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A Treatise on Concrete

CHAPTER I

ESSENTIAL ELEMENTS IN CONCRETE CONSTRUCTION

The forming of concrete structures is essentially a manufacturing operation, and requires more close attention to detail both in the design and the building than most other classes of construction. For the benefit of those who are not thoroughly experienced, a number of the most essential elements are recorded below with references to pages upon which more detailed information may be obtained.

General properties of materials and of concrete are outlined in Chapter Ia on Concrete Data, and Chapter II, page 11, gives in elementary form an outl ne of the process of concreting.

CEMENT

	PAGE
Except for unimportant structures, the cement should be sampled and tested in a laboratory	63
Even if not tested, cement should be purchased with the requirement that it must pass the specifications of the American Society for Testing Materials	29
Portland cement is the only cement that can be used for all kinds of concrete work	12

SAND

Tests of the sand, unless it comes from a bank which has been previously tested, are as necessary as tests of the cement	159
Even a small amount of vegetable matter in sand prohibits its use	154b
Fine sand, even if free from vegetable matter, makes a much weaker concrete than coarse sand. If it is necessary to use fine sand, therefore, the proportion of cement should be increased	136, 159a
If the grains are mostly less than $\frac{1}{32}$ inch diameter, nearly double the amount of cement should be used than with an equally clean sand having mixed grains running up to $\frac{1}{4}$ inch, in order to obtain equal strength	159a
For unimportant work, fine sand, if clean, may sometimes be used, but it is usually cheaper to import a coarse sand and use leaner proportions	149, 159a

COARSE AGGREGATE

PAGE

The maximum size of the stones should be such that the concrete is readily placed around the steel reinforcement and into the corners of the forms. For reinforced concrete a maximum size of one inch is frequently specified.......... 34

If the stone contains dust, it must be uniformly distributed throughout the stone, and the proportion smaller than ¼ inch should be determined by test and considered as sand when proportioning.. 34

Soft stone should be avoided in important structures.......... 390

Gravel, if used, must be clean; that is, the particles must be free from coating of vegetable matter or clay which will retard the setting or prevent the cement from sticking to the pebbles... 34, 386

Gravel can be washed satisfactorily only with special apparatus.... 250

REINFORCEMENT

All steel should be subject to the bending test.......... 415

Steel must be placed in exact position called for on plans.......... 37

Steel must be fixed in place so that it cannot be moved during the process of concreting.......... 37

Round steel can be safely used in reinforced concrete since with proper imbedment the concrete adheres to it with sufficient bond to develop the full strength of the steel at its elastic limit....... 461

Square and flat bars do not bond as well as round.......... 463

Deformed bars, that is, bars with irregular surfaces, are especially useful where the stress [illegible]s off rapidly, as in footings...... 463, 645, 670

Deformed bars are also advantageous for temperature reinforcement 500

Structural steel, like T-bars and I-beams, are not so good for reinforcement as plain round or deformed steel bars.......... 465

Structural steel may be used in columns either to take the entire load with concrete around it for protection, or else to act with the concrete. Although generally less economical than plain bars, it may permit smaller sized columns.......... 497

High carbon steel, if of satisfactory quality and thoroughly tested, may be used with a higher working stress than mild steel...... 38, 414

High carbon steel, unless of special quality, is apt to be brittle, and should not receive higher working stress than mild steel....... 413

Steel will not rust if completely surrounded with concrete of a wet consistency.......... 327

Changes in temperature will not cause separation of steel from the concrete.......... 287

PROPORTIONING, MIXING AND PLACING

PAGE

Proportions must be accurately measured.......... 251

Mixing must be thorough; concrete is improved by long mixing.... 251

Machine mixing is better than hand mixing.......... 255, 372

Enough water must be used in reinforced concrete so that the mass will just flow sluggishly around the steel to thoroughly imbed it. 36, 280

For foundations of mass concrete, a jelly-like mass which will shake when being rammed is best.......... 36, 280

If concrete stiffens in barrows or in mixer it indicates that the cement has a "flash" set and it should not be used.

If cement with a flash set has been used inadvertently the concrete must be soaked with water until it hardens.

Old and new concrete must be bonded for tight work....... 37, 284, 338

Joints in floor construction should be made in center of span...... 37a, 284

Surface treatment must be skillful, roughening is usually best...... 288

Plastering on external surfaces should be avoided.......... 288

FORMS

Forms must be braced securely to avoid being thrown out of line by the concrete or by the workmen.......... 19, 37, 294

Struts and braces supporting the forms must be strong enough to withstand the weight of the concrete above it and also a construction load of 50 to 75 pounds per square foot.......... 294, 617

Boards and planks need but few nails unless the forms are built so that the pressure tends to separate them from the cleats..... 620

Forms should be tight enough to prevent mortar flowing away and leaving unsightly stone pockets.......... 37, 623

Forms should be thoroughly cleaned of all dirt and chips before laying concrete. A steam hose is effective for this purpose.... 36

Column forms should be made with cleanout opening in lower end.

Forms cannot be straightened or lined up after concrete is placed 295

Wall forms usually may be removed in 24 to 48 hours.......... 296

Forms supporting reinforced members should be left in place until the concrete rings sound and is not readily chipped by a blow from a pick. In mild weather 1 to 4 weeks is usually sufficient, according to the character of the member.......... 296

Great caution must be used in cold weather, as the concrete sets slowly; sometimes the forms must remain until warm weather.. 296

If dead load, that is, weight of the concrete itself, is large, the forms must be left longer for concrete to attain sufficient strength..... 296

PAGE

Earth must not be backfilled against a wall until it is 3 to 4 weeks old unless forms are left in place and braced................ 620

DESIGN

Reinforced concrete should be designed by experienced engineers.. 702

Bending moments must be selected for individual conditions....433, 439

Neither steel nor concrete must be overstressed in any part.... 418, 420

A T-beam must be deep enough to prevent overstressing concrete in the flange... 424

Width of flange of T-beam is limited by span and thickness of slab.. 423

Steel must be placed across the top of a girder............ 422, 443

A continuous beam or slab must be designed at its support to resist negative bending moment. This requires as much steel at the top over the support as at center of member in the bottom... 428

Provision must be made for compression in the bottom of a continuous beam or slab at the support.............................. 428

Shear in a T-beam must be studied to see that the stem is large enough 424

Vertical or inclined steel is usually necessary to resist diagonal tension. 445

Bars must be small enough to resist the bond stress.............. 457

Ends of bars must be imbedded far enough to provide bond sufficient to prevent danger of pulling out............................ 464

Columns may be reduced in size by using rich proportions, vertical reinforcement, hooping, or a combination of these............ 489

Hooping serves to increase the toughness of the column............ 492

The working strength of a hooped column, however, must *not* be based on its ultimate crushing strength............................ 495

ESTIMATING.

Cost of materials is readily estimated from the quantity used....24, 231

Cost of labor of mixing, and placing concrete can be estimated with close approximation.................................... 24, 25

The cost of forms and incidental expense are the most difficult items to correctly estimate and vary largely with surrounding conditions. For this reason, estimates for reinforced concrete must be based upon very accurate data and large experience.......... 26

CHAPTER I*a*

CONCRETE DATA

DEFINITIONS

SEE PAGE

Aggregate is the inert material, such as sand, broken stone, etc., with which the cement or other adhesive material is mixed to form concrete or mortar. The term is sometimes erroneously applied to the coarse material, such as broken stone, only.

Akron Cement is a Natural cement from the vicinity of Akron, N. Y. 49

Beton is the French word for concrete.

Beton-Coignet is a mixture of hydraulic lime, cement, and sand.... 42

Concrete* is an artificial stone made by mixing cement, or some similar material — which after mixing with water will set or harden so as to adhere to inert material, — and an aggregate composed of hard, inert particles of varying size, such as a combination of sand or broken stone screenings, with gravel, broken stone, cinders, broken brick, or other coarse material.

Concrete Rubble is masonry of large stones, usually of derrick size, with joints of concrete instead of mortar...................... 296

Density represents the ratio of the sum of the volumes or mass of the particles, or absolutely solid substance, of a material contained in a measured unit volume to the total measured unit volume.. 138*a*

Granolithic is concrete consisting of Portland cement and fine broken stone or sand troweled to form a wearing surface............ 600

Grappiers Cement (*Ciment de grappiers*) is made in France from particles which have escaped disintegration in the manufacture of hydraulic lime.. 50

Hydrated Lime is specially prepared powdered slaked lime........ 53

Hydraulic Lime contains lime and clay in such proportions that it hardens under water.................................... 52

James River Cement is a Natural cement from the James River Valley 49

Laitance is decomposed cement formed in the presence of an excess of water.. 302

Laitier Cement (*Ciment de laitier*) is the French name for Puzzolan or slag cement.. 50

*Also applied to mixtures of an aggregate with a material such as asphalt — which liquefies on application of heat.

SEE PAGE

Lime of Teil (*Chaux du Teil*) is a celebrated hydraulic lime of France 52

Louisville Cement is a Natural cement from the vicinity of Louisville, Ky. 49

Mortar is a mixture of cement or lime and sand or other fine aggregate having water added so as to make it like a paste.

Natural Cement is made from natural rock containing the required constituents in approximately uniform proportions.......... 49

Parker's Cement is a term sometimes used in England for Natural or Roman cement 49

Paste is a mixture of neat, *i.e.*, pure, cement or lime with water.

Portland Cement is made from an artificial mixture of materials containing lime and clay.......... 48

Puzzolan Cement is a mechanical mixture of slaked lime with blast furnace slag, or with natural puzzolanic matter, such as volcanic ash.......... 50

Reinforced Concrete is concrete in which steel is imbedded to increase its strength.

Roman Cement is the English name for Natural cement.......... 49

Rosendale Cement is a Natural cement from the Rosendale District in eastern New York State 49

Rubble Concrete is concrete in which large stones are placed.......... 296

Sand Cement or **Silica Cement** is a mechanical mixture of Portland cement and fine sand.......... 42

Slag Cement is the name sometimes given to Puzzolan cement.... 50

Vassy Cement (*Ciment de Vassy*) is a common French Natural cement 49

Voids are the spaces throughout a mass of concrete, mortar, or paste that are filled with air or water.......... 135

WEIGHTS AND VOLUMES

Portland Cement weighs per barrel, net..........	376	lb.	29
" " " " bag "	94	"	29
Natural Cement weighs per barrel, net..........	282	"	31
" " " " bag, net	94	"	31
Cement Barrel weighs from 15 to 30 lb., averaging about	20	"	
Portland Cement is assumed in standard proportioning to weigh per cubic foot..........	100	"	217
Packed Portland Cement, as in barrels, averages per cubic foot about	115	"	219
Packed Portland Cement based on 3.5 cubic feet barrel contents weighs per cubic foot	108½	"	

SEE PAGE

Loose Portland Cement averages per cubic foot about ...	92	lb.	219
Volume of Cement Barrel, if cement is assumed to weigh 100 lbs. per cubic foot	3.8	cu.ft.	217
American Portland Cement Barrel averages between heads about	3.5	" "	218
Foreign Portland Cement Barrel averages between heads about	3.25	" "	219
Natural Cement Barrel averages between heads about	3.75	" "	
Weight of Paste of neat Portland cement averages per cubic foot about	137	lb.	376
Volume of Paste made from 100 lb. of neat Portland cement averages about	0.86	cu.ft.	229
Volume of Paste made from one barrel of neat Portland cement averages about..........	3.2	" "	229
Weight of Portland Cement Mortar in proportions 1:2½ averages per cubic foot	135	lb.	
Weight of Concrete and Mortar varies with the proportions as well as with the materials of which it is composed			362
Weight of Portland Cement Concrete per cubic foot....			611
Cinder Concrete averages	112	"	
Conglomerate Concrete averages..........	150	"	
Gravel Concrete averages..........	150	"	
Limestone Concrete averages..........	148	"	
Sandstone Concrete averages	143	"	
Trap Concrete averages	155	"	
Loose Unrammed Concrete is 5% to 25% lighter than concrete in place, varying with the consistency			277

CEMENT TESTING FOR SMALL PURCHASERS

Soundness. A sound cement will not go to pieces on the work. The test is therefore of greatest importance, and is often the only one necessary. Take about ½ pound, or one cupful, of Portland cement and mix by kneading 1½ minutes with sufficient water to form a paste of a consistency like putty. Press portions of the paste on to 3 pieces of window glass 4 inches square, so as to make 3 pats each about 3 inches in diameter and ½ inch thick at center tapering to a thin edge, and place in moist air for 24 hours. Then keep one pat in air at moderate temperature (about 60° or 70° Fahr.) for 28 days, keep second pat in water for 28 days, and place third pat in loosely closed vessel over boiling water and keep there for five hours. Reject cement if any pats show radial cracks or curl or crumble. The air pat should not change color. Portland cements may be accepted on the steam test alone if time is limited. Natural cements should be subjected to water and air but not to steam. (See p. 79.)

Fineness. The finer the cement of a certain class the higher is its value. Sift 5 ounces of dry cement containing no lumps through a sieve about 6 to 8 inches diameter with 100 meshes per linear inch. Not more than ½ ounce of either Portland or Natural cement should remain on sieve. To compare quality of two brands otherwise similar, sift through a 200-mesh sieve and choose the finer cement. (See p. 67.)

Setting. A quick-setting cement is difficult to handle on the work and a too slow setting cement delays removal of forms. If a Vicat needle cannot be obtained for testing, use the Gillmore needles, — two steel rods, one, one-twelfth inch diameter at its end, loaded to weigh ¼ pound, the other, one-twenty-fourth inch diameter loaded to weigh 1 pound. A pat of pure Portland cement paste made like the soundness pat must not be able to support the weight of the lighter needle until 30 minutes after mixing, and must support the heavier needle in less than 10 hours. A paste or mortar or concrete has reached its final set when it will support a pressure of the thumb without indenting. (See p. 70.)

Purity. "Provide a glass-stoppered bottle of muriatic acid, two shallow white bowls or two ½-inch by 6-inch test tubes, a glass rod, and a pair of rubber gloves. Put in a bowl or a tube as much cement as can be taken on a nickel 5-cent piece; moisten it with half a teaspoonful of water; cover with clear muriatic acid poured slowly upon the cement while stirring it with the glass rod. Pure Portland cement will effervesce slightly, and will give off some pungent gas and will gradually form a bright yellow jelly without any sediment. Powdered limestone or powdered cement-rock mixed with the pure cement will cause a violent effervescence, the acid boiling and giving off strong fumes until all the carbonate of lime has been consumed, when the bright yellow jelly will form. Powdered sand or quartz or silica mixed with cement will produce no other effect than to remain undissolved as a sediment at the bottom of the yellow jelly. Reject cement which has either of these adulterants."* (See p. 65.)

Tensile Strength. The tensile test is frequently unnecessary with a standard brand of cement employed in ordinary construction. Neat Portland cement should test at least 500 pounds in 7 days and 600 pounds in 28 days. Mixed with three parts standard sand by weight, it should test at least 150 pounds in 7 days and 200 pounds in 28 days. (See p. 30.)

*Judson's City Roads and Pavements, 1902.

Specific Gravity. The test requires delicate apparatus and is seldom necessary. Specific gravity of Portland cement should exceed 3.1. (See p. 30.)

Magnesia must not exceed 4%. (See p. 30.)

Sulphuric Anhydride must not exceed 1.75%. (See p. 30.)

Color is no indication of quality. (See p. 113.)

Weight is no indication of quality. (See p. 114.)

PROPERTIES OF SAND AND SCREENINGS

SEE PAGE

Sharpness of grain is not necessary 154a

Quality of sand is chiefly dependent upon the coarseness and relative coarseness of its grains 147

Clay or **Loam** in sand is sometimes injurious to mortars because introducing too much fine material, while in other cases it may be beneficial because the fine material is needed 154a

Specific Gravity of dry sand may be taken at 2.65 163

Voids in sand cannot be accurately determined by pouring water into it, but can be found by weighing the sand and finding its moisture 165

Comparison of Sands cannot be made by a study of voids because of the effect of varying degrees of moisture 177

Moist Sand measured loose is lighter in weight than loose dry sand .. 176

Coarse Sand requires less water than fine sand, and when mixed with cement makes a denser mortar 216

Fine Sand with grains of uniform size weighs nearly the same when dry and has nearly the same percentage of voids as screened coarse sand. Fine sand with ordinary moisture is, on the other hand, lighter and more porous than coarse sand 170

Mixed Sand usually weighs more and contains a smaller volume of voids than coarse or fine sand 171

PROPERTIES OF COARSE OR MIXED AGGREGATE

Equal Spheres if symmetrically piled in the theoretically most compact manner would have 26% voids, but by experiment it is found that in practice it is impossible to pile them so as to get below 44% voids 169

Voids are approximately equal in the different portions of a dry material which has been screened to uniform sizes 170

Smallest Percentage of Voids occurs in a mixture of sizes so graded that the voids of each size are filled with the largest particles which will enter them 171

STRENGTH OF CONCRETE AND MORTAR

REINFORCED CONCRETE

SEE PAGE

Cinder Concrete requires a low percentage of steel.............. 515

Rods should be Imbedded a proper length in each direction, and also, if possible, anchored.................................. 465

WATER-TIGHTNESS OF CONCRETE AND MORTAR

Excess of Cement increases water-tightness.................... 339

Aggregates should be carefully proportioned and graded......... 339

Clean Gravel is better than broken stone for water-tight concrete.. 339

Quaking or Wet Consistency produces best results................ 338

Lay Concrete in one continuous operation......................... 338

Layers of Waterproof Material are sometimes necessary........... 343

EFFECT OF SEA WATER

No Cement or other hydraulic product has yet been found which presents absolute security against the decomposing action of sea water.. 309

Fine Sand must never be used in sea water construction........... 316

Density and imperviousness are essential qualities for concrete or mortar designed to resist sea water.......................... 316

Sulphates are the most injurious compounds in sea water.......... 310

Aluminum should be low in Portland cement used in sea water 312

Lime should be as low as possible in cements used in sea water..... 313

Puzzolanic material is a valuable addition to cement for sea water construction.. 313

Gypsum, for regulating the time of setting, may be added only in smallest possible quantity to cements which are used in sea water 310

EFFECT OF FREEZING

Natural Cements may be completely ruined by freezing............ 320

Setting and **Hardening** of Portland cement in concrete or mortar is retarded by freezing.. 321

Ultimate Strength of Portland cement concrete and mortar appears to be but slightly, if at all, affected by freezing................ 321

Thin Scale is apt to crack from the surface of walks or walls which have been frozen.. 320

Heating the **Materials** hastens setting and retards the action of frost. 323

Salt Lowers the freezing point.................................. 323

FIRE AND RUST PROTECTION

SEE PAGE

Mix Concrete Wet to render it impervious........................ 329

Protection of Steel requires ½ inch to 2 inches of concrete.......... 333

Cinders do not corrode metal.................................. 329

DATA ON HANDLING CONCRETE

Average load of broken stone or gravel for wood wheelbarrow . 2.4 cu. ft.

" " " sand for wood wheelbarrow.................. 2.5 " "

Large load of broken stone or gravel for iron wheelbarrow on short haul in concrete work .... 3.0 " "

Large load of sand for iron wheelbarrow on short haul in concrete work .... 3.5 " "

Average load of ordinary concrete* for iron wheelbarrow .... 1.9 " "

Large " " " " " " " .... 2.2 " "

Number of shovelfuls of concrete per barrow in average load .. 13

" " " " " " " " large " " .. 15

Average net time of one man filling wheelbarrow with concrete, 1⅓ min.

Quick " " " " " " " " " 1 "

Average quantity concrete* mixed, wheeled 50 ft., and rammed, per man, per day of 10 hours†....................... 2.2 cu. yd.

Large quantity concrete* mixed, wheeled 50 ft. and rammed, per man, per day of 10 hours†........................ 3 " "

Average quantity concrete* laid as above with a gang of 15 men per day of 10 hours† .... 33 " "

Large quantity concrete* laid as above with a gang of 15 men per day of 10 hours† .... 47 " "

Approximate average quantity of concrete* leveled and rammed in 6-inch layers, per man, per day of 10 hours.......... 11 " "

Approximate large quantity of concrete* leveled and rammed in 6-inch layers, per man, per day of 10 hours.......... 16 " "

Approximate average surface of rough braced plank form built and removed by one carpenter per day of 10 hours ...... 25 sq. "

CHANGING FOREIGN TO AMERICAN MEASURES

To convert values of kilograms per square centimeter to pounds per square inch, multiply the former by 14.2 (more exactly 14.2234).

To convert values of pounds per square inch to kilograms per square centimeter, multiply the former by 0.07 (more exactly, 0.07031).

*All measurements of concrete are reduced to terms of quantity in place after ramming.

†Note that the leveling and ramming, but not the labor on form, are included in this item.

To convert values of pounds per square inch to tons (2,000 lb.) per square foot, divide the former by 14 (more exactly 13.89).

To convert Centigrade to Fahrenheit temperatures, multiply the former by 1.8 and add 32° to the product.

To convert Fahrenheit to Centigrade temperature, deduct 32° from the former and divide by 1.8.

One millimeter = 0.0394 inch
One centimeter = 0.3937 "
One meter = 39.37 inches or 3.281 feet
One square centimeter = 0.155 square inch
One " meter = 10.764 square feet or 1.196 square yards
One cubic centimeter = 0.061 cubic inch
One " meter = 35.31 cubic feet, or 1.308 cubic yards
One liter = 61.02 cubic inches or 0.0353 cubic foot, or 1.057 U. S. liquid quarts or 0.2642 U. S. liquid gallon
One gram = 0.0353 avoirdupois ounce
500 grams = 1.1 pounds avoirdupois
One kilogram = 2.2046 pounds avoirdupois
One tonne or metric ton = 2204.62 pounds or 1.1023 tons (of 2,000 lb.)
One English penny = $0.0203
One " shilling = $0.2433
One " pound = $4.8665
One French franc = $0.193
One German mark = $0.238

CHAPTER II

ELEMENTARY OUTLINE OF THE PROCESS OF CONCRETING

This chapter is not written for experienced civil engineers and contractors, nor for those who desire to make a scientific study of methods and principles. On the contrary, it is merely an elementary outline, indicating to the inexperienced the various steps which must be taken with this class of masonry. In subsequent chapters the various divisions of the subject are treated in detail.

The question as to whether concrete is preferable to some other form of masonry may often resolve itself into a question of cost. The cost, in turn, is dependent upon the character of the structure, the rate of labor and the price of the various materials entering into the work. Portland cement concrete has been laid in large masses at as low a price as $3 per cubic yard, while for thin walls built under disadvantageous conditions the cost of constructing molds may cause it to run as high as $30 per cubic yard, and in the case of ornamental work even above this. Before estimating the cost in any case, the materials must be chosen and the relative proportions of the ingredients determined from a consideration of the design of the structure.

WHERE CONCRETE MAY BE USED

By far the largest proportion of Portland cement concrete is laid in heavy foundation work and in other structures, such as tunnels and subways, below the surface of the ground. It is peculiarly adapted for foundations of engines or machinery, heavy walls, piers, etc. In the former the concrete is often carried all the way up to the base of the engine or machine, instead of being topped with brick or stone. It is widely used for sidewalks or floors upon the ground level, and for suspended floors. When suitably reinforced with steel, it furnishes probably the most economical and effective material for fire-proof construction. Its use for walls of buildings is largely increasing, but on account of the very indefinite time required in the building and moving of forms the cost may largely exceed the original estimate unless the builder is experienced in this class of work. Under favorable conditions, however, a 6-inch wall of concrete will cost no more, and usually less, than a 12-inch wall of brick work, and will be