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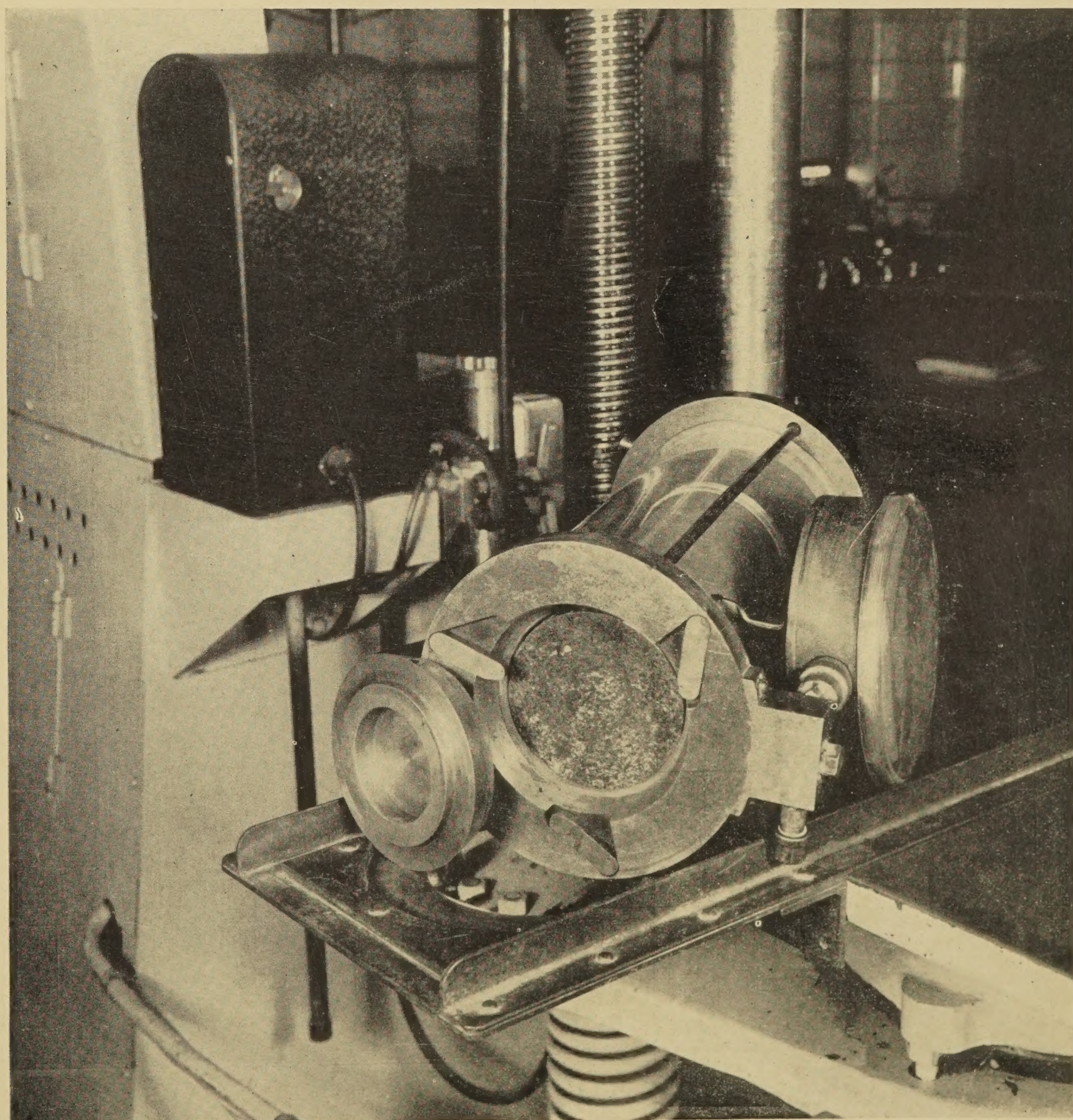

An improved triaxial compression cell, in which specimens are quickly placed and removed through a bottom opening

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BUREAU OF PUBLIC ROAD

U. S. DEPARTMENT OF COMMERC

E. A. STROMBERG, Ed

n Improved Triaxial Compression Cell for Testing Bituminous Paving Mixtures

B THE PHYSICAL RESEARCH BRANCH
BREAU OF PUBLIC ROADS

Reported [1] by C. A. CARPENTER, Senior Materials Engineer
J. F. GOODE, Highway Research Engineer
and R. A. PECK, Assistant Materials Engineer

The triaxial compression test is unquestionably a useful tool in research investigations of bituminous mixtures, but present-day types of cells have two difficulties that hamper their use. The fixed-sleeve triaxial compression cell, with its rubber sleeve attached to the top cell plate, introduces an indeterminate stress component into test results because the top of the sleeve has to stretch as the specimen is deformed vertically. The free-sleeve cell, in which the sleeve is attached to the upper bearing plate, eliminates this indeterminate but must be dismantled for insertion and removal of each specimen.

The Bureau of Public Roads laboratory has now devised a new cell with the advantage of the free-sleeve type in properly measuring stresses, and none of its disadvantages in manipulation. The new cell has a circular opening in the base plate through which the specimen is easily inserted or withdrawn. The plug for the opening, which serves as the bottom bearing plate for the specimen, is quickly attached or released by three latches.

Compressed air is ordinarily used in applying lateral pressure to the specimen, but the new cell is also fitted for high temperature tests with hot water as the heat and pressure-transmitting agent. An added feature is a perforated copper shell to protect the operator if the lucite cylinder bursts under pressure.

HE triaxial compression test for bituminous paving mixtures, through the work Messrs. Hveem, Endersby, Smith, and rs, has been developed to the point re its value as a research tool cannot loubted. There is little question that it rs a direct and reasonably simple solu- of the problem of how to evaluate the factors, cohesion and internal friction, bituminous mixtures.

he application of the information ob- able by means of the triaxial test to problems of investigating the stability existing pavements and designing new of adequate stability is not simple. s has been amply demonstrated by Dr. Leod in two outstanding papers.[2, 3]

ecognition of the fact that the applica- of triaxial test data is not a simple cess does not in any way constitute a icism of the tool. On the contrary, it its to a wealth of possible lines of in- igation and special application. At the e time, in recognizing the value of the xial compression test as a research tool, e is intended no implication prejudicial he simple, direct tests that have been nd useful in the more or less routine k of designing bituminous mixtures in laboratory.

Present-Day Cells

here are two details, one technical and other pertaining to convenience of op- ion, of several present-day triaxial cells are subject to criticism. It is the pur- of this paper to report on the efforts he past several years to overcome the difficulties that have given rise to these criticisms.

The first, or technical, criticism arises from the fact that several triaxial cells, in order to provide for maximum convenience of operation, have been designed with full specimen-sized openings through both the top and bottom plates with the rubber sleeve attached to the upper and lower plates around the peripheries of these openings. This type of cell has been called the "fixed-sleeve" type.

From the standpoint of convenience in inserting and removing test specimens, this arrangement is ideal. Unfortunately, however, it introduces in the test results an indeterminate stress component. As the test specimen is deformed by the downward movement of the plunger, the sleeve, being held tightly against it by the surrounding fluid pressure, is prevented from slipping by friction. Thus, the part of the sleeve immediately below the line of attachment to the upper end plate has to stretch just as much as the test specimen is deformed vertically in the test. This stretching cannot be produced without external force. The stronger and tougher the rubber sleeve, the greater is the force required to stretch it as the testing plunger moves down with the deforming specimen. Some of the sleeves now in use, particularly those of neoprene, are extremely strong and resistant to this stretching. Furthermore, there appears to be no satisfactory way of calibrating the equipment in order to correct for the extra force involved, because the length of the stretched section of the sleeve is indefinite and variable.

Several years ago the soils laboratory of the Bureau of Public Roads made an extensive study of the various types of triaxial cells then in use [4] and then designed a very much simplified cell that embodied in one unit what appeared, from a technical standpoint, to be the most desirable features of the several types then in use.

[1] Presented at the annual meeting of the Association Asphalt Paving Technologists, Denver, Colo., Feb. 951.

[2] *Airport evaluation in Canada*, by Norman W. Leod. Highway Research Board, Research Report 4 B, October 1947.

[3] *The stability of granular and cohesive materials in ial compression*, by Norman W. McLeod. Proceed- of the Association of Asphalt Paving Technolo- , 1948.

[4] *Essential features of triaxial shear tests*, by C. A. Hogentogler and E. S. Barber. PUBLIC ROADS, vol. 20, No. 7, September 1939.

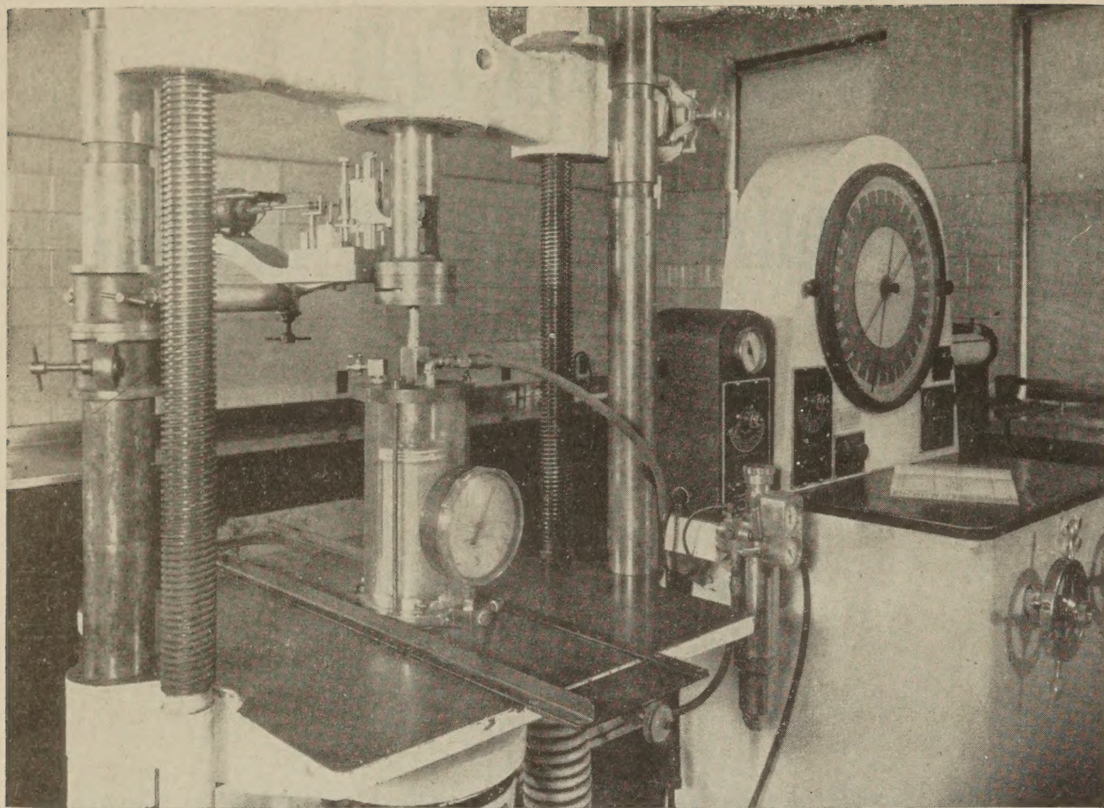


Figure 1.—The cell, with specimen in place, ready for test. Note the compressometer above.

The New Public Roads Cell

Figure 2 is a diagrammatic sketch of new cell. As in all free-sleeve types, rubber sleeve is attached to the tes plunger. In this model, the testing plu or plate is positioned within the cell actuated by a polished stainless-steel th rod which operates through a lap-fini bronze bushing in the top plate of the

The new and special feature of this is the opening in the base plate, which mits the insertion of test specimens dir into the sleeve, and also their rem without disassembling the cell. Thus the operational advantages of the fi sleeve type cell are gained, while stil taining the technically desirable free sl which permits the testing of the speci without developing the indeterminate s component mentioned above.

The bottom of the rubber sleeve is tached to the lower plate of the cell ar the periphery of the opening by mear two interlocking clamping rings in a ma not essentially different from that use some of the fixed-sleeve cells. The

Most important of the features incorporated in the Public Roads design was the so-called free rubber sleeve. In the free-sleeve type of cell, the upper end of the rubber sleeve is attached not to the top plate of the cell but to an upper bearing plate, which was designed to operate entirely within the pressurized zone. This eliminated the longitudinal stretching of the sleeve and the indeterminate vertical force component that the stretching entailed.

Much of the simplification of design that was attained was made possible by adopting air, rather than liquid, for the cell pressure medium. The air is taken from a compressor and passed through a flow-type back-pressure regulator which delivers it at the desired gage pressure. The desired pressure is easily maintained by simple manipulation of the pressure-regulator controls even when there is considerable leakage of air from the cell.

The second criticism, applicable to the free-sleeve cells, is based on operational difficulties. The criticism arose from the inherent characteristics of these cells: namely, that it was necessary to disassemble the cell and disconnect the sleeve from the interior, upper bearing plate in order to insert or remove each test specimen. The Public Roads cell was designed so that this involved a minimum of inconvenience, but, when utilized for testing bituminous mixtures, it was found that a modification of design would be advantageous for this special application in order to facilitate the testing of a larger number of specimens in a given time. The desired result has been obtained by designing a new cell which provides for the insertion and removal of test specimens through an opening in the base plate.

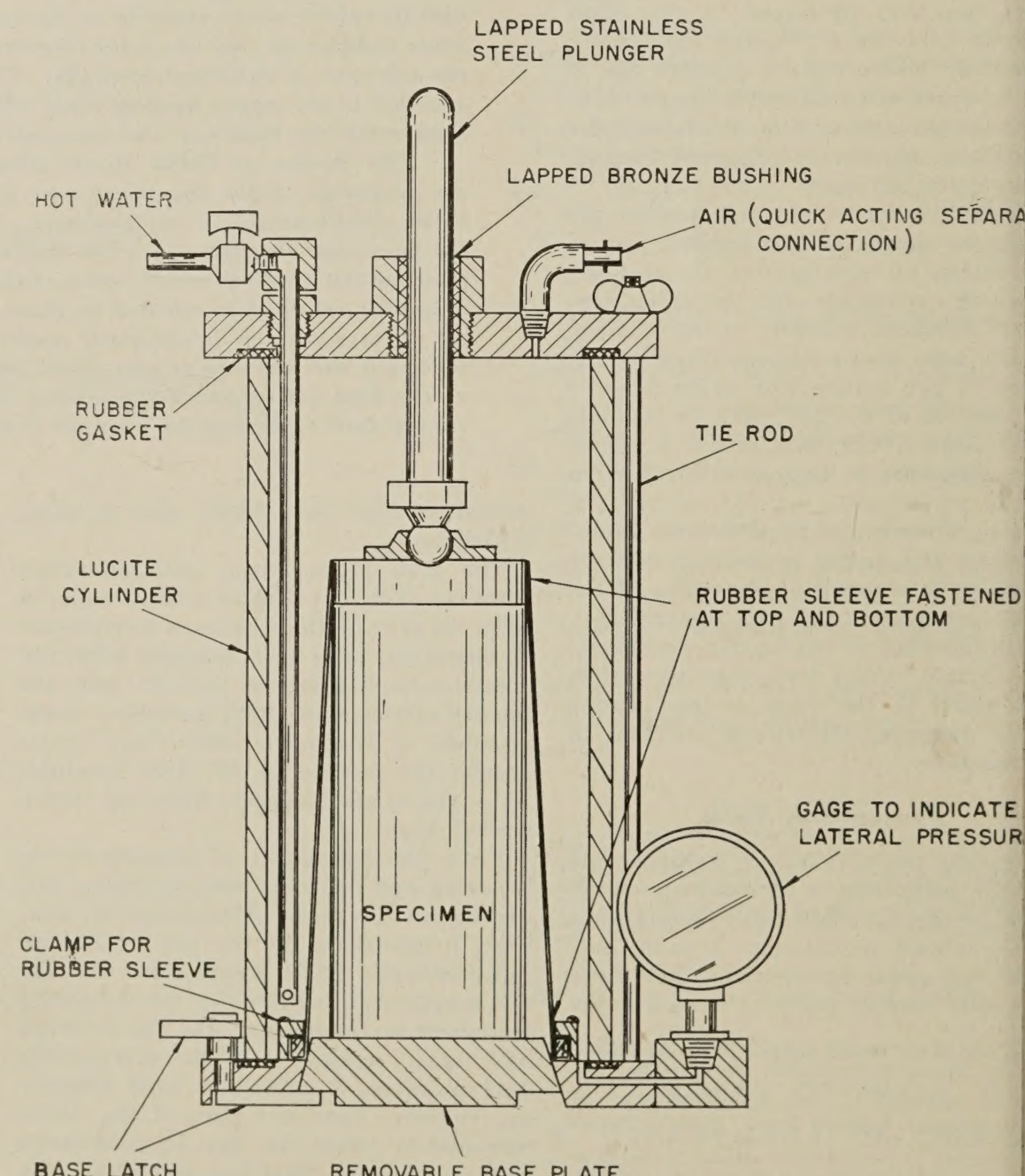


Figure 2.—Diagrammatic sketch of improved triaxial cell.

or rest for the specimen is not pro- d with a sealing gasket and, therefore, not provide full maintenance of pore sure when testing water-saturated spec- ıs. In general, the maintenance of pore sure in testing saturated bituminous tures is not desired. If needed, the gn can be modified to provide for seal- the plug so that pore pressure will be ntained.

characteristic of all free-sleeve cells probably should be mentioned here is the cell pressure is applied not only rally on the test specimen, but also the top except for the relatively small ı of the thrust rod (see fig. 2). Because this fact it is necessary, before com- ıng the values for cohesion and friction, orrect the indicated total vertical load adding to it the quantity, unit cell pres- e times net area of bearing plate.

Air or Water Pressure Used

s long as the test is made only at oratory room temperature with the spec- n brought to 77° F. before inserting it the cell, air is the most convenient fluid use in applying the lateral pressure. does not cause rusting of the equipment, leakage leaves no liquid to dispose of, it is usually more conveniently avail- e under suitably controlled pressure. wever, in order to provide for at least ıe investigational testing at higher tem- atures, provision has been made for in- ducing hot water into the cell and for ermining the temperature of this water the time the compression test is run. n the present design, the hot water is plied directly from a hot-cold mixing through a hose to the hot water fitting the upper left (see fig. 2). The cell is ed with water at a temperature just ghtly above the desired test temperature. e water is allowed to cool to test tem- rature as indicated by a thermometer stened to the inner surface of the lucite inder. The specimen is then inserted, desired pressure is applied by means of acting on top of the water, and the npression test is made. Regardless of at predetermined test temperature is ing used, all test specimens are brought that temperature in an automatically ntrolled air bath or oven before being serted in the cell. This method of testing elevated temperatures takes somewhat nger than would be necessary if it were ssible to circulate water at the correct mperature continuously through the cell cause, in the present set-up, the water s to be blown out and replaced with armer water as often as the temperature lls noticeably below the desired test tem- erature. This has not proved to be par- cularly inconvenient, however, because it kes so little time to insert a specimen and ake a triaxial test in this equipment. ence, it is possible to complete several sts before the water has to be changed.

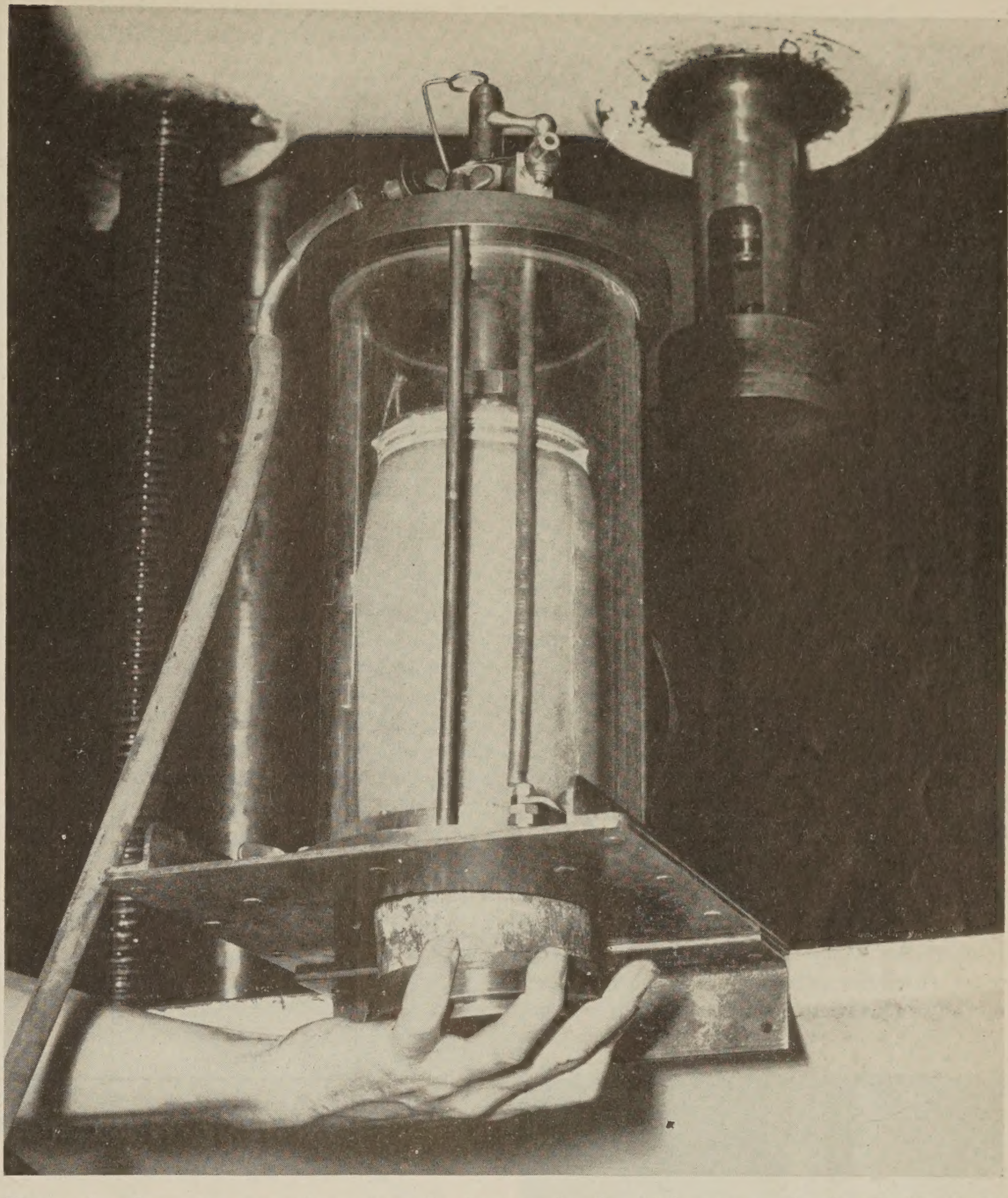


Figure 3.—Inserting a specimen into the improved cell, which rests on the detachable shelf.

The Cell in Use

The cover photograph shows the cell lying on its side, with a specimen in place for testing. The bottom plug is at the left, leaning against the base plate of the cell. The three latching bars are necessary to prevent the air pressure from blowing the specimen and plug back out through the bottom opening and thus lifting the entire cell off the platen of the testing machine.

The cell is shown resting on a special bracket and centering guide that may be attached to or removed from the testing machine in a matter of seconds. The bracket shelf has an opening through it large enough for the test specimen and the plug to pass through freely and is so arranged that the cell can be slid easily directly onto it from the platen of the testing machine or from the shelf onto the machine in a vertical position. This arrangement adds materially to the convenience and speed of operation.

Figure 3 shows the operation of inserting a test specimen or of removing one. Note that the rubber sleeve is considerably enlarged to permit free movement of the specimen. This enlargement of the sleeve is obtained by drawing a slight vacuum on the cell through the rubber tube and needle valve at the left and top, respectively. In this view, one of the bottom latch levers is shown just above the edge of the bracket shelf and slightly to the right of center of the cell. The vertical steel rod in the foreground is one of the three tie rods with top wing nuts which provide for quick disassembly of the cell for cleaning and drying. Just to the right of the tie rod and inside the cell, between the lucite cylinder wall and the rubber sleeve, is a copper tube with one bottom side opening and an external stop cock at the top. This assembly is provided for introducing and removing hot water when tests are to be made at elevated temperatures. It does not have any function when air alone is used as the cell-pressure medium.

Replacement Sleeves

Replacement sleeves are made up in the laboratory as often as needed. The stock material is dental dam rubber which is purchased in sheets 0.01 inch thick, 36 inches wide, and in any length desired. To make a sleeve for a 4- by 8-inch test specimen, a strip of rubber about 10½ inches wide and 36 inches long is cut from the stock sheet, attached along all edges to a supporting frame, and coated on portions of both sides with one coat of cold patching rubber cement. The supporting frame has an opening 10½ inches wide and 38 inches long. The rubber is attached to the frame by means of adhesive tape, some stretching of the sheet being necessary in order to accomplish this. To simplify the following discussion, one end of the rubber sheet will be referred to as end *A* and the other *B*. In applying the rubber cement, the upper side is coated from end *A*, a distance of about 25½ inches toward end *B*, leaving the last 12½ inches toward end *B* uncoated. The under side is coated from end *B* toward end *A*, a distance of 25½ inches. After the cement has dried thoroughly in the air, the adhesive tape holding end *B* to the frame is removed. A 4-inch-diameter mandrel is laid on this end, which is uncoated on its upper side. The rubber sheet is then fastened with adhesive tape to the face of the mandrel. Then the mandrel is rolled toward the other end, pulling the rubber loose from the adhesive tape on the edges of the frame as it goes along. Three com-

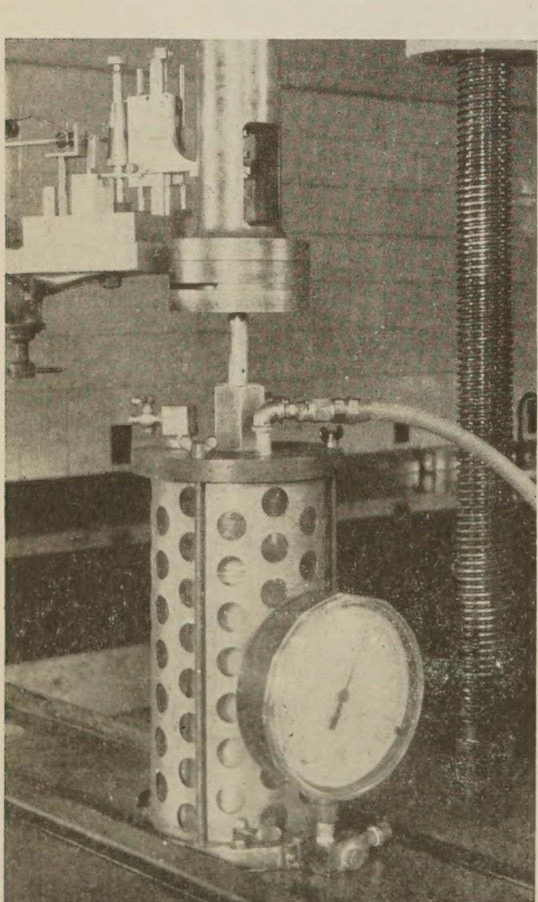


Figure 4.—The triaxial cell encased in its protective perforated copper guard.

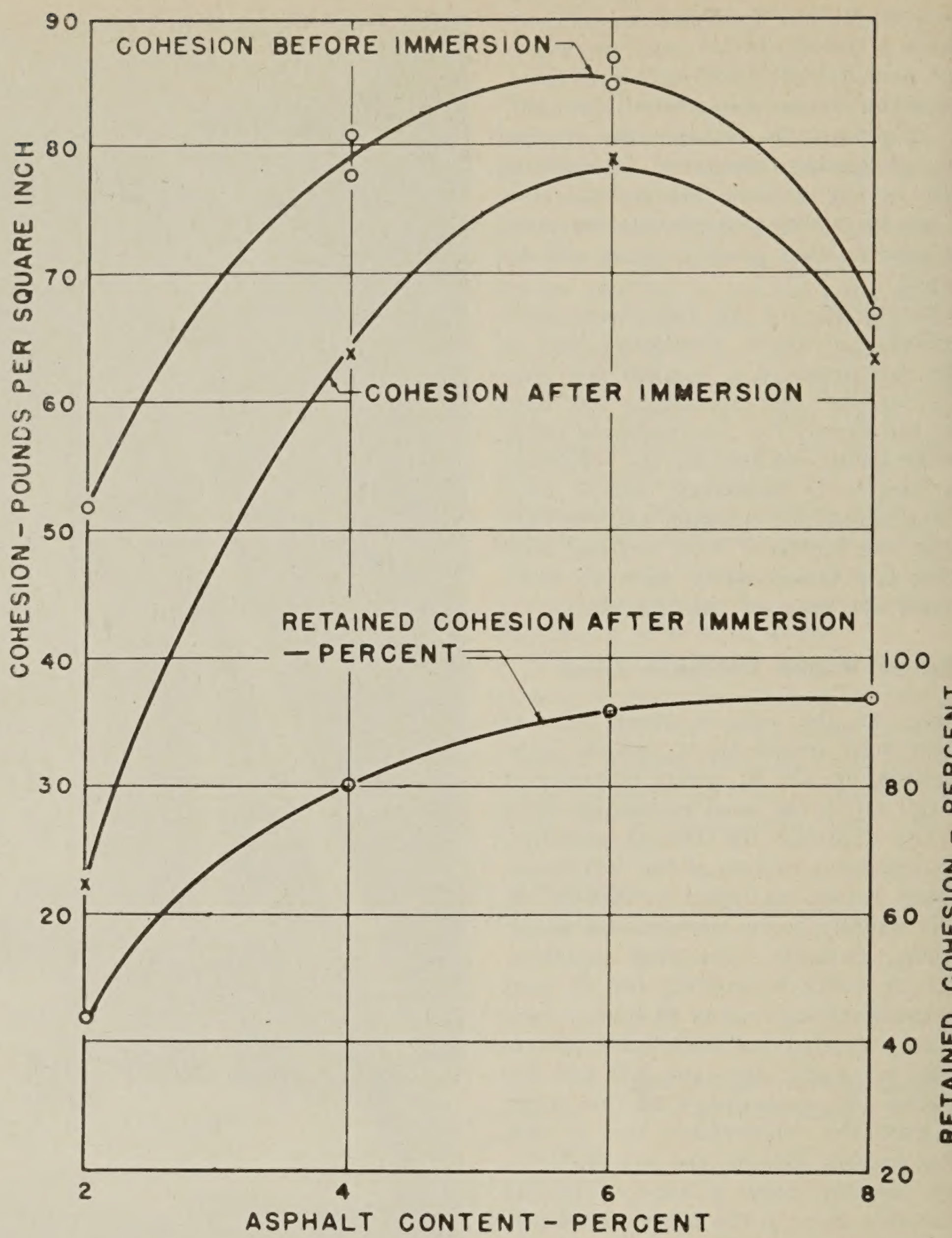


Figure 5.—Effect of asphalt content on cohesion and secondary effect of immersion.

plete wraps are made and the material provides sufficient overlap to produce a four-ply joint. The result is a three-ply rubber sleeve which, because of its laminated structure, is extremely tough and durable. Because of its thinness and the fact that it is composed of new, live natural rubber, the sleeve is so resilient that it has no appreciable stiffness and has, therefore, no detectable effect on the test results that can be attributed to its physical character.

Because, in wrapping the cement-coated sheet on the mandrel, one of the uncoated ends is applied first and the other uncoated end goes on last, the inside and the outside of the finished sleeve are not fouled with unneeded cement. The operation of removing the sheet from the supporting frame and wrapping it on the mandrel requires considerable care to prevent folding, wrinkling, or creasing, and to maintain a suitable tension while the rolling is being done. The first few attempts are quite apt to be disappointing, but it will be found that a satisfactory technique can be de-veloped and that the resulting product is highly satisfactory from a technical standpoint.

To remove the finished sleeve from the mandrel it is simply rolled back at one end and turned wrong side out, the strip of tape being pulled loose from the mandrel in the process. Final preparation of the sleeve for installation in the cell consists of trimming off the inside flap formed by the tape and squaring the ends, also by trimming.

The sleeve is attached to the upper plate or plunger of the cell by first cementing and then wrapping with cotton cord or large rubber bands. As previously noted, it is attached around the bottom plate opening with two interlocking clamping rings which are screwed to the bed plate, the folds of the sleeve around the lower clamping ring constituting the seal gasket. The extra 2½ inches of sleeve length provided by cutting the orig-

Table 1.—*Effect of varying the asphalt content of bituminous mixtures on cohesion, friction, and unconfined compressive strength before and after immersion*

Parts asphalt ›er 100 of ıggregate	Results [1] of tests—						Retention of characteristics after immersion	
	On dry specimens			On wet specimens [2]				
	Unconfined compression	Cohesion	Friction	Unconfined compression	Cohesion	Friction	Retained strength [3]	Retained cohesion [4]
	P.s.i.	*P.s.i.*	*Tan ø*	*P.s.i.*	*P.s.i.*	*Tan ø*	*Percent*	*Percent*
2	290	52	1.19	....	....	....	....	....
2	268	....	....	113	23	1.08	41	44
4	374	81	.96	....	....	....	....	....
4	384	78	1.03	....	....	....	....	....
4	379	....	....	248	64	.74	65	81
6	376	87	.83	....	....	....	....	....
6	369	85	.85	....	....	....	....	....
6	392	....	....	276	79	.61	73	92
8	258	67	.70	....	....	....	....	....
8	248	....	....	220	64	.56	87	96

[1] Averages of three determinations.
[2] After immersion in water at 120° F. for 4 days.
[3] Retained strength = (strength after immersion ÷ average of dry strengths for same mixture) × 100.
[4] Retained cohesion = (cohesion after immersion ÷ average of dry cohesions for same mixture) × 100.

›p 10½ inches instead of 8 inches wide needed for making these connections and trimming.

Testing Practice

'igure 1 shows the cell in place on the ten of the testing machine with the air-ssure hose from the back-pressure regu-›r connected at the upper right of the . and the pressure gage mounted on the e of the cell. Tests are currently being de at cell pressures of 0, 30, and 60 ınds per square inch. Also shown in ure 1 is the compressometer that is used obtaining load-deformation recordings all the tests. The feeler of the com-›ssometer is actuated by a polished bear-; face in the stem of the upper bearing ıte of the testing machine on a line which an extension of the vertical axis of the t specimen. The recording drum may seen at the right of the large load indi-tor dial.

In conducting triaxial tests in the Public ›ads laboratory, as well as all other com-essive tests of bituminous paving mix-res, the specimens are stressed to failure continuously increasing loading and, erefore, continuously increasing deforma-›n. A rate of vertical deformation of 0.05 ›h per minute per inch of specimen height used. Thus, if the test specimen is 8 ›hes high, the platen speed is 0.4 inch r minute and for a 4-inch specimen it is : inch per minute. Although this unit te of deformation was selected somewhat bitrarily and possibly has no superiority er any other reasonable rate, it is ex-›mely important that all test results that e to be compared with one another for aluation of one or more characteristics ould be obtained under some inflexible t of standard conditions. The plastic or mi-plastic bituminous mixtures are es-cially sensitive to such factors as rate of formation and temperature. High rates deformation result in high cohesion values and high compressive strength values, while high temperatures have the opposite effect and result in low cohesion and compressive strength values. Therefore, the greatest care must be exercised to maintain the rate of deformation and the specimen temperature as nearly constant as possible during the tests.

Up to this point, the features and techniques having to do primarily with the production of satisfactory test data have been considered. Before presenting illustrative test data, mention should be made of the difficulty that was experienced in the early use of the triaxial test for bituminous mixtures because of the adhesion of the specimen to the rubber sleeve and to the upper bearing plate or plunger. A simple solution for this trouble was found to be a light dusting of the specimen with powdered talc just before making the test. This practice has not only eliminated the operational difficulties, but has added materially to the useful life of the rubber sleeve, first, by keeping it free of bituminous material which tended to soften it eventually and second, by protecting it to some extent from being punctured or ruptured by specimens having abrasive or porous surfaces.

A Cell Guard

A recent addition to the cell has been made to guard the operator against injury in case of failure of the lucite cylinder to withstand the internal air pressure. Recently, an operator in a State laboratory

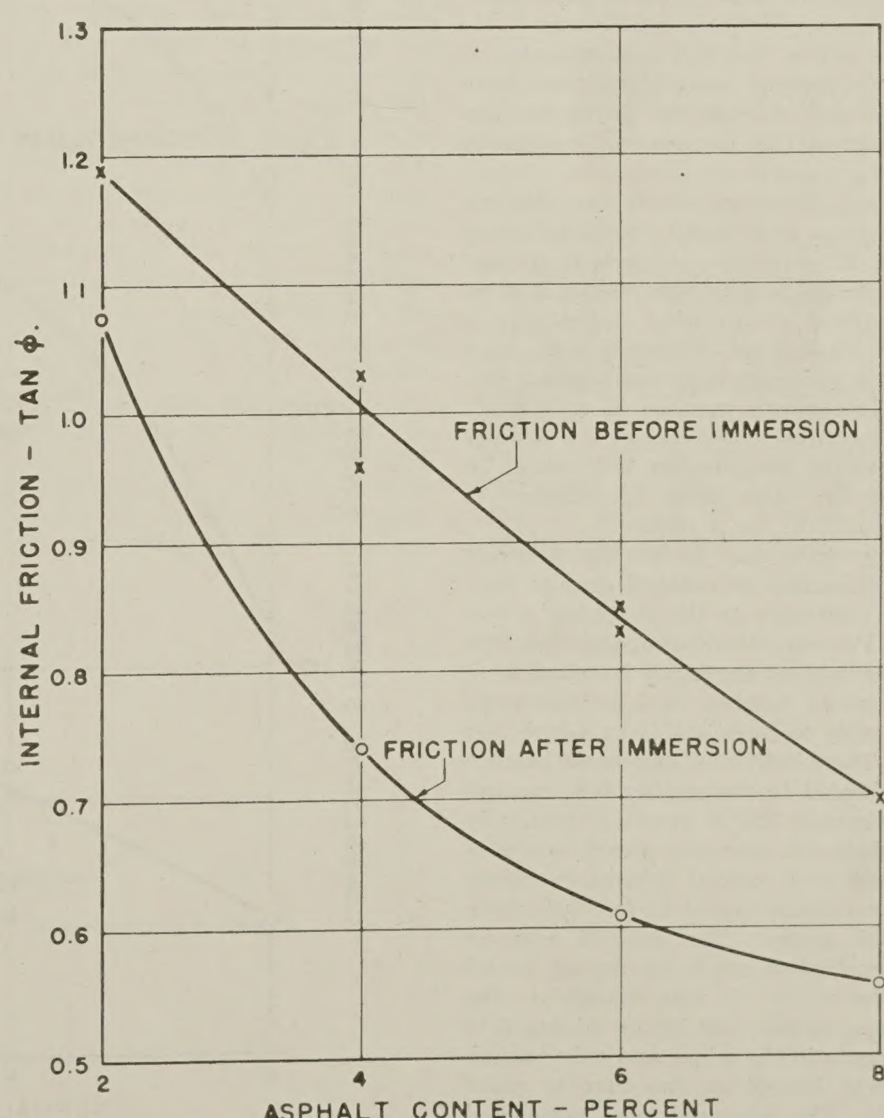


Figure 6.—Effect of asphalt content on internal friction and secondary effect of immersion.

was seriously injured by flying particles of lucite when the internal air pressure exploded the cylinder. The use of compressed air always entails the danger of an explosive rupture of the equipment. This danger is not present when a liquid pressure medium is used, unless the liquid is pressurized with compressed air. Figure 4 shows the protective addition—a perforated sheet-copper shield that has been placed around the lucite cylinder to cushion a possible rupture and to retard the flight of broken pieces of lucite. It is believed that this is an important precaution that should be taken even though the equipment may have been pretested at a pressure considerably higher than that to be used in normal operation.

Of course, the lucite might be replaced by a brass or steel cylinder, but the transparent cylinder has the definite advantage of permitting observation of test conditions, some of which have a bearing on the results, and the perforated copper shield does not interfere seriously with this feature of the lucite cylinder.

Preliminary Tests With New Cell

While the primary purpose of this paper is to describe the equipment that has been developed in the Public Roads laboratory for the triaxial compression testing of bituminous paving mixtures, it will be of interest to present some data that have been developed in order to convey an idea of how successfully the present equipment performs.

In table 1, there are shown the data resulting from a preliminary investigation of the effect of variations in asphalt content on the cohesion and friction values and on the unconfined compression values for a series of bituminous mixtures that were identical in all respects except asphalt content. A secondary purpose of this study was to determine the effect, on the triaxial and unconfined compression test values, of immersing the same series of mixtures in water at 120° F. for 4 days.

The aggregate used in all the mixtures was a combination of crushed granite having little resistance to the stripping action of water, Potomac River sand, and limestone dust. The various aggregate fractions were weighed out in batches, each of just sufficient quantity to form one 4- by 4-inch test cylinder. These individual aggregate batches were preheated to the mixing temperature of approximately 325°F. in an automatically controlled electric oven and then mixed with the asphalt in a special laboratory mixer having a maximum capacity of slightly more than 2,000 grams. The asphalt was an 85–100 penetration grade having an actual penetration of 95. It was brought to the mixing temperature just before adding it to the aggregate in the mixer and only enough asphalt was heated at one time to make one batch. The mixtures were compacted in a double-plunger cylindrical mold under a load of 3,000 pounds per square inch after first being carefully spaded around the edge and leveled in the mold to reduce surface voids and local strains during compression. This initial spading and leveling with a thin-bladed spatula has been employed for several years and has been found to aid materially not only in producing specimens of more uniform appearance, but specimens having more uniform densities and less aggregate degradation than was the case before it was adopted. The 4- by 4-inch specimens were used because it was desired to include the previously mentioned study of the effect of water and it had been found that 4- by 8-inch specimens were very difficult to handle after immersion without deforming them and rendering the test results somewhat erratic. All compression tests were made at 77°F. on both dry and wet groups.

Test Results

The data shown in table 1 have been plotted in figures 5–8 to show graphically the various relations to be investigated. Figure 5 shows the effect on the cohesion values resulting from varying the asphalt content from 2 to 8 parts by weight per 100 parts of aggregate, both before and after immersion in water. In the bottom curve, the gradually increasing tendency of the richer mixtures to resist the action of the water is shown by plotting the percentage of the cohesion of the dry specimens that was retained after the immersion period, against the asphalt content of the mixtures. The rise of the cohesion curves for both the dry and wet specimens from relatively low values for the lean mixtures to optimum values for some intermediate asphalt content and then the quick falling off of the cohesion values for the excessively rich mixture are characteristic. Of special interest is the indication, which might be expected, that the lean mixtures may be very susceptible to the action of water, while the 8-percent mixture, having its pore spaces virtually sealed or filled with asphalt, is almost unaffected by immersion insofar as the cohesion reflects this effect.

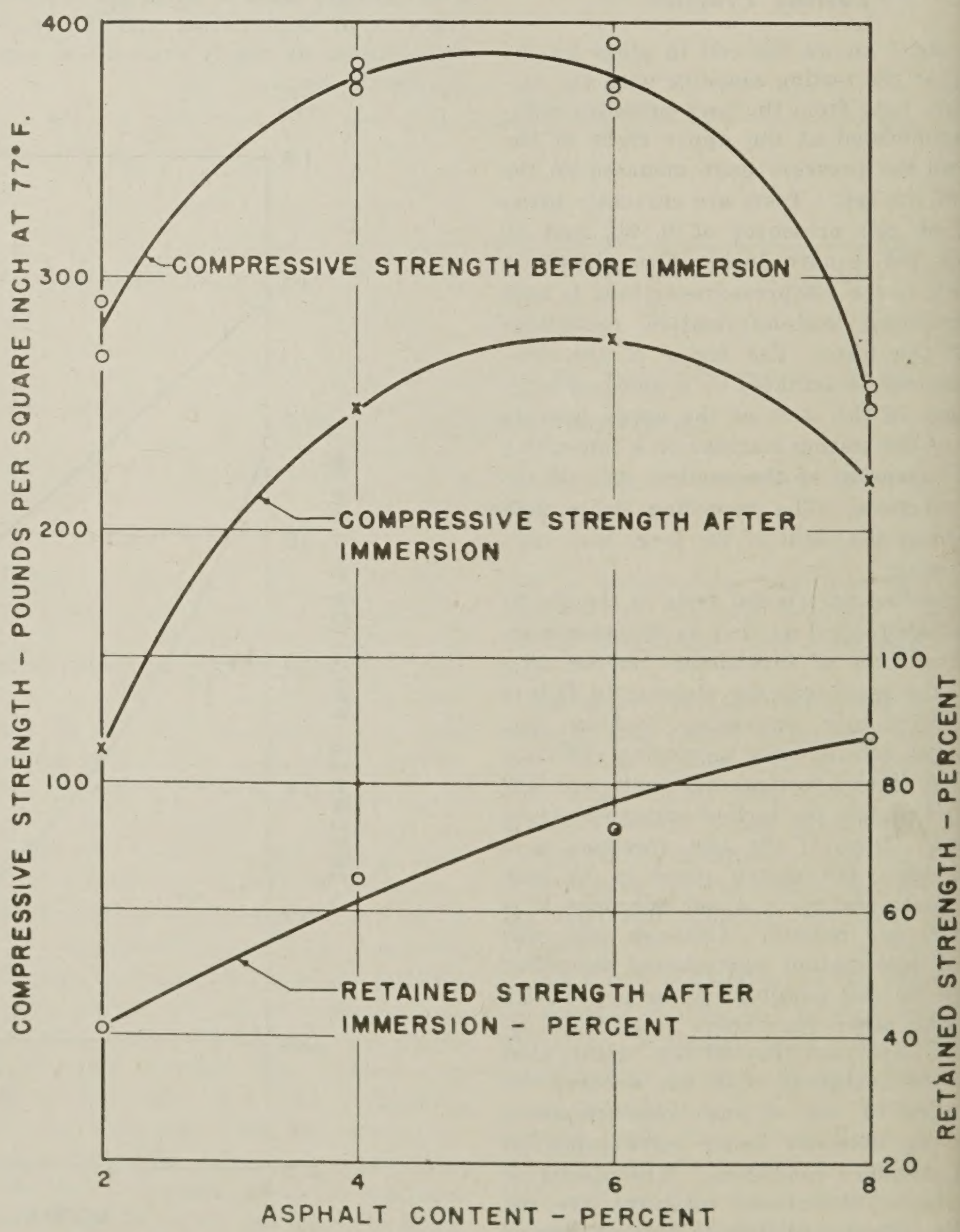
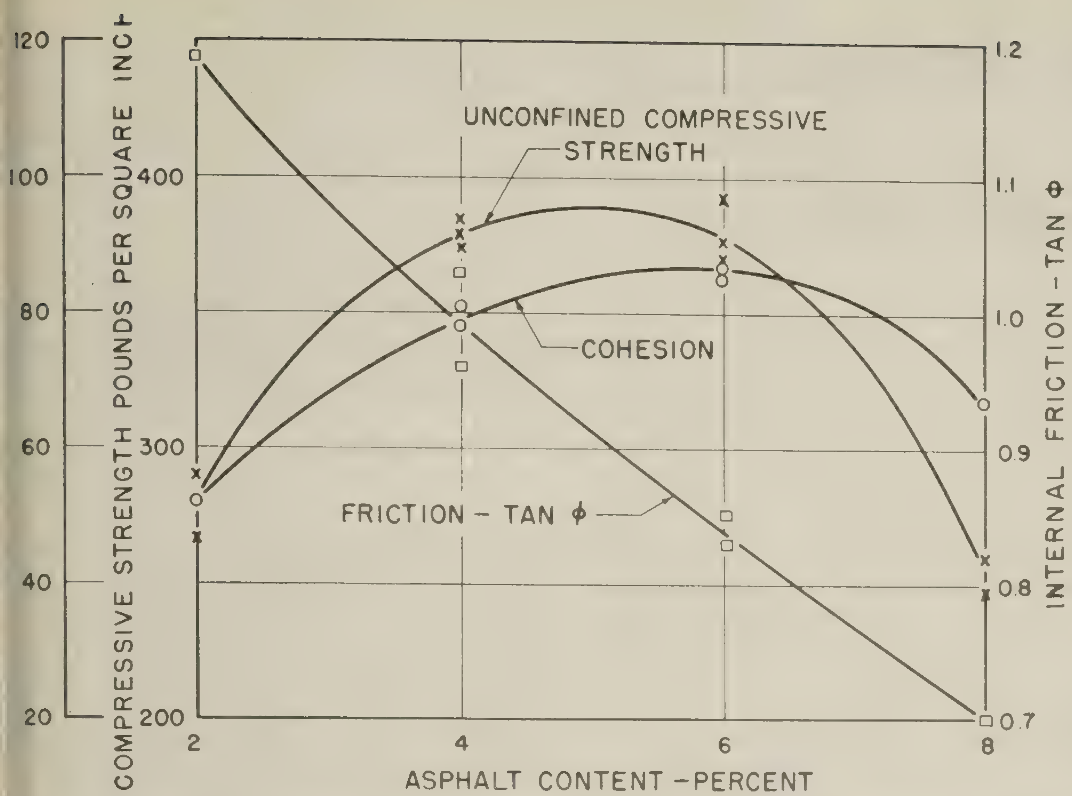


Figure 7.—Effect of asphalt content on unconfined compressive strength and secondary effect of immersion.



igure 8.—Effect of asphalt content on cohesion, unconfined compressive strength. and internal friction.

Figure 6 shows the effect of increasing ›halt content in reducing, at an almost iform rate, the internal friction of the xtures prior to immersion. On super- al consideration of the lower curve, show- ; the additional loss in friction when the ecimens were immersed, it might seem gical that the very lean mixture is af- :ted much less than any of the others, in- ding those of intermediate or near-opti- m asphalt content.

On more careful analysis, it appears that s might be explained in this way: The n mixture contains so little asphalt that internal friction is almost the same as it of the aggregate itself. However, it kes little difference how much water ers the mixture, insofar as the effect on ction is concerned, because water has such a low viscosity that without pore pressure it has almost no effect on the friction of granular aggregates. The mixtures of intermediate asphalt content still have enough pore spaces to admit considerable amounts of water, but the pore openings are probably enough restricted by asphalt so that, when the specimens are loaded, the water creates some pore pressure as shearing occurs and thus affects the internal friction to a marked degree. The very rich mixture admits little water and, therefore, as compared to the mixtures before immersion, is less affected than the intermediate ones. It seems fairly safe to assume that a little more asphalt would completely seal out the water and, at some point to the right, the two curves might become one. At such a point both the cohesion and internal friction would be so low that the mixture would have only as much supporting value as would be possessed by asphalt alone.

Figure 7 shows relations between unconfined compressive strength and asphalt content that are strikingly similar to the cohesion curves of figure 5, probably indicating that the unconfined compression values are affected more by the cohesion factor than by the internal friction. This is also indicated in figure 8 where the cohesion, unconfined compression, and friction values for the water-free specimens are shown in their relation to each other. However, the influence of friction is also to be seen in the compression values at the right, in that as soon as the cohesion values pass the maximum and begin to fall off the compression curve falls at an increasing rate, as if drawn downward by the rapidly falling friction curve.

While the test data that have been presented are not extensive, it being the purpose of this paper to describe certain developments in the equipment and techniques rather than to report extensively on the application, it is felt that they are consistent and indicative of the characteristics of the materials. In most respects, the data tend to corroborate the findings of other investigators who have used essentially similar equipment.

As to the choice of cell type, it appears that any one of several that are in use today can be used successfully. The widespread interest in the triaxial test and the numerous very stimulating papers and reports that have been written recently on the subject indicate that the triaxial test is definitely a valuable research tool. Its demonstrated value as such will justify considerable effort to select or develop the most convenient and dependable model possible and then to standardize it so that those who use the triaxial method of test may speak the same language when they want to discuss the factors that affect cohesion and internal friction.

Highway Control Sections
Their Establishment and Use

BY THE FINANCIAL AND ADMINISTRATIVE RESEARCH BRANCH BUREAU OF PUBLIC ROADS

Reported by GORDON D. GRONBERG, Highway Economist

The division of a highway system into permanently established highway control sections provides logical, practical, and convenient units for which a vast amount of highway cost and performance data may be recorded in an organized fashion. The use of a uniform accounting system is important if the data so compiled are to be of value.

Cost data obtained from control sections are used in the preparation of highway construction and maintenance budgets and for analyses and comparisons of construction and maintenance costs by surface types, roadway widths, surface thicknesses, year of construction, and topographic locations. Special investigations have been undertaken by control sections to study soil conditions, influence of traffic on various surface types, costs per vehicle-mile, and construction and maintenance economics.

THERE exists today in every State a great need for a centrally located and organized body of data relating to every phase of highway management, operation, and performance. The increasing demands for all kinds of information for planning, programing, administrative, and legislative purposes have highlighted this need. The most effective means of accomplishing the assembly of such a vast amount of data in an organized fashion is through the establishment of highway control sections.[1]

In essence, the control section procedure involves the division of the highway system into convenient, practical units for which design, construction and maintenance cost, inventory, and performance records are kept on a uniform and continuing basis. Once established, the units are permanently fixed so that records maintained through the years will be directly comparable. The control section system described in this article has already been adopted by 17 States.

One of the problems that has confronted the highway administrator has been the recording of highway expenditures in a manner that will permit comparisons of construction and maintenance costs for various sections of the highway system. It has generally been impossible, in the past, to correlate construction costs with maintenance costs, as maintenance sections were often consolidated, eliminated, or adjusted from year to year. The establishment of control sections and the reporting of construction and maintenance costs on a uniform basis will make these comparisons possible.

Uniform construction and maintenance operation and cost records kept for permanently designated control sections enable States to make comparisons of costs based on similar pieces of property; factual information can be obtained on various kinds of highway work as affected by climate, traffic, etc.; and studies can be undertaken on the annual costs for each control section.[2] The information is also of fundamental value in the management of a highway department on an efficient basis.

Nature of Control Sections

Highway control sections are segments of highway whose termini are county lines and major intersecting routes. In certain cases, other criteria such as changes in topography (mountainous or non-mountainous), traffic characteristics, and adaptability as maintenance sections have been used. Where a bridge is encountered at the termini of two control sections or at a county line, the bridge and approaches are usually included in their entirety in one or the other control section. In some States, because of shared financial responsibility, etc., it has been necessary to distribute a proportionate share of the cost of such bridges to each county. Major structures, interchanges, traffic circles, Y connections, ramps, etc., are included either with the control section on the main or through route or with the route on which they were constructed. These special highway facilities can also be set up as separate control sections, if desired.

The essential attributes of a desirable control section are fourfold. The control section should be, first, a unit with a reasonably uniform traffic volume throughout its length; second, a logical unit for development to the same general type and standard; third, a practical unit for reporting maintenance costs; and fourth, a convenient unit for the compilation of statistical and research data involving the assembly and correlation of construction and maintenance expenses, service-life characteristics, traffic data, design standards, etc.

The length of control sections varies, depending on the frequency of intersections, changes in topography, etc. In the eastern part of the United States the average length is 5 to 8 miles, in the central part from 10 to 12 miles, and in the western part from 15 to 18 miles.

Once established, control sections are permanent units of the highway and are not to be changed except as necessitated by relocation or where extensions of or additions to the highway system are encountered in the future. These control sections are utilized by each division of the highway department—planning, programing, right-of-way, design, construction, maintenance, and accounting.

Control sections have already been adopted in 17 States, and are under discussion in many of the remaining States. Control sections are established on the entire State highway system. In a few States they have also been established on the State-aid roads in addition to the State highway system. It is of interest to note that control sections have been put into use in Puerto Rico and in Turkey.

The general objectives of the control section procedure are clear cut and should not be made complicated or rendered burdensome by the incorporation of too much detail. Further, before control sections are put into operation the field personnel should be carefully schooled and fully instructed in the most practical methods of reporting operations and costs.

[1] *Highway control sections,* by Fred B. Farrell. American Highways, vol. 25, No. 1, January 1946. Published by the American Association of State Highway Officials. *Also,* Report of the Committee on Highway Costs, Department of Economics, Finance, and Administration, Highway Research Board. Highway Research Correlation Service Circular No. 61. May 1949.

[2] *A procedure for determining the annual cost of a section of rural highway,* by H. W. Hansen. PUBLIC ROADS, vol. 26, No. 7, April 1951.

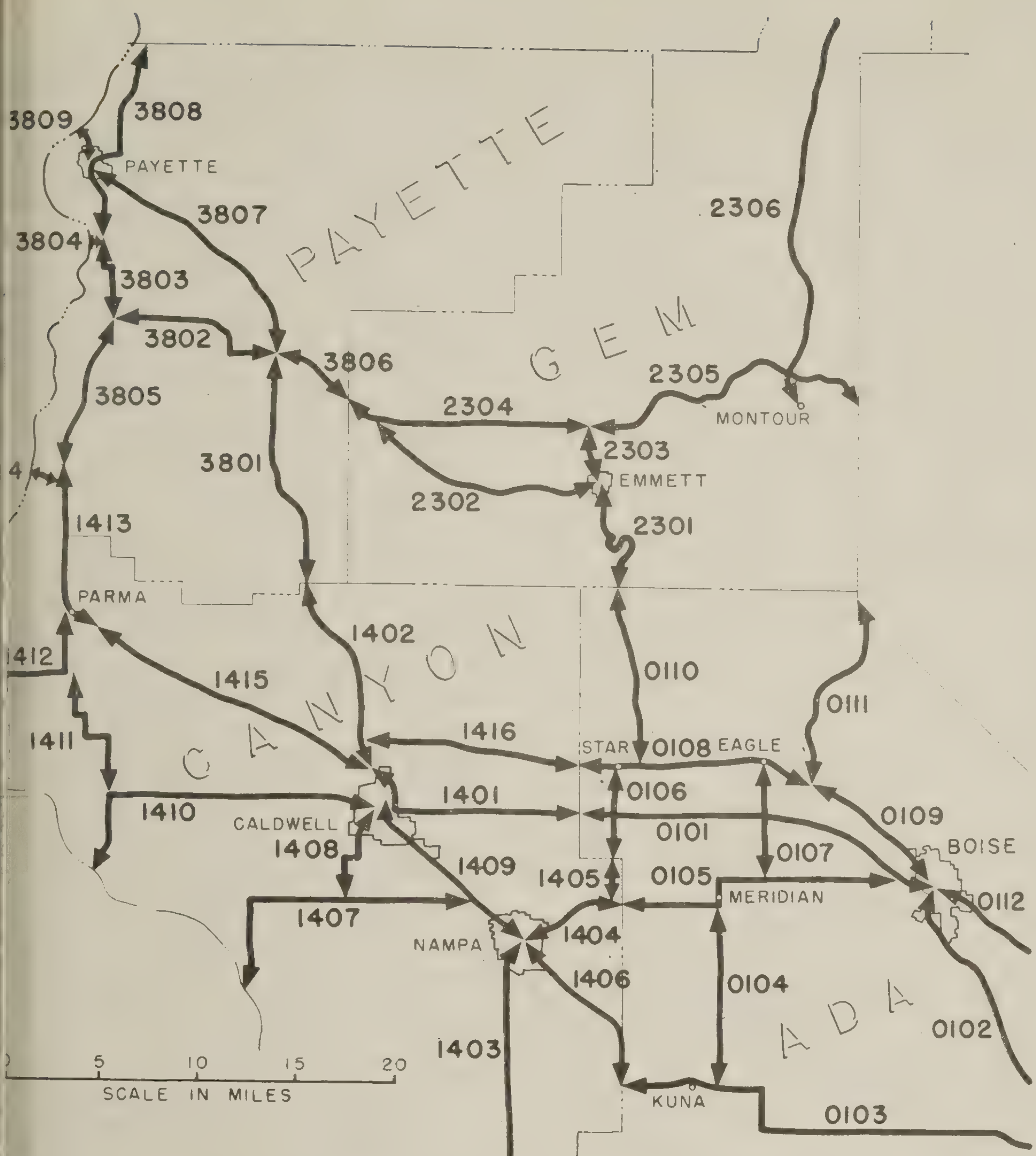


Figure 1.—A portion of the control section system in Idaho.

Establishing Control Sections

For an average State the establishment control sections on the State highway stem, involving selection and designation termini and other preliminary work cessary in outlining a general plan of eration, can usually be accomplished in or 3 weeks. In making the change-over the new procedure, the work of drafting ntrol sections on county maps, preparing ntrol section descriptions, revising pay ll and other forms, and instructing field rsonnel in the use of new forms and ding procedures ordinarily takes from to 8 months.

A control section committee, composed of e heads of the various divisions of the ghway department, is usually organized ien a State undertakes the establishment control sections. Any proposed changes control section termini or the addition new sections due to relocations or additions to the system are subject to the review id approval of the committee. It is also e function of this committee to supervise e drafting of control sections on county aps, to write control section descriptions, prepare manuals of instruction for reporting costs by uniform cost classification, and to coordinate its activities with those of the Bureau of Public Roads in Federal-aid route and project numbering and other matters of joint interest.

Once control sections have been established, a special project under the highway planning division of the State highway department can be set up to bring the historical construction data, particularly construction costs, up to current status on a control section basis for use in various types of economic road cost analyses.

Numbering and Termini

It is general practice to use a four- to six-digit number to identify the control section. The first two or three digits usually indicate the county number in alphabetical order, and the last two or three digits indicate the section number within the county.

Figure 1 shows a portion of the control-section set-up established in Idaho. These control sections are a fixed series of road sections upon which all construction costs, maintenance costs, traffic, and other operational data are kept by the State as a matter of permanent record.

Figure 2 illustrates the suggested procedure for handling control section termini at rural road intersections. As shown at the left in the figure, where the main route intersects a secondary route, the main route is continuous and the secondary route breaks at the intersection. As shown at the right in the figure, where the main route intersects a more important secondary route, the volume of traffic at the intersection warrants a break in both routes. This can be handled by dividing the main route into two control sections with a Y connection in each section, or by treating the entire intersection as a separate control section.

The principle of control sections can also be applied to city streets, in which case each block and each intersection becomes a control section.[3] Figure 3 illustrates the method of establishing control sections in cities.

[3] *Milwaukee methods of determining and controlling lengths of blocks and intersections*, by R. W. Gamble. Proceedings of the Highway Research Board, vol. 26, 1946.

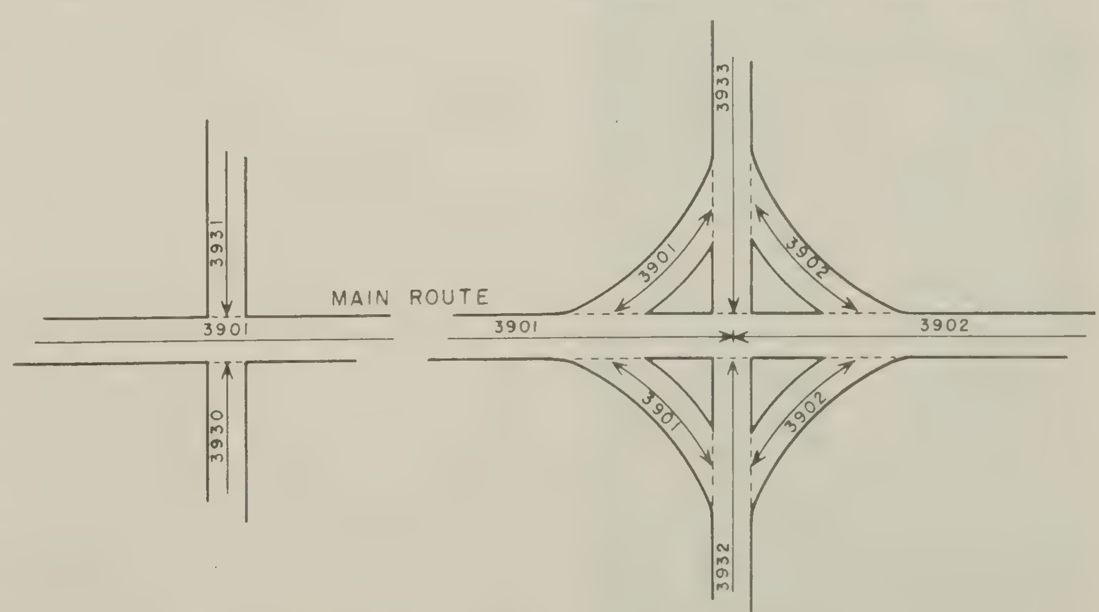


Figure 2.—Control section termini at rural intersections.

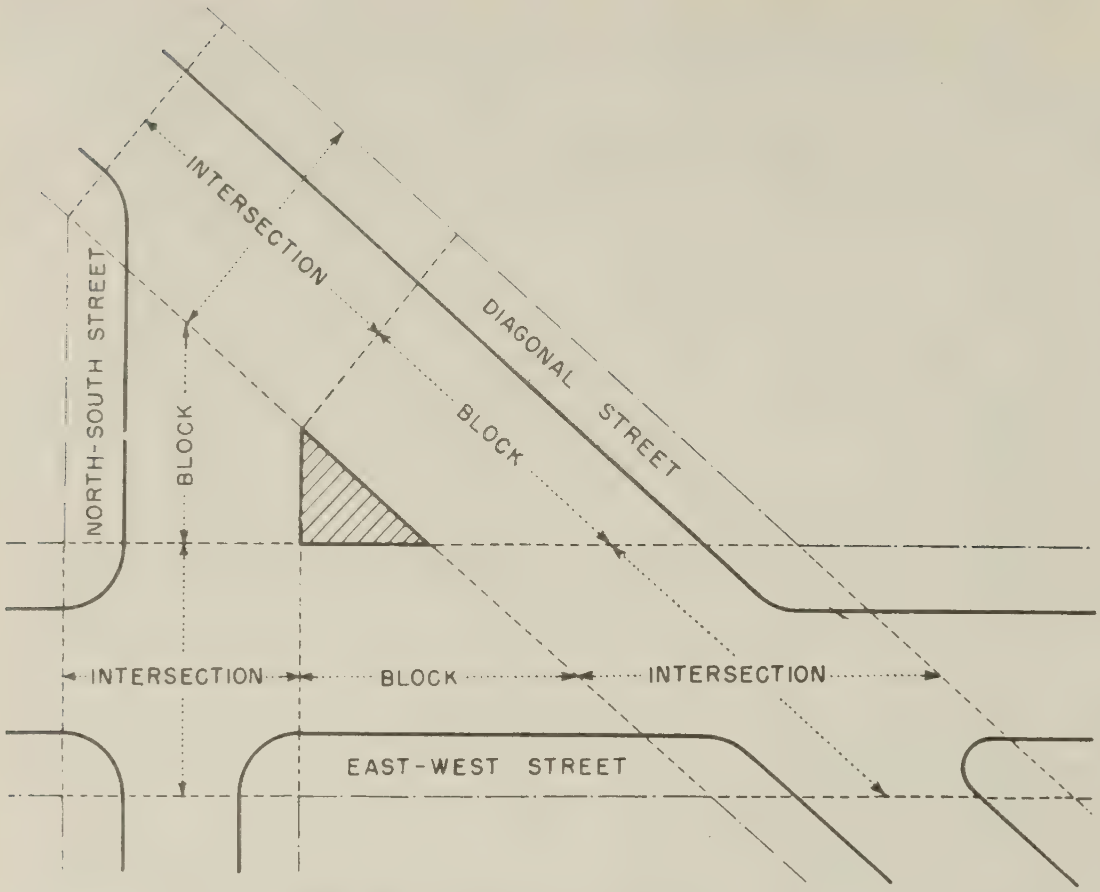


Figure 3.—Control section termini in a city.

Figures 4 and 5 are examples of the methods that have been used by various States to physically designate control section termini. In Maine (fig. 4), the control section number that can be seen from the road is the section being entered. In Nevada (fig. 5), the posts are set at an angle and both control section numbers are visible from the road. Control sections in Nevada are designated by two letters and two numbers, the former identifying the county and the latter identifying the control section within that county.

Figure 4.—A Maine control section marker.

Subsections

The various divisions of the highway department may, for their own purposes, desire to break down control sections into smaller segments. To accomplish this, control sections can be divided into subsections at urban limits, changes in surface type, variation in widths and ages, and for such highway facilities as bridges, interchanges, traffic circles, and grade crossings. Subsections are also utilized for traffic or accident studies, soil condition surveys, or any special purpose or study that a State desires to undertake. The establishment of subsections is ordinarily left to the discretion of each division of the highway department. Accordingly, the subsections may not be uniform among the various divisions.

There is no specifically recommended system of numbering subsections. One system in use involves numbering subsections consecutively within a control section, utilizing a two- or three-digit number. If it is desired to identify particular types of highway facilities, then blocks of numbers can be used for unincorporated or incorporated areas, bridges, special types of intersections, traffic circles, etc.

Another system uses, as an identifying number for each subsection, the distance, in hundredths of a mile, that the subsection is from the western or southern end of the control section. It may be preferable to ignore the actual direction of the individual control section and use the prevailing direction of the route on which the control section is located. In this manner, all subsections will be numbered according to mileages measured in the same general direction on any particular route, thus facilitating the preparation of logs, etc. If this scheme is used the first subsection within each control section will be numbered 0000, indicating that the subsection starts at one end of the control section. A subsection numbered 0351 would be the subsection starting 3.51 miles from the western or southern end of the control section.

Uniform Cost Accounting

From the standpoint of keeping cost records, only part of the job has been accomplished when control sections have been established. It is equally important that the costs themselves be reported on a uniform, logical, and practical basis.

The adoption of a uniform system of accounts by State highway departments will enable comparisons of costs and accomplishments among States to be made which would lead to more effective ways and means for planning, programing, constructing, and maintaining highways. Similar advantages can be obtained by local governmental units having responsibilities for road affairs.[4]

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[4] *Is cost accounting worth its cost [to counties?]* Better Roads, vol. 20, No. 9, September 1950. *A uniform cost accounting system for Wisconsin county highway departments*, by W. B. Blair, Western Builder, June 1, 1950. *A standardized system of fiscal and cost accounting* (manual for the office of the county engineer in the counties of Kansas), by a Committee of the Kansas County Engineers Association, August 19..

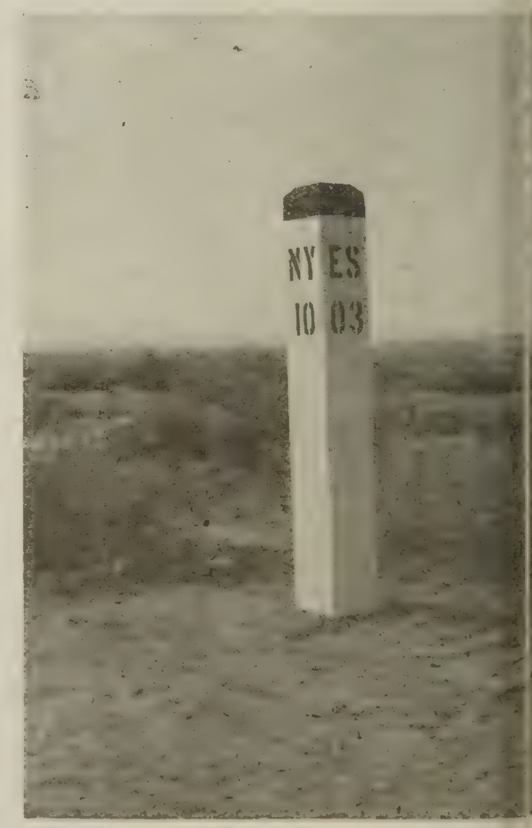

Figure 5.—A Nevada control section marker.

he construction and maintenance cost reported by control sections are being by the officials of the State highway artments in planning financial, construc-, and maintenance programs. One of more recent uses being made of the truction and maintenance cost data is determination of the annual cost of ions of the highway. Such work is cur-ly under way in connection with the ial load-condition surveys.

practical and efficient system of cost unting has long been recognized as an ntial part of the routine functions of ghway agency. The generally accepted le on accounting procedures is the pre-inary manual of accounting procedure State highway departments prepared by Subcommittee on Uniform Accounting he American Association of State High- Officials. In a 1949 survey [8] of the unting procedures of the State highway artments it was found that there were 10 States which kept construction cost unts that conformed to or had only or deviations from the recommended ac-nts of the Subcommittee. In 3 States construction accounts had major devia-s from the recommended accounts, and 35 States no classified construction ac-nts were kept at all.

ccording to the survey, however, even in tes which have established uniform con-uction and maintenance cost accounts re are cases where sound accounting ctices are violated to an extent that im-rs the value of the cost records obtained. of the most frequent deviations from recommended procedures is in the pro-ing of many items of expense.

ne of the objectives of the uniform ac-nting system is to show the true expen-ures for construction and maintenance, ardless of whether construction or main-ance funds are involved, whether the k is done by contract or day labor, or ether it is performed under the super-ion of construction or maintenance divi-ns. In many States, additions and bet-ments to the highway system are done maintenance forces and paid for from intenance funds. Since additions and terments are construction and not main-ance, in that they are capital invest-nts which increase the value of the high-y facilities, they should be reported as struction even though maintenance funds used and maintenance personnel per-m the work.

Construction Cost Accounts

onstruction cost accounts have been rec-mended by the Subcommittee on Uniform counting of the American Association of te Highway Officials for recording con-uction operations, and have been adopted 17 States in connection with the establishment of control sections. The recommended construction accounts are as follows:

1. *Right-of-way:*
   - Purchase cost.
   - Costs in lieu of purchase.
   - Damages.
   - Expenses.
   - Right-of-way fence costs.
   - Right-of-way marker costs.
2. *Preliminary engineering:*
   - Salaries.
   - Expenses.
   - Equipment rentals for field parties on reconnaissance.
   - Materials investigations.
   - Foundation tests.
   - Office engineering in connection with field surveys.
   - Plans and estimate preparations.
   - Supplies for field parties.
3. *Construction engineering:*
   - Salaries.
   - Expenses.
   - Supplies.
   - Equipment rentals for field engineering.
   - Inspection costs.
   - Office engineering expenses.
   - Materials testing and inspection.
   - Preparation of final reports.
   - Project and station markers.
4. *Roadway drainage and grading:*
   - Clearing and grubbing.
   - Excavation of earth and rock.
   - Fine grading and excavation of subgrade.
   - Overhaul.
   - Borrow.
   - Back sloping and finishing earth shoulders.
   - Purchase cost of earth fill for roadway when title to land remains with seller.
   - Grading for approaches and driveway entrances.
   - Widening of shoulders, fills, and grade line changes.
   - Moving buildings, structures, and fences when not a right-of-way consideration.
   - Selection of material for subgrade.
   - Frost boil prevention work.
   - Rolling and compacting fills.
   - Shoulder lift when required by resurfacing roadway.
   - Fills for bridge and overpass approaches.
   - Open drainage ditches.
   - Channel changes.
   - Tile and other subdrains, except beneath roadway surfaces.
   - Dikes and levees.
5. *Drainage and earthwork protective structures:*
   - Culverts of 20-foot span or less.
   - Farm entrance culverts.
   - Flumes and wash checks.
   - Storm sewers.
   - Retaining walls.
   - Riprap and revetments.
   - Jetties, cribbing, and rock fills.
   - Slope walls.
   - Cattle passes and cattle guards.
   - Slope drains, catch basins, and manholes.
   - Gutters when not integral with roadway surface.
6. *Roadway surface and base:*
   - All materials used for subgrade treatment, and for base or roadway surface.
   - All materials used for curb and gutters when integral with surface and base.
   - Additions of bituminous seal coats, surface treatments, mats, or retreads which add ¾ inch or more in thickness in one operation.
7. *Improved shoulders and approach surfacing:*
   - Surfacing of shoulders, side approaches, and turnouts where type of material used is superior to adjacent roadside and inferior to roadway surface.
8. *Bridges, viaducts, grade separation structures, and tunnels:*
   - Structures over 20-foot span.
   - Excavation for above.
   - Excavation for approach structures (earth fill approaches included under roadway).
   - Concrete, steel, and wood structural work.
   - Protective structures of riprap.
   - Breakwaters, cribbing, retaining walls, and pier protection.
   - Roadway paving and sidewalks when integral with structure.
9. *Traffic and pedestrian service, and miscellaneous facilities:*
   - Guard fences.
   - Guide posts.
   - Permanent snow fences (structures or plantings).
   - Route and direction markers.
   - Signs.
   - Safety and signal devices.
   - Railroad crossing signals.
   - Highway lighting.
   - Pedestrian underpasses and overheads.
   - Sidewalks.
   - Permanent traffic lane stripes.
10. *Roadside development:*
    - Initial seeding, sodding, and planting of shoulders, back slopes, and roadside for the purpose of landscape and for protection of earthwork.
    - Bridle paths.
    - Roadside parks.
    - Picnic grounds.
    - Shelter houses.
    - Diversion ditches for protection of plantings.

Costs of adjustment of utility and other property, and detour expense during construction, where these items are carried separately in the contract pay items or where the work is done by day labor, may be classified separately if the State so desires, or they may be allocated to whichever

[8] *Status of fixed asset and maintenance cost accounting by State highway departments*, by the Committee on Highway Costs, Department of Economics, Finance, and Administration, Highway Research Board. Highway Research Correlation Service Circular 76, August 1949.

of the construction cost classifications they are applicable.

Reporting total construction costs of a completed project or addition and betterment job by these construction classifications will necessarily require a recapitulation of the items in each contract. This can be most satisfactorily accomplished by requiring that preliminary estimates, contractor's estimates, final vouchers, etc., show the groupings of the individual items into major classifications.

Maintenance Cost Accounts

The following maintenance cost accounts, recommended by the Subcommittee on Uniform Accounting, are in operation in the majority of the State highway departments:

1. *Routine roadway surface operations:*
    - Patching holes and rough spots.
    - Patching ruts and blow-ups.
    - Repair of raveled edges.
    - Sanding bleeding spots.
    - Spot sealing.
    - Temporary traffic ways.
    - Dragging.
    - Blading.
    - Reshaping.
    - Scarifying.
    - Cleaning and raking.
    - Picking up oversize rock.
    - Filling and trimming expansion joints and cracks.
2. *Special roadway surface operations:*
    - Application of dust palliatives when done annually or when the application does not result in a permanent improvement.
    - Replacement of sand, sand-gravel, gravel, crushed stone, etc., on the same or a similar type of surface.
    - Reprocessing or reconditioning bituminous surfaces or shoulders when little or no new materials are added.
    - Bituminous surface treatment.
    - Seal coating, when applied later than the following construction season.
    - Light road-mixing operations.
    - Major patching by special crews.
    - Mud-jacking.
    - Protection and handling of traffic during above operations.
    - Addition of mats or retreads less than ¾-inch thickness.
3. *Shoulders and side approaches:*
    - Patching.
    - Dragging.
    - Blading.
    - Filling ruts.
    - Replacing washouts.
    - Reseeding or resodding, including original seeding on old work.
    - Ribbon bituminous treatment (without excavation).
    - Second or subsequent bituminous treatment.
    - Replacement of gravel or stone.
4. *Roadside and drainage:*
    - Repairing cuts, fills, slopes, and washouts.
    - Removal of minor slides.
    - Cleaning or retrenching drains, channels, and culverts.
    - Maintaining drainage structures (20 feet or less).
    - Removal and burning of weeds.
    - Removal of debris.
    - Planting or removal and trimming of trees.
    - Brush removal.
    - Planting or removal of shrubs.
    - Seeding and sodding to prevent erosion.
    - Care and replacement of special roadside development projects.
    - Repair and maintenance of sidewalks, dikes, riprap, retaining walls, pumping stations, slope pavement, right-of-way fences.
5. *Traffic services:*
    - Repair, repainting, and resetting of direction markers, route markers, signals, and gates, and the other safety devices.
    - Magnetic dragging to remove iron.
    - Traffic lane and guide line painting.
    - Repair and repainting of guard rails.
    - Highway lighting.
    - Electricity for the operation of signals.
    - Operation of comfort stations and picnic grounds.
    - Detours not chargeable to construction or other maintenance operations.
6. *Snow, ice, and sand control:*
    - Erection and removal of snow fence.
    - Removal of snow and ice.
    - Sanding icy surfaces.
    - Snow and ice removal to open waterways.
    - Removal of sand drifts.
7. *Structures (more than 20 feet in length):*
    - Repair, maintenance, and operation of:
        - Bridges.
        - Tunnels.
        - Subways.
        - Overhead grade separations.
        - Other structures.
    - Operating expense of ferries.
8. *Extraordinary maintenance:*
    - Special repairs and maintenance due to flood, storm, fire, major landslides or other catastrophe on:
        - Roadway surface.
        - Roadbed.
        - Shoulders.
        - Roadside.
        - Drainage facilities.
        - Safety devices.
        - Structures.
    - Handling and protecting traffic during emergency.
9. *Maintenance general expense:*[6]
    - Prorata of district office and/or headquarters office expense chargeable to maintenance.
    - Field maintenance supervision.
    - Purchase and repair of small tools.
    - Rental charges on inactive equipment.

Maintenance costs should be further broken down into objects of expenditure. The following objects of expenditure are s gested by the Subcommittee on Uniform counting: (1) Materials, supplies, and s ices; (2) salaries and wages; and equipment operation. A further breakd of these objects will depend on the requ ments or desires of each State high department.

Problems Encountered

The establishment of control sections the adoption of uniform cost accoun procedures have posed many problems the States. There are no standard gu to follow in solving these problems; far they have been handled individuall each State. However, so that the cost formation from States that have ado uniform accounting and cost keeping cedures will be on a uniform basis, st should be given to the solution of t problems, and recommendations prepa for consideration and adoption. Some the problems that have been encount are detailed in the following paragraph

Equipment rental rates.—It is essen that the States which adopt control sect and uniform accounting have equipm rental rates so that proper charges ca made to the control sections on which w by State forces is performed. In s States rates are already established an operation while in others it is necess that they be computed. These rental r usually include depreciation, repairs, f oil, storage, shop overhead, and insura The application of the rates varies f State to State. Some include the tr time of the equipment to and from the while others charge only the actual t the equipment is in operation at the job s

Travel time.—When labor is paid for t to and from the job and travel time du the day between jobs, the problem ar as to the proper procedure for charging this travel time. Whether the char should be made on a daily basis to con sections on which work was performed held in suspense and distributed o monthly basis must be determined. If charges are made directly to control tions, those which are the greater dist from the garage or district office are nalized by excessive travel time.

Sign and marker costs.—Some State h way departments manufacture their road signs and markers. Costs are in a suspense account and distributed the basis of the number of signs markers used in each control section. other States the costs of the signs markers are determined by the previ year's costs and the overruns or underr (over or under a specified percentage) corrected at the end of the year.

Labor, equipment, and materials char —The reliability of the distribution of m tenance cost data in large measure depe upon the accuracy with which labor, eq ment, and materials are charged by foremen or timekeepers to individual

[6] Suspense account, prorated to other cost items during or at the end of the accounting period.

of road. Constant check-ups accom- ed by simplification of burdensome or licated cost keeping procedures should corporated as part of the administra- control exercised over maintenance ations.

ederal-aid Route Renumbering

connection with the establishment of rol sections in recent years it has been practice of most States to avail them- s of the opportunity to renumber the ral-aid routes and redesignate the ral-aid projects. When adapting the ral-aid procedures to a control section p in a particular State, it is desirable such changes as are necessary be ac- plished with the minimum number of stments. The expansion of the Fed- -aid systems in the past has been ac- plished by chronologically numbering es as they were added, with the result there is no logical pattern of number-

overcome this deficiency, many of the es have employed a numbering proce- which gives the approximate geograph- location of a route within a State. In procedure, continuous routes within or ss the State are selected in accordance present-day traffic patterns. They are numbered from south to north and n west to east; with sufficient numbers g skipped to provide for expansions, as es are added or modified, without losing initial advantage of the geographical ngement.

oute numbers 1 to 9 are usually re- ed for the interstate system, 10 to 99 the Federal-aid primary system, and to 9,999 for the Federal-aid secondary em. This system of numbering, where number of digits identifies the road em, will not be adequate for those tes where the Federal-aid primary sys- routes are in excess of 99.

ederal-aid Project Redesignation

he Federal-aid highway system in the iority of States is composed of numerous rt Federal-aid projects for which the ject number does not indicate system or te identification. When redesignating Federal-aid projects, the old Federal- projects are handled as complete units order to preserve the integrity of the leral-aid records that have accumulated ing the past 30 years. To accomplish s objective, the Federal-aid system is ided into new Federal-aid route sections, varying in length up to 100 miles, which embrace one or more complete old Federal-aid projects. Federal-aid route sections are numbered from west to east for routes originating in the west and from south to north for routes originating in the south. Projects are numbered with the digits preceding the dash representing the route number and the digit following the dash representing the route section number. For example, the first improvement on route 1, route section 1 would be designated as 1–1(1) in which the number within parentheses represents the project agreement number.

Figure 6.—Route sections and control sections on a portion of Maine Federal-aid route 1.

For the Federal-aid secondary system, the routes are not divided into sections and the entire route becomes the project. For example, the first improvement on route 100 would be 100(1) in which the number within parentheses represents the project agreement number.

Figure 6 shows a section of Federal-aid route 1 in Maine that has been renumbered to conform with the new numbering procedure, divided into route sections (new Federal-aid projects) which contain a number of old Federal-aid projects in their entirety, and broken down into control sections for record keeping purposes.

Federal-aid route 1 is not to be confused with U S or State route 1. Federal-aid route numbering and U S or State route numbering are not necessarily colinear. For example, in figure 6, the portion of Federal-aid route 1 south of Brunswick is U S 1, from Brunswick to Winslow is U S 201, from Winslow to Newport is State routes 11 and 100, and from Newport to Bangor is U S 2.

Design Problems in the Use of Local Aggregates for Bituminous Surface

BY THE PHYSICAL RESEARCH BRANCH
BUREAU OF PUBLIC ROADS

Reported [1] by J. T. PAULS, Principal Highway Engi
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Local aggregates often have to be used in constructing hot-mix bituminous road surfaces, sometimes in areas of severe or unusual climate. If the aggregates are substandard in quality or gradation, special design problems are involved which must be given careful attention. This article describes several studies of this nature.

Three points of timely interest relating to design are emphasized in these studies. First, the effectiveness of chemical additives in preventing water damage to hot asphalt mixtures has not been clearly established. Second, while crushing of rounded or weathered aggregates may increase resistance of the mixture to displacement in a dry condition, it may at the same time reduce the mixture's resistance to water action. Third, the behavior of mixtures containing both clay and limestone is unpredictable when subjected to water action.

BITUMINOUS road surfaces of the hot-mix type must often be constructed in areas where the use of local aggregates is imperative. In many cases, these local aggregates fail to meet recognized standards with respect either to quality or to gradation. Their successful use in bituminous mixtures, therefore, requires the solution of special design problems. These problems may be complicated when bituminous surfaces are to be built in regions where severe or unusual climatic conditions prevail.

It is the purpose of this report to describe briefly several examples of design studies of this nature. These examples illustrate some of the special considerations that must be taken into account when the contemplated construction involves the use of local aggregates having unusual properties, or when the bituminous roadway will be subjected to severe weather conditions. It is believed that a discussion of these studies will be of general interest to those who may encounter similar problems.

The data presented in this paper were abstracted from unpublished reports of laboratory studies of bituminous mixtures in which the use of local aggregates was an important factor. Each study was selected for inclusion by reason of some distinguishing feature requiring special consideration in design. Each also represents an area of differing climatic condition—southern Alaska, northern Alaska, and one of the Gulf States.

The first Alaska study was featured by the hydrophilic properties of most of the aggregates and the importance of this property in a region of heavy rainfall. Features of the second Alaska study were the unstable character of the natural aggregate and the severe weather conditions. The principal feature of the Gulf State study was the necessity to choose between using local aggregate in a relatively low cost sand-asphalt surface and using imported aggregate in a more expensive bituminous concrete.

Observations of Interest

The test results obtained in these studies either developed or emphasized three points relating to design that are of timely interest. First, the effectiveness of chemicals added to asphalt in preventing water damage to hot mixtures has not been clearly established. Second, although crushing of round and weathered particles of aggregate increases resistance of the mixture to displacement in a dry condition, it may have the effect of reducing the resistance of the mixture to water action, due to changes in surface characteristics of the particles other than angularity. Third, the behavior of mixtures containing both clay and limestone, when subjected to water action, is unpredictable. The behavior appears to be somewhat dependent on the kinds of c and limestone involved.

In abridging the studies for inclu in this report, it was thought desirable present only those phases of design that sumed importance owing to singularitie the local conditions. For this reason studies as presented should not be con ered as being patterns of general des procedure. It is believed, however, that information developed will be found value in dealing with similar problems countered in designing bituminous mixtu around the use of other local aggrega

Study 1.—SOUTHERN ALASKA

In this study, investigating local ag gates from a number of sources in south Alaska, it was desired to obtain informat relating to the use of these aggregates bituminous mixtures, with particular erence to resistance to the action of wa In case mixtures containing these ag gates were found to be unsatisfactory this respect, it was desired to determ whether improvement could be made using asphalt treated with a chemical ditive. This aspect of design was of sential importance because of the extrem wet climate of the region, the annual ra fall being about 90 inches.

Although aggregates from 13 sour were included in the study, information only one will be described here, in the terest of brevity. The methods used testing this particular aggregate will se as an example of the general procedu used with all the materials in the stu Several special mixtures containing this gregate were prepared, and the results the tests on these mixtures are of particu interest.

Petrographic analysis showed this m terial to consist of rounded and subangu schist, granite, gneiss, quartz, and gra diorite. Its apparent specific gravity w 2.74. Prior to preparing bituminous m tures, the aggregate was separated o

[1] Paper presented at the 1949 annual meeting of the Association of Asphalt Paving Technologists.

Table 1.—*Gradation of aggregate, study 1*

Passing sieve size—	Material as received	Material as used
	Percent	*Percent*
½-inch	80	
inch	72	
-inch	66	100
;-inch	58	88
;-inch	54	80
o. 4	42	64
o. 10	31	46
o. 40	8	12
o. 80	1.4	2
o. 200	.4	1

ch sieve and the oversize material re- d. The gradings of the sample as re- d in the laboratory and of the material ed in the mixtures are shown in table 1. ree groups of mixtures were then pre- d, using 85–100 penetration asphalt. first group contained untreated as- . The others contained asphalt treated a chemical additive in the proportion and 2 percent by weight of the asphalt. ll these mixtures 4.5 parts of bitumen 00 parts of aggregate, by weight, were . Cylindrical specimens 4 inches in eter and 4 inches high were molded each mixture, and immersion-compres- tests made. The procedure used in aring the mixtures and testing the imens was that described in PUBLIC os in 1948 [2]. The test results are shown ble 2 (mixtures 1–3).

Results of Tests

he results of tests on the three groups ixtures showed compressive strengths the dry specimens that, while not high, ld be considered adequate. Tests on specimens after immersion showed that mixture containing untreated asphalt been damaged considerably in the soak- process. Although the stability-reten- values of the mixtures containing ted asphalt were higher than those con- ing untreated asphalt, the results ved that the additive in either propor- used was not highly effective in pre- ing damage by water action. It there- seemed desirable to determine whether not resistance to the action of water could be improved by means other than treating the asphalt.

Former work had indicated that the stability-retention of mixtures may often be improved by incorporating a hydrophobic filler. Accordingly, another mixture was prepared using untreated asphalt. In the prior untreated-asphalt mixture the only filler had been the 1 percent of natural dust. In the second mixture (No. 4 in table 2) limestone dust was added to the aggregate in an amount sufficient to produce a combined aggregate having 6 percent passing the No. 200 sieve. This increase in filler permitted the use of 5 percent asphalt. In preparing the mixture for the last specimen of the usual set of six, 0.5 percent hydrated lime was added to the batch after the asphalt had been added. Immersion-compression tests were then made on these specimens, with the results also shown in table 2 (mixtures 4 and 4A).

Comparing the results of the limestone-dust mixture (No. 4) with those of the corresponding mixture (No. 1) containing the small amount of natural dust, the improvement due to the addition of the limestone dust was striking, with respect both to the compressive strength of the dry specimens and to the retained strength after immersion. Also, although the test value obtained on only one specimen cannot be considered as more than indicative, the considerably higher compressive strength after immersion of the single specimen containing lime hydrate, as compared with the average of two corresponding specimens that did not contain this material, suggested that mixtures containing this aggregate would be substantially improved by incorporating hydrated lime in the proportion used in the test mixture.

[2] urther developments and application of the ersion-compression test, by J. T. Pauls and J. F. e. PUBLIC ROADS, vol. 25, No. 6, December 1948.

Conclusions Drawn

The test results led to the following conclusions as they apply to the one aggregate discussed here:

1. Tests on the dry mixtures showed compressive strengths that would be considered adequate for the expected traffic.

2. Immersion-compression tests showed that mixtures containing this aggregate would require some kind of special treatment if they were to be used successfully under unfavorable moisture conditions.

3. The one additive used in these tests was not highly effective in preventing damage due to water action. Some additives appear to be more effective than others when used with certain aggregates, and it is possible that additives other than the one used in these tests might be more satisfactory with this aggregate. Also, it has not been clearly determined whether or not the effect of chemical additives is changed by the elevated temperatures required in preparing hot mixtures. It may be that these temperatures alter the properties of the additive and so reduce its effectiveness.

4. Resistance to the action of water of bituminous mixtures containing this aggregate could be improved by adding limestone dust as a filler. The addition of small proportions of hydrated lime might also be very effective.

Study 2.—NORTHERN ALASKA

This study concerned the design of a bituminous mixture for pavement construction in northern Alaska, in a region having much more severe weather conditions than the area involved in the Alaska job in study 1. The air temperature exceeds 32° F. for a very short period in summer only, and seldom exceeds 60° F. The entire area was overlaid to a considerable depth with coarse sand and fine gravel. At all times other than during the short summer season, this material was icebound, and surface stability was not a problem. During the brief warm period, however, the sand and fine gravel were loose and unstable to such a depth as to require some form of surface stabilization.

Table 2.—*Results of immersion-compression tests, study 1*

Mixture No.	Parts bitumen to 100 parts aggregate, by weight	Parts additive to 100 parts asphalt, by weight	Characteristics of specimens, as molded [1]			Characteristics of specimens after 4 days immersion at 120° F. [1]			
			Specific gravity	Air voids	Compressive strength, 77° F.	Absorption	Volume increase	Compressive strength, 77° F.	Retained strength [2]
				Percent	*Lb./sq. in.*	*Percent*	*Percent*	*Lb./sq. in.*	*Percent*
1	4.5	0	2.21	13.7	165	5.2	1.7	94	57
2	4.5	1	2.22	13.3	180	5.5	1.7	120	67
3	4.5	2	2.22	13.3	174	5.7	1.7	124	71
4 [3]	5.0	0	2.30	9.4	238	[4] 2.4	[4] 1.7	[4] 197	83
4A	5.0	0	[5] 2.31	9.1	....	2.2	1.2	[5] 238	[6] 100

[1] Except as noted, values are the average for three specimens.
[2] Retained strength = (compressive strength of immersed specimens ÷ compressive strength of dry specimens) × 100.
[3] Mixture contained 5 percent added limestone dust.
[4] Average value for two specimens.
[5] Same as mixture 4, except that 0.5 percent hydrated lime was added following addition of the bitumen. Only one specimen was molded, due to insufficient material.
[6] Based on compressive strength of mixture 4 as molded.

Table 3.—*Gradation of aggregate, study 2*

Passing sieve size—	Original material	Material after crushing and recombining
	Percent	*Percent*
⅜-inch	100	100
No. 4	87	98
No. 8	38	68
No. 10	30	56
No. 20	9	20
No. 30	7	14
No. 40	5	11
No. 50	4	7
No. 80	1.2	3.4
No. 100	.8	2.6
No. 200	.6	1.6

The aggregate consisted of predominately subangular fragments of dark, fine-grained volcanic rock, rhyolite and andesite, quartz and some quartzite. Its apparent specific gravity was 2.65, and absorption 0.9 percent. Stripping tests were made on the ⅜-inch to No. 4 sieve fraction of the aggregate, using both the Nicholson and static immersion methods. Two grades of asphalt were used: 85–100 penetration, and 200–300 penetration. Results of both test methods with both grades of asphalt showed 100-percent retention of bituminous coating. The gradation of the natural aggregate is shown in the second column of table 3.

In order to determine its compactibility, vibratory compaction tests of the aggregate were made. To investigate the possibility of improving density by altering the gradation, three samples were prepared for test. One sample consisted of the natural aggregate. In the second sample the percentage of material passing the No. 10 sieve was increased to 40 percent by sieving and recombining. In the third sample, only material passing the No. 10 sieve was used. The vibratory density test results of the three materials showed air voids of 26.6 percent in the material of unaltered gradation, 25.4 percent in the material containing 40 percent passing No. 10 sieve, and 25.4 percent in the material all passing No. 10 sieve.

Trial Mixtures

A limited number of trial mixtures of asphalt and aggregate were then prepared. The objectives of the preliminary work were, first, the selection of an appropriate grade and proportion of asphalt, and second, some indication of the stability to be expected from mixtures containing the natural aggregate and from mixtures containing aggregate altered by manipulating the gradation or by other means.

In consideration of the severe moisture and temperature conditions at the job site, the use of a penetration grade asphalt seemed desirable. Moreover, since the natural aggregate was lacking in mechanical stability due to smoothness and roundness of the particles, it was decided to include in the trial mixtures a 40–50 penetration asphalt as well as an 85–100 asphalt. Four aggregate combinations were used in the trial mixtures: (1) the natural aggregate, (2) aggregate prepared from the native material by sieving and recombining so that 40 percent passed the No. 10 sieve, (3) aggregate prepared from the native material by sieving so that 50 percent passed the No. 10 sieve, and (4) aggregate prepared by crushing the 62 percent naturally retained on the No. 8 sieve and recombining the product of the crusher with 38 percent originally passing the No. 8 sieve. Crushing the larger size fractions, of course, resulted in marked alteration of particle shape. The change in gradation is shown in the third column of table 3.

Cylindrical test specimens, 4 inches in diameter and 4 inches high, were molded from the trial mixtures and tested in compression at two temperatures: 60° F. and 77° F. The former temperature was selected by reason of its being the normal maximum air temperature at the job site, and the latter was used in order to correlate the test values in this study with those obtained in other work.

To conserve material, the 85–100 penetration asphalt specimens, after having been tested at 77° F., were reheated and remolded for testing at 60° F. The specimens containing 40–50 penetration asphalt were first tested at 60° F., then reheated, remolded, and tested at 77° F. Although the strength of recompressed specimens is usually higher than that of original ones, sufficiently clear indications of the effect of the variable in the preliminary work were shown in the test results, which are given in table 4.

The results of these preliminary tests led to the following observations:

1. Specimens containing 85–100 penetration asphalt and the natural aggregate produced compressive strengths at either test temperature that would be considered inadequate for the purpose intended.
2. Use of 40–50 penetration asphalt with natural aggregate produced considerably higher stability than was obtained with 85–100 asphalt.
3. Alteration of aggregate gradation by separation and recombination failed to provide sufficient stability.
4. Alteration of aggregate gradation and particle shape by crushing resulted in pronounced improvement in stability.

Final Mixture Types

Based on the results of the preliminary tests three types of mixtures were prepared. One was composed of the natural aggregate and 5 percent asphalt; the second was composed of aggregate altered by crushing and recombining, and 5 percent asphalt; and the third was composed of the crushed and recombined aggregate and 6 percent asphalt. The grade of asphalt used in these mixtures was 40–50 penetration. Prior to mix-

Table 4.—*Results of tests on preliminary specimens, study 2*

Composition of specimen	Proportion of asphalt	Compressive strength—	
		at 60° F.	at 77° F
	Percent	*P.s.i.*	*P.s.i.*
Group 1: with 88 penetration asphalt and—			
Natural aggregate	3	126	3
Do	4	126	7
Do	5	120	3
Altered aggregate, 40 percent passing No. 10 sieve	4	138	4
Altered aggregate, 50 percent passing No. 10 sieve	4	137	4
Group 2: with 47 penetration asphalt and—			
Natural aggregate	4	205	7
Do	4½	236	8
Do	5	249	8
Altered aggregate, with 62 percent crushed aggregate	5	302	11

[1] In group 1, the tests at 77° F. were made first, and the specimens were then reheated and remolded for testing at 60° F. In group 2, the tests at 60° F. were made first, and the specimens were then reheated and remolded for testing at 77° F.

Table 5.—*Final tests on specimens containing local aggregate and 40-50 penetration asphalt, study 2*

Composition of specimens	After 7 days immersion at 77° F.		After 7 cycles of freezing and thawing		Compressive strength at—		Retained stability
	Absorption	Swell	Absorption	Swell	60° F.	77° F.	
	Percent	*Percent*	*Percent*	*Percent*	*P.s.i.*	*P.s.i.*	*Percent*
Natural aggregate, with 5 percent asphalt	(2)	(2)	.....	.....	191	91	.....
	5.2	1.3	.....	.....	.....	85	9
	.....	.....	4.9	3.4	.....	82	8
Aggregate altered by crushing, with 5 percent asphalt	(2)	(2)	.....	.....	230	122	.....
	7.3	0	.....	.....	.....	98	8
	.....	.....	6.4	.2	.....	101	8
Aggregate altered by crushing, with 6 percent asphalt	(2)	(2)	.....	.....	295	155	.....
	7.4	0	.....	.....	.....	121	7
	.....	.....	6.0	.1	.....	129	8

[1] Retained stability = (compressive strength of specimens after conditioning at 77° F. ÷ compressive strength of dry specimens at 77° F.) × 100.
[2] No immersion.

;, the aggregate was heated to 320° F. d the asphalt to 300° F. Mixing was ne in a kitchen-type mixer. The tempera- re of the mixtures at molding was 225° The molding load was 3,000 pounds per uare inch, held for 2 minutes. Eight ecimens of each mixture were prepared. these, four were tested in compression at ° F. and 77° F. without treatment other an overnight storage at laboratory tem- rature. The other four specimens were aced in a vacuum bath to accelerate satu- tion of the specimens by water. The ecimens were covered with water and cuum applied for 20 minutes, the degree vacuum used being 27 inches of mercury. llowing this operation, two of the speci- ens were placed in a water bath at 77° F. r 7 days. The other two specimens were bjected to seven freezing and thawing cles, each cycle consisting of 4 hours ex- sure to a temperature of —10° F. and 20 urs immersion in water at 77° F. These ecimens were also tested for compressive rength at 77° F. Prior to testing, meas- ements were made of the volume change d absorption of the specimens that had en subjected to immersion and to freezing d thawing. Results of the principal ries of tests are shown in table 5, and l to the following observations:

Comparing the compressive strengths of e two groups of dry specimens containing percent asphalt, it is seen that the use crushed aggregate resulted in substantial creases in stability at both test tempera- res.

Immersion in water at 77° F. produced tle stability reduction in the natural ag- egate specimens. The somewhat lower ability retention noted in corresponding ecimens containing crushed aggregate ight be explained either by the higher rcentage of water absorption or by the ssibility that the bitumen coatings on eshly crushed particles may be more sceptible to water action than those on e surface of weathered particles of the me aggregate. Incidentally, since this udy was made, the use of the vacuum bath as been dropped from the immersion- mpression test procedure because it pro- ced high water absorption in mixtures at otherwise were resistant to water per- eation.

Alternate freezing and thawing resulted little loss of stability in the natural ag- regate mixture, and the crushed aggregate ixture showed slightly lower retention of rength. The stability losses due to im- ersion and to freezing and thawing were ssentially the same for both crushed ag- regate mixtures.

Recommendations Made

These observations led to the following ecommendations for designing a bitumi- ous mixture for the particular conditions f the job:

1. The aggregate should be altered by rushing the portion retained on the No. 8 sieve, and recombining the crushed material with the portion passing the No. 8 sieve.
2. A hot mixture should be used.
3. The asphalt used should be one of the lower penetration grades, such as 40–50 penetration.
4. The optimum percentage of asphalt for density and workability will probably fall within a range of 5.5 to 6.5 parts of asphalt to 100 parts of aggregate by weight. In consideration of prevailing temperature and moisture conditions the use of a rich mixture within these limits, consistent with workability, would be desirable.

Study 3.—A GULF STATE

This study for the design of a bituminous surfacing for a section of park roadway in one of the Gulf States, is presented by way of contrast to the other two studies, where special considerations were required because of a short working season, low temperatures, high rainfall, and the necessity to use the aggregate found at hand. All the conditions were different in the parkway design problem. The climate is mild, the working season long, rainfall is moderate, and a choice was possible between local aggregates and commercially produced aggregates. The problem was to determine whether or not a satisfactory sand-asphalt surface course could be made, using sand from pits near the roadway. If this were not possible, it was required to design a bituminous concrete mixture containing sand and crushed gravel from one of two commercial sources. The sand-asphalt type would, of course, be much less expensive.

The sand-asphalt study was limited to the use of 85–100 penetration asphalt and emulsified asphalt of the mixing type. Use of 85–100 penetration asphalt only was desired in the design of the bituminous concrete mixtures.

Sieve analysis, specific gravity and absorption determinations, and petrographic analysis were made on all the aggregates. Results of these tests are given in tables 6 and 7. Results of tests to determine the clay content and plastic properties of the three pit sands, S-4, S-5, S-6, are shown in table 8. It was apparent from visual examination that the sands from the commercial sources were free from clay.

Two of the local sands, S-4 and S-5, were from different parts of the same pit, and in order to determine the advantage of blending them, vibratory density tests were made on several combinations with the results shown in table 9.

Sand-Asphalt Mixtures

Sand-asphalt mixtures were prepared for Hubbard-Field stability and immersion-compression tests. Since the vibratory tests failed to show any advantage in blending sands S-4 and S-5, only the one that showed the higher density, S-5, was included in these mixtures. The test characteristics of the two bituminous materials used follow.

Table 6.—*Results of petrographic analysis and specific gravity and absorption determinations, study 3*

Kind of material	Field sample No.	Apparent specific gravity	Absorption	Petrographic analysis
			Percent	
Commercial sand	S–1	2.66	0.7	Quartz and chert.
Do	S–3	2.66	.3	Angular and subangular fragments of quartz with some chert and sandstone.
Pit sand	S–4	2.66	1.4	Angular fragments of quartz.
Do	S–5	2.65	1.6	Angular fragments of quartz, with some feldspar.
Do	S–6	2.66	2.7	Do.
Commercial gravel	G–1	2.61	3.2	Chert with some quartz.
Do	G–2	2.63	3.7	Chert with some quartz and sandstone.
Do	G–5	2.62	2.5	Angular and subangular fragments of chert with some quartz.
Do	G–6	2.63	2.7	Angular and subangular fragments of chert and quartz.

Table 7.—*Gradation of aggregate, study 3*

Percentage of material passing sieve size—	Commercial sand		Pit sand			Commercial gravel			
	S–1	S–3	S–4	S–5	S–6	G–1	G–2	G–5	G–6
1½-inch						100		100	
1-inch						93		96	
¾-inch						82	100	83	
½-inch						55	93	41	
⅜-inch	100	100				37	94	21	100
No. 4	99	96				9	31	1	24
No. 10	96	87	100		100		4		1
No. 20	90	75	98	100	98				
No. 30	81	64	94	98	93				
No. 40	62	46	83	91	76				
No. 50	31	22	60	65	45				
No. 80	7	5	18	28	18				
No. 100	4	3	11	23	15				
No. 200	1	1	6	14	12				

Table 8.—*Clay content and plastic properties of pit sands, study 3*

Sample No.	Hydrometer analysis of material passing No. 10 sieve			Physical constants of material passing No. 40 sieve	
	Sand	Silt	Clay	Liquid limit	Plasticity index
	Percent	*Percent*	*Percent*		
S-4	92	1	7	NP [1]	NP
S-5	86	3	11	NP	NP
S-6	86	4	10	17	NP

[1] NP = not plastic.

Table 9.—*Results of vibratory density tests on blends of local sands, study 3*

Composition of blend		Solids after vibration
Sand S-4	Sand S-5	
Percent	*Percent*	*Percent*
100	0	66.7
80	20	67.4
60	40	67.8
40	60	68.4
20	80	69.4
0	100	69.3

Emulsified asphalt:

Specific gravity, 77°/77° F. 1.013
Viscosity, Saybolt Furol, 77° F. 126
Demulsibility, 50 ml. 0.1 N. $CaCl_2$ soluble, percent 0
Sieve test, percent retained 0
Settlement test, percent (creaming) difference . . . . —0.8
Stone coating test . . . . Pass
Mixing test, percent . . . . Broken 1.0
Dehydration test, loss, percent 80.5
Miscibility test . . . . Pass
Distillation test, residue, percent . . 62
Test on residue:
- Penetration, 77° F., 100 gm, 5 sec. 186
- Ductility, 77° F., cm 72
- Total bitumen (soluble in CS_2), percent 98.02
- Organic matter insoluble, percent. 1.08
- Inorganic matter insoluble, percent 0.90
- Ash by ignition, percent 1.12
- Specific gravity, 77°/77° F. 1.018

85-100 penetration asphalt:

Specific gravity, 77°/77° F. 1.027
Flash point, ° F. 520
Softening point, ° F. 115.2
Penetration, 77° F., 100 gm., 5 sec. . . 93
Ductility 77° F., 5 cm./min., cm. 180
Loss, 163° C., 5 hours, percent 0.12
Penetration of residue 85
Total bitumen (CS_2) 99.99
Organic matter insoluble, percent . . . 0.01
Oliensis test . . . . Negative

In the hot mixtures, two proportions of asphalt were used with each of the sands S-5 and S-6: 9 and 10 parts of aggregate, by weight. In the cold mixtures two proportions of emulsified asphalt were used with each sand: 7 and 9 parts of water-free bitumen to 100 parts of air-dry aggregate, by weight. For each sand and with each type and proportion of bituminous material, two types of aggregate were used, one consisting of the sand alone and the other composed of a combination of sand and limestone dust.

Mixing was done in a kitchen-type mixer. For the hot mixtures the mixing temperatures of aggregate and asphalt were 325° F. and 300° F., respectively. For the cold mixtures, each batch of aggregate was moistened with 3 percent of water prior to adding the emulsified asphalt, to facilitate dispersion of the emulsion.

Two types of test specimens were molded from each batch. Hubbard-Field test specimens were 2 inches in diameter and 1 inch in height. Specimens for the immersion-compression test were 2 inches in diameter and 2 inches high. Stability test specimens were made in sets of three, and immersion-compression specimens in sets of six. Hot-mixture specimens were molded immediately after mixing. Cold mixtures were cured in a loose condition for 18 hours after mixing in a 140° F. oven. The temperature of hot mixtures at the time of molding was 260° F., and that of the cold mixtures was 140° F. All specimens were compacted under a static load of 3,000 pounds per square inch. They were cured in the 140° F. oven for 24 hours after molding, after which period they were allowed to cool to room temperature for density and volume measurement.

The Hubbard-Field specimens were tested at a temperature of 140° F. The results are given in table 10. For the immersion-compression tests the immersion water temperature was 120° F., and the test temperature was 77° F. The immersion-compression test results of the sand-asphalt mixtures are also shown in table 10.

In general, the Hubbard-Field stability values obtained for mixtures containing sand from either of the two local pits, with either type of bituminous material, would be considered satisfactory. Mixtures containing either of the sands and the lower proportion of emulsified asphalt appeared dry, with many poorly-coated particles or agglomerations. Use of the higher proportion of emulsified asphalt resulted in improved appearance, although the mixture still would be considered to be lean.

Table 10.—*Hubbard-Field stability tests and immersion-compression tests on sand-asphalt mixtures, study 3*

Composition of specimen	Parts limestone dust to 100 parts sand, by weight	Parts bitumen to 100 parts aggregate, by weight	Hubbard-Field stability test: Characteristics of specimens as molded			Immersion-compression test: Characteristics of specimens as molded			Characteristics of specimens after 4 days immersion at 120° F.			
			Air voids	Voids in aggregate	Hubbard-Field stability at 140° F.	Air voids	Voids in aggregate	Compressive strength	Absorption	Swell	Compressive strength	Retained strength
			Percent	*Percent*	*Lb.*	*Percent*	*Percent*	*Lb./sq. in.*	*Percent*	*Percent*	*Lb./sq. in.*	*Percent*
Sand S-5 with 85-100 penetration asphalt	0	9	18.5	34.2	850	19.3	34.8	181	7.3	5.7	52	29
	0	10	17.2	34.2	870	17.9	34.8	208	6.6	5.4	71	34
	6	9	16.2	32.0	1,260	16.9	32.6	272	7.5	8.1	58	21
	6	10	14.2	31.8	1,310	14.8	32.2	288	6.3	7.4	85	30
Sand S-5 with emulsion asphalt	0	7	21.4	33.5	1,340	21.3	33.5	152	7.0	10.9	13	9
	0	9	17.5	33.2	1,470	17.1	32.9	204	5.1	6.8	29	14
	6	7	20.9	33.1	1,340	20.4	32.7	169	(1)	(1)	(1)	0
	6	9	16.1	32.0	1,620	15.7	31.8	239	7.5	9.5	14	6
Sand S-6 with 85-100 penetration asphalt	0	9	18.7	34.1	1,170	19.4	34.6	233	7.4	5.2	69	30
	0	10	17.8	34.7	1,150	17.3	34.3	258	6.0	4.9	102	40
	6	9	17.4	33.0	1,350	15.4	32.3	297	7.9	8.9	64	22
	6	10	15.5	33.0	1,300	14.7	32.3	313	6.9	8.1	91	29
Sand S-6 with emulsion asphalt	0	7	20.6	33.0	1,200	20.8	33.1	155	9.5	6.0	15	10
	0	9	16.5	32.4	1,320	15.5	32.5	190	6.6	3.9	32	16
	6	7	18.9	31.4	1,300	18.8	31.4	192	[2] 14.1	[2] 14.9	[2] 8	[2] 4
	6	9	14.2	30.6	1,490	14.3	30.7	249	8.1	5.2	21	8

[1] These specimens cracked and failed after 3 hours immersion.
[2] These specimens cracked during the immersion period.

Observations Made

'he immersion-compression tests indi-
ed that sand-asphalt mixtures containing d from either pit would be unsatisfactory resistance to loss of stability due to the ion of water. From the test data, the owing observations are of interest:

. Mixtures containing either of the ds and the penetration grade asphalt wed better resistance to water action n those containing the same sand and emulsion in corresponding proportions bitumen. It is likely that the lower re- ance of the emulsion mixtures was due lack of complete and uniform coating vided by the proportions used.

. With one exception, dry specimens of tures containing either of the sands l the penetration-grade asphalt had her compressive strengths than those taining the same sand and the emulsion corresponding proportions of bitumen.

.. With either sand, mixtures contain- limestone dust showed greater stability s due to immersion than corresponding in sand mixtures. No explanation for s is clear at this time, although similar enomena were observed in early work developing the immersion-compression t. It may be that certain types of lime- ne are more reactive than others when nbined with certain types of clay.

l. The percentage of air voids was high, n in the mixtures containing limestone st and the higher proportion of each uminous material. The advantage to be ined by reducing the air voids by addi- nal amounts of asphalt and filler with se particular sands is extremely doubtful, view of the very low values for retained ength obtained for all the mixtures in immersion-compression test.

Bituminous Concrete Mixtures

The design of the alternate bituminous ncrete mixtures presented no special diffi- lty. The results of Los Angeles abrasion ts made on the coarser gravels from commercial sources (using A.A.S.H.O. designation grading A) showed abrasion loss of 15.1 percent for sample G-1 and 18.0 percent for sample G-5.

Static immersion tests made on the ⅜-inch to No. 4 fraction of the gravels gave the results shown in table 11.

From density tests made on molded specimens of a series of trial mixtures, the optimum proportions of coarse and fine aggregates were determined. From these trial mixtures a range of bitumen contents was also determined. Final mixtures were then prepared, and immersion-compression tests made, using the procedure followed in study 1. The results are shown in table 12. In this table, mixtures 1 and 2 are the wearing course and leveling course mixtures, respectively, containing sand and gravel from source *A*. Mixtures 3 and 4 are corresponding mixtures containing aggregates from source *B*. Although the compressive strengths of dry specimens containing aggregate from source *A* were higher than those of the specimens containing aggregate from source *B*, the results in both cases indicated sufficient stability for park roads on which traffic is not expected to be heavy. The immersion tests indicated satisfactory resistance to water action for all four mixtures.

As the result of this study, it was concluded that the use of sand-asphalt would not be recommended for this project, and that the use of the more expensive bituminous concrete would be justified.

Table 11.—*Static immersion test of gravels, study 3*

Sample	Area remaining coated after 24 hours immersion in water at—		
	100° F.	120° F.	140° F.
	Percent	*Percent*	*Percent*
G–1	95	85	80
G–5	90	80	50

Table 12.—*Composition of bituminous concrete mixtures and results of immersion-compression tests, study 3*

	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Coarse aggregate, sample No	G–1	G–2	G 5	G 6
Coarse aggregate, percent by weight	56	65	49	55
Fine aggregate, sample No	S–1	S–1	S 3	S 3
Fine aggregate, percent by weight	38	29	45	39
Limestone dust added, percent by weight	6	6	6	6
Gradation of composite aggregate, percentage passing—				
1-inch sieve	100	....	100	....
¾-inch sieve	93	100	94	....
½-inch sieve	77	99	74	....
⅜-inch sieve	66	96	62	100
No. 4 sieve	48	55	50	57
No. 10 sieve	42	36	45	41
No. 20 sieve	40	32	40	35
No. 30 sieve	37	29	35	31
No. 40 sieve	30	24	27	24
No. 50 sieve	18	15	16	15
No. 80 sieve	9	8	8	8
No. 100 sieve	8	7	7	7
No. 200 sieve	7	6	6	6
Parts asphalt to 100 parts aggregate, by weight	6.0	6.0	5.3	5.5
Characteristics of specimens as molded:				
Air voids, percent	8.7	10.2	8.9	8.1
Voids in mineral aggregate, percent	21.0	22.2	19.4	19.5
Compressive strength, lb. per sq. in	184	181	151	155
Characteristics of specimens after 4 days immersion:				
Absorption, percent	2.2	2.3	2.0	1.7
Volume change (swell), percent	.4	.4	0	0
Compressive strength, lb. per sq. in	178	176	159	164
Retained strength, percent	97	97	100	100

Title Pages for Volumes 24 and 25

In years past the Bureau of Public Roads has issued an alphabetically arranged index for each volume of PUBLIC ROADS, the last being that for volume 23 (March 1942-June 1944). The indexing was discontinued at that time for lack of personnel, and has not been resumed.

Searching through the long series of alphabetically arranged volume indexes is always time consuming and often unsatisfactory. It has therefore been decided to discontinue permanently the indexing of individual volumes. Instead, a far more useful reference work will be published, in the form of a cumulative index covering all articles in PUBLIC ROADS volumes 1–26. This will probably include a chronological listing of articles, an alphabetical list of authors, and a classification of articles according to subject matter.

The cumulative index will probably be published some time in 1952, after the issuance of the last issue number of volume 26. Readers are requested to please withhold orders for the cumulative index until after announcement of its actual publication. Neither the Bureau or the Superintendent of Documents can handle advance orders.

Because there are many who regularly bind each volume of PUBLIC ROADS, we will continue to print a title page for each volume, in which will appear a list of the articles and their authors. The title pages for volumes 24 and 25 are being mailed to all subscribers of PUBLIC ROADS.

The title pages will also serve as useful interim supplements to the cumulative index. While no definite plans have as yet been made, it is probable that supplemental cumulative indexes will be published periodically in the future, perhaps at intervals of 5 or 6 years.

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

PUBLICATIONS of the Bureau of Public Roads

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

ANNUAL REPORTS

(See also adjacent column)

Reports of the Chief of the Bureau of Public Roads:
1937, 10 cents. 1938, 10 cents. 1939, 10 cents.

Work of the Public Roads Administration:

1940, 10 cents.	1942, 10 cents.	1948, 20 cents.
1941, 15 cents.	1946, 20 cents.	1949, 25 cents.
	1947, 20 cents.	

Annual Report, Bureau of Public Roads, 1950. 25 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.
Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.
Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.
Part 4 . . . Official Inspection of Vehicles. 10 cents.
Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.
Part 6 . . . The Accident-Prone Driver. 10 cents.

UNIFORM VEHICLE CODE

Act I.—Uniform Motor-Vehicle Administration, Registration, Certificate of Title, and Antitheft Act. 10 cents.
Act II.—Uniform Motor-Vehicle Operators' and Chauffeurs' License Act. 10 cents.
Act III.—Uniform Motor-Vehicle Civil Liability Act. 10 cents.
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Act V.—Uniform Act Regulating Traffic on Highways. 20 cents.
Model Traffic Ordinance. 15 cents.

MISCELLANEOUS PUBLICATIONS

Bibliography of Highway Planning Reports. 30 cents.
Construction of Private Driveways (No. 272MP). 10 cents.
Economic and Statistical Analysis of Highway Construction Expenditures. 15 cents.
Electrical Equipment on Movable Bridges (No. 265T). 40 cents.
Factual Discussion of Motortruck Operation, Regulation, and Taxation. 30 cents.
Federal Legislation and Regulations Relating to Highway Construction. 40 cents.
Financing of Highways by Counties and Local Rural Governments, 1931–41. 45 cents.
Guides to Traffic Safety. 10 cents.
Highway Accidents. 10 cents.
Highway Bond Calculations. 10 cents.
Highway Bridge Location (No. 1486D). 15 cents.
Highway Capacity Manual. 65 cents.
Highway Needs of the National Defense (House Document No. 249). 50 cents.
Highway Practice in the United States of America. 50 cents.
Highway Statistics, 1945. 35 cents.
Highway Statistics, 1946. 50 cents.
Highway Statistics, 1947. 45 cents.
Highway Statistics, 1948. 65 cents.
Highway Statistics, 1949. 55 cents.
Highway Statistics, Summary to 1945. 40 cents.
Highways of History. 25 cents.
Identification of Rock Types. 10 cents.
Interregional Highways (House Document No. 379). 75 cents.
Legal Aspects of Controlling Highway Access. 15 cents.
Local Rural Road Problem. 20 cents.
Manual on Uniform Traffic Control Devices for Streets and Highways. 75 cents.
Mathematical Theory of Vibration in Suspension Bridges. $1.25.
Principles of Highway Construction as Applied to Airports, Flight Strips and Other Landing Areas for Aircraft. $1.75.
Public Control of Highway Access and Roadside Development. 35 cents.
Public Land Acquisition for Highway Purposes. 10 cents.
Roadside Improvement (No. 191MP). 10 cents.
Selected Bibliography on Highway Finance. 55 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks (FP–41). $1.50.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces. 10 cents.
Transition Curves for Highways. $1.25.

Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.

ANNUAL REPORTS

(See also adjacent column)

Public Roads Administration Annual Reports:
1943. 1944. 1945.

MISCELLANEOUS PUBLICATIONS

Bibliography on Automobile Parking in the United States.
Bibliography on Highway Lighting.
Bibliography on Highway Safety.
Bibliography on Land Acquisition for Public Roads.
Bibliography on Roadside Control.
Express Highways in the United States: a Bibliography.
Indexes to PUBLIC ROADS, volumes 17–19, 22, and 23.
Road Work on Farm Outlets Needs Skill and Right Equipment.

U.S. GOVERNMENT PRINTING OFFICE: 1951—911332

STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF JUNE 30, 1951

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM: PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$15,739	$13,745	$7,010	360.9	$7,345	$3,714	162.7	$16,948	$8,208	408.5	$38,038	$18,932	932.1
Arizona	1,255	7,553	5,308	160.6	892	516	13.2	4,340	3,109	49.9	12,785	8,933	223.7
Arkansas	4,028	12,852	6,757	423.1	5,325	2,656	175.3	13,360	6,838	360.1	31,537	16,251	958.5
California	9,165	39,858	6,713	182.9	19,295	9,230	75.5	62,867	30,679	287.9	122,020	46,622	546.3
Colorado	3,586	4,345	2,455	151.1	4,507	2,495	121.5	13,357	7,315	273.1	22,209	12,265	545.7
Connecticut	3,236	6,247	3,174	17.9	2,805	1,588	7.2	8,637	4,618	8.1	17,689	9,380	33.2
Delaware	2,774	1,004	599	22.5	10	9		5,235	2,553	19.1	6,249	3,161	41.6
Florida	4,719	12,932	6,615	292.6	7,751	4,075	117.2	19,897	9,787	417.9	40,580	20,477	827.7
Georgia	8,165	11,487	5,896	142.2	9,722	3,977	68.3	31,873	15,970	680.3	53,082	25,843	890.8
Idaho	5,431	8,414	5,309	339.4	2,308	1,416	87.9	8,115	4,580	233.5	18,837	11,305	660.8
Illinois	21,889	34,192	18,635	324.3	19,238	9,688	212.0	68,177	35,139	550.0	121,607	63,462	1,086.3
Indiana	11,887	37,216	18,633	222.6	8,869	4,306	181.9	16,955	8,611	96.3	63,040	31,550	500.8
Iowa	3,886	9,563	4,389	392.9	9,068	4,453	434.9	19,417	10,077	596.9	38,048	18,919	1,424.7
Kansas	7,542	7,885	3,783	1,183.4	6,130	3,074	306.9	12,557	6,263	517.2	26,572	13,120	2,007.5
Kentucky	2,830	22,196	11,473	330.0	3,370	1,659	58.2	16,837	8,244	272.9	42,403	21,376	661.1
Louisiana	6,214	15,663	7,430	105.9	8,505	3,994	65.5	17,727	9,005	201.7	41,895	20,429	373.1
Maine	3,989	6,203	3,420	61.5	817	367	6.0	7,792	4,150	70.2	14,812	7,937	137.7
Maryland	4,557	3,692	1,851	27.4	5,460	3,179	45.8	11,585	5,131	48.2	20,737	10,161	121.4
Massachusetts	2,477	15,424	5,231	34.5	5,845	2,241	1.6	70,124	34,909	59.3	91,393	42,381	95.4
Michigan	6,685	23,665	11,874	571.2	10,898	5,080	260.3	48,853	21,287	363.7	83,416	38,241	1,195.2
Minnesota	4,638	6,596	3,552	957.8	8,705	5,009	659.7	26,327	13,825	735.6	41,628	22,386	2,353.1
Mississippi	8,639	4,194	2,127	152.7	9,555	5,130	227.0	12,772	6,413	374.0	26,521	13,670	753.7
Missouri	10,286	24,661	12,726	752.9	15,498	7,876	401.8	33,337	17,522	553.1	73,496	38,124	1,707.8
Montana	5,163	16,745	10,176	524.2	5,194	3,014	152.2	13,285	7,998	262.6	35,224	21,188	939.0
Nebraska	9,234	12,572	6,640	458.7	5,068	2,480	98.7	16,508	8,598	525.0	34,148	17,718	1,082.4
Nevada	3,631	5,642	4,710	174.1	546	468	34.9	3,141	2,595	130.8	9,329	7,773	339.8
New Hampshire	2,887	2,720	1,534	18.8	406	179	5.7	5,652	2,807	49.9	8,778	4,520	74.4
New Jersey	4,937	12,283	6,131	22.5	9,252	4,612	3.0	15,459	7,303	23.6	36,994	18,046	49.1
New Mexico	3,249	3,673	2,354	122.6	2,520	1,605	46.9	10,181	6,502	215.5	16,374	10,461	385.0
New York	33,162	75,612	39,586	233.9	17,721	8,100	170.9	112,005	52,515	250.2	205,338	100,201	655.0
North Ca	5,027	16,147	8,010	393.7	5,010	2,379	117.0	28,623	13,924	625.2	49,780	24,313	1,135.9
North D	2,251	11,075	5,657	1,652.8	7,038	3,512	467.8	7,501	3,742	618.4	25,614	12,911	2,739.0
Ohio	14,656	31,484	14,590	276.1	5,333	2,719	163.4	81,954	41,637	342.5	118,771	58,946	782.0
Oklahoma	3,640	16,563	7,620	272.7	5,950	3,306	123.2	23,916	12,088	392.8	46,429	23,014	788.7
Oregon	1,238	3,418	2,060	33.5	4,064	2,230	96.8	16,121	8,981	217.9	23,603	13,271	348.2
Pennsylvania	14,919	17,718	9,124	52.9	15,487	7,739	52.9	86,629	42,704	232.0	119,834	59,567	337.8
Rhode Island	2,056	5,613	2,806	45.7	889	445	2.5	14,673	7,455	17.0	21,175	10,706	65.2
South Carolina	3,345	11,996	6,193	261.5	2,122	1,043	54.5	10,424	5,417	229.9	24,542	12,653	545.9
South Dakota	2,200	8,125	4,754	754.6	5,580	3,056	291.5	10,919	6,603	671.0	24,624	14,413	1,717.1
Tennessee	4,638	12,545	6,147	273.5	8,601	4,033	198.6	24,344	11,540	343.5	45,490	21,720	815.6
Texas	10,453	11,254	5,104	81.7	18,037	9,175	198.2	49,328	23,340	776.2	78,619	37,619	1,056.1
Utah	2,864	4,987	3,764	109.6	1,299	951	39.6	5,478	3,999	165.1	11,764	8,714	314.3
Vermont	1,122	4,636	2,463	61.6	843	427	6.2	4,563	2,242	32.4	10,042	5,132	100.2
Virginia	7,067	19,400	9,551	518.3	11,831	5,905	275.0	14,738	7,236	280.5	45,969	22,692	1,073.8
Washington	3,857	9,927	3,893	174.4	4,384	2,040	97.7	21,323	10,391	132.0	35,634	16,324	404.1
West Virginia	3,819	11,866	6,477	124.1	4,291	2,151	60.1	9,130	4,630	99.8	25,287	13,258	284.0
Wisconsin	7,835	21,029	11,547	555.5	11,178	5,261	203.2	19,129	9,512	482.4	51,336	26,320	1,241.1
Wyoming	1,294	2,044	1,300	48.3	1,976	1,287	60.3	9,363	5,877	276.2	13,383	8,464	384.8
Hawaii	1,452	8,289	3,810	15.3	1,157	378	.5	9,343	3,498	23.7	18,789	7,686	39.5
District of Columbia	3,521	2,864	1,432	.7	2,965	1,482	3.2	1,175	780		7,004	3,694	3.9
Puerto Rico	3,060	10,500	4,902	46.8	4,065	1,961	14.4	8,781	3,910	36.0	23,346	10,773	97.2
TOTAL	316,194	700,314	347,295	14,518.4	334,725	167,670	6,729.3	1,180,775	592,057	14,629.6	2,215,814	1,107,022	35,877.3

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NOTE: Unprogramed balances include apportionment made June 21, 1951.