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RE-ENFORCED CONCRETE.*

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Owing to lack of time to prepare a formal paper, the speaker will confine himself to some remarks on the practical phases of this subject, hoping that the discussion may bring out new and useful points.

This material has been called by various name, *e. g.*, armored concrete, concrete steel, ferro-concrete, and steel concrete, but recent authors generally prefer the term, re-enforced concrete, which is doubtless the most appropriate of any.

Re-enforced concrete is generally made from a combination of Portland cement, water, sand and gravel or broken stone in which are embedded iron or steel bars in such a manner as to re-enforce the concrete, especially where the structure is subjected to tensile stresses. Portland cement mixed with sand and water makes an excellent paint for preserving iron or steel, adhering to the metal very firmly and protecting it thoroughly against corrosion. It can easily be made water tight, and its durability is beyond question. These properties of cement mortar can be utilized in re-enforced concrete. This material is well adapted for moulding into a monolithic structure, which does not disintegrate when subjected to shocks such as are produced by railroad trains and vibrates much less for a given load than structural steel. Correctly designed re-enforced concrete structures are not liable to sudden failures, as is the case with ordinary concrete, but gives warning by the falling off of the surface concrete long before the point of failure is reached.

The writers on the theory of re-enforced concrete differ quite widely in their views, but it is hoped that many of the points of difference may be settled by a committee which has been appointed by the American Society of Civil Engineers to investigate the subject in connection with the Engineering Congress.

*Meeting of Structural Section, November 22, 1904.

In Europe various public authorities have investigated re-enforced concrete and laid down rules governing the design and materials for structures of re-enforced concrete. The regulations of the Prussian Government are very conservative. The Swiss Government rules for design are based on the method of Ritter, a well known authority on the subject. There are no uniform rules for design in France; each constructor uses his own methods. New York and Philadelphia are about the only cities in the United States that have formulated any reasonably definite rules on the subject. These rules are incorporated in the building laws and, in the light of well known facts, appear unnecessarily severe.

The speaker feels that the materials and workmanship are the most important considerations in re-enforced concrete construction, and it is essential that they be as nearly perfect as it is at all practicable to make them.

For Portland cement the standard specifications of the Am. Soc. C. E. or those of the U. S. army engineers are good and insure good cement. This is the most important material, as it is that which binds the other materials together, and upon the firmness with which they are bound together depends the strength and durability of the structure. The speaker would call your attention to the boiling test, which is found in some specifications and is sometimes abused. This should be carefully done with clean water free from mud, acid or alkali. If it boils too violently it is liable to break the pat of cement. For that reason the speaker prefers the steam test, which is believed to be fully as efficient a test to determine constancy of volume.

The purity and cleanliness of the aggregate are very important points. Good clean gravel is good, but it is impossible to make good concrete from the gravel that is commonly used in this city dredged from the Pittsburgh harbor and containing large quantities of oil, mud, coal, sewage, etc. Gravel must be thoroughly washed and promptly rejected if it contains oil. Cement will not adhere to anything that is oily. Crushed limestone is good, if it is strong, but it must be always borne in mind that no concrete is stronger than the aggregate of which it is composed. Crushed Beaver valley sandstone is good, but is not very strong in tension. Broken stone makes a stronger concrete than gravel

and for re-enforced concrete the speaker prefers an aggregate that will pass a three-quarter inch sieve. Small aggregates tamp better around the steel re-enforcement. Cleanliness and purity in the sand is at least as important as in the aggregate. The speaker is strongly of the opinion that sand for re-enforced concrete should be graded and regulated much as is done abroad. Concrete is like any other manufactured article, it is impossible to obtain satisfactory results without first-class materials properly put together. The French seem to have taken the lead in grading sand for mortars. M. Feret, chief of the laboratory Ponts et Chaussees at Boulogne, has recently published the results of some tests in which the sand and aggregate were carefully graded. In these tests everything that is retained on a 5 millimeter (2 inch) sieve is graded as aggregate. Everything that passes a 5 millimeter mesh sieve and is retained on a 2 millimeter mesh sieve is graded as coarse sand; all between two millimeters and one-half millimeter (.02 inch) in size is graded as medium sand and everything finer than that as fine sand. His tests indicate that coarse sand makes a considerably stronger mortar than medium sand, and still stronger than fine sand, that a mixed grade of sand makes the mortar stronger yet, and that the maximum of strength is obtained when the sand is of the coarse and fine grades exclusively, the quantity of the former being double that of the latter.

The proper proportion of the ingredients will depend upon the nature of the work. Water tight work requires a large proportion of cement, and the greater proportion of cement the greater the compressive strength.

The speaker is of the opinion that the usual method of specifying the proportions of the ingredients of concrete—entirely by volume—is erroneous. He thinks the cement should be specified by weight and the other ingredients by volume. He knows of a contract in which the engineer specified a certain number of barrels of cement to the cubic yard of sand, etc. The question as to whether packed barrels or loose barrels were meant was decided in favor of the contractor, who thus saved 800 barrels of cement in a very small contract.

The strength of concrete depends largely on the strength of the mortar which it contains, therefore the proportions of sand,

cement and water should be determined first. The maximum strength of the concrete will be obtained when the mortar just fills the voids in the aggregate, but on account of the impossibility of obtaining absolutely perfect mixing, the mortar must be in excess; in fact, to make a concrete absolutely free from voids, about 40 per cent. excess mortar is needed.

Concrete is usually made so wet as to be sloppy. This is done to reduce the amount of ramming necessary, but it is not the best practice. It gives the cement a tendency to work to the top, and the aggregate to settle. This is peculiarly objectionable in columns. Wet concrete, however, is almost a necessity in re-enforced concrete on account of the practical impossibility of properly ramming dry concrete around the re-enforcements. It is, therefore, usual to use a plastic concrete and a large margin of safety in the design. The French determine the proper consistency of mortar for concrete work by specifying that if a sample of mortar be taken out five minutes after mixing, its appearance must not change on standing three minutes longer. Another method is to place some mortar on a trowel and drop it off; if it falls off clean it is wet enough. Another method is to mould a ball of mortar gently in the hand; water should just appear on the surface of the ball. Still another method is to drop the ball twenty inches onto a hard surface; the ball should retain its shape.

For re-enforcement the speaker is in favor of using a medium open-hearth or Bessemer steel such as is used for ordinary structural steel work. Some use a very high carbon steel, but he is not in a position to indorse it.