THE DESIGN OF A CONCRETE MIXTURE

BERT MYERS AND MARK MORRIS

Engineer of Materials and Tests and Research Engineer, Iowa Highway Commission

The procedure followed in the design of a concrete mixture for the use of an aggregate known locally as Platte River "sand-gravel" was reported by R W Crum in the Proceedings of the Seventh Annual Meeting of the Highway Research Board Experience with the application of this design was reported by Myers in the Proceedings of the Ninth Annual Meeting of the Highway Research Board This design provided for the use of "sand-gravel" without the addition of any other aggregate Since "sand-gravel" is a coarse sand containing ten to twelve per cent of small gravel pebbles, this concrete had characteristics more nearly resembling those of mortar than those of ordinary concrete

The present paper describes the design of a mixture for the use of this same "sand-gravel" with crushed limestone to produce a more common type of concrete mixture Consequently the method that was followed should have a more direct application to problems commonly encountered in the design of concrete mixtures than the method of design previously used for the "sand-gravel" alone

Although the mixture designed by Crum produced concrete that had very satisfactory strength, concrete pavements in which it was used developed an unusual number of transverse cracks Previous use of similar mixtures had indicated that this might be expected This mixture has been used in the construction of a considerable mileage of concrete pavement in the south-western part of the state of Iowa because no other satisfactory aggregate has been available in that region

Early in 1930, crushed limestone became available for use in combination with the sand-gravel on a few projects The Iowa Highway Commission desired to use such a combination with normal ratios of fine to coarse aggregate for the reason that the addition of the coarse aggregate could probably be relied upon to provide a mixture that would produce concrete of such character that fewer transverse cracks might be expected in the pavement than were obtained when the sand-gravel was used alone Further they wished to accomplish the economic saving that could be gained by taking advantage of the rather unusual concrete-making properties of the sand-gravel This required the design of a concrete mixture for the use of these two materials The designing of this mixture was the work of Mr Morris

This paper describes the designing of this mixture and reports some data obtained from studies of the concrete produced by it in the laboratory and in the field as used in pavement

The design reported by Crum was according to the method described by Talbot and Richart, (Bulletin No 137, Engineering Experiment

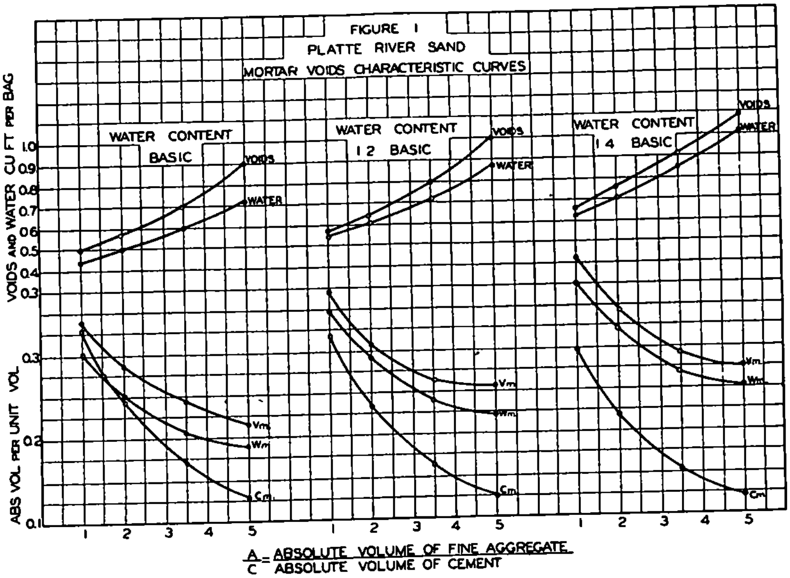

Figure 1

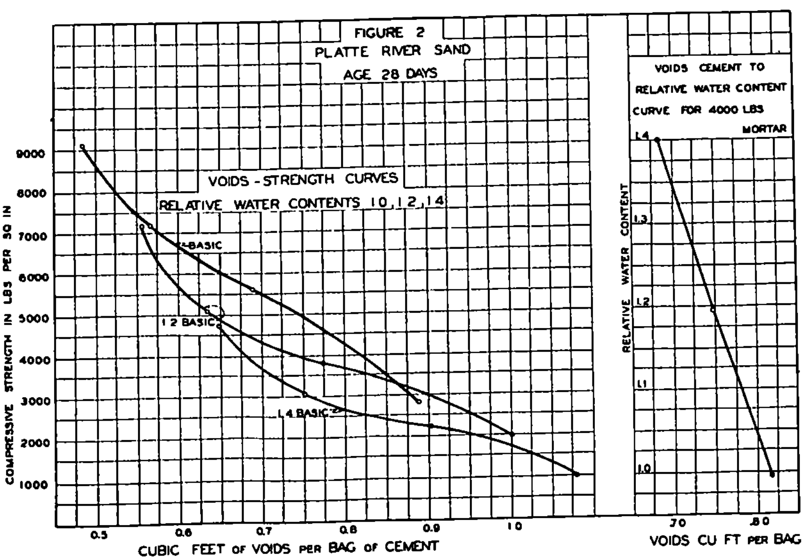

Figure 2

Station, University of Illinois) The same method was followed in the design now being reported except for some slight variations

The mortar voids characteristics upon which the mixture was based were determined from specimens in which the mortar was consolidated in the molds by rodding instead of tamping in the manner described by Talbot and Richart A rather extensive series of tests had indicated that, in the laboratories of the authors, data from rodded specimens gave a more reliable basis for the design of plastic mixtures than did data obtained from tamped specimens

In Bulletin No 137, Talbot and Richart designed concrete from the voids-strength relationship for mortar of basic water content and applied a reduction factor in case the water content of the mortar in the concrete was to be other than basic

Previous laboratory studies, which included concrete mixtures of 47 different sands and a single coarse aggregate, indicated that for the kind of mixture ordinarily used in concrete pavements, accurate values for the strength of concrete could not always be expected when this reduction factor was applied Figures 6, 7 and 8 show data from this series which illustrate cases where accurate results were obtained by following the method of Talbot and Richart including the use of the reduction factor

Figures 9, 10 and 11 show data from the same series which illustrate cases where the same method did not give accurate results

It is not within the scope of this paper to discuss the conditions under which some variation in the application of the method of Talbot and Richart may be necessary to provide accurate data for estimating the strength and yield of concrete There is no intention to suggest that the variations from Talbot's method used by the authors in this case constitutes the only adaptation of the method that may give accurate results

For the reasons suggested above, the design of this mixture was based upon the voids-strength characteristics of mortar of the exact relative water content which was expected to be used in the concrete These characteristics were determined by the interpolation between values determined for mortars prepared with basic, 1 2 and 1 4 relative water content

Talbot's work does not seem to provide a means for pre-determining the water content which will be required to produce concrete of a consistency suited to a specific use The quantity of water used in a concrete mixture has a well known effect upon the strength of the concrete Since it also has a marked effect upon the yield from a given quantity of dry materials, it has a considerable effect upon the cost per unit volume of concrete In the case being reported, the degree of accuracy desired in estimating the quantity of each of the various materials required for a unit volume of concrete was two per cent or less This degree of accuracy seems desirable under the highly competitive conditions existing in the highway paving business in Iowa Competitive bids are received upon the proposition of the bidder furnishing all labor and materials Contracts are usually awarded to the lowest bidder Since the cost of the materials may represent seventy per cent of the total cost of the work, an accurate basis for estimating the quantity of materials required is necessary to avoid a serious financial hazard Experience has demonstrated that as the contractor's hazards are reduced the cost of work is reduced

Experience with concrete in which the only aggregate used was sand-gravel, indicates that mortar of basic water content will be sufficiently plastic for use in a concrete pavement This experience also indicates that mortar of basic water content will, as usually placed in a pavement slab, have greater density than mortar of any other water content

The plasticity of concrete will depend not only upon the kind of solid materials and the relative amounts of water, cement, fine aggregate and coarse aggregate that are assembled to form concrete, but also upon the thoroughness with which these materials are mixed together Therefore, with the kind and amounts of solid materials remaining constant, the quantity of mixing water required to produce concrete of a given degree of plasticity will vary if the thoroughness of mixing is varied

The density of concrete will depend not only upon the kind of solid materials and the relative amounts of water, cement, fine aggregate and coarse aggregate present in the mixture but also upon the plasticity of the mixture and the manner in which the concrete is placed

Talbot and Richart seem to imply that the quantity of mixing water which will result in concrete of maximum density is that which is required for basic water content of the mortar portion of the concrete The data they have presented prove quite conclusively that this was true for the conditions under which their work was conducted The authors of this paper have not found this to be true when the concrete is mixed, placed and consolidated in the manner in which concrete is usually mixed, placed and consolidated on rural highway paving work in Iowa They have found that an additional quantity of water in excess of that required for basic water content of the mortar is necessary to produce concrete which will have maximum density when so placed in a pavement slab They have found that this additional required quantity of water varies with the kind of coarse aggregate used It is greater when the coarse aggregate is broken limestone than when it is gravel This difference is apparently due to characteristics other than the absorption of the aggregate as it is still apparent after corrections are made for absorption

It seems reasonable to suppose that the additional water necessary to restore concrete to the same degree of plasticity as the mortar to which coarse aggregate was added to produce the concrete may be that which is required to wet the surfaces of the particles of coarse aggregate

In order to arrive at some estimate of the relationship between the quantity of water required to produce mortar of a given degree of plasticity and the quantity of water required to produce the same degree of plasticity in concrete made from the same sand, a study of concretes has been conducted This study was conducted in the same manner as that for determining the basic water content of mortar except that the cylinder used was 6 inches in diameter by 12 inches high and the concrete was deposited in the mold and consolidated in the manner prescribed in the A S T M specifications for molding specimens for compression tests of concrete

The quantity of water necessary to produce concrete which has maximum density when deposited in this cylinder in this way has been referred to by the authors of this paper as "basic water content of concrete" By similar studies made in the field on concrete mixtures being used in concrete pavement construction it has been found that for the over-sanded mixtures commonly used in Iowa the concrete which seemed to be most satisfactory for the work had approximately basic water content, determined as outlined above

In order to arrive at some estimate of the quantity of water necessary in the concrete to be designed, the basic water content was determined for a trial mixture composed of the same aggregates as were to be used The proportion used in this trial mixture was 1–2 306–3 459 by absolute volume This was selected because it is a proportion commonly used in concrete pavement construction in Iowa and in it the ratio of fine to coarse aggregate is 1 1 5 which was the same as that proposed for use in the designed mixture

In the design being reported the principal requirements to be met were that

1 The compressive strength of the concrete should be 4000 pounds per square inch at 28 days
2 The ratio of fine aggregate to coarse aggregate should be as 1 is to 1 5
3 The consistency of the concrete should be such as would give a slump of approximately 1½ inches

The known factors were

1 The average values for the crushing strength of 2 x 4 inch mortar cylinders made from the sand to be used These specimens were made up with a wide range of values for the ratio of aggregate to cement and relative water content
2 The values for the voids-cement ratio of these specimens
3 The relation between the voids-cement ratio and the strength values of these specimens

4 The basic water content of the concrete for a mixture of the materials to be used when mixed in the proportions, 1–2 306–3 459 by absolute volume

5 The relative water content of the mortar in the concrete at basic water content of the concrete in the trial mixture as referred to the basic water content of the mortar in the same specimens

The factors that had to be estimated were

1 The amount of additional water required in the designed mixture in excess of the amount required for basic water content of the trial mixture to produce the desired consistency in the mixture to be designed

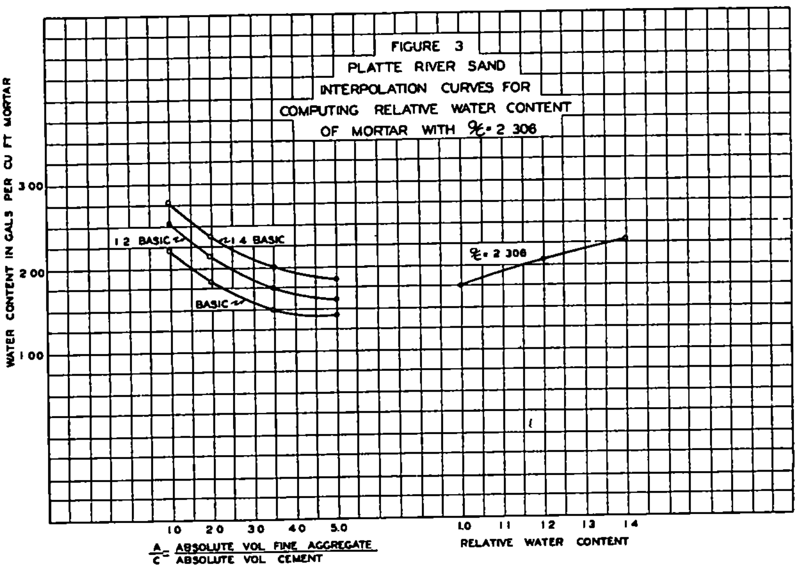

Figure 3

2 The effect of field mixing upon the consistency and density of the concrete as compared to laboratory mixing

3 The basic water content of concrete of exactly the proportions of the mixture to be designed

The designing of the mixture, from data available and estimates made from experience, was carried out as follows

1 From the study of the trial mixture it was found that at basic water content this concrete contained 2 099 gallons of water per cu ft of mortar The aggregate cement ratio of the mortar in this concrete was 2 306

2 From the curve at the right of Figure 3 it is found that for $a/c = 2\ 306$ and water content of 2 099 gallons per cubic foot of mortar the relative water content of the mortar is 1 215 The

three curves at the left of Figure 3 are derived from the characteristics of the mortar by plotting the amount of water for various values of a/c and relative water content in terms of gallons of water per cubic foot of mortar The interpolation curve at the right is derived from the three curves at the left by obtaining from these curves the quantity of water for a/c = 2 306 for basic, 1 2 and 1 4 relative water content and plotting each of these values against the corresponding value for relative water content

3 From the mortar-voids studies of the sand being used and other sands it was known that the result of this design would be a

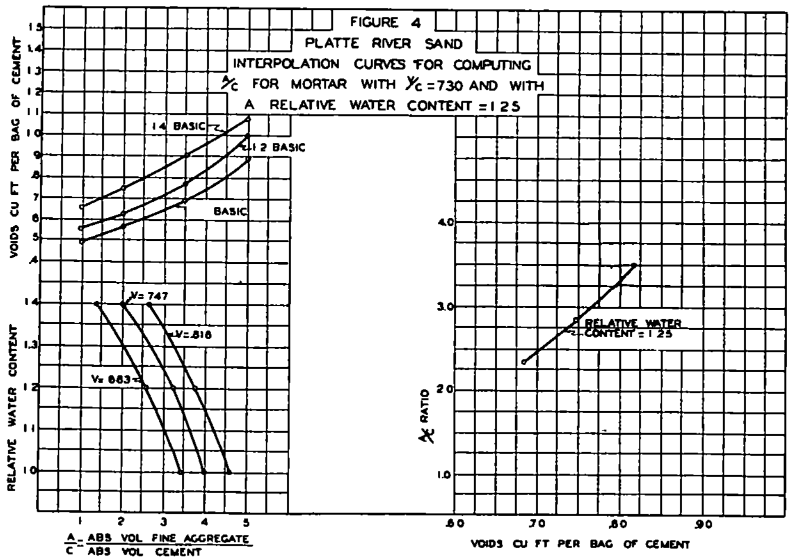

Figure 4

mixture having a greater aggregate-cement ratio than that of the trial mixture It was therefore assumed that the amount of water necessary to produce the desired consistency in the designed mixture probably would be slightly greater than that represented by 1 215 relative water content of the mortar in the trial mixture Within the knowledge of the designers there was no method for determining exactly the quantity of water necessary for the designed mixture Therefore, an additional quantity in excess of 1 215 was estimated from data already given and the experience of the designers The quantity as finally estimated was 1 25 relative water content for the mortar

Then, proceeding with the design upon the basis of this assumption, it is found from the interpolation curve at the right of Figure 2 that at a relative water content of 1 25 for a strength of 4000 pounds per square inch the voids-cement ratio is 0 730 cubic foot of voids per bag of cement The three curves at the left of Figure 2 are the ordinary voids-strength curves for the sand used The interpolation curve at the right is derived from the three curves at the left by obtaining from these curves the v/c for 4000 pounds per square inch for basic, 1 2 and 1 4 relative water content and plotting these values against the corresponding water content

4 From the interpolation curve at the right of Figure 4 it is found that for v/c = 0 730 cubic foot per bag, and relative water con-

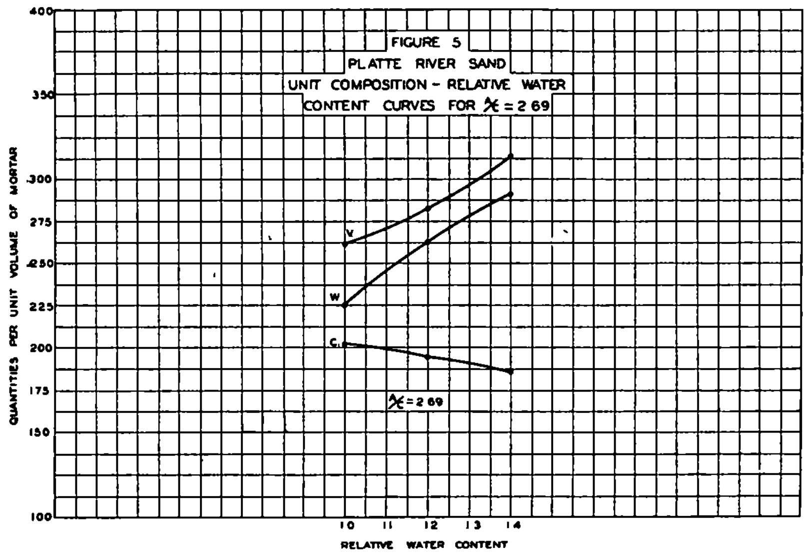

Figure 5

tent 1 25 the aggregate cement ratio for the mortar in the designed proportion will be 2 69 The three curves at the upper left of Figure 4 are derived from the motar-voids characteristics of the sand The three curves at the lower left of Figure 4 are derived from the three upper curves for the v/c values for mortar of basic, 1 2 and 1 4 relative water content and a strength of 4000 pounds per square inch from the curves in Figure 2 From the three curves at the lower left of Figure 4, the curve at the right is derived by determining the values of a/c for a relative water content of 1 25 for v/c = 0 683, 0 747 and 0 818 and plotting these values against the corresponding value for v/c

5 From Figure 5 it is found that a cubic foot of mortar will contain

	Cubic feet absolute volume per cubic foot of mortar
Cement	0 193
Water	0 271
Voids	0 288

And since $a/c = 2\ 69$ and $c = 0\ 193$, $a = 0\ 193 \times 2\ 69 = 0\ 519$ The difference between total voids and water is air voids, or $0\ 288 - 0\ 271 = 0\ 017$ Then each cubic foot of mortar will contain

	Cubic feet absolute volume
Cement	0 193
Aggregate	0 519
Water	0 271
Air voids	0 017
Total	1 000

6 To make concrete, coarse aggregate is to be added to this mortar in the amount of 1 5 times the quantity of fine aggregate or $0\ 519 \times 1\ 5 = 0\ 779$ thus producing 1 779 cubic feet of concrete Then by dividing each of the quantities given above by 1 779, the unit composition of the concrete is obtained as follows

	Cubic feet absolute volume per cubic feet of concrete
Cement	0 1085
Fine aggregate	0 2918
Coarse aggregate	0 4378
Water	0 1523
Air voids	0 0096
Total	1 0000

This composition gives the proportion of solid materials by absolute volume, 1–2 69–4 04

The quantity of cement required per cubic yard of concrete is

$$\frac{0\ 1085 \times 27 \times 62\ 4 \times 3\ 14}{376} = 1\ 528 \text{ barrels}$$

The water-cement ratio for this concrete is·

$$\frac{0\ 1523 \times 62\ 4}{0\ 1085 \times 62\ 4 \times 3\ 14} = 0\ 447 \text{ pound of water per pound of cement or}$$

5 04 gallon per bag

Since the designers of this mixture had little data as to the relative effects of laboratory mixing and field mixing upon the consistency of concrete mixtures, they feared that the designed mixture might not prove to have the desired degree of workability in the field Therefore, in the mixture specified for use in the field, the aggregate-cement ratio was decreased slightly and the specified maximum water-cement ratio increased accordingly The proportion specified was 1–2 65–3 98 by absolute volume The specifications provided for slight adjustments in the proportion to allow for an increase in the aggregate-cement ratio if the quantity of water actually required in the field were less than the specified maximum This resulted in the use, in the field, of a mixture that was very near the designed mixture in every respect

Table I is a comparison of the design data, with the data obtained from studies of the concrete used for approximately fifteen miles of pavement The tests were made upon specimens or samples secured by placing on the subgrade a hemispherical cast-iron dish having a radius of six inches This dish was filled as the concrete was deposited in the pavement slab After all finishing operations were completed, the

TABLE I

	Concrete designed	Concrete used
Water cement ratio, pound per pound	0 447	0 445
Water cement ratio, gallon per bag	5 04	5 01
Absolute volume of cement per cubic foot of concrete	0 1085	0 1092
Absolute volume of water per cubic foot of concrete	0 2918	0 2895
Absolute volume of coarse aggregate per cubic foot of concrete	0 4378	0 4342
Absolute volume of air voids per cubic foot of concrete	0 0096	0 0143
Absolute volume of solids per cubic foot of concrete	0 8353	0 8329
Voids-cement ratio, cubic foot per bag	0 730	0 733
Barrels of cement per cubic foot of concrete	1 528	1 536

hemisphere with the concrete it contains was removed and the density of the concrete determined The computations were based on the assumption that the various materials have been measured accurately The data given are averages of the values obtained from 10 such density determinations made at intervals on each of five days or a total of 50 determinations These data should be representative since the amount of water used on those days was approximately the average used throughout the work

The design of a concrete mixture may be said to be successful if (1) the resulting mixture has a consistency suited to the use for which the concrete is intended, (2) the strength of the concrete obtained is that desired, and (3) the quantities of the various materials required to produce a given volume of concrete are approximately those which could be estimated from the design data

In the case of this design, the mixture had a consistency entirely satisfactory for the purpose for which the concrete was designed From the data given it can be shown that the quantity of cement used per cubic yard of concrete was 0 52 per cent greater and the quantity of aggregate used per cubic yard of concrete was 0 8 per cent less than the quantity estimated in the design Therefore, on the jobs on which this concrete was used where the delivered costs of materials were cement, $1 80 per barrel—fine aggregate, $1 30 per ton—coarse aggregate, $1 90 per ton, the cost of the materials required to produce a cubic yard of concrete was 0 03 per cent less than would be estimated from the design data

Table II gives data as to the crushing strength of the concrete produced in the field

TABLE II

	Crushing strength			Mean variation from average
	Minimum	Maximum	Average	
	pounds per square inch	*pounds per square inch*	*pounds per square inch*	*per cent*
Design, age 28 days			4,000	
50 specimens carefully made in the field by laboratory crew—age 28 days	2,910	5,050	4,170	8 85
96 specimens made in the field by paving inspectors—age 28 days	2,880	5,270	4,109	10 6
7 cores taken from pavement—ages 33 to 38 days	3,760	4,750	4,243	
45 cores taken from pavement—ages 40 to 75 days	3,530	6,800	4,370	

While the range of strengths in each of the series in Table II seems quite large, it should be remembered that these are specimens made and stored under field conditions The mean variation from the average compares quite favorably with strength data from tests of other field specimens For instance, the strength data for 93 similar specimens from a pavement built at the same time in the same locality using the standard arbitrary proportions of the Iowa Highway Commission show a mean variation from the average of 9 5 per cent which compares with the mean variation of 8 85 for the 50 specimens and 10 6 for the 96 specimens from the designed mixture From these data it would appear that the design was successful in producing concrete of satisfactory consistency, and strength and in providing accurate data for estimating the cost of materials required for a unit volume of concrete

Although the method of design followed varies in some details from that outlined by Talbot and Richart in Bulletin No 137, it seems to the authors that these variations are slight and are logical applications of the basic principles stated by Talbot and Richart The mixture was

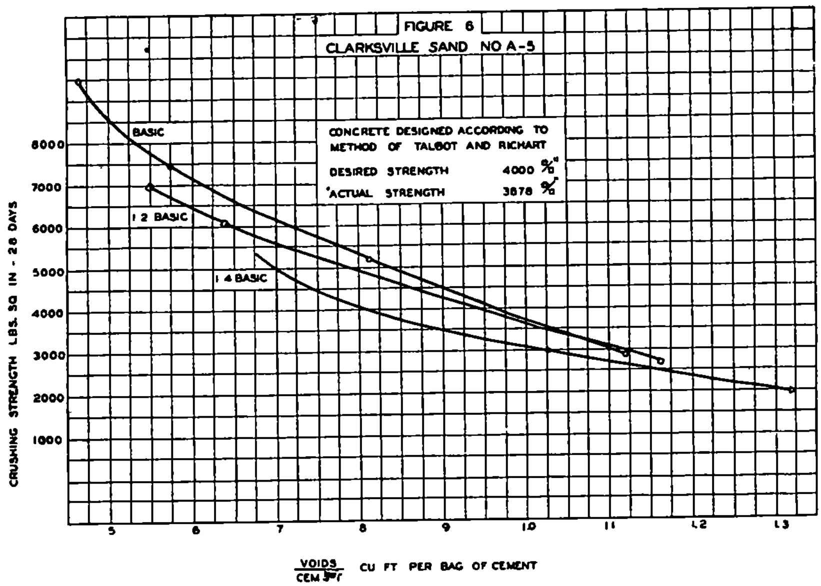

Figure 6

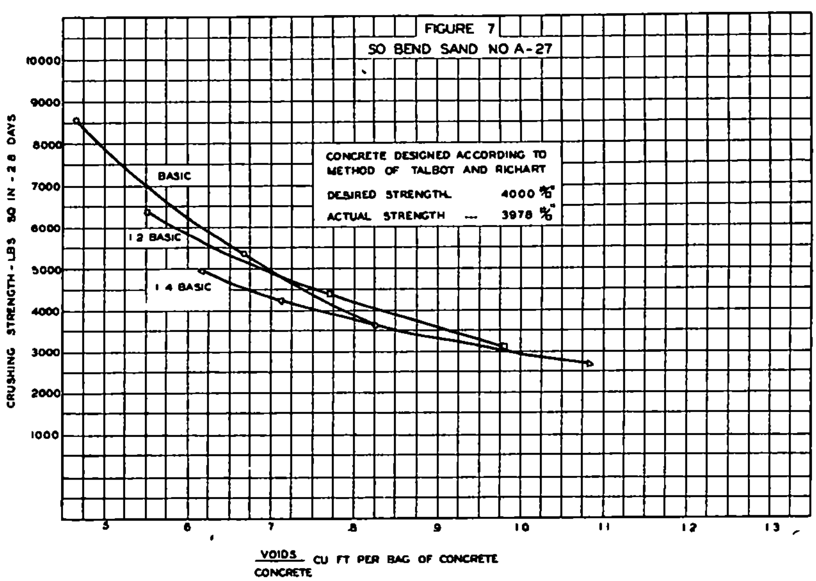

Figure 7

designed from the mortar-voids characteristics of the particular sand at the relative water content to be used in the concrete Talbot and

Richart suggest designing concrete mixtures from the voids-strength relationships of mortar of basic water content through the device of

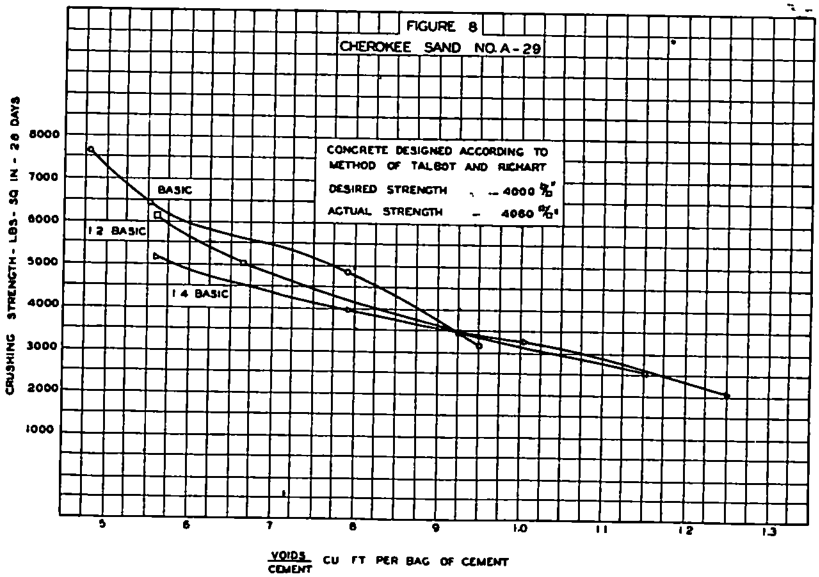

Figure 8

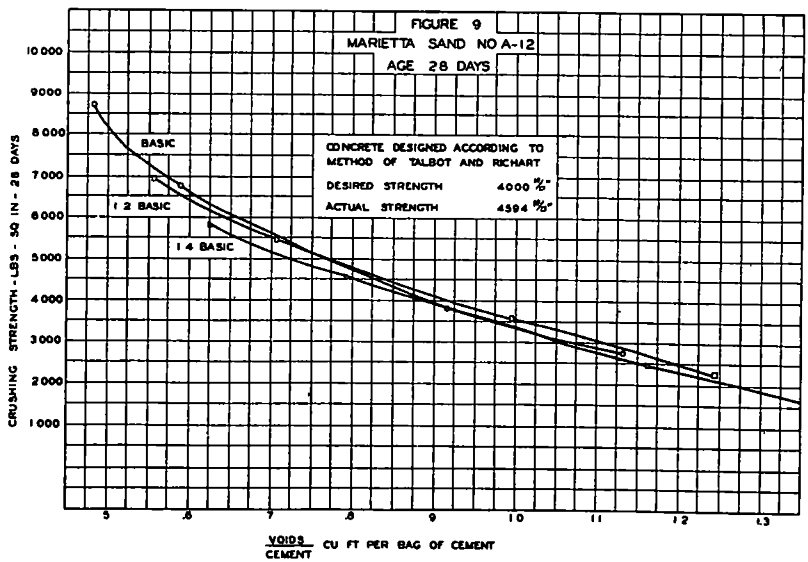

Figure 9

applying a reduction factor in case the consistency desired requires a water content other than basic It seems a logical application of the basic principles of their method to design the concrete mixture from the characteristics of mortar of the relative water content required for the concrete

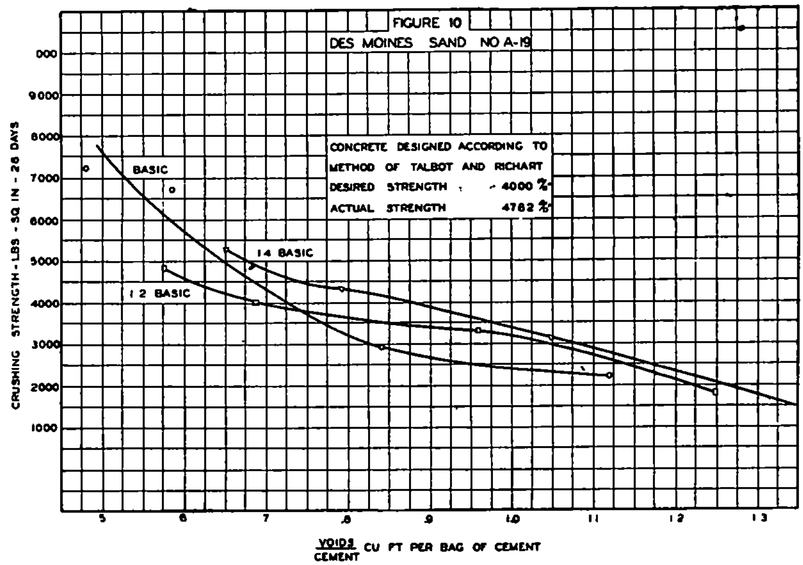

Figure 10

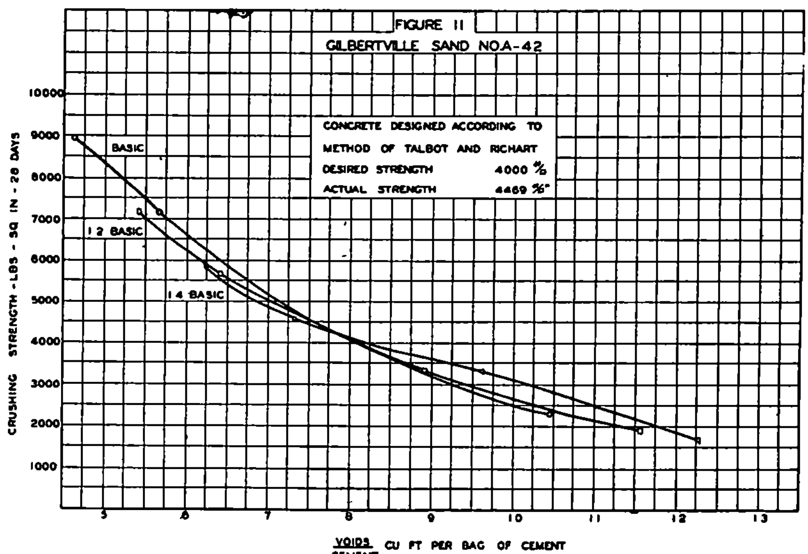

Figure 11

The device used by the authors for arriving at an estimate of the amount of water required for the desired degree of workability in the designed mixture was not suggested by Talbot and Richart A possible improvement upon the device used would be to design a mixture exactly according to the method of Talbot and Richart for a relative water content of say 1 2 and use the proportion thus obtained for a trial mixture for the study of the amount of water required for basic water content of the concrete Since this proportion would closely approximate that of the final design, the amount of water thus determined might be assumed as that required Again it seems only a logical application of the basic principles of the method to determine the amount of water required for the concrete by a study of the concrete conducted in a manner similar to that followed in the study of the mortar

The degree of success attained in this case confirms the authors in a belief they have held for several years, that in the work of Talbot and Richart are to be found the basic principles underlying the rational design of concrete mixtures

DISCUSSION

ON

THE DESIGN OF A CONCRETE MIXTURE

MR C N CONNER, *American Road Builders Association* I would like to ask if with this design there is any reduction in transverse cracking of roadway slabs

MR MYERS I cannot tell you that because the concrete was only constructed last year and we do not yet have a record of the cracks I expect that there would be because previous use of the same material—with a richer mixture—in combination with crushed stone, showed only a normal cracking

DR A N TALBOT, *University of Illinois* I want to express my appreciation of the work which has been done, particularly by the Highway Departments of Iowa, Illinois, and other States, in recent years, in making a study of the design of concrete and of other things connected with it, like the estimate of the amount of materials used A determination of the quantities to be used as shown by this paper indicates that a reasonable estimate can be made and also that a fair advance determination of the strength of concrete can be obtained A method of obtaining the strength at given relative water content, as mentioned by Mr Myers, is within the lines of those who dealt with these methods at the beginning and who thought this would follow as the logical way of handling such matters on work where relative water contents of certain kinds will be used By relative water content, of course, is meant the amount of water to be used in the concrete mixture as compared with the amount which would govern the concrete of maximum density

With reference to the use of the amount of limestone in each particular case, if a smaller amount were used, 10 or even 20 per cent, and a proportionately larger amount of the fine aggregate, with a lower water content to obtain the same degree of workability, I do not know that there should be any particular difference in the number of cracks that would develop The matter referred to by Mr Myers on the relation to workability of the different proportions, can hardly work out from the methods of study It is something on which other data would be necessary and on which study is needed to devise a test for the effect of different qualities upon workability and relative water content To my mind the use of this method of handling materials for concrete and dealing with the design is just in that it gives a better conception of what the combination is made up of, than methods based upon bulk measures

Mr R B Gage, *New Jersey State Highway Department* Mr Myers has certainly given this subject considerable study and the results secured are very interesting Unfortunately, he did not state whether these tests were made with more than one brand of cement Since he did not so state I assume that only one brand of cement was used The strength tests we have secured on our pavements in New Jersey indicate that if he had used different cements, the results might have varied considerably from what he has reported Our specifications for such pavements permit only the use of one brand of cement The contractor is at liberty to select any brand which complies with the requirements, but after he has made such a selection, other brands cannot be substituted for the one thus selected The compressive strength required for the concrete used in different pavements is established for each contract during the initial stage of construction It has been known for a number of years that different cements will produce different strength concretes when the other conditions are identical Consequently, in order that the strength of the concrete used in a pavement might not be established with a high strength cement and the balance of the pavement constructed with a low strength cement, which might be very injurious to a contractor, we introduced the above requirement

On some contracts where the yardage of concrete was considerable, the contractors have been allowed to construct one-half of the pavement with one cement and the other half with another brand, which required that we would have to establish two different strengths for the concrete used in the pavement In such cases, the same material, same contractor and same conditions existed during the construction of both halves of the pavement, the only variable being the brand of cement used We have found that the concrete in one-half of such a pavement might have a compressive strength at twenty-eight days of 6,200 pounds per square inch and the concrete in the other half might have an average compressive strength at twenty-eight days of 4,900 pounds per square inch

If the latter compressive strength represents the best that could be secured with the brand of cement that was used and if the compressive strength originally established called for a 6,200 pound concrete, the contractor would be very heavily penalized on the concrete constructed with the weaker brand of cement and, no doubt, in many cases would be forced into bankruptcy It must be admitted that the different strengths will also be secured with different sands, but in many cases the only variable is the cement The pavement cited above may show the extreme variations in strengths that might be secured but we have many pavements in which the variation would run from 300 to 800 pounds

Again, cements appear to vary greatly in their ability to hold the water required for proper preparation Concrete constructed with certain cements will loose this excess water as soon as the concrete has been properly placed and finished This excess water will be forced to the surface in the form of a sheet and either run off or evaporate This does not always injure the strength of the concrete but may leave it more or less porous on the surface On the other hand, if this same excess water appears on the surface of the pavement when a cement is being used that is capable of holding the water required for its proper preparation, an entirely different grade of concrete will be secured In the latter case, the compressive strength of the concrete will be greatly reduced and its porosity correspondingly increased, the resulting product being a pavement that will, no doubt, scale and fail prematurely In drawing conclusions based upon the consistency of the concrete and the quantity of water used, the character of the cement is a factor of vital importance but, unfortunately, to date there does not appear to be any particular test that will differentiate two grades of portland cement

MR STANLEY M HANDS, *Division of Highways, State of California* The procedure to follow in designing a concrete mixture is not necessarily confined to one method The California method fixes water by trial proportions Each is an attempt to put together the cement, sand and coarse fractions in such a manner that the least amount of water is required to give satisfactory fabrication of the mixed concrete

The relationship of the solid portions of the mix each to the other and to the whole is not complicated until the water demand of these is considered It is assumed that if the absolute volume of all ingredients are the same for two mixes the strength will be equal for the same materials If two or more proportions are calculated to the same absolute volume the strengths would be the same if each of the proportions required the same amount of water to give proper plasticity It would, therefore, be interesting to know how much the water will change with the proportions of materials and why it changes

The usual void theory and surface area theory do not account for all relationships which have been observed, first, as to Iowa materials and later, on a more extended scale, for California materials There are materials in both states which may be used in varying proportions of fine and coarse For these materials, if the absolute volume of the proportions is equal, the amount of mixing water does not change Therefore, two batches having different component parts and different weights have been designed to give the same strengths and, neglecting structure and other characteristics of the materials, these proportions gave the same quality of concrete Where the proportion of fines was greatest, the surface area must have been the greatest If the proportions were changed, the voids must change There seems to be some other thing that enters into the problem which influences workability and yield The "water demand" phenomena needs explanation

The suggestion has been made by those who are investigating oil mixes that the bitumen index or oil coverage factor is a function of the adsorbtive power of the aggregates and varies for each material Also for each material the bitumen index figure varies in some manner as the diameter of the particle

Assuming these relationships for adsorption to be true for all fluids and materials, the laboratory staff of the Division of Highways, State of California, have attempted to determine the volume of water for any proportions for given materials on a basis of the water demand per cubic foot of those materials when saturated surface dry The basis for this work is the trial mix By means of carefully prepared grading and proportions covering a wide range of yields the actual water required to give a normal consistency of concrete was determined The surface area equivalents for the combined cement and aggregates are determined from the oil mix tables The surface area equivalent of the component parts of the mix is determined from surface area of the combined grading The W/C ratio is the product of the surface area equivalent for one cubic foot of material and the water index for that material Therefore, if three widely divergent mixes are used for the calculations, the water index for each of the ingredients can be had by solving the three equations for the water index of the cement, sand and coarse aggregate Adjustments in the field are easily made as follows

Proportions 1 1 61 2 95

Water demand = Proportions times Surface area equivalents times water index

For cement 1 × 22,800 square feet × 0 00000675 lnear feet = 0 154 cubic foot

For sand 0 61 × 1990 square feet × 0 000033 linear foot = 0 205 cubic foot

For C A 2 95 × 262 square feet × 0 000579 linear foot = 0 448 cubic foot

Total water demand for 1 1 61 2 95 mix = 0 707 cubic foot

which compares very favorably with a water cement ratio of 0 71 which was found to be satisfactory for workability and yield Other comparisons are 1 1 39 2 54 calculated *W/C* 0 645 actual 0 65, 1 1 17 215 calculated *W/C* 0 56 actual 59, and 1 1 95 3 59 calculated *W/C* 0 828 actual 0 836

It would seem, therefore, that it might be possible to determine the water demand in some such units so that the yield for a satisfactory concrete mixture could be predetermined The tests have been duplicated for materials used on the Bay Shore Highway pavement in South San Francisco, California The proportions were calculated to the same absolute volume including the water The reduction factor was 98 per cent The absolute volume of the proportions was 3 83 and the water was 0 747 making a total of 4 58 cubic feet of concrete per sack The reduction factor reduces this to 4 49 Two different six sack proportions were run and 105 batches made 106 cubic yards of concrete on the grade for the first and 200 batches of concrete made 198 cubic yards for the second The workability was satisfactory at all times

The California system of designing proportions to fit the material has developed the fact that the least amount of water to give satisfactory fabrication is not the product of similar grading and proportions The inherent character of the materials is an important factor It would not seem unreasonable to assume that the so-called "good" grading curves for materials are an expression of this character in terms of screen diameters The "fool-proof" mixes are those made from materials with those characteristics which compensate for the change in the proportions to maintain the constant water demand Such materials were used on the Bay Shore job

Mr Meyers and Mr Morris have raised an important question The concrete making properties of materials should not be disregarded The economies can not be fully established perhaps, but experience shows that there is a saving to be made by proper selection of proportions for given aggregates This saving is passed on to the state In many cases it is quite an item