U.S. Department of Transportation
Federal Highway Administration

PORTLAND CEMENT CONCRETE MATERIALS MANUAL

Associate Administrator
for Engineering and Program Development
Office of Highway Operations
Construction and Maintenance Division
Materials Branch

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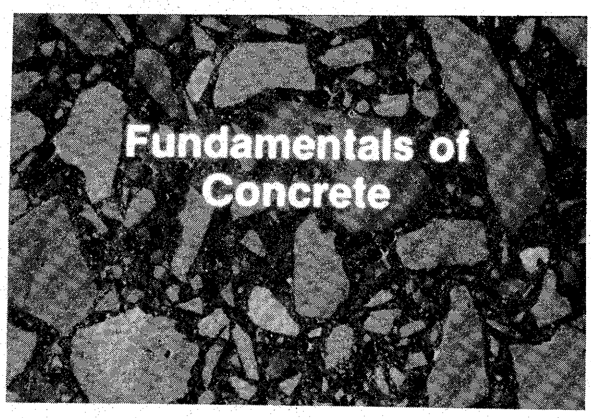
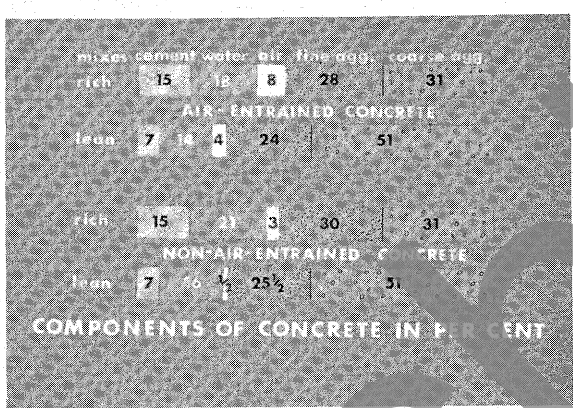
FUNDAMENTALS OF CONCRETE

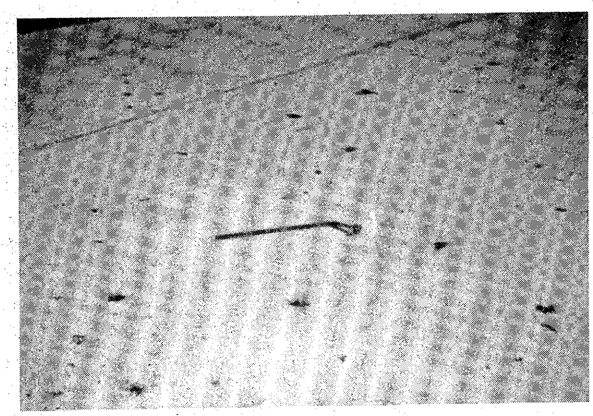


1. This introduction will provide an overview of the fundamentals of concrete and act as a frame of reference for the remainder of the course. To begin we ask the question, What is concrete? In response concrete can be defined as a mixture of two ingredients: aggregates and paste. The paste binds the aggregate into a rock-like mass as a result of a chemical reaction called hydration.

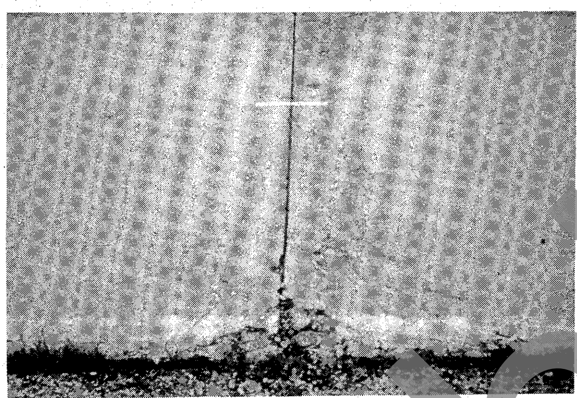


2. The paste portion of the concrete, that is, water, cement and air, makes up about 25 to 40 percent of the volume. The aggregate both coarse and fine, makes up the remaining 60 to 75 percent. Bars 1 and 3 are considered to be rich mixes and bars 2 and 4 are lean mixes. Rich mixes are ones that have a high percentage of paste. Note that the air content ranges from 1/2 percent in non-air entrained concrete to 8 percent in air entrained.

3. Aggregates make up most of the volume and, therefore, should consist of particles with adequate strength, 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 with particle sizes up to 1/4 inch. Coarse aggregates can start with particles retained on a No. 4 sieve and range up from there. A continuous gradation of sizes provides for efficient use of the cement and water paste.

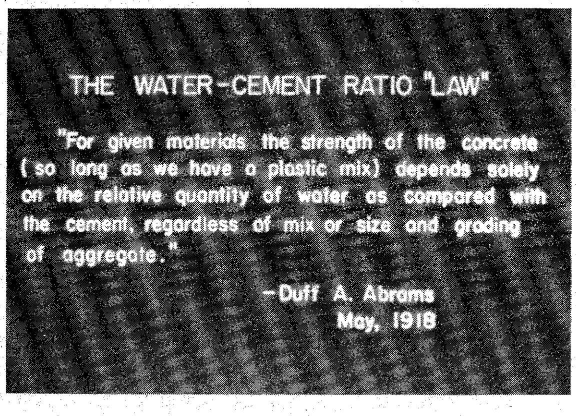


4. A number of problems associated with concrete can be traced to poor quality aggregates. Here, soft aggregates have caused pop outs in the concrete surface.



5. Another aggregate problem is that of "D" cracking. This is a problem with the pore structure of the aggregate and manifests itself through this characteristic cracking pattern.

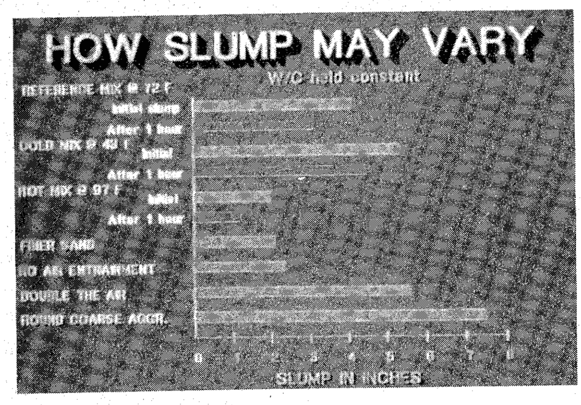
6. Some aggregates will react with the alkali content of the cement. When this happens the concrete expands resulting in this map cracking pattern.



7. The quality of concrete also depends upon the quality of the paste. Each particle of aggregate should be coated with paste and all spaces between aggregate particles should be completely filled. The cement paste contains Portland Cement, water, and entrapped or purposely entrained air. As we have all heard many times before, the strength of the concrete is determined by the water/cement ratio. The principle was understood as far back as 1918. The indiscriminate addition of water will increase the w/c ratio and adversely affects 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 bond between concrete and reinforcement
   - 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 semifluid, capable of being molded by hand. A plastic mix keeps the components in place and does not allow segregation during transport. Plastic concrete should not crumble but flow sluggishly.



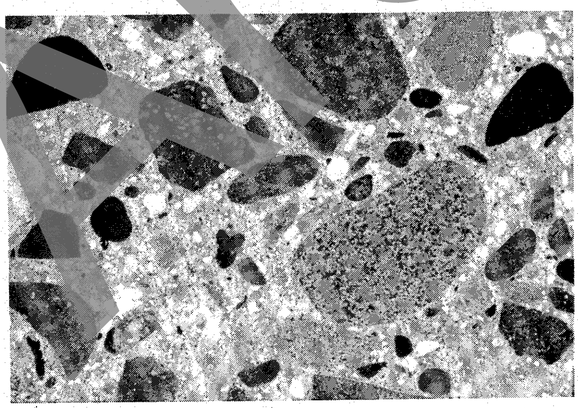
9. Plastic concrete should be uniform from batch to batch. In order to have a finished product that is of consistent quality throughout, then each batch of plastic concrete, that goes into a structure, must be the same. A commonly used measure of uniformity or consistency is slump. A number of factors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

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

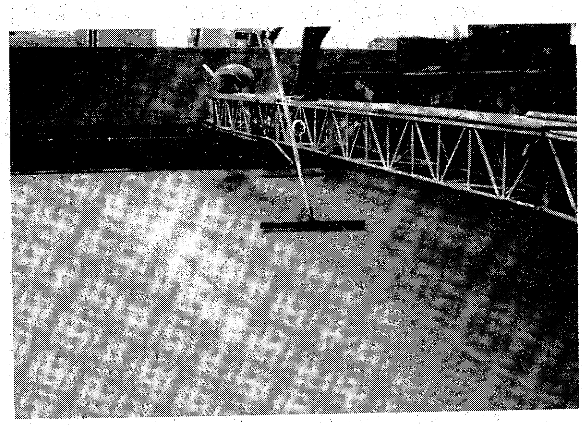
12. Consolidation is another important consideration of fresh concrete. Vibration sets the particles in concrete into motion, allowing the mix to become mobile. This allows the concrete to mold to forms and around reinforcing. Vibration permits the use of stiff mixtures with a larger proportion of fine aggregate. Also, vibration allows the use of high coarse aggregate content concrete. 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. Over vibration or vibrating normally workable mixes can cause segregation.

13. Conversely, under consolidation can result in honeycombing. Here, all of the entrapped air has not been driven off through vibration.

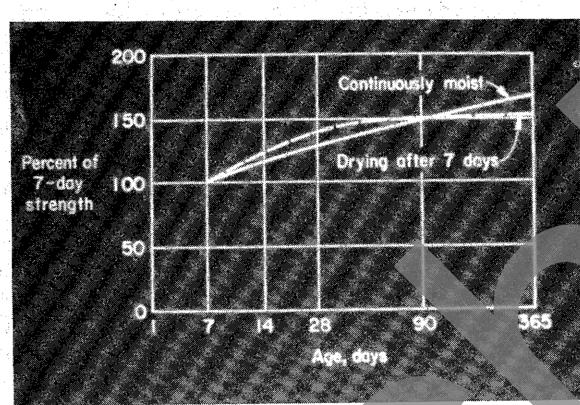


14. The binding quality of Portland Cement is due to the chemical reaction between the cement and water called hydration. Portland Cement is a complicated chemical made up of many compounds. The chemical composition of cement is transformed during hydration to form calcium hydroxide (lime) and calcium silicate hydrate. The properties of concrete, including setting time and strength depend upon the formation of this later compound. Knowledge of the heat released during hydration and the rate of the reaction are important to proper construction planning.

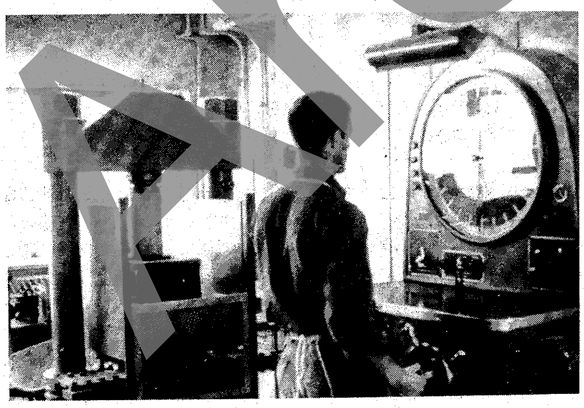
15. Hardened concrete should be durable, that is, it should have the properties of strength, abrasion resistance and resistance to freezing and thawing.

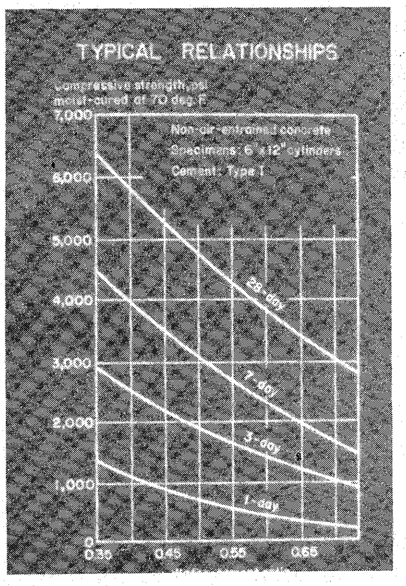


16. Concrete gains its strength through the hydration process. Concrete will continue to hydrate as long as there is moisture available for the reaction. If we cure the concrete under moist conditions, therefore, the concrete will continue to gain strength. Here you can see that after 7 days, concrete 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 because it is dry, is no indication that it has hydrated enough.

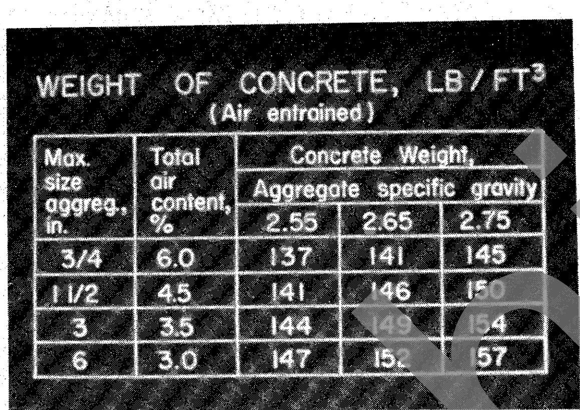


17. Strength is normally considered the primary property of concrete quality. Compressive strength is needed for bridges and structures, flexural is needed for pavements and slabs. As a general rule of thumb, flexural strength of normal weight concrete is about 8 to 10 times the square root of the compressive strength.





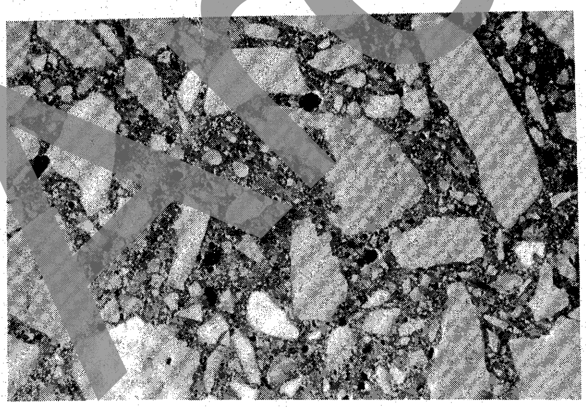
18. The principle factors affecting strength of concrete are its water/cement ratio and its age. This slide shows compressive strengths for a range of water/cement ratios and ages. Note how strength increases with a decrease in w/c ratio and an increase in age. Air entrained concrete tends to have slightly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



WEIGHT OF CONCRETE, LB / FT³
(Air entrained)

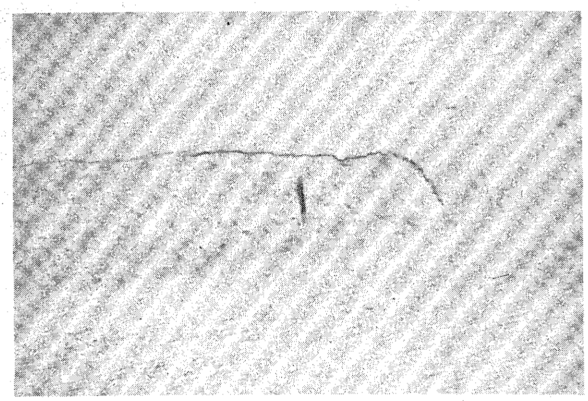
Max. size aggreg., in.	Total air content, %	Concrete Weight, Aggregate specific gravity 2.55	2.65	2.75
3/4	6.0	137	141	145
1 1/2	4.5	141	146	150
3	3.5	144	149	154
6	3.0	147	152	157

19. Concrete that is normally used in highway work has a unit weight (or density) of 140 to 150 pcf. The unit weight test can be used to determine the uniformity of concrete from batch to batch. Factors which determine the unit weight are the density of the aggregate, the amount of air, 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 15 pcf and heavy weight concrete can run as high as 375 pcf.



20. In order for concrete to have a long life and low maintenance, it must be durable. In addition to high strength, durable concrete must be resistant to freezing and thawing, be watertight, abrasion resistant, and crack free.

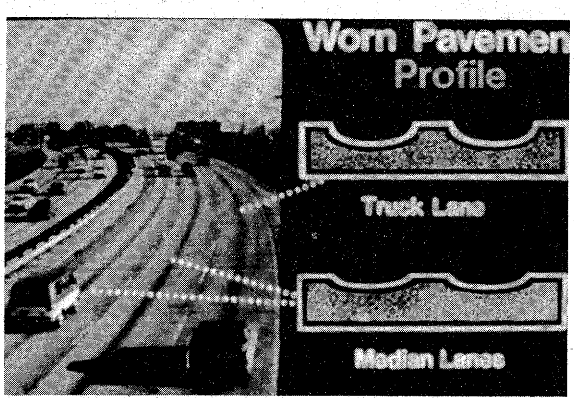
Nondurable concrete suffers from deterioration often caused by the freezing of the water in the paste. With air entrained concrete, however, resistance to freeze thaw is greatly improved. During freezing, the air bubbles provide chambers for the particles to expand into.



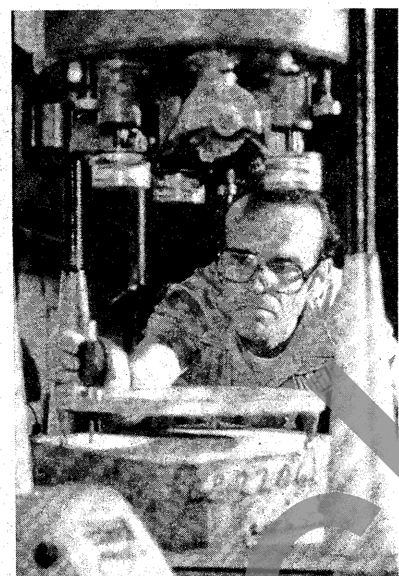
21. Concrete made without air entrainment are subject to scaling. Under severe conditions, however, even air entrained concrete can exhibit scaling.

22. Concrete exposed to weather or severe conditions should be watertight. Water can penetrate the concrete depending upon its permeability. If the intruding water contains a high chloride content then the concrete could deteriorate to the point of failure.

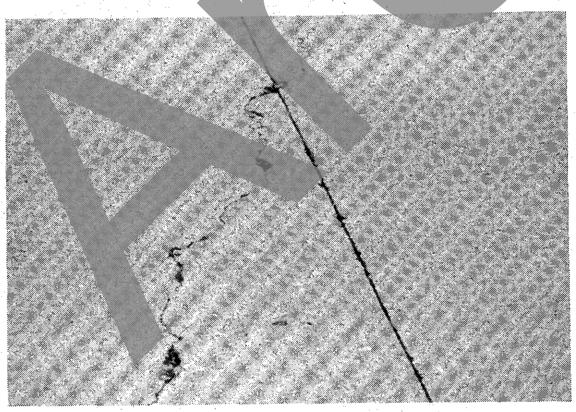
23. Watertightness of the concrete depends on the water/cement ratio and the length of moist curing. Here you can see the apparatus for making watertightness test on cement mortar disks. If the results of there tests were to be plotted, it would indicate that the lower the water/cement ratio the less leakage occurs. Also, it can be shown that the longer specimens are moist cured the more watertight the concrete.



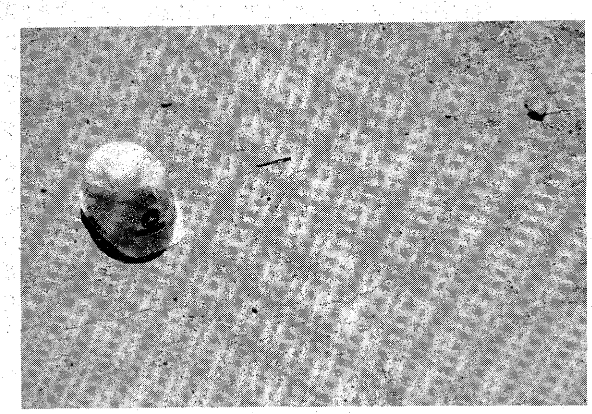
24. Depending on the use of the concrete, abrasion resistance becomes an important consideration. Concrete pavements can become worn with age, particularly where studded tires have been used. Worn pavements can become slippery if the aggregates are easily abraded.



25. This slide shows the test apparatus for measuring abrasion of concrete used in pavements. The strength of the concrete, as well as the type of aggregate will influence the results.

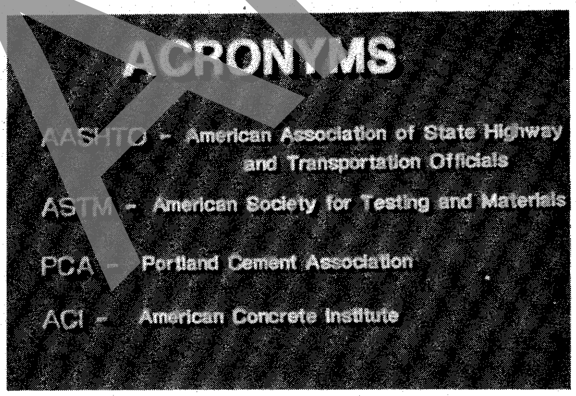


26. One final consideration for obtaining durable concrete is the control of cracking. Cracking can be caused by applied loads, expansion and contraction or by drying shrinkage. Proper placement of joints in concrete work can reduce the amount of cracking. In concrete pavements, timely sawing of joints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



27. Plastic shrinkage cracks result when the water in the concrete evaporates from the surface at too fast a rate. These problems are most common when doing concrete in hot weather.

28. In this slide we have summarized those items that are necessary for durable concrete.



29. The material presented on concrete was taken from the best available sources. These include AASHTO, ASTM, PCA, and, ACI.

30. In conclusion, we will try to emphasize, in this course, 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 and a higher production rate.

PORTLAND CEMENT

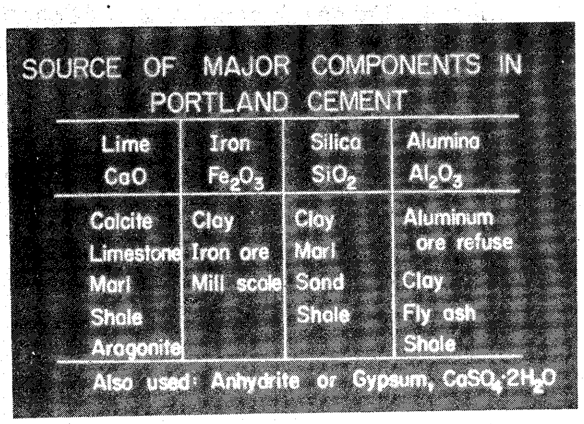
1. Portland Cements, by definition, are hydraulic cements; that is, they set and harden by reacting with water. The process is called hydration.

   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 quarried on the Isle of Portland in the English Channel.

   The first U.S. patent on Portland Cement was made in 1872.

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.

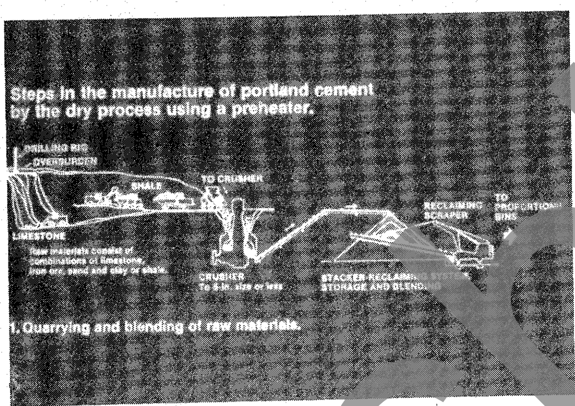


SOURCE OF MAJOR COMPONENTS IN PORTLAND CEMENT

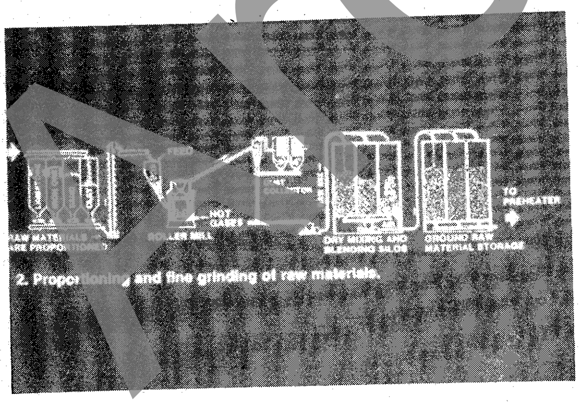
Lime CaO	Iron Fe_2O_3	Silica SiO_2	Alumina Al_2O_3
Calcite	Clay	Clay	Aluminum ore refuse
Limestone	Iron ore	Marl	Clay
Marl	Mill scale	Sand	Fly ash
Shale		Shale	Shale
Aragonite			

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

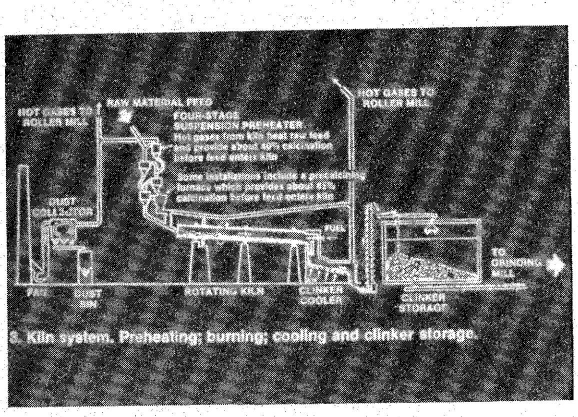
4. The four major chemical components that must be present in the raw materials in order to produce Portland Cement are Lime, Iron, Silica, and Alumina. Sources for these raw materials are illustrated here. Note that some raw materials are available from the same source.



5. The raw materials can be combined in either a dry or a wet process. This slide 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 into 5-inch, or smaller, size.



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

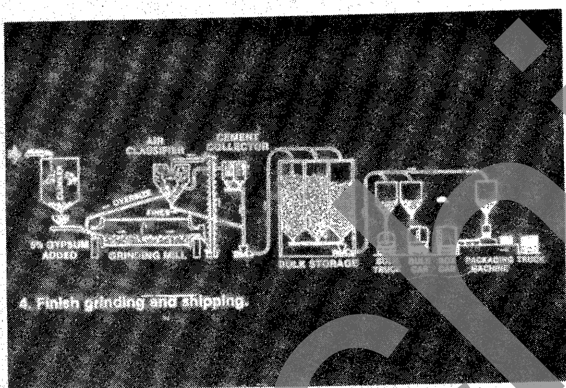


3. Kiln system. Preheating; burning; cooling and clinker storage.

7. The raw materials are preheated, then enter the kiln where temperatures are between 2600 and 3000 degrees F and 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.

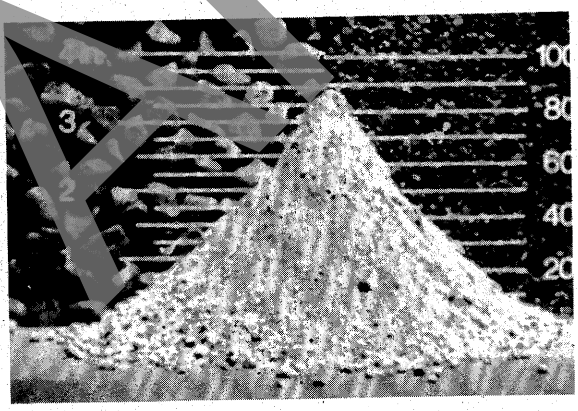
The cement clinker consists essentially of hydraulic calcium silicates.



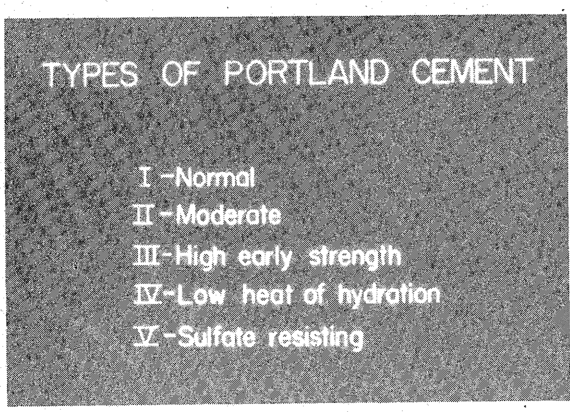
4. Finish grinding and shipping.

8. The clinker is cooled, pulverized, and then stored or shipped.

Note the addition of gypsum which is added to control setting time and helps in obtaining optimum strength.



9. After the final grinding, the cement is a fine powder whose particles are so small that they could pass through a sieve with 40,000 openings per square inch.



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

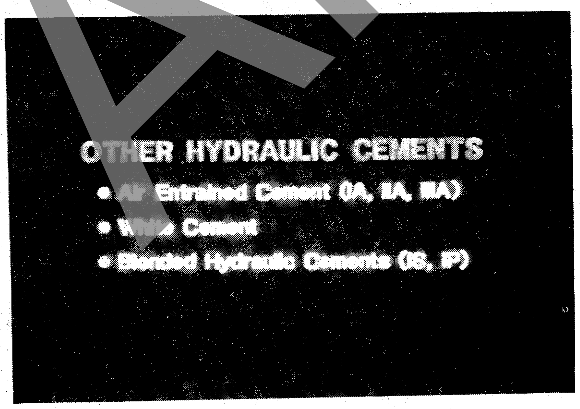
- <u>Type I</u> is a general purpose cement that is used when there are no extenuating circumstances.

- <u>Type II</u> 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.

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

- <u>Type IV</u> 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.

- <u>Type V</u> is **a high sulfate-resistant cement.**

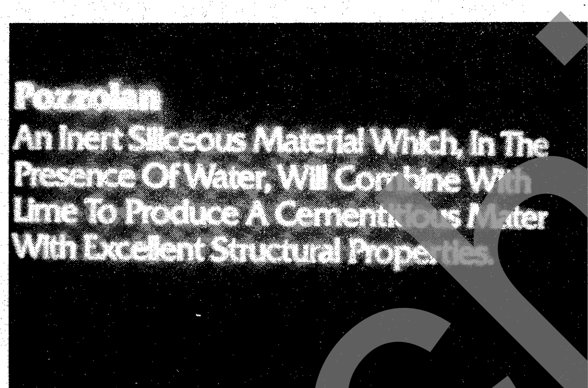


11. There is also other less common types of hydraulic cements. For example, there are <u>Type IA, IIA and IIIA cements</u> that corresponds to the Types I, II and III except that a small amount of air-entraining agent is interground with the clinker.

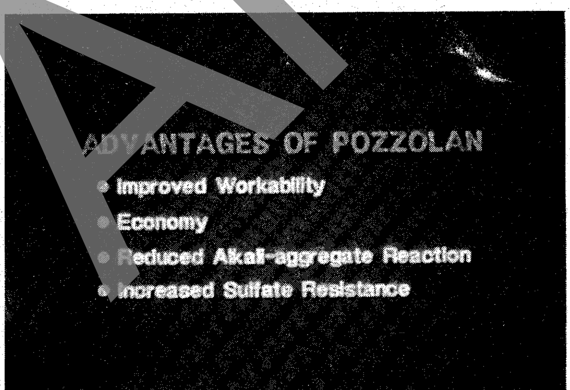
It is possible to specify a **white Portland Cement;** however, this is used mostly for architectural purposes or for color contrast, such as in curbs and median barriers.

Blended hydraulic cements (ASTM C 595) consist of Portland Cement combined with some other ingredient.

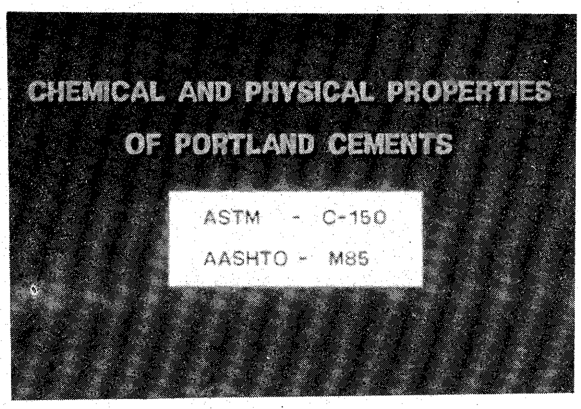
There are several types of blended cements depending upon what is added to replace the cement in the clinker. Type IS cements are ones that have had blast-furnace slag added. As much as 65 percent to 75 percent slag may be substituted for the cement. Type IP cements have had a pozzolan added in place of a portion of the cement clinker.



12. <u>A Pozzolan</u> is a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will react chemically 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 accounts for between 15 percent and 40 percent of the weight of the cement.**



13. Just briefly, some of the advantages of using a Pozzolan are: improved workability, economy, reduce alkali-aggregate reaction, increase sulfate resistance, and reduced heat generation, volume change and bleeding.



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

COMPOSITION OF CEMENTS

Type	Compound, %				Wagner fineness, m^2/g
	C_3S	C_2S	C_3A	C_4AF	
I	55	19	10	7	0.18
II	51	24	6	11	0.18
III	56	19	10	7	0.26
IV	28	49	4	12	0.19
V	38	43	4	9	0.19
White	33	46	15	2	

15. Now let's look at what distinguishes one type of cement from another. When the clinker is formed during the manufacturing process, four principal compounds are created. The figures shown in the chart represents a typical composition.

- Tricalcium silicate (C3S) hardens 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 puts a maximum of 35 percent on only Type IV.

- Dicalcium silicate (C2S) hardens slowly, thus it is responsible for low heat of hydration and ultimate strength. Type IV (Low heat of hydration) cement has the highest percentage of dicalcium silicate. C150 puts a minimum on dicalcium silicate of 40 percent for type IV cements.

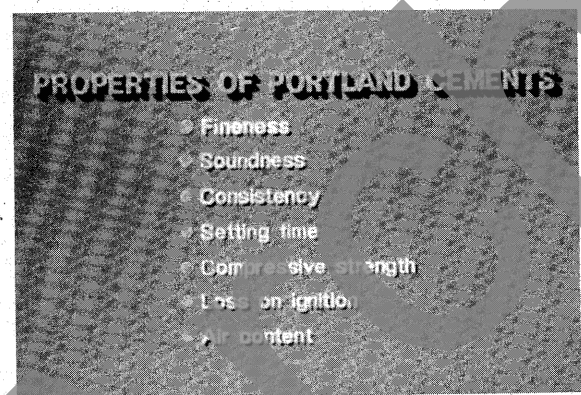
- Tricalcium aluminate (C3A) liberates large amounts of heat in the first days of hardening and contributes to early strength development. High amounts of this material, however, contribute adversely to the resistance to sulfate attack. Consequently, Type III cement (High Early Strength) has a higher percentage of C3A than Type V (Low Sulfate).

C 150 has maximums as follows:

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

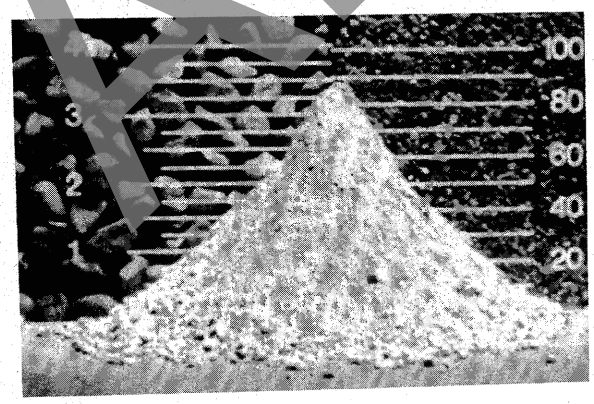
- Tetracalcium Aluminoferrite (C4AF) reduces the clinkering temperature, thus assisting in the manufacturing process. It acts like a flux in burning the clinker. A maximum of 20 percent, on Type V only, appears in C 150.

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



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

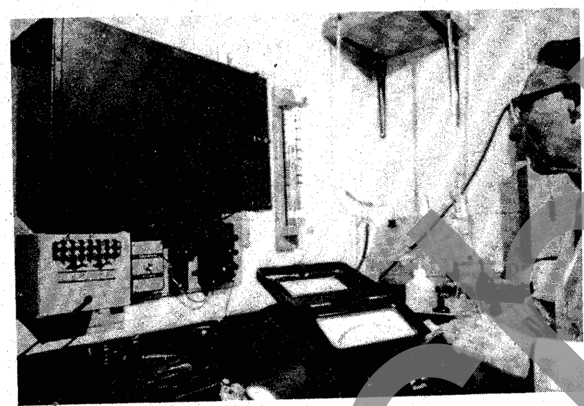
Let's look at some of these in more detail.



17. You remember it was said that the ground-up clinker is fine enough to pass through a mesh with 40,000 openings per square inch.

This fineness of the cement affects the rate of hydration. Greater fineness increases the surface available for hydration causing greater early strength and more rapid generation of heat. Type III cement, therefore, has a high fineness. 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.

The significant difference between AASHTO M 85 and ASTM C 150 concerns the fineness of the cement. AASHTO M 85 requires a coarse cement which will result in higher ultimate strengths and lower early strength gain.



18. This apparatus 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 gathered on a photoelectric cell that generates a measurable amount of electricity. Through calibration, the fineness can be determined from the electricity generated. This test is AASHTO T 98 or ASTM C 115.

The measures of fineness is known as specific surface and is the summation of the surface area, in square centimeters, of all particles in one gram of cement.

19. Another accepted test for fineness is the Blaine air permeability test, ASTM C 204 or AASHTO T 153.

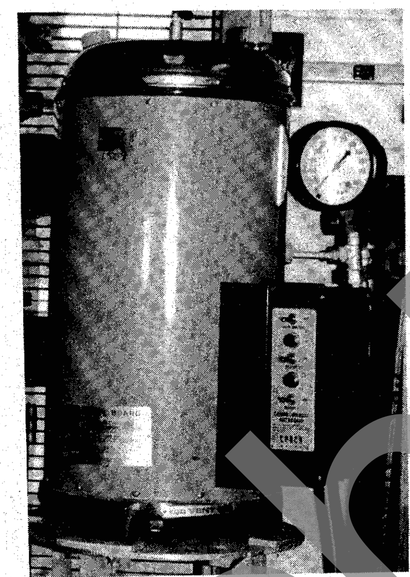
This test consists of a means of drawing a definite quantity of air through a prepared bed of cement. The fineness can be calibrated to the air flow through the cement.

Most modern cements have a Blaine fineness that ranges from 2600 to 5000 sq cm/g.

ASTM classification of cements requires a minimum of 2800 for Type I cement.

Cements with a fineness below 2800 may produce concrete with poor workability and excessive bleeding.

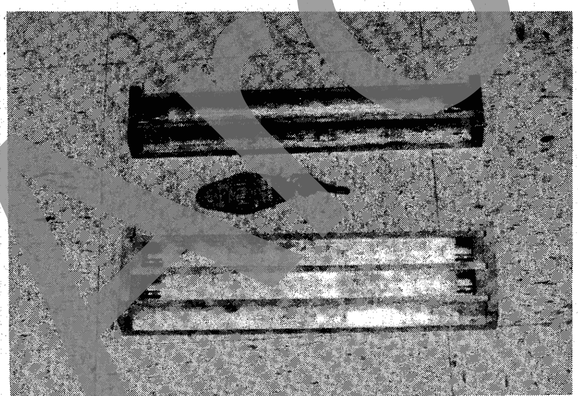
There is an approximate correlation between the Wagner and Blaine methods. The Blaine method is equal to about 1.8 times the Wagner method.



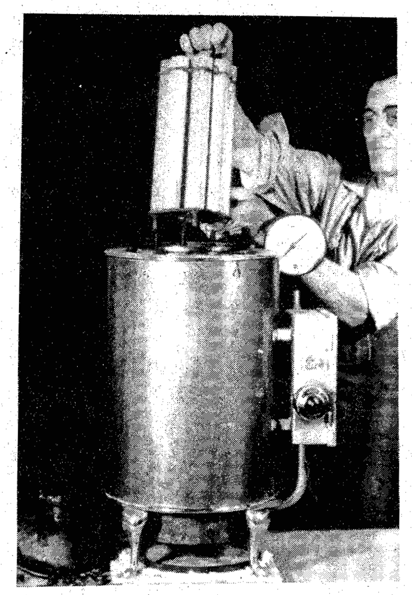
20. **Soundness refers to the ability of hardened cement paste to retain its volume after setting.**

Expansion of the cement is caused by excessive amounts of lime or magnesia in the cement.

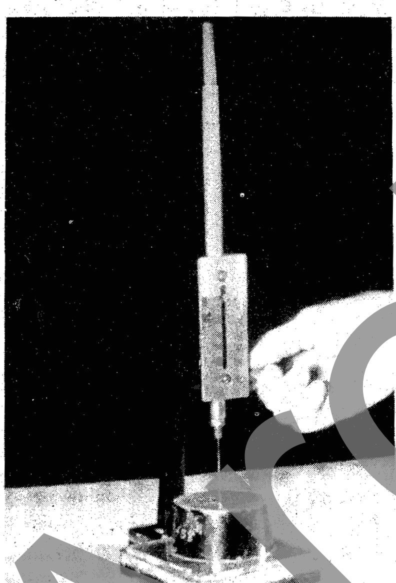
The test for cement soundness is the Autoclave expansion test. This is ASTM C 151 or AASHTO T 107.



21. One-inch by one-inch cross section molds are used to form cement paste specimens 11 and 1/4 inches long. After curing for 24 hours, the specimens are measured for length and then placed into the autoclave.



22. The specimens will be subjected to saturated steam at 295 PSI for 3 hours. The specimens are 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.

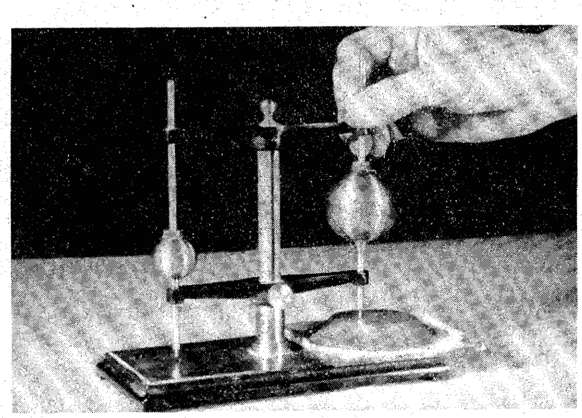


23. The cement should not set up too soon nor should it occur too late.

Setting time tests are performed to determine if normal hydration is taking place in the first few hours.

Demonstrated here is the <u>Vicat apparatus</u> 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 is test C 191 in ASTM or T 131 in AASHTO.

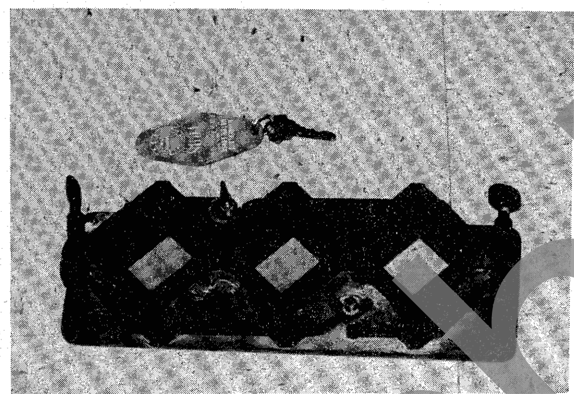
The Vicat apparatus is also used to determine the consistency of cement. Consistency means the cement's ability to flow. In this test, the needle is replaced with a 10 cm diameter plunger. Normal consistency is defined as a 10 mm drop of the plunger in 30 seconds. The moisture content used to obtained this consistency is then used for mixing the paste in the setting time test. (ASTM C 187)



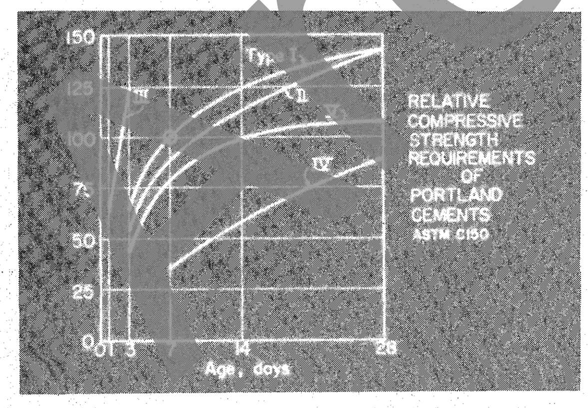
24. Another test for setting time is the <u>Gilmore test</u>. The apparatus is shown here.

In this test, two needles with different weight 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.

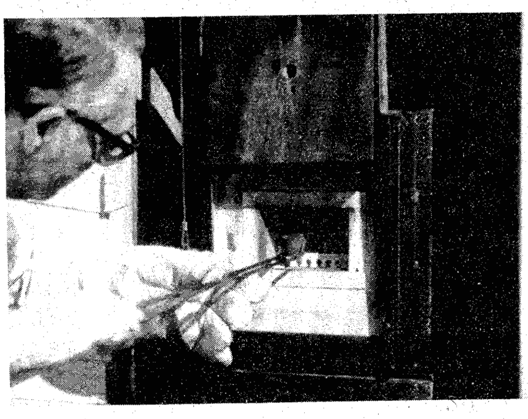
There is no correlation between these tests and the setting time of concrete. ASTM designation is C 266, AASHTO is T 154.



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



26. For a Type I cement, 7-day strength of one inch mortar cubes should not be less than 2800 PSI. Using that as a reference, this slide shows the relative compressive strength requirements for the various cements at various ages. Compressive strength testing is described in AASHTO T 106 or ASTM C 109.

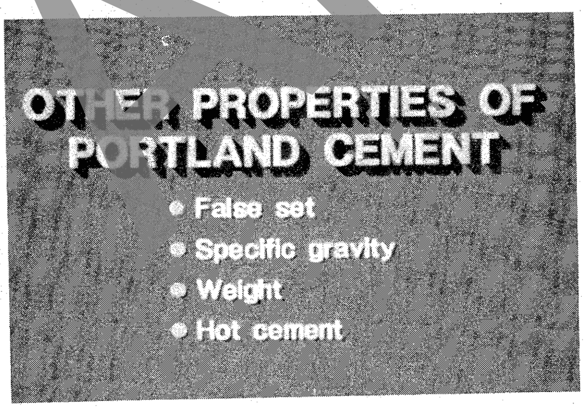


27. This slide shows a technician performing a **loss on ignition test.** The cement sample is heated to 1000 degrees C until it reaches a constant mass. The mass loss can then be calculated. This is test ASTM C114.

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 1/2 inch, 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.

First is **False set.** This 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 in the United States is usually measured by the bag at 94 pounds. **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.

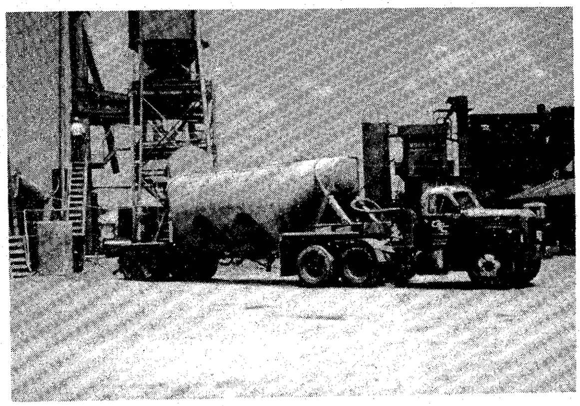
Hot or green cement is sometimes encountered. Sometimes during peak periods cement plants will have difficulty keeping up with demand. Consequently, cement may be coming directly from production to the concrete plant. Also, cement may become hot due to silos being located in direct sunlight. When this happens, cement at elevated temperatures could be used in concrete. This could cause stiffening of the concrete mix. An upper limit of 150 to 180 degrees F is recommended for cement.

30. One final item to cover on cement is **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, with bags stacked on pallets and not against an outside wall.

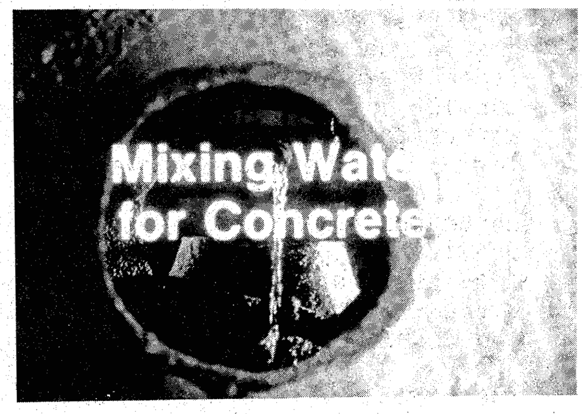
When storing bagged cement outdoors, they should be stacked on pallets and covered all over with a waterproof covering; they should not be stored where they will get wet from ponded or runoff rain water.



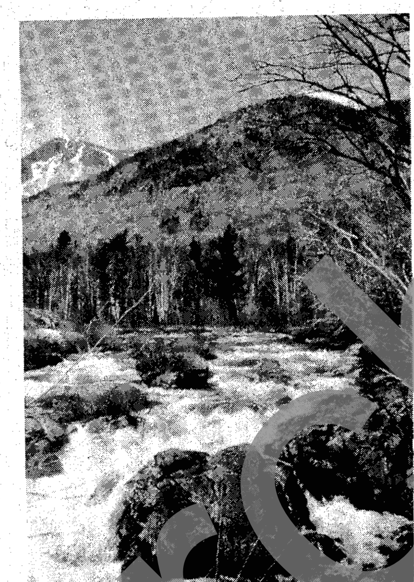
31. Most cements that arrive on a construction project will be by bulk. Storage of bulk cement should be in a watertight bin or silo. Separate compartments or bins should be provided for each type of cement. Transportation should be in vehicles with watertight and properly sealed lids. Cement conveyance 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.

The result of improper storage and handling is lumpy cement. Loss on ignition or strength tests should be performed on cements that have been stored for long periods of time.

MIXING WATER



1. The next concrete ingredient that we want to consider is water.



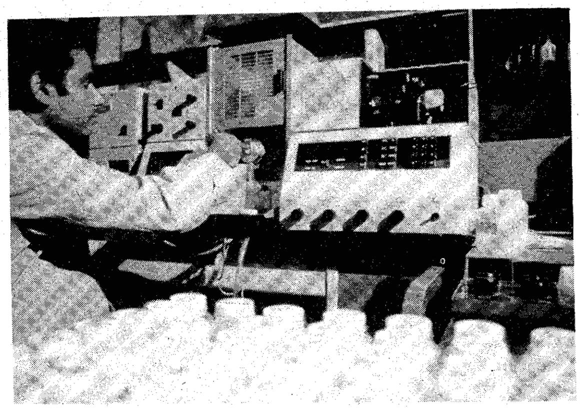
2. **Water has two main functions; it reacts with the cement during hydration and it acts as a lubricant, contributing to the workability of the concrete.** Because of this, it is important that the water be relatively pure. What is meant by pure?

3. In general, potable water is suitable for use as mixing water for concrete. Water suitable for making concrete, however, may not be suitable for drinking.

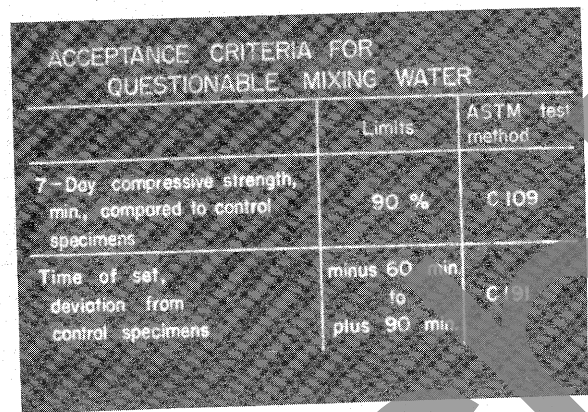
   Two criteria should be considered when evaluating water for concrete.

   - Will the impurities affect the concrete quality?

   - What level of impurity can be tolerated?



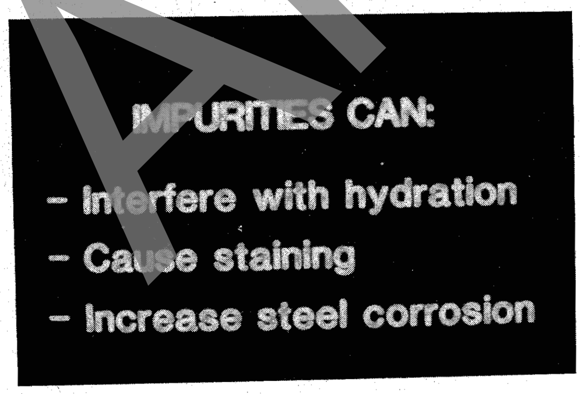
4. When the water is of questionable quality, it should be tested to determine if there are impurities in the water. Here an atomic absorption spectrophotometer is being used to detect metallic or chloride ions.



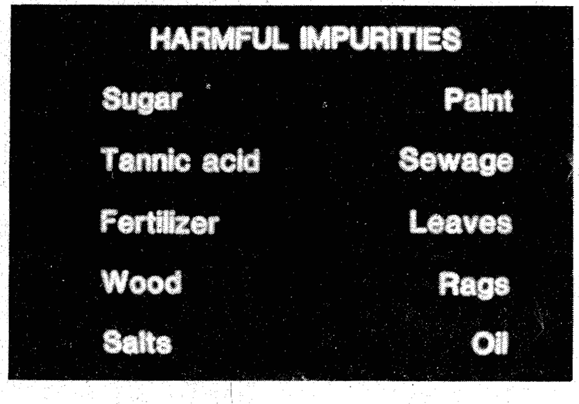
ACCEPTANCE CRITERIA FOR QUESTIONABLE MIXING WATER

	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

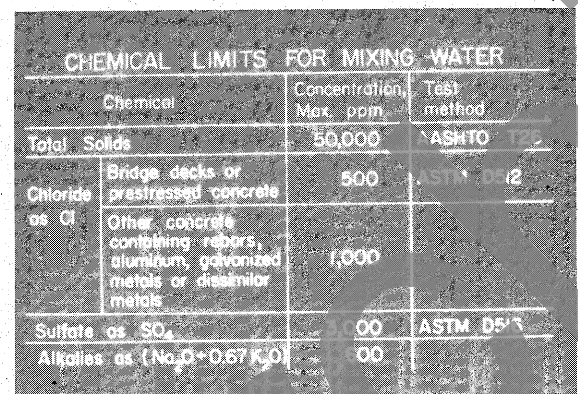
5. The water's affect on the physical properties of the concrete should be performed to determine if the levels of impurities will be harmful. **Strength and time of set tests should be performed.** Mortar cubes made with the proposed water should have 7 and 28 day strength at least equal to 90 percent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



6. Impure water can shorten or extend the setting time of concrete as well as cause efflorescence, staining, or corrosion of reinforcing.



7. Water that is considered to be harmful may contain excessive amounts of the items indicated on the slide. 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 to become contaminated, particularly well water.



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 $(Na_2O + 0.67 K_2O)$		600	

8. **The limits for certain chemicals** for 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 or dissolved solids exceed 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 **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 wash 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.

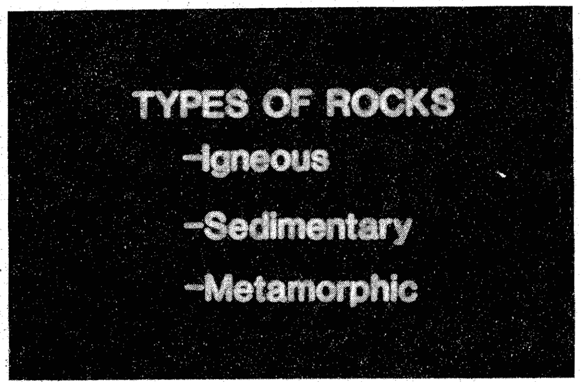
12. In conclusion, if the water is drinkable, it is usable for all aspects of a concrete operation. If there is any question about the concrete-making quality of the water, a sample should be submitted for evaluation. If the water does not have any particular taste, odor, or color, and does not fizz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

AGGREGATES

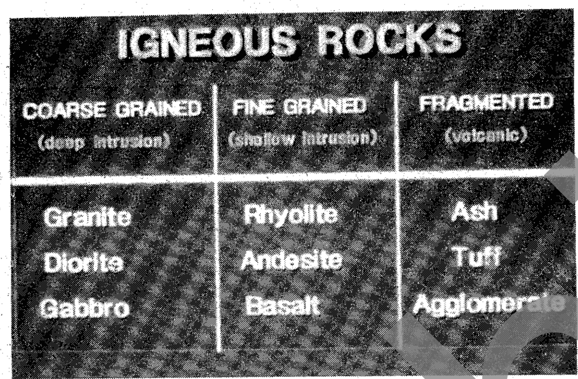
1. Aggregates constitute about 60 percent to 80 percent of the volume of concrete and have a strong influence on the concrete's properties. Aggregates must conform to certain standards. **For best results, they should be clean, hard, strong, durable particles free of absorbed chemicals, clay or other materials that could affect hydration or bond.**

   Aggregates that should not be used are ones that are friable (readily crumbled), ones that contain shale or ones that contain other soft and porous materials. Aggregate with these characteristics can cause surface defects such as popouts.

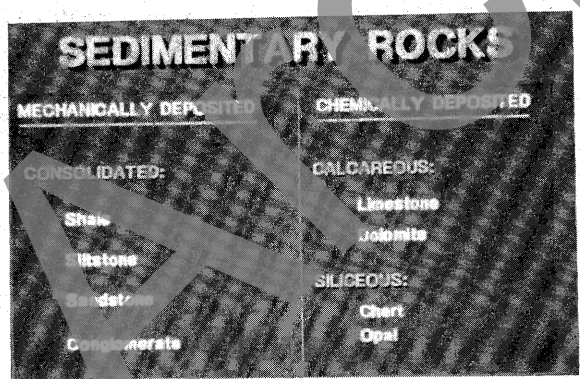
2. Naturally occurring concrete aggregates are a mixture of minerals and rock. **Minerals** are defined as naturally occurring inorganic substances of a definite chemical composition and a specific crystalline structure. **Rocks** are generally composed of one or more minerals. Rocks compose most of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



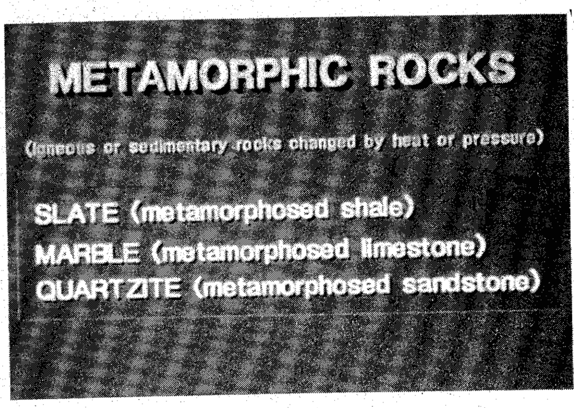
3. **Rocks are classified in accordance with their origin; that is igneous, sedimentary and metamorphic.**



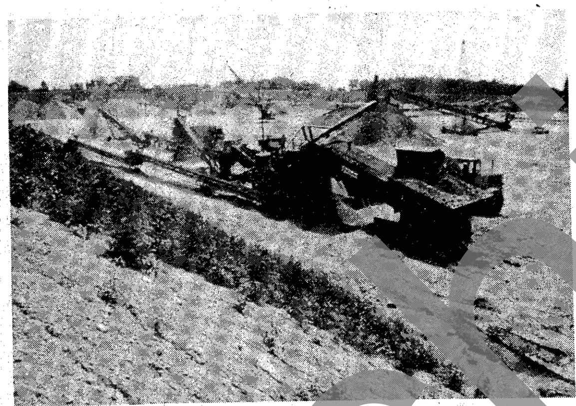
4. **Igneous rocks** are those that have cooled from a molten rock mass. Igneous rocks can be subdivided into intrusive or coarse grained and extrusive or fine grained. Intrusive is formed during slow cooling of the molten mass and are exemplified by granites. Extrusive are cooled more quickly, such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



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.

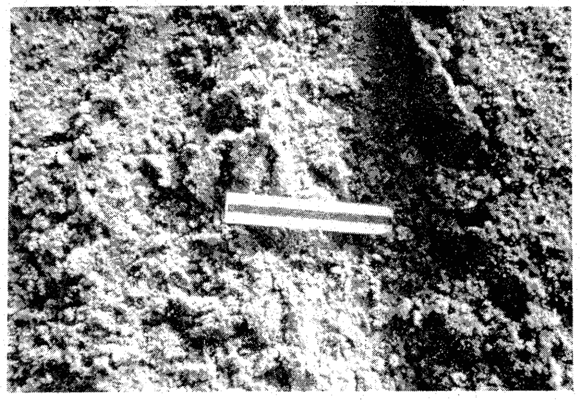


6. **Metramorphic rocks** start out as either igneous or sedimentary rocks. Through the application of heat, pressure, water or any combination of these, the rock is physically altered or metamorphosed into a new type of rock. Sedimentary rocks, which undergo metamorphosis are generally harder, tougher 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.

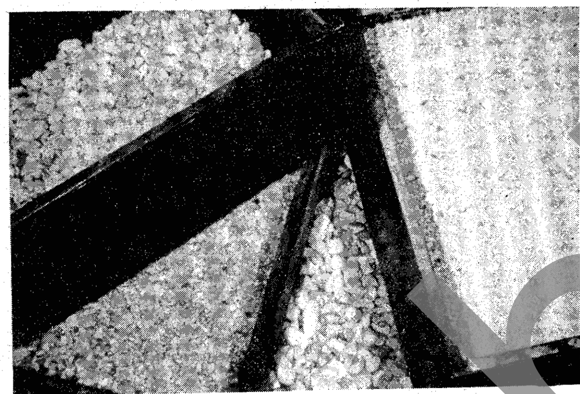


7. Concrete aggregate sources are generally gravels and crushed stone. Naturally occurring aggregates are called gravels. Sometimes gravels are put through a crushing operation to reduce their size or to improve their shape. Some artificial aggregates are used but generally for specific purpose concretes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

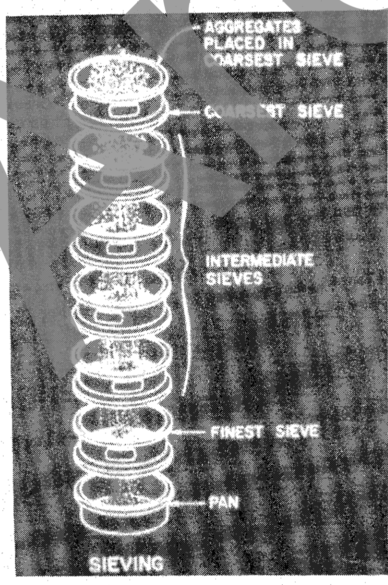
8. About half of the concrete aggregates used in the United States come from gravels, the other half come from a rock source such as a quarry where the rock has been put through a crusher.



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 the **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 W/C 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 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 doing 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)

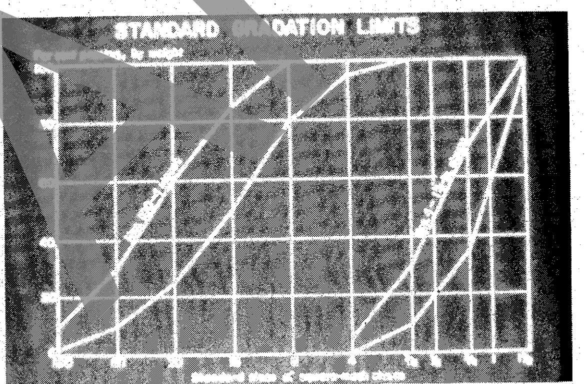
12. To make testing of aggregates more manageable, the aggregates are generally divided into two classifications; coarse aggregate and fine aggregate. The distinction between these two size classes is based on whether or not the aggregate will pass a particular sieve.

The most common sieve used for this purpose for concrete is the 4.75 mm. (No. 4) 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 slide 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 assures you that there will be no gaps in your 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.

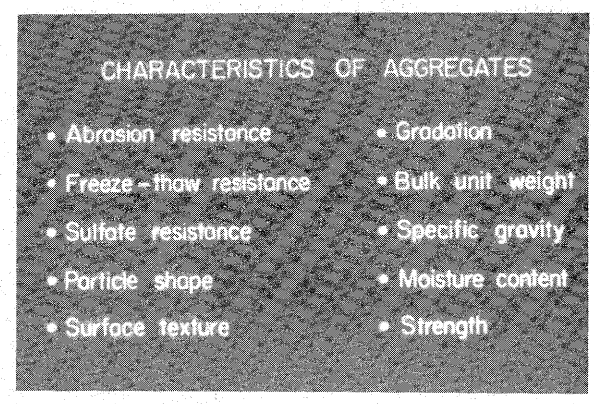
SIEVE ANALYSIS AND FINENESS MODULUS OF SAND

Sieve	Percentage passing (by weight)	Cumulative percentage retained (by weight)	Percentage retained between sieves *
No. 4	98	2	
No. 8	85	15	13
No. 16	65	35	20
No. 30	45	55	20
No. 50	21	79	24
No. 100	3	97	18

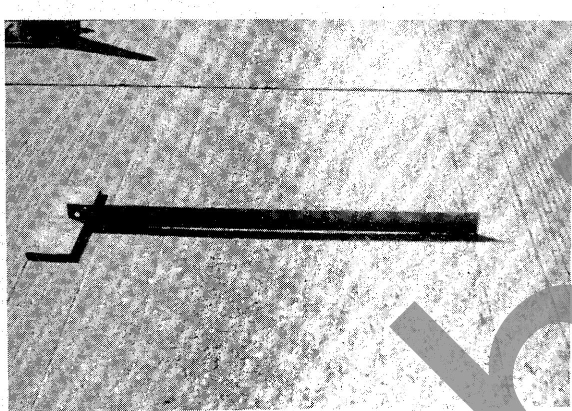
Fineness modulus = 283 ÷ 100 = 2.83

*ASTM C33 limitation: 45 %

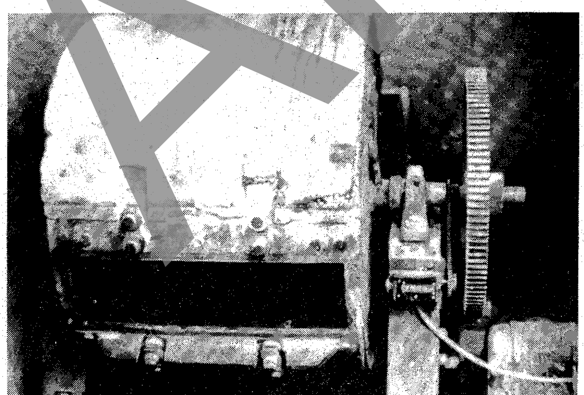
15. One important characteristic that can be determined from the fine aggregate gradation is the **fineness modulus. This is simply the sum of the total percentages retained on each of a specified series of sieves divided by 100.** This value represents an average particle size. Aggregate gradations having the same fineness modulus 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 fineness modulus of the aggregate. **The fineness modulus 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 fineness modulus the coarser the aggregate. The cement content will vary inversely with the fineness modulus. A very large amount of very fine material, that is material passing the number 200 sieve, will cause the FM to go down. In addition, a low FM will reduce the air content and more air entrainment will be required. ASTM C 33 or AASHTO M 6 specifies the sieve sizes to be used and recommends the 0.2 tolerance.



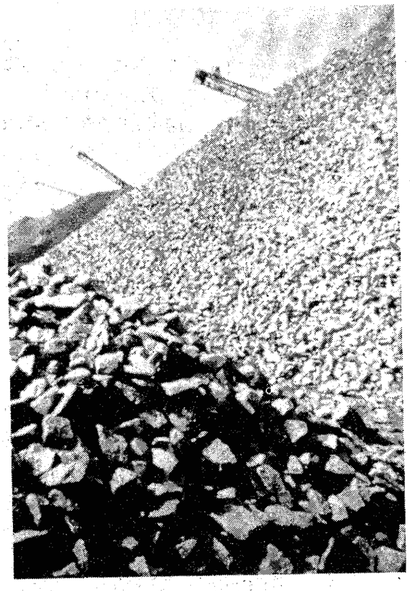
16. There are a number of other characteristics of the aggregates that we need to be concerned with. We will take a look at some of the ones listed here.



17. **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.



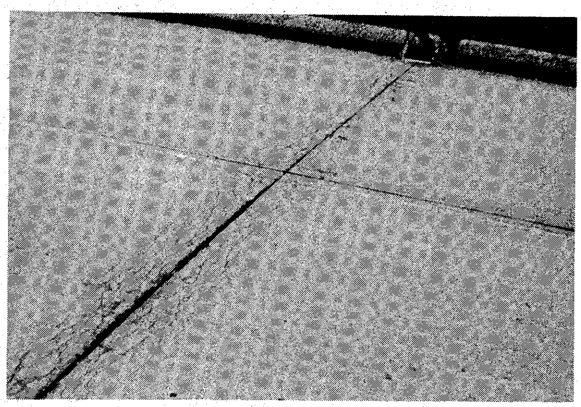
18. The common test for abrasion resistance is the <u>L.A. abrasion test</u>, ASTM C 131 or ASTM C 535 or AASHTO T96. In this test the percentage of material worn away is measured.



19. Another reason for performing the L.A. abrasion test is to determine the aggregates susceptibility to introducing additional fines into the concrete mix as a result of the aggregate degrading during handling, stockpiling and mixing.

20. Approximately 90 percent of the United States is classified as regions of severe weather, thus subjecting concrete to **freeze-thaw damage**. This kind of damage is related to the aggregate's porosity, absorption, permeability and pore structure or in other words, the aggregates soundness. An aggregate particle may absorb so much water that the expansion due to freezing cannot be accommodated in the concrete. If this occurs near the surface of the concrete, a popout or spall will occur.

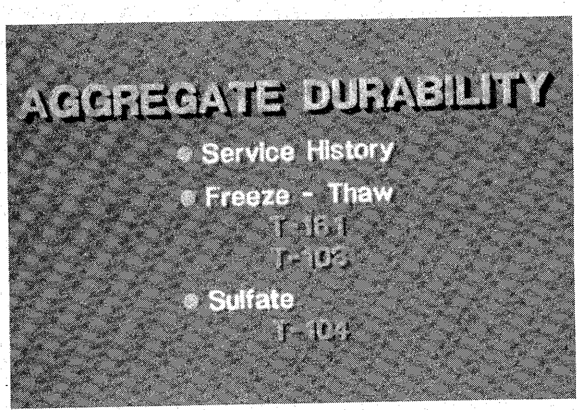
21. **D-Cracking** of concrete is a familiar form of distress in pavements. **D-Cracking is associated with a coarse aggregate that is non-durable when it becomes saturated with water and is subjected to freeze-thaw cycles.** It is a function of the pore properties of the aggregates. Water can become trapped in the pores. When the concrete is exposed to freezing temperatures, the water in these pores will freeze and cause the aggregate to crack. While the cracking begins in the coarse aggregate, it will propagate thru the mortar mix. Aggregates that can exhibit these properties include some limestones, some dolomites, and cherts.



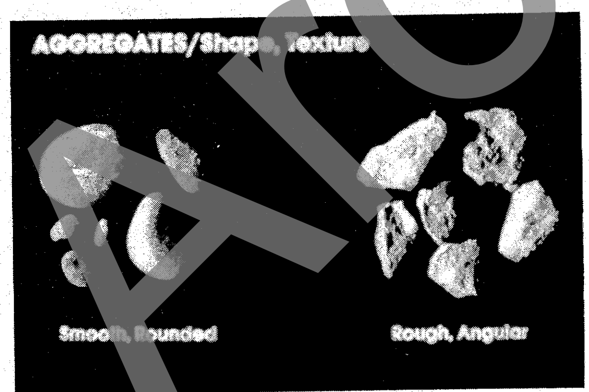
22. The resulting distress in concrete pavement is the cracking pattern shown here. An accumulation of water, under the pavement, in the base and subbase will saturate the underside of the slab. With freezing and thawing cycles, the cracks start in the saturated aggregate in the bottom of the concrete and work their way up. As more cracks develop, more avenues are available for moisture to penetrate deeper into the concrete. The solution to this kind of distress is to select aggregates that perform better in freeze thaw cycles. To eliminate sources susceptible to D-cracking could eliminate many sources in some States. As a result, several States test each bed of material in each source and eliminate portions of sources accordingly.

Reducing the maximum size of the coarse aggregate has improved durability of some aggregates and of course the installation of drainage to carry free water away from the pavement is very helpful. D-cracked concrete can be recycled provided freeze thaw tests are performed on the new mix.

23. 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.

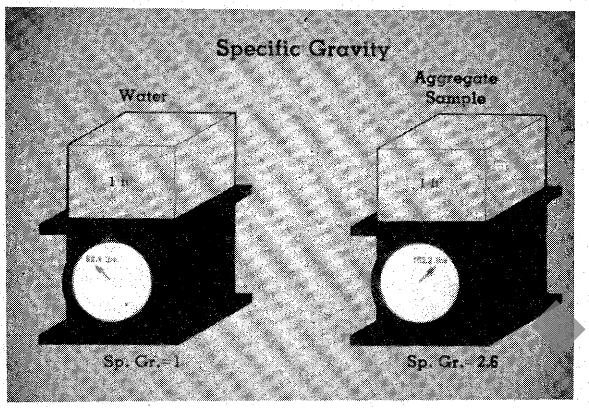


24. There are several ways to evaluate the performance of aggregates under freeze- thaw conditions; first and perhaps most useful is the past performance history of the aggregate. Second, if an aggregate has an unknown history, it can be subjected to a freeze-thaw test in accordance with ASTM C 666 or AASHTO T 161. **In this test, concrete samples made with the aggregates are subject to alternating freezing and thawing while being submersed 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, sulfate tests are not always repeatable.

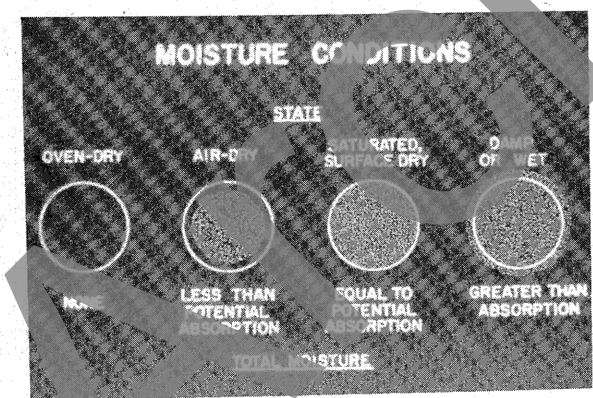


25. **Particle shape** influences the properties of fresh concrete more than the properties of hardened concrete. Rough angular aggregates require more water to produce workable concrete then smooth, rounded aggregates. If more water is required, then more cement will be required to maintain the same 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.



26. 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.



27. Since the aggregate weight will vary with its moisture condition, specific gravity is determined at a fixed moisture content. There are four possible moisture conditions:

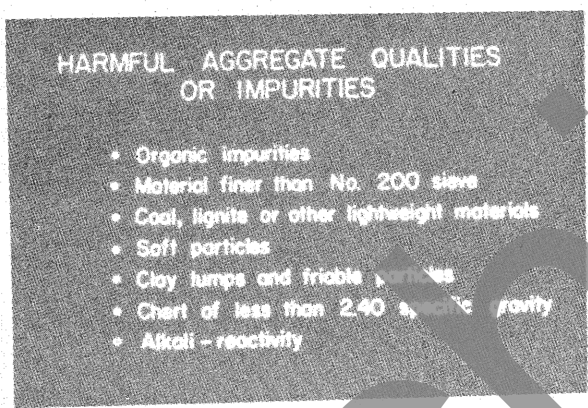
a. In the **damp or wet** condition, the aggregate pores are filled and free water is present on the aggregate surface. Aggregates in this condition would provide excess water to a concrete mix.

b. Aggregates which have a dry surface with variable amounts of water in the pores are in an **air-dried** condition and would take water from a concrete mix.

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

d. In the **saturated, surface dry** (SSD) condition, the pores are filled but the surface is dry. Laboratory mix designs are normally made with saturated surface dry aggregates; therefore, the amount of water added during actual job mixing must be adjusted for the moisture condition of the aggregates.

28. 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.

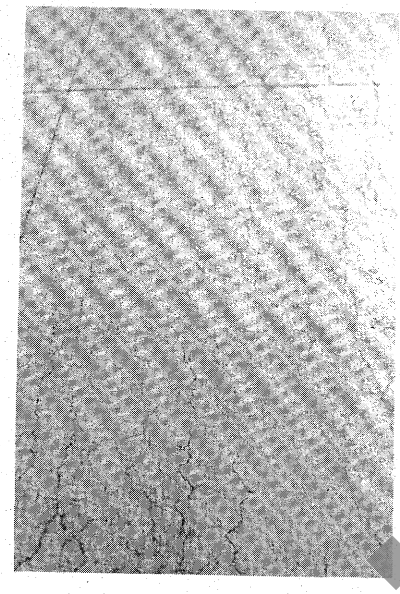
- Material finer than the No. 200 sieve, such as silts and clays, can cause a thin dust-like coating of the aggregate, thus weakening the bond between the aggregate and paste and resulting in low strength concrete.

- Coal and lignite can affect the durability of concrete.

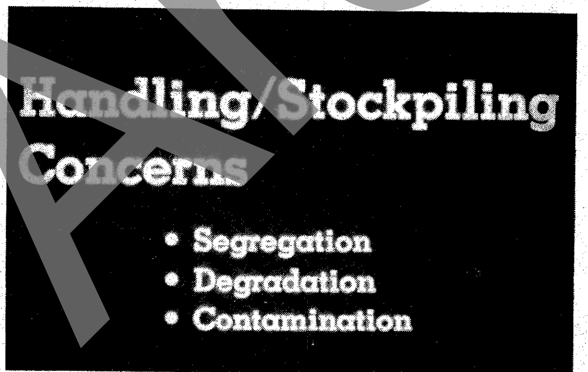
- Soft particles will cause a loss in durability and wear resistance. They could also cause popouts.

- Clay lumps in concrete may absorb some of the mix water and may break down from freezing and thawing or wetting and drying. The results are reduced durability, reduced wear resistance, and popouts.

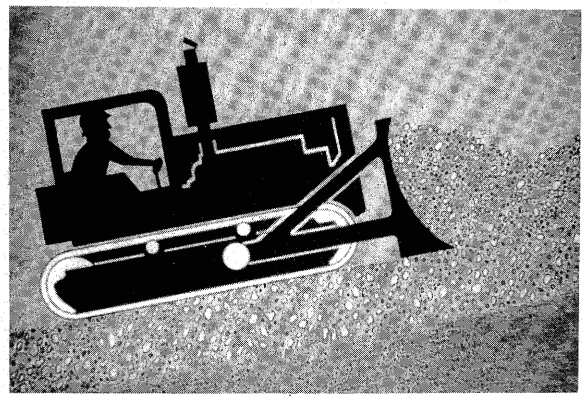
- Chert also affects the durability of concrete and due to its high absorption, can cause popouts.



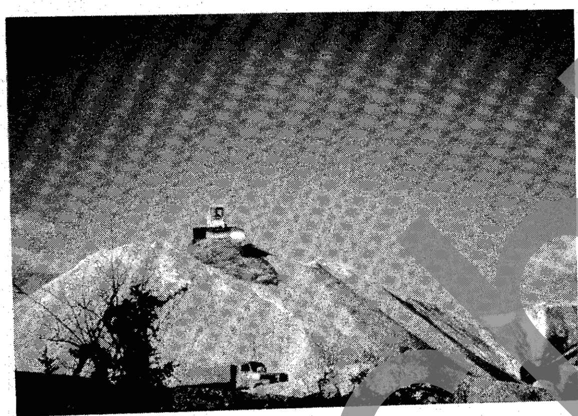
29. **Siliceous aggregates and certain limestones and dolomites have the potential of reacting with the alkali in the cement.** This can cause abnormal expansion or map cracking in concrete. Deterioration can be minimized by limiting the alkali content of the cement to 0.6 percent when reactive aggregates are suspected or known. Also the addition of an adequate amount of a suitable pozzolan can prevent this reaction. While the problem can occur whenever reactive aggregates are encountered, it is more prevalent in the western and southern states. Probably the best determination of an aggregate's applicability is through its service record. If the aggregate source has been producing quality concrete, it can generally be concluded that it 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 done to ensure suitability for making concrete.



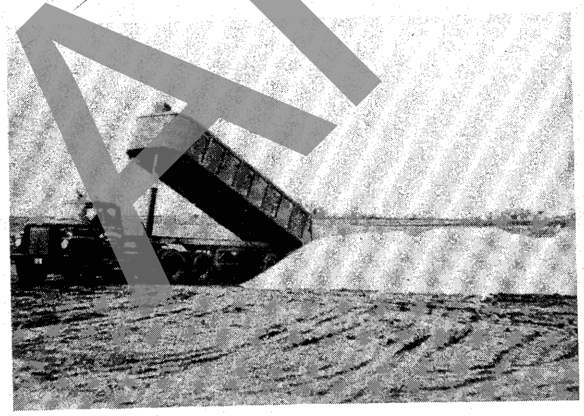
30. The objectives of a well designed aggregate storage and handling system are to provide an adequate supply of aggregates and to prevent segregation, breakage and contamination.



31. The preferred method of building stockpiles is to build them up 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.



32. Even stockpiles properly constructed by dozers can result in segregation if the materials are pushed over the edge.



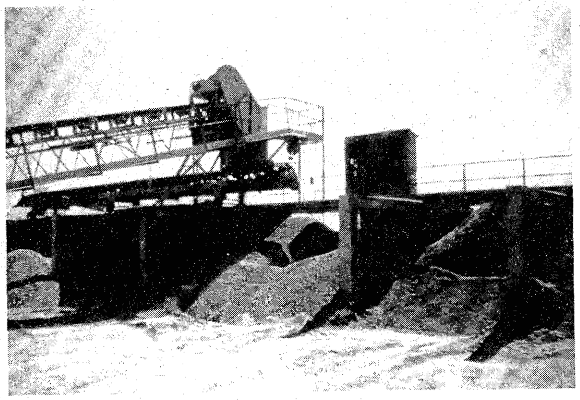
33. Aggregate stockpiles should also be constructed on smooth, hard surfaces in order to prevent contamination from underlying soils.

34. 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.

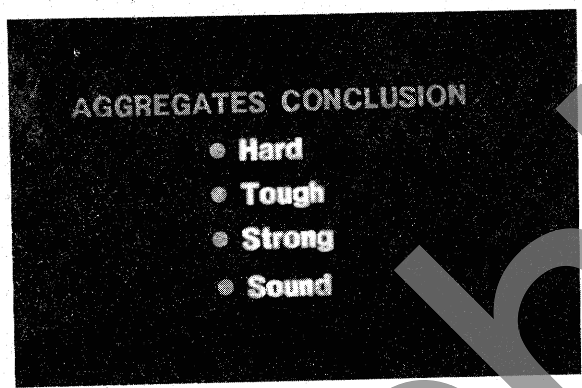
35. Slices from a stockpile made with a front-end loader should be from bottom to top so that each slice contains a portion of each horizontal layer. Care should also be taken to avoid taking material from the very bottom of the stockpile where existing soils could contaminate the aggregates.

36. Conical stockpiles should be avoided, because of segregation, unless the materials can be satisfactorily remixed when it is reclaimed. 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.

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

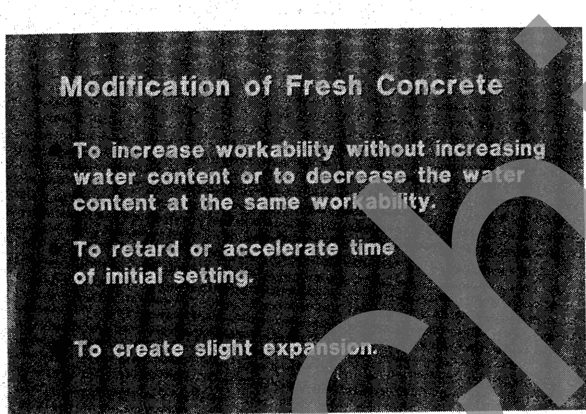


38. In conclusion, aggregates should be hard in order to resist grinding, tough to withstand impact, strong to stand up under heavy loads and sound to remain whole during freezing and thawing.

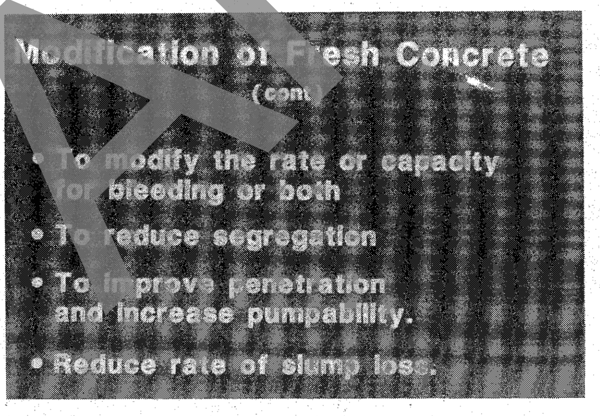


ADMIXTURES FOR CONCRETE

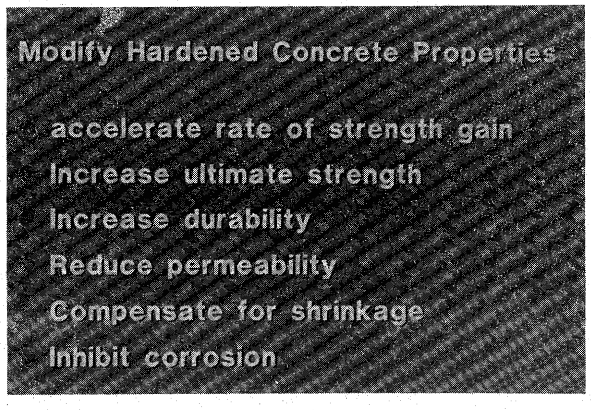
1. An admixture is defined by ASTM as: " A material other than water , aggregates, and hydraulic cement that is used as an ingredient of concrete or mortar and is added to the batch immediately before or during mixing." Admixtures can be used to modify both the plastic and hardened properties of portland 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. We can use admixtures to enhance the following properties of plastic concrete: increase workability at the same water content, change the rate of set, compensate for shrinkage,...

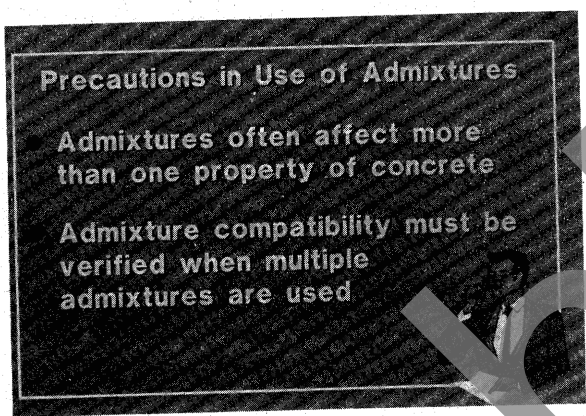


3. reduce bleeding, reduce segregation , improve pumpability, and reduce the rate of slump loss.

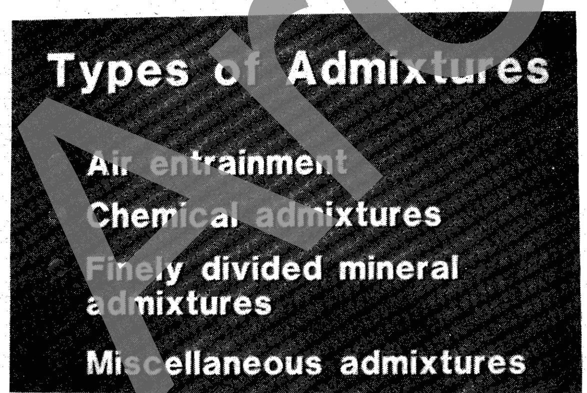


4. Admixtures are also used to enhance the following properties of hardened concrete: accelerate the rate of strength gain, increase ultimate strength, increase resistance to freeze-thaw damage, increase the resistance to alkali aggregate reactions, increase the resistance to sulfate attack, ...

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. In addition, when multiple admixtures are used the 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.

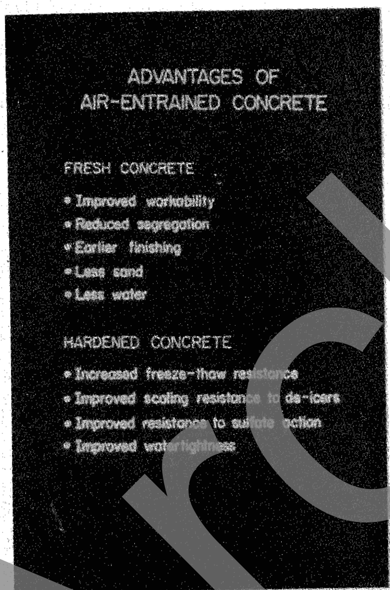


6. There are three basic types of admixtures which are used in portland cement concrete. They are air entraining, chemical, and finely divided mineral admixtures.

7. **Air entraining admixtures** are the most commonly used admixtures in the industry today and are used in almost all concrete. These admixtures create and introduce microscopic air bubbles into the concrete. The primary reason for air entrainment is for freeze-thaw durability.

The specification requirements for air entraining admixtures are contained in AASHTO M 154 and ASTM C 260.

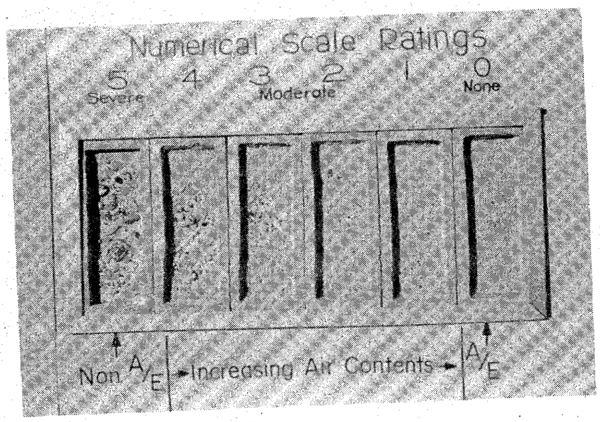
The dose of air entraining agents are in the order of 0.05 percent of active ingredient by weight of cement. The actual dose will very with the particular mix and application.



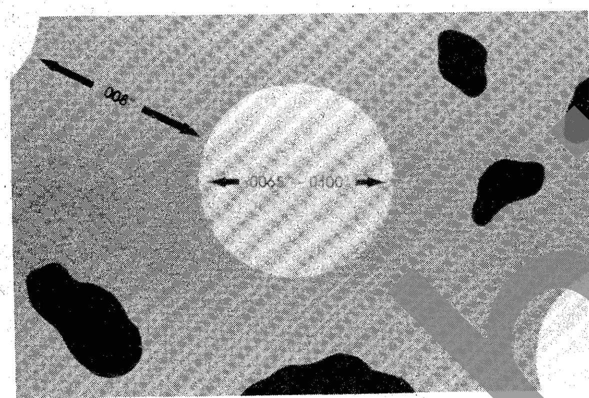
8. In hardened concrete air-entrainment, in addition to providing resistance to freeze-thaw cycles, can also increase the water tightness, improve scaling resistance to de-icing salts, and increase resistance to sulfate attack.

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 will also typically require less sand and water because of the increase in workability of the mixes.

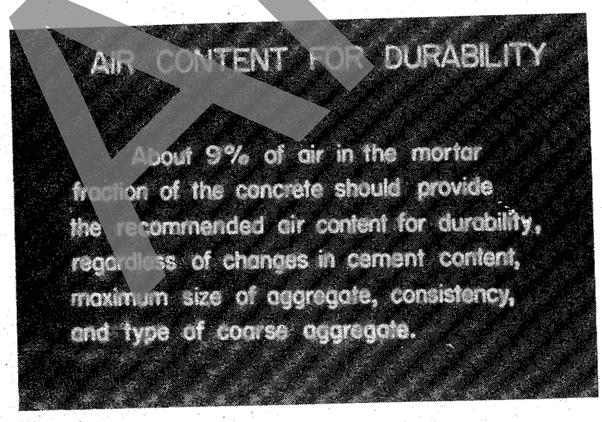
9. For each 1 percent increase in air content, the compressive strength will be reduced by 2 to 6 percent.



10. The reason for freeze-thaw damage is centered around the expansive nature of freezing water. The principal behind entrained air is to allow room for the expansion of the water/ice so the expansive pressure will not damage the concrete.

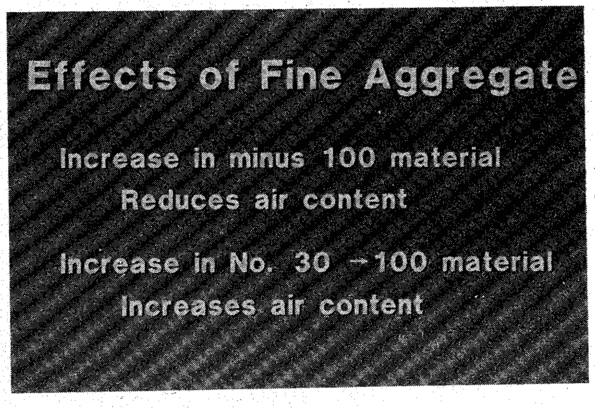


11. When we measure the air content in concrete both entrapped air and entrained air is measured. Entrapped air does not help in freeze-thaw durability. Freeze-thaw durability is achieved by proper size air bubbles and spacing. **Ninety percent** of the air entrained bubbles are less than **4 millionths** of an inch.



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 includes 2 to 3 percent entrapped air which does not provide any benefit to the concrete.

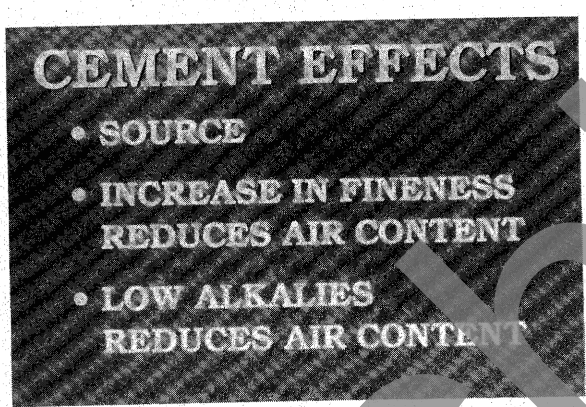


13. The gradation of the fine aggregate will affect the ability of the concrete to entrain air.

    An increase in the amount of material passing the No. 100 sieve will result in a reduction of air content.

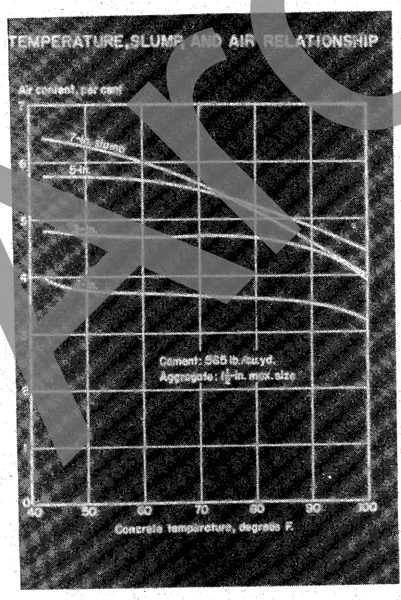
    An increase in the amount of material between the No. 30 sieve and the No. 100 will result in an increase in air content.

    The fineness modulus can be used to indicate that a change has occurred in the gradation of the fine aggregate.



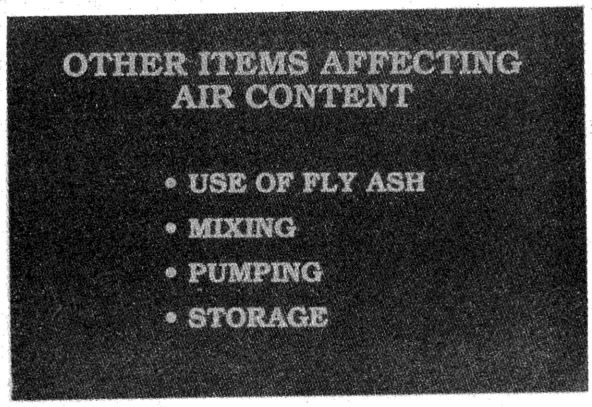
14. The properties of the portland cement can also affect the ability of the mix to entrain air. An increase in fineness or low alkalies will result in a reduction of air content.

    A change in source of cement may also affect the air entraining capability of the concrete.



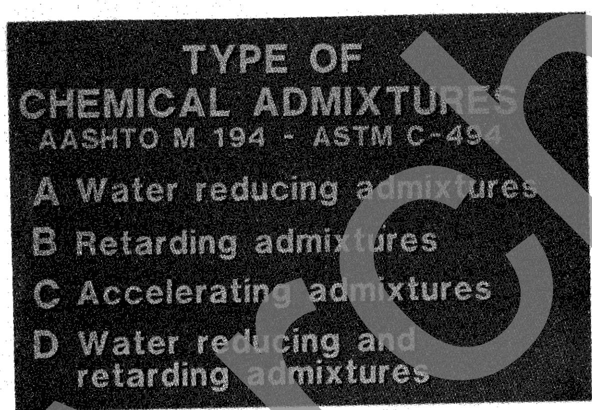
15. As the temperature increases the air content will decrease. As a result it may be necessary to adjust the amount of air entraining admixture during the course of a placement.

    An increase in slump may result in an increase in air content.

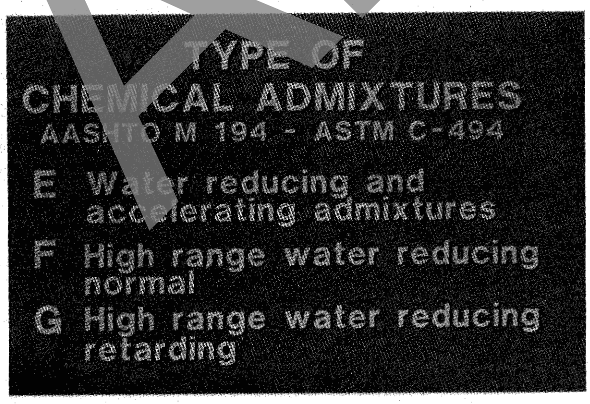


16. Other items may also affect the ability of the concrete to entrain air.

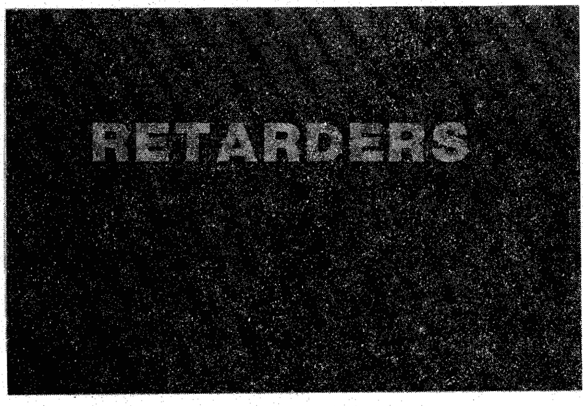
- The use of a non uniform fly ash may result in a large variability in the air content. This is discussed later in this chapter.
- Excessive amounts of mixing can reduce the amount of air in the concrete.
- Pumping concrete will reduce the air content in the concrete. This will be discussed further in the chapter on conveying, placing and finishing.
- Admixtures stored for longer than 6 months should be tested.



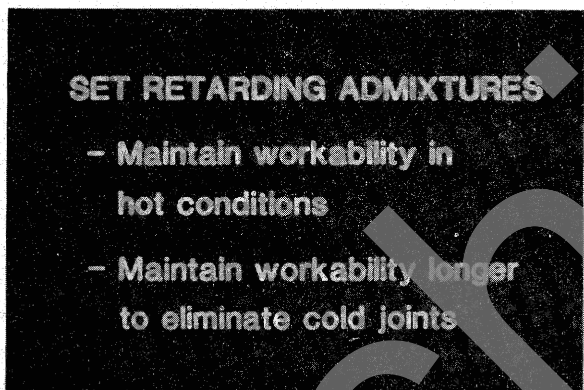
17. The specification requirements for **chemical admixtures** are contained in AASHTO M 194 and ASTM C 494. All admixtures have specific set requirements. In addition, the Type A,D,E,F,and G admixtures have water reducing requirements. The specifications also allow lower durability than mixtures without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



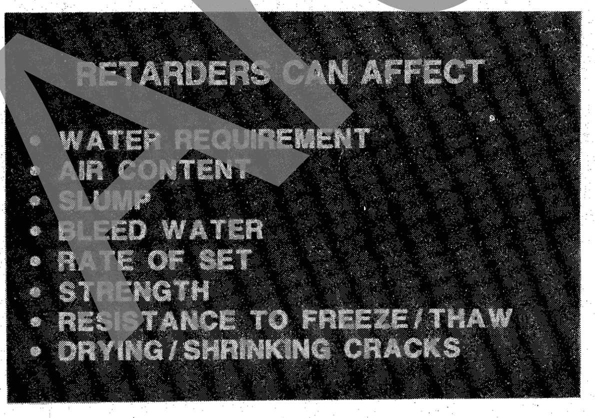
18. We will discuss the properties of the admixtures in the following categories: retarders, water reducers, accelerators, and high range water reducers (superplasticizers).



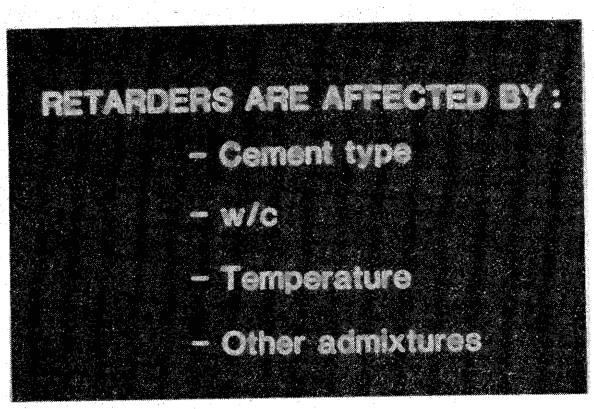
19. **Retarders** are the second most commonly used admixture in the highway industry. Most retarders are also water reducers. The most common use is in the construction of bridge decks. Most retarders are water reducers.



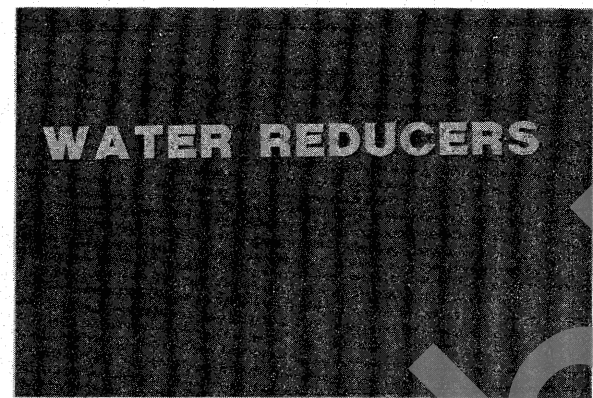
20. Set retarding admixtures are used primarily to offset the accelerating and damaging effect of high temperature and to keep concrete workable during the entire placing operation. This will help avoid the formation of cold joints. In addition, it will prevent damage to bridge decks which would occur due to dead load deflection during a placement.



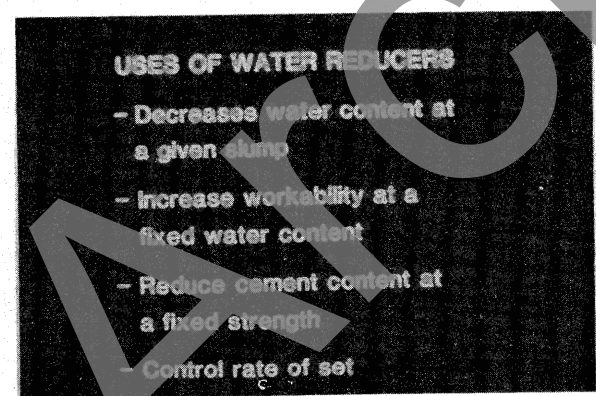
21. The retarder can affect, 1) water demand, 2) air content, 3) slump, 4) bleed water, 5) rate of set, 6) strength, 7) resistance to freezing and thawing, and 8) drying shrinkage. Bleeding may increase with some admixtures. The specifications allow an increase in shrinkage. Different chemicals which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



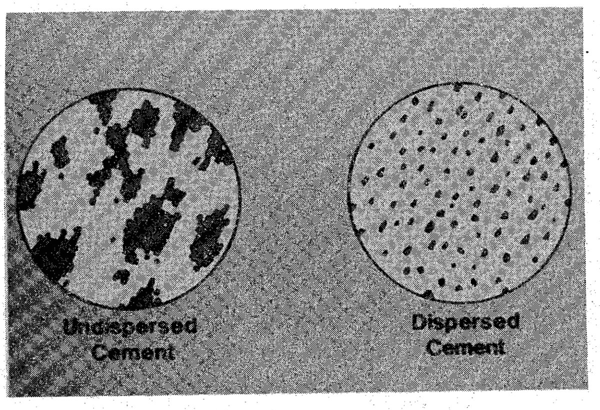
22. The specific effects of set retarding admixtures vary with cement, water content of the mix, concrete temperatures, ambient temperatures, and the presence of other admixtures.



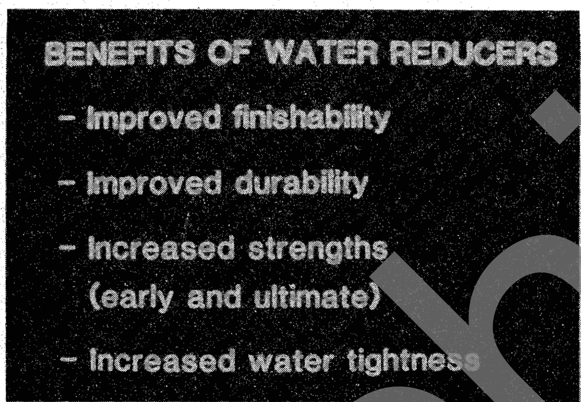
23. The use of **water reducers** by the highway agencies have been increasing over the last few years. They have been used primarily in bridge decks, low slump concrete overlays, and patching concrete.



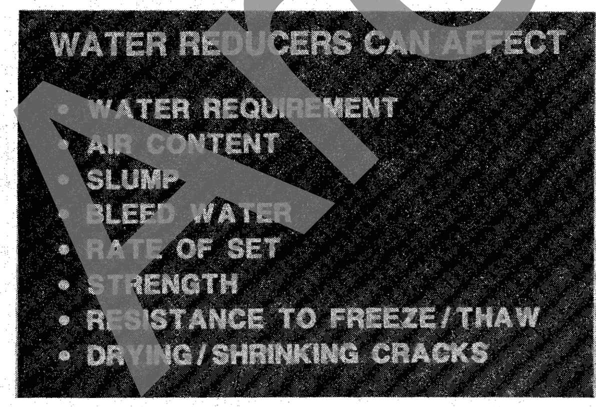
24. At first, water reducing admixtures were used just for what their name implies - to reduce the amount of water needed to achieve a given slump. Water reducing admixtures can provide many additional benefits going far beyond reducing the water content, including control of rate of set and providing 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 reducers are capable of reducing water contents up to 12 percent.**



25. Water reducers are dispersion agents. Cement particles have a tendency to clump together. This reduces 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 that form. When water reducers are used the cement is dispersed and as hydration proceeds, water can react much more fully with each of the cement particles so that the concrete realizes its full potential strength.

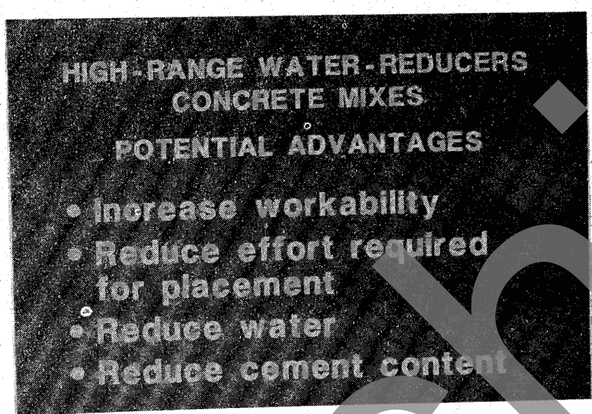


26. Water reducers have several other benefits. In addition to being a workability agent, water reducers improve finishability and enhances many hardened concrete properties, such as water tightness, durability, permeability,and both early and ultimate strengths.



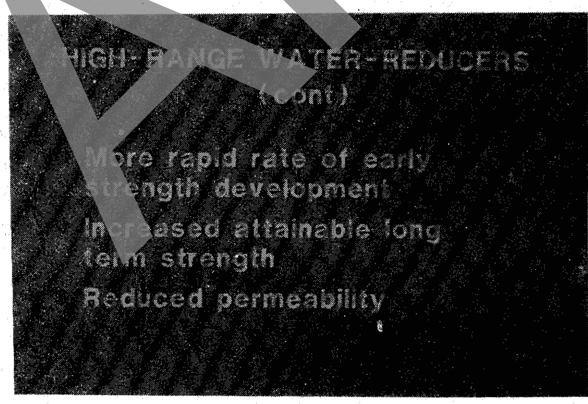
27. The water reducer can affect, 1) water demand, 2) air content, 3) slump, 4) bleed water, 5) rate of set, 6) strength, 7) resistance to freezing and thawing, and 8) drying shrinkage. Bleeding may increase with some admixtures. The specifications allow an increase in shrinkage. Different chemicals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

28. Another class of admixture that is being used more frequently in construction work is the **high-range water reducer (HRWR).** They are also known as superplasticizers. **HRWR may permit water reductions of 12 to 25 percent while maintaining the desired workability.** Most State highway agencies allow their use in prestressed concrete. Several State highway agencies also allow their use in bridge deck concrete.

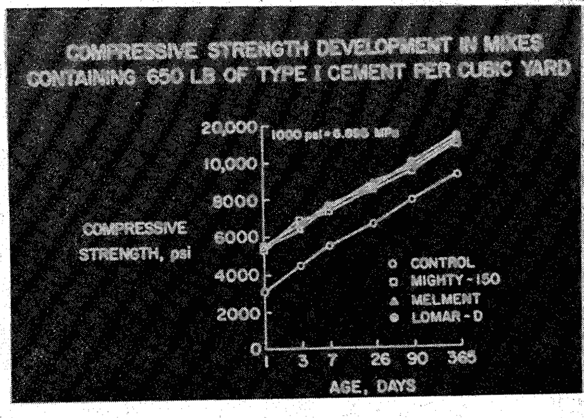


29. HRWR have several potential advantages. They will allow reduced water contents to maintain workability or increase workability at the same water contents which will reduce required placement effort. They may also allow a reduction of cement and retain strength by reducing the water content. Reductions in cement contents must be made with caution to insure that durability will not be decreased.

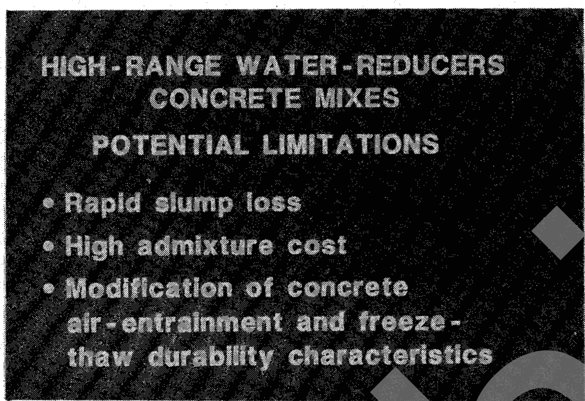
Six-inch slumps can be obtained with normal water cementitious ratios or the water cementitious ratio can be dropped below 0.35 with the same workability.



30. In addition, HRWR will increase the strength gain, increase ultimate strength, and reduce permeability due to lower water cementitious ratios.

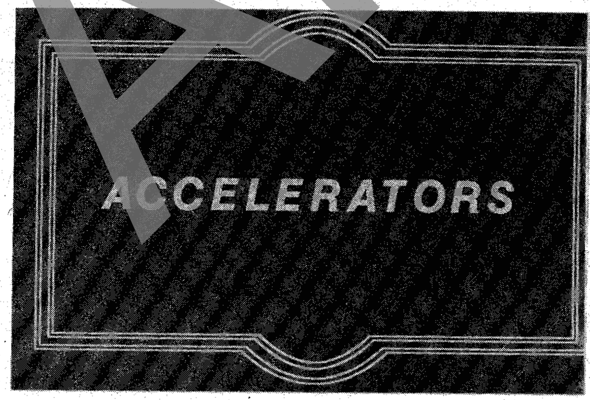


31. The accompanying graph reflects the strength gain that is attainable with HRWR.

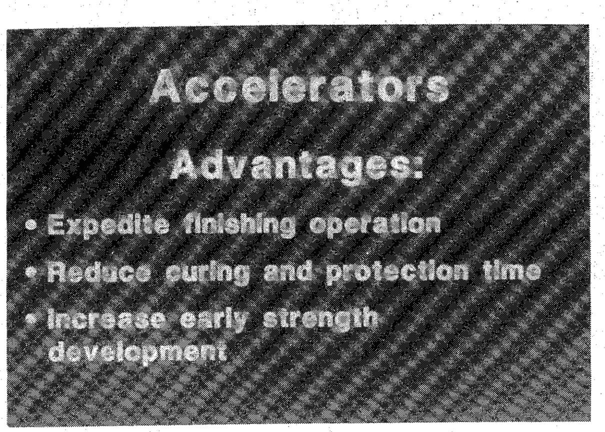


32. HRWR also have several limitations. The concretes which contain HRWR will lose slump between 30 minutes and an hour. Redosing is not recommended since it may increase slump but not increase workability. In order to get the admixture dispersed in a truck mixer at full capacity, a 3-inch slump is required. Reducing the size of the load to 1/2 to 2/3 the capacity of a truck mixer will allow dispersement of the admixture in low slump concretes. The admixture significantly affects the air void system in the concrete. In order to compensate for disruption of the air void system and maintain freeze-thaw durability it is necessary to increase the typical air content from 6.5 percent to 8 percent.

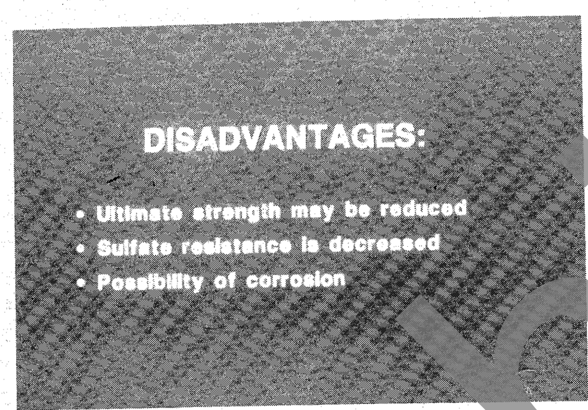
In addition, the admixtures are fairly expensive.



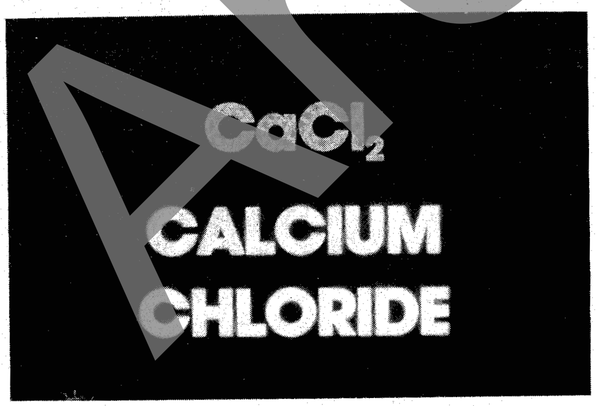
33. **Accelerators** have been slowly gaining acceptance with State highway departments. They are most commonly used in concrete that is used in repair work where traffic considerations do not allow long closures.



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 by weight of cement to assure no affect on 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 & Air Temp.: 70°F

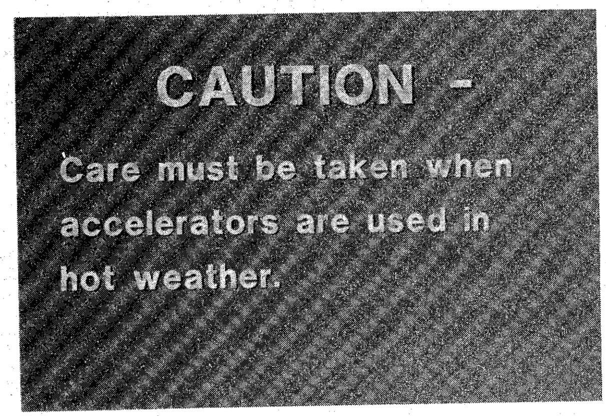
	PLAIN	1%	2%
	HR:MIN	HR:MIN	HR:MIN
Initial Set	5:05	3:30	2:35
Final Set	6:50	4:55	3:35

38. Accelerators will also reduce the setting time of concrete. The accompanying table shows the test results on 70 degree F concrete that is placed at 70 degree F. 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.

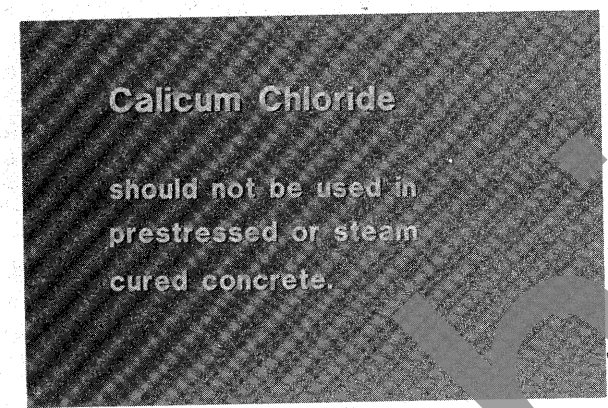
SETTING TIME AFFECTED BY:

- Cement
- Dosage
- Temperature
- Other factors

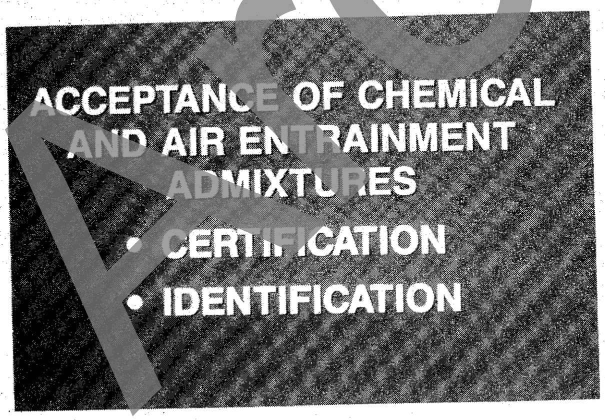
39. When using calcium chloride, the setting time will also be affected by other conditions such as type or brand of cement, concrete temperature, admixture dosage, water, and other admixtures.



40. Care must be taken when accelerators are used in hot weather. Detrimental effects such as rapid setting and shrinkage cracks may develop.



41. Calcium chloride accelerators should never be used in prestressed concrete or concrete that will be steamed cured. Both of these types of structures are more prone to corrosion. The use of calcium chloride in recommended amounts will not cause progressive corrosion of conventional steel reinforcement under normal conditions when adequate cover is provided.



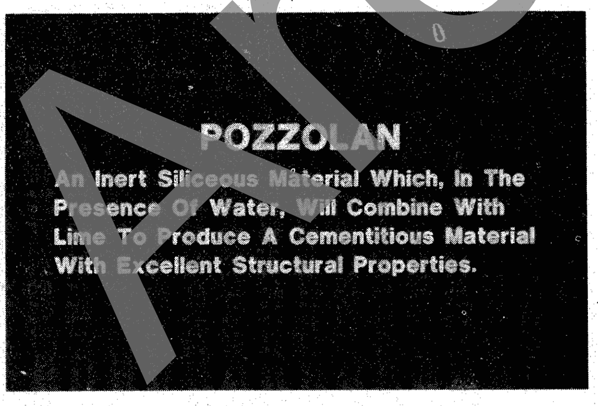
42. The requirements for air entraining agents and chemical admixtures are based on their effect on the set times, bleeding, strength and resistance to freezing and thawing.

The basic method for acceptance is approved list and certification by the manufacturer.

Many States perform identification tests on samples of the admixtures taken at the concrete plants to assure the material is the same as that evaluated to place the admixture on the approved list. The identification tests include: solids content, density, infrared spectrophotometry, pH, and chloride content.

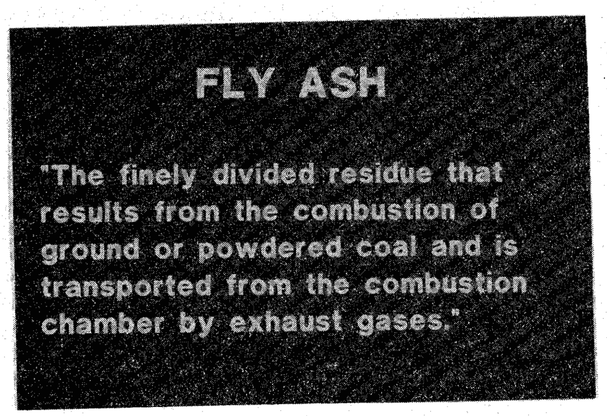
All admixtures should be stored according to the manufactures recommendations. It should be noted that some admixtures become more viscous as they get colder. Admixtures may be damaged or require mixing after freezing.

43. We will discuss three types of **finely divided mineral admixtures**: fly ash, granulated blast furnace slag, and silica fume. These three admixtures can be used to: reduce alkali-silica reaction, improve sulfate resistance, and reduce permeability. Fly ash and granulated blast furnace slag have been shown to increase workability and reduce heat of hydration.

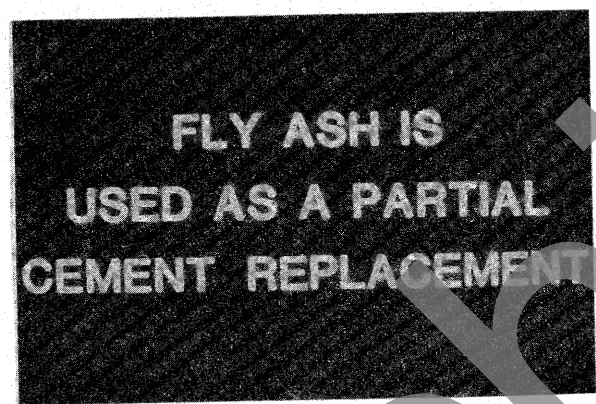


44. Fly ash and silica fume are **pozzolanic** in nature i.e., they form cementing agents by combining with the calcium hydroxide that is produced from the hydration of the cement.

Granulated blast furnace slag is a cementitious material.

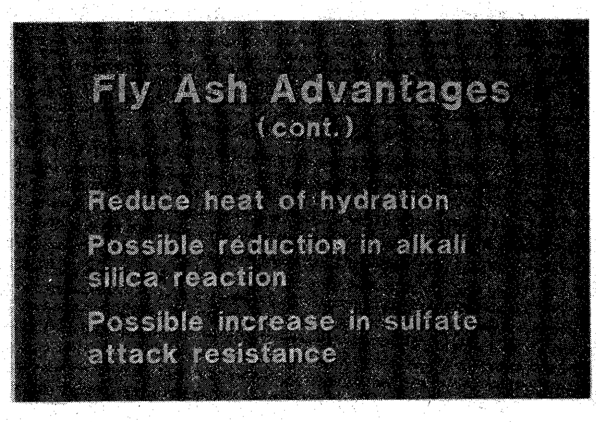


45. The most commonly used of these admixtures is **fly ash**. Fly ash is a waste product which is transported from the combustion chamber by exhausted gases and is the result of burning of powdered coal at electric power generation plants. Fly ash is divided into two classes, class F and class C. The differences in the two types of fly ash center on the reactivity of the fly ash class C being more reactive than class F. Fly ash is specified in AASHTO M 295 and ASTM C 618.

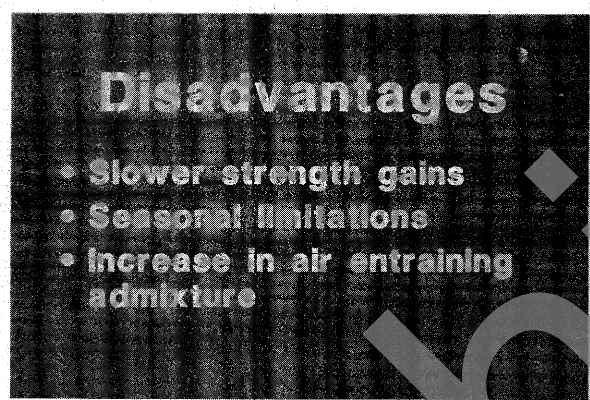


46. Fly ash is used as a partial replacement for portland cement. State highway agency specifications will allow between 15 and 25 percent of the cement to be replaced with fly ash on a 1 - 1.2 to 1 ratio based on the weight on the material. Since fly ash weighs less than cement (fly ash S.G.= 2.65 compared 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 will improve the workability of the mix, the fineness will also reduce bleeding, the permeability is reduced 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 be reduced due to less cement and alkali reaction with the fly ash, and sulfate resistance can be improved. Some fly ashes, particularly Class C fly ash, may adversely affect the sulfate resistance of the concrete.

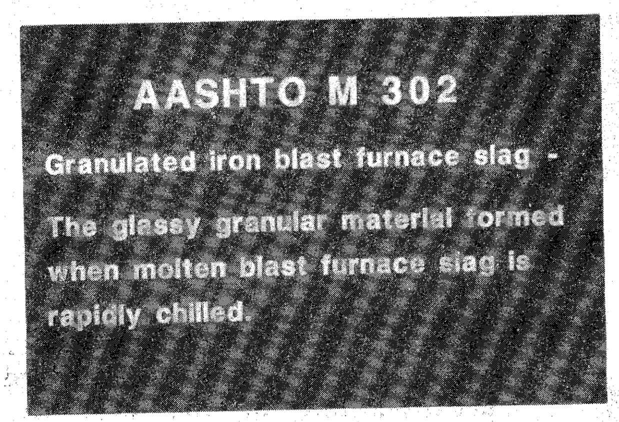


49. Fly ash also has several disadvantages: The rate of strength gain will be reduced, the pozzolanic reaction will cease at 40 degrees F so cutoff dates should be used, and the use of fly ash will require additional amounts of air-entraining admixtures.

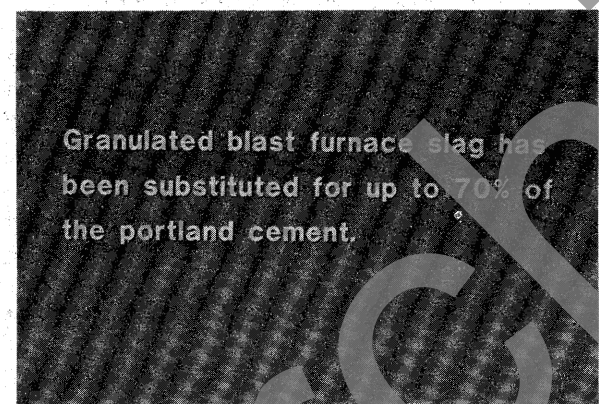
50. The fineness and the carbon content of the fly ash will affect the air content of the mix. However, the uniformity of these properties is more important than the actual values. The operation of the power plant affects the variability of the fly ash. Therefore, source approvals and certifications should be based on individual power plant production.

Any time air entrained concrete is specified, the fly ash specification should include the optional uniformity specifications.

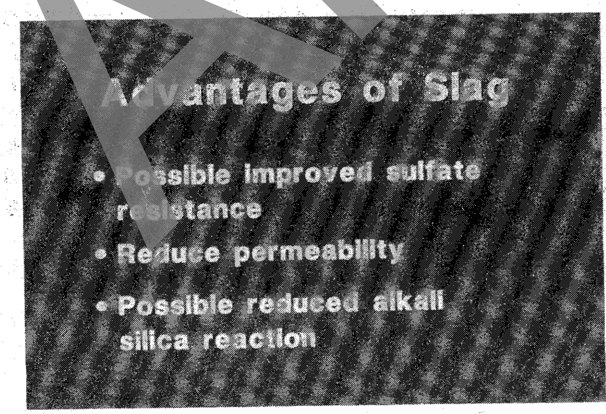
An easy way of determining if the fly ash is uniform is to take air content tests on each load of concrete until it is determined that the source of fly ash is uniform.



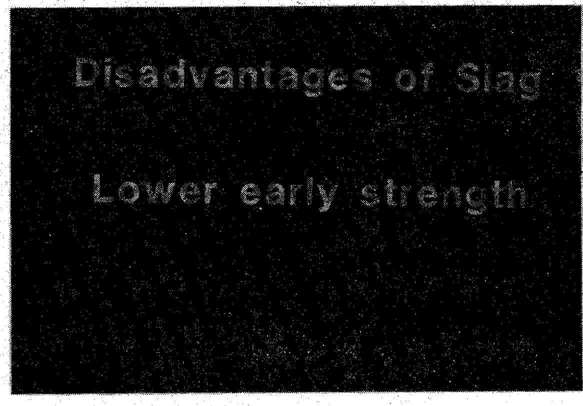
51. **Granulated blast furnace slag** is the glassy granular material formed when molten blast furnace slag is rapidly chilled. Granulated blast furnace slag is specified in AASHTO M 302.



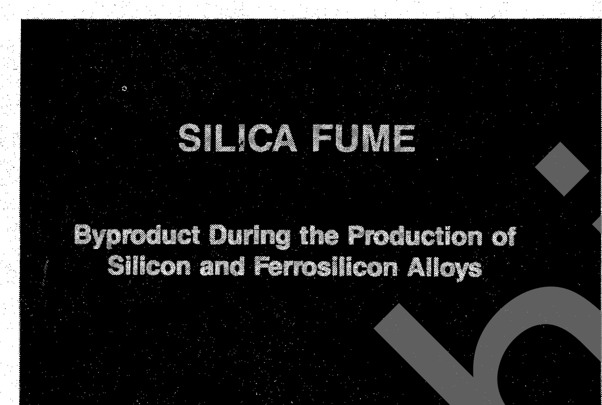
52. Granulated blast furnace slag has been substituted for up to 70 percent of the portland cement. The typical replacement rate is in the range of 50 percent.



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.



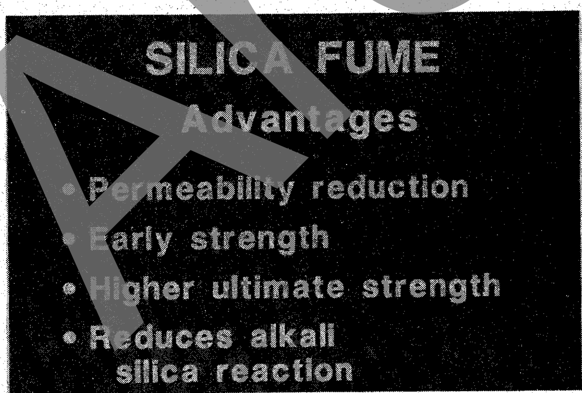
54. The primary disadvantage to using granulated blast furnace slag is lower early strength.



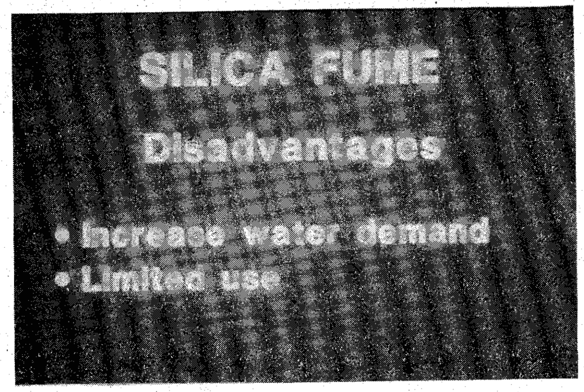
55. **Silica fume** is a new admixture. There currently is not a standard specification for the material. Silica fume is the by-product of the production of silicon and specialty steels. It is almost a pure siliceous material.

As with fly ash silica fume relies on the pozzolanic reaction and fine particle effect for strength gain.

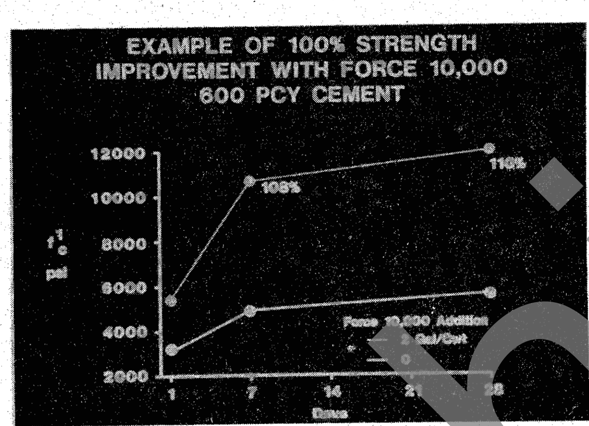
Silica fume has been used by some States as a replacement for cement in bridge deck concrete. Replacement rates are in the range of 5 to 15 percent.



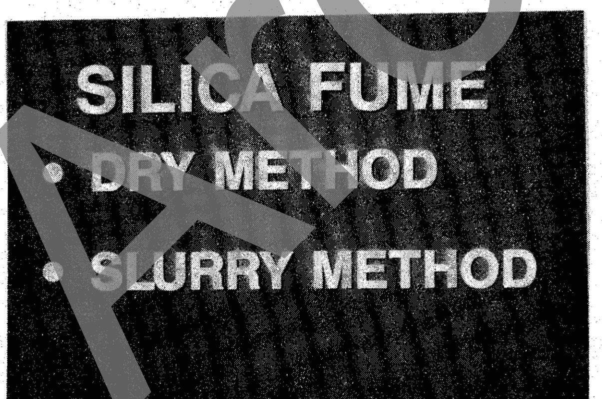
56. Silica fume has several advantages: as most pozzolans the concrete which contains silica fume has a reduction in the permeability due to the products of pozzolanic reactivity; Early strength due to the lower water cementitious ratios; Higher ultimate strengths due to the pozzolanic reactions; and Reduction in alkali-silica reaction.



57. Silica fume also has several disadvantages: 1) high water demand requires water reducers with 5 percent replacements and high range water reducers with higher substitution rates; and 2) the material has not been used long enough to get a history on the performance of concrete which contains the admixture.



58. Currently, silica fume is being used as an additive to concrete mixes in order to obtain very high strength concrete and not as a substitute for cement. It should also be noted that the controversy surrounding the need for air-entraining admixtures in high strength concrete (compressive strength >12,000 PSI) also extends to concrete containing silica fume.



59. In general it is necessary to use a high range water reducer (HRWR) when silica fume is used since the material is very fine which significantly increases the water demand. The admixture is commercially available in two forms: dry without a HRWR and in a slurry which contains a HRWR.

MISCELLANEOUS ADMIXTURES

- LATEX
- SHRINK COMPENSATING
- CORROSION INHIBITORS
- COLORING AGENTS

60. Latex, corrosion inhibitors, shrink compensating admixtures and coloring agents are not currently the subject of an ASTM or AASHTO specification.

Latex modified concrete has been used by many State highway agencies as the wearing course and protection system for bridge decks. It is important to use an acceptable latex modifier. Some of the latex modifiers on the market are not suitable for use in bridge decks. The latex solids to cement ratio should 0.15 to 1. It should be noted that curing is extremely important for decks constructed of this material.

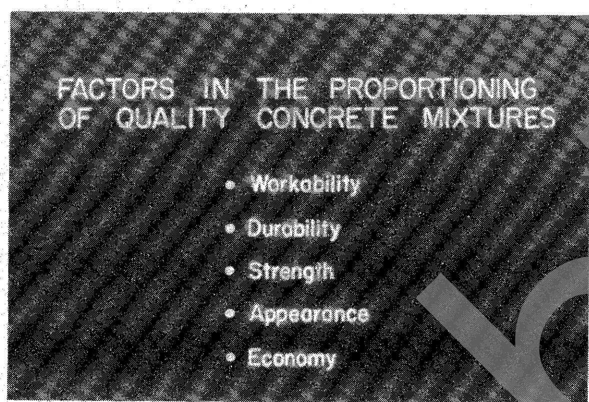
Shrinkage compensating admixtures which contain granulated iron will cause the concrete to expand and compensate for drying shrinkage. The control of the expansion is critical in avoiding damage to the concrete.

Corrosion inhibitors are still under study. There is controversy about the effectiveness of these admixtures.

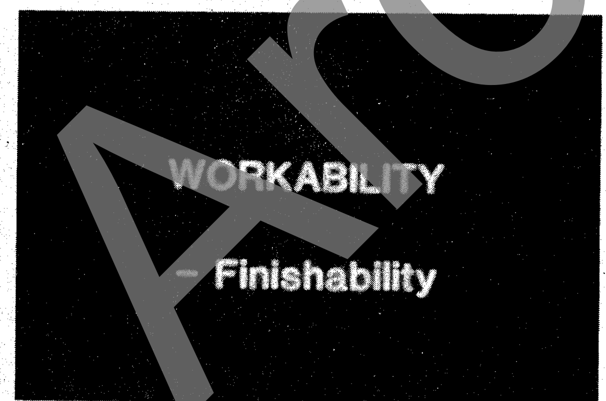
Additions of **Coloring agents** should be limited to no more than 10 percent by weight of cement. However, it should be noted that additions in excess of 6 percent by weight of cement can affect the properties of the concrete. The most common effect is to increase the water demand therefore reducing strength. Carbon black will also significantly reduce the effectiveness of the air entraining admixture and will require a significant increase in the amount of required air entraining admixture.

PROPORTIONING NORMAL CONCRETE MIXES

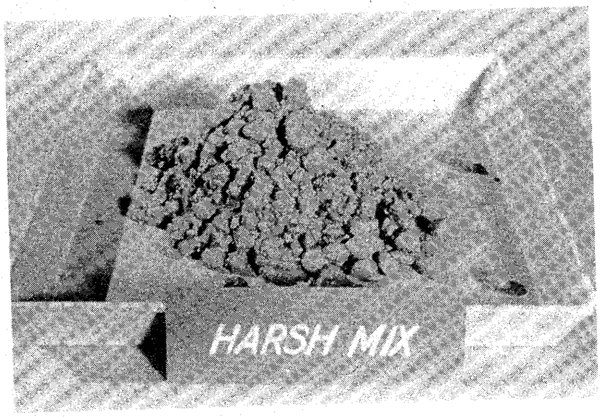
1. This section will discuss the factors that are considered in proportioning concrete mixes. This section will also go through an example of the procedures used in proportioning concrete mixes.



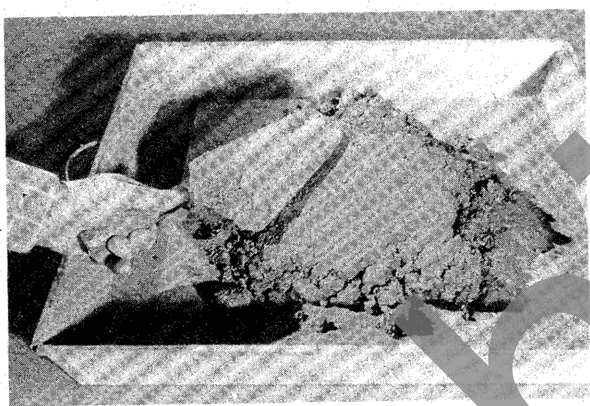
2. The following factors and associated criteria will be discussed: workability, durability, strength, appearance, and economy.



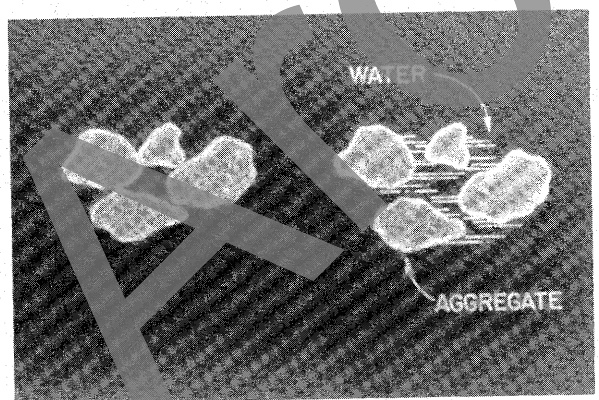
3. The term **workability** in concrete construction is used to indicate how well the concrete finishes or how easily the concrete closes up when a hand trowel is used on it. It is also necessary for the mix to be tight enough so that excessive bleeding will not occur. Evaluation of workability in a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



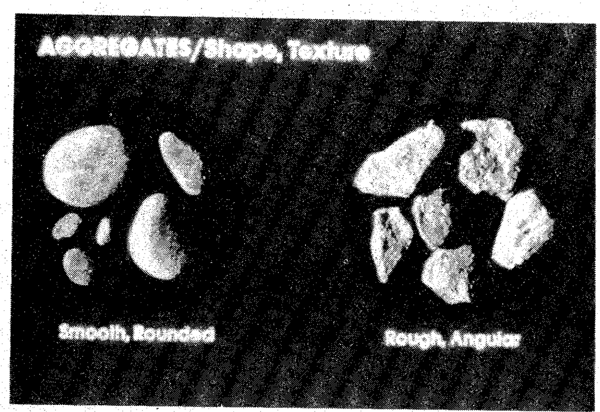
4. A **harsh** mix is one that does not close well under a trowel. The trowel may tear the surface when it is used on the concrete.



5. 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.

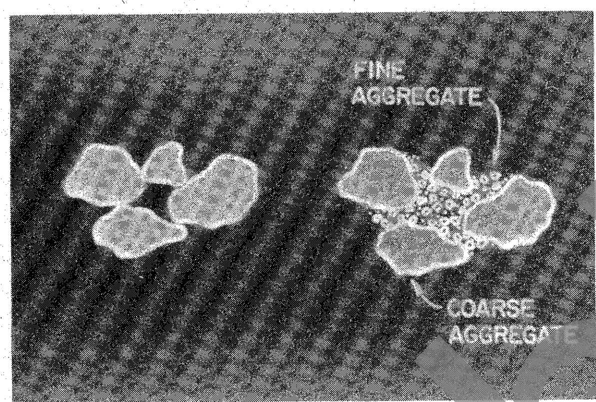


6. There are several factors that affect the workability of concrete. The one having the most effect and the easiest to understand is the water content. Water in a concrete mix acts as a dispersing agent, that puts more space between aggregate particles and acts as a lubricant.



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.

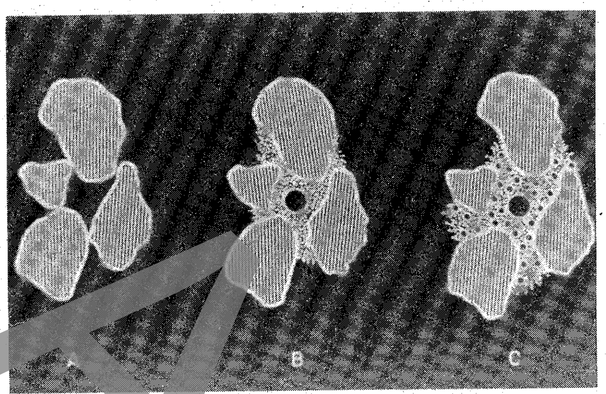


8. **Gradation** particularly of the fine aggregates, can have a significant influence on slump. Aggregates that are relatively fine have more surface area to be coated by the cement paste. This results in less space between particles and an increase in the particle friction and interaction, resulting 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 may be reached where more cement is needed in the mix to maintain the concrete strength.

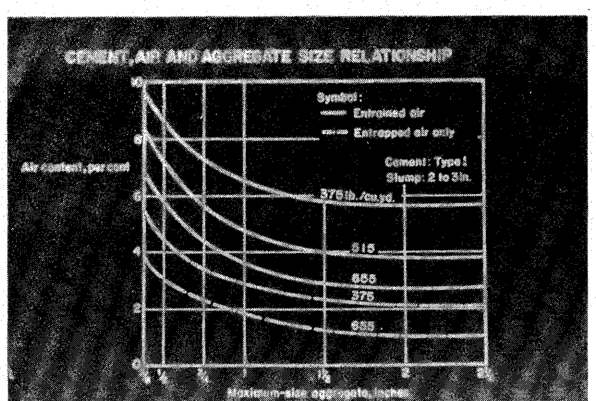
If workability problems occur the total gradation should be examined. The workability problem may be due to a gap gradation.



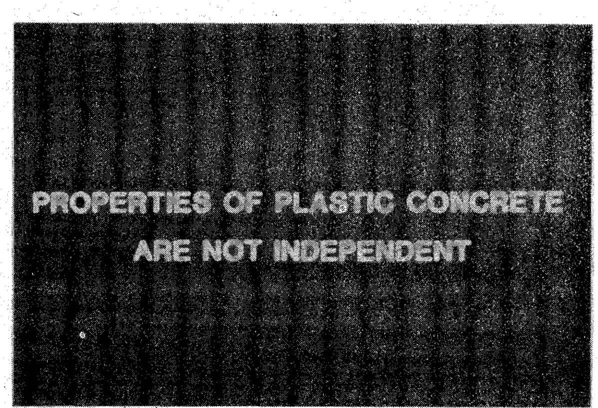
9. The use of **admixtures** such as water reducers, air-entrainment agents, retarders and accelerators also affect workability.

A system of properly entrained air in the plastic concrete increases the workability and slump in the concrete mix. The entrained air helps spread the coarse particles apart, thereby minimizing particle interference. Air bubbles act similar to fine aggregate by adding equivalent surface area into the mix. This improves workability while tieing up the water in the mix which keeps bleeding to a minimum. The admixture used to entrain air also affects the surface tension of the water. This tends to make the concrete mix more cohesive, which is especially important for holding a firm vertical edge for slip form operations.

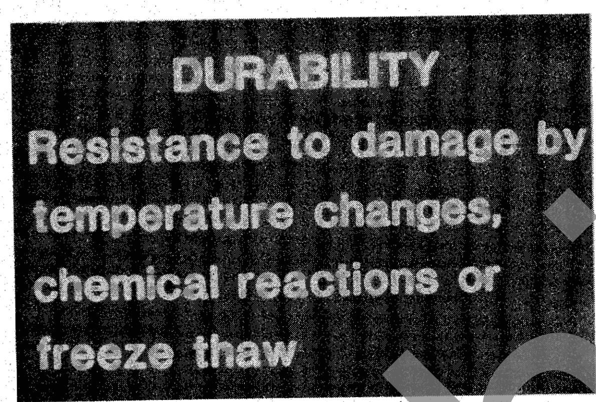
The use of other admixtures can also affect workability. Water reducers, for example, can be used to increase workability and slump. Retarders extend the time the mix stays workable and accelerators increase the workability for a very short period of time.



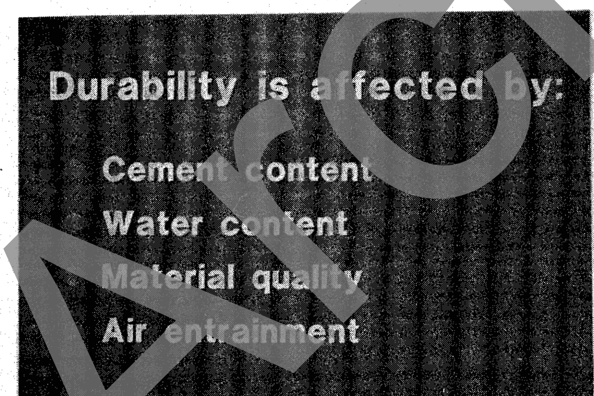
10. As the top size of the coarse aggregate is decreased, the amount of air entrained by a given dosage of admixture will increase. As the amount of cement is increase the air content will decrease.



11. It should be readily apparent that the properties of plastic concrete are not independent. In addition to the properties already discussed temperature will also affect the workability of the mix. Any change in one property of the mix will affect the other properties. This is the balancing act that takes place when a concrete mix is proportioned.



12. For concrete to be durable it has to be resistant to potential damage caused by weather, chemical reactions such as aggregate reactions, and/or chemical attack such as sulfate or deicing salts.



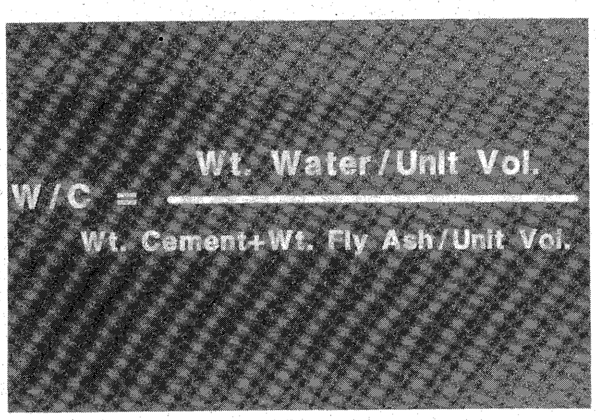
13. **Durability** is affected by several factors:

The cement content affects the strength and permeability of the concrete. Excessive amounts of cement can cause problems since additional water is needed for workability. Only about 1/2 of the water is used for hydration when the remaining water leaves the concrete it causes shrinkage which results in cracking. Even if shrinkage cracks do not occur the voids left by the excess water will result in a more permeable concrete.

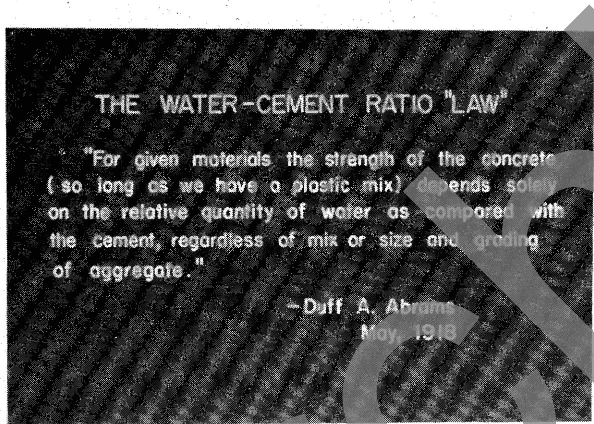
As the water content increases the strength decreases and the permeability and shrinkage of the concrete increases.

The quality of the cement will affect the resistance of the concrete to chemical attack and the quality of the aggregate will affect the resistance to aggregate durability problems.

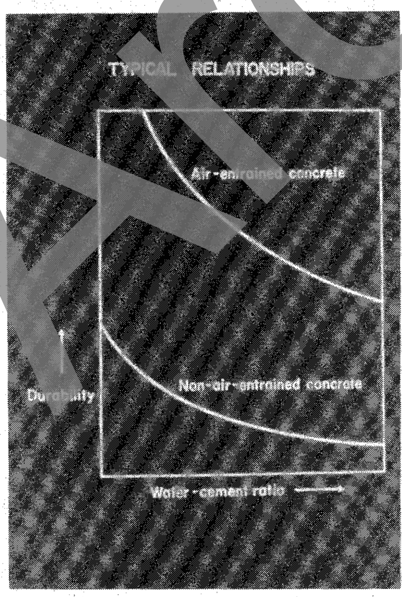
Air entrainment which provides protection against freeze-thaw, deicing salt attack and sulfate resistance.



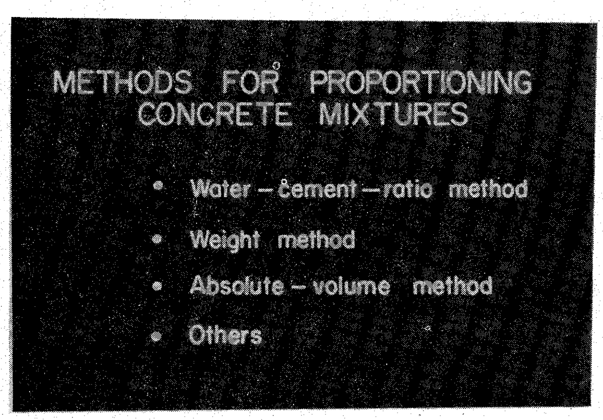
14. The water-cementitious ratio is the ratio by weight of water to cementitious material. This term is the equivalent to the term water-cement ratio except the cementitious material includes cement and any pozzolanic material.



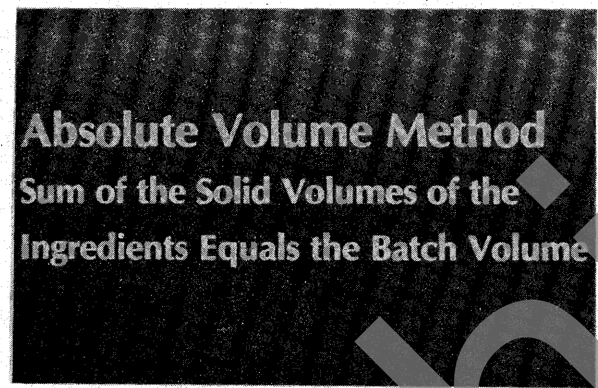
15. **As the water-cementitious ratio is lowered the strength increases providing the same materials are used.**



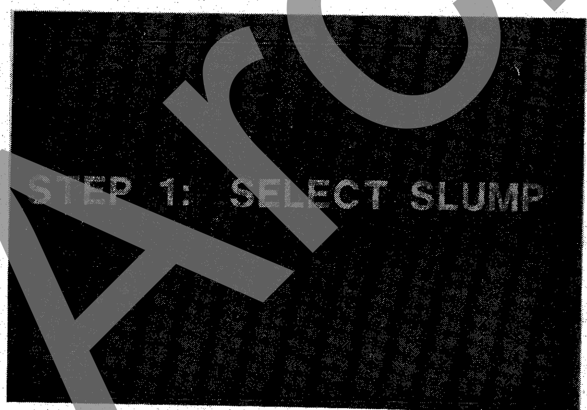
16. Durability goes up with air-entrainment and lower water cementitious ratios.



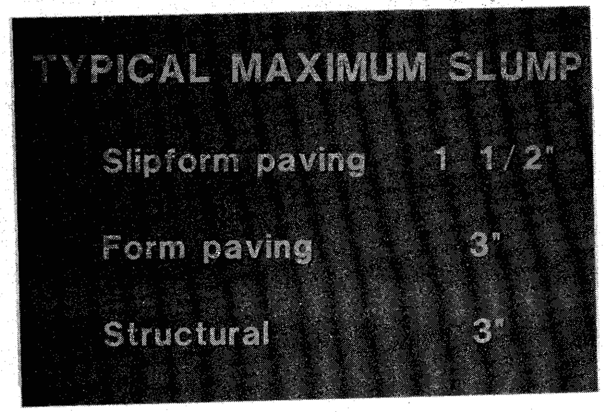
17. There are several ways to proportion concrete. All methods in one way or another eventually require making adjustments to the proportions based on the materials weight volume relationships since concrete is batched by weights.



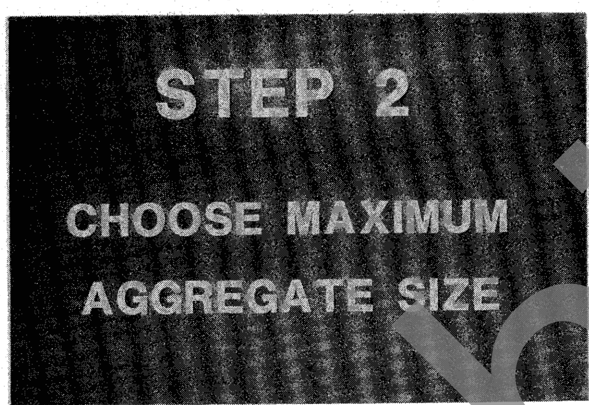
18. The following discussion and example will center on the **absolute volume method** since most state highway departments will perform proportioning based on a modification of this method.



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.

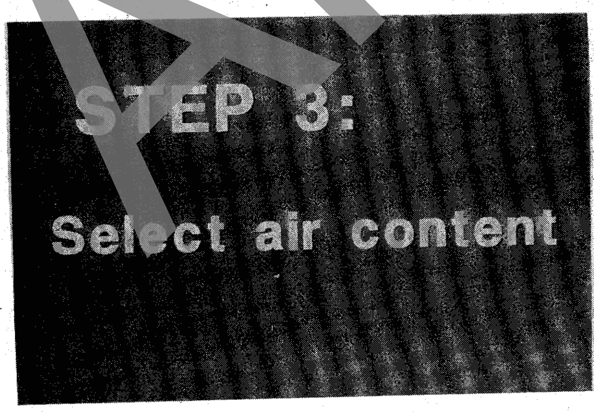


20. In the case of highway construction the maximum slumps for the various types of construction is spelled out in the specifications.

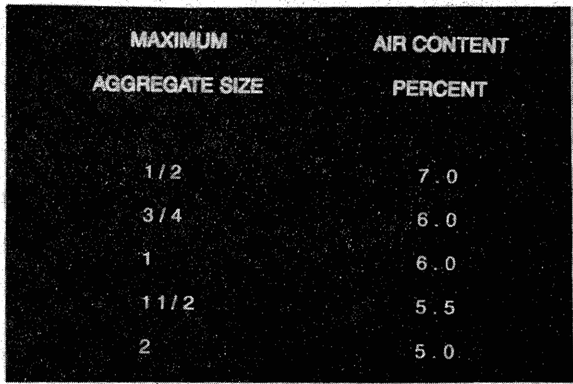


21. Second, the **maximum size aggregate** is then chosen. This should be chosen according to the type of construction, the clearance around the reinforcing steel, and the clearance between the rebar and the forms. The typical maximum aggregate size will be 1 to 3/4 inches.

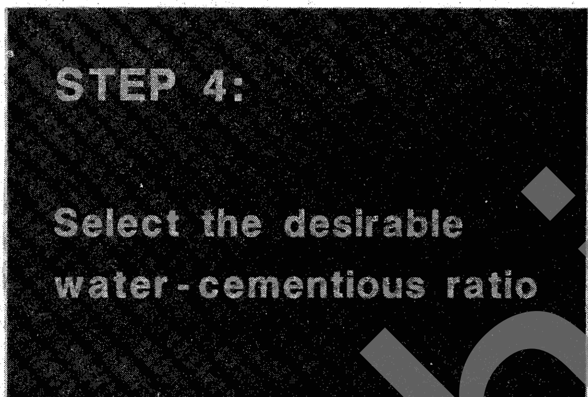
As the maximum aggregate size increases the more economical the mix becomes do to lower crushing costs. However, as the maximum aggregate size increases the potential for aggregate segregation problems increase. Aggregate segregation will result in variability in the workability of the mix.



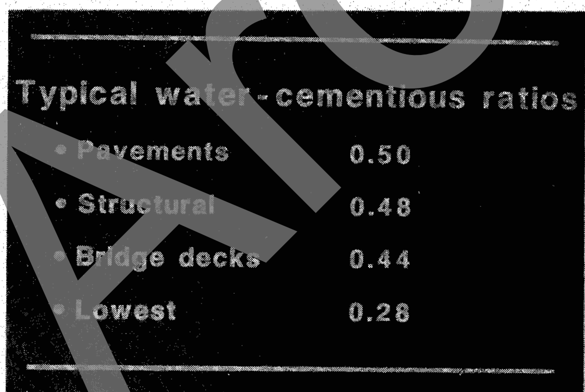
22. Third, the **air content** is chosen based on the maximum size aggregate and the exposure.



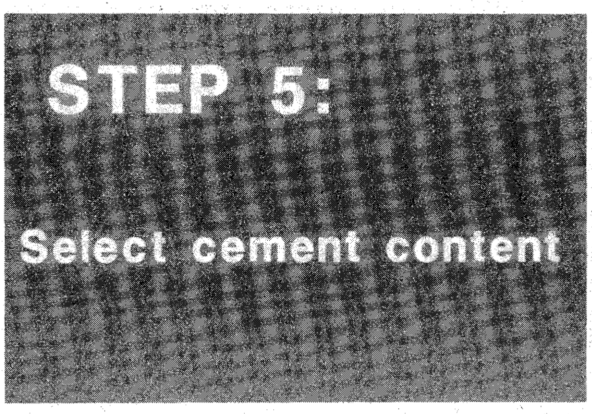
23. For severe exposure and a maximum aggregate size of 1 1/2 inches the recommended air content would be 5.5 percent.



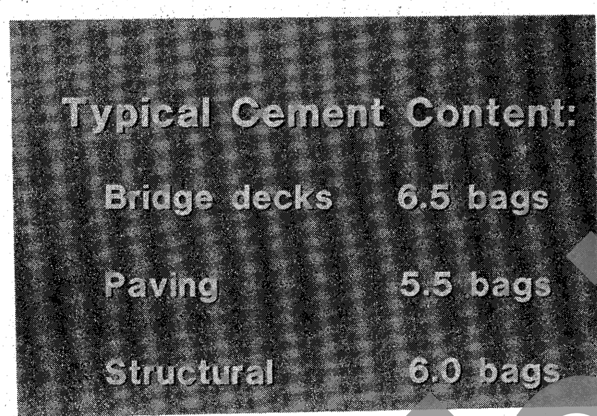
24. Fourth, the **water-cementitious** (w/c) ratio is picked. The selection of the w/c ratio is based on the desired strength, durability, and economy of the mix.



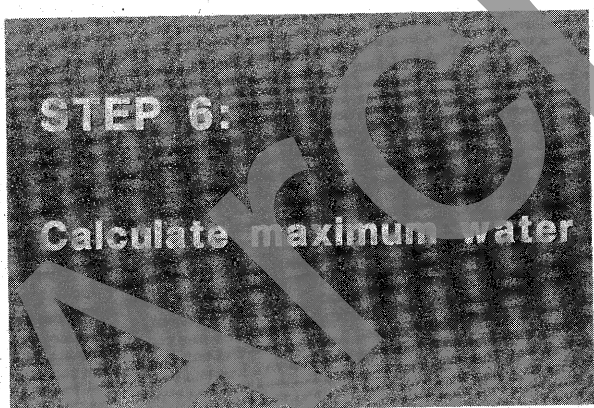
25. In order to maintain workability it usually costs more to obtain lower w/c ratios. A 0.44 w/c ratio is attainable with greater attention to aggregate gradations and proportioning. While w/c ratios in the range of 0.28 will require the use of a high range water reducer. Any water in excess of that needed for hydration of the cement will result in a more permeable concrete. Theoretically, the water needed to completely hydrate cement if the cement was properly dispersed is in the range of a water-cementitious ratio of 0.24.



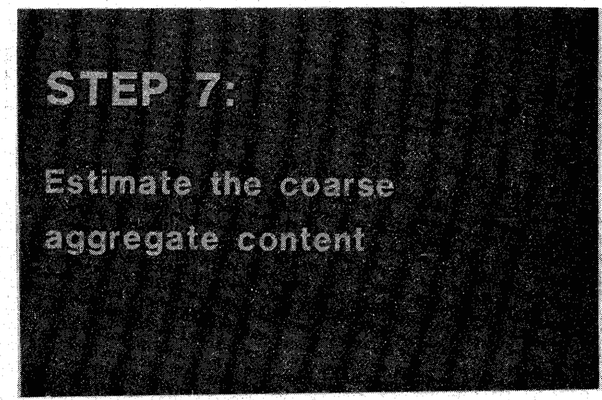
26. Fifth, the **cement content** is selected based on the desired strength, exposure, and expected construction variability.



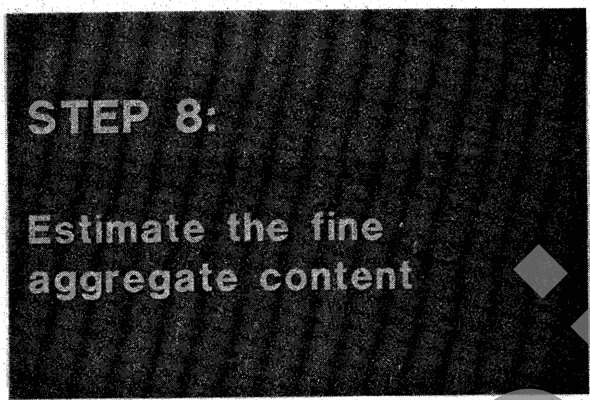
27. These are typical cement contents used by highway agencies to obtain the above desired properties. They fall in line with the recommendations in ACI for severe exposure.



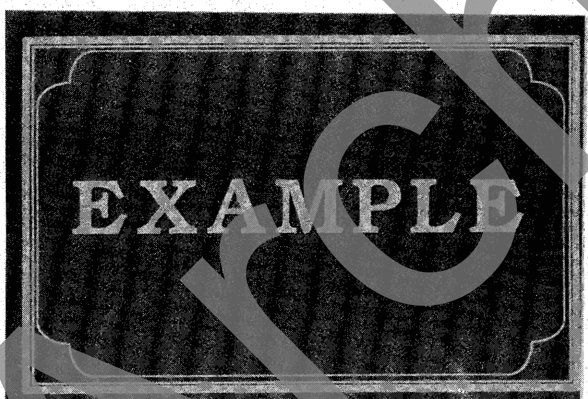
28. Sixth, at this point the **maximum allowable water** is calculated by multiplying the maximum water-cementitious ratio and the minimum cement content. The maximum water should not have to be used for paving and structural concrete.



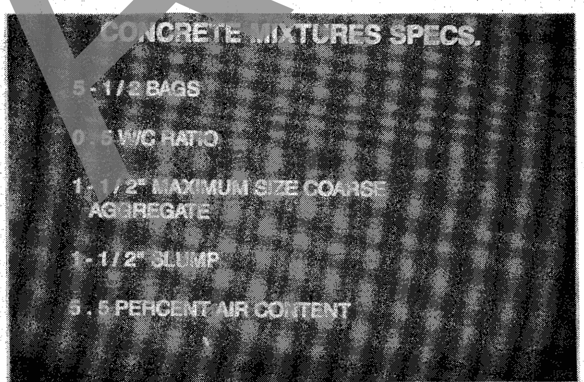
29. Seventh, the **estimate of the volume of coarse aggregate** in the mix is made based on the maximum aggregate size and the fineness modulus of the fine aggregate.



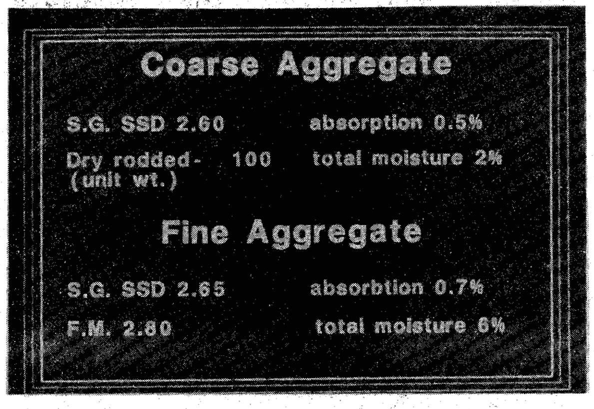
30. Finally, the estimate of the fine aggregate is the volume that is left over after the volumes of cement, water, air, and coarse aggregate are accounted for.



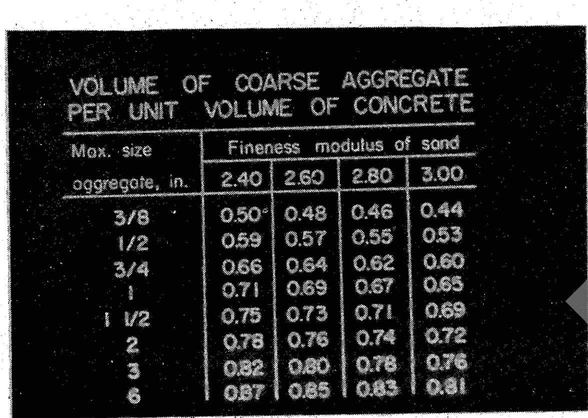
31. At this point an example of proportioning will be presented.



32. The following is specified criteria for the mix.



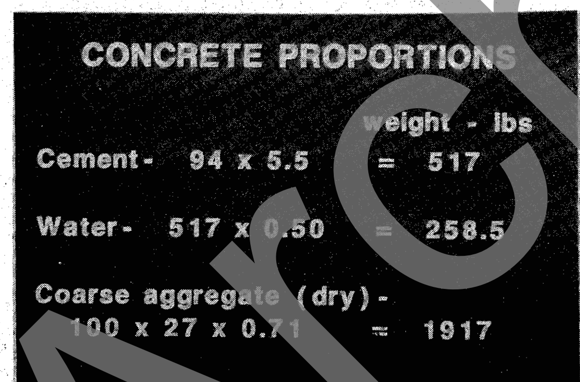
33. The physical properties of the aggregate is provided in this slide.



VOLUME OF COARSE AGGREGATE PER UNIT VOLUME OF CONCRETE

Max. size aggregate, in.	Fineness modulus of sand 2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
1/2	0.59	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1 1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

34. At this time the volume of coarse aggregate is determined from this chart. A coarse aggregate volume of 0.77 is found by entering the chart with a maximum size aggregate of a 1 1/2 inch and a fineness modulus of 2.80.

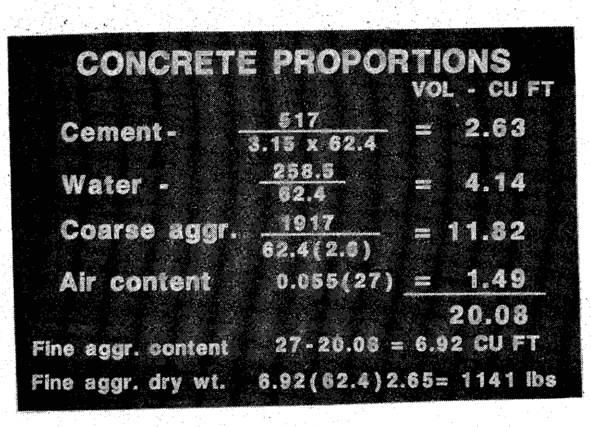


35. The weight of the cement, water and coarse aggregate is determined.

The **weight of the cement** is determined by multiplying the weight of a bag of cement (94 pounds) and the required number of bags.

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 (100 pounds per cubic foot), the volume of a cubic yard of concrete in foot, and the previously determined volume of coarse aggregate to be included in the concrete mix.

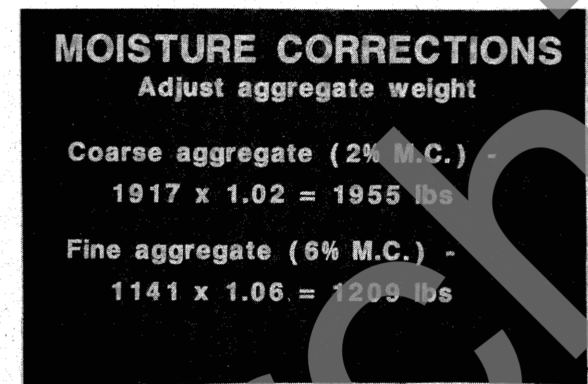


36. At this point the absolute volumes of the mix are determined and the weight of the fine aggregate is determined.

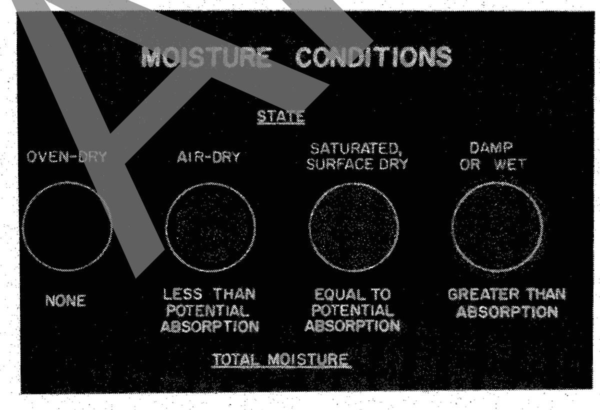
The **volumes of the cement, water and coarse aggregate** are determined directly from the previously determined weights and their specific gravities.

The **air content volume** is found directly by percent air content of the mix.

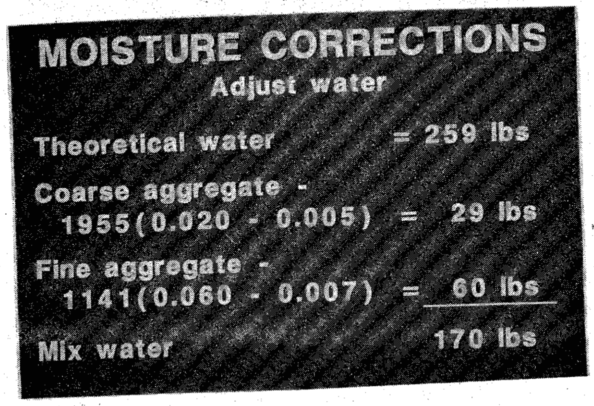
The **volume of the fine aggregate** is the volume remaining after the volumes of the other materials are calculated. The weight of the fine aggregate is then determined from the volume and its specific gravity.



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.

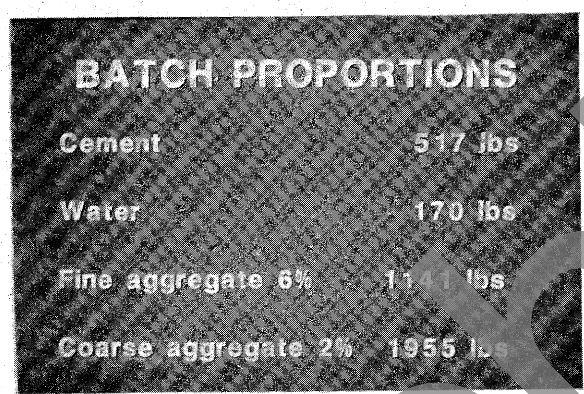


38. At this point corrections in the amount of water to be added to the mix needs to be made for the moisture content of the aggregate and the capability of the aggregate to absorb water. The maximum water-cementitious ratio is based on the total free water not the total water in the mix. The free water is the water content above that required to obtain a saturated surface dry condition in the aggregate.



39. The amount of free moisture in the aggregate is determined by multiplying the adjusted aggregate weight by the difference in the moisture content and the absorption of the aggregate.

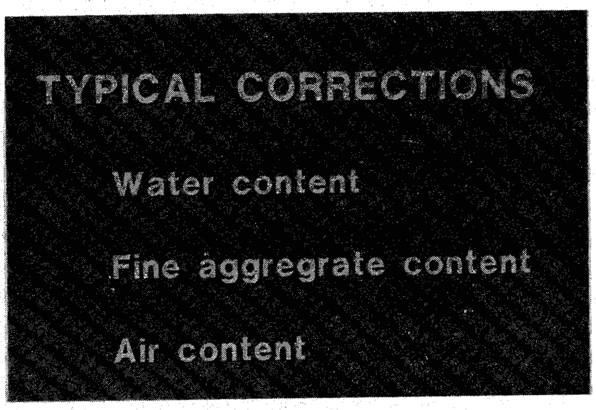
The free moisture from both aggregates is then subtracted from the theoretical maximum water content to obtain the batch weight for the water



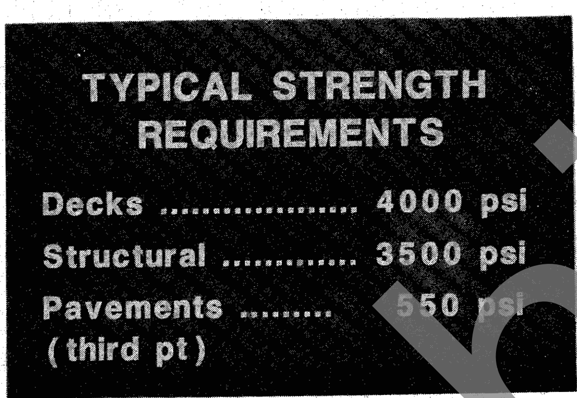
40. This slide shows the resulting batch weights.

41. At this point a trial batch would be performed 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.



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.



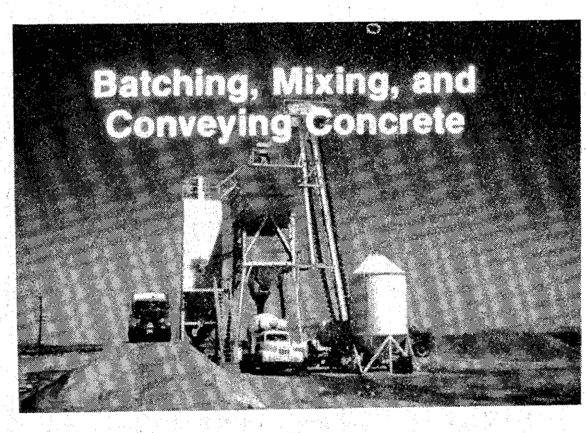
43. The final item to discuss is the strength requirements of concrete.

The **minimum specified strengths** indicated on the slide are based on the design of the structure that will incorporate the concrete.

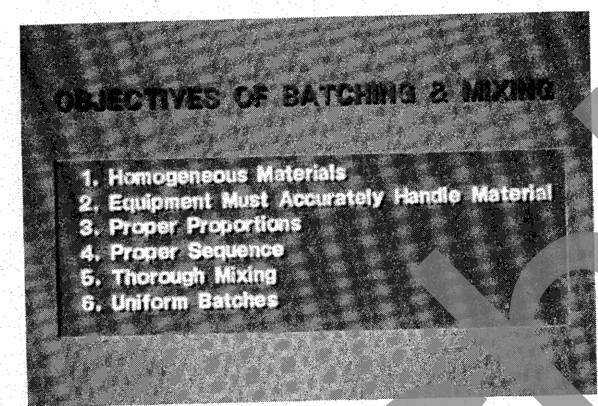
The **mix design strength** needs to reflect the required minimum strength plus the anticipated variability caused by the entire concrete operation. The variability in compressive strength for good construction can be expected to be 500 psi. Therefore, the mix design strength would equal the minimum specified strength plus 900 psi to compensate for this variability. These numbers are derived from ACI 318.

The specified w/c ratios and cement contents reflect both durability and the mix design strength.

BATCHING



1. Batching is the first step in the physical production of concrete. It consists of the accurate measurement of the ingredients to form a discrete batch of concrete. Following batching the material is thoroughly mixed until it is uniform and all materials are evenly distributed.



2. The aim of batching and mixing is to produce a uniform concrete containing the required proportions of materials. The proportions of materials must be consistent in order to assure this uniformity. Errors in the measurements of the ingredients during batching will cause variation in the workability, strength and durability. There are six objectives to batching and mixing. They are:

   1) Materials must be homogeneous and nonsegregated prior to and during production. Aggregates can become undersized as a result of handling operations, thus altering the gradation.

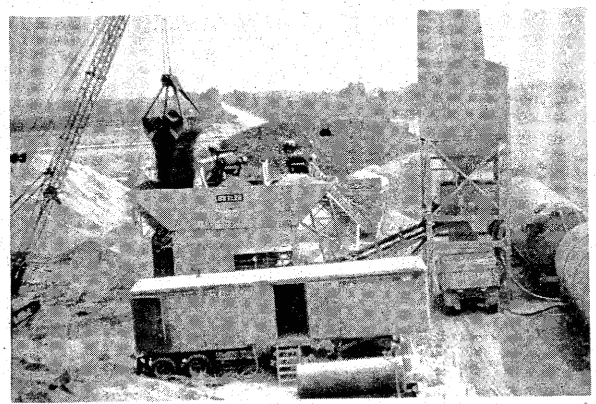
   2) The batching and mixing equipment must accurately handle material and must be capable of easily changing the quantities when required.

   3) The proper proportions of materials must be maintained from batch to batch.

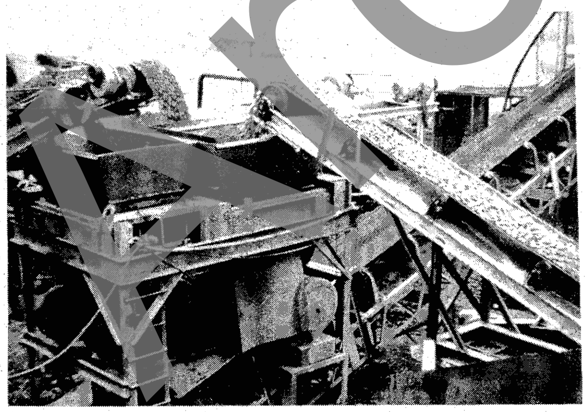
   4) Materials must be introduced to the mixer in the proper sequence.

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

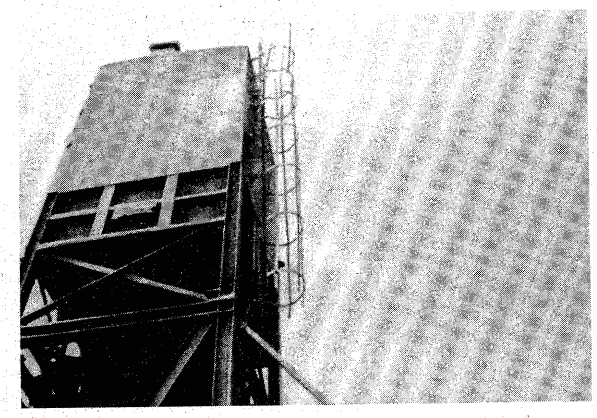
6) The concrete discharged from batch to batch will be uniform and homogeneous.



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.

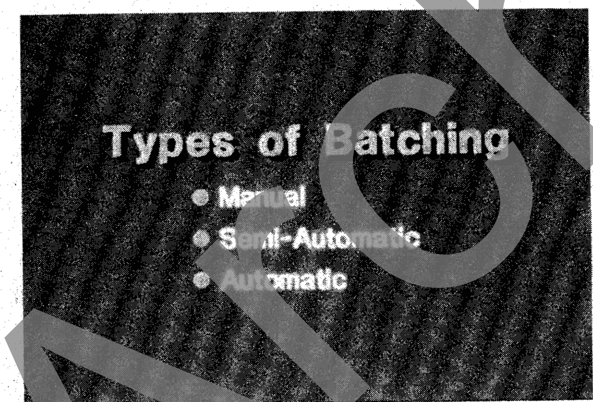


4. **Conveyor belts should also be positioned so that the aggregates will drop into the bins without hitting the sidewalls.** As with stockpiles, aggregates supplied by conveyor belts should not fall from great heights because degradation, segregation, and loss of fines can occur. Bins should be kept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



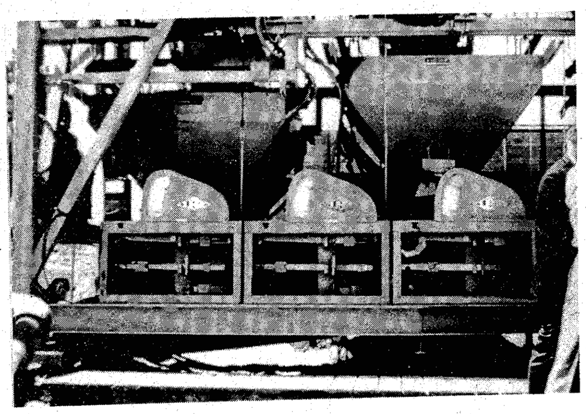
5. The **cement storage system** should provide for dry storage. The silos should be weatherproof and vented to prevent moisture from accumulating. Interiors of bins should be smooth to allow for the free removal of cement. Each bin or silo is equipped with a gate and conveyor system. The conveying system 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 an inspection made to assure that there is no build up of cement. Drawing the silo empty once a month can prevent cement caking. Cement build ups could break off and produce cement lumps in the finished concrete. Fly ash, when it is used, is handled similarly to cement.



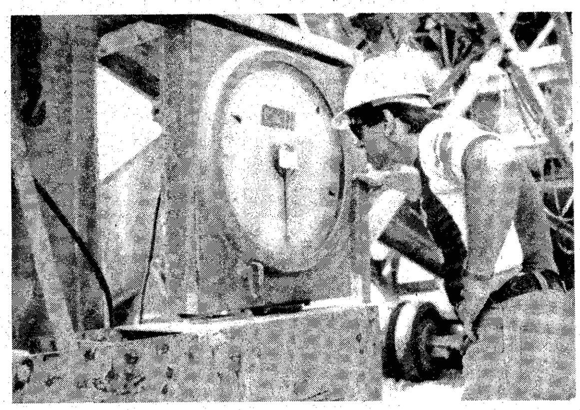
6. **Batching can be done by one of three methods. Manual batching is done by hand and is only recommended for small jobs. In a semi-automatic system the operator manually opens the aggregate bin gates to begin the charging of the batcher.** The gates are then closed automatically when the desired weight 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.

7. **In most cases batching will be done by weight rather than volume.** This is done because of the inaccuracies involved in measuring aggregates and cements by volume. Water and admixtures can be added by either volume or weight.

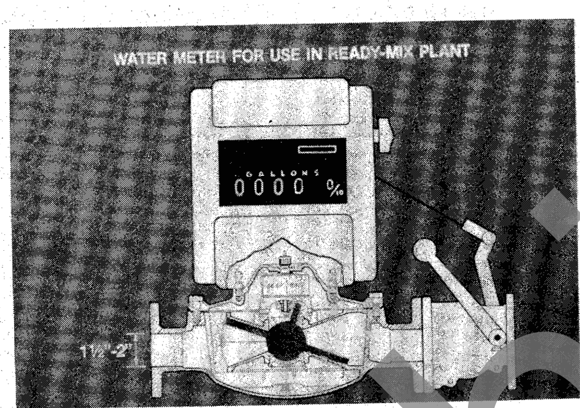


8. **The tolerance requirements for scales and meters** used for proportioning aggregates, cements, water and admixtures are found in the specifications. It is important that these scales or meters be test loaded and checked for compliance with specifications on a periodic basis. **Normal tolerance would be in the range of 1 percent for cement, 1 percent for water, 2 percent for aggregates, and 3 percent for admixtures.**

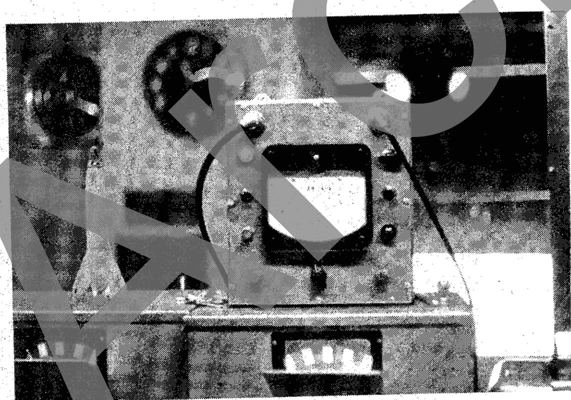
9. Each concrete plant should be provided with **a set of 50 pounds weights** or calibrating and testing weighing equipment. The scales should be checked over the range of weights expected. This is accomplished by loading the weights on the scale, checking the accuracy, removing the weights, loading material onto the scale up to the weight just checked, and loading the test weights on once again. In this way, the scales are checked at the higher loads.



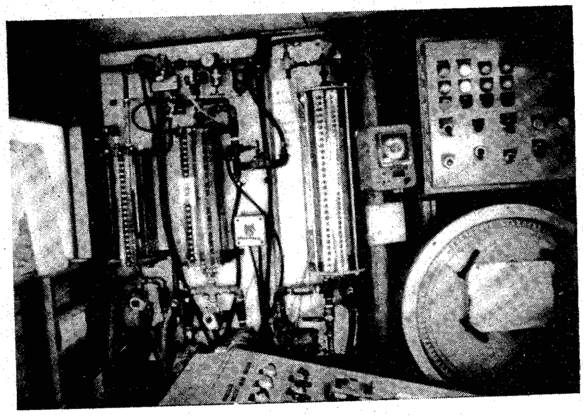
10. During the progress of the work, the scale read out system should be visually monitored to assure that it returns to zero after the material has been discharged from it. If it does not return to zero, this would indicate that some material was left in the batcher and the resulting batches are light.



11. Likewise, the water that is used in the concrete should have it's metering system calibrated. Most modern plants add water through a **flow meter,** which must be calibrated to assure the accuracy of the measurement. The water system should not have any leaks between the meter and the mixer. Older systems that batch water by weight or volume should also have there systems calibrated.

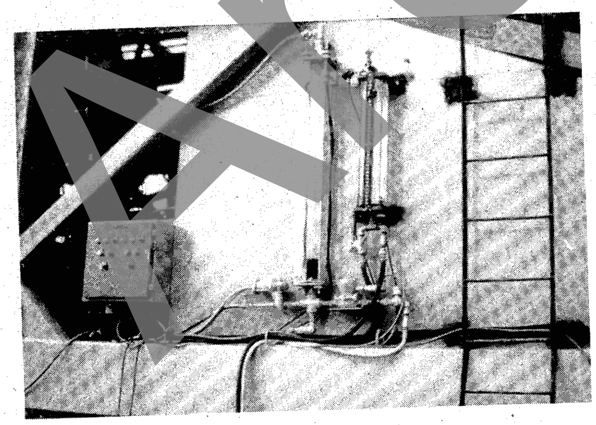


12. The free water in the aggregate must be accounted for proper control of mixing water. Sand moisture meters are acceptable. When properly maintained and calibrated they will satisfactorily indicate the general magnitude of the sand moisture content. Moisture readings should be checked against regular control tests.



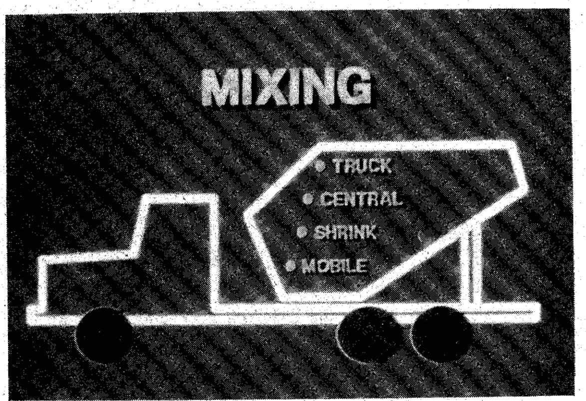
13. Admixtures are commonly provided in liquid form and may be dispensed into the mixer by weight or volume. Dispensers should be large enough to measure a full batch of admixture for each batch of concrete. It is desirable that the dispensing system be integrated with any batching interlocking system. 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 to the desired volume and totally discharges for each batch.

14. The dispensing equipment must 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.



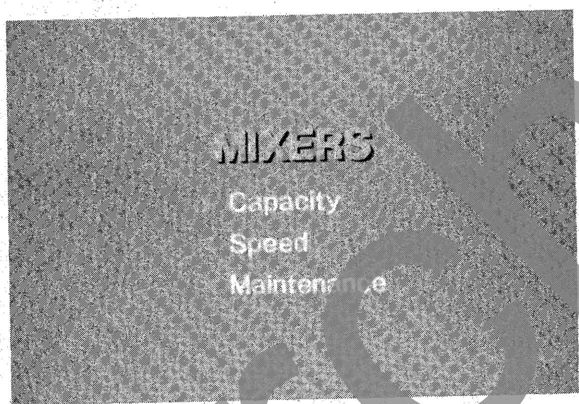
15. **The introduction of admixtures into a concrete batch involves the rate of discharge, the timing in the batching sequence, and the medium used.** Changing the time at which the admixture is added during the mixing cycle can, in some cases, vary the effectiveness. Likewise, variations in the application rates will adversely 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

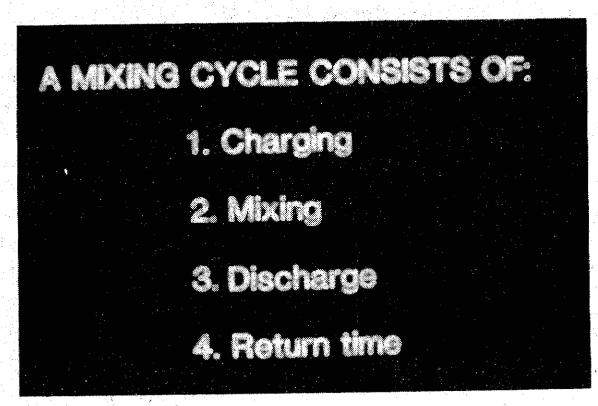


17. Regardless of the type of mixing plant, there are certain factors that each have in common:

    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.

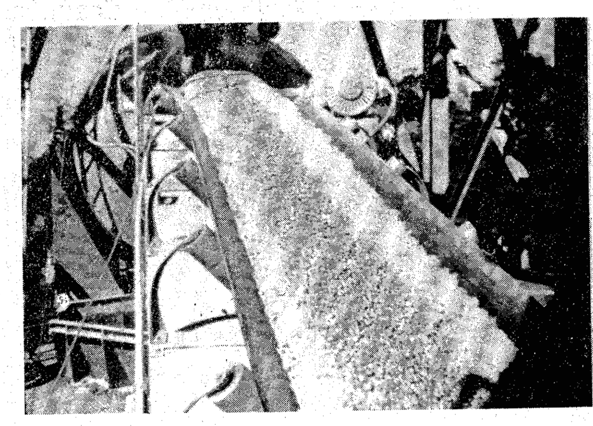
    3) **Maintenance** - Mixers should be clean and in good condition. Materials should not leak from the mixer and mortar should not build up on the blades. A very important consideration is blade wear. Blades need to be checked periodically and a mark placed on them to gauge wear. Plans showing blade design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



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

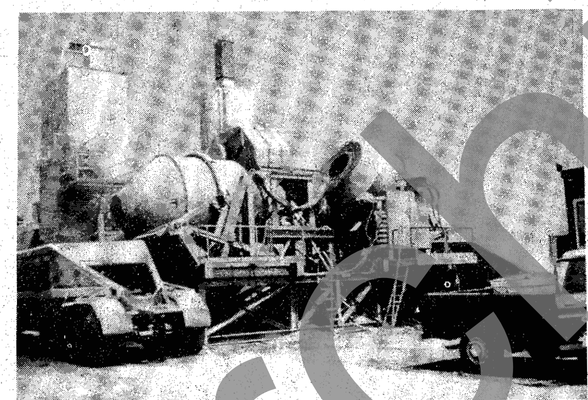
19. **Charging time** begins when the batching is completed and materials are entered into the drum. Charging continues until all solid materials are in the mixer and it is ready to start the mixing cycle.

20. The **charging of materials** into the mixer is an important consideration. Loading must be done to prevent the packing of material in the head of the drum. A blend of water, cement, and aggregate from start to finish may cause problems such as head pack (sand and cement) and poor mixing. 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.

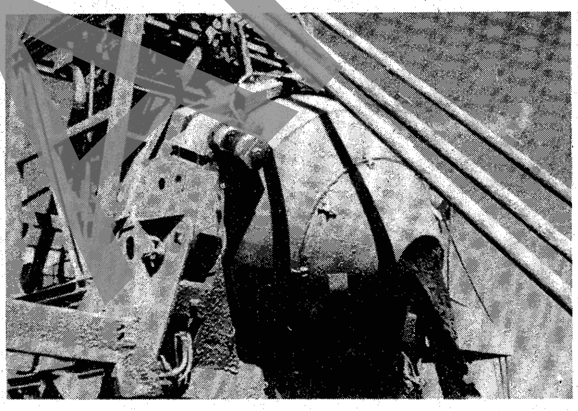


21. The charging of the mixer begins by adding water to the mixer followed closely by the aggregate. Water should continue to flow throughout the mixer charging. During the aggregate flow the coarse aggregates should start first then the sand. The sand flow should end just before the last of the coarse aggregate. Cement should be added starting about 3 seconds after the aggregates. Cement should end about 10 seconds before the last of the aggregates.

In general, admixtures should be added with the water. When more than one admixture is used, separate discharge pipes should be provided for each. Care should be taken to keep admixtures from coming together as they enter the mixer.



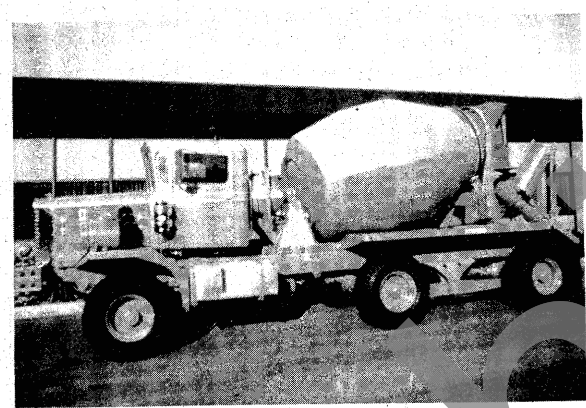
22. **Mixing time** commences with the first mixing revolution of the drum. In a stationary type of mixer this begins when the charging ends. In a truck mixer this may not begin until after the truck arrives at the project site. Water may be charged for a period of up to 25 percent of the mixing time. The mixing time ends when the first mixed concrete is discharged from the mixer.

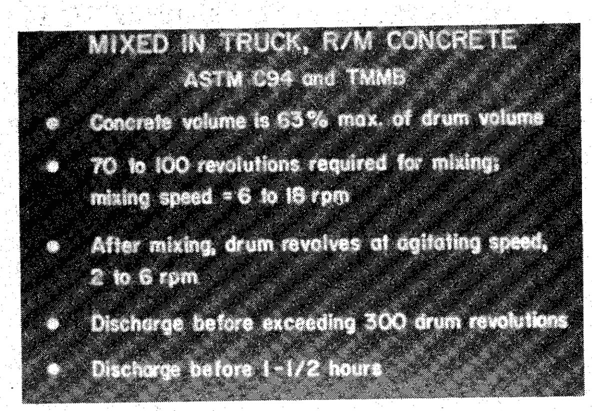


23. **Discharge time** is the time from when the first particle of concrete starts leaving the mixer until the mixer is empty. The slump of the concrete will generally determine the discharge time of any mixer. The discharge may be into forms, conveying equipment or agitating transportation equipment.

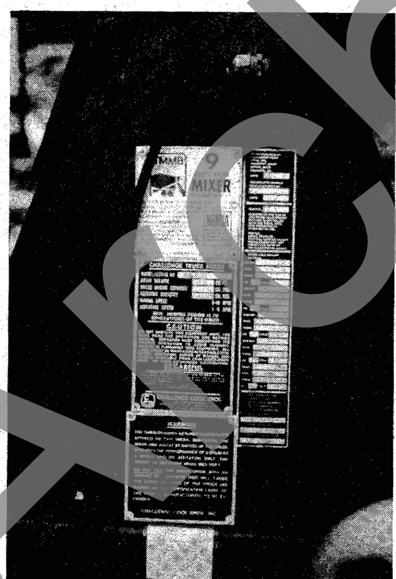
24. The **return time** is the time from the instant the mixer is empty to when it is ready to be charged again. In a central mix operation this return time could be only a matter of seconds. For a truck mixer the return time could be a matter of hours as the truck returns to the batching location.

25. **Truck mixing** is the most common type of mixing. Common sizes range from 7 cubic yards to 10 cubic yards, however much larger mixers are available. They are classified as an inclined axis mixer 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.

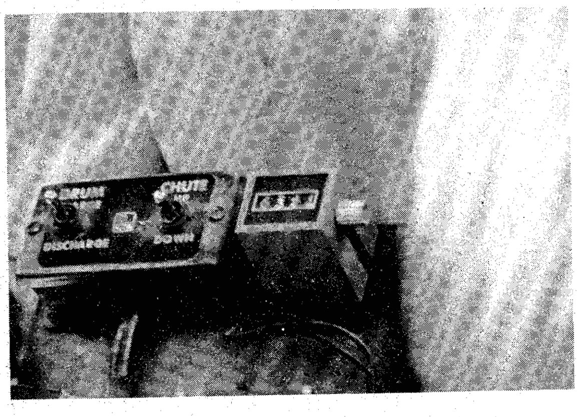




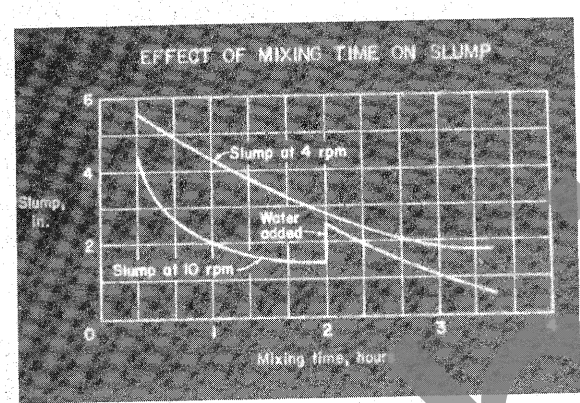
26. This chart summarizes the mixing specifications. **Mixing should be done within 70 to 100 revolutions and at the recommended drum rotation speed.** After mixing, the drum should revolve at the recommended agitating speed. **The concrete is required to be delivered and discharge completed within 1 1/2 hours or before the drum has revolved 300 times after the introduction of the water to the cement.** This limit is to prevent the degradation of softer aggregates and to prevent a slump loss that occurs with increased mixing revolutions. **Note also that the mixing capacity is only 63 percent of the drum volume when being used as a mixer.** The large number shown on the plate is the mixing capacity. If a truck mixer is being used to transport previously mixed concrete the agitating capacity of the drum is 80 percent of the drum volume.



27. 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 capacity for mixing, the capacity for agitating, and the mixing and agitating speeds. Truck mixers must not mix and transport a batch larger than the capacity shown. 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 a percentage of the drum volume.

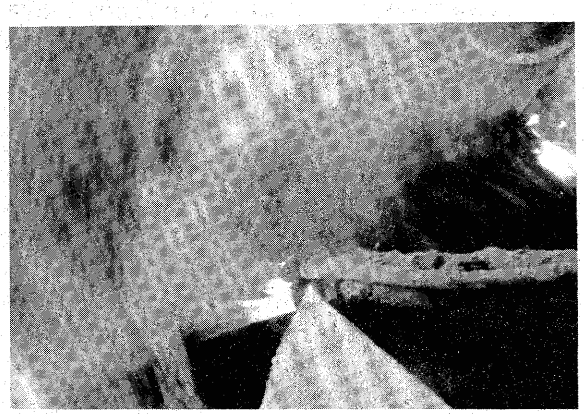


28. All truck mixers should be equipped with a **revolution counter**. Some counters are readily resettable while others must be reset at the plant. Inspectors must observe that mixing is done in compliance with the revolutions required by their specifications. Generally, the requirements for mixing will be in the range specified by AASHTO M-157 or ASTM C94.



29. The effect of too much mixing is shown here in this chart presented by PCA. Over mixing is not desirable 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.

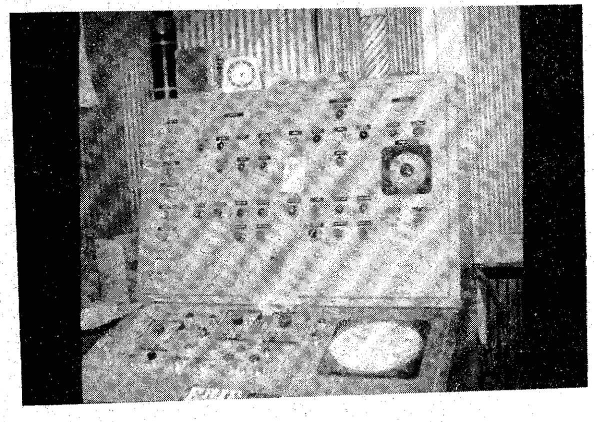
30. A check on the thoroughness of mixing can be made by performing a **uniformity test.** This involves test samples of concrete from different places in the load, performing normal concrete tests, and comparing the results against preestablished tolerances. **For truck mixers, a uniformity test is performed by comparing results after 15 percent and 85 percent of the load has been discharged.** A typical tolerance would be within 1 inch for slumps under 4 inches. ASTM C94 specifies the procedures for conducting a uniformity test.



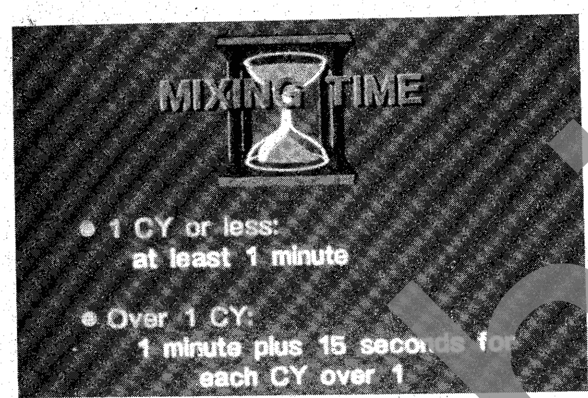
31. One problem with truck mixers that requires special consideration is the uncontrolled addition of water.

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 1 gallon of water per cubic yard of concrete will result in a 1 inch 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 interdependence of slump and air content (improper admixture usage).

32. **Central mixers** are stationary mixers that are of four general types: Non-tilting, Tilting, Vertical Shaft, and Horizontal Shaft. **The tilting type** is shown here and is the most common. It has a capacity of from 2 to 15 cubic yards. 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, a truck mixer operating at agitating speed, or a special non-agitating truck.



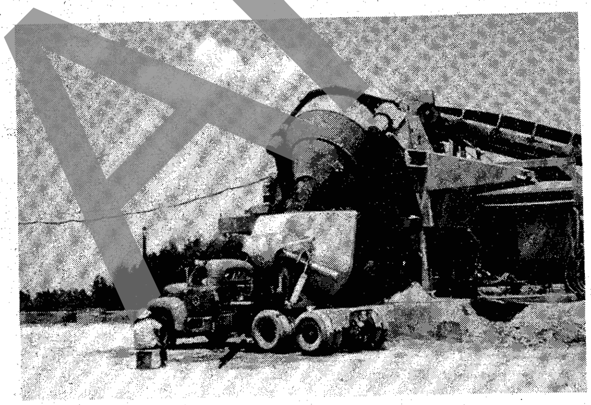
33. Some central mix plants have a **slump meter** on the control panel. The slump meter is nothing more than an electrical meter which measures the effort or the current necessary to drive the mixing drum. The stiffer the mix, the more resistance is offered and consequently, the more energy it takes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



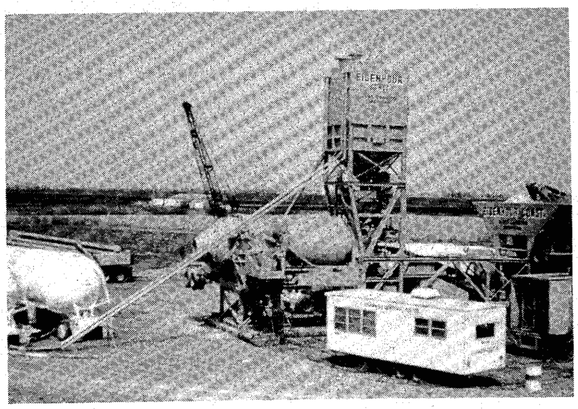
34. AASHTO M157 suggests that where no performance test have been made on a central mixer, the following **mixing times** apply:

- For mixers with a capacity of 1 cubic yard or less, mix for at least 1 minute.
- For mixers of greater capacity, increase mixing time by 15 seconds for each cubic yard, or fraction thereof, of additional capacity.

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.

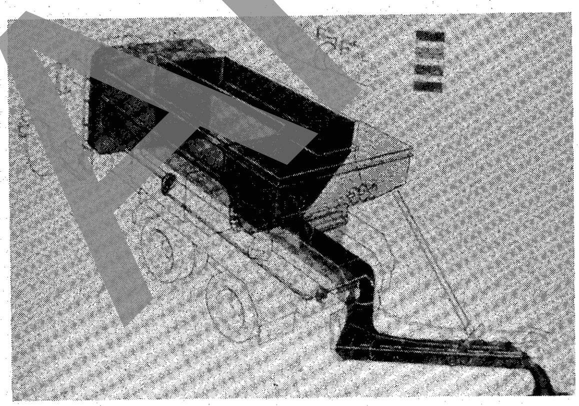


35. As was stated for truck mixers, central mixers should have a **uniformity test** performed periodically. Again, samples are taken at the 15 percent and 85 percent discharge stage and the results compared to predetermined tolerances.



36. **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.

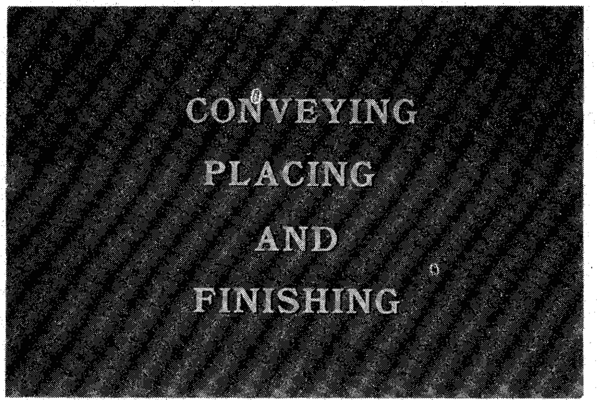
37. **Mobile batcher mixers** are special trucks that batch by volume. They continuously mix concrete as the dry ingredients and water are fed into the mixer. Mixing time is only about 7 seconds. Mobile mixers are used for small quantities when on site mixing is advantageous. This would include pavement 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.



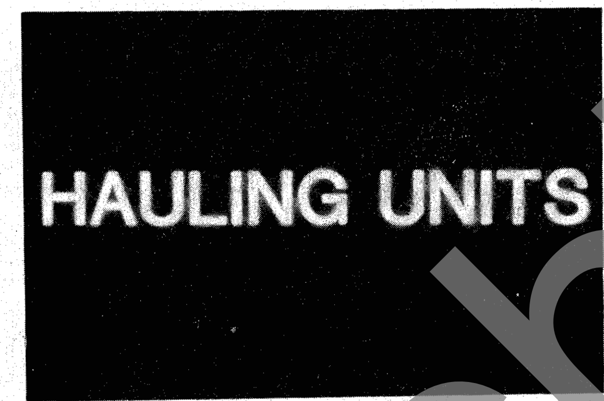
38. Mobile mixers need to be calibrated prior to their use and should be recalibrated if there is a change in material sources. Copies of the calibration should be available for the use of the inspector. The mobile mixer consists of bins for sand, coarse aggregate, cement and water. The aggregate bins have belts at the below a calibrated gate.

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 4 to 12 cubic yards.

CONVEYING, PLACING, AND FINISHING



1. This part of the course will center on conveying, placing and finishing. The section will cover the construction procedures for both structural concrete and paving concrete.

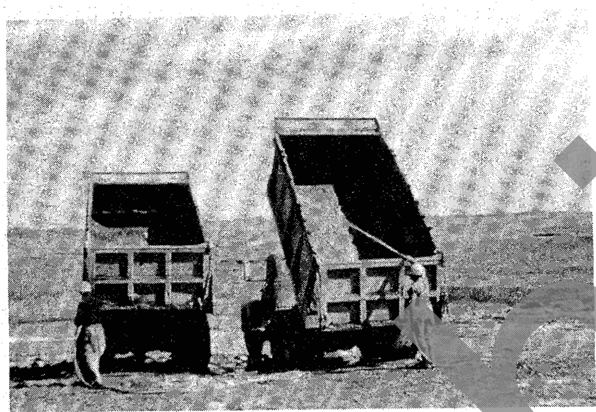


2. The first item that we will discuss are the hauling units. There are several types of hauling units and several of these have special uses.

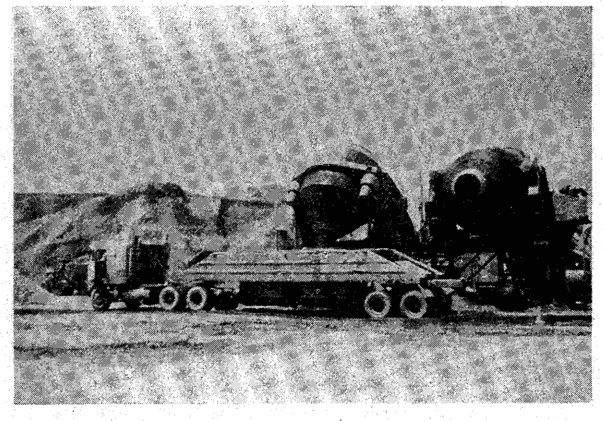
3. The **truck mixer** is used as a hauling unit. It is typically used for structural concrete and will sometimes be used for small paving projects. Caution needs to be used when truck mixed concrete is used for any type of slip form operation due to uniformity considerations. The trucks should be inspected prior to use to insure that the blade configuration is correct, blade wear is not excessive, water meter is calibrated and the revolution counter works. With all hauling units care must be taken to insure that the trucks are cleaned. Care must also be taken to remove or account for all the wash water.

4. **Agitator truck** 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.

5. **End dumps** are only used in paving concrete 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.



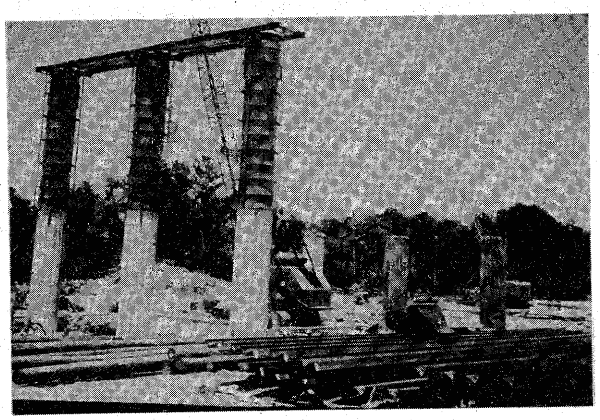
6. **Side dumps** also do not have agitation. The same statements about the end dumps apply to the side dumps.



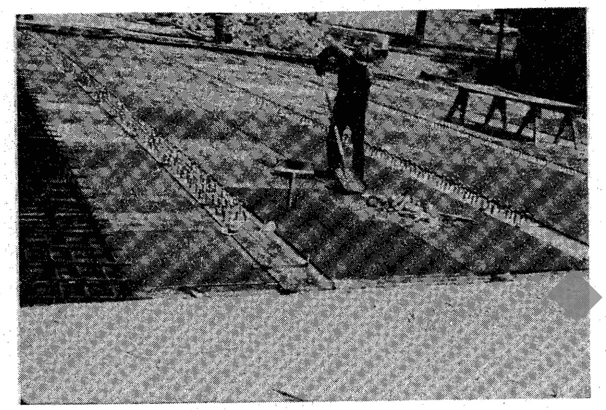
7. **Bottom dumps** are also used in paving concrete operations. Their use should be limited due to the possibility of contaminating the concrete with dirt from the trucks tires. The vehicles should also be limited to short hauls.

8. The last type of hauling device is the **mobil mixer**. These are typically used for patching concrete and deck overlays. The mixing section of this course goes into more detail on the proper operation of this piece of equipment.

9. 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.

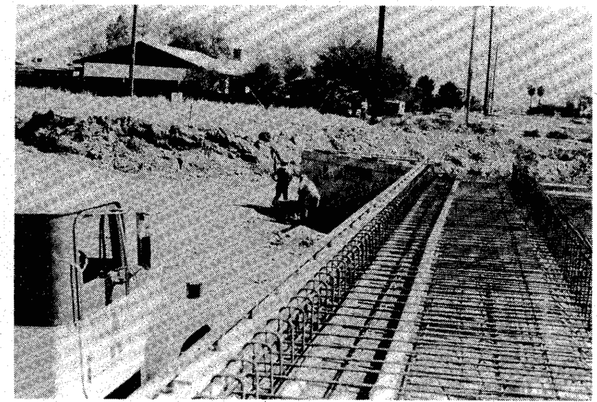


10. In structural concrete it is important that the forms be tight to prevent mortar from coming out of the forms. It is also necessary that the forms be rigid and well braced to insure that the forms will not bulge or collapse.

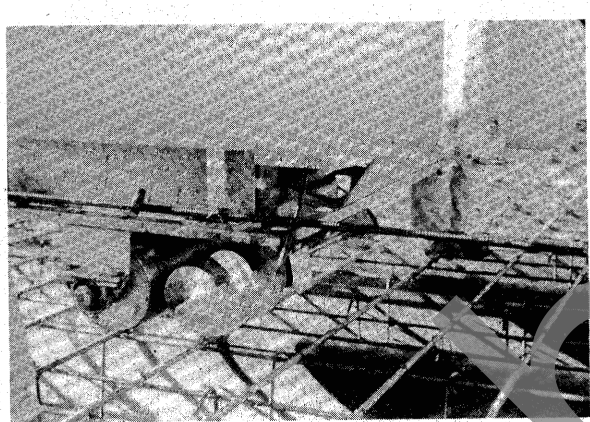


11. The **forms** also have to be cleaned to insure that the concrete will not be contaminated. It is also necessary that the forms be coated with a form release agent to insure that they can be removed without damaging the concrete unless stay-in-place forms are being used.

12. The **reinforcing steel** needs to be free of scale, placed in the proper position, and tied properly. A sufficient number of chairs need to be used to avoid movement of the reinforcing steel. Proper clearances must also be maintained. Rebar splices should also be performed properly. The lap should be at least 30 bar diameters. The coating on epoxy coated rebars should be repaired when nicks and holidays are present. At least every other joint should be tied. When epoxy coated rebar is used coated tie wire and chairs should be used. Reinforcing steel should be stored properly at the project site. In all cases the steel should not come in contact with the ground. Epoxy coat steel should be stored so the coating will not be damaged in handling.

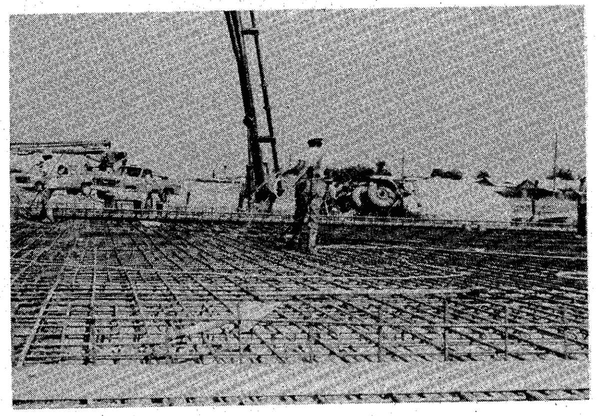


13. On bridge deck construction, the screed rail must be properly positioned. The rail must be set to compensate for the dead load deflection which will occur during placement. Particular attention needs to be placed on reviewing the adequacy of the support of the rail. Some forms which overhang may not provided adequate support to insure proper grade and cross section.



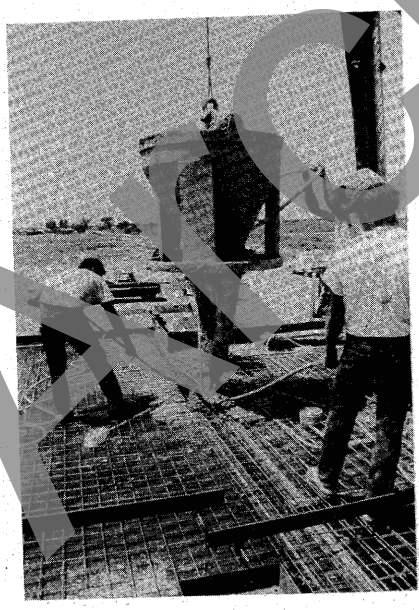
14. A dry run should also be made with the screed prior to beginning a concrete placement. This provides an opportunity to check the cover on the rebar and to check the depth of the section. Typically a piece of 2x4 is tied to the bottom of the screed to perform the check.

15. If proper cover on the rebar is not maintained cracks such as these can occur above the rebar. This condition will lead to quick deterioration of the deck in this location.

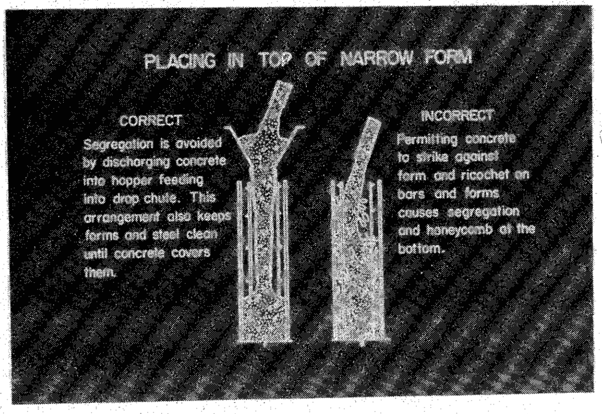


16. Immediately prior to placement the forms and the steel should be wet down. This insures that water will not be absorbed by wood forms and also cools down the reinforcing steel and metal forms so a flash set will not occur at the point where the concrete touches the metal.

17. **Concrete needs to be placed as close as possible to its final location.** One method of doing this is to use the **chute** on the delivery truck. The chute is capable of swiveling and extensions can be put on the chute.



18. **Buckets** are often used in structural work to convey the concrete from the trucks to the forms. In order to prevent segregation of the mix the concrete should not free fall more than 4 feet. The capacity and the number of buckets should match the capacity of the rest of the operation.

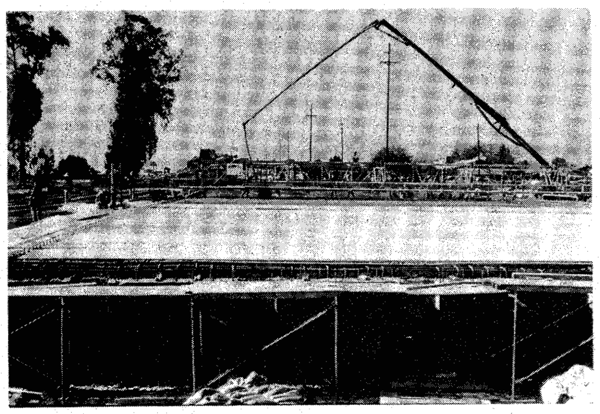


19. **Drop chutes** should be used when placing concrete in tall forms. This will prevent segregation and honeycombing from occurring due to long drops and material bouncing off the rebar.

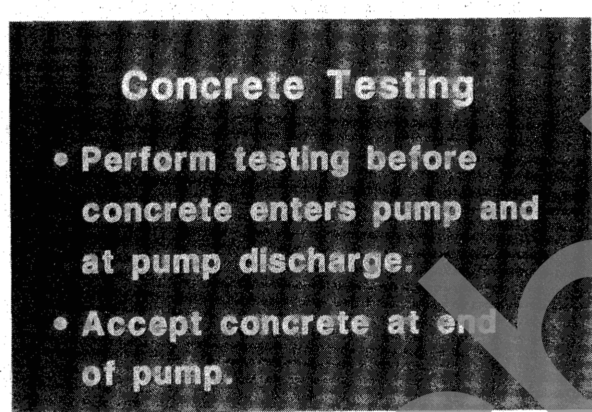
20. **Concrete buggies** are usually not used in highway construction because of the time and labor involved.

21. **Conveyors** have been used often for bridge deck placement where the placement is a considerable length away from the end of the bridge. Attention needs to be placed at the discharge end of the conveyor to insure that segregation will not occur. During hot windy days it may also be necessary to shield the conveyor to prevent the concrete from losing workability.

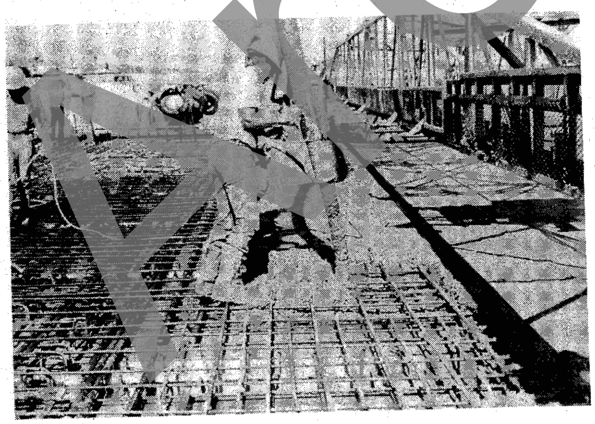
As a rule of thumb conveyors with a smooth belt should be restricted to an angle of 20 to 25 degrees. Conveyors with corrugations should be restricted to an angle of 30 to 35 degrees. This is to insure that the concrete will not flow on the belt.



22. **Pumping operations** can seriously affect the plastic properties of the concrete. The temperature of the concrete will rise, the air content will fall, and there will be a drop in workability. The longer and higher the pumping operations the more severe the affect will be. It should also be noted that aluminum pipe should not be used in the equipment. The aluminum will abrade and will react with the concrete and form expansive gases which are detrimental to concrete.



23. In order to know the effect the pumping operation will have on the concrete it is necessary to perform air, slump, and temperature tests on the concrete before and after it leaves the pump. It will be necessary to do this testing every time there is a significant change in the temperature of the concrete.

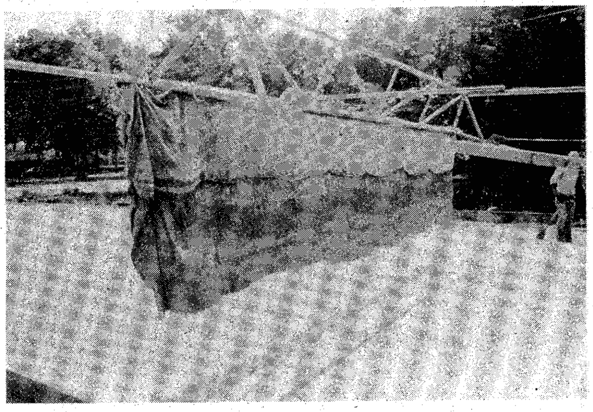


24. As with all placing operations the concrete should be placed as close to its final location as possible. **The acceptance tests should be performed on samples taken at the point of discharge.**

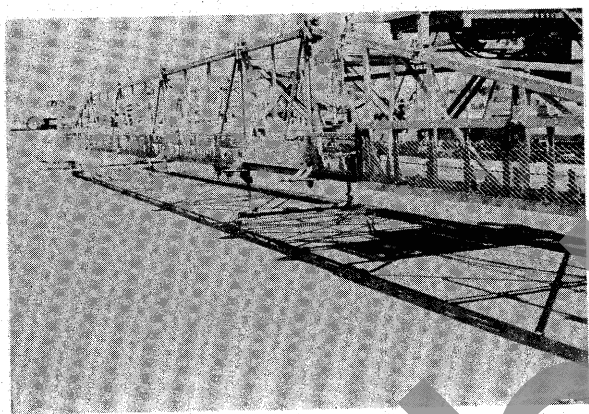
25. Proper **consolidation** is necessary to insure that voids or segregation will not occur. The vibrator should be held vertical and moved every 5 to 15 seconds. Longer vibration time will tend to segregate the mix.

The recommended frequency for vibrators varies with the diameter of the vibrator. They range from 10,000 to 15,000 VPM for 3/4 to 1.5 inch diameter vibrators to 8,000 to 12,000 VPM for 2 to 3.5 inch diameter vibrators. The effective range of a 2 to 3.5 inch diameter vibrator is 7 to 14 inches. Vibrators should never be used to move concrete. The vibrator should not come in contact with either the reinforcing steel or the forms. If this occurs the mix could segregate.

26. **Finishing** of a bridge deck is accomplished by the use of a bridge deck finishing machine. The machines are self propelled. The machines screed and finish the concrete to the desired cross section. If additional finishing is necessary due to imperfections it should be done with a float immediately after the bridge deck machine passes or after the bleed water evaporates. No finishing should be performed when bleed water is present since this will work the water into the surface raising the w/c ratio and cause deterioration of the surface. Water should never be added to the surface to aid finishing.



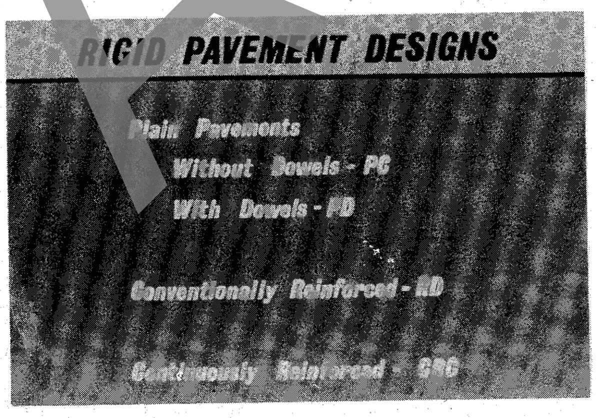
27. Micro-texture in the deck can be obtained with an artificial turf drag or a burlap drag. The **burlap drag** should be kept moist. Water should not be added to the burlap while it is on the deck. The burlap also should not have a large build up of concrete on it. A burlap drag alone is not sufficient texturing for traffic over 40 miles per hour.



28. The final texturing operation consists of **tining** the surface to obtain a good macro-texture. A one foot area next to the barrier should not be tined in order to facilitate drainage. The tines should be 0.08 inches wide and spaced 3/4-inch apart and 4 to 6 inches long. This should result in grooves that are spaced 1/2 to 3/4-inch apart and a depth of 1/8 to 3/16-inch. Overlapping of the texturing needs to be avoided to insure that the resulting thin fins will not break off.

FHWA Technical Advisory T 5140.10 "Texturing and Skid Resistance of Concrete pavements and Bridge Decks" contains further guidance on this subject.

Some States will also use a float with grooves to obtain the same type of texture or will saw grooves into the surface.

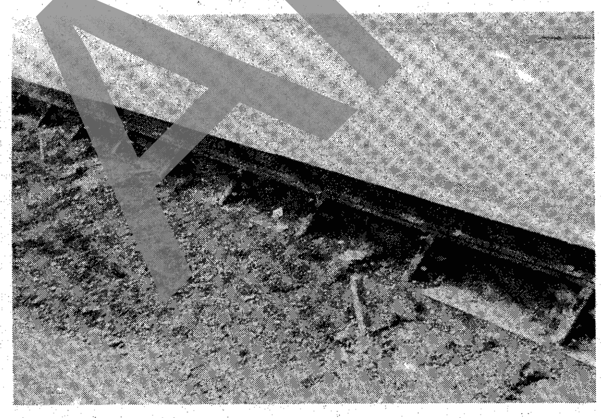


29. There are three basic designs for concrete pavements; **plain, reinforced**, and **continuously** reinforced. Plain concrete pavements can be designed with or without dowels. Reinforced concrete pavements can be designed as either conventionally reinforced jointed pavements or continuous reinforced pavements. These details will affect the construction operations for concrete paving. There are

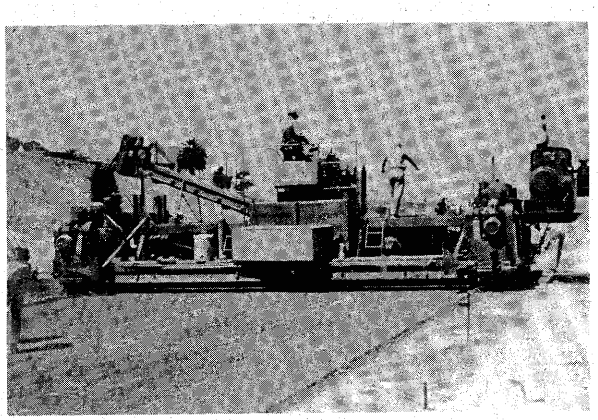
many types of concrete placing equipment. This course will discuss the specific construction operations for several paving trains but not the capability of specific types of equipment which may be capable of performing several of the operations.

30. 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 check for horizontal alignment by using a string line. Forms should be mechanically cleaned prior to bring used.

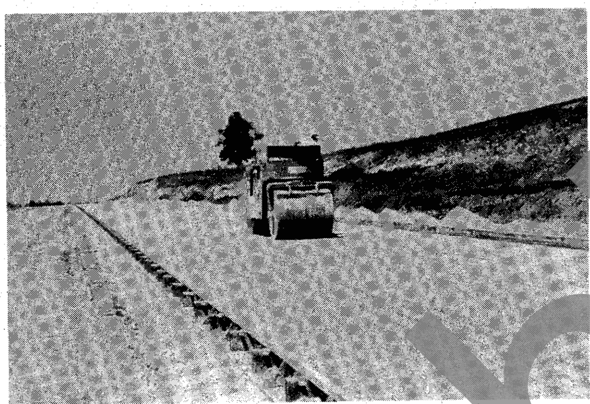
31. Vertical alignment is checked by using a rolling straight edge. The grade of the forms itself is set from a string line.



32. The forms should be sitting on a solid subbase with no shims. The forms should have stakes in each of the three pockets of a 10 foot form and two keys to lock each of the stakes.

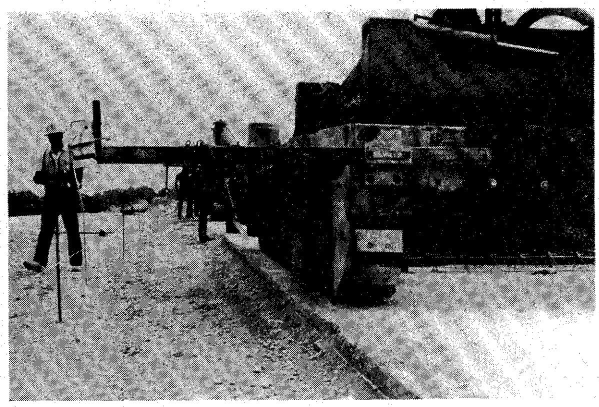


33. Fine grading is performed at this point in a slip form paving operation if a non stabilized based is used. In the case of a slip form operation the grade control is taken off of the string line. In the case of form paving a template will ride on the forms to mark high points on the subbase.



34. Once the fine grading is completed moisture is added to the subbase to the material up to the optimum moisture content. Then the subbase is recompacted to the proper density.

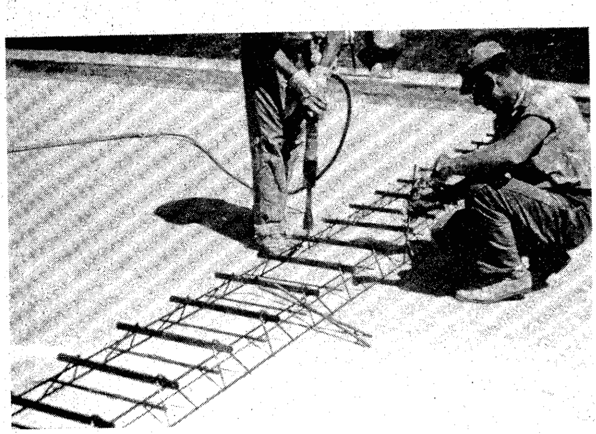
35. When a **cement treated subbase** is used it is very important to have a proper bond breaker between the subbase and the concrete pavement. This will help to prevent the random transverse cracks in the subbase from reflecting up through the concrete pavement. The typical bond breaker is a double coat of curing compound.



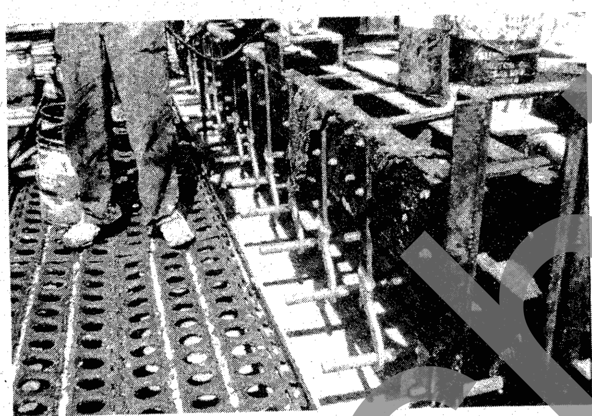
36. In the case of slip form paving the grade control is accomplished with a string line. It should also be noted that the subbase should extend at least 2 feet on each side of the pavement in order to accommodate the tracks of the paving equipment. This will help assure a smooth riding surface.

37. Dowels must be lubricated in order to allow them to move as the pavement expands and contracts. In this case the dowels are dipped in a lubricating agent.

38. In this case the dowel bars have been greased. Care needs to be taken so that only a thin film of lubricating agent is applied to the bars. If to much lubricating agent is allowed to remain on the bars a void will be formed around the bar and the dowels will not perform properly.

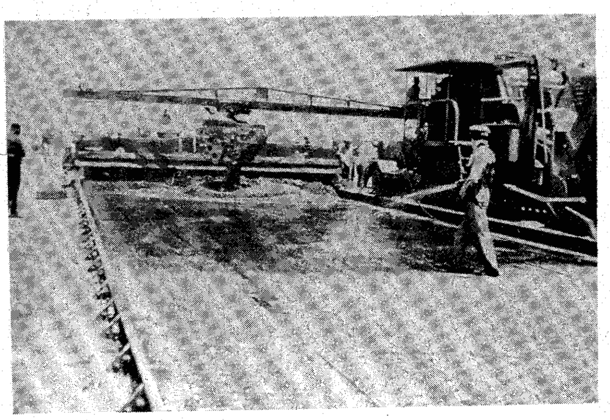


39. Dowels may be placed in steel supporting baskets which are secured to the subbase ahead of paving operation. The baskets must be in proper alignment and securely fastened to the subgrade so that they will not move during construction. It is also necessary to cut the tie wires once the baskets have been secured to the subbase.



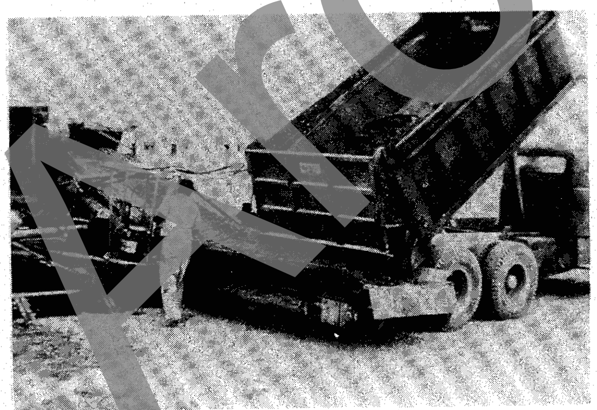
40. Dowel bars can also be placed with **implanters**. In this case the dowel bars are vibrated into their final position.

41. Since alignment is critical the final location of the dowel bars should be checked. In this case the concrete is carefully removed so the location of the dowel bar can be determined.



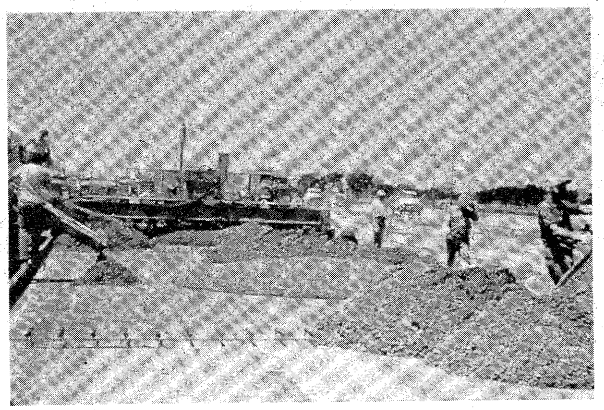
42. Just in front of the paving operation the subbase should be wet down. This cools off the subbase and also insures that water from the concrete will not be absorbed into the subbase.

43. Concrete can be spread in a number of ways. The method of concrete placement will depend to a degree on the type of reinforcing steel that is used and the way that it is placed. In this case a side dump is placing the concrete into a mechanical spreader which will distribute the concrete uniformly across the pavement.

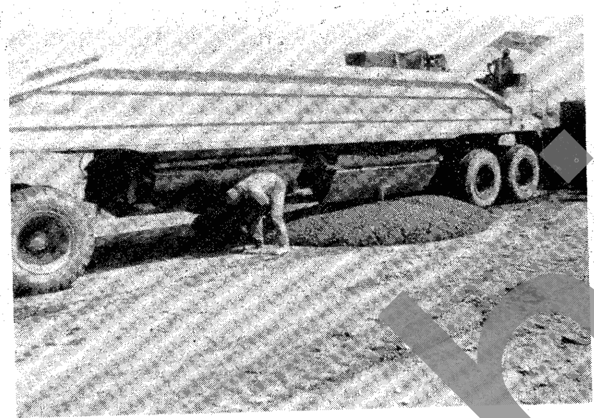


44. Here an end dump is placing the concrete on a conveyor which will take the concrete to a mechanical spreader.

Both this method and the previous method will insure that the haul vehicles will not contaminate the base material or the concrete.

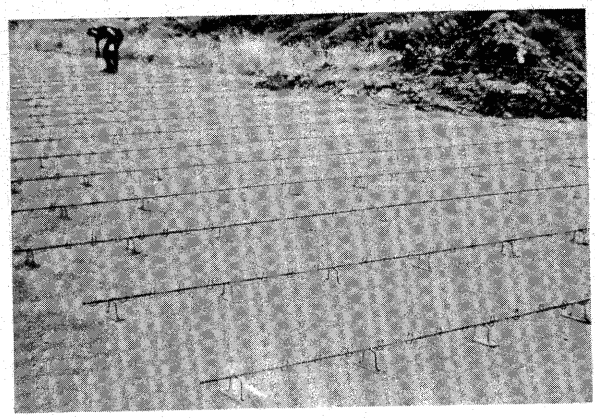


45. Concrete can also be placed by chutes. This operation is not uniformly spreading the concrete across the pavement. This will cause problems in the operation of the paver. Also note the lack of uniformity in the concrete.



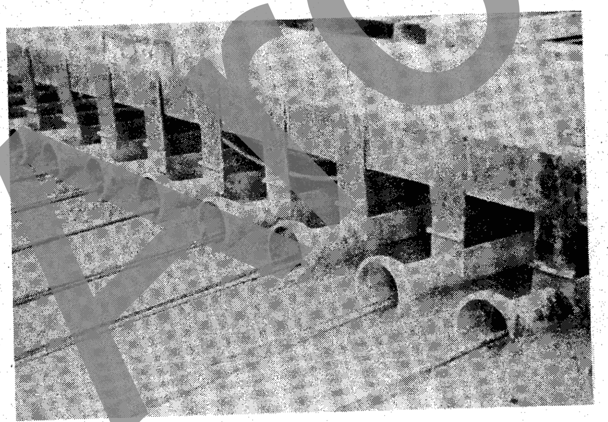
46. Bottom dumps can also be used to place concrete. This type of operation should also be avoided since dirt on the wheels of the trailer will contaminate the concrete.

47. End dumps with spreader boxes can also be used to place concrete.



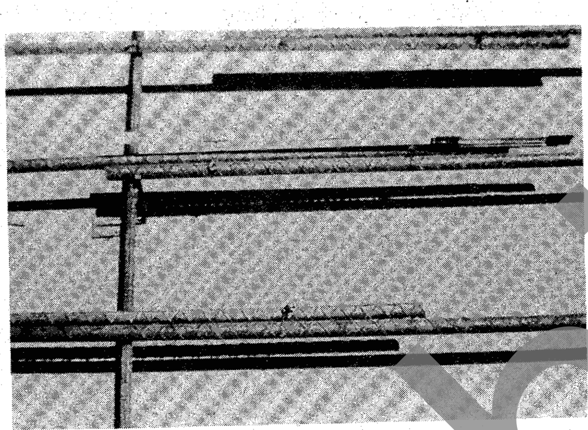
48. Reinforcing steel can be placed in concrete in several ways. Placing the steel on the subbase prior to placement of the concrete is the best way to insure that the steel will be in the proper location. If the chairs are placed on a bituminous subbase, plates must be used under the chairs to insure that the chairs will not sink into the subbase.

49. The placement of the reinforcing steel on the chairs. It should be noted that the steel should be free of oil, dirt, and scale.

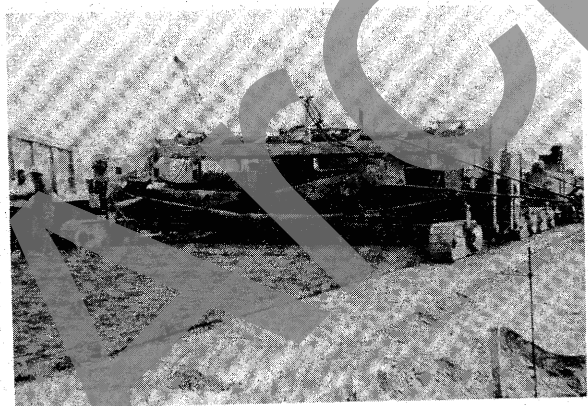


50. Reinforcing steel can also be placed by tube feeds.

51. The tube feed holds the steel in the proper location while the concrete is being placed and consolidated. It should be noted that the steel will not be placed as accurately with this method as the method where chairs are in used.



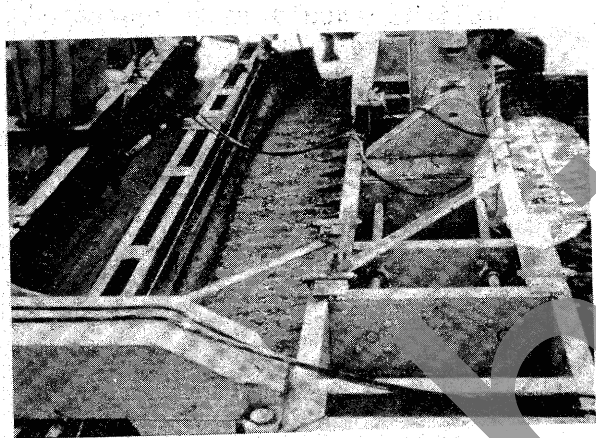
52. The rebar splices should be at least 30 bar diameters and the splices should be staggered to insure that a weak plane will not develop.



53. Reinforcing mats should be free of oil, dirt, and scale.

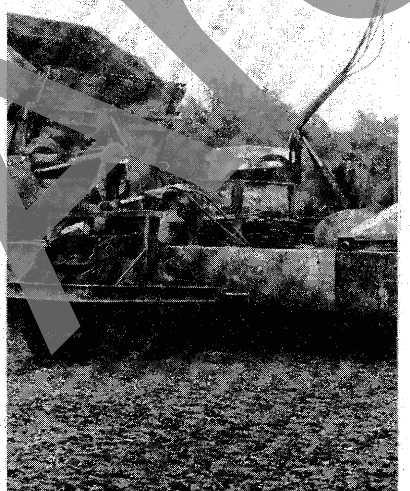
Reinforcing mats can be placed between two layers of concrete. This type of construction can be accomplished by using two course construction as shown here or by using a mesh depressor.

54. The mats need to be overlapped according to the dimension of the mats to insure bond development. They need to be securely tied to insure that they will not move. In jointed pavements, the edge of the mats should be at least 3 inches away from the center of the contraction joints.

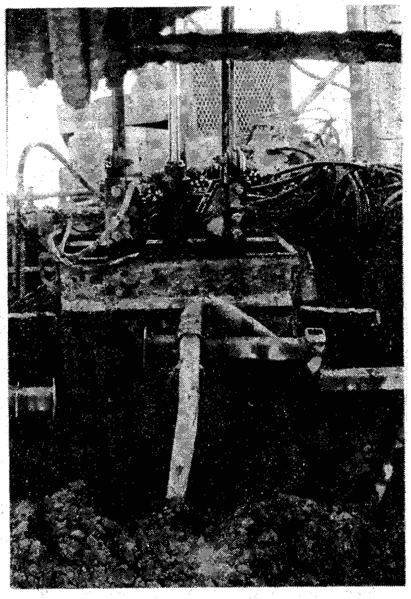


55. A mesh depressor can also be used to place reinforcing steel. In this operation, the reinforcement is placed on top of the struck-off concrete and then depressed. This machine moves over a concrete mat and with its large grid, depresses the mesh into the pavement through pressure and vibration. Adjustable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

Depth checks for mat placement should be performed periodically.



56. Transverse tie bars can be placed by two methods. In this case the tie bars are being placed by a wheel. They should be placed at approximately 1/2 the depth of the pavement.



57. The tie bars can also be placed with a hydraulic inserter with the aid of a vibrator.

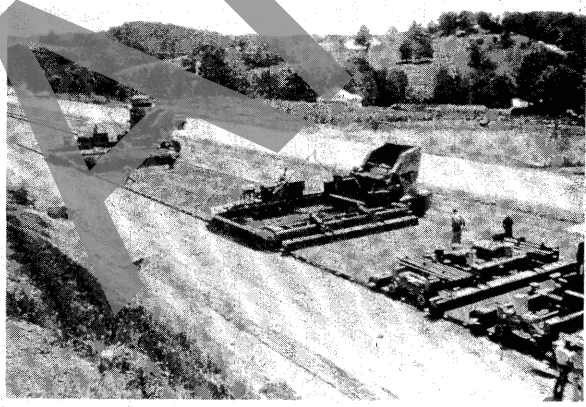
58. However, care needs to be taken that the inserter will not drip hydraulic fluid. The hydraulic fluid will contaminate the concrete and increase the air content which will form an area of weakness.

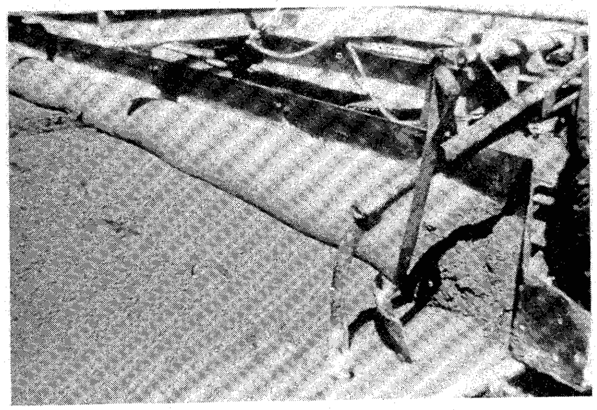
59. **Form paving** can be placed in two course or in one course. The two course operation will be discussed in detail.

60. The first operation is to uniformly distribute the concrete to insure uniform loading of the screed.

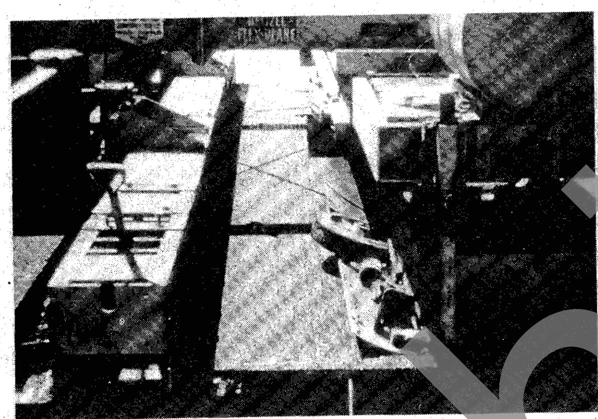
61. The first screed will then strike off the first layer to approximately 2/3 the depth of the pavement. It is also important to note that vibrators are used at the edge of the forms. The screed consolidates and strikes off the concrete as oscillates back and forth across the pavement. If dowel baskets are used the concrete in this area must be vibrated with spud vibrators prior to the screeding operation. The screed should have a uniform 4 to 6 inch roll of concrete in front of the screed. In a form operation it is necessary to have scrapers on the equipment to keep concrete off the forms directly in front of the wheels. This will insure a smooth riding pavement.

62. The reinforcing steel is then placed as discussed earlier and the second lift of concrete is spread.

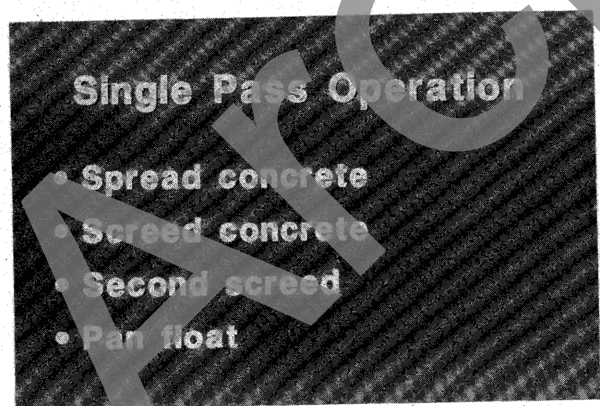




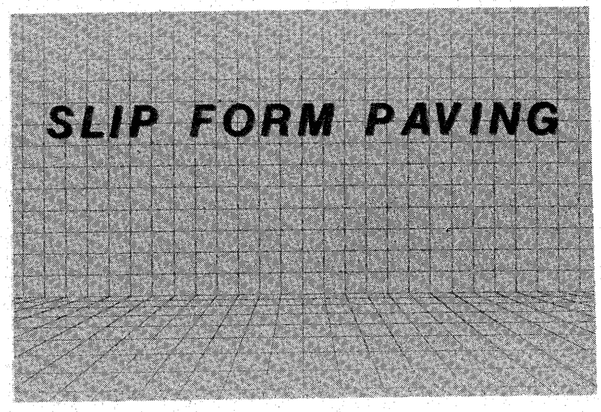
63. Then the second course of concrete is placed and screeded. It should be noted that it is important to place the second lift of concrete within 30 minutes of the first lift to avoid a cold joint. There should also be a uniform 4 inch roll of concrete in front of the second screed. This screed also consolidates by its oscillating movement.



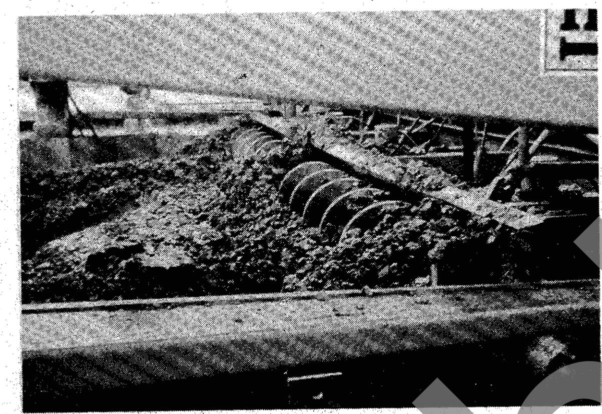
64. A third screed leaves the surface of the concrete 1/4 inch high and should have a uniform 2 inch roll of concrete ahead of it. The pan float which is tapered to force the concrete into the proper cross section follows. With the exception of correcting finishing errors by hand the pavement is ready for texturing.



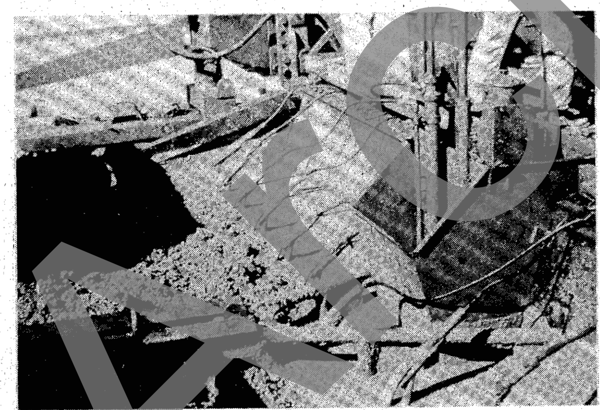
65. A single pass operation will consist of the following operations: the concrete will be spread, the concrete will be screeded with spud vibrators at the edge of the forms, steel will be implanted if called for, a vibrating screed will be used to consolidate the concrete, and a pan float will finish the operation.



66. **Slip form paving** can also be placed in one or two courses. Contractors use slip form paving on most large projects.



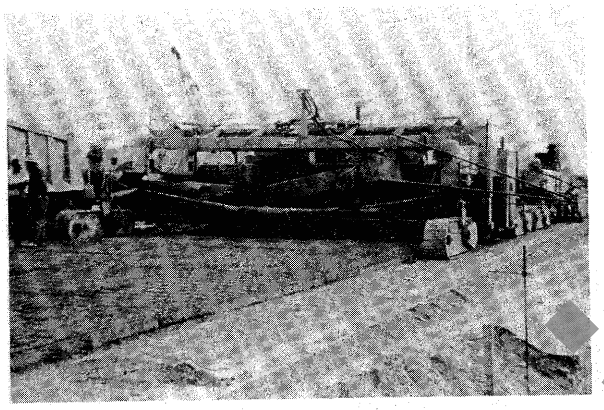
67. The first operation is to uniformly distribute the concrete across the pavement.



68. The entire concept of slipform paving depends upon the pavers ability to consolidate low slump concrete into a dense plastic mix that will maintain its shape after passing through the paver. In a slip form paver the consolidation is performed by spud vibrators. Vibrators are generally spaced not to exceed 24 inches. They are used with a concrete slump of from one to three inches and can accommodate paving speeds up to 20 feet per minute. Slipform pavers should be equipped with automatic cutoff switches so that if the machine stops, the vibrators will automatically shut off. Vibrators should be checked periodically with a tachometer to make sure that their frequency is within the specified range. Replacement vibrators should always be available.

A concrete head or surcharge should be maintained over the vibrators during placing operations. This surcharge head should be approximately 4 to 8 inches. However, too large of a surcharge may cause ripples behind the screed or extrusion plate.

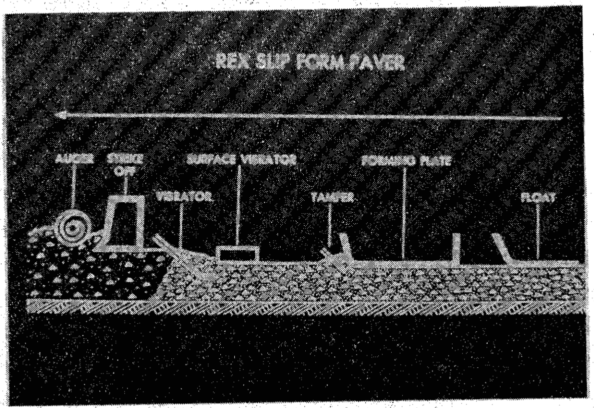
With a two course operation the first course will be struck off to approximately 2/3 the depth of the pavement.



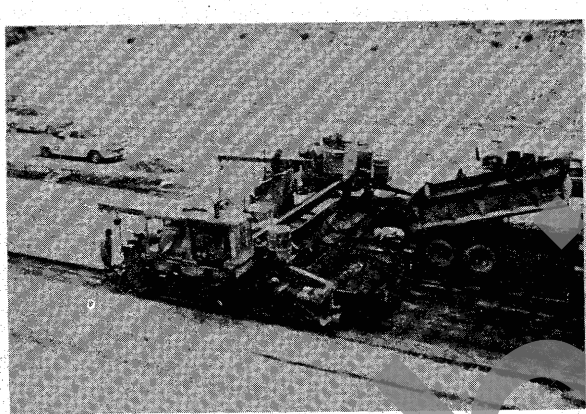
69. At this point the steel will be placed and the second lift of concrete will be spread.

70. The second screed will then finish the second course. This piece of equipment contains the gang vibrators, strike off, vibrating screed, and pan float.

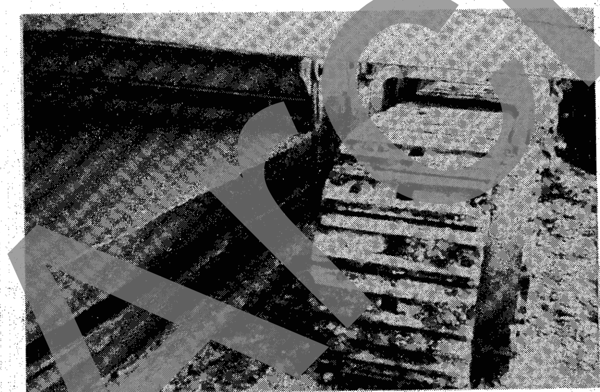
71. The **tie bars** are inserted manually as shown on this picture.



72. The one course operation is depicted by the cross section of the Rex paver. If the pavement was to be reinforced the steel would be placed prior to the paver.

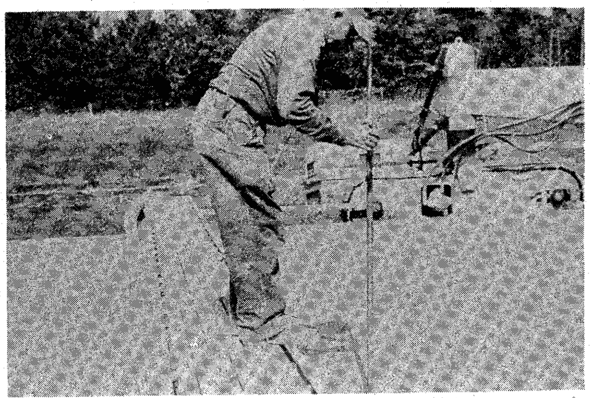


73. If the pavement is jointed non reinforced concrete pavement the entire operation can be performed by one piece of equipment.



74. The goal of a good slipform operation is to have **no edge slump**. This will insure a good riding project. It is very important to have a consistent slump concrete in order to obtain the desired results.

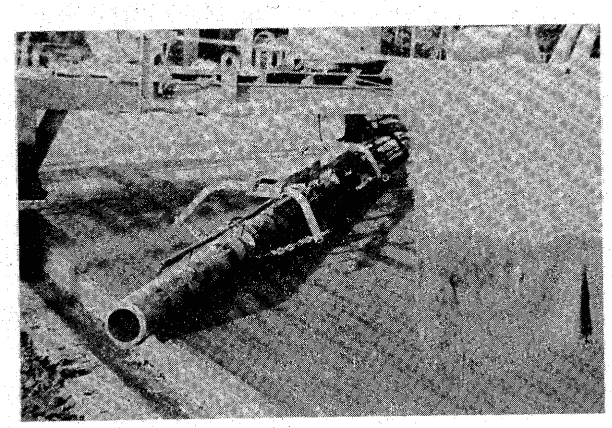
A uniform head of material in front of the paver along with maintaining a continuous operation is important to a good product. This will maintain a constant pressure behind the slipform paver and result in a smoother surface. Too large a roll will tend to raise the paving machine and leave a ripple caused by the excessive surge. If the concrete roll looks watery and does not roll, just slides, check the slump - it is probably too high. If the appears to be just about right but does not roll smoothly, the air content may be too high. Proper consolidation is achieved when the surface of the concrete is smooth and the submerged coarse aggregate is barely visible on the concrete surface or immediately under the surface.



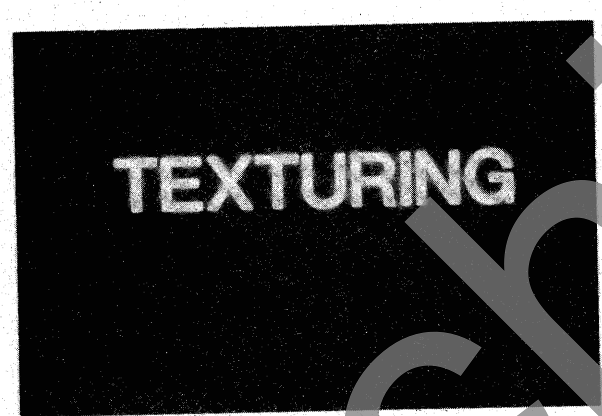
75. At this point the **depth** of the pavement should be checked. The check is made by stabbing the pavement. With some types of subbase it may be necessary to put plates on the subbase at predetermined locations so the pavement can be checked accurately at those locations.

76. Once the paver has completed the finishing the pavement should be checked with a **straight edge.** The straight edges are 10 feet long and should never be used to correct surface imperfections. The cross scope should also be checked.

77. 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.

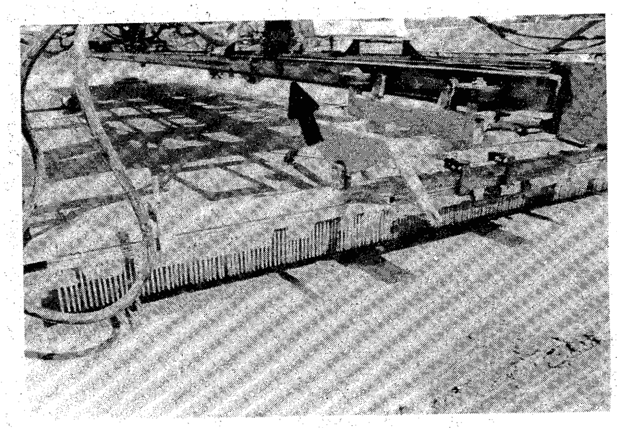


78. Some contractors will elect to use a **tube finisher**. This equipment uses a magnesium tube float which operates in a diagonal direction to the centerline of the pavement. Quite often this equipment will also include a burlap drag. This equipment is designed to correct minor variations and to seal the surface. It is not intended to move concrete. This equipment is easily misused by the contractor. Excessive water must not be used with this equipment. Any residue collected by the tube 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 cope of the pavement.

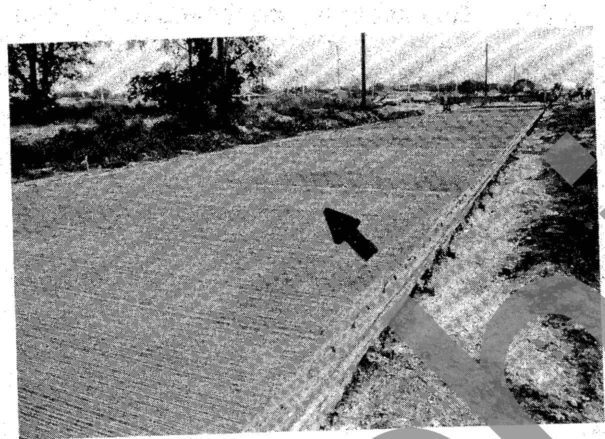


79. Proper texturing is required to provide a good, safe skid-resistant surface. A proper texture is obtained by first using a burlap drag followed by a tining machine.

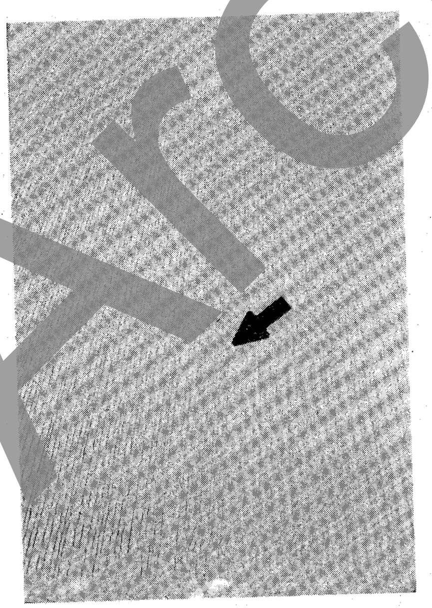
80. The burlap drag should be kept wet at all times. If the drag starts to pull aggregate to the surface, it can indicate that the concrete is not consolidated properly or that there is not enough sand in the mixture to provide for a good tight surface.



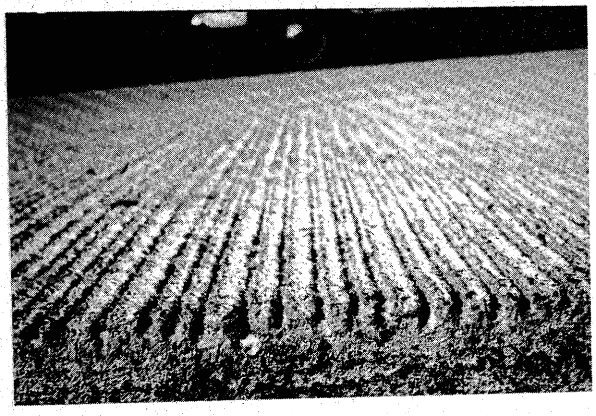
81. The final texturing operation consists of **tining** the surface to obtain a good macro-texture. The tines should be 0.08 inches wide and spaced 3/4-inch apart and 4 to 6 inches long. This should result in grooves that are spaced 1/2 to 3/4-inch apart and a depth of 1/8 to 3/16-inch.



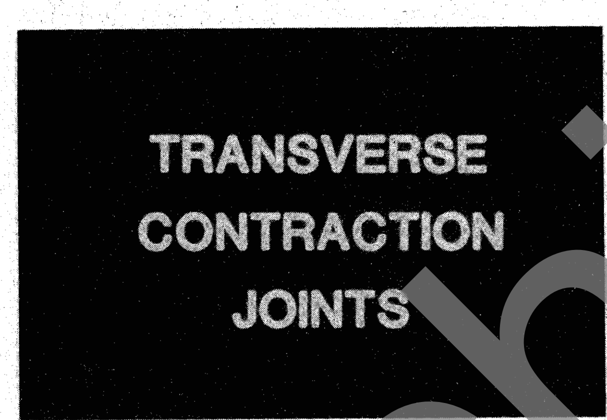
82. The surface at the joints should not be tined to insure a vertical surface for good adhesion of the joint sealing material.



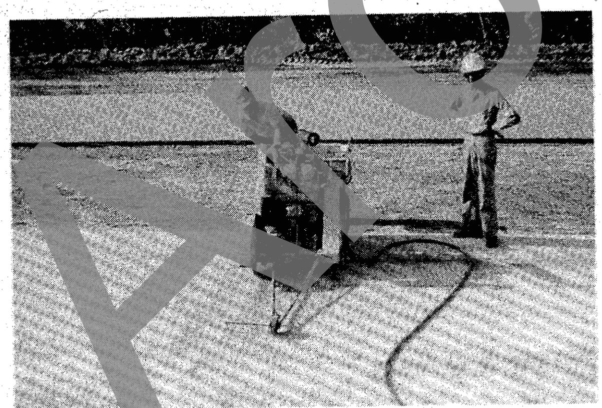
83. Overlapping of the texturing needs to be avoided to insure that the resulting thin fins will not break off.



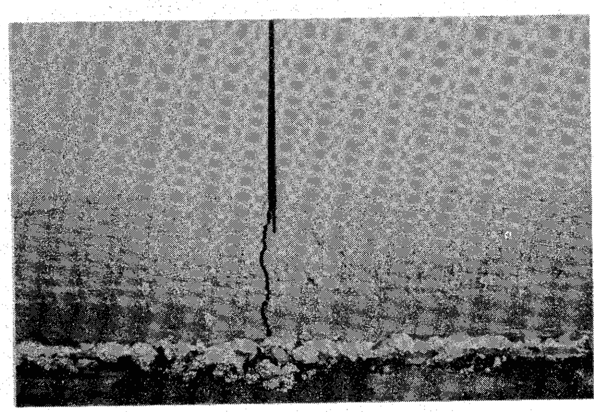
84. Timing is critical to produce a proper texture. The texturing should begin when the concrete is plastic enough to allow for at least a 1/8 inch deep groove but dry enough to prevent the concrete from flowing back into the grooves. As the tine approaches the very edge of the slab, it should be lifted off the pavement to prevent damage to the edge of the pavement slab. With very harsh mixes containing low percentages of sand or manufactured sands with low slumps, it is very difficult to achieve the desired texture.



85. **Transverse contraction joints** are used to control the shrinkage cracking that will occur in jointed pavements. The cracking generally occurs within 4 to 24 hours after the concrete has been placed.



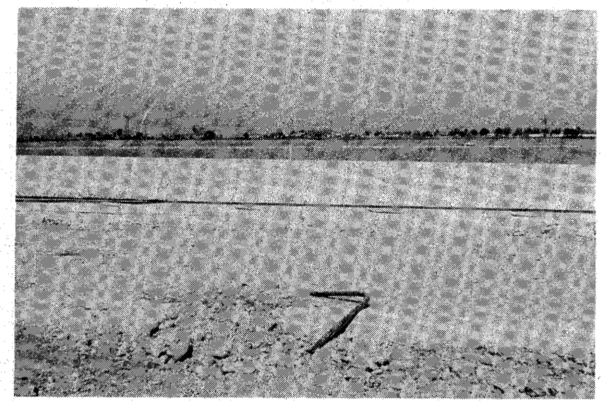
86. Contraction joints are made by sawing with a diamond blade. Sawing is a critical operation which must be done at the proper time and in the proper location. It is necessary that diamond blades be cooled with the application of water. Standby saws should be available at all times in case of breakdowns.



87. The depth of the sawcut should be at least 1/3 the slab thickness plus 1/4 inch in order to prevent random cracking.

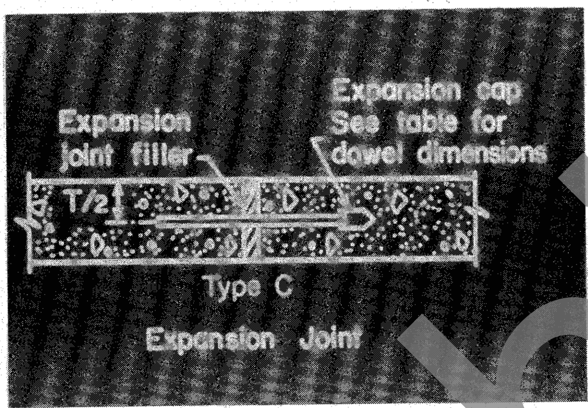
88. If sawed at the proper time, the transverse contraction joints will have a slight raveling at the top edge. If no raveling occurs, it is probably because the sawcut is being made a too late. A slight amount of raveling is desirable. Sudden drops in temperature or cooling from rainstorms on particularly hot days, calls for quick action by the contractor to prevent random cracking. Sawing should begin as soon as the concrete has hardened enough to permit sawing without causing excessive raveling. 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 the contractor will have to come back and saw the intermediate joints at a later point in time.

89. If sawing operation is being performed late, the concrete may crack ahead of the saw before a 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 was allowed to be continued, the concrete between the crack and the sawcut would eventually spall out.



90. The concrete must be marked appropriately so that sawing is done directly above the centerline of the dowel baskets.

The lath indicates the location of the nail which locates the center of the basket.



91. **Expansion joints** are placed to allow for the expansion of concrete in hot weather. These are generally found in areas such as bridge approaches and ramps.

The following items need to be looked at to insure that a transverse expansion joint is installed properly.

1) The joint assembly should be securely fastened to the subgrade;

2) The dowels must be in proper alignment and the trailing edge of the dowel must be fully supported;

3) The expansion filler material must be perpendicular to the pavement surface;

4) The filler material must be continuous from edge to edge of the pavement and for the full-depth of the slab;

5) The top edge of the filler material must be 1/2 inch below the pavement surface;

6) The top edge of the filler should be protected with a removable metal channel cap;

7) The free end of the dowel bars must be equipped with appropriate expansion joint metal caps having about a 1 inch clearance provided in the metal cap for expansion of the slab;

8) The concrete must be placed carefully around the expansion joint material;

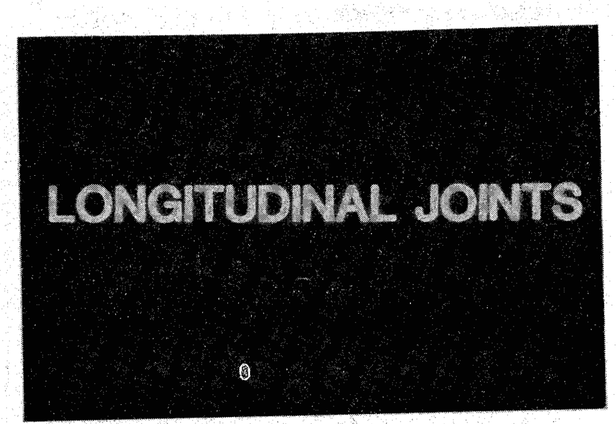
9) The paving equipment must not come in contact with the expansion material as the concrete is being struck off;

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

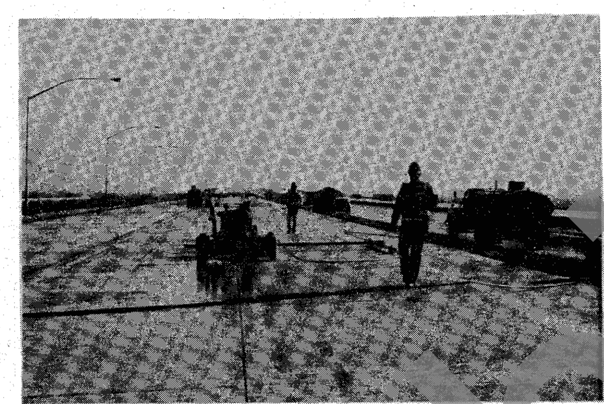
11) The expansion joint must be properly edged and finished and the metal cap removed;

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

92. 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 headerboards. 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.



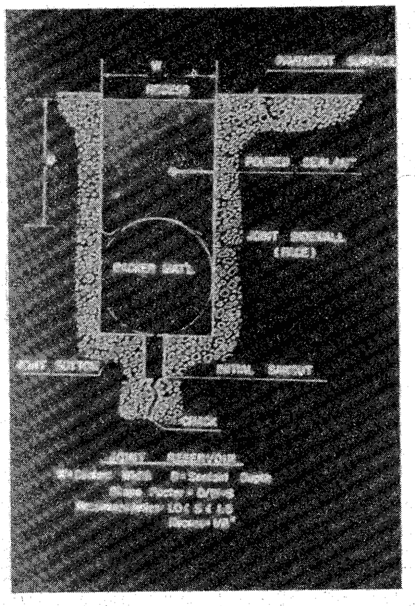
93. **Longitudinal joints** should be sawed. The plastic ribbon method for forming longitudinal joints has not been shown effective in preventing random longitudinal cracks.



94. Experience has shown that it is better to saw the longitudinal joint at the same time or immediately following the transverse joints. This is particularly true on thinner pavements and placements wider than 24 feet. 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 1/4 inch in width and to a depth of at least 1/3 of the pavement thickness.

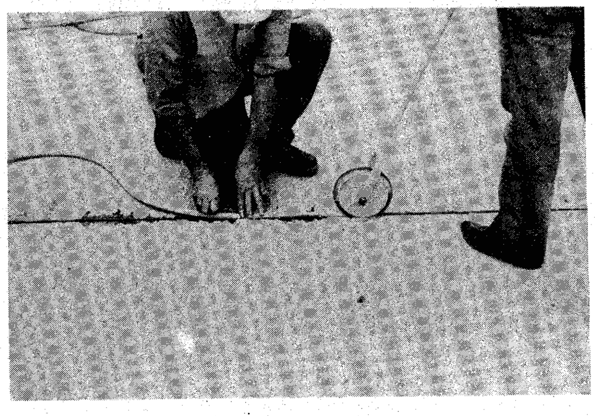
95. Joints are sealed to prevent incompressibles, from getting into the joint which would cause spalling or blow-ups when the pavement expands in hot weather.



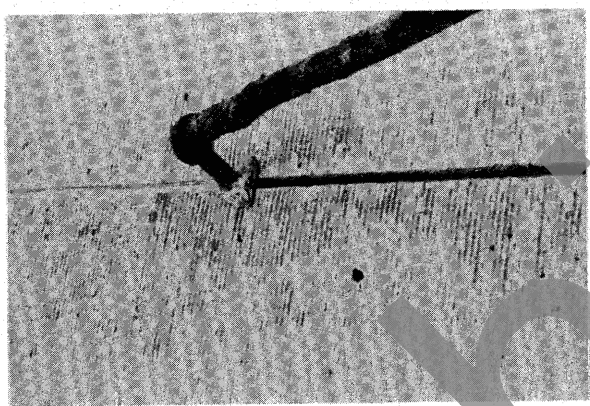
96. The performance of liquid joint seals is dependent upon the shape factor of the reservoir which is simply the depth to width ratio of the reservoir. The shape factor insures that the joint material will perform satisfactorily. The shape factor will vary with the type of joint sealant used. The backer 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 the 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.

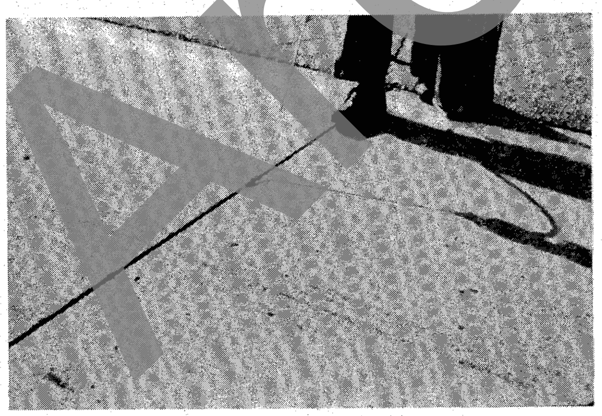
98. Immediately prior to installing the backer rod, the joint should be blown with compressed air and be left completely free of water and debris.



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



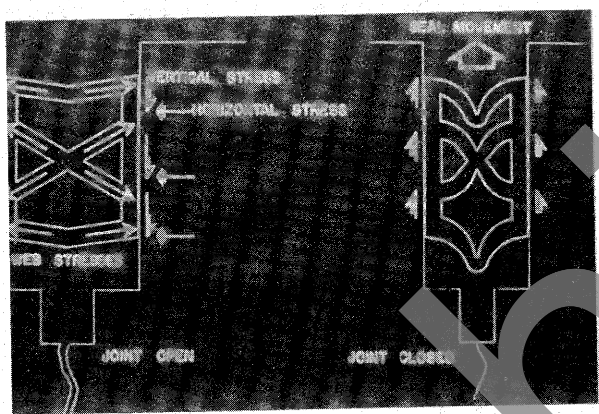
100. Regardless of the sealant type used, all joints should be sealed in a neat and workmanlike manner. The surface of the sealant should be at least 1/4 inch beneath the surface of the pavement. All excess materials should be removed from the surface. This is necessary to prevent traffic from picking up the sealant.



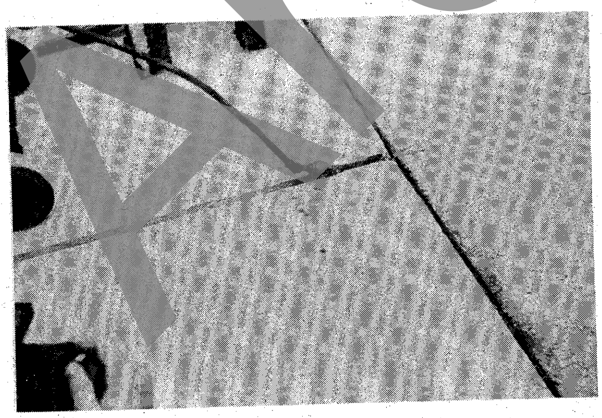
101. Some sealants such as silicon require that the surface be tooled.

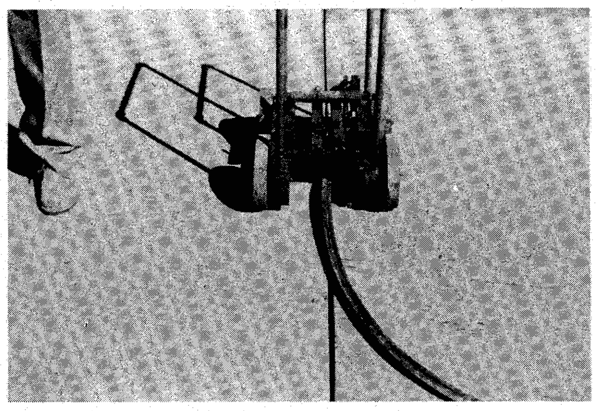
102. There are a number of preformed **compression seals** on the market for sealing concrete pavement joints.

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.

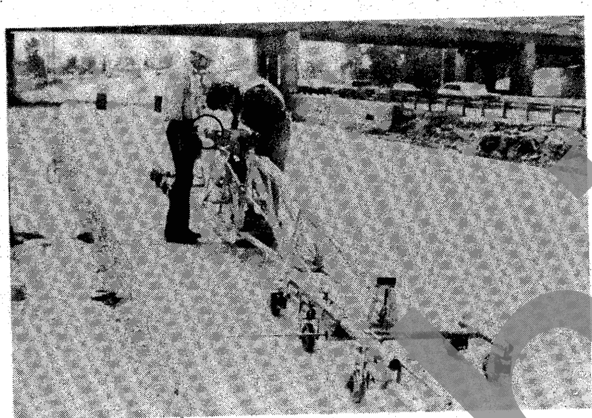


104. After the second sawing operation a lubricant is used to install the seal.



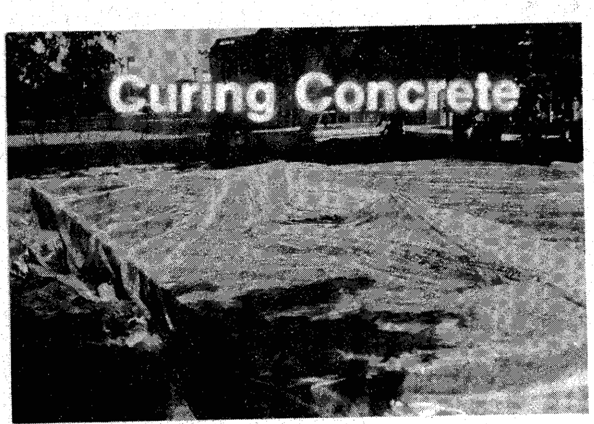


105. The compression seal must be installed with a special machine capable of placing the material in a compressed state without cutting, twisting or distorting the sealant material itself. The sealant material is installed to a depth approximately 1/8 inch below edge of the joint. Splices in the sealant material are not permitted in any 24 foot width joint.

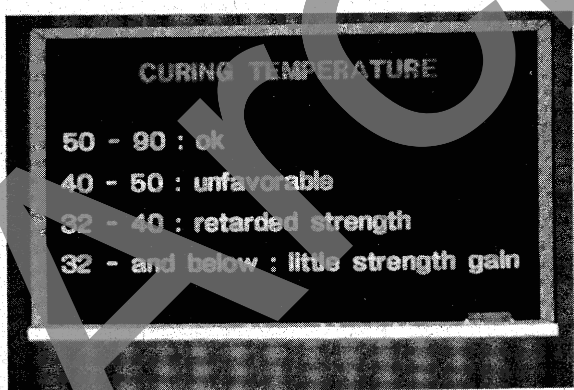


106. Many States are now specifying **rideability**. The most common method for specifying rideability involves the profilagraph. Seven inches per mile has been found to be reasonably attainable.

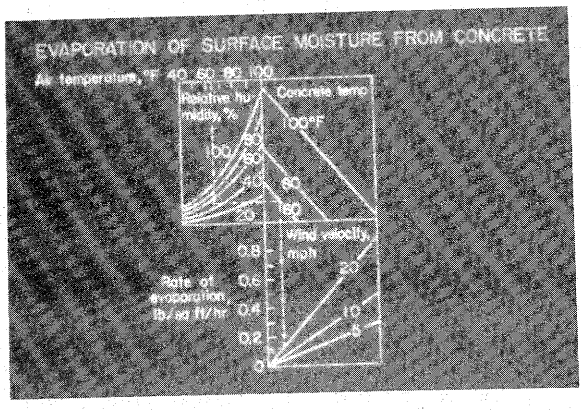
CURING



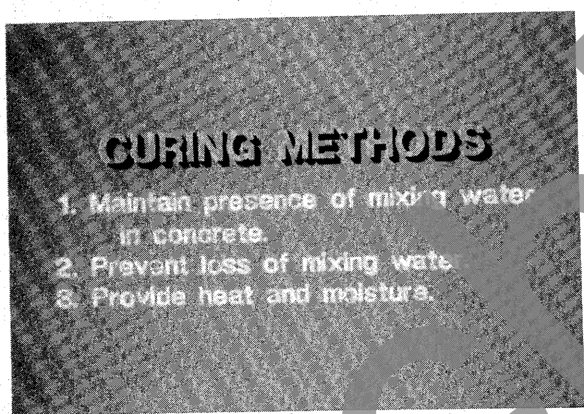
1. **Curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early life in order to allow desired properties of the concrete to be developed.** When cement and water are combined, a chemical reaction called hydration takes place. The extent to which this reaction takes place will determine the strength, durability, watertightness, wear resistance, and resistance to freezing and thawing of the concrete. Most concrete contains more water than is necessary to complete the hydration process. Any appreciable loss of water, however, due to evaporation, or otherwise, could delay or prevent hydration. Hydration is rapid during the early stages of concrete, therefore, retaining water during the first several days is important. The retention of moisture for curing is accomplished by applying water or preventing excess evaporation.



2. The curing of concrete is also dependent upon temperature since the rate of hydration will vary with temperature. Hydration proceeds very slowly at low temperatures. At 50 degrees F conditions are unfavorable for hydration, at 40 degrees F early strength is retarded and at 32 degrees F little or no strength occurs. As a general rule of thumb, curing temperatures above the expected "in service temperature" of the concrete should also be avoided.



3. We are concerned about losing too much moisture from the concrete through evaporation. Air temperature, humidity, and wind velocity effect the rate of hydration. This chart provides a graphic method of estimating the evaporation under various weather conditions. **As a general rule, and as recommended by ACI, when an evaporation rate of .2 lb/sq ft/ hr are 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.

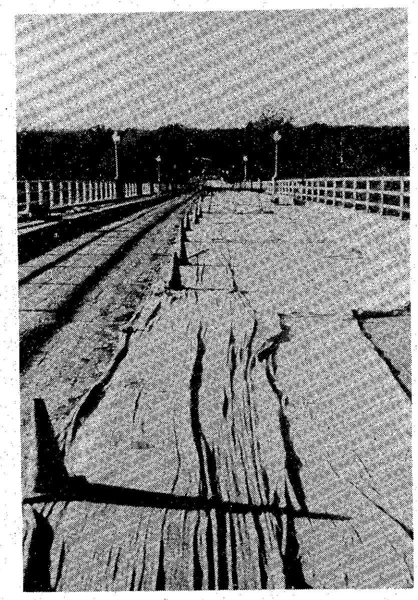


4. Curing methods can be categorized into three groups:

   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 electric forms.



5. Perhaps the most effective method of curing concrete is by the **moist or water method.**

   On small flat surfaces, 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 that could be harmful to the concrete such as fertilizers or sugar. 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.

In summary, there are several precautions with 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.

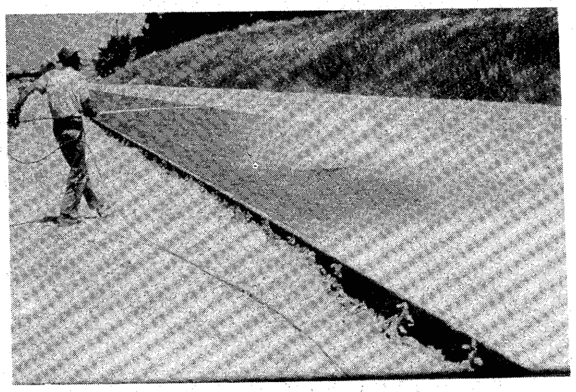
6. Other methods of moist curing include earth, sand, sawdust, straw, or hay. These methods should be looked at carefully to be sure that they will not react with the concrete or cause staining. Here hay is being used to cure a concrete curb. The hay will have to be wet down when they are finished placing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

7. The second major 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 thus reducing 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 and joints should be sealed with tape or bituminous material. They 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.

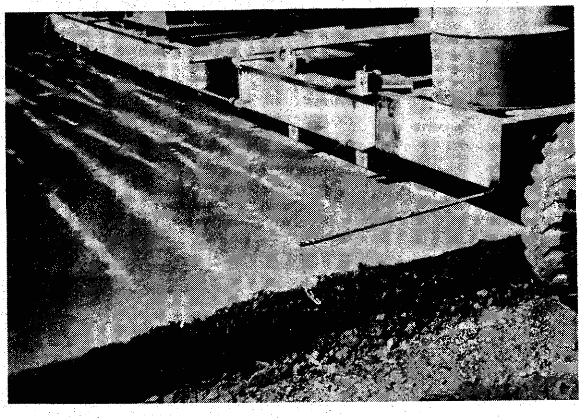
9. Sometimes plastic sheets are used in conjunction with moist curing methods. This reduces the need to periodically wet the coverings. As moisture from the concrete condenses, it is trapped by the plastic. The covering material, in this case burlap, absorbs the moisture and returns it to the surface.



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. Upon application, 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. It can be applied by hand but for large paving projects power driven equipment is more common. Spray nozzles on equipment should be arranged to prevent wind blown loss.

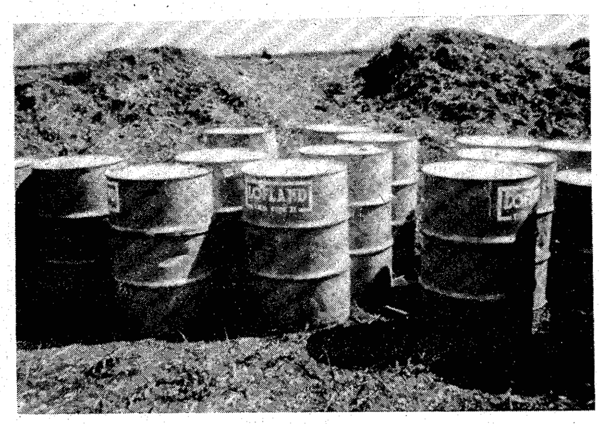
12. In this picture, either they have waited to long to apply the curing compound, since it has set up enough for the man to stand on it, or the man is destroying the texture.



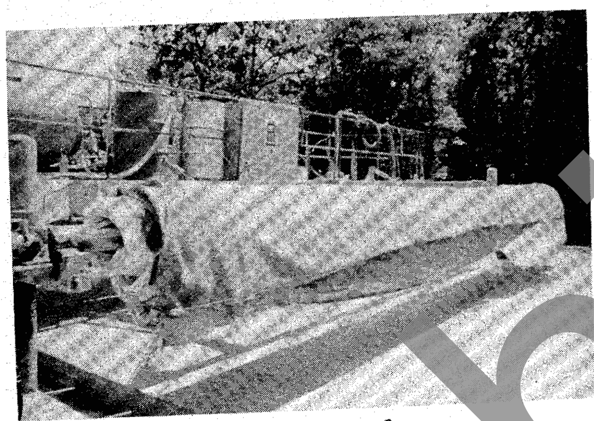
13. Uniform coating with the compound is important. Skips, insufficient coverage or even pinholes will allow evaporation of moisture from the concrete.

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 than the application rate was exceeded. The application equipment must be calibrated. An inspectors 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.



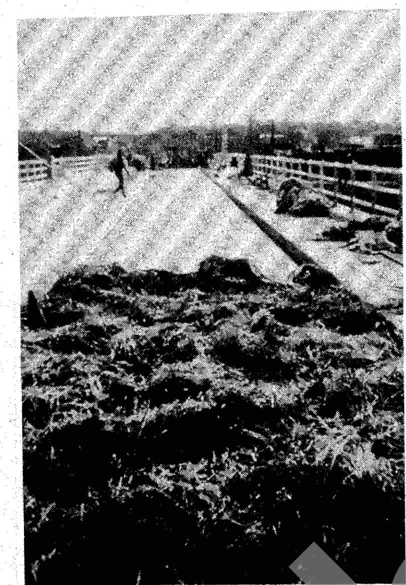
16. Prior to the start of a concrete placement operation that will use curing compound, the inspector should verify that the compound being used is approved or meets the specifications. A sufficient quantity should be on hand to complete the operation so as to avoid any delay or disruption.



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.

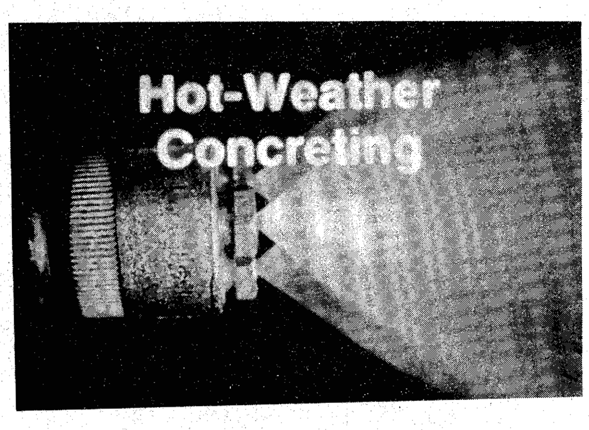
18. The third general method of curing involves the use of **steam.** Steam curing is advantageous where accelerated strength gain is important or where additional heat is required in cold weather. Steam curing, in order to be effective, should enclose the concrete. Steam curing, therefore, does not 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

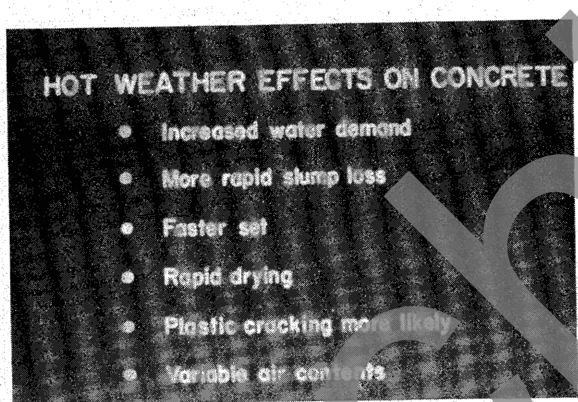
normal cycle followed in steam curing. It has been found effective to delay the start of curing by 2 to 5 hours since this adds to the 24 hour strength. The steam temperature is then increased to a maximum of 150 to 175 degrees F. The product is then kept at that temperature until the desired strength 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. 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.

HOT WEATHER CONCRETING





1. **Hot weather can be defined as a condition 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.

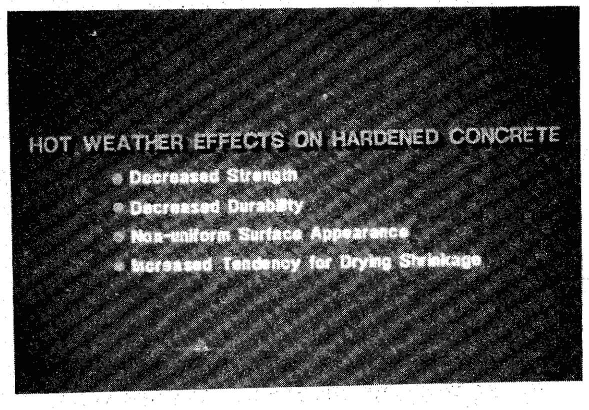
   b. Increased loss of slump (with a tendency to add water at the job site).

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

   d. Critical need for prompt early curing.

   e. Increased tendency for plastic cracking.

   f. Difficulty in controlling air contents.



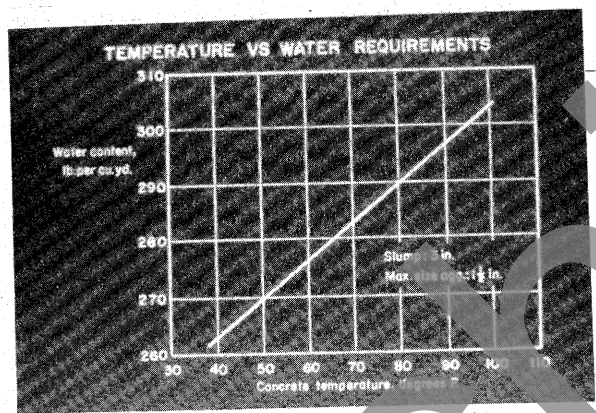
3. The effects of hot weather can also influence the concrete in the hardened state:

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

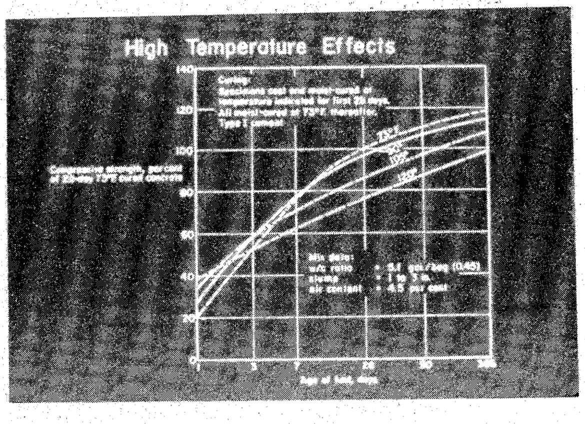
   b. Decreased durability and water tightness.

   c. Non-uniform surface appearance.

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

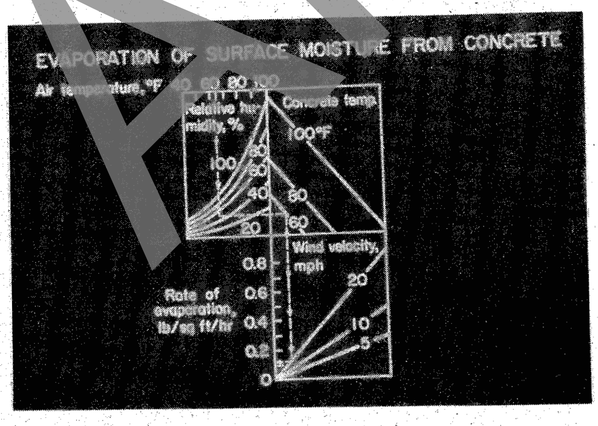


4. It has been shown, by the concrete industry, that an increase in temperature of a concrete mix results in a decrease in slump. **As a rule of thumb, a 20 degree increase in the mix temperature will result in a one inch decrease in the slump.** In order to keep the slump constant, therefore, water 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.



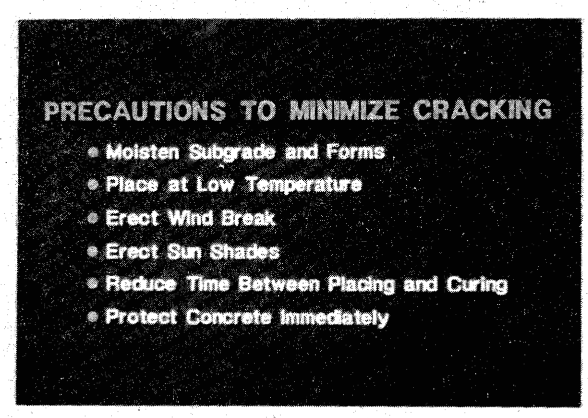
5. **Another interesting study has shown that an increase in the mix temperature adversely effects the ultimate strength even when the slump and water/cement ratio are held constant.** It is recommended practice to prepare trial batches for a concrete operation. Trial batches done in a laboratory would be mixed around 73 degrees. 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 .2 lb per square foot 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 .2 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.

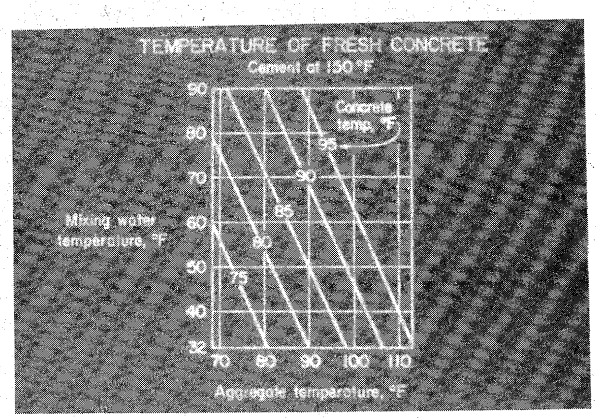
   c. Erect wind breaks to reduce the wind velocity.

   d. Erect sun shades to reduce concrete surface temperatures.

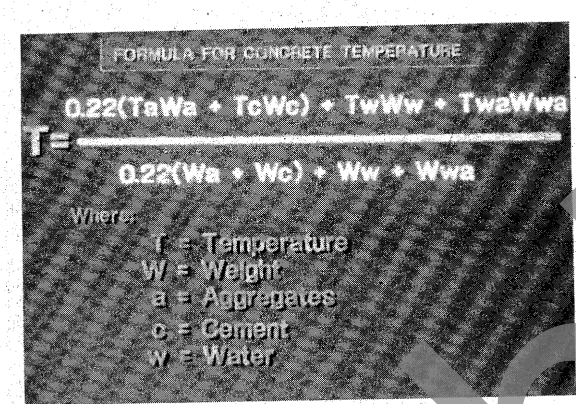
   e. Reduce the time between placing and curing by eliminating delays.

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

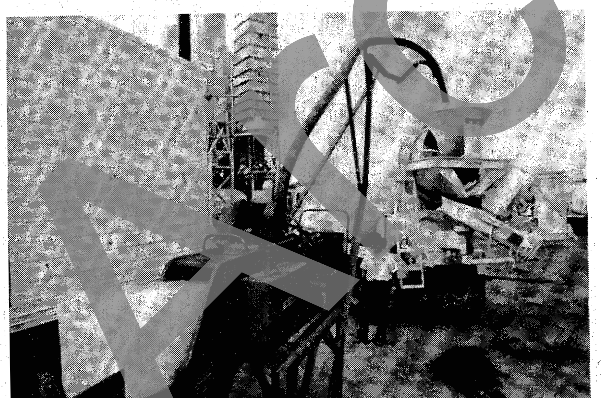
9. Normal precaution for hot weather concrete, above and beyond the requirements for reducing evaporation, is to control the temperature of the concrete ingredients. The contribution of each material in a concrete mixture to the initial temperature of the concrete is related to the temperature, specific 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 90 degrees and water at 50 degrees will result in a mixture at 85 degrees.

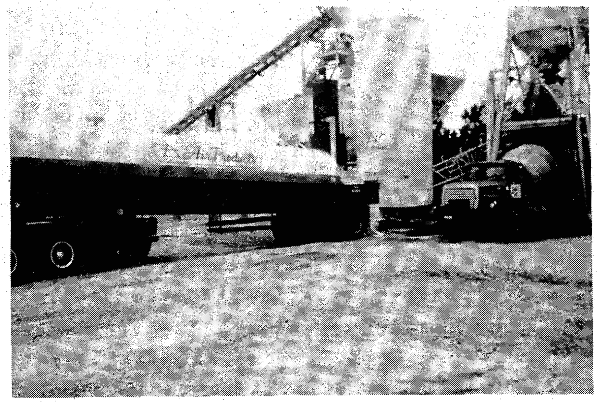


11. A formula has been developed that takes into account the effect that each of the ingredient's weight and temperature will have on the overall concrete temperature. Various values can be tried until a desirable concrete temperature is achieved.

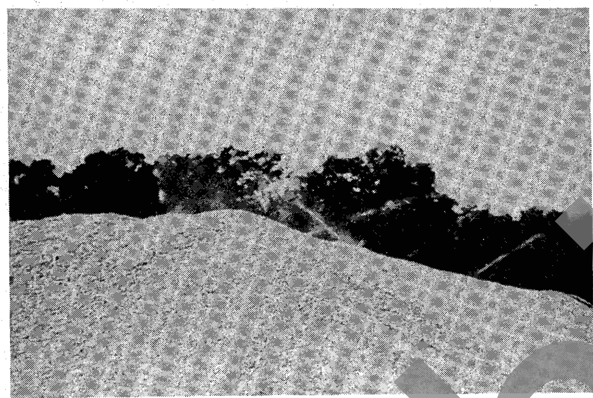


12. **Mixing water, of all the concrete ingredients, has the largest effect per unit weight because its specific heat is four to five times that of the other ingredients.** Water is also the easiest to cool. Naturally cooled or refrigerated water can be used. When this isn't practical, ice may be added to the mix as a portion of the water.

The use of crushed, shaved or chipped ice is acceptable provided it is added directly to the mixer as part of the mix water and totally melted by the time the concrete is placed. Ice must be accurately weighed and substituted for and equal weight of water.



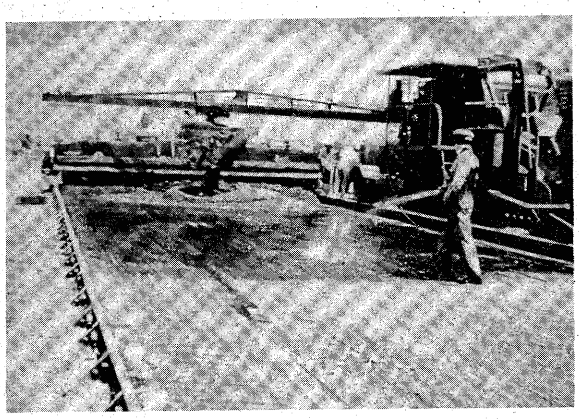
13. Liquid nitrogen has also been used to reduce the concrete temperature. The liquid nitrogen can be used to cool the concrete by injecting it into mix or to cool the mix water or to cool the aggregates.



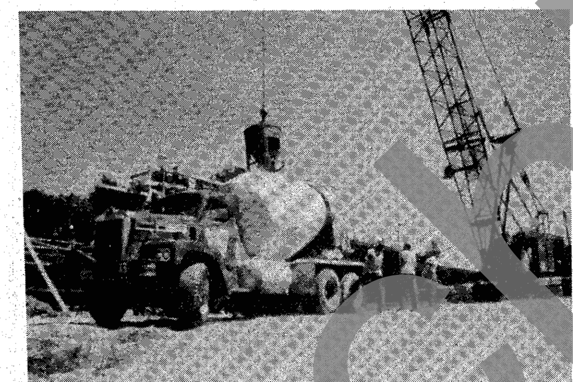
14. Aggregates can have a pronounced effect on the temperature of concrete because they represent about 60 percent to 80 percent of the weight of the mix. **To lower the temperature of the mix by 10 degrees only requires a 15 degree reduction in the aggregate temperature.** There are several methods 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 150 to 180 degrees is specified for cement temperatures.** Cement temperatures above this could cause stiffening of the concrete. As a general rule of thumb and an easy way to remember the temperature impact the following can be used:

> For a 1 degree decline in concrete temperature you need a 2 degree decline in aggregate temperature or a 4 degree decline in water temperature or an 8 degree decline in cement

temperature. (1:2:4:8 note the doubling pattern.)

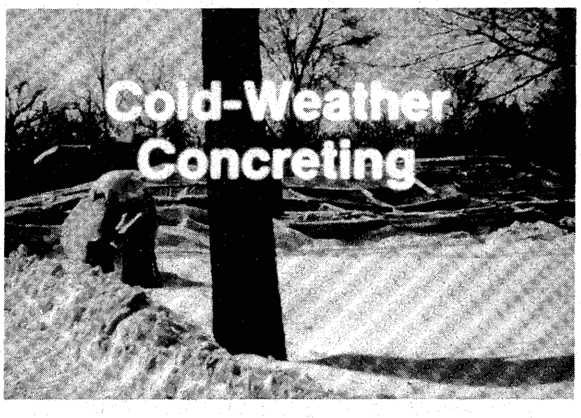


15. There are a number of physical precautions that can be taken to alleviate the affect of hot weather. **One way to cool things down is to fog the forms, reinforcing, and subgrade just prior to the placement.** In addition, fogging can be used to cool the surroundings and provide humidity during finishing.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

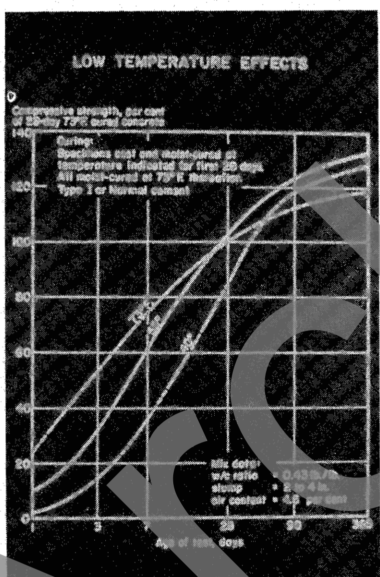


16. In order to reduce solar heat gain, it is recommended that mixers, belts, chutes and hoppers be shaded. Where this is not possible, less heat will be absorbed if they are painted white. **Studies have shown that a white drum exposed to the sun for 1 hour will keep the concrete 2.5 degrees cooler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

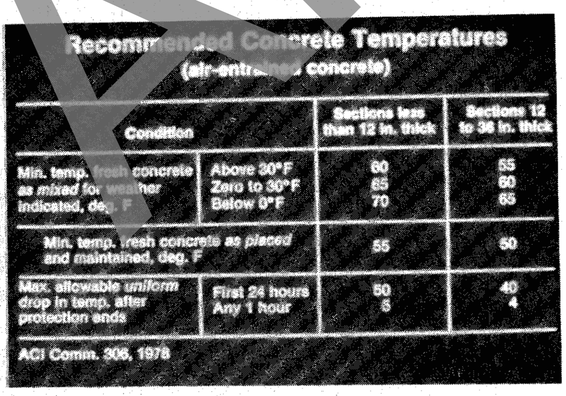
17. Scheduling, so that concrete is placed promptly upon arrival at the job site is also effective in hot weather. If delays occur, the adverse affect of prolonged mixing can be minimized by stopping the mixer and then agitating intermittently. During hot weather the time limit for discharge can be reduced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



1. Concrete placed in cold weather must have the same characteristics as concrete placed under normal weather conditions, that is, strong, durable concrete that satisfies the intended service requirements. Concrete placed during cold weather must be properly manufactured, placed and protected. The amount of special precautions will increase as the temperature decreases. **Cold weather is defined as a period when the mean daily temperature, for three consecutive days falls below 40 degrees F.** When the temperature rises above 50 degrees F, for more than half of any 24 hour period, then the concrete is no longer considered winter concrete.

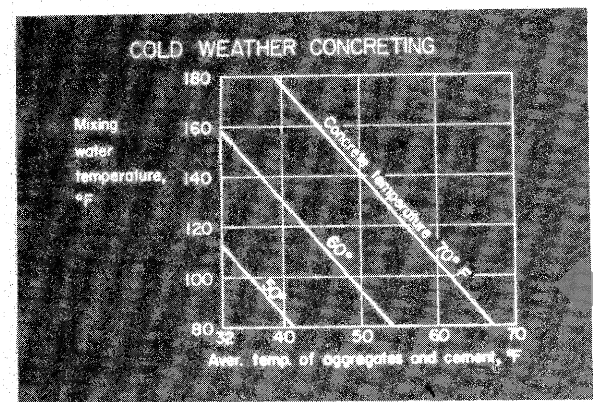


2. As the temperature of concrete goes down, the rate of hydration goes down. As was stated previously, very little hydration occurs below freezing and no hydration occurs below 14 degrees F. At cold temperatures strength gain is slowed because of the slowing of hydration. This effect is illustrated in this slide. 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.



3. The American Concrete Institute has developed this guideline for the mixing and placing temperatures of cold weather concrete. Naturally the thicker the concrete placement the lower the temperature since a thicker section will generate more heat through hydration. The mixing temperatures are slightly above the placing temperature in order to allow for heat loss during transportation.

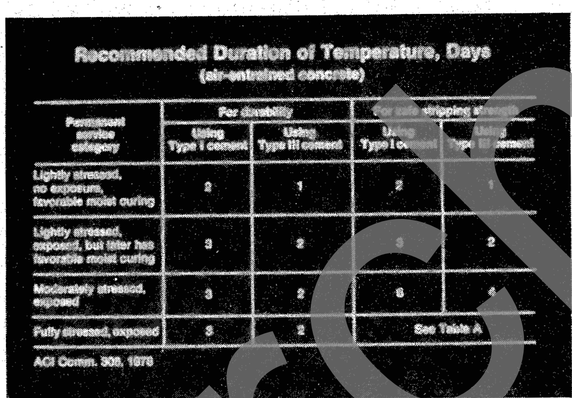
The temperature of the concrete as mixed should be maintained at not more than 10 degrees above those minimums recommended in this table. At higher temperatures the heat loss will be greater, thus offsetting the advantage of higher mixing temperatures. In addition, more water will be required for the same slump resulting in the possibility of plastic shrinkage cracking.



4. Once the temperature of the concrete mix has been established, then consideration must be given to the temperature of the ingredients. You will recall that for hot-weather concrete the ingredients had to be cooled, for cold-weather concrete the ingredients will have to be heated. The principles are the same only reversed. Also as in hot-weather concrete, the ingredient that is easiest to heat is the water. In this chart you can estimate the required increase in water temperature based on the combined temperature of the aggregates and cement.

   Because of the specific heat of water, its impact per unit weight on the temperature of the mix is greater than an equal weight of aggregates. **It may be necessary to heat the aggregates, however, since they may be frozen.** Frozen lumps of aggregates could survive the mixing process and remain as unmixed lumps in the concrete. In addition, frozen aggregates could thaw during mixing and contribute unaccounted for water. The recommended method of treating aggregates is to circulate steam through pipes in the stockpile.

5. **Plans to protect fresh concrete from freezing and to maintain desired temperatures during curing should be made well in advance.** Equipment and materials should be at the site before frosts are expected, not after the concrete has been placed and freezing begins. All surfaces that will come in contact with the fresh concrete should at least be a few degrees above freezing. Subgrades, forms and reinforcement should also be free of snow and ice to prevent concrete freezing. Frozen subgrades can be thawed by insulating them several days prior to the concrete placement and hot-air jets can be used to remove frost, snow and ice. Thawed subgrades may have to be recompacted.



Recommended Duration of Temperature, Days
(air-entrained concrete)

Permanent service category	For durability		For safe stripping strength	
	Using Type I cement	Using Type III cement	Using Type I cement	Using Type III cement
Lightly stressed, no exposure, favorable moist curing	2	1	2	1
Lightly stressed, exposed, but later has favorable moist curing	3	2	3	2
Moderately stressed, exposed	3	2	6	4
Fully stressed, exposed	3	2	See Table A	

ACI Comm. 306, 1978

6. For cold-weather concrete, the temperature of the freshly placed concrete should be maintained as close as possible to the placing temperatures previously shown. The duration of maintaining these temperatures is shown here. The columns headed "for durability" list the length of time required to provide adequate durability against exposure to freezing and thawing. The column marked "for adequate stripping strength" list the temperature at which bottom forms can be removed. **You should keep in mind that below 32 degrees F hydration significantly slows and that below 14 degrees F hydration ceases.** Also note that for the worst case an additional table is referred to. That table is depicted in the next slide.

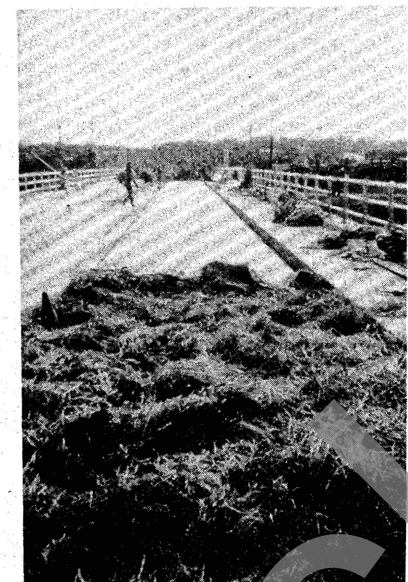
TABLE A. Recommended Duration of Temperature

(fully-stressed, exposed air-entrained concrete)

Required percentage of design strength	Days at 50°F			Days at 70°F		
	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	16	18	12
95	29	35	26	23	24	20

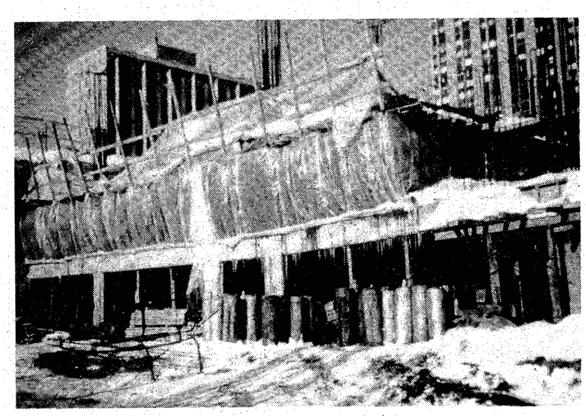
ACI Comm. 306, 1978

7. As you would expect the duration of the temperature must be significantly increased 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.

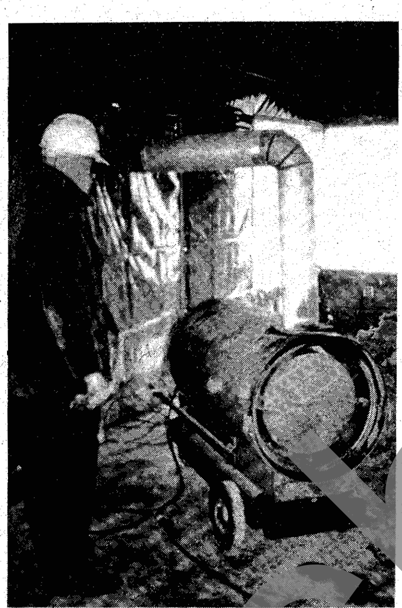


8. In order to maintain desired temperatures, advantage should be taken of the heat of hydration generated by the concrete itself. This heat may be retained by some type of **insulation**. Typical insulating materials are polystyrene foam sheets, foamed vinyl blankets, and straw. When straw is used, 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.

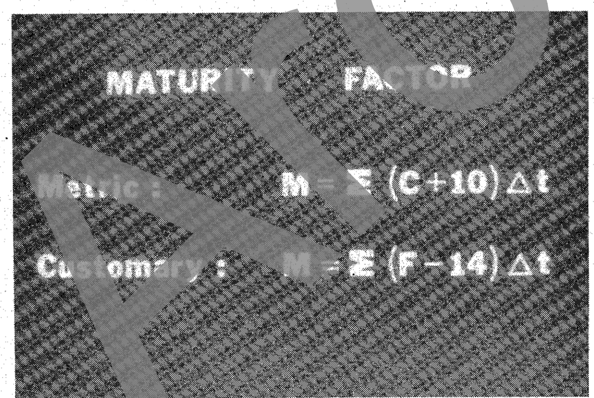
9. Forms built for repeated use can be permanently insulated. Insulating materials should be protected from the weather.



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.

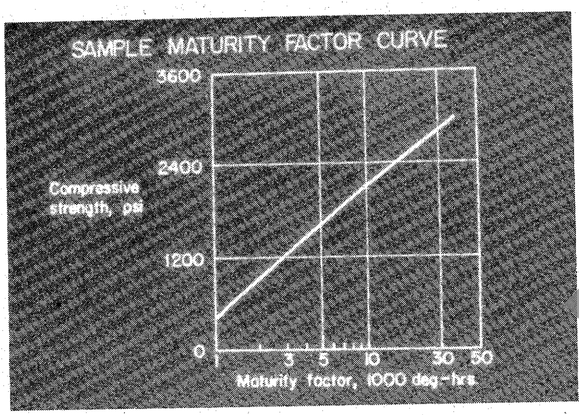


11. Heat may be supplied to enclosures by live steam, forced hot air, or stationary heaters. Caution is necessary with heaters. Fresh concrete exposed to carbon dioxide from the heaters or their exhausts will cause a soft chalky surface in the hardened state. **The carbon dioxide will react with calcium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



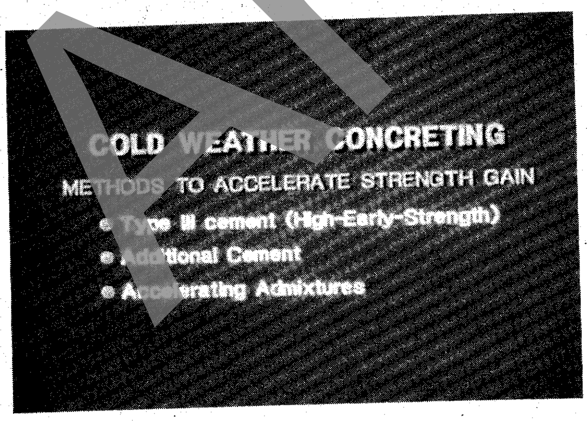
12. You will recall the previously shown chart with the recommended periods for continuing to heat concrete before stripping forms. This assumes that construction loads on the structure will be less than those expected when the structure is put in service. The concrete at that time would have reached curing conditions. But what about the situation where higher loads may be applied to the concrete before it has reached its ultimate strength? The industry has developed a system that utilizes **maturity factor.** The formulas are shown here where F

and C are temperatures and delta T is the duration of curing in hours for any given temperature. What this method says is that since strength gain is a function of time and temperature, estimates of strength can be made in the field if we know the time-temperature versus maturity relationship of the same concrete under laboratory conditions.

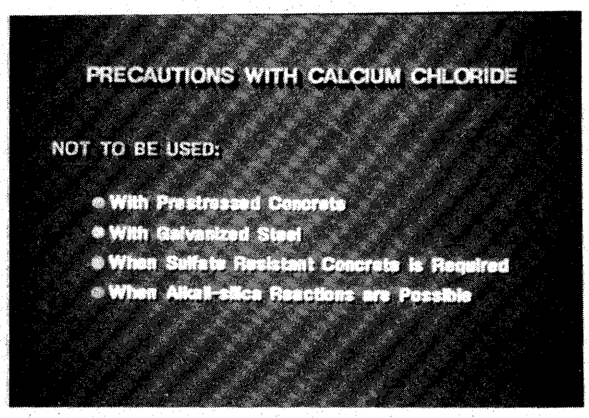


13. **The strength-maturity factor curve is established by performing compressive tests at various ages on a series of cylinders of a concrete similar to that which will be used in the field.** These cylinders would be cured in the laboratory at 73 degrees F. In the maturity equations just shown there would be no need for a summation since there was only one curing temperature.

Equipped with this relationship in the field, it would be possible to estimate the concrete's strength if the degree-hours are known. If records are kept of the temperature that the concrete is subjected to and the time it is subjected at that temperature, the equations can be used to sum the degree-hours and estimate the strength.



14. **High strength at an early age is desirable in winter construction in order to reduce the length of time temporary protection is required.** The added cost of these extra efforts may be offset by earlier reuse of forms or reduced heating costs during the protection period. Type III, or high-early- strength cement, may be used thus taking advantage of the increased heat of hydration. The cement content can be increased by up to 1/3 for the same reasons. 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:

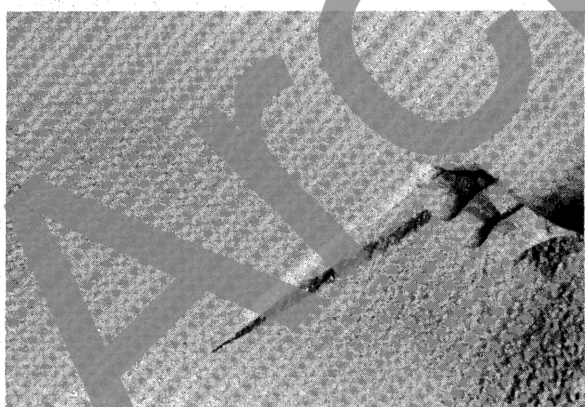
a. Do not use with prestressed concrete.

b. Do not use with galvanized steel.

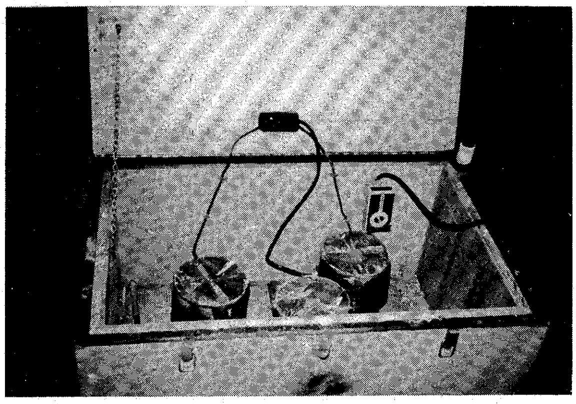
c. Do not use when the concrete will be exposed to sulfates.

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

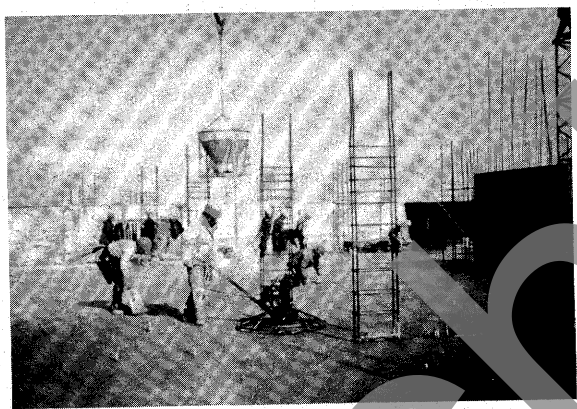
The use of so called anti-freeze compounds or other materials to lower the freezing point of concrete should not be used. It is always recommended that prior testing be performed to evaluate any acceleration plan. In such testing similar materials and similar field conditions should utilized.



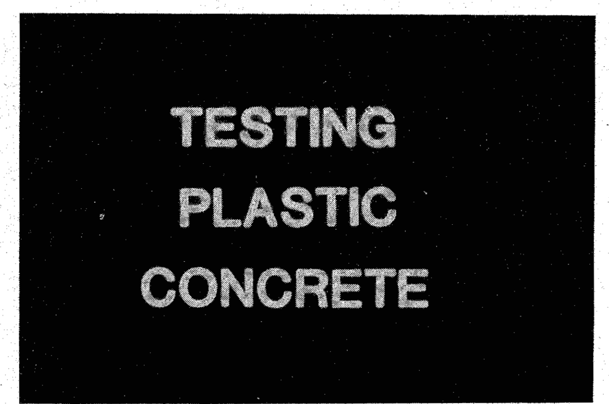
16. **Inspecting personnel should keep a record of the weather conditions and the temperature of the concrete.** Thermometers are needed to record the temperature of the concrete at delivery, at placing, and as maintained during the protection period. After the concrete has hardened the temperature can be recorded with special surface thermometers, measuring devices embedded in the concrete or by thermistors or thermocouples.



17. Concrete test cylinders must be maintained at a temperature between 60 degrees F and 80 degrees F 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.



1. Testing of the concrete is important to ensure that the quality of the concrete is equal to or exceeds the specifications. If the concrete does not meet the specifications at the time of testing corrections must be made or the load 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**.

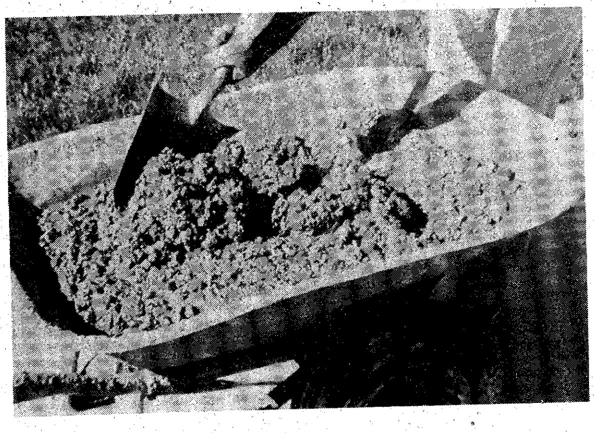
   The frequency for sampling and testing concrete will appear in the State's sampling and testing program.

   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.

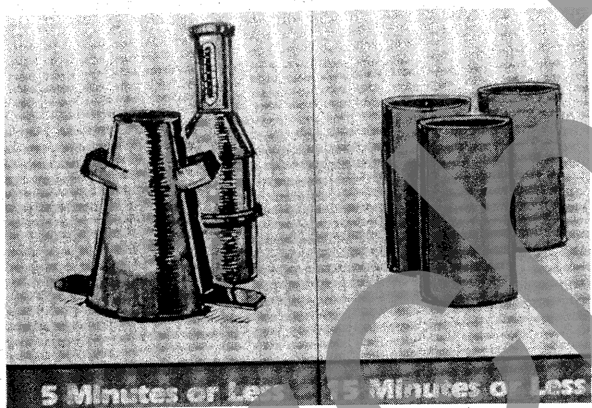
3. When sampling concrete from a ready mix or transit mixer or an agitator truck the concrete should be sampled at two or more regularly spaced intervals during the discharge of the middle portion of the batch. The sample should be taken by repeatedly passing the sampling device through the entire discharge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

sampling device. In no case should the **time elapsed** between obtaining the first and final portions of the sample exceed **15 minutes.**



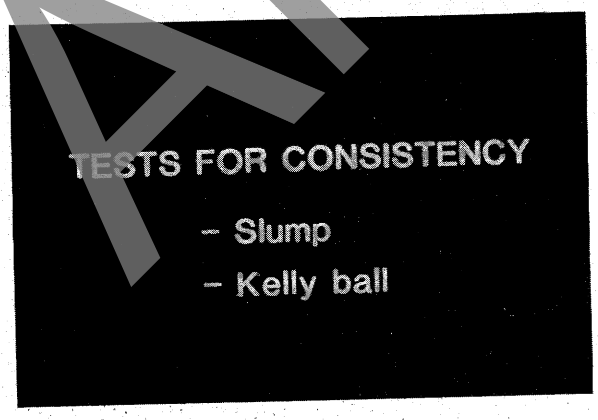
4. Once the samples are obtained they must be combined and remixed prior to performing the tests.

   The sample size should be large enough to perform all of the tests. Air, slump, 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.

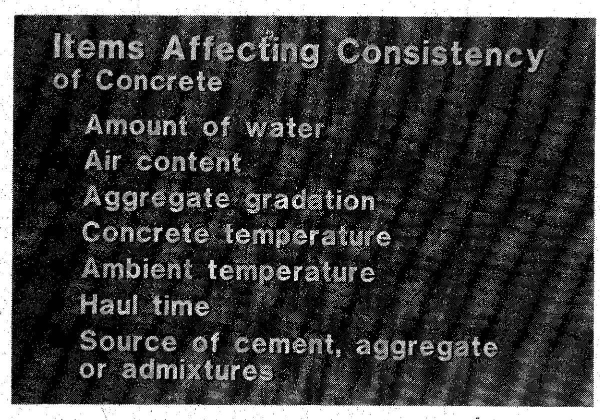


5. Tests for **slump** and **air content** must begin within **5 minutes** after sampling is completed.

   Specimens which are being cast for **strength** tests must be started within **15 minutes** after taking the sample.



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 and not necessarily the water content.



7. Many items can affect the consistency of the concrete.

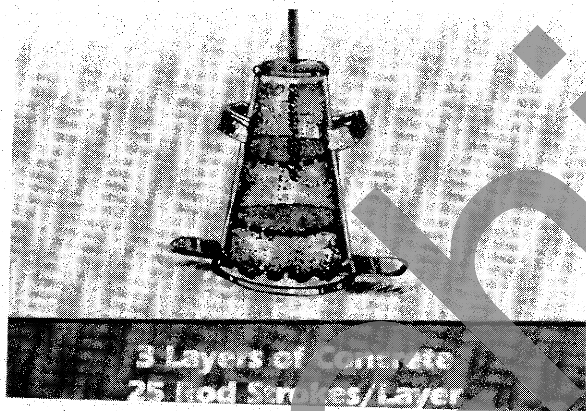
   An increase in the amount of water will increase the slump.

   An increase in the air content will increase the slump.

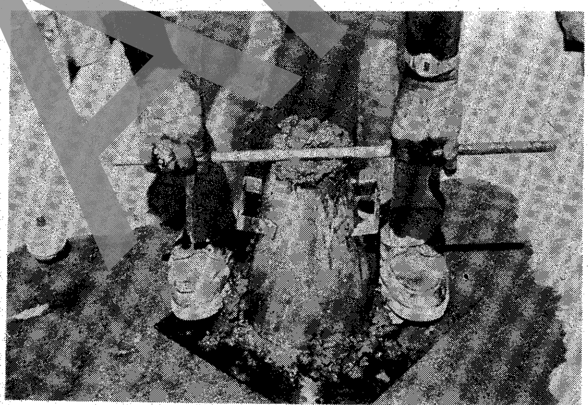
   A decrease in concrete and ambient temperatures will increase slump.

   An increase in haul time will decrease slump.

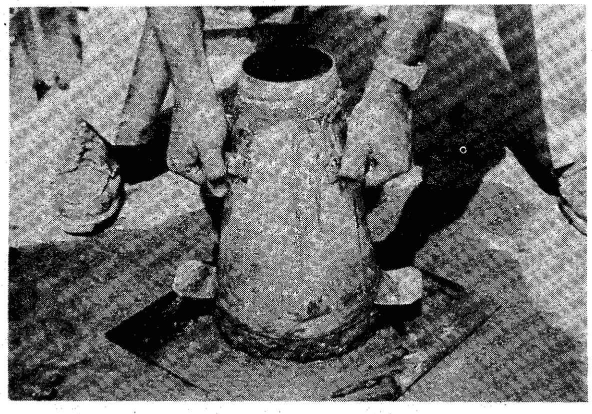
   The aggregate gradation, and a change in source of cement, aggregate, and admixtures may affect the slump of a concrete mix.



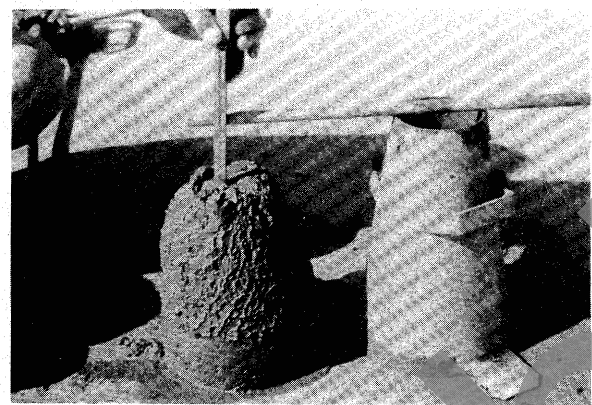
8. The first step in the **slump test** is to make sure that the equipment is wetted down adequately. The cone must be filled with three layers of approximate equal volume. Then each layer is rodded 25 times. For the first layer, the rod should be slightly inclined and approximately half the strokes 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 try to keep an excess of concrete above the top of the mold at all times.



9. Next the last layer is screeded with a rolling motion of the tamping rod. During the entire test it is important to have the base of the cone secured so the contents will not be disturbed.



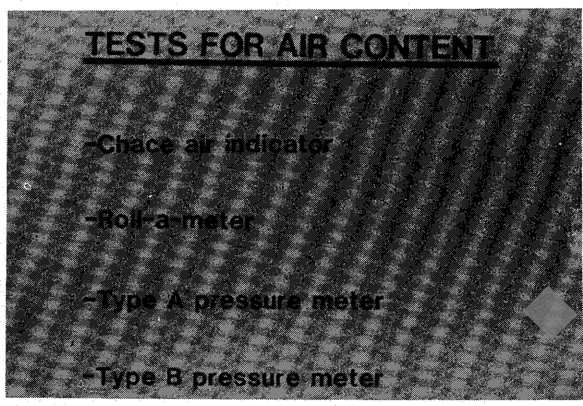
10. After the cone has been struck off, the cone must be cleaned and any overflow must be removed from the base of the cone. The cone is then released from its mountings, if so equipped, and **slowly lifted without twisting.** The lifting motion should be **completely vertical and should take from three to seven seconds.** From filling the cone to lifting the cone should be completed in the time limit of **2 1/2 minutes.**



11. After the cone has been removed, it is placed inverted next to the cone 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.** This value should be measured and recorded to the **nearest 1/4 inch.**

12. Running of the Kelly Ball test is a fairly simple operation. First the apparatus is zeroed and the surface of the concrete to be tested is leveled and smoothed by using a small wood float. The location of the test should be a minimum of 9 inches from any concrete edge. The Kelly Ball should not be used on concrete less than 8 inches in depth. The apparatus is set on the level surface. The handle is held vertical 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 1/4 inch. A minimum of three readings**

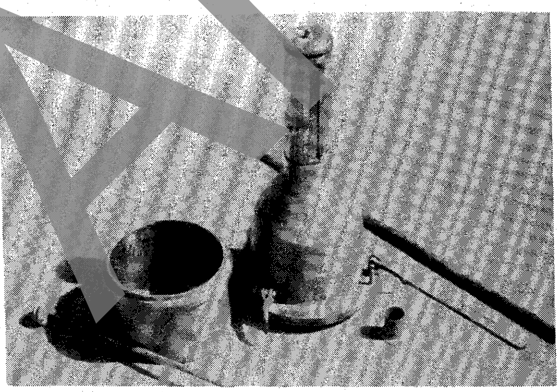
from a batch is needed. These readings should not be taken at any location where there is not at least 6 inches between the stirrup of a previous test and the point that is to be tested. The difference between the highest and lowest readings should not be more than one inch.



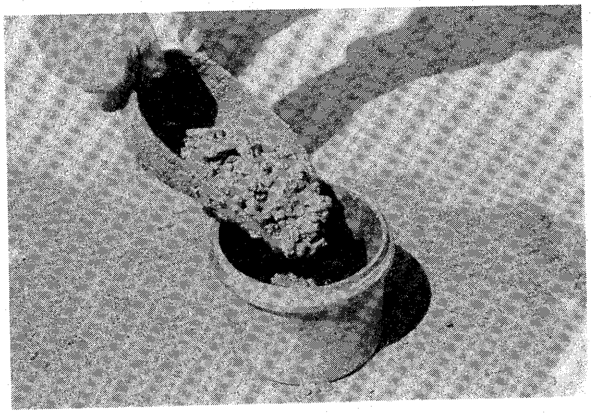
13. There are several methods currently used for determining the **air content** of the plastic concrete.

One method that is sometimes used for determining a rough approximation of air content is by using the Chace Air Indicator. Another type is the Roll-a-meter. These two methods determine the volume of air in the concrete mix by displacement of air with water.

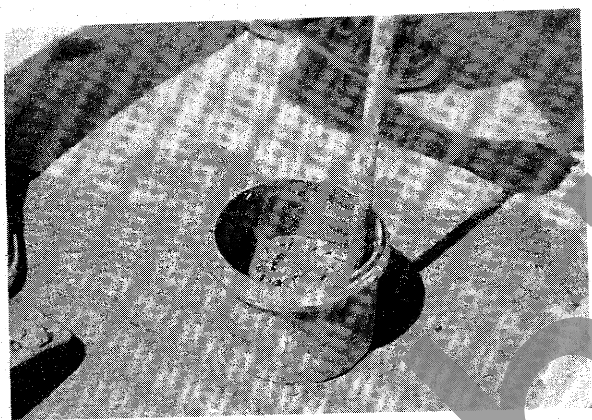
The other two types of air meter in use are the Type A pressure meter and the Type B pressure meter. These two pressure meters use pressure and volume relationships of gasses to determine the total air content. The total volume of air is indicated simply by reading a pressure gauge mounted on the meter.



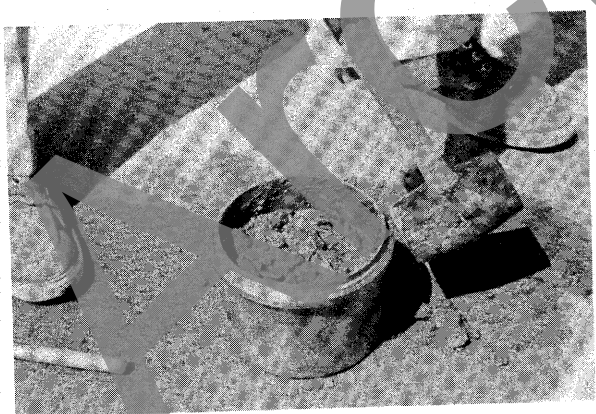
14. The roll-a-meter determines air content of a concrete mix by volumetric methods. The procedure for performing the test is contained in AASHTO T 196. **This method must be used whenever porous aggregates are used in a concrete mix.**



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

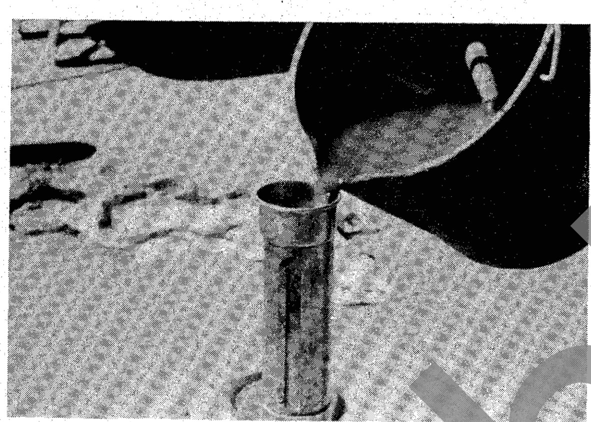


16. After the concrete has been placed in the base the layer should be tamped 25 times.



17. After the layer of concrete is put into the base and the concrete has been tamped with the tamping rod, it is necessary to remove voids 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 the preceding layer approximately one inch. The process is repeated until the base of the container is completely filled.

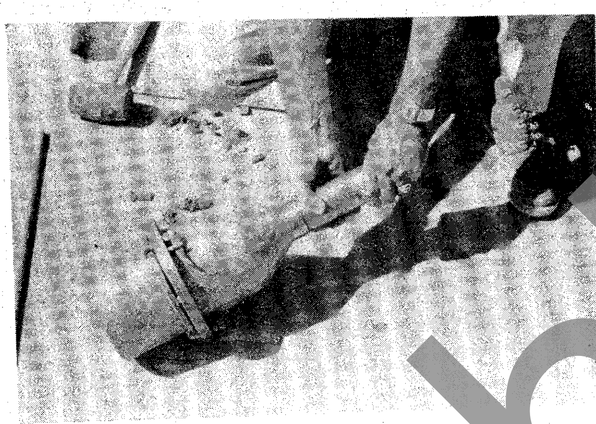
18. The base of the roll-a-meter is struck off with a smooth back and forth sawing motion of the strike-off bar. The surface should be smooth and flat. After the top is struck off, the lip of the roll-a-meter should be wiped clean and the top firmly attached to the base.



19. The meter is now filled to the zero mark with water using the special funnel which insures that the surface of the concrete is not disturbed during the filling operation.

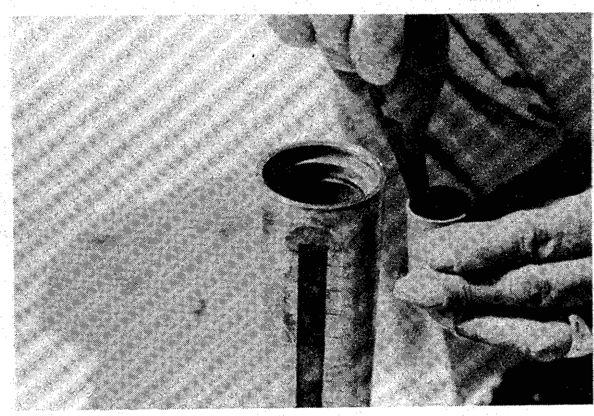
20. The gauge is topped off with a small squeeze bulb.

21. The screw cap is attached and tightened. Then the 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.**

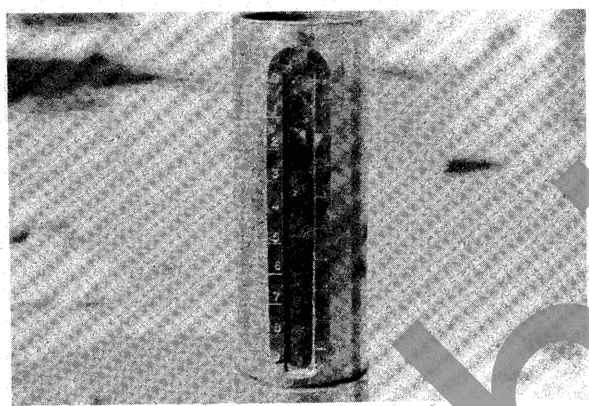


22. The meter should be rocked and rolled on its flange with the neck elevated until it appears that all the air has been removed from the concrete. **If all of the concrete is not put into suspension the resulting air content will be low.**

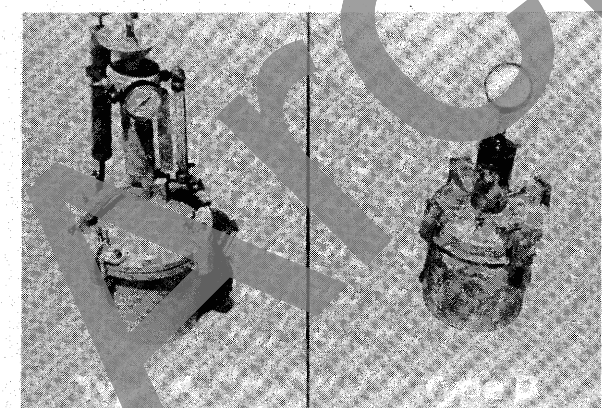
23. Set the meter upright, jar it lightly and allow it to stand until all the air rises to the top of the meter. Repeat this process until no further drop in the water column is observed.



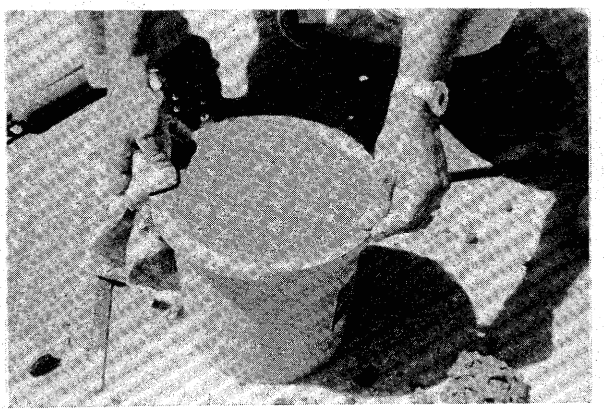
24. After rolling is completed, measured quantities of alcohol are placed into the meter. The number of units of alcohol which are placed into the air meter must be recorded. The purpose of the alcohol is to disperse any foam which forms as a result of the mixing action.



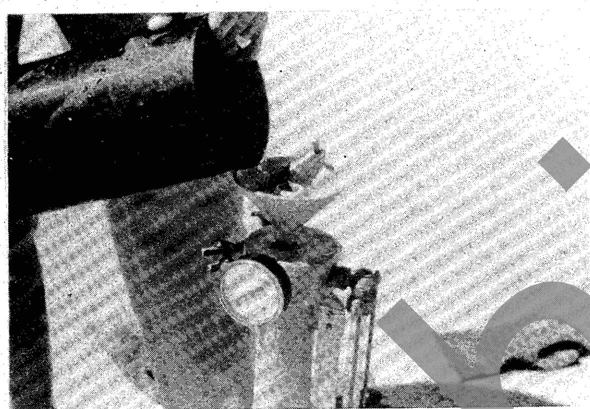
25. The air content is determined by taking a direct reading at the bottom of the curve formed by the water in the neck of the roll-a-meter. For each cup of alcohol placed in the meter one percent is added to the reading shown on the air meter. **The air content is recorded to the nearest 0.1 percent.**



26. <u>Pressure meters</u> determine the volume of air in a concrete mix using pressure-volume relationships. These pressure-volume relationships are reduced to such a form that 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.

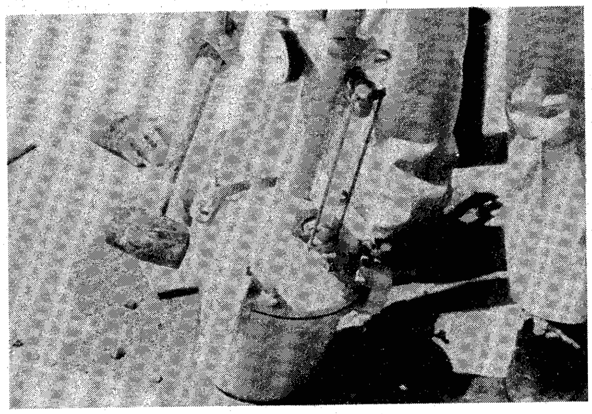


27. For both pressure meters, the apparatus is wet down and the base is filled in the same manner as was done with the volumetric meter. It is very important to clean the surface of the flange in order to get a good seal. The rubber gasket in the top of the meter should also be dampened. Then the cover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

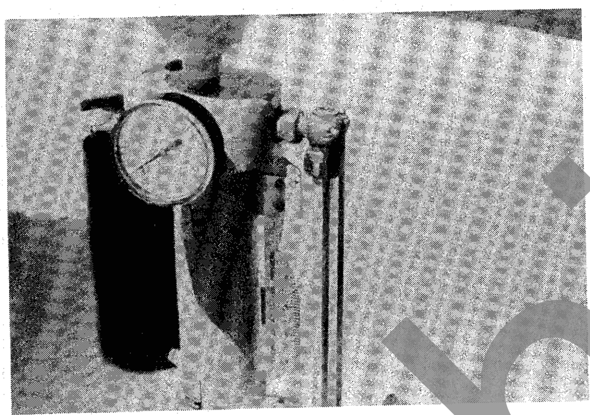


28. For the type A air meter, water is then added above the concrete by pouring it into the top of the fill tube.

29. Water is added until the level rises to about the four percent mark on the glass standpipe gauge.

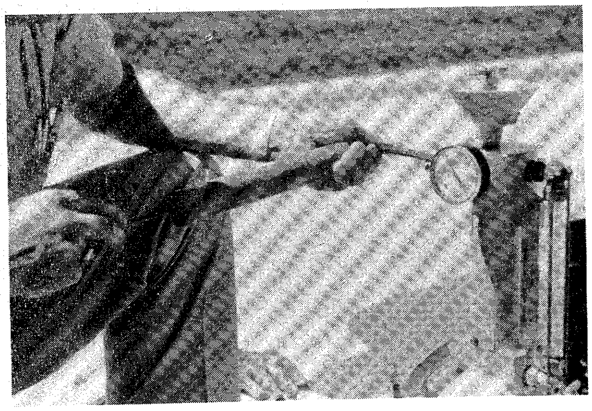


30. The entire meter is tilted and the cover is rapped with the rubber mallet to release any air entrapped above the concrete.

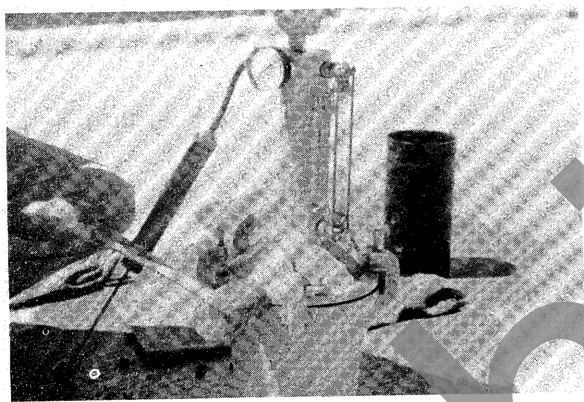


31. The meter is returned to the upright position and the water column is filled until water discharges from the top valve, shown in the upper left-hand corner of this slide. Tap the sides of the meter lightly with the mallet to insure that no air is trapped within the meter.

32. The water level is brought down to the initial fill line which is slightly above zero, by using the lower drain valve on the meter.



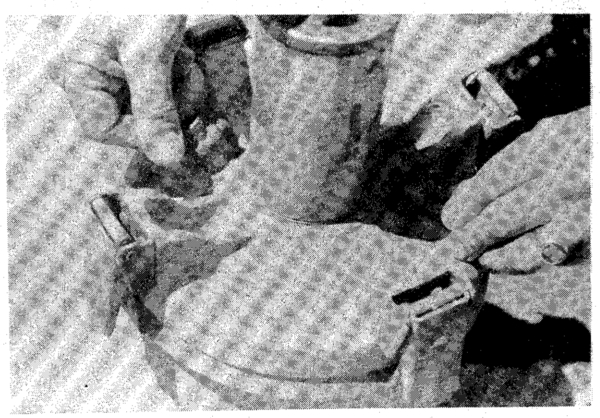
33. The vents at the top of the water column and the top valve on the fill tube are closed. The air meter is pumped until the pressure is slightly above the desired test pressure as shown on the gauge.



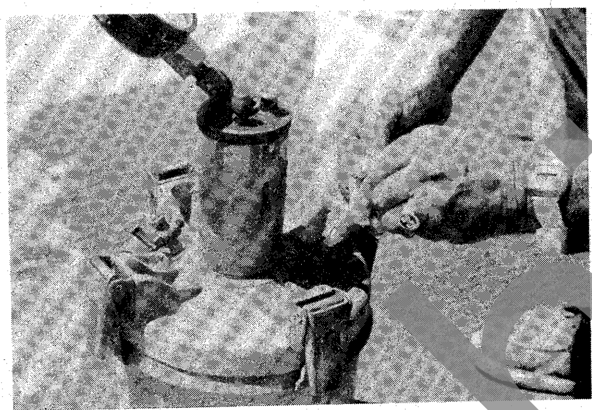
34. The sides of the meter are tapped with the mallet in order to free any air bubbles which might be in the meter.

35. The air content is determined by reading the level on the water column. The air content is recorded to the nearest 0.1 percent.

After the air content has been determined, the air pressure must be gradually released through the vent at the top of the water column and the sides of the meter should be tapped lightly for one minute. **The water level on the column gauge should be at zero when this step is completed.**

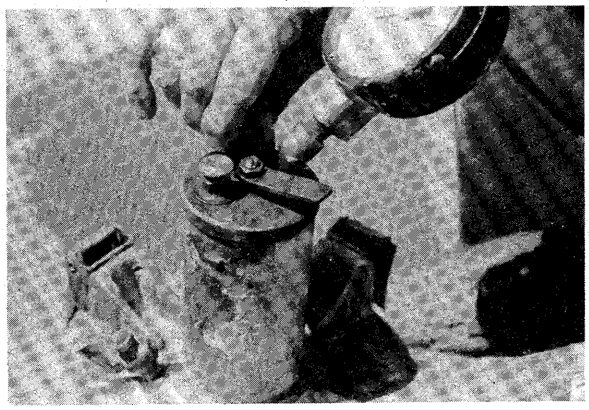


36. The type B pressure meter is filled in the same way as the volumetric meter and the type A pressure meter. Both petcocks on the meter are opened and the cover is clamped on the meter.

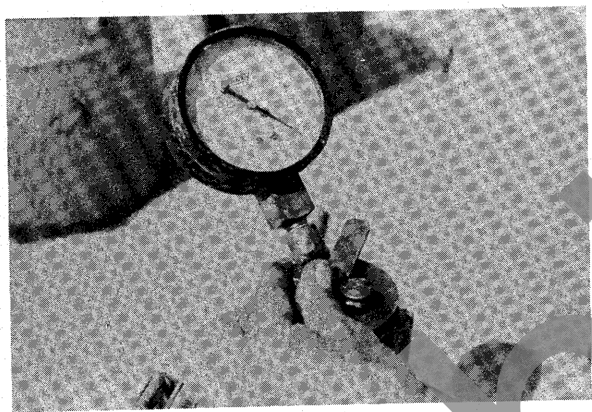


37. Water is injected into one petcock with a rubber syringe until it comes out the other petcock. The procedure is repeated with the other petcock. This procedure is alternated between the petcocks until no air bubbles appear in the water being ejected from either petcock. The meter should be jarred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

38. The petcocks and the air bleeder valve located at the top of the pressure meter are closed.

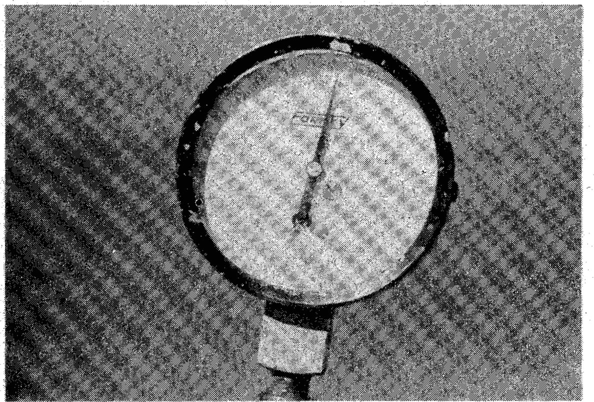


39. Air is pumped into the air chamber until the gauge hand is on the initial pressure line. This is usually between the two and three percent mark on the pressure gauge, depending upon the calibration.



40. The meter is adjusted at this time by pumping or using the bleeder valve and tapping the gauge lightly.

41. The main air valve is opened by pushing down on the release lever. The sides of the base rapped sharply and the gauge is 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 previous steps repeated.



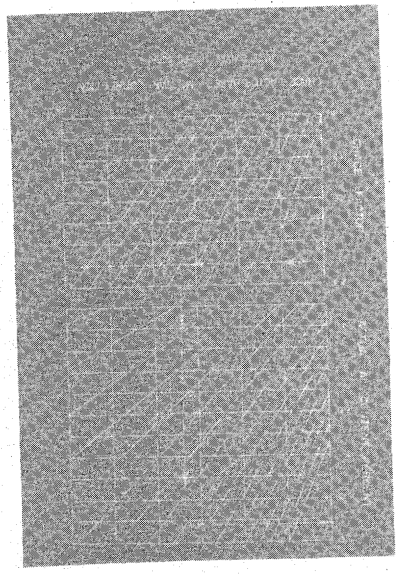
42. The air content is read directly from the gauge in terms of a percentage and recorded to the nearest 0.1 percent.

On paving projects air content tests are run on concrete samples taken from 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 - 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.

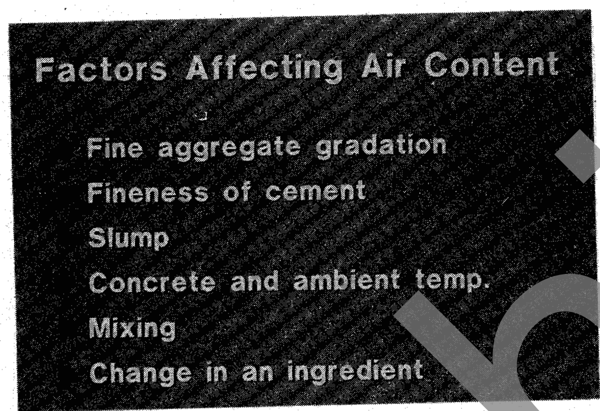
43. The Chace Air Indicator is very useful for screening loads of concrete. **It can be used for acceptance but not rejection.**

The procedure is run on material passing the No. 10 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 shook until the mortar is released from the thimble and a reading is taken.



44. In order to determine the air content, it is necessary to go into a chart with the reading, the mortar content, and the chace factor for the particular indicator. **A single test result consists of an average of two readings.**

This chart and the test procedure are contained in AASHTO T 199.



45. Many things affect the ability of a concrete to entrain air.

An increase in the material between the No. 30 and No. 100 sieve will increase the air content. However, an increase in the amount of minus No. 100 material will decrease air content.

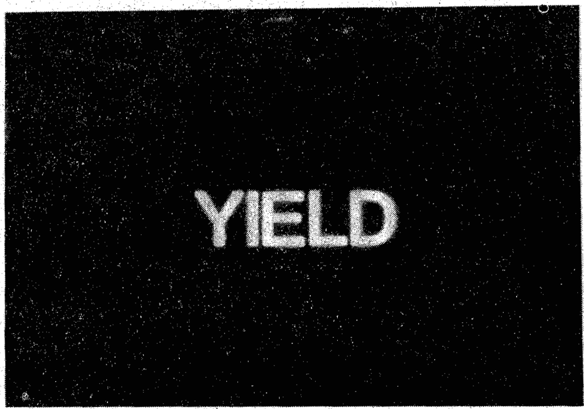
An increase in the fineness of cement will decrease the air content.

An increase in slump will increase the air content.

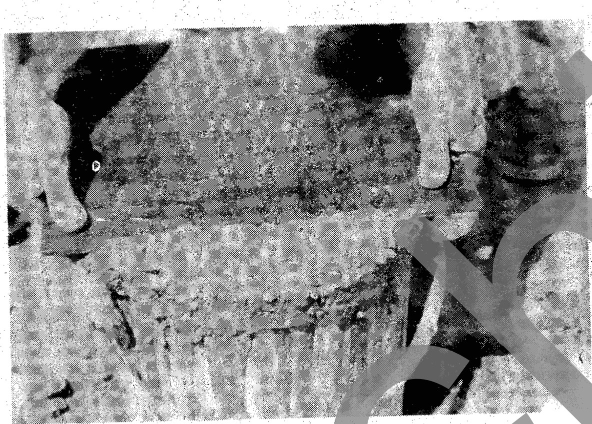
As the temperature of the concrete and ambient air increases the air content will decrease.

Excessive amounts of mixing will drive the air out of the mixture.

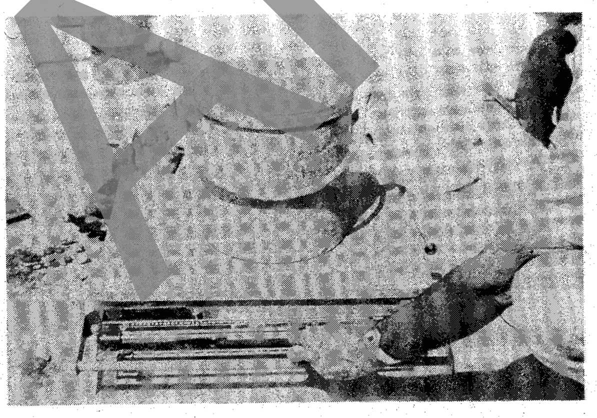
Any change in the sources of the ingredient materials can affect the air content of the mix.



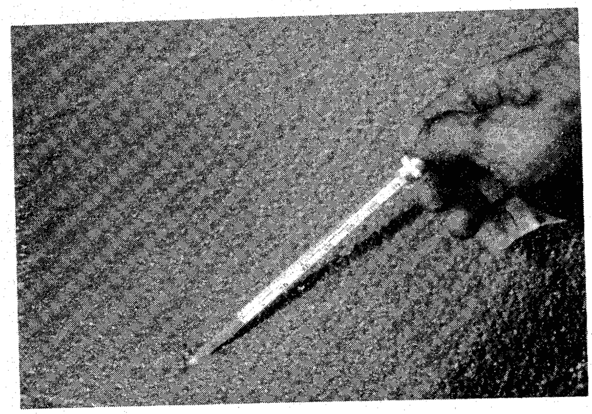
46. Concrete yield is the volume of concrete produced per batch of concrete. The yield is calculated from the results of the unit weight tests. The yield is found by comparing the theoretical unit weight to the unit weight found in the field. A difference in the unit weights indicates that the proportions of the ingredients in the mix are not correct. A high yield may indicate that a correction for holding water was not made, i.e. replacing the heavier materials for water. A low yield may indicate either two much water is being added or not enough cement is being added.



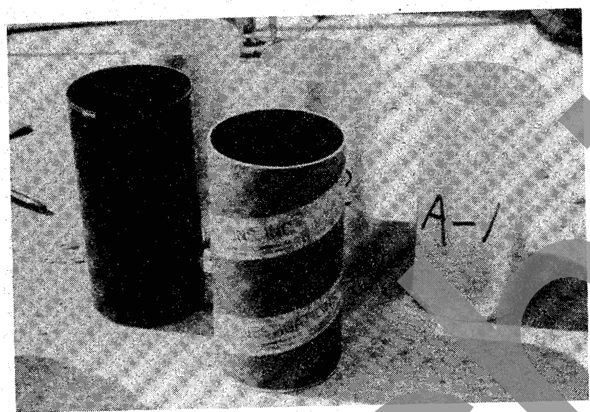
47. The yield bucket is wet down and filled in the same manner as with the air tests. However, a metal or glass plate is used to strike off the unit weight container. This is done by pressing the strike-off plate onto about 2/3 of the surface. The plate is withdrawn with a sawing motion to finish only the covered area. Next, cover the original 2/3 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.



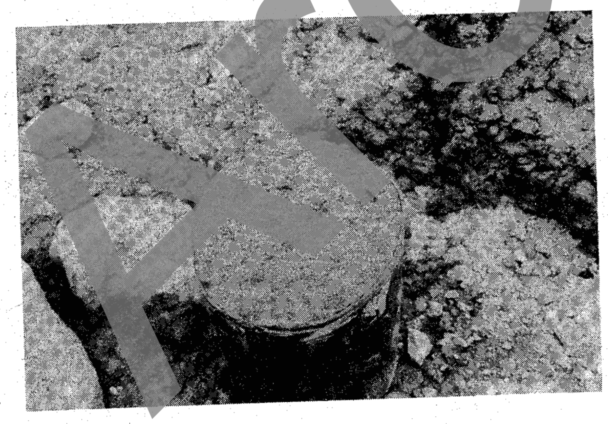
48. The sides and the bottom of the bucket are cleaned and weighed. The unit weight is calculated by subtracting the tare weight from the gross weight and divide by the container volume. Finally, calculate the yield by dividing the total weight of all the materials batched, (the water, cement,aggregates and admixtures) by the unit weight. Also, calculate the relative yield by dividing the unit weight as 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. The procedure for determining temperature is contained in ASTM C 1064. **The maximum temperature in State specifications runs between 85 and 90 degrees F.**

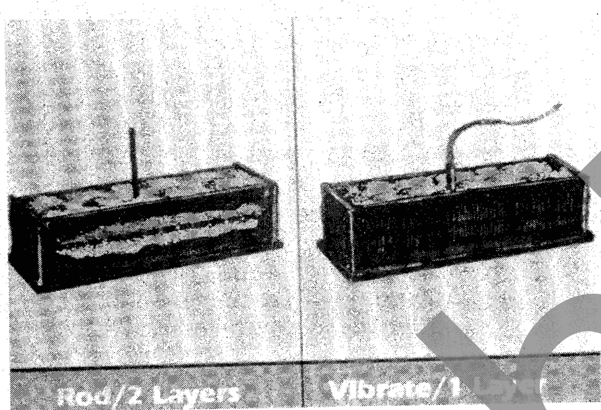


50. Metal, cardboard or plastic containers may all be used as **concrete cylinder molds**. Most States use 6 inch diameter by 12 inch high molds while some States have gone to 4 inch diameter molds which are 8 inches high. The 4x8 molds should only be used with mixes where the maximum size aggregate is equal to or less than 1 1/4 inch.

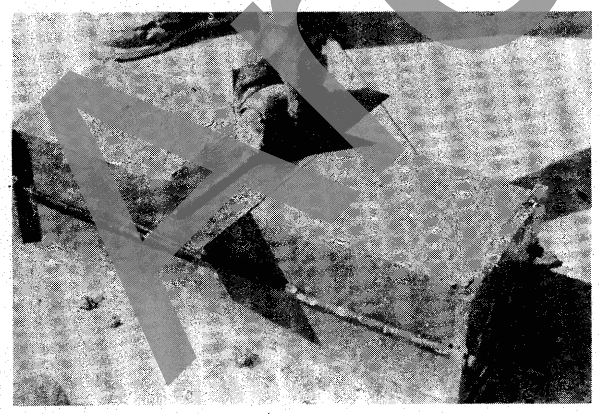


51. The cylinders must not deform during molding.

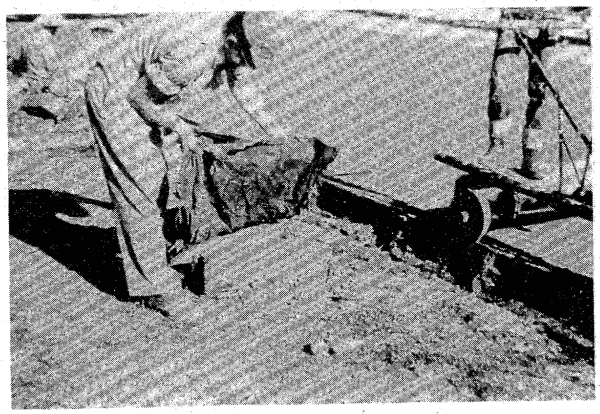
52. Concrete cylinders are made by the identical method that was used in filling the base of the air meters. Concrete placed in three equal layers and rodded 25 times a layer.



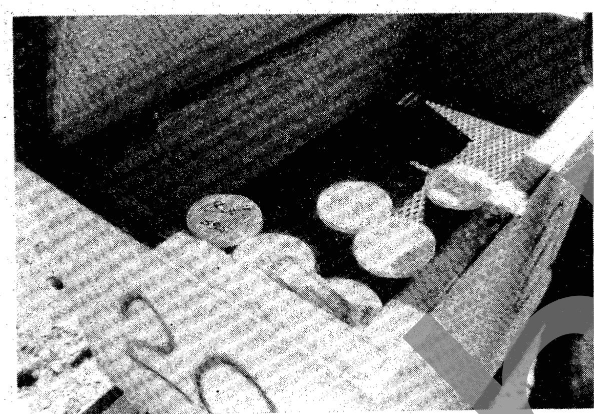
53. <u>Flexural specimens</u> are made in <u>a mold</u> which will result in a specimen which is 6x6x20 inches. Once the concrete is placed in the mold the perimeter should be spaded with a trowel. Concrete beams may be either rodded or vibrated. If the beams are to be rodded, they must be rodded in two equal layers, once for each 2 square inches of area (60 times for a standard beam). If they are to be vibrated, they will be vibrated in one layer at three points along the specimen.



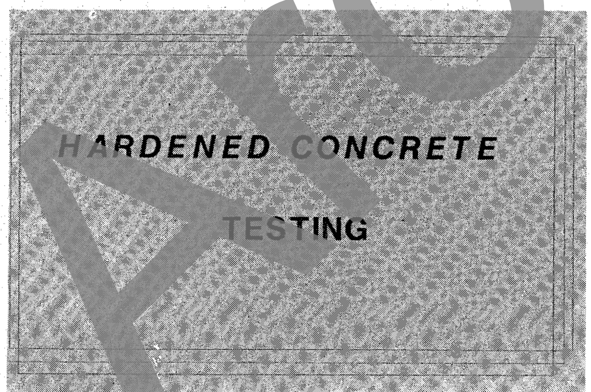
54. It is also necessary to tap the sides of the beam using a mallet in order to properly close any holes left in the beam by the tamping rod. With either procedure, the final step is striking off the surface of the specimen using a wood float or trowel.



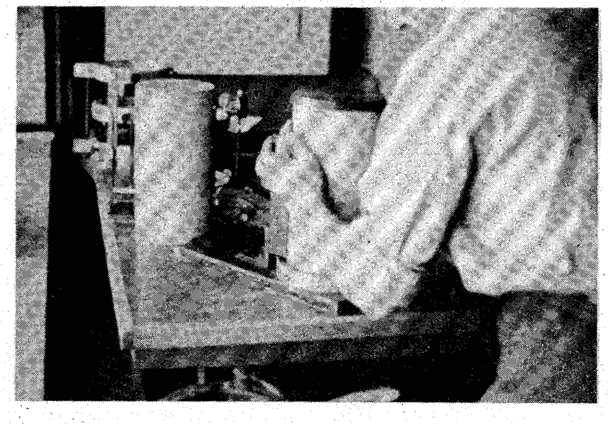
55. If the specimens are going to be used for form removal or opening pavement to traffic the specimens should be stored and cured in the same manner as the structure.



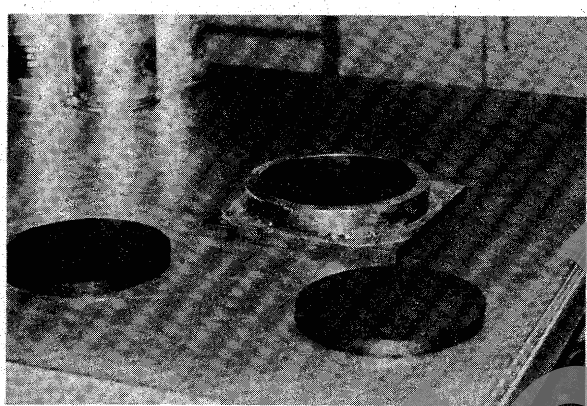
56. If the specimens are going to be used for determining the quality of the concrete, the initial cure should be at 60 to 80 degrees F for 24 + or minus 8 hours. The mold should then be removed and the specimen should be cured in saturated lime water, moist sand pits, curing box, or other suitable means to control temperature and moisture loss. If the specimens are to be transported prior to 48 hours the molds can stay on the specimens until the transportation is complete.



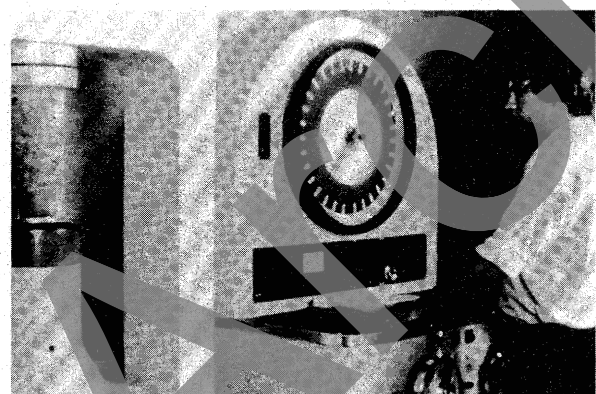
57. **Testing hardened concrete.** In most States the concrete quality control tests are performed in either the district or central materials lab while the construction control tests (opening to traffic or form removal) is handled on the project.



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



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



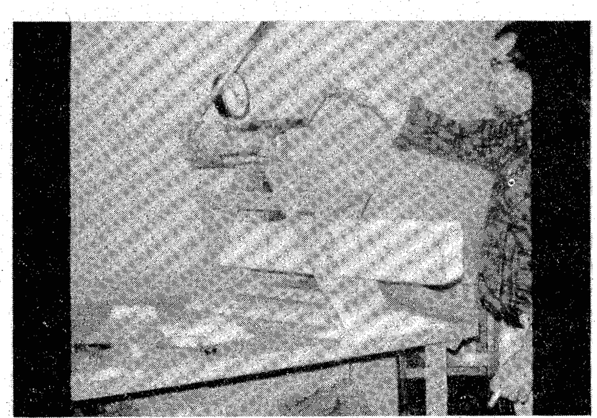
60. The test specimens must be tested in the moist condition. Dry specimens will break higher than moist specimens.

The testing device 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.

The testing device should be calibrated at least once a year.

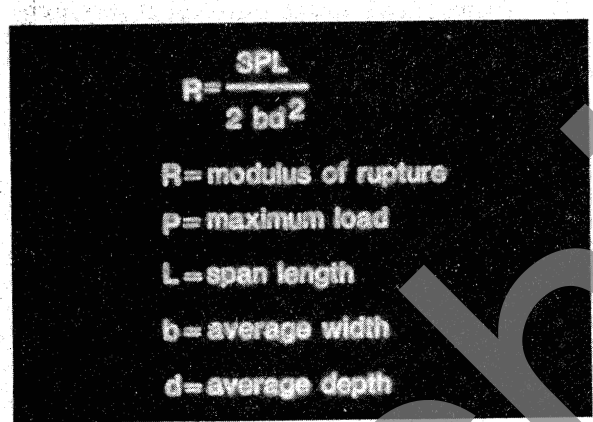
It is necessary to average the compressive strength of two test specimens to obtain one test result.

Failing cylinders should be broken completely since the pattern of the break will help determine the cause of the failure.

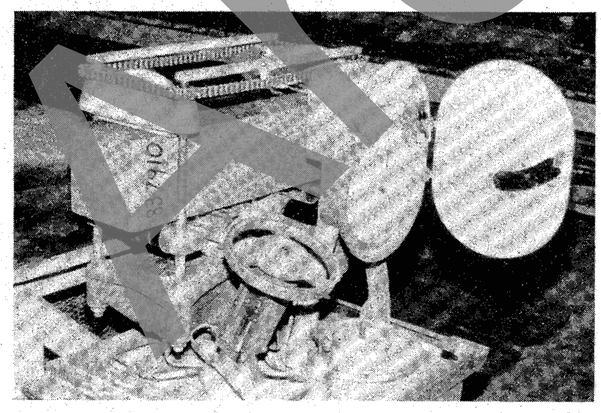


61. **Flexural strength** can be determined by center point or third point loading. The testing machines should be calibrated once a year.

The **center point** procedure is shown here. The span is from support to support. The edge of the specimen needs to be at least 1 inch 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 in the photograph.



63. The **third-point** flexural test device is shown here. The same items concerning loading and orientation of the specimen are the same as those indicated for center-point loading. The test procedure appears in AASHTO T 97. It should be noted that the third-point loading test is the most severe strength test. The location of the fracture will determine if the test result will be used or which of the two formulas will be used for determining flexural strength.

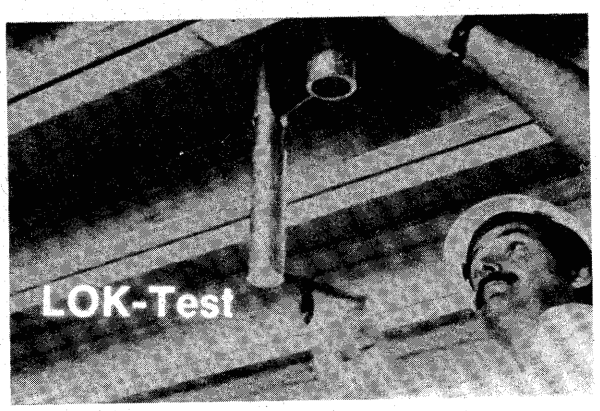
64. The Rebound Hammer is used for determining the approximate strength of rock. It has also been used as a crude device for determining strength of concrete. The best way to utilize the device is compare results from the device on a part of the structure which has satisfactory strength to the results 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 C807.

65. The first step in using the Windsor Probe is to fire three probes into the concrete. The average penetration of the probes is determined by using 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.

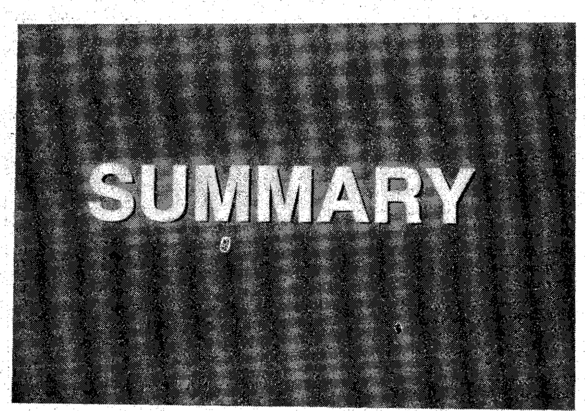
The test procedure is contained in ASTM C803.



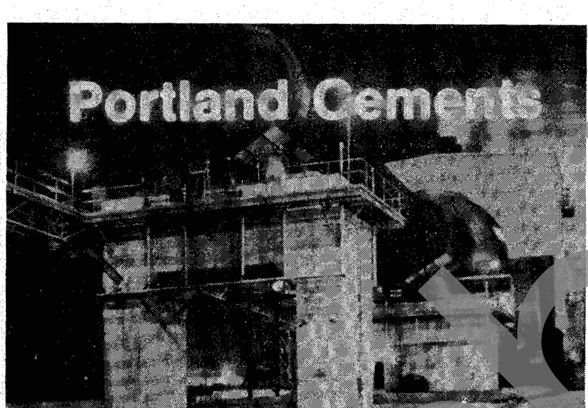
66. The first step in using the LOK-test device is to cast studs into the concrete. The device is placed on a stud and the strength of the concrete is determined by the amount of torque that is needed to pull the stud out of the concrete. The device is typically used in the construction industry to determine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

The test procedure is contained in ASTM C900.

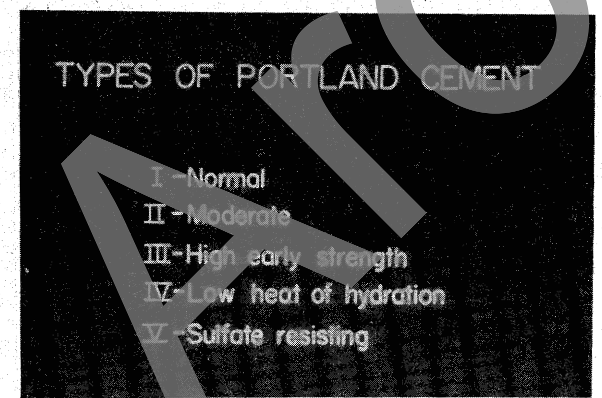
SUMMARY



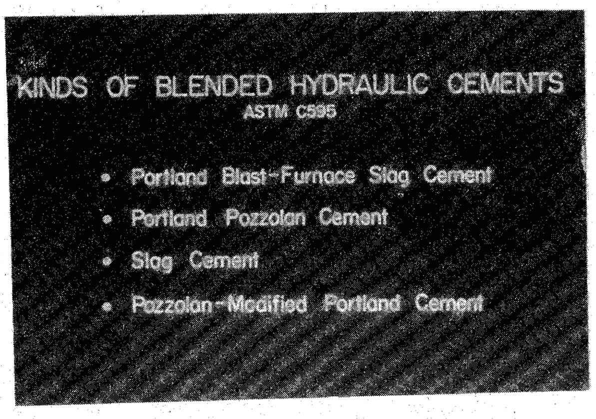
1. This section of the course will consist of a brief summary of the major points that were covered in the course.



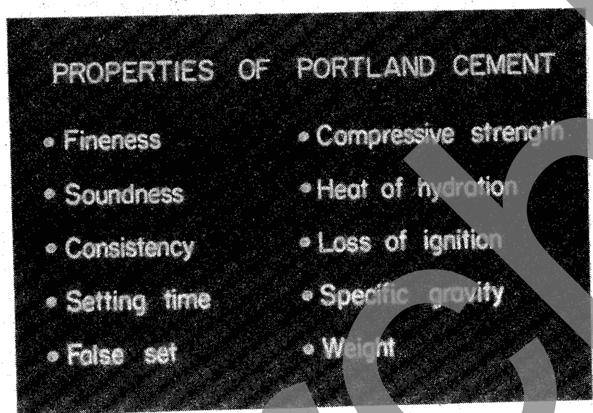
2. Portland cements are hydraulic cements. These cements combine chemically with water to form a hard mass during the hydration process. The four main chemical ingredients of Portland cement are lime, iron, silica, and alumina.



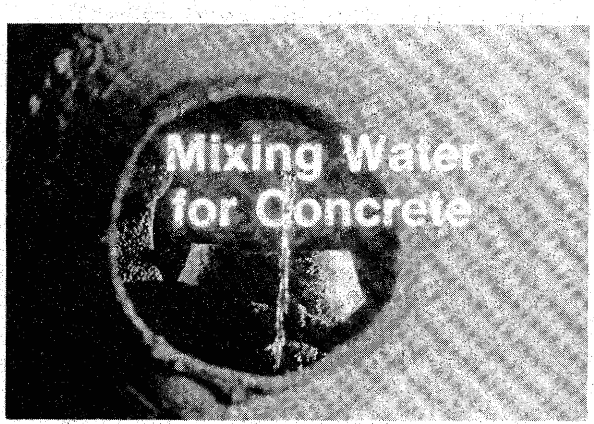
3. There are five principal types of cement. Types I, II, and III also have air entrained forms which are designated by an A after the numeral. In highway construction, types I, II, and III are typically used. Type I is specified for most uses. Type II is specified by some agencies for general use because of the lower heat of hydration and by all agencies where sulfate attack may occur. Type III is specified where high early strength is desired.



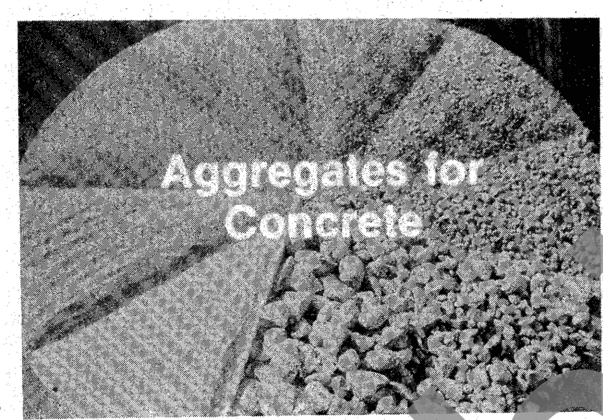
4. There are also blended cements. The blended cements can be made by intergrinding or an "intimate blend" of fly ash or granulated blast furnace slag with portland cement. Type IP is Portland Pozzalon Cement which is made with 15 to 40 percent fly ash. Type I(PM) is called Pozzalon-Modified Portland Cement and has less than 15 percent fly ash. Type IS is called Portland Blast- Furnace Slag Cement and contains between 25 and 65 percent slag. Type I(SM) is called Slag-Modified portland cement and contains less than 25 percent slag. Types S and P would not be used in highway construction.



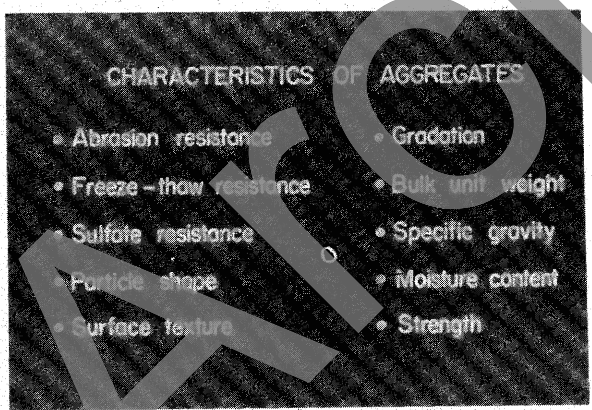
5. Properties of Portland Cement. The fineness of the cement will affect the water demand, air content, and rate of strength gain. An increase in fineness will increase both the water demand and the rate of strength gain and will reduce the air content of a mix. Soundness is an indicator of whether the cement will create detrimental expansion. Consistency, setting time, and false set criteria are specified to insure that a concrete mix will have good working properties. A high loss of ignition will indicate that some hydration has occurred and the cement is not suitable for use. Heat of hydration is important from the standpoint of strength gain and ultimate strength. Typically higher heat of hydration will cause higher early strength gains and lower ultimate strengths.



6. For the most part if the water is potable it can be used for making concrete. Water that is not potable may also be suitable for making concrete. In all cases, if there is any question concerning the suitability of the water it should be tested.



7. Aggregates make up 60 to 80 percent of the volume in concrete and as such have a significant affect on the workability of the fresh concrete and the durability of the hardened concrete.

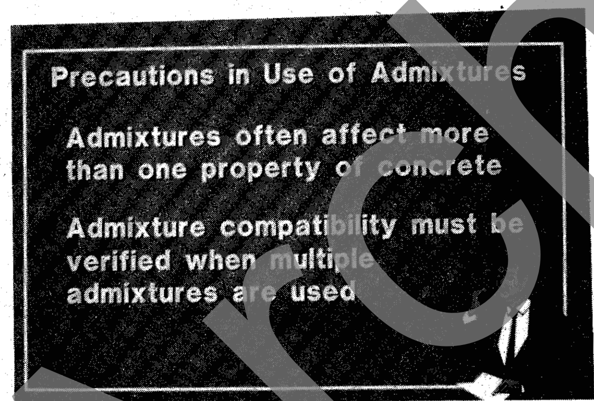


8. The particle shape, surface texture, gradation, and moisture content of the aggregate have a significant affect on the water demand and workability of a concrete mixture. The more rounded and smoother the particles are the more workable the mix will be and the lower the water demand will be. The finer the mix is the more cement is required to maintain a proper matrix. Gap gradations also increase the water demand and increase bleeding to maintain workability.

Abrasion resistance, freeze-thaw durability, sulfate resistance, and alkali resistance relate to long term durability of the concrete. Sulfate attack is due to sulfate in some ground waters. Alkali reaction occurs between siliceous and some carbonate aggregates and the alkali in the cement.

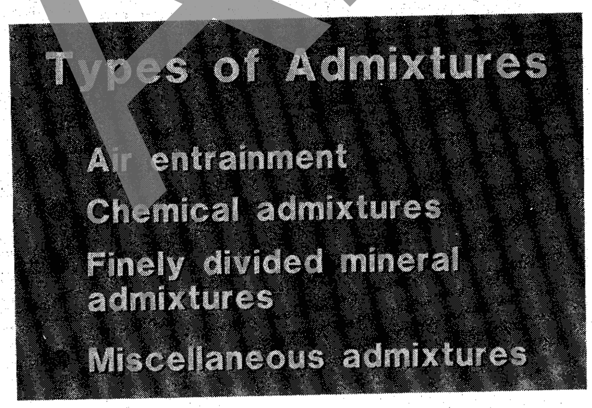
The unit weights and specific gravites are important for batching operations. In proportioning mixes the volumes of materials are what is determined. Batching is done by weights so the specific gravities are used to change the volumes determined in proportioning to the weights for batching operations.

9. By definition an admixture is any material other than water, aggregates and hydraulic cement that is used as an ingredient in concrete. Admixtures are not to be used as a substitute for good concrete proportioning. They can be used to enhance properties of well designed and proportioned mixes.

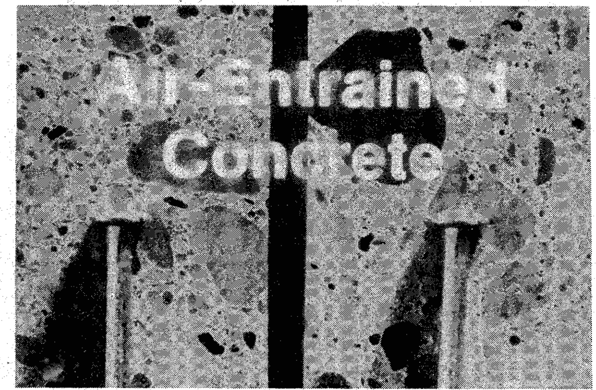


10. Admixtures often affect more than one property of the concrete.

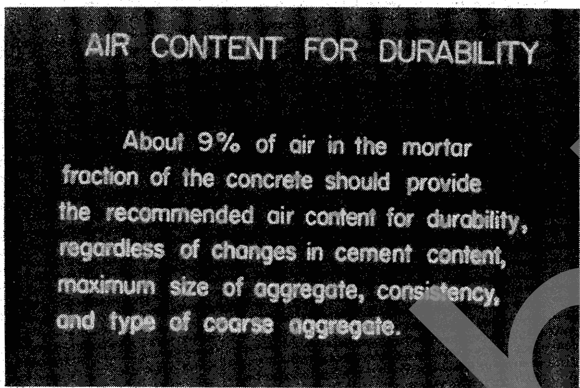
Admixture compatibility must be verified when multiple admixtures are used.



11. There are four basic types of admixtures: air-entraining admixtures, chemical admixtures, finely divided materials, and miscellaneous materials.



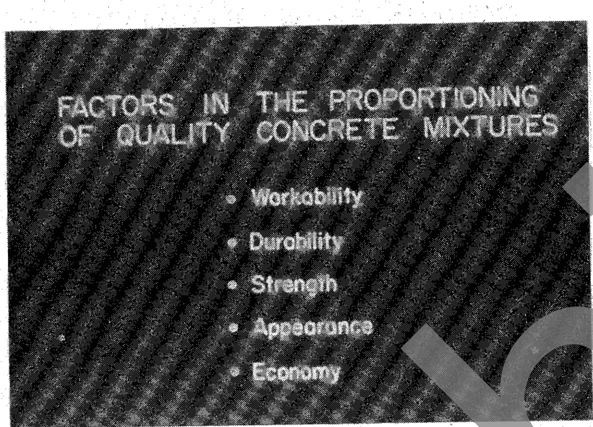
12. Air-entraining admixtures are used in most of the concrete mixes used in highway construction. The major benefit of these admixtures is to insure freeze-thaw durability. The admixture also has several other benefits. It reduces bleeding, increases workability, improves water tightness, improves sulfate resistance, and increases the resistance to scaling by de-icing salts.



13. The proper air content for durability requires about 9 percent air in the mortar portion of the mix. This will include both entrained air and entrapped air. The required air content will thus vary with the maximum size of the coarse aggregate.

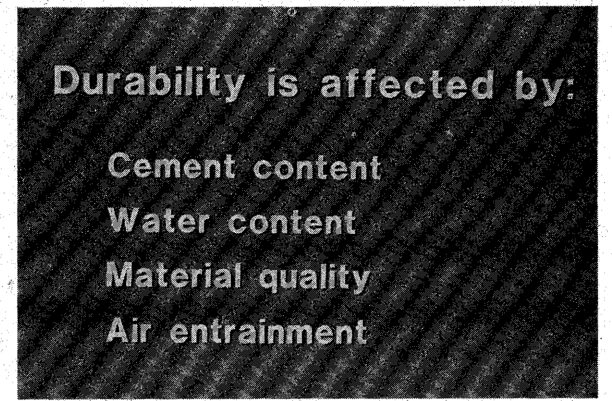
14. There are seven types of chemical admixtures. However, the admixtures can be placed in four general categories; set retarders, water reducers, accelerators, and high range water reducers. It should be stated that most water reducers are set retarders. The most common accelerator is calcium chloride. Caution should be used when accelerators are used in the hot weather.

15. Fly ash and silica fume are pozzolanic materials, that is they combine with calcium hydroxide from the hydration process and form cementitious material. Blast furnace slag is a cementitous material. Blast furnace slag and fly ash will reduce early strength gain while increasing ultimate strength. Silica fume has the capability of increasing early and ultimate strength but when used without a water reducer will increase water demand.

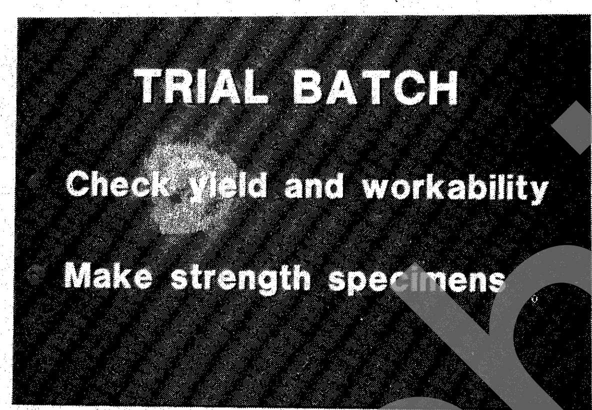


16. When concrete mixes are proportioned the workability, durability, strength, appearance, and economy have to be taken into consideration.

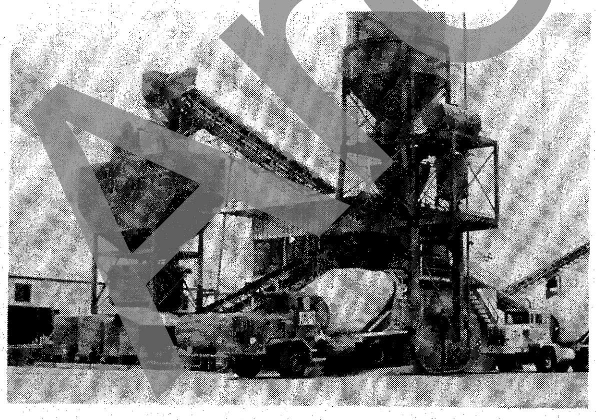
17. The workability of the concrete mixes are affected by the water content; aggregate gradation, shape, and texture; admixtures; and temperature.



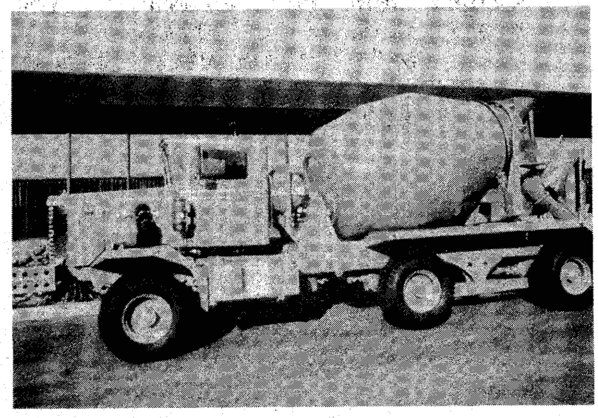
18. The durability of concrete mixtures is affected by the cement content, water content, material quality, and air-entrainment. A minimum amount of cement is required for strength and reduction in permeability. However, too much cement will lead to an excessive amount water being added to the mix that will cause shrinkage problems. The water content needs to be kept low to insure proper strength. The aggregate, cement, water and admixtures must be of high quality to avoid chemical attack and freeze-thaw damage.



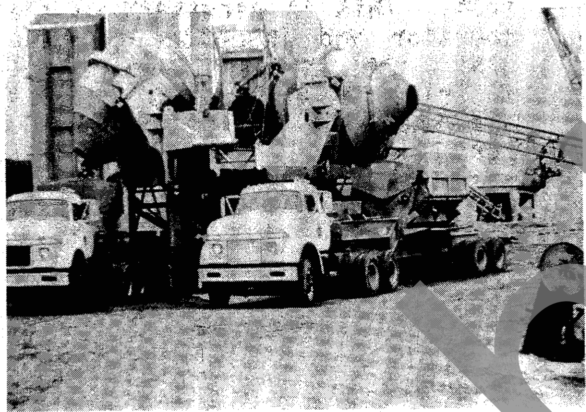
19. When the proportions are chosen it is necessary to perform a trial batch to insure that the concrete mix will have the desired properties.



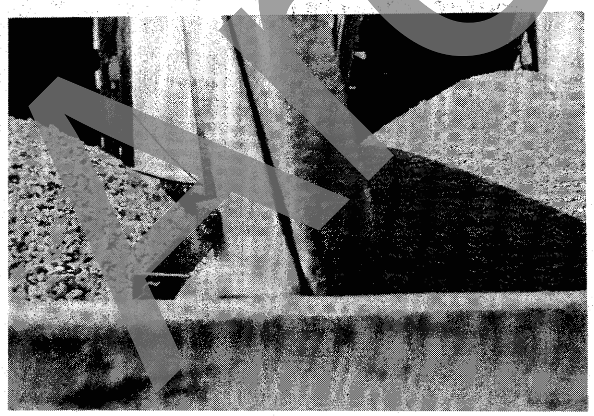
20. The batch plants are only capable of weighing and measuring the proper amount of material into a truck mixer. The mixing itself occurs in a truck mixer.



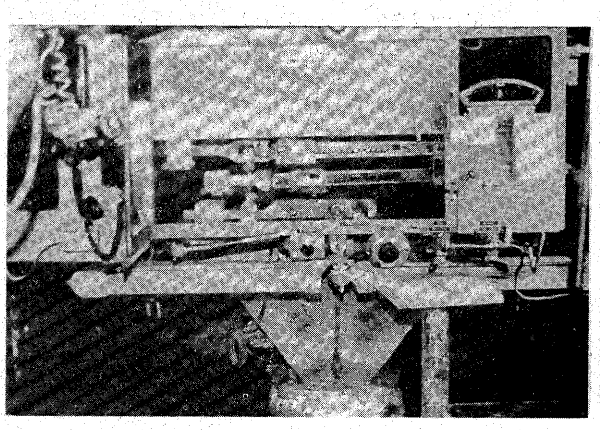
21. The truck mixer should be inspected annually to insure proper operation. The drum should be checked for a build up of concrete and blade wear. The easiest method for determining the efficiency of mixing in the truck is to perform a uniformity test on the mix produced. The trucks need to be equipped with revolution counters and if water is allowed to be added at the site the truck should be equipped with a water meter.



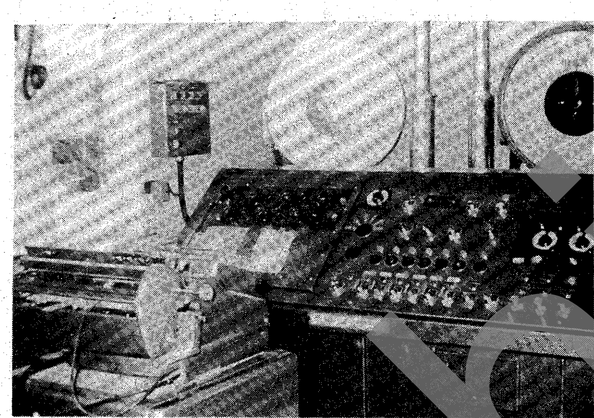
22. In a central mix operation both batching and mixing are accomplished at the plant.



23. As with all aggregate mixtures, aggregate stock piles need to be built and maintained properly. The bins in the plant need to be properly separated to avoid intermingling of the aggregate.

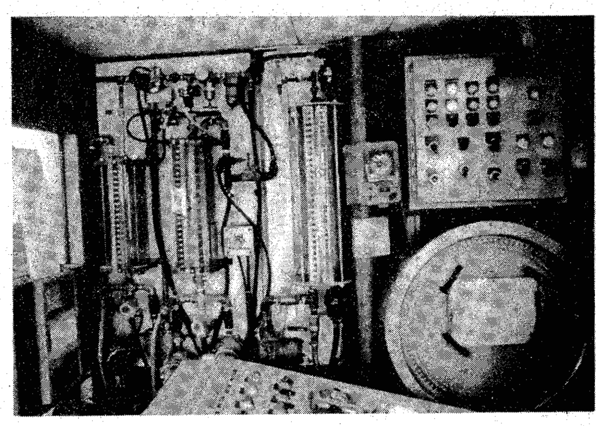


24. In most cases batching operations will be performed by weight and not volume. The scales need to calibrated once a year and sensitivity checks should be performed at least once a week.

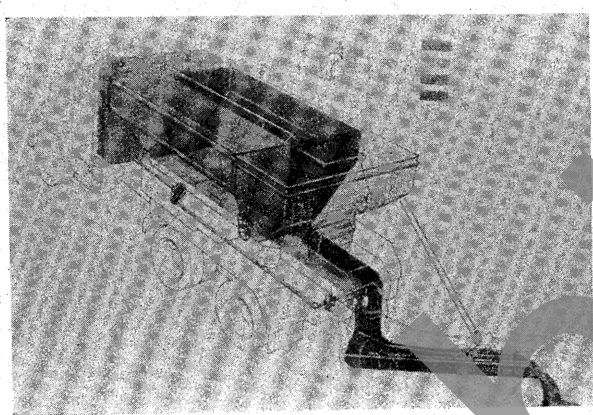


25. The dials should be visible to the operator in the control room. This is necessary so the operator and inspector can see that the proper amount of material is going into the mix and that the scales return to zero.

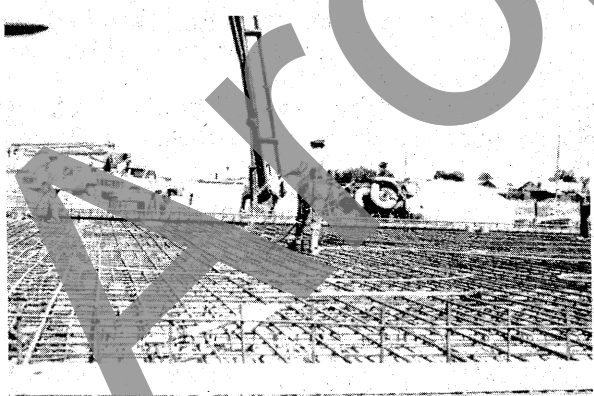
26. The admixture barrels should be properly stored and labeled to avoid contamination, dilution, and/or freezing.



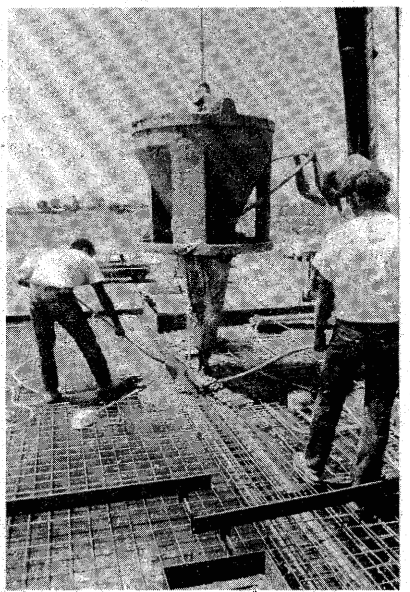
27. The admixture dispensers should be visible to the operator. This is needed to insure that the correct amount of admixture is being dispensed into the mix.



28. The only exception to batching by weights is the mobil mixer which relies on volumetric batching.



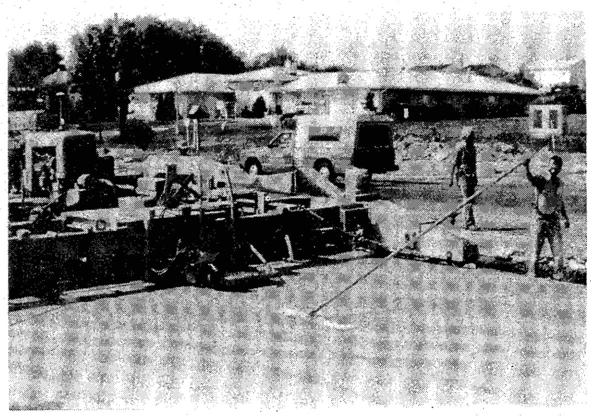
29. The first operation in finishing and placement of concrete is to wet down the forms/base material to insure that the concrete will not lose water. This also cools down the reinforcing steel in order to insure that a flash set will not occur at the point where the concrete touches the steel.



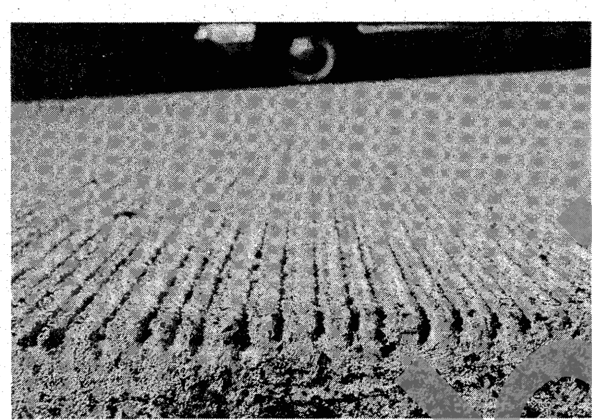
30. The concrete should be placed as close to the final location as possible. Concrete should not be dropped more than 4 feet.

31. Vibrators should be moved every 5 to 15 seconds in order to avoid segregation. The vibrators should be held in a vertical position and should never be used to move concrete.

32. A straight edge should not be used to move concrete.

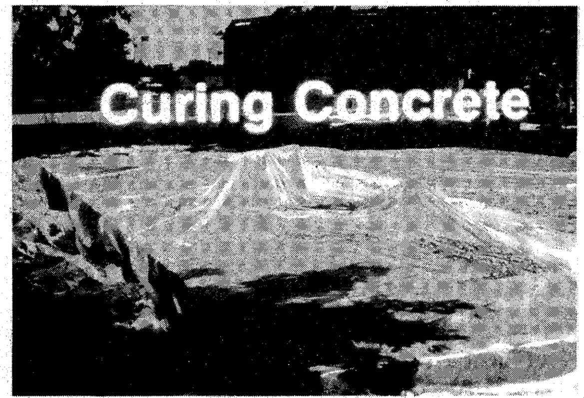


33. If any additional finishing is required it should be performed immediately after the finishing machine prior to bleed water appearing on the surface or after the bleed water has evaporated. Under no circumstances should any finishing occur when bleed water is present. If the bleed water is worked into the surface the surface will deteriorate due to the higher water cement ratio.

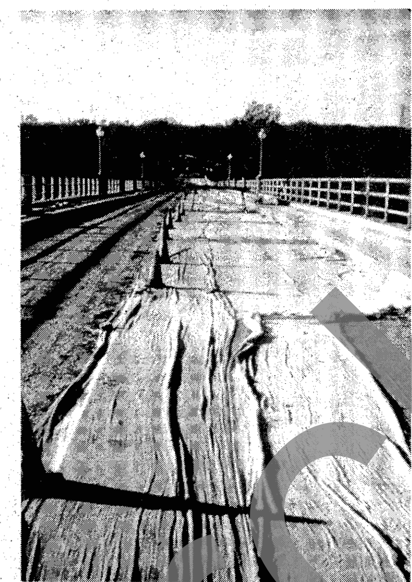


34. Texturing must be performed at the proper time. If performed too early the tining operation will pull up the coarse aggregate. If it is performed too late the surface will not receive the proper texture. A proper texture should be 1/8 inch deep and should be spaced between 1/2 and 3/4 inch.

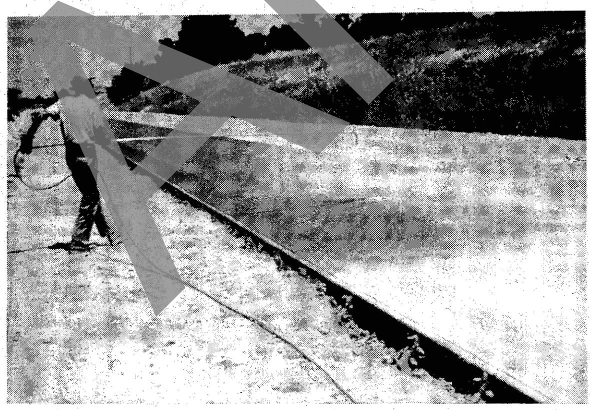
35. The timing of sawing of transverse joints is critical. It must be performed as soon as the concrete has hardened enough to prevent excessive raveling. A slight amount of raveling is desired. The sawing operation should be continuous. It may be necessary to saw every third joint to prevent random cracking and return to saw the remaining joints at a later time.



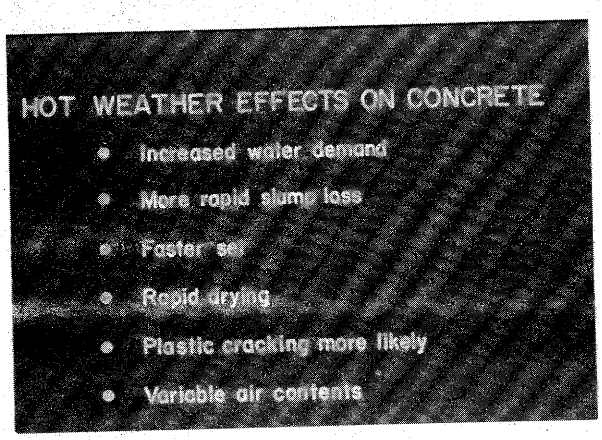
36. Proper curing consists of maintaining a satisfactory moisture content and temperature for the hydration process to occur. The moisture content can be maintained by applying water or preventing excessive evaporation.



37. The most effective method of curing is to use water. This can be accomplished by ponding, spraying, fogging, or using wet coverings such as wet burlap. Wet burlap requires attention to insure that the burlap does not dry out.



38. Moisture can be retained by sealing the surface. This can be performed by the use of plastic sheets, impervious paper, or membranes. Curing compounds must be agitated during application and a uniform coat must be applied to all exposed surfaces. Curing compounds must not be used on surfaces that will receive additional concrete since the compounds act as a bond breaker.



39. Hot weather can have the following undesirable effects on concrete:

    a. Increase water demand.

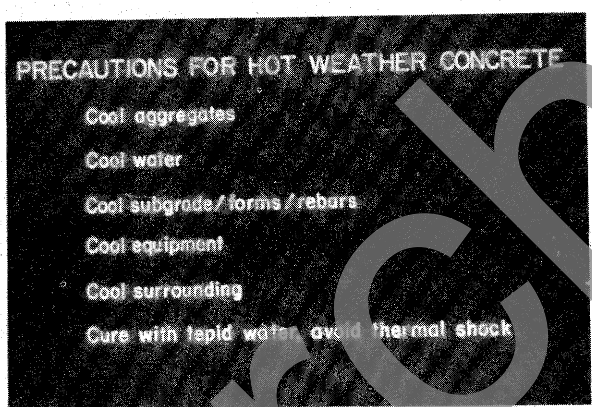
    b. Loss of slump causing more water to be added at the site.

    c. Handling and finishing problems due to faster set.

    d. Faster drying which requires prompt curing.

    e. Tendency for plastic shrinkage cracks.

    f. Difficulty in controlling air contents.



40. The damaging effects of hot weather concreting can be diminished by the following actions:

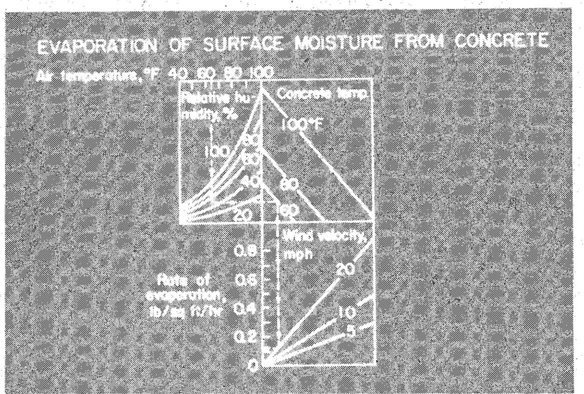
    a. Cool aggregates by sprinkling stockpiles.

    b. Cool water, use ice, or use liquid nitrogen.

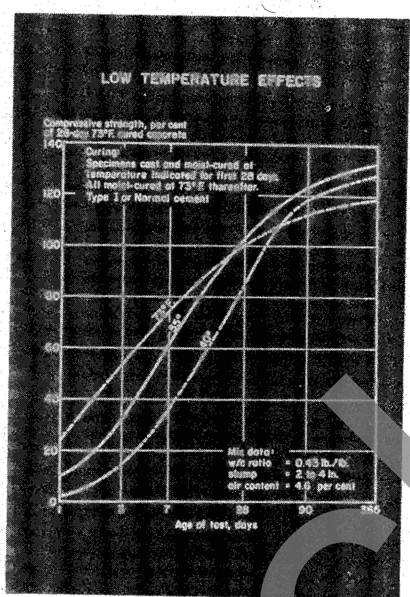
    c. Water down the subgrade, forms, and/or rebars in order to cool them.

    d. Cool the surrounding area with a fog spray, set up wind breaks, set up sun shades, and place concrete at the lowest temperatures possible.

    e. Cure the concrete with tepid water to avoid cracks due to thermal shock.

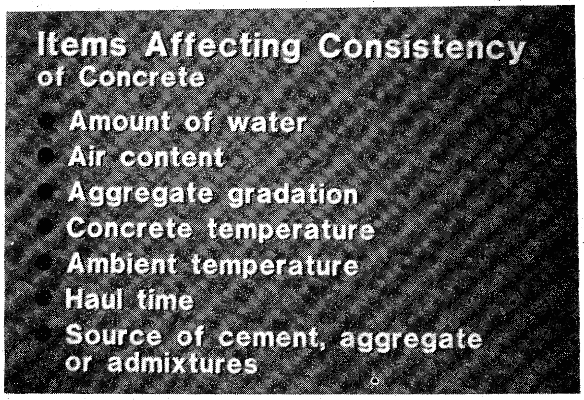


41. Plastic shrinkage cracking can occur when the evaporation rate exceeds 0.2 lbs per square foot per hour. Precautionary measures should be used when this rate is exceeded. The following chart can be used to estimate if the limit is being exceeded.



42. As the temperature of the concrete goes down the hydration of the concrete slows down. This decreases the strength gain of the concrete. As the temperature of the concrete decreases it will be necessary to maintain protection longer so that the concrete can obtain the desired strength.

43. In order to maintain the temperature of the concrete insulation or artificial heat can be used. The concrete can not be allowed to freeze.



44. In controlling concrete mixes it must be remembered that slump can be affected by the following items:

Amount of water.

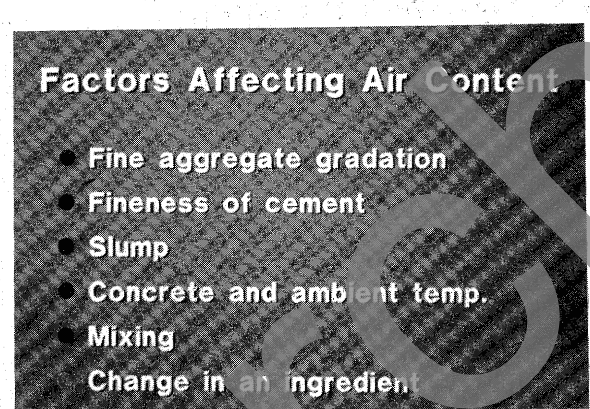
An increase in air content will increase slump.

A change in the aggregate gradation will affect the matrix of the concrete and therefore its slump.

An increase in concrete or ambient temperature will decrease slump.

An increase in haul time will decrease the slump.

A change in the source of any ingredient in the concrete may affect the slump.



45. Many things may affect the air content in concrete:

An increase in the material passing the No. 100 sieve will decrease the air content, however, an increase in the material between the No. 30 and No. 100 sieves will increase the air content.

An increase in the slump will increase the air content.

An increase in the ambient or concrete temperature will reduce the air content.

Excessive mixing and vibration will decrease the air content.

Any change in any of the ingredients in the concrete can affect the air content.

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