to be attained. The cost of good and sufficient inspection is low, in the light of the guaranties assured and the benefits derived.

The writer takes pleasure in recommending to any person interested in obtaining concise and dependable information on "The Design and Construction of Concrete Pavements," the booklet published by the Portland Cement Association under that title. It will be found to set forth briefly and completely, and in a practical and sensible manner, all of the information that is required to design a concrete pavement in a fundamentally correct way.

SCIENTIFIC CONTROL OF STREET PAVING MATERIAL

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I shall not attempt at this time to outline or discuss in any way the merits of the various methods of scientifically controlling paving materials. Whether the materials are controlled by weight, volume, specified modulus of rupture or compressive strength, or otherwise, depends upon the engineer and the locality where the construction is proposed. It is my intention merely to try to prove the important fact that scientific control of paving materials in some way is the only guarantee to the engineer that he has determined by a practical method some definite fair value of this paving product, in comparison to its cost. Merely to specify the mix determines no fair value in relation to its cost. This subject, as outlined, would therefore be better understood if titled "Practical Control of the Street Paving Dollar."

Very few cities have attempted scientifically to control paving materials in any way. The application of such control in its fullest extent to street and alley construction presents problems unlike those encountered in county and state highway construction. Its application in the cities in some cases demands a drastic change in the paving industry, as well as changes in the relation of the engineer to the contractor. Indianapolis specifies a minimum strength of concrete, requiring 2000 lbs. per square inch compressive strength for foundation pavements and 3500 lbs. per square inch compressive strength for standard concrete pavements before acceptance. By this method we are attempting to control scientifically the paving materials in a practical way. This specification has been in force for the last three years.

In determining a definite quality of concrete, a certain value naturally is placed thereon, which in my estimation is eliminat-
ing an enormous waste which had taken place preceding the adoption of this specification. Statistics proved that the majority of the loss or waste, in not procuring fair value for this product, was due to the ignorance of all those concerned in not combining materials properly to secure the highest quality finished product. The facts presented at this time, regarding the control of paving materials as applied in Indianapolis, are given in relation to high compressive strength concrete only. Four or five thousand cylinders have been tested and the results obtained are used in presenting this report.

The materials are controlled on our paving projects by a practical method requiring practically no equipment except what is used on most paving projects in the country. The results obtained were secured by assisting the contractor educationally in procuring high-strength concrete. Much of the credit for the results obtained during the last three years must be given to our City Civil Engineer, Mr. A. H. Moore, and the testing laboratory, under the supervision of Mr. C. H. Underwood and his assistant, Mr. A. S. Burns. Both the laboratory engineers, being very capable of maintaining proper control of materials in concrete, have always aided the contractor in eliminating defects or poor workmanship resulting in defective concrete. All materials have been tested and all cylinders moulded as recommended by the A.S.T.M. Until last year, cylinders were cured in the laboratory for 28 days before testing. Now contracts are accepted if 14 day tests are above the minimum strength required.

The progress made in securing better concrete in Indianapolis during the last five or six years will be outlined by giving test results and general precedence. During the years 1925, 1926, and 1927 moulded concrete cylinders were completed as the work progressed on all projects and later tested for compressive strength. The defective cylinders were analyzed, and the engineer immediately investigated the conditions on these particular projects and ordered necessary changes to eliminate the failures if possible. A continual check was made on these concretes until the quality of the concrete was satisfactory. No specified strength was required during these three years and the testing reports served merely as a source of information to the engineer as to the quality of concrete being produced. However, numerous changes were made regarding specifications, and the contractor was educated as to the importance of water control, proper proportioning, and proper grading of materials. The old chute-type mixer became obsolete; accurate measuring devices were insisted upon. Strike-off batchers and timers were required on all types of mixers. The results obtained from tests completed during the years 1925, 1926, and 1927, when strength was not specified as compulsory in the specifications, were as follows:
Average compressive strength of all cylinders tested for concrete foundations was 25% over the minimum which is required today. Thirty-two per cent of the cylinders were below the minimum. The average compressive strength of all cylinders tested for standard concrete pavements, including alleys, was 10% under the minimum now required.

Minimum Strength Specifications

Since the year 1928, specifications requiring a minimum compressive strength of concrete on all paving projects before acceptance have been in force. The following results show an enormous increase in the quality of concrete placed in the city streets of Indianapolis during the last three years. The average compressive strength of all concrete tested for foundation is now 40% above that required. The percentage of cylinders which tested below the minimum now required is 5 1/2%. The average compressive strength of cylinders representing standard concrete pavements, including alleys, is now 20% above the minimum required, and the percentage of cylinders tested which were below minimum required is now but 8%.

It seems hardly possible that such an increase in the quality of concrete could take place without any increase in cost to the contractor. Although the laboratory engineering force and equipment were increased, it is not difficult to estimate the enormous dividends the city laboratory has paid the taxpayers during the last three years. Analysis of the yearly reports shows that the compressive strength of concrete being placed today specifying 1.18 barrels per cubic yard is as high as the concrete produced in 1927 which specified a mix of approximately 1.50 barrels per cubic yard. This remarkable increase and progress is due to elimination or modification of the following practices which were in the past quite prevalent and which were the most serious: the use of all fine or quicksand in the mix in place of concrete sand; sloppy mix; dirty or unsatisfactory grading of coarse aggregate; allowance for bulking of sand; adjusting of the mix for workability.

Before a specified strength was required of concretes, the engineering department held the sole responsibility for the acceptance or condemnation of materials used. If it was impossible for the department to approve or condemn it, it nevertheless entered into the concrete, and its quality remained an unknown quantity indefinitely. At the present time the approval or rejection of materials has become an inherited problem for the contractor and the material-man, who now insist that proper materials are delivered to the project. The contractor and material-man have become more interested in
the entire construction of the slab, and in so doing have raised the standards of their organizations, which is naturally beneficial to both.

Pavements are not accepted until test reports are submitted to the engineer, designating the results. Sections of pavement showing deficiency in compressive strength are considered unsatisfactory and a reduction in price per square yard of this section is made in proportion to the deficiency. In other words, the contractor is paid for the quality of his product, for value received, regardless of cost. These moulded cylinders are taken at frequent intervals, as often as six or eight times daily, depending upon the speed of the contractor, the size of the project, and the efficiency of his organization. When the test reports covering moulded cylinders indicate serious defects, the core drill removes additional cylinders which are tested and a complete check is made of the pavement before acceptance. The testing laboratory also keeps the engineering department well informed as to the quality of product being produced. When cylinders are questionable, the engineering department analyzes the quality of the contractor's product so that he may adjust his mix and eliminate his trouble at once before a serious deduction could be possible. It is not difficult to assume what an increase would now take place in the strength of concrete if scientifically controlled at an efficient plant set-up.

**Central Mixing Plants**

Indianapolis is about to adopt an alternate specification to control scientifically the paving material at central mixing plants, if established, requiring specified strength concrete through co-operation with the contractor, scientifically preparing the mix for a definite quality or value to be received. Other cities are gradually adopting the practice of scientific control of paving materials through central mixing plants and are distributing the scientifically prepared product to the individual project, either by transit mix or agitating truck bodies. At present, the method and cost of transit seems to be the controlling factor in its practicability. There is no question that a product of higher quality can be produced at less cost at a scientifically controlled plant than on the project.

This change in the paving industry makes the contractor a producer or manufacturer of a marketable product, and I most certainly would recommend that the cost of this product should depend entirely upon its quality as delivered, provided at all times it is of workable nature to complete a satisfactory pavement. His ability as a manufacturer in producing this product surely would also determine the cement content, as well as the material content, depending also upon the quality
of the materials entering into the mix. In other words, the specified quality only should be regarded as constant. At the present time, no consideration whatsoever is given the contractor whose contract is of a better product than his competitor. It would seem that the irresponsible contractor could soon be eliminated and the efficient, reliable contractor be rated as to the quality of his product and receive all benefits which he would rightfully deserve. Since the value of his product today is not a deciding factor, the responsible, efficient manufacturer or contractor can do nothing but pray that his honesty, ability, and financial standing may influence the officials to award him the contract even though he is a higher bidder.

The average contractor with a standard paver is producing today approximately a cubic yard of concrete every one or two minutes while in operation. No one can legitimately dispute the fact that it is gross negligence to manufacture such a product at a cost of from $300 to $500 per hour and place as a supervisor over its production someone who has been told merely that cement, sand, and gravel of a certain mix combined, produce good concrete. It certainly is practical and efficient to produce information to prove in some manner a fair value for such an expensive product before it is ready for service. If a specified mix should produce a product having a certain strength or load capacity, yet no evidence is produced showing that it will carry even half its proper load, it is most natural to assume that a financial loss is taking place. Every paving engineer and contractor who is truly interested in this great industry should demand scientific control of street paving materials in some manner to insure value received and to raise the standards of the engineering profession as well as the paving industry. If a commercial manufacturer under average conditions were to market a product of as great a value as concrete with as little attention given to its quality or value as in some paving projects, his industry would soon pass out of existence.

As a summary the following conclusions are predominant:

(a) Scientific control of street paving materials results in predetermined strength of concrete and higher quality at less cost.

(b) Predetermined strength of concrete results in predetermined economy as well. However, this economy in adopting scientific control of materials can only be predetermined when a specified strength is required. The advantages then appear on the cost sheet; otherwise the increase in life of the slab or ability to withstand more stress than that for which it was designed are the only advantages to gain and they can only be estimated.