

BELL SYSTEM PRACTICES
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CONCRETE AND MORTAR

INSPECTION INFORMATION

CONCRETE

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1. CONCRETE AND CEMENT DEFINED

1.01 Concrete is a construction material composed of aggregate particles, such as sand, gravel, slag, or crushed stone, held together in a binding medium of cement and water.

1.02 The cement generally used in concrete is portland cement which is made by grinding together materials containing limestone and clay and then burning the mixture until it is on the point of melting. When the resulting clinker is pulverized and a small amount of gypsum added, the product is portland cement, which possesses the property of combining chemically with water and hardening in its presence.

1.03 Within a few hours after concrete is prepared by mixing together proper quantities of cement, water, and aggregates, the resulting mixture hardens because of the chemical reaction, generally called hydration, between the cement and the water. The aggregates are inactive ingredients merely used as fillers.

1.04 The chemical reactions which cause concrete to harden require, for completion, (a) time, (b) the presence of moisture and (c) favorable temperatures. During the process of hardening, a certain amount of the water chemically combines with the cement to become a part of the permanent solid structure of the concrete. For handling purposes, more water must be used than is necessary for the chemical processes associated with hardening of the cement. The uncombined water remains distributed within the paste and as this water slowly evaporates, the space it occupies becomes air voids. Under favorable conditions of moisture and temperature, the chemical reactions continue indefinitely which causes more of the water in the paste to become permanently combined with the cement. Thus, the strength, hardness, watertightness, and durability of the concrete, continue to improve over a considerable period of time.

2. PROPORTIONING CONCRETE

2.01 In proportioning concrete the most important factor affecting strength, watertightness, durability and other qualities is the amount of mixing water used in relation to a given quantity of cement. If this mixture of cement and water is thought of as a paste, which on hardening, binds together the various aggregate particles which are combined in making concrete, the basic principle underlying the production of good concrete may be more readily understood.

2.02 Other factors being equal, anything that affects the quality of the paste likewise affects the quality of the concrete. The quality of the paste is mainly determined by the proportions of cement and water—the more water used in addition to the ideal amount, the more the paste will be diluted causing a greater number of air voids in the concrete. The greater the number and size of air voids in the concrete, the less will be its ability to resist crushing, prevent the penetration of water, and withstand abrasion, weather and other elements that cause disintegration of concrete.

2.03 In addition to the concrete having the required strength, watertightness and durability qualifications, it must also have the quality of being workable at the time of placing. "Workability" may be considered as the ease with which fresh

concrete can be properly placed and compacted without separation of the materials. The major consideration controlling workability is the quantity of aggregate used in a concrete mixture with a given amount of water-cement paste. Another and somewhat opposed consideration affected by the proportion of aggregate to paste is that of economy—obtaining the maximum bulk of concrete from a given quantity of cement by mixing it with the greatest possible amount of aggregate.

2.04 As the proportion of aggregate to paste is increased the mixture stiffens, is accordingly less workable, and in the extreme, cannot be properly manipulated by the usual placing methods. In the opposite direction decreasing the aggregate improves workability but the yield of concrete per unit of cement is reduced and economy is adversely affected. Carried to the extreme, too little aggregate in proportion to the paste results in an over-fluid mix in which the larger size aggregates are no longer held in suspension in the mass but sink to the bottom to form stone pockets. In proportioning concrete, therefore, the objective will be to arrive at a proper compromise between economy and ease of placing without incurring the penalties associated with working toward either extreme.

2.05 As the amount of water in relation to cement is increased, the volume of cement paste available to coat the aggregate particles is greater and consequently more aggregate can be added to the mixture. The yield of concrete per unit of cement is thus increased and the mix becomes more economical. This advantage, however, is offset by the lowered quality of the concrete, since, as mentioned above, strength and other desirable characteristics of concrete are directly related to the amount of water used per unit of cement. This relation is discussed further under "Selection of Water-Cement Ratio."

3. SELECTION OF WATER-CEMENT RATIO

3.01 The term "water-cement ratio" indicates the total amount of mixing water, usually expressed in gallons, to be used per unit of cement, usually expressed in sacks. Thus if the water-cement ratio is specified as 6 for a particular job, then 6 gallons of mixing water are to be used for each sack of cement. The amount of moisture contained in the aggregates must be determined and considered as a part of the mixing water.

3.02 The selection of the proper water-cement ratio depends upon the usage that the concrete is to be subjected to, both as to strength requirements and to exposure. As stated before, the amount of mixing water used controls the strength,

watertightness, durability and other qualities of the concrete. Concrete for manholes must have high strength and watertightness qualifications and, therefore, a relatively low water-cement ratio of 6 gallons of water per sack of cement has been selected for job-mixed concrete for this type of usage. Concrete for protection of conduit generally does not require these qualities to the same degree so a higher water-cement ratio of 7-1/2 gallons of water per sack of cement has been selected for job-mixed concrete for this usage.

4. AGGREGATES

4.01 Aggregate for concrete is an inert mineral filler used with water-cement paste for economy. The aggregate particles should be clean, hard, strong, and durable. It is very important that only clean aggregates be used because dirty aggregates may lead to failure of the concrete or increase the cost. Dirt may prevent hardening of the cement or cause disintegration. It is also important that the aggregates be well graded from coarse to fine within the limits prescribed in G45.120.1. Well graded aggregates contain fewer voids to be filled with cement paste because the small particles fill the spaces between the larger particles.

4.02 In general, aggregates obtained from established plants with adequate washing and screening facilities ordinarily will ensure uniformity in grading, cleanliness and quality. A visual inspection of coarse aggregate from such sources should be sufficient to assure the inspector or supervisor that the aggregate is satisfactory. Fine aggregate requires more careful examination to check for cleanliness. However, the tests which are described in G45.210.1 should only be necessary when the fine aggregate is obtained from new sources not definitely established as being reliable.

4.03 The natural mixture of fine and coarse aggregates as taken from a gravel bank or crusher seldom is suitable for concrete unless first screened to separate the fine material from the coarse and then recombined in the correct proportion for the class of concrete being made.

4.04 Aggregates for concrete should be selected and proportioned to give the most economical results consistent with proper placing. Coarse aggregate presents less total surface to be coated with cement paste and is therefore more economical than fine aggregate. However, if the voids between the coarse particles are not filled, the mixture is harsh, usually overwet, and almost invariably results in honeycombing in the finished product. Although increasing the proportions of fine materials makes for smoother working mixes, excessive propor-

tions of fine aggregate present greater total surface areas to be coated, which may exceed the covering capacity of the available paste. These factors fix within rather narrow limits the range of proportions which can be used with economy. The proper proportions, however, vary with different aggregates and must be determined by trial in the field.

5. CONSISTENCY

5.01 The total amount of aggregate that can be used with given amounts of cement and water will depend upon the consistency required by the conditions of the job. The term "consistency" relates to the state of fluidity of the mix. Two other terms, "plasticity" and "workability" are also often used in describing the character of fresh concrete. "Plasticity" is used to describe a degree of consistency of concrete. A plastic mass does not crumble but flows sluggishly without segregation such as occurs in the more fluid mixtures. Neither the very dry, crumbly mixes nor the very fluid, watery mixes are regarded as of plastic consistency. Concrete with a low water-cement ratio is not necessarily of a stiff consistency. "Workability" as mentioned before is used to describe the ease with which concrete can be placed in a particular location. A stiff, plastic mixture with large aggregate, which is workable in a large open form, would not be workable, for example, in a thin wall with complicated reinforcement.

5.02 Mixes of a stiff consistency permit more aggregate to be crowded into the cement paste and thus give a larger volume of concrete. Stiffer mixes cost less for materials than the more fluid mixes, but the cost of handling and placing increases when excessively stiff mixes are used. The use of such mixes may also result in harshness and honeycomb. On the other hand, mixes that are over-fluid require more cement and cannot be placed without segregation of the materials. With these factors in mind, the proper proportions can be determined in the field so that the concrete will be neither harsh nor honeycombed on the one hand nor porous and filled with stone pockets on the other.

5.03 The consistency of concrete is generally expressed in terms of the number of inches that a mass of the fresh concrete will slump under specified conditions. Obviously, a mixture that is stiff will not slump as much as a more fluid mixture. The method of measuring the consistency is known as the "Slump Test" which is described in detail in G45.210.1.

5.04 The slumps recommended in G45.140.1 were selected on the basis of the use and workability required of the concrete. The inspector or supervisor should check the

slump at sufficiently frequent intervals to satisfy himself that concrete with the specified slump is being produced. The natural tendency for workmen to produce wet mixtures in order to lessen the work of placing and compacting should be carefully restrained.

6. TRIAL MIXES

6.01 Due to the variable factors affecting concrete mixtures, it is impracticable to establish a table that will give the correct quantities of cement, mixing water, fine aggregate, and coarse aggregate to produce a concrete entirely suitable for a particular job. The grading of the fine and coarse aggregates affects the amount required of each to combine with the other to obtain a well graded mixture of combined aggregates. In general, the ratio of fine to coarse aggregate will vary between 35 and 65 per cent. The finer the sand or the coarser the gravel, the lower will be the percentage of sand required. The grading of the aggregate mixture will affect the amount of the water-cement paste needed, with the finer mixtures requiring more paste. The quantity of mixing water to be added at the mixer is affected by the amount of moisture contained in the aggregates. The only proportion that remains constant in producing a concrete mix with the required strength and watertightness characteristics is the selected water-cement ratio. The particular ratio which has been adopted for a specific job should be adhered to without any significant change. Increasing the water ratio of the water-cement paste will lower the quality of the concrete. Decreasing the water proportion will also decrease the amount of aggregate that can be used with a given amount of cement, thereby causing loss of economy.

6.02 With the above factors in mind, the most desirable combination of materials to produce a workable mixture should be quickly determined in the field by trial mixes as described in G45.140.1.

6.03 A common error made by the inexperienced concrete workman is to use a larger proportion of coarse aggregate than is desirable. This condition, which should be guarded against, increases the yield of concrete but at the expense of workability and quality.

7. MEASUREMENT OF MATERIALS

7.01 After the most suitable combination of materials has been determined for the class of concrete required, the combination must be carefully maintained throughout the course of the work. Each batch of concrete should be as nearly uniform as possible in all respects with the other batches. This

requires accurate measurement of the materials and thorough mixing of the concrete.

7.02 The most accurate method of measuring aggregate materials is by weight and if weighing equipment is available this method should be used.

7.03 When moisture is added to dry sand, the sand increases in volume when measured in a loose condition. This increase in volume is called "bulking" and may be as much as 20 to 30 per cent. Further addition of water tends to decrease the volume until it is about the same as dry sand. Bulking may cause errors when sand is measured by volume and is a factor that should be considered when measurement is done by that method. Coarse aggregates are not appreciably affected by bulking.

7.04 When aggregates are to be measured by shovels, each man in the mixing crew should be required to check the number of shovelfuls he takes in handling exactly one cubic foot of material. This is done by counting the number of shovelfuls of each material required to fill a cubic foot box or a cement sack, which holds 1 cubic foot.

7.05 When aggregates are to be measured by wheelbarrows, each barrow should be marked on the inside for 1 cubic foot, 2 cubic feet, etc. This marking can be done by dumping a cubic-foot box or a cement sack full of material in the barrow, leveling and making a mark at that level. This can be repeated with another cubic foot of material, etc. until the barrow is calibrated.

7.06 Accurate measurement of mixing water throughout the duration of the job is essential. If the mixer used is equipped with a water tank and measuring device, the measuring device should be checked at regular intervals to ensure that it is operating properly. If the mixer is not equipped in this manner, an ordinary 12-quart galvanized pail marked off in gallons, one-half gallons and one-quarter gallons (quarts) may be used for measuring water.

8. MIXING

8.01 Thorough mixing is essential for high quality and uniform concrete. Inexperienced workmen are inclined to shorten the mixing time in order to increase the volume of concrete produced in a given time. The inspector or supervisor should restrain this tendency if it appears.

9. READY-MIXED CONCRETE

9.01 In general, the use of ready-mixed concrete for underground construction in localities where such concrete is available affords a convenient and economical means of obtaining concrete of uniformly good quality.

9.02 When ordering ready-mixed concrete, as much time as practicable should be allowed the supplier for delivery. Directions as to location of the job and time the delivery is desired should be explicit in order to avoid delays. For convenience, flexibility and economy, the variety of mixes employed for a particular job should be limited as much as possible. The quantity of concrete ordered should be computed carefully so enough concrete will be available to complete the section being poured. Section G40.055.1 provides tables of material quantities.

9.03 Slump tests should be made as frequently as necessary to ensure that the consistency of ready-mixed concrete falls within the limits specified. This may mean that every batch delivered should be tested, particularly if the consistency does not appear from visual inspection to be uniform. If the slump is less than that specified, the batch can usually be suitably modified as described in G45.145.1. If the slump is greater than the maximum specified, the batch of concrete may be refused. However, if the slump is reasonably close to the limit desired and the inspector or supervisor is satisfied that the specified water-cement ratio has been adhered to, he may accept the batch if it can be deposited and compacted without segregation.

9.04 Routine compression strength tests of ready-mixed concrete should not be required. Occasional checks, however, may be made to ensure that the concrete purchased possesses the qualities expected of it. This is particularly true when ready-mixed concrete is purchased from new suppliers.

9.05 When ready-mixed concrete is employed, the inspector or supervisor should make sure that the truck delivering the concrete is not loaded beyond its rated mixing and carrying capacity and also that the water measuring device on the truck is working properly.

10. CONVEYING

10.01 When wheelbarrows or buggies are used to convey the concrete from the mixer to the place of deposit, care is required to prevent segregation of the materials in the concrete. Planks should be placed for runways over rough ground. In addition, concrete so conveyed should have a consistency as stiff as the placing conditions of the job permit.

11. PREPARATION FOR PLACING

11.01 Before concrete is placed, the inspector or supervisor should check for the following items:

- (a) All forms or other places of deposit should be free from standing water or from a flow of water that would wash

away the cement paste from the concrete mixture. All debris and ice should also be removed.

(b) Manhole wall reinforcement, if any, should be placed as specified and tied securely in position. Other reinforcement should be ready for convenient installation in the manhole floor or roof as specified.

(c) Check to ensure that concrete thickness will be as specified.

(d) Forms should be thoroughly wetted (except in freezing weather) or oiled.

(e) If fresh concrete is to be placed against concrete that will have already hardened, the directions for making construction joints should be followed as outlined in G45.150.1.

12. PLACING

12.01 Concrete segregation is the separation of the coarse aggregate from the mortar and is caused mainly by movement, lateral or vertical, of the concrete mixture after it has left the mixer but before it has been placed in its final position. The more fluid the mix the more it will segregate, the coarse aggregate settling and the finer and lighter materials—particularly the water—rising. The principal results of segregation are stone pockets and porosity which may weaken the structure and will certainly allow the infiltration of water. For this and other reasons, placing the concrete in its final position is considered the most critical operation of concrete construction.

12.02 The rather common practice of depositing the concrete at one point and allowing the material to flow to distant points is one of the major causes of segregation. Another common practice causing segregation is that of allowing the concrete to drop freely into the forms for the entire depth of a manhole. Excessive puddling or tamping also causes separation of the materials. Constant supervision is required to prevent defective concrete from being formed by segregation.

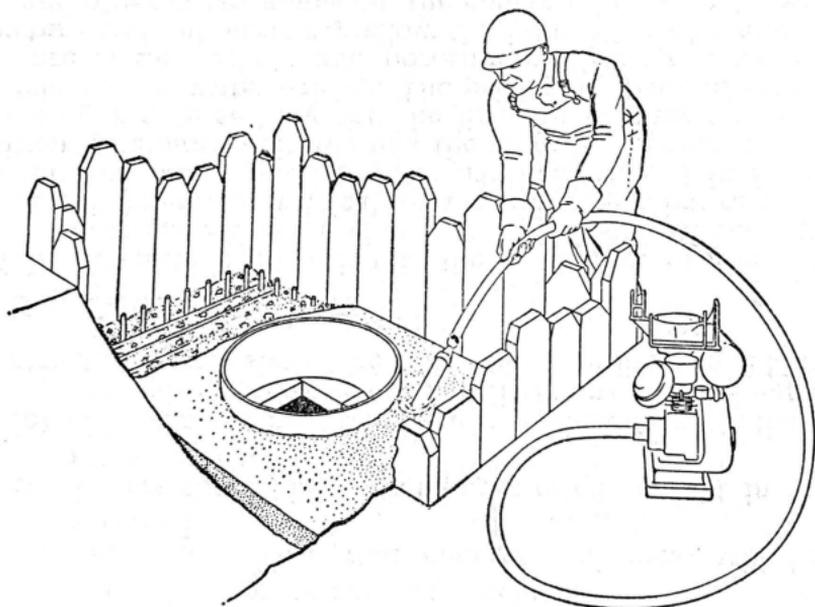
12.03 Care should also be exercised to see that the forms are completely filled with the concrete and the reinforcement well inclosed. Light spading of the concrete next to the forms will prevent honeycombing and provide a good surface.

12.04 When concrete is placed in deep layers a gradual increase in the water content of the upper portion is quite certain to result because of the increased pressure on the lower portions. The excess water should be worked to a low point, without causing a flow of water which might wash out cement. The water should then be removed. The stiffer the consistency of the concrete the less will be the tendency for water to collect on the surface.

13. VIBRATION OF CONCRETE

13.01 It has been well established that the use of high-frequency vibrators for compacting fresh concrete has many advantages over hand puddling. The greatest advantage is that concrete of much stiffer consistency can be placed and compacted economically with a vibrator. Stiffer mixtures require less mixing water and the less mixing water used the greater will be the strength of the concrete using a given quantity of cement. Viewed from the standpoint of economy, the stiffer the mix that can be efficiently placed within the limits of plasticity, the more concrete can be produced of a given strength per sack of cement.

13.02 Of the several different types of mechanical vibrators available, the internal type, which has a vibrating head that is inserted in the mass of concrete, is generally preferred for manhole construction. These may be driven either pneumatically or by means of a flexible shaft and should have a frequency of at least 3600 impulses per minute when operating under load. A typical vibrator of the internal type is illustrated below :



13.03 The operator should be cautioned against over-vibration and the use of the vibrator to redistribute concrete improperly placed in the forms. Excessive use of the

vibrator will result in concentration of coarse aggregate at the bottom and of fine aggregate and water at the top. Attempts to use the vibrator to shift masses of concrete laterally may cause separation of mortar from the coarse aggregate and produce honeycomb. Concrete having a slump of more than 5 inches should not be vibrated.

13.04 As the concrete of the walls is placed, each layer deposited should be vibrated thoroughly before the succeeding layer is placed. While in operation, the element of the vibrator should be inserted in the concrete vertically and slowly withdrawn at regular intervals 18 to 30 inches apart. Usually, vibration periods of from 5 to 15 seconds per point of insertion are sufficient. The correct period can be gaged to some extent by the surface movement and texture of the concrete and by the appearance of cement paste where the concrete is in contact with nearby forms or reinforcing. The entire depth of each new layer should be vibrated, and ordinarily the vibrator should penetrate the layer below for several inches to ensure thorough union of the layers.

13.05 In shallow concrete, as in the floors and roofs of man-holes, some consolidation can be obtained by using the vibrator in a horizontal position, although care must be exercised not to displace any reinforcement in the process. Thorough consolidation is equally as important in shallow slabs as it is in deep, narrow walls, but because the work is more accessible, adequate compaction can readily be obtained by ordinary spading methods.

14. CURING OF CONCRETE

14.01 As stated in Paragraph 1.04, the chemical reactions which cause concrete to harden require for completion, (a) time, (b) the presence of moisture and (c) favorable temperatures. In order to provide favorable conditions for this hardening or "curing", the procedures outlined under this subject in G45.150.1 should be followed. Usually, it will be sufficient to protect only the concrete in manhole roofs or pavement replacement against loss of heat or moisture.

15. REMOVAL OF FORMS

15.01 Forms must never be removed until it is certain that the concrete has hardened sufficiently to be self-sustaining. Low temperatures retard the hardening processes of concrete, and, therefore, in severe weather it may be necessary to increase the minimum periods for removal of forms, as specified in G45.150.1.