FEATURE ARTICLES

Asphalt Pavements From the Ancient East to the Modern West

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The first asphalt pavement thus far discovered was constructed about 2,500 years ago, although the materials that compose all asphalt pavements today have been available in usable form for at least 100,000,000 years. All asphalts are derivatives from crude petroleum which was formed during the Cretaceous or early Tertiary periods. The rock, sand, and gravel that make up 90 to 95 percent of the typical pavement is even older by several billion years.

Archaeological studies and excavations in ancient cities of the East disclose that man was using asphalt about as early as any other building material. This means he began about 5,000 years ago. It seems, however, that an early Californian became mixed up with asphalt much earlier, because bones found recently in the asphalt pool at Rancho La Brea in Los Angeles have been dated as being some 9,000 years old. Just another example of Californians being first in an important field!

The oldest reported structure in which asphalt was used is a water storage tank in the ancient city of Mohenjo Daro in the Indus Valley of Northwest India. This ruin is dated as having been built about 3200 B. C.

Asphaltum was used by most of the early civilizations in the regions bordering on the eastern Mediterranean. It was used by the Egyptians to embalm the bodies of the common people, and the very word "mummy" was derived from the Persian word "mumia," meaning bitumen. The Egyptians constructed boats or coracles by weaving a tight vessel of twigs or reeds and then waterproofing with asphalt. Moses undoubtedly owed his survival among the bulrushes to the asphalt coating on his "basket."

Lumps of solid or semi-solid bitumen were gathered from the surface of the Dead Sea and along the banks of the Euphrates River. Mention of asphalt appears in several places in the Old Testament, and Noah was admonished to use it to waterproof the Ark. A major bank protection project using brick cemented with asphalt was constructed along the banks of the Tigris River in 1300 B. C. This work is still serving to protect the banks from erosion.

The oldest record of street paving with asphalt is an inscription on a brick dated between 625 and 604 B. C. This records the paving of the Procession

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Street in Babylon "with asphalt and burned brick." Further mention of bitumen appears at intervals in writings by both Greeks and Romans down through the years.

Moving up to more modern times, in 1595 Sir Walter Raleigh visited the pitch lake on the island of Trinidad, which had been discovered by Columbus on his third voyage in 1498. Sir Walter reported enthusiastically on the virtues of the material for caulking "shippes." About 1720 a Greek physician named Eyrinis d'Eyrinis described a deposit of bituminous sandstone in the Val de Travers in Switzerland. He claimed that the vapors from the asphaltic exudate would cure many of the ills of mankind.

There is little mention of these European deposits of rock asphalt for the next 100 years, but finally some trials for paving purposes were made in 1834.

The first asphalt road of record was constructed from Paris to Perpignan in 1852. It was not until 1869 that the first asphalt pavement in England was placed on Threadneedle Street in London. In 1870 the Belgian chemist, Dr. E. J. DeSmedt, paved the street in front of the city hall in Newark, New Jersey. While pavements of coal tar, pitch, crushed rock, and sand had been constructed in Washington, D. C., and elsewhere in the East, this date of 1870 has been generally accepted as the beginning of asphalt paving in the United States. However, S. F. Peckham reports that asphalt pavements had been known "since time immemorial" prior to 1865 in Southern California.

In 1876 a commission of army engineers appointed by President Grant recommended that Pennsylvania Avenue in Washington be paved with sheet asphalt using natural asphalt from Trinidad Lake. A young schoolteacher named Amzi Alonzo Barber had secured a franchise to export Trinidad Asphalt and was awarded a portion of the paving contract. Seven years later the Barber Asphalt and Paving Company was formed. Later Barber hired Captain Francis Vincent Greene, who had been Assistant Paving Engineer for the District of Columbia. Captain Greene became a brigadier general in the Spanish-American War and ultimately president of The Barber Company. The name Barber-Greene is well known today.

About 1847 one Samuel Warren, together with three brothers and a cousin, organized a company to apply a patented roofing material consisting of pine pitch, coal tar, and sand. Of this group, Mr. E. B. Warren was one of the founders of the Barber Asphalt Company and became one of the group importing Trinidad Asphalt. Mr. H. E. Warren was the father of seven sons who later (in the year 1900) formed the famous Warren Brothers Company and first promoted the use of California Oil Asphalt in the eastern states, and also developed the patented pavement called "Bitulithic."

By 1899 the Barber Asphalt Company, the Warren Chemical and Manufacturing Company, and The Warren Scharf Company were all merged into a group operating under the title of The General Asphalt Company of America, which came to be referred to quite often as "The Asphalt Trust." Later Barber withdrew from the combine and formed the A. L. Barber Company, which utilized Burmudez Asphalt. For five years following 1904 there was a state of controversy, maneuvering, political manipulation, and general international skulduggery that at times threatened diplomatic relations between this country and Venezuela. In 1901 George Copp Warren introduced California Oil Asphalt to the East. It was claimed to be "the best and purest asphalt known." The records show that 20,000 tons were used in the year 1902. By 1938 the total consumption of asphalt in the United States had increased to nearly 5,000,000 tons, and in 1968 the total was reported as approximately 30,000,000 tons. Refined oil asphalt from California, Texas, the midcontinent fields, and Mexico had completely displaced natural asphalt from Trinidad and Burmudez.

In 1901 Frederick J. Warren (of the Warren Brothers firm) had applied for a patent on a type of paving which he had named "Bitulithic." Departing from the then-current practice, Warren proposed that fine and coarse particles of aggregate be mixed uniformly from top to bottom of the pavement layer, thereby "securing both stability and solidity." The era of patented pavements had begun, and during the following years many trade names were coined and products promoted with often extravagant claims for real or fancied properties.

Among the better known patented pavements may be listed "Willite" (which required an admixture of copper sulfate), "Romanite," "National Pavement," "Imperial," "Indurite," and "Macasphalt." Not to be outdone, the Warren Company registered such additional trade names as "Warrenite," "Bitrock," "Puritan," "Bitustone," "Rockphalt," and "Acme" Asphalt.

There were many legal contests as the holders of the patents, especially the Warren Brothers, brought suit against any user where there was the slightest ground to charge infringement of the patents. However, about 1919 the city of Topeka, Kansas, began using a type of mix that was nothing more than a sheet asphalt to which had been added a small amount of half-inch size coarse rock. In the ensuing trial the judge ruled that Topeka mix was not an infringement on the Warren patents. Soon after this decision the era of patented pavements came to an end in the United States.

Among the more successful patented pavements was "Amiesite," named after its inventor, Dr. Joseph Hays Amies. Amiesite was a cold-mixed product using a kerosene-type cutter stock and a small amount of hydrated lime. It gained a good reputation and Mr. A. W. Dow expressed the opinion that much of the success with Amiesite was due to the use of hydrated lime. Another cold-mixed product was called "Colprovia," which was one of several types using a hard powdered asphalt and a carefully specified and controlled fluxing oil.

It may be pertinent to point out, however, that all of the numerous and various types of asphalt pavement mixtures have one thing in common—all are mixtures of stone particles and asphalt, and regardless of special names and proprietary specifications all are variants of the same thing, and all depend on the same basic principles for successful performance. It seems that the materials really do not care what they are called by promoters, salesmen, or engineers—they will all continue to act and respond to the same natural laws.

The years in which the patented types of asphalt pavements dominated the paving scene were colorful and furnished many good examples of the competitive spirit and the means by which products are often pushed or promoted for use. Both the Barber Asphalt Company and the Warren Brothers maintained large, well-equipped laboratories to measure the properties of asphaltic mixtures and perhaps to impress the prospective customer with the quality of the product.

Anyone writing today about the activities of the years between 1900 and 1920 must largely depend upon his memory of the tales and recollections of the departed old-timers who were familiar with some part of the work. It has been reported that the Warren Company had a large laboratory in a two-story building in Portland, Oregon, devoted entirely to testing materials for asphalt pavements. I have no record or knowledge of just what tests were performed, but in order to get jobs it was also necessary to have salesmen or promoters call on city councilmen, county supervisors, and other public officials in order to persuade them that they should specify asphalt pavement. It has been reported that Warren Brothers had developed experienced and capable construction superintendents or foremen who were very rigid and uncompromising about quality and would, without hesitation, discard many batches from the hot plant until it was in their opinion "just right." However, with the increase of business due to the activities of the promoters the firm expanded so fast that they did not have enough experienced "old-time" "hot stuff" foremen or superintendents and were forced to depend more and more on less experienced men, and as a result there were failures and unsatisfactory jobs. It has been said that when Warren Brothers wished to build a "show job" the care exercised and the quality of the finished pavement left little to be desired. The "show job" was expected to sell many others.

A story—possibly apocryphal—that has come down concerns an asphalt paving promoter (not necessarily with the Warren Brothers) who invented a small portable mechanical device to demonstrate the superior qualities of asphalt pavements as compared to portland cement concrete. This contrivance consisted of a small motor-driven mechanism operating two trip hammers, one on either end of a walking beam. For the demonstration, a compressed block or specimen of an asphalt pavement was placed under one hammer and a block of concrete under the other. The machine was then started and the steel hammers pounded alternately the asphalt and the concrete with what was obviously complete mechanical impartiality. In a short time, of course, the concrete specimen would be cracked or spalled and the asphalt specimen be little the worse for wear—especially if a fairly rich mixture had been used in the specimen. I have been told that many thousands of square yards of pavement were sold on the strength of this "scientific demonstration." Few, if any, of the city fathers or perhaps engineers for that matter ever stopped to question whether or not pavements on the street would be required to withstand the effects of a steel hammer.

In 1924 Mr. C. S. Pope, Construction Engineer for the California Division of Highways, developed and patented a mechanical spreading machine that was patterned after the concrete paving spreaders. Because asphalt pavements had always been spread by hand "rakers" it was felt that raking was an essential part of spreading and placing an asphalt pavement. Consequently, the first spreaders were equipped with mechanically operated teeth that were dragged through the mix creating small longitudinal lines that actually introduced vertical planes of weakness as evidenced by the propensity of cracks to follow these rake marks. The requirement for raking was abandoned after a few years. However, the mechanical spreaders have become almost universal in use and have greatly improved the appearance and riding qualities of the asphalt pavement. For the first few years following 1924 it was the practice to broadcast asphalt-coated coarse screenings over the surface of the pavement after initial rolling and these screenings were rolled in with the final pass of the tandem roller. This was to increase the skid resistance, which had become recognized as a serious defect in the older rich sheet asphalt and "Topeka" type of pavement.

INTERMEDIATE OR LIGHT ASPHALTIC ROAD SURFACES

The use of road oils or liquid asphalts is a development that started in the West and spread widely over states to the East. The earliest recorded use of road oil that I could find is a reference to the use of crude petroleum to oil the road on Ortega Hill on the outskirts of Summerland, California, in 1894. A report by James W. Abbot, Special Agent, Office of Public Road Inquiries, Los Angeles, in 1902 refers to experimental work done in Los Angeles County in 1898. Abbot states, "The sole purpose of this work was to lay the dust, which, churned beneath the wheels of the increasing traffic during the long dry season in that region, became a most serious nuisance." I can recall seeing oiled roads in the vicinity of Petaluma, California, in the year 1904. Oiling of existing wagon roads continued by many of the California counties, but the state highway department did not make much use of either road oil or asphalt except for a few jobs of sheet asphalt on the early concrete pavements and the use of Topeka mix in 1920 to 1924 to overlay some of the concrete pavements that were beginning to show distress.

The increasing evidence of distress and damage to the first thin concrete pavements led the new State Highway Engineer of California, R. M. Morton, to embark in 1924 on a program of placing heavy gravel road surfaces on the newly constructed grades with the intent of providing a base for a future concrete pavement. However, in the years 1922 to 1926, traffic was increasing so rapidly that the gravel surfaces were being worn away at the rate of 1 inch of surfacing a year while the roads became dusty and rough or corrugated in the process.

Along with most of the western states, Oregon had built many miles of gravel road surfacing—generally using a small maximum size stone that was easy to shape and make smooth with a grader or "blade" but which was also peculiarly subject to the phenomenon of "washboarding." Few today can appreciate the roughness that could develop. As Resident Engineer in 1924, I "presided" over a contract that produced a gravel road surface that within a month after being placed developed a corrugated roughness so extreme that the "valleys" between each bump or ridge were about 6 inches deep! This road was so rough that rugged mountain drivers followed crude "detours" through the brush and rough terrain alongside the highway rather than travel on our new "improved" surface.

Faced with similar problems, Oregon in 1923 was the first of the western states to begin a program of treating the gravel surfaces with road oil or liquid asphalt. Oregon developed two types of treatments. One called the "oil mulch" was intended to be a substitute for the endless watering that was being employed, and it was expected that this "oil mulch" would be kept smooth by frequent blading. A very low viscosity oil was used. The second type, using a heavier grade of oil, was termed the "oil mat" and was to all intents and purposes the same as present-day surface treatments or "seal coats." California hastened to follow the lead set by Oregon and hired Mr. C. L. McKesson to head the laboratory and to handle all materials control and the light oil program as well. The oil mat was generally satisfactory in California, especially if applied to a well-compacted, smooth, firm, gravel surface. The oil mulch was less satisfactory, but it was interesting to find that even with the light oil many stretches of road would consolidate, form a smooth glazed surface, and eliminate all problems of grading and watering. However, chief engineers are sometimes hard to convince, and I recall that as a Maintenance Superintendent I was required to scarify and loosen up these nice, smooth dustless sections "because that was not the way it was supposed to act!"

The new oiling program was also applied to many miles of existing roads in Southern California across the desert connecting to Arizona and Nevada. Here, too, the maintenance men found that after some blading the sandy granular materials that are common to the desert regions would generally compact and form smooth dustless surfaces that required little or no maintenance. Finally the idea thus demonstrated percolated to the design and planning departments, and in 1926 a section between Victorville and Barstow on the road to Las Vegas was surfaced by spreading a well-graded gravel on the road, adding a slow-curing oil, and mixing with road graders and harrows to form a pavement some 3 inches thick and 18 feet wide. This project was so successful that C. L. McKesson, Materials and Research Engineer for the California Division of Highways, and Walter N. Frickstadt, Highway Engineer for the Bureau of Public Roads, collaborated on a report entitled "Light Asphaltic Oil Road Surfaces."

One of the problems that faced engineers in these early days of the light oil road mix was the question of how much or how little asphalt should be used. It was soon apparent that the ideas inherited from the East were not workable in the West, as one could not come even close to filling the voids in the aggregate with the low-viscosity road oils and still develop a stable surface. (Incidentally, while most of the liquid asphalt used was actually a heavy, slow-curing road oil, it was often specified as "fuel oil" because the railroads had established a lower rate for hauling fuel oil than for road oil. The railroads had need of fuel oil but not much interest in furthering competition from highways.)

Following their work and observations on the Victorville-Barstow job, McKesson and Frickstadt proposed a formula for calculating the amount of oil needed in a dense-graded "oil mix." The formula was $P = 0.015a + 0.03b + 0.17c$, where P is the percent of oil required, a is the present of material retained on a No. 10 mesh sieve, b is the percent of material passing the No. 10 and retained on the No. 200, and c is the amount of material passing the No. 200 sieve.

While the road-mixing process could and did produce some excellent road surfaces, there was always a problem of achieving uniformity. As a result it was a logical step to try plant-mixing, and the first such project in California was on the desert road east of Indio. The immediate success on this project led to others, but the good results of the first job were not consistently achieved and many of the early plant mix jobs were anything but satisfactory. The most frequent defect was raveling of the surface, indicating a lack of asphalt. It was evident that color of the mix or the McKesson-Frickstadt formula were not reliable guides.

In California we began in 1930 to explore a method based on surface area analysis of the aggregate. After some preliminary work and encouraging results, the work of A. R. Ebberts came to hand. Ebberts had developed a formula for correcting extraction results made on plant samples. He used the term "bitumen index" to denote the amount of asphalt by weight on one unit of surface area. We adopted this term from Ebberts' work, but it became a part of a formula for calculating the optimum asphalt content required by a given aggregate rather than a means for correcting extraction results as proposed by Ebberts.

The application of the Surface Area Formula required that an estimated allowance be made for the degree of roughness on the particle surfaces, and this evaluation was made by "eye" and "experience." Not every engineer had the necessary experience and quite a few seemed not to have the ability to estimate particle surface roughness by eye, so a more positive method was desirable—one that did not depend on having an experienced man to make the evaluation. Out of this need came the Centrifuge Kerosene Equivalent method, whereby the effective superficial surface area of the coarse and fine particles passing a No. 4 sieve was evaluated by measuring the amount of kerosene that a carefully weighed sample would retain against a centrifugal force of 400 times gravity. The coarse aggregate was evaluated by saturating with No. 10 lubricating oil, draining, and then weighing the amount of oil retained. Results of the CKE method were calibrated against stabilometer values, and a very high degree of correlation was developed. In fact, after years of experience it may be said that the CKE method indicates the optimum amount of asphalt in at least 95 percent of the cases.

The next consideration that logically follows the question of optimum asphalt content is the matter of "stability" or the ability of the asphalt pavement to resist plastic deformation. There are several synonyms for this condition, such as "pushing," "shoving," "rutting," and "grooving," and for the benefit of the younger generation, "grooving" was not thought to be "groovy." It has been known since the earliest days of asphalt paving activity that too much asphalt will almost inevitably produce instability, while a deficiency may lead to cracking and/or raveling of the surface. I do not know who proposed the first stability test for asphalt paving mixtures, but among those that have come to my attention are the Skidmore shear test developed by Hugh Skidmore of the Chicago Paving Laboratory, an impact test by Besson, a rolling test by Emmons, a horizontal shear test by Burggraf, a complex lateral and vertical shear by Emmons and Anderson, the Hubbard-Field test by Prevost Hubbard and Frederick C. Field (this latter is still in use today in certain areas), and the Marshall test by Bruce Marshall. Finally, I suppose I must mention the Hveem Stabilometer, although modesty prevents my saying (what must be obvious to anyone) that it is the only really reliable and significant one of the group! It may be pertinent to point out that the Stabilometer test is the only one of those thus far devised that does not subject the specimen to rupture or breaking in order to indicate "stability." Instability on the road is rarely manifested or accompanied by any breaking or rupture of the asphalt layer. A highly stable pavement may crack or break but an unstable one usually will not.

It is difficult to keep to a strictly chronological arrangement in recounting the various developments because many different phases were being explored and worked on by different individuals at the same time. For example, within a year after the "first" oil mix job was constructed in California, the State of Arizona began similar work with equal success, which means with a similar percentage of failures. For example, Arizona engineers noticed that certain sections seemed to be in good condition until the first rain. The surface in such cases would soften, disintegrate, and become rough, developing potholes under traffic. Julian Powers and Wayne O'Hara of the Arizona Central Laboratory suspected that some form of emulsification was taking place. They consulted the literature and found a test for demulsibility of steam cylinder oil. They set up a test procedure using the fine sand and dust from the jobs showing distress and found that when vigorously agitated in a laboratory mixer the dust would separate from the oil in the presence of water. Thus, the "demulsibility" test was born and was applied to the fine dust or filler. Later Wayne O'Hara found that the oil-treated materials from the same failures would develop appreciable expansion or "swell" when covered with water and measured with a sensitive dial gage.

California adopted both of these tests and soon found that some of the California failures could be accounted for by aggregates that would not hold asphalt in the presence of water when subjected to high-speed traffic. An explanation was sought in the scientific literature, and it was found that the colloidal or surface chemists had long recognized the phenomenon of preferential wetting and that certain solids would have a greater "affinity" for some liquids than for others. Hence, in California we renamed the demulsibility test, terming it the "water-asphalt preferential test."

About this time A. R. Ebberts, working in the laboratory of the Allegheny County Highway Department in Pennsylvania, investigated the effects of water on various types of filler dust. He found that silica dusts had a greater "affinity" for water than did limestone, and he applied the terms "hydrophilic" (water-loving) and "hydrophobic" (water-fearing). Ebberts' test was confined to the fine dust or filler, as was the demulsibility or water-asphalt preferential test originated in Arizona. However, it was soon evident that failures and distress due to water action could not be ascribed solely to the dust or filler alone. Wayne O'Hara of Arizona soon developed the swell test and later California came up with the "water-vapor susceptibility test." This last test seems to correlate better with road performance than does any other.

As the years passed other tests were devised and proposed to detect the wetting affinities of aggregates and asphalts. Best known perhaps is the "stripping test" by Victor Nicholson—later modified by joint effort of The Asphalt

Institute and the Bureau of Public Roads. The stripping test is still widely applied to stone chips or screenings for seal coats. A test was developed in Europe known as the Riedel-Weber boiling test. In this test, a small sample of the fine aggregate mixed with the asphalt is placed in a test tube and boiled vigorously over a Bunsen burner. A series of sodium carbonate solutions is used ranging from 0.1 M to 0.8 M. The samples are boiled first in distilled water and then in increasingly stronger solutions until one is found that is strong enough to strip the asphalt. This permits giving a quantitive rating to the strength of adhesion. The test proved to be quite severe, and many materials from reasonably satisfactory roads would not meet the test. Another test that is widely used is the "immersion-compression test." This is simply an unconfined compression test performed on a compacted specimen before and after soaking in water. The test is only comparative, as many satisfactory mixes do not have a very high unconfined compression value even before soaking and are lower in the dry state than some other poorly rated materials after immersion in water.

Once the problem of stripping and the adverse action of water had been given some publicity, a period of promotion began for a number of special wetting agents or compounds claimed to promote the adhesion of asphalts to aggregates in the presence of water. I do not have a complete list of all these proprietary products, but it can be said that virtually all showed some beneficial effects when subjected to laboratory tests but few if any gave enough improvement in the field to justify the cost. Some of the better known additives were "Kling," "No-Strip," "Armeen T," and "Treatolite." Hydrated lime is one of the most effective anti-stripping agents for some aggregates, but not all.

Along with the use of slow-curing oils and cutbacks was the development of emulsified asphalts, primarily for seal coat and surface treatment applications. It was first contended that emulsions could be used cold without heating, but increasing experience demonstrated that emulsions generally handle better if heated moderately. The know-how of emulsion manufacture is perhaps one of the most involved and complex of modern technology. While a wide variety of types and performance may be introduced into the emulsion field, it does require the attention of someone who thoroughly understands the theory and practice of emulsion manufacture and use. One manufacturer once complained that it required more scientific and technical know-how to run the emulsion plant than for all the rest of the refinery put together.

One of the first of the emulsified asphalts to be offered to the highway engineer was that manufactured under the Lay-Kold patents. Lay-Kold contained clay as the emulsifying agent and the patents were later acquired by the American Bitumuls Company. The American Bitumuls Company manufactured emulsions according to a patent developed in France and became a subsidiary of the Standard Oil Company of California. Today this work is all handled by the Chevron Asphalt Company.

Many advantages and virtues have been claimed for the emulsified form of road-building asphalt. Early problems developed when it was found that the rate of break on the road depended on a number of factors such as ambient temperature, amount of wind movement, and, above all, the prevailing humidity. It was also found that emulsions would break differently on limestone aggregates compared to siliceous materials, for example. In order to overcome this latter problem emulsions of the cationic type were developed. It had long been known that positively charged emulsions would adhere better to negatively charged aggregates, and vice versa.

The ability to control the application of emulsified asphalt and to avoid the excess that too often resulted with hot asphalt or even cutbacks made emulsions attractive for use in seal coat construction and surface treatments. A development in recent years called "slurry seal" utilizes the latest type "quickset" emulsified asphalt. Emulsified asphalts were extensively promoted for soil stabilization but the success in this field was not spectacular and on the whole did not equal the results with portland cement or lime. Nevertheless, emulsified asphalts are here to stay and will undoubtedly continue to have a place in highway and airport surfacing work. Present-day smog control may eliminate cutback asphalt entirely, and then emulsions may well be the only form of liquid asphalt permitted.

With the tremendous expansion of road and street construction in the United States and throughout the world came evidence that after a time all of the asphalt pavements were not giving the same performance even though constructed with the same aggregates, by the same contractors, and under the same specifications. It was evident that some pavements lacked durability, and without trying to relate all the tremendous amount of experience, opinions, and test data, it is sufficient to say that beyond question certain asphalts become hard and brittle after a relatively short time on the road while others retained their properties of ductility and resisted hardening for many years. Cracked asphalts invariably gave poor durability.

One of the first methods for differentiating between asphalts was the test developed by G. L. Oliensis in 1933. Mr. Oliensis classified asphalts according to "homogeneity" or "heterogeneity." The test consisted of dissolving a small quantity of asphalt in a partial solvent (generally called Oliensis solvent) and then placing a drop of the solution on a standard disc of filter paper or on glass. If the asphalt spot was uniform without noticeable evidence of a dark ring it was said to be homogeneous. If a dark ring formed around the spot it was said to be heterogeneous. Mr. Oliensis did not say that one was a good asphalt and the other poor, but engineers quickly adopted the spot test as a guard against cracked asphalt.

The question of asphalt durability has proved to be one of the most baffling problems to solve. In fact, there are no test methods today that will unerringly distinguish between a durable and a nondurable asphalt. A tremendous amount of work has been carried out in many laboratories. Among tests devised is the thin film test developed by the Bureau of Public Roads. This test is undoubtedly on the right track, but unfortunately the thin films used in the tests are not even close to being as thin as the average film of asphalt on the surface of the stone in an asphalt mix. John Skog in California has devised laboratory equipment that will expose the asphalt to heat and an oxydizing stream of air. This device is called the "rolling thin film test" and will within 75 minutes reduce an asphalt to the same state of hardening and brittleness as is ordinarily found after mixing in a hot plant.

Reproducing the hardening that takes place on the road over a period of years has proved to be a more difficult problem.

Before concluding I wish to say something more about the men who have contributed to the science of paving with asphalt. These are the men who are largely responsible for the fact that present-day engineers can design and build asphalt pavements with positive knowledge of the materials and factors involved.

It is impossible to list all who have made important contributions, partly because of space limitations and also because of limitations on the part of the writer, who will readily admit to ignorance of many individuals, activities, and actions that have had an influence. Therefore, I can only tell it as it has come to me.

It seems that modern asphalt technology begins with three men who were working at the beginning of the 20th century. They have already been mentioned, but, to repeat, I again list Mr. Frederick J. Warren (of the famous

Warren Brothers), who patented the "Bitulithic" pavement about 1901. Bitulithic and the Warren Brothers dominated the paving industry for over 20 years, and the company is still one of the large firms active in highway construction. The second individual is Mr. Clifford Richardson, who wrote the first comprehensive textbook, entitled "The Modern Asphalt Pavement" and published in 1905. It may be pertinent to note that Richardson did not develop or promulgate any new theories covering the behavior of asphalts and asphalt pavement but rather related in considerable detail the accumulated experience with various types of materials, with sands of different gradings, and the observed effects of heavy traffic compared to light traffic on sheet asphalt streets. Richardson's influence was so widespread that some western engineers spent a great deal of effort trying to find sands that conformed to the gradations that were typical of the eastern rivers with which Richardson was familiar. It finally appeared that the best eastern sands were not necessarily the "best in the West."

Clifford Richardson's book was an excellent compendium of the technical and practical knowledge that had been accumulated up to 1905. Mr. Richardson was a chemist by profession.

The third individual and the one who has undoubtedly had the most far-reaching and long-lasting effect on asphalt pavement technology is Mr. Allan W. Dow, who was one of the first to devise laboratory tests to replace the rule-of-thumb methods and begin the age of standardization and precise control of asphalts and their use in pavements. For instance, in the early years asphalts were shipped to the job in wooden barrels, and each barrel was liable to be of a different consistency. It was the job of the plant foreman to blend the harder and softer barrel lots in order to produce something approaching uniformity. In the absence of any test method the foreman would chew a small piece of asphalt and thus gage the consistency. Some of the more progressive asphalt manufacturers would furnish the users with a small box of "chewing samples" so that the foreman might "calibrate his jaw," so to speak.

Later someone tried to evaluate consistency by thrusting a sewing machine needle into the asphalt and judging the hardness or consistency by the depth the needle would penetrate. A No. 2 cambric sewing machine needle was the "standard." The chewing test was perhaps the most scientific as it at least had the advantage of temperature control. In any event Dow developed the Dow Penetrometer to permit a sample to be tested under careful temperature control, with a standard needle and under a standard weight. It might have been better if Dow had elected to try to simulate the chewing by a small "kneading machine." The penetration test has never really pleased the asphalt technologists of a later day.

Among the variabilities of early-day asphalts was the occasional lack of ductility caused by impurities such as paraffin wax or mineral matter. The versatile plant foreman would twist up a small sample between his fingers and then stretch it to see whether it could be pulled into an elongated thread or would break after being stretched only a short distance. If the asphalt should break after a short stretch it was called logically enough "short." Dow simulated this test almost exactly in his Dow Ductility Machine, which stretches a sample floating in a water bath under controlled temperature. The idea that asphalts should be ductile or be capable of being stretched for great distances seems to be natural to most engineers in spite of the fact that no one seems to expect the adjacent particles in a stable paving mixture to have any such freedom of movement.

There were no especially significant developments in the technology of asphalt paving for the next 20 years—at least none that are known to the writer.

After 1925 there was a stirring of interest in the qualities and purpose of the filler dust that had long been considered an essential part of the dense graded asphalt pavement. As is customary in any study of materials involving the mineral aggregates, the question of effect on voids and density was thoroughly thrashed out as it has been done many times. Also, the effect of filler dust on stability was explored and as long as the investigator was using a test, such as the Hubbard-Field, that is highly sensitive to tensile strength it could be shown that adding filler would improve "stability." About this time, 1929, A. R. Ebberts published his report on the "emulsifying effect of asphalt fillers."

Names associated with development of stability tests are Prevost Hubbard and Frederick C. Field and Hugh Skidmore of the Chicago Paving Laboratory. Other stability tests were proposed by Walter Emmons of the University of Michigan and another by Emmons and Anderton. Fred Burggraf, director of the Highway Research Board for many years, also proposed a horizontal shear test. About 1931, the author developed the Hveem Stabilometer and the Cohesiometer. In later years, Bruce Marshall developed the Marshall test.

The problem of measuring skid resistance of pavements engaged the attention of Ralph Moyer of the University of Iowa (and later with the University of California). Professor Moyer developed a trailer equipped with electric brakes and established safe minimum limits for the coefficient of friction of wet pavements.

Test tracks or test highways have been built in many places and by many agencies. In spite of the Bates Road Test in 1922 and others constructed by the Bureau of Public Roads at Arlington, Virginia, there were still many unresolved questions, arguments, and differences of opinion, and thus in 1952 the Western Association of State Highway Officials authorized building of a test track in southern Idaho. This project was confined to asphaltic pavement types, and the findings at the termination in 1954 were not too conclusive except to indicate that a 4-inch depth of pavement would withstand more traffic than would a 2-inch thick layer. This was not a particularly novel or earth-shaking conclusion, but the highway engineers were stimulated to investigate further and to compare asphalt concrete with portland cement concrete. This resulted in the construction in 1956 of the now world-famous AASHO Test Road in Illinois, which was terminated in 1960.

Time and space do not permit giving any sort of discussion of the two test roads and the findings, but the AASHO road in Illinois was easily the most expensive ever undertaken, costing the participating agencies some $27 million. While at first appearance the concrete pavement sections were in much better shape than the asphalt sections, nevertheless the tapered sections showed a remarkable performance of the thick asphalt pavement. These thick sections performed much better than comparable sections with crushed stone or cement-treated bases, and as a result in recent years the asphalt industry has adopted as a slogan the term "deep strength" to convey the peculiar strength properties of their product.

Another move that has affected the present practice of using asphalt is the long-standing urge on the part of the manufacturers to reduce the number of grades available to the engineer. This urge is primarily and perhaps solely prompted by the desire to save money. Virtually all manufacturers claim that storage tanks are always in short supply and that, if they are required to maintain a number of grades of asphalt ready for shipment, then the cost to the manufacturer is inevitably increased. It can be debated whether this is a basic economic factor of serious moment but nevertheless the industry feels that it is and have long promoted specifications that tend to reduce the number of asphalt grades available.

There is some justification for this position on the part of the asphalt refineries. At one time there were over 35 different grades of asphalt appearing in State Highway Specifications and this was by no means all because the counties, cities, and other agencies would have variants or additional grades. Around 1930 some of the outraged manufacturers pointed out that they had to maintain in their specification book over 300 separate test values for road-building asphalts. There may be some excuse for the industry trying to cut down on the number of grades. In any event, the grade reduction movement began first in reducing the number of grades of the liquid asphalts and then doing the same with the penetration grades of paving asphalt. Another step in the streamlining of asphalt specifications is the dropping of the older types of viscosity tests such as the Saybolt-Furol and substituting the more scientific kinematic viscosity with the viscosity expressed in accepted "fundamental units." Great claims were made for the virtues of being scientifically sound and it was implied or actually stated that a superior asphalt would inevitably result. The author of this paper must admit to being a skeptic and probably backward as well, but thus far I am unaware of any discernible improvement in asphalts solely attributable to the use of "fundamental units" in measuring viscosity. However, this too is history and belongs in the past.

Another problem that has plagued the asphalt pavement designer since the advent of the automobile is the question of skid resistance. Slipperiness has long been associated with asphalt pavements, particularly the sheet asphalt and Topeka types, and in general may be said to stem from two causes or factors. First was the lack of a sound test basis for establishing the optimum asphalt content. Second is the use of aggregates that possess or develop smooth or polished surface characteristics. The use of stability tests that tend to show higher values with the richer mixes is a practice that tends to aggravate the slippery pavement problem. This problem has long been recognized in England, and the British engineers have for many years been experimenting with skid measuring devices usually incorporated in a side-car attached to a motorcycle. Testing a slippery pavement with such a device seems to be among the more hazardous ways of making a living. Probably the man whose name has been most constantly associated with measurements of skid resistance if Ralph Moyer, now retired from the University of California. While associated with the University of Iowa, Professor Moyer began a series of road tests and reported several findings that have had a definite influence on the design of asphalt pavements. His most significant conclusion was that coarse textured, noisy road surfaces were not necessary and that the highway skid resistance could be obtained with surface textures presented by ¼-inch size particles that were exposed to the traffic and not coated with an excessive amount of asphalt. Work in California has been carried on for many years and it was shown that skid resistance properties were associated with the type of aggregate used and that a given stone—granite, for example—would develop about the same skid resistance regardless of the macroscopic texture of the surface. In other words, it was the microscopic texture of the stone particles rather than whether the road surface was open graded, dense graded, or a seal coat type. In the eastern United States problems with slippery pavements are very widely traceable to the polishing of certain types of stone under the action of vehicle tires. The soft limestone aggregates are noted for this polishing effect, both in portland cement and asphalt pavements.

Another property of pavements, although not necessarily confined to asphalt types, is the development of deflections or bending under passing heavy loads. Relatively expensive equipment was used to measure deflections until Mr. A. C. Benkelman, while on the WASHO test road in Idaho, developed the "Benkleman beam." "Benk" richly deserves mention on any list of those who have contributed to the technology of asphalt pavements today.

Any engineering material must inevitably be affected by the "atmosphere" in which it is used or considered for use. Thus far we have considered largely the engineers, chemists, and other technical men who have devoted their active lifetime to the improvement of asphalt pavements. We have also mentioned the contractors and the construction industry that have been involved. There is, however, still another influence and that is the agencies created and financed by the industries to disseminate information and to assist those who may use the product. Agencies of this type are The Asphalt Institute and the Portland Cement Association.

To oversimplify a complex and ever-changing situation, it may be said that for many years the asphalt industry generally followed the policy of recommending relatively thin asphalt pavements relying on some other material such as gravel, crushed stone, or cement-hardened materials for a supporting base. The almost universal sales argument from the asphalt industry was based on lowest first cost. This policy paid off in many cases—notably the original choice of pavement on the New Jersey Turnpike, where asphalt concrete represented a saving of several million dollars over the portland cement alternate. However, this policy in effect "caught up" with them when the results of the AASHO test road became apparent. Here the light asphalt sections failed completely and under less traffic than was required to fail the heavier portland cement concrete sections.

In contrast, the policy of the Portland Cement Association has always been to encourage the use of stronger, heavier pavements. This has usually resulted in barring portland cement concrete from all but the heaviest traveled main-line highways, on account of the initial cost. With the results of the AASHO Road Test available and observation of many miles of state highways it appears today that there is less difference in first cost than formerly

ALLAN W. DOW
1866-1955

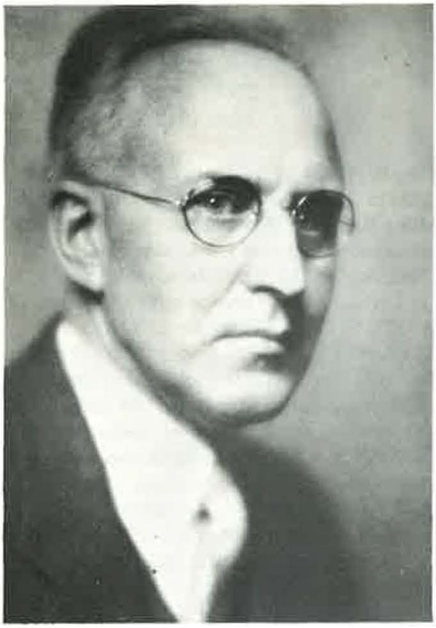
The originator of the penetration and ductility tests for asphalts, Allan W. Dow died Dec. 8, 1955, at his home in New Milford, Connecticut. Mr. Dow was a graduate of the Colombia School of Mines in 1888; Assistant Chemist for the Barber Asphalt Company 1889 to 1894; Inspector for Paving, District of Columbia, 1895 to 1906; associated with Francis P. Smith in the firm of Dow and Smith, 1906 to 1932; Vice President and Chief Engineer of Colprovia Roads, Inc., 1935 to 1939. He was a member of the following technical societies: Association of Asphalt Paving Technologists, American Institute of Chemical Engineers, American Society for Testing and Materials, American Chemical Society, American Road Builders' Association, and American Association for the Advancement of Science.

CLIFFORD RICHARDSON
1856-1932

Internationally known authority on asphalt pavements, Clifford Richardson published the first major treatise on asphalts and asphalt pavements in 1904 under the title "The Modern Asphalt Pavement". Mr. Richardson was a graduate in chemistry from Harvard University in 1877 (he was a classmate of Theodore Roosevelt); principal Assistant Chemist, U. S. Department of Agriculture 1877 to 1887; Inspector of Asphalt and Cement 1887 to 1896; Superintendent of Tests for the Barber Asphalt Company, 1896 to 1900; and operated the New York Testing Laboratory, 1900 to 1921. He was a member of many organizations and an honorary member of the Association of Asphalt Paving Technologists.

PREVOST HUBBARD

Prevost Hubbard is best known for his joint effort with Frederick C. Field in developing the Hubbard-Field Stability Test. From 1905 to 1911 he was with the Bureau of Public Roads as Assistant Chemist, Chief Chemist, Chemical Engineer, and Chief, Division of Road Material; from 1911 to 1915, he was a consulting engineer; from 1915 to 1919, Bureau of Public Roads, Tests and Research; and from 1919 to retirement in 1947 with The Asphalt Institute as Research Engineer. He has been called the "Dean Emeritus of Asphalt Research."



FREDERICK C. FIELD
1875-1948

Chemist and Research Engineer Frederick C. Field was born in Collingwood, Ontario, in 1875. He worked for the City of Seattle and Calgary, Canada; from 1924 to 1947 he was with the Asphalt Association (later The Asphalt Institute); he also worked closely with the U. S. Corps of Engineers on the Mississippi revetment work. Probably his best known achievement was the Hubbard-Field Stability Test, which was one of the first devices for measuring the "stability" of asphalt paving mixtures. The test is still in use by many agencies especially in the eastern states.

A. C. BENKELMAN

Born in Michigan in 1895, A. C. Benkelman graduated from the University of Michigan in 1919 with a B. S. degree in engineering. From 1919 to 1928 he was with the Illinois Highway Department; Soils Engineer on the Bates Road Test; from 1928 to 1934 with the Michigan Highway Department as Research Engineer on soils, frost action, and pavements; from 1934 to 1956 with the U. S. Bureau of Public Roads in charge of structural design of flexible pavements; worked on the Hybla Valley Test Track; from 1956 to retirement was associated with the Highway Research Board. While with the WASHO Road Test, he developed the "Benkelman Beam", an economical portable device for measuring the deflections of pavements under heavy wheel loads. Mr. Benkelman was given the Distinguished Service Award of the Highway Research Board in 1962.

ALFRED R. EBBERTS
1896-1949

Born in Pittsburgh on May 3, 1896, Alfred R. Ebberts graduated from Cornell University with a B. S. degree in chemistry. Mr. Ebberts was on active duty in World War I as a Lieutenant in the 8th Field Artillery of the 7th Division. After several other positions, in 1925 he became Engineer of Tests for Allegheny County, Pa. It was during this time that he called attention to the "emulsifying effects of silica filler dust." In 1934 he was associated with Colprovia Company. In 1939 he went to California and was the Associate Physical Testing Engineer in the California Materials and Research Department. He was a member of the American Chemical Society, the American Society for Testing and Materials, and the American Society of Civil Engineers.

FREDERICK J. WARREN
1866-1905

Frederick J. Warren was inventor of the "Bitulithic" patented pavement. Warren Brothers Company was formed in 1899 and Frederick Warren became the first president, serving from 1900 to 1905. Prior to 1900 he had been with the Barber Asphalt Company of Denver. He pioneered in the development and placement of sheet asphalt. In 1900 he applied for a patent on a dense graded hot mix asphalt concrete pavement having high "stability" and low voids. The patent was granted in 1903 and the new mix was named "Bitulithic". In conjunction with his brother, George Copp Warren, he was instrumental in bringing to the attention of Eastern engineers the fact that the "residue from California crude oil was the purest and best asphalt for the dense graded type of mixture".

GENE ABSON
1897-1963

Born on October 6, 1897, in Blue Island, Illinois, Gene Abson lived all his life in the Chicago area. He graduated in 1920 from Wabash College with a degree in chemistry. In 1920 he joined the Chicago Paving Laboratory as a chemist, and in 1922 began operating the Chicago Paving Laboratory with Hugh Skidmore, first president of the AAPT. Abson was one of the charter members of the AAPT, served on the Board of Directors, and was president in 1940. He was a member of the American Institute of Chemists, American Institute of Chemical Engineers, American Association for the Advancement of Science, the Highway Research Board, Chicago Chemist's Club, and the American Society for Testing and Materials. Gene Abson is probably best known for the development of the Abson Recovery Test, which permits recovering asphalt from the pavement.

WAYNE G. O'HARRA

Wayne G. O'Harra was born July 1, 1903, in Rapid City, S. D. He received his B. S. degree in metallurgical engineering and a civil engineer degree from the South Dakota School of Mines and Technology. He joined the Arizona Highway Department in 1928 as its first chemist. Arizona was entering the "oil mix" pavement work, and he was assigned to study the failures. His work lead to the swell and demulsibility tests. Mr. O'Harra advanced to Materials Engineer in 1954, then became Assistant State Engineer—Location and Design, and moved up to become Deputy State Engineer in 1970, from which he retired later that year. He was President of the Arizona Section of ASCE and National Director in 1958-1962. He was given the "Award of Merit" from the University of Arizona, and the Arizona Section of ASCE bestowed the John C. Park Award for Outstanding Civil Engineer Achievement.

appeared and probably less difference in annual upkeep and maintenance than was formerly believed.

Regardless of minor changes and developments, asphalt pavements have been serving mankind for many years, and they will continue to do so for a long time to come. It is said that 94 percent of the highway mileage in the United States is surfaced with asphalt, and an even higher percentage applies to the enlightened western states.

ACKNOWLEDGMENTS

I wish to acknowledge the contributions of many people who have assisted in preparing this discussion of the history of asphalt pavements, "from the ancient East to the modern West."

First, I must mention Mr. W. R. Lovering, Division Paving Engineer of The Asphalt Institute, who assisted with advice, reference material, and review of the text. Most of all I wish to express thanks for making available the services of his secretary, Virginia Ford, who typed the numerous rough drafts as well as the final manuscript. I am grateful to Mr. Arvin S. Wellborn, Chief Engineer of The Asphalt Institute, for making available his files on the history of asphalt and for arranging to secure photographs of famous individuals associated with the development of asphalt pavements.

I wish to acknowledge the kindness of D. G. Tunnicliff, Chief of Technical Services, Warren Brothers Company, who sent copies of the magazine, SPREADER, and a brochure entitled "A History of the Warren Brothers Company and Its Founders."

I wish to thank Mr. John Skog of the Materials and Research Department of the California Division of Highways and Mr. Ernest Zube for participating in discussions on the statements made and material included in the report.

Finally, I should like to acknowledge my indebtedness to the many engineers and others who have in the past 50 years told me tales of the "good old days" and events of earlier times in the history of asphalt paving in the United States. Most of these men have gone to that land where the streets are reportedly "paved with gold," and I am sure have been spared any further contact with "hot stuff."

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