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THE FIRST INTERNATIONAL SOIL CONGRESS AND ITS MESSAGE TO THE HIGHWAY ENGINEER

By CHARLES TERZAGHI, Massachusetts Institute of Technology, Research Consultant to the Bureau of Public Roads

DURING the third week of the month of June, Washington, D. C., welcomed more than 200 representatives of soil science from about every part of the civilized world. The meeting was the result of the cooperative efforts of the International Society of Soil Science, the American Society of Agronomy, and the United States Department of Agriculture.

The papers and discussions covered practically the whole field, the application of soil science to highway engineering representing a very small part of it. For this very reason the congress offered a favorable opportunity to survey the various possibilities for future more intimate cooperation, and to revise if necessary some of our conceptions by discussing them with scientists, who approach similar problems from a different angle. However, before dealing with the present situation as revealed by the congress, it may be useful to review briefly the principal points of contact between soil science and highway engineering.

THE SOIL SCIENTIST'S AND THE AMERICAN HIGHWAY ENGINEER'S ATTITUDE TOWARD THE SOIL

Until some 15 years ago road construction was essentially considered a problem in surveying combined with the application of a few simple rules of construction. Very little, if any, attention was paid to the subgrade. Since then various methods have been tried for distinguishing between poor, medium, and good subgrades, and considerable study has been given to the physical properties of the subgrade materials. Nevertheless the tendency exists to consider the road as detached from the landscape, the road consisting of an artificial layer of construction material superimposed on a layer of natural material with a variable resistance. According to this conception, the subgrade represents a second layer of construction material previously deposited by nature, either to the advantage or to the detriment of the engineer. Hence the efforts of the engineer have been exclusively directed toward establishing a simple classification for expressing the relative quality of this second layer.

In contrast to this the soil scientist considers the soil as inseparably connected with geographical and climatic facts. His research extends not only over the surface but also includes the stratification of the ground in a vertical sense (subdivision into A, B, and C horizons). His soil lives, has a definite age, a certain history, and has a considerable number of properties independent of those inherent in the material of which the soil consists. As a matter of fact, most of the papers presented at the congress dealt with the soil not as a material but as a local product which reflects in its properties a great number of different factors, such as the parent material, the age, the drainage conditions, the type of vegetation, the climatic conditions, and many others. Under such circumstances, it is from the soil scientist's view hardly possible to pass reliable judgment on anything concerning a soil without considering it in connection with geomorphological, climatological, and structural facts.

As an example, let us consider what the geomorphologist calls a dissected peneplain—that means an ancient mountain chain which in the course of time was first reduced to almost a plain and subsequently was dissected by a system of rivers and brooks. As a result, the landscape consists of many plateaus with a more or less undulating surface separated from each other by valleys with steeper slopes. Many such peneplains can be found throughout the world, the plateau landscapes of central New England among them. The landscape as faced by the observer represents the result of a series of geological events, viz, the formation of a mountain chain by uplift, the gradual wearing down of the crests and peaks by atmospheric agencies and creep until they practically disappeared, subsequent lifting of the plateau and the formation of the valley system. Hence the landscape reflects in its orographic detail a rather intricate history. The same is true for the anatomy and the morphological features of the soil which, like a living skin, covers the landscape.

As a matter of fact, the skin is the only part of the landscape which actually participated in the modification of the surface topography. It is within and immediately beneath the skin where the process of rock destruction and transportation took place, and the skin represents what was left of the material which in former days was located above it. As a consequence, the skin is everywhere precisely as old as the part of the landscape which it covers, the age being very different in different localities. On the plateau the soil is very old and varies in addition according to the nature of the parent rock located beneath and according to whether it covers the highest or the lowest spots of the area. Along the slopes the soil is very much younger. It is in a state of continuous, comparatively rapid movement down the slopes (creep). Again, at the same age and slope its character (degree of granulation, average moisture content, permeability, etc.) may be different, according to whether it covers a north or a south slope, whether it is located near the edge of the plateau or near the bottom of the valley, on a low crest or between two crests. In brief, the physiographic character of the landscape as revealed by the presence of crests, valleys, and hollows may be considered a very simplified picture of a corresponding variety in age, composition, and structure of the soil skin which covers it.

HIGHWAY ENGINEER HAS IGNORED GEOMORPHOLOGICAL FACTS

Until a short time ago the American highway engineer cared but very little about all these geomorphological details. He located his line, sampled the narrow strip of land which in future will represent the road, trusting that a definite relation may exist between the behavior of the road and the physical properties of the raw material of which the soil at that particular location consists. Yet in constructing his road on top soils with similar physical character his efforts may lead to success or failure, depending on the particular location of his section, which, in turn, governs the hydrogeological conditions. The laboratory investigation of the raw material extracted from one particular stratum fails to inform him about some vital factors; for instance, the local moisture conditions which, in our assumed case, may be different in spite of the identity of the raw materials. These and similar conditions can only be investigated on the ground by a competent observer; but until quite recently no attempt was made by American highway engineers to organize a field service for investigating and recording the geomorphological facts which have a bearing on highway construction.

Here is the point from which the Russian engineers started. The Russian attempts to establish scientific principles for subgrade investigations originated at a very much later date than the American ones. The American experiences were at their disposal. In addition to this it was in Russia where, for the first time, a systematic study was made of the intimate relations which exist between the soil, the physiographic character of the landscape, and the climatic conditions. (V. V. Dokoutchaev, 1896–1900, and his distinguished disciples N. M. Sibirtzev and K. D. Glinka.) Hence from the very beginning the Russian highway engineers realized the weaknesses inherent in the American method.

THE RUSSIAN METHOD OF SUBGRADE INVESTIGATION

The Russian attitude toward the subgrade problem was recently discussed in a paper presented by N. Y. Prokhorov to the U. S. S. R. Academy of Sciences. (1927, Russian Pedological Investigations, XII.) This paper contains a rather severe criticism of the American methods of subgrade investigation and gives a very interesting review of what has been done in Russia to improve upon them. As a result of some preliminary work carried out in 1923, a new department was created in 1924 under the title "Highway research bureau of the central department of local transport of the people's commissariat of ways and communications," including subdivisions for laboratory investigations, engineering, economic studies, soil science, and field observations (highway research parties). The program of the organization clearly expresses the tendency to study the subgrade in connection with the landscape and the climate as a natural body and not a "chance association of pulverized matter." Soil tests made in the laboratory similar to those practiced in the United States form part of the program but at the same time are considered second in importance. The main efforts were directed toward establishing standard methods for expressing the results of field observations on road maps which show not only the character of the narrow strip of land to be occupied by the road but also the adjoining belt, together with its hydrogeological characteristics and the stratification of the soil from the surface down to the parent material. (See, for instance, P. K. Khmyznikov, Methods for Mapping Soil Formations in Connection with Highway Construction; V. S. Makarevich, The Road as an Object of Study for the Geographer; Geomorphological and Pedo-Botanical Maps for Highway Purposes, for the Saratov Colony near Leningrad, plotted by P. K. Khmyznikov.)

During the short period of its existence the highway research bureau has established highway experimental stations north of the Caucasus, in Kharkov (Ukraine), and in the Far East. Others are planned in Moscow, Karelia, and Novosibirsk. Field studies are made on experimental highways and on existing roads which have proved to be either outstanding failures or successes (for instance, of a remarkably well preserved road 200 miles long, between the Reynovo station on the river Amur and the Aldan gold fields). Several new road projects were handled in intimate cooperation with some of the most prominent soil scientists with special consideration of the possibilities for improving the quality of the subgrade by admixture of foreign material to be extracted from "subgrade quarries." (A. E. Nazarenko, Admixture of Subgrade in the Construction of Common Roads.) V. V. Nikitin and B. V. Gervais are engaged in a study of the methods for investigating and recording climatological facts for highway purposes. Thus, in spite of the brief existence of the highway research bureau, it is probable that there has been accumulated in the Russian publications sufficient material to enable us to pass judgment on how far the Russian engineers have succeeded in turning their intentions into practice.

A COMPROMISE BETWEEN THE AMERICAN AND THE RUSSIAN METHOD DESIRABLE

There is no denying that the Russian method of dealing with the subgrade problem has much in its favor. A laboratory test, no matter how perfect it is, tells only part of the story. The other, and probably more important, part has to be learned by direct observation in the field. As a matter of fact, by its own initiative and without any knowledge of the Russian precedent, the Bureau of Public Roads has included in its program of the proposed condition survey the cooperation of both a soil scientist and a geologist. The first is expected to furnish information on the soil profile and the second on the geological and hydrogeological conditions. Yet, for the time being, this measure merely expresses the fact that the presence of a gap is felt. The question of how to fill the gap is still open. It remains to determine what to observe and how to condense the results of the observations into a reasonable amount of data. In connection with these questions a thorough study of the Russian experiences undoubtedly may prove to be both very stimulating and very helpful.

Yet even the Russian procedure is still in an initial stage of development. For this reason it was particularly profitable to get at the soil congress first-hand information concerning where we stand at present and to investigate how best to take advantage of the recent developments in that field. In what follows an attempt is made to present the results of this investigation and to comment upon the future possibilities of keeping in contact with the different branches of soil science.

AGREEMENT NOT YET REACHED ON SYSTEM OF SOIL CLASSIFICATION

Soil classification for foundation purposes was discussed in a paper presented by the writer. It should, however, be stated in advance that this classification has nothing in common with any of the soil classifications worked out by the soil scientists. Foundations are established on or within the C horizon which, by its very nature, merely represents "an accumulat.on of pulverized material." Hence the classification for foundation purposes is based exclusively upon mechanical properties, as is the classification of any other kind of inorganic construction material. In contrast to this the soil scientist dwells upon the properties of the top soil and of the B horizon, which are in a state of continuous change and which, in addition, represent the result of a gradual development.

In constructing a road we depend upon the resistance of the subgrade. Hence the mechanical properties (compressibility, elasticity, consistency, etc.) of the layer which supports the road are factors of importance and the classification of the raw material of which this layer consists ought to be based on purely mechanical characteristics. Yet at the same time the prevalent moisture conditions and the subdrainage depend on the soil profile and on the position of the area within the landscape. For properly investigating and expressing these facts we depend upon the methods and the experience of the soil scientist. Therefore we are vitally interested to learn to what extent the soil scientist has succeeded in developing and standardizing his methods in that particular field.

From what was presented at the congress it seems evident that the original Russian method of classifying the soils according to the factors instrumental in their history has been superseded by a classification based upon properties inherent in the soil. For several years this new method has been strongly advocated by C. F. Marbut, of the United States Department of Agriculture, and to-day its merits seem even to be recognized by the representatives of the Russian school. At the same time it is obvious that no final agreement has yet been reached concerning the properties on which such classification should be based. Charles F. Shaw, in his classification of California soils, considered the following properties: (1) Origin (order), (2) lime content (class), (3) parent rock (division), (4) character of hardpan layer (family), (5) age (stage), (6) color (group), (7) various other properties (series). S. A. Zakharov bases his classification on the following properties: (1) Color, (2) structure, (3) porosity and compactness, (4) depth, (5) character of Neo formations (concretions and holes), (6) soil skeleton, and (7) soil profile. J. Hendrick and G. Newlands, of Aberdeen, Scotland, give much importance to the mineralogical composition of the "fine sand fraction," which, according to their opinion and experience, is closely related to the composition of the finest soil constituents. M. M. McCool, Michigan, calls our attention to the importance of the percentage of colloids present in the soil, yet admits that the properties of two soils with an equal colloid content may be very different depending on the nature of the colloids. A. F. Lebedev, from Rostov on the Don, claims that soil mapping based on the determination of soil types is "indefinite and incomplete, the point of view of the investigator prevailing." He proposes to prepare separate maps showing the distribution of the moisture content or mechanical composition, reaction facts, air content, and other physical facts. The value of such maps would remain unaffected by a change in our methods of soil classification and broaden the field of possible application of the results of surveys.

HIGHWAY ENGINEERS MUST SECURE ASSISTANCE OF SOIL SCIENTISTS

As a result of the lack of agreement combined with a rather general confusion concerning the terminology of soil science, we are still very far from a universally accepted method of soil survey. But even within the same State, for instance, within the boundaries of the United States, it is very difficult for the highway engineer to take advantage of the information accumulated in the records of the Bureau of Soils. The soil classification of the bureau is based on all the properties of the soils irrespective of whether or not they have an effect on their quality as subgrades. As a consequence, the soil maps show an alarmingly great variety of soils, hardly any soil type occurring beyond the limits of a rather restricted area. Many of these soils may, from the highway engineer's point of view, be perfectly identical. On the other hand, the same soil type may be rather different in its properties as a subgrade according to its location within the landscape and according to the hydrogeological conditions existing in its vicinity.

The only method for remedying this situation seems to consist in securing the services of soil scientists who, in addition to their expert knowledge in the field of soil science, are thoroughly familiar with the requirements of highway engineering. Because of their training in soil science, they would be in a position to take full advantage of the achievements of science in this particular field. On the other hand, through their permanent contact with the highway engineer they would learn to discriminate between those properties of the soils which have a bearing on road construction and those which can be considered as unimportant. The activities of such highway soil scientists would ultimately lead to a soil morphology similar to that which serves as a basis for general soil surveys yet simplified and modified for highway purposes. The modification of the basic principles would be associated with a modified method of soil mapping specially adapted for highway purposes. The results of the soil tests would merely serve as a check on the information obtained by the soil scientists in the field.

That is precisely the way in which things have developed in Russia since 1924, and, according to N. J. Prokhorov's statement, both the field methods and the methods for soil mapping for highway purposes have been brought to a certain degree of perfection. It is obvious that the task involved in developing such methods is a job neither for the average highway engineer nor for the average soil scientist, because the existing methods must be adapted to an altogether new field of application. Such work requires a keen gift of observation and independent judgement combined with an unusually broad knowledge in the field of geomorphology, hydrography, and soil science. Yet, since we find some of the very best names connected with the Russian venture (Glinka, Gedroiz, Krynin, and many others), much labor and disappointment could be avoided by a more intimate contact with the work of the Russian investigators.

An exceptional position in the soil system is occupied by the soils of almost purely organic origin (peat, muck, and others). In contrast to the other soils they are almost international in their character, each type of peat deposit occurring in widely separated parts of the globe. This fact was brought out by A. P. Dachnowski of the United States Department of Agriculture. He distinguishes between four fundamental types of peat and develops the basic principle for the classification of soils of organic origin. The bearing of Doctor Dachnowski's investigations on highway engineering has already been suggested in a paper, published in the February issue of PUBLIC ROADS.[1] Because of the

[1] Fill Settlement in Peat Marshes, by V. R. Burton, PUBLIC ROADS, vol. 7, No. 12, Feb. 1927.

uniform character of peat deposits, it will ultimately be possible to utilize the experience gained in one locality in similar construction work to be executed in many other places. Hugo Osvald, of Jönköping in Sweden, showed very instructive cross sections of two peat bogs in Maine.

NEW DEVELOPMENTS IN SOIL PHYSICS PRESENTED

In the field of soil physics one can not escape the depressing feeling that much time and efforts is wasted because the investigators are quite often unfamiliar with some—if not with all—of the physical principles involved in their investigations. Compression tests are made without paying any attention to the laws of the resistance of materials. Authors speak about "permeability" as if the permeability of a soil could be expressed by a single numerical value, and no distinction is made according to whether the permeable system has a perfectly rigid or a deformable structure. Moisture equivalent and plasticity are discussed as if they had no connection with the common laws of physics. The same is true for what concerns the volume changes and the capillary phenomena. Yet there are some noteworthy exceptions to this rule, which is proved, for instance, by the high standard of the work performed at the Rothamsted Agricultural Experiment Station in Harpenden, England.

The efforts of the Bureau of Public Roads formed part of the subject of a paper presented to the congress by the writer. They essentially consist in a systematic study of the purely mechanical properties (compressibility, elasticity, consistency, permeability, and the like) of the raw material of the soils and in an attempt to correlate all these properties with the results of simple and rapid routine tests. As a result of this attempt, the bureau expects to establish what may be called a calibration of the simple routine tests—a set of charts by means of which one could determine without any further effort all the different features of the mechanical character of the soil. Since, for each example, the routine tests do not require more than about one hour of actual work, the calibration may ultimately represent the most efficient means for rapidly investigating any given material, regardless of the purpose of the investigation. It is clearly recognized that the information thus obtained will form a fraction only of the information required for judging the character of a subgrade. Yet, within its limits, the method will fully serve its purpose, securing a maximum of information with a minimum effort. B. A. Keen and J. R. H. Coutts, of the Rothamsted Experimental Station, presented valuable data on the effect of the organic constituents on the physical properties of the soils. By treating their samples with hydrogen peroxyd, they succeeded in almost completely removing the organic constituent without materially changing the character of the inorganic fraction. By using this method they removed the organic constituents from 40 different samples and investigated the physical properties of both the treated and the untreated samples. The investigations included the hygroscopic water content, the water content at 50 per cent relative humidity, the volume change due to drying, and the "sticky limit." The test results showed among other things that the removal of the organic material caused a lowering of the "sticky limit."

L. Smolik concluded from some of his experiments that the fresh soil contains a higher percentage of very fine material (particles smaller than 0.002 millimeters) than the same soil after being dried at room temperature.

One of the most interesting physical facts brought to the attention of the congress concerns the effect of electro-endosmose on the coefficient of friction between wet soil and steel. By sending an electric current through the soil the coefficient of friction between the negative electrode and the soil decreases, the amount of the decrease ranging between zero and 80 per cent of its original value, and the rate of decrease depending on the intensity of the current and the water content of the clay. According to the diagram exhibited by B. A. Keen, of the Rothamsted Experimental Station, a decrease of 80 per cent in friction value corresponds to a water content of 20 to 23 per cent and to a voltage of about 60. A further increase of the voltage has but little effect on the friction. At the surface of contact between the soil and the positive electrode the friction shows a corresponding increase. According to Prof. J. Schetelig, of Oslo, Norway, tests were made in Norway which seem to show that the sudden decrease in internal friction associated with the sliding of certain blue glacial clays is also an electric phenomenon caused by a change in the state of polarization at the boundary between the mica flakes and the water. These discoveries certainly will have sooner or later an important bearing on every branch of engineering dealing with soils.

METHODS FOR INVESTIGATING DRAINAGE PROPERTIES IN CONTROVERSIAL STATE

The methods for investigating the drainage properties of the soils are, as it seems, still in a very controversial state. For the time being five different methods are used for estimating the drainage properties, viz, (1) mechanical analysis (Kopecky, Fauser) (2) hygroscopicity (Rodewald-Mitscherlich), (3) determination of the specific surface of the soil (Zunker), (4) direct determination of the permeability of the undisturbed soil (Freckmann, Jaenert, Schroeder), and (5) from observations while lowering the groundwater level. There are claims that every one of these methods is successful, yet the results obtained by means of the various methods vary within wide limits. This, after all, is not surprising, because the mere presence of drains changes the nature and the permeability of the adjoining soil in a way which can certainly not be predicted from the result of a permeability test performed in the laboratory. Hence it was enjoyable to learn at the congress about the increasing attention paid to actual field tests. W. J. Schlick, of the Iowa State College; F. O. Bartel, of the United States Department of Agriculture; and R. Janota from Prague, Czechoslovakia, reported on the results of rather extensive tests made in the field for the purpose of investigating the relations which exist between the permeability of the underground (according to the results of laboratory tests), the position of the water table, and the run-off. Janota supplemented his data with the results of observations concerning the changes which occurred in the soil while draining it.

C. W. Botkin, of the New Mexico college, investigated in the laboratory the effect of alkali and fertilizers on the permeability of Gila clay and Gila clay loam. He found that all those ingredients which cause flocculation also increase the permeability, while the deflocculating agents made the soil more impermeable.

Some interesting observations concerning the importance of irrigation by condensation were reported by A. F. Levedoff. The amount of water drawn by the top soil of the semiarid regions of southern Russia out of the air during the night by condensation was found to be not less than 70 millimeters per year (about 3 inches). L. B. Olmstead, of the Department of Agriculture, presented thermograph records showing the variations in temperature of the air and of the soil at a depth of 1, 6, and 18 inches, on a bare, uncultivated plot at Arlington, Va.

NEW EVIDENCE THAT QUANTITY OF COLLOIDS DOES NOT DETERMINE CHARACTER OF SOIL

There are few facts in soil science which acted stronger on the imagination of foundation and highway engineers than did the colloid content of the soils. It was apparently believed that the "soil colloid" is a specific and well-defined substance with very unusual properties, and that the quantity of this substance present in the soil alone is sufficient to determine the character of the soil. The soil congress merely brought some new and rather convincing evidence that the soil colloids may differ from each other as widely as the properties of the soils. Thus, Saute Mattson, of Sweden, reported on the results of tests with seven different soil colloids whose ratio of SiO_2 to $Al_2O_3+Fe_2O_3$ ranged between the limits 0.55 and 3.82. The red and yellow colloids with a low ratio were found to absorb considerably more anions from hydrochloric and sulphuric acid than did the gray colored ones with a high ratio. The same investigator, by treating the colloidal fraction of a soil with $AlCl_3$, succeeded in splitting the fraction up into two parts with considerably different ratios of SiO_2 to $Al_2O_3+Fe_2O_3$.

M. M. McCool, of Michigan, observed a remarkable difference in color and tenacity between those colloids which accumulated at the base and those colloids which formed the top part of the sediment in the tubes of the supercentrifuge, although both colloids came out of the same soil. Some soils with 20 per cent colloids extracted from a B horizon were found to be far more tenacious than others with 40 to 70 per cent. These few examples may be sufficient to demonstrate once more that the quantity of colloids present in the soil is far away from determining the character of the soil. In order to learn something about the soil it is also necessary to determine the type of the colloids contained in the soil and their state of adsorptive saturation. Under these conditions, soil chemistry may provide us sooner or later with some useful supplementary routine tests, but the center of gravity of our laboratory methods will continue to reside in the physical soil testing.

CERTAIN SOIL INGREDIENTS ATTACK CONCRETE

The only aspect of soil chemistry which is of vital interest to the highway engineer concerns the effect of certain soils on concrete. G. Wiegner and H. Gessner, from Zürich, reported on the results of very extensive investigations made by the "commission for the investigation of the deterioration of concrete pipes in reclamation districts." In certain parts of Switzerland the deterioration of cement pipes occurred on an alarming scale. Subsequent investigations showed that the cement pipes were damaged even in localities where no detrimental effect of soil conditions on the pipes was expected. The destruction was found to be due to acidic soil reaction, to the presence of carbonic acid in the ground water, the presence of a high content of gypsum (certain peat deposits), or of a high content of magnesium (certain soils rich in lime). Great density of the concrete or mortar is apt to retard but not to prevent the ultimate destruction. Based on the results of the investigations, the commission considers it necessary to request an analysis of the subsoil in connection with any reclamation project which involves a considerable investment in cement or concrete drainage pipes. It may be that concrete road surfaces, too, could be damaged in contact with soils whose ingredients attack the cement. If this be the case, the experiences incorporated in the reports of the Swiss commission may be of great value.

The Russian delegates exhibited a most instructive set of complete soil profiles showing the variation with varying depth of the hygroscopic water content, the humus content, the content in Fe_2O_3, Al_2O_3, SiO_2, the percentage of particles smaller than 0.01 millimeter present in the soil, and the base adsorption in calcium equivalent. Although such profiles have no direct bearing on highway problems, they demonstrate the necessity of investigating not only the topsoil but the whole soil profile.

METHODS OF TESTING DISCUSSED

Among the discussions on the methods of testing, the methods for performing the mechanical analysis maintained their prominent place. Wiegner and Gessner, of Zurich, exhibited a very ingenious device whose operation merely requires the dispersion of the soil by shaking the apparatus, the turning on of a light, and the setting in motion of a revolving film. One or two days later the grain size curve can be taken from the drum. (Price approximately $150.) The Rothamsted Agricultural Experiment Station showed another apparatus by means of which the mechanical composition of the soil can be determined from the density of samples withdrawn from the sedimentation tank with a pipette.

Yet it still remains doubtful to what extent the results of the analysis can be relied upon and how the samples should be treated prior to the analysis so as to secure perfect dispersion. Charles F. Shaw and E. V. Winterer, of the University of California, call attention to a fundamental error associated with every type of mechanical analysis based on the velocity of settling. On account of their electric charge, the particles do not move vertically downward but diagonally toward the wall, and the process of sedimentation proceeds simultaneously with a flocculation near the walls of the vessel. Hence, he raises the question whether it is possible at all to determine the percentage of particles smaller than 0.002 millimeter with a reasonable degree of accuracy by any method based on the rate of settling. G. J. Bouyoucos, of the Michigan Agricultural Experiment Station, goes even further than that. He states that the colloidal content of soils as indicated by the hydrometer method is very much higher than the one determined by mechanical analysis, to such an extent that a new and radical textural reclassification of the soils is needed. M. M. McCool, of Michigan, too, points out that the results obtained by the standard method of mechanical analysis do not represent the true amounts of fine sand, silt, and clay. Finally, considering the amount of labor required to prepare the samples for the mechanical analysis and the uncertainty of the effect of such treatment on the soil, the analysis remains a rather unattractive test.

Yet even discarding the mechanical analysis from the routine program, the necessity exists to separate the coarse sand fraction from the finer material. For this kind of work a very convenient tool has been invented by M. Koehn and R. Albert. It is based on the principle of separation of the particles according to grain size by an upward current of water. The current is produced by a centrifugal pump coupled with a motor which, by means of a special type of coupling, accurately regulates the speed of the flow. Thus the separation of the soil into fine and coarse constituents proceeds automatically.

How to determine and express the color of the soils is another rather important problem. At the Bureau of Public Roads the color standards and color nomenclature by Robert Ridgeway are used. This method is neither accurate nor convenient, and the names of the colors mean nothing except to those who are thoroughly familiar with both the colors and the standard. As a result of the labors of the soil colors standards committee of the American Soil Survey Association, a factorial system of color description will soon be available for general use. According to this system, the different colors can be produced by the rapid rotation of colored disks, the value of the color being expressed by the percentage of space occupied by the elementary colors on the revolving disk. The Russian soil experts use W. Ostwald's system, which is essentially based on the ratio between color, black and white. T. M. Bushnell points out that the soil colors do not include more than 6 per cent of all the existing colors.

NEW DYNAMOMETER MAY BE USEFUL TO HIGHWAY ENGINEER

A very important innovation consists in the Rothamsted self-registering dynamometer. This dynamometer serves for measuring the variations in the resistance of the ground against the cutting action of the plow. It essentially consists of a curved brass tube filled with oil, the tube being inserted between the tractor and the plow. The strain produced in the tube by the pull of the tractor is recorded on a traveling strip of celluloid with a magnification of 20 to 1. By traveling with a plow back and forth over a field, the data were obtained for plotting the curves of equal resistance. The results furnished by such operations disclosed the important fact that the resistance of the soil varies within wide limits, from point to point, even on fields which according to their appearance seemed to be perfectly uniform. Repeating the test at different times of the year under different moisture conditions, practically the same curves of equal resistance were obtained, although the absolute values of the resistance were very different.

This reminds us of the fact that in a vertical sense, too, the character of the strata varies from point to point, and the data obtained by the Rothamsted tests give us some conception of the importance of the errors due to the limited number of samples taken in the field in connection with road surveys. It may be that the Rothamsted dynamometer could be used in connection with the soil survey for road-construction purposes. A dynamometer record would cover the full length of the road. It would give us reliable information concerning the variations in the resistance of the ground. It would disclose the presence of weak or excessively humid spots and would serve as a guide for properly selecting the soil samples. Yet the application of the dynamometer method would obviously be confined to surveys on level or very slightly inclined ground outside of forested districts.

Finally, the tools for sampling should be mentioned. A. P. Dachnowski, of the Department of Agriculture, displayed the tools which he uses in his investigation of peat deposits. His peat sampler furnishes undisturbed cores of peat 6 inches long and with a diameter of three-fourths of an inch. This tool certainly should be used by every highway engineer who has to deal with peat deposits. The Missouri Agricultural Experiment Station exhibited a tool for obtaining cores 16 inches long, with a diameter of 6 inches, from the bottom of pits. It consists of a core barrel which closely fits the specimen and of a rotating shell whose lower edge is provided with three cutting knives. By rotating the shell, a groove is cut all around the specimen. As soon as the top of the core arrives at the upper edge of the core barrel, the shell is withdrawn and the core remains protected by the barrel and surrounded by an annular space. H. H. Musselman, of the Michigan State College, exhibited a sampler for taking marl cores.

CONCLUSIONS

The first international soil congress gave to the highway engineer a chance to survey the possibilities for a closer cooperation with the Bureau of Soils and similar institutions. From the papers presented at the congress it became evident that the methods used by the soil scientist require a rather thorough modification to be applicable to highway engineering. At the same time it was learned that the Russian highway engineers, in close cooperation with their soil experts, have made what seems to be a successful effort to work out the required modifications, thus making it possible to utilize the results of soil research to full advantage. Hence, it seems desirable to make a careful survey of the present practice of the Russian methods of subgrade investigation.

Among the different branches of soil science, soil genesis, soil morphology, and the methods of soil survey undoubtedly have the most direct bearing on highway engineering. The results obtained in the field of soil physics are helpful inasmuch as they deepen our insight into the mechanics of soil behavior. Soil chemistry may, sooner or later, furnish some useful supplementary routine tests. Yet, as a whole, the points of contact between soil chemistry and highway engineering are of minor importance.

Valuable data were presented concerning the detrimental effect of certain soil solutions on cement pipes and on concrete.

Among the new tools which were developed during the last few years the following seem to be of interest to the highway engineer: A machine for automatically extracting the sand fraction out of the soil, the Rothamsted self-registering dynamometer, and various tools for obtaining undisturbed samples of soil.

ANALYSIS OF CONCRETE ARCHES

PART 2.—ANALYSIS OF UNSYMMETRICAL ARCHES

By W. P. LINTON, Highway Bridge Engineer, and C. D. GEISLER, Associate Highway Bridge Engineer, United States Bureau of Public Roads

PART 1 of this article, published in the preceding issue of PUBLIC ROADS, presented the derivation of formulas for arch design and the calculations for the design of a symmetrical arch using the forms which have been developed to lessen the labor and chances of error in arch calculations. It will be assumed that the reader is familiar with the preceding article, and an example will be worked out for an unsymmetrical arch, explaining only such steps as have not already been discussed.

FORMULAS FOR UNSYMMETRICAL ARCHES

The following formulas for unsymmetrical arches were derived. They are applicable to either symmetrical or unsymmetrical arches, but for symmetrical arches it is much easier to use them in the simplified form previously explained.

$$V_o=\frac{\frac{1}{2}\sum_a^l(z-k)\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)-\frac{G}{C}\times\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)}{F-\frac{BG}{C}}$$

$$H_o=\frac{V_oB-\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)}{C}$$

$$M_o=\frac{dx}{\Sigma\Delta}\frac{1}{2}\sum_a^l(z-k)\Delta+H_o\frac{\Sigma y\Delta}{\Sigma\Delta}-V_o\frac{dx}{2}\frac{\Sigma z\Delta}{\Sigma\Delta}$$

$$M_x=M_o+[V_oz-(z-k)]\frac{dx}{2}-H_oy$$

$$V_t=\frac{\frac{2r}{(dx)^2}+20\frac{G}{C}}{F-\frac{BG}{C}}etE$$

$$H_t=\frac{V_tB+20etE}{C}$$

$$M_t=-H_t\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)+V_t\frac{dx}{2}\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$$

$$N_x=H\cos\phi+V_x\sin\phi$$

$$f_c=\frac{N}{A}\pm M\frac{h}{2I}$$

$$B=\frac{1}{2}\Sigma z\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$$

$$C=\frac{1}{dx}\Sigma y\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)+\Sigma\frac{\cos\phi}{A}$$

$$F=\frac{1}{2}\Sigma z\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$$

$$G=\frac{1}{dx}\Sigma z\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$$

CALCULATIONS FOR AN UNSYMMETRICAL ARCH

An unsymmetrical arch of the dimensions shown in Figure 1 is to be designed to carry a live load of 125 pounds per square foot and to withstand a rise of temperature of 30° F. or a fall of 40°.

The general method of procedure is identical with that described for symmetrical arches. The dimensions of the arch ring and reinforcement may be arrived at by any of the methods in general use, and a drawing similar to Figure 1 is prepared on a scale of 1 inch to 3 feet. For unsymmetrical arches it is necessary to draw the entire arch ring.

Computations are entered in 12 tables, which can be conveniently arranged on six sheets of letter-size paper grouped as presented here. Bold-face type is used to indicate the results of calculations, and plus and minus signs which are the same for all arches and may be printed on the blank forms. Since the arch is unsymmetrical, the tables must be filled out for the entire arch in every case. As in the preceding example for a symmetrical arch, coefficients will be determined for a load of unity at the various points, and these coefficients will be applied to the dead and live load to determine the stresses.

Table 1. Computations for Δ.—This table is filled out in the same way as Table 1 for the symmetrical arch and requires no additional explanation.

Table 2. Computations for $\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$.—The value of this expression, which appears in the formula for V_o, was not found for the symmetrical arch, since it is multiplied by G, which in the case of the symmetrical arch is zero. The value of y for each of the 20 points is scaled and recorded in column 12. The value of $y\Delta$, column 13, is the product of the corresponding values of y and Δ in columns 12 and 11. The sum of column 13 should be divided by the sum of column 11 and the value of $\frac{\Sigma y\Delta}{\Sigma\Delta}$ is recorded in the place provided on the same sheet with Tables 1 and 2.

Column 14 is computed by subtracting $\frac{\Sigma y\Delta}{\Sigma\Delta}$ from each value of y. Column 15 is computed by multiplying each term in column 14 by the corresponding term in column 11. If the work in columns 13, 14, and 15 is correct, the sum of column 15 will be zero.

Columns 16 and 17 are computed in exactly the same manner as explained for columns 36 and 37 of Table 4 for symmetrical arches. The figure opposite point 20 in column 16 is always zero. To this add the figure opposite point 20 in column 15 with its proper algebraic sign and write the result in the next space in column 16. To this add algebraically the next figure in column 15 which is opposite point 19, and set down the sum in column 16 opposite point 18. Then add the next figure in column 15 and continue this process to the top of the page. Since the sum of column 15 is zero, the top figure in column 16, opposite point 1, will be numerically equal to the top figure in column 15.

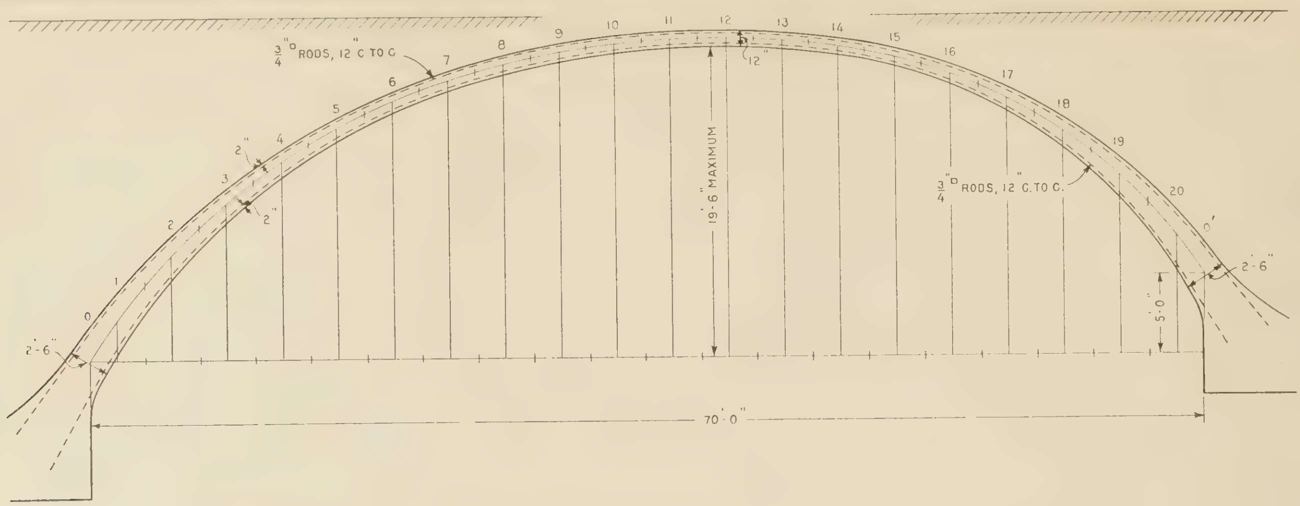

Fig. 1.—Sketch of Arch Ring Showing Principal Dimensions and Load Points

Table 1.—*Computations for* Δ Table 2.—*Computations for* $\frac{1}{2}\Sigma(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Points	h	h^3	I_c	$\frac{h}{2}$	$\left(\frac{h}{2}-d'\right)$	$\left(\frac{h}{2}-d'\right)^2$	I_s	$I=I_c+I_s$	ds	$\Delta=\frac{ds}{I}$	y	$y\Delta$	$y-\frac{\Sigma y\Delta}{\Sigma\Delta}$	$\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$	$\sum_a^l\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$	$\frac{1}{2}\sum_a^l(z-k)\Delta\times\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$
0	2.50	15.625	1.302	1.25	1.08	1.166	0.136	1.438	——	——	0.00	——	——	——	——	——
1	2.32	12.487	1.041	1.16	.99	.980	.115	1.156	6.05	5.23	2.55	13.3365	− 14.950856	− 78.1930	+ 78.1932	+ 2347.96
2	1.92	7.078	.590	.96	.79	.624	.073	.663	5.30	7.99	7.10	56.7290	− 10.400856	− 83.1028	+ 161.2960	+ 2269.77
3	1.60	4.096	.341	.80	.63	.397	.046	.387	4.65	12.02	10.55	126.8110	− 6.950856	− 83.5493	+ 244.8453	+ 2108.48
4	1.34	2.406	.200	.67	.50	.250	.029	.229	4.10	17.90	13.06	233.7740	− 4.440856	− 79.4913	+ 324.3366	+ 1863.63
5	1.20	1.728	.144	.60	.43	.185	.022	.166	3.93	23.67	15.06	356.4702	− 2.440856	− 57.7750	+ 382.1116	+ 1539.29
6	1.10	1.331	.111	.55	.38	.144	.017	.128	3.75	29.30	16.58	485.7940	− .920856	− 26.9811	+ 409.0927	+ 1157.18
7	1.08	1.260	.105	.54	.37	.137	.016	.121	3.65	30.17	17.68	533.4056	+ .179144	+ 5.4048	+ 403.6879	+ 748.09
8	1.06	1.191	.099	.53	.36	.130	.015	.114	3.60	31.58	18.60	587.3880	+ 1.099144	+ 34.7110	+ 368.9769	+ 344.40
9	1.04	1.125	.094	.52	.35	.122	.014	.108	3.55	32.87	19.26	633.0762	+ 1.759144	+ 57.8231	+ 311.1538	− 24.58
10	1.02	1.061	.088	.51	.34	.116	.014	.102	3.50	34.31	19.72	676.5932	+ 2.219144	+ 76.1388	+ 235.0150	− 335.73
11	1.00	1.000	.083	.50	.33	.109	.013	.096	3.50	36.46	19.92	726.2832	+ 2.419144	+ 88.2020	+ 146.8130	− 570.74
12	1.00	1.000	.083	.50	.33	.109	.013	.096	3.50	36.46	20.00	729.2000	+ 2.499144	+ 91.1188	+ 55.6942	− 717.56
13	1.00	1.000	.083	.50	.33	.109	.013	.096	3.51	36.56	19.95	729.3720	+ 2.499144	+ 89.5407	− 33.8465	− 773.25
14	1.02	1.061	.088	.51	.34	.116	.014	.102	3.54	34.71	19.62	681.0102	+ 2.119144	+ 73.5555	− 107.4020	− 739.40
15	1.06	1.091	.099	.53	.36	.130	.015	.114	3.60	31.58	19.00	600.0200	+ 1.499144	+ 47.3430	− 154.7450	− 632.00
16	1.10	1.331	.111	.55	.38	.144	.017	.128	3.70	28.91	18.05	521.8255	+ .549144	+ 15.8757	− 170.6207	− 477.26
17	1.20	1.728	.144	.60	.43	.185	.022	.166	3.88	23.37	16.60	387.9420	− .900856	− 21.0530	− 149.5677	− 306.64
18	1.40	2.744	.229	.70	.53	.281	.033	.262	4.25	16.22	14.60	236.8120	− 2.900856	− 47.0519	− 102.5158	− 157.07
19	1.84	6.230	.519	.92	.75	.562	.066	.585	4.88	8.34	11.75	97.9950	− 5.750856	− 47.9621	− 54.5537	− 54.55
20	2.26	11.543	.962	1.13	.96	.922	.108	1.070	5.90	5.51	7.60	41.8760	− 9.900856	− 54.5537	0.0000	0.00
0′	2.50	15.625	1.302	1.25	1.08	1.166	.136	1.438	——	——	5.00	——	——	——	——	——
										$\Sigma\Delta$ 483.16	$\Sigma y\Delta=$	8455.7136		0.0000		+ 7,590.02

Span $l=70.00$ feet. $dx=3.50$ feet. $\frac{\Sigma y\Delta}{\Sigma\Delta}=17.500856$ $I_c=\frac{h^3}{12}$ $I_s=\left(\frac{h}{2}-d'\right)^2 nA_s$

The figure in column 17 opposite point 20 is zero. In the next space opposite point 19 set down the figure taken from column 16 opposite point 19 with its proper algebraic sign. To this add algebraically the figure taken from column 16 opposite point 18 and set down the result in column 17 opposite point 18. Continue this summation to the top of the page. Column 17 will then contain the values $\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$ for a load of unity placed successively at each load point.

Table 3. Computations for $\frac{1}{2}\sum_a^l(z-k)\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$.—The values of z which are always the same when the arch ring is divided into 20 parts, are permanently printed in column 19. Columns 20, 21, and 22 are computed as indicated at the heads of the columns. After column 20 is computed the value of $\frac{\Sigma z\Delta}{\Sigma\Delta}$ is determined and the result set down in the space provided on the sheet containing Tables 3 and 4. If the arch were symmetrical $\frac{\Sigma z\Delta}{\Sigma\Delta}$ would equal 20, and when unsymmetrical it should not differ from 20 a great amount unless the arch is very far from being symmetrical.

Column 23 is computed from column 22 in the same way that column 16 was computed from column 15. The sum of column 22 should be zero if the numerical work is correct and the top figure in column 23 opposite point 1 should be numerically equal to the top figure in column 22. Column 24 is computed from column 23 in the same way that column 17 was computed from column 16. Column 24 will contain the values of $\frac{1}{2}\sum_a^l(z-k)\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$ for a load of unity placed successively at each load point.

Table 4.—Computations for ***B, C, F, and G.***—These terms are constant for any particular arch ring, since

TABLE 3.—*Computations for* $\frac{1}{2}\sum_a^l (z-k)\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$

TABLE 4.—*Computations for* **B**, **C**, **F**, *and* **G**

18	19	20	21	22	23	24	25	26	27	28	29
Points	z	$z\Delta$	$z-\frac{\Sigma z\Delta}{\Sigma\Delta}$	$\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$	$\sum_a^l\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$	$\frac{1}{2}\sum_a^l(z-k)\Delta\times\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$	$z\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$	$y\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$	$\cos\phi$	$\frac{\cos\phi}{A}$	$z\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$
0	0								0.549		
1	1	5.23	− 19.606714	− 102.5431	+ 102.5432	19,309.05	− 78.19	− 199.39	.575	.248	− 102.54
2	3	23.97	− 17.606714	− 140.6776	+ 243.2208	19,206.51	− 249.31	− 590.03	.666	.347	− 422.03
3	5	60.10	− 15.606714	− 187.5927	+ 430.8135	18,963.29	− 417.75	− 881.44	.764	.477	− 937.96
4	7	125.30	− 13.606714	− 243.5602	+ 674.3737	18,532.48	− 556.44	− 1,038.16	.844	.630	− 1,704.92
5	9	213.03	− 11.606714	− 274.7309	+ 949.1046	17,858.10	− 519.98	− 870.09	.896	.746	− 2,472.58
6	11	322.30	− 9.606714	− 281.4767	+ 1230.5813	16,909.00	− 296.79	− 447.35	.940	.854	− 3,096.24
7	13	392.21	− 7.606714	− 229.4946	+ 1460.0759	15,678.42	+ 70.26	+ 95.56	.962	.890	− 2,983.43
8	15	473.70	− 5.606714	− 177.0600	+ 1637.1359	14,218.34	+ 520.67	+ 645.62	.975	.920	− 2,655.90
9	17	558.79	− 3.606714	− 118.5527	+ 1755.6886	12,581.21	+ 982.99	+ 1,113.67	.987	.948	− 2,015.40
10	19	651.89	− 1.606714	− 55.1246	+ 1810.8150	10,825.52	+ 1,446.64	+ 1,501.46	.996	.976	− 1,047.40
11	21	765.66	+ 0.393286	+ 14.3392	+ 1796.4758	9,014.70	+ 1,852.24	+ 1,756.98	.999	.999	+ 301.12
12	23	838.58	+ 2.393286	+ 87.2592	+ 1709.2166	7,218.23	+ 2,095.73	+ 1,822.38	1.000	1.000	+ 2,006.96
13	25	914.00	+ 4.393286	+ 160.6185	+ 1548.5981	5,509.01	+ 2,238.52	+ 1,786.34	.998	.998	+ 4,015.46
14	27	937.17	+ 6.393286	+ 221.9110	+ 1326.6871	3,960.41	+ 1,986.00	+ 1,443.16	.990	.970	+ 5,991.60
15	29	915.82	+ 8, 393286	+ 265.0600	+ 1061.6271	2,633.72	+ 1,372.95	+ 899.52	975	.920	+ 7,686.74
16	31	896.21	+ 10.393286	+ 300.4699	+ 761.1572	1,572.10	+ 492.15	+ 286.56	.948	.862	+ 9 314.57
17	33	771.21	+ 12 393286	+ 289 6311	+ 471.5261	810.94	− 694 75	− 349.48	.903	.752	+ 9 557.83
18	35	567.70	+ 14.393286	+ 233 4591	+ 238.0670	339 41	− 1,646 82	− 686 96	.812	580	+ 8.171.07
19	37	308.58	+ 16.393286	+ 136.7200	+ 101.3470	101 35	− 1.774 60	− 563.55	.718	.390	+ 5.058.64
20	39	214.89	+ 18.393286	+ 101.3470	0.0000	0.00	− 2,127.59	− 414.61	.605	.268	+ 3,952.53
0′	40								.558		
		ΣzΔ=9956.34		Σ=0.0000			Σ=+4,695.93	+ 5,310.19		Σ=14.775	+ 38,618.12

$$\frac{\Sigma z\Delta}{\Sigma\Delta}=20.606{,}714$$

$$C=\frac{1}{dx}\sum_a^l y\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)+\sum_o^l\frac{\cos\phi}{A}=1{,}531.97$$

$$\frac{G}{C}=.875797$$

$$F=\frac{1}{2}\sum_o^l z\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)=19{,}309.06$$

$$\frac{BG}{C}=2{,}056.34$$

$$B=\frac{1}{2}\sum_o^l z\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)=\frac{1}{2}\sum_o^l \text{Col. }25=2{,}347.965$$

$$G=\frac{1}{dx}\sum_a^l z\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)=1{,}341.6943$$

$$F-\frac{BG}{C}=17{,}252.72$$

$$\frac{1}{C}=0.000{,}652{,}75$$

$$\frac{1}{F-\frac{BG}{C}}=0.000{,}057{,}961{,}9$$

they are independent of the loading. The values in column 25 are computed by multiplying each term in column 15 by the corresponding value of z in column 19. $\boldsymbol{B}$ is equal to one-half the sum of column 25 and $\boldsymbol{G}$ is equal to $\frac{1}{dx}$ times the sum of column 25. Their values should be set down in the places provided on the sheet containing Tables 3 and 4.

Column 26 is computed by multiplying each term in column 15 by the corresponding value of y in column 12. Cos ϕ (see fig. 3, Pt. I) in column 27 might be computed from the formula $\cos\phi=\frac{dx}{ds}$, but since $\cos\phi$ varies so little for small angles more accurate results will be obtained by computing $\sin\phi$ from dimensions scaled from the drawing and then taking the corresponding values of $\cos\phi$ from a table of trigonometric functions. This may be done on a supplementary sheet of paper. It is not necessary to find the values of ϕ as only $\cos\phi$ is wanted now, but the values of $\sin\phi$ should be kept because some of them will be wanted later.

Column 28 is computed by dividing each term in column 27 by A, the area of the arch ring section, which for practical purposes may be taken as equal to h (column 2).

$\boldsymbol{C}$ is equal to the sum of column 28 plus $\frac{1}{dx}$ times the sum of column 26. Its value should be set down in the space provided below Table 4.

Column 29 is computed by multiplying each term of column 22 by the corresponding value of z in column 19. $\boldsymbol{F}$ is equal to one-half the sum of column 29 and its value should be set down in the space provided below Table 4. Values of other expressions below Table 4 are found as indicated and require no particular explanation.

Table 5. Computations for V_o.—V_o is computed from the formula

$$V_o=\frac{\frac{1}{2}\sum_a^l(z-k)\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)-\frac{G}{C}\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)}{F-B\frac{G}{C}}$$

Column 31 is copied from column 24. Column 32 is computed by multiplying each term in column 17 by $\frac{\boldsymbol{G}}{\boldsymbol{C}}$. Column 33 is computed by subtracting each term in column 32 from the corresponding term in column 31 and the numerical work may be checked by subtracting the sum of column 32 from the sum of column 31. Column 34 is computed by dividing each term in column 33 by $\left(\boldsymbol{F}-\boldsymbol{B}\frac{\boldsymbol{G}}{\boldsymbol{C}}\right)$. Column 34 now contains the values of V_o for a load of unity placed successively at each load point. The top figure in column 34, that is the value of V_o for a unit load at point 1, should equal unity, but allowance should be made for the inaccuracy due to dropping of decimals.

TABLE 5.—*Computations for V_o* | TABLE 6.—*Computations for H_o* | TABLE 7.—*Computations for M_o*

30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Points	$\frac{1}{2}\sum_a^l (z-k)\Delta \times \left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)$	$\frac{G}{C}\times$ Col. 17	Col. 31 − Col. 32	$V_o = \frac{\text{Col. 33}}{F-\frac{BG}{C}}$	V_oB	Col. 35 − Col. 17	$H_o = \frac{\text{Col. 36}}{C}$	Δ	$\sum_a^l \Delta$	$\frac{1}{2}\sum_a^l (z-k)\Delta$	$\frac{dx}{\Sigma\Delta}\times$ Col. 40	$H_o\frac{\Sigma y\Delta}{\Sigma\Delta}\times$	$V_o\frac{dx}{2}\frac{\Sigma z\Delta}{\Sigma\Delta}$	M_o = Col. 41 + Col. 42 − Col. 43
0														
1	19, 309. 05	+2, 056. 34	17, 252. 71	1. 0000	2, 347. 96	0. 00	0. 000	5. 23	477. 93	4, 736. 59	34. 312	0. 000	36. 062	− 1. 750
2	19, 206. 51	+1, 987. 86	17, 218. 65	. 9980	2, 343. 27	73. 50	. 048	7. 99	469. 94	4, 258. 66	30. 850	. 840	35. 990	− 4. 300
3	18, 963. 29	+1, 846. 60	17, 116. 69	. 9921	2, 329. 42	220. 94	. 144	12. 02	457. 92	3, 788. 72	27. 445	2. 520	35. 777	− 5. 812
4	18, 532. 48	+1, 632. 16	16, 900. 32	. 9796	2, 300. 07	436. 44	. 285	17. 90	440. 02	3, 330. 80	24. 128	4. 988	35. 326	− 6. 210
5	17, 858. 10	+1, 348. 11	16, 509. 99	. 9569	2, 246. 77	707. 48	. 462	23. 67	416. 35	2, 890. 78	20. 941	8. 085	34. 507	− 5. 481
6	16, 909. 00	+1, 013. 45	15, 895. 55	. 9213	2, 163. 18	1, 006. 00	. 657	29. 30	387. 05	2, 474. 43	17. 925	11. 498	33. 224	− 3. 801
7	15, 678. 42	+ 655. 17	15, 023. 25	. 8708	2, 044. 61	1, 296. 52	. 846	30. 17	356. 88	2, 087. 38	15. 121	14. 806	31. 403	− 1. 476
8	14, 218. 34	+ 301. 62	13, 916. 72	. 8066	1, 893. 87	1, 549. 47	1. 011	31. 58	325. 30	1, 730. 50	12. 536	17. 693	29. 087	+ 1. 142
9	12, 581. 21	− 21. 53	12, 602. 74	. 7305	1, 715. 19	1, 739. 77	1. 136	32. 87	292. 43	1, 405. 20	10. 179	19. 881	26. 343	+ 3. 717
10	10, 825. 52	− 294 03	11, 119. 55	. 6445	1, 513. 26	1, 848. 99	1. 207	34. 31	258. 12	1, 112. 77	8. 061	21. 124	23. 242	+ 5. 943
11	9, 014. 70	− 499. 85	9, 514. 55	. 5515	1, 294. 90	1, 865. 64	1. 218	36. 46	221. 66	854. 65	6. 191	21. 316	19. 888	+ 7. 619
12	7, 218. 23	− 628. 44	7, 846. 67	. 4548	1, 067. 85	1, 785. 41	1. 165	36. 46	185. 20	632. 99	4. 585	20. 388	16. 401	+ 8. 572
13	5, 509. 01	− 677. 21	6, 186. 22	. 3586	841. 98	1, 615. 23	1. 054	36. 56	148. 64	447. 79	3. 244	18. 446	12. 932	+ 8. 758
14	3, 960. 41	− 647. 56	4, 607. 97	. 2671	627. 14	1, 366. 54	. 892	34. 71	113. 93	299. 15	2. 167	15. 611	9. 632	+ 8. 146
15	2, 633. 72	− 553. 50	3, 187. 22	. 1847	433. 67	1, 065. 67	. 696	31. 58	82. 35	185. 22	1. 342	12. 181	6. 661	+ 6. 862
16	1, 572. 10	− 417. 98	1, 990. 08	. 1153	270. 72	747. 98	. 488	28. 91	53. 44	102. 87	. 745	8. 540	4. 158	+ 5. 127
17	810. 94	− 268. 55	1, 079. 49	. 0626	146. 98	453. 62	. 296	23. 37	30. 07	49. 43	. 358	5. 180	2. 257	+ 3. 281
18	339. 41	− 137. 56	476. 97	. 0276	64. 80	221. 87	. 145	16. 22	13. 85	19. 36	. 140	2. 538	. 995	+ 1. 683
19	101. 35	− 47. 77	149. 12	. 0086	20. 19	74. 74	. 049	8. 34	5. 51	5. 51	. 040	. 857	. 310	+ . 587
20	0. 00	0. 00	0. 00	. 00	0. 00	0. 00	. 00	5. 51	0. 00	0. 00	0. 000	0. 000	0. 000	0. 000
0′														
	195, 241. 79	6, 647. 33	188. 594. 46	10. 9311	25, 665. 83	18, 075. 81	11. 799			30, 412. 80	220. 310	206. 492	394. 195	+ 32. 607

$$V_o=\frac{\frac{1}{2}\sum_a^l(z-k)\Delta\left(z-\frac{\Sigma z\Delta}{\Sigma\Delta}\right)-\frac{G}{C}\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)}{F-\frac{BG}{C}}$$

$$H_o=\frac{V_ob-\frac{1}{2}\sum_a^l\left(z-k\right)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)}{C}$$

$$M_o=\frac{dx}{\Sigma\Delta}\frac{1}{2}\sum_a^l(z-k)\Delta+H_o\frac{\Sigma y\Delta}{\Sigma\Delta}-V_o\frac{dx}{2}\frac{\Sigma z\Delta}{\Sigma\Delta}$$

$$\frac{dx}{\Sigma\Delta}=0.007244 \qquad \frac{dx}{2}\frac{\Sigma z\Delta}{\Sigma\Delta}=36.06175$$

Table 6. Computations for H_o.—H_o is computed from the formula,

$$H_o=\frac{V_oB-\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)}{C}$$

V_ob is computed by multiplying each term in column 34 by the value of B and entered in column 35. The term $\frac{1}{2}\sum_a^l(z-k)\Delta\left(y-\frac{\Sigma y\Delta}{\Sigma\Delta}\right)$ has already been recorded in column 17, so the numerator of the equation for H_o is computed by subtracting each term of column 17 from the corresponding term of column 35. The numerical work is checked by subtracting the sum of column 17 from the sum of column 35. H_o is then computed by dividing each term in column 36 by C. The top figure of column 35 should be equal to the top figure of column 17 and the top figure of column 36, should be zero.

Table 7.—Computations for M_o.—M_o is computed from the formula,

$$M_o=\frac{dx}{\Sigma\Delta}\frac{1}{2}\sum_a^l(z-k)\Delta+H_o\frac{\Sigma y\Delta}{\Sigma\Delta}-V_o\frac{dx}{2}\frac{\Sigma z\Delta}{\Sigma\Delta}$$

For convenience the values of Δ are copied in column 38 from column 11. Columns 39 and 40 are computed by summing up column 38 in the same way as previously explained for other similar columns. Columns 41, 42 and 43 are computed as indicated by the headings and no further explanation is necessary. M_o is computed in column 44 by adding the corresponding members of columns 41 and 42 and subtracting the corresponding member of column 43. M_o for a uni load at point 1 is always numerically equal to $\frac{dx}{2}$ and the numerical work in computing column 44 may be checked from the totals of columns 41, 42 and 43.

Tables 8, 9, and 10. Computations for moments at points 2, 11 and 0′.—Having determined the values of H_o, V_o, and M_o, other points must now be selected for detailed examination as to stress conditions. In this case points 2 and 11 have been selected and point 0′ should always be included. Values of H_o, V_o and M_o are copied in columns 46, 47 and 48.

The bending moment at any point is computed from the formula

$$M_x=M_o+m_x-H_oy.$$

For any particular point, z and y are constant and k depends on the position of the load. For point 2, z is equal to 3 and the value of y is taken from column 12 of Table 2.

Column 49 is computed by multiplying the values of V_o in column 47 by z. This is done only for the points to the left of the one for which the moment is being computed because the formula $m_x=[V_oz-(z-k)]\frac{dx}{2}$ is used only where z is greater than k. For the points to the right, m_x is found by the formula $m_x=V_oz\frac{dx}{2}$. Column 50 is computed by subtracting $(z-k)$ from the values of V_oz in column 49. For a unit load at point 1, $V_oz-(z-k)$ will be unity in all cases so its value is permanently printed in the tables. In column 51, M_2 is computed for points 1 and 2 by multiplying

Table 8.—*Computations for M_2* Table 9.—*Computations for M_{11}* Table 10.—*Computations for M_o'*

45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
				Point 2, $z=3$; $y=7.10$					Point 11, $z=21$; $y=19.92$					Point 0′, $z=40$; $y=5.00$				
Points	H_o	V_o	M_o	V_oz	$V_oz-(z-k)$	m_2	H_oy	M_2	V_oz	$V_oz-(z-k)$	m_{11}	H_oy	M_{11}	$40\ V_o$	$40\ V_o-(40-k)$	m_o'	H_oy	M_o'
0	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——
1	0. 000	1. 0000	− 1. 750	3. 0000	1. 0000	1. 750	0. 000	0. 000	21. 0000	1. 0000	1. 750	0. 000	0. 000	40. 0000	+ 1. 0000	+ 1. 750	0. 000	0. 000
2	. 048	. 9980	− 4. 300	2. 9940	2. 9940	5. 240	. 341	+ . 599	20. 9580	2. 9580	5. 176	. 956	− . 080	39. 9200	+ 2. 9200	+ 5. 110	. 240	+ . 570
3	. 144	. 9921	− 5. 812			5. 209	1. 022	−1. 625	20. 8341	4. 8341	8. 460	2. 868	− . 220	39. 6840	+ 4. 6840	+ 8. 197	. 720	+ 1. 665
4	. 285	. 9796	− 6. 210			5. 143	2. 024	−3. 091	20. 5716	6. 5716	11. 500	5. 677	− . 387	39. 1840	+ 6. 1840	+ 10. 822	1. 425	+ 3. 187
5	. 462	. 9569	− 5. 481			5. 024	3. 280	−3. 737	20. 0949	8. 0949	14. 166	9. 203	− . 518	38. 2760	+ 7. 2760	+ 12. 733	2. 310	+ 4. 942
6	. 657	. 9213	− 3. 801			4. 837	4. 665	−3. 629	19. 3473	9. 3473	16. 358	13. 087	− . 530	36. 8520	+ 7. 8520	+ 13. 741	3. 285	+ 6. 655
7	. 843	. 8708	− 1. 476			4. 572	6. 007	−2. 911	18. 2868	10. 2868	18. 002	16. 852	− . 326	34. 8320	+ 7. 8320	+ 13. 706	4. 230	+ 8. 000
8	1. 011	. 8056	+ 1. 142			4. 235	7. 178	−1. 801	16. 9386	10. 9386	19. 143	20. 139	+ . 146	32. 2640	+ 7. 2640	+ 12. 712	5. 055	+ 8. 799
9	1. 136	. 7305	+ 3. 717			3. 835	8. 066	− . 514	15. 3405	11. 3405	19. 846	22. 629	+ . 934	29. 2200	+ 6. 2200	+ 10. 885	5. 680	+ 8. 922
10	1. 207	. 6445	+ 5. 943			3. 384	8. 570	+ . 757	13. 5345	11. 5345	20. 185	24. 043	+2. 085	25. 7800	+ 4. 7800	+ 8. 365	6. 035	+ 8. 273
11	1. 218	. 5515	+ 7. 619			2. 895	8. 648	+1. 866			20. 268	24. 263	+3. 624	22. 0600	+ 3. 0600	+ 5. 355	6. 090	+ 6. 884
12	1. 165	. 4548	+ 8. 572			2. 388	8. 271	+2. 689			16. 714	23. 207	+2. 079	18. 1920	+ 1. 1920	+ 2. 086	5. 825	+ 4. 833
13	1. 054	. 3586	+ 8. 758			1. 883	7. 483	+3. 158			13, 179	20. 996	+ . 941	14. 3440	− . 6560	− 1. 148	5. 270	+ 2. 340
14	. 892	. 2671	+ 8. 146			1. 402	6. 333	+3. 215			9. 816	17. 769	+ . 193	10. 6840	− 2. 3160	− 4. 053	4. 460	− . 367
15	. 696	. 1847	+ 6. 862			. 970	4. 942	+2. 890			6. 788	13. 864	− . 214	7. 3880	− 3. 6120	− 6. 321	3. 480	− 2. 939
16	. 488	. 1153	+ 5. 127			. 605	3. 465	+2. 267			4. 237	9. 721	− . 357	4. 6120	− 4. 3880	− 7. 679	2. 440	− 4. 992
17	. 296	. 0626	+ 3. 281			. 329	2. 102	+1. 508			2. 301	5. 896	− . 314	2. 5040	− 4. 4960	− 7. 868	1. 480	− 6. 067
18	. 145	. 0276	+ 1. 683			. 145	1. 030	+ . 798			1. 014	2. 888	− . 191	1. 1040	− 3. 8960	− 6. 818	. 725	− 5. 860
19	. 049	. 0086	+ . 587			. 045	. 348	+ . 284			. 316	. 976	− . 073	. 3440	− 2. 6560	− 4. 648	. 245	− 4. 306
20	0. 000	0. 0000	0. 000	0. 000	0. 0000	0. 000	0. 000	0. 000	0. 000	0. 0000	0. 00	0. 000	0. 000	0. 0000	− 1. 0000	− 1. 750	0. 000	− 1. 750
0′	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——
	11. 799	10. 9311	+32. 607			53. 891	83. 775	+2. 723			209. 219	235. 034	+6. 792			+ 65. 177	58. 995	+ 38. 789

$$M=M_o+m_x-H_oy$$

$$m_x=\begin{bmatrix} z>k \\ V_oz-(z-k) \end{bmatrix}\frac{dx}{2}$$

For check:

Σ Col. 48 + Σ Col. 51 − Σ Col. 52 = Σ Col. 53.
Σ Col. 48 + Σ Col. 56 − Σ Col. 57 = Σ Col. 58.
Σ Col. 48 + Σ Col. 61 − Σ Col. 62 = Σ Col. 63.

the figure in column 50 by $\frac{dx}{2}$. For the other points m_2 is computed by multiplying the value of V_o in column 47 by $z\frac{dx}{2}$.

H_oy is computed by multiplying the values of H_o in column 46 by the value of y for the point under consideration. M_2 in column 53 is computed by adding the corresponding terms in columns 48 and 51 and subtracting the corresponding term in column 52. The numerical work may be checked from the totals of those columns. M_x for a load at point 1 will be zero in all cases because, for a unit load at point 1, M_o is equal $-\frac{dx}{2}$ and m_x is equal to $+\frac{dx}{2}$ and H_o is equal to zero.

Tables 9 and 10 are compiled in exactly the same manner as Table 8. Since M_o' should always be computed the numerical value of z is used in the column headings.

Table 11. Computations for thrust, shears, and moments due to dead load.—This table is filled out in the same manner as Table 8 of part 1. The values of H_o, V_o, M_o, M_2, M_{11}, and M_o' are copied from columns 37, 34, 44, 53, 58, and 63 in columns 65 to 70. The weight of the dead load applied at each point is computed as shown below and tabulated in column 71. The weight of the concrete is assumed to be 150 pounds per cubic foot and the fill above the arch ring 110 pounds per cubic foot. The dead load applied at each point is therefore equal to 150 hds + 110 h_fdx, in which h is the depth of the fill above the arch ring at each point and may be scaled from the drawing. Values of h and ds are found in columns 2 and 10 of Table 1. After column 71 is filled out the table is completed by multiplying the coefficients for a load of unity in the preceding columns by the actual dead load in order to get the values in the remaining columns of the table.

Calculation of dead load

Point	h (ds)	150 h(ds)	h_f	110 dx h_f	Dead load
1	14. 05	2, 105	17. 1	6, 600	8, 700
2	10. 20	1, 530	13. 3	5, 130	6, 660
3	7. 45	1, 115	10. 1	3, 900	5, 015
4	5. 50	825	7. 7	2, 960	3, 785
5	4. 72	708	5. 9	2, 270	2, 978
6	4. 13	620	4. 5	1, 730	2, 350
7	3. 95	592	3. 4	1, 310	1, 902
8	3. 82	573	2. 5	960	1, 533
9	3. 70	555	1. 8	690	1, 245
10	3. 57	535	1. 3	500	1, 035
11	3. 50	525	1. 0	385	910
12	3. 50	525	1. 0	385	910
13	3. 51	527	1. 0	385	912
14	3. 61	541	1. 4	540	1, 081
15	3. 82	573	2. 0	770	1, 343
16	4. 07	610	2. 9	1, 120	1, 730
17	4. 66	700	4. 3	1, 660	2, 360
18	5. 95	893	6. 1	2, 350	3, 243
19	9. 00	1, 350	8. 5	3, 270	4, 620
20	13. 35	2, 003	12. 1	4, 650	6, 653

Table 12. Computations for maximum stresses.—This table is the same as Table 9 (pt. 1) for symmetrical arches and is filled out in the same way except for the differences in the formulas due to the lack of symmetry. Column 78 is filled out as explained for column 75 of the symmetrical arch forms. The dead load moments, thrusts, and shears are found in Table 11, and copied in the proper places in columns 80, 81, and 82.

The live load has been assumed as 125 pounds per square foot which gives 125 dx = 437.5 pounds per load point. As in the case of the symmetrical arch we wish to find the maximum stress at each point and the stress is a function of the moment, thrust and shear and as has been pointed out it is not necessarily maximum at the same time that the moment is, but it is so nearly so that this is assumed to be the case. The maximum positive live load moment at point 0 is found by multiplying the sum of all of the positive quantities in column 67 by 437.5. The horizontal thrust which

TABLE 11.—*Computations for H_o, V_o, and M due to dead load*

64	65	66	67	68	69	70	71	72	73	74	75	76	77
Points	Unit load						D. L.	Dead load					
	H_o	V_o	M_o	M_2	M_{11}	M_o'		H_o	V_o	M_o	M_2	M_{11}	M_o'
1	0	1.0000	− 1.750	0	0	0	8,700	0	8,700	− 15,225	0	0	0
2	.048	.9980	− 4.300	+ .599	− .080	+ .570	6,660	320	6,647	− 28,638	+ 3,989	− 533	+ 3,796
3	.144	.9921	− 5.812	− 1.625	− .220	+ 1.665	5,015	722	4,975	− 29,147	− 8,149	− 1,103	+ 8,350
4	.285	.9796	− 6.210	− 3.091	− .387	+ 3.187	3,785	1,079	3,708	− 23,505	− 11,699	− 1,465	+ 12,063
5	.462	.9569	− 5.481	− 3.737	− .518	+ 4.942	2,980	1,377	2,852	− 16,333	− 11,136	− 1,544	+ 14,727
6	.657	.9213	− 3.801	− 3.629	− 530	+ 6.655	2,350	1,544	2,165	− 8,932	− 8,528	− 1,246	+ 15,639
7	.846	.8708	− 1.476	− 2.911	− .326	+ 8.000	1,900	1,607	1,655	− 2,804	− 5,531	− 619	+ 15,200
8	1.011	.8066	+ 1.142	− 1.801	+ .146	+ 8.799	1,530	1,547	1,234	+ 1,747	− 2,756	+ 223	+ 13,462
9	1.136	.7305	+ 3.717	− .514	+ .934	+ 8.922	1,245	1,414	909	+ 4,628	− 640	+ 1,163	+ 11,108
10	1.207	.6445	+ 5.943	+ .757	+ 2.085	+ 8.273	1,035	1,249	667	+ 6,151	+ 783	+ 2,158	+ 8,563
11	1.218	.5515	+ 7.619	+ 1.866	+ 3.624	+ 6.884	910	1,108	502	+ 6,933	+ 1,698	+ 3,298	+ 6,264
12	1.165	.4548	+ 8.572	+ 2.689	+ 2.079	+ 4.833	910	1,060	414	+ 7,800	+ 2,447	+ 1,892	+ 4,398
13	1.054	.3586	+ 8.758	+ 3.158	+ .941	+ 2.340	915	964	328	+ 8,014	+ 2,890	+ 861	+ 2,141
14	.892	.2671	+ 8.146	+ 3.215	+ .193	− .367	1,080	963	288	+ 8,798	+ 3,472	+ 208	− 396
15	.696	.1847	+ 6.862	+ 2.890	− .214	− 2.939	1,345	936	248	+ 9,229	+ 3,887	− 288	− 3,953
16	.488	.1153	+ 5.127	+ 2.267	− .357	− 4.992	1,730	844	199	+ 8,870	+ 3,922	− 618	− 8,636
17	.296	.0626	+ 3.281	+ 1.508	− .314	− 6.067	2,360	699	148	+ 7,743	+ 3,559	− 741	− 14,318
18	.145	.0276	+ 1.683	+ .798	− .191	− 5.860	3,245	471	90	+ 5,461	+ 2,590	− 620	− 19,016
19	.049	.0086	+ .587	+ .284	− .073	− 4.306	4,620	226	40	+ 2,712	+ 1,312	− 337	− 19,894
20	0	0	0	0	0	− 1.750	6,650	0	0	0	0	0	− 11.638
	11.799	10.9311	+ 61.437	+ 20.031	+ 10.002	+ 65.070	58,965	18,130	35,769	+ 78,086	+ 30,549	+ 9,803	+ 115,711
			− 28.830	− 17.308	− 3.210	− 26.281				−124,584	− 48,439	− 9,114	− 77,851
										− 46,498	− 17,890	+ 689	+ 37,860

TABLE 12.—*Computations for unit stresses*

78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
										Extrados	Intrados	Maximum stresses			
		H	M	V	$H \cos \phi$	$V \sin \phi$	N	$\frac{N}{A}$	$M\frac{h}{2I}$	$\frac{N}{A}+M\frac{h}{2I}$	$\frac{N}{A}-M\frac{h}{2I}$	Extrados		Intrados	
												+	−	+	−
	D. L.	+ 18,130	− 46,498	+ 35,769	+ 9,953	+ 29,903	+ 39,856	+ 106	− 280	− 174	+ 386	− 174	− 174	+ 386	+ 386
Point 0	+C. L. L.	+	+		+		+	+	+						
sin ϕ=0.836.	+U. L. L.	+ 4,094	+ 26,879	+ 1,843	+ 2,248	+ 1,541	+ 3,789	+ 10	+ 162	+ 172	− 152	+ 172			− 152
cos ϕ=0.549.	−C. L. L.	+	−		+		+	+	−						
Area=377.	−U. L. L.	+ 1,068	− 12,613	+ 2,940	+ 586	+ 2,458	+ 3,044	+ 8	− 76	− 68	+ 84		− 68	+ 84	
$\frac{h}{2I}$=0.00603.	+T.	+ 761	+ 11,335	+ 55	+ 418	+ 46	+ 464	+ 1	+ 68	+ 69	− 67	+ 69			− 67
	−T.	− 1,014	− 15,113	− 73	− 557	− 61	− 618	− 2	− 91	− 93	+ 89		− 93	+ 89	
								Total excluding temperature stresses					− 242		
											Total	+ 67	− 335	+ 559	+ 167
	D. L.	+ 18,130	− 17,890	+ 27,069	+ 12,075	+ 20,193	+ 32,268	+ 110	− 180	− 70	+ 290	− 70	− 70	+ 290	+ 290
Point 2	+C. L. L.	+	+		+		+	+	+						
sin ϕ=0.746.	+U. L. L.	+ 3,175	+ 8,764	+ 1,607	+ 2,115	+ 1,199	+ 3,314	+ 11	+ 88	+ 99	− 77	+ 99			− 77
cos ϕ=0.666.	−C. L. L.	+	−		+		+	+	−						
Area=293.	−U. L. L.	+ 1,987	− 7,572	+ 2,738	+ 1,323	+ 2,043	+ 3,366	+ 12	− 76	− 64	+ 88		− 64	+ 88	
$\frac{h}{2I}$=0.01005.	+T.	+ 761	+ 6,221	+ 55	+ 507	+ 41	+ 548	+ 2	+ 62	+ 64	− 60	+ 64			− 60
	−T.	− 1,014	− 8,297	− 73	− 675	− 54	− 729	− 3	− 83	− 86	+ 80		− 86	+ 80	
								Total excluding temperature stresses					− 134		
											Total	+ 93	− 220	+ 458	+ 153
	D. L.	+ 18,130	+ 689	+ 569	+ 18,112	+ 26	+ 18,138	+ 113	+ 25	+ 138	+ 88	+ 138	+138	+ 88	+ 88
Point 11	+C. L. L.	+	+		+		+	+	+						
sin ϕ=0.046.	+U. L. L.	+ 3,361	+ 4,376	+ 356	+ 3,358	+ 16	+ 3,374	+ 21	+ 158	+ 179	− 137	+ 179			− 137
cos ϕ=0.999.	−C. L. L.	+	−		+		+	+	−						
Area=161.	−U. L. L.	+ 1,801	− 1,404	+ 51	+ 1,799	+ 2	+ 1,801	+ 11	− 51	− 40	+ 62		− 40	+ 62	
$\frac{h}{2I}$=0.0361.	+T.	+ 761	− 1,803	+ 55	+ 760	+ 3	+ 763	+ 5	− 65	− 60	+ 70		− 60	+ 70	
	−T.	− 1,014	+ 2,403	− 73	− 1,013	− 3	− 1,016	− 6	+ 87	+ 81	− 93	+ 81			− 93
								Total excluding temperature stresses							− 49
											Total	+ 398	+ 38	+ 220	− 142
	D. L.	+ 18,130	+ 37,860	− 23,196	+ 10,117	+ 19,253	+ 29,370	+ 78	+ 228	+ 306	− 150	+ 306	+ 306	− 150	− 150
Point 0′	+C. L. L.	+	+		+		+	+	+						
sin ϕ−0.830.	+U L. L.	+ 4,039	+ 28,468	− 1,197	+ 2,254	+ 994	+ 3,248	+ 9	+ 172	+ 181	− 163	+ 181			− 163
cos ϕ=0.558.	−C. L. L.	+	−		+		+	+	−						
Area=377.	−U. L. L.	+ 1,123	− 11,498	− 2,771	+ 627	+ 2,300	+ 2,927	+ 8	− 69	− 61	+ 77		− 61	+ 77	
$\frac{h}{2I}$=0.00603.	+T.	+ 761	+ 11,380	+ 55	+ 425	− 46	+ 379	+ 1	+ 69	+ 70	−68	+ 70			− 68
	−T.	− 1,014	− 15,153	− 73	− 566	+ 61	− 505	− 1	− 91	− 92	+90		− 92	+ 90	
								Total excluding temperature stresses						− 73	− 313
											Total	+ 557	+ 153	+ 17	− 381

$N = H \cos \phi + V \sin \phi$ $\qquad f_c = \frac{N}{A} \pm M \frac{h}{2I}$

occurs at the same time as this maximum moment is found by adding up the quantities in column 65 for the points which give a positive moment and multiplying the sum by 437.5 The vertical shear which occurs at the same time as the maximum moment is found in the same way. The maximum negative moment and the thrust and shear which occur at the same time are found by placing loads at all of the points which give negative moments. These values are recorded in the proper places in Table 12.

The live-load moments and thrusts at the other points are found in the same way. In determining the shear for the other points it should be remembered that V_o in column 66 is the coefficient for the left reaction which is equal to the coefficient for the vertical shear at point 0, but not at other points if there are loads between the point where the shear is desired and the left reaction. If there are any loads to the left of the point under consideration, the shear is found by adding up the proper quantities in column 66 and then subtracting 1.00 for each load to the left. The quantity thus obtained is multiplied by the live load per load point, as shown in the following computations:

Live-load moments, thrusts, and shears

Live load = 125 pounds per square foot.
= 125×3.5 = 437.5 pounds per load point

Point 0:	
$+M = 437.5\times61.437 =$	26,879
$H = 437.5\times 9.357 =$	4,094
$V = 437.5\times 4.212 =$	1,843
$-M = 437.5\times28.830 =$	12,613
$H = 437.5\times 2.442 =$	1,068
$V = 437.5\times 6.719 =$	2,940
Point 2:	
$+M = 437.5\times20.031 =$	8,764
$H = 437.5\times 7.258 =$	3,175
$V = 437.5\times(4.673-1.00) =$	1,607
$-M = 437.5\times17.308 =$	7,572
$H = 437.5\times 4.541 =$	1,987
$V = 437.5\times 6.258 =$	2,738
Point 11:	
$+M = 437.5\times10.002 =$	4,376
$H = 437.5\times 7.683 =$	3,361
$V = 437.5\times(3.813-3.0) =$	356
$-M = 437.5\times 3.210 =$	1,404
$H = 437.5\times 4.116 =$	1,801
$V = 437.5\times(7.117-7.0) =$	51
Point 0′:	
$+M = 437.5\times65.070 =$	28,468
$H = 437.5\times9.233 =$	4,039
$V = 437.5\times(10.265-13.0) =$	1,197
$-M = 437.5\times26.281 =$	11,498
$H = 437.5\times2.566 =$	1,123
$V = 437.5\times(0.666-7.0) =$	2,771

These moments, thrusts, and shears are tabulated in the proper places in columns 80, 81, and 82.

The values of V_t are found from the equation

$$V_t = \frac{\frac{2r}{(dx)^2} + 20\frac{G}{C}}{F - B\frac{G}{C}} etE$$

In substituting in this equation, e, the coefficient of expansion of the concrete, is assumed to be 0.000006. E, the modulus of elasticity of the concrete, is taken as 2,000,000 pounds per square inch or 288,000,000 pounds per square foot, and t has been assumed as +30° F. and −40° F. These values with other values already determined when substituted in the equation give values of V_t as +55 and −73.

The formula for H_t given on page 95 reduces to

$$H_t = \frac{V_t B + 34{,}560t}{C} = \begin{matrix} +761 \\ -1{,}014 \end{matrix}$$

The values of V_t and H_t are the same for every point.

M_t is different for every point and substitution in the formula on page 95 gives the following:

For point 0,

$$M_{t,o} = -V_t\frac{dx\Sigma z\Delta}{2\ \Sigma\Delta} + H_t\frac{\Sigma y\Delta}{\Sigma\Delta} = \begin{matrix} +11{,}335 \\ -15{,}113 \end{matrix}$$

For point 2,

$$M_{t,2} = M_{t,o} + 3V_t\frac{dx}{2} - 7.1H_t = \begin{matrix} +6{,}221 \\ -8{,}297 \end{matrix}$$

For point 11,

$$M_{t,11} = M_{t,o} + 21V_t\frac{dx}{2} - 19.92H_t = \begin{matrix} -1{,}803 \\ +2{,}403 \end{matrix}$$

For point 0′,

$$M_{t,o}' = M_{t,o} + 40V_t\frac{dx}{2} - 5H_t = \begin{matrix} +11{,}380 \\ -15{,}153 \end{matrix}$$

Table 12 is completed in the same manner as the similar table for the symmetrical arch.

Stresses in steel and concrete.—As in the example for the symmetrical arch, the maximum stresses in Table 12 should be examined to determine if the tensile strength of the concrete will be exceeded. In the present example the tension in the concrete at the extrados at point 0 is 335 pounds per square inch, the concrete will crack and the tension must be taken by the steel. The stresses should therefore be computed in accordance with the theory of flexure and direct stress. The calculations for point 0 differ from those given in the example for a symmetrical arch as there is reinforcement in both the top and bottom of the arch ring. In this case the diagrams on page 399 to 402 of Hool and Johnson's Concrete Engineers' Handbook are used and it will be assumed that the reader is familiar with these diagrams and the theory related to them. It should be noted that x_o and t in Hool and Johnson's diagrams are the same as u and h in this article.

The following calculations are made to determine the stress in steel and concrete at point 0. The worst condition at point 0 is caused by a negative moment due to dead load, maximum negative moment due to live load, and a negative moment due to a fall of temperature.

	M_o	N
D. L.	−46,498	+39,856
−L. L.	−12,613	+3,044
−T	−15,113	−618
	−74,224	+42,282

$u = \frac{-74224}{+42282} = -1.76$ feet, eccentricity of thrust.

$\frac{u}{h} = \frac{1.76}{2.5} = 0.70$ feet (value of $\frac{x_o}{t}$ in Hool and Johnson).

$\frac{d'}{h} = \frac{.17}{2.5} = 0.068$ { (d' = distance from center of steel to surface of concrete).

$P_o = \frac{2\times\ .5625}{144\times2.5} = .0031$ per cent steel.

From the diagram on page 399 of Hool and Johnson (for $d' = 0.05t$ in which t is the same as h) with $P_o = 0.0031$ and $\frac{u}{h} = 0.70$, k is equal to 0.310, and from diagram on page 400 (for $d' = 0.10t$), k is equal to 0.300. As $\frac{d'}{h}$ is 0.068 we should use a value of k between the two or about 0.305.

(Continued on page 104)

COMPARISON OF TRUCK AND RAILROAD TONNAGE BETWEEN COLUMBUS AND SELECTED OHIO CITIES

AN EXTRACT FROM THE REPORT ON A SURVEY OF TRANSPORTATION ON THE STATE HIGHWAY SYSTEM OF OHIO

IN order to determine what proportion of the total tonnage of commodities moving between cities is hauled by motor truck, and also to develop the factors influencing the choice of motor truck or railroad, an analysis was made of the net tonnage hauled between Columbus and 34 Ohio cities by motor truck and rail lines.

The cities selected are located from 7 to 134 highway miles from Columbus and were chosen to permit an analysis of the effect of length of haul upon the proportions of tonnage transferred by motor truck and railroad, respectively. Hillsboro and Johnstown, both having indirect rail connections with Columbus, were selected to determine the effect of indirect rail connections upon motor-truck transportation. Commercial Point, Dublin, Reynoldsburg, and Rome were selected to ascertain the amount of tonnage hauled by truck between points having no railroad facilities.

Motor truck net tonnage and railroad carload and less-than-carload tonnage data for an average month of 1925 were taken as the basis for this comparison, as shown in Figure 1, the size of the circles for each city indicating the total net tonnage transported.

It is apparent that distance is an important factor in the amount of tonnage hauled by motor truck. Between Columbus and Akron, Cincinnati, and Toledo, distances of over 100 miles, a very small part of the total tonnage is hauled by truck, while between Columbus and Grove City and between Columbus and Alton, distances of 8 and 9 miles, respectively, almost all of the tonnage is transported by motor truck.

Table 1 presents a summary of the relation between motor truck and rail tonnage according to length of haul.

TABLE 1.—*Proportion of motor truck and railroad net tonnage according to length of haul for average month, 1925* [1]

Length of haul (highway miles)	Motor truck		Rail (carload)		Rail (less than carload)		Total	
	Tons	*Per cent*	*Tons*	*Per cent*	*Tons*	*Per cent*	*Tons*	*Per cent*
Less than 20	6,091	84.5	1,112	15.4	10	0.1	7,213	100.0
20–39	5,973	54.7	4,803	44.0	145	1.3	10,921	100.0
40–59	2,299	32.0	4,484	62.4	404	5.6	7,187	100.0
60–99	980	24.2	2,409	59.4	663	16.4	4,052	100.0
100 and over	157	2.3	5,280	77.4	1,383	20.3	6,820	100.0

[1] Based upon tonnage between Columbus and 30 cities having rail connections.

Although other factors besides length of haul influence the proportions of total tonnage hauled by motor truck and rail lines, respectively, and although the number of cities in each zone of haul (Table 1) is not large, there is clearly indicated the tendency for the proportion of motor-truck tonnage to decreases with increase in distance. For hauls of less than 20 miles, 84.5 per cent of the total tonnage is transported by motor truck; between 20 and 39 miles, motor-truck tonnage is 54.7 per cent of total tonnage; and for the longer hauls, motor-truck tonnage is 32, 24.2, and 2.3 per cent, respectively. As the percentage of motor-truck tonnage decreases with increase in distance both rail, carload, and less-than-carload tonnage increase. No appreciable amount of less-than-carload tonnage is noted under 40 miles. Between 40 and 59 miles the less-than-carload tonnage is 5.6 per cent of the total and this percentage increases to 20.3 for distances of 100 miles or more.

Among other factors controlling the proportion of total tonnage hauled by truck are the type of commodities and rail facilities. An illustration of the former is indicated in the movement between Columbus and Johnstown. Although Johnstown is only 22 miles from Columbus by highway and 41 miles by railroad, 73.1 per cent of the tonnage is hauled by rail, practically all of which moves in carload lots. This high percentage of rail tonnage, considering the comparatively short highway mileage and the longer rail connection, is due to the type of commodity transported, 95.7 per cent of the total tonnage being gravel, sand, and stone. These commodities can not be economically hauled by motor truck for this distance, as is indicated by the fact that the average length of haul for trucks hauling gravel, sand, and stone in Ohio is only 10 miles.

The influence of indirect rail connection upon the proportion of motor truck and rail tonnage is shown between Columbus and Hillsboro, a distance of 65 miles by highway and 97 miles by railroad. Between these points 47.5 per cent of the total tonnage is carried by motor truck. Reference to Table 1 shows that, under normal conditions, between 40 and 59 miles, only 32 per cent of the total tonnage is carried by motor truck, and that between 60 and 99 miles the corresponding figure is 24.2 per cent. It is evident that the relatively high percentage of motor-truck tonnage between Columbus and Hillsboro is due, in large part at least, to the fact that the distance by highway is 32 miles shorter than the distance by railroad.

EFFECT OF SALTS IN MIXING WATER ON STRENGTH OF MORTAR STUDIED

The bureau of engineering research of the University of Texas is now studying the results of a series of tests to determine the effect of various salts in mixing water on the strength of cement mortar. These tests have been made over a period of three years and a report is to be made soon.

The bureau has recently moved into new and more commodious quarters and an enlarged program of research work is being planned for the future, according to F. E. Giesecke, director of the bureau.

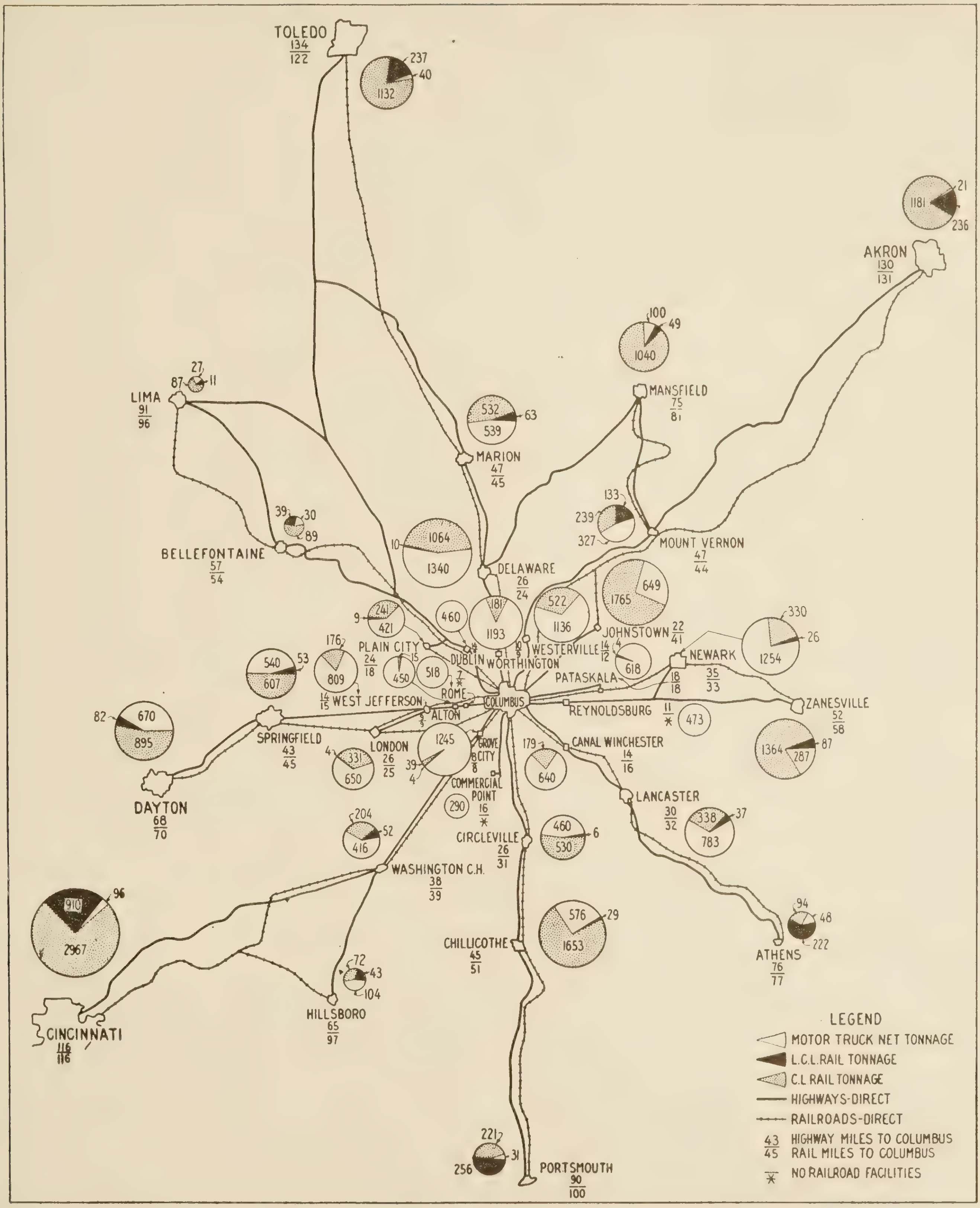

Fig. 1.—Comparison of Motor Truck and Railroad Net Tonnage Between Columbus and Selected Ohio Cities

YADKIN RIVER BRIDGE TEST IN PROGRESS

Preliminary studies of the effect of temperature variations on the arch ring of the bridge over the Yadkin River between Albemarle and Mount Gilead, N. C., are now in progress. The measurements recently begun constitute the first of a series of tests which will be made on the bridge, a Federal-aid structure, during the coming summer and autumn. The bridge, which will be submerged early next year by back water from a dam now under construction, is being tested under the joint auspices of the bureau and the North Carolina State Highway Commission with the aid of an advisory committee of distinguished engineers.

The temperature of the concrete is being determined at various depths in the arch ring by means of thermometers inserted in holes drilled in the arch and filled with cup grease to exclude the air. Simultaneously with the temperature readings, measurements of the deflection of the crown of the arch are made from the datum afforded by a taut piano wire. The wire is fixed at one end and passes over a pulley at the other and is kept at a uniform tension by means of a weight. The preliminary temperature studies are being made for the purpose of correcting for temperature the results obtained in subsequent loading tests.

Representatives of the advisory committee inspected the bridge on May 15 and 16 and agreed upon a program of test procedure. The loading is to consist of tanks filled with water and so constructed as to be moved readily to desired positions. Distribution of stresses will be determined for various positions of the loads. If time and sufficient funds are available, impact tests will be made, using heavy trucks for loads. Following this, an attempt will be made to load the bridge to destruction with water tanks.

The loading measurements will include the deformations of the concrete, the deflections and change in curvature of the arch ribs, and the movements of the piers. Preparations for the loading measurements are being made as rapidly as possible. A ferry will be operated across the river in order to permit closing the bridge prior to the completion of the replacing structure.

Exact measurements of the existing bridge are now being taken and an analysis of the structure will be made by the Beggs deformeter method, using a model constructed in accordance with these measurements, in order to determine the relation between the actual behavior of the structure under load and the behavior as determined by the analysis.

PRODUCTION COSTS OF BROKEN STONE

The United States Department of Agriculture has recently issued Miscellaneous Circular No. 93, Direct Production Costs of Broken Stone, by George E. Ladd, economic geologist, division of tests, Bureau of Public Roads. This circular contains a detailed report of cost analyses of operations at a number of quarries of various sizes, involving production of broken stone in various kinds of rock, and discusses generally the conditions which affect costs. The report describes in detail the character of each of the quarries studied and gives direct costs of the various operations, such as stripping, drilling face, breaking bowlders by various methods, face blasting, etc. Some quarries, where methods of operation were changed after the studies were made, were studied during the following season in order to compare the two different methods of operation. Tables of detailed costs for each quarry are followed by tables and discussions analyzing each of the major operations for all of the quarries studied. The bulletin will be of great value to quarry operators, engineers, and others having to do with the production of broken stone in determining if operations are being efficiently conducted by comparison with other quarries operating under similar conditions. It will also be useful in determining the efficiency of operations in rock excavation for highway and other purposes.

It is believed that its greatest usefulness lies in the suggestions it contains for producers who wish to adopt a cost-keeping system based on units of operation.

HIGHWAY BRIDGE LOCATION

Important principles governing the location of highway bridges are discussed in United States Department of Agriculture Bulletin 1486D, Highway Bridge Location, by C. B. McCullough, bridge engineer, Oregon State Highway Commission. In this bulletin Mr. McCullough presents the results of a long experience in the location of highway bridges, discussing the subject with reference to first cost, maintenance, operation, and relation to the highway of which it is a part.

Location of minor structures is discussed in some detail, giving desirable and undesirable features in alignment of highway and culvert location. Cost considerations involved in the location of large structures are treated under the headings length of crossing, angle of crossing, foundation conditions, and permanency of channel. It is pointed out that a location at first thought to be most desirable, may, after careful investigation, prove to be more costly than some other location which is apparently less advantageous. The bulletin also discusses maintenance considerations, alignment, grade-line treatments, traffic influence on bridge location, and location over navigable waters.

(Continued from page 101)

The diagram on page 402 is for $\frac{d'}{h}=0.10$.

To use the diagram for $\frac{d'}{h}=0.05$, P_o should be divided by 0.790 according to instructions below the diagram. As the value of $\frac{d'}{h}$ in this case is 0.068 we should divide P_o by about 0.84, which gives a value of $P_0=0.0037$ for use with the diagram. Using a value of $P_o=0.0037$ and $k=0.305$ we find from the diagram that $L=0.0900$. Then substituting in the equation given by Hool and Johnson, $f_c=\frac{M}{Lbt^2}=\frac{12\times 74{,}224}{0.0900\times 12\times (30)^2}=$ 916 pounds per square inch, and $f_s=nf_c\left(\frac{d}{kt}-1\right)=$ $15\times 916\left(\frac{28}{305\times 30}-1\right)=28{,}300$ pounds per square inch.

Stresses are computed at all points where Table 12 indicates that the concrete will crack and if necessary the design of the arch ring is revised. Usually a slight modification is sufficient to keep within the limits of the specifications.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.

DEPARTMENT BULLETINS

No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387D. Public Road Mileage and Revenues in the Southern States, 1914.
388D. Public Road Mileage and Revenues in the New England States, 1914.
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463D. Earth, Sand-Clay, and Gravel Roads. 15c.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537D. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917. 5c.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
*724D. Drainage Methods and Foundations for County Roads. 20c.
*1077D. Portland Cement Concrete Roads. 15c.
*1132D. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
1259D. Standard Specifications for Steel Highway Bridges adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279D. Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.
1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 94C. TNT as a Blasting Explosive.
331C. Standard Specifications for Corrugated Metal Pipe Culverts.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.
93M. Direct Production Costs of Broken Stone.
105M. Federal Legislation Providing for Federal Aid in Highway Construction and the Construction of National Forest Roads and Trails.

FARMERS' BULLETINS

No. *338F. Macadam Roads. 5c.
*505F. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *739Y. Federal Aid to Highways, 1917. 5c.
*849Y. Roads. 5c.
914Y. Highways and Highway Transportation.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.
Vol. 10, No. 5, D-12. Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

JUNE 30, 1927

STATES	FISCAL YEARS 1917-1926			FISCAL YEAR 1927									BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1926			PROJECTS COMPLETED SINCE JUNE 30, 1926			*PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 18,226,411.34	$ 8,725,985.09	1,298.3	$ 1,834,960.34	$ 889,114.85	101.9	$ 6,750,331.59	$ 3,219,304.80	393.7	$ 80,614.39	$ 40,307.19	1.9	$ 3,021,963.07	Alabama
Arizona	10,949,878.25	5,863,772.35	729.8	860,072.45	583,396.92	71.0	1,398,735.50	961,236.28	62.7	364,876.07	347,611.63	19.1	2,918,225.82	Arizona
Arkansas	18,364,544.50	7,666,698.35	1,323.0	3,972,470.13	1,858,494.40	237.6	2,854,174.10	1,386,642.91	211.5	977,873.98	284,001.03	19.4	1,687,863.31	Arkansas
California	27,142,596.90	13,003,592.30	1,058.0	7,985,672.14	3,963,434.52	248.3	7,420,526.19	3,420,728.79	151.4	103,357.10	62,014.26	4.5	4,106,482.13	California
Colorado	13,905,904.64	7,127,288.18	745.0	1,591,217.27	807,010.73	84.0	6,291,181.71	3,074,539.39	276.1	35,740.10	20,057.34	2.9	2,673,436.36	Colorado
Connecticut	5,414,567.19	2,100,585.80	117.1	982,825.10	343,414.74	20.2	5,314,155.45	1,478,079.22	63.9	1,246,486.94	290,040.13	13.0	594,246.11	Connecticut
Delaware	4,918,052.29	1,781,665.60	124.3	1,318,974.26	563,906.82	35.2	796,771.28	312,891.57	32.9	363,426.80	133,352.00	11.0	47,867.01	Delaware
Florida	3,832,680.26	1,824,362.32	132.9	3,644,176.05	1,803,550.28	112.2	8,856,112.63	3,897,634.31	196.3	1,190,401.52	398,091.78	24.2	1,060,766.31	Florida
Georgia	24,791,206.97	11,664,237.86	1,794.0	7,160,229.53	3,436,994.54	379.6	8,069,503.82	3,985,165.58	333.7	218,347.39	104,500.11	0.3	1,220,263.91	Georgia
Idaho	11,061,198.14	5,882,112.70	724.7	2,164,317.31	1,193,414.46	110.8	2,648,283.40	1,650,659.48	199.1	218,700.00	129,336.00	9.3	639,297.36	Idaho
Illinois	44,116,611.86	20,619,995.74	1,377.7	4,422,370.30	2,161,520.86	153.1	10,166,322.21	4,867,016.84	355.8	5,327,734.75	2,635,383.13	187.0	2,702,710.43	Illinois
Indiana	16,949,425.87	8,172,125.19	534.3	6,423,291.87	3,066,443.01	198.2	16,073,034.11	7,567,438.31	476.9	1,892,125.60	946,012.79	68.8	379,107.70	Indiana
Iowa	29,062,375.40	11,926,302.10	2,114.8	5,243,763.46	2,469,301.65	369.6	14,294,224.35	6,290,951.47	564.6	1,525,541.13	694,163.89	44.1	149,842.89	Iowa
Kansas	32,826,601.64	12,590,489.25	1,160.6	4,615,459.97	2,140,340.23	334.6	14,589,667.80	5,739,789.74	684.6	1,426,825.52	585,824.06	167.0	476,499.72	Kansas
Kentucky	20,737,706.10	8,492,082.25	758.3	2,478,894.43	1,018,612.50	116.6	9,527,523.23	4,494,951.93	416.5	703,382.30	341,033.44	42.8	284,075.88	Kentucky
Louisiana	13,830,592.68	6,144,739.99	1,055.9	2,046,959.52	949,152.22	122.8	4,118,538.00	1,935,266.43	140.9	1,143,779.00	309,000.00	0.9	947,557.36	Louisiana
Maine	8,747,552.76	4,192,507.39	303.6	1,817,247.30	665,945.28	54.0	2,887,249.06	992,794.43	74.8	87,912.01	43,956.00	5.6	1,250,418.90	Maine
Maryland	10,924,943.10	5,112,991.22	423.3	865,260.83	411,947.05	54.5	814,475.47	373,185.64	33.9	1,388,142.23	574,800.00	66.6	87,252.09	Maryland
Massachusetts	18,353,757.71	6,657,260.62	374.5	2,316,488.31	768,667.53	35.9	5,990,010.14	1,540,245.69	92.9	170,221.48	35,235.00	2.3	2,196,417.16	Massachusetts
Michigan	25,997,240.78	11,827,052.30	963.0	5,980,007.59	2,501,432.69	121.2	11,900,759.33	5,428,748.35	365.3	1,166,057.73	564,720.00	26.3	2,235,102.66	Michigan
Minnesota	37,170,985.95	15,586,116.56	3,181.9	7,928,662.52	3,460,029.11	461.6	7,150,669.77	2,112,898.90	370.0	445,813.35	3,000.00	19.4	550,476.43	Minnesota
Mississippi	15,146,088.52	7,414,534.10	1,129.0	3,185,142.23	1,589,760.52	185.1	6,756,572.72	3,268,960.98	363.7	769,751.42	384,875.69	65.2	777,765.71	Mississippi
Missouri	28,989,166.92	13,736,014.85	1,543.2	13,400,123.49	5,945,011.63	401.6	9,250,411.52	3,833,292.27	266.8	1,465,419.89	688,525.82	68.4	988,766.43	Missouri
Montana	11,400,983.81	6,333,465.89	1,054.9	1,454,011.91	953,822.80	96.7	1,715,050.00	1,426,969.48	129.8	3,157,854.36	1,874,899.88	305.9	4,387,225.95	Montana
Nebraska	11,533,401.62	5,474,202.52	1,768.3	4,623,638.63	2,265,183.87	478.3	12,604,690.58	6,216,951.27	1,305.1	2,389,493.82	1,191,542.77	166.6	1,072,492.57	Nebraska
Nevada	7,558,195.51	5,130,934.59	538.8	2,863,153.80	2,458,234.09	314.8	1,520,113.16	1,314,359.67	182.7				840,196.65	Nevada
New Hampshire	4,992,558.60	2,377,450.07	237.6	876,339.16	401,477.98	27.2	1,024,537.73	460,853.90	30.8	353,623.55	152,535.79	8.8	142,799.26	New Hampshire
New Jersey	16,346,301.01	5,098,342.21	290.3	5,881,939.07	2,397,022.27	26.0	7,416,614.44	1,700,398.56	111.3	541,849.05	88,620.00	5.9	117,647.96	New Jersey
New Mexico	12,404,337.77	7,339,657.38	1,427.0	931,913.17	597,940.68	79.2	3,338,904.18	2,586,415.22	233.6				1,636,135.72	New Mexico
New York	43,224,279.79	17,911,957.19	1,197.0	10,958,805.65	3,781,998.46	242.3	37,212,953.00	9,416,593.95	579.8	11,227,933.00	2,468,927.50	155.6	4,100,934.90	New York
North Carolina	27,009,419.47	11,177,337.94	1,257.9	8,286,429.74	3,341,565.22	202.2	2,696,070.16	1,296,705.92	87.6	1,429,333.80	649,189.75	36.8	965,763.17	North Carolina
North Dakota	12,313,311.40	6,031,859.78	2,193.1	3,568,247.15	1,714,433.90	522.5	5,184,096.96	2,825,402.95	738.9	1,896,476.71	931,726.17	320.8	440,187.20	North Dakota
Ohio	47,699,532.90	17,371,787.03	1,364.1	4,921,858.59	1,959,589.73	150.9	11,536,410.43	4,484,341.32	334.3	903,840.00	326,640.00	20.8	4,351,646.92	Ohio
Oklahoma	28,247,950.33	13,159,999.15	1,178.9	2,134,006.75	957,590.06	89.2	4,029,281.98	1,714,249.20	251.2	1,032,760.60	485,430.65	71.5	1,494,408.94	Oklahoma
Oregon	17,027,878.42	8,593,214.79	939.2	2,555,706.34	1,448,238.15	115.8	2,447,526.13	1,276,070.18	62.4	50,108.85	25,696.80	9.9	718,329.08	Oregon
Pennsylvania	61,366,150.80	21,560,732.04	1,188.8	16,360,023.42	4,756,888.28	345.5	15,832,234.37	4,890,636.70	323.1	3,598,343.75	1,246,728.54	64.2	2,219,530.44	Pennsylvania
Rhode Island	3,988,616.09	1,558,829.06	86.7	1,244,797.29	439,650.00	29.3	1,291,855.67	338,055.00	22.6	573,638.37	153,338.74	9.3	543,321.20	Rhode Island
South Carolina	15,020,639.90	6,766,322.93	1,481.9	1,981,400.03	760,665.87	86.5	6,561,820.95	2,799,135.49	235.8	473,781.64	129,765.91	22.9	400,621.80	South Carolina
South Dakota	17,468,373.19	8,603,826.97	2,181.2	1,793,690.05	903,698.57	321.7	3,563,268.21	1,913,591.91	623.6	714,883.33	393,185.77	131.5	572,550.78	South Dakota
Tennessee	21,624,631.57	10,276,584.02	780.0	2,658,403.46	1,274,873.53	88.7	8,792,828.20	3,614,687.07	225.7				1,729,212.38	Tennessee
Texas	69,183,673.48	27,440,254.72	4,920.2	9,006,572.89	4,126,705.73	546.2	15,244,074.93	6,770,640.89	535.1	1,224,473.97	580,397.47	54.7	6,185,704.19	Texas
Utah	8,253,178.03	5,098,440.68	546.4	901,199.30	668,639.27	82.5	2,300,008.82	1,748,044.39	173.5	599,097.13	439,213.87	37.6	711,346.79	Utah
Vermont	4,242,042.64	2,017,699.51	134.5	795,075.59	331,156.50	18.2	2,136,881.86	819,113.52	41.7	1,207,603.13	423,554.61	27.4	42,607.86	Vermont
Virginia	21,990,249.44	10,386,728.11	1,005.5	4,853,775.80	2,151,415.14	163.4	4,884,311.35	1,975,028.87	109.4	871,834.24	357,382.24	19.0	74,673.64	Virginia
Washington	17,078,511.63	7,782,909.46	668.6	1,105,994.34	463,642.49	42.5	3,690,460.86	1,750,600.00	68.2	237,489.59	65,000.00	10.1	1,215,156.05	Washington
West Virginia	9,473,716.44	4,141,062.65	392.9	951,130.88	432,685.36	26.5	7,132,862.00	2,934,191.85	238.2	722,352.42	325,736.82	26.9	312,470.32	West Virginia
Wisconsin	24,856,508.19	10,392,705.73	1,592.1	3,034,993.97	1,455,153.17	137.4	9,835,564.55	4,592,758.80	375.5	696,107.82	308,320.00	19.4	2,560,332.30	Wisconsin
Wyoming	10,928,302.56	6,040,887.05	1,133.5	1,722,409.59	1,098,380.00	182.4	2,404,653.81	1,557,096.95	177.5				804,279.00	Wyoming
Hawaii				343,664.15	97,440.00	6.5	1,786,323.89	562,362.64	29.7				805,975.36	Hawaii
TOTALS	966,692,834.36	426,178,703.58	52,526.6	188,047,767.12	83,828,987.66	8,431.0	340,102,631.60	142,817,679.01	13,356.1	56,215,409.83	22,233,674.57	2,395.6	69,440,955.18	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 79,432,586.10 Federal aid $ 34,877,220.48 Miles 3,252.1