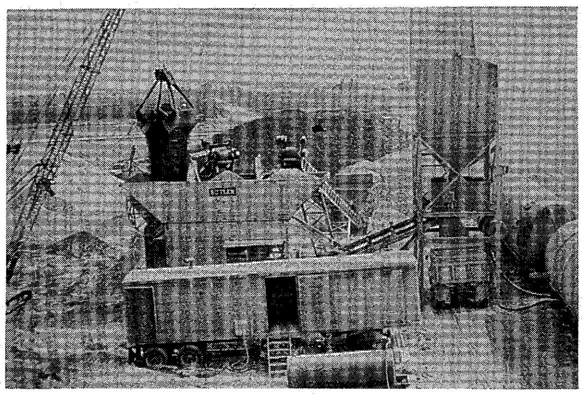
Minimum Recommended Strengths

Pavements. . . . . . . (third pt)	3.8 MPa
Structural	24.1 MPa
Decks.	27.6 MPa

43. The final item to discuss is the strength requirements of concrete. The **minimum specified strengths** indicated here are based on the design of the structure that will incorporate the concrete. The **mix design strength** needs to reflect the required minimum strength plus the anticipated variability caused by the entire concrete operation. For example, ACI 318 requires adding 6.2 MPa to the design strength if the variability (standard deviation) is between 3.4 MPa and 4.1 MPa. The specified w/c ratios and cement contents reflect both durability and the mix design strength.

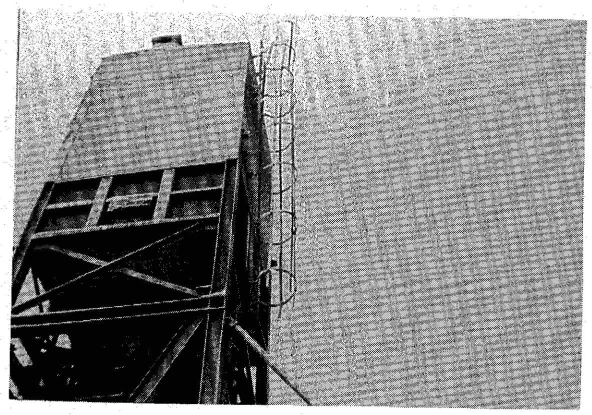
5) **Thorough mixing** occurs with all aggregate particles completely coated with cement paste.

6) The concrete discharged from batch to batch will be **uniform and homogeneous.**

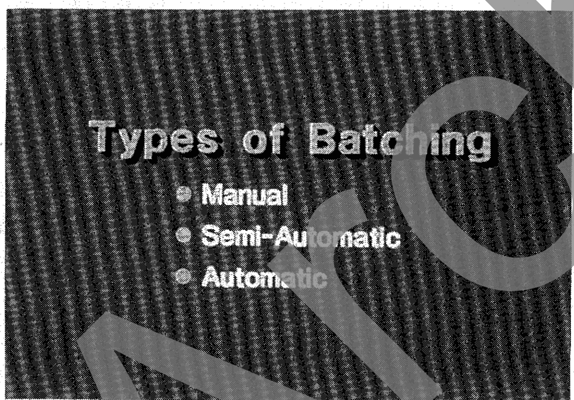


3. The batching operation begins with the transportation of the ingredients from their storage or stockpile areas to the weighing system. There are several items that should be considered with respect to the transportation of ingredients. **First, with respect to aggregates, there should be adequate separation between the feeding bins.** In order to achieve the desired concrete quality the aggregates must be properly proportioned. Any spill over of aggregates on the feeding bins will vary the aggregate proportions in the resulting concrete. Partitions between the bins should prevent spill over. Crane buckets should discharge only slightly above the bins in order to avoid segregation. One way to reduce the possibility of segregation is to increase the number of size fractions and batch each one separately.

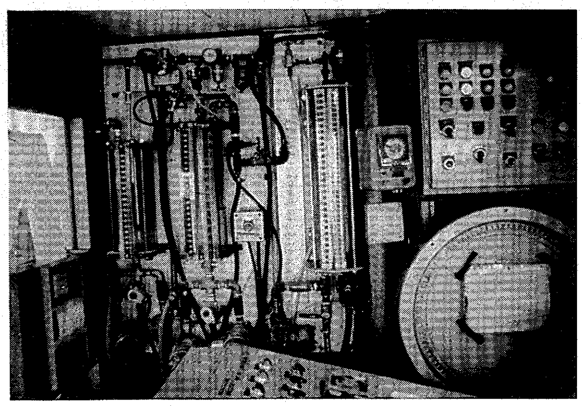
4. **Conveyor belts should also be positioned so that the aggregates will drop into the bins without hitting the sidewalls.** As with stockpiles, aggregates supplied by conveyor belts should not fall from great heights because degradation, segregation, and loss of fines can occur. Bins should be kept nearly full to reduce breakage and segregation.



5. The **cement storage system** should provide for dry storage. The silos should be weatherproof and vented to prevent moisture accumulation. Interiors of bins should be smooth to allow for the free removal of cement. Each bin or silo is equipped with a gate and conveyor system. The conveyor system should provide consistent flow of cement with precise cutoff. In addition the system should be isolated from the elements since even the moisture in the air can cause the cement to partially hydrate. Cement silos should be emptied periodically and inspected to ensure that there is no build up of cement. Emptying the silo once a month can prevent cement caking. Cement build ups could break off and produce cement lumps in the finished concrete. Fly ash, should be handled similarly to cement.

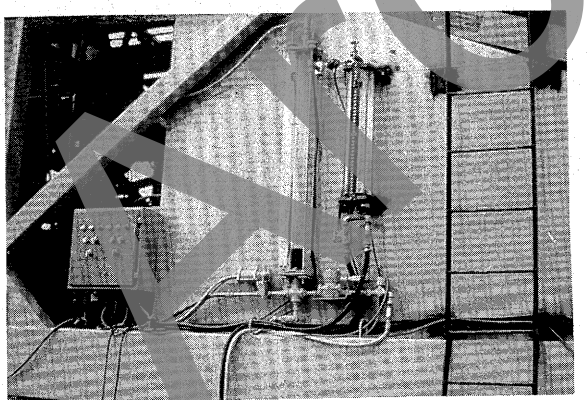


6. Batching can be done by one of three methods. **Manual** batching is done by hand and is only recommended for small jobs. In a **semi-automatic** system the operator manually opens the aggregate bin gates to begin the charging of the batcher. The gates are then closed automatically when the desired weight is achieved. Interlocks prevent charging and discharging from an aggregate bin at the same time. In a fully **automatic** system all material flow is controlled from a single starting switch. Once scales return to zero, recharging of the bins can begin.

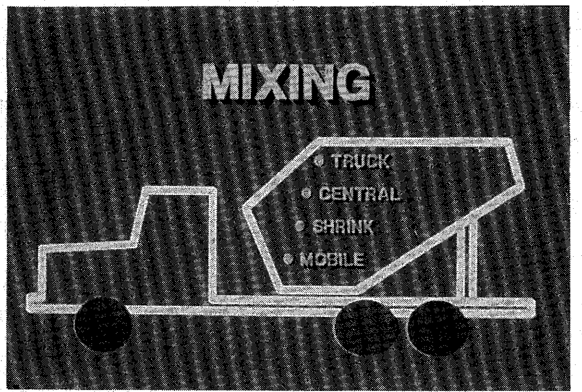


13. Admixtures are commonly provided in liquid form and may be dispensed into the mixer by weight or volume. Dispensers should be large enough to measure a full batch of admixture for each batch of concrete. It is desirable that the dispensing system be integrated with any batching interlocking system. The volumetric container system is considered the most reliable and is the most common method. This type should have either a sight glass or a transparent container and be located so that the plant operator and inspector can visually check to see that the container fills and totally discharges the desired volume for each batch.

14. The admixture dispensing equipment should be flushed with water occasionally to minimize the possibility of material accumulation which will impair the equipment performance or dispense erroneous quantities. In addition, containers for admixtures should be plainly identified and the solutions protected from contamination, dilution, evaporation, and freezing. If need be, storage tanks should be agitated during batching to prevent settlement of the solutions.

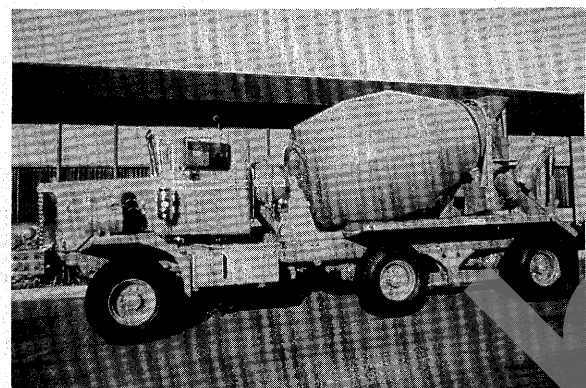


15. Factors to be considered in the introduction of admixtures to the batch are the rate of discharge, the timing in the batching sequence, and the medium used. Changing the time at which the admixture is added during the mixing cycle may vary the effectiveness. Likewise, variations in the application rates will effect the performance of the admixture. In general, liquid admixtures should be added into the stream of mixing water being added to the batch. If different types of admixtures are being used, they should be added to the batch separately unless it is known that they can be mixed together satisfactorily. In any event, the recommendations of the manufacturer should be followed.

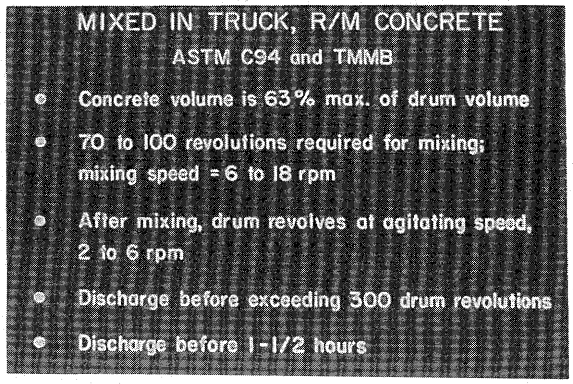


16. Thorough **mixing** is essential for the production of uniform concrete with all ingredients evenly distributed. Ready mixed concrete is mixed for highway purposes by one of four methods:

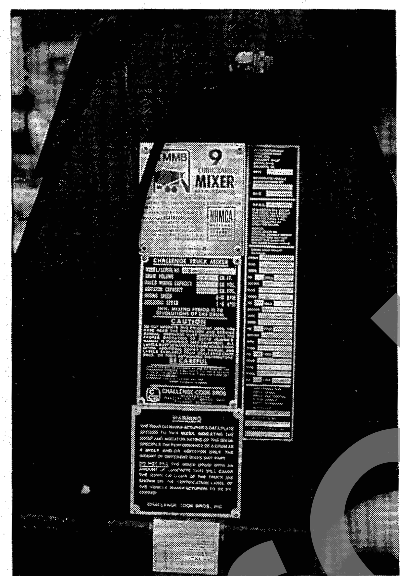
1) Truck mixed (including at site and transit mixed)
2) Central mixed
3) Shrink mixed
4) Mobile mixed



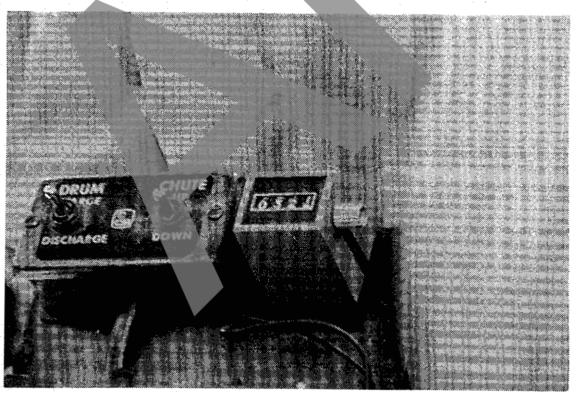
17. **Truck mixing** is the most common type of mixing. Common sizes range from 5.5 to 7.5 cubic meters, however much larger mixers are available. Truck mixers are classified as inclined axis mixers and come with either front or rear discharge. Truck mixing is a process by which previously proportioned concrete materials are transferred into the truck mixer where all mixing occurs. Several methods are available for accomplishing mixing with a truck mixer. Materials can be weighed into the truck at the plant while the drum is revolving, the drum is then stopped and the truck proceeds to the job site. At the jobsite, the mixer begins to revolve and the mixing is started. Another procedure would be to complete the mixing at the producers yard and then transport the concrete. Finally, ingredients may be dry batched, delivered to the site, water added and mixing commenced.



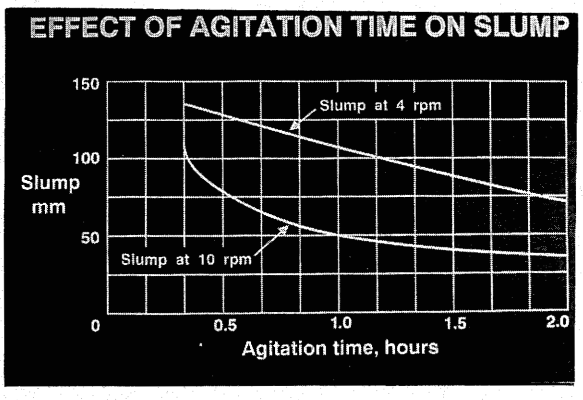
18. This chart summarizes the mixing specifications. Mixing should be done within 70 to 100 revolutions and at the recommended drum rotation speed. After mixing, the drum should revolve at the recommended agitating speed. The concrete is required to be delivered and discharge completed within 1-1/2 hours or before the drum has revolved 300 times after the introduction of the water to the cement. This is to prevent degradation of softer aggregates, slump loss that occurs with increased mixing revolutions, and strength loss as hydration begins.



19. Truck mixers are required to have a **manufacturer's certified rating plate.** The rating plate will indicate the use for which the mixer is designated. It will indicate the mixing and agitating capacities, and the mixing and agitating speeds. Truck mixers must not mix and transport a batch larger than the rated capacity. If it is being used only as an agitator, it can hold a greater capacity. The large number shown on the plate is the mixing capacity and is 63 percent of the total drum volume. If concrete has previously been mixed, then 80 percent of the total drum volume can be used for agitation and transport.

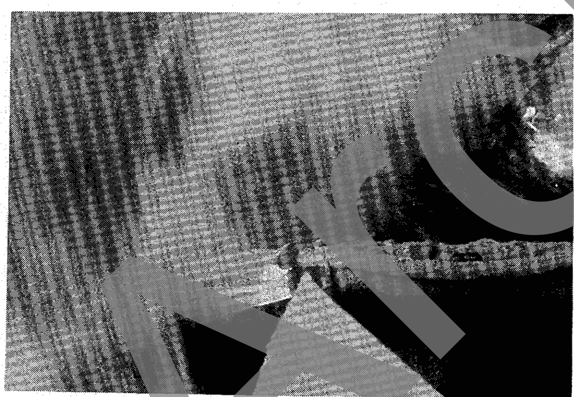


20. All truck mixers should be equipped with a **revolution counter.** Some counters are easily reset while others must be reset at the plant. Inspectors must observe that mixing is done in compliance with the revolutions required by their specifications. Generally, the requirements for mixing will be in the range specified by AASHTO M 157 or ASTM C 94.

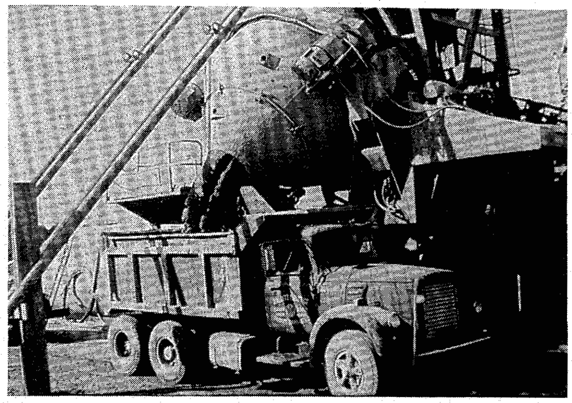


21. The effect of mixing time on concrete slump is shown in this chart presented by PCA. Excessive mixing is undesirable as it causes the aggregate to break down into fines due to the grinding action. These fines act like sand thus increasing the need for water in order to maintain the same consistency. Consequently, over mixing results in a slump decrease. Also, over mixing may drive out entrained air.

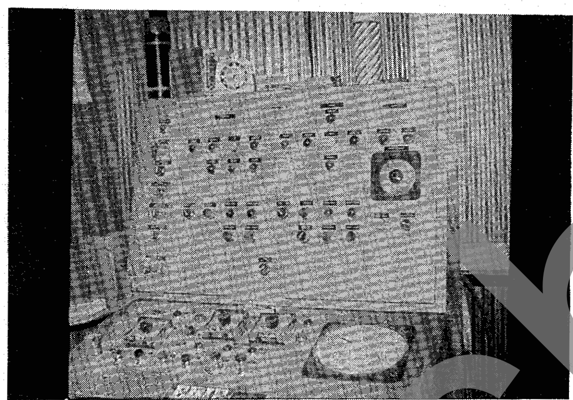
22. A check on the thoroughness of mixing can be made by performing a **uniformity test**. This involves obtaining samples of concrete from different places in the load, performing normal concrete tests, and comparing the results against preestablished tolerances. For truck mixers, a uniformity test is performed by comparing results after 15 percent and 85 percent of the load has been discharged. A typical tolerance would be ± 25 mm for slumps under 100 mm. ASTM C 94 specifies the procedures for conducting a uniformity test.



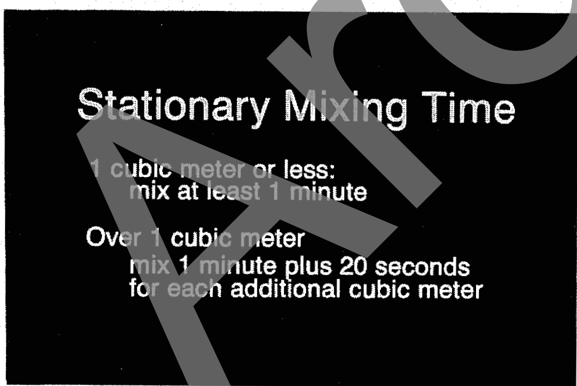
23. One problem with truck mixers that requires special consideration is the uncontrolled addition of water. This can result in a reduction of concrete quality. The addition of water either undetected by an inspector or unquantified, can alter the slump and significantly change the water-cement ratio. Under normal conditions, the addition of 5 liters of water per cubic meter of concrete will result in a 25 mm increase in the slump. Slump loss can occur between the time of mixing and placing. Rather than add water, actions should be taken to correct the causes of the slump loss. Slump loss can be associated with higher temperatures, absorptive aggregate, changes in aggregate gradation, false set, accuracy of water batching equipment or the inter-dependence of slump and air content (improper admixture usage).



24. **Central mixers** are stationary mixers that are of four general types: Non-tilting, Tilting, Vertical Shaft, and Horizontal Shaft. **The tilting type** shown here is the most common. It has a capacity of from 1.5 to 11.5 cubic meters. While the other types are not as common, the vertical shaft mixer is often used when high strength concrete is required. These are often referred to as "pan" mixers and do a better job of mixing very dry concretes than drum type mixers. In a central mix plant all of the mixing is done in the plant and the concrete is delivered to the placing site in an agitating truck or a special non-agitating truck.



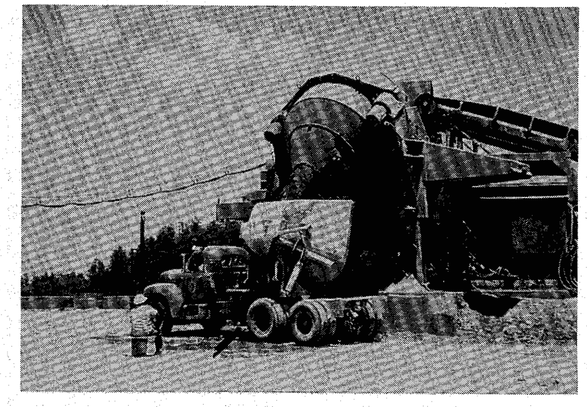
25. Some central mix plants have a **slump meter** on the control panel. The slump meter is nothing more than an electrical meter which measures the effort necessary to drive the mixing drum. The stiffer the mix, the more resistance is offered and consequently, the more energy it takes to drive the drum. This instrument can provide a good indication of the consistency of the mix.



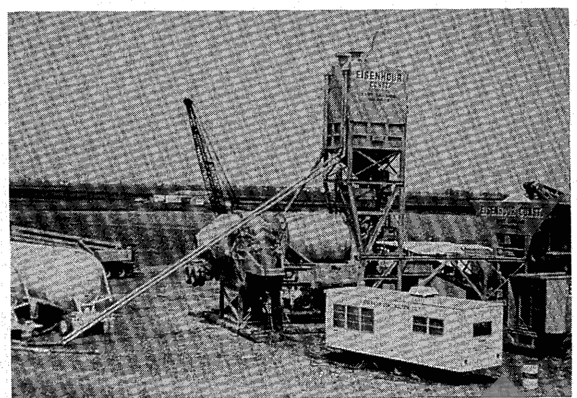
26. AASHTO M 157 suggests that where no performance tests have been made on a central mixer, the following **mixing times** apply:

- For mixers with a capacity of 1 cubic meter or less, mix for at least 1 minute.
- For mixers of greater capacity, increase mixing time by 20 seconds for each additional cubic meter, or fraction thereof.

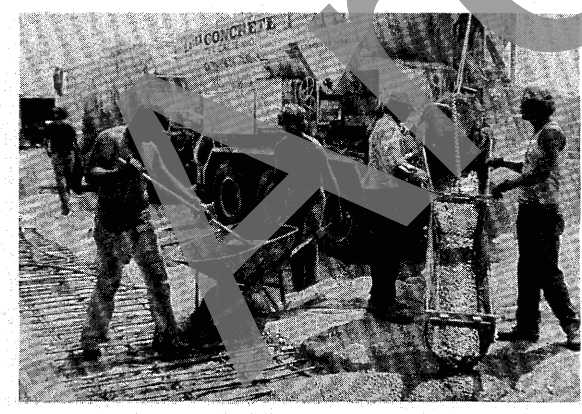
Final mixing times may be based on the results of mixer performance tests. Interlocks that prevent discharge prior to completion of the mixing should be a part of all mixers.



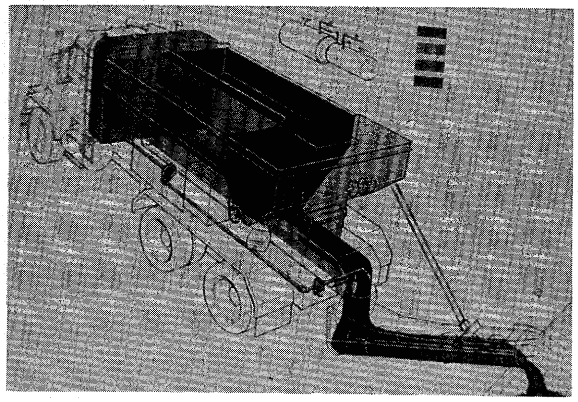
27. As was stated for truck mixers, central mixers should have a **uniformity test** performed periodically. Again, samples are taken at the 15 percent and 85 percent discharge stage and the results compared to predetermined tolerances.



28. **Shrink mixed concrete** is first partially mixed in a stationary or central mixer and then mixed completely in a truck or subsequent mixer. The first part of the mixing is performed in the central mixer for 15 to 30 seconds and is only long enough to intermingle the ingredients. This method is sometimes used in order to increase the efficiency of the central mix plant. The amount of mixing in the truck mixer would be determined by doing a uniformity test. Other aspects of mixing with this method are the same as the other methods. Shrink mixing is sometimes used for lightweight concrete where absorptive aggregates are included.



29. **Mobile batcher mixers** are special trucks that batch by volume. They continuously mix concrete as the dry ingredients and water are fed into the mixer. Mixing time is only about 7 seconds. Mobile mixers are used for small quantities when on site mixing is advantageous. This would include pavement repairs, and bridge decks when special concrete, such as latex or low slump is required. The advantage of the mobile mixer is that it produces fresh concrete thus improving its strength.



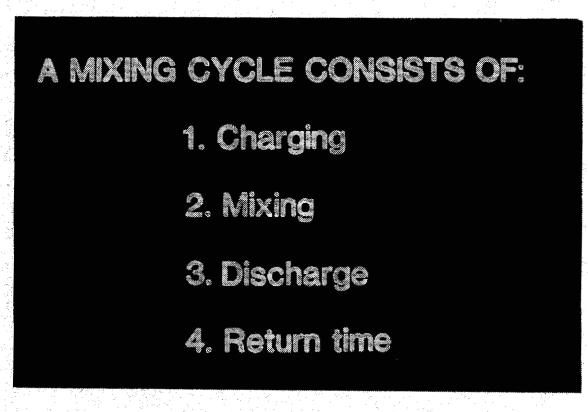
30. Mobile mixers need to be calibrated prior to their use and should be recalibrated if there is a change in material sources. Copies of the calibration should be available for the use of the inspector. The mobile mixer consists of bins for sand, coarse aggregate, cement and water. The aggregate bins have a belt below calibrated gates. The aggregate belt is interconnected to the cement feed. Water and admixtures are proportioned with flow meters. The inspector should witness the introduction of admixtures. Mixer sizes range from 3 to 9 cubic meters (4 to 12 cubic yards).

31. Regardless of the type of mixing plant, there are certain factors that each have in common:

1) **Capacity** - Mixers should have a rating plate that shows the maximum capacity. The batch size should not exceed the manufacturers rated capacity shown on the plate.

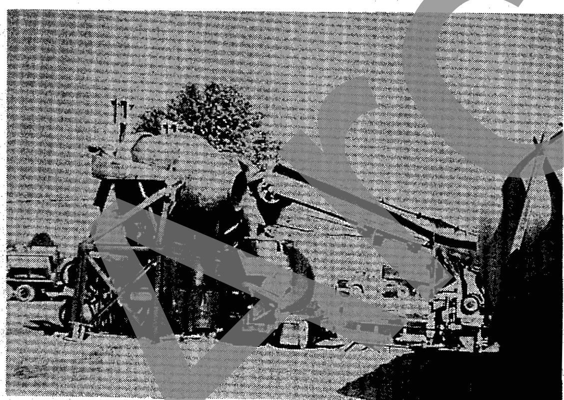
2) **Speed** - Likewise, the mixer should be operated at the optimum speed as stated by the manufacturer.

3) **Maintenance** - Mixers should be clean and in good condition. Materials should not leak from the mixer and mortar should not build up on the blades. A very important consideration is blade wear. Blades need to be checked periodically and a mark placed on them to gauge wear. Plans showing blade design and dimensions should be available for all mixers.

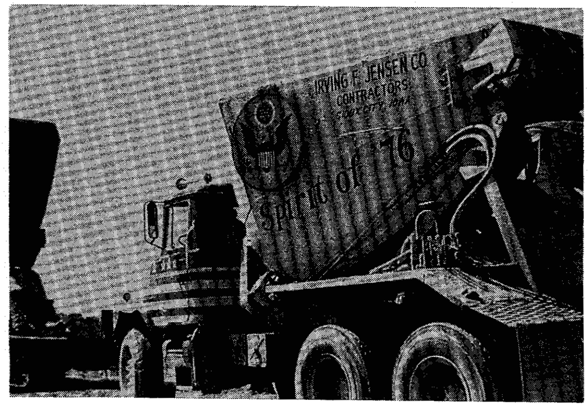


32. A **mixing cycle** consists of these four steps regardless of the type of mixer. Charging time, mixing time, discharge time and return time.

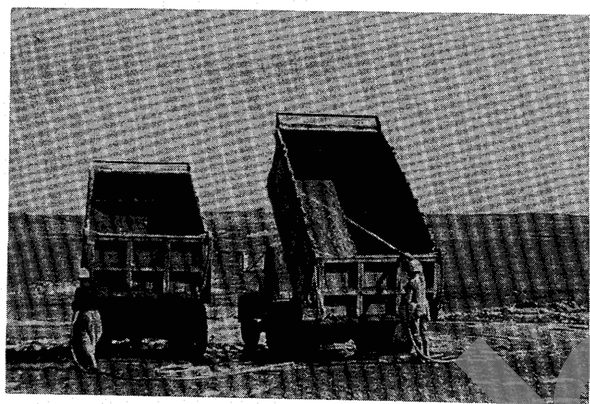
33. **Charging** time begins when the batching is completed and materials are entered into the drum. Charging continues until all solid materials are in the mixer and it is ready to start the mixing cycle.



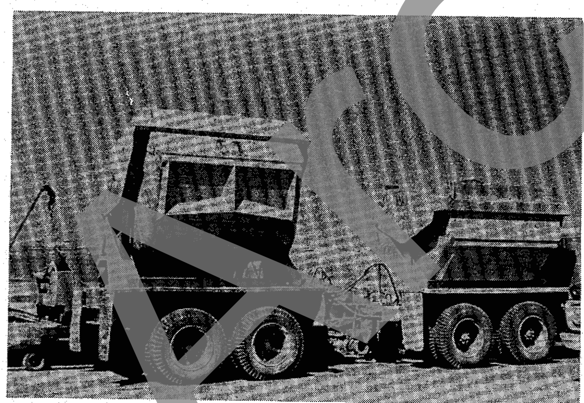
34. The charging of materials into the mixer is an important consideration. Proper loading must be done to prevent the packing of material in the head of the drum. If water, cement, and aggregate are blended from start to finish it may cause problems such as head pack (sand and cement) and poor mixing. Instead, some water and coarse aggregate should start ahead of the sand and cement. Also about one quarter to one third of the water should be added after all other ingredients have been charged.



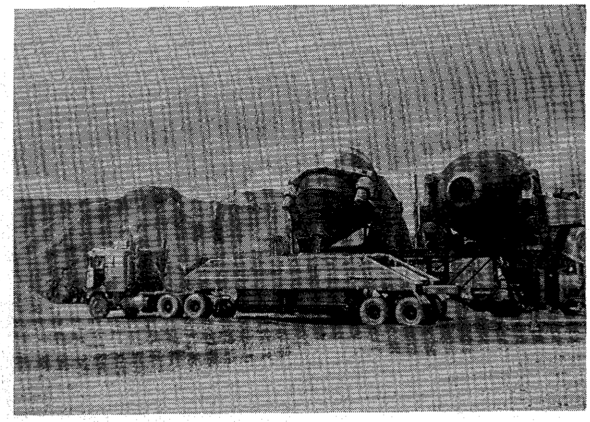
41. **Agitator trucks** can only haul concrete. These types of trucks are used for all types of construction but typically would be used on structural concrete and small paving projects. They have a distinct advantage over transit mix trucks in that the concrete must be mixed in a central mixer. This results in a more uniform concrete.



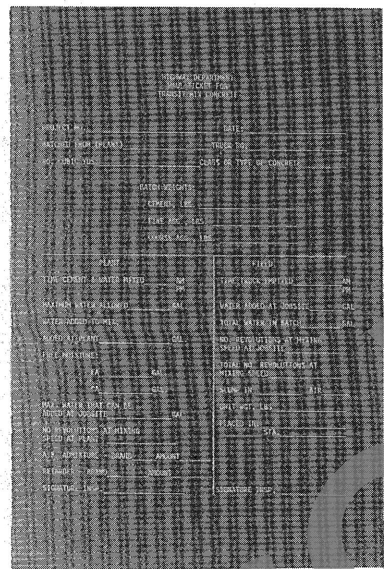
42. **End dumps** are only used in concrete paving operations. They should be used only on short hauls since segregation of the mix may occur on longer hauls due to the lack of agitation. The truck beds themselves should be clean and tight.



43. **Side dumps** also do not have agitation. The same statements about the end dumps apply to the side dumps.

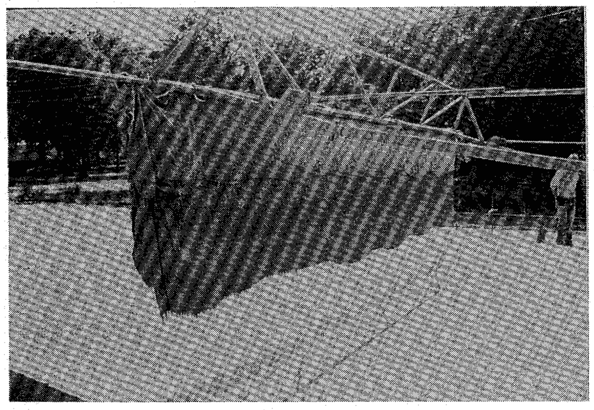


44. **Bottom dumps** are also used in paving concrete operations. Their use should be limited due to the possibility of contaminating the concrete with dirt from the trucks tires. The vehicles should also be limited to short hauls.

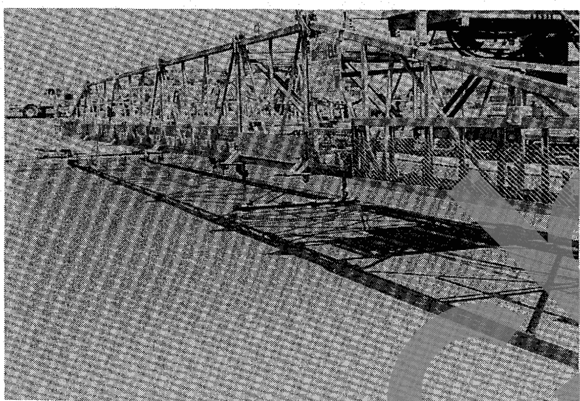


DATE:
TRUCK NO.
CLASS OR TYPE OF CONCRETE
BATCH WEIGHTS:
CEMENT, LBS.
PLANT
FIELD
MAXIMUM WATER ALLOWED
TOTAL WATER IN BATCH

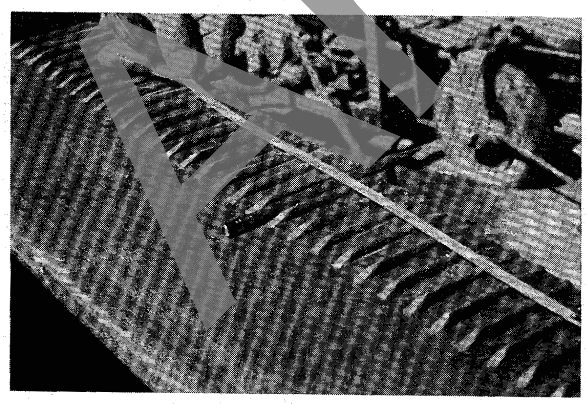
45. All concrete that is shipped to the job should have a **concrete ticket**. The ticket needs to contain the batch weights for all the materials, the amount of concrete delivered, and the time that mixing started. In addition, the ticket which accompanies concrete that is delivered in truck mixers should also indicate the number of mixing revolutions that were performed at the plant, the starting revolution on the counter before it leaves the plant, and the allowable water that can be added to the mix at the site.



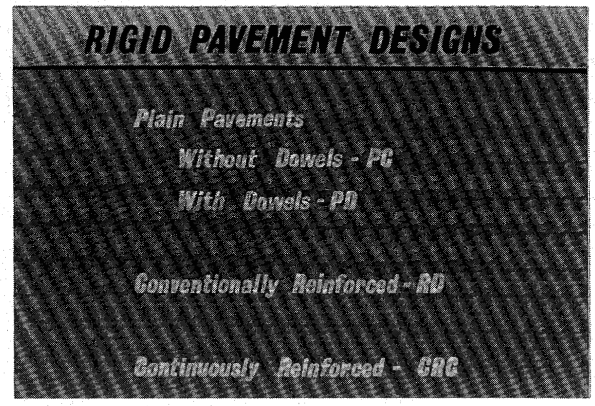
22. Texturing of a bridge deck is required to obtain an adequate skid resistance. Micro-texture is obtained with an artificial turf or burlap drag. The burlap should be kept moist and free of a buildup of excess concrete.



23. For traffic speeds over 65 kilometers per hour, a proper macro-texture must also be provided. This is accomplished by tining the concrete surface. The tines should be 2 mm wide, spaced 20 mm apart, and be 100 to 150 mm long. To aid drainage, an area 300 mm wide next to the barrier should not be tined. FHWA Technical Advisory T 5140.10 "Texturing and Skid Resistance of Concrete Pavements and Bridge Decks" contains further guidance on texturing.

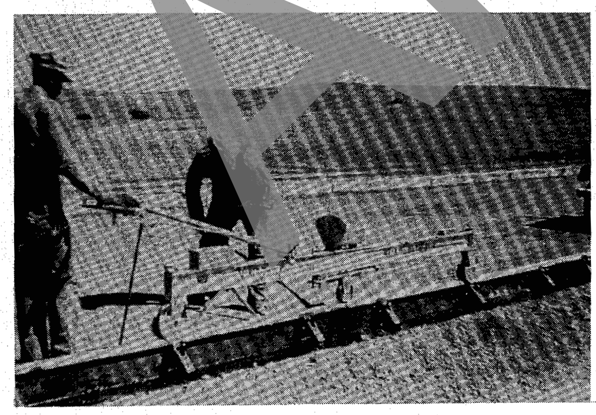


24. Some states will use a "fin float" instead of tines to obtain the macro-texture. The grooves may also be sawn in the surface.

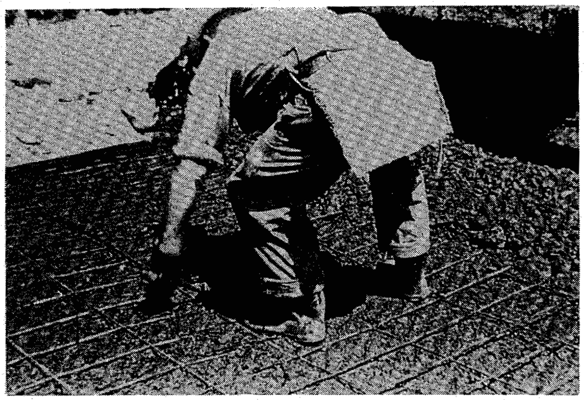


25. There are three basic designs for concrete pavements; **plain, reinforced,** and **continuously** reinforced. Plain concrete pavements can be designed with or without dowels. Reinforced concrete pavements can be designed as either conventionally reinforced jointed pavements or continuously reinforced pavements. These details will affect the construction operations for concrete paving. There are many types of concrete placing equipment. The general construction procedures for both form and slip form paving will be discussed, but not the capability of specific types of equipment which may be capable of performing several of the operations.

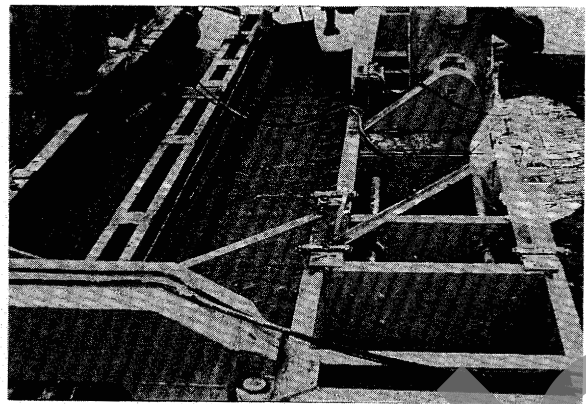
26. Grade control is important to all types of construction. Forms provide this control when they are used. For that reason it is necessary to have a flat, well compacted area for the forms to sit on. Forms need to be checked for horizontal alignment by using a string line. Forms should be mechanically cleaned prior to being used.



27. Vertical alignment is checked by using a rolling straight edge. The grade of the forms is set from a string line.

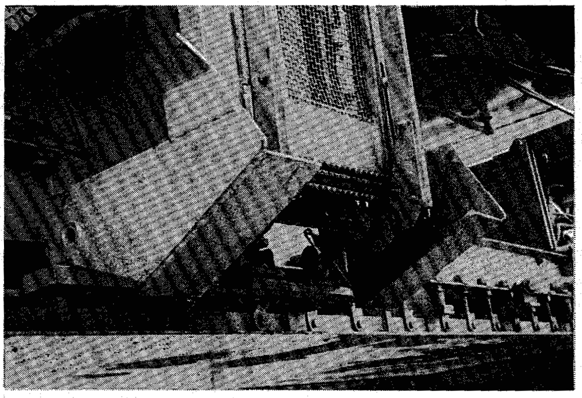


46. The reinforcing mats need to be overlapped at their edges to insure bond development. The lap length varies according to the dimension of the mat's openings. The mats need to be securely tied to insure that they will not move. In jointed pavements, the edge of the mats should be at least 75 mm away from the center of the contraction joints.

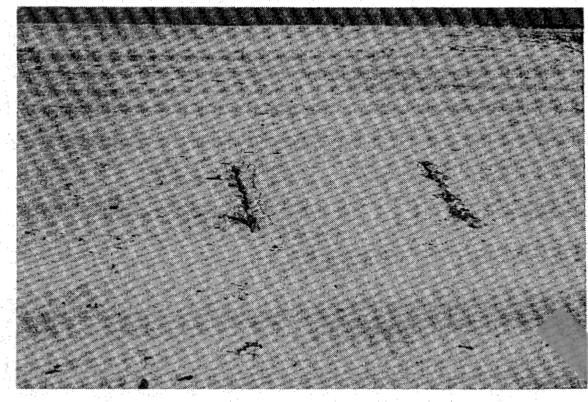


47. A mesh depressor can also be used to place reinforcing steel. In this operation, the reinforcement is placed on top of the struck-off concrete and then depressed. This machine moves over a concrete mat and with its large grid, depresses the mesh into the pavement through pressure and vibration. Adjustable stops are set to automatically stop the grids at any desired depth. It is important to note that the vibration on the grids should be stopped when the grid reaches the desired depth in order to prevent segregation due to excessive vibration. Depth checks for mat placement should be performed periodically.

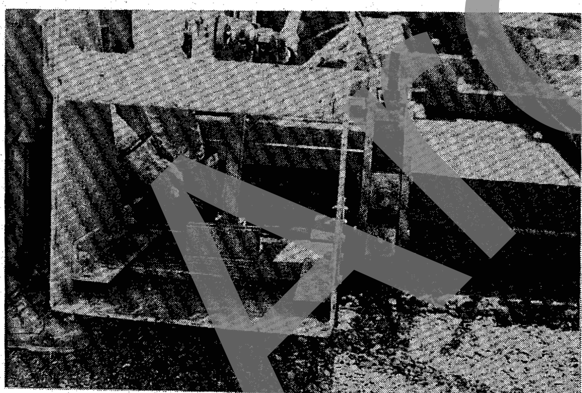
48. Transverse tie bars which are to be placed at approximately one-half the pavement depth can be placed by several methods. Here the tie bars are being placed by a wheel which rotates at a speed related to the speed of the paver.



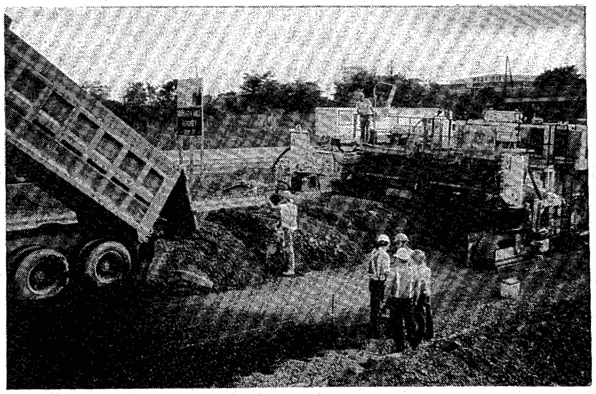
49. The tie bars can also be placed with a hydraulic inserter which vibrates the bar into place. When this method is used the hydraulic inserter should be monitored for hydraulic leaks. Hydraulic fluid will contaminate the concrete and form a weak area.



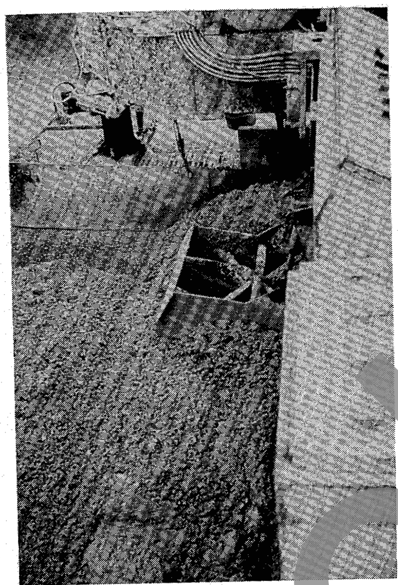
50. With any inserter, it is important to insure that any voids or surface imperfections left by the inserter are completely closed in the finishing operations.



51. Another type of tie bar inserter is this hydraulic device which inserts bent tie bars in the edge of a slip formed slab.

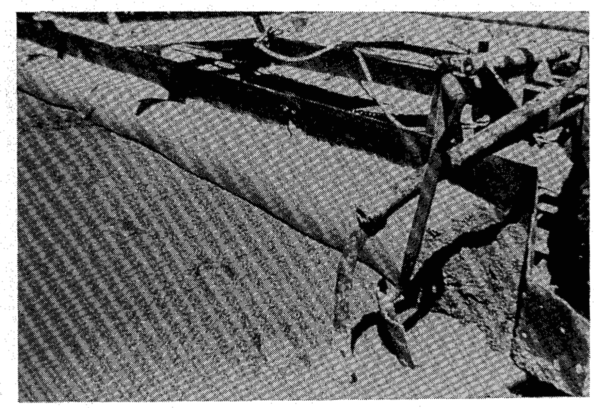


58. When no mechanical spreader is used in front of the paver, the paver should have a method of spreading the windrow of concrete.

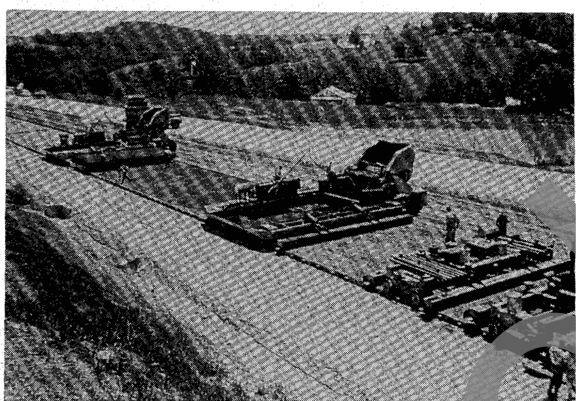


59. Here the paver is equipped with a spreader which moves back and forth through the windrow spreading the concrete.

60. After the concrete has been placed on the base, the pavers can begin their work. Concrete pavements can be placed in one or two courses.

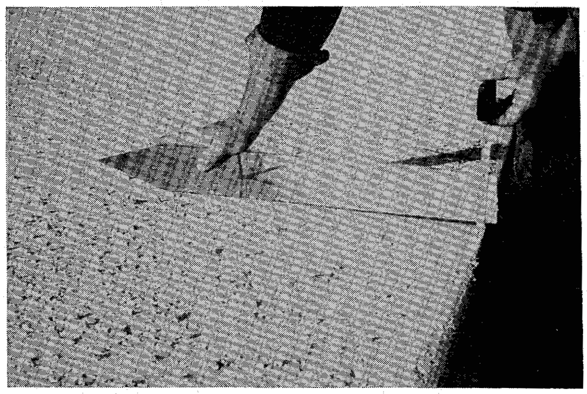


61. In a two course operation, the first layer of concrete will be screeded to approximately 2/3 of the pavement depth. This screed on a form paving operation consolidates the concrete as it oscillates back and forth across the pavement. It is important to note that a spud vibrator should be used adjacent to the forms. Another important feature to note is the scraper which keeps the screed rail free of concrete to insure a smooth ride. There should be a uniform 100-150 mm roll of concrete in front of the screed. If dowel baskets are used, spud vibrators should be used to consolidate the concrete in this area prior to screeding.

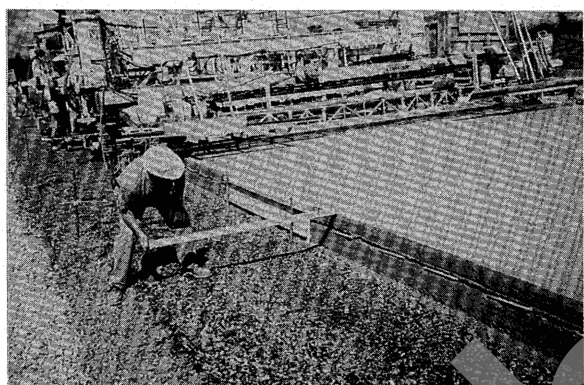


62. After the first course of concrete is placed and screeded, the reinforcing steel is placed and the second course of concrete is spread and screeded. In order to prevent the formation of a cold joint, the second course should be placed within 30 minutes of the first course.

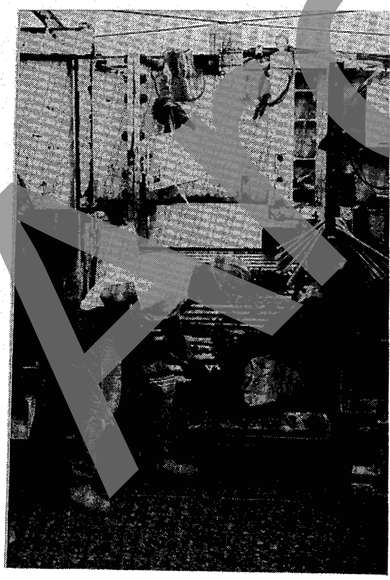
63. A third screed leaves the surface of the concrete 5 mm high and should have a uniform 50 mm roll of concrete ahead of it. The pan float which is tapered to force the concrete into the proper cross section follows. With the exception of correcting finishing errors by hand, the pavement should be ready for texturing.



70. It is important in slip form paving to maintain a vertical edge. In order to prevent edge slump and produce a smooth ride, it is necessary to maintain a consistent concrete slump.

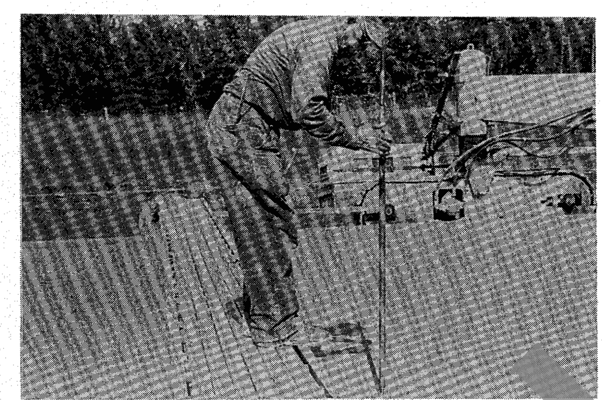


71. If edge slump does occur, it is important to detect it quickly. Repairs can be made with a bulkhead and hand finishing.



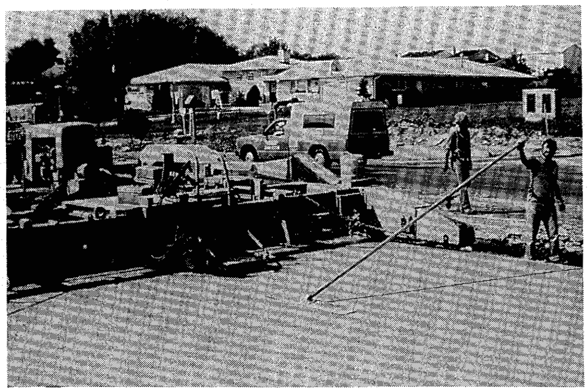
72. Maintaining a constant roll of material in front of the screed is also important to achieving a smooth riding pavement. If the concrete roll looks watery and slides, the slump is probably too high. If the concrete looks rocky and has many voids, the slump is too low. If the concrete looks good but does not roll smoothly, the air content may be too high. If excess material begins to build in front of the screed, it will have to be removed.

73. If the excess concrete is not removed, it can lift the screed and result in a hump in the pavement.

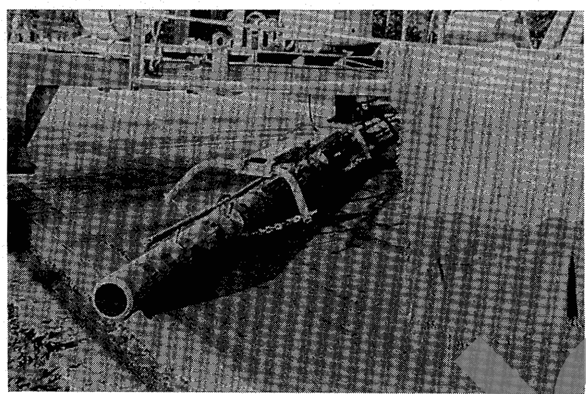


74. The **depth** of the pavement should be checked behind the paving operation. The check is made by inserting a measuring device vertically through the concrete to the subbase. With some types of subbase it may be necessary to install plates at predetermined locations so the pavement can be accurately checked.

75. Once the paver has completed finishing the pavement should be checked with a **3 m straight edge.** The cross slope should also be checked at this time. Straight edges should be used only for checking the surface, and not to correct surface imperfections.



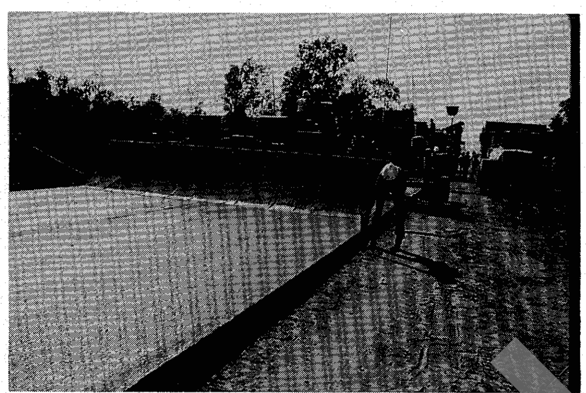
76. If surface imperfections are found they should be corrected with a bull float. However, it should be noted that no finishing should occur when bleed water is present. If finishing is performed when bleed water is present the water will be worked into the surface raising the water cement ratio and cause future surface deterioration.



77. Some contractors will elect to use a magnesium **tube float**. These floats are designed to correct minor variations and to seal the surface, but are not intended to move concrete. This equipment is easily misused by the contractor. When using a tube float, water must not be added to the concrete surface to aid in finishing. Any bulidup of paste on the tube float should be wasted over the edge of the slab. Care needs to be taken to insure that the tube finisher does not alter the cross slope of the pavement.

78. An automatic float such as this may also be used.

79. Proper texturing is also required to provide a skid-resistant surface on pavements. A proper texture is obtained by first using a burlap drag followed by a tining machine.



80. The burlap drag should be kept moist at all times. If the drag starts to pull aggregate to the surface, it can indicate that the concrete is not consolidated properly or that there is not enough sand in the mixture to provide for a good tight surface.

81. The final texturing operation consists of **tining** the surface to obtain a good macro-texture. The tines should be 2 mm wide, spaced 20 mm apart, and be 100 to 150 mm long. This should result in grooves spaced 15 to 20 mm apart and 3 to 5 mm deep. FHWA Technical Advisory T 5140.10 "Texturing and Skid Resistance of Concrete pavements and Bridge Decks" contains further guidance on this subject.

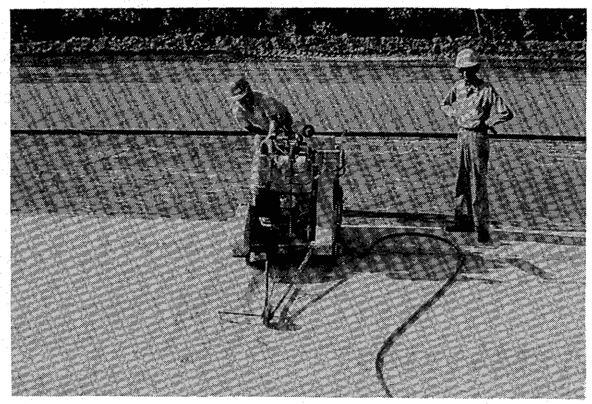
10) Concrete should be placed simultaneously on both sides of the expansion material to provide equal pressure. The concrete should be hand vibrated;

11) The expansion joint must be properly edged and finished and the metal cap removed;

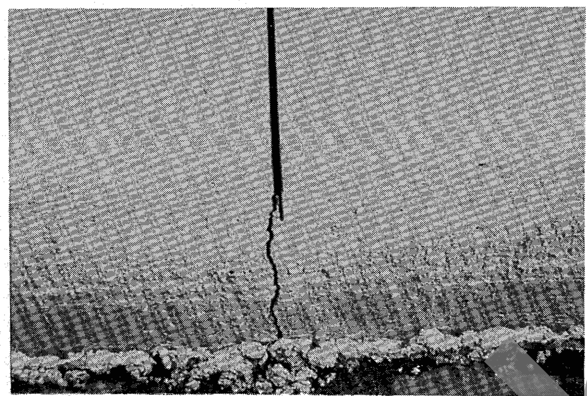
12) No concrete must be left over the expansion material.

86. A continuously reinforced pavement design requires special attention at transverse construction joints. Sheets of plywood or steel should be placed over the reinforcement just outside the bulkhead or header boards. The trailing edge of the reinforcing steel should be completely supported. Special care must be taken to provide additional hand vibration at all header joints in order to get good consolidation of the concrete.

87. **Transverse contraction joints** are used to control the shrinkage cracking that will occur in jointed pavements. Since the cracking generally occurs within 4 to 24 hours after the concrete has been placed, transverse contraction joints should be cut as soon as practical.

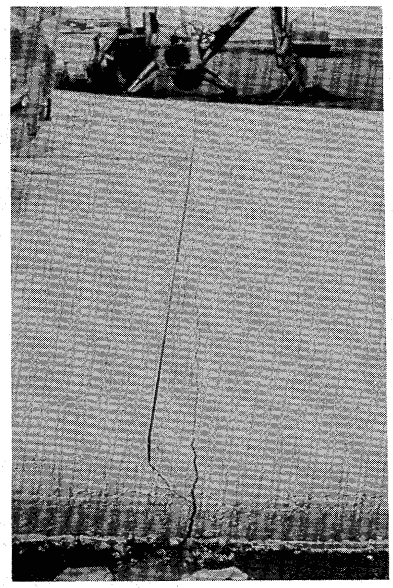


88. Contraction joints are made by sawing with a diamond blade. Sawing is a critical operation which must be done at the proper time and in the proper location. It is necessary that diamond blades be cooled with the application of water. Standby saws should be available at all times in case of breakdowns.



89. The depth of the saw cut should be at least one-third the slab thickness plus 5 mm in order to prevent random cracking.

90. Sawing should begin as soon as the concrete has hardened enough to permit sawing without causing excessive raveling. A slight amount of raveling is desirable. However, if no raveling occurs, the sawing is likely too late. Sudden drops in temperature or cooling from rainstorms on particularly hot days call for quick action to prevent random cracking. Sawing should be continued through night and day regardless of weather conditions. It is sometimes necessary to saw every third or fourth joint to relieve initial stresses and then saw the intermediate joints at a later point in time.

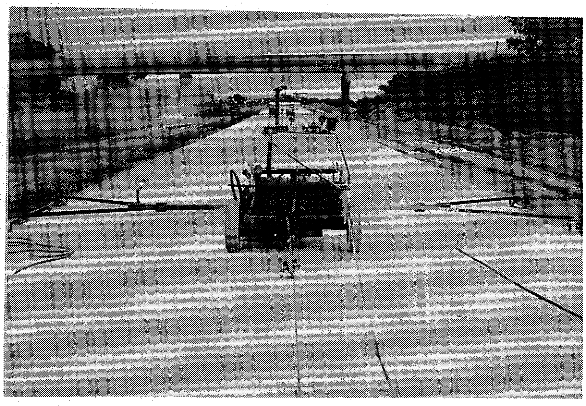


91. If sawn too late, the concrete may crack ahead of the saw before the joint is completed. When this happens, the operator should stop immediately and move to the next joint. The crack will then act as a joint and should be routed and sealed properly. If the operation is allowed to continue, the concrete between the crack and the saw cut will eventually spall out.

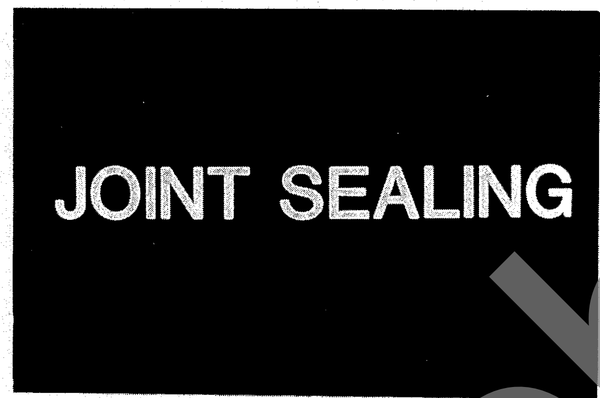
92. The concrete must be marked appropriately so that sawing is done directly above the centerline of the dowel baskets. Here a nail has been driven into the subbase to mark the centerline of the dowels and orange paint is being used to mark the location of the nail.

LONGITUDINAL JOINTS

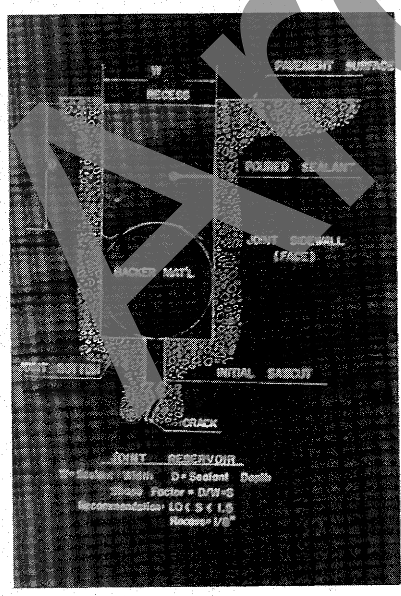
93. **Longitudinal joints** should be sawed. The plastic ribbon method for forming longitudinal joints has not been shown effective in preventing random longitudinal cracks.



94. Experience has shown that it is best to saw the longitudinal joint at the same time as or immediately following the sawing of the transverse joints. This is particularly true on thinner pavements and placements wider than 7.3 meters. It is also necessary to saw as early as possible when large drops in temperature are expected. At no time should construction equipment be allowed on the pavement prior to the sawing of the longitudinal joint. Longitudinal joints are generally sawed 5 mm wide to a depth of at least one-third of the pavement thickness.

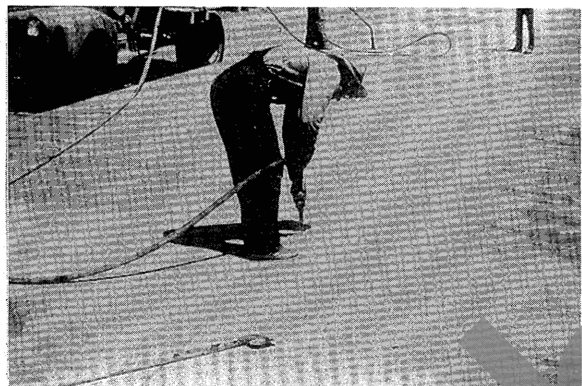


95. Joints are sealed to prevent incompressible materials from getting into the joint which would cause spalling or blow-ups when the pavement expands in hot weather.



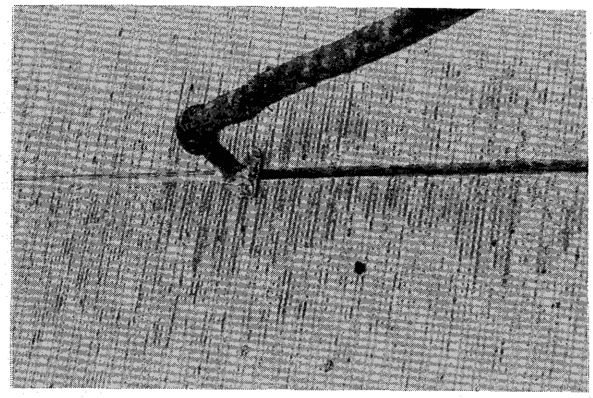
96. To perform satisfactorily, liquid joint sealants must have the proper shape factor, or depth to width ratio. The shape factor will vary with the type of joint sealant used. The backer rod is used at the bottom of the joint to insure the proper depth of the sealant and to act as a bond breaker to prevent bottom side adhesion. The backer rod should be slightly larger than the width of the joint.

97. Following a second sawing operation, which will provide the proper shape the newly exposed joint face must be cleaned with either a wire brush or sandblasting. Sandblasting is preferred and should incorporate multiple passes until the surfaces are free of any traces of saw cutting fines that might prevent bonding of joint sealant material.

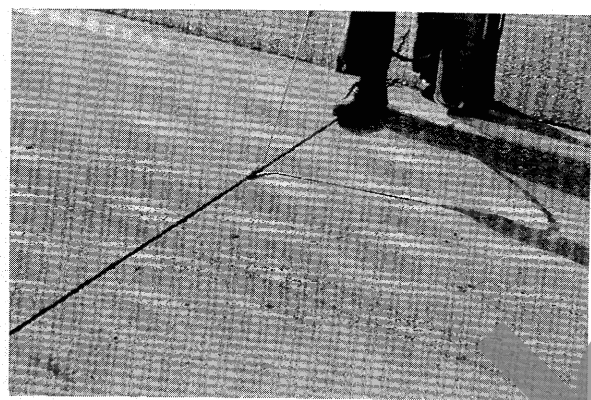


98. Immediately prior to installing the backer rod, the joint should be blown with compressed air and be left completely free of water and debris.

99. Following cleaning and drying of the joint faces, the backer rod is installed to the appropriate depth with the inserting tool.

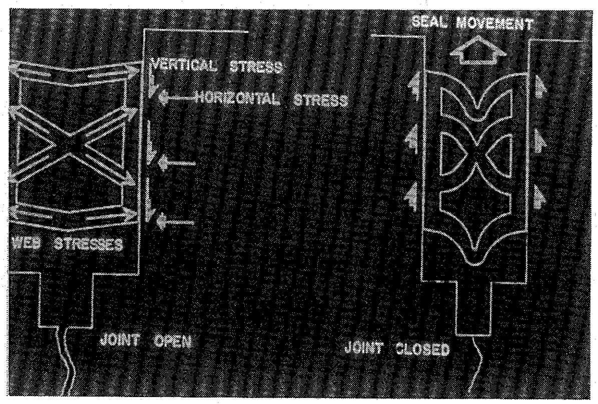


100. Regardless of the sealant type used, all joints should be sealed in a neat and workmanlike manner. The surface of the sealant should be at least 5 mm beneath the surface of the pavement. All excess materials should be removed from the surface. This is necessary to prevent traffic from picking up the sealant.

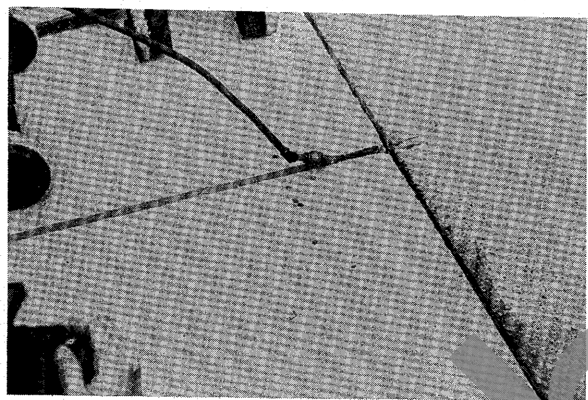


101. Some sealants such as silicon require that the surface be tooled.

102. There are a number of preformed **compression seals** on the market for sealing concrete pavement joints.

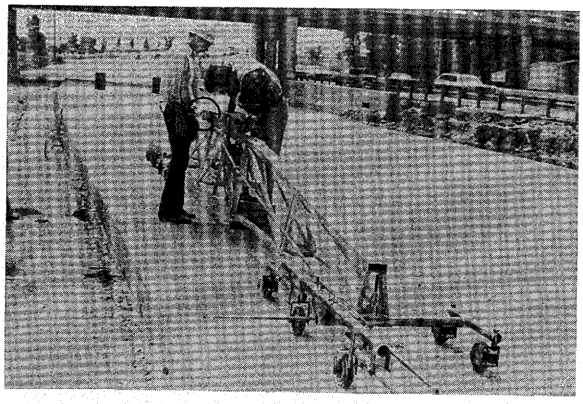


103. Compression seals are made of tubular material with an internal web. The compression seal relies heavily on the joint and its shape for good performance. They must be properly positioned and remain in compression even when the joint is opened to its maximum width for proper performance. For this reason it is important that the width of the seal correspond to the amount of movement expected (length of panel) and the width of the joint.

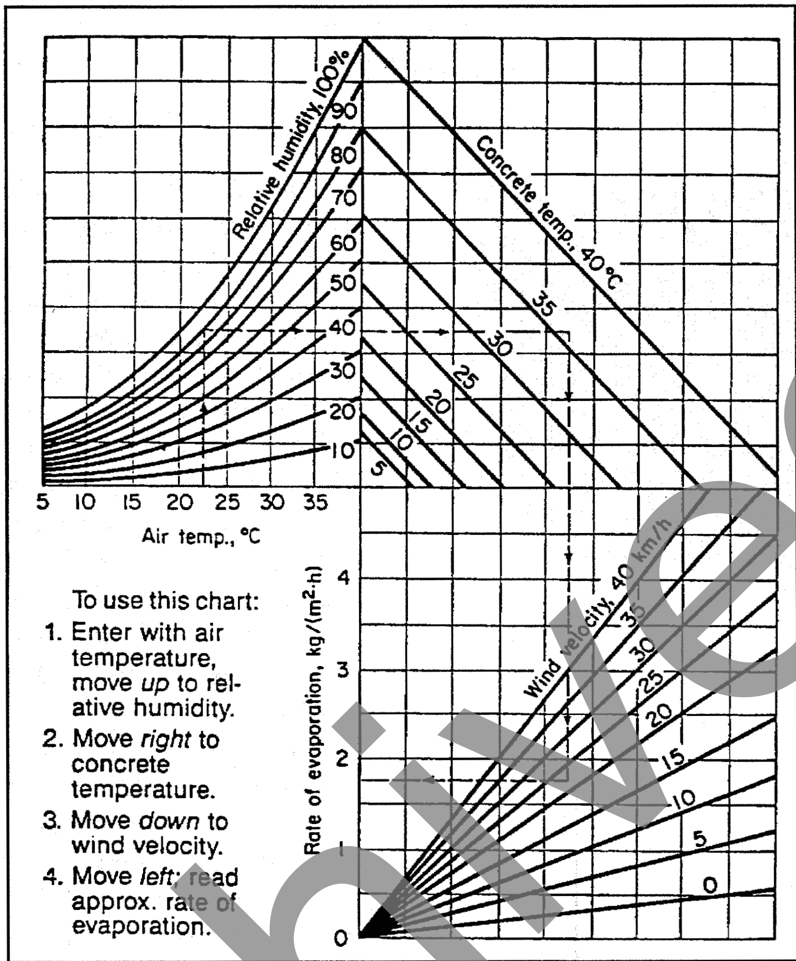


104. After the second sawing operation a lubricant is used to install the seal.

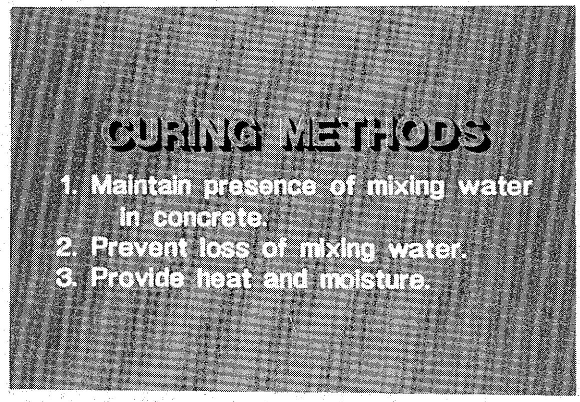
105. The compression seal must be installed with a special machine capable of placing the material in a compressed state without cutting, twisting or distorting the sealant material itself. The sealant material is installed to a depth approximately 3 mm below edge of the joint. Splices in the sealant material are not permitted in any 7.3 m width joint.



106. Many States now now have **rideability** specifications. The most common method for measuring rideability is the profilograph. 10 cm/km has been found to be reasonably attainable.



3. Moisture loss through evaporation must be controlled. Air temperature, humidity, and wind velocity affect evaporation and hence the rate of hydration. This chart provides a graphic method of estimating the evaporation under various weather conditions. ACI recommends that when an evaporation rate of **1 kg/m² per hour** is encountered, steps need too be taken to prevent excessive evaporation. Some states have incorporated this chart into their specifications and will not allow a contractor to place concrete when adverse conditions are present.

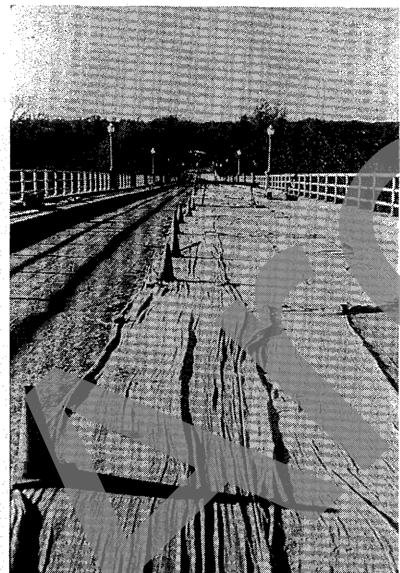


4. Curing methods can be categorized into three groups:

   1) Methods that **maintain the presence of mixing water** in the concrete during early hardening. These methods include ponding, spraying, fogging, and saturating with wet coverings.

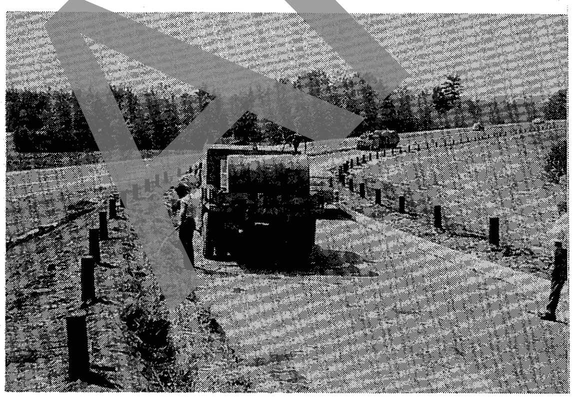
   2) Methods that **prevent loss of water** by sealing the surface. These include impervious papers, plastic sheets, or membranes.

   3) Methods that **accelerate strength gain** by supplying heat and moisture. This would include steam curing or electrically heated forms.

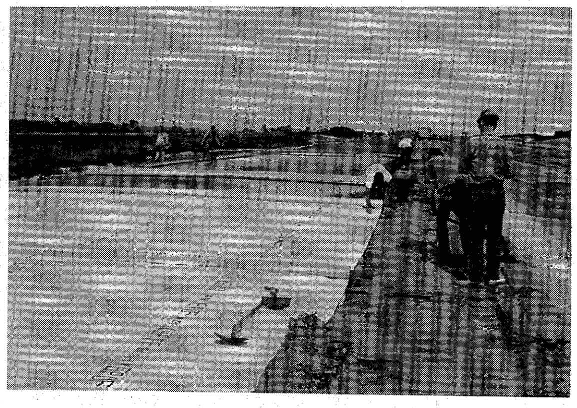


5. Perhaps the most effective method of curing concrete is by the **moist or water method.** On flat surfaces of small areas, such as pavements, sidewalks and floors, this may be accomplished by flooding the concrete with water, a method referred to as **ponding.** This method requires considerable labor and supervision and is not a common method in highway construction. (Concrete test cylinders are cured in this manor since it is an efficient method of preventing loss of water.) **Wet burlap** and other moisture retaining fabrics are a more viable means of keeping the concrete moist. In most circumstances the wet coverings can be placed almost immediately without damaging the surface. If texture is an important concern, however, such as on pavements, care must be taken when installing the coverings.

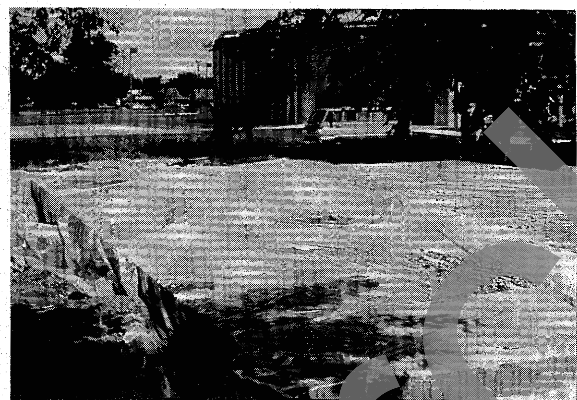
Wet burlap is most readily available and can be used on most concrete operations since it can conform to the concrete shape and remain in contact with the surface. Burlap must be free of any substance, such as fertilizers or sugar, that could be harmful to the concrete. Also the burlap should be nonstaining to the concrete surface. The burlap must be kept continuously moist, therefore, periodic wetting will be required. The covering should not be allowed to dry out since it could absorb moisture from the concrete. At the end of the curing period, however, the covering should be allowed to dry before it is removed. An alternative to periodic wettings would be to keep the surface moist through constant **spraying or fogging.** In this operation a fine mist is applied through soaking hoses or ordinary lawn sprinklers. There are several precautions to be taken when moist curing. First, the quality of the water must be considered if staining would be objectionable. Second, consequences of runoff must be considered. Third, intermittent sprinkling is not acceptable if the concrete is allowed to dry out between applications. And finally, care should be taken to avoid erosion of the concrete surface due to a heavy water flow.



6. Other methods of moist curing include earth, sand, sawdust, straw, or hay. These methods should be looked at carefully to be sure that they will not react with the concrete or cause staining. Here hay is being used to cure a concrete curb. The hay will have to be wet down when they are finished placing the concrete.

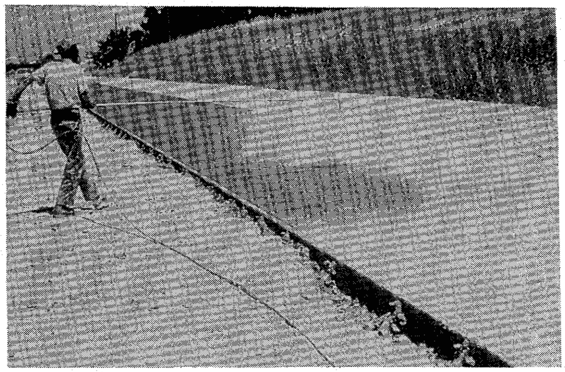


7. The second method of curing concrete includes those systems that seal the surface and prevent the loss of mix water. These systems have the advantage of not requiring periodic wetting and thus reduce the likelihood of the concrete drying out. Also, these systems can be easier to handle and less costly depending on the situation. **Impervious paper** is usually made up of two sheets of kraft paper cemented together by a bituminous material. Sheets should be wide enough to totally cover the work. Any joints should be sealed with tape or bituminous material. Sheets can be applied as soon as their application will not cause damage to the surface. Note here that the paper is white and reflects heat, a preferable situation during hot weather.

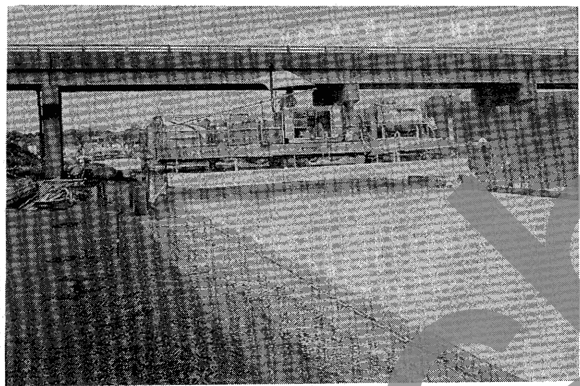


8. **Plastic sheets** are lightweight, effective moisture barriers that are easy to apply. Like the impervious sheets, the plastic should be applied as soon as possible as long as the surface is not damaged during application. The plastic should be placed wrinkle free if possible. Wrinkles can cause discoloration in the concrete due to differential hydration. Clear polyethylene is common and has little effect on heat absorption. Black film can be used during cool weather and white film can be used during hot weather.

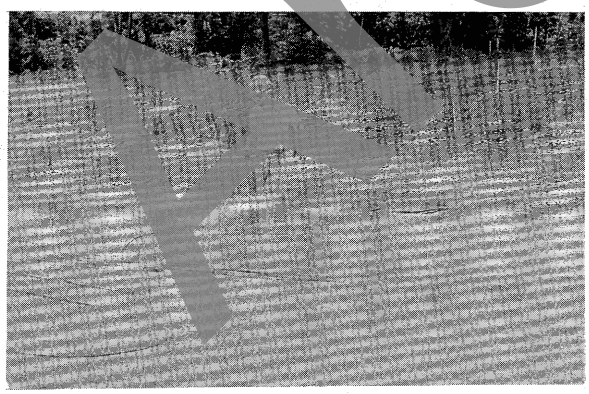
9. Sometimes plastic sheets are used in conjunction with moist curing methods. This reduces the need to periodically wet the coverings. As moisture from the concrete condenses, it is trapped by the plastic. The covering material, in this case burlap, absorbs the moisture and returns it to the surface.



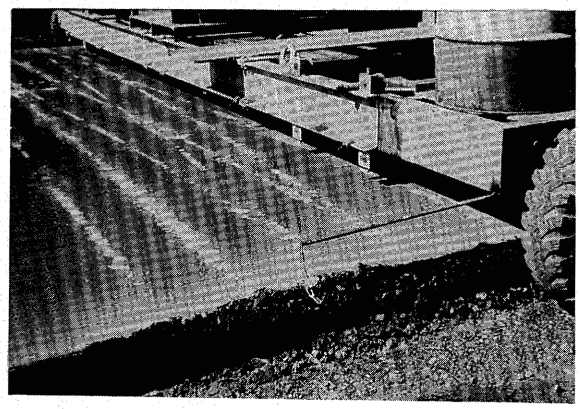
10. A common form of sealing curing is the **white pigmented curing compound**. This material is the accepted method for curing large areas such as pavements. When properly applied, the material forms a membrane that effectively seals in the moisture. Membranes also come in clear liquid, however, the white is usually used since it has the advantage of visibility for coverage and can reduce heat gain on sunny days. Membrane curing on pavements has the added advantage of preserving the macro texture. Other forms of curing such as burlap may cause damage to the texture if they are dragged across the pavement during application.



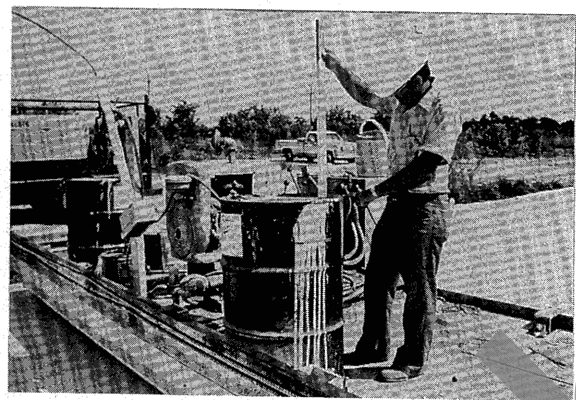
11. Curing compounds should be applied as soon as finishing is completed. The concrete should have no visible sheen but not be so dry that the compound is absorbed into the concrete. Application before all free water has evaporated will prevent the formation of cracks. Large paving projects usually use power driven equipment, but it can also be applied by hand. Spray nozzles on equipment should be arranged to prevent wind blown loss.



12. In this picture, either they have waited to long to apply the curing compound, since it has set up enough for the man to stand on it, or the man is destroying the texture.



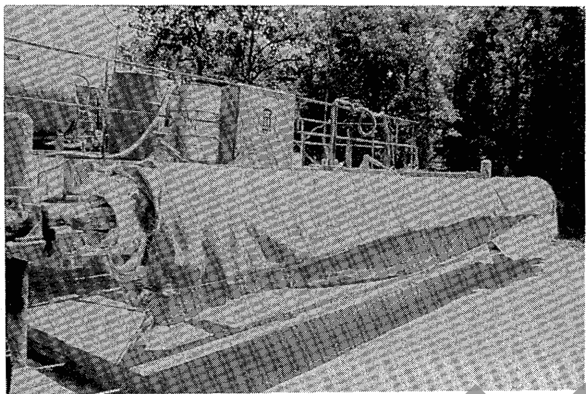
13. Uniform coating with the compound is important. Skips, insufficient coverage or even pinholes will allow evaporation of moisture from the concrete.



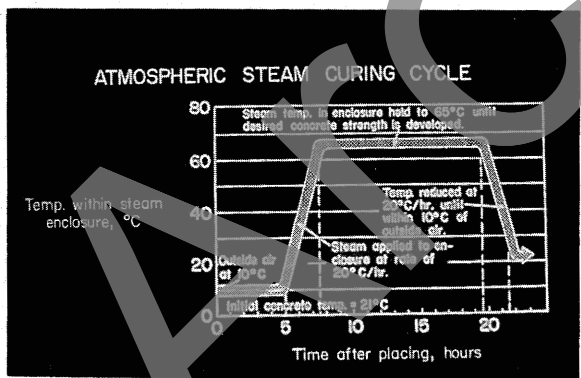
14. Curing compounds should be thoroughly mixed and agitated during the application. Coverage should be in accordance with specifications. If there is evidence of run off or the compound accumulates in grooves then the application rate was exceeded. The application equipment must be calibrated. An inspector's job would be to verify the rate of application and the uniformity of the application. By measuring the quantity used and measuring the area covered an application rate can be determined.

15. An important consideration for membrane curing is to cover all surfaces. Vertical faces, as illustrated by the edge of this pavement, must also be covered. One final consideration with respect to the use of membranes is that they should not be used on surfaces that will receive additional concrete. The membrane acts as a bond breaker.

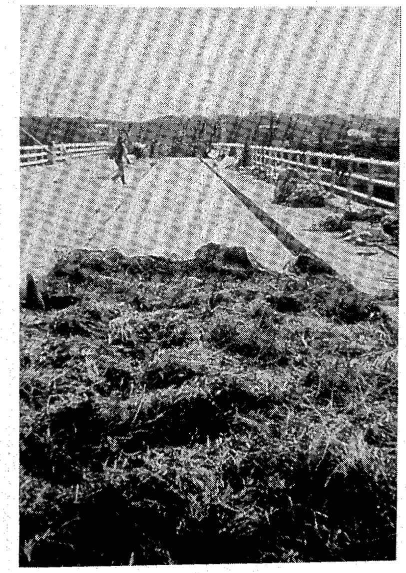
16. Prior to the start of a concrete placement operation that will use curing compound, the inspector should verify that the compound being used is approved or meets the specifications. A sufficient quantity should be on hand to complete the operation so as to avoid any delay or disruption.



17. Some states require that if a contractor is going to use a membrane on a pavement, he provide blankets to cover the pavement in case of rain. Here the contractor has provided a roll of paper backed burlap directly behind the membrane applicator. The covering should be of sufficient length, width and thickness to protect the pavement and edges adequately. When the rain stops, the covering should immediately removed and repairs made to the concrete and curing compound applied where it was washed off. Prior planning and prompt action can minimize the affects of rain.



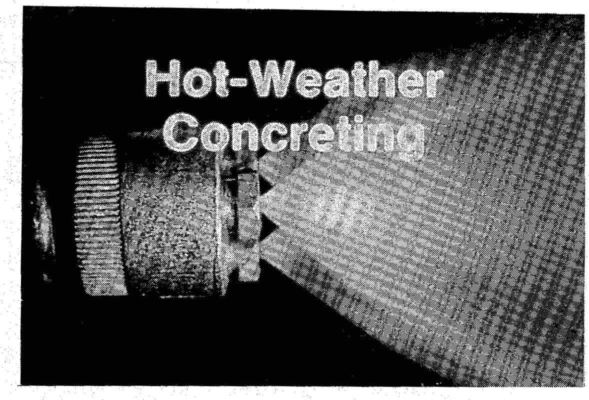
18. The third method of curing involves the use of **steam.** Steam curing is advantageous where accelerated strength gain is important or where additional heat is required in cold weather. Steam curing, in order to be effective, should enclose the concrete. Steam curing, therefore, does not lend itself to most highway uses. It is a common method, however, for curing many highway products such as pipes, manholes, and barriers. This chart shows the normal cycle followed in steam curing. It has been found effective to delay the start of curing by 2 to 5 hours since this adds to the 24 hour strength. The steam temperature is then increased to a maximum of 65°C to 80°C. The product is then kept at that temperature until the desired strength is gained.



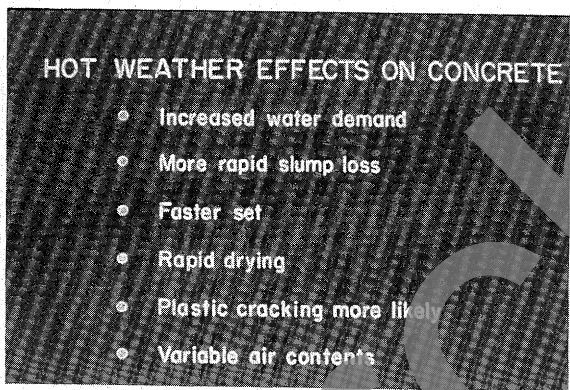
19. The length of time that concrete must be protected by curing is dependent upon the type of cement, required strength, weather, and future exposure conditions. This time could vary from a few days for Type III cements to as much as three weeks for other special mixes. Design properties are improved by curing, therefore, the curing period should be as long as practical. The minimum curing period should correspond to the time required to develop 70 percent of the design strength. When strength gain is critical to the structure or the progress of the work, cylinders can be made and cured under the same conditions, and then tested for strength.

Chapter 10

HOT WEATHER CONCRETING



1. Hot weather conditions can be defined as those of high temperature, low humidity and high winds either individually or in combination. Concrete mixed and placed under hot weather conditions requires an understanding of the effect of these environmental conditions on the concrete properties and operations. The effects of hot weather occur in the summer months in the northern states and can occur year round in the more arid climates. The effects of hot weather are more pronounced during periods of rising temperatures and lowering humidity.



2. The undesirable effects of hot weather on fresh concrete are as follows:

a. Increased water demand.

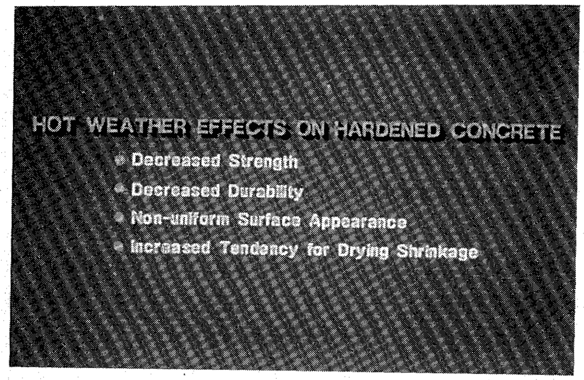
b. Increased loss of slump, resulting in a tendency to add water at the job site.

c. Increased rate of setting resulting in difficult handling, finishing, and curing.

d. Critical need for prompt early curing.

e. Increased tendency for plastic cracking.

f. Difficulty in controlling air contents.



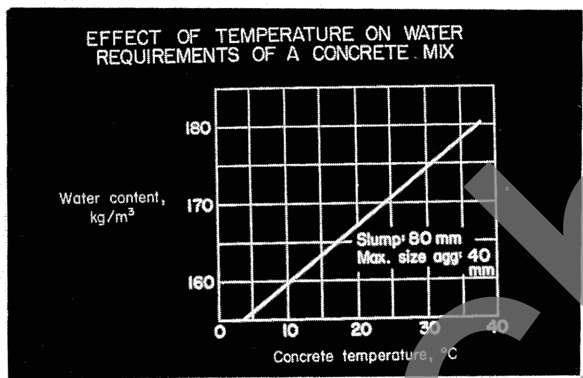
3. The effects of hot weather can also influence the concrete in the hardened state:

   a. A decrease in strength due to an increase in water (that is adding water at the job site).

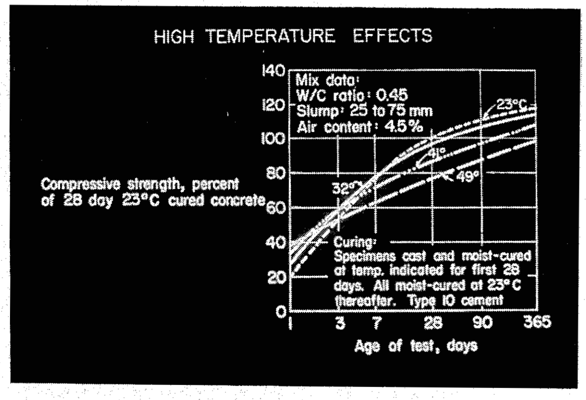
   b. Decreased durability and water tightness.

   c. Non-uniform surface appearance.

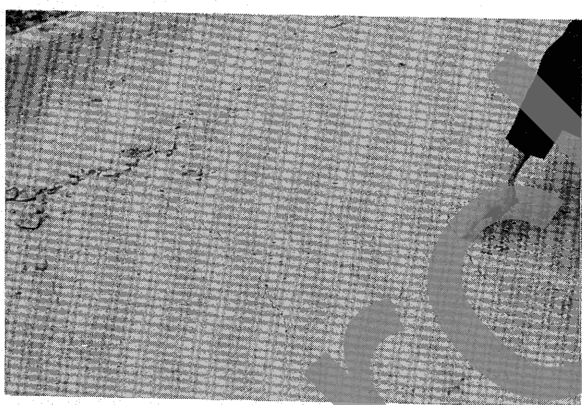
   d. An increased tendency for drying shrinkage and differential thermal cracking.



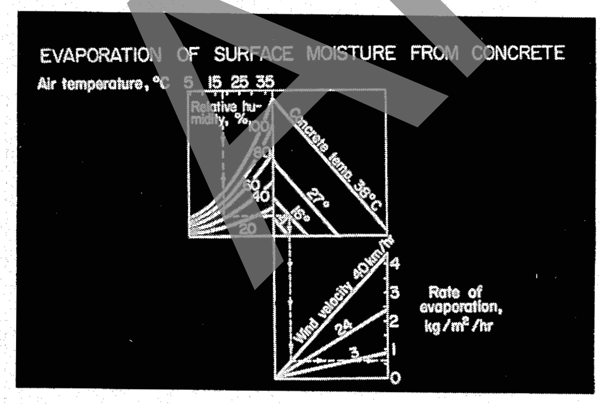
4. It has been shown, by the concrete industry, that an increase in temperature of a concrete mix results in a decrease in slump. As a rule of thumb, a 11°C increase in the mix temperature will result in a 25 mm decrease in the slump. In order to keep the slump constant, therefore, water will have to be added to the mix. This slide shows the relationship between mix temperature and water demand in order to maintain a constant slump. All too often on a construction project the crew will be faced with this problem with loss of slump. The standard field fix is to increase the water. Unfortunately what is overlooked is the corresponding impact on the water/cement ratio. A increase in the water will raise this ratio and result in a decrease in concrete strength and durability.



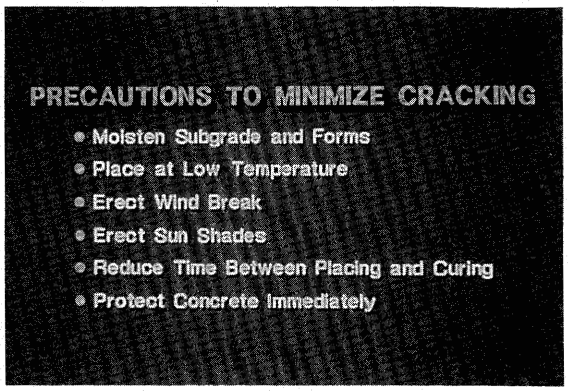
5. Another interesting study has shown that an increase in the mix temperature adversely effects the ultimate strength even when the slump and water/cement ratio are held constant. It is recommended practice to prepare trial batches for a concrete operation. Trial batches done in a laboratory would be mixed around 23°C. This may not represent the actual conditions that will be encountered at the placement site. Because of the effect of temperature, trial batches should duplicate, to the maximum extent possible, the actual field conditions expected at the time of the placement. Another consideration is that higher temperatures reduce the setting time, thus reducing the time for transporting, placing and finishing the concrete. This should be taken into account when preparing for a concrete placement.



6. In a normal concrete operation, water from the mix will rise to the surface of the placement and evaporate. This water is known as **bleed water**. When the weather is such that the bleed water evaporates faster than it can rise to the surface, than plastic shrinkage cracks will occur.



7. There is no way to predict with certainty when plastic cracking will occur. As a rule of thumb, however, when the environmental conditions are such that the rate of evaporation from the surface is 1 kg/m^2 per hour then precautionary measures should be taken. High concrete temperature, high air temperature, high wind and low humidity could result in conditions that would exceed this limit. This chart can be used to estimate if the limit is being exceeded.



8. There are some precautions that should be taken when conditions are favorable for evaporation. These should be taken into consideration when planning a hot weather concrete operation:

    a. Moisten the subgrade and the forms.

    b. Place concrete at the lowest possible temperature by cooling the aggregates and/or the mixing water.

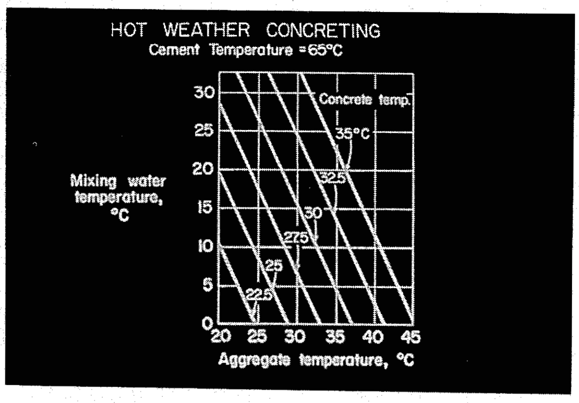
    c. Erect wind breaks to reduce the wind velocity.

    d. Erect sun shades to reduce concrete surface temperatures.

    e. Reduce the time between placing and curing by eliminating delays.

    f. Protect the concrete immediately after placing by a suitable means such as with a fog spray.

9. A precaution for hot weather concrete, besides reducing evaporation, is to control the temperature of the ingredients in the concrete. The contribution of each material in a concrete mixture to the initial temperature of the concrete is related to the temperature, specific heat, and quantity of each material.

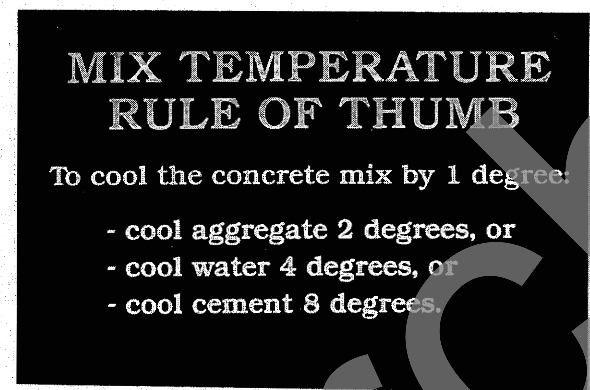


10. The relationship between the temperature of fresh concrete and its components is shown here. For example, a mixture made with aggregates at 32°C and water at 10°C will result in a mixture at 30°C. The formula for this chart is as shown:

$$T = \frac{0.925(TaMa + TcMc) + TwMw + TwaMwa}{0.925(Ma + Mc) + Mw + Mwa}$$

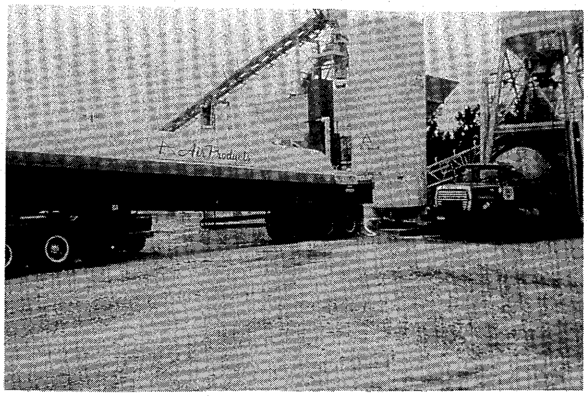
Where:

T = Temperature
M = Mass
a = aggregate
c = concrete
w = water
wa = free water on the aggregate

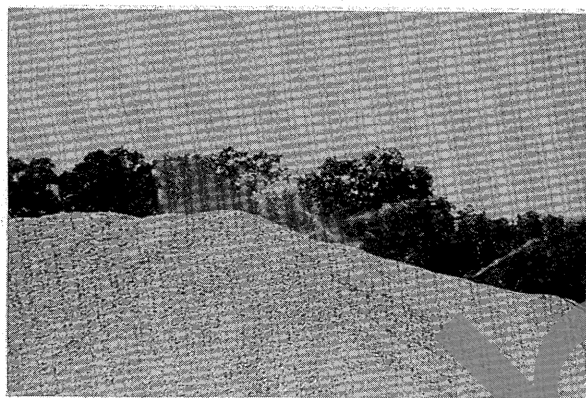


11. To easily estimate the effect of the individual component temperatures on the final concrete mixture temperature use this general rule of thumb. Note the 1:2:4:8 doubling pattern.

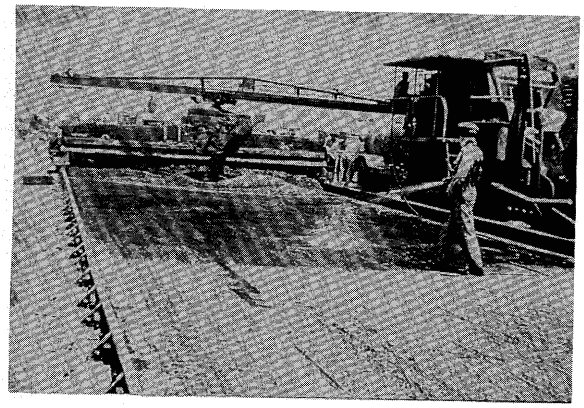
12. Mixing water influences temperature the most per unit weight of all the concrete ingredients. The specific heat of water is four to five times that of the other ingredients. Water is the easiest of the materials to cool or refrigerate before adding it to a mix. If this isn't practical, or economical, ice may be utilized instead. The use of crushed, shaved or chipped ice is acceptable, provided it is added directly to the mixer as part of the mix water, it is completely melted, and it is thoroughly mixed by the time the concrete is placed. Ice must be accurately weighed and substituted for and equal weight of water.



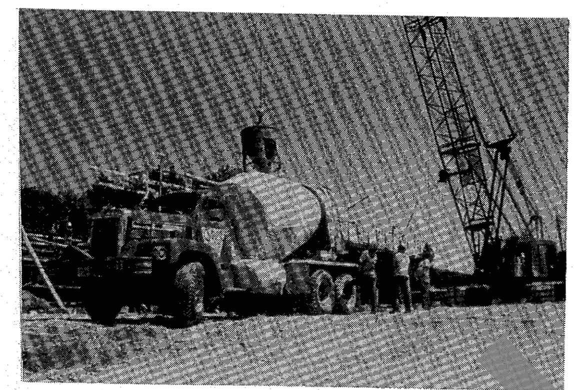
13. Liquid nitrogen has also been used to reduce the concrete temperature. The liquid nitrogen can be used to cool the concrete by injecting it into mix or to cool the mix water or aggregates.



14. Aggregates can have a pronounced effect on the temperature of concrete because they represent about 60 percent to 80 percent of the weight of the mix. To lower the temperature of the mix by 6°C (10°F) only requires a 8°C (15°F) reduction in the aggregate temperature. There are several methods of cooling the aggregates. The simplest and most common would be to build the stock pile in the shade or to sprinkle the stockpile with water. Sprinkling cools through evaporation. Caution is advised here, however, as haphazard sprinkling can lead to variation in surface moisture on the aggregates. Cement temperature has only a minor effect on the concrete temperature because of its low specific heat and relatively small quantity. In general, an upper limit of 65°C to 80°C (150°F to 180°F) is specified for cement temperatures. Cement temperatures above this could cause stiffening of the concrete.



15. There are a number of physical precautions that can be taken to alleviate the affect of hot weather. One way to cool things down is to fog the forms, reinforcing, and subgrade just prior to the placement. In addition, fogging can be used to cool the surroundings and provide humidity during finishing. Fogging nozzles should be used, not regular garden hose nozzles.



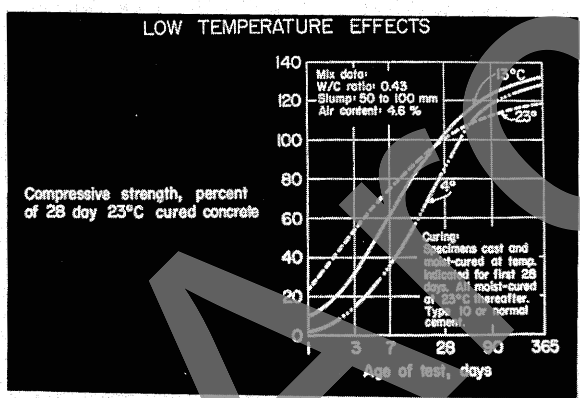
16. In order to reduce solar heat gain, it is recommended that mixers, belts, chutes and hoppers be shaded. Where this is not possible, less heat will be absorbed if they are painted white. Studies have shown that a white drum exposed to the sun for 1 hour will keep the concrete 1.5°C (2.5°F) cooler than a red or other dark colored drum.

17. Scheduling, so that concrete is placed promptly upon arrival at the job site is also effective in hot weather. If delays occur, the adverse affect of prolonged mixing can be minimized by stopping the mixer and then agitating intermittently. During hot weather the time limit for discharge can be reduced from 1-1/2 hours to 1 hour or even 45 minutes.

Chapter 11

COLD WEATHER CONCRETING

1. Cold weather is defined as a period when the mean daily temperature, for three consecutive days falls below 4°C. When the temperature rises above 10°C, for more than half of any 24 hour period, then the concrete is no longer considered winter concrete. Concrete placed during cold weather must be properly manufactured, placed and protected so that it will have the characteristics of concrete placed under normal weather conditions. The amount of special precautions will increase as the temperature decreases in order to ensure that strong, durable concrete that satisfies the intended service requirements is produced.



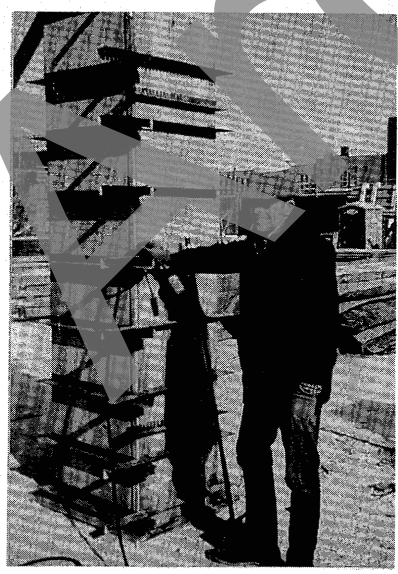
2. As the temperature of concrete goes down, the rate of hydration goes down. As was stated previously, very little hydration occurs below freezing and no hydration occurs below -10°C. This graph shows that at cold temperatures, strength gain is slowed because of the slowing of hydration. Note that when normal curing is applied, in this case at 28 days, the ultimate strength is the same or greater than concrete placed at normal temperatures.

TABLE A: Recommended Duration of Temperature (fully-stressed, exposed air-entrained concrete)						
Required percentage of design strength	Days at 10°C			Days at 21°C		
	Type of Cement			Type of Cement		
	I	II	III	I	II	III
50	6	9	3	4	6	3
65	11	14	5	8	10	4
85	21	28	16	18	18	12
95	29	35	26	23	24	20

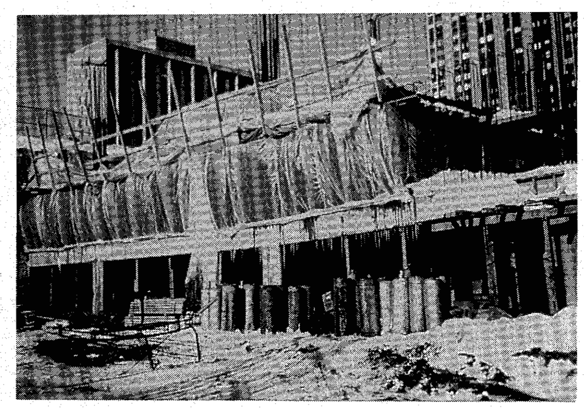
ACI Committee 306, 1978

7. The duration of the temperature must be significantly lengthened if significant strength gain is desired. These two charts are predicated on the basis that following these short periods sufficient curing occurs and that the concrete is not subject to freezing in a saturated condition.

8. In order to maintain desired temperatures, advantage should be taken of the heat of hydration generated by the concrete. This heat may be retained by some type of **insulation**. Typical insulating materials are polystyrene foam sheets, foamed vinyl blankets, and straw. When straw is used, some type of covering, such as polyethylene plastic film, is needed in order to keep the straw in place. Corners and edges of concrete are the most vulnerable and need to be checked for freezing. Charts and graphs are available to provide information on insulating values of various materials.

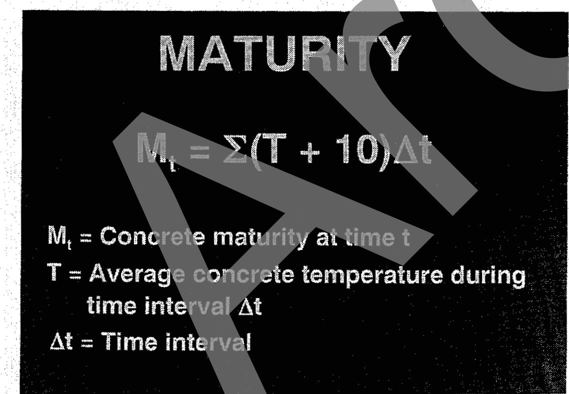


9. Forms built for repeated use can be permanently insulated. When they are not in use, the forms with the insulating materials should be protected from the weather.

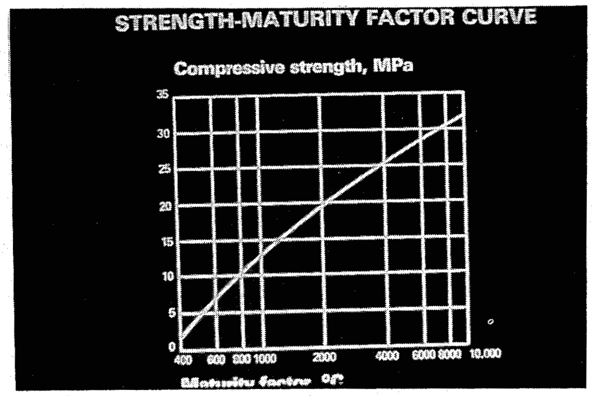


10. **Heated enclosures** can be used to protect concrete during cold weather. Enclosures can be made of wood, canvas, or polyethylene. Plastic enclosures that admit daylight are preferred. The enclosure needs to be able to withstand wind and snow loads. Sufficient space should be provided above and around the concrete to allow the free flow of warmed air.

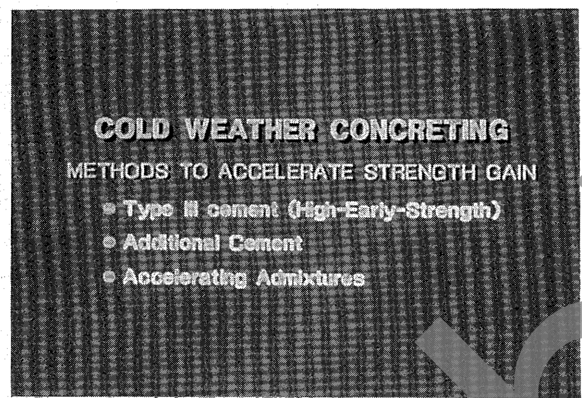
11. Heat may be supplied to enclosures by live steam, forced hot air, or stationary heaters. Caution is necessary with heaters. Fresh concrete exposed to carbon dioxide from the heaters or their exhausts will cause a soft chalky surface in the hardened state. The carbon dioxide will react with calcium hydroxide on the concrete surface to form a weak layer of calcium carbonate. An indirect fired heater as shown here is the preferred method.



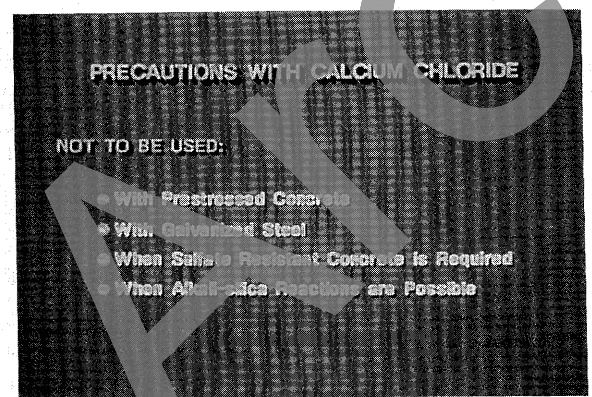
12. A previously shown chart gave recommended curing temperatures and periods to allow safe stripping of forms. However, occasions may arise where it is desirable to know the in-place strength of the concrete before stripping forms or allowing loading of the structure. One available method for determining the in-place strength is the **maturity factor**. The maturity method is based on the principal that the strength of concrete is a function of its time-temperature history. The maturity of the concrete can be calculated using this formula and correlated to the concrete strength.



13. The correlation between the strength and maturity of a given concrete mix can be established by performing compressive tests on a series of cylinders at different maturities and plotting the test results against the maturities. These cylinders are typically cured in the laboratory at 23°C. Equipped with this predetermined relationship and the time-temperature history of the concrete, the equation can be used to determine the maturity and the strength-maturity relationship can be used to estimate the in-place strength of the concrete.



14. High early concrete strength is desirable in winter construction to reduce the length of time temporary protection is required. Any added cost of these extra efforts may be offset by earlier reuse of forms or shortened heating times for the protection period. To accomplish this one could use Type III, high-early-strength cement, with its increased heat of hydration, the cement content could be increased by up to one third of the original, or finally, some type of accelerator could be used.



15. Some water-reducing accelerators have been found to accelerate strength gain. More common, however, is the addition of calcium chloride. Some precautions are necessary with calcium chloride:

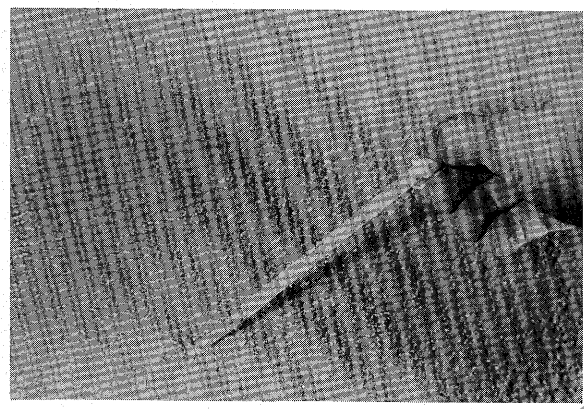
a. Do not use with prestressed concrete.

b. Do not use with galvanized steel.

c. Do not use when the concrete will be exposed to sulfates.

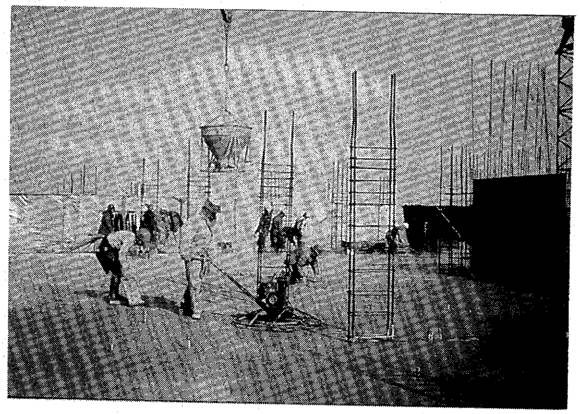
d. Do not use when alkali-silica reactions are possible.

It is always recommended that prior testing be performed to evaluate any acceleration plan. In such testing similar materials and similar field conditions should utilized. The use of so called anti-freeze compounds or other materials to lower the freezing point of concrete should not be used, as they have been found to work only minimally, and may damage the concrete more than they help.



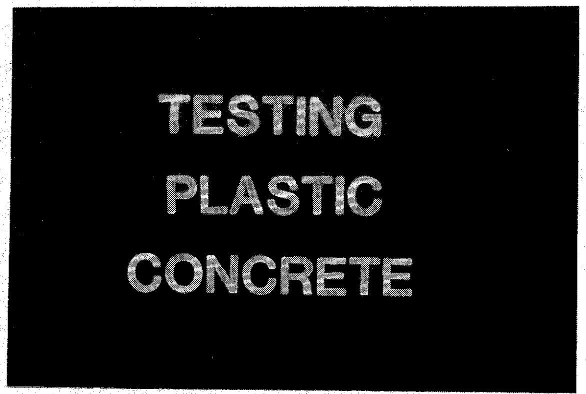
16. Inspection personnel should keep a record of the weather conditions and the temperature of the concrete during the entire curing period. Thermometers are needed to record the concrete temperature at delivery, and at placement. After the concrete is no longer plastic and curing commences, the temperature can be recorded during the protection period with special surface thermometers, "Hi-Lo" thermometers, or by thermistors or thermocouples embedded in the concrete.

17. Concrete test cylinders must be maintained at a temperature between 15°C and 25°C at the job site for 24 hours and then taken to the laboratory. At the job site, it is recommended that the cylinders be kept in a curing box with an accurate temperature control. In addition to the laboratory cured specimens it is often useful to field cure cylinders to get a more accurate reading of the structures true strength.



18. In conclusion, concrete can be placed safely throughout winter months provided certain precautions are taken. The concrete mixture and its temperature should be adapted to the construction procedure and ambient weather conditions. Plans should be made to protect the concrete with enclosures and windbreaks. Portable heaters, insulated forms, and blankets should be ready to maintain the concrete temperature during the protection period. Forms, reinforcing steel, and subgrades should be unfrozen and clear of snow and ice at the time concrete is placed. Thermometers and adequate storage facilities for the test cylinders should be available to verify the work.

Chapter 12
CONCRETE TESTING

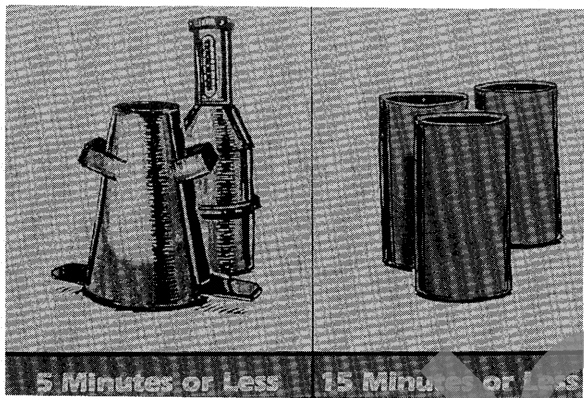


1. Concrete testing is important to ensure that the quality of the concrete equals or exceeds the specifications. If the concrete does not meet specifications, corrections must be made or the load must be rejected. If transit mixers are used it may be possible to correct a low slump in the field. Otherwise corrections will be required at the plant.

2. To insure proper testing at the paving site, it is important that the samples be representative of the concrete mix. AASHTO T 141 gives the procedure for **sampling fresh concrete.** The frequency for sampling and testing concrete will appear in the State's sampling and testing program. In general, concrete which is mixed in truck mixers should be tested more frequently than concrete mixed in central mix plants due to the increased variability in truck mixed concrete. Also, sampling and testing frequencies should increase when variability in the test results are noted.

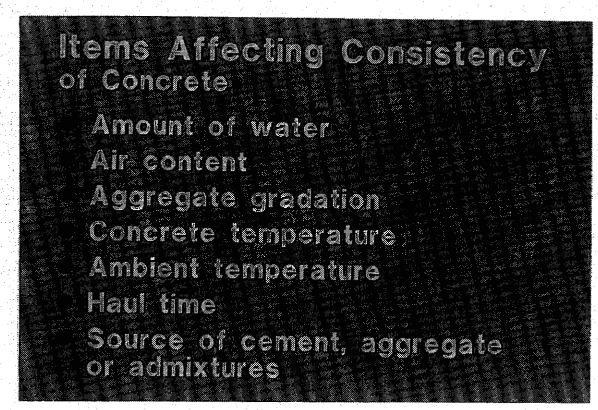
3. When sampling concrete from a ready mix or transit mixer or an agitator truck the concrete should be sampled at two or more regularly spaced intervals during the discharge of the middle portion of the batch. The sample should be taken by repeatedly passing the sampling device through the entire discharge stream or by diverting the flow into the sampling device.

4. Once the samples are obtained they must be combined and remixed prior to performing the tests. The sample size should be large enough to perform all of the tests. Air, slump, yield, and strength tests should be performed on the concrete obtain from the same sample. However, no concrete used in one test should be reused in another test.

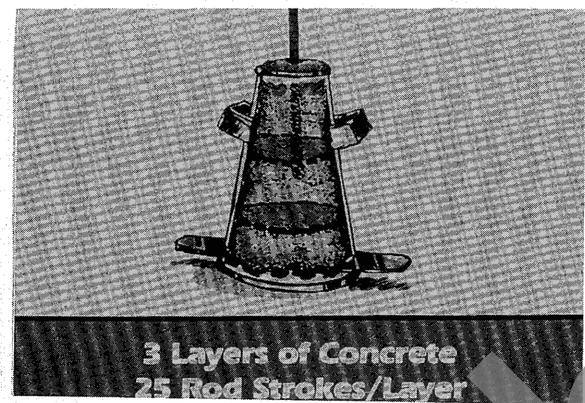


5. Tests for **slump and air content** must begin within **5 minutes** after sampling is completed. Specimens which are being cast for **strength** tests must be started within **15 minutes** after taking the sample. In no case should the **time elapsed** between obtaining the first and final portions of the sample exceed **15 minutes.**

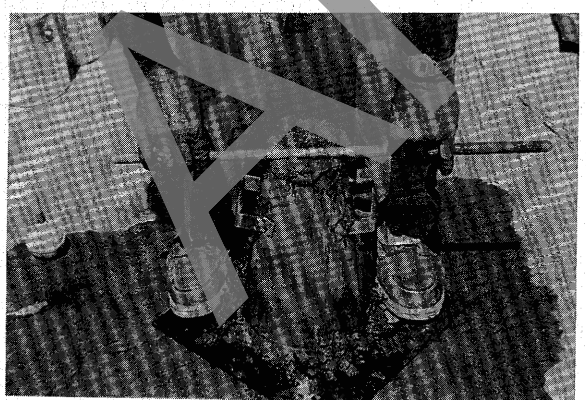
6. There are two tests which can be used to determine the consistency of the concrete mix, the slump test and the Kelly Ball Penetration Test. Of these, the slump test is the most universally recognized. If the test results are not uniform it indicates that something has changed.



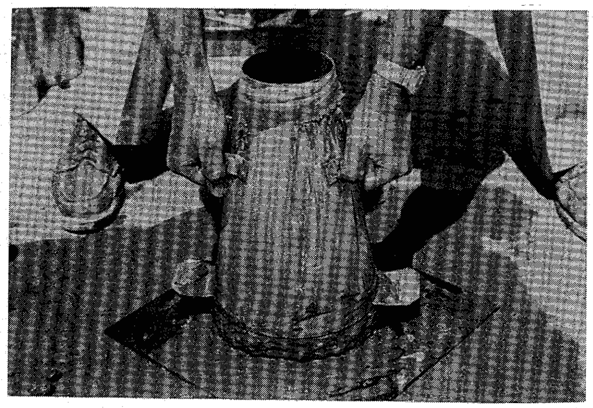
7. Many items can affect the consistency of the concrete. An increase in the amount of water will increase the slump. An increase in the air content will increase the slump. A decrease in concrete and ambient temperatures will increase slump. An increase in haul time will decrease slump. The aggregate gradation, and a change in source of cement, aggregate, and admixtures may affect the slump of a concrete mix.



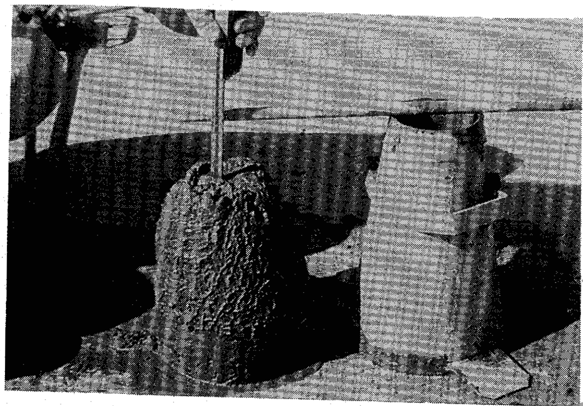
8. When doing the **slump test**, make sure that the equipment is clean and wetted down adequately. The cone must be filled with three layers. Each layer should be of approximate equal volume, and rodded 25 times. For the first layer, the rod should be slightly inclined and approximately half the strokes should be made near the perimeter and half of the strokes near the middle of the cone. When the subsequent layers are added, it is important to slightly penetrate the layer below. When rodding the top layer, it is important to keep an excess of concrete above the top of the mold at all times.



9. When it has been properly filled, the cone is then screeded with a rolling motion of the tamping rod to smoothly strike off the excess concrete. During the entire test it is important to have the base of the cone secured so the contents will not be disturbed.

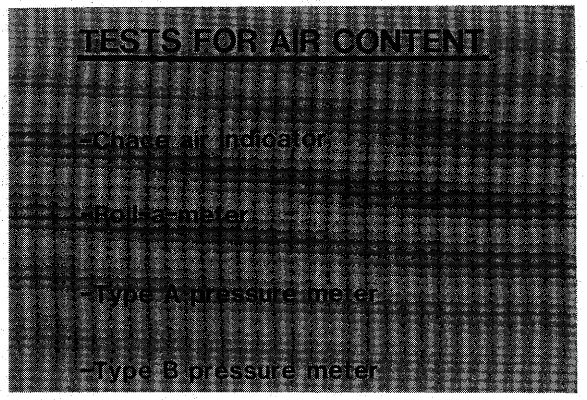


10. After it has been struck off, the cone and the area around its base must be cleaned and the material removed. The cone is then released from its mountings, if so equipped, and slowly lifted without twisting. The lifting motion should be completely vertical and should take from three to seven seconds. The time limit of the test should not exceed 2-1/2 minutes from the initial filling to the final lifting of the cone.

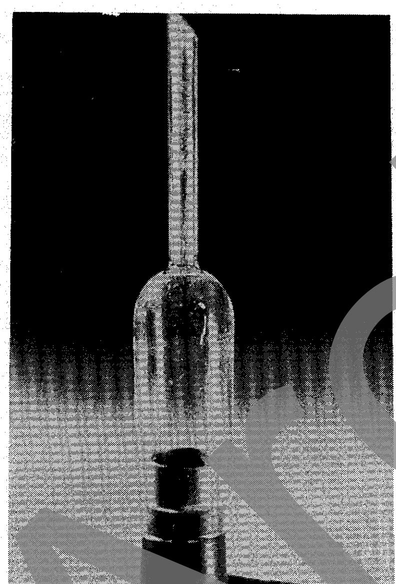


11. After the cone has been removed, it is placed inverted next to the concrete and the tamping rod is placed across the base of the cone. The difference in height between the cone and the concrete is the slump. The slump should be measured at the center of the displaced concrete, and recorded to the nearest 5 mm.

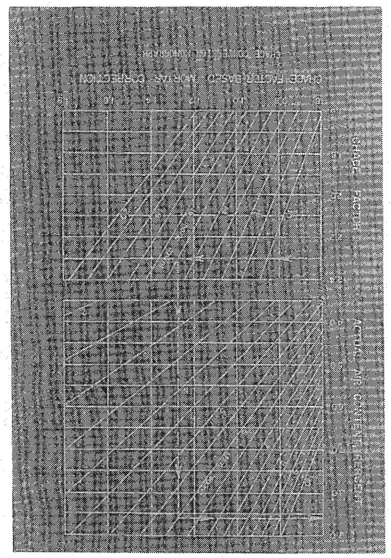
12. The **Kelly Ball test** is a fairly simple test. The apparatus is zeroed and the surface of the concrete to be tested is leveled and smoothed using a small wood float. The test location should be a minimum of 230 mm from any concrete edge. The Kelly Ball should not be used on concrete less than 200 mm in depth. The apparatus is placed on the level surface and the ball is allowed to penetrate the concrete on its own weight. In no case should the ball be dropped into the concrete as this will cause false readings. When the ball comes to rest, the handle is released and the penetration is read to the nearest 5 mm. At least three reading must be taken and their average is the result for the test. These readings should not be taken at any location where there is not at least 150 mm between the stirrup of a previous test and the point that is to be tested. The difference between the highest and lowest readings should not be more than 25 mm.



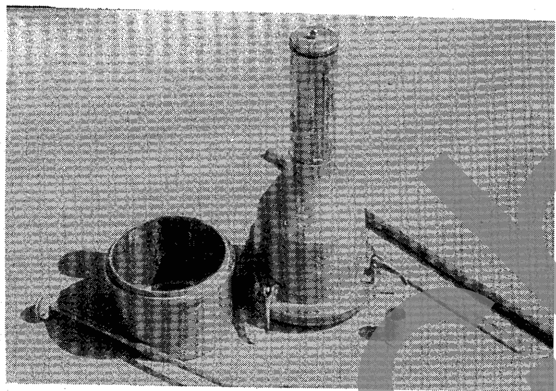
13. **Air content** of plastic concrete can be determined by several methods. One method sometimes used for a rough approximation is the **Chace Air Indicator**. Another more accurate method is the **roll-a-meter.** These two methods determine the volume of air in the concrete mix by **displacement** of air with water. Two other types of air meter in use are the **Type A and Type B pressure meter**. These two pressure meters use **pressure and volume** relationships of gasses to determine the total air content. The total volume of air is indicated simply by reading a pressure gauge mounted on the meter.



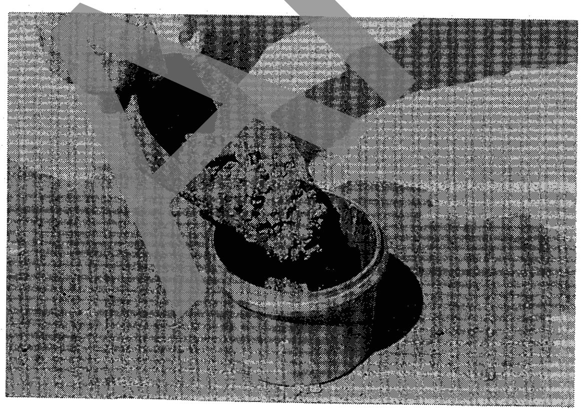
14. The **Chace Air Indicator** is very useful for checking air content in concrete. While it can be used for acceptance, it cannot be used for rejection. The procedure is run on material passing the 2.00 mm sieve. The mortar is placed in the thimble and rodded 25 times with a paper clip size wire. Then the thimble is placed into the tester up to the test mark and alcohol is added to the mark. The tester is shaken until the mortar is released from the thimble. A reading is then taken. A single test result consists of an average of two readings.



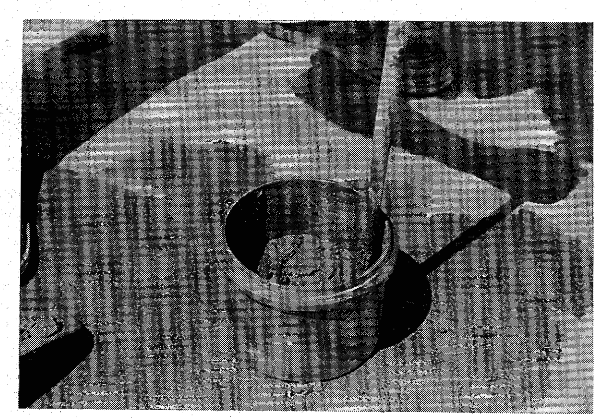
15. In order to determine the air content, it is necessary to enter the chart with first the chace factor for the particular indicator, then the mortar content, the reading, and the actual percent air content will be shown at the exit. This chart and the test procedure are contained in AASHTO T 199.



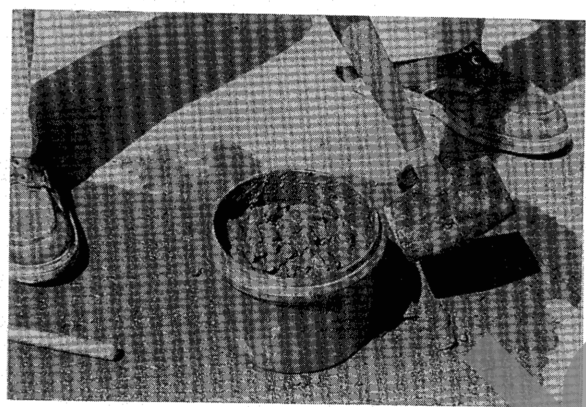
16. The roll-a-meter determines air content of a concrete mix by volumetric methods. The procedure for performing the test is contained in AASHTO T 196. This method must be used whenever porous aggregates are used in a concrete mix.



17. The first steps in determining the air content using a roll-a-meter is to wet down the apparatus and fill the base with concrete. This should be done in three equal layers.

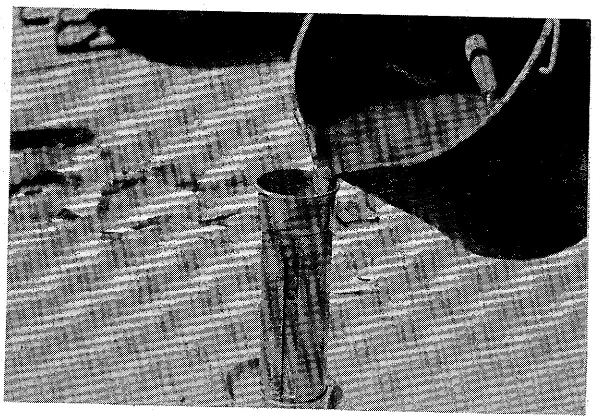


18. After each layer of concrete has been placed in the base, it should be rodded 25 times.

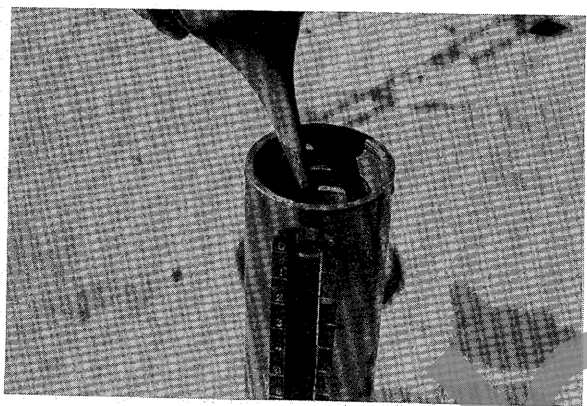


19. With each layer, it is necessary to remove any voids resulting from the rodding. This is done by tapping the base with a rubber mallet ten to fifteen times or until the holes are closed. As each layer is added, the tamping rod should penetrate into the preceding layer approximately 25 mm. The whole process is repeated for a total of three times until the base of the container is completely filled.

20. The base of the roll-a-meter is struck off with a smooth back and forth sawing motion of the strike-off bar. The concrete surface should be smooth, flat, and the lip of the roll-a-meter be wiped clean. The top can then be firmly attached and sealed to the base.

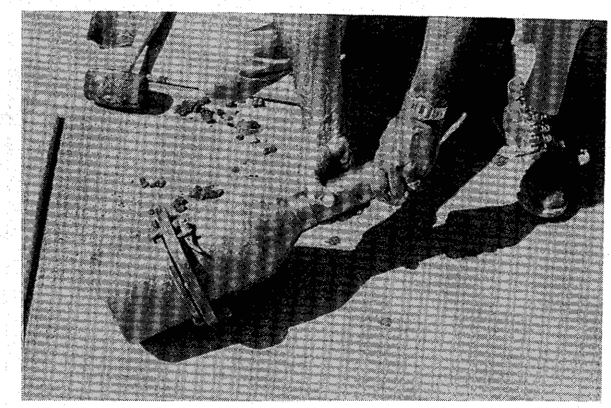


21. The roll-a-meter is then filled with water to the zero mark, using the special funnel which insures that the surface of the concrete is not disturbed during the filling operation.

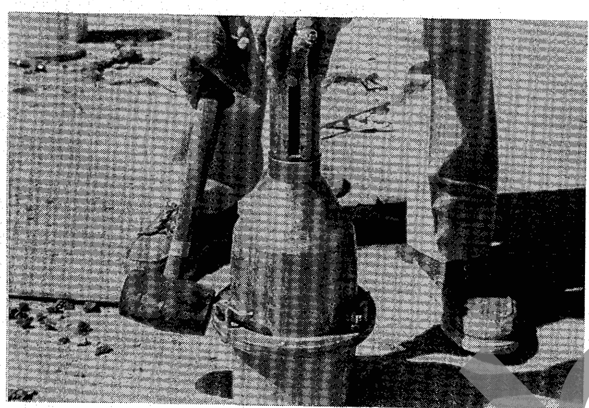


22. The gauge is topped off with a small squeeze bulb.

23. The screw cap is attached and tightened. Then the roll-a-meter is inverted and agitated until the concrete is released from the base. If all of the concrete is not released from the bottom of the base, the resulting air content reading will be low.

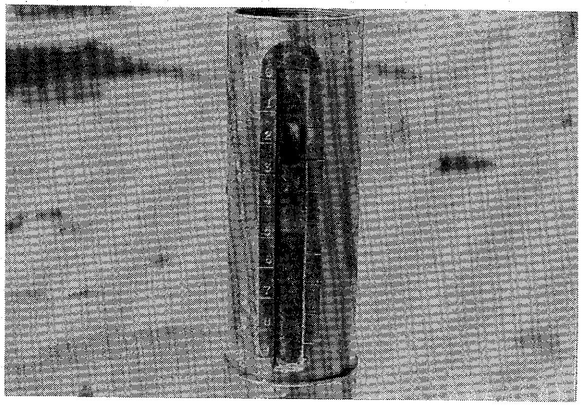


24. The roll-a-meter is rocked and rolled on its flange with the neck elevated until it appears that all the air has been removed from the concrete. If all of the concrete is not put into suspension the resulting air content will be low.

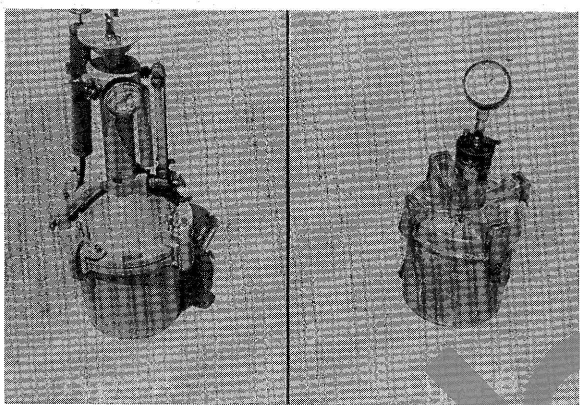


25. The roll-a-meter is set upright, jarred lightly, and allowed to stand until all the air rises to the top of the meter. This process is repeated until the water drop in the column stabilizes.

26. After rolling is completed, measured quantities of alcohol are placed into the meter. The number of units of alcohol which are placed into the air meter must be recorded. The purpose of the alcohol is to disperse any foam which forms as a result of the mixing action.

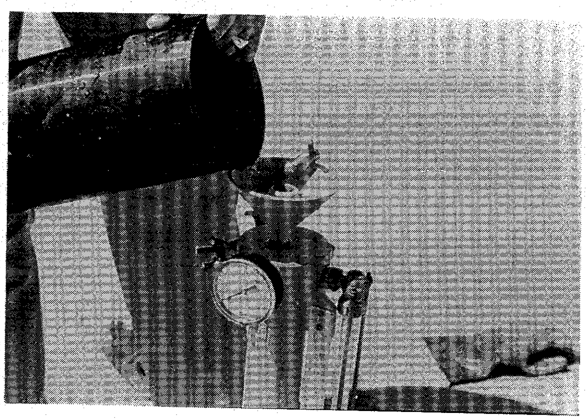


27. The air content is determined by taking a direct reading at the bottom of the curve formed by the water in the neck of the roll-a-meter. For each cup of alcohol placed in the meter one percent is added to the reading shown on the air meter. The air content is recorded to the nearest 0.1 percent.

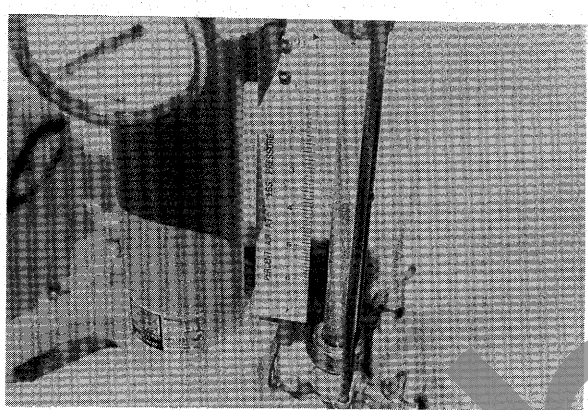


28. **Type A and Type B pressure meters** determine the volume of air in a concrete mix using pressure-volume relationships. The air content can be read directly from a gauge mounted on the top of the meter. These gauges must be recalibrated when they are used at different altitudes. The test procedure is contained in AASHTO T 152.

29. For both pressure meters, the apparatus is wet down and the base is filled in the same manner as was done with the volumetric meter. It is very important to clean the surface of the flange in order to get a good seal. The rubber gasket in the top of the meter should also be moistened. Then the top cover is clamped on.

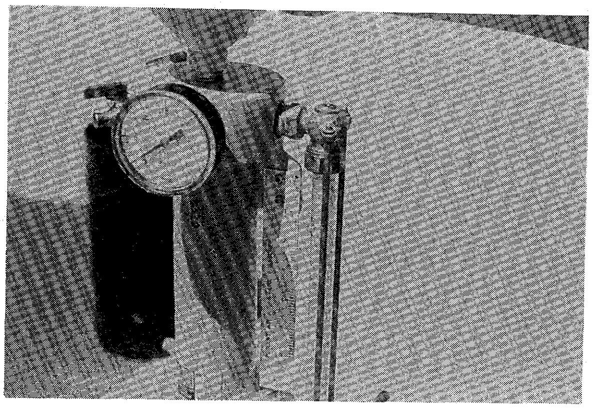


30. For the Type A air meter, water is added above the concrete by pouring it into the top of the fill tube.

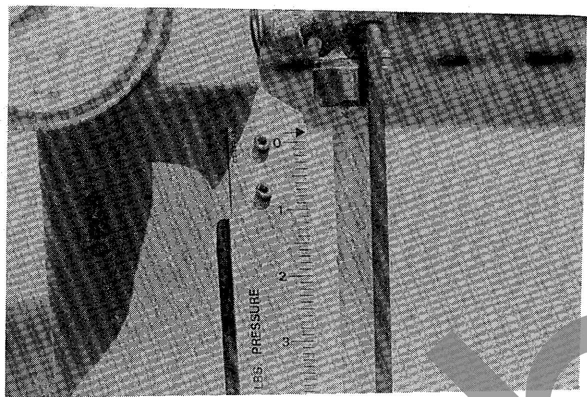


31. Water should be added until the level rises to about the four percent mark on the glass standpipe gauge.

32. The entire meter is tilted and the cover is rapped with the rubber mallet to release any air entrapped above the concrete.

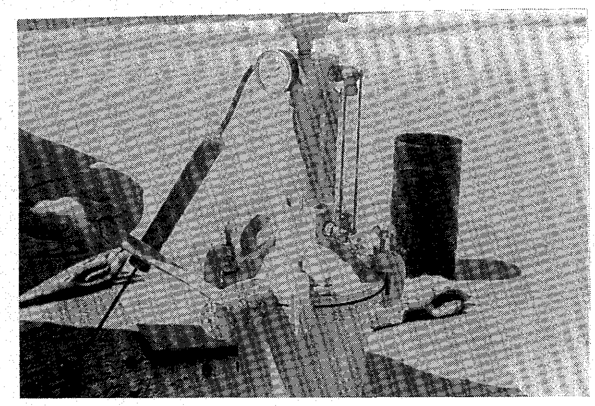


33. The meter is returned to the upright position and the water column is filled until water discharges from the top petcock shown to the left of the round air gauge. The side of the meter is tapped lightly with the mallet to insure that no air is trapped within the meter.

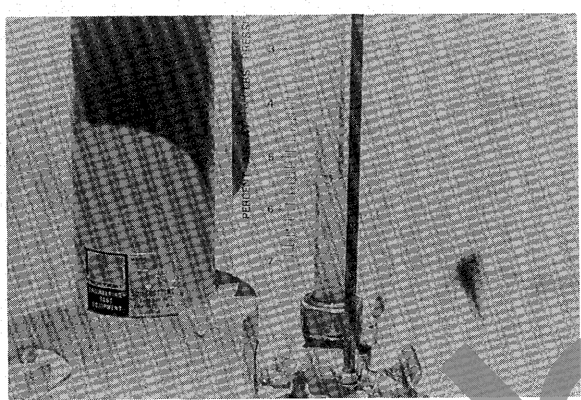


34. The water level is brought down to the initial fill line which is slightly above zero, by opening the lower petcock on the meter.

35. The petcock at the top of the water column and the top valve of the fill tube are closed. The air meter is pressurized until the required test pressure is achieved as shown on the gauge.

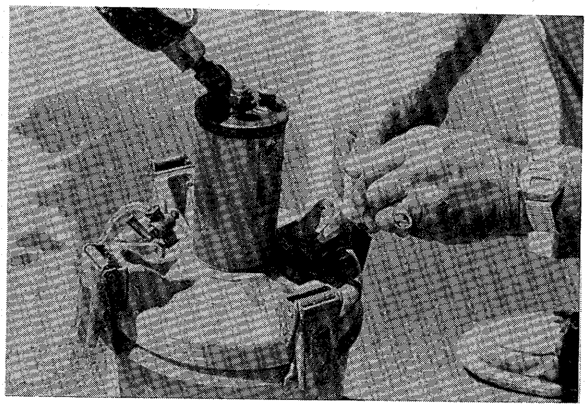


36. The sides of the meter are tapped again with the mallet to free any air bubbles which might be in the meter.

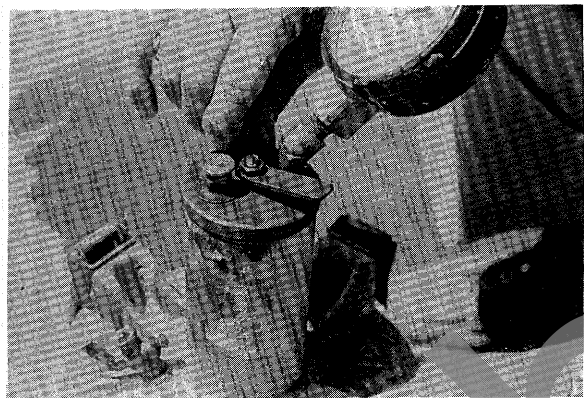


37. The air content is determined by reading the level on the water column, and is recorded to the nearest 0.1 percent. After the air content has been determined, the air pressure must be gradually released through the petcock at the top of the water column while the sides of the meter are tapped lightly for one minute. The water level on the column gauge should return to zero when this step is completed.

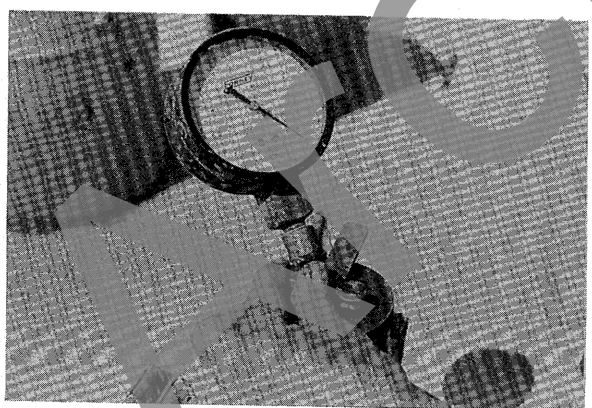
38. The **Type B pressure meter** is filled in the same way as the volumetric meter and the Type A pressure meter. Both petcocks on the meter are opened and the cover is clamped on the meter.



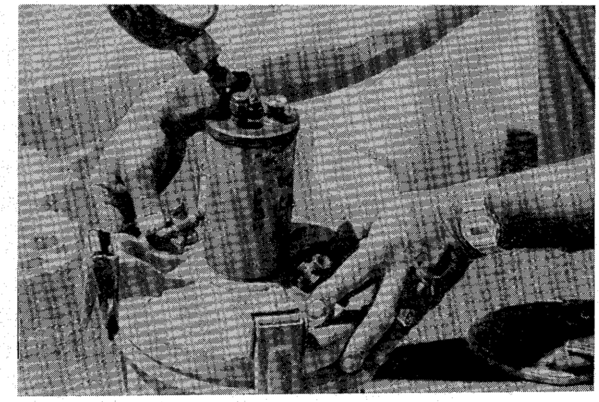
39. Water is injected into one petcock with a rubber syringe until it comes out the other petcock. The procedure is repeated with the other petcock. This procedure is alternated between the petcocks until no air bubbles appear in the water being ejected from either petcock. The meter should be jarred gently to help release any air bubbles that may be trapped in the top of the meter.



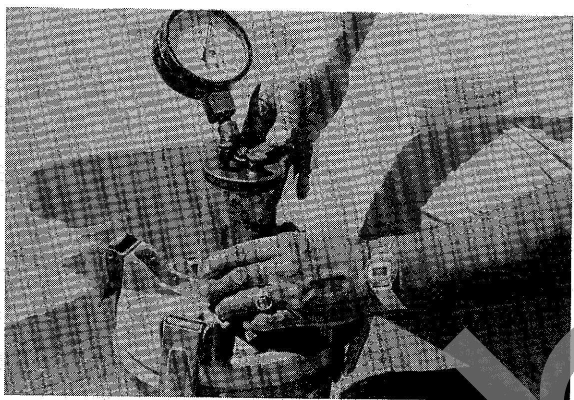
40. The air bleeder valve at the top of the pressure chamber is closed and air is pumped into the air chamber until the gauge hand is on the initial pressure line. This is usually between the two and three percent mark on the pressure gauge, depending upon the calibration.



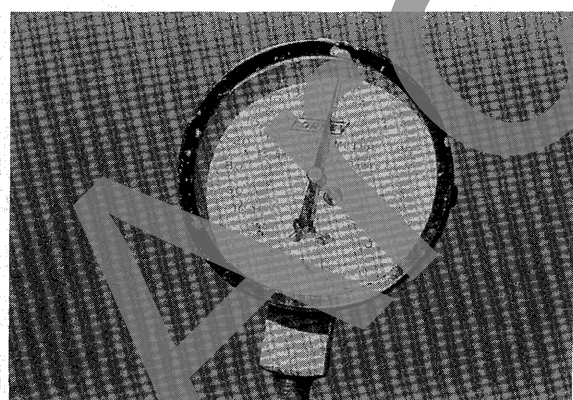
41. The meter is adjusted to the initial pressure line at this time by pumping or using the bleeder valve and tapping the gauge lightly.



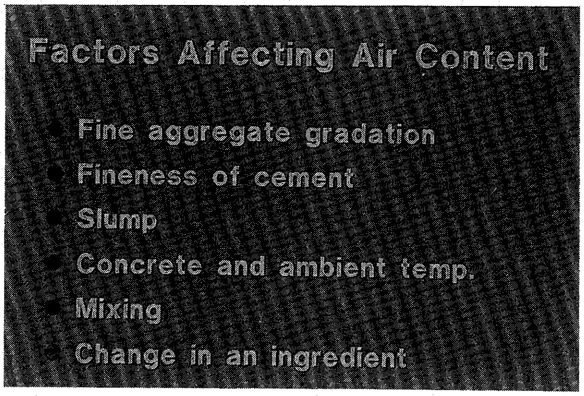
42. The petcocks are closed.



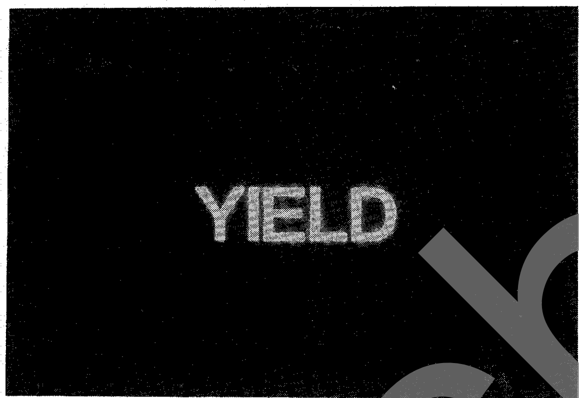
43. The main air valve is opened by pushing down on the release lever. The side of the base is rapped sharply and the gauge is lightly tapped. The tapping of the gauge is continued until the needle comes to rest. If the needle does not come to rest, it indicates there is an improper seal between the top and bottom of the meter. The contact surface should be cleaned and the test repeated.



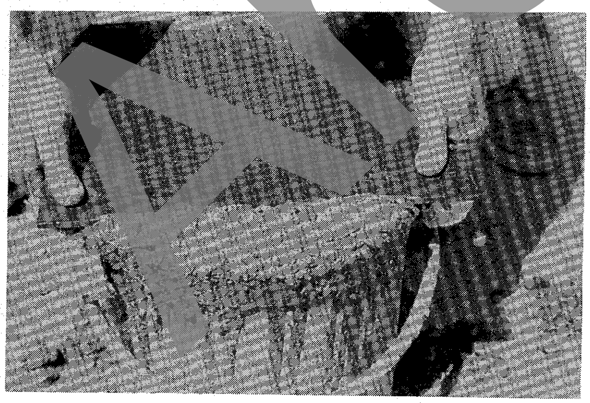
44. The air content is read directly from the gauge, and recorded to the nearest 0.1 percent. Air content tests are run in front of the paver. It is also recommended that occasional tests be run from immediately behind the paver. This information can be useful in making sure that the proper air content is being attained in the mix. Typically, the concrete will loose from 1 to 1-1/2 percent air through normal placing, vibration and finishing methods. When concrete pumps are used the acceptance point for air content is at the end of the discharge to insure that the proper air content is obtained. It is also desirable to test the concrete before it is placed in the pump in order to determine the amount of air that is lost during the pumping operation.



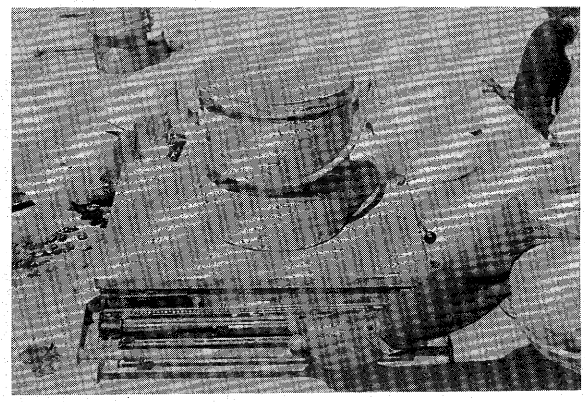
45. Many things affect the ability of a concrete to entrain air. An increase in the material between the 600 μm and 150 μm sieves will increase the air content. However, an increase in the amount of minus 150 μm material will decrease air content. An increase in the fineness of cement will decrease the air content. An increase in slump will increase the air content. As the temperature of the concrete and ambient air increases the air content will decrease. Excessive amounts of mixing will drive the air out of the mixture. Any change in the sources of the ingredient materials can affect the air content of the mix.



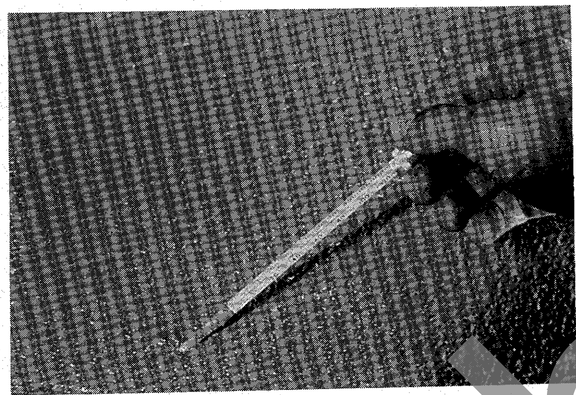
46. Concrete **yield** is the volume of concrete produced per batch of concrete. The yield is calculated from the results of the unit weight tests. The yield is found by comparing the theoretical unit weight to the unit weight found in the field. A difference in the unit weights indicates that the proportions of the ingredients in the mix are not correct. A High yield may indicate that heavier materials such as aggregate or cement were substituted for the water. A low yield may indicate either two much water or not enough cement was added.



47. While the yield bucket is wet down and filled in the same manner as with the air tests, the strike off technique is different. Flatten about two thirds of the concrete surface by pressing the strike-off plate onto the top of the bucket. The plate is withdrawn with a sawing motion to finish only the covered area. Next, cover the original two thirds surface again and advance the whole plate while applying vertical pressure and a sawing motion until the entire surface of the unit weight bucket has been struck-off. Finally, screed the entire surface with the inclined edge of the plate.

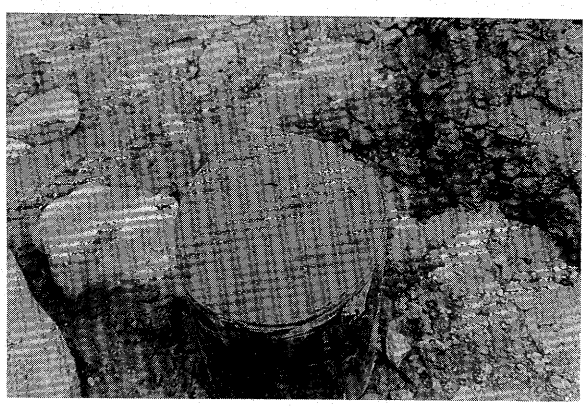


48. The sides and the bottom of the bucket are cleaned and weighed. The unit weight is calculated by subtracting the tare weight from the gross weight and divide by the container volume. Finally, calculate the yield by dividing the total weight of all the materials batched, (the water, cement,aggregates and admixtures) by the unit weight. Also, calculate the relative yield by dividing the unit weight tested by the theoretical unit weight designed. The result is the relative yield.



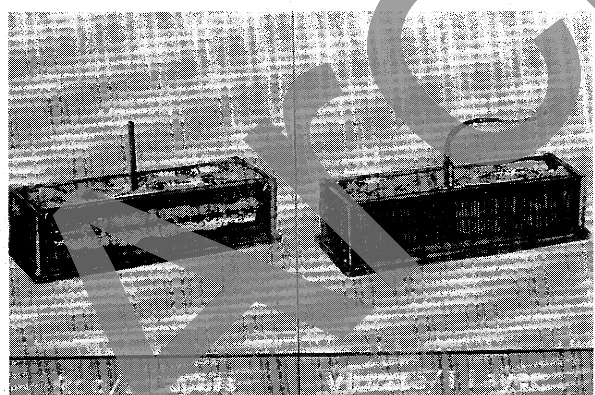
49. Some agencies will also require a **temperature test** to be taken during testing. ASTM C 1064 outlines the procedure. Maximum temperatures in State specifications usually run between 30°C and 32°C.

50. Metal, cardboard or plastic containers may all be used as **concrete cylinder molds.** Most States use 150 mm diameter by 300 mm high molds while some States have gone to 100 mm diameter molds which are 200 mm high. The smaller molds should only be used with mixes where the maximum size aggregate is equal to or less than 31.5 mm.

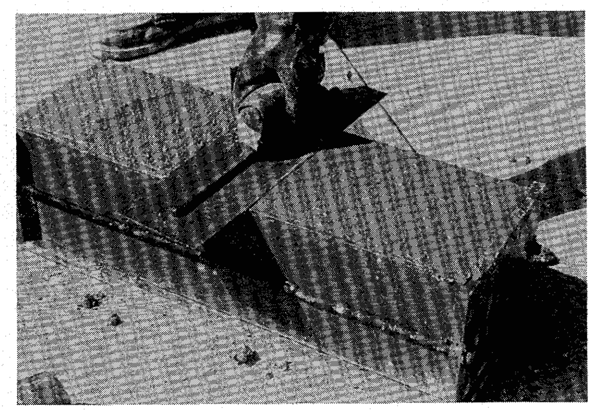


51. The cylinder molds must not deform during their preparation.

52. Concrete cylinders are made by the identical method that was used in filling the base of the air meters. Concrete is placed in three equal layers and rodded 25 times a layer.



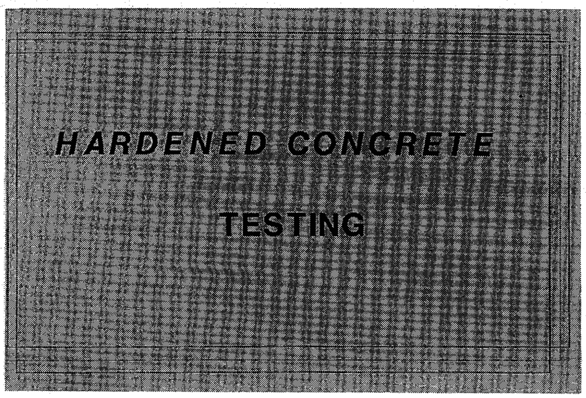
53. **Flexural specimens**, called concrete beams, are made from molds which measure 150 X 150 X 510 mm. Once the concrete is placed in the mold the perimeter should be spaded with a trowel. Concrete beams may be either rodded or vibrated. If the beams are to be rodded, then each layer must receive 60 evenly distributed roddings. If they are to be vibrated, they will be vibrated in one layer at three points along the specimen.



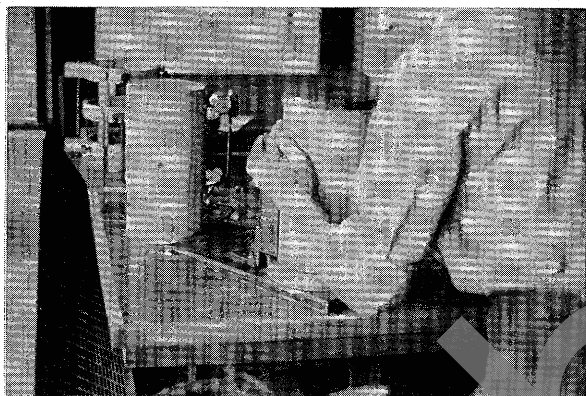
54. It is also necessary to tap the sides of the beam using a mallet in order to properly close any holes left in the beam by the tamping rod. With either procedure, the final step is to strike off the surface of the specimen with a trowel or wood float.

55. If the specimens are to be used to determine when forms may be removed or the pavement opened to traffic, the specimens should be stored and cured in the same manner as the structure.

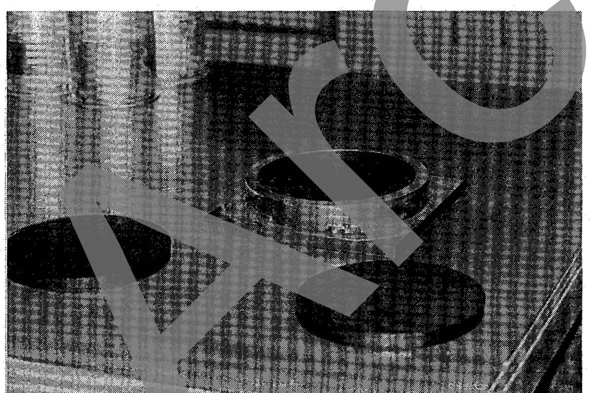
56. If the specimens are to be used to determine the quality of the concrete, the initial cure should be at 15°C to 25°C for 24 hours plus or minus 8 hours. The mold should then be removed and the specimen cured in saturated lime water, moist sand pits, curing box, or other suitable means to control temperature and moisture loss. If the specimens are to be transported prior to 48 hours the specimens can stay in the molds until the transportation is complete.



57. **Hardened concrete tests** are performed to determine either compressive or flexural strengths. In most States the concrete quality control tests are performed in either the district or central materials lab while the construction control tests (opening to traffic or form removal) is handled on the project.

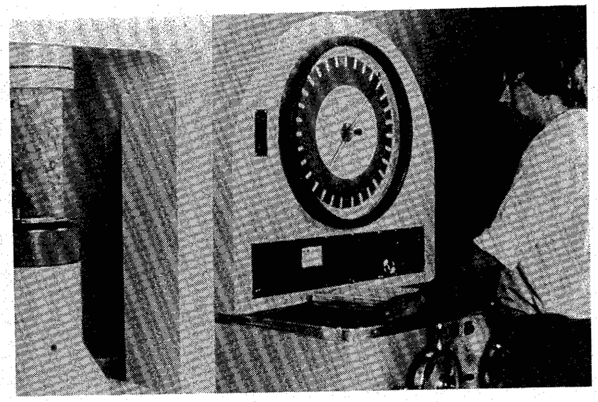


58. Prior to testing the concrete for compressive strength, the cylinders need to be capped to insure uniform distribution of the loads. In this case the cylinders are capped with a sulphur compound. The sulphur caps need to cure prior to breaking. The sulphur also should be tested periodically.

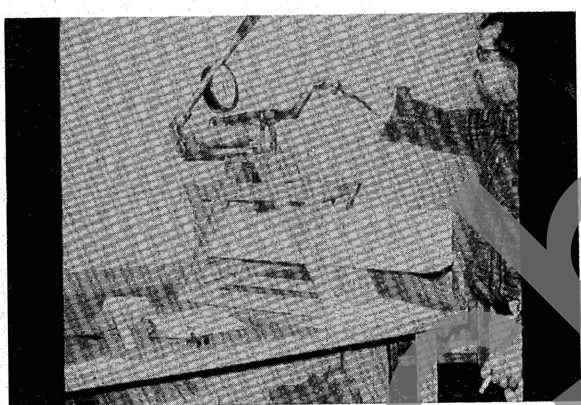


59. Many States now use **neoprene** material for caps. The specifications for the material is contained in an annex to AASHTO T 22. It should also be noted that neoprene caps are reusable for up to 100 cylinder breaks.

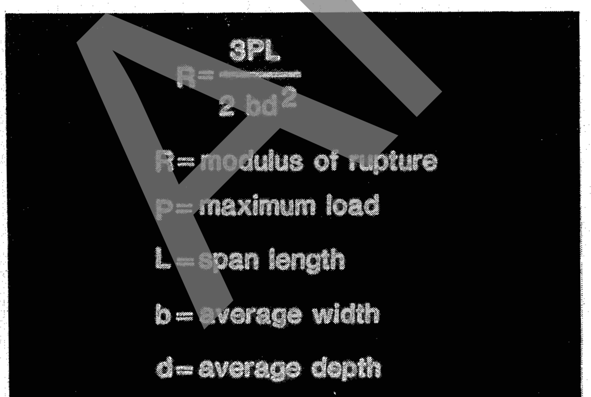
60. For accurate results, specimens must be tested in the moist cured condition. Dry specimens will break at higher pressures than moist specimens. The testing device should be calibrated at least once a year, and must be capable of applying the load continuously without shock. This requirement is necessary since concrete is capable of withstanding a higher impact load then a continuous load. It is necessary to average the compressive strength of two test specimens to obtain one test result. Should some cylinders fail to reach the expected strengths, they should be completely broken, since the breakage pattern may indicate the cause of the failure.

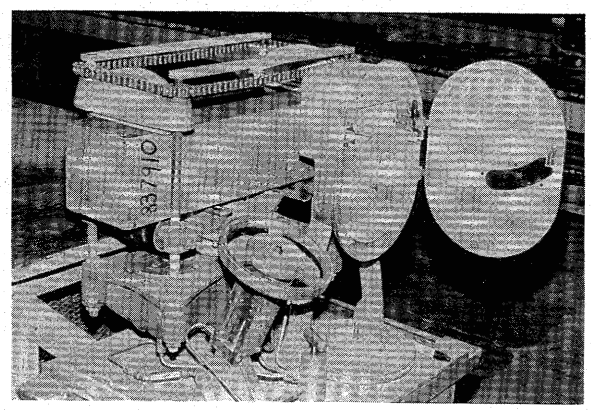


61. **Flexural strength** can be determined by either center point or third point loading. These testing machines should also be calibrated once a year. The **center point** procedure is shown here. The span is from support to support. The edge of the specimen needs to be at least 25 mm from the center of the support. Again the load needs to be applied continuously without shock. The test procedure appears in AASHTO T 177.



62. It is important to measure the specimen to insure the flexural strength is determined properly. Three measurements are taken and averaged. The center-point flexural strength is determine from the formula shown here.

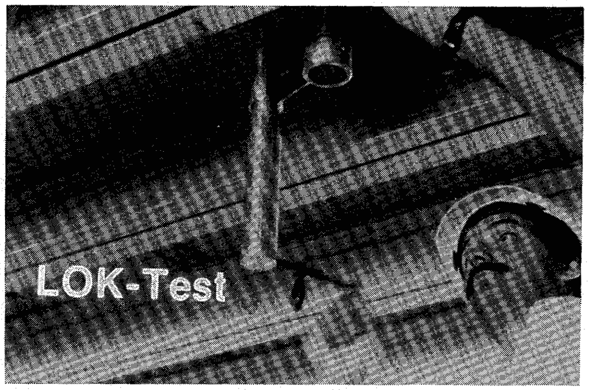




63. The **third-point** flexural test procedure appears in AASHTO T 99, and the device is shown here. The same items concerning loading and orientation of the specimen are the same as those indicated for center-point loading. Third-point load tests subject the material to procedures that are more rigorous than other strength tests. Depending on the fracture location, either the actual test result can be used, or one of the two equations in T97 must be used to compute the flexural strength.

64. Several methods exist for **nondestructive** concrete strength testing. The **Rebound Hammer** is used for determining the approximate strength of rock. It has also been used as a crude device for determining strength of concrete. The best way to utilize the device is compare results from the device on a part of the structure which has satisfactory strength to the results taken on a suspect area. The "strength result" should be based on 10 tests. The readings are subject to error depending on the surface that the device hits and whether it comes in direct contact with a piece of aggregate. In this way the device can be used to determine portions of the structure which need further investigation. The test procedure is contained in ASTM C 807.

65. Another method is the **Windsor Probe.** The first step is to fire three metal probes into the concrete. The average penetration of the probes is determined by using a triangle device. The strength is then found by entering a chart with the depth of penetration. This is not a standard test and is not typically used in highway construction. The test procedure is contained in ASTM C 803.



66. An additional method is the **LOK-test**. The first step is to cast studs into the concrete. The device is placed on a stud and the strength of the concrete is determined by the amount of torque that is needed to pull the stud out of the concrete. The device is typically used in the construction industry to determine when the forms can be removed. However it is not typically used in highway construction. The test procedure is contained in ASTM C 900.

In conclusion, concrete must be tested in both its plastic and hardened state to ensure it will fulfill its intended function. Various methods exist to test for each characteristic, and the one best suited to the needs can be selected.

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